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HYDROELECTRIC PROJECT
FEDERAL ENERGY REGULATORY COMMISSION
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WATANA AND DEVIL CANYON SITES

PROBABLE MAXIMUM FLOOD

DRAFT REPORT

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SUSITNA JOINT VENTURE

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APPENDIX

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SUSITNA HYDROELECTRIC PROJECT

PROBABLE MAXIMUM FLOOD
FOR
WATANA AND DEVIL CANYON SITES

Report by

Harza-Ebasco Susitna Joint Venture

Prepared for

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SECTION 1

INTRODUCTION

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1.0 INTRODUCTION

This report presents the results of a study made to estimate probable maximum floods (PMFs) at two potential damsites, Watana and Devil Canyon, for the Susitna Hydroelectric Project. The derived PMFs will be used to select design floods for spillways and other related facilities at the two sites.

A PMF study for the two sites was conducted by the U.S. Army Corps of Engineers (COE) in 1975 (1)[1] and 1979 (2). The COE study was reviewed by Acres American Incorporated (ACRES) to determine its adequacy and it was concluded that a further anlaysis of PMF was required in view of its sensitivity to snowpack and probable maximum precipitation (PMP). The revised PMF analysis by ACRES, is presented in their feasibility report (3). This analysis, however, has the following weaknesses:

A. On PMP

1. Six storms which occurred within the Susitna River basin or its vicinity were used in the analysis. Transposition of storms from outside of the basin but within the region of similar hydrometeorological characteristics was not considered. This limits the size of samples used in the analysis.

2. An isohyetal map of a single storm (July 1980) was used as the basis for preparing isohyetal maps of the storms used in the analysis. The general practice is to use a mean seasonal or mean annual isohyetal pattern for this purpose.

3. It was assumed that the August 8-17, 1967 storm could occur in mid-June and was maximized to obtain the PMP. It was used to combine with an unlimited snow and ice water equivalent for glacial sub-basins and a very conservative snowpack in

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[1] Indicates reference at the end of text.

other sub-basins. This tends to yield an overly conservative estimate of PMF.

4. Probably, realizing the inaccuracy in the isohyetal pattern, the sub-basin average rainfalls were determined by Thiessen's method.

B. On Rainfall-Runoff Relation

1. The "Streamflow Synthesis and Reservoir Regulation (SSARR)" computer model (4) was used by ACRES to develop the PMF hydrographs at Watana and Devil Canyon sites. The model was calibrated for the Susitna basin (1, 2) using two flood events of August 1967 and June 1972 and verified using the flood of 1971. The model utilizes seven empirical relationships involving 12 parameters to define the rainfall-runoff relationships. A reliable estimation of the parameter values requires the calibration of the model for more flood events.

2. The overland and channel routing scheme (4) used in the model to define flood hydrographs at desired locations also needs to be ascertained from a number of flood events.

Because of the above weaknesses, the present study was undertaken to upgrade the ACRES study for a better estimation of PMF which can be confidently used for design purposes.

1.1 SCOPE OF THE STUDY

The study provides major refinements in the estimation of PMP and its areal and time distribution. Seasonal variability of PMP also is considered. Snowmelt criteria are provided to combine snowmelt with PMP during the snowmelt periods. Unit hydrographs are developed and refined through a calibration of the U.S. Army Corps of Engineers computer program, HEC-1 (5). The major work elements involved include:

1. Estimation of PMP
2. Selection of snowmelt criteria
3. Derivation of unit hydrographs
4. Reconstitution of historic floods
5. Derivation of PMF
6. Comparison of derived PMF with historic floods and 100-year flood, and
7. Comparison of derived PMF with previous estimates.

1.2 SETTING

1.2.1 The Basin

The drainage basin upstream of the Devil Canyon site is located approximately between latitude 62°05' and 63°40' North and longitude 146°10' and 149°30' West in South Central Alaska, approximately 140 miles north-northeast of Anchorage and 110 miles south-southwest of Fairbanks (Exhibit 1). The drainage areas upstream from the Devil Canyon and Watana damsites are about 5,810 and 5,180 square miles (mi^2) respectively. The proposed damsites are about 152 and 184 river miles upstream from the river's mouth at Cook Inlet.

The basin is geographically bounded by the Alaska Range to the north, the Talkeetna mountains to the west, the Wrangell mountains to the east and the Chugach mountains to the south. The topography is varied and includes rugged mountainous terrain, plateaus, broad river valleys and lakes. Mount McKinley is located on the northwest divide of the basin. Elevations in the basin range from approximately 1,000 feet above mean sea level (ft, msl) at Devil Canyon site to over 7,000 ft,msl near the head reaches of the Susitna River.

Three major glaciers - West Fork Susitna, East Fork Susitna and Maclaren, exist in the basin. The landscape consists of barren bedrock mountains, glacial till-covered plains and exposed bedrock cliffs in canyons and along streams. Soils are typical of those formed in cold, wet climates and have developed from glacial till and out-wash. They include the acidic, saturated, peaty soils of poorly drained areas, the acidic relatively infertile soils of the forest and gravels and sands along the river(6). The basin is generally underlain by discontinuous permafrost.

1.2.2 The River

The Susitna River originates in the East Fork and West Fork Susitna Glaciers at an altitude of about 7,800 ft,msl and travels a distance of about 318 miles before discharging into Cook Inlet. The head waters of the Susitna River and the major upper basin tributaries are characterized by broad, braided, gravel flood plains below the glaciers. Several glacierized streams exit from beneath the glaciers before they combine further downstream. The West Fork Susitna River joins the main river about 18 miles downstream from the Susitna Glaciers. Below this confluence, the river develops a split-channel configuration with numerous islands and is generally constrained by low bluffs for about 55 miles (6).

The Maclaren River draining the Maclaren Glacier and a few small lakes, and the non-glacial Tyone River draining Lake Louise and swampy lowlands of the South Eastern part of the basin, join the main river downstream of Denali (Exhibit 2). Below this confluence, the river flows west for about 96 miles through steep-walled canyons before reaching the mouth of Devil Canyon. The major tributaries entering this reach are: Black River, Goose Creek, Kosina Creek, Watana Creek and Tsusena Creek.

River gradients average about 14 feet per mile (ft/mi) in a 54-mile reach upstream of Watana, about 10.4 ft/mi from Watana to the entrance of Devil Canyon and about 31 ft/mi in a 12-mile reach between Devil Creek and the outlet of Devil Canyon (6).

The Susitna River is a typical natural glacial river with high turbid summer flow and low, clear winter flow. The river generally starts rising in early May. The high flows during July through September are associated with general frontal type or thunderstorm activities. The May through June flows are caused by snowmelt combined with rainfall. The average summer and winter flows at a few selected stream gaging stations are given in Table 1. Exhibit 2 shows the locations of the stream gaging stations. Exhibit 3 shows the general streamflow characteristics of the river (7). Recorded annual peak flows of the Susitna River at Gold Creek are shown on Exhibit 4.

The river flow rapidly decreases in November or December as the river freezes. The break-up generally occurs in early May.

The river carries a significant amount of suspended sediment during flood season. Glacial silt mostly contributes to higher concentration in summer.

1.2.3 Sub-basins

The drainage basin upstream of the Devil Canyon damsite was divided into ten sub-basins as shown on Exhibit 2. The boundaries of the sub-basins were selected at Watana damsite, at stream gaging stations upstream from Watana and downstream of major tributaries entering the main river. The purpose of the sub-division was:

1. To properly account for the areal variation of the PMP as indicated by the isohyetal pattern;

2. To differentiate between predominantly glacial area (sub-basins 8 and 10), swampy area with lakes (sub-basin 5) and other areas;

3. to have sub-basins of reasonable size for developing unit hydrographs; and

4. To account for storage effect of the main river channel.

1.3 CLIMATE

The climate of the Susitna River basin is typical of interior Alaska. The winters are long, summers are short and there is considerable variation in daylight between these seasons.

Mean annual precipitation is about 20 inches in most of the southeastern part, which increases to about 40 inches near Devil Canyon and to about 70 inches over the northeastern watershed divide near Susitna Glacier (Exhibit 5). The mean temperature ranges between about -5°F in winter and 55°F in summer. Table 2 gives mean monthly temperatures and precipitation at selected stations in the vicinity of the basin. Exhibit 6 shows the locations of the climatological stations.

1.4 HYDROMETEOROLOGICAL NETWORKS

1.4.1 Stream Gaging Stations

U.S. Geological Survey (USGS), Water Resources Division, Alaska is maintaining a number of stream gaging stations on the Susitna River and its major tributaries. The gaging stations selected to study rainfall-runoff characteristics of the basin and to develop unit hydrographs representative for the basin above Devil Canyon, are listed in Table 3 and shown on Exhibit 2.

R&M Consultant Incorporated (R&M), Alaska established a gaging station on the Susitna River at Watana as part of the investigation program for Susitna Hydroelectric Project. The data at this station are of short period and hence not used in this study. R&M also established a number of staff gages upstream from the Devil Canyon and Watana damsites for a short period to study hydraulic properties of the river.

1.4.2 Climatological Stations

U.S. National Weather Service (NWS) is maintaining a number of precipitation and temperature stations in the Susitna basin (Cook Inlet Climatic Sector) and its vicinity (Central and South Central Sectors). However, there is no station located in the Susitna basin upstream from the Devil Canyon damsite. The stations are located either along railroad and highway routes or places easily accessible by ground transportation. Some of these stations pertinent to the current study are shown on Exhibit 6.

R&M, as part of the investigation program for Susitna Hydroelectric Project, established seven climatological stations: Sherman, Devil Canyon, Watana, Kosina Creek, Tyone, Denali and Susitna Glacier during 1980-1981. These stations also are shown on Exhibit 6. The climatic elements observed at each station include: precipitation (daily and hourly), solar radiation, temperatures, dewpoints, wind velocity and direction and sunshine hours.

1.4.3 Snow Stations and Snow Courses

U.S. Soil Conservation Service (SCS) is maintaining a number of snow courses (see Table 4) within or in the vicinity of the Susitna basin. The stations are shown on Exhibit 6. The data for the first six stations are available for about 14 to 19 years (up to 1981) while the other stations have only two to six years of data.

The NWS Alaska Region also has some measurements of snow water equivalents at a number of stations within or in the vicinity of the Susitna basin but the data at the stations of interest have frequent discontinuities.

SECTION 2

GENERAL APPROACH

TABLES
EXHIBITS

2.0 GENERAL APPROACH

The PMFs for the two damsites are derived by estimating the PMP through a hydrometeorological analysis and applying the PMP to the unit hydrographs. This involved primarily estimation of PMP by transposition and moisture maximization of major historic storms, estimation of snowmelt based on snow course and meteorological data, estimation of infiltration rates based on soil type, vegetative cover and permafrost, derivation of unit hydrographs based on recorded rainfall and flood data, convolution of rainfall excess increments and unit hydrographs, routing of sub-basin flood hydrographs through the channel system and estimation of baseflow.

For the purpose of this study, the Susitna River basin above Devil Canyon was divided into ten sub-basins as discussed under "Sub-basins". In the following discussions, the basins upstream of the Watana and Devil Canyon damsites are referred to as "Watana Basin" and "Devil Canyon Basin", respectively. When both basins are involved, they are referred to as "the Basins". Exhibit 7 shows the general topography of the Basins.

The PMP estimates were derived based on transposition and moisture maximization of the Chena storm of August 12-14, 1967 for a duration of 72 hours. Two storms could occur in sequence within a much longer period to result in a larger total rainfall. While such a sequence may be critical for a larger basin, the duration of 72 hours was considered to be sufficiently long for the Basins under study.

A depth-duration relationship was developed for the 72-hour PMP to provide maximum depths for shorter durations. A "bell-shaped" distribution of PMP increments was adopted for sequential maximization. Seasonal variation of PMP also was estimated.

