SUSITNA
HYDROELECTRIC PROJECT

FEDERAL ENERGY REGULATORY COMMISSION
PROJECT No. 7114

STREAMFLOW FORECASTING FEASIBILITY STUDY

Prepared By

HYDEX CORPORATION

Under Contract To

HARZA-EBASCO
SUSITNA JOINT VENTURE

FINAL REPORT

JUNE 1985

Document No. 2832

ALASKA POWER AUTHORITY

Document No. 2832
Susitna File No. 4[illegible].9.2

SUSITNA HYDROELECTRIC PROJECT

STREAMFLOW FORECASTING FEASIBILITY STUDY

Report by
Hydex Corporation

Eugene L. Peck
Thomas N. Keefer

Under Contract to
Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
June 30, 1985

EXECUTIVE SUMMARY

1. Objective

The objective of the Susitna Hydroelectric Project is to optimize the use of water for power generation while meeting environmental constraints, such as requirements for fisheries and wildlife. The purpose of this study is to provide information on hydrological forecasting methods (including basic data requirements) to assist the Alaska Power Authority in developing an effective water supply forecasting program for the project.

Only about half of the annual runoff from the Susitna Basin originates from snowfall during the winter months (October-April) and acurate forecasts of this snowmelt contribution to the seasonal runoff are possible. The question of how accurately runoff from summer (May-September) precipitation can be forecasted is more difficult, but forecasts of runoff for two to three weeks in advance are possible.

For accurate long-term forecasts of the total seasonal runoff, it is necessary to have a knowledge of;

(a) the amount of runoff that will be contributed from rainfall and snowfall (including glacier ice) that have occurred in the basin,

(b) short-period weather forecasts,

(c) current seasonal trends of precipitation and temperature, and

(d) statistical indices of climatological conditions for the rest of the forecast period.

An operational forecast program can be developed that will provide short and long-term forecasts of runoff of sufficient accuracy to successfully operate the Susitna Hydroelectric Project and achieve the objective stated above. This will require the collection of additional information on the precipitation regime of the basin and application of hydrological models. To cost effectively accomplish the collection of required basic data and to develop an operational forecasting service for the project, the following recommendations should be followed.

2. Basic Data Collection Program

A. Findings

The current data collection program does not provide sufficient information to support either the development nor the operation of an hydrological forecasting service.

B. Recommendations

In order to have sufficient information for development of an operational forecasting service the following actions should be taken during the period until the project becomes operational;

(1) Discontinue measuring at meteorological stations (except at Watana base camp and for other specialized purposes) all meteorological variables except precipitation, temperature and wind movement,

(2) Operate and collect in real time measurements from 12 meteorological stations shown on Figure 2, page 24,

(3) Continue to collect snow survey information (in cooperation with SCS) for sites shown on Figure 3, page 26,

(4) Continue to collect streamflow records from the three USGS gaging stations, and

(5) Summarize and archive all basic data collected for the forecast program.

When the project becomes operational do the following;

(1) Collect in realtime streamflow, reservoir stage and information on reservoir release of water,

(2) Continue collection in real time measurements from the 12 meteorological stations, and

(3) Continue collection of snow survey measurements from those sites whose data are found to be required for the operational forecast program.

It is recommended that data collection be accomplished using a satellite telemetering system.

3. Development of Operational Forecasting Service

A. Even with the additional basic data proposed above, it would not be possible, using presently available models and climatological information, to forecast the runoff for the Susitna Basin with sufficient accuracy. Additional studies need to be accomplished to improve the utility of models that are currently used for forecasting runoff from other glacierized basins in Alaska. Actions to be taken include;

A. Climatological Studies

(1) Develop seasonal isohyetal (average precipitation maps) for the Susitna Basin.

(2) Develop climatological statistics of May-September weather conditons for Susitna Basin required for extending short-term supply forecasts to seasonal forecast (semi-conceptual model).

B. Model Studies

(1) Arrange for application of hydrological forecasting models to basin as recommended in Chapter 3. Models to be considered for use are:

(a) Anderson NWS snowmelt model

(b) Quasi-conceptual seasonal runoff model

(c) NWSRFS and the SSARR soil moisture accounting models

4. Other Considerations

Other actions to be considered in the future for improving the forecasting service include:

(1) Adjusting precipitation records (especially snowfall) to reduce variability and bias introduced by wind action on gage catch,

(2) Incorporating satellite techniques for enhancing the knowledge of the magnitude and distribution of summer thunderstorm precipitation,

(3) Using aerial gamma radiation surveys to obtain better knowledge of the areal distribution and magnitude of the snow cover on non-glacierized areas,

(4) Using meteorological information (such as upper air measurements of moisture and wind) to improve knowledge of precipitation over the high areas of the basin, and

(5) Obtaining reliable measurements of the areal extent and of the seasonal water balance of the primary glaciers in the basin.

TABLE OF CONTENTS

APPENDICES

APPENDIX A MAPS OF MONTHLY PRECIPITATION, SUSITNA RIVER BASIN

APPENDIX B PLOTS OF DAILY DISCHARGE AND DAILY PRECIPITATION, SUSITNA RIVER BASIN

APPENDIX C RESULTS OF MULTIPLE REGRESSION ANALYSIS, SUSITNA RIVER BASIN AT DENALI, ALASKA

APPENDIX D EXPLANATORY INFORMATION, DEFINITIONS OF STATES AND PARAMETERS, AND SCHEMATIC DIAGRAMS FOR CONCEPTUAL HYDROLOGICAL MODELS

APPENDIX E R & M CONSULTANTS LETTER OF MARCH 8, 1985.

CHAPTER 1

INTRODUCTION

1. Background

The Susitna Hydroelectric Project includes the construction of two dams, Watana and Devil Canyon, on the main channel of the Sustina River. The Watana damsite's drainage area is 5,180 square miles, the Devil Canyon's, 5,810. The project is designed to provide electricity to the Railbelt area of Alaska for well into the next century and to have flow regimes that will minimize impact on fisheries and other environmental resources.

The proposed Watana Reservoir will have 9.7 million acre feet of storage of which 3.7 million will be active storage. The Devil Canyon Reservoir will not have any significant amount of active storage. Since power requirements are greatest during the winter, the project is designed to have as much water in storage as possible by September of each year.

During visits by Eugene L. Peck and Thomas N. Keefer to Anchorage, Alaska, and Chicago, Illinois, in December 1984, discussions were held with representatives of Harza-Ebasco and the Alaska Power Authority (Mr. Eric A. Marchegiani). The following information pertinent to hydrological forecasting for the project was received.

Based on the discussions held in December 1984, the following hydrological forecasts are required for the operation of the project:

(1) Forecasts of seasonal May-September inflow to Watana Reservoir (long-term forecasts),

(2) Forecasts of inflow to Watana Reservoir for two-week periods (short-term forecasts).

The long-term seasonal forecasts are necessary to schedule releases from the reservoirs to ensure the maximum water storage by September. These forecasts are required at semi-monthly intervals starting on April 1 but possibly as early as January 1 of each year. Each forecast should be a probability forecast for the May-September runoff (or for forecasts after May 1 for the period from the date of the forecast through September). These forecasts, used in conjunction with standard reservoir operational rule curves, will permit the reservoir operators to plan for having maximum water storage in the Watana Reservoir prior to the winter.

The short-term forecasts (inflow to Watana Reservoir for the next two weeks) are required daily from May through September.

CHAPTER 1

INTRODUCTION

1. Background

The Susitna Hydroelectric Project includes the construction of two dams, Watana and Devil Canyon, on the main channel of the Sustina River. The Watana damsite's drainage area is 5,180 square miles, the Devil Canyon's, 5,810. The project is designed to provide electricity to the Railbelt area of Alaska for well into the next century and to have flow regimes that will minimize impact on fisheries and other environmental resources.

The proposed Watana Reservoir will have 9.7 million acre feet of storage of which 3.7 million will be active storage. The Devil Canyon Reservoir will not have any significant amount of active storage. Since power requirements are greatest during the winter, the project is designed to have as much water in storage as possible by September of each year.

During visits by Eugene L. Peck and Thomas N. Keefer to Anchorage, Alaska, and Chicago, Illinois, in December 1984, discussions were held with representatives of Harza-Ebasco and the Alaska Power Authority (Mr. Eric A. Marchegiani). The following information pertinent to hydrological forecasting for the project was received.

Based on the discussions held in December 1984, the following hydrological forecasts are required for the operation of the project:

(1) Forecasts of seasonal May-September inflow to Watana Reservoir (long-term forecasts),

(2) Forecasts of inflow to Watana Reservoir for two-week periods (short-term forecasts).

The long-term seasonal forecasts are necessary to schedule releases from the reservoirs to ensure the maximum water storage by September. These forecasts are required at semi-monthly intervals starting on April 1 but possibly as early as January 1 of each year. Each forecast should be a probability forecast for the May-September runoff (or for forecasts after May 1 for the period from the date of the forecast through September). These forecasts, used in conjunction with standard reservoir operational rule curves, will permit the reservoir operators to plan for having maximum water storage in the Watana Reservoir prior to the winter.

The short-term forecasts (inflow to Watana Reservoir for the next two weeks) are required daily from May through September.

These forecasts will provide the necessary information to adjust the seasonal inflow forecasts, to prevent encroachment on dam freeboard requirements and to satisfy downstream river requirements with a minimum reduction in storage.

2. Purpose and Scope

This study is to provide information on hydrological forecast methods (and on basic data requirements) that will help the Alaska Power Authority develop an effective forecasting service that will ensure that the project's objectives are achieved (i. e., to maximize the use of the reservoir's inflows for energy generation and to provide flow regimes in the reach of the river below the reservoirs that will minimize the impact on fisheries and other environmental resources).

The scope of the study is:

(1) To review sets of alternative forecast systems that could be used for operational forecasting for the project;

(2) To evaluate each method's ability to provide the required type, accuracy, frequency and lead time of forecasts; and

(3) To provide information on the basic data requirements associated with each alternative forecast system.

The approach to the study is:

(1) To meet with Harza-Ebasco and Alaska Power Authority personnel to more fully understand the needs for the operational forecasting service;

(2) To meet with state, federal and other agencies in Alaska to evaluate the benefits that can be achieved from cooperation with such agencies for developing and operating a forecast service;

(3) To review the methodologies and the basic data requirements for a forecasting service;

(4) To review specific forecasting methods and evaluate their usefulness for the project;

(5) To provide a list of alternative sets of forecast methods together with information on the accuracy, sensitivity and data requirements for their operational use; and

(6) To present a draft of a final report and to meet with Harza-Ebasco officials to review the draft and submit a final report.

A discussion of the basic data needs for preparing short and long-term hydrological forecasts for the Susitna Basin and specific recommendations for changes in the existing data collection network are presented in Chapter 2. Forecast model technology is discussed in Chapter 3, with reviews of alternative forecasting methods. Information and recommendations for an operating hydrological forecasting service for the project and discussions on collection and processing of data, computer and manpower requirements and cost factors are presented in Chapter 4.

The executive summary following the Table of Contents contains recommendations for collecting and processing basic data for the operational forecasting service for the Susitna Hydroelectric Project.

CHAPTER 2

DATA REQUIREMENTS

1. RESULTS OF FIELD TRIP TO ALASKA

During the week of December 10, 1984, Eugene L. Peck and Thomas N. Keefer visited Anchorage and discussed the present data collection network of the Susitna River Basin with many agencies and organizations in Alaska. They also surveyed much of the upper Susitna Basin by helicopter. Considerable information was furnished by Harza-Ebasco prior to the field trip. Jeffrey H. Coffin, R & M Consultants, Inc., furnished additional information with his letter of December 19, 1984.

Hydex personnel were impressed with the attention given to the development of the data network for the basin. The cooperative attitude expressed by federal and state representatives, by R & M Consultants and by personnel of Harza-Ebasco was appreciated.

The major meetings held during the visit in Alaska with brief comments on items discussed are listed below:

A. Harza-Ebasco Representatives.

General overview of the project and the cooperating agencies was given by E. J. Gemperline and Khalid Jawed. Other Harza-Ebasco personnel participated. The primary discussion items were forecast needs, wildlife habitat and other environmental requirements. Wayne Dyok provided information on power requirements and the reservoir levels that can be maintained at different times of the year. Eric Marchegiani, Alaska Power Authority, provided specific information on forecast needs. It was clear that the primary forecast need is for accurate estimates of the seasonal inflow from early in the calendar year through August 1. A secondary need is for short-term water supply forecasts (inflow to reservoir for next two weeks) from May through September. No specific need is foreseen at the present time for river forecasts for the river below the Devil Canyon Reservoir. It was felt that the operation of this portion of the river could be accomplished by knowledge of reservoir releases.

B. R & M Consultants.

Jeff Coffin and Steve Bredthauer advised us of their data collection program and provided information on R & M's overall activities. They have considerable first hand knowledge of the Susitna River Basin and the data collection program.

C. Soil Conservation Service.

George Clagett provided complete records of all snow survey records that have been collected by the SCS in Alaska. George is knowledgeable of snow conditions in Alaska and is very willing to cooperate. George classified each snow survey course in the Susitna Basin on the basis of representativeness.

D. Alaska State Climatologist.

Jim Wise, Artic Environmental Information and Data Center, supplied a photocopy of portions of an annual precipitation map for Alaska that covers the Susitna River Basin. The office has printouts of all climatological records that have been collected by the National Climatic Center in Asheville, N. C., and provided copies of records for some stations that operated for a short period of time in the Susitna Basin.

E. U. S. Geological Survey.

Raymond S. George, Larry Leveen and others discussed present streamflow measuring stations and the proposal to establish a station upstream of the high water level of the major reservoir.

F. National Weather Service.

The hydrologist in charge, Jerry Nibler, and members of his staff and the meteorologist in charge, Edward Diemer, provided several reports and personal information on precipitation, snowfall and thunderstorm climatology of Alaska. These reports will be of value for understanding the precipitation regime of Alaska. Jerry also provided complete sets of parameters for the eleven basins in Alaska that have been calibrated using the National Weather Service River Forecast System's (NWSRFS) conceptual model.

G. University of Alaska.

Will Harrison, glaciologist, Geophysical Institue of the University of Alaska, presented an interesting discussion on glaciers and their relation to streamflow and sediment discharge in the Susitna Basin. He discussed the effects of surges in the discharge of runoff from the glaciers and the resulting very large changes in the sediment discharge. He supplied considerable information on the long term changes in the glaciers that indicate the glaciers have, on the average, been wasting for the last 30 years and therefore a substantial portion of the streamflow of the Susitna River has originated from this source. From his observations of the glaciers and snow cover on the glaciers during the past three years he has computed the winter and summer balance (loss or gain of the glacier during the season) and the annual balance. These estimates indicate that some of the glaciers in the Susitna Basin have grown while others appear to have wasted during the past three years.

The information furnished by Dr. Harrison, especially on the percentage of the stream discharge for specific subbasins that originate from the glaciated areas, will help in evaluating various models for forecasting snowmelt runoff. However, our opinion, and one that is apparently shared by Dr. Harrison, is that his observations are more important for estimating the effect of glacier contribution to the long-term (30-year) streamflow than for use in forecasting water supply during a specific season.

2. ACCURACY AND REPRESENTATIVENESS OF BASIC DATA

In establishing a basic data network for a hydrological forecasting service several factors are important. For precipitation and snow cover measurements two important factors are sometimes not given the attention they deserve for the data to be of maximum value. The first, and most critical of these factors, is the effect of wind (gage exposure) in reducing the gage catch and causing variation in the measurements relative to the true precipitation at the site. The second factor is the need to have the site "exposed" to the general paths of storms so that the records represent the average true precipitation for the general area (representativeness). Information on these two factors are presented in the following sections.

A. Gage Exposure

Hydrologists have long recognized that deficiencies exist in precipitation measurements, especially for snow fall. Errors in precipitation data account for a large portion of the inaccuracies in precipitation-runoff relationships and in the simulated streamflow from operational hydrological models. Our inability to evaluate adequately the areal average water equivalent of the snow cover is the greatest limitation on improving the reliability of snowmelt forecasting (1).

Snowfall is the most difficult form of precipitation to measure. Most precipitation gages have an orifice that is exposed in a horizontal plane for intercepting falling precipitation. The effect of wind on a gage is the largest cause of measurement error (2). Wilson (3) demonstrated that snowfall and snow cover measurements that were most representative of the actual snowfall had the highest correlation with streamflow measurements of small basins in the high Sierra Mountains. Brown and Peck (4) showed that the reliability of a precipitation measurement (snowfall) was related to how well the site of the gage was protected from wind movement. Larson and Peck (5) showed that the accuracy of conceptual models for simulating snowmelt streamflow was enhanced when precipitation measurements are adjusted for bias in catch due to wind action on the precipitation gage. Figure 1, from Larson and Peck (5), presents a summary of gage catch deficiencies that have been observed in measuring rainfall and snowfall in relation to the average wind measured at the gage orifice.

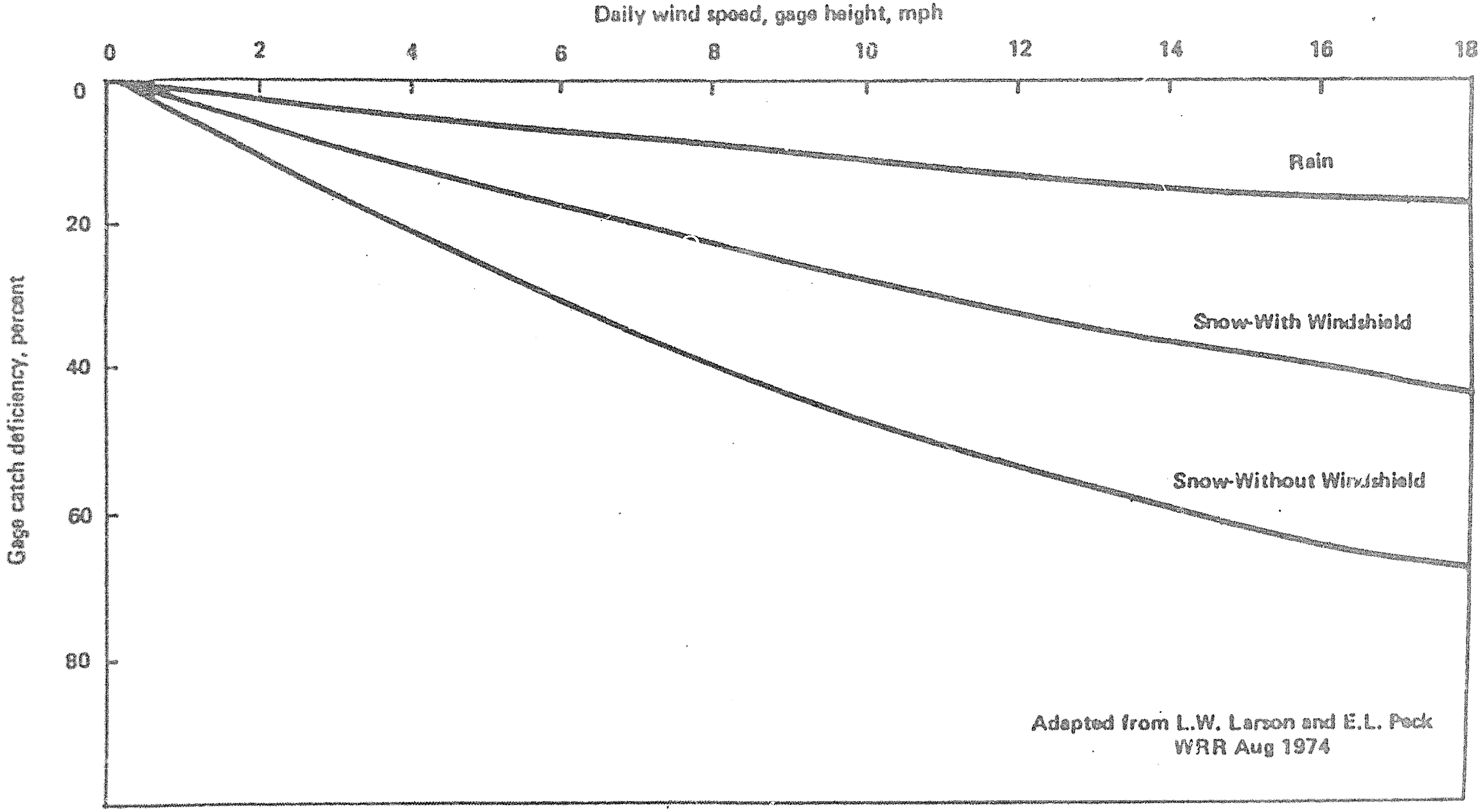


Figure 1. Effect of wind speed on catch of U. S. precipitation gages

The precipitation measurement problem has received considerable attention by international meteorological and hydrological organizations. During the 1972 World Meteorological Organization symposium on Distribution of Precipitation in Mountainous Areas held in Geilo, Norway, the problems of measuring precipitation in mountainous areas were discussed (6). The conclusions stated that the most reliable and consistent measurements are those obtained at sites that are well protected from adverse wind action. It was also reported that adjusting precipitation records using wind measurements was a good method to reduce the bias and variability induced by wind on the orifice.

Measurements of the average water equivalent of the snow cover may also be greatly affected by wind. Snowfall on the site may be blown from the location by very low (less than 5 mph) wind speeds. Sites located at the edge of forests or other cover may collect amounts of snow greater than the average snowfall.

B. Representativeness of Precipitation and Snow Cover Measurements.

Although it may seem obvious, it is not always recognized that precipitation (snowfall) and snow survey measurements are most valuable for forecasting snowmelt runoff when the measurements are representative of the true snowfall at the site.

Ideal exposure for observational sites for other meteorological parameters such as wind, temperature, humidity and evaporation are different than those for precipitation. For these measurements the best sites are those that are somewhat open to wind movement.

For snowfall and snow survey measurements the gaging sites should be away from the immediate influence of trees, buildings and water bodies and in such a position as to afford a fair representation of surrounding condtions. A station should not be sited upon, or close to, steep slopes, ridges, cliffs or hollows. For some purposes (e. g., modeling crop conditions) the station location should be situtated to measure the conditions in the agricultural field. However, for use in modeling river basin conditions the site location should represent average conditions in the basin rather than those of local conditions.

The location of the site with respect to the general direction of storm movement during periods of precipitation is an important factor as to how well the precipitation at the site relates to the average precipitation in the general area. In this report this is referred to as the representativeness of the site. Based on experience in developing procedures for forecasting water supply for the mountainous areas of the western United States, locating gages at sites that are "exposed" to the general direction of storms is an important factor for the data to be of most value. Recent work by Hydex in developing techniques for network design in mountainous areas has also demonstrated that a measure of how well a site is "exposed" to general storm movement is an important parameter for understanding the relation of average precipitation at one location with average values at other locations.

In summary, for precipitation or snow survey information to be of most value for forecasting the seasonal snowmelt runoff in mountainous areas, it is important to know the relation of the precipitation catch to the true precipitation and how well the site is "exposed" (representativeness) to the general direction of movement of storms.

For high elevation basins like the Susitna there may not be many sites that provide protection from wind and are also well "exposed" to the general direction of storm movement. In the following discussions the need for protected and representative sites where precipitation and snow survey measurements are made is a major consideration.

Consideration is also given to the techniques for adjusting precipitation measurements to correct for wind effects and to obtaining enhanced knowledge of precipitation at high elevations by using meteorological parameters to extrapolate measurements observed at lower elevations. The advantages of remote sensing are also presented.

3. EVALUATION OF EXISTING DATA COLLECTION PROGRAM

The data requirements for the forecasting service depends to some extent on the models selected. How well the data collected meets the forecasting program needs depends upon the network design and on the accuracy and representativeness of the observations.

A. Data Requirements for Long-term Seaonal Forecasting

Data requirements for preparing long-term seasonal water supply forecasts may be different than those for short-term forecasts during the May-September period. For seasonal forecasts issued on or before May 1 a knowledge of the winter precipitation (and/or water equivalent of the snow cover) is required. Comments on the usefulness of the measurements from the established meteorological stations in the basin for long-term seasonal forecasting are given below.

(1) *Air Temperature.* Temperature measurements are not specifically required for most forecast models unless there are periods of winter snowmelt. Temperature measurements have been used along with wind movement for adjusting precipitation records for deficiencies in gage catch (7).

Observations now recorded in the basin are the maximum, minimum and mean air temperature in degrees Celsius.

(2) Wind Measurements. Like temperature, wind measurements are not required for forecasting long-term seasonal runoff. Wind measurements are used to adjust precipitation records for deficiencies in gage catch and to estimate precipitation at high elevations using meteorological models.

Six daily values for wind are recorded at the meteorological stations: average wind speed in m/s, maximum gust speed in m/s, direction of maximum gust in degrees, resultant wind direction in degrees, resultant wind speed in m/s, and prevailing wind direction to 16 points of the compass.

(3) Moisture (humidity and dew point) Measurements. Generally models that forecast seasonal water supply generally do not require input of moisture measurements. Measurements of moisture could have some value for computing sublimation in snowmelt models.

Daily values of the mean daily relative humidity in percent and the mean daily dew point in degree Celsius are recorded at the meteorological stations.

(4) Precipitation. Precipitation, along with measurements of the water equivalent of the snow cover, is the most important meteorological input for models forecasting seasonal water supply during the winter.

Precipitation is generally not measured at the meteorological stations during the winter except occasionally for the month of April. Precipitation measurements are available from the Wyoming gage at the Watana meteorological station.

(5) Radiation Measurements. Measurements of solar (short wave) and long wave radiation are not generally required for seasonal water supply forecasts made during the winter. The need for radiation measurements, especially during the winter, is not clear.

Radiation measurements are made at some of the meteorological stations using a Photovoltaic Pyranometer (RS 1008) which measures incoming direct solar radiation and diffuse sky radiation. The only available information on this instrument was furnished by R & M Consultants. The instrument division of the National Weather Service, NOAA, has made no evaluation of the accuracy or reliability of this instrument. The following facts make the reliability of the recorded data during the winter months of questionable value:

(a) The information on the pyranometer states that the cosine response of the instrument is true over a range of 70 degrees. It is not clear if this is 35 degree each side of vertical or 70 degrees from the vertical. In any event, during the winter months the sun is at a very low angle and the response of the instrument to the solar radiation would not be accurate.

(b) Most of the instruments observed during the field survey were covered with snow and ice. This probably occurs often during the winter especially following periods of snowfall and the sensors remain in this condition until the snow and ice are blown off, melted off, or are removed during an inspection visit.

(c) The brouchure on the instrument furnished by R & M Consultants provides some information on the effects of temperature on the change in output for constant radiant input. However, this information is furnished relative to 28 degrees Celsius and only down to 0 degrees Celsius. How the instrument responds to the very cold temperatures of Alaska is not known.

(6) Snow Course Measurements. The depths and water equivalent of the snow cover are read near five stakes that are installed in the ground along a line extending north from the instrument shelter at some of the meteorological stations. Because these sites are generally open to wind movement, the depth of the snow cover is primarily limited to the height of the stubble along the snow course. Except for those stations which have natural protection from wind movement (such as at the Sherman station) these measurements are of no value to the water supply forecasting program.

Some snow courses established by the Soil Conservation Service and by R & M Consultants have aerial markers that are read from helicopters or light aircraft. This technique has proven successful in other high elevation snow areas where some water equivalent measurements for computing snow density are available at similarly located stations. The value of the readings is related to the windiness (exposure) of the aerial marker snow stake site. If the immediate area is protected from wind movement, such as by trees or by terrain features, the readings can be of considerable value for seasonal water supply forecasting.

B. Results of Field Survey.

Comments on exposure of precipitation and snow survey measurements sites visited during the field trip on December 13, 1984, follow. The exposure classification for the immediate area of the gage or snow course is based on the system developed by Brown and Peck (4).

(1) Watana Camp Meteorological Station.

Exposure. The site is open and is classified as a windy site. There is a slight rise in the terrain to the north of the measurement site. The location is exposed to the west and the site is considered as representative for storms in the lower portion of the basin.

Precipitation. A Wyoming precipitation gage has been installed. However, the maintenance of gage is poor. The wind vanes dip in the middle of each section and the northern section was disconnected at top and hanging down. The precipitation gage catch in properly constructed Wyoming gages is considered to be more consistent (approximately 90 percent of true value) than a gage in a windy location without such protection.

Snow cover survey. Records of water equivalent or of snow depths from the five-stake snow course at the station are of little or no value for a water supply forecasting program.

(2) Monahan Flat Snow Course Station (SCS)

Exposure. The present site of the snow course is in trees southeast of lake. The classification of the exposure of the site is rated as fairly well protected to moderately windy. Prior to 1983 the SCS snow course was located in a much more open site and therefore records for the two periods are not comparable. Measurements have been made from both sites. All published records are from the old site. The SCS plans to published adjusted values for the entire period when a sufficient overlap of data is available. Snow appearance in the area during the field survey indicated that the wind movement at the Monahan survey site is much less than 5 miles to the south near the Denali Highway.

The station location is representative for the central portion of the upper Susitna basin

(3) Susitna Glacier Meteorological Station

Exposure. The measurement site is on a ridge between two forks of the Susitna Glacier. The primary drainage wind movement is below the elevation of the station. However, during storms, the site could be subject to strong wind movement. Therefore the exposure of the gage site is classified as windy. Snow course measurements at the site would be poor.

The site is open towards the southwest. The site is considered good for representing the upper portion of the basin. In fact, true precipitation or adjusted precipitation values from the site would be nearly ideal for representing the high elevation area of the basin.

(4) Caribou Snow Course

Exposure. The site is not protected from wind accompanying storms but is protected from general winds, especially the major drainage winds in the area. The site is classified as fairly well protected to windy. The measurement site is located in a saddle at a high elevation south of the Susitna Glacier. The snow course information is probably as good as one could obtain from a site at a high elevation in the basin.

The site is opened to the southwest and measurements should be representative of snowfall at high elevations in the basin.

(5) Denali Meteorological Station

Exposure. The gage site is completely open with no protection from wind. Due to this and the fact that the site is subject to strong drainage winds, the gage site is classified as very windy. The precipitation gage was in need of repair and was also unlevel. The precipitation gage in use does not have sufficient strength for the winds experienced at this site. Snow course data observed at five surface stakes extending north from the instrument shelter are considered useless. A location a half mile to the northeast of the present site would place the gage in trees and out of the path of the strong drainage winds that originate in the glaciers upstream from the station. Relocation of the gage would reduce the bias and variability of the precipitation measurements in relation to true precipitation.

The location of the present site (or the proposed one) is considered to be such that true information on the actual precipitation at the site would be representative of the precipitation at the middle elevations of the basin.

(6) Tyone Meteorological Station (Discontinued)

Exposure. The site is in thinly scattered trees near the Tyone River. No strong wind movement was evident from snow patterns. The gage site is classified as fairly well protected to moderately windy.

The measurements would be considered as representative of a large portion of the lower drainages of the Tyone and Oshetna River Basins.

(7) Kosina Meteorological Station

Exposure. The location of the gage is open with little or no protection by trees. The appearance of snow in the area of the gage indicates fairly strong wind action. The gage site is classified as windy. A location to the north at lower elevation in trees would provide a much better measurement of precipitation and snow cover.

Accurate measurements at this site would be representative of a large area of the middle Susitna Basin around the proposed Watana Reservoir.

(8) Devil Canyon Meteorological Station

Exposure. The station is located on a small ridge with protection from wind movement afforded by the general terrain. The gage can be affected by wind during snowfall. Although the exposure of the present gage site is fairly good (classified as fairly well protected) relocating the precipitation gage just to the north off the ridge and in trees would enhance the protection for the gage (to well protected).

The site is considered to be representative of a large portion of the lower middle basin.

(9) Sherman Meteorological Station

Exposure. The gage can be affected only by strong downdrafts during storms. The site is classified as well protected. In fact, because of the good protection the snow builds up on the wind sensors. During the field visit the wind sensors were completely inoperative because of snow and ice accumulation. Snow survey measurements at the site are considered to be very good.

The station location with respect to general storms makes the site very good for representing precipitation and/or snow cover for the lower portions of the basin near the village of Gold Creek.

C. Field Observation of Wind Movement in Basin.

The light snow cover that existed over the basin during the aerial survey on December 13, 1984, provided an unusual opportunity to observe the general wind movement patterns of the basin. The snow cover for regions with light wind movement was smooth and unbroken. In other areas the snow was blown into ridges or showed other evidence of wind action. The area having the most effect of wind action was approximately 10 miles west of Denali near Butte Lake. Strong wind effects were seen south of Butte Lake as far as Deadman Lake. Flying north from Butte Lake over the Denali Highway towards Monahan Flat the wind effects became less observable. There was little evidence of strong wind movement in the immediate area of Monahan Flat.

Drainage winds originate over the Susitna, West Fork Susitna and East Fork glaciers and flow downhill towards the confluence of the West and East Forks of the Susitna River. The wind flow tends to split near Denali with a major flow westward towards Butte Lake and the rest moving down the main Susitna River channel.

D. Evaluation of Snow Course Information

The location of all snow course sites (SCS and R & M) not visited during the field survey were located on U. S. Geological Survey maps and the terrain features for each site were reviewed. The stations have been well located and are considered to be representative of the snow cover in the general area of each site.

The following evaluation of exposures for snow survey courses in the Susitna Basin was provided by George Clagett, SCS snow survey supervisor, based on his personal experience:

Table 1

Classification of Snow Course Exposures
by George Clagett

Snow Course	Classification
Cathedral Creek (new)	?
Clearwater Lake (reactivated)	poor
Devils Canyon (aerial marker in trees)	good
Fog Lakes	fair
Horsepasture Pass (aerial marker)	fair
Jatu Pass	fair
Lake Louise	excellent
Malemute 2 (new)	?
Monahan Flat (and precip gage)	fair
Monsoon Lake (new)	?
Square Lake	excellent
Tyone River (reactivated)	good
West Fork Glacier	excellent
Watana Camp (Wyoming gage)	poor

4. Data Requirements for Hydrological Forecasting.

The data used in hydrological forecasts can be divided into two groups: the material required to develop the forecasting method (calibration or parameter estimation) and the information needed to operate the forecast (operation). Data requirements depend upon the forecast method used, the time period of the forecast and the hydrological characteristics of the basin.

Factors affecting the decision to use different hydrological forecasting models are discussed in Chapter 3, Model Technology. Although available data may restrict the actual choice of forecasting methods, the recommendations for changes in the network presented in this chapter assume that the project will support a network that will meet realistic requirements and that a physically based (conceptual) model will be an alternative (at least for headwater areas).

Calibration of a model requires conventional time-series of hydrological information (i.e., precipitation, temperature and streamflow) as well as information on constant basin and river characteristics, such as subcatchment areas, area of woodland, soiltype, channel dimensions and slopes, and, in the case of the Susitna Basin, on glaciers.

For operational forecasting, data requirements include the hydrometeorological data specified by the forecasting scheme to characterize the state of the catchment immediately before the issue of the forecast and may include a measurement of the forecast element itself for monitoring the forecast performance or updating the forecast model.

Only the hydrometeorological data required to calibrate and operate forecast models are discussed in this chapter. Because of the unusual climatic conditions in the Susitna River Basin, special attention has been given to problems of collecting accurate and representative measurements and to evaluating the existing collection network.

5. Climatological Data Requirements for Model Calibration

A primary data need for calibration of a forecast model is time series of precipitation, water equivalent of the snow cover, air temperature and streamflow. Care must be taken to insure that there is not a bias between the data used to develop the forecast procedure and the data used for operational forecasting. Consistency of the records is as important for calibration as having records of sufficient length of the required data.

The application of any hydrologic model to a basin requires experience and hydrologic expertise for best results. A statistical model (commonly referred to as a black-box model) can be adopted to a basin without considerable knowledge of the hydrological characteristics of the watershed. The overall operational accuracy of a black-box model may not greatly differ whether applied by someone with experience or by one without much experience. However, for application of a conceptual model the operational accuracy from an experienced hydrologist and from one without much experience can be greatly different.

To best adapt a conceptual model to a basin, the modeler should understand the mathematical representation of the model and how this relates to the real world. In applying a conceptual hydrologic model to a basin the model representation must relate to the real world conditions. Thus, the components of the basic water balance equation

$$\text{Discharge} = \text{Precipitation minus Basin Losses plus Change in Storage} \qquad (1)$$

must be realistic. If this condition is not met the calibration (parameter estimation) may be biased and the model, while demonstrating a good relationship for the calibration period, might not be of much value for conditions not covered by the calibration period. This has been demonstrated in the paper "Advantages of Conceptual Models for Northern Research Basins Studies" by Eugene L. Peck and Thomas R. Carroll (8). This paper also demonstrated that additional information not used in the calibration can not be used at a later time to improve the model's accuracy if the calibration is not in line with real world conditions.

To insure that the calibration of a model in mountainous areas is in line with real world conditions the modeler must have a good knowledge of the basin's average precipitation. This requires accurate maps (isohyetal) of the seasonal precipitation that are most related with streamflow. At the present time there are three isohyetal maps of annual precipitation for the Susitna River Basin. These were prepared by NOAA in March 1974 (9), by the SCS in August 1981 (10) and by the State Climatologist for Alaska (11). As far as can be determined, the maps were developed using only station means for whatever periods of record were available -- not specifically taking into account topographic effects and probably not making maximum use of snow course measurements.

A good method for developing isohyetal maps in cold climate mountainous areas is the anomaly technique developed by Peck and Brown (12). In this technique the authors develop maps for seasonal periods during which storm paths are fairly consistent and significant relationships can be established between average precipitation values and topographic features. These relationships are used in preparing the seasonal isohyetal maps. These seasonal maps are graphically added to obtain annual maps. The technique has provisions for using snow cover measurements to provide additional estimates of winter season precipitation. Relationships between annual precipitation values and topographic characteristics are not generally adequate for preparing annual maps directly.

A substantial portion of the May-September streamflow in the Susitna River Basin results from precipitation that occurs during the winter months of October-April. The most useful application of any conceptual (and even statistical) model for forecasting the long-term water supply runoff for the basin could be achieved only with the use of an accurate and representative isohyetal map for the October-April winter season.

Measurements of year-round precipitation are very limited for the Susitna Basin. The actual calibration of any model to the basin should be delayed until this lack of data is improved. As discussed in Chapter 3, the period of time that records are required for calibration depends to some extent on the range of conditions that are covered by the records available for use in calibration. Most ideally, as wide a range (from very high precipitation years to years with very light precipitation) should be available. If a wide range of conditions does exist, four to five years of records may be sufficient to obtain a good calibration for a conceptual model. As many as 20 to 30 years of records may be required for application of a statistical (black box) model.

6. Operational Data Requirements

The primary concern in forecasting with any model is the uncertainty of the forecasts. Measurement errors, model errors and the natural variability of meteorological inputs are causes of uncertainty in the forecasts. Methods exist to evaluate the accuracy of hydrological instrumentation, to quantify the natural hydrological variability of meteorological inputs and to assess the accuracy of the hydological models by empirically comparing simulated results with observed data.

A major source of uncertainty for forecasts whose lead time (time from forecast issuance to observed flows) is greater than the time of concentration (time from occurrence of rainfall to observed flows) is the uncertainty in future weather conditions, especially the occurrence of precipitation. Thus an early seasonal forecast issued on February 1 has a high degree of uncertainty since precipitation for a considerable portion of the season has not been observed.

Since the Susitna Hydroelectrical Project forecasting need is primarily for short- and long-term water supply forecasts from May through September the primary data requirement is for measurements that adequately describe the magnitude and spatial distribution of precipitation (especially snowfall) in the basin. Accurate and representative measurements of the snow cover as of April 1 have been found to be very useful in describing the average winter snowfall and for forecasting the runoff that results from that snow cover in basins where there is little snowmelt prior to April 1. This is in part due to the fact that the snow cover as of April 1 is generally near or at the maximum water equivalent of the snow cover for the season.

For forecasting seasonal water supply runoff on dates other than April 1 (using the April snow course data), accurate and representative measurements of precipitation (rain and snowfall) are required. Therefore, for seasonal forecasts prior to April 1, for seasonal forecasts after April 1, and for short-term water supply forecasts, precipitation measurements are essential for an operational forecast program for the Susitna River Basin.

Data required to support a hydrological forecast program in the Susitna River Basin are discussed by data type in the following paragraphs:

a. Streamflow. Streamflow measurements are made by the U. S. Geological Survey. Ideally, observations of river stages (for conversion into discharge values) should be available in real time for all forecast points.

b. Reservoir Storage. To compute reservoir inflow, lake stage values (for converting into reservoir storage) should be available in real time for all reservoirs for which inflow water supply forecasts are to be issued.

c. Reservoir Releases. As for reservoir storage, real time information on the amount of water released from reservoirs should be available for all reservoirs for which forecasts are prepared. The information would also be required to forecast river conditions below the reservoirs for environmental and river operations.

d. Snow Cover. The primary snow measurements required are water equivalent for selected snow courses. The Soil Conservation Service (SCS) has recommended procedures for establishing and operating snow survey stations. Measurements of the water equivalent of the snow cover should be available either in real time or at set times during the season. The SCS also establishes snow markers for reading the depth of the snow cover from aircraft. Some of these are in use in the Susitna Basin. The National Weather Service has an operational program to measure the average water equivalent of the snow cover by means of aerial gamma radiation surveys (13). These measurements provide average values of the water equivalent (or measure the soil moisture) of the snow cover for an area about 1500 feet wide and from 6 to 10 miles in length compared to the small area of a single snow course. Such measurements would be of value for the Susitna River Basin.

e. River Ice. Measurements of ice cover on rivers is not critical for the water supply forecasting program. They are of value for other hydrological or environmental purposes.

f. Glacier Measurements. Information on magnitude of snow and ice making up the glaciers in the Susitna Basin would be of potential value for use in the water supply forecasting program. Knowledge of the areal extent is an important factor that could be obtained from aerial (or satellite) photographs prior to the beginning of snowfall in each season. Other factors that could be of value include periodic measurements of the albedo of the snow cover on the glaciers, measurements to determine the winter balance (what comes in during the winter period) and the summer balance (what snow and ice melts during the summer) and measurements to determine during a season if a glacier is accumulating additional ice or is wasting.

Except for measurements of the areal extent of the glaciers prior to winter and possibly remote sensing measurements of the albedo of the snow cover, no other measurements listed above are presently available or useful for operational forecasting. Techniques for handling snow and ice melt from glaciers in an operational forecasting program will be covered in Chapter 3, Model Technology.

g. Precipitation. Measurements of precipitation and snow cover are the primary inputs for models that forecast water supply for basins such as the Susitna River Basin. For seasonal forecasts issued monthly, only measurements of monthly precipitation and/or the water equivalent of the snow cover may be sufficient to provide generalized outlooks prior to beginning of the snowmelt season. Short-term forecasts of water supply (i.e. inflow to a major reservoir for the next two weeks) require daily measurements of precipitation (snowfall and rainfall), air temperature and forecasts of future precipitation and temperature conditions. The same measurements would also be required to produce revised forecasts of the subsequent reservoir inflow for the rest of the season.

h. Meteorological. Various hydrological forecast models require meteorological measurements of temperature, wind, radiation and evaporation. In addition, knowledge of meteorological conditions (i.e., parameters relating to precipitation and storm wind direction) can be used to improve the knowledge of the magnitude and variation of precipitation in a basin. Remote sensing measurements of precipitation, snow cover and soil moisture may also be used as inputs or for updating some hydrological forecast models. Comments of need for meteorological measurements are given below:

(1) Temperature. Measurements of air temperature are required in most snowmelt forecast models. Air temperature is also used in many conceptual hydrological models to estimate the form of the precipitation (solid or liquid). It is assumed that daily temperature measurements (maximum and minimum temperature) will be required for the recommended operational program.

