A HYDROLOGIC ANALYSIS OF THE
GULKANA NATIONAL WILD RIVER
ALASKA

by

David A. Ellerbroek

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Golden, Colorado
Date 4/10/89

Signed:
David A. Ellerbroek

Approved:
Dr. Ronald R. Cohen
Thesis Advisor

Golden, Colorado
Date 4/10/89

Dr. John C. Emerick
Associate Professor and Acting Head, Department of Environmental Science and Engineering Ecology

ABSTRACT

The problem of incomplete or inadequate flow records is common on remote rivers in Alaska. As part of an instream flow water rights assessment, prepared by the Bureau of Land Management, a hydrologic analysis was developed for the Gulkana River in south-central Alaska. This analysis quantified the natural flow regime, and developed relationships between discharge, flow attributes, and channel morphology.

The Gulkana River has six years of streamflow data recorded by the United States Geological Survey. This data record is less then the recommended ten year period required for traditional Log-Pearson Type III flood frequency analysis. A streamgage correlation was performed, using a gage of longer record, to extend the existing stream flow record and provide sufficient data for Log-Pearson Type III analysis . Regression techniques were used for the stream gage correlation.

Regional analysis was also performed to develop flood frequency records based upon the physical characteristics of the Gulkana River basin. Regional analysis involves using equations with basin characteristics as the independent variables to derive streamflows. Mean annual flow can also be used, if known, to derive flows with other recurrence intervals. Both of these techniques were used in this study.

Hydraulic geometry relations were developed from field surveys using Manning Equation methods. This allowed development of mathematical relationships between flow, channel attributes, and normally occurring discharges. Hydraulic geometry techniques were also utilized to compute bankfull capacity flows which were related to an annual recurrence of 1.5 years.

The Gulkana River was found to be dominated by snowmelt runoff with peaks occurring in late May. Response to summer rainfall is rapid though tempered by basin characteristics. Permafrost is an important geologic control of run-off response preventing subsurface infiltration. The 100-year return flood is approximately three times the magnitude of the mean annual discharge.

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Chapter 1

INTRODUCTION

1.1 The Context of the Study

The upper portion of the Gulkana River was made a portion of the National Wild and Scenic Rivers System by the Alaska National Interest and Conservation Act of December 2, 1980. This designation includes the Mainstem of the Gulkana River, from the outlet of Paxson Lake to Sourdough, Alaska. The Middle and West Forks of the river were also included in the Wild and Scenic River Designation. The Wild and Scenic Rivers Act of 1968 (P.L. 90-542) states that "selected rivers of the nation which, with their immediate environment, possess outstanding remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or similar values, shall be protected in free flowing condition, and they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations."

As part of a water rights assessment and instream flow study conducted by the Bureau of Land Management, it was necessary to develop hydrological information concerning the Gulkana's natural flow regime. These summaries were used to quantify the Gulkana's natural flow regime so that flow levels necessary to maintain the attributes for which the river was made part of the Wild and Scenic River system could be maintained. These attributes include outstanding fishing, boating, and camping opportunities. Hydrological summaries were developed along important segments of the river. These summaries were used to develop relationships between alternate flows and important channel and morphological features. Relationships were quantified between stream discharge, channel width, channel depth, wetted perimeter, and cross-sectional area.

The problem of developing hydrological summaries was made more difficult by the fact that only six years of stream gage record existed. The United States Geological Survey ran a stream gage at Sourdough, Alaska from 1972-1979, and in 1982. Flood frequencies were derived using these data and synthetic flow records obtained using indirect regional methods.

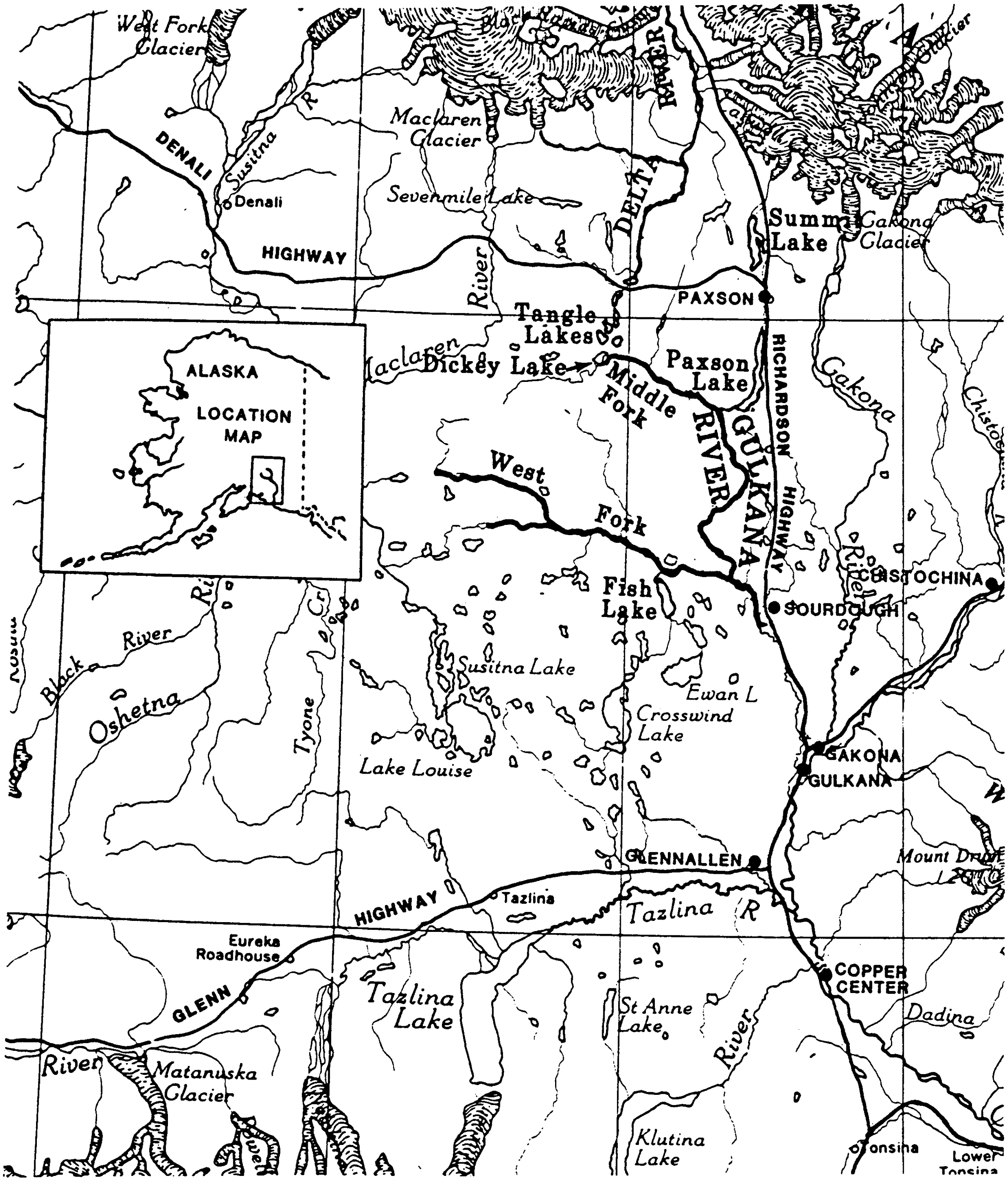
1.2 Site Description

The Gulkana River is located in south-central Alaska about 200 road miles east of Anchorage. The Gulkana drains approximately 2,140 square miles; and the watershed area above the Sourdough Bridge is 1,759 square miles. The Mainstem of the river originates at Summit Lake at an elevation of 3,210 feet in the foothills of the Alaska Range (See Figure 1.1).

Directly above Summit Lake, the Gulkana Glacier is prevented from draining into Summit Lake by a low divide of glacial material in the outwash plain (Lyle, 1980). In the past, this low divide has shifted, allowing glacial run-off to reach Summit Lake (Moffit, 1912). This reworking of the glacial material, and shifting of the drainage divide, ended in 1929 with the construction of the Richardson Highway across the Gulkana Glacier outwash plain. The construction permanently diverted the glacial run-off from the Gulkana Basin.

The origin of the Gulkana River headwaters is of interest because of the clearwater nature of the river. The Gulkana is the only major clearwater tributary to the Copper River. The other large rivers are of glacial origin and have

Figure 1.1 Location Map of the Gulkana River



high suspended sediment contents. The clearwater nature of the Gulkana makes it an important salmon spawning area and popular recreation spot. The nonglacial origin of the river and the filtering action of headwater lakes, combine to keep the waters of the Gulkana free from large amounts of sediment. It should be noted that even in years when the Gulkana Glacier contributed to the Summit Lake outflow its volume would have been relatively small, and the filtering action of the lakes would have kept the Gulkana clear (HCRS, 1978).

The Gulkana mainstem is 103 miles long from its origin at Summit Lake to the confluence with the Copper River. From Summit Lake, the Gulkana flows 11.6 miles to Paxson Lake. Paxson Lake is approximately 10 miles long and a mile wide, and was formed by the damming of a notch cut in the east trending bedrock. The notch was dammed with a moraine left by a retreating glacier. From Paxson Lake, the river flows 51 miles to the Sourdough Bridge. The section of the mainstem from Paxson Lake to the Sourdough Bridge was included in the Wild and Scenic River designation, and is the portion included in this study.

The Mainstem has two major tributaries, both of which were included in the Wild and Scenic River designation. The

Middle Fork drains the north slopes of the Alphabet Hills, and flows through Dickey Lake before joining the mainstem three miles downstream from Paxson Lake. The Middlefork flows for 25 miles from Dickey Lakes to its confluence with the mainstem.

The West Fork of the Gulkana River originates in the lake country to the west of the Mainstem. The West Fork has two major tributaries, the North and South Branches. Both of these branches originate in a series of lakes at approximately 2,500 feet. The North and South Branch flow for approximately 31 miles, after leaving a chain of lakes, before joining to form the West Fork. The West Fork then flows for approximately 48 miles before reaching the Mainstem. The Mainstem joins the West Fork 39 miles below Paxson Lake.

1.3 Physiographic Regions

The Gulkana River Basin lies in the intermontane Copper River Basin, in south-central Alaska, and is part of the Pacific Mountain Physiographic Providence (Wahrhaftig, 1965). The Copper River Basin is surrounded by the Alaska Range to the north, the Chugach Mountains to the south, the Wrangell Mountains to the east, and the Talkeetna Mountains to the west.

The Copper River Basin has been divided into two physiographic regions. The Gulkana Upland encompasses the northern third of the basin, and the Copper River Lowlands makes up the lower two-thirds (Wahrhaftig, 1965). The Copper River Lowland has been further sub-divided into the true Copper River Lowlands to the east, and the Lake Louise Plateau to the west (Wahrhaftig, 1965).

The Gulkana Upland Region is characterized by east-west trending ridges at 3,500 to 5,500 feet in elevation. The ridges are cut by north-south trending notches formed by glacial ice or meltwater. These notches are often occupied by long narrow lakes such as Paxson Lake. The ridges are separated by two to ten miles of lowland (Wahrhaftig, 1965).

The Gulkana Upland acts as a hydrological divide. Waters originating in the south and east portions of the region are part of the Copper River drainage and include the upper Mainstem and the Middle Fork of the Gulkana River. These waters eventually run to the Gulf of Alaska. The south and west portion of the Gulkana Uplands drain into the Susitna River, and from there to the Cook Inlet. To the north, the drainage flows into tributaries of the Yukon River, and then into the Bering Sea (Lyle, 1980).

The Copper River Lowland is further divided into two physiographic regions. The eastern portion of the Copper River Lowland is called the true Copper River Lowland. This area is described as a smooth plain varying from 1,000 to 2,000 feet elevation, with deep cut river canyons (Wahrhaftig, 1965). The Copper River Lowlands drain into the Copper River.

The western half of the Copper River Lowlands is the Lake Louise Plateau, characterized by rolling upland topography from 2200 to 3500 feet in elevation. One feature of the Lake Louise Plateau is known as "stagnant ice topography" (Lyle, 1980). Stagnant ice topography is the result of blocks of ice being left behind by retreating glaciers. As these blocks melt, they become embedded in glacial drift, resulting in hollows and troughs that fill with water and become bogs or lakes. The Lake Louise Plateau is dotted with myriad lakes and bogs. The Lake Louise Plateau drains into the Copper River Basin in the south and east portions. The northern area flows into the Susitna River.

The Mainstem and the Middlefork of the Gulkana originate in the Gulkana Uplands region. After the confluence with the Middlefork, the Mainstem flows for approximately 20 miles before entering the Copper River Lowland. The transition zone from the Gulkana Highlands to Copper River Lowland is marked by a section of rapids, as the river cuts through glacial moraines before reaching the lowlands.

The West Fork begins in the lakes of the Lake Louise Plateau at approximately 2,500 feet. The West Fork flows into the Copper River Lowlands before joining the Mainstem.

1.4 Surficial Geology

Glacial deposits are widespread in southern Alaska, and glacial processes are still active in many areas today. The surficial geology of the Gulkana Basin shows evidence of its recent Pleistocene glaciation. Extensive deposits exist that are the result of ice and frost action and mass wasting processes. Permafrost is common throughout the Gulkana Basin (Pewe, 1975).

The Gulkana Upland and Lake Louise Plateau show features associated with a wide variety of glacial processes. Terminal and ground moraines are common throughout the area. Thick deposits of ground moraine are formed when glacial drift held in place by an ice sheet is released as the glacier retreats.

Esters and kames are also found in the Gulkana Uplands and Lake Louise Plateau (Lyle, 1980). Esters are the bottom of old glacial streams, and kames are formed by the deposition of gravel between ice sheets or between an ice sheet and a slope.

The Copper River Lowland is relatively rare in Alaska in that they represent the only large lacustrine deposits in the state. These deposits were formed during Pleistocene glacier advances when glacial ice blocked the exits from the basin, producing a huge lake (Pewe, 1975).

The lacustrine deposits are made up of finely grained sand, silt, and clay, with some layers of volcanic ash. Some evidence exists for as many as three major periods of deposition. Each depositional period corresponding to a glacial advance and blocking of the basin (Pewe, 1975). As the Gulkana downcuts through these sediments, high bluffs of fine grained sediments are exposed. The river also becomes entrenched as the sediment banks are stabilized by the action of permafrost. Another effect of the lacustrine sediments is to increase the turbidity of the river.

1.5 Soils

Both the Lake Louise Plateau and the Copper River Lowland have poorly drained, deep, clayey soils, with a thick top layer of organic material. The organic material acts as an insulator, and permafrost is only one to two feet below the surface (Pewe, 1975). In areas where the layer of organic material is not present, such as valley slopes and the fine grained lacustrine sediments, the permafrost begins at two to five feet below the surface. In all places, the permafrost is at least 100 feet thick, and in areas continues to as deep as 500 to 600 feet below the surface (Lyle, 1980).

Permafrost is present in all areas except below large lakes and streams. The presence of permafrost forms an impenetrable layer below the surface that prevents infiltration of water to the subsurface. This results in the extensive bogs and muskeg which dot the region. Permafrost is also important in contributing to the rapid response of the area to precipitation events.

The soils of the Gulkana Upland tend to be shallow, well drained, and gravelly to loamy (Lyle, 1980). As a result, the permafrost tends to be deeper, at six to ten feet below the surface, and the Gulkana Upland lacks the muskeg that characterizes the other regions. However, the permafrost still plays an important role in establishing the basin's response to precipitation events by limiting subsurface infiltration.

1.6 Vegetation

Black spruce forest dominates the large areas of the basin that are characterized by poorly drained soils and lower elevations. In areas with more well-drained soils, such as the Gulkana Uplands, a mixed forest of spruce, birch, and aspen exists. Treeline is at approximately 2,500 to 3,000 feet.

Above treeline, tundra exists, with low growing herbaceous plants, shrubs, and grasses. Tundra exists along Paxson Lake, and in the higher areas of the Gulkana Uplands Region. A permafrost free area that is along the river corridor supports the larger trees that grow in the region.

1.7 Climate

The climate of the Gulkana Basin is affected by its nearness to large mountains and the Gulf of Alaska. Storms moving out of the Gulf tend to lose their moisture over the Chugach Mountains before reaching the Gulkana Basin. Annual average precipitation for the basin is 15 inches (USDI, 1983). Temperature extremes are large. The lowest recorded temperature recorded at Gulkana, Alaska was -65 degrees fahrenheit, with a record high of 91 degrees fahrenheit. The average monthly temperature is 26.8 degrees fahrenheit (Lyle, 1980).

Climatic factors play an important role in establishing the hydrological response of the Gulkana River. The most important factor is the presence of permafrost. Permafrost prevents subsurface infiltration, and allows rapid response of the basin to precipitation and snowmelt.