Estimation of snowmelt was also necessary to determine the most critical combination of PMP during the melting period and the snowmelt. In the regions of high latitudes, such a combination in later spring or early summer may cause a more severe flood than the all-season PMP (greatest rain of any season, likely to occur in July-August) alone. Therefore, criteria were developed for snowmelt computations. These criteria included: sequences of critical air temperatures, dewpoint temperatures (indices to the air moisture content), winds and solar radiation. Values of those parameters were computed for the duration of the PMP storm as well as for critical days prior to and after the PMP. In addition, the most severe snowpack that can be possible before the PMP storm was estimated.

A unit hydrograph was derived for each sub-basin using the dimensionless graph-lag curve techniques. Infiltration rates were initially estimated for each sub-basin using information on soil types, vegetative cover and permafrost. These rates were refined by simulating historic flood events recorded at the stream gaging stations on the Susitna River upstream from and at Gold Creek. The simulation was performed by using the HEC-1 computer program (5).

The HEC-1 computer program (5) was also used to derive the PMF at Watana and Devil Canyon sites resulting from the PMP.

For comparison with the flood resulting from July-August PMP, floods also were derived using mid-May and mid-June PMP in combination with a critical snowmelt prior to, during and after the PMP. The most severe floods were adopted as the PMFs for the Basins.

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SECTION 3

PROBABLE MAXIMUM PRECIPITATION

3.0 PROBABLE MAXIMUM PRECIPITATION

PMP is defined as "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year" (8). A recent NWS publication (9) gives a slightly modified version of this definition by substituting the words "over a given size storm area at a particular geographic location" for the words "over a particular drainage area." This modification, which has been agreed to by the COE and the U.S. Bureau of Reclamation (BUREC), is based on the consideration that a storm isohyetal pattern cannot coincide exactly with the shape of a basin. There are as yet some unknowns with regard to meteorological parameters that are important to rainfalls. It is also uncertain how these parameters interact to cause extreme situations. Because of these short comings it is customary to refer to PMP values as estimates.

3.1 ESTIMATION OF PMP

3.1.1 Methods of Estimation

For the relatively flat regions typified by much of the U.S. east of the 105th meridian, estimation of PMP has become quite standardized. First, major rains of record are thoroughly analyzed. Then the pertinent ones for a particular region of concern are transposed to the region and adjusted for possibly greater moisture than was available in the original storms. Smooth curves enveloping these storm rainfall depths for various durations, area sizes and seasons are then constructed to give generalized estimates of PMP which have quite well stood the test of time. For the western states, the effects of mountains on rainfall magnitude and distribution greatly reduces the confidence in transposing storms. Therefore, an orographic precipitation computation model or adjustment of non-orographic PMP by various techniques is most commonly used. Details of such procedures may be found in the series of reports published by the NWS (10). They also can be found in a report published by World Meteorological Organization (11).

For the Basins, the topographic features (Exhibit 7) are important in setting the level of PMP. This makes it difficult to transpose storms from other regions. In spite of the difficulties, storms were transposed to the Basins to estimate the PMP because experience has shown that unless this is done the PMP estimate will not stand the test of time. In other words, the storm sample over any particular location is generally insufficient for a reliable PMP analysis. An additional problem for Alaska is that relatively few rainfall observations are available for high elevations. The problem of estimating how much rain fell in the mountains during severe storms at low elevations adds additional subjectivity to the PMP estimation.

3.1.2 Extreme Rainstorms

The greatest areal rainfall of record in the general region of the Basins occurred on August 12-14, 1967. It centered (as far as is known) on the Chena River, a tributary of the Tanana River, extending east of Fairbanks. An isohyetal map analyzed by the NWS (12) for the 3-day period is shown on Exhibit 8. All available rainfall catches, including several unofficial values obtained from a survey of the region soon after the storm, are also shown. The two greatest depths are an official 8.1 inches at Clear Airport and an unofficial 8.5 inches to the north of the Chena River.

Considerable analysis of the data, including streamflow runoff particularly for the tributaries of the Tanana, by the NWS resulted in the estimated rainfall depths in the mountains of up to 11 inches as shown on Exhibit 8. The streamflow measurements provided rainfall estimates for some tributaries where no rainfall measurements were available.

The heaviest rainfall centers were located on southwest facing slopes of the mountain to the north of the Tanana River where inflowing moist air is lifted and rainfall intensified. Rainfall depths observed during the 3-day period, within or in the vicinity of the Susitna basin reached 4.5 inches at McKinley Park and 4.1 inches at Trims Camp. There is little doubt that somewhat greater depths occurred on the nearby ridges as indicated on the map (Exhibit 8). However, they most likely are less than the depths to the north of the Alaskan Range which bounds the Susitna drainage. This range rises up to above 6000 feet to the south of the "Chena" rainfall centers.

The meteorological features associated with this extreme storm rainfall have been studied in some detail by E.D. Diemer of the U.S. Weather Bureau. His work was incorporated in a U.S. Geological Survey Water Supply paper (13), and is attached to this study as Appendix A. Some of the outstanding broad scale weather features of the storm were:

1. Abnormally high pressure in the Gulf of Alaska, which was helpful in setting up a strong pressure gradient that induced large quantities of moisture from the Pacific Southwest of Alaska into the low elevation "corridor" extending from about the mouth of the Yukon River to the extreme rainfall location;

2. An arctic weather front in a pressure trough at approximately latitude 65°N and dipping down to the Bering Sea; and

3. A series of low pressure centers, including that associated with typhoon "Hope", moving along the Arctic front; Typhoon Hope was responsible for bringing much moisture into the system and itself may have been responsible for the most extreme rain on August 12.

The series of low pressures and associated rainfall persisted from about August 8 to August 15, but exceptionally heavy precipitation occurred primarily on August 12.

In a PMP study for the Yukon River Basin (14), it was found that an extreme rainfall with a measured rainfall of over 5 inches occurred near Holy Cross on September 10-12, 1915. This storm had many features similar to those of the Chena Storm. A high pressure prevailed in the Gulf of Alaska and a low pressure center in the Bering Sea, with an associated cold front extending to the south, quickly moved into the central portion of Alaska. Holy Cross is located near the center of the low elevation corridor along which moisture through greater depth can extend into Central Alaska. When this is accompanied by other necessary atmospheric features, extreme rainfalls can occur. The 5 inches at Holy Cross included 3 inches in 3 hours on September 12. An isohyetal map of the storm is given in Figure 8-5 of the Yukon River Basin study (14).

Efforts to find greater storms on the Susitna basin itself, led to the August 23-25, 1955 storm centered at Talkeetna where 4.66 inches of rain was measured. No measurements are available within the Basins. However, with 2.27 inches at Summit near the northern divide, there could have been considerable rain in the Basins.

3.1.3 PMP Estimation

The foregoing discussion clearly points to the Chena storm of August 12-14, 1967 as being the most extreme known in the general vicinity of the Basins. Through transposition and adjustment, it constituted the basis for the current PMP estimates.

In numerous PMP studies a base rainfall index is used to transpose a storm from one mountainous location to another. A mean seasonal or mean annual precipitation (MAP) map is often selected as the index. Some studies, however, have used a rainfall frequency map such as that for 100-year, 24-hour rainfall. The principle behind the use of such an index is that it more nearly reflects the orographic effects on extreme rainfalls. A mean precipitation map can be the result of many "run of the mill" rains and, therefore, is not necessarily a good measure of extreme rainfall.

The basic procedure in adjusting and transposing storms using an index, is to multiply the observed rainfall by the ratio of the index in the transposed location to that where the rainfall occurred.

A study (15) by the Soil Conservation Services (SCS) gives a detailed MAP map (Exhibit 5) for the Susitna River basin. The map was based on streamflow and snow course data as well as all recorded rainfall data. Unfortunately, such an analysis is not available for the Chena River basin and its vicinity where the Chena storm of 1967 occurred.

A study by the NWS (16) gives rainfall frequency maps covering Alaska. However, since they are based on only a few and low-elevation rainfalls, they cannot be used with confidence in a PMP estimate.

Because a reliable MAP map is not available for the Chena basin and reliable rainfall-frequency maps are not available for both the Chena and Susitna basins, the Basins' terrain was analyzed instead to transpose and adjust the storms. This essentially involved the estimation of rainfall that could have occurred in the Basins rather than in the Chena basin, if the storm tracks and other meteorological features were optimum to the Susitna basin.

The Basins are surrounded by higher mountains, the Alaska range to the north, the Talkeetna mountains to the west, the Chugach mountains to the south and Wrangell mountains to the east. The lowest passes (down to about 2,000 ft,msl) for atmospheric moisture inflow are in the Talkeetna mountains. The NWS study (16) includes a map of Alaska, showing generalized elevations (see Exhibit 9) that are barriers to moisture inflow.

The barrier to moisture inflow for the entire Susitna basin averages 3,000 feet. The barrier to moisture inflow for the Chena basin where the 1967 storm centered is estimated to be about 1000 ft,msl.

The adjustment for a 3000 feet barrier was based on the atmospheric moisture derived from the maximum 1000-mb, 12-hour persisting dewpoint of 61°F, assuming a saturated atmosphere with a pseudo-adiabatic lapse rate. The temperature of 61°F was taken from the regionally and seasonally smoothed 12-hour persisting dewpoint maps covering Alaska (17) for the month of July, for a location some distance towards the optimum moisture source for the Basins. The resulting adjustment is 0.79 as computed in Table 5.

Additional adjustment was made for maximum atmospheric moisture (moisture maximization). The dewpoint representative of the storm moisture and the maximum dewpoint (both measured near McGrath, Exhibit 1) are 55°F and 61°F, respectively. This gives moisture maximization adjustments of 1.36 which agrees with the one used by the NWS (14). The combined adjustment to the Chena storm is, therefore, 1.07 (0.79 x 1.36).

The Chena storm isohyetal pattern was located and oriented in the Basins as shown on Exhibit 10. Both the 10- and 11-inch centers are set in the regimes of highest MAP in the Susitna basin (see Exhibit 5).

The average rainfall depths over Watana and Devil Canyon Basins, based on Exhibit 10, are 6.4 and 6.7 inches respectively. Multiplying these by the combined moisture maximization and barrier reduction factor of 1.07, the estimated 72-hour PMP of the two Basins are 6.8 and 7.2 inches respectively.

3.2 TIME DISTRIBUTION OF PMP

The time distribution of the 72-hour PMP giving maximum depths for shorter durations was based partially on experience with extreme rains in other regions. This was necessary because hourly rainfall for the Chena storm were not available.

In relatively flat regions, the magnitudes of 6/24-hour and 24/72-hour ratios of extreme rainfalls are related to rain area size; the smaller the area, the larger are the ratios. This relationship plus rainfall experience in the mountainous regions of the lower 49 states led to the adoption of rain ratios of 0.46 to 0.52 for 6/24-hour and 0.54 to 0.60 for 24/72-hour PMP for several basin sizes in the Tanana River Study (12). The ratios for the sizes of the Basins are 0.50 for 6/24-hour and 0.60 for 24/72-hour precipitation. During the August 12-14 storm, 12 rainfall stations in the Chena area recorded over 3 inches of rainfall. The recorded data indicated 24/72-hour rainfall ratios of 0.41 to 0.75. The average ratio is 0.57 compared to the adopted ratio of 0.60.

Applying the above selected ratios and fitting a smooth curve to the resulting three PMP values, the 6-hour incremental PMP values were obtained as listed in Table 6. The values are expressed in percent of 72-hour PMP as well as in inches.

A "bell shaped" distribution of the PMP increments (greatest value in the center of the storm period with next smaller values alternately on either side) was adopted. This, in general, agrees with the time distribution of rain in the Chena storm.

3.3 CHECKS ON THE PMP ESTIMATES

Some checks on the general level of PMP for the Basins are in order.