(2) Evaporation. Estimates of the rate of daily evaporation in a basin are not generally required for seasonal water supply forecasting but may be used for short-term forecasting. Evaporation estimates can be based on pan measurements or derived from meteorological measurements of wind, temperature and some measure of incoming solar radiation (i.e., such as percentage of cloudiness).

(3) Wind. Wind measurements are not used directly in most hydrological models. However, wind measurements can be useful in

adjusting precipitation measurements to account for adverse wind action that reduces the precipitation catch. Wind measurements may also be used in estimating evaporation and for computing wind surges in reservoirs.

(4) Radiation. Some snow melt models use radiation as an input. However, based on experience of the National Weather Service River Forecasting Service, it is very difficult to obtain and to maintain consistency in radiation measurements for operational forecasting. There are alternative methods for obtaining estimates of radiation. Unless there is a clear need for radiation measurements, their use should be avoided.

(5) Meteorological Parameters. Upper air parameters can be used to enhance the knowledge of the magnitude and distribution of precipitation in relation to topography. Such parameters can be used for this purpose in conjunction with point precipitation measurements or with information obtained by remote sensing (e.g., radar or satellite observations).

7. Recommendations for Changes in Data Collection Program

R & M Consultant Stephen Bredthauer's letter of March 8, 1985, (Appendix E) comments on the preliminary recommendations for changes in the location and operation of the meteorological stations in the basin have been considered in the following recommendations:

Caribou Snow Survey site

We agree with Bredthauer's recommendation to operate a meteorological station at the Caribou snow survey site. However, it is believed that May-September precipitation measurements at a site with similar exposure as that for the Susitna Glacier station would be very valuable for the project.

Tyone site

We agree that there may be a better site for the Tyone station.

Devil Canyon Site

We agree that the station could be moved to the High Lake location for the reasons indicated.

Kosina Site

We agree with relocating to a site near a lake. However, we feel the station should not be moved too far since its location fills a major gap in the proposed network.

A. Changes in Winter Measurement Program

The location of the meteorological and snow survey (snow courses and aerial markers) stations are well selected to represent the various areas of the Susitna River Basin. However, the data collection program does not provide sufficient accuracy or quantity of information on the precipitation for the entire area. As indicated in the previous sections some of the data being collected during the winter months are not required for support of a water supply forecasting program. Recommendations for changes in the data collection program during the winter months are:

(1) Discontinue all measurements at meteorological stations except precipitation, wind movement and air temperature at observation time.

(2) Increase the number of stations at which meteorological data are collected during the winter to those shown on Figure 2 and as indicated in Table 2.

(3) Install equipment for telemetering meteorological measurements.

(4) Develop or purchase (see chapter 4) computer and software capability for collecting and processing the meteorological measurements and to monitor and evaluate the data in real time.

(5) Maintain March 1, April 1 and May 1 snow surveys at snow courses and of aerial markers for the stations shown on Figure 3 and as listed in Table 3. Possible improvements in locations of snow survey stations should be discussed with George Clagett, SCS snow survey supervisor, based on his evaluation of the sites as listed in Table 1. The number of snow survey stations required for the operational forecasting may be reduced when actual forecast procedures are developed.

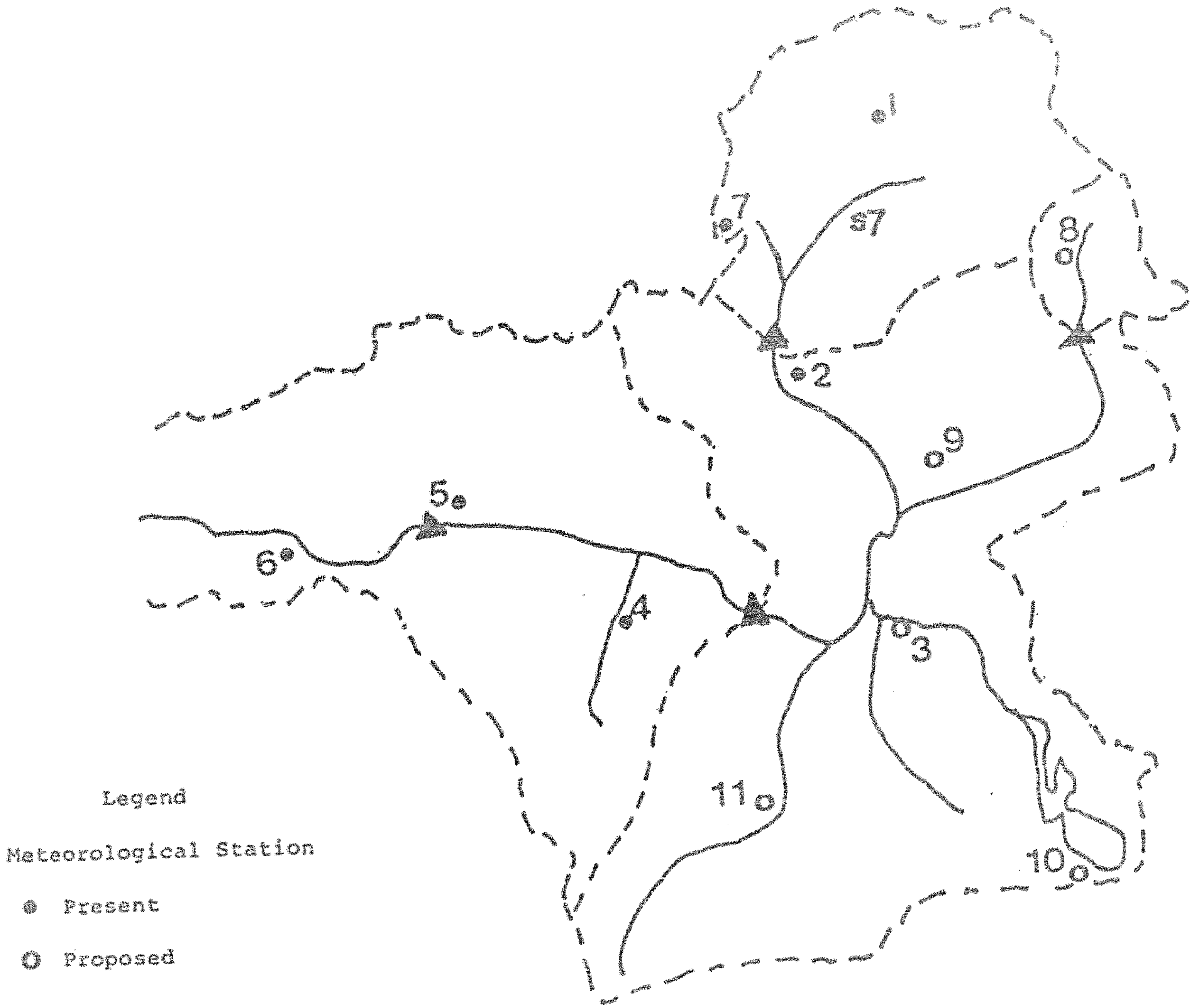


Figure 2. Meteorological Stations, Present and Proposed, Susitna River Basin

TABLE 2

Recommended Meteorological Stations

Map No.	Station	Changes and Variables to Measure
1	Susitna Glacier	Discontinue. Locate a precipitation station to operate May-Sep with similar exposure and distance to high mountains and not requiring over-glacier service flights.
2	Denali	Relocate to protected site (precipitation, temperature and wind movement)
3	Tyone	Reactivate at protected site (precipitation, temperature and wind movement)
4	Kosina	Relocate to protected site (precipitation only)
5	Watana	Rehabilitate Wyoming gage (precipitation, temperature and wind movement for water supply forecasting, other variables as required)
6	Devil Canyon	Relocate to High Lake (precipitation only)
7	Monahan Flats	Establish at SCS location (precipitation, and temperarture and wind movement)
7s	Caribou	Establish at snow survey site (precipitation, temperature and wind) Consider installation of Wyoming shielded gage.
8	Cathedral Creek	Establish a precipitation gage only in protected site with exposure to southwest and not requiring over-glacier service flights for May-Sep period only.
9	Clearwater Lake	Establish at snow couse location in protected site if possible or consider Wyoming gage installation. (precipitation, temperature and wind movement)
10	Lake Louise	Establish at snow course location in protected site if possible (precipitation only)
11	Square Lake	Establish at snow course location in protected site if possible (precipitation only).
	Sherman Station	Discontinue if not needed for other purposes.

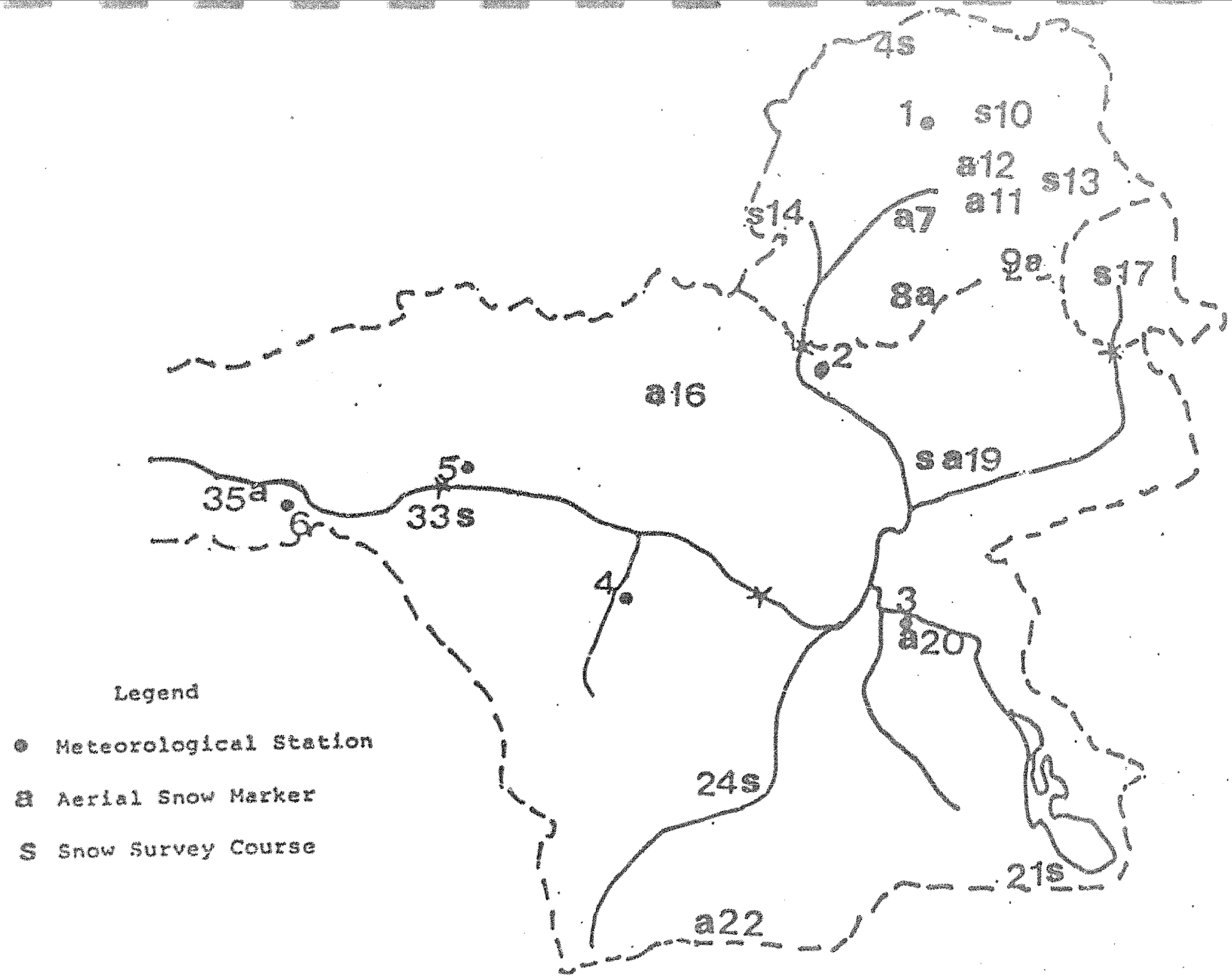


Figure 3 Snow Survey and Meteorological Stations, Present and Proposed, Susitna River Basin

TABLE 3

Snow Survey Courses

Map No.	Station
4s	West Fork Glacier
7a	Caribou
8a	Valdez Creek
9a	Boulder North
10s	Susitna Glacier Main Fork
11a	East Fork Susita Glacier
12a	Pyramid
13s	Jatu Pass
14s	Monahan Flat
16a	Butte Creek
17s	Cathedral Creek
19a/s	Clearwater Lake
20a	Tyone River
21s	Lake Louise
22a	Horsepasture Pass
24s	Square Lake
33s	Fog Lakes
35a	Devil Canyon

B. Recommended changes in data collection program during the summer months (May-September).

The forecasting program will require daily streamflow information for the Susitna River at Denali, the MacLaren River near Paxson and the station to be established in lieu of the Susitna River at Cantwell. Recommendations for the summer operations for streamflow gaging stations are;

(1) Install equipment at the three U. S. Geological Suvey stream gaging stations listed above for telemetering river stages. When reservoirs are in operation, information on reservoirs stages and reservoirs releases will also need to be telemetered.

(2) Maintain the meteorological stations listed in Table (2).

(3) Develop computer and software capability for collecting and processing the streamflow and meteorological data and to monitor and evaluate the data in real time.

(4) Continue pan evaporation measurements at the Watana Camp. The equipment consists of a Class A point measurement evaporation pan equipped with water temperature sensors. A pan anemometer should be installed. The site should be an open site and as free as possible from influence of wet areas.

(5) Collect at the Watana Camp station (and possibly at other sites around the Watana Reservoir) additional meteorological measurements required for other purposes. These may include long and short wave radiation measurements, humidity measurements and additional wind measurements.

8. Other Recommendations

To insure that the forecasting program will operate at maximum efficiency when the reservoir is completed, the following actions must be taken in the near future to have adequate information for calibration of the forecast models.

A. Data Collection Program

The data collection program recommended in the previous section should be commenced as soon as practicable.

B. Preparation of Seasonal Isohyetal Maps

Isohyetal maps (October-April, May-September and annual) should be developed for the Susitna Basin. The maps should be based on physiographic relations and make maximum use of the large amount of information available on precipitation patterns for Alaska. This includes studies on meteorological patterns associated with snowfall (14), studies on frequency of occurrence of thunderstorms (15) and studies on storm movements (16).

C. Techniques for Adjusting Snowfall Measurements

Techniques to adjust precipitation (snowfall) measurements using wind movement measurements to improve their accuracy and representativeness for use in the hydrological forecasting models (as discussed in section 2 of this chapter) should be developed so that the techniques can be applied prior to calibration of the models.

9. Future Items for Consideration

Depending upon the success of the calibration and operational use of the hydrological forecasting models, other actions may be considered in the future. These may include reviewing the use of satellite information to improve knowledge of the temporal and spatial distribution of precipitation, the use of aerial gamma radiation surveys to measure water equivalent of the snow cover over non glacierized areas and the use of meteorological models to improve the knowledge of precipitation at the higher elevations of the basin.

CHAPTER 3

MODEL TECHNOLOGY

1. Factors for Selecting Forecast Models

Many excellent hydrometeorological reports on the Susitna Basin have been furnished by Harza-Ebasco and no effort is made to summarize the findings of these reports. However, there are several factors that have an important bearing on the hydrological regime of the basin that need to be given special consideration in selecting models for forecasting the short- and long-term streamflow for the basin.

A. Data Limitations

A primary consideration as to the type of model that can be used is the adequacy and availability of basic data for applying the model to a basin. The only hydrometeorological basic data that has been recorded continuously in the basin for a fairly long period of time have been streamflow measurements by the U. S. Geological Survey and snow survey measurements by the Soil Conservation Service. Records of other hydrometeorological parameters (precipitation, temperature, wind, radiation, etc.) have been collected by R & M Consultants in the basin since 1980 and are discussed in the Chapter 2.

One result of a sparse data base is a limitation on the use of statistical models for forecasting seasonal runoff. Correlations between long-record, consistent precipitation and/or snow course observations and streamflow records are required for the development of these procedures. The only records in the Susitna Basin of sufficent length for developing a statistical relationship with the streamflow records are snow course measurements. Even these are limited in their usefulness because some of the snow courses are subject to considerable wind action and some have been moved and do not provide a consistent index to the average snow cover.

Correlations between April 1 snow course records and May-September runoff for subdrainage areas in the Susitna Basin indicate that less than half of the variability (coefficient of determination, r^2, less than 0.50) of the runoff is attributed to the winter snowfall. Marchegiani (17) found a coefficient of determination of 0.61 between a May 1 index (weighted April water equivalent from four snow course in the basin and the April precipitation at Gulkana, Alaska) and the April-September runoff for the Susitna River at Gold Creek, Alaska. Since precipitation has been measured for only a few years in the basin it is difficult to develop a statistical index procedure using existing records that would be an improvement over that found by Marchegiani. It is evident from the low April 1 water equivalents observed at most SCS snow courses and from the low coefficients of determination reported above that a large portion of the total runoff from the basin results from precipitation during the months of May through September.

B. Glaciers

Information on glaciers in the basin is limited to a short period of time and no consistent periodical measurements of the areal extent of the glaciers, of the depth of firn ice or of the perennial snow accumulation on the glaciers are available. William Harrison of the University of Alaska and R & M Consulants (18) have determined that wasting of the glaciers during the past 30 years was a considerable percentage of the average runoff during that period. Recent calculations by Harrison (private communication) indicate that 32 percent of the runoff of the Susitna River at Denali is from summer melt from the glaciers and that approximately 11 percent of the flow at Watana damsite is from summer melt from glaciers.

Larry Mayo, U. S. Geological Survey, Fairbanks, Alaska, furnished the schematic diagram shown in Figure 5 depicting the relative values of the annual precipitation and runoff at various elevations for the Yukon Tanana Uplands and the Alaska Range area east and southeast of Fairbanks (private communication). The upper line on Figure 4 indicates the total precipitation which is divided into the amount that is from rainfall, snowfall and the amount that is perennial snow accumulation. The lower dashed line indicates the total water losses from the basin which is divided into the evaporation loss, snowmelt runoff, rain runoff and the perennial ice ablation. Although the relative amounts of the various portions of the precipitation and runoff would be different for the Susitna Basin, the diagram provides information that is important to consider in selecting or developing a model for forecasting the runoff from the glaciated portion of the basin.

The information on Figure 4 indicates that on the average there is no runoff from rain on the glacier at elevations above 2100 meters. Mayo has stated that rain water above this elevation is retained in the snow cover of the glacier and becomes part of the perennial snow cover. This snow cover either contributes to the runoff at a later time as snowmelt ablation or becomes part of the firn ice of the glacier.

C. Climatic Regime

The drainage area of the Susitna Basin is subject to considerable difference in climatic conditions. The eastern portion of the drainage area (lower elevations of the Maclaren River basin and the Tyone River basin) are subject to a continential climate as is the upper portion of the Copper River Basin (repesented by the Gulkana Meteorological Station of the National Weather Service). The climate of the lower reaches of

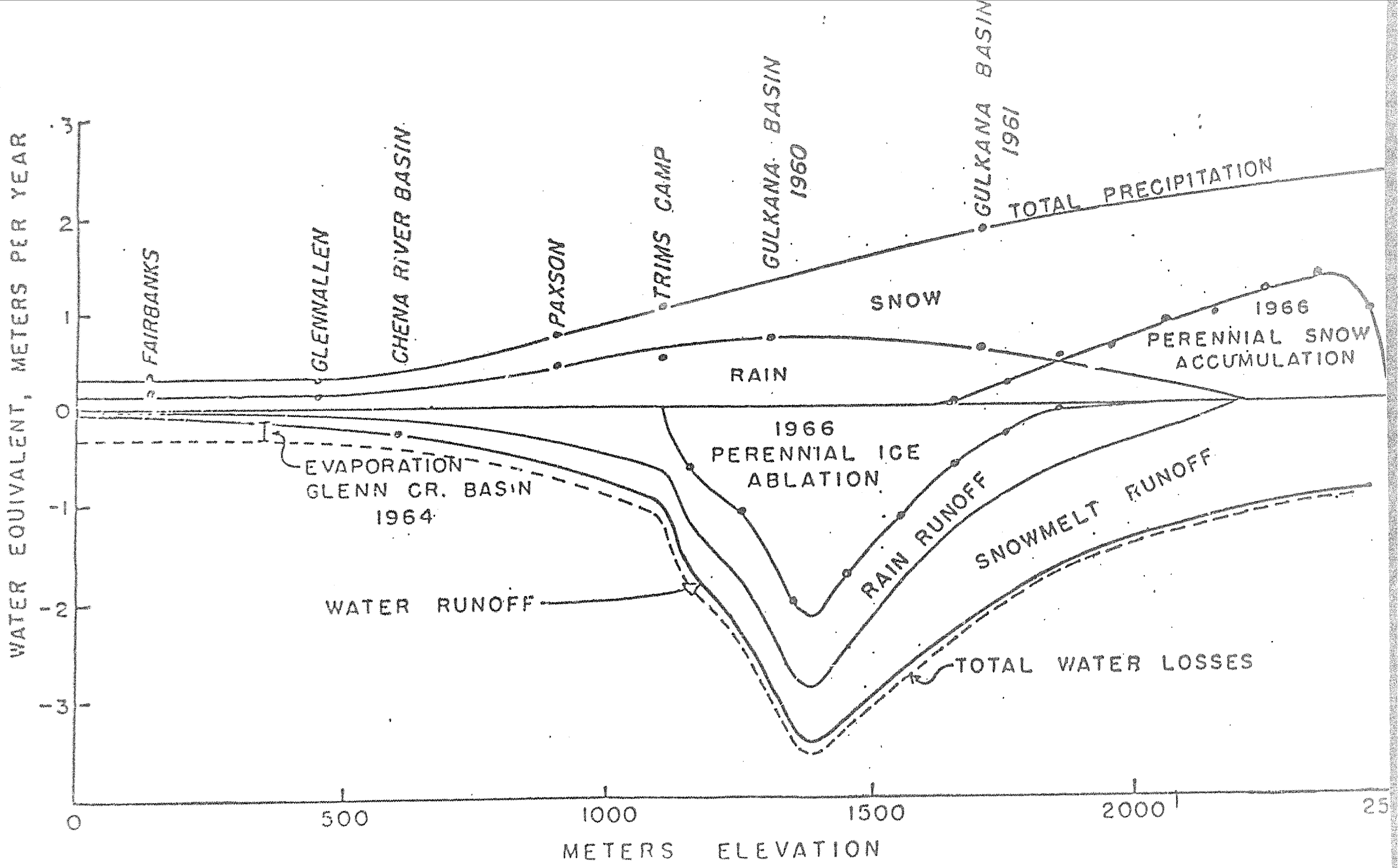


Figure 4. Distribution of precipitation and runoff with elevation - Yukon-Tanana Uplands east and southeast of Fairbanks, Alaska (L. Mayo)

the Susitna River Basin west of the Talkeetna Mountains can be classifed as modified maritime (represented by the Talkeetna Meteorological Station of the National Weather Service).

Most of the drainage area of the Susitna River Basin above the Watana damsite is in a transition zone which is subject to both modified maritime and continental climatic conditions.

The precipitation data that has been collected by R & M Consultants from 1980 to 1984 were reviewed to evaluate the effects of the varying climatic conditions over the basin. Maps showing monthly values of recorded precipitation for stations located in and near the upper Susitna River Basin are presented in Appendix A. R and M Consultants have indicated that measurements from the meteorological stations operated in the basin may not include all snowfall. In general, it appears that precipitation in October and April (the only maps available for the winter months) is in line with the amounts that occur over the Cooper River Basin and is representative of continental climate conditions.

During the summer, the precipitation over the upper Susitna River Basin is more representative of a maritime climate. The large amounts of precipitation recorded during some July and August months at the Susitna Glacier station (Maps A-4, A-6 and A-7) are a result of the inflow of moisture from the Gulf of Alaska. Studies of thunderstorm activity in Alaska as discussed in Chapter 2 (15) also show that this area of the basin is subject to considerable thunderstorm activity in July, August and sometimes September. The thunderstorms form over the southern and western Talkeetna Mountains and move to the northeast.

It is evident that a large percentage of the upper Susitna Basin, especially the primary and west forks of the Susitna River, recieve a major portion of their annual precipitation during these summer months. Studies on the Gulkana Glacier east of the Susitna Basin have shown that fairly heavy preciptiation does occur on this basin during the late summer months. However, the upper elevations of the Susitna Basin may receive more summer thunderstorm precipitation than does the upper elevations of the Gulkana Glacier. One reason is that the high mountains of the Alaskan Range are oriented as to receive maximum precipitation from thunderstorms that move from the southwest and that originate over the Talkeetna Mountains. The mountains above the Gulkana Basin are also similarly oriented. However, the overall summer thunderstorm activity in this area is probably somewhat less since the mountains where the thunderstorms originate are lower in elevation and are also more glacierized.

D. Runoff and Precipitation-Runoff Analyses

(1) Runoff Analyses.

Daily discharge records from streamgaging stations in the upper Susitna Basins were plotted for the summer months for the years 1981, 1982, 1983 and 1984. Daily precipitation as recorded at the Paxson and the Talkeetna weather stations operated for and by the National Weather Service were also plotted for the same periods as the daily discharges. For each year the following plots are presented in Appendix B:

1. Susitna River near Denali, Alaska

2. Maclaren River near Paxson, Alaska

3. Susitna River near Cantwell by solid line and combined daily flow for Denali plus Paxson by dashed line

4. Daily precipitation for Talkeetna and Paxson

A subjective review of these plots for the Susitna River at Denali and of the temperature variations that occured each year provide a good view of the runoff characteristics of this basin. During the months of May and June rises in air temperature result in an increase in the snow and ice melt with only a small lag between the rise in temperature and a rise in the discharge. Following heavy rain during the later months of July, August and September there are also fairly rapid responses in the discharge.

For the Maclaren River near Paxson, increases in discharge resulting from increases in air temperature during May and June appear to be less noticable and generally start later. The rises resulting from rainfall during the latter part of the summer are more in line with those for the Susitna above Denali. Review of the combined plots (Cantwell and Denali plus Paxson) shows that the contribution from the intervening area below the upper gaging stations and above the Cantwell gaging station (indicated by the spacing between the dashed and solid lines) during May and June varies considerably in relation to the amount of runoff from the glacierized areas above the upstream gaging stations.

Semilog plots of the daily discharges for May-September for 1981-1984 for the Denali and Paxson streamflow stations and for the runoff contributed by the intervening area are presented in Apendix B (Figures B17 through B-28). Review of these plots for May and June each year shows that the discharge peaks resulting from snowmelt at the Denali and Paxson gaging stations are fairly well correlated with possibly a longer delay of one to two days in the time to peak for the Denali station hydrograph.

An interesting fact observed from the Denali and Paxson plots is the gradual decay in the flows during August and September (day 93 to day 153). The decay in runoff results from the decrease in the areal extent of the snow cover. Peaks in the runoff resulting from rain are superimposed on the decay curve. This is an indication that a snowmelt model that accounts for variability in the areal extent of the snow cover should model the basin snowmelt very well.

(2) Precipitation-runoff relationships

Studies on Probable Maximum Precipitation for the Susitna River Basin were received from Harza-Ebasco (19 and 20). These reports contained results of studies on unit hydrographs for subbasins of the area and some application of the HEC-1 rainfall-runoff procedure. In the report prepared by Acres (20) the SSARR (Streamflow Synthesis and Reservoir Regulation) model developed by the U. S. Army Corps of Engineers was adapted to the entire basin above Gold Creek for part of the years of 1964, 1971 and 1972. The above applications of precipitation-runoff models to the basin are sufficient to demonstrate that the basin can be reasonably fitted with models. The accuracy of the relationships was limited because of the lack of precipitation and temperature data from within the basin.

Although it was not planned to fit any model during this study, in order to better understand precipitation-runoff relationships for the area and to obtain a knowledge of the relative importance of different basic data, some statistical analyses were performed. These included correlations of snow course, precipitation and temperature data with streamgaging records for the Susitna River at Denali, the Maclaren River at Paxson, the Susitna River near Cantwell and for the lower intervening area of the basin (the area above Cantwell gaging station excluding the area above the Denali and Paxson stations).

The August runoff of the Susitna River at Cantwell has a 0.77 correlation with the combined runoff observed during August at the Denali and Paxson streamgaging stations. Using the precipitation recorded during August at Talkeetna as an additional variable increases this correlation to 0.84 even though Talkeetna is over one hundred miles away. It is also interesting that the July-September Talkeetna precipitation has a correlation of 0.77 with the July-September runoff from the lower intervening area above Cantwell.

Summer runoff for the glacierized basins is not as well related to precipitation observations. The best single correlation with the May-September runoff of the Susitna River at Denali is with the April 1 snow survey data observed at Monahan Flats ($r = 0.60$ or a coefficient of determination of only 0.36). This indicates that the winter precipitation accounts for only a small portion of the May-September runoff of the Susitna River above Denali. Other factors that influence how much runoff will occur during the May-September period for this basin are:

1. Amount of energy received in the basin during the summer months

2. The summer precipitation over the basin

3. The amount of snow carryover in the basin

A multiple correlation analysis was made to determine if the effect of each of the above factors could be found using the avaialable data base. Monthly departures from the average temperatures at the Talkeetna meteorological station for five months (May through September) were summed each year for an index of the amount of energy received during the runoff period. The May-September precipitation at Talkeetna was used as an index of the summer precipitation in the basin. The May-September precipitation of the previous year was used as an index of the amount of snow that was carried over from the previous year. Most of this is seen as patches of snow on non-glacierized areas at higher elevations prior to the snow cover of the current year.

The data used in the correlation anlysis and the statistical results are shown in Appendix C. The final correlation using all four variables was 0.81 and the separate contribution indicated for each of the four variables appears to be significant from the t and F test statistics.

Although the correlation is not high, the results are very good since the analysis was made using only seasonal values for data recorded a very long distance from the basin. The results support the hypotheses that the winter precipitation for the Susitna basin above Denali accounts for about half of the total runoff from the basin during the period from May to September.

A trend analysis was made on the basic data. This gave a correlation of 0.52 between the May-September runoff and time (year to 2 digits)) with a trend towards increasing amounts. This could be related to changes in the discharge measurements, changes in the amount of wasting of the glacier, a real trend towards wetter years or a combination of these factors.

During meetings with the various scientists in Anchorage an interesting statement was made by William Harrison. It was his observation that during years with very heavy precipitation there seemed to be less runoff than would be expected for the Susitna River at Denali. He also stated that there seemed to be a negative correlation between summer precipitation and the May-September runoff. Although no conclusive evidence has been developed to prove Harrison's statements, the results of the correlation studies using monthly means values seem to substantiate to some degree his observations. In addition precipitation records observed in the lower Susitna Basin do correlate negatively with the May-September runoff of the Susitna River at Denali.

There is no way to prove the interactive role played by precipitation and temperature in the Susitna River basin above Denali without detailed measurements from the basin. However, assuming that the results of the correlations analyses made using available monthly values are related to the true conditions, some observations can be made. When heavy precipitation occurs during the summer months the cloud cover is much greater and the amount of energy reaching the basin is reduced. Although the total runoff from the basin may be greater than it would have been with less summer precipitation, the amount added to the perennial snow cover above elevation 2100 could be greater than the amount ablated. Thus the amount of snow added to the perennial snow cover (and on the non-glacierized areas) during those years with heavy summer precipitation (and consequently proportional less snowmelt) should be much greater than during years with light summer precipitation. This supports the use of the previous May-September precipiation to account for the apparent increase in runoff during the current year.

The method selected for forecasting the May-September runoff of the Susitna River at Denali and the Maclaren River near Paxson should take into account the importance of the summer precipitation and the carryover effects. If accurate and consistent measurements of the perennial snow cover on the glaciers and of the carryover snow cover of the non-glacierized areas of the basin were available they could be used to account for this factor. However, such measurements are difficult to obtain. Without such measurements, techniques can be developed to handle this effect for forecasting the seasonal water supply. This can be done by finding a variable, such as the previous May-September precipitation, that is an index to the amount of carryover and correlating this variable with the errors in the forecast procedure for the seasonal runoff.

2. Model Alternatives

The factors discussed in the previous section are the primary ones to be considered in selecting the models for use in the forecasting program for the Susitna River Hydroelectric Project. Another important factor for consideration is the ability of the model to be updated using real time streamflow measurements and/or other hydrometeorological measurements that may become available in real time in the future.

The first part of this section consists of a review of the models that could be used for forecasting short- and long-term runoff in the basin. This includes discussions on accuracy of the forecasts for the various models and on the sensitivity of the models to the basic data input.

The term "modelling of hydrological systems" generally means the application of mathematical and logical expressions which define the quantitative relationships between the flow characteristics (output) and the flow-forming factors (input). This is a very general definition which covers an entire spectrum of approaches. At one extreme are the purely empirical statistical "black box" techniques that make no attempt to model the internal structure and response of the catchment system. At the other extreme are techniques involving complex systems of equations based on physical laws and concepts, the so-called conceptual models. Both the statistical black box and the conceptual models are deterministic models and any classification of a particular model to one class or the other forces a decision on the degree of empiricism. In this review the terms black box and conceptual will be used to classify the models.

Most deterministic models must be calibrated to a basin using past records of hydrometeorological variables to determine a set of paramters to fit the model to a particular basin. In general, black box models require a longer length of record to determine the most suitable parameter set. For conceptual models some of the parameters can be determined directly from physical characteristics of the basin (i.e., soil type) and from analyses of streamflow records (i.e., coefficients for ground water discharge).

Because the Susitna basin has a large percentage of runoff resulting from melting of snow and glacier ice, special attention is given to review of approaches for forecasting the melting of snow and ice.

Water supply forecasts for basins with considerable snow cover (and glaciers) are made by three basic techniques:

a. Snowmelt forecasts,

b. Conceptual models, and

c. Time series analysis.

The models for forecasting the snowmelt will be considered first, followed by a review of conceptual models for forecasting the entire runoff from a basin (complete or in conjunction with a snowmelt model). Many snowmelt models use a simple degree day approach as an index of snowmelt.

A. MODELS FOR FORECASTING SNOWMELT AND RUNOFF FROM GLACIERIED BASINS

(1) USSR Modeling

V.G. Konovalov (21, 22) and others in the USSR have developed tecnniques for forecasting snowmelt and glacier melt. For mountainous areas, most of the models compute snowmelt by elevation zones and require considerable input of snow measurements. For glacier melt forecasting, Konovalov (21) has discussed the relative importance of knowing the ratio of the accumulation and ablation areas of the glacier. In addition, he has stressed the need for computing the separate estimates of the volumes of melting of pure ice, ice under the moraine, old firn and winter and summer snow making up the total volume of melting from a glacier region. The data requirements for these approaches are deemed to be more than necessary for the Susitna project.

(2) Models for Predicting Runoff from Glacierized Basins

Andrew Fountain (U.S. Geological Survey, Tacoma, Washington) has provided a copy of a chapter (23) prepared by him and Wendell V. Tangborn (HyMET Company, Seattle, Washington) for an unpublished report by the Working Group on Snow and Ice Hydrology of Glacierized Basins, International Commission on Snow and Ice, International Association of Hydrological Sciences. This report, "Contemporary Techniques for Predicting Runoff from Glacierized Basins," provides comments on the advantages and disadvantages of several models and includes a table summarizing the main features of each mondel.

Most of the models reviewed in the report are research models that have been applied to only a single basin. Exceptions to this are the model by E. A. Anderson (National Weather Service, Silver Springs, Maryland) which has been applied operationally by the national forecasting services in the United States and Canada (including 11 basins in Alaska) and the Tangborn model which was reported as being applied to three basins in Canada.

(3) Eric Anderson Model (NWSFRS Snowmelt Model)

The Snow Accumulation and Ablation Model of the National Weather Service (NWS) has been in operational use by the NWS since 1973 (24). Nibler, National Weather Service River Forecast Center, Anchorage, Alaska, has modified the model to include the presence of glaciers in the basin. The snowpack depletion curve (area of snowcover as a function of snowpack water equivalent) was altered so the minimum snowcovered area is equal to the basin's glacierized area. This area is then assigned a snowpack thickness greater than what could be lost by summer ablation.

Nibler reports that this modification works satisfactorily for estimates of seasonal runoff from glacierized basins, but it is disappointing for daily forecasts. Calculated runoff has a very quick and "flashy" response relative to the more slowly responding observed runoff, which he suggests is caused by neglecting storage factors of the glaciers. Parameter values for eleven basins that are forecasted operationally by the NWS in Alaska have been furnished by Gerald Nibler (private communication). For most of these basins the model has been applied with two zones (based on elevation).

Although the NWS Anderson snowmelt model has generally satisfactory results, certain deficiencies do exist. Insufficient knowledge of the actual occurrence (and of the normal precipitation during the various seasons of the year) of precipitation at higher elevations can result in runoff volume errors. There is also a problem in classifying precipitation as to rain or snow based solely on maximum-minimum temperatures. This is mainly a problem in basins where both rain and snow frequently occur during the same event. The above are deficiencies in basic data and not in the structure of the model and would be applicable to all models.

The Anderson Model uses temperature as the sole index to snowmelt but not in a degree day approach. Under certain temperature conditions the use of air temperature as the sole index of snowmelt has proven to be inadequate. This can occur under clear skies with abnormally cold temperatures (underpredicts), under very warm temperatures with little or no wind (overpredicts) and with very high dew points and high winds (underpredicts). The latter two conditions would not be a factor in the Susitna Basin. The first condition should not be a major one because of the high amount of cloudiness that occurs during snowmelt period in the basin. In any case, these conditions affect the timing and magnitude of the peak runoff more than the total volume for a period.

The Anderson model was reviewed in a report prepared by the authors for the National Aeronautics and Space Aministation (NASA), a diagram from that report (25) illustrating the model is included in Appendix D (Figure D-1). Also included in Appendix D are listing of the states and parameters for the model (Table D-1 and D-2). Information on the schematic diagram and on the definitions of states and parameters as used in the NASA report is included in Appendix D.

The parameters for the Anderson model have been found to be related to climatic and physiographic characteristics and reasonable initial parameter values can be obtained from a knowledge of typical conditions over a watershed.

A discussion on the possible application of his model to the Susitna Basin was held with Eric Anderson. Anderson believes that for glacierized basins the daily forecast values of runoff would have more variance than observed values but that this effect would tend to average out for longer periods (such as for a two-week forecast). He also stated that reliable seasonal maps of precipitation would be required to properly calibrate the model. He agreed with Gerald Nibler that a separate zone should be included and assigned a large water equivalent value for the glacierized area of the basin. With an areal depletion curve as used in his model, he believes that you would not need many zones (probably 2 but a maximum of 3). For models not having an areal depletion curve many zones would be required as is done in the USSR. Anderson furnished an unpublished report summarizing the findings of the recent comparison study on snowmelt models discussed in the next section.

Anderson has fitted his model in Alaska. An interesting result is the difference in the shape of his curves for distributing melt factors through the year as shown in Figure 5. In the contiguous United States the curve is a sine wave; in Alaska the curve stays at a minimum until it starts to rise sharply during April. Anderson attributes this to the differences in length of sunlight and is a reason why the streams in Alaska do not have a significant increase in snowmelt runoff until after May 1 as may be seen in the report on Daily Flow Statistics of Alaskan Streams by Chapman of the NWS (26).

(4) WMO Comparison of Snowmelt Models

During the period 1978-1983 the World Meteorological Organization (WMO) carried out an international comparison of conceptual models of snowmelt runoff (27). The final report of this study has not been released by WMO but comparison figures have been furnished to the participants and were reviewed in Anderson's office. Three models developed in the United States were included in the WMO comparison study and the calibration used in the comparison study were those fitted to each basin by the authors of the models.

The unpublished paper furnished by Anderson was prepared for WMO by two Canadians (28). The statistics for the results of the calibration and verification runs for the three U. S. models are summarized below and are considered to be more representative than most comparison studies where the models are often calibrated by hydrologists who may not be experienced in calibrating the models compared.

The U. S. models included in the WMO comparison study were:

a. NWS Anderson Model

b. The Precipitation-runoff Modeling System (PRMS) of the U. S. Geological Survey

c. The Streamflow Synthesis and Reservoir Regulation Model (SSARR) of the U. S. Army Corps of Engineers

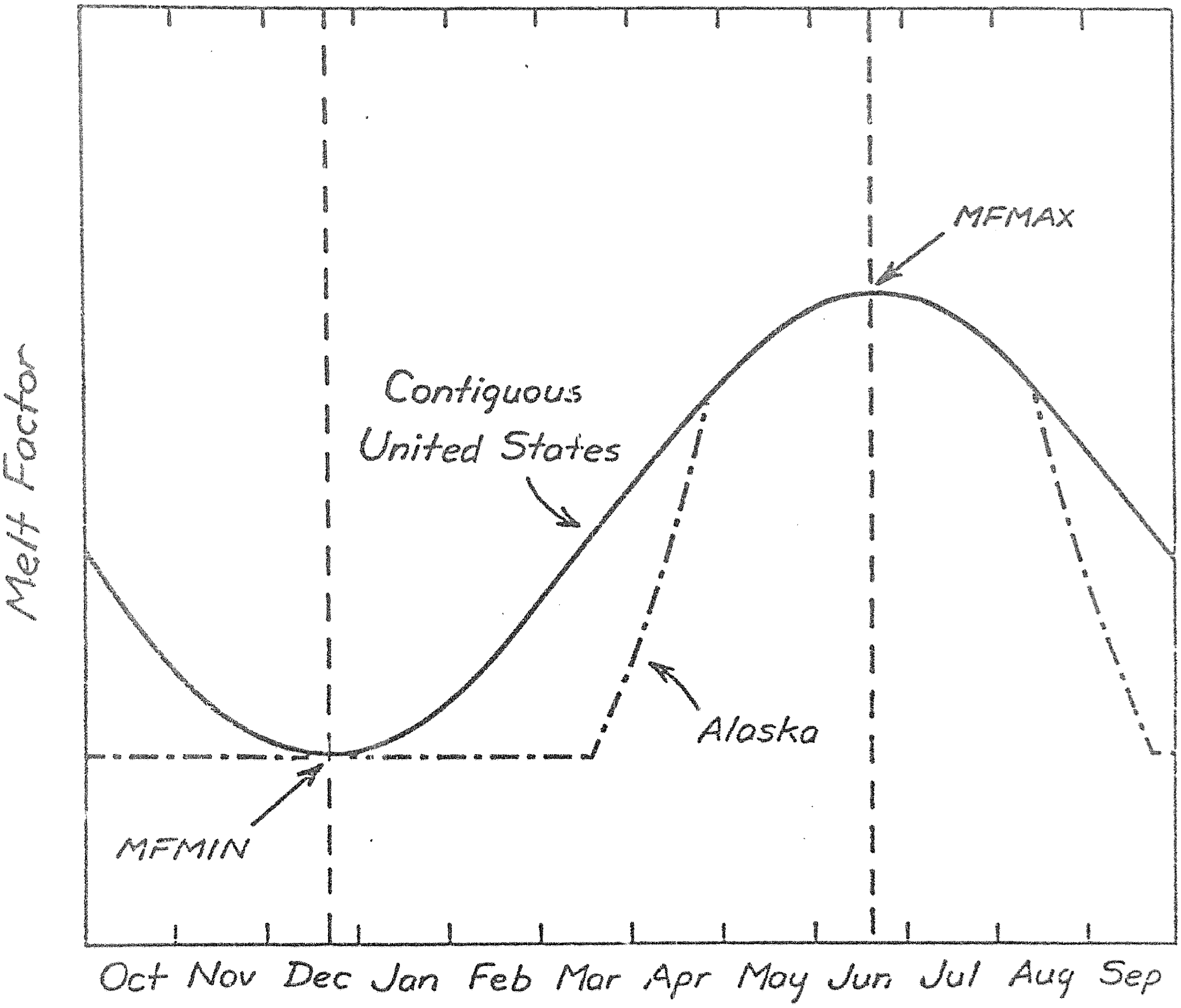


Figure 5. Seasonal variation in melt factors used during non-rain periods.