Another important climatic factor affecting the hydrology of the Gulkana is the formation of aufeis. Aufeis is the formation of successive sheets of ice over the channel and is thought to be caused by subsurface water rising through the channel substrate. Aufeis can affect streamflows in two important ways. Winter flows can approach zero, for certain stream segments, due to the storage of water in the surface ice. Also, during spring break-up, water may run over the ice in a channel overflowing the stream banks and may cause channel cutting and migration (Lamke, 1979). Aufeis formation is common in Alaska, and may take place on segments of the Gulkana during extreme winter conditions.

CHAPTER 2

METHODOLOGY

2.1 Hydrological Record

Most of the data used in hydrology are historical data. The variables that are analyzed are the result of natural hydrological events that have been observed in the past. One of the principle problems in hydrology is the prediction of the probability of occurrence of future events based on the analysis of historical data.

A variable in hydrology can represent a continuous or discontinuous series (Chow, 1964). An example of a continuous series in hydrology is the annual hydrograph. The discontinuous series is represented by variables such as mean monthly flow and flood peak flows. Quite often a continuous series of hydrologic data is analyzed over a certain time period to create a discontinuous series. This is advantageous because the discontinuous series can then be further analyzed using statistical techniques.

Hydrologic data are subject to many types of errors. Since hydrologic variables are obtained by observation, they are subject to human error. This type of random or systematic error results in a data set that is nonhomogeneous. Random errors may be present because of errors in measurement. Systematic errors result in trends or errors in one direction in the data.

Nonhomogeneity in data can also result from changes in the hydrologic condition of the drainage basin. Changes can result from natural causes such as fires or landslides, or man-made alterations such as urbanization. Nonhomogeneity in hydrologic data should be considered before analysis. This is especially important when the available data series is small, that is, where the sample size is smaller than about fifty items (Yevdjevich, 1964).

The existing data set on the Gulkana River, of only six years, represents an extremely small time series. A data set of this size can easily be nonrepresentative of the long-term flow regime of the river. Natural fluctuations in climatic conditions can result in short term flows that are not representative of the average long term annual flows. It is quite possible that the data set on the Gulkana was gathered during such a period.

Solutions to the problem of a nonrepresentative data set and methods of analysis will be discussed in this chapter. Methods of extending a short hydrologic record include stream gage correlation and regional analysis. Both of these methods involve the use of multiple linear regression techniques. Professional judgement may also be utilized in the final analysis of the hydrologic record.

2.2 Frequency Analysis

Frequency analysis is used to determine the probability of a certain magnitude event occurring in a specified time period. The time period is known as the return period or recurrence interval. The return period is the time in years during which a discharge rate will be equaled or exceeded. The probability of the occurrence of a given event can be given as

$$t_r = 1/p \tag{Eq. 2.1}$$

where

t_r = return period (years)

p = probability of occurrence of a given event (expressed as decimal) (1/ years)

Return periods are used in the engineering design of hydraulic structures.

In using frequency analysis, a specific frequency distribution must be assumed, which the frequency distribution is likely to follow. The frequency distribution should be supported by an understanding of the natural system, or by experience with similar frequency series (Gray, 1970).

All of the observations used in a frequency analysis should be the result of the same process. The population of the data should be homogeneous. For example, floods resulting from rainfall run-off should not be analyzed with floods from the outburst of glacial dammed lakes. A population of hydrologic events occurring before an area is urbanized should be separated from post urbanization data. Processes that are not related should be treated separately.

Often in analyzing hydrologic data the population is small, and the number of frequency distributions that could be fitted to the data is large. With small populations realistic probability levels can not be assigned to a given event (Gray, 1970).

A generalized equation for hydrologic frequency analysis has been proposed (Chow, 1964). Chow expressed this equation as

$$x/\mathbf{x} = 1 + KC_v \qquad \text{(Eq. 2.2)}$$

where

x = the observed variate

$\mathbf{x}$ = mean value of a set of X variates

K = frequency factor which is a property of a given frequency distribution at a given probability level

C_v = coefficient of variation of a set of X variates

Equation 2.2 can also be written as:

$$x = \mathbf{x} + KS \qquad \text{(Eq. 2.3)}$$

where

S = standard deviation of a set of X variates

The generalized equation is applicable to many probability distributions used in hydrologic frequency analysis. Relationships can be derived between the frequency factor and the corresponding recurrence interval for a given distribution. This relationship can be expressed using tables known as K-T curves (Chow, 1964). The statistical parameters required for the proposed distribution are computed, and the frequency factor for a given recurrence interval is determined from the K-T curves. The magnitude of the event is then determined from equation 2.2.

The United States Water Resources Council (U.S.W.R.C.) has recommended use of the Pearson Type III distribution with log transformed data (log-Pearson Type III) in Bulletin #17B (1981). Flood events are a succession of natural events that do not fit any one statistical distribution. The log-Pearson Type III was chosen as a standard. The Pearson curves only have a slight theoretical basis, though they have been used to define a variety of hydrologic phenomena (Chow, 1964).

Flood frequencies can be computed using either an annual or partial-duration series (U.S.W.R.C., 1981). The annual flood series is used when only one flood event per year is considered. The annual series is made up of the maximum flood peaks for each year. Ten years of annual peak data are recommended for log-Pearson Type III analysis (U.S.W.R.C., 1981).

The United States Water Resource Council in Bulletin #17B recommends the following procedure for fitting a log-Pearson Type III distribution to a series of annual peaks. The base ten logarithms of the discharge, Q (ft/s), are computed by the equation:

$$\text{Log } Q = \mathbf{x} + KS \qquad \text{(Eq. 2.4)}$$

where

$\mathbf{x}$ = mean logarithm (ft/s)

S = standard deviation of logarithms

K = a factor that is a function of the skew coefficient and selected exceedance probability

Values for K are given in Appendix 3 of Bulletin #17B (United States Water Resource Council, 1981).

The mean value of the logarithm of the annual peak flows, standard deviation and station data skew coefficient are given by the following equations.

$$\mathbf{x} = \text{summation of } X / N \qquad \text{(Eq. 2.5)}$$

$$S = [\text{sum } (X - \mathbf{x})^2 / (N - 1)]^{0.5} \qquad \text{(Eq. 2.6)}$$

$$= [(\text{sum } X^2) - (\text{sum } X)^2 / N / (N - 1)]^{0.5}$$

$$G = N \text{ sum } (X - \mathbf{x})^3 / (N - 1)(N - 2)\ S^3 \qquad \text{(Eq. 2.7)}$$

$$= N^2 (\text{sum } X^3) - 3N(\text{sum } X)(\text{sum } X^2) + 2(\text{sum } X)^3 / N(N - 1)(N - 2)\ S^3$$

where

X = logarithm of the annual peak flow (ft/s)

N = number of items in data set

$\mathbf{x}$ = mean logarithm (ft/s)

S = standard deviation of logarithms

G = skew coefficient of logarithms

Formulas for computing the standard errors of the mean annual logarithm, standard deviation of the logarithm, and skew coefficient of the logarithm are given in Appendix 2 of Bulletin #17B. The equations are listed below.

$$SE_G = [6N(N - 1)/(N - 2)(N + 1)(N + 3)]^{0.5} \qquad \text{(Eq.2.8)}$$

$$SE_S = S\ (1 + 0.75G^2)_{0.5} / 2N \qquad \text{(Eq. 2.9)}$$

$$SE_x = S / (\mathbf{N})^{0.5} \qquad \text{(Eq. 2.10)}$$

where

SE_G = Standard error of sample skew coefficient, for which samples from a normal distribution can be estimated

SE_S = Standard error of the sample standard deviation

SE_x = Standard error of the sample mean

N = Number of items in a data set

Skew coefficients of the station record are sensitive to extreme events. A generalized skew coefficient can be computed for regions of forty or more stations within a one hundred mile radius. The accuracy of the estimated station skew coefficient can be improved through weighting with the generalized regional skew coefficient (U.S.W.R.C., 1981).

When using frequency analysis, it is assumed that the array of flood information represents a time sample of random independent events. Climatic trends are assumed not to have affected the sample population. It is also important that watershed conditions have not changed during the sample period. It is important that the annual series be made up of homogenous events.

There is no one procedure that can be adopted to accurately define the flood frequencies for any given watershed (U.S.W.R.C., 1981). Statistical analysis using log-Pearson Type III distribution is just one technique. Elements of uncertainty will still remain. Other techniques that can be used include stream gage correlations and multiple-regression techniques that use basin and precipitation characteristics as independent variables to predict flood frequencies. Professional judgement by an experienced hydrologist also plays a role in the final determination and resolution of flood frequencies.

2.3 Regional Analysis

Regional analysis involves the prediction of hydrologic events based on the relationships between characteristics within hydrological homogeneous areas. Hydrologic homogeneity requires that the occurrence of a particular hydrologic event, within a defined area, is equally likely to occur within a tolerable statistical difference (Chow, 1964). Statistical homogeneous areas are delineated by statistical regional analysis. Point data, representing a time series, can be analyzed using frequency analysis; the frequency analysis can then be extended from a point to an area using regional analysis (Chow, 1964). Regional analysis can be used to average point data analysis and represent the frequency characteristics of an area. Regional analysis can also be used to move data from one geographic location to another. Relationships can be developed between the mean annual flood and the watershed characteristics for a homogeneous area.

A test for regional homogeneity has been developed by the United States Geological Survey (Chow, 1964). The ten year flood values, from the probability curve at each station in a region, are expressed as ratios to the mean annual flood. These ratios are averaged to determine the mean annual ratio for the area. Recurrence intervals corresponding to the mean annual flood times the average ten year ratio are determined from the station's probability curves. These recurrence intervals are plotted against the number of station record years. If the points for all the stations fall within two control curves the region is considered homogeneous (Chow, 1964).

The test for homogeneous regions is designed to determine if the station records vary by amounts greater than expected by random chance. Records not varying by more than expected by the operations of chance are considered to represent different aspects of the same process. These records can be grouped to form regions (Chow, 1964).

Regional analysis techniques have been developed for predicting streamflows in Alaska by Parks and Madison (1985). Regional analysis is an useful technique in areas such as Alaska where streamflow data has been collected sporadically. Many streams in Alaska have never been gaged or have discontinuous records. Regional analysis techniques provide a quick and cost-effective method of estimating the magnitude and recurrence of peak flows.

Parks and Madison began their study by computing the flood frequency values for the 246 stations in Alaska that had ten years or more record. Peak values were computed according to the procedures in U.S.W.R.C. Bulletin #17B (1981). The computed values were grouped according to homogeneous regions, as determined by the U.S.W.R.C..

For the computation of peak flow frequency, streams in which peak flows result from the breakout of glacial dammed lakes were not used (Parks and Madison, 1985). Peaks resulting from the outbreak of glacial dammed lakes are not analogous to peaks resulting from snowmelt or rainfall runoff. A homogeneous population must be used for comparing hydrologic events from different locations.

Multiple linear regression techniques were used to relate the frequency and magnitude of the flow events to basin characteristics within a homogeneous region (Parks and Madison, 1985). The general form of a multiple linear regression is shown below.

$$y = a + b_1x_1 + b_2x_2 + \dots + b_nx_n \qquad \text{(Eq. 2.11)}$$

where

y = the hydrologic characteristic (dependent variable)

a = the regression constant

b's = the regression coefficients

x's = the basin characteristics (independent variables)

n = the number of basin characteristics

The relationships between hydrologic variables is not always linear. The relationship between basin characteristics and flow values is more nearly linear when the data are log transformed (Benson and Carter, 1979). The general log-transformed equation is:

$$\text{Log } y = \text{Log } a + (b_1 \text{Log} x_1) + (b_2 \text{Log} x_2) + \ldots + (b_n \text{Log} x_n) \qquad \text{(Eq. 2.12)}$$

An equivalent expression is:

$$y = a x_1^{\,1}\; x_2^{\,2}\; \ldots\; x_n^{\,n} \qquad \text{(Eq. 2.13)}$$

Parks and Madison performed a stepwise regression of the data. A stepwise regression brings in the independent variables one at a time (Parks and Madison, 1985). Variables are eliminated or retained on the basis of their significance. The process was used for all the independent variables (basin characteristics), until the best possible one variable equation was found (Parks and Madison, 1985). The process was then used to find the best possible two and three variable equations for the n independent variables.

The two terms commonly used to describe the accuracy of a regression equation are the standard error of estimate (SE) and the correlation coefficient (r^2) (Parks and

Madison, 1985). The standard error of estimate gives an indication of the variance of the regression and how well the estimated values, used to determine the equation fit, the resulting equation. A standard error of estimate indicates that two-thirds of the values used fall within plus or minus the standard error when compared to the computed values. The coefficient of determination (r^2) is a general indication of how well the data fits the equation. The coefficient of determination times 100 is the amount of dependent variable variation explained by the equation. The standard error and coefficient of determination were used to describe the accuracy of the resulting regression equations in this study.

Equations were developed for four categories of independent variables. These included basin characteristics, channel width, mean annual flow, and 2-year flood flow (Parks and Madison, 1985). The equations developed from channel width, as an independent variable, were not considered reliable (Parks and Madison, 1985). The most reliable estimates of flood flow volumes were made using basin characteristics and mean annual flow as independent variables. The equations based on the 2-year flood flows were considered less reliable (Parks and Madison, 1985).

The equations based on basin characteristics were developed from the U.S.G.S. Streamflow/Basin Characteristic File. The physical characteristics and climatic conditions of a basin directly affect the frequency and magnitude of the flow events. A regression equation relating run-off and basin characteristics is warranted, since these processes are related.

Flow characteristics at gaging stations were related to combinations of physical and climatic conditions in a stepwise fashion (Parks and Madison, 1985). The best equation was found to be based on precipitation and watershed area. The standard error and the coefficient of determination were used to determine the best equation. Adding other variables did not significantly increase the reliability of the equations (Parks and Madison, 1985).

Regression equations were also developed using the mean annual flow as an independent variable. The mean annual flow can be developed for stations having five or more years of record (Parks and Madison, 1985). The mean annual flow represents the average of the mean discharge for all the years of record. The equations for estimating flows from the mean annual flow were developed using stations with ten or more years of operation.

Table 2.1 gives the parameter values of the best fit regression equations for south-central Alaska. The general form of the equation is shown along with the standard error and r^2 associated with each equation.

For the two, five, and ten year return interval flows, the standard errors are largest for the equations that use mean annual flow as an independent variable. Parks and Madison (1985) report standard errors in log units. The standard error for the mean annual flow equations are 0.26 log units for the two and five years flows and 0.27 log units for the ten year flows. A standard error of 0.26 log units equals 82% positive and 55% negative error. A standard error of 0.27 log units is equal to approximately 86% positive error and 54% negative error.

For the 25, 50, and 100 year return interval flows, the set of equations that used watershed area and mean annual precipitation as independent variables had the greatest amount of error. The standard errors range from 0.28 to 0.31 log units. This equals approximately from 90 to 104% positive error and from 49 to 52% negative error.

Despite the large amounts of error present in the equations, regional analysis is a useful for predicting flows. In areas of Alaska that do not have any streamgage

Table 2.1 Parameter Values for Regional Equations

Area (x_1) Rainfall (x_2)			Mean Annual Flow (x_1)	
P_2	log a= −0.69		log a= +0.93	r^2= .95
	b_1= +0.87	r^2= .93	b_1= +0.95	SE= .26
	b_2= +1.31	SE= .25		
P_5	log a= −0.25		log a= +1.13	r^2= .94
	b_1= +0.83	r^2= .93	b_1= +0.92	SE= .26
	b_2= +1.19	SE= .25		
P_{10}	log a= +0.03		log a= +1.23	r^2= .94
	b_1= +0.81	r^2= .92	b_1= +0.91	SE= .27
	b_2= +1.13	SE= .26		
P_{25}	log a= +0.25		log a= +1.36	r^2= .93
	b_1= +0.79	r^2= .90	b_1= +0.90	SE= .28
	b_2= +1.05	SE= .28		
P_{50}	log a= +0.44		log a= +1.44	r^2= .92
	b_1= +0.77	r^2= .89	b_1= +0.89	SE= .29
	b_2= +0.99	SE= .29		
P_{100}	log a= +0.63		log a= +1.52	r^2= .91
	b_1= +0.75	r^2= .87	b_1= +0.88	SE= .30
	b_2= +0.94	SE= .31		

data available, regional analysis may be the only tool available to determine flows.

The independent variables are represented by P_n. P_2 corresponds to the magnitude of the two year flood. The standard errors (SE) are given in log units. The coefficients of determination are shown as r^2.