In the Yukon Report (14), the greatest depths of non-orographic rainfall found for the non-coastal regions of Alaska came from the September 10-12, 1915, 3-day storm centered at Holy Cross. All rainfall depths reported were at low-level valley stations. For the sizes of the drainage areas above the Watana and Devil Canyon, the moisture maximized rainfall for this storm is 6.4 inches. This value is somewhat greater than the estimated non-orographic component of 5.9 inches (also moisture maximized) for the August 12-14, 1967 storm (12).

The following adjustments were made to the 6.4 inches rainfall:

1. Adjusted it for a 3000 feet barrier. This resulted in 4.5 inches, (6.4 x 0.7); and

2. Augmented it for orographic effects in the Basins. This was based on a relationship between 3-day PMP and elevation that was developed for the Yukon Report (14, Fig. 2-9). Based on this relationship and the area versus elevation curve for Devil Canyon Basin, the non-orographic rainfall was augmented to have an areal average depth of 5.0 inches for a 3-day period. This is considerably smaller than the recommended PMP value of 7.2 inches for the basin.

Another comparison was made by adjusting the low elevation non-orographic rainfall by using a relationship of PMP to MAP for the west facing slopes of the Sierra Nevada in California. A reasonably high correlation exists between these two parameters (see Exhibit 11). Table 7 shows the computations to obtain orographic rainfall for the basin above Watana. Column (2) is taken from Exhibit 11 for the MAP bands in Column (1). Column (3) shows the PMP for each MAP band expressed in percent of PMP for the MAP band of smaller than 20 inches. The non-orographic rainfall of 4.5 inches based on the September 1915 storm adjusted for barrier effects corresponds to an MAP of 20 inches in the atana Basin. Using this base value and the percentages in Column (3), the corresponding value for each MAP band is calculated in Column (4). Column (5) shows the percent of area in each band and Column (6) shows the weighted depths. The resulting rainfall depth for Watana Basin is 5.4 inches. Similar computations give 5.3 inches for the basin above Devil Canyon which is quite similar to the 5.0 inches obtained, using the 3-day PMP vs elevation relationship.

A check on whether the PMP values are too high is based on desirable consistency from location to location. Consistency in itself does not lead necessarily to the best estimate of PMP. However, when over ten times the amount of effort is put into estimates for nearby areas, there is a good reason to desire consistency with such estimates. Furthermore, such consistency is a way of taking into account the thoughts of other experts having somewhat different philosophies on acceptable levels of PMP. With this in mind, the estimated PMP values were compared with those derived for the Tanana River basin by the NWS (12). That study was made for three drainage areas of 317, 1380, and 19,000 mi^2, all well exposed to the southwest corridor of moisture inflow with relatively low barriers. Part of these drainages was in the area of extreme rainfall during the Chena storm of August 12-14, 1967. The 6-, 24- and 72-hour PMP depths for these drainages, when plotted against area on semi-log paper, could be connected by a reasonably smooth depth-area curve. This indicates a consistency among the PMP estimates. The PMP values from the current study (6-, 24- and 72-hours) are well enveloped by the smooth curves of the Tanana basin. This is as it should be because the upwind barriers which practically surround the Basins, reduce moisture inflow to the Basins. At the least, from this comparison, we can say that the estimates are not unreasonably high.

Other checks, such as comparisons of ratios of PMP to 100-year maximum rainfalls would be desirable. Unfortunately, as mentioned previously, reliable estimates of 100-year rainfall covering all the region of concern are not available.

3.4 ANALYSIS OF OBSERVED STORM DEPTHS IN SUSITNA BASIN

As discussed earlier it is apparent that the rainfall of the Chena storm (August 12-14, 1967) in the Susitna basin was less than that on the slopes north of the Alaska range. However, it may be of interest to make an estimate of the rainfall on the Susitna basin making use of the detailed available MAP for the basin (15). The steps taken to make this estimate by using isopercental maps, are described below:

1. Plot the storm rainfalls for all stations in and surrounding the Basins;
2. Express these rainfall amounts as a percent of the station MAP;
3. Prepare isopercental map based on the percents obtained in Step 2 above; and

4. Multiply percents obtained from the isopercental map with MAP at the corresponding points to prepare the storm isohyetal map or calculate the average storm rainfall depth.

The reliability of the estimated areal pattern and magnitude of storm rainfall is dependent on the degree to which the patterns of major storm rainfalls are similar to the pattern of MAP. It has been shown (18) that the pattern are quite similar in strong orographic regions like the Sierra Nevadas of California where a relativley few winter storms contribute largely to the MAP. In other orographic regions, such similarity may or may not exist depending on dominant rainfall patterns.

The analysis using the isopercental techniques gives areal rainfall of 2 to 3 inches for the Basins during the August 1967 storm (Exhibit 12). When this is multiplied by the moisture maximization factor of 1.36, the resulting rainfall is consider ably smaller than that obtained by transposing and adjusting the portion of the 1967 storm near Chena to the Basins.

The August 23-25, 1955 storm gave 4.66 inches of rainfall at Talkeetna. This is the second greatest 3-day rainfall found close to the Basins. In the same manner as just described for the August, 1967 storm, the average rainfall over the Susitna basin was determined for this storm. The estimated average depth is also between 2 and 3 inches. Exhibit 13 shows the analysis followed to reach this estimate.

3.5 SEASONAL VARIATION OF PMP

One index to the seasonal variation of PMP is the variation from month to month of greatest precipitation observed at stations located within or in the vicinity of the Basins. The longer the period of record, the more stable such a record and the better the index. Table 8 shows the stations used and the resulting average seasonal variation of maximum one-day precipitation. All stations had their maximum values in June or July with one exception; Alpine where the maximum occurred in March.

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Another index to seasonal variation is the maximum available moisture in the Basins based on the maximum 12-hour persisting dewpoints (17). These values are shown in Table 9 for mid-month from March through August.

Yet another index is maximum monthly observed precipitation at stations of long record. The stations used in this comparison were the same as those used for maximum one-day precipitation (see Table 10).

Exhibit 14 shows the above described data along with the adopted seasonal variation. The adopted mid-April, mid-May and mid-June values are 53, 73 and 93 percent respectively, of the all-season PMP.

3.6 SUB-BASIN RAINFALL

Average rainfall over each sub-basin resulting from the 72-hour PMP was determined by planimetering the areas between isohyets shown on Exhibit 10, averaging over the area of the sub-basin and multiplying by the combined moisture maximization and barrier reduction factor of 1.07. The smoothed depth-duration curve (values expressed as percent of 72-hour PMP), discussed under "Time Distribution of PMP" (Exhibit 15) was used to derive 3-hour incremental percentages. These percentages were arranged sequentially as discussed under "Time Distribution of PMP". The 3-hour duration was selected based on the lag times for the sub-basins (see section entitled "Unit Hydrographs"). Table 11 shows the resulting 3-hour rainfall increments for each sub-basin.

SECTION 4

SNOWMELT

TABLES

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4.0 SNOWMELT

Based on the sizes of Watana and Devil Canyon Basins and other hydrologic characteristics, the snowmelt computations were considered necessary for the months of May and June. The combined snowmelt and rainfall was computed for a 3-day period assuming the PMP to begin on May 16 and on June 16. Snowmelt was also computed for the periods prior to and after the 3-day period.

4.1 MAXIMUM SNOW WATER EQUIVALENTS

The 100-year maximum snow water equivalents were considered to be a conservative estimate of available snow for melt in combination with the PMPs in mid-May and mid-June. These were estimated based on available snow course data and adjusted for higher elevations using the factors developed by NWS in HMR 42 (14).

The snow survey stations within or in the vicinity of the Susitna River basin are listed in Table 4. The data for the stations vary from 2 to 19 years.

The maximum snow water equivalents on all courses were measured either on April 1 or May 1. However, the values on the two dates were not significantly different. Therefore, the maximum water equivalents were assumed to occur on May 1.

Frequency analyses were made to derive 100-year maximum water equivalents on snow courses with 14 to 19 years of data (first six stations in Table 4). These values ranged between 6.0 to 12.9 inches. A 95 percent one-sided upper confidence limit was computed because 14 to 19 years of data are not sufficiently long to provide a reliable estimate of 100-year water equivalents. The stations from which data were available are also too few for the relatively large Basins. The values with the confidence limit ranged between 7.4 to 18.1 inches. The altitude of the five stations varies between 2,270 and 3,100 feet with the sixth station at 4,160 feet. The average of the six stations, about 14.0 inches, was considered representative for elevation between 2,000 and 3,000 feet.

4.1.1 Variation of Snowpack With Elevation

In the absence of high-elevation precipitation records in the Susitna River basin, the variation of snowpack with elevation developed by NWS for the Yukon River Basin (HMR 42, Table 24) was adopted. The average value of 14.0 inches, representative for 2,000 to 3,000 ft elevation zone, was adjusted by the factors given in HMR 42 (14). The estimated water equivalents thus derived are given in Table 12 for elevations between 1,000 to 9,000 ft.

4.1.2 Beginning Date of Melt

May 12 was used as the date of beginning of snowmelt for the 3-day PMP starting on May 16. This date was selected based on trials to have a combination of snowmelt and rainfall that would produce maximum flood with the adopted temperature sequences (see the sub-section entitled "Temperatures").

For the PMP starting on June 16, the date of beginning of snowmelt was taken as May 15. However, the temperature sequence was selected such that minimum snowmelt occurred between May 15 and June 11 (see the sub-section entitled "Temperatures"). This will allow maximum remaining snow for melt immediately prior to and during the PMP.

4.2 WINDS

Wind data are needed for various elevations in the snowmelt computation. Because upper air wind observations are not available in the Susitna basin, the 100-year maximum winds for Fairbanks were adopted for this study. The 100-year Fairbanks winds were determined by the NWS (14) by computing free air 100-year wind speed adjusted to 24-hour duration for the 950-, 850-, 800- and 700-mb levels (corresponding approximately to 2000, 5000, 7000 and 10,000 ft,msl). Fifteen years of data was used in the computation. Winds accompanied by sub-freezing temperatures (at the level being considered) were excluded from the analysis. A comparison of the resulting 100-year values with maximum winds during the Chena Storm of August 12-14, 1967 at Fairbanks, indicated the former values exceeded the latter by 7 to 19 percent depending on the level.

The free air 24-hour wind speeds were then adjusted to anemometer level (usually about 40 feet above the ground surface) by comparisons of anemometer level wind speeds at Gulkana Glacier, elevation 4,800 ft,msl, with concurrent free air wind speeds at Fairbanks. Gulkana Glacier is about 135 miles to the southeast of Fairbanks. The average ratio of the Gulkana wind speeds to the Fairbanks free air wind speeds at 4,800 ft was estimated to be 0.6. This ratio was applied to the Fairbanks free air winds at all levels to estimate surface wind speeds. Exhibit 16 shows the 100-year free air wind speeds at Fairbanks and the estimated surface wind speeds (anemometer level) over unforested terrain, both for a 24-hour duration.

Variation of wind speed with respect to duration up to 30 days were estimated in the referenced NWS study (14). This was based on winds of 12-hour to 30-day durations during May and June when temperatures were about 8°C and above at 900 mb. Table 13 shows the wind speeds by 1000 feet elevation bands from 2000 to 10,000 feet. The NWS recommends the use of these data for the basins with lateral extents up to 60 nautical miles. The lateral extent of the Basins is about 55 nautical miles.

The three days of greatest wind speeds were assumed to coincide with the 3-day PMP storm. For two days prior to the storm, the lowest speeds shown on Table 13 were used. This is the time when weather conditions are changing prior to the advent of the storm. Tables 14 and 15 show the arrangement of daily wind speeds used in the snowmelt computation for May and June PMP, respectively.