The statistical values of the simulated and observed streamflow were compared in the unpublished study for significance using four statistical variables. A value for each of the four statistical variables was computed for the calibration-complete year, calibration-snowmelt period, verification-complete year, and verification-snowmelt period) for each of the three river basins that were calibrated by all three of the U. S. models. This provided a total of 48 cases. For each case, each model's results were compared with the results of the model having the best statistical value for that case. Those that were found to be as significant as the best model for that case (within a 95 percent confidence interval) were considered to be as good as the model that had the best statistical value and were considered as a tie for first place.

Tables showing the ranking of the models for each of the 48 cases were presented in the unpublished report. The following indicates how often each of the three U. S. models were ranked in first place;

NWS Ranked first in all 48 cases

PRMS Ranked first in 22 cases

SSARR Ranked first in 21 cases

The Anderson model is the most physically based snowmelt model in use today and the results of the test program indicate its accuracy and reliabity for forecasting basins in different climates. The model was developed from physical concepts using detailed measurements of all measurable variables yet was designed to use only standard measurements of precipitation and temperature.

B. Conceptual Soil Moisture Accounting Models

Five conceptual soil moisture accounting models were selected to be considered as alternatives for the operational system for the Susitna Hydroelectric Project. These are:

Tangborn Model (HyMet)
National Weather Service River Forecast System (NWSRFS)
Precipitation-Runoff Modeling System (PRMS)
Stanford Watershed Model (SWM)
Streamfow Synthesis and Reservoir Regulation (SSARR)

Three of the above models were included in the review of models completed by Hydex for NASA (25) and by the WMO (30). This study provided a good method to study and compare models. Since information on three of the models is available in the form used in the NASA study it was felt it would be beneficial to have all models in the same format.

The authors of the two models that were not included in the NASA study were contacted to obtain more complete information on the models and their structure. Wendell V. Tangborn (HyMet Company, Seattle, Washington) furnished information on the HyMet model and George H. Leavesley (U. S. Geological Survey, Denver, Colorado) on the PRMS model. Schematic diagrams and definitions of states and parameters for the two models were prepared and submitted to Tangborn and Leavesley for review. The schematic diagrams and lists of definitions for all five models are presented in Appendix D along with the same material for the Anderson Snowmelt Model.

A glossary of terms used in review of the models for NASA and a legend for the schematic diagrams as originally published in the NASA report (25) are reproduced in Appendix D. By developing the diagrams and studying the states and parameters used in the models, a reasonable understanding of the structure and operation of each model can be achieved. Based on this knowledge, and on our experience, comments on the models for possible selection for the project are given below.

(1) HyMet Model (Diagram D-2, Tables D-3 and D-4)

(a) Data Requirements

The operation of the model requires only the standard measurements of precipitation, temperature.

(b) Field Experience

The HyMet model is being used operationally for seasonal forecasting in the Pacific Northwest and in Central Arizona. As far as can be determined there is no complete documentation for calibration or operational use of the model.

Short term streamflow forecasts of 1-3 days duration require weather forecasts of precipitation and temperature. Seasonal forecasts are based on regressing indices of the total water in storage (in snow cover, soil, surface and groundwater) in the basin on the day of the forecast with subsequent runoff for a specified time period.

(c) Accuracy

The model has not been included in any of the WMO comparison tests and no results of comparison with other models have been found. The only available results are those published by the author with little or no supporting information for evalulating the model performance.

(d) Use in Snow and Glacierized areas

It is evident from the Diagram in Figure D-2 that the original Tangborn model has been adapted for use in glacierized areas. Tangborn furnished a paper "Prediction of Glacier Derived Runoff for Hydroelectric Development" (29) which presents the basis for the glacier protion of the model. The paper reports on the analyses made for two small basins in British Columbia, Canada. The assumption is made that englacial storage of water (from ablation of snow, firn and ice, and precipitation) occurs during the period from November 1 to July 14 and that outflow from this stored water occurs from July 15 to October 31. From the information furnished on the model it was not clear exactly how the model handles the states in the model for firn ice and glacier net balance. Because the precipitation input to the glaciers in the Susitna Basin is considerably different than for glaciers along the west coast of North America (less than half of the input during the winter compared to a very large percentage for glaciers along the west coast of the United States), it is not certain if the adjustment technique for englacial storage as used in the paper would be of direct value for the Susitna Basin.

For glacierized areas the HyMet model uses up to five elevation, zones and snow accumulation for each altitude is determined using standard precipitation measurements from one or two selected weather stations. The snow, firn and ice melt are calculated from the mean air temperature and the range of daily temperature.

(e) Updating

A technique using the error for a short-term forecast as an index to the error in the seasonal forecast is used for adjusting the seasonal forecast on the basis of comparison of simulated and observed flows. For example, a seasonal forecast prepared as of May 1 uses the error in the simulated versus observed flows during May for revising the seasonal forecast. This has more value for basins where the major portion of the input for the seasonal flow occurs prior to the date of the forecast. It is not certain how it would work for the Susitna Basin. The updating procedure has not been incorporated into the short-term forecasting method (31).

The soil mositure accounting structure of the model is similar to other models and it is clear that the model was not developed with the concept of having states of the model to relate directly to measureable hydrological variables in the real world. There is no indication that techniques have been developed that would objectively use remote measurements (i. e., water equivalent of the snow cover) for updating the model.

(f) Operational Factors

Unless the model was applied by the HyMet Company the lack of documentation for the model would be a serious limitation. There is insufficient information to determine how the model would be used for short and long-term forecasting.

(2) NWSRFS Model (Diagram D-3, Tables D-5 and D-6)

(a) Data requirements.

The operation of the model requires only standard measurements.

(b) Field Experience

The NWSRFS is used operationally throughout the United States and Canada. There is complete documentation for the NWS River Forecast System and for each of the models used. A report on techniques for catchment modeling and initial parameter estimation for the NWSRFS soil moisture accounting model was published by Peck (32).

(c) Accuracy

The NWSRFS was included in the WMO comparison study on soil moisture accounting models and although no formal comparison was reported on the results, a review of the published comparison indicates that the model performed as well or better than any of the models tested. The Hydrologic Research Laboratory of the NWS did an extensive testing program in 1971. Three models were compared with a continuous API model developed for the test program. The models tested were the Sacramento RFC Hydrologic Model (later adapted as the NWSRFS model), the SSARR model and the Stanford IV model. Based on those tests the Stanford model was selected for the NWSRFS. Later additional tests were made and it was determined that the Sacramento model was more adaptable to all forecast situtations and this model was accepted for the soil moisture accounting model for the NWSRFS.

(d) Use in Snow and Glacierized Areas

The NWSRFS is used in many snowmelt areas and in some glacierized areas. The model has been calibrated and is used to forecast 11 streams in Alaska of which one has some glacierized area. Parameters for these calibrations have been furnished by Jerry Nibler of the Anchorage River Forecast Center of the NWS.

(e) Updating

There are several updating techniques for the NWSRFS (33) ranging from simple blending approachs to objective techniques for adjusting states in the model using correlation methods (34) and a full state-space estimation theory approach. A method to update the snowmelt model when used in conjunction with the soil moisture accounting model was developed by Carroll (35). Techniques for updating the NWSRFS using soil moisture and water equivalent of the snow cover were investigated during the studies by Hydex for NASA (36).

(f) Operational Factors

The model has been used for operational forecasting for many years.

(3) PRMS Model (Diagram D-4, Tables D-7 and D-8)

(a) Data requirements.

The model uses standard measurements but requires considerable information on basin characteristics for application.

(b) Field Experience

The model was developed for use in studying effects of land use changes and therefore has been prepared only for prediction use where all data for one year (or a long period of time) is imput at one time. There is nc operational model for use in forecasting but Leavesley states that they plan to prepare one.

(c) Accuracy

The only known evaluation of the model that has been published is that reported above from the WMO snowmelt comparison study.

(d) Use in Snow and Glacierized Areas

The model has a component for handling snowmelt runoff as may be seen on the schematic diagram (Figure D-4) and it is based on energy balance equations. The model has not been adapted for glacier areas.

(e) Updating

Since there is no forecasting mode there are no updating techniques.

(f) Operation Use

The model is well documented (37).

(4) SWM Model (Diagram D-5, Tables D-9 and D-10)

(a) Data Requirements

Same as for NWSRFS model

(b) Field Experience

The model has been used throughout the world by the authors but it is not certain where the model is presently being used.

(c) Accuracy

The SWM was included in the test conducted by the NWS Hydrologic Research Laboratory and in the WMO comparison tests. In both studies the results were very comparable to those for the NWSRFS.

(d) Use in Snow and Glacierized Areas

The model has been used in snow melt areas but no information is available for glacierized areas. The Anderson model is used for snowmelt modeling.

(e) Updating

The authors have updating techniques using observed streamflow but no specific information is available.

(f) Operational Factors

Similar to those indicated for the NWSRFS.

(5) SSARR Model (Diagram D-6, Tables D-11 and D-12)

(a) Data Requirements

Standard measurements.

(b) Field Experience

The SSARR model has been used throughout the world and is used operationally by the joint NWS-Corps of Engineers river forecast center in Portland, Oregon. Excellent documentation exists for the model.

(c) Accuracy

The SSARR model is primarily a river routing and reservoir regulation model. The components for its soil moisture accounting and snowmelt components are not as conceptual as for the other models considered. Tests conducted by the NWS and the WMO (on both the soil moisture accounting and the snowmelt comparisons) have shown the model to have more limitations in forecasting for individual basins.

(d) Use in Snow and Glacierized Areas

The model has been used in many snowmelt areas. There is no component for accounting for glaciers. The model has been used to calibrate the Susitna River Basin for the months of August and September using standard tables by Bredthauer of R and M Consultants.

(e) Updating

Some subjective methods for updating the model operationally have been used. However, the structure of the model (large use of tables) makes it very difficult to develop procedures for objective updating the model. Analysis by Hydex for NASA has determined that the use of remote sensing measurements for updating the states of the model would be very difficult.

(f) Operational Factors

There are no known problems for using the SSARR model operationally.

3. Forecast Errors

Knowledge of the sources of error that would occur in forecasting short- and long-term runoff of the Susitna River is an important factor for determining the forecast models that should be used. Possible sources of forecast errors are shown by the schematic diagram in Figure 6; these are model, basic data and climatological.

Model error results from the fact that the model (and its parameterization) does not accurately represent the real world. The magnitude of the model error in forecasts of short- and long-term seasonal runoff would be approximately the same for either a statistical or a conceptual approach.

The accuracy of a seasonal forecast for water supply depends on the ability to know the true basin averages of hydrometeorological parameters used in the model. Even if a perfect model and a perfect set of parameters were available, inadequacies in basic data would introduce large errors in the forecasts of the May-September runoff for the Susitna River Basin. The basic data error for the winter precipitation (due to fairly good correlations among the April 1 snow course measurements) is probably less than the data error for forecasts during the summer thunderstorm period. Improvement in the knowledge of the actual precipitation by proper locating gages, by adjusting precipitation measurements for gage catch deficiencies, and by improvements in the network (additional stations and representative exposures as recommended above) all help to reduce the basic error component of the total forecast error.

The climatological portion of the forecast error results from future weather conditions which are unknown at the time the forecast is issued. The percentage of the total error due to climatological error for forecasts for the Susitna Basin above Denali is directly related to the percentage of the total input that has occurred up to the date of the forecast. Since this is approximately less than half of the total seasonal input as of April 1, the climatological error is probably much greater for the Susitna River Basin than for basins where the percentage of the seasonal input is much larger prior to April 1.

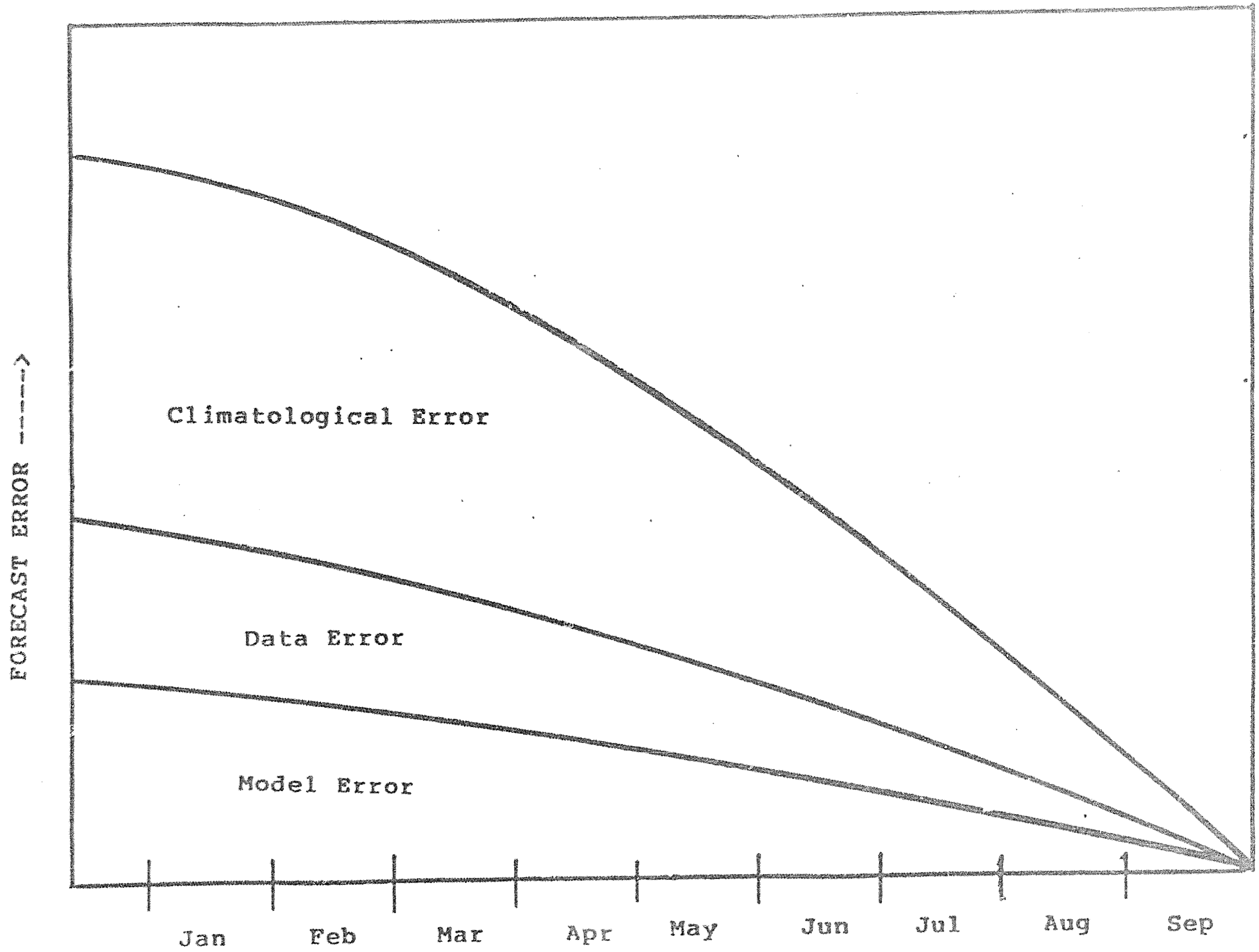


Figure 6. Schematic diagram of sources of forecast errors

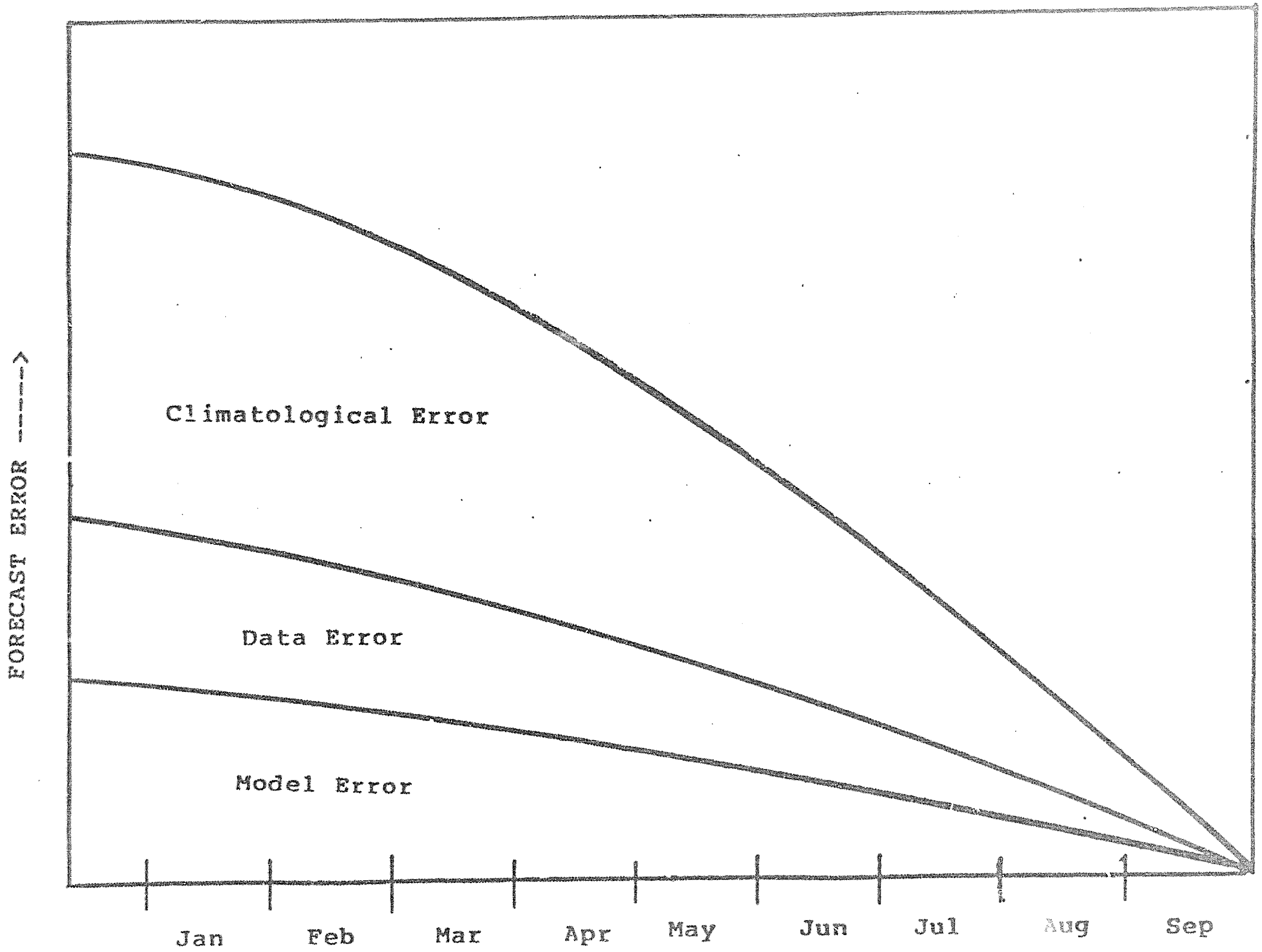


Figure 6. Schematic diagram of sources of forecast errors

It is not possible to determine the relative errors (climatological, basic data and model) that would be associated with each model without completely applying the models to the Susitna River Basin. However, the climatological error should be approximately the same for each model used. The basic data error associated with the use of the five models reviewed is primarily dependent upon the basic data and only marginally on how the data are processed in the models. It is assumed that the basic data error and the model error may be approximately the same for forecasts prepared using the PRMS, SWM, HyMet or NWSRFS models ..d somewhat greater for the SSARR model.

The actual error of the forecasts finally developed for the project will depend much more on other factors than on the selection of the model or models to be used. Basic data error resulting from inconsistency (change in time or inconsistencies in the data used for calibration and for operational forecasting) can be very great. The successful application (and minimum forecast error) using any model depends to a large extent on the experience of the modeler and on the characteristics of the basin.

One advantage of using a conceptual model over a black box regression model is the increased ability to forecast extreme (dry or wet) conditions that were not experienced in the set of data used for calibration of the model. For a conceptual model to realize this advantage the input data for the model should be as representative of "true" values as possible. For calibration an accurate knowledge of climatological averages of the magnitude and distribution of the seasonal precipitation over the basin is required (seasonal isohyetal maps). For operational use information on the climatological averages of the possible weather conditions for the rest of the season are required (statistical indicies of climatological conditions).

The only way to reduce the climatological error of forecast is by using forecasts (that have information content) of future weather conditions. Availability of short- and long-range weather forecasts and monthly outlooks have been summarized by Nibler (38). Forecasts of temperature and quantitative precipitation forecasts (QPF) are available from the National Meteorological Center, National Weather Service, Suitland, Maryland, and are received directly by the NWS offices in Anchorage. Specific forecasts of precipitation and temperature conditions are issued for 12-hour periods for the next 48 hours. Other prognostic information issued for up to 72-hours periods and for 6-10 days ahead can be used to derive forecasts for precipitation and temperature for up to 10 days in the future. In addition, information on expected average monthly values is *available from published monthly outlooks for Alaska.*

4. Model Recommendations

Several individuals with whom the study has been discussed have indicated that forecasting the snow and ice melt from the glacierized portions of the basin would be difficult. However, based on the review of the hydrometeorological data for the basin and the results of previous model studies, it is believed that the Anderson model will provide the accuracy and reliability for such forecasting when used with available updating procedures and real-time measurements of the streamflow. Thus, the Anderson model is recommended for use in forecasting snow and ice melt for the project.

The lack of accurate and consistent data for a number of years (except for some snow survey and streamflow data) makes if difficult, if not impossible, to use regression type "black-box" approaches for forecasting the long-term water supply runoff.

Assuming a realistic knowledge of the magnitude and variability of seasonal precipitation is provided by the proposed basic data collection program, simple quasi-conceptual models can be used to prepare long-term forecasts of the water supply runoff. Forecasts of the long-term water supply runoff can also be prepared by extending the forecast periods for the conceptual models discussed in this report. This can be done by initializing the model as of the date of the forecast by using measurements of the water in storage (in the snow cover and englacial), by using forecast weather conditions for the near future and by applying Extended Streamflow Prediction (ESP) procedures used by the National Weather Sevice (39) for time periods for which weather forecasts are available.

The long-term water supply forecasts can be issued in terms of conditional probability that will provide considerably more information for the reservoir operations than a simple volumetric forecast. For example, probability distribution relations can be produced providing the expected probability of occurrence of the range of water supply that could be expected. Such information is valuable for reservoir operational decision making.

The time and expense to develop a data base and process all data for use in forecast modeling is considerably greater than the time required to test and evaluate the use of different forecast models. Therefore, it is recommended that more than one model be tested for the soil moisture accounting and the long-term forecast models for the project. This is considered viable in view of the fact that the actual operation of the reservoirs will not commence for several years. Recommendations for models that should be investigated for use in the project are:

A. For short-term forecasting:

(1) NWS Anderson snow ablation and accumulation model for forecasting snow and glacier melt for the basin.

(2) Test the SSARR and NWS models for soil moisture accounting and use as a routing model.

B. For long-term forecasting;

(1) Use the conceptual forecast model selected for issuing short-term water supply runoff to forecast long-term (from date of forecast to September 30) water supply using weather forecasts and Extended Streamflow Prediction procedures.

(2) For early season forecasts (prior to May 1) develop a simple quasi-conceptual model based on watershed conditions as of April 1 and statistics of climatological conditions during the May-September period.

CHAPTER 4

OPERATIONAL CONSIDERATIONS

1. Introduction

This chapter addresses operational matters, covering such items as who might run the operational models, how necessary data might be relayed to a central location, and system maintenance as well as recommendations for a data collection system for the Susitna Hydroelectric Project.

2. Operation of the Forecast Models

In the long run, the goal for the forecast models should be routinely operated by persons not necessarily trained in hydraulics and hydrology. In the short run, however, this will be both impractical and impossible. For approximately one to two years the models should be watched and run by the persons who set them up. At the same time, "Hands-on" training for the hydrologist who will have operational responsibility for the models should take place. At the end of the one to two year period, most of the operational procedures will have been ironed out and the electric utility or other operators of the dams can take full responsibility. After an additional year of experience the models will have been "fine tuned" and much of the day-to-day operations can be turned over to less technically trained people.

Several options are open to the operators of the reservoir system in choosing who should run the models. The first choice will probably be to use an in-house hydrologist. A second choice is to contract out the modeling in the same way that the data collection and maintenance are currently contracted to R&M Consultants. Hydex Corporation, for example, could both set up and operate the models by making use of data relayed to the GOES central satellite receiving site in Wallops Island, Virginia (more on satellite systems shortly). Hydex could also set up and run the models for the two-year shakedown period and at the same time train in-house personnel for long-term operations.

3. Data Collection and Relay

The most sophisticated of models for the Susitna River Basin will be useless unless sufficient and timely data are available for their operation. This section provides an analysis of ways to obtain the necessary data.

The section includes a short summary of current data collection and relay methods, a discussion of requirements for operational forecasting, several alternative communications schemes, and recommendations.

A. Existing Data Collection Methods

The existing data collection methods are well summarized in previous portions of this report. At the present time all data from the Susitna Basin is recovered by helicopter and to a limited extent by ground transportation after having been recorded by automated weather or stream gaging stations. Data from the basin are thus available at approximately monthly intervals. The time delay from collection until the data are processed into useful form can run from one to seven weeks.

B. Data Collection Requirements for Operational Modeling

Discussions held during the field trip to Alaska indicate that operational forecasts will be required as often as daily during the summer months. The forecast time interval dictates the minimum time which can elapse between recording of data in the field and recovery and processing.

Models can obviously be run at any time. However, if the sophistication of rainfall-runoff models is to be used to maximum advantage (i.e., if short time interval runoff from thunder storms is to be modeled) then data must be available at short intervals and soon after the events occur. Hourly data in real or near-real time would not be an unreasonable requirement.

C. Alternative Data Gathering Systems

(1) Continue Present Methods

One alternative which must be given consideration is to continue data gathering just as it is done now. This may, in fact, be a satisfactory alternative during the winter months where forecasts will not be made as often. During the summer the frequency of site visits could be increased to weekly or biweekly. Further automation of the data handling process could take place so that data can proceed directly from the field tapes in a form suitable for input to the models. Current methods can not provide the timely information needed for rainfall/runoff modeling in the late summer period.

(2) Automated Telemetry Systems

There are several types of automated telemetry systems available for the Susitna Basin Project. Each system requires field processing and telemetry hardware, a communications link or links, central receiving equipment, and data processing equipment.

(3) Field Site Hardware

Most current automated telemetry systems make use of field hardware called "Data Collection Platforms" (DCPs). DCPs incorporate microprocessors, optional tapes or other form of storage, and one or more telemetry modules. The telemetry modules can be line of sight radio transmitters, satellite transmitters, or telephone modems, some even including voice capability. The meteor burst system (to be discussed later) uses remote data terminals that operate only with that system.

DCP's are designed to interface with a wide variety of stream gaging and meteorological equipment. They are widely used by the U.S. Geological Survey, Corps of Engineers and other agencies. They are normally small in size and powered by 12-volt batteries charged by solar panels. Currently there are three U.S. firms actively manufacturing DCPs. They are Sutron Corporation, Handar Corporation, and Synergetics Corporation. All of the firms have sizeable numbers of platforms in service and all offer similar capabilities in distinctly different packages.

Considerable experience by government agencies indicates that the use of DCPs and real-time data obviates the need for on-site recording. This is contrary to the suggestion by R&M Consultants (R&M review memo dated March 8, 1985) that additional mechanical recorders be added at each site. The telemetry equipment has been found to be more reliable than on-site recording instruments. It makes little sense to make duplicate recordings of bad data on-site. No good data is no good data whether recorded on-site or telemetered to some central location and recorded there. Not only that, but the odds on the central site computer functioning properly are much higher than for any field recorder. The less moving parts in the field, the better. However, there would be some value in retaining on site precipitation recorder during the period when data are being collected for model calibration purposes.

(4) Central Receiving Stations

Central receiving equipment is specific to the communictions link used. Line of sight radio systems require an antenna, (usually a whip or Yagi mounted on a tower) a receiver, and an RF modem (modulator-demodulator) for data recovery in computer compatible form. Satellite systems also require an antenna, but this must be a 3 to 5 meter dish permanantly focused on the satellite being used. A receiver, demodulators, and multiplexing equipment are also required to reduce incoming data to computer compatible form. Telephone systems require only a modem to receive incoming calls and interface with a computer. Enormous variations are possible in central site data processing equipment. Options vary from desktop personal computers to minicomputers capable of not only receiving the data but processing it in real-time and updating the models.

4. Alternatives for the Susitna Basin

At the current time the writers believe that there are three alternatives for the Susitna Basin:

(1) A combined line-of-sight radio (with or without voice capability) and telephone system,

(2) A satellite system with a variety of central site options, and

(3) A Meteor Burst system.

The alternatives are discussed below.

A. Line-of-Sight and Telephone System

The wide open nature of the Susitna Basin makes a line-of-sight system reasonably attractive. It should be possible to relay data from virtually any part of the basin to a central location such as Watana using a minimum number of repeaters. Two or three should be sufficient. The system can be designed strictly for data purposes or it may be combined with a voice network for use in managing the reservoirs. A small minicomputer at Watana can save the data and relay it to Anchorage on a daily basis by telephone. The assumption being made, of course, is when the reservoirs are built that phone service will follow. If such is not the case then line-of-sight is probably not a practical alternative.

Discussions during the field trip indicate that thunderstorms are a frequent occurrence in the Susitna basin. Thunderstorms are the most frequent cause of failure in line-of-sight systems. Lightning strikes near repeaters nearly always cause failures. Any system should probably be designed with dual data paths (multiple repeaters) to minimize data loss and allow for time to repair. Hot standby repeaters could also be considered. Hot standby uses duplicate transmit/receive equipment with a spare ready to take over the minute the operational unit fails. The cost for hot standby is fairly substantial since it doubles the amount of equipment at each repeater.

It is possible to design a line-of-sight system using polling, wherein the central sight queries the field sites for data. This requires more complex equipment on both ends and is not recommended. DCPs are easily capable of determining when data should be sent and with great reliability.

B. Satellite Data Relay System

An attractive way to recover data from the Susitna Basin is by means of the GOES (Geostationary, Operational Environmental Satellite) system. The GOES system, owned by NOAA, is the same satellites which provide the satellite weather pictures seen on television newscasts. The Data Collection System (DCS) on the satellites provide 256 channels for environmental data transmission. The two U.S. GOES satellites provide sufficient geographic coverage to send data from Florida to Alaska with no intermediate repeaters. GOES is truly the "ultimate" line-of-sight repeater.

The GOES satellite data collection system has been in use for many years. The U. S. Bureau of Reclamation operates a network of over 150 DCP's in the upper Snake River Basin for which part of the area has cold temperature extremes similar to those experienced in the Suisitna River Basin (near Yellowstone Park Wyoming). The contractor in charge of the system maintenance is paid based on the percentage of data received (percentage of 15 minutes readings from many types of sensors). The formula is such that the contractor receives full payment for data reception of 95 percent or greater, 90 percent payment for 90 to 95 percent reception and so on until no payment is received if reception falls below 50 percent. To date the contractor has received 100 percent payment over the life of the contract. The U. S. Bureau of Reclamation officials in charge of the project using the GOES system is Dan Lute, USBOR, Box 043, 500 West Fort Street, Boise, Idaho, 83724, telephone 208-334-1976.

A newly installed GOES collection system at high elevations along the Rocky Mountains in Colorado for the Office of the Colorado State Engineer has been demonstrating similar performance as that for the USBOR in Idaho after initial installation bugs were worked out.

C. Meteor Burst Communications

The third method for relaying data from the Susitna River Basin is the Meteor Burst or Meteor Trail technique. Meteor Burst communications make use of ionization trails in the atmosphere to reflect high frequency (HF) radio signals. The trails take the place of the satellite in the GOES system or the repeaters in the line-of-site systems.

Meteor Burst systems are, by nature, more complex than satellite or line of site systems. First, the systen is two-way. A base station sends out signals to one or more remotes requesting them to report stored data. The remotes then send out data signals. The requirement for a polling scheduler and on-site receivers more than doubles the cost of the hardware over a one-way system. Second, the meteor burst field sites require 2 to 3 times the average power to operate as a satellite or other one-way system. The receiver at the site must be on at all times and 3 to 5 times the transmitter power (25 to 40 watts) is required to bounce signals off a meteor trail as compared to a satellite (8 watts) or line-of-site repeater (2 to 4 watts). Expressed in a different way, that battery will last 3 to six times as long as the same battery powering a meteor burst station when both transmit the same message length. Finally, meteor burst hardware are larger in physical size than satellie or line-of-site systems. The transmission units are larger, and much larger solar panels and more batteries are required.

Meteor burst's one true advantage is the presenc of a receiver at the remote sites. It is possible to send and receive text messages at the remotes which may offer some further safety for field crews in remote locatins.

The basic cost of a meteor burst remote station is roughly twice the cost of a satellite DCP, exclusive of the accessories and installation. Accessory cost is also higher with antennas costing 2 to 3 times as much as GOES ($500 to $700 compared to $250) or line-of-site.

At a meeting with Harza-Ebasco and Alaska Power Authority officials in Anchorage, Alaska, on May 30, 1985, George Clagget, SCS, Anchorage Alaska, indicated that considerable improvement has been experienced in the operation of the SNOTEL data collection program (meteor burst system) of the SCS. However, Clagget did not have detailed information on the performance of their system. Contact was made with the SCS offices in Washington, D. C. and in Portland, Oregon to obtain first hand information. Art Crook, Water Supply Forecasting Staff, Soil Conservation Service , Portland, Orgeon (503-221-2843) supervises the SNOTEL program for the SCS and provided information on the system.

Figure 7 and Table 4 were provided by Crook and provides specific information on the SNOTEL system performance (for data collected by two master stations, one in Boise, Idaho, and one in Ogden, Utah) from February 1981 to May 1985. The solid line on Figure 7 represents the percentage (by a four-month moving average) of sites that successfully responded during the once-a-day colletion period (from 0500 to 0800 local time). The dashed line represents what the SCS believes the collection percentage would have been assuming that the collection would have been accomplished with present day software (5 percent improvement) and without a master station failure during the 1983-84 winter.

D. Comparison of Meteor Burst and GOES Satellite Systems

As indicated in the above dicsussion a radio line-of-site system is not recommended primarily because of the need for repeater stations and the thunderstorm activity of the area. There are many factors to be considered in making a decision between Meteor Burst and the GOES Satellite system. Cost of the initial hardware and accessories (including antennas) is much

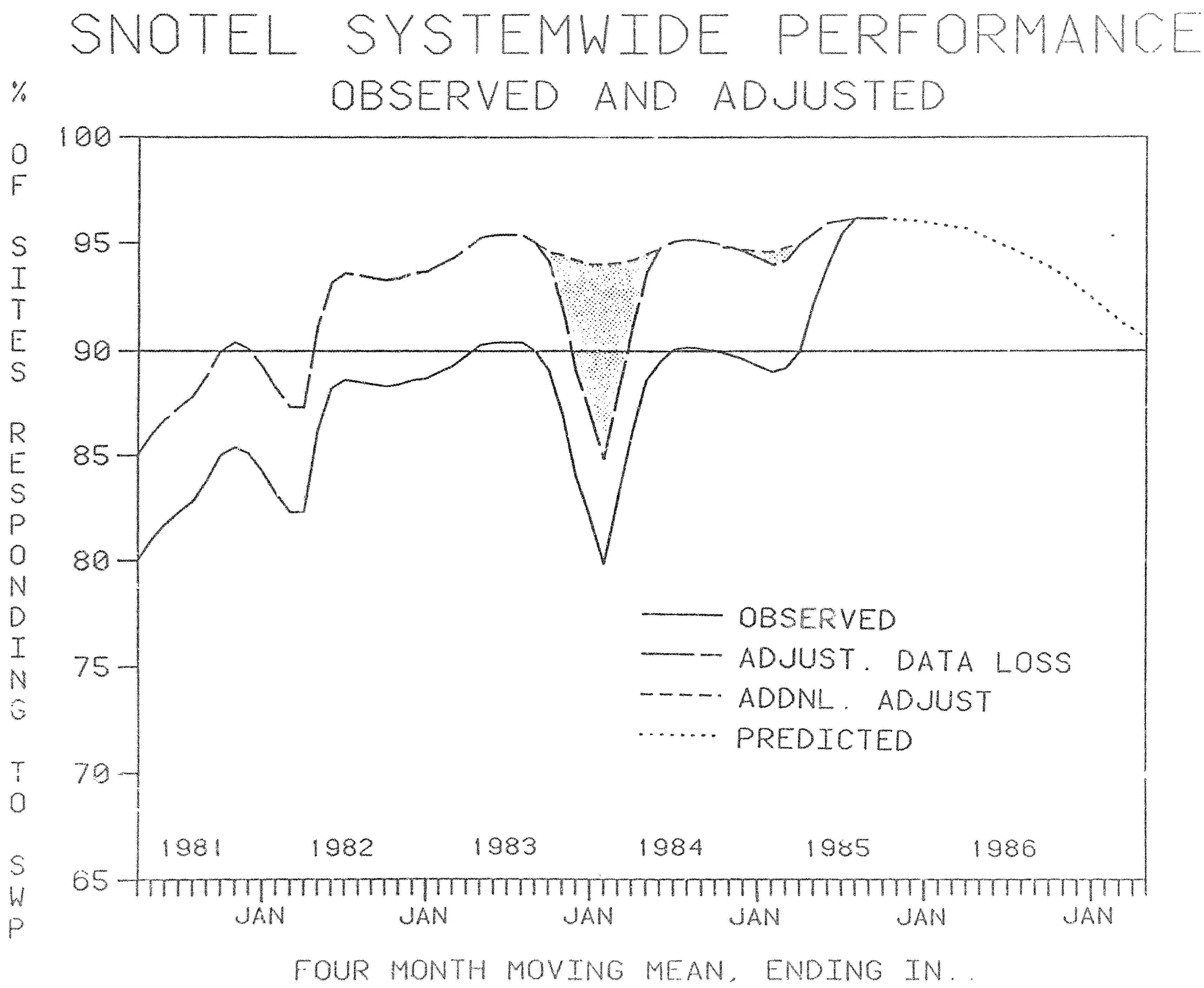

SNOTEL SYSTEMWIDE PERFORMANCE
OBSERVED AND ADJUSTED
% OF SITES RESPONDING TO SWP
100
95
90
85
80
75
70
65
OBSERVED
ADJUST. DATA LOSS
ADDNL. ADJUST
PREDICTED
1981
1982
1983
1984
1985
1986
JAN
JAN
JAN
JAN
JAN
JAN
FOUR MONTH MOVING MEAN, ENDING IN..

Table 4

Monthly Average Percentage of Sites Reporting
Daily Nomial Polls

	1981	1982	1983	1984	1985
January	----	81.6	89.3	79.2	88.4
February	74.1	78.8	88.2	82.5	87.5
March	80.2	83.8	91.1	85.4	91.5
April	82.5	85.6	90.0	87.3	93.4
May	82.7	90.4	89.5	90.5	96.1
June	80.4	89.2	91.6	90.8	----
July	81.7	88.8	90.9	84.4	----
August	84.1	86.6	89.4	90.1	----
September	----	87.7	88.9	89.9	----
October	85.7	89.7	90.2	89.3	----
November	86.0	88.7	86.5	90.7	----
December	85.5	87.2	80.6	89.5	----

less for the GOES system. Installation costs would be very comparable. Maintenance costs would also favor the GOES system since the power requirements for the Meteor Burst system is much greater.

The reliability of the two systems for once a day collection of reports is assumed to be about the same based on recent performance information. However, the reliability of cbtaining 15 minutes or hourly readings for an entire day would be much greater using the GOES system.

The two way communication potential of the Meteor Burst system was indicated as a plus by the federal agencies in Alaska that attended the May 30, 1985, meeting. However, this would be of advantage only during the maintenance visits. For the Bureau of Reclamation network for the Snake River Basin this is often only once a year. The GOES system does allow for text ("related text") and emergency messages to be sent from the DCP. In fact, NOAA, owner of the GOES satellite, currently operates a program called SEAS (Shipboard Environmental data Acquisition System) which prefaces each data transmission with text detailing weather and ship locations. The message are keyed in by the shipboard operators. If it is truly important to have the meteor burst 2-way messages it may be best to buy a single transmittor for the Meteor Burst system for use by the servicing field crews to carry and operate it in cooperation with the SCS meteor burst system.

When operation of the hydroelectric system commences there will undoubtedly be a greater need for data for short periods of time, i. e., for information on reservoir releases and downriver streamflow to ensure that envirornmental requirements below the reservoirs are satisfied. The added reliability of the GOES system for collecting 15 minute or hourly data for the entire day would be of value.

5. Recommendation

Based on the above considerations, it is recommended that the GOES satellite system be investigated for use in the project. This should include an onsite field survey to ensure that all selected sites requiring collection of data can be seen by the satellite.

6. **Cooperation on Data Reception**

A large number of firms and agencies own and maintain GOES data receiving stations. The U. S. Geological Survey, for example, operates a portion of its own gaging network by means of a receiving station in Anchorage. Any such site can collect the necessary data and hold it for telephone transfer to the computer where the models will be run. The geographic coverage of GOES is emphasized by the fact that Hydex Corporation using the Sutron Corporation downlink in Herndon, Virginia could easily receive the data, run the models, and return the answers to Anchorage. In the initial stages, however, the U.S.G.S. site will certainly be attractive.