Regional analysis is useful in areas of inadequate flow records. The regression equations developed by Parks and Madison (1985) can be used for estimating streamflows in Alaska. Equations using basin characteristics as the independent variables give the best estimate of streamflows of ungaged streams (Parks and Madison, 1985). Stations having five years or more of record can also use the mean annual flow to determine streamflows (Parks and Madison, 1985).

2.4 Interstation Correlation

Interstation correlation is used to lengthen the record of a station by developing a relationship with a station with a longer record. The relation among the concurrent events, at the two stations, is used to estimate the nonobserved events at the station with the shorter record. The observed and estimated events represent a time series, which can be used to estimate the mean, variance, and skewness of the events (Matalas and Jacobs 1964).

Interstation correlation is based upon several assumptions. The events should be independently distributed in time. The concurrent events, of the two sequences, should have a joint normal distribution. The relationship between the concurrent events should be defined by a linear regression. Lastly, no changes should occur in the hydrologic regimes with which the sequences are associated (Matalas and Jacobs 1964).

The data used in a correlation analysis should be reasonably homogeneous (Yevjevich, 1972). Heterogeneity in data can lead to spurious correlations. A high correlation between two variables does not mean that a cause and effect relationship exists between the two variables (Haan, 1977).

The fact that the peak flows on two streams are correlated, does not mean that a peak flow on one stream causes a peak flow on the second stream. It is more likely that the same external factors are operating on the two watersheds (Haan, 1977).

Spurious correlation can be caused by the clustering of data (Yevjevich, 1972). An example of spurious correlation can made through analyzing the monthly flows of two rivers. If the two rivers have concurrent wet and dry seasons, two distinct clusters of data will exist. Within the individual clusters, the correlation of the two sets of flows may be close to zero. If the wet month values are much higher then the dry month values, and the heterogeneity of the data is disregarded, the correlation for the entire data set can be large. This is spurious correlation (Haan, 1977).

Stream gage records can be correlated using linear regression analysis. If the correlation shows that the variables are linearly related, the linear relation allows the prediction of the dependent variable from the independent variable . A straight linear regression is generally fitted to the data populations analytically by the least squares method of deviations from the line (Yevjevich, 1972). The regression line is sometimes fitted graphically on the principle of minimizing the deviations from the line, by leaving the same amount of scattered points on each side of the line.

Once the regression relation is computed, it can be used to predict the values at the station with missing records. One is free to choose with which variable is taken as independent and which is dependent. If one station has N_1 observations, and the other $N_1 + N_2$ observations, it seems reasonable to use the longer record as the independent variable, to obtain estimates for the shorter record as the dependent variable (Yevjevich, 1972). The observed and estimated events (derived for the station of shorter record) can then be used as a lengthened record to gain estimates of magnitude and frequency of flood events by using frequency analysis.

The regression and correlation analysis is one of the oldest statistical techniques in hydrology (Yevjevich, 1972). It can be used to fill in missing data or extend the record of short stations. It is important to make sure that correlation is not spurious. Correlation should only take place between homogeneous events.

2.5 Open Channel Flow and Channel Geometry

Open channel flow involves a free surface, which is the interface between two fluids, water and the atmosphere (Chow, 1959). A free surface is subject to atmospheric pressure. Open channel flow is complicated by the fact that the free surface of the water may change with time. The discharge of the channel, depth of flow, and slope of the water surface will change with changes in the free surface.

Flow in open channels may be either laminar or turbulent, resulting in different velocity distributions. Laminar flow occurs when the Reynolds number is less then 500. Turbulent flow occurs when the Reynolds number is greater then about 2,000 (Gray, 1970). The Reynolds number is given by:

$$N_R = VR/v \qquad \text{(Eq. 2.14)}$$

where

V = the average flow velocity (ft/sec)

R = the hydraulic radius A/P (ft)

A = the flow area (sq ft)

P = the wetted perimeter (ft)

v = the kinematic viscosity (ft^2/sec)

Turbulent flow is the most common condition in most open channels, however laminar flow may occur during overland flow (Gray, 1970).

The Reynolds number describes the affect of viscosity relative to inertia. The flow is laminar if the viscous forces play a significant role in determining the flow behavior. In laminar flow, the viscous forces are strong relative to the internal forces of the flow. The flow is turbulent if the viscous forces are weak relative to the internal forces (Chow, 1959).

In laminar flow, the water appears to move in smooth paths or streamlines. In turbulent flow, the water appears to move in irregular paths, Between turbulent or laminar flow there is a mixed or transitional state.

The effect of gravity on open channel flow is expressed by the Froude number (Chow, 1959). The Froude number expresses the ratio of the internal to gravitational forces. The Froude number is given as:

$$F = V / (gD)^{0.5} \qquad \text{(Eq. 2.15)}$$

where

V = the mean velocity (ft/s)

g = the acceleration of gravity (ft/sec^2)

D = the hydraulic depth (ft)

The hydraulic depth (D) is defined as the cross-sectional area of the water normal to the direction divided by the width of the free surface.

When the Froude number equals unity, the flow is said to be critical. If the Froude number is less then one, the flow is subcritical. When the Froude number is greater then one, the flow is supercritical (Chow, 1959).

The Froude number describes the mechanics of water waves. Water waves may be created by a sudden change in the local depth of the water. Changes in the local depth may be caused by obstacles that displace the water above and below the mean water surface. This displacement creates a wave that exerts a weight or gravity force (Chow, 1959). A gravity wave can propagate upstream in water of subcritical flow, but not in water of supercritical flow (Chow, 1959).

Two other terms used to describe flow are steady flow and uniform flow. Steady flow occurs when the velocity at a point does not change with time. Uniform flow means the vector quantity of velocity does not change along a streamline (Chow, 1964).

Two equations for uniform flow in open channels are the Chezy and Manning Equation. The Manning Equation is commonly used in North America. In Europe, the Chezy Equation is popular (Gray, 1970). The Manning Equation is:

$$V = 1.49\ R^{.67}\ S^{0.5}\ /\ n \qquad \text{(Eq. 2.16)}$$

where

V = the mean velocity of flow (ft/s)

R = the hydraulic radius (ft)

S = the slope

n = the Manning's roughness factor

The Chezy equation is:

$$V = C\ [RS]^{0.5} \qquad \text{(Eq. 2.17)}$$

where

C = the Chezy discharge coefficient

The two equations are similar in form. A relation can be developed between the two equations (Gray, 1970).

$$C = 1.49\ R^{.17}\ /n \qquad \text{(Eq. 2.18)}$$

This equation indicates the Chezy discharge coefficient is a function of the Manning roughness factor and the hydraulic radius.

Several elements affect the value of Manning's roughness factor. Chow (1959) has listed the factors as boundary conditions, conditions of alignment and cross-section, and obstructions. Boundary conditions include the size and shape of bed and bank material, and the amount of vegetation. Prior flow conditions may affect the boundary conditions. For example, high flows may flatten vegetation lowering the value of Manning's roughness coefficient (Gray, 1970).

Secondary currents and turbulence are created by changing flow conditions. Changes in alignment, such as bends and meandering, and changes in the cross-sectional shape and size of the channel, increase the value of Manning's n over that of similar straight channels (Gray, 1970). Obstructions, such as fallen trees, increase the value of Manning's n. Table 2.2 gives values of Manning's n (Gray, 1970).

Professional judgement and experience are useful in applying a proper Manning's n value to a stream reach. Inexperienced hydrologist often have problems estimating n values when first working in the field.

When using the Manning equation for a section of a stream, a section should be chosen that is uniform through-out. Changes in the hydraulic character of the stream should not take place. Straight sections that are clear of debris and exhibit uniform flow conditions will have the most uniform values for Manning's n through-out. Manning's n values are only an approximation and should be chosen with care and evaluated as a possible source of error.

Table 2.2 Manning Roughness Coefficients for Streams

Stream Type	N Value
1. Clean straight, no rifts or pools	0.030
2. Same as above, more stones and weeds	0.035
3. Clean, winding, some pools and shoals	0.040
4. Same as above, more stones and weeds	0.045
5. Sluggish reaches, weedy, deep pools	0.070
6. Very weedy, deep pools, or heavy timber	0.100
7. Mountain streams, no vegetation, with steep banks	
a. Gravel, cobbles, and few boulders	0.040
b. Cobbles with large boulders	0.050

Source: Gray, D.M. Principles of Hydrology. Syosset, New York: Water Information Center.

In applying the Manning Equation, the greatest difficulty lies in determining the value of the roughness coefficient (Chow, 1959). Values may be estimated from tables or from pictures provided by the U.S.G.S.. Sound professional judgement and prior experience are helpful. Beginners often have problems applying a proper value. Selecting a value for the roughness coefficient is really a matter of estimating the channel's resistance to flow. Channels may have different values for different flow conditions.

Values can also be back-calculated using the other parameters in Manning's Equations. This data can be acquired through stream channel surveys. The channel can be mapped and values for the area and hydraulic radius calculated. Discharge is determined by multiplying average velocity by the cross-sectional area. The version of Manning' s Equation used is:

$$Q = 1.49\ A\ R^{.67}\ S^{.5}\ /\ n \qquad \text{(Eq. 2.19)}$$

where

A = the cross-sectional area (ft^2)

Q = the discharge (ft^3/sec)

Values for the discharge, cross-sectional area, hydraulic radius, and slope are determined from stream surveys. These values are inputted to equation 2.19 and the equation is solved for the roughness coefficient. The calculated value of n can be used to develop relationships between discharge the other parameters in the equation. This is done by varying the depth in the cross-section, and using the channel geometry to solve for the hydraulic radius and cross-sectional area. The Manning Equation solves for the discharge. Data can be plotted to show the relationships between discharge and the other parameters of Manning's Equation. The relationships can also be shown mathematically by developing equations to explain the variation of the channel parameters with depth. The equations are expressed as simple power functions (Bray, 1982) These equations usually have the form:

$$Q = aX^b \qquad \text{(Eq. 2.20)}$$

where

Q = the discharge (ft/s)

X = the selected channel parameter

a & b = constants

In choosing a site for a stream survey, the limitations of the Manning's Equation should be kept in mind. The site should display, as nearly as possible, uniform flow conditions. The flow of the streamlines should be parallel.

Within the chosen reach, the flow characteristics should not change. Flow discontinuities, such as waterfalls and channel obstructions, should be avoided. The stream gradient should be determined over a length several times greater than the channel width.

Velocity is not constant in the vertical profile of streams. Velocity is usually greatest at some point beneath the surface, and least at the channel bottom. A number of methods exist for estimating the average velocity in the field. The average velocity can be estimated by averaging measurements at 0.8 and 0.2 of the total depth. This is considered the best method be estimate average velocity (Gray, 1970). The average velocity can also be estimated as the velocity at 0.6 of the total depth.

Field techniques and the equations of open channel flow, such as Manning's Equation, can be used to quantify the hydraulic geometry of a channel reach. This method allows the development of relations between discharge and other flow attributes. These relations can be shown either graphically or mathematically.

Chapter 3

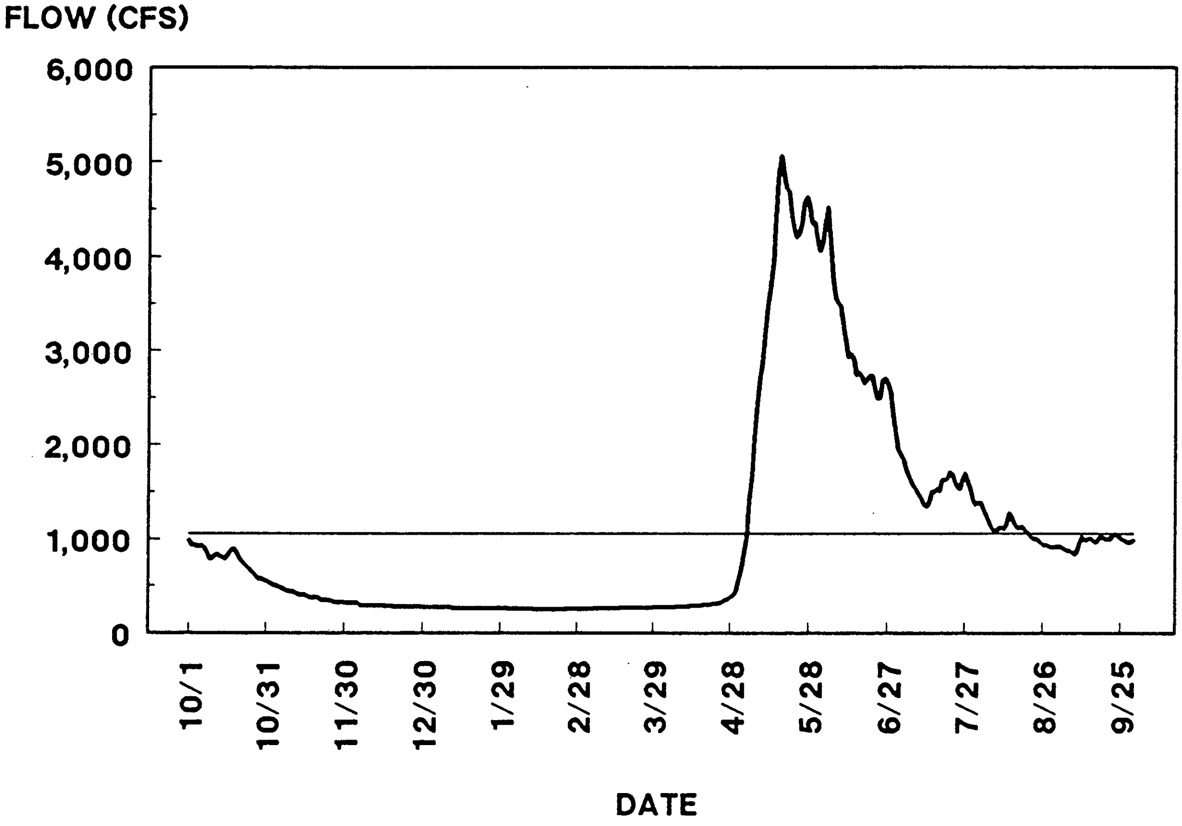
Hydrologic Analysis

3.1 Analysis of Existing Data

The existing data from the U.S.G.S. stream gage, at Sourdough, Alaska was used to develop hydrologic summaries for the Gulkana River. The gage was operated from October of 1973 through October of 1978, and May through September of 1982. The streamgage data was acquired through the use of the U.S. West database, Hydrodata, which is made up of U.S.G.S. streamgage data. A mean annual hydrograph was constructed by averaging the daily flows for the period of record. See Figure 3.1. Since the hydrograph is only based upon seven years of data, it may not represent an adequate description of the actual average flow conditions for the river.

The hydrograph can be regarded as the integral expression of the physiographic and climatic conditions that govern the relation between precipitation and runoff (Chow, 1964). The hydrograph represents the time distribution of runoff at Sourdough. Based on interruption of the

Figure 3.1 Average Annual Hydrograph at Sourdough, AK.



hydrograph, spring runoff begins towards the end of April. This would correspond to breakup of ice formed during the winter, and the beginning of snow melt. For approximately the next 10-15 days the river is rising. This period represents the rising limb of the hydrograph. Peak flow occurs in mid May. This main peak is from snowmelt runoff. After the mid May peak, the river is generally falling, as shown by the receding limb of the hydrograph.

The general recession of the hydrograph during this period is broken by a succession of abrupt short peaks. These peaks represent summer storms, which cause the river to rise. The response of the watershed to rainfall is rapid. This is due to the lack of infiltration caused by permafrost forming an impervious barrier to vertical flow. The effect of the permafrost layer is tempered somewhat by the storage of runoff by lakes and bogs. However, during our field study of the river, we experienced a extended period of rainfall and were able to witness rises in stage of one foot over a period of eight hours.

After computation of the mean annual hydrograph, the next step was to calculate the mean monthly flows for the Sourdough gage. This was done by averaging the daily flows for all the days of a month. The mean monthly flows for each year were then averaged. See figure 3.2.

The mean monthly flows represent a time series, like the average annual hydrograph, but with a longer sample interval. The start of the rising limb of the hydrograph in late April is masked, since the flows for the total month are averaged. May is the month of highest flows, with flows steadily decreasing afterward. January and February have the lowest flows of the year.