4.3 AIR TEMPERATURE

4.3.1 Prior to and During the PMP Storm

Daily temperature data at Anchorage were obtained from the National Climate Center, Asheville, North Carolina for the period from 1917 to 1981. These data were used to determine annual maximum for 1-, 2-, 3-, 10- and 30-day temperatures for the months of April, May, and June respectively. Frequency analyses were then made for each of the five durations and for each of the three months to determine the 100-year maximum temperatures. Smooth curves were drawn through the computed temperatures for each month in order to estimate the 100-year values for each duration from 1 to 20 days. From these values, the daily temperatures were computed for a 20-day period, as shown in Table 16.

These temperatures are applicable for elevations up to 2000 ft,msl. Above that, a decrease of 3°F for each 1000 feet increase in elevation was assumed. The highest daily temperatures were placed two days prior to the beginning of the PMP as suggested by observed temperatures prior to major storms. Tables 14 and 15 show the sequences of daily temperature used in the snowmelt computation for May and June PMP, respectively. In these sequences, daily temperatures 2°F higher than the daily dew points are used for the period of the PMP.

The beginning date of melt for June PMP was assumed to be May 15 as discussed under "Maximum Snow Water Equivalents". A sequence of temperatures was derived for May 15 through June 11 (prior to highest temperature assumed to occur before the PMP starting on June 16) based on minimum daily temperatures at Anchorage for the period 1917 through 1981 (Table 15). This provided minimum snowmelt during May 15 through June 11 so that maximum amount of snowpack would be available at the onset of PMP.

4.3.2 After the PMP

The temperatures after the third day of the PMP are arranged according to the procedures given in HMR 42 (14). Starting with the highest temperature from Table 16, the temperature is decreased by 0.5°F for the next day and an additional 0.5°F for each succeeding day (see Tables 14 and 15).

4.4 DEWPOINTS

4.4.1 Prior to the PMP

Daily dewpoints were assumed to be 14°F lower than the daily air temperatures prior to the storm. This is based on conditions during major storms in Alaska. However, during the several days immediately prior to the PMP, when the dewpoint temperature estimated based on this criterion exceeded those during the PMP, the dewpoints were reduced as shown in Tables 14 and 15. This is because the dewpoints during the PMP are based on the enveloping of observed values and should not be exceeded.

4.4.2 During the PMP

These are based on maximum persisting dewpoint maps analyzed by the NWS (17). All available stations in Alaska plus those in Canada between Alaska and Washington State inland to about 170° west longitude, were used in the analysis. Table 17 shows the 12-hour persisting values and the daily values for the three-day period of PMP. They are based on the variation of observed maximum dewpoints during major storms in Alaska and elsewhere. As with the temperatures, the dewpoints given in Table 17 are to be reduced by 3°F for each 1000 feet increase in elevation above 2000 feet. Tables 14 and 15 show the dewpoint sequences adapted for various elevation bands.

4.4.3 After the PMP

After the third day of the PMP, the dew points were assumed to be slightly lower than those during the PMP as shown in Tables 14 and 15.

4.5 RADIATION

Radiation reaching the snow surface as solar radiation (short-wave radiation) and infrared radiation (long-wave radiation) during the snowmelt season was computed using the data and procedures given in HMR 42 (14). The net daily radiation (sum of short-wave and long-wave radiation) for mid-May and mid-June PMP are given in Tables 18 and 19.

Solar radiation data are available at eight climatological stations (Susitna Glacier, Denali, Tyone River, Kosina Creek, Eklutna, Watana, Devil Canyon and Sherman) within the Susitna basin (Exhibit 6) for the period from July 1980 to September 1982. These data could not be used effectively because of the short period of records.

HMR 42 provides detailed analyses of short-wave and long-wave radiation for the Yukon River Basin located between latitudes 59° and 69°. Since the Susitna basin is located between latitudes 62° and 64°, the HMR 42 data were considered applicable for the Basins.

4.5.1 Serial Numbers

Computations of short- or long-wave radiation require serial numbers assigned to all days for which computations are made. These numbers are used to derive ratios of maximum observed radiation to clear-weather radiation (HMR 42, pages 53-54). Serial numbers prior to, during and after the PMP were assigned following the procedures given in HMR 42.

4.5.2 Short-wave Radiation

The short-wave radiation was computed using maximum daily clear-weather short-wave radiation and the ratios of maximum observed radiation to clear-weather radiation. Since short-wave radiation intensity increases with elevation because of lessening optical air mass and lessening interception by water vapor, variation of radiation with elevation also was considered using the data from HMR 42.

4.5.3 Long-wave Radiation

The long-wave radiation was computed as typical downward radiation from the air, including water vapor, plus the radiation from partial cloud-cover minus upward radiation. Elevation adjustments were not made because these were considered to be insignificant.

4.6 HEC-1 SNOWMELT SUB-ROUTINE

The snowmelt sub-routine of HEC-1 computer program developed by COE (5) was used to compute daily snowmelt rates for rainy and rainfree periods. The program can compute daily snowmelt rates either using degree-day or energy-budget method. The basic equations for snowmelt are taken from COE's publication EM1110-1-1406(19). The simplified energy-budget equations used by the program are given below:

Melt during rainy period:

$$\mathrm{SNWMT} = \mathrm{COEF}\ (.09 + (.029 + .00504\ \mathrm{WIND} + .007\ \mathrm{RAIN})\ (\mathrm{TMPR} - \mathrm{FRZTP}))$$

Melt during rainfree period:

$$\mathrm{SNWMT} = \mathrm{COEF}\ (.002\ \mathrm{SOL}\ (1-\mathrm{ALBDO}) + (.0011\ \mathrm{WIND} + .0145)\ (\mathrm{TMPR}-\mathrm{FRZTP}) + .0039\ \mathrm{WIND}\ (\mathrm{DEWPT}-\mathrm{FRZTP}))$$

in which

SNWMT = snowmelt in inches per day in an elevation zone of a basin;

COEF = a dimensionless term, usually assumed 1.0;

WIND = wind speed in miles per hour (mi/hr) at 50 feet above snow surface, average for the basin;

RAIN = precipitation in inches per day, assumed to fall as snow if zone temperature is less than FRZTP plus 2°F; snowmelt is subtracted and snowfall is added to the snowpack in each zone;

TMPR = air temperature at bottom of lowest elevation zone are adjusted to higher zones by lapse rate (TLAPS); a rate of 3°F per 1000 feet elevation difference was adopted for this study.

FRZTP = index temperature °F at which snow will melt, assumed 32°F in this study;

ALBDO = program computes values as $(0.75/D^{.2})$ with maximum value of 0.4, D is number of days since last snowfall;

DEWPT = dewpoint °F at bottom of lowest elevation zone, are adjusted to higher zones by 0.2 TLAPS; and

SOL = net radiation in langleys per day, average for the basin.

The energy-budget method was used in this study. The TMPR, DEWPT and WIND data are given in Tables 14 and 15 for May and June, respectively. The SOL data are given in Tables 18 and 19. Initial water equivalents and drainage areas in each 1000 feet elevation zone are given in Table 20. "RAIN" is the PMP starting on May 16 or June 16. Based on seasonal variation of PMP (Exhibit 14) the PMP occurring on May 16-18 and on June 16-18, is about 73 and 93 percent of July-August PMP respectively. Table 11 shows sub-basin rainfalls based on July-August PMP. These values were adjusted by a factor of 0.73 and 0.93 respectively to derive mid-May and mid-June PMP for combination with the corresponding snowmelt.

SECTION 5

UNIT HYDROGRAPHS

5.0 UNIT HYDROGRAPHS

Unit hydrographs were derived for 10 sub-basins upstream of the Devil Canyon site and the sub-basin between Devil Canyon and the stream gaging station on the Susitna River at Gold Creek (sub-basin 11). The dimensionless graph - lag curve technique described in "Design of Small Dams" (20, pages 64-67) was used. Four average dimensionless graphs were derived based on observed flood hydrographs at selected stream gaging stations and used for sub-basins 1 and 4; 2, 3 and 7; 5, 6 and 9; and 8 and 10 respectively. One lag curve was used for all sub-basins.

5.1 DIMENSIONLESS GRAPHS

5.1.1 Historic Flood Events

Daily streamflow records for the period 1961 to 1981 at 19 stream gaging stations (Exhibit 2, Table 21) were examined to select high flood events for deriving dimensionless graphs. Prior to this period, the years of maximum floods of record as reported in the USGS Water Resources Data, were examined. Daily rainfall data at key stations also was reviewed to select flood events.

The daily flows generally show rising trend in May. High flows continue during the months of June through September and occasionally high flows could occur in November. Eighty-four flood events were selected at 19 stations (Table 21).

5.1.2 Derivation of Dimensionless Graphs

Hourly streamflow data for the selected flood events were obtained from the USGS sub- district office in Anchorage. These data were examined and flood hydrographs with reasonably well defined peaks and recessions were selected. Generally, floods from larger drainage basins have multi-peaks whereas those from smaller basins show fluctuations on rising or falling limbs of hydrographs.

A total of 24 dimensionless graphs were derived using procedures outlined in "Design of Small Dams" (20, pages 64-69). The selected flood events are marked with an asterisk in Table 21. The following table summarizes the number of dimensionless graphs derived for each gaging station.

Stream Gaging Station	No. of Dimensionless Graphs
Eagle River at Eagle River	2
Caribou Creek nr. Sutton	3
Susitna River nr. Denali	2
Little Susitna River nr. Palmer	6
Maclaren River nr. Paxson	3
Talkeetna River nr. Talkeetna	4
Willow Creek nr. Willow	2
Deshka River nr. Willow	2

The dimensionless graphs at each of the above stations were carefully examined. The graphs of the Little Susitna River nr. Palmer and the Susitna River nr. Denali were judged to be inconsistent in shapes and times to peaks, and hence were not used in further analysis.

The watershed characteristics (overland and channel slopes, vegetative cover, soils, presence of glaciers and lakes, etc;) of the remaining six basins and the sub-basins above the Susitna River at Gold Creek were compared and the following dimensionless graphs were judged to be representative for the sub-basins.

Sub-basins	Dimensionless Graphs
1, 4 and 11	Average of 4 graphs derived for Talkeetna River
2, 3 and 7	Average of graphs derived for Eagle River, Caribou Creek and Willow Creek.
5, 6 and 9	Average of graphs derived for Deshka River.
8 and 10	Average of graphs derived for Maclaren River.

Exhibits 17 to 22 show the dimensionless graphs for various basins. Exhibit 23 shows the average dimensionless graphs.

5.2 LAG CURVE

The hydrographs of the 24 flood events analyzed to derive the dimensionless graphs and the hourly rainfall data available in the vicinity of the basins above the stream gaging stations were used to develop a lag curve defined by the following equation:

$$T = A \left[\frac{L.L_c}{\sqrt{S}} \right]^B$$

in which

T = Lag time, defined as the time from the center of rainfall excess to half the volume of direct runoff, hours;

L = Length of longest stream from outlet to watershed divide, miles;

L_c = Length of main stream from outlet to intersection of perpendicular from centroid of the basin to stream alignment, miles;

S = Overall slope of longest stream from outlet to watershed divide, ft/mi;

A = Coefficient, intercept on logarithmic scale; and

B = Exponent

5.3.1 Watershed Parameters of the Basins

The watershed parameters, L, L_c and S, of the basins above the gaging stations for which the dimensionless graphs were derived, were determined from USGS topographic maps of 1:63,360 scale. These parameters are listed in Table 22.

5.2.2 Lag Times

Hourly rainfall data for the period corresponding to the flood events analyzed for the dimensionless graphs were obtained from the National Technical Information Service, Springfield, Va. (NTIS) for four stations, Anchorage, Big Delta, Gulkana and Talkeetna, in the vicinity of the Basins. These data indicated that hourly records were missing for most of the flood events because of non-functioning of the the recording gages.

Hourly rainfall data collected by R&M during 1980-81 at stations within the Susitna basin also were reviewed to obtain data corresponding to flood events on the Maclaren River near Paxson or Susitna River near Denali.