A satellite system using the U.S.G.S. site would require only an investment in DCPs and sufficient telephone equipment and software to take the data from the ground station to the computer where the models will be run. Larger, more modern ground stations in the $50,000 to $100,000 range come with complete data base software and model interfaces. This more sophisticated system should be considered if cooperation with U.S.G.S. is not desirable.

7. **Purchase of dedicated ground station**

Purchase of a dedicated ground station will have to be weighed on the basis of cost effectiveness. Such stations are available with a wide range of capabilities and corresponding wide range in prices.

There are currently only two manufacturers of ground stations in the U.S. - Sutron Corporation and Synergetics Corporation. Sutron is the newer of the two corporations and offers more data handling capability and smaller, fully digital electronics. Synergetics has more stations in place. The market is highly competitive. The simplest receiving site from either manufacturer costs approximately $27,000. For that price the user receives an antenna, frequency downconverter, receiver, cabling, and demodulators for monitoring the satellite channels. Also included is a personal computer to select channels on a time schedule basis and to store and print out data. Such bottom end receive sites are minimally useful and are usually used as "front ends" for larger systems.

To increase the receiving site capability is primarily a matter of adding computer capacity. Manufacturers offer increased processor and disk space in roughly $10,000 dollar increments. A realistically useful receive site with a computer capable of running the real-time models and a good data base will cost approximately $60,000 without such extras as an uninterruptible power supply or installation. Additional money must be considered for data handling software. Sutron offers a license data base package designed to provide real-time data displays and to interface with models. It currently lists for $25,000. This is approximately the cost for single-purpose custom software if a "bare bones" receiving site is interfaced to an existing computer.

8. Budget Estimation Figures

Detailed budgeting at this time is not practical. However, estimates of telemetry system costs are needed for planning purposes. The following are reasonable price estimates in 1985 dollars for various items which would be needed for a satellite system:

- Data collection platforms - satellite (includes antenna, solar panels cables, batteries and insulated container), and — $4,500 ea.
- Minimum satellite ground station for interface to existing computer (includes $25,000 custom software), or — $52,000 ea.
- Satellite ground station capable of running real-time models as well as receiving data (includes data base software). — $85,000 ea.

9. Additional Recommendations

If the Susitna Hydroelectric Project will have a line-of-sight communications system installed for other reasons it would make sense to multiplex in the data gathering and combine the maintenance. However, if no such system is planned a satellite system as recommended above seems highly attractive.

If sufficient funds are available a ground station should be purchased. The USGS site is fairly old technology and the data handling software for it is primitive by today's standards. A new receive site could be purchased with on-line quality control, a complete data base, and sufficient capability to run all the forecasts.

In the mean time, it would make a great deal of sense to buy DCPs and place them at the existing data gathering network sites. Data should be monitored daily and as-needed maintenance undertaken. By using DCPs and the USGS ground station it is possible to know immediately when problems occur and would considerably up the reliability of data retrieval. If DCPs are used it will be possible to get rid of the on-site recorders. Such a move would also up the reliability of the sites. All data recording would take place in data files on the computer that receives the data.

The considerable experience of R&M Consultants in the installation and maintenance of the current system would seem to indicate them as a logical choice to install and maintain a satellite system. They have accurately defined the cost of needed instruments and varying kinds of maintenance schedules. They could easily be trained in the installation and setup of DCPs.

REFERENCES

1. E. L. Peck 1972, Snow Measurement Predicament, Water Resources Research, Vol. 8, No. , Feb. 1972

2. C. E. Israelsen 1967, Reliability of Can-type Precipitation Gage Measurements, Tech. Rep. 2, Utah State Water Res. Lab., Utah State U., Logan, Utah, July

3. W. T. Wilson 1954, Analysis of Winter Precipitation in the Cooperative Snow Investigations, Monthly Wea. Rev., 82, pp. 183-199, July

4. M. J. Brown and E. L. Peck 1962, Reliability of Precipitation Measurments as Related to Exposure, Jour. of Appl. Meteoro. June

5. L. Larson and E. L. Peck 1974, Accuracy of Precipitation Measurements for Hydrologic Modeling, Water Resources Research, Vol. 10, No. 4, August

6. E. L. Peck 1973, Discussion of Problems in Measuring Precipitation in Mountainous Areas, Symposium on Distribution of Precipitation in Mountainous Areas, Geilo, Norway, Nov. 1, WMO/OMM, No. 326, Geneva, Switzerland

7. E. G. Bogdanova 1968, Estimate of the Reliability of the Characteristics of the Shortage in Solid Precipitation Due to Wind, Sov. Hydrol. Selected Papers, Engl. Transl., No. 2

8. E. L. Peck and T. R. Carroll 1979, Advantages of Conceptual Models for Northern Research Basin Studies, Third Symposium IHP Reg. Working Group on Northern Research Basins, Quebec City, Canada, June 11-15.

9. G. D. Kilday 1974, Mean Monthly and Annual Precipitation, Alaska, NOAA Tech. Memo. NWS AR-10, Anchorage, Alaska Mar.

10. SCS 1981, Mean Annual Precipitation, Susitna River Basin, Alaska, Prepared by SCS WSTC Carto Unit, M7-N-24165-1, August

11. J. Wise 1984, Annual Precipitation Map for Alaska, Unpublished, Personal Correspondence

12 E. L. Peck and M. J. Brown 1962, An Approach to the Development of Isohyetal Maps for Mountainous Areas,

Jour. G/o. Res. Feb.

13. T. R. Carroll and K. G. Vadnais 1980, Operational Airborne Measurement of Snow Water Equivalent Using Natural Terrestrial Gamma Radiation, Proc. 48th Annual Western Snow Conf., Laramie, Wyo., April

14. D. L. Finch and J. P Walker 1979, Snowfall at Anchorage, Alaska Associated with Cold Advection, NOAA Tech. Memo. NWS AR-25, Oct.

15. G. K. Grice 1976, Thunderstorm Climatology of Alaska, NOAA Tech. Memo. NWS AR-14, Feb.

16. D. Blanchet 1983, Chugach National Environmental Atlas, Chugach National Forest, Alaskan Region, Rep. No. 124.

17. E. A. Marchegiani 1985. A Relationship Between Snow Course Information and Runoff, Unpublished Paper.

18. R & M Consultants and W. D. Harrison 1981, Alaska Power Authority Susitna Hydroelectric Project, Task 3 - Hydrology Glacier Studies, Report prepared for Acres American Incorporated, Buffalo, New York.

19. Harza-Ebasco Susitna Joint Venture 1984. Watana and Devil Canyon Sites Probable Maximum Flood, Draft Report, Document No. 457 Jan.

20. Acres American Inc. 1980. Appendix A2, Watana and Devil Canyon Sites Probable Maximum Flood, Subtask 3.05

21. V. G. Konovalov 1980. Melting and Runoff in Glacier Basins, Soviet Hydrology, Selected Papers, Vol 19, No. 1

22. V. G. Konovalov 1980. Model of the Movement of the Snow Line on a Glacier During the Ablation Period, Soviet Hydrology, Selected Papers, Vol. 19, No. 2

23. A. G. Fountain and W. V. Tangborn 1985. Contemporary Techniques for Predicting Runoff from Glacierized Basins, unpublished by Working Group on Snow and Ice Hydrology of Glacierized Basins, International Comm on Snow and Ice, IAHS (private communication)

24. E. A. Anderson 1973. National Weather Serivce River Forecast System - Snow Accumulation and Ablation Model, NOAA Tech. Memo. NWS Hydro-17, Silver Spring, Md. Nov.

25. E. L. Peck, R. S. McQuivey, T. N. Keefer, E. R. Johnson, and J. L. Erekson 1981. Review of Hydrologic Models for Evaluating Use of Remote Sensing Capabilities, NASA CR 166674 Mar

26. D. L. Chapman 1982. Daily Flow Statistics of Alaskan Streams, NOAA Tech. Memo. NWS AR-35, Anchorage, Alaska, Oct

27. WMO, Unpublished report on Intercomparison of Snowmelt Model (private communication from E. A. Anderson)

28. G. Cavadias and G. Morin 1985. Approximate Confidence Intervals for Numerical Verification Criteria used in Hydrological Models. Applicatipon to the WMO Intercomparison of Conceptual Models of Snowmelt Runoff. Unpublished report (private communication) Jan

29. W. V. Tangborn 1984. Prediction of Glacier Derived Runoff for Hydroelectric Development, Geografiska, 66A, 3

30. WMO 1975. Intercomparison of Conceptual Models used in Operational Hydrological Forecasting, Operational Hydrology Report No. 7, WMO - No. 429, Geneva, Switzerland

31. W. V. Tangborn 1977. Application of a New Hydrometeorological Streamflow Prediction Model, Western Snow Conf. Apr

32. E. L. Peck 1976. Catchment Modeling and Initital Parameter Estimation for the National Weather Service River Forecast System, NOAA Tech. Memo. NWS Hydro-31, Jun

33. E. L. Peck, E. R. Johnson, K. M. Krouse, T. R. Carroll and J. C. Schaake, Jr 1980. Hydrological Update Techniques Used by the US National Weather Service, Proceedings of the Oxford Symposium, IAHS-AISH Publ. No 129 Apr

34. W. T. Sittner and K. M. Krouse 1979. Improvement of Hydrologic Simulation by Utilizing Observed Discharge as an Indirect Input (Computed Hydrograph Adjustment Technique - CHAT), NOAA Tech. Memo. NWS Hydro-38, Feb

35. T. R. Carroll and K. G. Vadnais 1980. Operational Airborne Measurement of Snow Water Equivalent Using Natual Terrestrial Gamma Radiation, Western Snow Conf. Apr

36. E. R. Johnson, E. L. Peck and T. N. Keefer 1983. Creating a Bridge Between Remote Sensing and Hydrologic Models, NASA CR 170517 Jan

37. G. H. Leavesley, R. W. Lichty, B. M. Troutman and L. G. Saindon 1983. Precipitation-Runoff Modeling System: User's Manual, Water-Resources Investigations Report 83-4238, U. S. Geological Survey, Denver, Colo.

38. G. J. Nibler. Information Content of River Forecasts, Unpublished Paper (private communication)

39. T. M. Twedt, J. C. Schaake, Jr., and E. L. Peck 1977. National Weather Service Extended Streamflow Prediction, Western Snow Conf. Apr

APPENDICES

APPENDICES

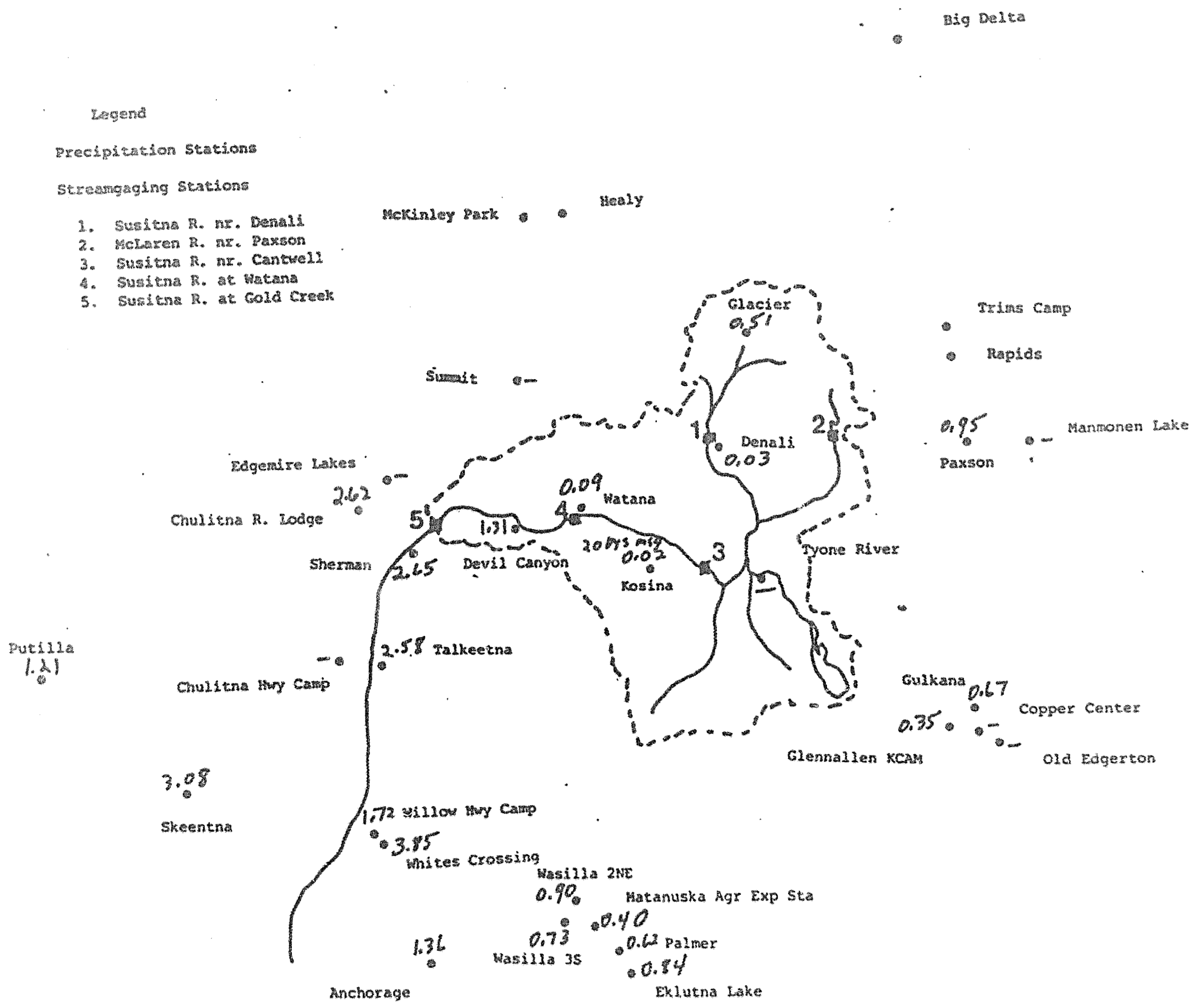


Figure A-1 Precipitation April 1983

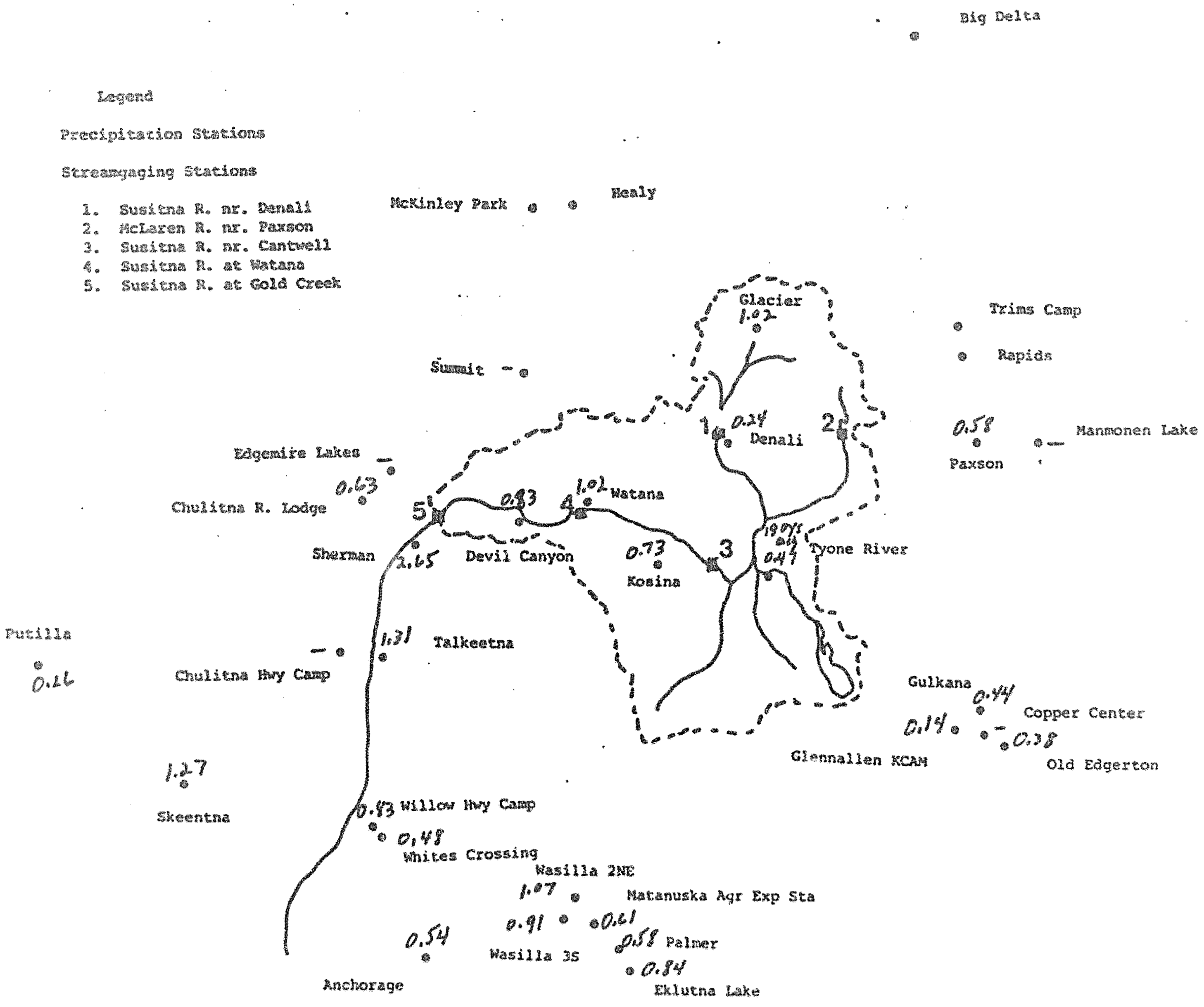


Figure A-2 Precipitation May 1982

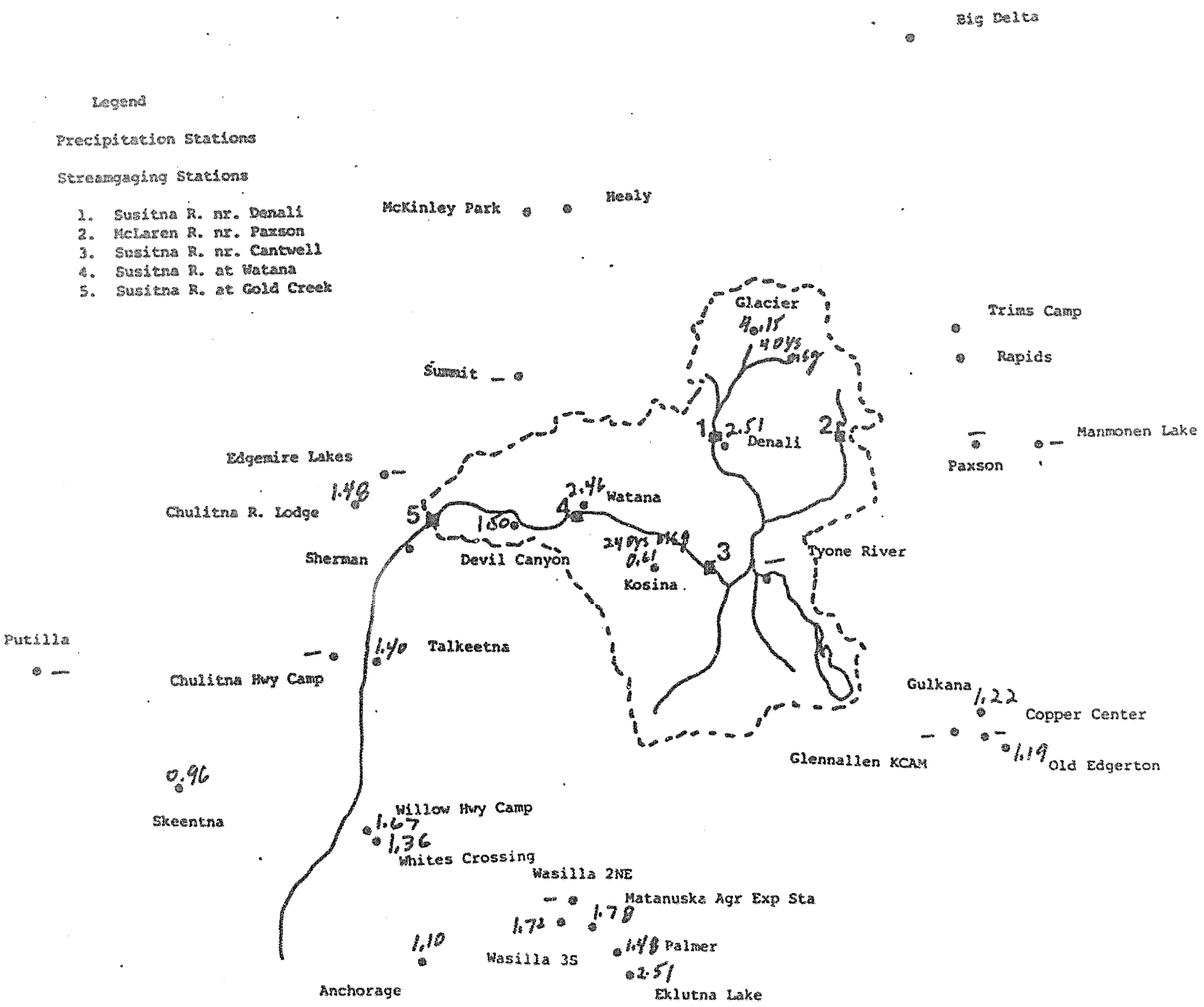


Figure A-3 Precipitation June 1984

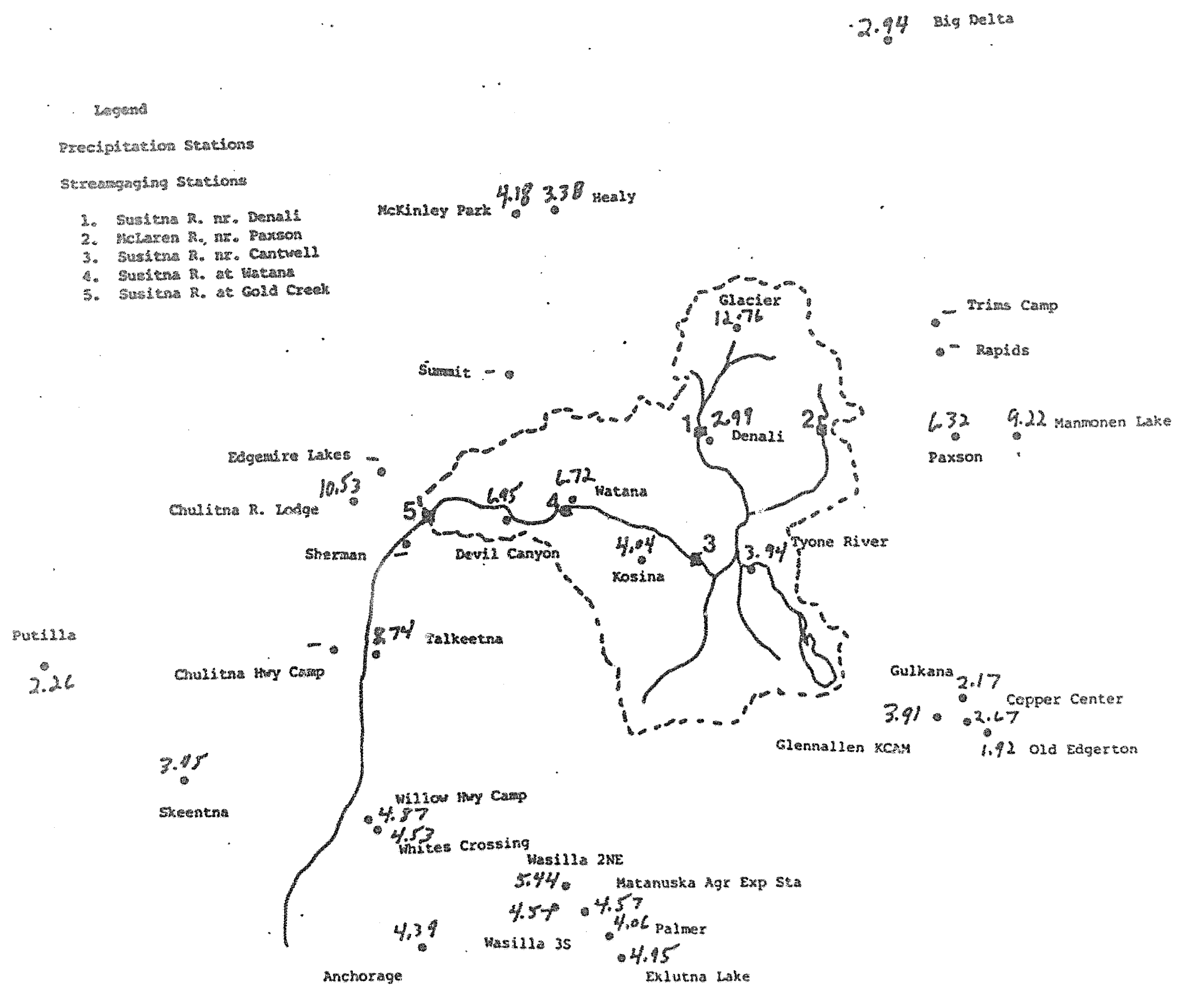


Figure A-4 Precipitation July 1981

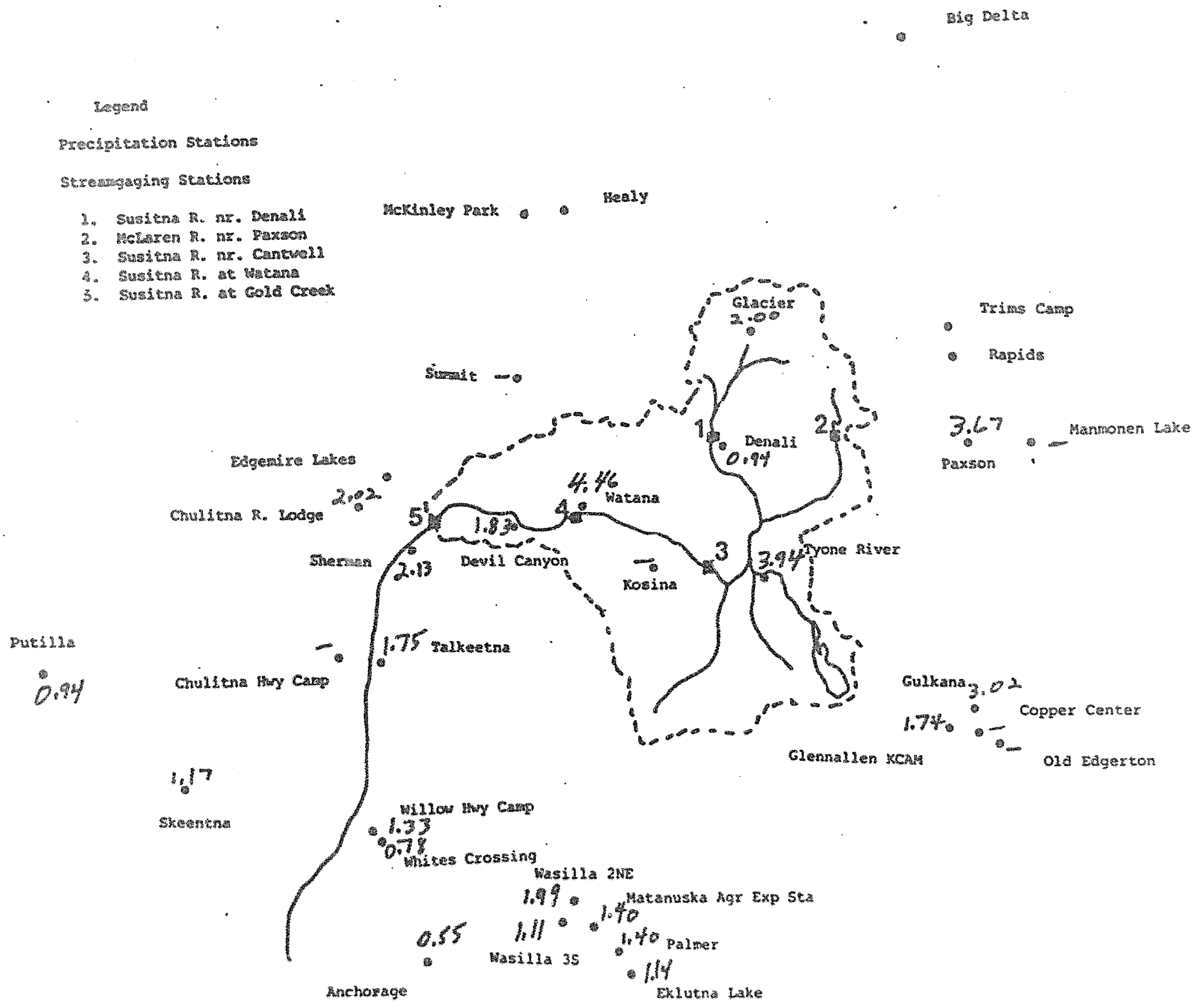


Figure A-5 Precipitation July 1983

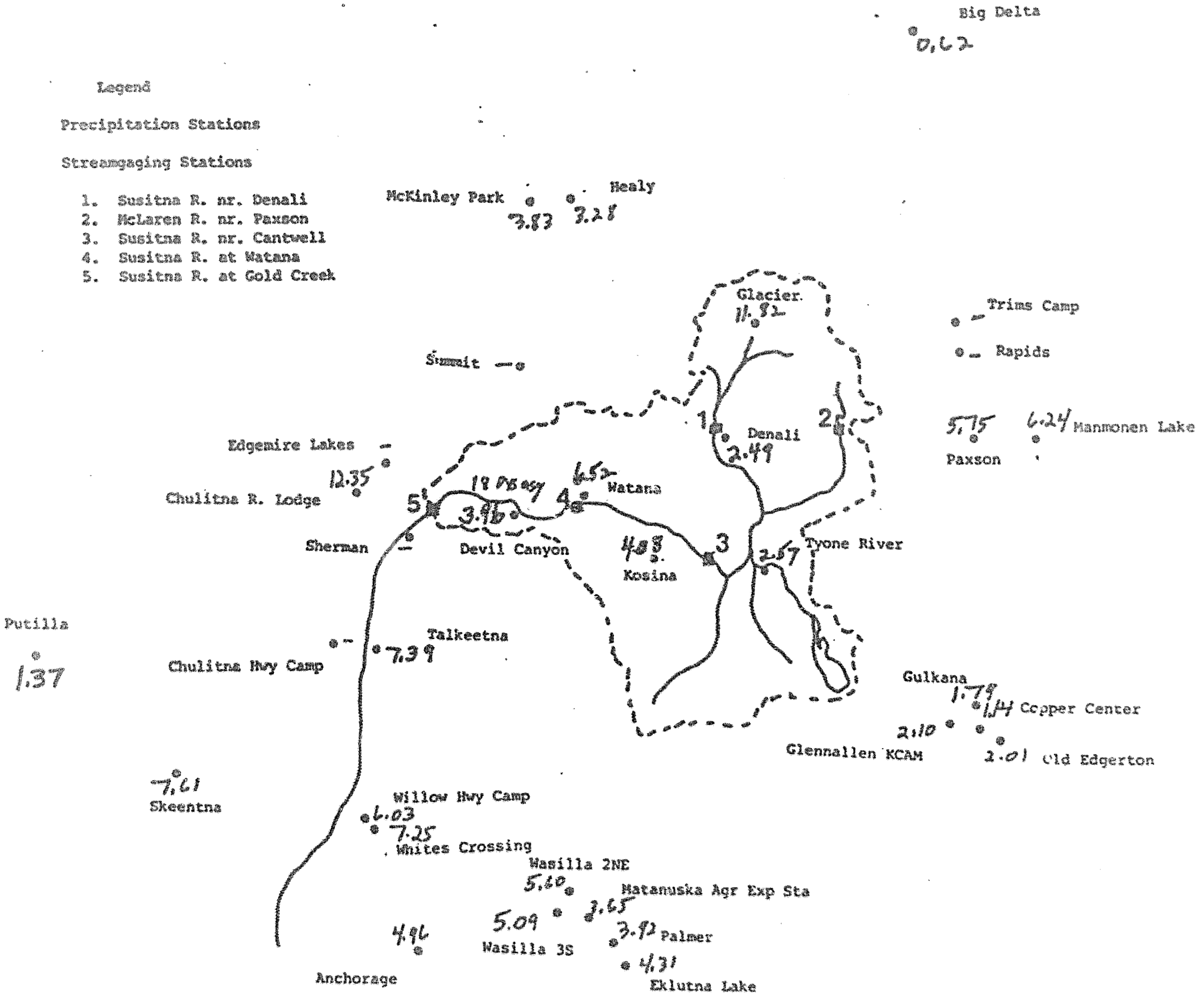


Figure A-6 Precipitation August 1981

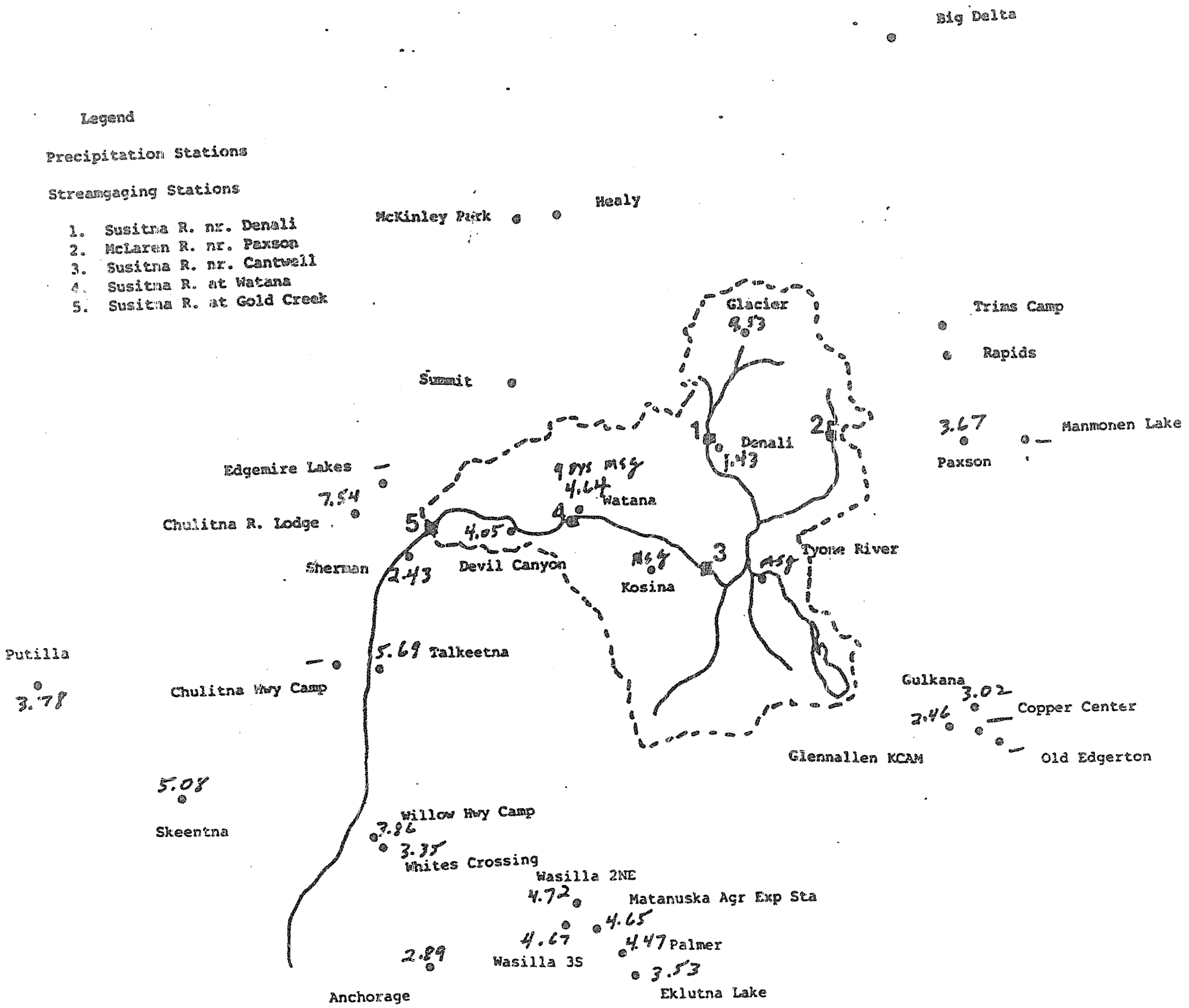


Figure A-7 Precipitation August 1983

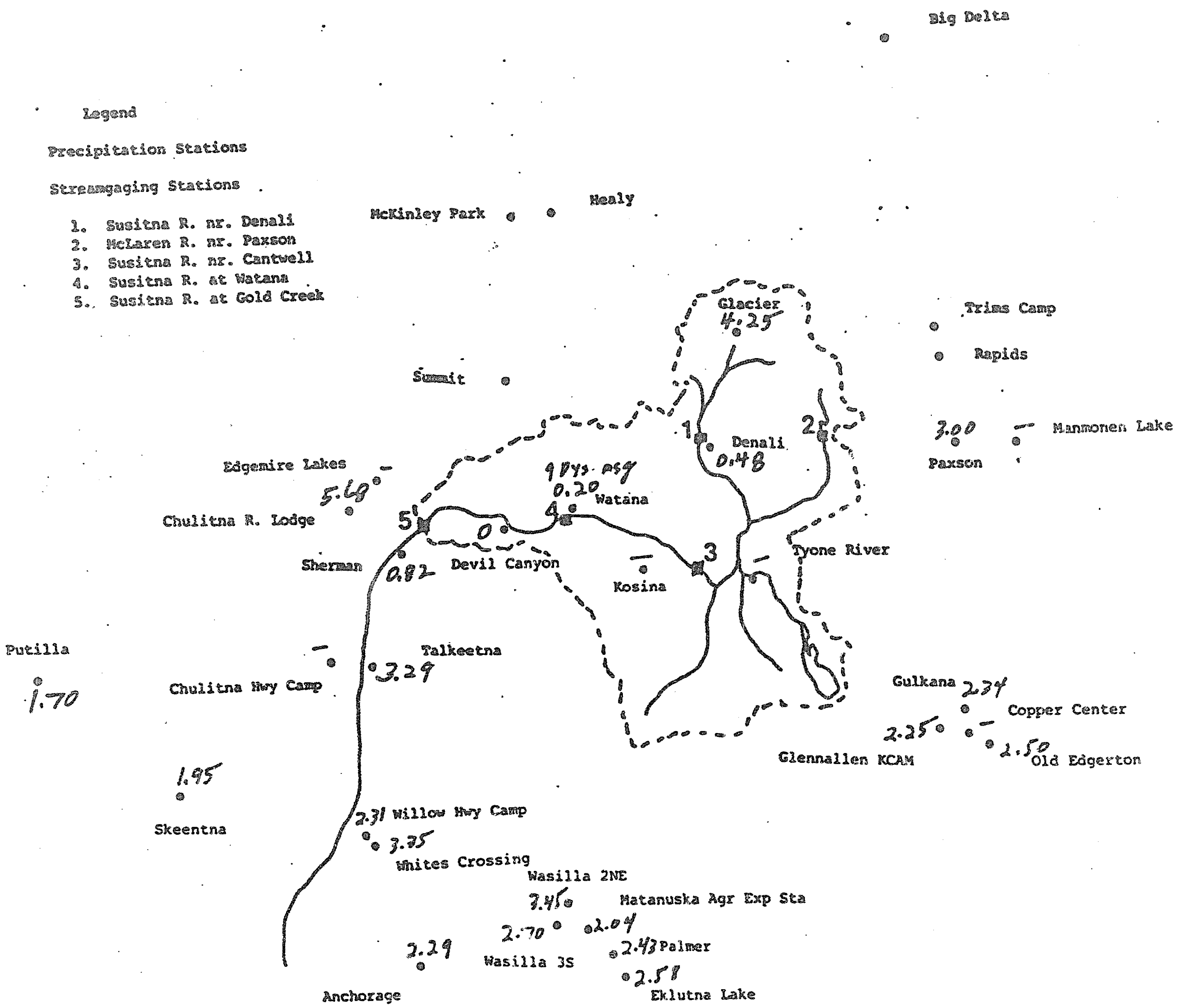


Figure A-8 Precipitation September 1983

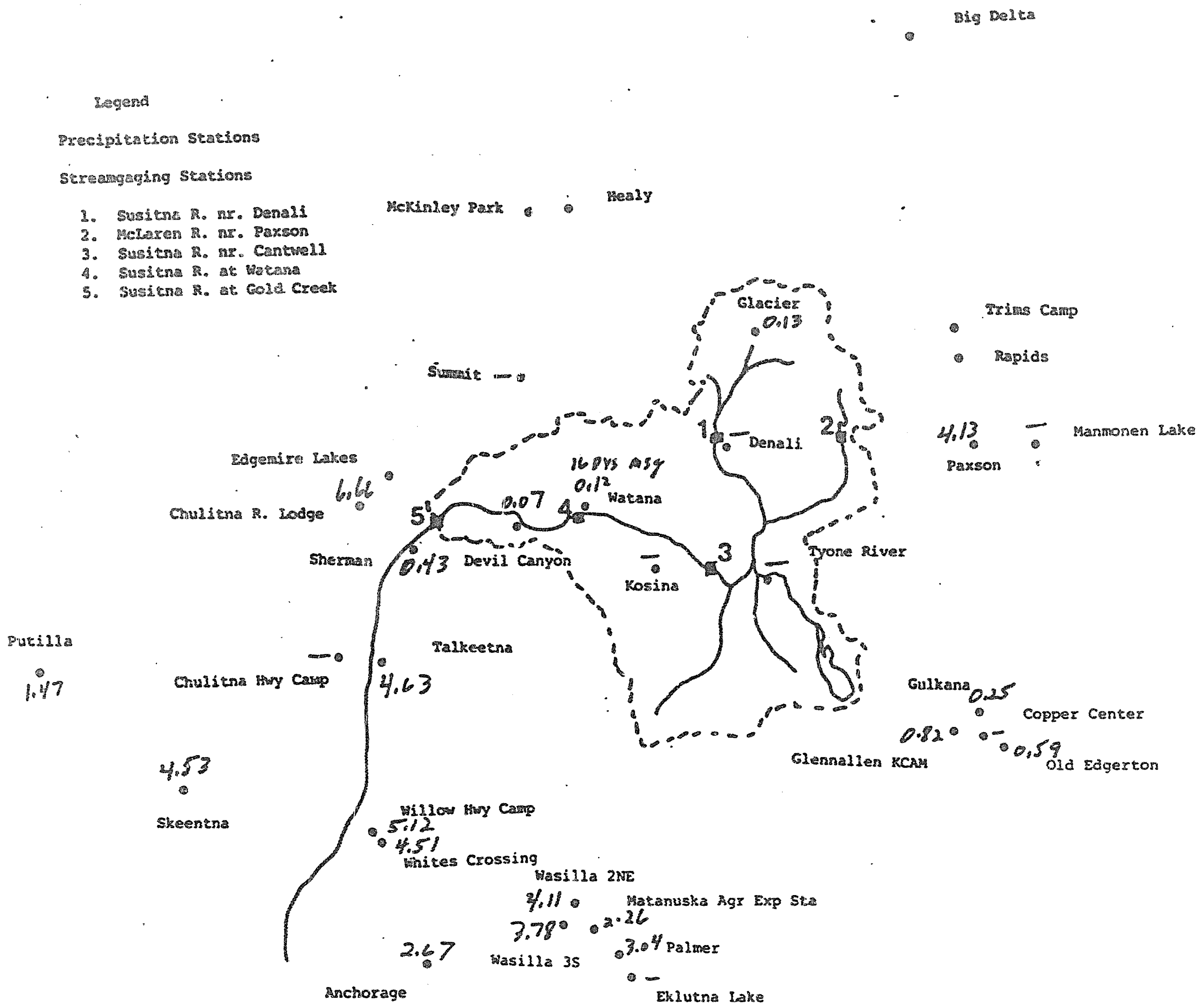


Figure A-9 Precipitation October 1983

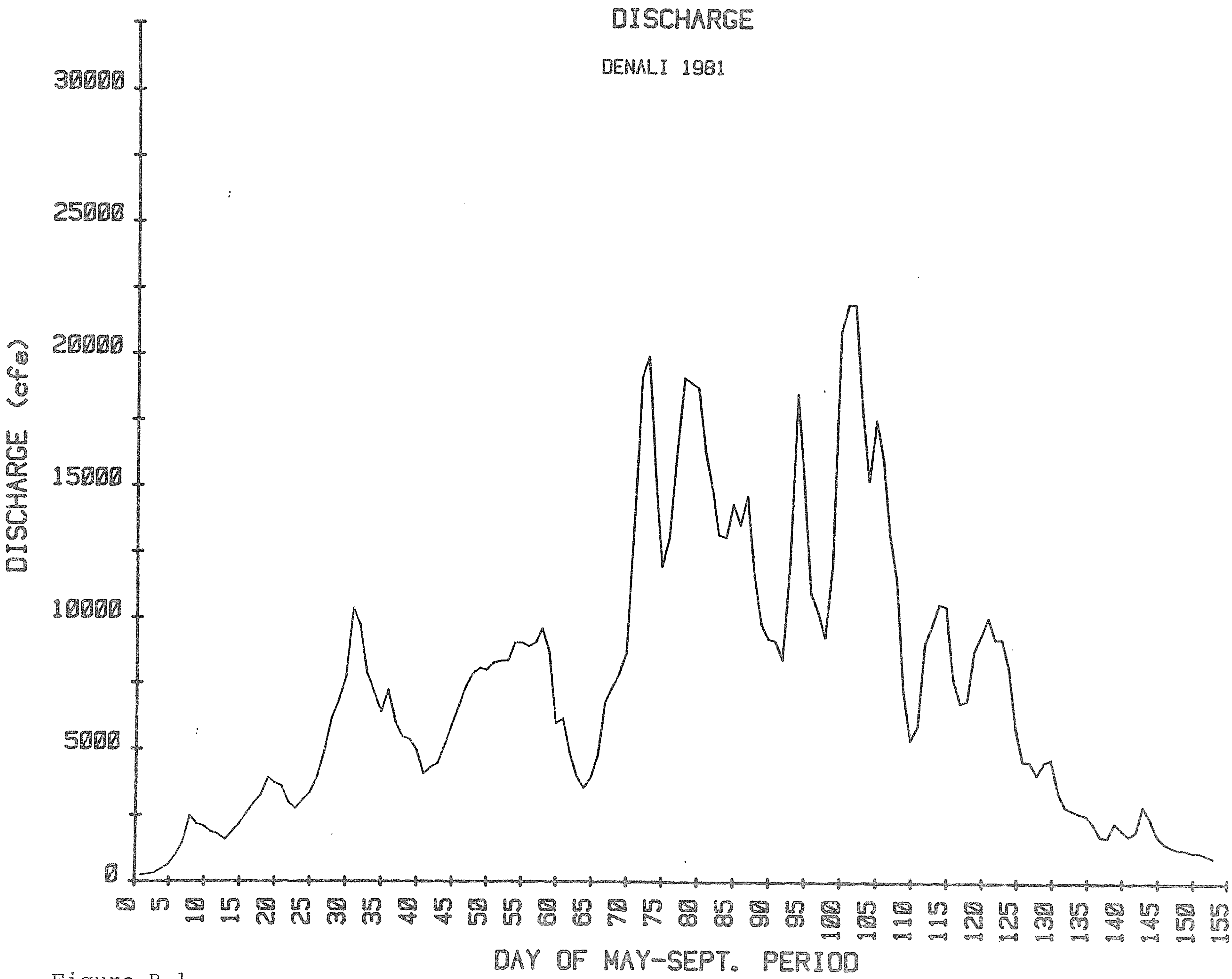

DISCHARGE
DENALI 1981
DISCHARGE (cfs)
30000
25000
20000
15000
10000
5000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-1