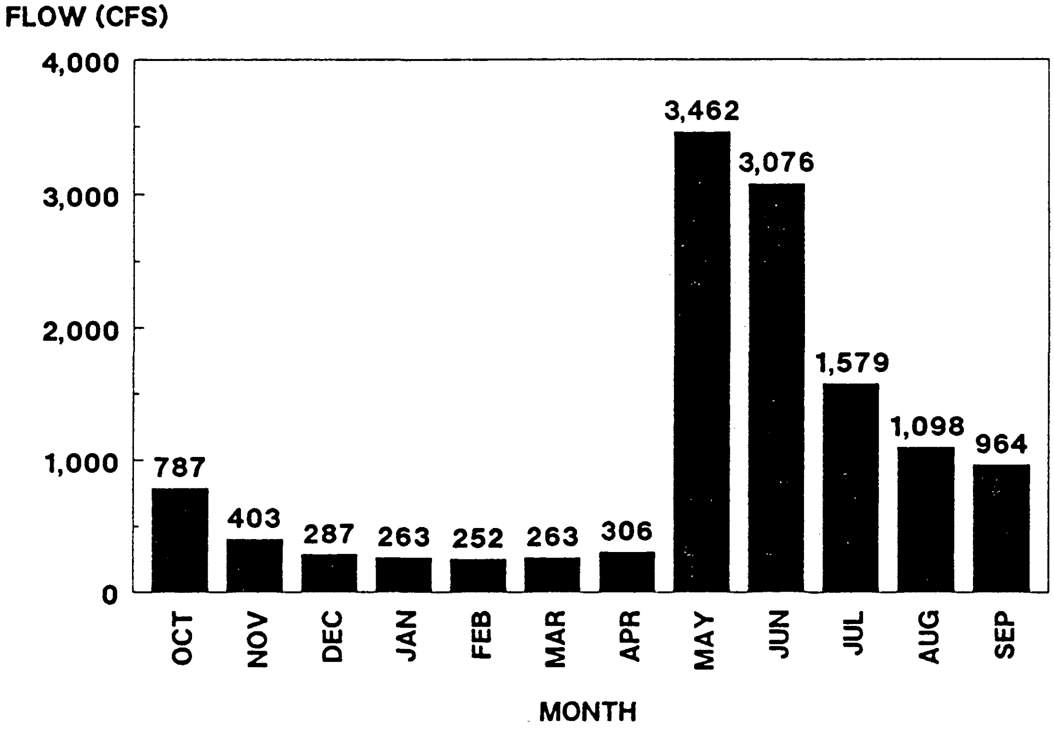
Since the data set representing a relatively short time period, it was decided to determine if flows during this period were representative of the longterm average flows of the river. An analysis was made of the Susitna River, near Gold, Alaska, to see if flows during the period of record on the Gulkana varied from the longterm average.

The Susitna lies due west of the Gulkana. The western part of the Lake Louise Plateau drains into the Susitna River. The West Fork of the Gulkana has its headwaters in the eastern portion of the Lake Louise Plateau. The streamgage on the Susitna had been operating for 35 years from 1950 to 1985. 1985 is the last year in the U.S. West database.

The mean monthly flows on the Susitna River were averaged for the entire period of record and for 1973-1978

Figure 3.2 Mean Monthly Flows

Gulkana River at Sourdough, AK.



and 1982 when the Gulkana gage was operating. A ratio was taken of the entire period of record to the shorter period. It was found that the flows for the 1973-1978 and 1982 period were lower for all the months except March and April. See Figure 3.3. The difference was most pronounced for the months of July, August, and September. See table 3.1.

Mean monthly flows for the Sourdough gage were corrected to account for the low flows occurring during 1973-1978 and 1982. This was done by adjusting the calculated mean monthly flows by the ratio found from the Susitna data. The corrected mean monthly flows for Sourdough are shown in figure 3.4. The numeric data is shown in table 3.2..

Flood frequencies were developed using the streamgage data. The seven years of data represented less than the recommended 10 years of peak flows recommended by the U.S.W.R.C. (1981). The weather was also known to be somewhat drier then the longterm norm. The Susitna correlation had shown that flows on the Gulkana during 1973-1978 and 1982 were approximately 91.3% of the Susitna's 35 year average. However, it was decided to compute the flood frequencies using the available data to provide a comparison with the synthetic flow data that was derived afterward. The

Figure 3.3 Mean Monthly Flows, Susitna River at Gold, AK.

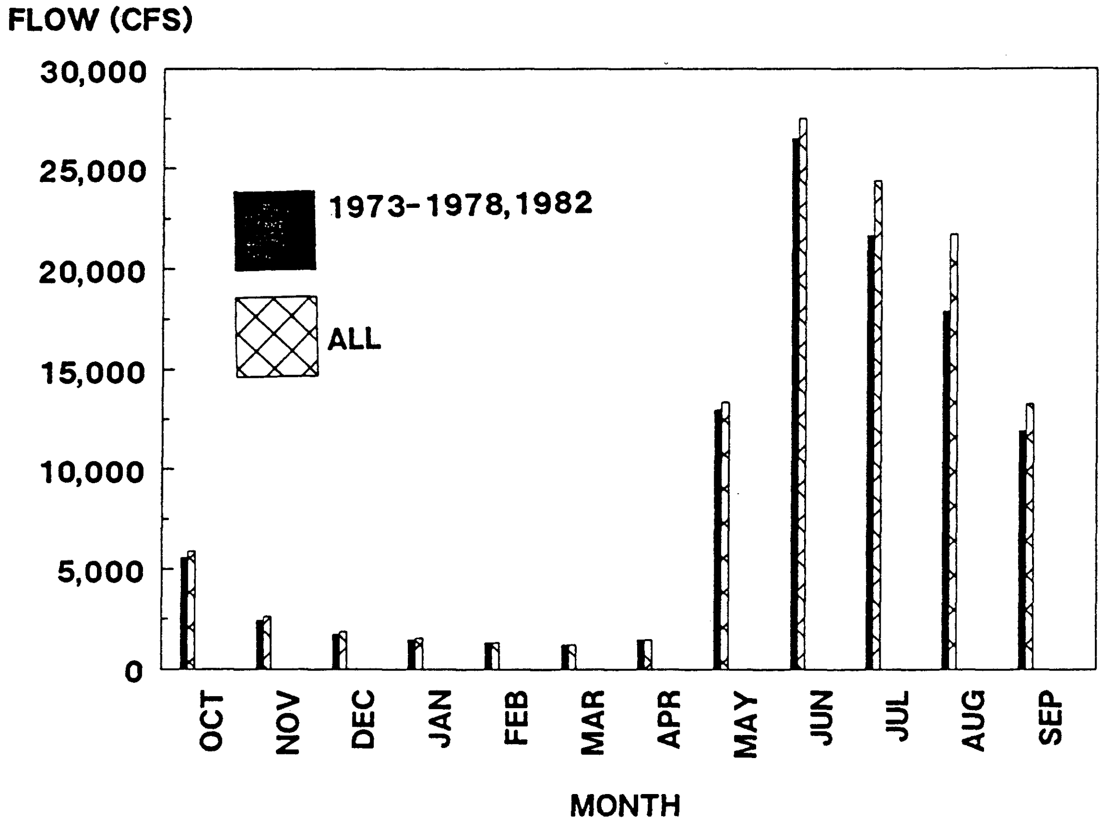


Table 3.1 Mean Monthly Flows, Susitna River at Gold, AK.

	1950-1985	1973-1978, 1982	RATIO
OCT	5,904	5,562	0.942
NOV	2,609	2,415	0.926
DEC	1,846	1,722	0.933
JAN	1,535	1,439	0.937
FEB	1,325	1,310	0.989
MAR	1,197	1,211	1.010
APR	1,450	1,450	1.000
MAY	13,363	12,988	0.972
JUN	27,499	26,497	0.964
JUL	24,375	21,673	0.889
AUG	21,758	17,900	0.823
SEP	13,296	11,933	0.898

Figure 3.4 <u>Corrected Mean Monthly Flows</u>

<u>Gulkana River at Sourdough, AK.</u>

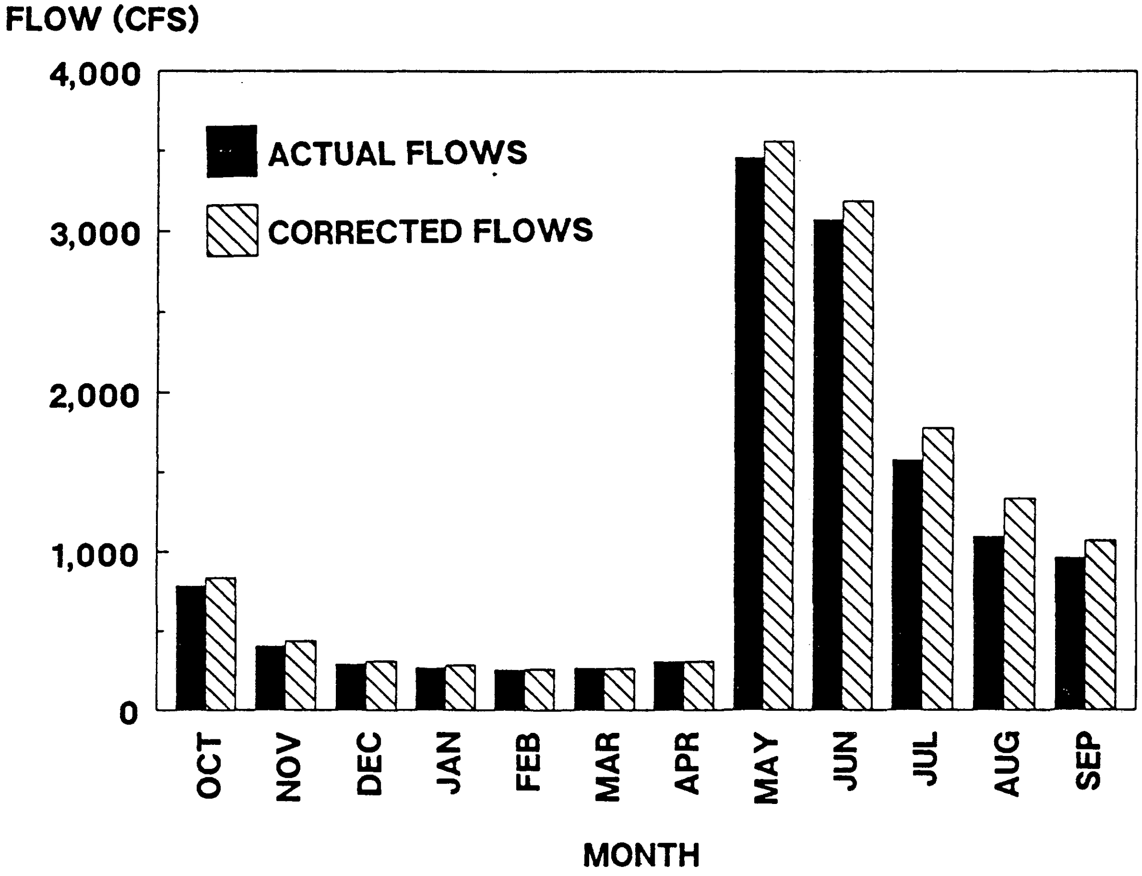


Table 3.2 Corrected Mean Monthly Flows
Gulkana River at Sourdough, AK.

	ACTUAL VALUES	CORRECTED VALUES
OCT	787	835
NOV	403	435
DEC	287	307
JAN	263	281
FEB	252	255
MAR	263	260
APR	306	306
MAY	3,462	3,561
JUN	3,076	3,191
JUL	1,579	1,776
AUG	1,098	1,334
SEP	964	1,073

magnitudes of the computed flood frequencies are given in table 3.3. Figure 3.5 shows the flood frequencies and the 95% confidence intervals. The computer program "fffreak", developed by U.S. West for use with Hydrodata, was used to calculate the flood frequencies. The program uses a log-Pearson Type III distribution according to the guidelines of Bulletin #17B (1983).

Flow durations were developed for the existing Sourdough data. Flow durations represent the magnitude of flow that is exceeded a certain percent of time. A flow of 1163 cfs was exceeded 90% of the time during the operation of the Sourdough gage. Ten percent of the time the flow at the Sourdough gage exceeded 4228 cfs. Table 3.4 lists the flow duration values for the Sourdough gage. The flow durations were calculated using "durfreak", an U.S. West program utilizing log-Pearson Type III distribution analysis.

Table 3.3 Flood Frequency Magnitudes for the Gulkana River from Streamgage Data Alone

	DISCHARGE (CFS)
2-YR FLOOD	8,040
5-YR FLOOD	8,880
10-YR FLOOD	9,220
25-YR FLOOD	9,520
50-YR FLOOD	9,680
100-YR FLOOD	9,790

Figure 3.5 Flood Frequency Magnitudes

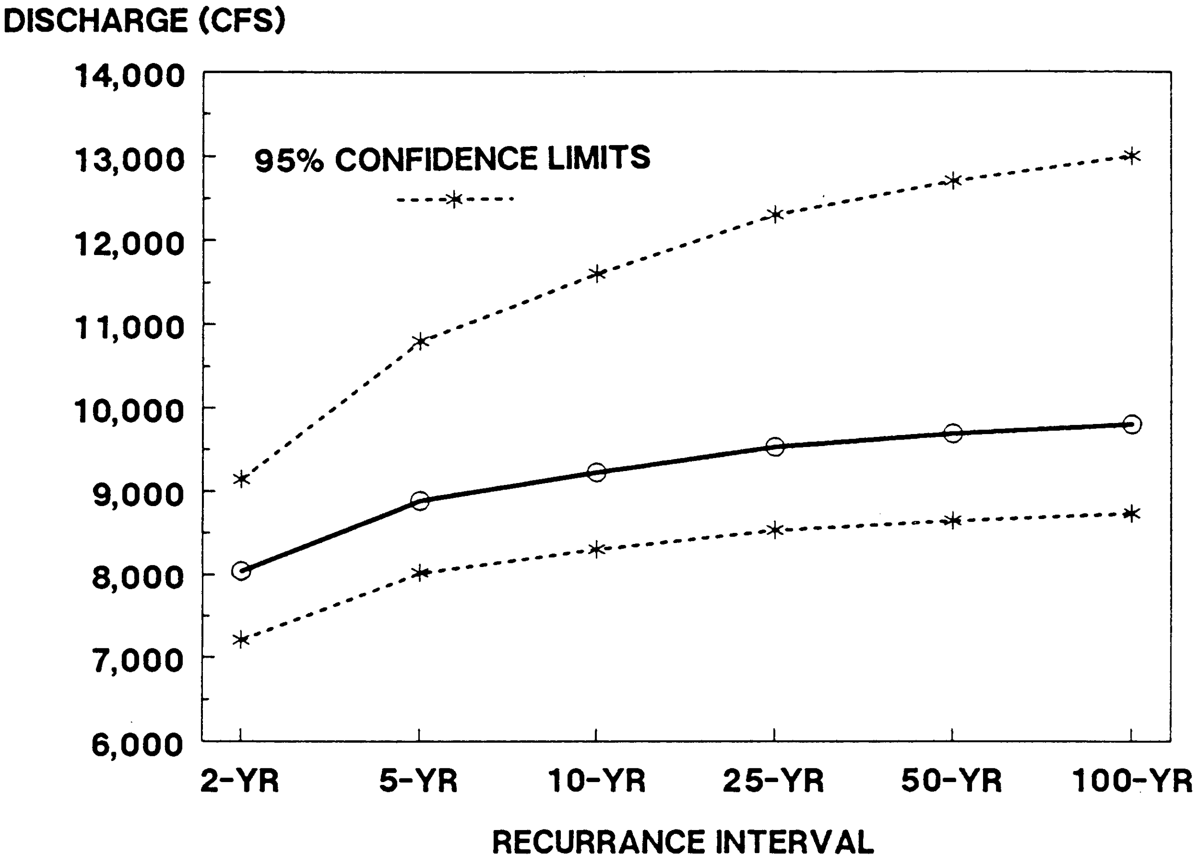


Table 3.4 Flow Duration Values

Gulkana River at Sourdough, AK.

	FLOW MAGNITUDE (CFS)
10% OF TIME EXCEEDED	4,228
25% OF TIME EXCEEDED	2,772
50% OF TIME EXCEEDED	1,811
75% OF TIME EXCEEDED	1,305
90% OF TIME EXCEEDED	1,163
30-DAY 10-YR LOWFLOW	198

3.2 Regional Analysis Results

Regional analysis was used to supplement the streamgage data at Sourdough. The regional analysis techniques used were those developed by Parks and Madison (1985). In order to perform the evaluation, basin area and mean annual precipitation were determined. The basin area was determined through digitizing a series of U.S.G.S. 7 1/2 minute quadrangles. This was made difficult by the extremely low relief of the Lake Louise Plateau. This area consists of chains of lakes and bogs, some of which may not have a direct hydrologic connection to the Gulkana River. The delineation was done with as much accuracy as possible. A basin area of 1759 square miles was calculated. The U.S.G.S. reports the watershed area as 1770 square miles. All of the calculations in this study used the 1759 value.

Mean annual precipitation values were taken from isohytel rainfall maps. An average value of 15 inches/ year was used. It seems likely that rainfall is not evenly distributed throughout the watershed. Areas of higher elevation probably receive more precipitation then do lower areas. The value of 15 inches/ year was chosen as a representative average for the entire basin.