The available hourly data could not be used to determine periods of rainfall excess for the floods analyzed and hence, the lag times for the basins could not be derived. Based on Harza experience on similar studies, the lag time was assumed to be equal to the time from rise of hydrograph to its peak. Depending upon the rainfall distribution pattern, this assumption could either underestimate or overestimate the lag time which, for the purpose of this study, is defined as the time from the center of rainfall excess to half the volume of direct runoff hydrograph. The estimated lag times for the basins are given in Table 22.

5.2.3 Lag Curve

The basin parameters ($LL_c \div \sqrt{S}$) and estimated lag times are plotted on Exhibit 24. A curve fitting most of the plotted points was assumed to be representative for the Susitna River basin. The resulting lag curve is:

$$T = 8.2 \left(LL_c \div \sqrt{S}\right)^{0.32}$$

5.3 SUB-BASIN UNIT HYDROGRAPHS

5.3.1 Watershed Parameters

The watershed parameters, L, L_c and S, of each sub-basin were determined from USGS topographic maps of 1:63,360 scale. These parameters are listed in Table 23. This table also shows the lag times for the sub-basins based on the curve shown on Exhibit 24.

5.3.2 Unit Duration

The unit duration is generally recommended as less than one fourth of the lag time. The lag times for the sub-basins vary from 18 to 79 hours. A unit duration of 3 hours was adopted for all sub-basins for uniformity. This duration also was used to compute sub-basin incremental rainfalls.

5.3.3 Unit Hydrographs

3-hour unit hydrographs were derived for each sub-basin using lag time given in Table 23 and respective dimensionless graph shown on Exhibits 23. The resulting unit hydrographs are shown on Exhibit 25.

SECTION 6

INITIAL ESTIMATES OF INFILTRATION RATES

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6.0 INITIAL ESTIMATE OF INFILTRATION RATES

The infiltration rates for the sub-basins were first estimated based on hydrologic soil groups in the sub-basins and the recommended infiltration rate associated with each hydrologic group as given in "Design of Small Dams" (20, page 64). The estimated rates were then refined as discussed under "Reconstitution of Historic Floods."

6.1 HYDROLOGIC SOIL GROUPS

"Exploratory Soil Survey of Alaska" (21) includes the Susitna River basin. Data included in this publication were used to identify the types of soils in each sub-basin. Table 24 gives the description of soils and relevant soil numbers are shown on Exhibit 26.

Based on the soil descriptions, a hydrologic group was assigned to each soil type (Table 24). Exhibit 27 shows the hydrologic soil groups.

6.2 PERMAFROST

The infiltration rates are affected by the presence of permafrost in the sub-basins. Exhibit 28 shows the permafrost map of the Susitna River basin. The map is derived using a permafrost map prepared by USGS (22).

6.3 INFILTRATION RATES

The estimated percentages of hydrologic soil groups in each sub-basin are given in Table 25. The recommended infiltration rates (20, page 64) for each group are:

Hydrologic Soil Group	Range of Minimum Rates inch/hour
A	0.30-0.45
B	0.15-0.30
C	0.08-0.15
D	0.02-0.08

Because of the presence of permafrost, the lower limit of recommended rates was used to derive weighted infiltration rate for each sub-basin. Table 25 shows the estimated rates.

SECTION 7

RECONSTITUTION OF HISTORIC FLOODS

TABLES

EXHIBITS

7.0 RECONSTITUTION OF HISTORIC FLOODS

Selected historic flood events at all gaging stations at and above Gold Creek for which adequate rainfall data were available were reconstituted using the HEC-1 computer program (5). The purpose of this reconstitution was:

1. To refine the estimate of infiltration rates for each sub-basin.
2. To determine channel routing coefficients for channel reaches between various sub-basins.
3. To check the validity of the unit hydrographs.

7.1 HEC-1 COMPUTER PROGRAM

The precipitation - runoff component of the HEC-1 computer program was used to reconstitute the floods. The model simulates the floods through five separate processes: computation of average rainfall, computation of interception/infiltration, transformation of rainfall excess to sub-basin outflow using unit hydrograph, addition of baseflow and flood routing.

Input data include primarily: point rainfalls with station weights or average basin rainfall, time distribution of rainfall (one distribution for whole basin or different distributions with weighting factors), drainage area, baseflow at the start of a storm, flow value below which recession starts, recession coefficient, initial retention loss and infiltration rate, unit hydrograph, routing coefficient and configuration of the basin indicating the sequence for combining and routing sub-basin floods. The output provides simulated flood hydrographs at desired locations in a basin and also a comparison between observed and simulated floods if observed flood hydrographs are given.

7.2 SELECTION OF FLOOD EVENTS

Daily streamflow records at four stream gaging stations - Susitna River near Denali, Maclaren River near Paxson, Susitna River at Cantwell and Susitna River at Gold Creek, were reviewed and three flood events, those of July 25-31, 1980, July 4-15, 1981 and September 11-22, 1982 were selected for reconstitution because of the availability of adequate precipitation data within the Basins.

Hourly streamflow data (obtained from the USGS sub-district office in Anchorage) are available at all four stations for the July 1980 flood. The hourly streamflow data on the Maclaren River near Paxson are not available for the July 1981 and September 1982 floods because the recording gage at the site did not function during the flood. Hourly data also are not available on the Susitna River at Cantwell for the July 1981 flood. Therefore, the observed and simulated flood hydrographs were compared at four locations for the July 1980 flood, two locations for the July 1981 flood and three locations for the September 1982 flood.

7.3 STORM PRECIPITATION

R&M started collection of climatological data at seven locations, Susitna Glacier, Denali, Watana, Devil Canyon, Kosina Creek, Tyone River and Sherman (Exhibit 6) in 1980-81. The available daily and hourly precipitation data for these stations for the periods of the flood events were obtained from annual publications of R&M.

Daily precipitation data collected by NWS at three locations closest to the Basins, Paxson, Gulkana and Talkeetna, also were obtained from NTIS.

7.4 RECONSTITUTION

The input data for the HEC-1 program for each sub-basin included: mean areal precipitation, initial estimate of infiltration losses, unit hydrograph, flow at the start of the storm and recession characteristics, initial estimate of channel routing coefficients for Muskingum method and observed flood hydrographs.

7.4.1 Precipitation

Average precipitation for each sub-basin was computed from isohyetal maps of the three storms shown on Exhibits 29-31 (See Table 26). Because of limited observed precipitation data for each storm, the isohyetal maps were prepared using isopercental technique.

The isopercental technique was used to estimate precipitation for those parts of the Basins where no precipitation stations are available. The station precipitation was expressed as percentage of the mean annual precipitation. Smooth curves were drawn through the plotted points and extrapolated to cover the Basins. The resulting isopercental maps are shown on Exhibits 32 to 34.

The derived isopercental maps were used with the mean annual precipitation map (Exhibit 5) to derive point precipitation at desired locations to prepare the isohyetal maps (Exhibits 29-31).

The time distribution of average precipitation for each sub-basin was based on available hourly precipitation data during the storm at a station within the sub-basin or closest to the sub-basin.

7.4.2 Infiltration Losses

The HEC-1 computer program provides four methods to compute infiltration losses (5). The initial and uniform loss rate method was used. Initial losses due to interception, depression storage and evapotranspiration were initially assumed and modified through a trial and error process. The constant infiltration rates were also initially assumed and refined through the same process. Table 25 shows the assumed and adopted rates.

7.4.3 Unit Hydrographs

Sub-basin unit hydrographs used in the reconstitution are shown on Exhibit 25.

7.4.4 Base Flow

The baseflow is computed by three input parameters, STRTQ, QRCSN, RTIOR in the HEC-1 computer program. STRTQ represents the initial flow in the river. It is affected by the long-term contribution of groundwater releases and is a function of antecedent condition. QRCSN represents the flow at which an exponential recession begins on the receding limb of the computed hydrograph. The RTIOR is recession decay rate.

The initial flow is estimated from the observed flow at the nearest gaging station by the drainage area ratios. RTIOR is estimated from the slope of recession of observed hydrograph. ORCSN for each sub-basin is assumed to be the same as STRTQ.

7.4.5 Channel Routing

The HEC-1 computer program provides a number of methods for channel routing. The Muskingum method was selected to route the sub-basin hydrographs through channel reaches. Initial estimate of routing coefficients, K and X, of each reach were provided.

The three historic floods were reconstituted by a trial-and-error method. The following procedure was used:

1. Adjust the recession coefficient, RTIOR, until the recession of the simulated hydrograph is similar to that of the observed hydrograph;

2. Adjust the precipitation losses (initial and uniform loss rate) of each sub-basin, until the volume and the peak flow of the simulated hydrographs match that of the observed hydrographs; and

3. Adjust routing coefficients "K" to match time to peak.

The results of the reconstitution are given in Tables 27 to 29 and shown on Exhibits 35 to 37. Table 30 shows the initial and uniform loss rates for the three storms. The uniform loss rates (infiltration rates) were kept the same for all three storms because these are indicative of the soil characteristics.

7.5 ANALYSIS OF THE RECONSTITUTION

7.5.1 Observed Rainfall and its Time Distribution

The amount of rainfall and its time distribution showed significant effect on s the volume and peak flow of the simulated hydrograph. It was realized that if recording rain gages had been available within a sub-basin, the shape of the simulated hydrographs could be improved significantly. Total storm precipitations also could be in error because of excessive extrapolation of isopercental lines.

7.5.2 Observed Hydrographs

These hydrographs are not available for all stations as discussed under "Selection of Flood Events." The recession parts of some of the available hydrographs appeared to be in error because these indicated a high constant flow for a number of days after the peak when no rainfall or excessive glacier melting was observed.

7.5.3 Unit Hydrographs

Sensitivity analysis indicated that changing the shape of unit hydrographs will not improve the results of reconstitution. Hence the unit hydrographs shown on Exhibit 25 were adopted without further adjustments.

7.5.4 Routing Coefficients

Changes in channel routing coefficients also did not improve the results of reconstitution. The adopted channel routing coefficients with routing scheme are shown on Exhibit 38.

SECTION 8

PROBABLE MAXIMUM FLOODS

8.0 PROBABLE MAXIMUM FLOOD (PMF)

Flood hydrographs were derived for the following cases as discussed under "General Approach".

1. Flood caused by July-August PMP combined with the August 1971 flood the peak of the 1971 flood was assumed to precede the PMF peak by 3 days

2. Flood caused by mid-May PMP and snowmelt based on critical temperature sequences prior to the PMP; and

3. Flood caused by mid-June PMP and snowmelt based on critical temperature sequences prior to the PMP,

The HEC-1 computer program (5) was used to derive the flood hydrographs. The 3-day PMP for the sub-basins given on Table 11 was used for July-August flood. These values were multiplied by 0.73 and 0.93 to obtain the May and June PMPs respectively. The snowmelts for combination with May and June PMPs were computed using snowmelt criteria discussed previously.

In all three cases, the initial retention loss was assumed to be negligible. The infiltration rates given in Table 30 were used.

The unit hydrographs given on Exhibit 25 were used. The routing scheme and Muskingum routing coefficients used are given on Exhibit 38.

The resulting hydrographs are summarized in Table 31.

The magnitudes and dates of occurrence of historic floods on the Susitna River at Gold Creek (Exhibit 4) were reviewed to select flood of record for July-August when all season PMP is likely to occur. The largest flood occurred in August 1971. This flood was transposed to the Devil Canyon and Watana sites, and was assumed to represent the combined contribution of antecedent storm, glacier melt and base flow for July-August PMF. The transposed 1971 flood was combined with the flood due to the PMP to yield the PMF. The combination was made such that the peak of the 1971 flood precedes the peak of the flood due to the PMP by 3 days. The resulting floods for Watana and Devil Canyon are summarized in Table 31 and shown on Exhibits 39 and 40.