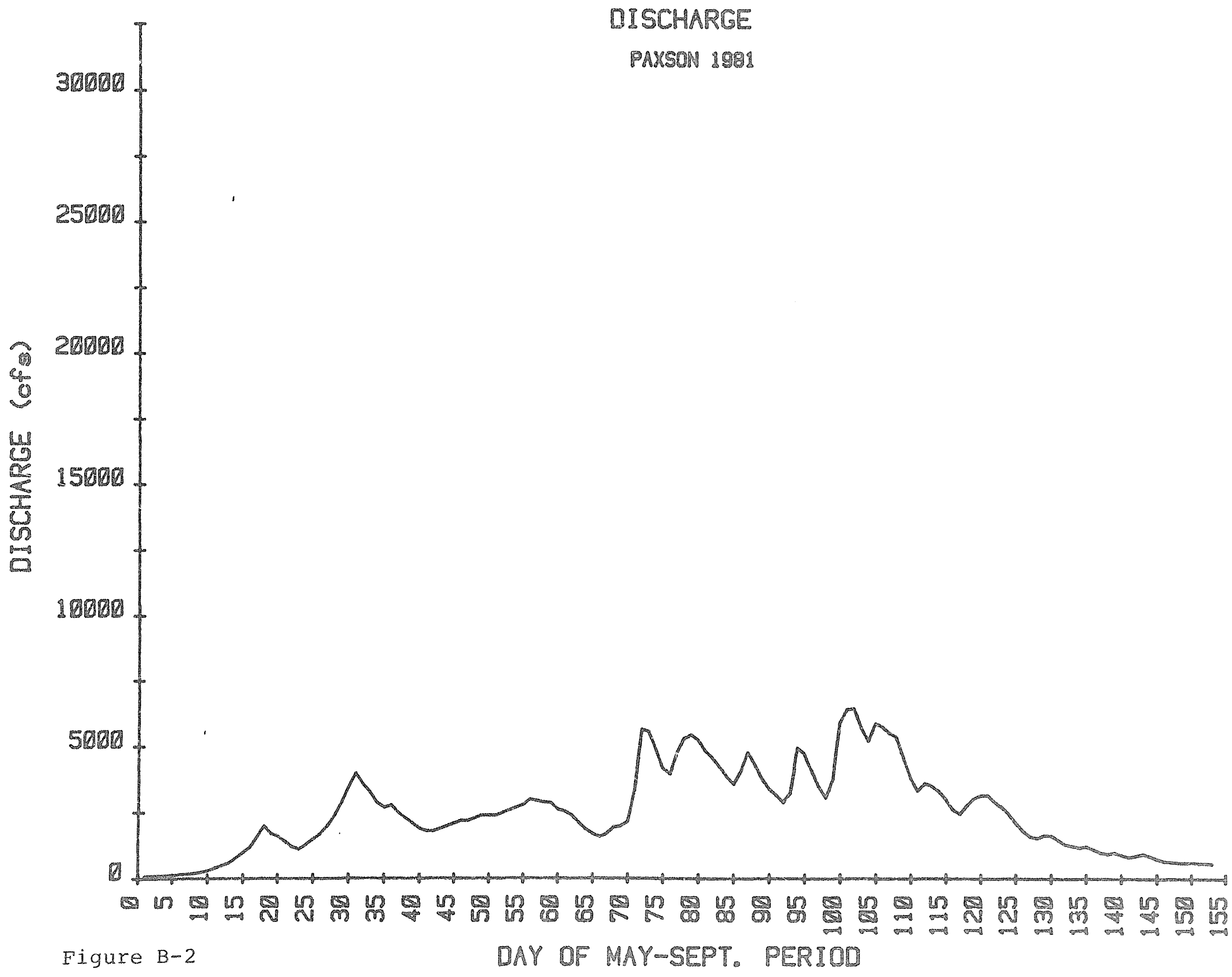

DISCHARGE
PAXSON 1981
DISCHARGE (cfs)
30000
25000
20000
15000
10000
5000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-2

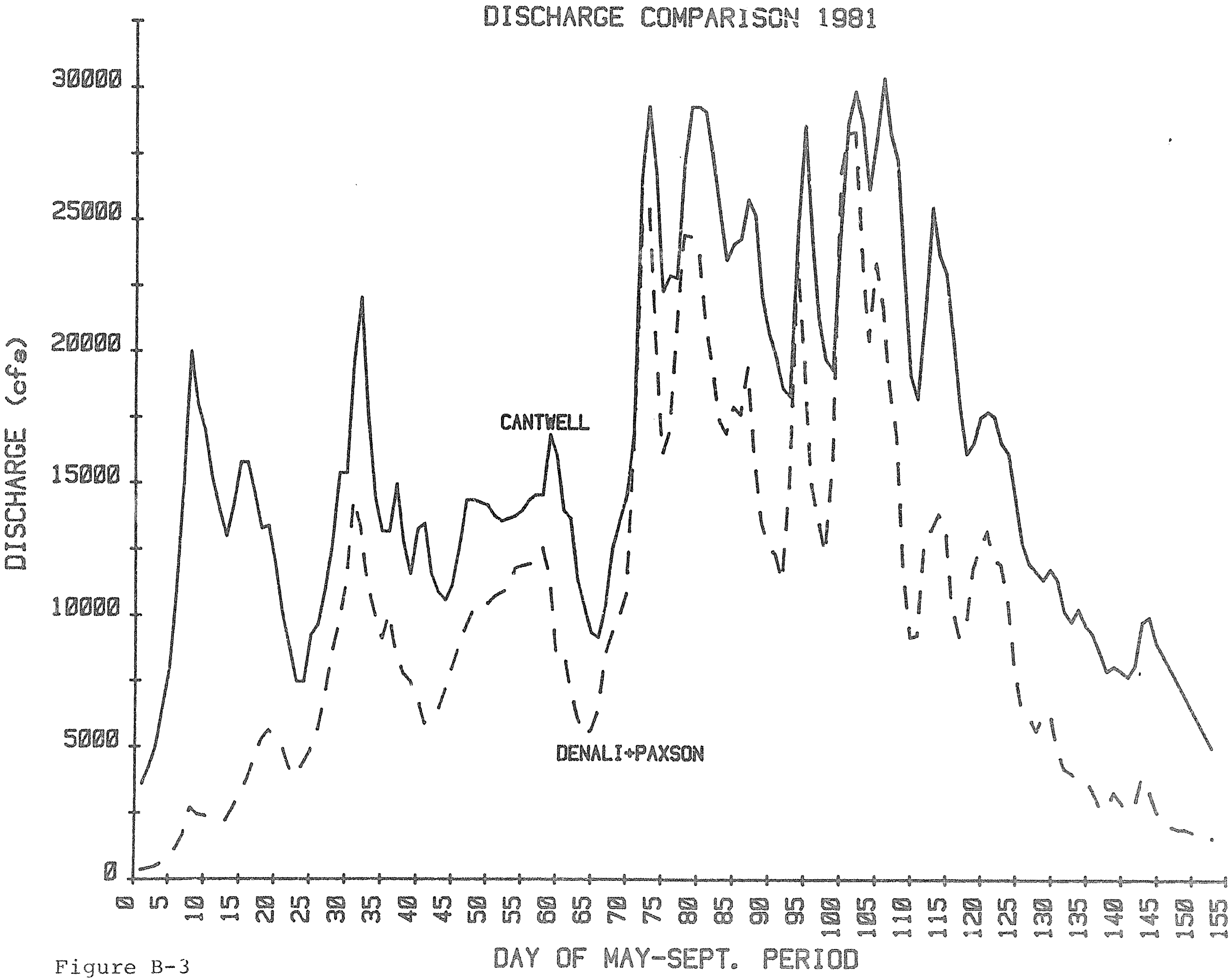

DISCHARGE COMPARISON 1981
DISCHARGE (cfs)
30000
25000
20000
15000
10000
5000
0
CANTWELL
DENALI+PAXSON
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-3

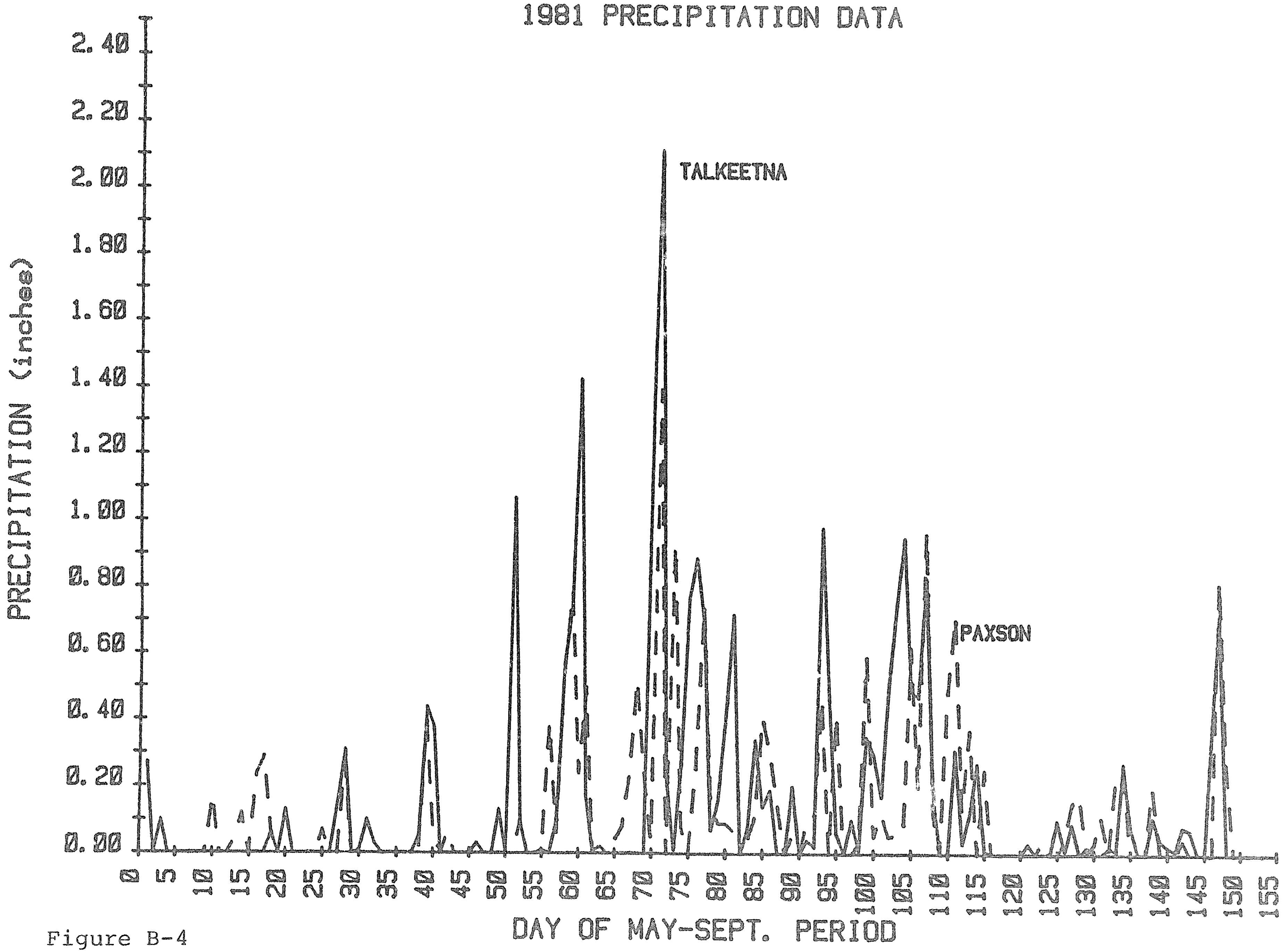

1981 PRECIPITATION DATA
PRECIPITATION (inches)
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
TALKEETNA
PAXSON
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-4

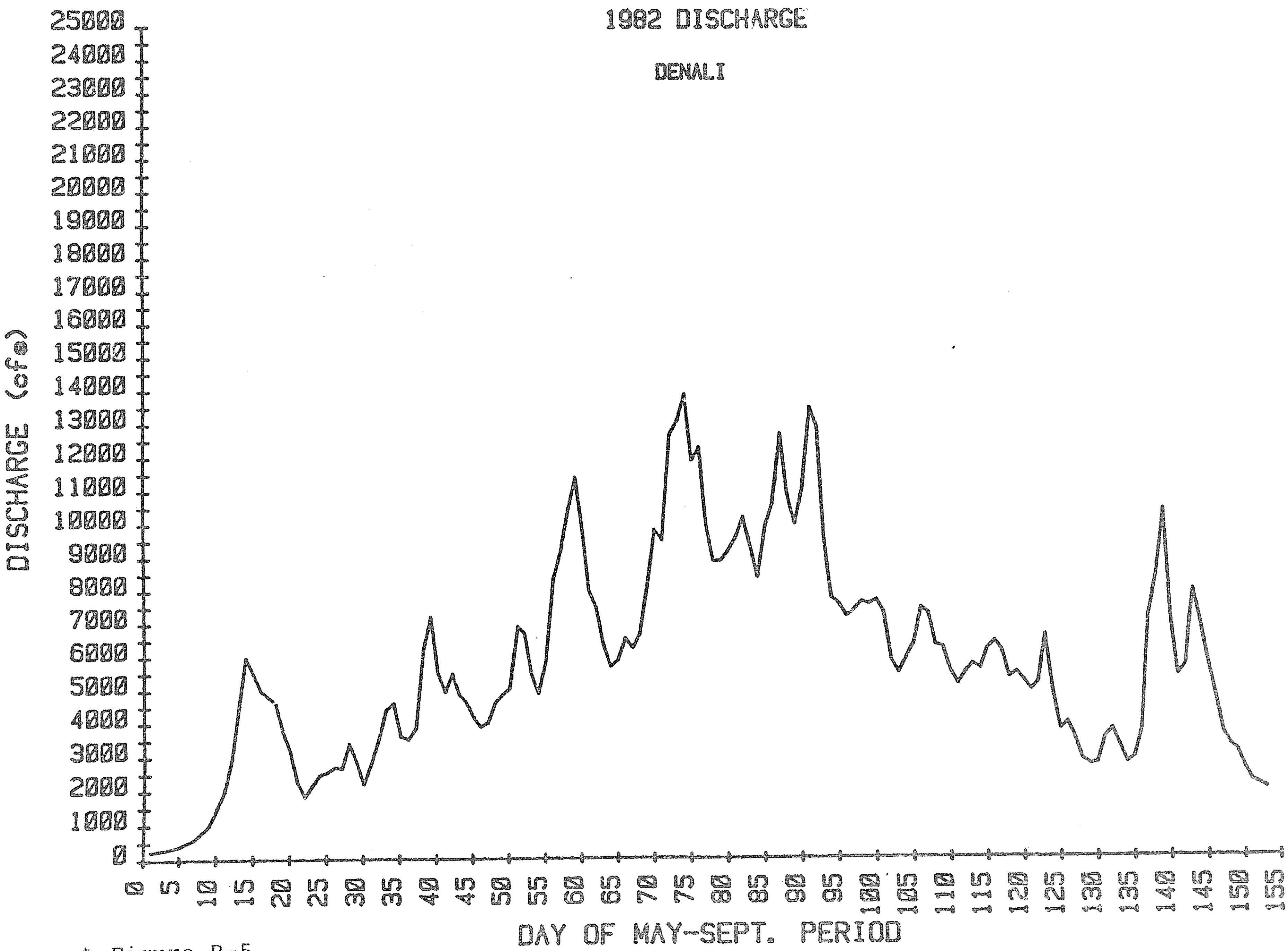

1982 DISCHARGE
DENALI
DISCHARGE (cfs)
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-5

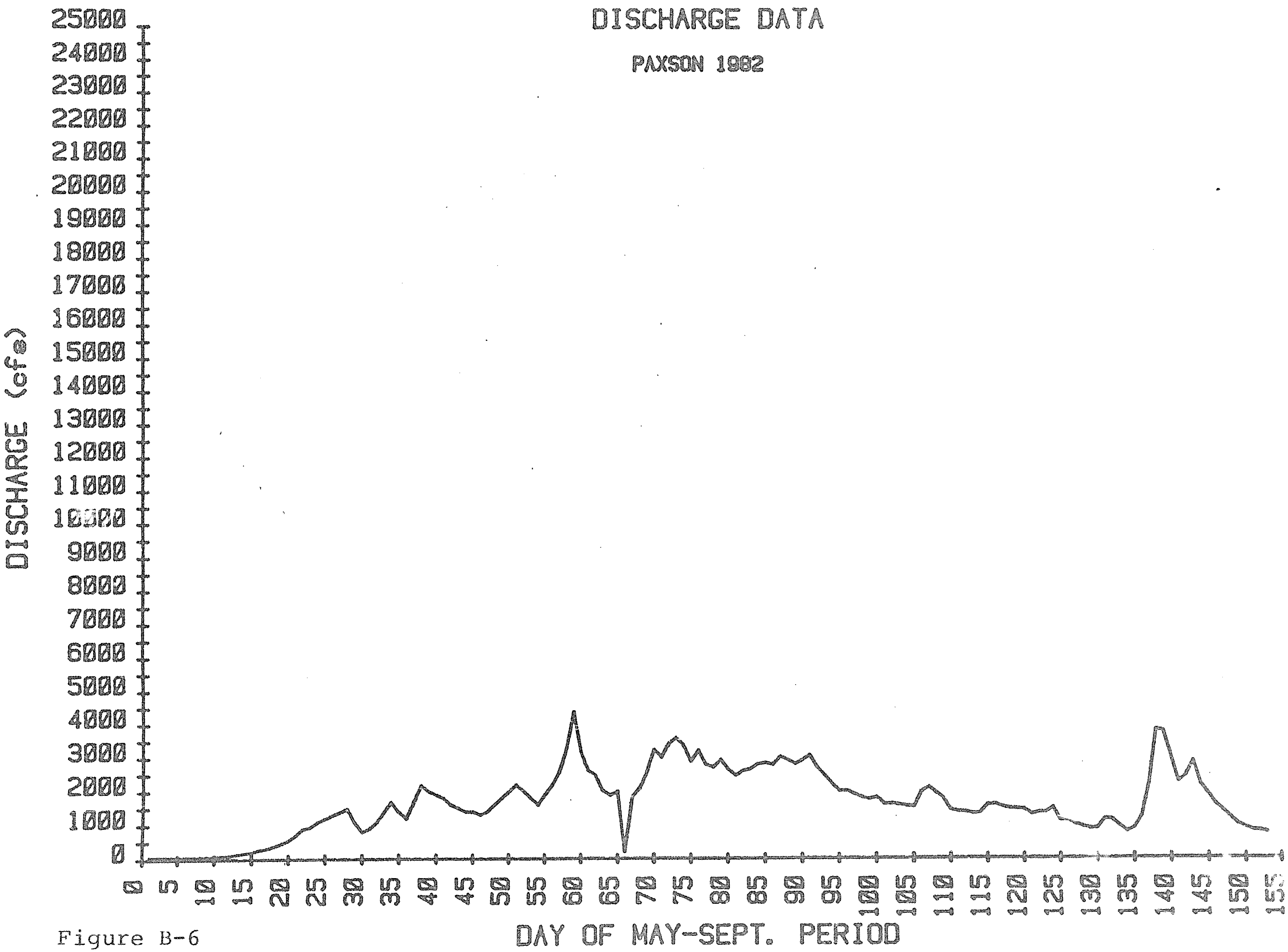

DISCHARGE DATA
PAXSON 1982
DISCHARGE (cfs)
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-6

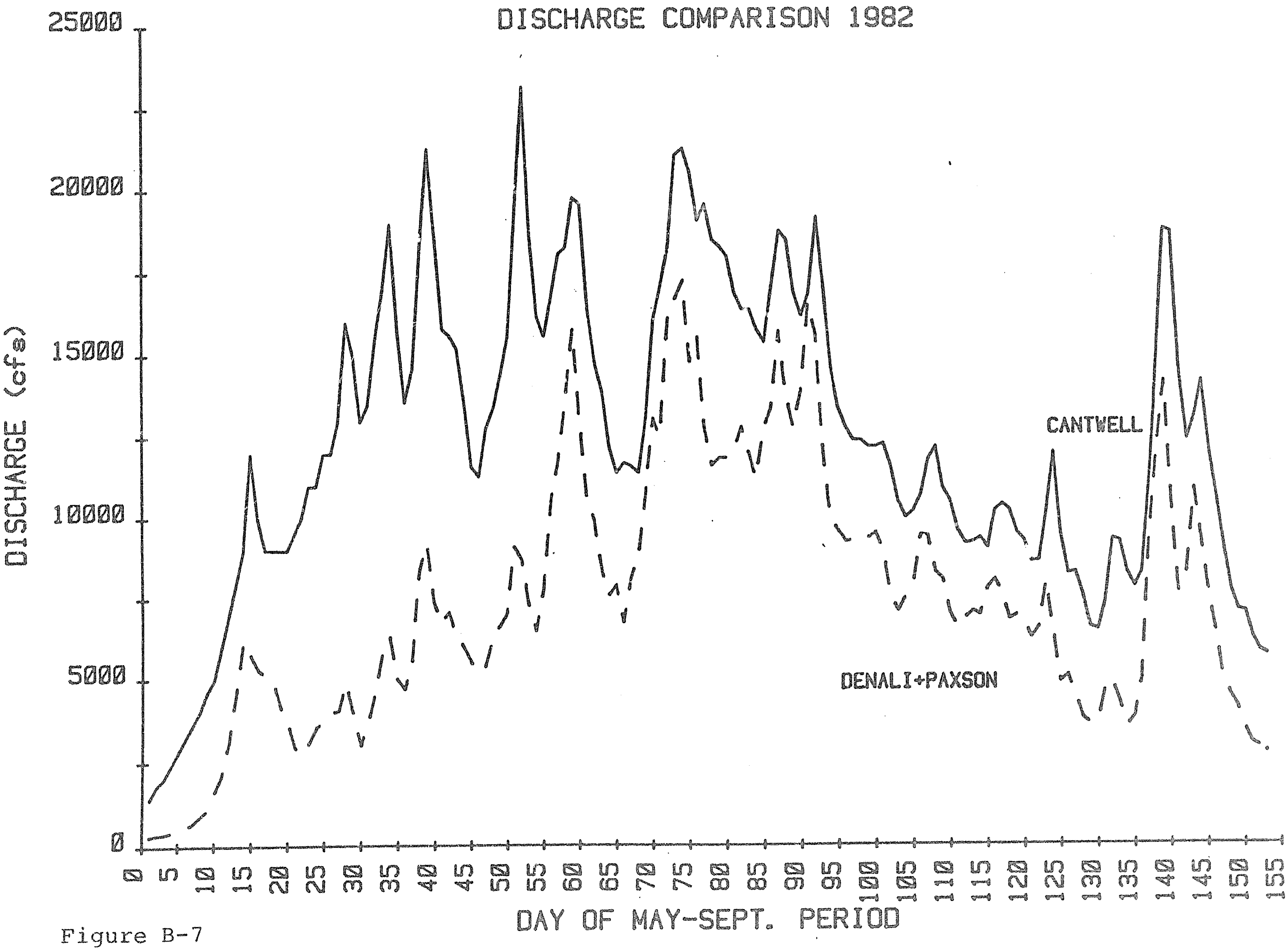
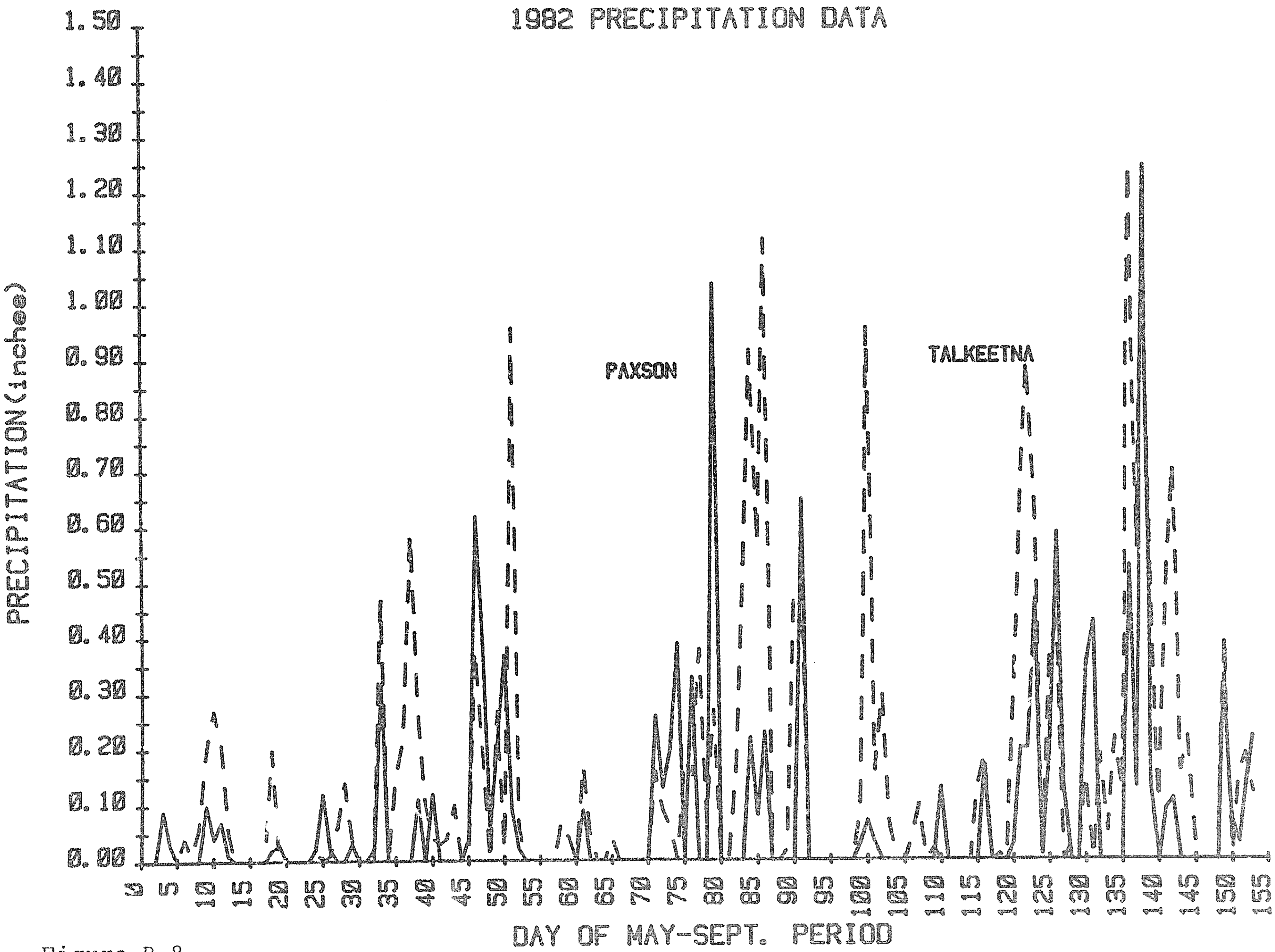

DISCHARGE COMPARISON 1982
DISCHARGE (cfs)
25000
20000
15000
10000
5000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD
CANTWELL
DENALI+PAXSON

Figure B-7



1982 PRECIPITATION DATA
PRECIPITATION (inches)
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
PAXSON
TALKEETNA
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-8

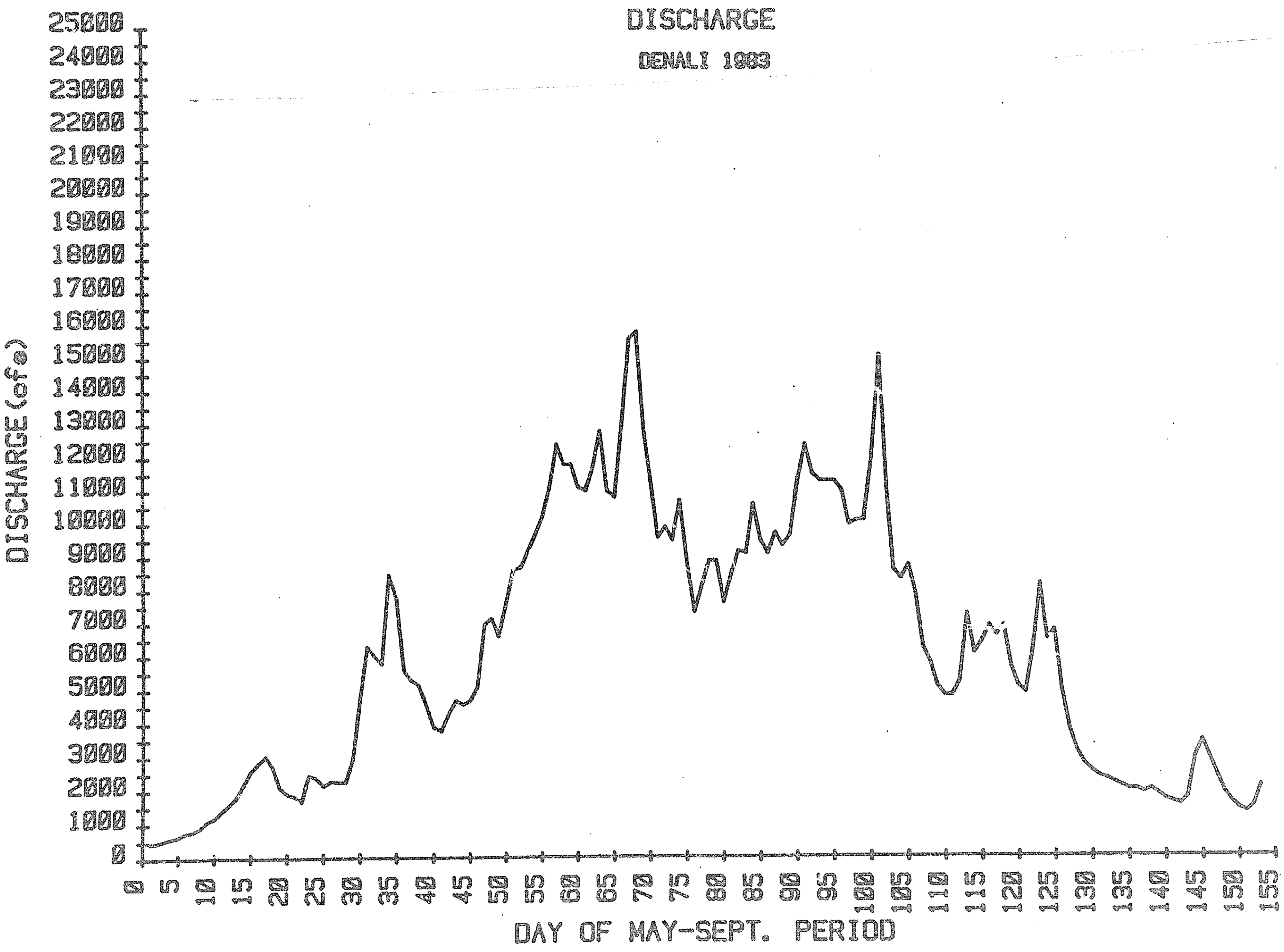

DISCHARGE
DENALI 1983
DISCHARGE (cfs)
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-9

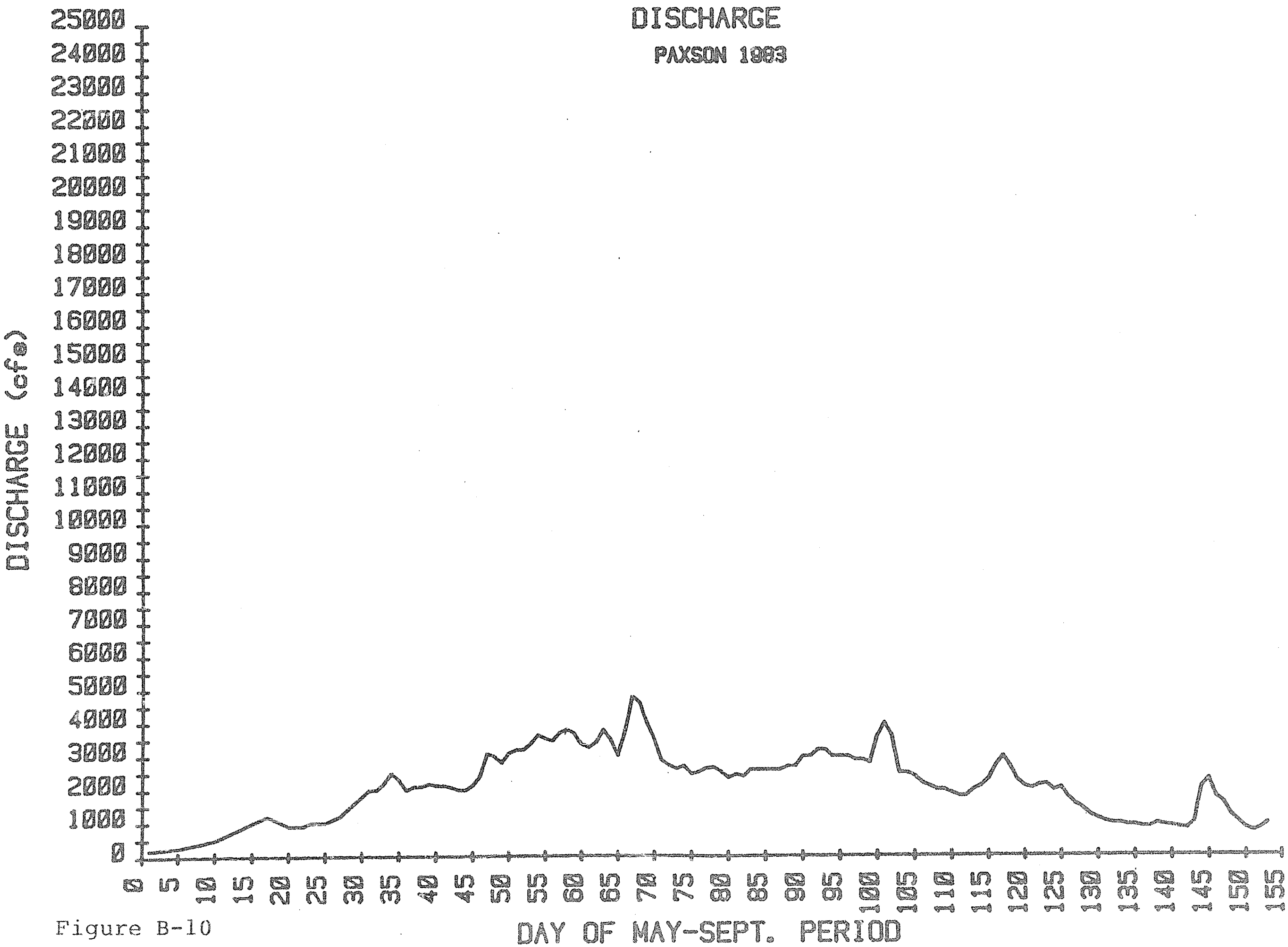

DISCHARGE
PAXSON 1983
DISCHARGE (cfs)
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-10

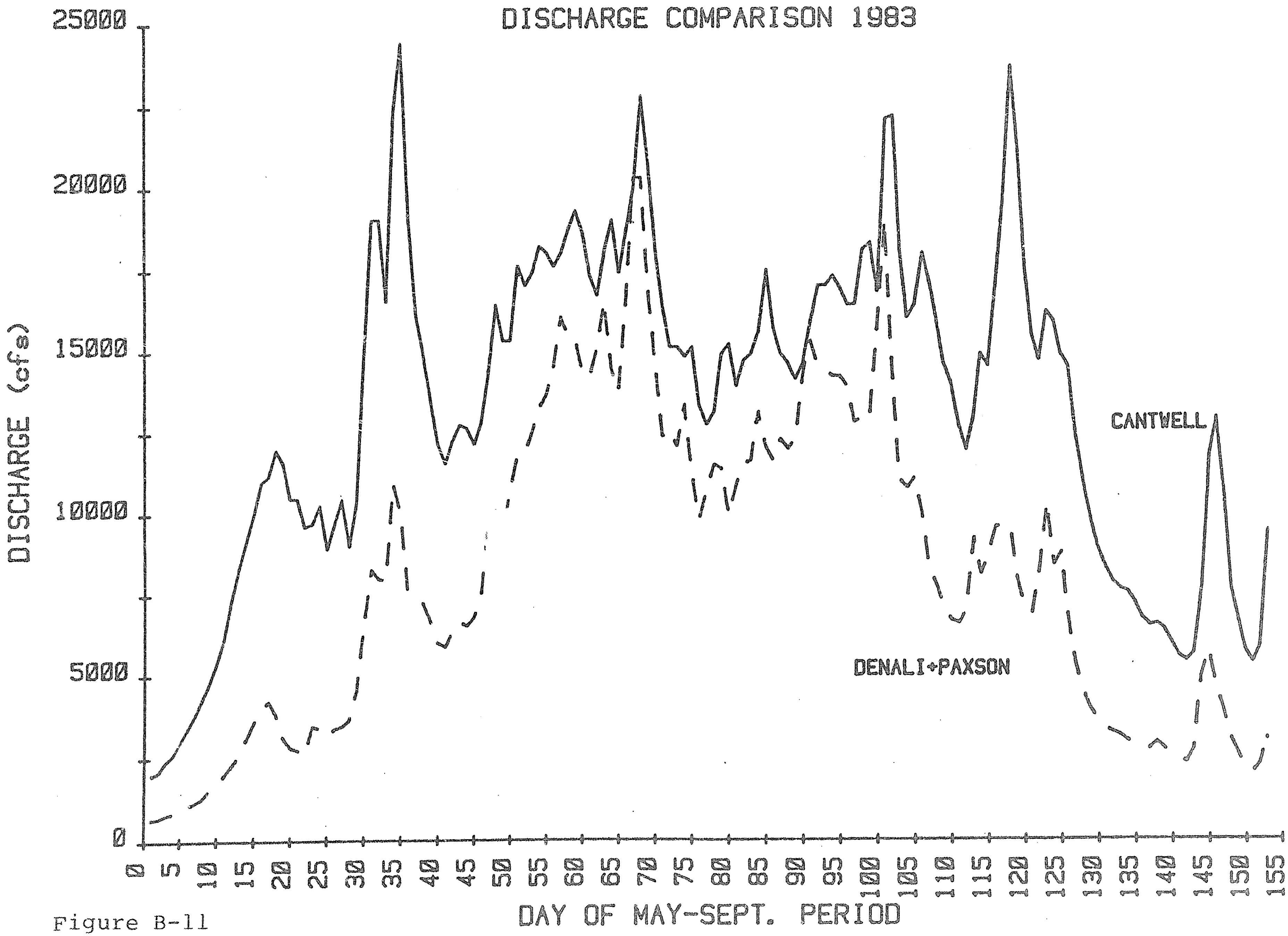

DISCHARGE COMPARISON 1983
DISCHARGE (cfs)
25000
20000
15000
10000
5000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD
CANTWELL
DENALI+PAXSON