Regional analysis equations were applied using watershed area and precipitation as independent variables. An estimation of flood flow values was also performed using mean annual flow as an independent variable. The mean annual flow was found by averaging the daily flows over the period of record of the Sourdough gage. The mean annual flow for the Gulkana River from 1973-1978 and 1982 was 1,063 cfs.

The 30-day, 10-yr low flows were also calculated using the equations developed by Parks and Madison (1985). The equations were used for both mean annual flow and watershed area/ precipitation as independent variables.

The equations for the regional analyzes were given in section 2.3.. The general form of the equation is:

$$\text{Log } y = a_1 + b_1 \text{Log} x_1 + b_2 \text{Log} x_2 \qquad \text{(Equation 3.1)}$$

where

y = the predicted flow magnitude

a = the regression constant

b = the regression coefficients

x = the basin characteristics

The values for the regression constants and coefficients are given in Table 2.1..

The results from the regional analysis are shown in table 3.5. Both sets of equations gave the same value for

Table 3.5 Flood Frequency Magnitudes

Gulkana River at Sourdough, AK.

From Regional Analysis

	AREA & PRECIPITATION	MEAN ANNUAL FLOW
2-YR FLOOD	4,897	6,456
10-YR FLOOD	9,772	9,772
25-YR FLOOD	11,481	12,303
50-YR FLOOD	12,883	13,804
100-YR FLOOD	15,135	15,135
30-DAY 10-YR LOWFLOW	195	74

the 100 year flood of 15,135 cfs. The equation using precipitation and watershed area as the independent variables gave a much lower value for the 2-year flood, 4897 cfs, as compared to 6,456 cfs predicted from the mean annual flow equation. Both equations also gave the same value for the 10-year flood of 9772 cfs. The values of the 25 and 50-years floods varied for the two equations by approximately 1,000 cfs, with the values predicted by the equation using watershed area and precipitation as independent variables being smaller.

The values predicted for the 30-day, 10-year low flow from the two equations were quite different. The watershed area and precipitation equation predicted a value of 198 cfs. The mean annual flow equation predicted 74 cfs.

The standard errors associated with the equations are quite large. The logarithms of the standard errors for the equations are given in table 2.1.. The standard errors range from 0.24 to 0.30 log base ten units. The equations predicting the longer return interval floods have the greatest error. The error in log units convert to 78 to 99.5% positive error, and 44 to 50% negative error. Though the errors associated with the equations are large they provide a means with which to compare other methods of flood magnitude determination.

3.3 Interstation Correlation

A streamgage correlation was developed between the Gulkana River record and the Susitna River, to lengthen the record of the Sourdough gage. The gaging station at Gold, Alaska on the Susitna River was chosen for the correlation. This site was chosen for a number of reasons. The streamgage record had the greatest amount of correlation with the Sourdough gage of all the stations analyzed. Other stations that were checked for correlation with the Sourdough gage included Squirrel Creek at Tonsina, the Tonsina River, the Copper River, and the Talkeetna River.

The Susitna is located, by Alaska standards, relatively close to the Gulkana. Both rivers are located in south-central Alaska, with the Susitna watershed directly west of the Gulkana Basin. The Susitna receives part of its runoff from the western portion of the Lake Louise Plateau. The eastern portion of the Lake Louise Plateau flows into the West Fork of the Gulkana.

The Susitna receives a large portion of its runoff from glacial melt. This is in contrast to the Gulkana which is dominated by snowmelt runoff. A glacial stream is not as susceptible to low flows caused by a lack of precipitation.

Glaciers provide a large pool of runoff storage that nonglacial streams do not have. A nonglacial stream would therefore be more susceptible to long periods of low flow.

These varying characteristics were considered when choosing the Susitna for the interstation correlation. The differences in the hydrologic regimes of the two rivers could result in a nonhomogeneous population and a spurious correlation. However, it was decided that this was not the case. The Susitna is subject to the same regional weather patterns as the Gulkana. The amount of precipitation that the basins receive is similar. The mean annual temperature ranges are also similar. Also the drainage basins of the two river are adjacent. The rivers both experience peak flows at the same time of year. These reasons justify using the Susitna at Gold station for the streamgage correlation.

A final factor affected the choice of the Susitna at Gold station. It was the Alaska situation. In Alaska, the general availability of streamgage data is extremely low, which is the entire reason for this study. The number of possible stations for analysis was low. All of the available stations in the Gulkana area were checked, and the Susitna was the best possible option. So while the Susitna may not have been the ideal choice, it was the best available.

The Susitna at Gold station meet the general qualifications listed in section 2.4 for performing a streamgage regression analysis. The events represented at both stations were independently distributed in time, and no changes in the hydrologic regime of either basin took place during the period of record of either station. The relation between the two stations was described by a linear regression. Some of the same external factors were acting on both basins.

The streamgage record from the Susitna at Gold station was checked against different types of distributions to see which type of frequency analysis best described the data. The distributions used were lognormal, type I extremal, Pearson type III, and log-Pearson type III. The log-Pearson type III distribution had the least amount of standard error associated with describing the distribution. Log-Pearson type III is recommended by the U.S.W.R.C. (1983) in Bulletin #17B and is used for all frequency analysis in this report.

The period of record at the Susitna at Gold station was from 1950 through 1985. For the regression analysis, the peak flows for the common years of record were used. The regression relation was used to extend the Gulkana record. The results were applied to a log-Pearson Type III analysis to produce a synthetic flood frequency distribution. The peak flows at the Sourdough and Gold stations are shown in table 3.6. The regression line and regression statistics for the correlation are shown in figure 3.6.. The correlation of these data was poor. However, the 1978 peak of the Susitna was anomalously low. The magnitude of the 1978 peak was 1.6 standard deviations from the mean. The analysis was reperformed with out 1978 data. Figure 3.7 shows the regression line for the correlation without the 1978 data. The regression without the 1978 data had a very strong correlation. The correlation coefficient was 0.83 for the regression. The values predicted from the correlation without the 1978 data were used for the synthetic flood flow analysis. The probable reason for the low flow on the Susitna is a cool overcast summer that did not produce much glacial runoff.

The peak flows predicted from the streamgage correlation were applied to a log-Pearson Type III analysis. The results of this analysis are shown in table 3.7. The magnitudes predicted ranged from 7704 cfs for the 2-year flood to 22,207 for the 100-year flood.

Table 3.6 Peak Flow Magnitudes

	GULKANA DATA	SUSITNA DATA
1973	8,840	54,100
1974	6,750	37,200
1975	8,110	47,300
1976	3,850	35,700
1977	9,170	54,300
1978	7,970	25,000
1982	4,820	37,900

Figure 3.6 <u>Streamgage Correlation</u>

<u>Gulkana River at Sourdough</u>

<u>Susitna River at Gold, Ak.</u>

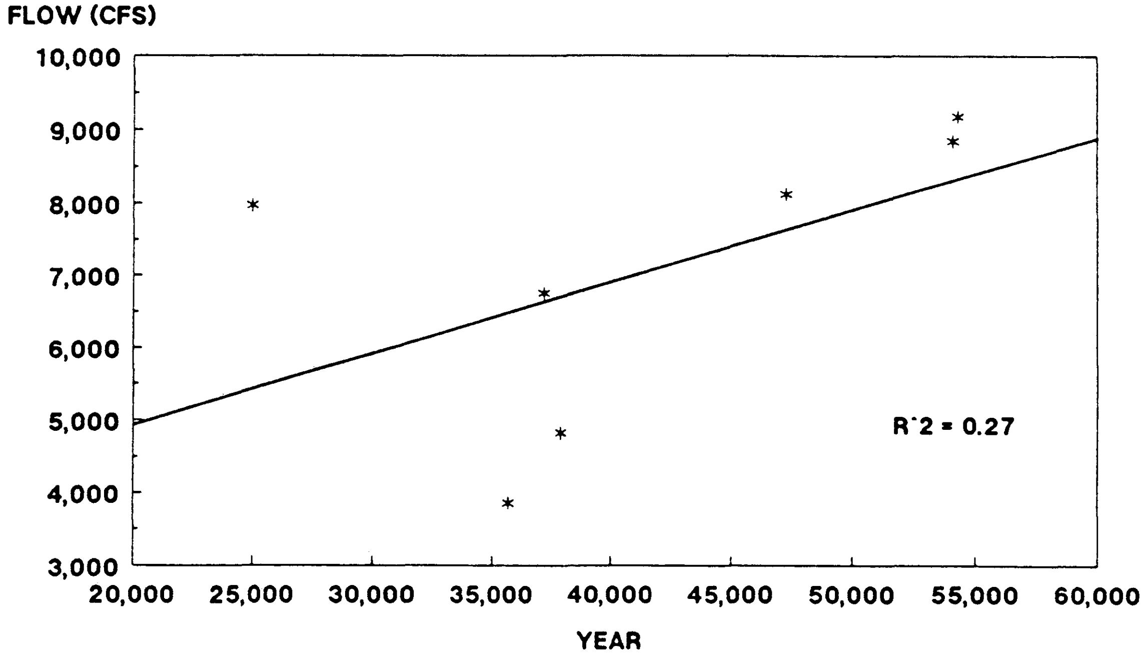


Figure 3.7 Streamgage Correlation With Out 1978 Values

Gulkana River at Sourdough

Susitna at Gold, AK.

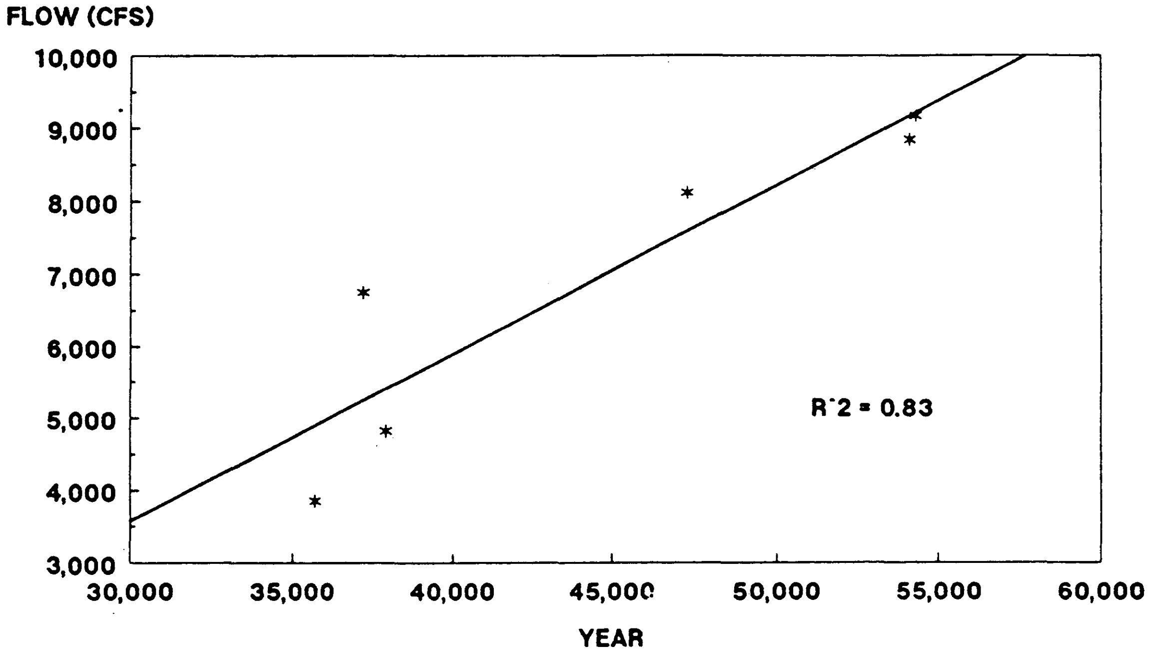


Table 3.7 Flood Frequency Magnitudes From Streamgage Correlation

	FLOW MAGNITUDE (CFS)
2-YR FLOOD	7,704
10-YR FLOOD	13,538
25-YR FLOOD	16,844
50-YR FLOOD	19,456
100-YR FLOOD	22,207

3.4 Channel Geometry Analysis

Channel geometry analysis was used to develop relations between discharge and flow attributes. Relations were developed between discharge and depth, wetted perimeter, velocity, and cross-sectional area. These descriptions are important components of an instream flow assessment. Understanding the hydraulic geometry of a river segment, allows the prediction of effects of alternative discharges on flow attributes. For example, by computing the relationship between discharge and wetted perimeter, predictions of affects of alternative discharges on fish habitat can be made. Depths and velocities are also important indicators of fish habitat and relations between these attributes and discharge are useful in habitat assessment. Channel width relations can also be developed and used to assess the quality of recreational boating and river aesthetics at alternative discharges. Channel geometry analysis supported the assessment of resource values during the Gulkana River Instream Flow Study.

River surveys were conducted at thirty-three sites within the river study corridor. These surveys were used to map channel features. Velocities were measured using a

Marsh-McBirney current meter. Discharges were calculated using mean velocities and channel cross-sectional area.

The Manning Equation was used to develop hydraulic geometry relations. Manning "n" values were back-calculated using discharges at the time of survey. The form of the Manning Equation used was:

$$Q = 1.49\ R^{.67}\ S^{0.5}\ A\ /\ n \qquad \text{(Equation 3.2)}$$

where

Q = discharge

R = hydraulic radius

A = cross-sectional area

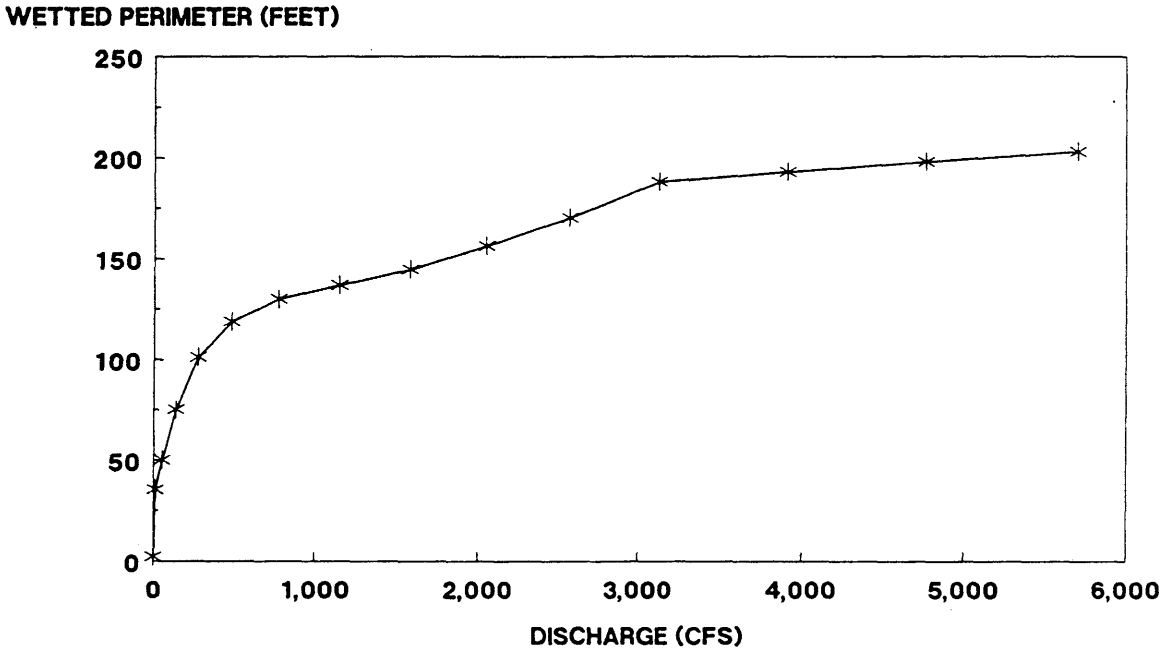
S = slope

n = Manning's roughness coefficient

Wetted perimeters are considered an important indicator of the availability of fish habitat. The inflection point of the discharge vs. wetted perimeter graph is a critical flow level, below which fish habitat is lost rapidly. An example of the use of this technique is the channel geometry analysis from river mile 40 on the Mainstem of the Gulkana River. See figure 3.8.

The inflection point of the graph occurs at approximately 3,100 cfs. At flows below this level wetted perimeters drop off rapidly. Flows of 3,100 cfs would be

Figure 3.8 Discharge vs. Wetted Perimeter



considered a critical flow level.