The May and June floods already include a substantial amount of runoff due to the critical snowmelt discussed under the section entitled "Snowmelt." Therefore, nominal values of baseflow were added to these floods. These values were assumed to be the mean monthly flows for May and June respectively. The resulting floods also are summarized in Table 31 and shown on Exhibits 39 and 40.

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SECTION 9

COMPARISON WITH FLOODS OF RECORD

TABLES

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APPENDIX

9.0 COMPARISON WITH FLOODS OF RECORD

The flood history in the general vicinity of the Susitna River Basin was reviewed. The maximum historic flood peaks at 43 gaging stations in South Central Alaska (where the Susitna River is located) are given in Table 32. These data are plotted and an envelope line drawn as shown on Exhibit 41. The unit discharges for the sizes of the basins above Watana (5,180 mi^2) and above Devil Canyon (5,810 mi^2) are about 25 and 24 cfs/mi^2, respectively. This gives the peak discharge of about 130,000 and 139,000 cfs respectively. The peaks of the May PMFs are about 2.5 times these values. The peaks of the July-August PMFs are about twice these values.

SECTION 10

COMPARISON WITH 100-YEAR FLOOD

TABLES

EXHIBITS

10.0 COMPARISON WITH 100-YEAR FLOOD

A flood frequency curve was developed for the Susitna River at Gold Creek based on annual maximum flood peaks for the period from 1949 through 1981 and using procedures given by United States Water Resources Council (24). The station skewness was used in the computations. Weibull's formula $[M \div (N+1)]$, in which "M" is the order number of flood peaks arranged in descending order of magnitude and "N" is the number of years of record, was used to determine the plotting positions of observed data. Exhibit 42 shows the resulting flood frequency curve.

The 100-year flood peak at Gold Creek (drainage area = 6,160 mi^2) is about 108,000 cfs. This peak was transposed to the two dam sites on the basis of 0.5 power of the drainage area ratios. The resulting flood peaks are about 99,000 cfs and 105,000 cfs at Watana and Devil Canyon, respectively. The respective May PMFs are about 3.1 times the 100-year flood at Watana and about 3.4 times the 100-year flood at Devil Canyon.

SECTION 11

COMPARISON WITH PREVIOUS PMF STUDIES

TABLES

11.0 COMPARISION WITH PREVIOUS PMF STUDIES

PMF studies have been made by the COE and ACRES for the Watana and Devil Canyon sites (1, 2, 3). However, these studies give details on derivation of PMF for Watana site only. PMF peaks and volumes from these studies and those from the present study are listed in Table 33. A brief discussion on previous studies relevant to the current study is provided below.

11.1 PMP

A comparison of Watana Basin average PMP is shown on Exhibit 43.

The COE PMP is based on tentative estimates of PMP provided by the NWS (1,3). The spring PMP is estimated to be about 70 percent of summer PMP. Thus, PMP used with snowmelt is about 6.3 inches.

ACRES estimated PMP based on six storms recorded within the Basins during 1955-1980. The isohyetal pattern of the July 1980 storm was considered to be well defined. The isohyetal patterns for the other storms were derived through isopercental technique using isohyetal pattern of the 1980 storm as the base map. Of the six storms, the August 1967 was most critical with a maximization factor of 2.0 in August. This storm was assumed to occur in June with a maximization factor of 1.4. This resulted in the estimated 10-day PMP of 8.7 inches for the Watana Basin. The weaknesses in the ACRES PMP estimate include, the development of isopercental and hence isohyetal pattern for the six storms analyzed using the isohyetal map of a single storm as the base map, the assumption of the August 1967 storm occurring in June and the combination of a long duration severe storm with extremely critical snowmelt. This has resulted in an overly conservative high flood volume.

The Harza estimate is based on direct transposition and maximization of summer storms. Seasonal variation of PMP was assumed to be similar to that of historical extreme rainfalls. The estimated all-season PMP for Watana is about 6.8 inches. The corresponding values for mid-May and mid-June are 5.0 and 6.3 inches respectively.

11.2 SNOWPACK WATER EQUIVALENT

The COE estimated a snowpack with an average water equivalent of 25 inches over the Watana Basin based on a minimum water equivalent contour map (1).

ACRES estimated a snow water equivalent of 27 to 99 inches over the Basin depending on the sub-basin. The estimate was based on judgements and to provide most critical snowmelt with PMP.

Harza estimates are based on 100-year snow water equivalents with 95 percent one sided upper confidence limit derived through a frequency analysis using 14 to 18 years of data at six snow courses. The estimated water equivalents were adjusted upward for higher elevations based on relationship developed by the NWS (14). The resulting water equivalents over the Basin range from 12.6 to 38.6 inches depending on the elevation zone (Table 12).

11.3 TEMPERATURE SEQUENCES

A comparison of temperature sequences adopted by the COE, ACRES and Harza are shown on Exhibit 44. Harza derived two sequences, one for mid-May PMP and the other for mid-June PMP.

The COE used the minimum temperature of record up to June 2 (observed at Summit in 1971), and after that the temperature sequences estimated by NWS (supplement 1, 3). These temperatures provided minimum snowmelt during May.

ACRES considered no snowmelt during May by using a constant temperature of 32°F. The temperature sequences prior to the PMP and during the PMP are nearly the same as those adopted by the COE (Exhibit 44). Because ACRES used much higher snowpack, the resulting flood peak and volume are significantly higher than those derived by COE (Table 33).

Harza used 100-year temperature sequences derived through frequency analyses using temperature data at Anchorage. The temperature sequences for mid-May PMP were adopted to provide most critical snowmelt with PMP. In case of mid-June PMP (which is 93 percent of July-August PMP), Harza considered it is overly conservative to assume that there will not be any melt during May and early June. Therefore, the temperature sequences were selected to provide minimum snowmelt during May and early June.

11.4 RAINFALL-RUNOFF RELATIONSHIP

The COE and ACRES both used SSARR computer model (4) to define the rainfall-runoff relationships. The values of the model parameters (seven relationships involving 12 parameters to define rainfall-runoff relationships plus six channel and watershed routing parameters two each for surface, sub-surface and baseflow) were originally estimated by the COE. ACRES changed the evapotranspiration relationship in ten sub-basins and runoff coefficient as function of soil moisture in two sub-basins. Estimation of a large number of parameter values using only a few flood events is subject to high uncertainties.

Harza's approach is discussed under the section entitled "General Approach." This approach is more realistic because the sub-basin response function (unit hydrographs) are based on a much larger number of flood events recorded on streams having similar characteristics. The resulting unit hydrographs were also tested through reconstitution of historic floods using the HEC-1 computer program (5).

11.5 PMF

Table 33 gives the PMF peaks and volumes for the three studies.

Comparing the COE results with those of Harza, Harza's May flood peak and volume respectively are about 24 and 13 percent higher. The volume of June flood is about 20 percent less than that of COE due to smaller snow pack available for melt in June. However, the June peak is about 8 percent higher.

The ACRES results are considerbly higher than those of the COE. Comparing ACRES PMF with Harza's May PMF, the ACRES flood peak and volume are about 6 and 79 percent higher, respectively. The higher volume is because of the extremely large snowpack assumed for June and the higher June PMP.

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TABLES

REFERENCES

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TABLES

Table 1

AVERAGE SUMMER AND WINTER FLOWS AT SELECTED STREAM GAGING STATIONS

Gaging Station	Drainage Area	Period of Record	Average Discharge Nov. to Apr.	Average Discharge May to Oct.
	(mi^2)		(cfs)	
Susitna River nr. Denali	950	6/57-9/66 7/68-9/79	281	5,230
Maclaren River nr. Paxson	280	6/58-9/79	106	1,840
Susitna River nr. Cantwell	4,140	5/61-9/72	923	11,600
Susitna River at Gold Creek	6.160	10/50-9/79	1,570	14,200
Chulitna River nr. Talkeetna	2,570	2/58-9/72	1,330	16,000
Talkeetna River nr. Talkeetna	2,006	6/64-9/79	716	7,330
Skwenta River nr. Skwenta	2,250	10/60-9/79	1,140	11,600

Table 2

AVERAGE PRECIPITATION AND TEMPERATURES AT SELECTED CLIMATOLOGICAL STATIONS

Station	Period of Record	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
A. Precipitation (inch)														
Fairbanks	1949-79	0.59	0.42	0.43	0.29	0.57	1.31	1.81	1.84	1.04	0.73	0.69	0.76	10.48
Big Delta	1942-79	0.37	0.27	0.29	0.27	0.87	2.38	2.59	1.97	1.12	0.54	0.38	0.39	11.44
Gulkana	1942-79	0.54	0.49	0.36	0.21	0.61	1.40	1.86	1.55	1.57	0.87	0.74	0.90	11.10
Rika's Landing	1969-79	0.43	0.25	0.26	0.40	0.76	1.83	2.04	1.79	0.98	0.81	0.91	0.50	10.96
Paxson Lake	1968-79	0.72	0.61	0.86	0.55	0.83	1.96	2.79	2.29	2.20	1.84	0.88	1.10	16.63
Talkeetna	1922-79	1.66	1.60	1.70	1.22	1.33	2.03	3.44	4.74	4.46	2.93	1.85	1.59	28.55
Summit	1951-75	.89	1.19	.86	.72	.60	2.18	2.97	3.09	2.56	1.57	1.29	1.11	19.03
B. Temperature (°F)														
Fairbanks	1949-79	-12.5	-5.3	8.4	29.9	48.1	59.4	61.5	56.6	45.1	24.9	3.5	-9.4	25.9
Big Delta	1942-79	-5.6	1.7	11.6	29.7	46.6	56.9	59.8	55.2	44.1	25.2	6.8	-4.2	27.3
Gulkana	1942-79	-7.7	2.3	14.0	30.0	43.5	53.7	57.1	53.3	43.6	27.4	6.6	-5.1	26.6
Rika's Landing	1969-79	-10.1	-2.1	11.6	30.5	46.8	56.5	59.4	54.8	44.0	25.1	4.2	-5.0	26.3
Paxson Lake	1968-79	-9.0	0.1	9.6	23.7	39.1	48.7	53.2	50.6	41.5	24.9	5.4	-3.2	23.7
Talkeetna	1922-79	8.2	15.1	20.0	33.0	44.7	54.7	57.9	54.9	46.1	32.8	18.4	9.2	32.9
Summit	1951-75	-0.6	5.5	9.7	23.5	37.5	48.7	52.1	48.7	39.6	23.0	9.8	3.0	25.0

Table 3

SELECTED STREAM GAGING STATIONS

No.	Name	Lat.	Long.	Drainage Area, mi^2	Period of Record
(1)	(2)	(3)	(4)	(5)	(6)
15277100	Eagle River at Eagle River	61°18'	149°34'	192*	Oct. 1965-Jun. 1981
15277410	Peters Creek near Birchwood	61°25'	149°29'	87.8	Aug. 1973-Sep. 1981
15281000	Knik River near Palmer	61°30	149°02'	1,180*	Oct. 1959-Sep. 1981
15282000	Caribou Creek near Sutton	61°48'	147°41'	289	May 1955-Sep. 1981
15284000	Matanuska River at Palmer	61°35'	149°04'	2,070*	Apr. 1949-Sep. 1981
15290000	Little Susitna River near Palmer	61°43'	149°14'	61.9	Jul. 1948-Sep. 1981
15291000	Susitna River near Denali	63°06'	147°31'	950	May 1957-Sep. 1966 Jul. 1968-Sep. 1981
15291200	Maclaren River near Paxson	63°07'	146°32'	280	Jun. 1958-Sep. 1981
15291500	Susitna River near Cantwell	62°42'	147°33'	4,140*	May 1961-Sep. 1972 Jun. 1980-Sep. 1981
15292000	Susitna River at Gold Creek	62°46'	149°41'	6,160*	Aug. 1949-Sep. 1981
15292400	Chulitna River near Talkeetna	62°34'	150°14'	2,570*	Feb. 1958-Sep. 1972 May 1980-Sep. 1981
15292700	Talkeetna River near Talkeetna	62°21'	150°01'	2,006	Jun. 1964-Sep. 1981
15292780	Susitna River at Sunshine	62°11'	150°11'	11,100*	May 1981-Sep. 1981
15294005	Willow Creek near Willow	61°47'	149°53'	166	Jun. 1978-Sep. 1981
15294010	Deception Creek near Willow	61°45'	149°56'	48	May 1978-Sep. 1981
15294100	Deshka River near Willow	61°46'	150°20'	592	Oct. 1978-Sep. 1981
15294300	Skwentna River near Skwentna	61°52'	150°22'	2,250*	Oct. 1959-Sep. 1981
15294345	Yentna River near Susitna Station	61°42'	150°39'	6,180*	Oct. 1980-Sep. 1981
15294350	Susitna River at Susitna Station	61°32'	150°31'	19,400*	Oct. 1974-Sep. 1981
15294450	Chuitna River near Tyonek	61°07'	151°15'	131	Oct. 1975-Sep. 1981
15294500	Chakachatna River near Tyonek	61°13'	152°22'	1,120*	Jun. 1959-Sep. 1972