Figure B-11

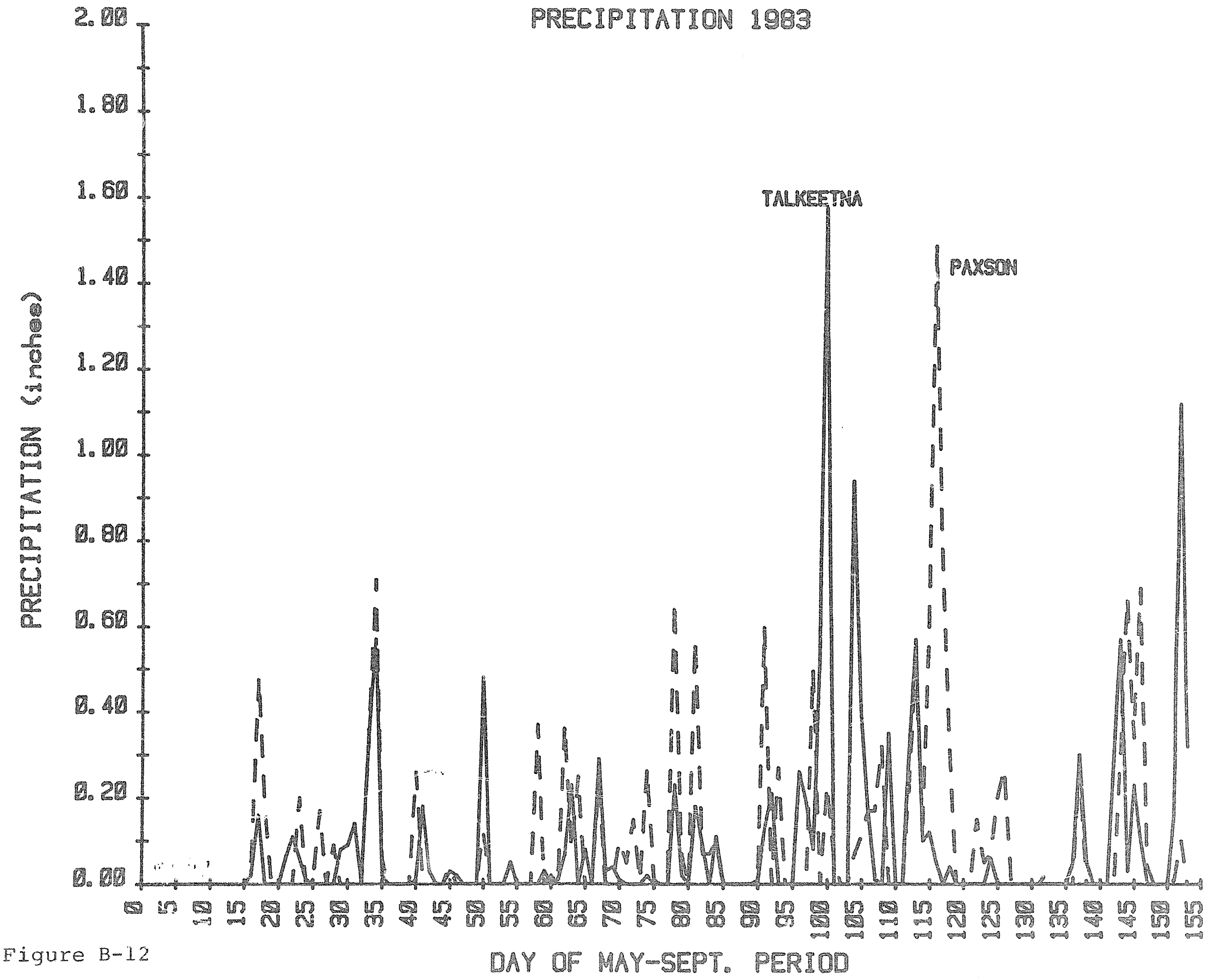

PRECIPITATION 1983
PRECIPITATION (inches)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
TALKEETNA
PAXSON
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-12

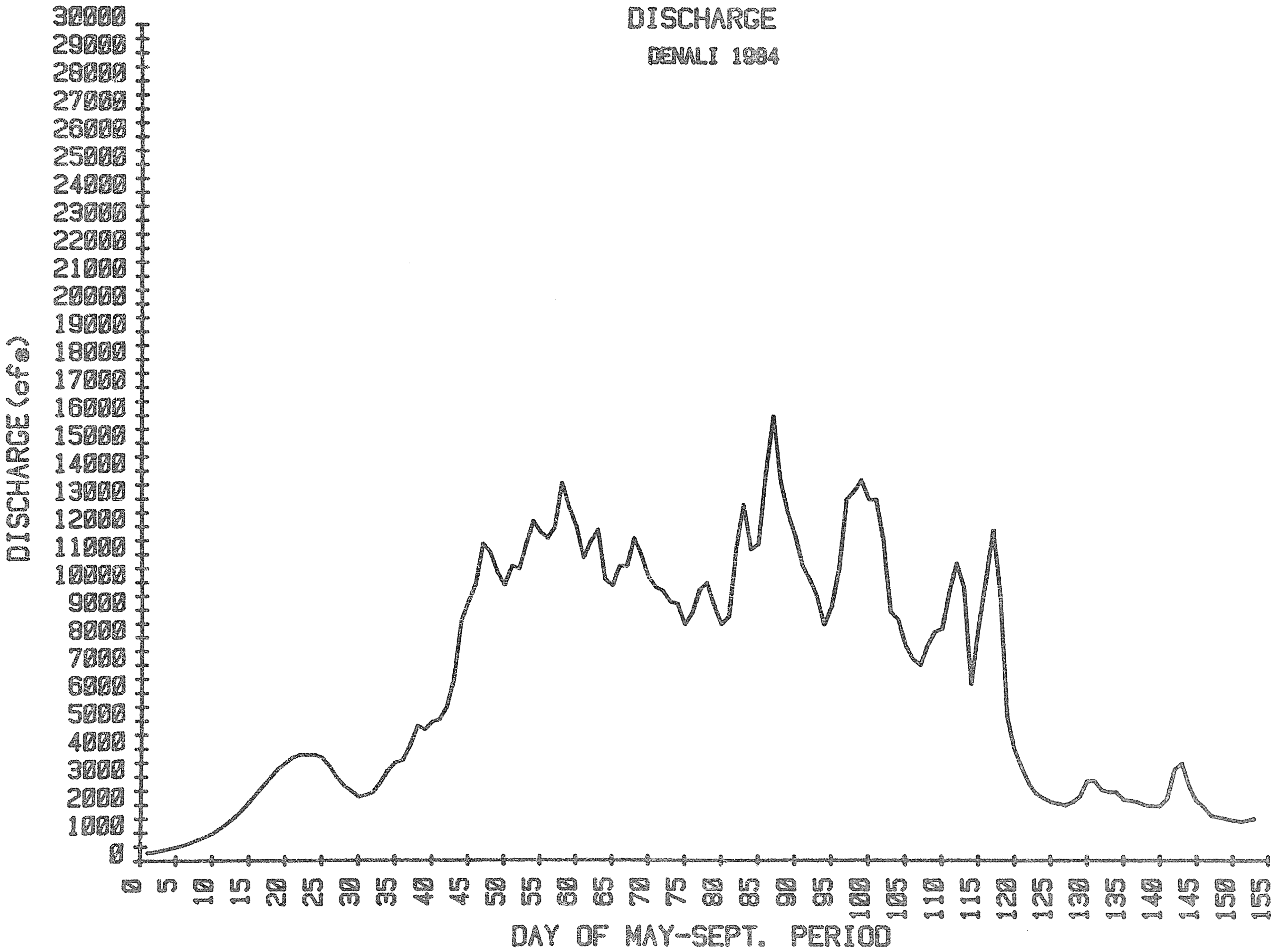

DISCHARGE
DENALI 1984
DISCHARGE (cfs)
30000
29000
28000
27000
26000
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-13

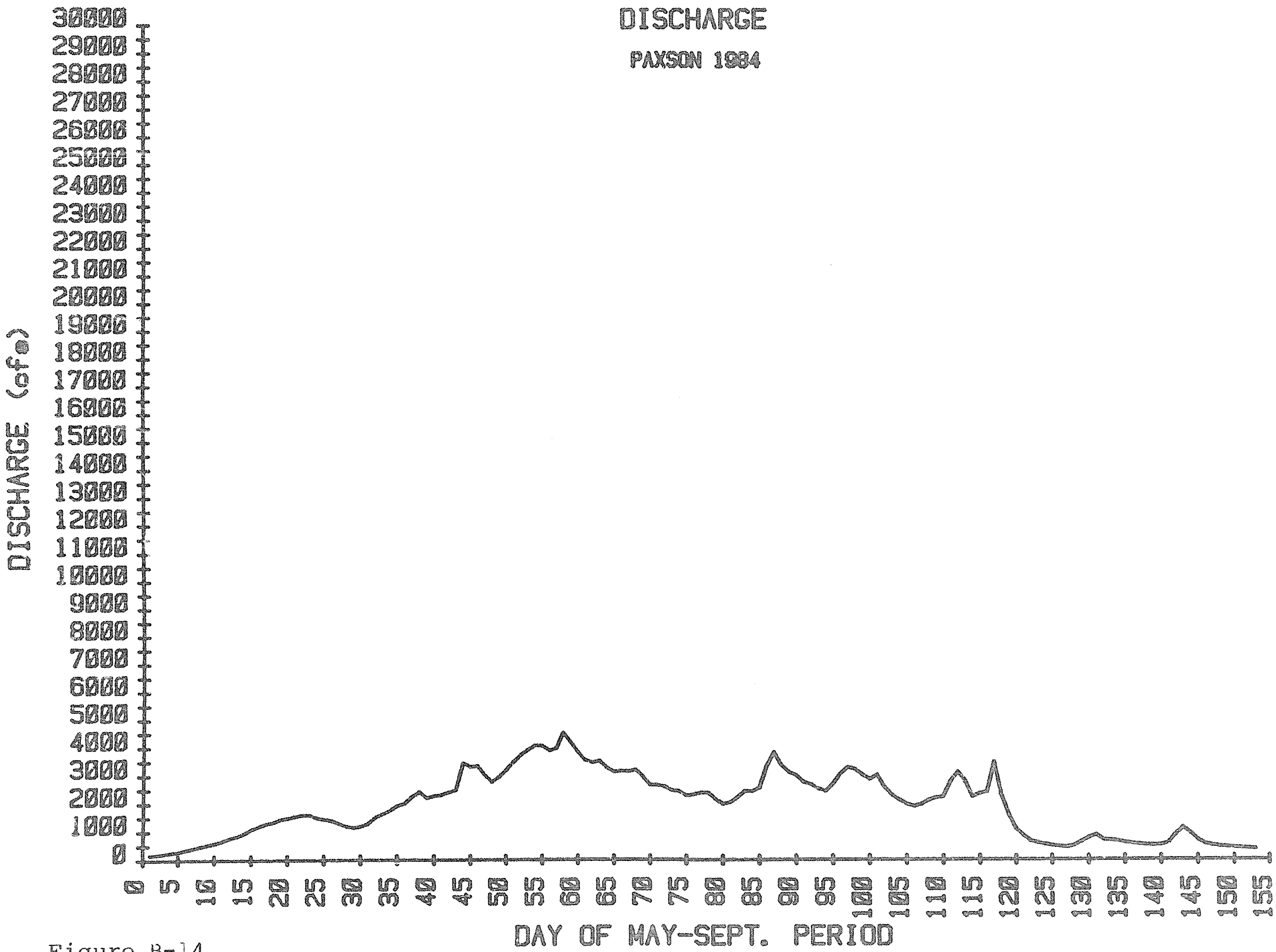

DISCHARGE
PAXSON 1984
DISCHARGE (cfs)
30000
29000
28000
27000
26000
25000
24000
23000
22000
21000
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-14

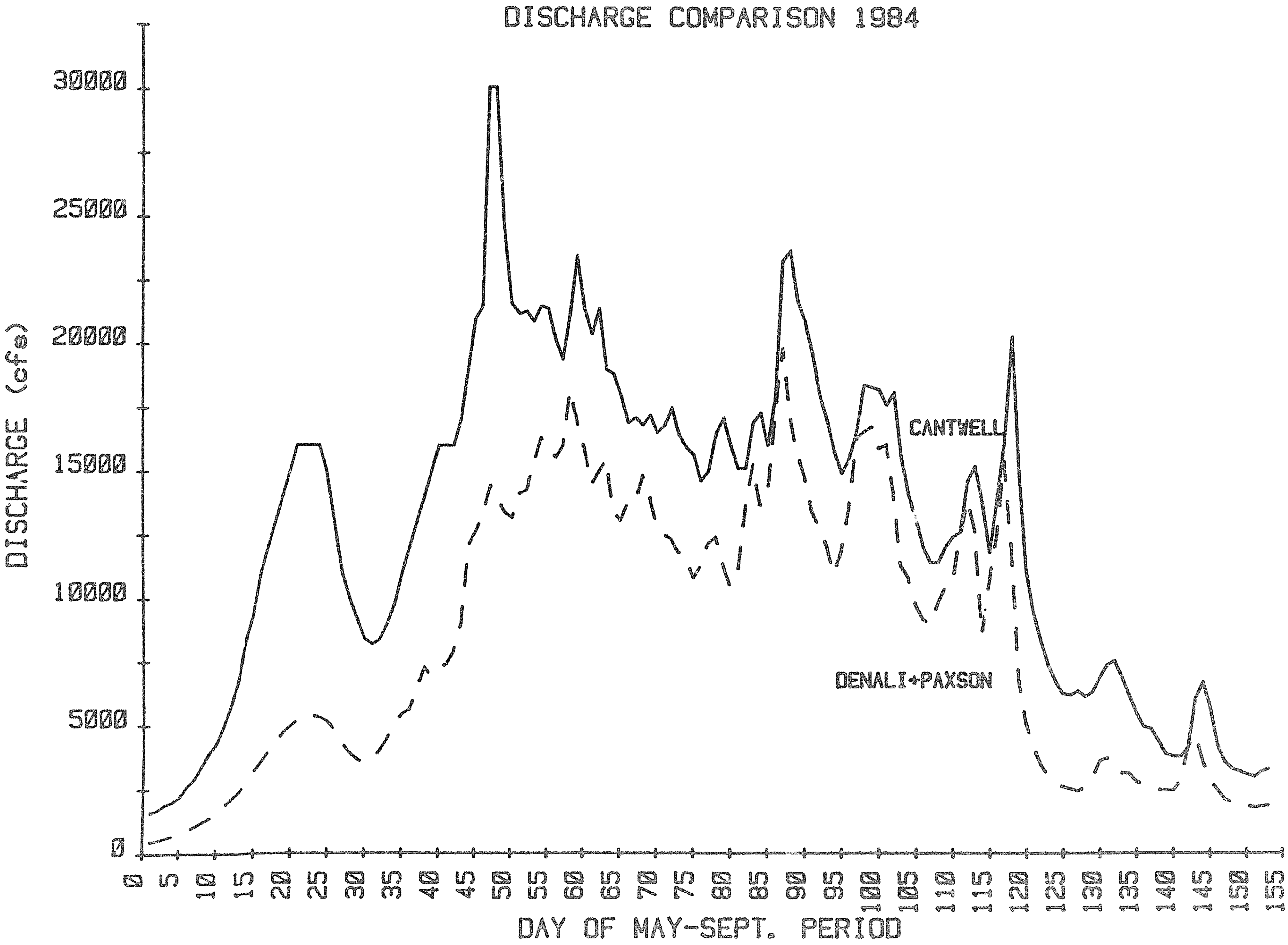

DISCHARGE COMPARISON 1984
DISCHARGE (cfs)
30000
25000
20000
15000
10000
5000
0
CANTWELL
DENALI+PAXSON
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
DAY OF MAY-SEPT. PERIOD

Figure B-15

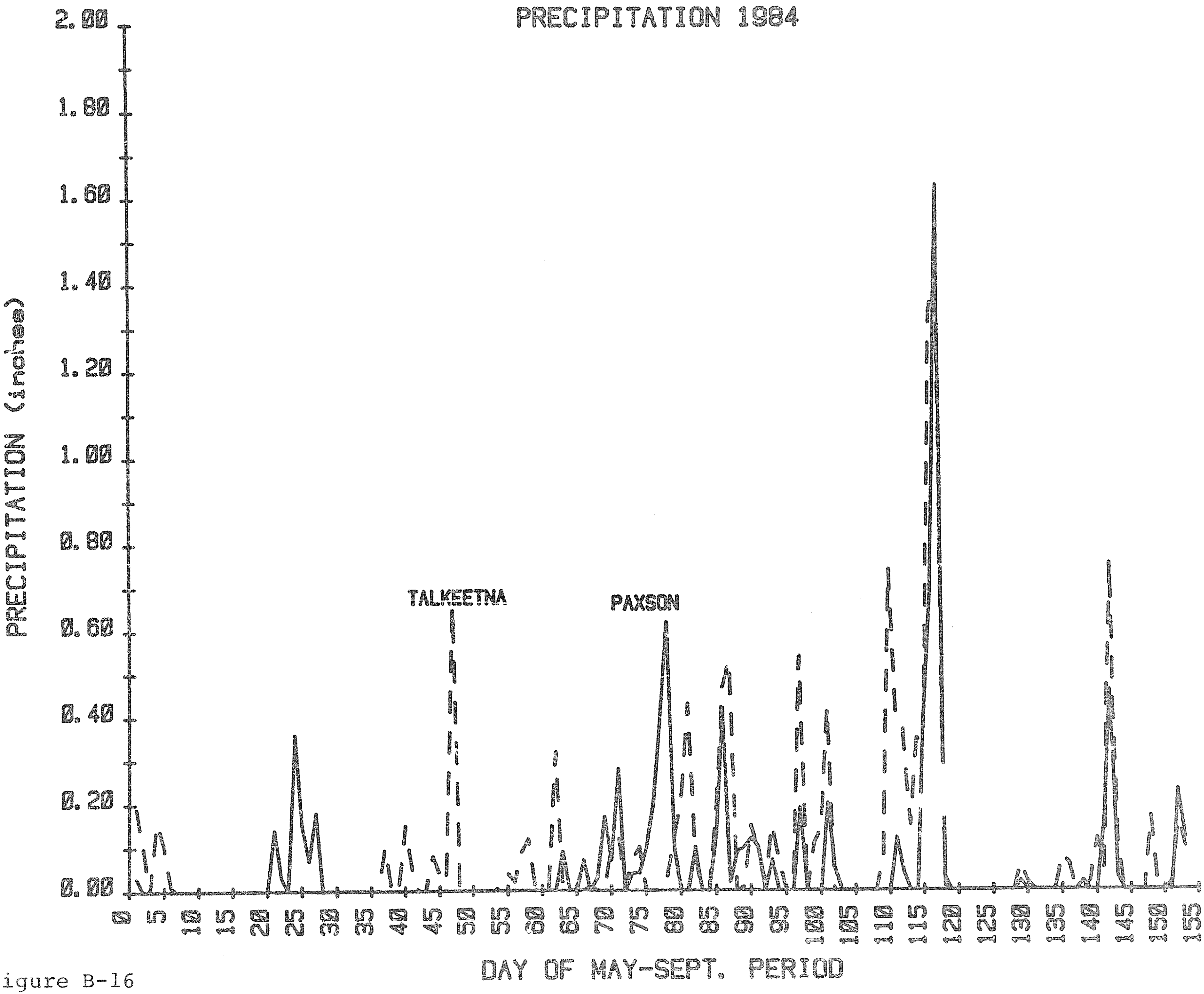

PRECIPITATION 1984
PRECIPITATION (inches)
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
TALKEETNA
PAXSON
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155
DAY OF MAY-SEPT. PERIOD

Figure B-16

DISCHARGE: DENALI 1981

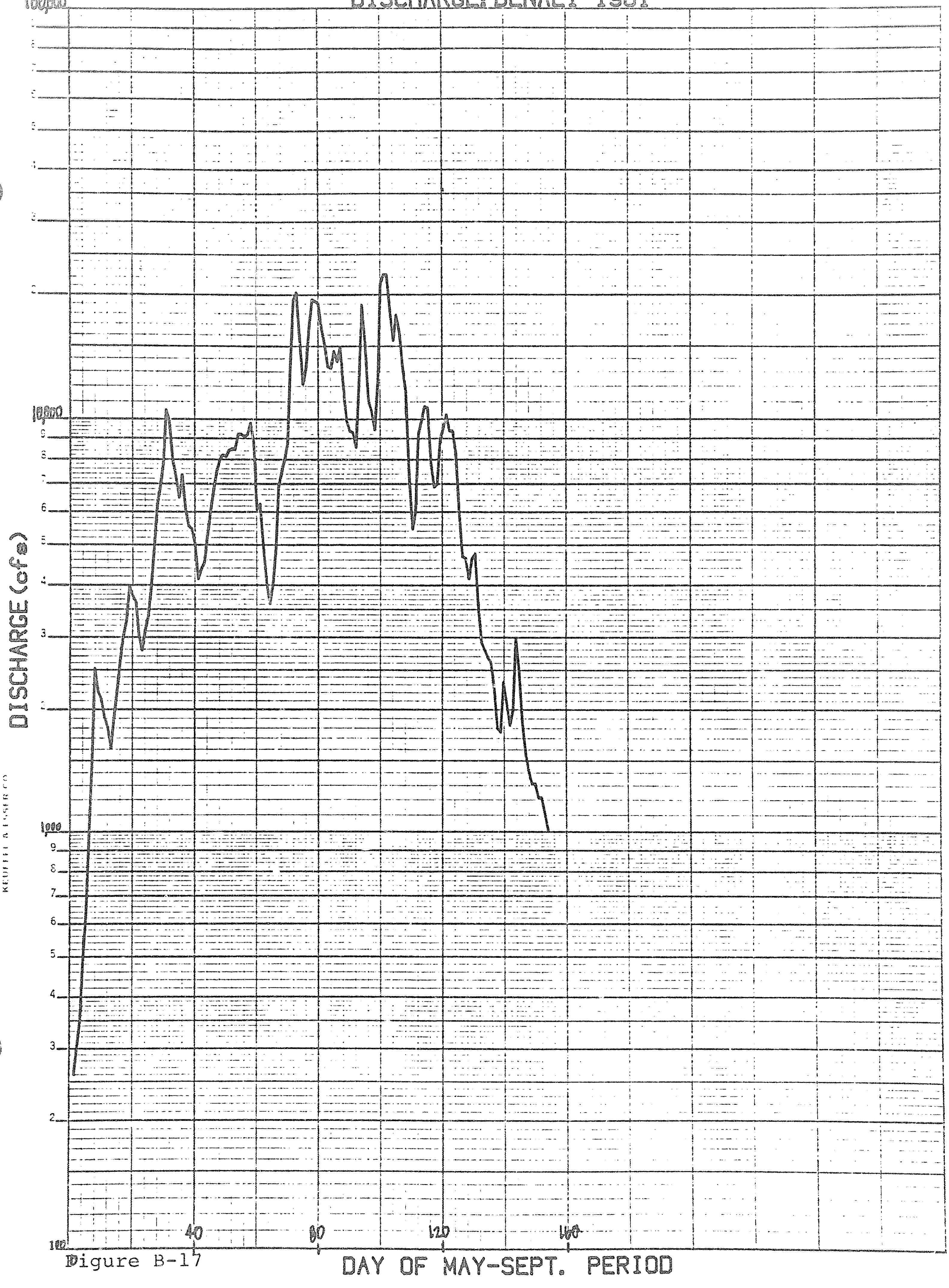
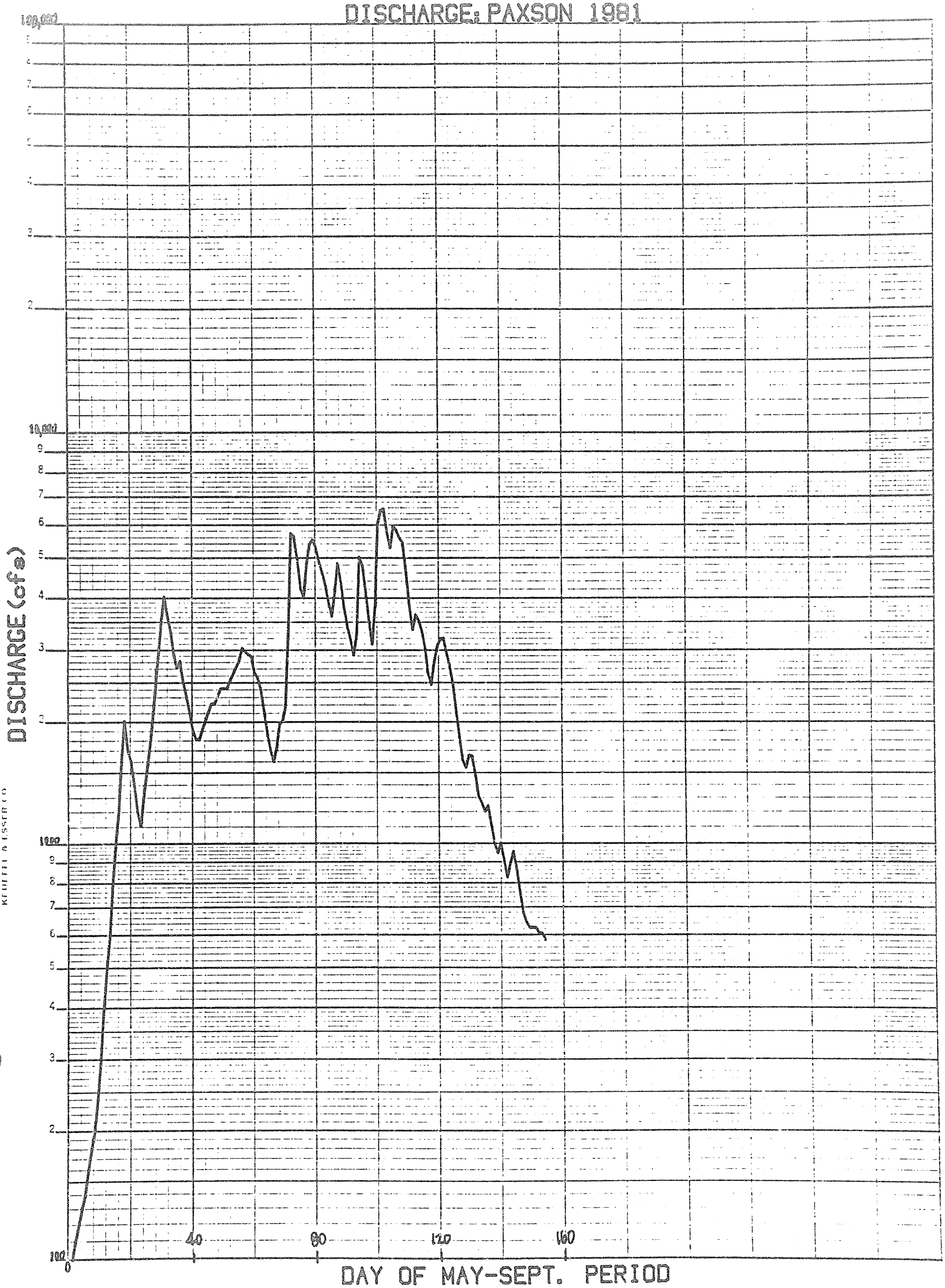


Figure B-17



DISCHARGE: PAXSON 1981
DISCHARGE (cfs)
100,000
10,000
1000
100
0
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-18

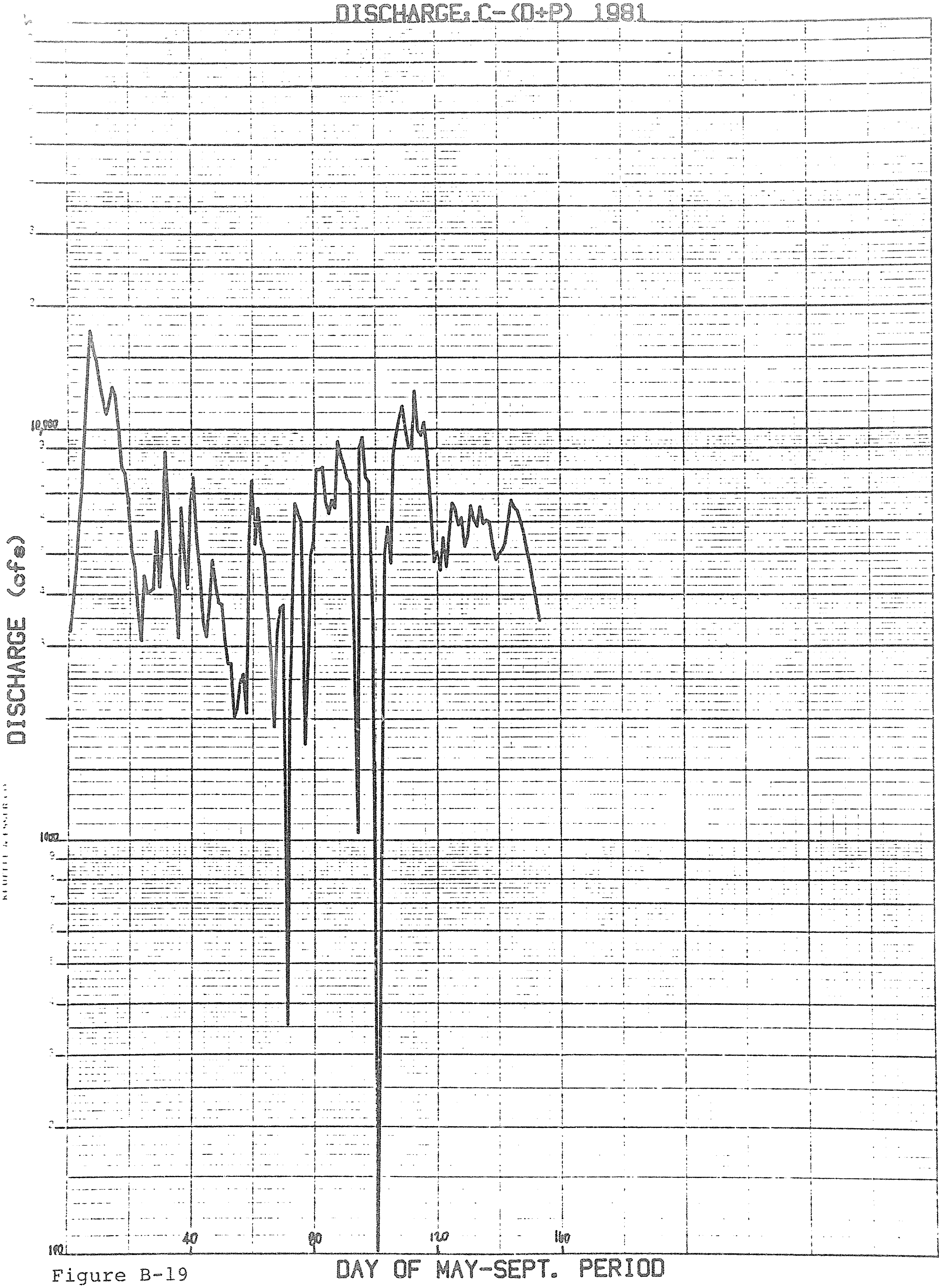
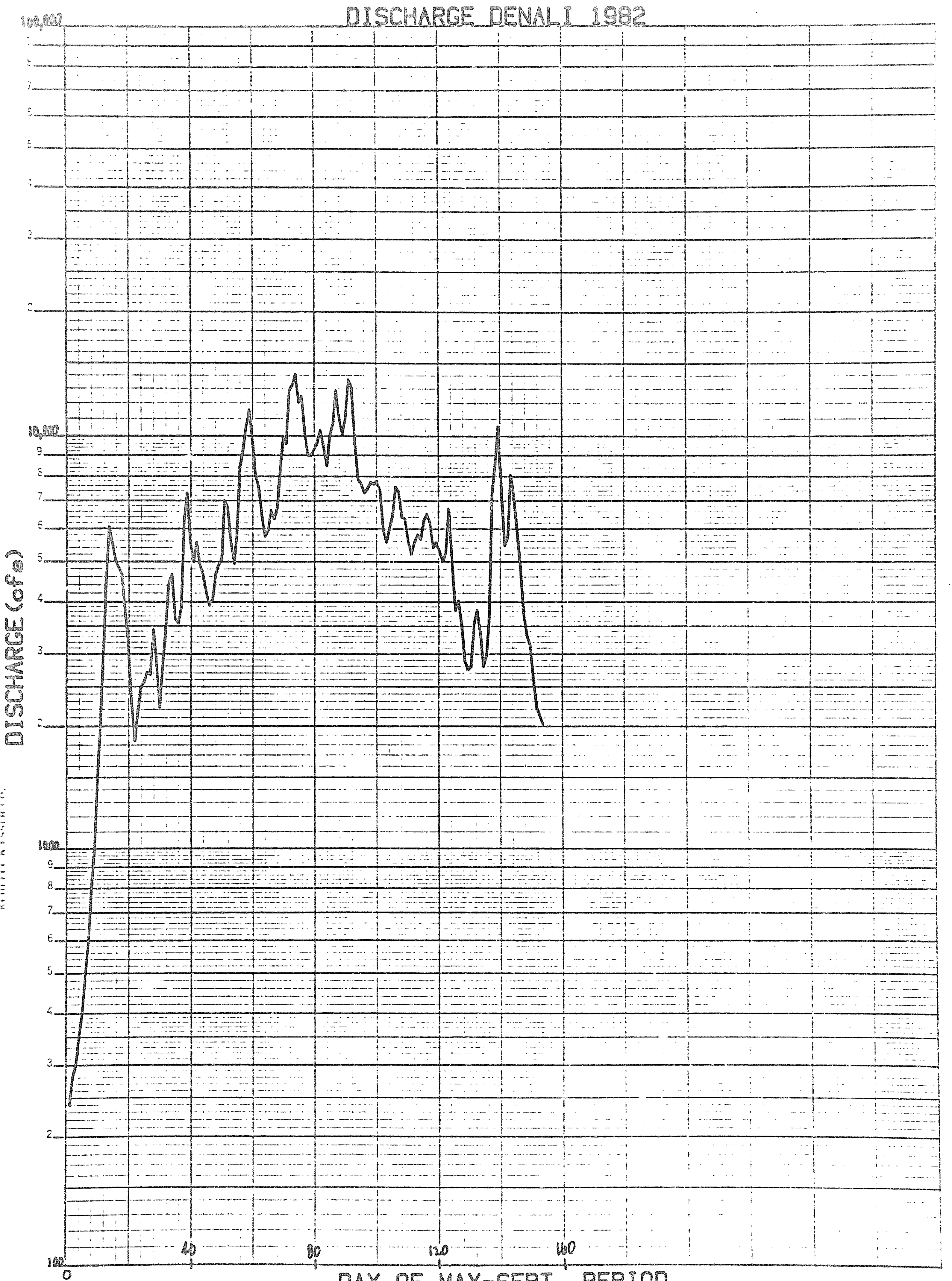

DISCHARGE: C-(D+P) 1981
DISCHARGE (cfs)
10,000
1000
100
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-19


DISCHARGE DENALI 1982
DISCHARGE (cfs)
100,000
10,000
1000
100
0
40
80
120
160
DAY OF MAY-SEPT. PERIOD
Figue B-20

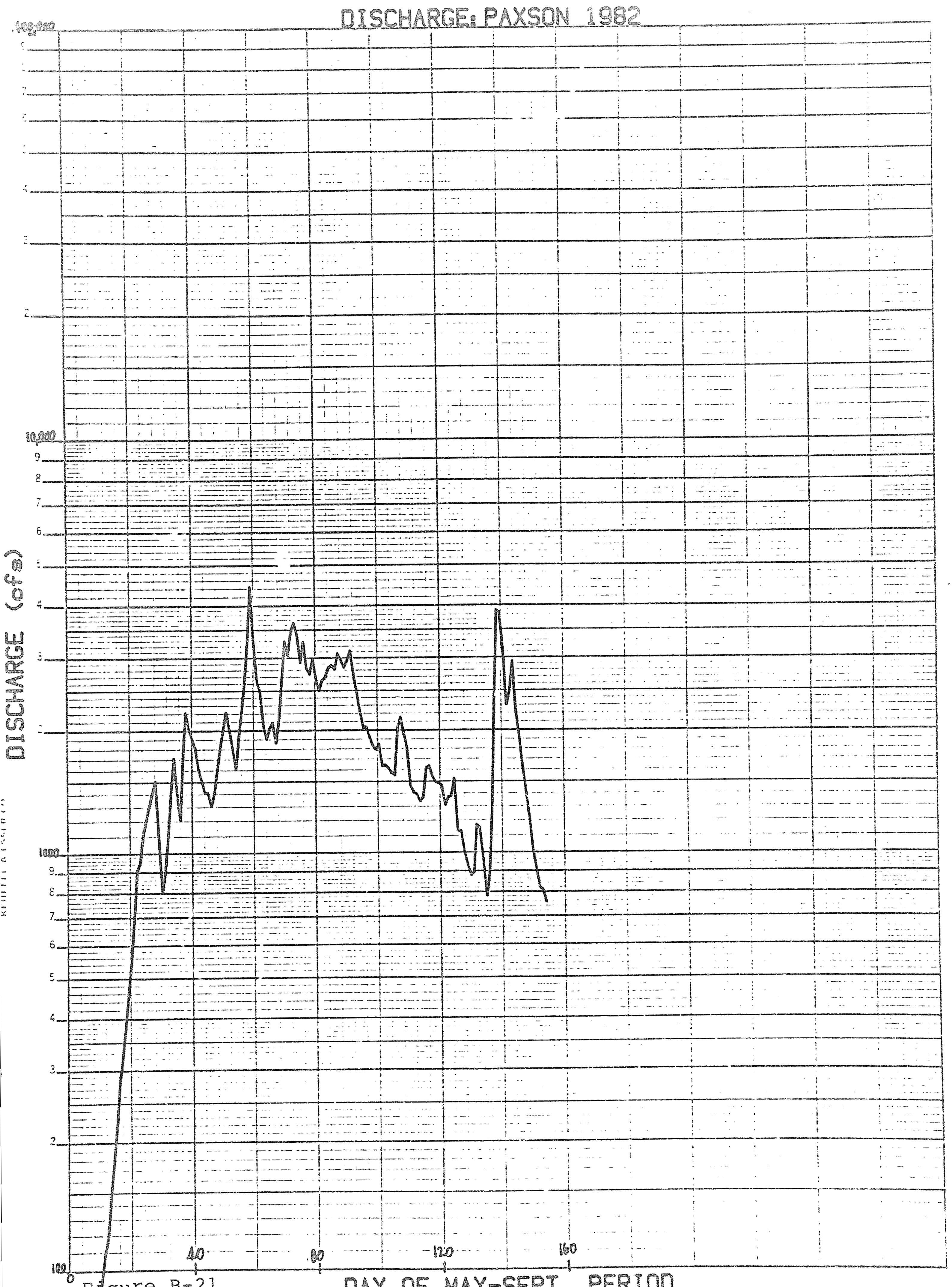
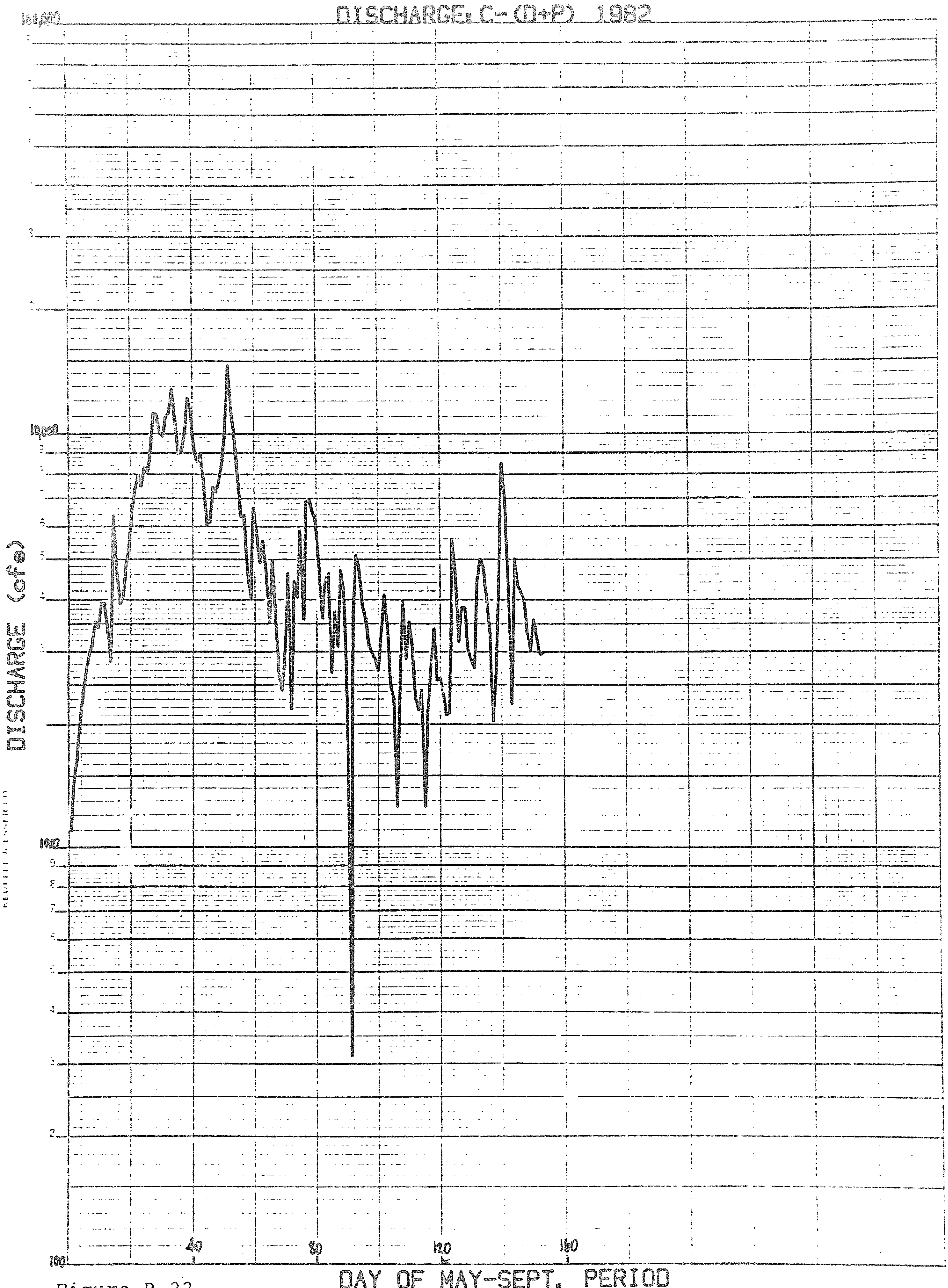
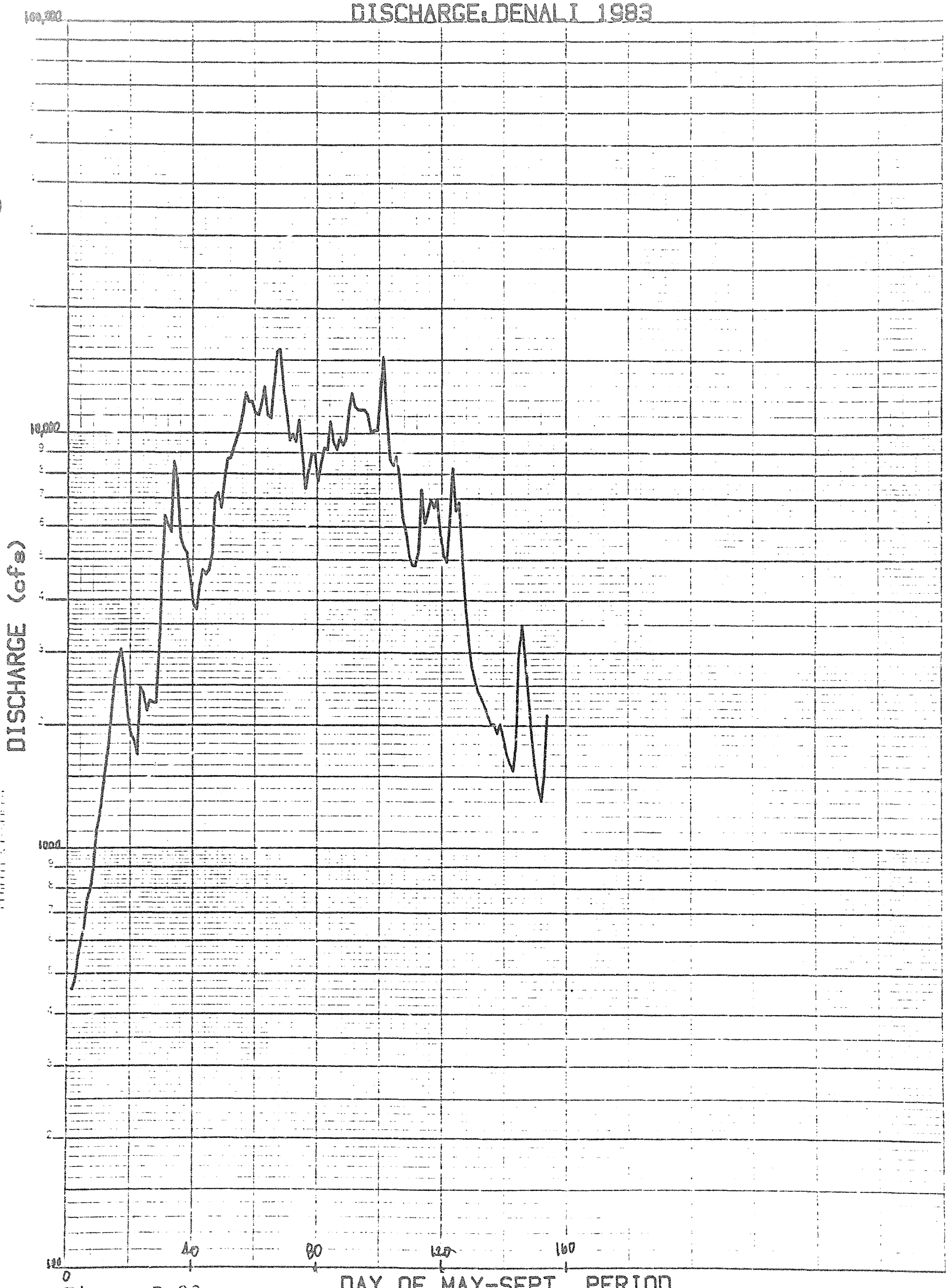