Regression analysis can also be used to describe discharge and wetted perimeters. The basic form of hydraulic geometry relations consists of a simple power function (Bray, 1982). The equation used is a power function of the form:

$$Y = aX^b \qquad \text{(Equation 3.3)}$$

where:

Y = the dependent variable

X = the independent variable

a = the regression coefficient

b = the regression exponent

The regression line for the wetted perimeter and discharge relationship is shown in figure 3.9. The equation for the line is:

$$Y = 13.1961\ X^{0.3329} \qquad \text{(Equation 3.4)}$$

where:

Y = wetted perimeter (ft)

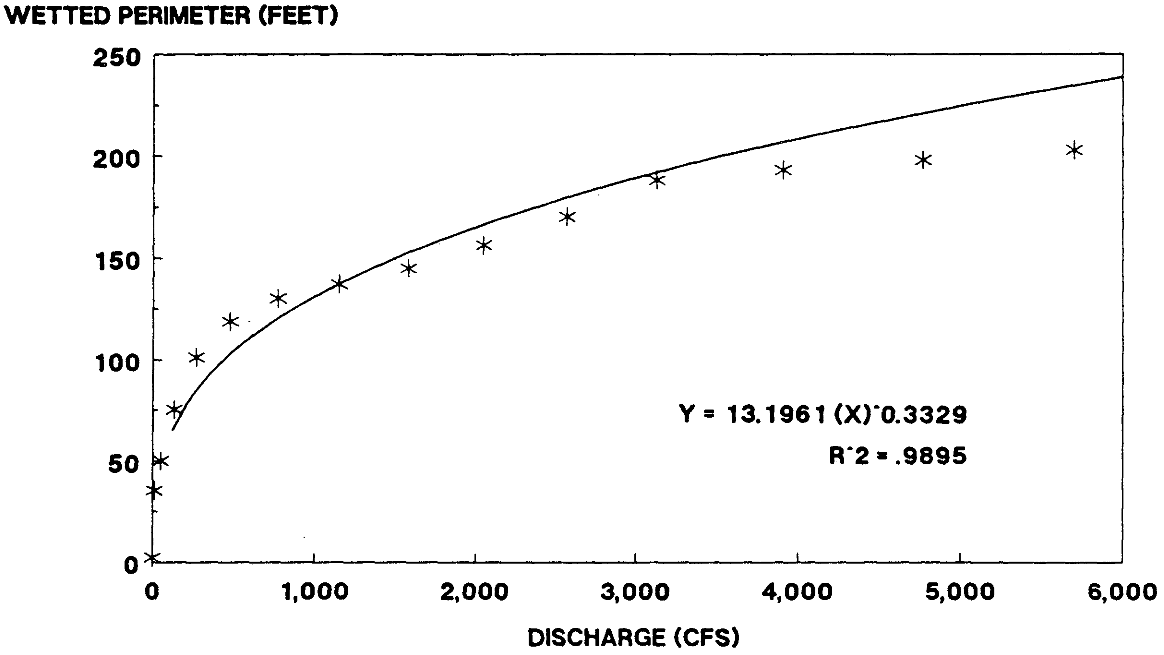
X = discharge (cfs)

The coefficient of correlation (r^2) is 0.9895. This shows a very strong correlation.

These equations and graphs are used to describe the "at-station hydraulic geometry" of the river. The at-station

Figure 3.9 Regression Analysis

Discharge vs. Wetted Perimeter



hydraulic geometry explains how the river behaves at a site on the river. The example above is on the Mainstem of the Gulkana at river mile 40. This is approximately 2 miles above the Sourdough streamgage. Hydraulic geometry relations were also developed for discharge and velocity, cross-sectional area, and depth at river mile 40.

Relations between discharge and depth were developed by the same methods as used in the wetted perimeter analysis. A depth of approximately 5 feet corresponds to a discharge of approximately 485 cfs. At a stage 13.7 feet, the discharge of equal approximately 5,700 cfs. See figure 3.10. Figure 3.11 shows the regression line describing the discharge and depth relationship. The equation of the line is:

$$Y = 0.4999\ X^{0.3751} \qquad \text{(Equation 3.5)}$$

where

Y = depth (ft)

X = discharge (cfs)

$R^2 = 0.9975$

The correlation for this regression is very strong.

The relation for discharge and cross-sectional area is shown is figure 3.12. At 775 cfs, a cross-sectional area of 440 square feet exists, above this point the relation between cross-sectional area and discharge is nearly linear.

Figure 3.10 Discharge vs. Depth

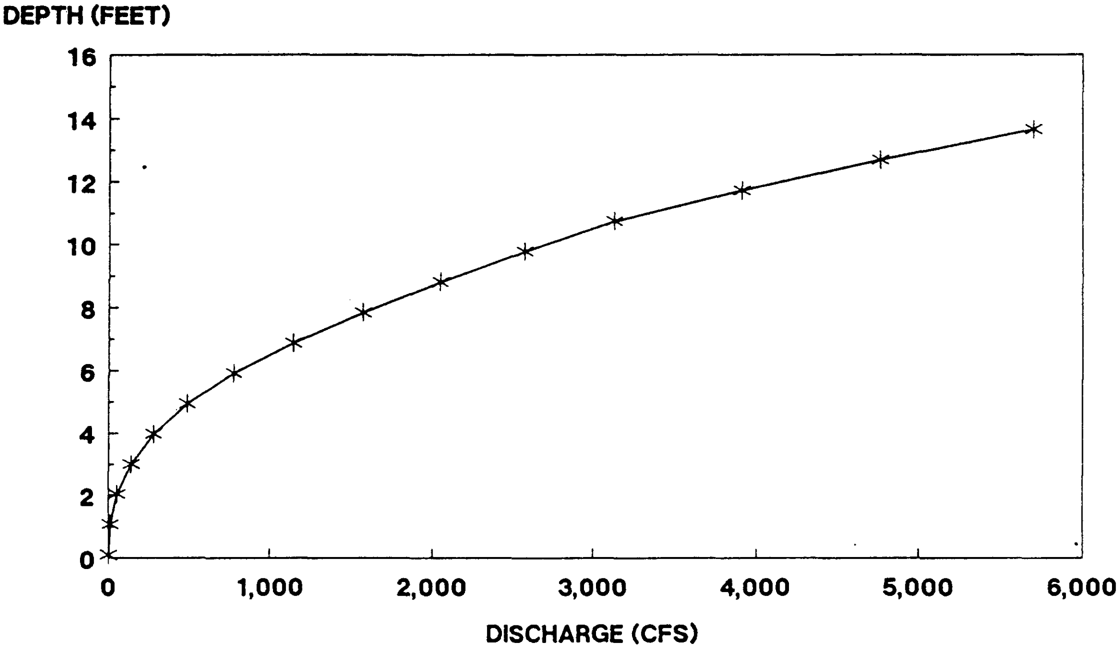


Figure 3.11 Regression Analysis

Discharge vs. Depth

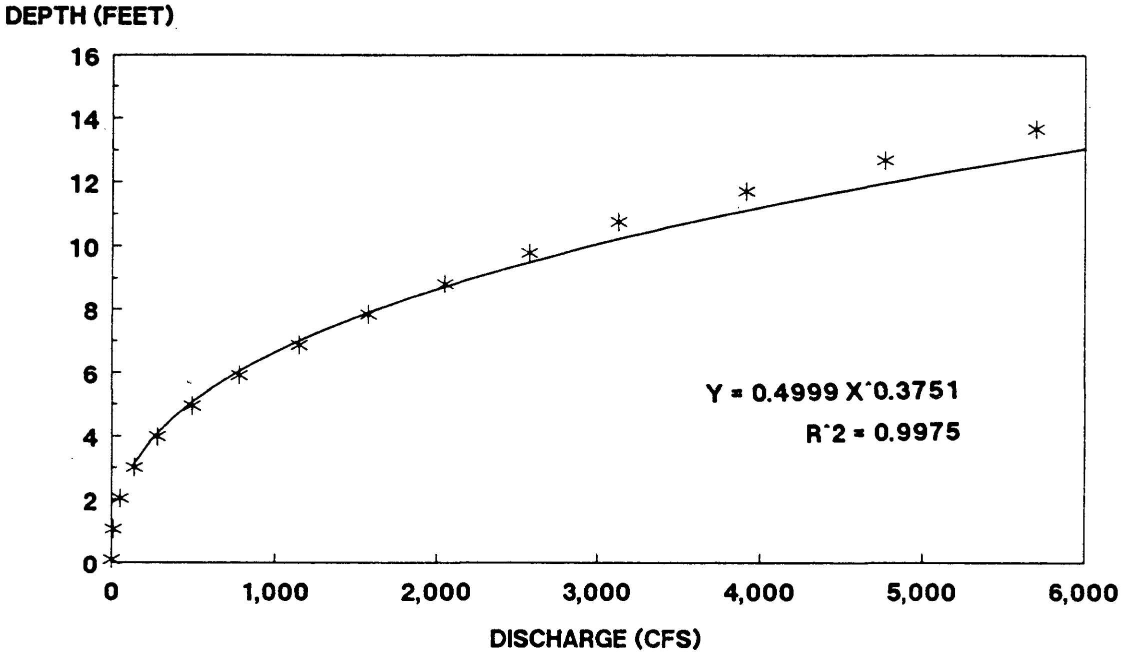
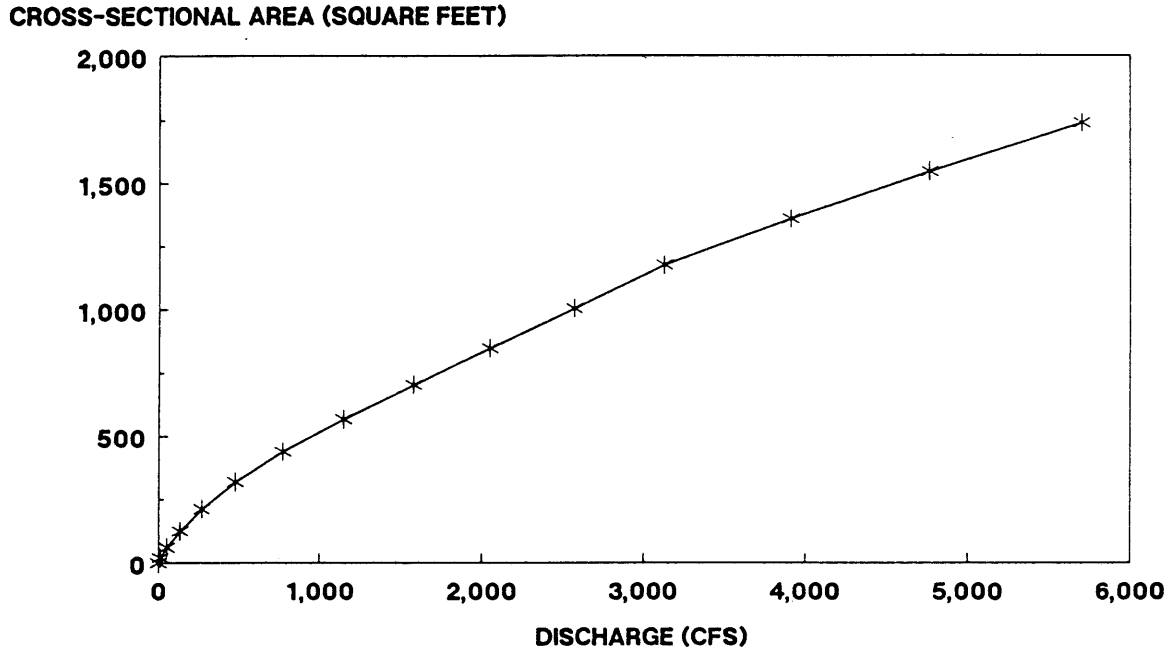


Figure 3.12 <u>Discharge vs. Cross-Sectional Area</u>



The regression line is shown in figure 3.13. The equation for the line is:

$$Y = 3.442\ X^{0.7249} \qquad \text{(Equation 3.6)}$$

where

Y = cross-sectional area (ft^2)

X = discharge (cfs)

$R^2 = 0.9998$

The correlation of this relationship is very close to an ideal value of 1.

The discharge and velocity data are shown in figure 3.14. A noticeable inflection occurs at approximately 2.65 ft/s. After this point the slope of the line is much steeper. The regression line does not fit this part of the data well. The regression line is shown in figure 3.15. The equation for the line is:

$$Y = 0.3199\ X^{0.2612} \qquad \text{(Equation 3.7)}$$

where

Y = velocity (ft/s)

X = discharge (cfs)

$R^2 = 0.9959$

Channel geometry analysis is useful for developing relations between discharge and flow attributes. These relations can be described graphically or through regression