* Approximate

Table 4

SNOW SURVEY STATIONS

No.	Station	Lat. (N)	Long. (W)	Elev. (ft)	Period of Record		
					From	To	No. of Years
1	Monahan	63°18'	147°39'	2,710	1964	1982	19
2	Clearwater Lake	62°59'	146°58'	3,100	1964	1981	18
3	Lake Louise	62°17'	146°30'	2,400	1964	1982	19
4	Little Nelchina	62°07'	147°36'	4,160	1968	1981	14
5	Oshetna	62°23'	147°29'	2,950	1964	1981	18
6	Fog Lakes No. 1	62°47'	148°30'	2,270	1964	1982	19
7	Devil Canyon	62°39'	149°18'	1,350	1977	1982	6
8	Buttle Creek	63°01'	147°54'	3,000	1981	1982	2
9	Cirque	63°28'	147°27'	4,700	1981	1982	2
10	Ice Cave	63°30'	147°25'	4,000	1981	1982	2
11	W. Fork Glacier	63°33'	147°10'	5,050	1981	1982	2
12	Mt. Hayes	63°31'	146°54'	4,150	1981	1982	2
13	Caribou	63°25'	147°05'	4,100	1981	1982	2
14	Male Mute	63°23'	147°11'	2,600	1981	1982	2
15	Jatu Pass	63°27'	146°44'	4,500	1981	1982	2
16	Pyramid	63°25'	146°53'	4,800	1981	1982	2
17	East Fork	63°24'	146°51'	2,850	1981	1982	2
18	Watana	62°50'	148°24'	2,200	1981	1982	2
19	Kosina Creek	62°42'	147°59'	2,600	1981	1982	2
20	Tyone River	62°40'	147°06'	2,500	1981	1982	2
21	Denali	63°06'	147°27'	2,700	1981	1982	2

Note: East Fork at elevation 5,200 ft, Valdez Creek and Boulder North were installed in 1982.

Table 5

COMPUTATION OF BARRIER ADJUSTMENT FOR TRANSPOSING THE AUGUST 12-14, 1967 STORM TO THE SUSITNA BASIN

Maximum 12-hour Dewpoint:	61°F
Total precipitable water:	1.45 in.
Precipitable water blocked by 3000 ft. barrier	.43 in.
Precipitable water in place, 1000 ft. barrier	.16 in.

$$\text{Adjustment} = \frac{1.45 - .43}{1.45 - .16} = 0.79$$

Table 6

6-HOUR ACCUMULATED AND INCREMENTAL PMP

	Hour											
	6	12	18	24	30	36	42	48	54	60	66	72
Accumulated Percent of 72-hour Value	30	43	53	61	68	74	80	85	89	93	97	100
Incremental 6-hour Percentages	30	13	10	8	7	6	6	5	4	4	4	3
Above Watana												
Accumulated PMP (in)	2.0	2.9	3.6	4.1	4.6	5.0	5.4	5.7	6.0	6.3	6.6	6.8
Incremental PMP (in)	2.0	0.9	0.7	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.2
Above Devil Canyon												
Accumulated PMP (in)	2.2	3.1	3.8	4.4	4.9	5.3	5.7	6.1	6.4	6.7	7.0	7.2
Incremental PMP (in)	2.2	0.9	0.7	0.6	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.2

Table 7

ADJUSTMENT OF BASE NON-OROGRAPHIC PMP FOR OROGRAPHY IN WATANA BASIN

MAP (in.) Band (1)	PMP from Graph (Exhibit 11) (2)	PMP in Percent of Base Value[1] (3)	PMP for Base Value of 4.5 in. at 20-inch MAP (4)	Percent of Area in Band (5)	Weighted Depth (in.) (6)
<20	6.5	100	4.5	36	1.6
20-30	7.3	112	5.0	27	1.4
30-40	8.6	132	5.9	15	.9
40-50	9.5	146	6.0	10	.7
50-60	10.3	158	7.1	5	.4
60-70	11.0	169	7.6	3	.2
>70	11.3	174	7.8	3	.2
					= 5.4

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[1] Base value is PMP at < 20 inches MAP.

Table 8

VARIATION IN GREATEST OBSERVED ONE-DAY PRECIPITATION OF RECORD FOR STATIONS NEAR THE SUSITNA BASIN WITH 10 OR MORE YEARS OF RECORD

Station	No.	March	April	May	June	July	August
Alpine	1	1.98	.80	.61	1.10	1.29	1.85[1]
		100	40	31	55	65	93[2]
Gunsight	2	.33	.61	.83	1.05	1.20	.70[1]
		27	51	69	87	100	58[2]
Gulkana	3	.81	.28	1.25	1.29	2.04	1.82[1]
		40	13	61	63	100	89[2]
Snow Shoe Lake	4	.60	.75	.94	.97	1.40	.95[1]
		43	53	67	69	100	68[2]
Rika's Landing	5	.30	.37	.69	1.30	1.22	1.11[1]
		23	28	53	100	94	85[2]
Rapids	6	1.07	1.28	.78	2.67	1.90	1.31[1]
		40	48	29	100	71	49[2]
Paxon Lake	7	.95	.73	.51	.90	1.78	1.00[1]
		53	41	28	51	100	56[2]
Avg. Percentage		46	39	48	75	90	71
Percent of July		51	43	53	83	100	78

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[1] Depth in inches

[2] Percent of highest value

Table 9

VARIATION IN PRECIPITABLE WATER ASSOCIATED WITH MAXIMUM 12-HOUR PERSISTING DEWPOINTS IN THE SUSITNA BASIN

Mid-month	March	April	May	June	July	August
Dewpoint (°F)	40	43	48	57	62	61
Precipitable water (in.)	.50	.59	.76	1.19	1.53	1.45
Percent of July	33	38	49	78	100	95

Table 10

VARIATION OF GREATEST MONTHLY PRECIPITATION (inches)

Station No. (see Table 8)	March	April	May	June	July	August
1	2.85	1.33	1.70	2.80	3.21	6.03
2	.56	.85	1.83	4.35	3.26	3.19
3	1.32	.82	1.51	4.07	3.32	4.19
4	.82	.83	2.29	3.54	4.26	3.13
5	.56	.78	1.44	3.52	4.59	2.94
6	1.55	1.29	2.02	6.73	5.91	4.38
7	2.65	1.60	1.52	3.20	5.74	4.44
Percent of July	34	25	40	93	100	93

EXHIBITS

Table 11

SUB-BASIN RAINFALL (inches)

Time (hr)	Arranged Sequence (%)	Sub-basins									
		1	2	3	4	5	6	7	8	9	10
0-3	1	.10	.08	.08	.06	.04	.08	.09	.09	.05	.08
3-6	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
6-9	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
9-12	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
12-15	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
15-18	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
18-21	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
21-24	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
24-27	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
27-30	4	.39	.33	.31	.24	.15	.33	.36	.35	.19	.32
30-33	5	.49	.43	.39	.32	.19	.42	.46	.45	.23	.39
33-36	5	.49	.43	.39	.32	.19	.42	.46	.45	.23	.39
36-39	19	1.86	1.59	1.49	1.16	.71	1.56	1.76	1.70	.88	1.47
39-42	11	1.08	.92	.86	.68	.42	.91	1.02	.98	.52	.86
42-45	7	.69	.59	.56	.44	.27	.58	.64	.63	.33	.54
45-48	6	.59	.50	.47	.38	.22	.49	.56	.54	.28	.46
48-51	4	.39	.33	.31	.24	.15	.33	.36	.35	.19	.32
51-54	4	.39	.33	.31	.24	.15	.33	.36	.35	.19	.32
54-57	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
57-60	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
60-63	3	.29	.25	.23	.18	.11	.24	.28	.27	.14	.23
63-66	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
66-69	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
69-72	2	.20	.17	.16	.12	.07	.16	.19	.18	.09	.15
Total		9.81	8.39	7.83	6.12	3.71	8.16	9.29	8.95	4.65	7.73

Table 12

VARIATION OF SNOWPACK WITH ELEVATION

Elevation Zone (ft)	Percent of 0-1,000 ft Elevation[1]	Snowpack Water Equivalent (in.)
0 - 1,000	100	12.6
1,000 - 2,000	103	13.0
2,000 - 3,000	111	14.0[2]
3,000 - 4,000	124	15.6
4,000 - 5,000	147	18.5
5,000 - 6,000	185	23.3
6,000 - 7,000	234	29.5
7,000 - 8,000	277	34.9
8,000 - 9,000	306	38.6

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[1] Taken from Table 2-5, HMR 42 (12).

[2] 100-year snow water equivalent with 95 percent one sided upper confidence limit, based on frequency analyses of annual maximum water equivalents observed at six snow courses in and around Susitna Basin with 14 to 19 years of record; elevations of snow courses ranged between 2,270 to 3,100 ft,msl with the exception of one station at 4160 ft,msl.

Table 13

MAXIMUM DAILY SNOWMELT WINDS (MPH) AT ANEMOMETER LEVEL

	Elevation Band (ft.)									
Day	500-1000	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000	9000-10,000
1	30	30	33	36	38	41	42	44	45	46
2	21	21	24	26	28	29	30	32	32	33
3	17	17	19	21	22	24	24	26	26	27
4	15	15	17	18	20	21	21	23	23	24
5	14	14	15	17	18	19	20	21	21	22
6	13	13	15	16	17	18	19	20	20	21
7	13	13	14	15	16	17	18	19	19	19
8	12	12	13	14	15	16	17	18	18	18
9	11	11	13	14	15	16	16	17	17	18
10	11	11	12	13	14	15	15	16	16	17
11	10	10	11	12	13	14	14	15	15	16
12	10	10	11	12	13	14	14	15	15	15
13	10	10	11	12	12	13	13	14	14	15
14	9	9	10	11	12	13	13	14	14	14
15	9	9	10	11	12	12	13	13	14	14
20	8	8	9	10	10	11	11	12	12	12

Source: HMR 42 (14).