DISCHARGE: PAXSON 1982
DISCHARGE (cfs)
10,000
1000
100
0
40
80
120
160
DAY OF MAY-SEPT. PERIOD

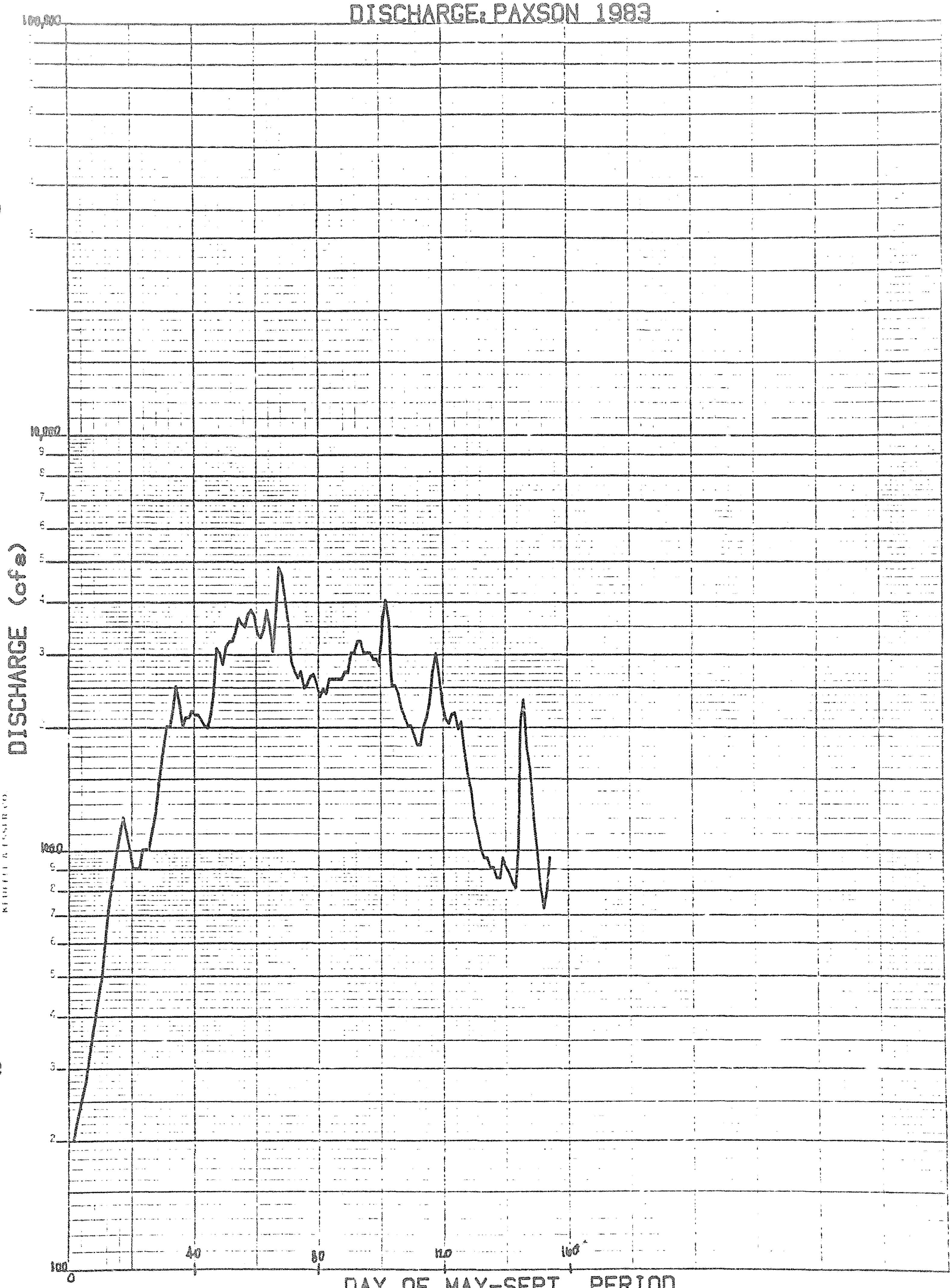
Figure B-21



DISCHARGE: C-(D+P) 1982
DISCHARGE (cfs)
100,000
10,000
1000
100
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-22


DISCHARGE: DENALI 1983
DISCHARGE (cfs)
DAY OF MAY-SEPT. PERIOD
100,000
10,000
1000
100
0
40
80
120
160
Figure B-23



DISCHARGE: PAXSON 1983
DISCHARGE (cfs)
100,000
10,000
1000
100
0
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-24

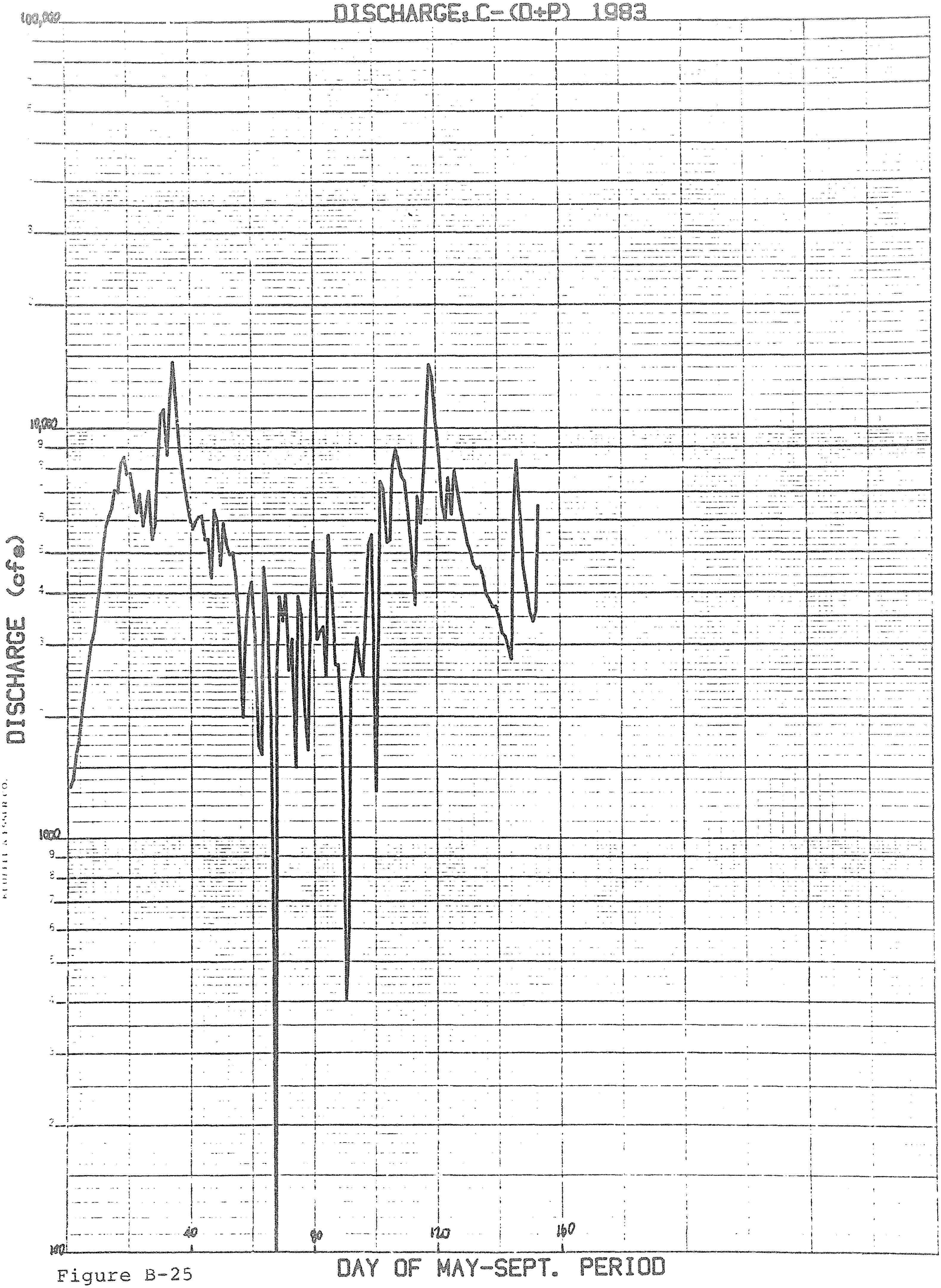
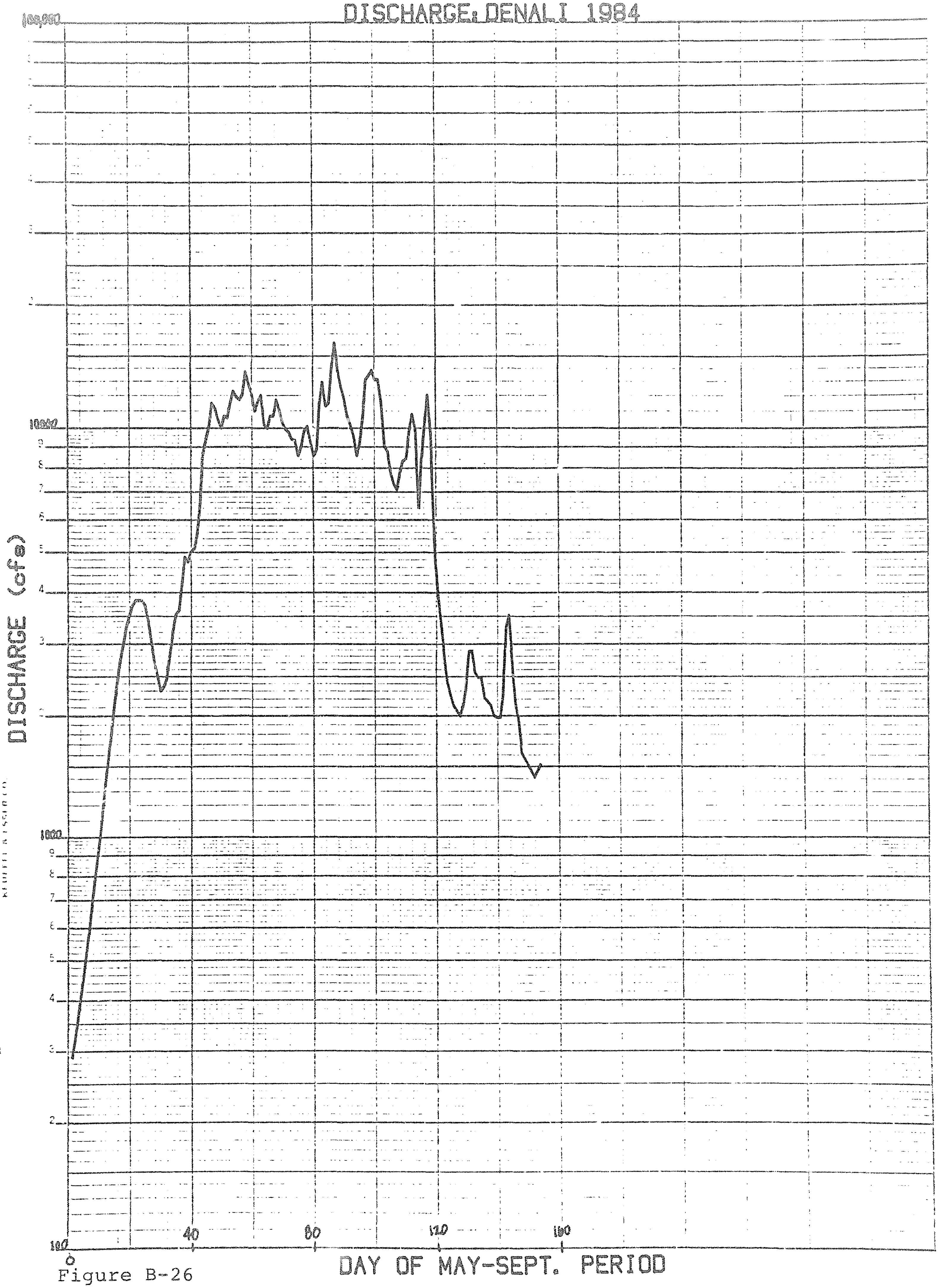

DISCHARGE: C-(D+P) 1983
100,000
10,000
1000
100
DISCHARGE (cfs)
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-25


DISCHARGE: DENALI 1984
100,000
10,000
1000
100
DISCHARGE (cfs)
0
40
80
120
160
DAY OF MAY-SEPT. PERIOD
Figure B-26

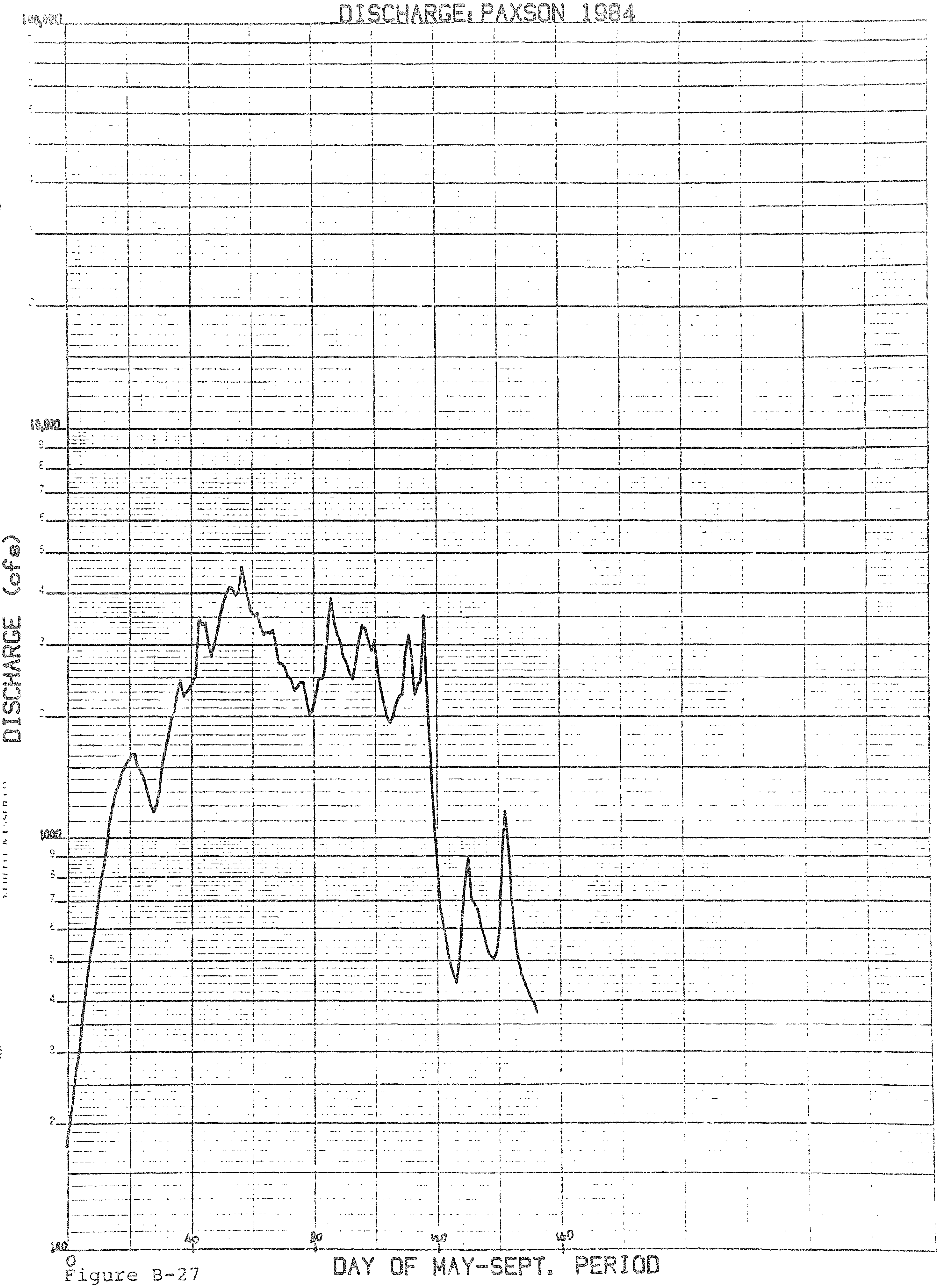
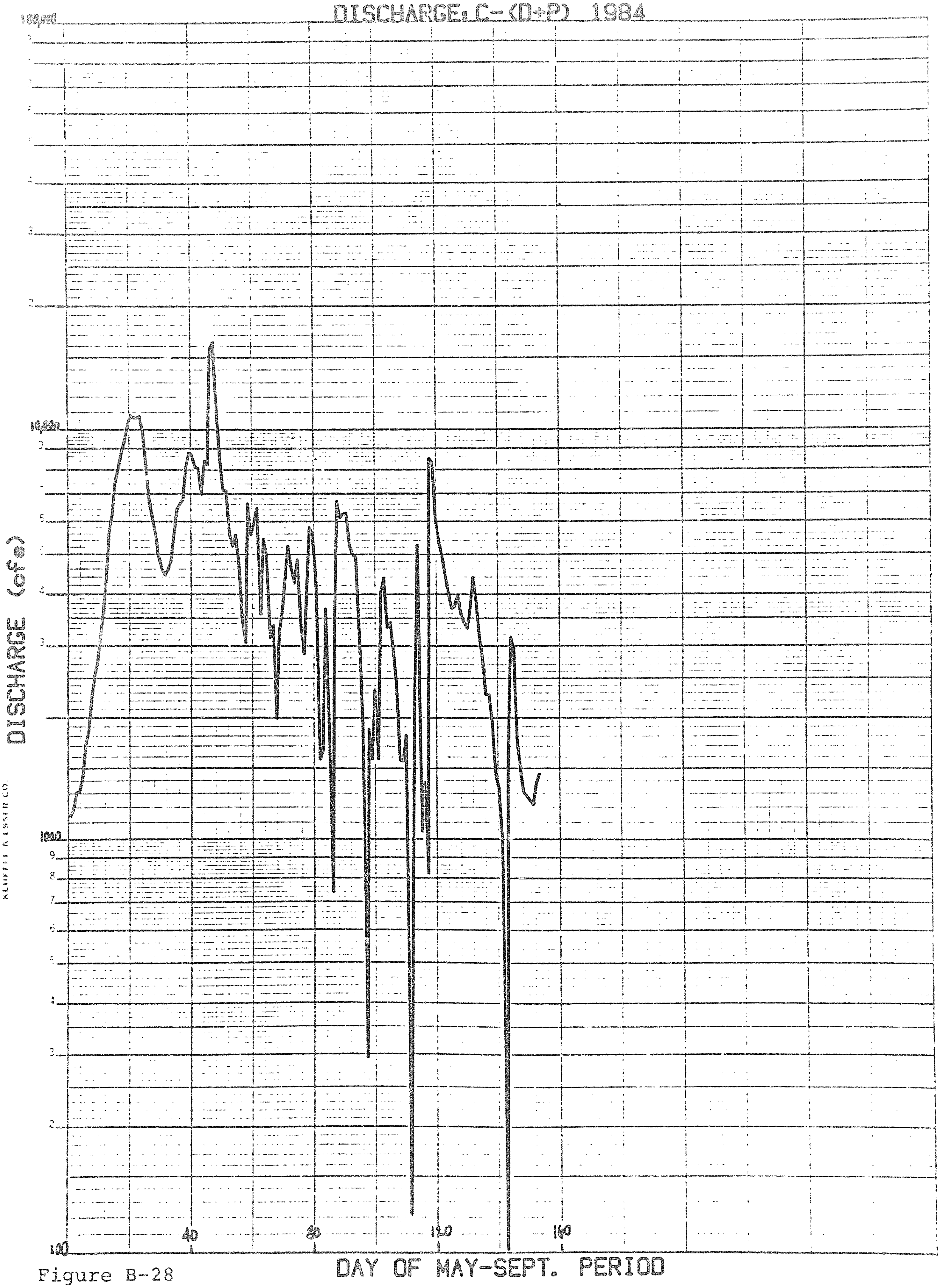

DISCHARGE: PAXSON 1984
DISCHARGE (cfs)
DAY OF MAY-SEPT. PERIOD
100,000
10,000
1000
100
0
40
80
120
160

Figure B-27



DISCHARGE: C-(D+P) 1984
100,000
10,000
1000
100
DISCHARGE (cfs)
40
80
120
160
DAY OF MAY-SEPT. PERIOD

Figure B-28

Appendix C

PROBLEM NUMBER ELP
REPLACEMENT AND DELETION 5

DEPENDENT VARIABLE IS NOW 2
NUMBER OF VARIABLES DELETED 1
VARIABLES DELETED... 1

ANALYSIS OF VARIANCE FOR REGRESSION

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARES	F VALUE
DUE TO REGRESSION............	4	5588.70508	1397.17627	8.07810
DEVIATION ABOUT REGRESSION...	14	2421.41992	172.95856	
TOTAL...	18	8010.12500		

INTERCEPT (A VALUE) IS 89.04927

VARIABLE NO.	VARIABLE NAME	MEAN	STANDARD DEVIATION	REG. COEF.	STD. ERROR OF REG. COEF.	COMPUTED T VALUE	PARTIAL CORR. COEF.
3	X1	68.42105	21.61871	0.4180351E+00	0.15317	2.72923	0.58931
4	X2	94.47368	55.95869	0.2557810E+00	0.06646	3.84881	0.71702
5	X3	158.52631	48.08485	0.1487537E+00	0.07585	1.96117	0.46424
6	X4	159.94736	53.22541	0.1018247E+00	0.06013	1.69349	0.41234
DEPENDENT							
2	Y	181.68420	21.09518				

COMPARE CHECK ON FINAL COEFFICIENT...... 0.10182

		INCREMENTS FOR INDEPENDENT VARIABLES				CUMULATIVE REGRESSIONS			
VARIABLE NO.	VARIABLE NAME	SUMS OF SQUARES	PROP. VAR.	F VALUE EACH TERM	STD. ERROR OF ESTIMATE	SUMS OF SQUARES	PROP. VAR. = R SQ.	F VALUE	MULTIPLE R
3	X1	2895.57861	0.36149	9.62448	17.34519	2895.57861	0.36149	9.62448	0.60124
4	X2	1556.51929	0.19432	6.99947	14.91230	4452.09766	0.55581	10.01026	0.74553
5	X3	640.57983	0.07997	3.29353	13.94620	5092.67676	0.63578	8.72796	0.79736
6	X4	496.02869	0.06193	2.86790	13.15137	5588.70508	0.69771	8.07810	0.83529

PROPORTION OF VARIANCE SPECIFIED TO LIMIT VARIABLES 0.00000

Variable No.	Variable Name	Descriptions
1	Year	Two digits for year (1962 = 62)
2	Y	May-September runoff, Susitna River at Denali, 1,000 acre feet
3	X1	Water equivalent, April 1 Monahan Flat snow course, 1/10 inches
4	X2	Sum of monthly departures from average temperature for May-September, Talkeetna degrees F (plus 10 degrees F)
5	X3	May-September precipitation, Talkeetna, 1/10 inches
6	X4	Value of X3 for previous year

Regression equation

$$Y = 21.1 + 0.42\ X1 + 0.26\ X2 + 0.15\ X3 + 0.10\ X4$$

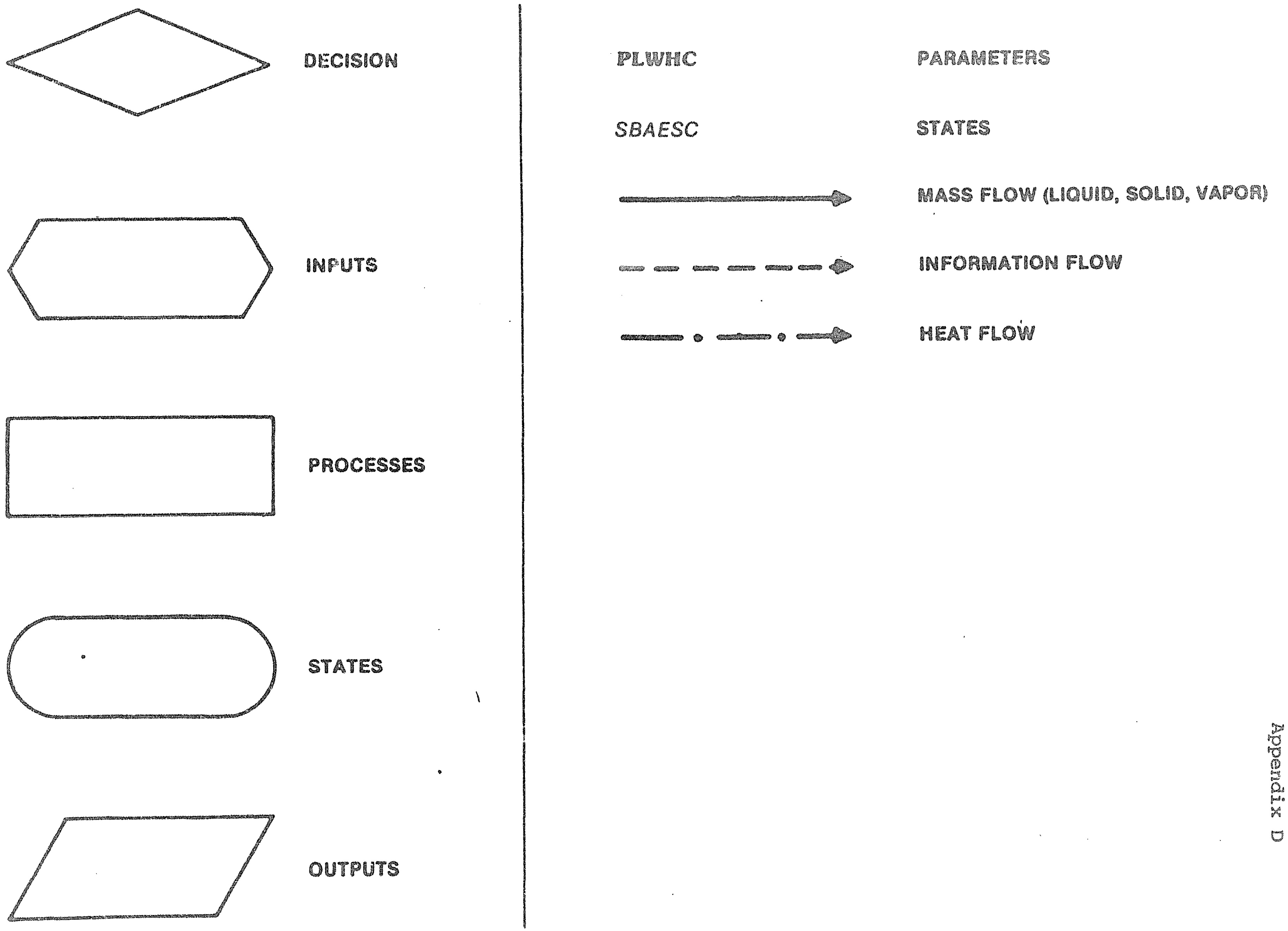


Figure D LEGEND FOR SCHEMATIC DIAGRAMS OF MODELS

Inputs

The set of driving forces required periodically by the model. Common examples are precipitation, potential evapotranspiration, and temperature. For most hydrologic models the inputs are all meteorologic factors, but some require inputs describing man's activities (cropping practices).

The key phrase in the definition of the inputs of a model is "required periodically." If it is possible to run the model without providing a value for a particular item, that item is not an input. Likewise, if the model can be run with a particular item provided only once or perhaps intermittently, that item is not an input. Some models, however, may have default values for certain inputs (e.g., precipitation is zero if not entered).

Parameters

The set of values that are changed to make a general hydrologic model apply to a particular location. Parameters ar constant with time or at most, vary only slightly with time as compared to inputs.

States

The set of internal model values sufficient to start the model. The states of the model completely define the past history of inputs. These are usually values of moisture stored in various model components (e.g. upper zone tension water contents), indices to model status(e.g.,API), or computational carryover values (e.g., the carryover values of a unit hydrograph operation). In each time step of operation, the model uses the initial values of the states along with parameters and inputs for that time step in order to compute the state for the next time step.

Outputs

Variables of interest that can be computed from knowledge of the states and inputs. Usual examples are streamflow and actual evapotranspiration. In many cases an output will be identical to some state of the model, but such does not have to be the case. The model may produce an output that is of vital interest to the model user but is not necessary to the model computations.

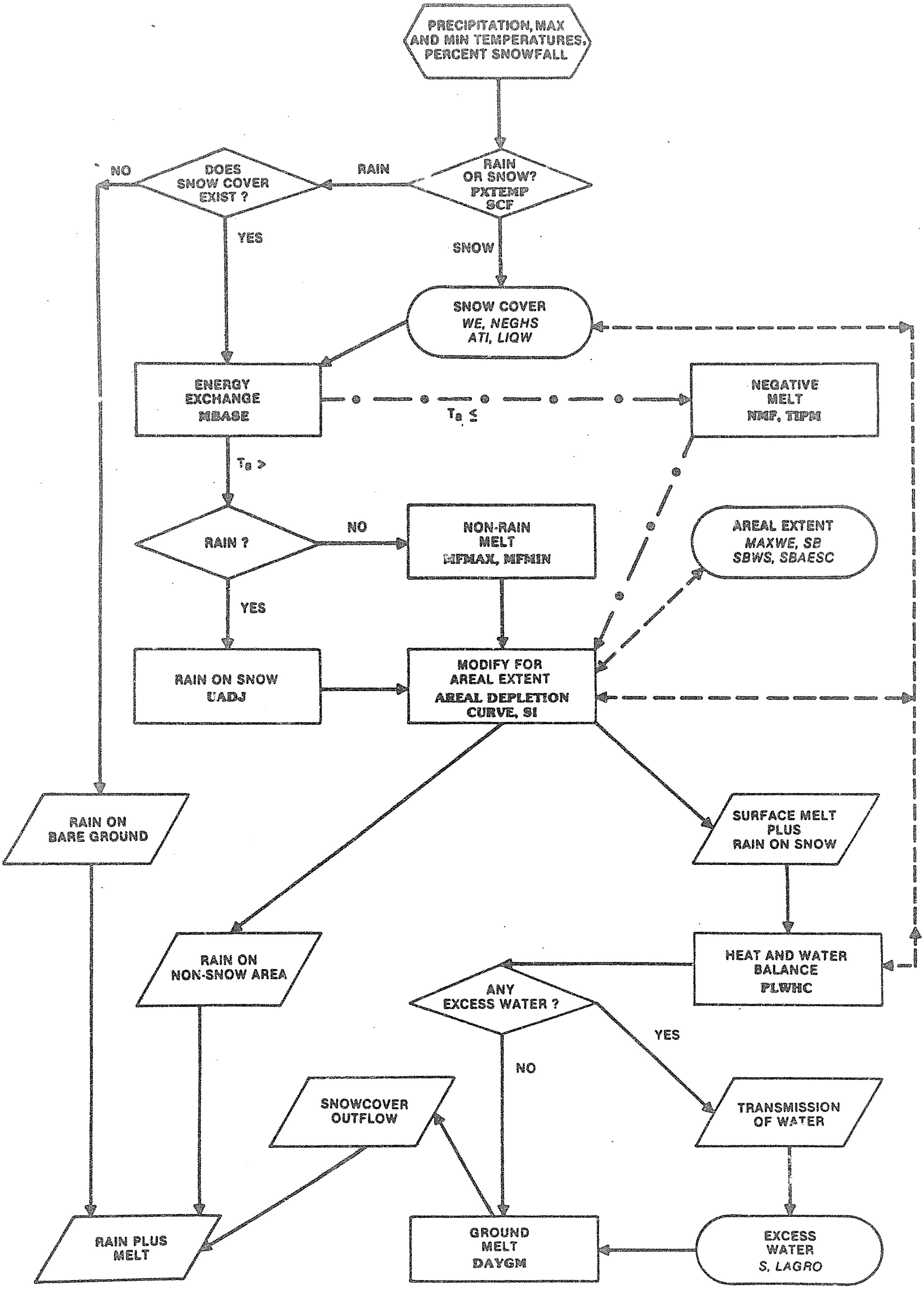


Figure D-1NWSRFS (ANDERSON) SNOWMELT MODEL SCHEMATIC DIAGRAM

Table D-1 PARAMETERS (DEFINITIONS) NWSRFS SNOWMELT MODEL

AREAL DEPLETION CURVE	Curve that defines the areal extent of the snow cover as a function of how much of the original snow cover remains. It also implicitly accounts for the reduction in the melt rate that occurs with a decrease in the areal extent of the snow cover.
DAYGM	Constant amount of melt that occurs at the snow-soil interface whenever snow is present.
MBASE	Base temperature for snowmelt computations during nonrain periods.
MFMAX	Maximum melt factor during nonrain periods; assumed to occur on June 21.
MFMIN	Minimum melt factor during nonrain periods; assumed to occur on December 21.
NMF	The maximum negative melt factor.
PLWHC	Percent (decimal) liquid water holding capacity; indicates the maximum amount of liquid water that can be held against gravity drainage in the snow cover.
PXTEMP	The temperature that delineates rain from snow.
SCF	A multiplying factor that adjusts precipitation data for gage catch deficiencies during periods of snowfall and implicitly accounts for net vapor transfer and interception losses. At a point, it also implicitly accounts for gains or losses from drifting.
SI	The mean areal water-equivalent above which there is always 100 percent areal snow cover.
TIPM	Antecedent temperature index parameter (range is $0.1 \leq TIPM \leq 1.0$).
UADJ	The average wind function during rain-on-snow periods.

Table D-2 STATES (DEFINITIONS) NWSRFS SNOWMELT MODEL

ATI	Antecedent Temperature Index; represents the temperature within the snow cover.
LAGRO	LAGRO and S together define the amount of excess liquid water in transit in the snowpack.
LIQW	The amount of liquid-water held against gravity drainage.
MAXWE	The maximum water-equivalent that has occurred over the area since snow began to accumulate.
NEGHS	Heat Deficit; the amount of heat that must be added to return the snow cover to an isothermal state at $0^{\circ}C$ with the same liquidwater content as when the heat deficit was previously zero.
S	S and LAGRO together define the amount of excess liquid water in transit in the snowpack.
*SB	The areal water equivalent just prior to the new snowfall.
*SBAESC	The areal extent of snow cover from the areal depletion curve just prior to the new snowfall.
*SBWS	The amount of water equivalent above which 100 percent areal snow cover temporarily exists.
WE	Water equivalent of the solid portion of the snowpack.

*These states are only used when there is a new snowfall on a basin with a partial snowcover.