Figure 3.13 <u>Regression Analysis</u>

<u>Discharge vs. Cross-Sectional Area</u>

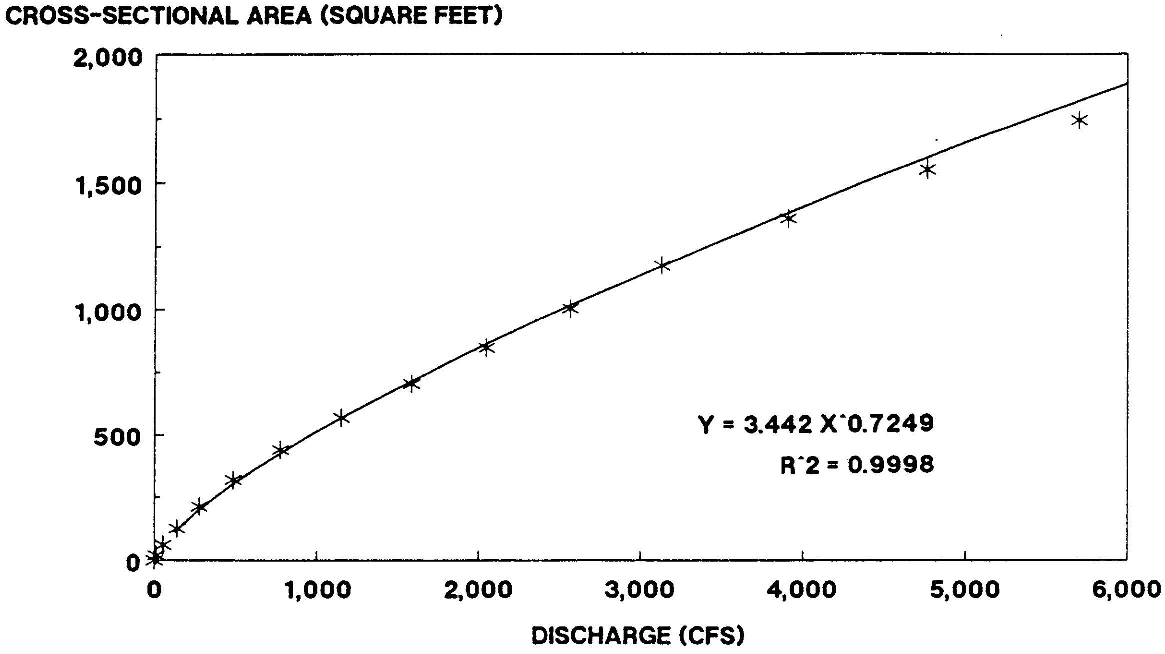


Figure 3.14 Discharge vs. Velocity

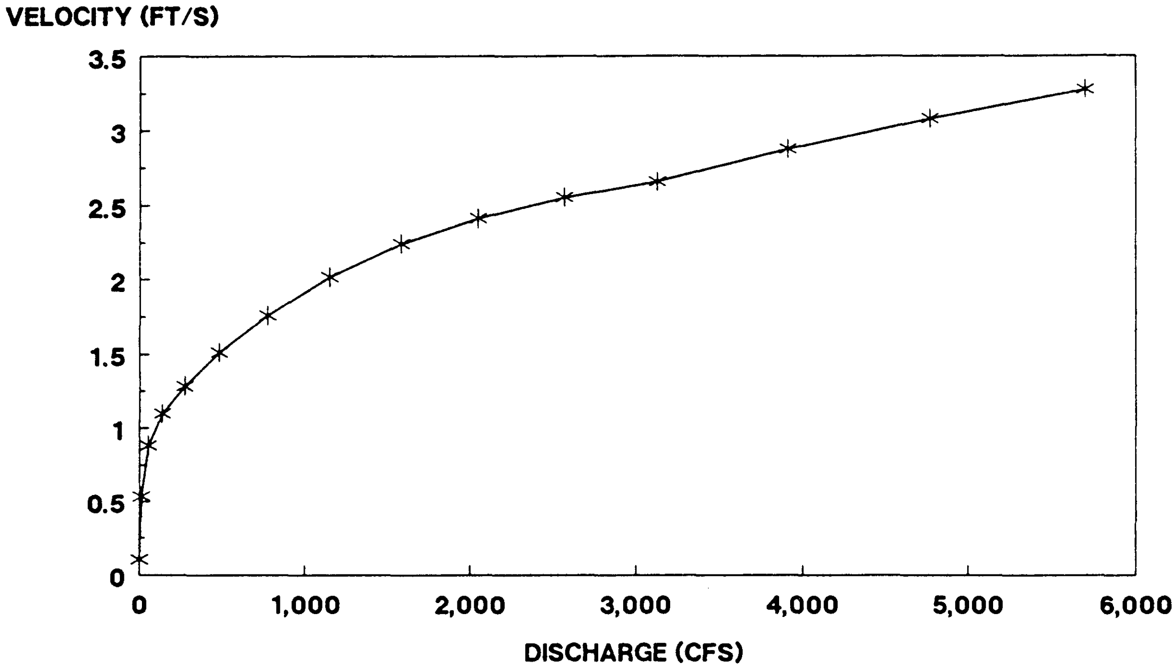
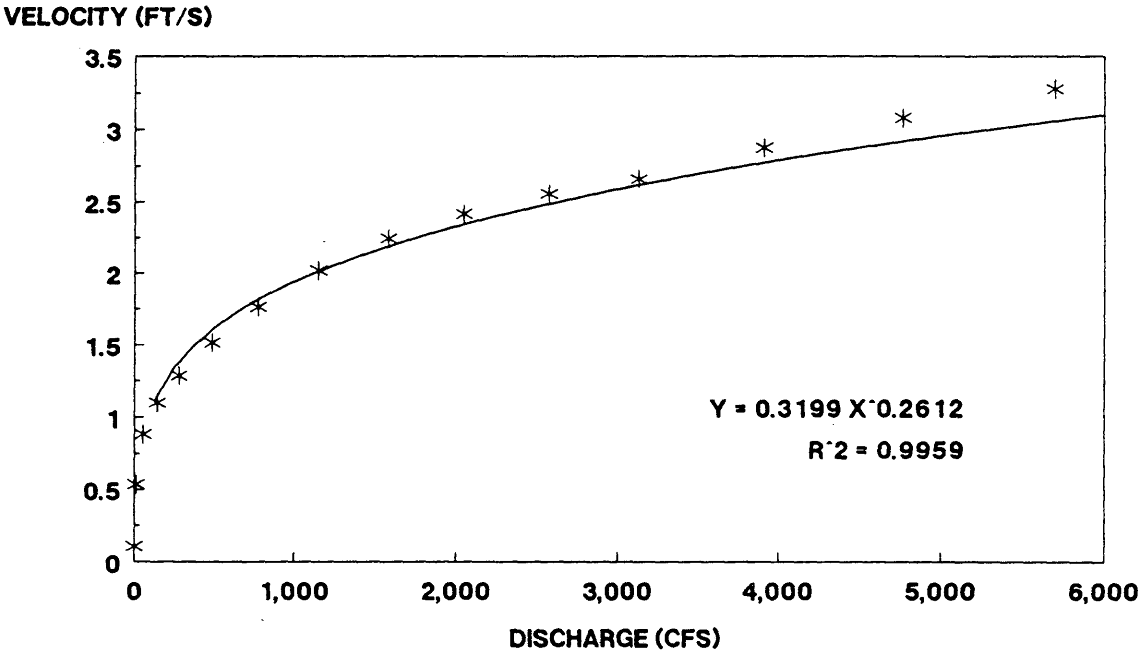


Figure 3.15 Regression Analysis

Discharge vs. Velocity



analysis. Channel geometry relations help predict the affect of alternative discharges on resource values.

Chapter 4

Conclusions

4.1 Differences from Flood Frequency Methodologies

The different methodologies used to calculate flood frequency magnitudes produced varying results. The three methods used were direct calculation from Sourdough streamgage data, indirect calculation using synthesized data from a streamgage correlation, and regional methods using basin characteristics as independent variables to predict flow magnitudes. Direct calculation from the Sourdough data was a stochastic process and uses a theoretic probability distribution to predict flows. Calculation from a synthesized streamgage record was both a stochastic and deterministic prediction. Regional equations use a deterministic approach to streamflow prediction, with basin characteristics determining streamflows. All of these methods have errors and uncertainties associated with them. By combining the three approaches, an accurate prediction of streamflows was made.

Table 4.1 shows the results of the different methodologies. The magnitudes of the 2, 10, 25, 50, and 100-year flows were predicted. The lowest value for the 2-year flow was predicted using regional analysis with mean annual precipitation and watershed area as the independent variables. The highest values, for all the flood flows, were predicted using the synthetic streamflow record from the streamgage correlation with the gage at Gold, Alaska on the Susitna River. Both regional analysis equations predicted the same magnitudes for the 10 and 100-year floods, of 9772 and 15,135 cfs respectively. The record from the Sourdough gage predicted the lowest magnitudes for the longer return interval flows.

Understanding the factors affecting the results of the different methods allows determination of the relevance of the results. The regional analysis equations were developed by studying streams in Alaska to develop equations to predict streamflows. This method would be biased toward the larger streams, since these are more often gaged in Alaska. The equations also have a large degree of certainty (Parks and Madison, 1985).

The equations based on watershed area and mean annual precipitation have errors associated with the determination

Table 4.1 Comparison of Flood Frequency Magnitudes

	2-YR. FLOW (CFS)	10-YR. FLOW (CFS)	25-YR. FLOW (CFS)	50-YR. FLOW (CFS)	100-YR FLOW (CFS)
REG. ANALYSIS #1	6,456	9,772	12,303	13,804	15,135
REG. ANALYSIS #2	4,827	9,772	11,481	12,883	15,135
SYNTHETIC RECORD	7,704	13,538	16,844	19,456	22,207
SOURDOUGH RECORD	7,154	9,841	10,647	11,101	11,459

REG. ANAL. #1 USES MEAN ANNUAL FLOW AS VARIABLE
REG. ANAL. #2 USES AREA & RAINFALL AS VARIABLES

of those variables. The watershed area, of the Gulkana Basin, was difficult to determine due to low relief. Mean annual precipitation is not constant within the Gulkana basin. The prediction for the 2-year flow from this equation was 2,000 to 3,000 cfs lower than the other methods.

Regional analysis using mean annual flow as an independent variable predicted flow magnitudes that were consistently between the extremes predicted from the other methods. Parks and Madison (1985) recommend using the mean annual flow, to predict streamflows, when 5 or more years of data exist. Seven years of data existed on the Gulkana. However, it was known from streamgage analysis that these values were lower then the long term norm.

Analysis using the Sourdough data alone produced low results for the higher magnitude floods. The Sourdough analysis was based on 7 years of data. The United States Water Resources Council (1981) recommends 10 years of streamgage data. The data was known to represent a dry period. The Sourdough data produced values for the 2 and 10 years floods within the extremes of the values predicted.

The results from the Susitna at Gold streamgage correlation were the highest of all the methods. The Susitna is a glacial stream and is not as prone to drought induced lowflows as a nonglacial stream. Local variations in basin characteristics and precipitation produce different runoff conditions on the Susitna than the Gulkana.

The factors affecting the outcomes of the different methods were considered when determining a final prediction. In general, the streamgage correlation data was known to be to high and the Sourdough data to low. The Sourdough date for the 2 and 10 year flows was consistent with the other methods. Of the two regional analyzes, using mean annual flow gave the most consistent results with the other methods. Mean annual flow was also known with more accuracy then mean annual precipitation.

The final determination was made by averaging the streamgage correlation data and the Sourdough data for the 2 and 10 years flows. The 25, 50, and 100 year flows were determined by averaging the streamgage correlation data and the regional analysis data using mean annual flow as the independent variable. The streamgage correlation data was used since it represented the high end of the predictions. The Sourdough data was used since 7 years of data were likely to make good predictions for the lower magnitude events, and because of the internal consistency of these predictions with the other results. The results predicted from this method were between the extremes of the values predicted for all flows. The longer return interval flows from the Sourdough data were invalid, since the period of record was to short to predict them. Regional analysis using mean annual flow had the most internal consistency of all the techniques used. Table 4.2 shows the results of the final determination for flood frequency magnitudes.

The predicted 100-year flow averaged between 3-4 times the magnitude of the mean annual peak discharge. This is due, in part, to the buffered nature of the watershed. The buffering is produced by the large amount of muskeg and a few large lakes.

Table 4.2 Predicted Flood Frequency Magnitudes

	2-YR. FLOW (CFS)	10-YR. FLOW (CFS)	25-YR. FLOW (CFS)	50-YR. FLOW (CFS)	100-YR FLOW (CFS)
PREDICTED VALUES	7,429	11,690	14,574	16,630	18,671

4.2 Transformation of Data

Once the final determination for the flood frequencies was made, the next task was to move the data to upstream points on the river corridor. The flood frequency magnitudes developed in section 4.1, and the flow durations from section 3.1 represented the magnitudes at the Sourdough streamgage. Upstream flow magnitudes were needed in order to determine instream flow needs. Points of interest included the confluence of the West Fork and Mainstem, the confluence of the North and South Branch of the West Fork, the Middle Fork confluence with the Mainstem, and the outlets of Dickey and Paxson Lakes.

The method used weighted the flow magnitudes according to the percentage of watershed area contributing to flow at that point. Flow magnitude at Sourdough was multiplied by the ratio of watershed area taken to a power determined from Parks and Madison (1985). See equation 4.1.

$$Y = X\ (\text{watershed area at } X \ / \ \text{area at } Y)^{a} \qquad \text{(Equation 4.1)}$$

where

Y = the flow magnitude at some point

X = the flow magnitude at Sourdough

a = a weighting factor from Parks and Madison

The weighting factors from Parks and Madison (1985) were the exponential values used for determination of flood frequencies from watershed areas.

The flood frequency values determined are shown in Table 4.3. Two year flows ranged from 399 cfs, at Dickey Lake, to 7,429 cfs at Sourdough. The 100-year flow ranged from 18,700 cfs at Sourdough to 1,503 cfs at the Dickey Lake outlet.

Mean monthly flows were moved to upstream points using the same methods. Magnitudes of the mean monthly flows are shown in Table 4.4. February flows ranged from 10 cfs at the Dickey Lake outlet, to 255 cfs at the Sourdough gage. May flows averaged from 3,561 cfs at Sourdough to 192 cfs at Dickey Lake.

Flow duration values from the Sourdough gage were transferred to upstream points. Watershed area weighting methods were used to move the data upstream. Values for the median (50% flow) were 1,811 cfs at Sourdough and 72 cfs at the Dickey Lake outlet. Flows exceeded 90% of the time were 1,163 cfs at Sourdough, 166 cfs at the Middle Fork confluence, 669 at the West Fork confluence, and 46 cfs at Dickey Lake. Table 4.5 shows the flow duration values.

Table 4.3 Upstream Magnitude of Flood Frequency Values

	2-YR. FLOW (CFS)	10-YR. FLOW (CFS)	25-YR. FLOW (CFS)	50-YR. FLOW (CFS)	100-YR FLOW (CFS)
DICKEY LAKE OUTLET	399	767	1,026	1,247	1,503
PAXSON LAKE OUTLET	1,155	2,065	2,693	3,196	3,757
MID. FORK CONFLUENCE	1,270	2,258	2,937	3,477	4,079
WEST FORK CONFLUENCE	4,501	7,332	9,264	10,655	12,142
S. BRANCH WEST FORK	963	1,744	2,283	2,721	3,213
N. BRANCH WEST FORK	1,203	2,146	2,795	3,314	3,893

Table 4.4 Upstream Magnitudes of Mean Monthly Flows

	DICKEY LAKE OUTLET	PAXSON LAKE OUTLET	MID. FORK CONFLUENCE	WEST FORK CONFLUENCE	S. BRANCH WEST FORK	N. BRANCH WEST FORK
OCT.	33	107	119	480	109	88
NOV.	17	56	62	250	57	46
DEC.	12	39	44	177	40	32
JAN.	11	36	40	162	37	30
FEB.	10	33	36	147	33	27
MAR.	10	33	37	150	34	27
APR.	12	39	43	176	40	32
MAY	192	552	609	2,158	570	463
JUN.	172	495	546	1,934	511	415
JUL.	71	227	252	1,018	231	186
AUG.	53	171	161	767	173	140
SEP.	43	137	152	617	139	113

Table 4.5 Average Daily Flow Durations

	10 PERCENT EXCEEDED	25 PERCENT EXCEEDED	50 PERCENT EXCEEDED	75 PERCENT EXCEEDED	90 PERCENT EXCEEDED
DICKEY LAKE OUTLET	168	110	72	52	46
PAXSON LAKE OUTLET	542	355	232	167	149
MID. FORK CONFLUENCE	602	395	258	186	166
WEST FORK CONFLUENCE	2,433	1,595	1,042	751	669
S. BRANCH WEST FORK	567	372	243	175	156
N. BRANCH WEST FORK	443	290	190	137	122

4.3 Field Validation of Bankfull Flows

The final step in the flood frequency determination process was the field validation of bankfull flows. According to the literature bankfull flows should be reached from every 1.5 to 2 years. Wolman and Leopold (1957) found that a bankfull flow occurs every 1 to 2 years. Emmett (1972) predicted a bankfull flow every 1.5 years from studying streams in the Copper River and Yukon basin. Parks and Madison (1985) use of value of 2 years for the recurrence of bankfull flows. Many factors affect the recurrence interval of bankfull flows in Alaska including the occurrence of permafrost and ice in bank and bed materials which can cause streams to more readily overflow their banks (Scott, 1978). The same basin and climatic factors that affect flood peaks affect the recurrence of bankfull flows (Riggs, 1978), and therefore the recurrence of bankfull flows will vary from basin to basin. The two year estimate of Parks and Madison (1985) will be used in this report.

Using channel survey methods, bankfull flows can be calculated. These flows can then be compared to the results of the predicted flood flow values. In this manner, a determination can be made if the calculated flood flows are reasonable given the bankfull flow magnitudes. This provides a rough check of the derived flood frequency magnitudes against actual field data. The limit of bankfull flows are determined in the field from breaks in the bank slope, the limits of permanent vegetation, and the edges of the flood plain (Riggs, 1978).

Stream channel surveys were conducted at some of the locations for which flood flows were determined. The bankfull flows were calculated by extending the stream channel surveys to the top of the channel banks. The Manning Equation was then used to determine the flows at bankfull stage.

Bankfull flows were calculated from field data from the outlet of Paxson Lake, the Middle Fork confluence with the Mainstem, and the West Fork confluence with the Mainstem. Figure 4.1 shows the cross-sectional profile of the river at the Paxson Lake Outlet. At the bankfull stage, the water surface is approximately 4.5 feet above the channel low point. This corresponds to a flow of approximately 1,300 cfs. See figure 4.2. The predicted 2-year flow at the Paxson Lake Outlet is 1,155 cfs.