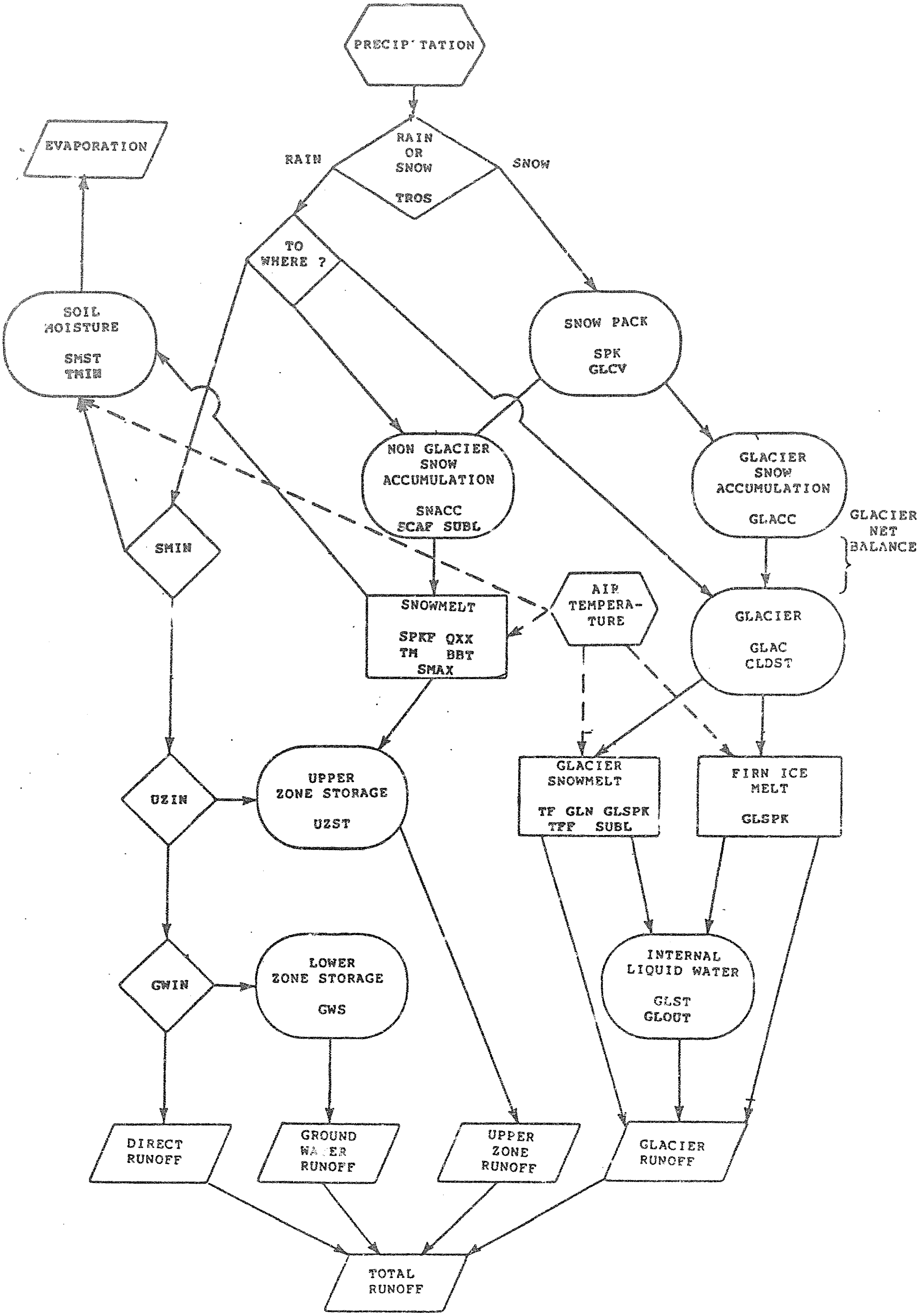


FIGURE D-2. HYMET MODEL SCHEMATIC DIAGRAM

HYDEX, April 1985

Table D-3 HYMET SIMULATION MODEL PARAMETERS

TROS	THRESHOLD TEMPERATURE FOR RAIN OR SNOW
TMIN	THRESHOLD TEMPERATURE FOR EVAPORATION
TMAX	THRESHOLD TEMPERATURE FOR SNOWMELT
SMIN	AMOUNT OF RAIN TO SOIL MOISTURE
SMAX	AMOUNT OF SNOWMELT TO SOIL MOISTURE
EFF	VARIATION IN MELT RATE DUE TO SUN ANGLE
TFF	VARIATION IN MELT RATE DUE TO RADIATION
QXX	SNOWMELT PRODUCED BY AIR TEMPERATURE
SPKF	DEPLETION OF SNOW COVERED AREA
SUBL	SUBLIMATION FROM SNOWPACK
UZIN	INPUT TO UPPER ZONE STORAGE
UZOUT	OUTPUT FROM UPPER ZONE STORAGE
GWIN	INPUT TO GROUNDWATER STORAGE
GWOUT	OUTPUT FROM GROUNDWATER STORAGE
GLCV	GLACIER COVER FRACTION
TF	GLACIER MELT DUE TO RADIATION
GLIN	INFLOW TO ENGLACIAL STORAGE
GLOUT	OUTFLOW FROM ENGLACIAL STORAGE
TFF	GLACIAL MELT DUE TO AIR TEMPERATURE
GLSPK	GLACIAL MELT FACTOR DUE TO ORIENTATION

Table D-4 HYMET SIMULATION MODEL STATES

SPK	SNOWPACK
SNACC	SNOW ACCUMULATION
GLAC	GLACIER MASS
SUMST	SOIL MOISTURE
UZST	UPPER ZONE STORAGE
GWS	GROUNDWATER STORAGE
GLST	ENGLACIAL STORAGE
CLDST	COLD STORAGE IN SNOWPACK
SCAF	SNOW COVERED AREA FRACTION
GBAL	GLACIER BALANCE
GLACC	GLACIER ACCUMULATION

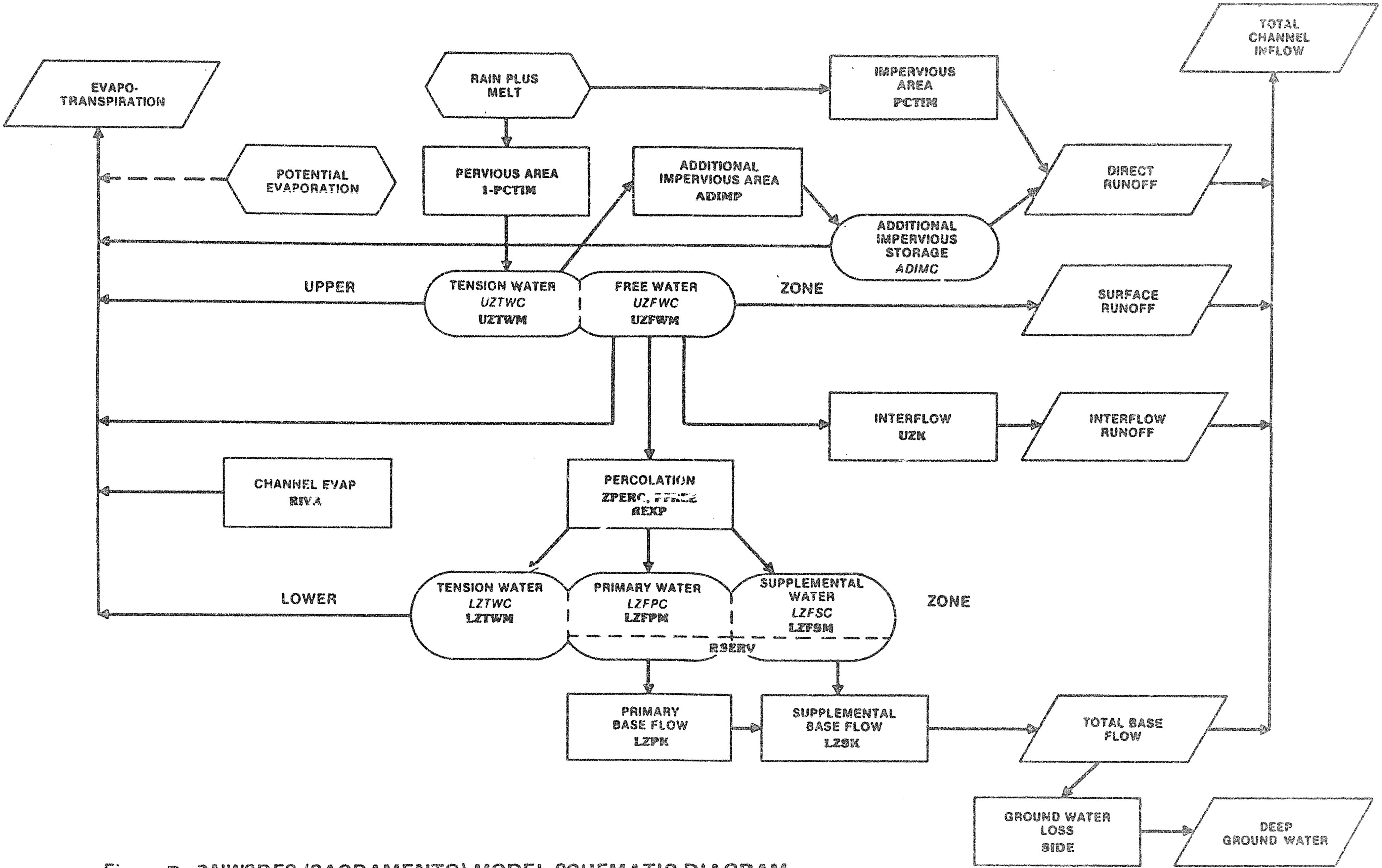


Figure D–3NWSRFS (SACRAMENTO) MODEL SCHEMATIC DIAGRAM

Table D-5 PARAMETERS (DEFINITIONS) NWSRFS MODEL

ADIMP	That fraction of the basin that becomes impervious as all tension water requirements are met.
LZFPM	Maximum capacity of lower zone primary free water storage.
LZPK	Lateral drainage rate of lower zone primary free water expressed as a fraction of contents per day.
LZFSM	Maximum capacity of lower zone supplemental free water storage.
LZSK	Lateral drainage rate of lower zone supplemental free water expressed as a fraction of contents per day.
LZTWM	Maximum capacity of lower zone tension water.
PCTIM	Fraction of impervious basin contiguous with stream channels.
PFREE	The percentage of percolation water that directly enters the lower zone free water without a prior claim by lower zone tension water.
RSERV	Fraction of lower zone free water not available for transpiration purposes (incapable of resupplying lower zone tension water).
REXP	An exponent determining the rate of change of the percolation rate as the lower zone deficiency ratio varies from 1 to 0 (1 = completely dry; 0 - lower zone storage completely full)
RIVA	Fraction of basin covered by riparian vegetation.
SIDE	The ratio of unobserved to observed baseflow.
UZFWM	Maximum capacity of upper zone free water.
UZK	Lateral drainage rate of upper zone free water expressed as a fraction of contents per day.
UZTWM	Maximum capacity upper zone tension water.
ZPERC	A fraction used to define the proportional increase in percolation from saturated-to-dry lower zone soil moisture conditions. This parameter, when used with other parameters, indicates the maximum percolation rate possible when upper zone storages are full and the lower zone soil moisture is 100 percent deficient.

Table D-6 STATES (DEFINITIONS) NWSRFS MODEL

ADIMC	Additional impervious area.
LZFPC	Lower zone free primary water storage.
LZFSC	Lower zone free supplemental water storage.
LZTWC	Lower zone tension water storage.
UZFWC	Upper zone free water storage.
UZTWC	Upper zone tension water storage.

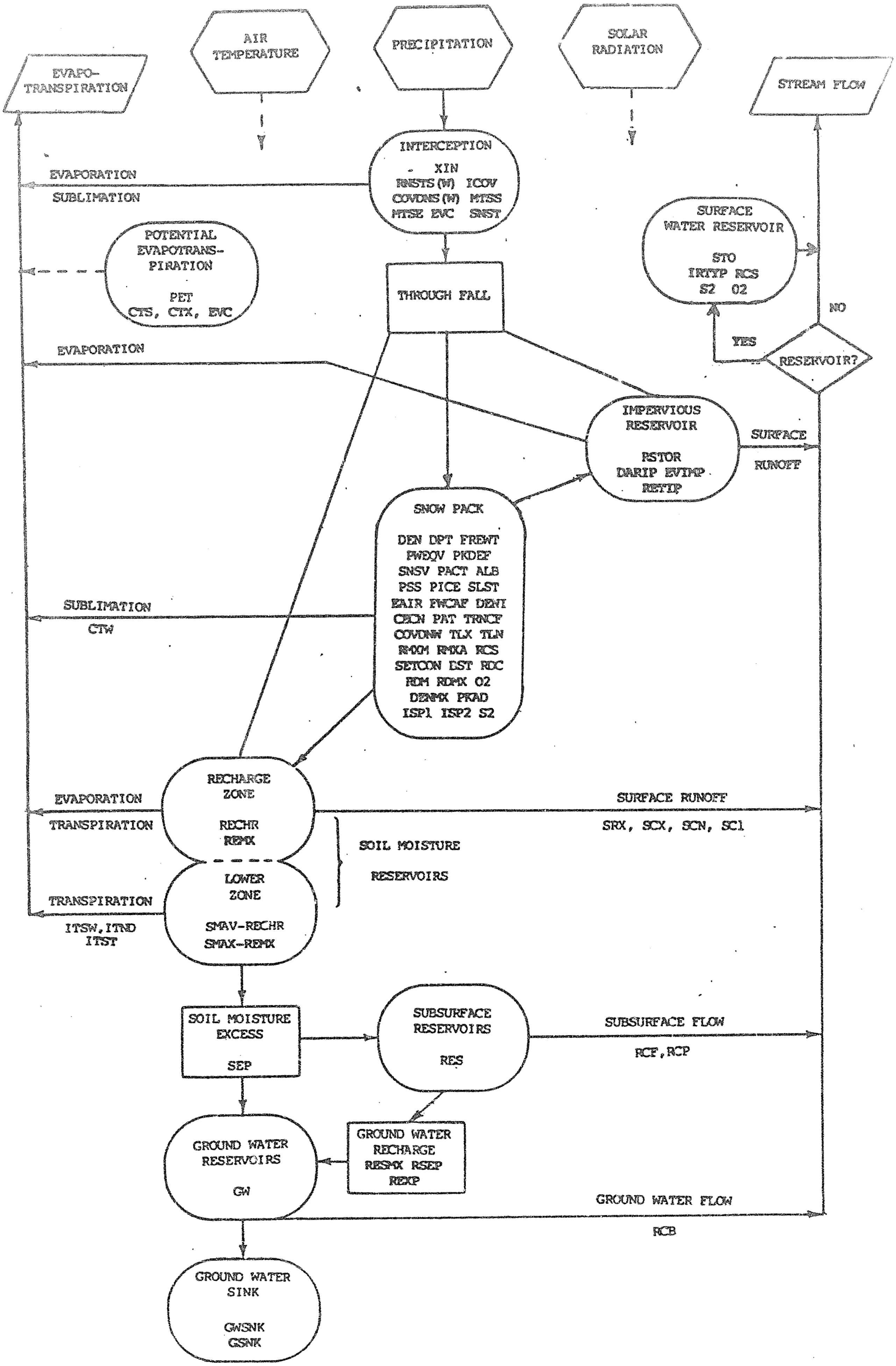


Figure D-4 PRMS MODEL SCHEMATIC DIAGRAM

TABLE D-7 PARAMETERS (DEFINITIONS) PRMS MODEL

BST	Temperature below which precipitation is snow and above which it is rain (degrees F or C).
CECN	Convection-Condensastion engery coefficient for months 1-12 (cal/degree above $0^{o}C$)
COVDNS	Summer cover density for major vegetation for each HRU (decimal percent)
COVDNW	Winter cover density for major vegetation for each HRU (decimal percent)
CTS	Air temperature coefficient for ET computation for months 1-12
CTX	Air temperature coefficient for ET computation for each HRU
DARIP	Impervious drainage area for each HRU (acres)
DENI	Initial density of new-fallen snow (decimal percent)
DENMX	Average maximum density of snow pack (decimal percent)
EAIR	Emissivity of air on days without precipitation
EVC	Evaporation pan coefficient for months 1-12
EVIMP	Evaporation loss from impervious area for each HRU (inches)
FWCAP	Free water holding capacity of snowpack (Decimal percent of snowpack water equivalent)
GSNK	Coefficient to compute seepage from each ground-water reservoir to a ground-water sink
ICOV	Vegetation cover type for each HRU (0= Bare, 1= Grasses, 2= Shurbs, 3= Trees)
IRTYP	Type of routing for each surface reservoir (8= Puls; 9= Linear)
ISP1	Julian date to start looking for spring snow melt stage
ISP2	Julian date to force snowpack to spring snow melt stage
ITNC	Month that transpiration ends for each HRU

RMXM	Proportion of rain in rain/snow event above which snow albedo is not reset for snowpack melt stage
RNSTS	Interception storage capacity of unit area of vegetation for rain during summer period, for each HRU (inches)
RNSTW	Interception storage capacity of unit area of vegetation for rain during winter period for each HRU (inches)
RSEP	Seepage rate from each subsurface reservoir to ground water reservoir (inches/day)
SCN	Minimum contributing area for surface runoff when ISSR1= 0; Coefficient in contributing area - soil moisture index relation when ISSR1= 1
SCX	Maximum possible contributing area for surface runoff as proportion of each HRU
SC1	Coefficient in surface runoff contributing area - soil moisture index relation
SEP	Seepage rate from soil moisture excess to each groundwater reservoir (inches/day)
SETCON	Snowpack settlement time constant
SMAX	Maximum available water holding capacity of soil profile for each HRU (inches)
SNST	Interception storage capacity of unit area of vegetation for snow, for each HRU (inches, water equivalent)
SRX	Maximum daily snowmelt infiltration capacity of soil profile at field capacity for each HRU (inches)
S2	Storage values in outflow/storage table for Puls routing (CFS days)
TLN	Lapse rate for minimum daily temperature for months 1-12 (degrees C or F)
TLX	Lapse rate for maximum daily air temperature for months 1-12 (degrees C or F)
TRNCF	Transmission coefficient for shortwave radiation through vegetation canopy for each HRU

ITST	Month to begin checking for start of transpiration for each HRU
ITSW	Tranpsiration switch for each HRU (0 = vegetation dormat; 1 = vegetation transpiring)
MTSE	Month that thunderstorm type events end
MTSS	Month that thunderstorm type events start
O2	Outflow-storage table values for Puls routing
PAT	Maximum air temperature, which when exceeded, forces precipitation to be all rain
PKAD	Adjusted snowpack water equivalent computed from observed snow course data
RCB	Routing coefficient for each groundwater reservoir
RCF	Linear routing coefficient for each subsurface reservoir
RCP	Non-linear routing coefficient for each subsurface reservoir
RCS	Surface storage reservoir linear routing coefficient for each reservoir
RDC	Y - Intercept for relation between temerature (X) and 1) degree day (Y) or 2) sky cover (Y) when MRDC= 1 or 2
RDM	Slope for relation between temperature (X) and 1) degree day (Y) or 2) sky cover (Y) when MRDC= 1 or 2
RDMX	Maximum percent of potential solar radiation (decimal)
REMX	Maximum value of RECHR for each HRU (inches)
RESMX	Coefficient for routing water from each subsurface reservoir to groundwater reservoir
RETIP	Maximum retention storage on impervious area for each HRU (inches)
REXP	Coefficient for routing water from each subsurface reservoir to groundwater reservoir
RMXA	Proportion of rain in rain/snow event above which snow albedo is not reset for snowpack accumulation stage

TABLE D-8 STATES (DEFINITIONS) PRMS MODEL

ALB	Computed ALBEDO for each Hydrologic Response Unit (HRU)
DEN	Density of snowpack on each HRU
DPT	Depth of snowpack on each HRU (inches)
FREWT	Free water content of snow on each HRU (inches)
GW	Storage in each ground-water reservoir (acre-inches)
GWSNK	Total seepage to ground water sink for each ground-water reservoir (acre-inches)
PACT	Snowpack temperature (Degrees C), each HRU
PET	Potential Evaporanspiration, computed by model (inches)
PICE	Portion of snowpack existing as ice on each HRU (inches)
PKDEF	Calories required to bring pack to isothermal state, each HRU
PSS	Accumulated sum of net precipitation beginning on the first day of snowpack formation
PWEQV	Water equivalent of snowpack on each HRU (Inches)
RECHR	Storage in upper part of soil profile where losses occur as evaporation and transpiration (inches)
RES	Storage in each subsurface reservoir (acre-inches)
RSTOR	Retention storage on imprevious area for each HRU (inches)
SLST	Number of days since last snowfall on each HRU
SMAV	Daily available water in soil profile for each HRU (inches)
SNSV	Depth of new snow on each HRU (inches)
STO	Initial storage in each surface reservoir (CFS-Days)
XIN	Interception for each HRU (inches)

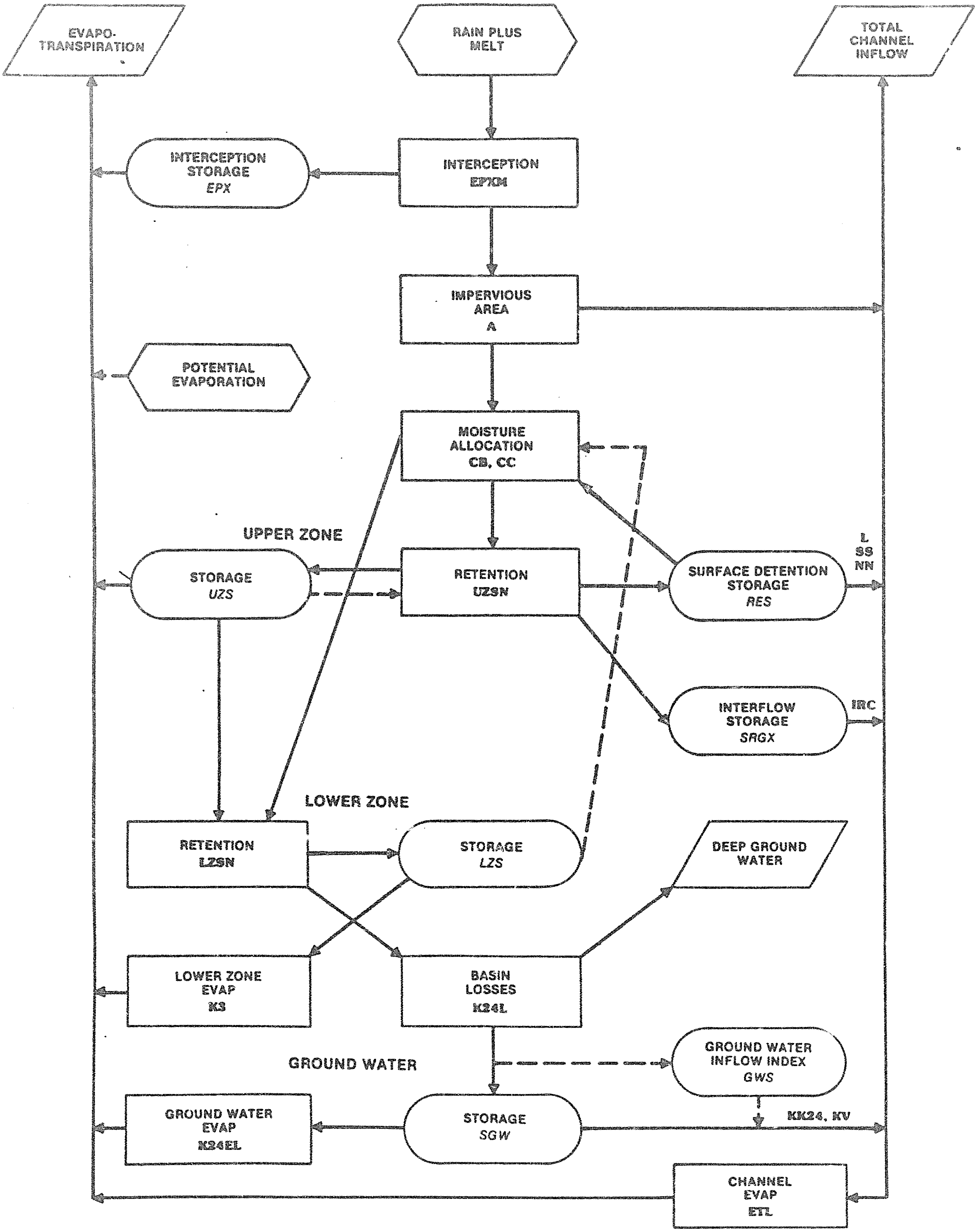


Figure D-5 STANFORD WATERSHED MODEL IV SCHEMATIC DIAGRAM

Table D-9 PARAMETERS (DEFINITIONS) STANFORD WATERSHED MODEL IV

A	Percent impervious area.
CB	Infiltration index.
CC	Interflow index, which determines the ratio of interflow to surface runoff.
EPXM	Maximum amount of interception storage.
ETL	Ratio of total stream and lake area to the total watershed area.
IRC	Daily interflow recession coefficient.
KK24	Daily groundwater recession coefficient.
KV	Weighting factor to allow variable groundwater recession rates.
K24EL	Percent of watershed stream surfaces and riparian vegetation.
K24L	Percent of groundwater recharge assigned to deep percolation.
K3	Evaporation loss index for the lower zone.
L	Overland flow length.
NN	Manning's "n" for overland flow.
LZSN	Nominal lower zone storage, an index to the magnitude of lower zone capacity.
UZSN	Nominal upper zone storage, an index to the magnitude of upper zone capacity.
SS	Overland flow slope.

Table D-10 STATES (DEFINITIONS) STANFORD WATERSHED MODEL IV

RES	Surface detention depth.
SRGX	Interflow storage.
SGW	Active groundwater storage.
GWS	Groundwater inflow index.
UZS	Upper zone storage.
LZS	Lower zone storage.
EPX	Interception storage.

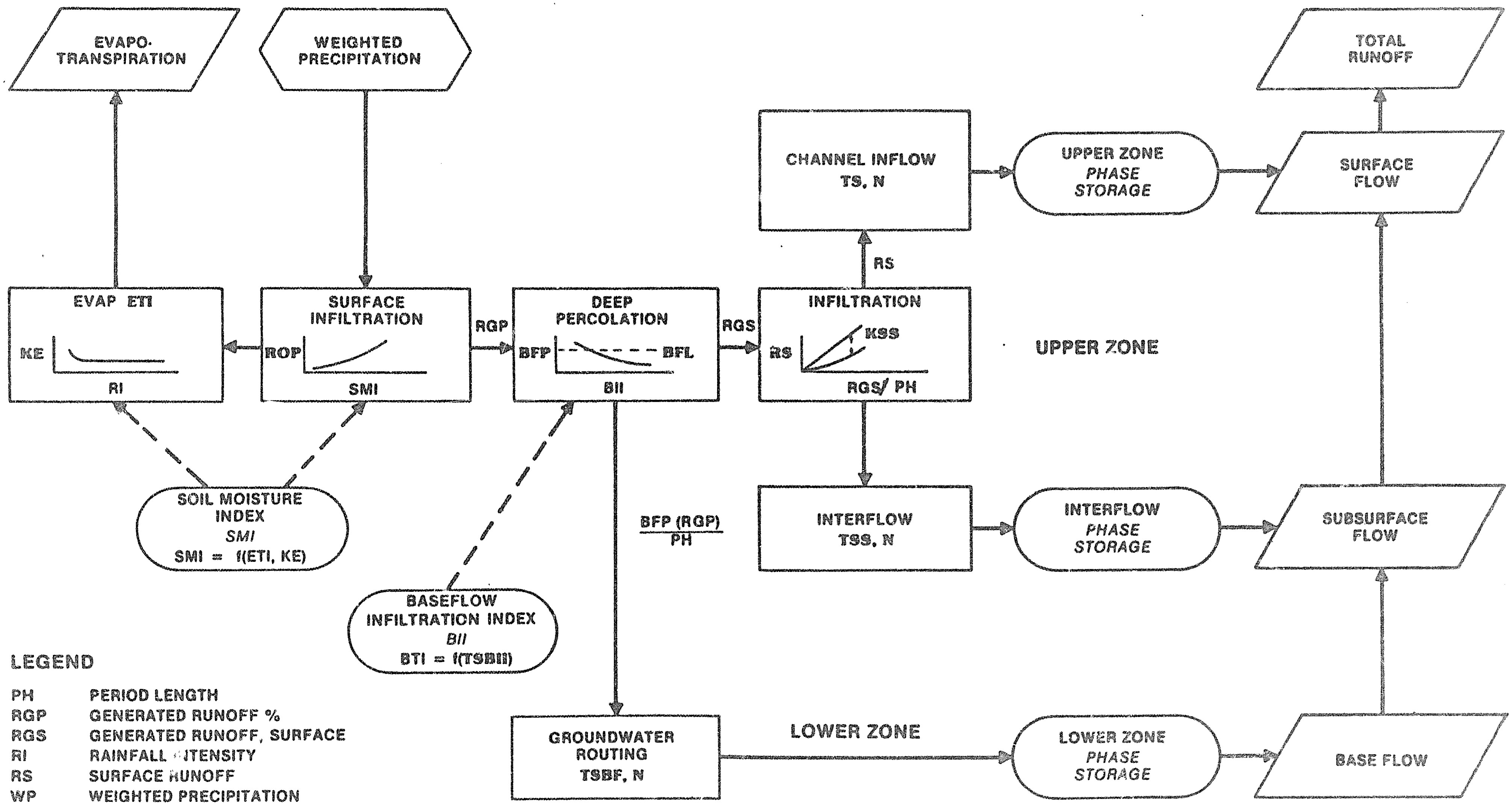


Figure D–6 SSARR MODEL SCHEMATIC DIAGRAM

Table D-11 PARAMETERS (DEFINITIONS) SSARR MODEL

BFL	Base flow infiltration limit.
BFP	Base flow, percent.
ETI	Evapotranspiration index.
KE	Percent effectiveness of ETI (function of rainfall intensity, RI).
KSS	Limiting subsurface infiltration rate.
N N N	Number of routing phases (surface flow) Number of routing phases (subsurface flow) Number of routing phases (baseflow).
ROP	Runoff percent.
RS	Surface runoff percent, function of RS/RGS table.
TS	Time of storage; surface flow.
TSS	Time of storage; subsurface flow (interflow).
TSBF	Time of storage; baseflow.

Table D-12 STATES (DEFINITIONS) SSARR MODEL

SMI	Soil Moisture Index.
BII	Base Flow Infiltration Index.
PHASE STORAGE	Phase storage (discharge or stage) for surface flow.
PHASE STORAGE	Phase storage (discharge) for subsurface flow.
PHASE STORAGE	Phase storage (discharge) for baseflow.

CONFIDENTIAL PRIVILEGED WORK
... IN ANTICIPATION
... RESTRICTED
DISTRIBUTION

APPENDIX E

R&M

R&M CONSULTANTS, INC.

March 8, 1985 R&M Nos. 452419 & 452443

Harza-Ebasco Susitna Joint Venture
711 "H" Street
Anchorage, Alaska 99501

Attention: Dr. Larry Gilbertson

Re: Review of Hydex Streamflow Forecasting Feasibility Draft Report

Dear Dr. Gilbertson:

We have examined Chapter 2 of Dr. Peck's draft report, dealing with data requirements for streamflow forecasting, and have several comments. These comments primarily address the major conclusions and recommendations in the report. A few additional recommendations are given for your consideration:

1. The objective of the hydrological-meteorological data-collection network will be to obtain input data for a streamflow forecasting system for the hydroelectric project. Other purposes of the data collection should be kept in mind, such as terrestrial game studies and impact monitoring. Many of the existing stations were established to support such efforts during the feasibility assessment. Future data requirements will be oriented toward project operation and monitoring.

2. An additional application currently being made of meteorological data is air quality modelling for the Watana site. Required parameters there are wind speed, wind direction, and standard deviation of the wind direction (known as sigma theta). The sigma theta has been measured since October 1984. At least one year of data is felt to be necessary for satisfactorily modelling of the air quality.

3. The network of existing and proposed met. (meteorological) stations in Figure 2 and Table 2 of the report recommends that data be collected at a total of 11 sites in the basin above Devil Canyon. Five stations would be at or near existing stations, one would be re-established at a former meteorological station site, and the other five would be new stations established at existing snow course sites. Factors which we consider important in selecting specific station locations at each site are:

   a. Ability for meteorological data from the site to be representative of a large area.

   b. Protection afforded by natural objects, such as trees.

LT1/151

c. Relationship to location where long-term data at the site have previously been collected.

d. Logistical advantages offered, such as accessibility by fixed-wing aircraft for winter maintenance and location on an efficient transportation route relative to the other stations to economize aircraft logistics.

e. Availability of and access by a local observer to provide "control" data in the event of a system failure.

4. The 11 total proposed sites, shown in Figure 2 of the report, fairly well cover the expanse of the upper basin. However, a few advantages may be offered by shifts in some of the locations. Considering each of the sites in numerical order, with report recommendations shown in parenthesis:

1) Susitna Glacier (retain existing site). Relocation to near a small lake, a few miles southwest of the existing site at the existing "Caribou" snow marker location would permit access by fixed-wing aircraft and still be exposed to much of the "glacier" weather conditions prevalent at the higher elevations.

2) Denali (relocate to protected site). This sounds favorable, likely utilizing the vegetated area to the north of the present site.

3) Tyone (reactivate). While this would be a good location, satisfactory data for the area could probably be obtained from sites 9, 10 and 11 around it.

4) Kosina (relocate to protected site). A more favorable location may be higher up in the Kosina Creek basin, where a greater percentage of the annual precipitation falls. As with site 1, above, a lake is present which would permit fixed-wing access.

5) Watana (rehabilitate Wyoming gage). Agree that this site's proximity to the base camp makes it favorable. Perhaps relocate to the north near a small lake and utilize a local observer.

6) Devil Canyon (consider small relocation). Rather than simply relocating to the trees near the present site, a complete move to near a lake on the other site of the Susitna River would offer fixed-wing access as well as natural wind protection. High Lake, which has a lodge and an airstrip, is a possible site, with potential for a local observer as well.

7) Monahan Flat (establish at SCS location). Agree.

8) Cathedral Lake (establish at snow course location in protected site if possible). Agree.

9) Clearwater Lake (establish at snow course location in protected site if possible). Agree.

10) Lake Louise (establish at snow course location in protected site if possible). Agree. Use local observer, if possible.

11) Square Lake (establish at snow course location in protected site is possible). Agree.

If site 3 is deemed superfluous, as discussed above, a new installation could be made in the upper Tsusena Creek basin. There is a fairly large "hole" in the data network in this area. The site would represent the upper elevations of the Tsusena and Deadman Creek watersheds and to some extent Watana Creek, each of which contributes to one of the two reservoirs. It is also close to the headwaters of Portage Creek, the largest tributary to the Middle Susitna River and an important salmon stream.

5. A few additional sites, besides the 11 discussed above, may offer advantages for other specific data-collection purposes. These are locations downstream of the project and would thus not be directly applicable to forecasting of streamflow into the reservoirs. The sites and suggested uses of the data are described below:

1) Middle Susitna River - Since mainstem Susitna flows in this reach, from Devil Canyon to Talkeetna, are of concern for fisheries habitat and spawning, knowledge of the meteorologic conditions influencing river inflow from below Devil Canyon Dam is important for forecasting and impact analysis. The existing station at Sherman could be continued, or a new station could be established at Gold Creek. Each site would offer shelter by surrounding trees. Sherman would offer an existing record which would be extended; Gold Creek would offer potential for a local observer.

2) Lower Susitna River - Temperature conditions in the lower basin are of concern because of their effect on river freeze-up and ice conditions. Some data have been collected for one season at Susitna River Mile 61. This station could be continued if desired.

6. Dr. Peck has noted that the important meteorological inputs for modelling and forecasting streamflow are precipitation, temperature, and wind speed. The one most important is precipitation, both summer and winter. The most efficient and economical hydro-meteorological system would consist of a series of weather stations at intervals throughout the watershed to record and ultimately transmit representative data to a central location. The system should provide the data for calibration and operation of the forecasting model, yet remain flexible enough to accommodate additional future requirements. By the time the hydroelectric project has become

operational, installations would most likely be transmitting real-time data to be utilized in the forecasting model to a central location.

7. The discussion of which parameters are necessary to measure at each site focused on precipitation, temperature, and wind speed, and minimized the importance of other data currently reported: wind direction, relative humidity, shortwave radiation, and longwave radiation. We feel also that these latter variables would not be critical for streamflow forecasting and could be dropped from the data-collection program except possibly for continued efforts during the summer at Watana. Relative humidity, in particular, currently poses great problems in assurance of reliable data. If not required, its omission would ease the data-reduction effort considerably. As noted, the radiation measurements are also difficult to obtain reliably, especially in the winter, and are not very applicable to streamflow forecasting models. Wind direction sensors have occasional winter problems, too, but the data would be useful for analyzing storm movements if it is not too difficult to continue the measurements. It is possible that measurement of temperature may be satisfactorily performed by recording only the daily maximum and minimum temperatures.

   Continued measurement of all the parameters could be desirable during the summer at Watana Camp to expand the data base for reservoir temperature modelling. Sensors could be more easily maintained on a daily basis once a camp is operated continuously.

8. Where installation of new equipment is planned for one or more sites, consideration should be given to installing mechanical stations (rather than the electronic digital instruments now in use). Advantages that could be offered include the following:

   - Lower initial cost. Since the stations record fewer parameters and are less technically sophisticated, they are less expensive.

   - Less expensive repairs. Sophisticated electronics in the existing stations are difficult to repair in the field.

   - Greater reliability.

   - No need for a special enclosure since artificial heat is not required. Existing stations do require a shelter and heat source.

   - An immediate visual record of the data provided on strip charts. This aids equipment troubleshooting at the site and can make data-reduction less costly, since the complete range of meteorologic analysis would not be required.

9. In consideration of the desire to improve reliability of the data record and reduce the amount of missing data, one of two approaches could be taken. The first would be to install a back-up system of sensors and recorder at each station, which would provide a partially

redundant record with the primary system. The data from the secondary would not need to be reduced unless a problem caused some of the primary data to be lost. Then only the data to replace the missing records would need to be obtained. Back-up equipment would consist of a thermograph to record continuous temperature and a precipitation can to permit measurement of accumulated precipitation.

The other alternative would be to install data-collection platforms at the station and telemeter the data for daily monitoring and review at the office. In this configuration, the redundant recorders would be useful but not necessary, but a commitment would have to be made to immediately maintain the field stations when data-collection or transmission problems are indicated.

10. The report recommendation to install data-collection platforms (DCP's) at data sites as soon as possible is very agreeable in concept. This would permit opportunity to get the system up and running before it is critically needed, would make real-time data available to benefit ongoing field operations, and would increase the reliability of the data-collection system. However, the ability to limit instrument down-time when problems are revealed via the telemetry depends on the ability to visit the site immediately. This is naturally subject to weather, daylight, and helicopter or other logistical considerations.

11. Along the same line as comment number 10, we do not agree with the report suggestion to remove on-site recorders after DCP's have been installed. Even with the telemetry, back-up recording systems are needed, especially if reliability of data-collection is a concern. Experience with data-collection in the Susitna and other remote Alaskan basins has shown that data can easily be lost from problems besides just sensor malfunctions. Losses can also occur due to malfunctions of the transmitter, receiver, or communication link or due to delays in access to the site caused by weather, daylight, or helicopter availability. Back-up data does not necessarily need to be reduced unless data gaps occur in the telemetry system.

12. Measurement of pan evaporation at Watana has been recommended in the report. These measurements have been collected at Watana since 1981. A pan anemometer, which aids in applying the data, has not been part of the installation but will be installed this season. Daily observations are recorded by hydrology staff or camp logistics personnel.

13. There are several statements in the report that snow surveys at existing weather stations are of no value. The reason the surveys were initiated, even though some of the areas are extremely windblown, was because game biologists were very interested in snow conditions in situ, i.e. , the snow depths that moose and caribou actually had to contend with in the open areas. Since regular visits are made to the sites, the data are very easily obtained. The statement is correct, however, in describing the windblown snow courses

as of little value to streamflow forecasting, so perhaps snow surveys could be performed in nearby protected areas as well.

14. As was mentioned above, retention of observers to record daily observations at selected sites would increase system reliability and provide data at times when the instrumentation goes down. Such information could even be transmitted by radio or telephone to a processing center if necessary. Observers would probably be available at the following sites:

(2) Denali (probably less than 100% of the year)
(5) Watana (as long as the camp is occupied)
(6) Devil Canyon (if moved to High Lake Lodge)
(10) Lake Louise

An additional alternative would be relocation of the Devil Canyon station to Gold Creek instead of to High Lake. Gold Creek is below both damsites but would represent Middle Susitna areas (in place of the existing Sherman station) and would offer reliable railroad personnel as observers.

15. Rough cost estimates have been developed for various instrumentation alternatives considered. These are listed below:

a. Approximate cost of continuing existing stations (including recommended improvements to each): $4,400 per station
$30,800 for 7 stations

Costs for reduction, review, handling, editing, and reporting of the electronic station data are estimated to be $1,230 per month per station, including labor and computer costs.

Reported data would include many of the same precipitation, temperature, and wind parameters currently reported (since the software already exists):

- Precipitation (hourly and daily totals)
- Temperature (daily min/max/average)
- Wind (daily resultant speed and direction, daily average speed, daily peak gust speed and direction, and daily prevailing direction. Wind roses could also continue to be prepared if desired. Wind sigma theta should continue to be measured at Watana, and reported when needed.)

The back-up data system would permit reporting of daily min/max/average temperatures and total accumulated precipitation since the last inspection.

The above estimate includes construction of new shelters, relocation where necessary, construction of Wyoming wind gages, and installation of a back-up data recorder at each site. Elimination of the back-up recorder would reduce the per-station cost approximately $1,200 ($8,400 for 7 stations).

The estimate does not include telemetry costs or helicopter costs for sling-loading to new sites.

These stations could be improved in turn, over several years if desired.

b. Approximate cost of acquiring mechanical weather stations:
$6,600 per station
$26,400 for 4 stations

Costs for reduction, review, handling, editing, and reporting of the mechanical station data are estimated to be $1,250 per month per station.

Reported data would include:

- Precipitation (daily total)
- Temperature (daily min/max/average)
- Wind (daily total wind run or daily average speed)

The back-up system would permit reporting of daily min/max/average temperatures and total accumulated precipitation since the last inspection.

The estimate includes purchase of mechanical instruments (precipitation, temperature, wind), purchase of a backup system to provide redundant measurements, installation of both systems, and construction of a Wyoming wind gage at each site. As above, elimination of the back-up system would reduce the per-station cost approximately $1,200 ($4,800 for 4 stations).

The estimate does not include telemetry costs or helicopter logistics for sling-loading to site.

c. Approximate cost of hiring local observer for daily observation:
$1,500 + $300/month
at each station

Costs for review, handling, and reporting of the observer data reports are estimated to be an additional $250 per month per station.

Reported data would include the same values listed above for the mechanical stations:

- Precipitation (daily total)

- Temperature (daily min/max/average)
- Wind (daily total wind run or daily average speed)

The estimate includes purchase of instruments (min/max thermometer, totalizing anemometer, and accumulating precipitation can), instrument shelter, Alter wind screen, and installation. Observers to be paid $10 per day.

16. Another consideration for measurement of precipitation at higher elevations, where greater amounts of precipitation fall, is installation of large-volume storage gages and recorders. The advantage of the larger site is that the danger of the gage overflowing and losing data during large rainstorms and snowstorms is reduced. The SCS currently operates one of these at the Monahan Flat site. The cost of installing additional storage gages is estimated to be approximately $5,000 per site, not including helicopter logistics. Additional installations would be beneficial at sites 1, 4, 8, and 11 in the list under comment 4, above, and at the Upper Tsusena site if established.

17. Operation of the 11-station network would increase field labor time and helicopter time during maintenance trips. The six existing stations can normally be maintained on a 1-2 day trip. A total of two to three days would probably be required to maintain the full 11 stations. Helicopter usage would be approximately four flight hours per day. The stations should continue to be inspected and maintained once per month to verify their proper operation. The logistics costs for maintenance trips would be slightly higher when Watana Camp is closed, since helicopter flights would originate and end in Talkeetna instead of at the camp.

18. An alternative logistics plan which should be considered in the network planning process is use of fixed-wing aircraft for access to the meteorologic stations. All stations recommended above for future station locations should be accessible by fixed-wing airplane most of the time, with the exception of the Upper Tsusena site suggested. For estimation purposes, using a helicopter cost of $320 per hour (Jet Ranger) and a fixed-wing cost of $200 per hour (Cessna 206), the following are approximate monthly costs for each alternative:

    1) Helicopter (2 days @ 6 hours per day = 12 hours per month)

    (12)(320) = $3,840/month

    2) Fixed-wing (2 days @ 6 hours per day = 12 hours per month, plus 1 hour from Watana Camp by helicopter)

    (12)(200) + (1)(320) = $2,720/month

19. As is emphasized in the report, data for streamflow forecasting will have to be available in a timely manner. This will best be accomplished by telemetry of the data from the stations, either by the telephone-repeater network or the GOES satellite system, and then incorporation into the data storage and modelling system, as Dr. Peck has discussed. The alternative selected depends primarily on other communication requirements of the project.

In summary, our recommendations at the present are:

1) To make sure field data needs of other environmental and engineering studies are considered and coordinated in design of the data-collection network. This would include terrestrial studies, air quality management, river ice monitoring, and fisheries monitoring, as well as the water supply forecasting.

2) Operate a total of eleven meteorological stations in the basin above the Devil Canyon damsite. Select sites in the vicinity of those proposed in the report in Figure 2 and Table 2, modified as discussed above in comments number 3 and 4.

3) Continue precipitation, temperature, wind speed, and wind direction measurements.

4) If not required for other purposes, measurement of relative humidity, solar radiation, and longwave radiation should be discontinued (with the possible exception of Watana).

5) The existing electronic digital recording meteorological stations should be maintained. There are seven recorders and associated sensors available for field use. The eighth unit also currently available should be retained as a spare. The field installations and shelters should be upgraded as described above.

6) Mechanical recording meteorological stations should be acquired and installed at four new sites to measure precipitation, temperature, and wind speed.

7) Hire local observers where possible to improve data reliability. This could be done at Denali, Watana, Devil Canyon and Lake Louise, and Gold Creek.

8) Install telemetry at one or more meteorologic stations to start development of the real-time data-collection system. Recorders should be retained at the stations even after installation of data-collection platforms.

9) Install back-up sensor and recorder systems to provide redundant measurements at stations which do not have either a local observer or a data-collection platform.

10) Continue snow surveys at existing weather stations but also make measurements in nearby protected areas to improve the data quality for forecasting and for development of isohyetal maps.

11) Consider conversion of the data-collection program to at least a partial fixed-wing aircraft network by selecting compatible station locations.

It is expected that these recommendations will be considered along with those of Dr. Peck in his report, and the data-collection programs for FY86 and beyond will be refined over the next several months. We look forward to working with you in the system planning effort. Thank you for the opportunity to comment on the report. If you have questions or comments on any of the above material, please do not hesitate to contact Jeff Coffin or myself.

Very truly yours,

R&M CONSULTANTS, INC.

Stephen Bredthauer

Stephen Bredthauer, P.E.
Susitna Hydrology Coordinator

SB:JHC;bje

cc: B.H. Wang
G. Gemperline