Figure 4.1 <u>Cross-Sectional Profile</u>

<u>Outlet of Paxson Lake</u>

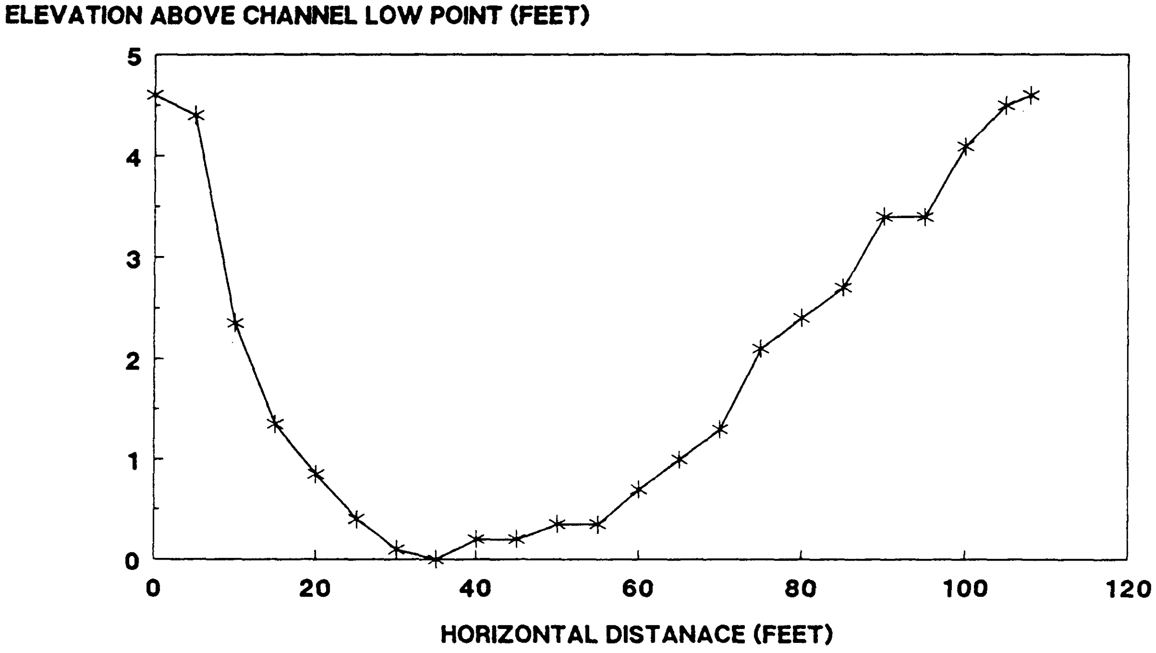
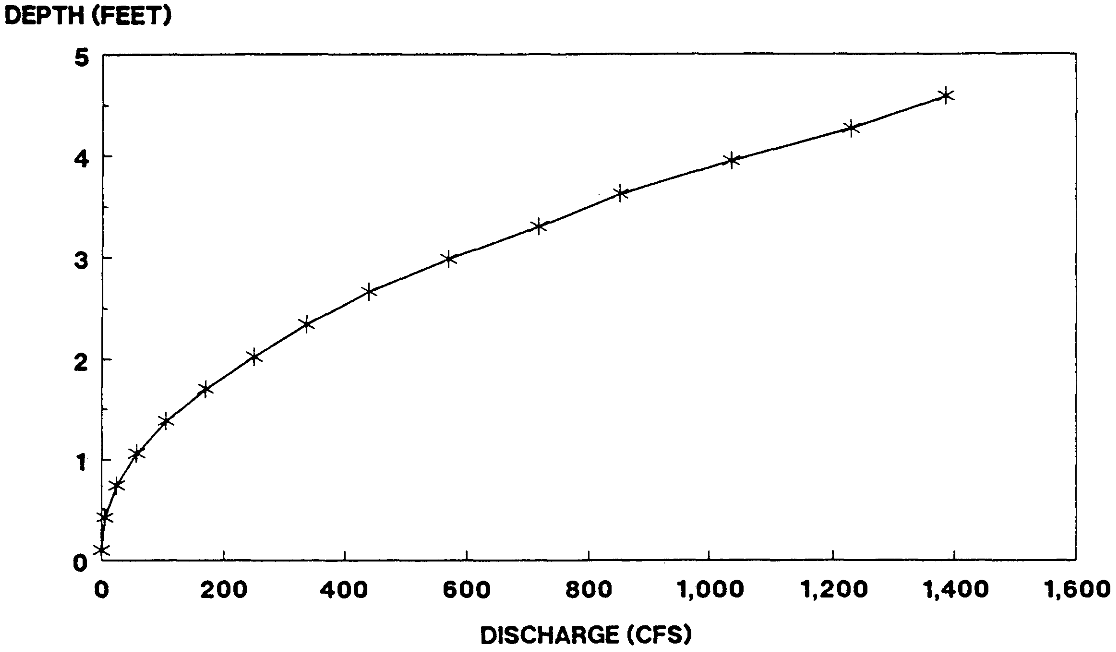


Figure 4.2 <u>Discharge vs. Depth</u>

<u>Outlet of Paxson Lake</u>



The same procedure was used for calculating flows at the Middle Fork Confluence with the Mainstem. At bankfull flow, the channel low point is approximately 8.1 feet below the water surface. See figure 4.3. This gives a bankfull flow of approximately 1,600 cfs. See figure 4.4. The predicted 2-year flow is 1,270 cfs.

At the West Fork Confluence, a bankfull maximum depth of 7.9 feet corresponds to a flow of approximately 3,350 cfs. See figures 4.5 and 4.6. The predicted 2-year flow is 4,500 cfs.

Table 4.6 compares the bankfull flows to the predicted 2-year flows for the three sites analyzed. Bankfull flows were lower than the predicted 2-year flows for the West Fork Confluence and higher for the Middle Fork Confluence and the Paxson Lake Outlet.

Given the degree of uncertainty over the recurrence interval of bankfull flows, the predicted 2-years flows are in relatively close agreement with the bankfull flows. This analysis shows that the derived flows are in the range of flows experienced on the Gulkana River.

Figure 4.3 Cross-Sectional Profile

Middle Fork Confluence

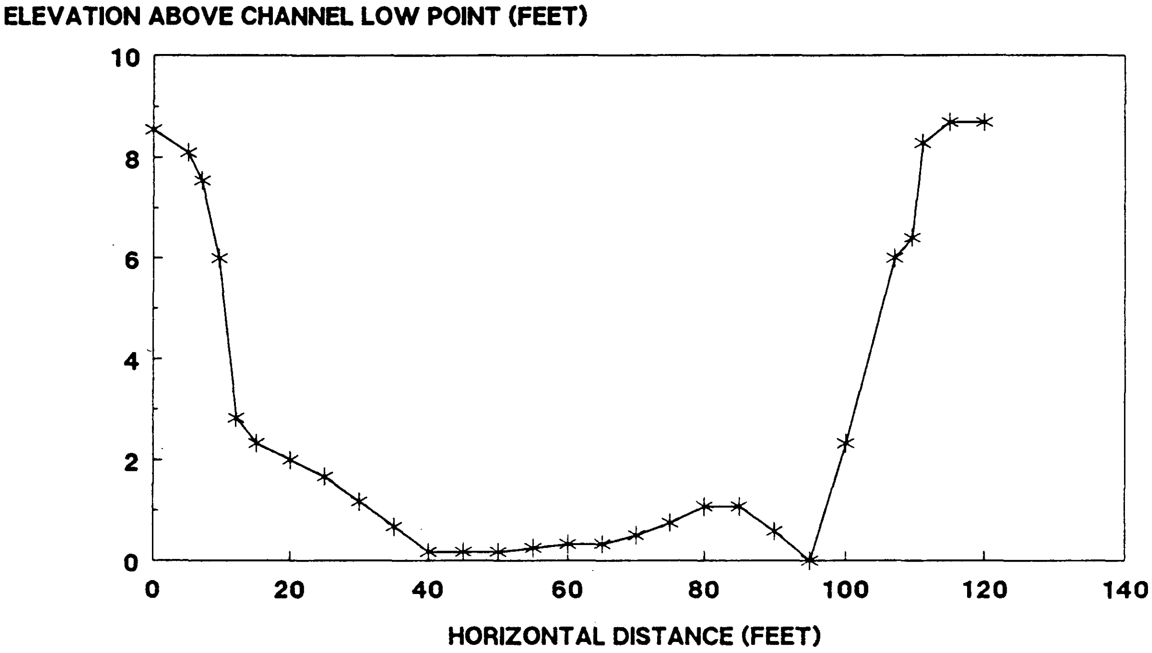


Figure 4.4 Discharge vs. Depth

Middle Fork Confluence

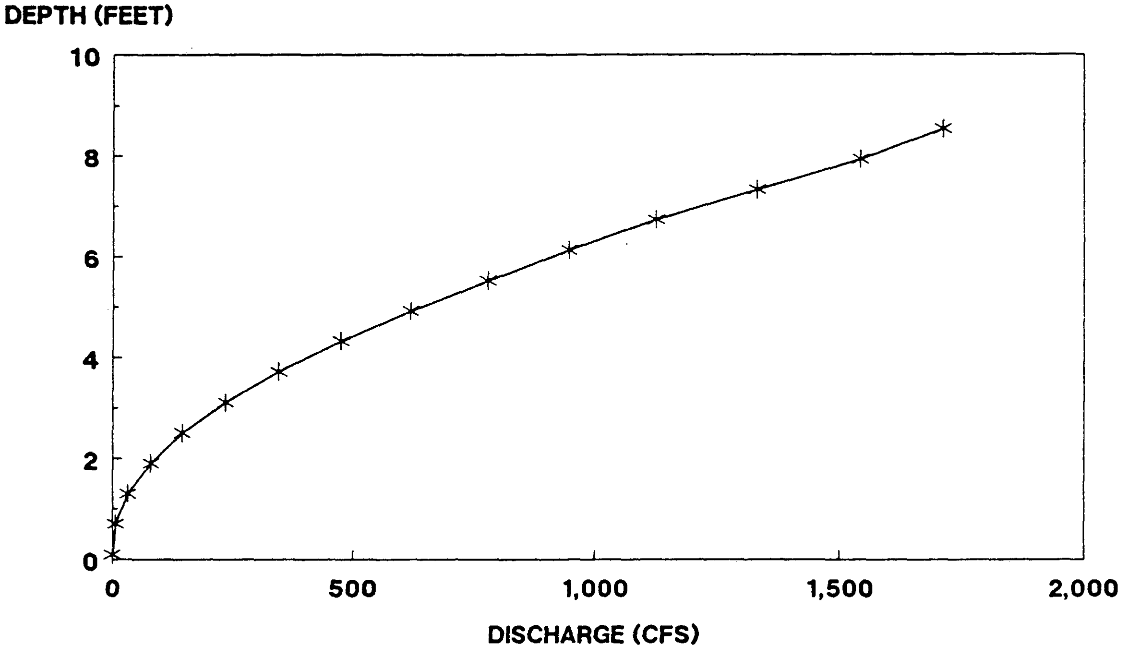


Figure 4.5 Cross-Sectional Profile

West Fork Confluence

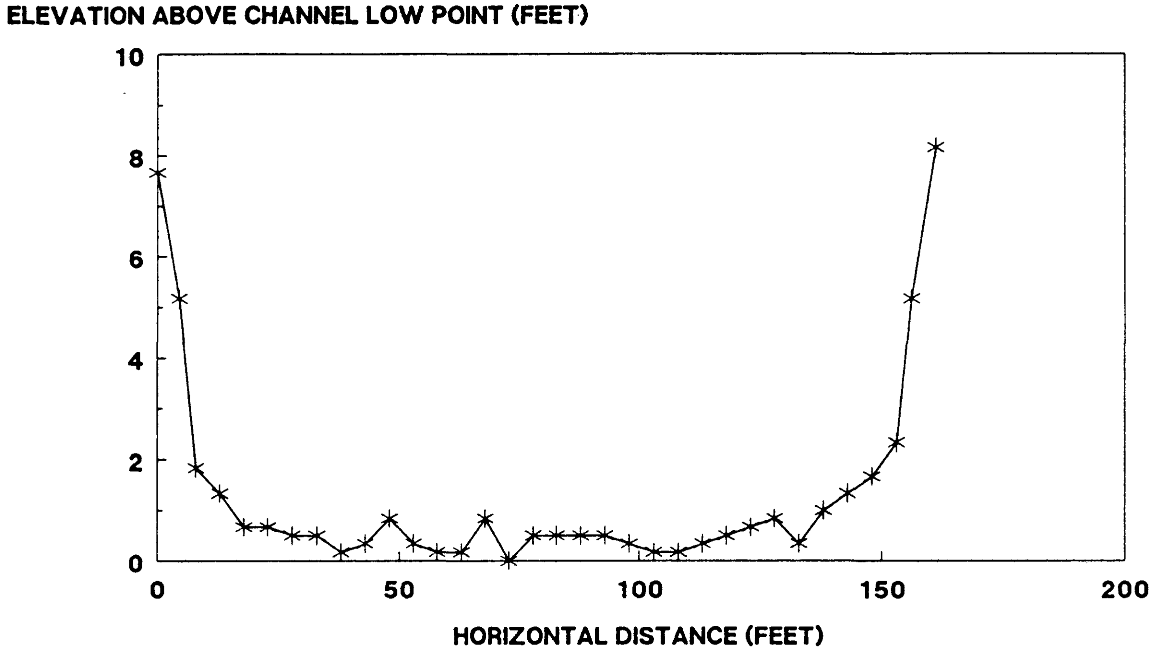


Figure 4.6 Discharge vs. Depth

West Fork Confluence

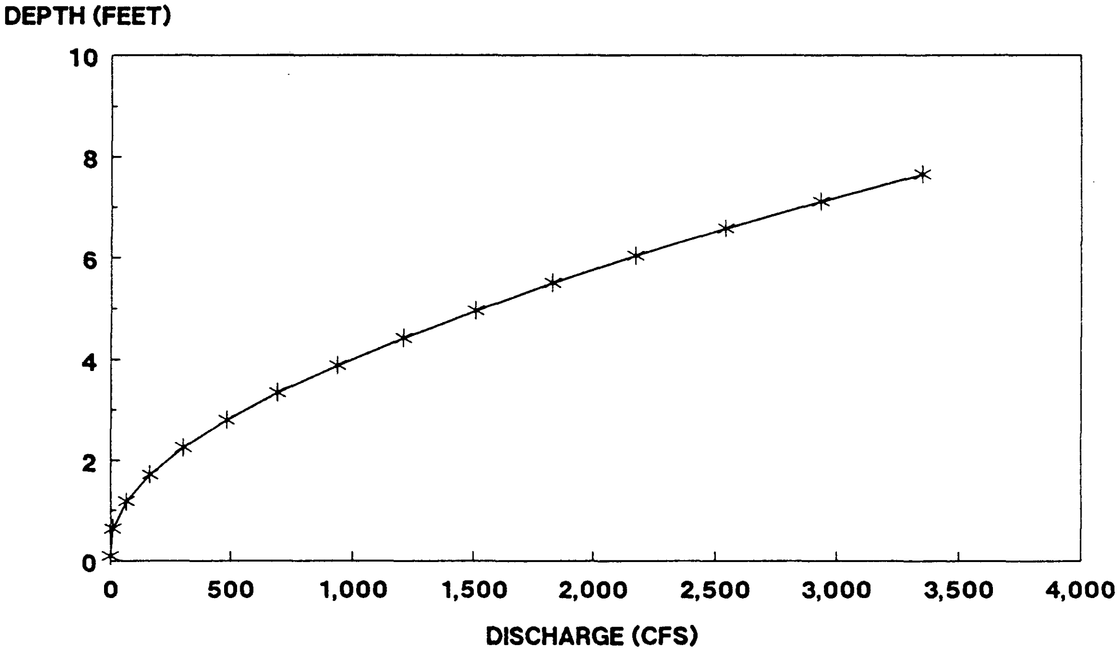


Table 4.6 Comparison of Bankfull and Predicted 2-Year Flows

	BANKFULL FLOW (CFS)	PREDICTED 2-YR. FLOW (CFS)
PAXSON LAKE OUTLET	1,300	1,155
MID. FORK CONFLUENCE	1,600	1,270
WEST FORK CONFLUENCE	3,350	4,500

Chapter 5

Summary

5.1 Concluding Remarks

The objective of this study was to quantify the natural flow regime of the Gulkana River. Flow summaries and relationships between discharge and flow attributes were developed in support of an Instream Flow Study conducted by the Bureau of Land Management. The quantification was made more difficult by the lack of long-term flow records.

Three methods were used to develop hydrologic summaries for the Gulkana River. Traditional hydrologic analysis was performed on the six years of existing flow records. This period of record was less then the 10 years of data recommended by the United States Water Resources Council (1981) for flood frequency determination. This period was also known to represent a relatively dry period. The analysis was developed to provide a comparison to the results with the other methods.

Regional analysis techniques were used to predict peak flows using equations developed by Parks and Madison (1983). Regional analysis predicts flows based on basin characteristics. Two sets of basin characteristics were used. Mean annual flow and watershed area and precipitation were used to predict flows. Mean annual flow was derived from the existing streamgage data.

The third technique used was to develop a streamgage correlation. The six years of streamflow data were used to perform a regression analysis with a streamgage at Gold, Alaska, on the Susitna River. The equation derived from the regression analysis was used to extend the record of the Gulkana data. A log-Pearson Type III analysis of this data was then performed.

Field survey techniques and Manning Equation methods were used to develop relations between discharge and flow attributes. Relations were developed between discharge and depth, wetted perimeter, cross-sectional area, and velocity.

Differing results from the three methods were resolved using professional judgement and an understanding of the factors affecting each method. A final prediction of flows was made by averaging the results of the regional analysis using mean annual flow and the Gulkana data for the 2 and 10-year flows. The 25, 50, and 100-year flows were predicted by averaging the streamgage correlation data and the regional analysis using mean annual flow.

Regional analysis methods were used to move flood frequency and flow duration values to upstream points. Predictions of flows at upstream points allowing an assessment of instream flow needs at these points.

Bankfull flows were calculated from field survey data. These data were compared to the predictions for the 2-year flows to provide a comparison. Bankfull flows are believed to occur from every 1 to 2 years in Alaska. A value of 2 years for the return period of bankfull flows was used in this report. Bankfull flows were found to be from 75% to 125% of predicted 2-year flows. The reasons for this error include uncertainty of the recurrence period of bankfull flows and errors associated with the prediction of the 2-year flow. Field calculation of bankfull flows is known with more certainty then the value of the estimated 2-year flow.

Through use of both direct and indirect methods, hydrologic summaries were developed for a remote Alaskan river. Professional judgement was used to arrive at a final conclusion. Through the use of a variety of methods, a wide range of results can be produced. By analyzing the factors affecting each result, and looking at the internal consistency within the results, a final prediction of the actual flow magnitudes can be made.

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