Table 14

ARRANGED DAILY SNOWMELT AIR TEMPERATURES, DEWPOINTS AND WIND FOR MAY PMP

Elev. Zone, ft	Air Temperatures[1] °F			Dewpoints[1] °F			Wind[2] mph		
Date	Up to 2,000	2,000-3,000	3,000-4,000	Up to 2,000	2,000-3,000	3,000-4,000	2,000-3,000	3,000-4,000	4,000-5,000
May 12	59.6	58.1	55.1	39.6	38.1	35.1	15	17	18
13[3]	65.4	63.9	60.9	40.4	38.9	35.9	17	18	20
14	62.2	60.7	57.7	42.0	40.5	37.5	10	11	12
15	58.0	56.5	53.5	44.0	42.5	39.5	10	11	12
16[4]	46.0	44.5	41.5	44.0	42.5	39.5	24	26	28
17[4]	48.0	46.5	43.5	46.0	44.5	41.5	33	36	38
18[4]	44.0	42.2	39.5	42.0	40.5	37.5	19	21	22
19	65.4	63.9	60.9	40.4	38.9	35.9	10	10	12
20	64.9	63.4	60.4	39.9	38.4	35.4	10	10	12
21	64.4	62.9	59.9	39.4	37.9	34.9	10	10	12
22	63.9	62.4	59.4	38.9	37.4	34.4	10	10	12
23	63.4	61.9	58.9	38.4	36.9	33.9	10	10	12
24	62.9	61.4	58.4	37.9	36.4	33.4	10	10	12
25	62.4	60.9	57.9	37.4	35.9	32.9	10	10	12
26	61.9	60.4	57.4	36.9	35.4	32.4	10	10	12

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[1] For lowest zone of a sub-basin:
Zone 1,000 - 2,000; sub-basins 1, 2, 3, 4
Zone 2,000 - 3,000; sub-basins 5, 6, 7, 8, 9
Zone 3,000 - 4,000; sub-basin 10

[2] For average elevation of a sub-basin:
Zone 2,000 - 3,000; sub-basins 5
Zone 3,000 - 4,000; sub-basins 1, 2, 3, 6, 7, 9
Zone 4,000 - 5,000; sub-basins 4, 8, 10

[3] Highest temperature two days before PMP.

[4] Three days of PMP.

Table 15

ARRANGED DAILY SNOWMELT AIR TEMPERATURES. DEWPOINTS AND WIND FOR JUNE PMP

Elev. Zone, ft Date	Air Temperatures[1] °F			Dewpoints[1] °F			Wind[2] mph		
	Up to 2,000	2,000-3,000	3,000-4,000	Up to 2,000	2,000-3,000	3,000-4,000	2,000-3,000	3,000-4,000	4,000-5,000
May 15	39.0	37.5	34.5	25.0	23.5	20.5	9	9	10
16	41.0	39.5	36.5	27.0	25.5	22.5	9	9	10
17	37.0	35.5	32.5	23.0	21.5	18.5	9	9	10
18	37.0	35.5	32.5	23.0	21.5	18.5	9	9	10
19	36.0	34.5	31.5	22.0	20.5	17.5	9	9	10
20	39.0	37.5	34.5	25.0	23.5	20.5	9	9	10
21	39.0	37.5	34.5	25.0	23.5	20.5	9	9	10
22	39.0	37.5	34.5	25.0	23.5	20.5	9	9	10
23	40.0	38.5	35.5	26.0	24.5	21.5	9	9	10
24	40.0	38.5	35.5	26.0	24.5	22.5	9	9	10
25	41.0	39.5	36.5	27.0	25.5	19.5	9	9	10
26	38.0	36.5	33.5	24.0	22.5	24.5	9	9	10
27	43.0	41.5	38.5	29.0	27.5	21.5	9	10	11
28	40.0	38.5	35.5	26.0	24.5	21.5	9	10	11
29	40.0	38.5	35.5	26.0	24.5	21.5	9	10	11
30	41.0	39.5	36.5	27.0	25.5	22.5	9	10	11
31	38.0	36.5	33.5	24.0	22.5	19.5	10	11	11
June 1	44.0	42.5	39.5	30.0	28.5	25.5	10	11	12
2	45.0	43.5	40.5	31.0	29.5	26.5	10	11	12
3	43.0	41.5	38.5	29.0	27.5	24.5	10	11	12
4	45.0	43.5	40.5	31.0	29.5	26.5	11	12	12
5	44.0	42.5	39.5	30.0	28.5	25.5	11	12	13
6	44.0	42.5	39.5	30.0	28.5	25.5	11	12	13
7	46.0	44.5	41.5	32.0	30.5	27.5	12	13	14
8	45.0	43.5	40.5	31.0	29.5	26.5	13	14	15
9	45.0	43.5	40.5	31.0	29.5	26.5	13	14	15
10	45.0	43.5	40.5	31.0	29.5	26.5	14	15	16
11	45.0	43.5	40.5	31.0	29.5	26.5	15	16	17
12	67.9	66.4	63.4	47.9	46.4	43.3	15	17	18
13[3]	72.0	70.5	62.5	47.0	45.5	42.5	17	18	20
14	69.8	68.3	65.3	49.8	48.3	45.3	10	11	12

Table 15 (Cont'd)

Elev. Zone, ft Date	Air Temperatures[1/] °F			Dewpoints[1/] °F			Wind[2/] mph		
	Up to 2,000	2,000-3,000	3,000-4,000	Up to 2,000	2,000-3,000	3,000-4,000	2,000-3,000	3,000-4,000	4,000-5,000
June 15	66.3	64.8	61.8	50.3	48.8	45.8	10	11	12
16[4/]	55.5	54.0	51.0	53.5	52.0	49.0	24	26	28
17[4/]	57.5	56.0	53.0	55.5	54.0	51.0	33	36	38
18[4/]	53.2	51.7	48.7	51.2	49.7	46.7	19	21	22
19	72.0	70.5	67.5	47.0	45.5	42.5	10	10	12
20	71.5	70.0	67.0	46.5	45.0	42.0	10	10	12
21	71.0	69.5	66.5	46.0	44.5	41.5	10	10	12
22	70.5	69.0	66.0	45.5	44.0	41.0	10	10	12
23	70.0	68.5	65.5	45.0	43.5	40.5	10	10	12
24	69.5	68.0	65.0	44.5	43.0	40.0	10	10	12
25	69.0	67.5	64.5	44.0	42.5	39.5	10	10	12
26	68.5	67.0	64.0	43.5	42.0	39.0	10	10	12

[1/] For lowest zone of a sub-basin:
Zone 1,000 - 2,000; sub-basins 1, 2, 3, 4
Zone 2,000 - 3,000; sub-basins 5, 6, 7, 8, 9
Zone 3,000 - 4,000; sub-basin 10

[2/] For average elevation of a sub-basin:
Zone 2,000 - 3,000: sub-basins 5
Zone 3,000 - 4,000; sub-basins 1, 2, 3, 6, 7, 9
Zone 4,000 - 5,000; sub-basins 4, 8, 10

[3/] Highest temperature two days before PMP.

[4/] Three days of PMP.

Table 16

MAXIMUM DAILY TEMPERATURE PRIOR TO SPRING PMP (°F)[1]

	Month		
Day	April	May	June
1	52.0	65.4	72.0
2	49.4	62.2	69.8
3	46.8	59.6	67.9
4	44.9	58.0	66.3
5	43.4	56.3	65.0
6	42.3	54.9	63.8
7	42.0	53.8	62.7
8	41.9	52.8	61.8
9	41.8	51.8	61.1
10	41.7	50.9	60.5
11	41.6	50.3	60.1
12	41.5	49.7	59.6
13	41.4	49.2	59.1
14	41.4	48.9	58.6
15	41.3	48.6	58.2
16	41.3	48.5	57.8
17	41.2	48.4	57.5
18	41.2	48.2	57.3
19	41.1	48.1	57.1
20	41.1	48.0	57.0

Note: These temperatures are applicable to elevation up to 2000 ft. For higher elevations subtract 3° for each 1000 ft above 2000 ft.

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[1] Based on 100-year return period temperatures at Anchorage.

Table 17

DEWPOINTS (°F) FOR 3-DAY MID-MONTH PMP STORM

	Month		
Sea Level[1]	April	May	June
Maximum 12-Hour Persisting Dewpoint	43.0	47.6	57.0
Greatest 1st day	41.5	46.0	55.5
Greatest 2nd day	40.0	44.0	53.5
Greatest 3rd day	37.0	42.0	51.2
For 2000-3000 Elevation Band			
Greatest 1st day	40.0	44.5	54.0
Greatest 2nd day	38.5	42.5	52.0
Greatest 3rd day	35.5	40.5	49.7

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[1] These dewpoints are applicable for elevations up to 2000 ft. Above this elevation decrease at the rate of 3°F per 1000 ft.

Table 18

DAILY NET RADIATION (Langleys) FOR MAY PMP

Date	Elevation Zones (ft) 2,000-3,000[1]	 3,000-4,000[2]	 4,000-5,000[3]
May 12	827	879	912
13	919	953	987
14	898	932	966
15	809	861	894
16[4]	756	789	821
17[4]	750	781	812
18[4]	714	745	775
19	832	865	898
20	949	985	1,020
21	955	990	1,026
22	922	957	991
23	896	930	964
24	880	913	947
25	863	896	928
26	813	845	877

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[1] Sub-basin 5
[2] Sub-basins 1, 2, 3, 6, 7, 9
[3] Sub-basins 4, 8, 10
[4] Three days of PMP

Table 19

DAILY NET RADIATION (Langleys) FOR JUNE PMP

Date	Elevation Zones, ft			Date	Elevation Zones, ft		
	2,000 3,000[1]	3,000- 4,000[2]	4,000- 5,000[3]		2,000 3,000[1]	3,000- 4,000[2]	4,000- 5,000[3]
May 15	438	462	487	June 1	548	577	605
16	443	468	493	2	554	583	611
17	450	475	500	3	565	594	623
18	456	481	506	4	577	607	636
19	460	485	511	5	579	609	639
20	463	489	515	6	590	621	651
21	470	496	522	7	603	634	665
22	476	502	528	8	622	653	685
23	480	506	532	9	641	674	707
24	483	509	536	10	673	696	730
25	487	513	539	11	697	732	767
26	494	520	547	12	863	902	940
27	500	527	553	13	884	923	961
28	506	533	560	14	846	883	920
29	509	536	563	15[4]	751	785	819
30	523	551	578	16[4]	705	732	759
31	535	563	591	17[4]	711	738	765
				18	674	701	727
				19			
				20	966	1005	1043
				21	961	1000	1038
				22	913	950	986
				23	883	918	954
				24	856	891	925
				25	817	850	883
				26	799	831	862

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[1] Sub-basin 5

[2] Sub-basins 1, 2, 3, 6, 7, 9

[3] Sub-hsins 4, 8, 10

[4] Three days of PMP

EXHIBITS

Table 20

VARIATION OF SNOWPACK AND MEAN ANNUAL PRECIPITATION WITH ELEVATION ZONES IN THE SUB-BASINS

	Elevation Zones, ft							
	1000-2000	2000-3000	3000-4000	4000-5000	5000-6000	6000-7000	7000-8000	8000-9000
Sub-basin 1								
Area (mi^2)	57	223	206	136	6	2		
Water Equivalent (in)	13.9	14.9	15.6	18.5	23.3	29.5		
MAP (in)	30	30	32	32	35	40		
Sub-basin 2								
Area (mi^2)	21	163	148	125	3			
Water Equivalent (in)	13.0	14.0	15.6	18.5	23.3			
MAP (in)	30	30	30	35	40			
Sub-basin 3								
Area (mi^2)	11	91	246	165	59	8		
Water Equivalent (in)	13.0	14.0	15.6	18.5	23.3	29.5		
MAP (in)	30	30	30	35	35	40		
Sub-basin 4								
Area (mi^2)	3	110	223	237	128	24		
Water Equivalent (in)	13.0	14.0	15.6	18.5	23.3	29.5		
MAP (in)	20	20	25	30	35	40		
Sub-basin 5								
Area (mi^2)		776	244	23	17			
Water Equivalent (in)		14.0	15.6	18.5	23.3			
MAP (in)		20	20	20	25			
Sub-basin 6								
Area (mi^2)		295	342	142	8	3		
Water Equivalent (in)		14.0	15.6	18.5	23.3	29.5		
MAP (in)		25	35	50	55	55		
Sub-basin 7								
Area (mi^2)		55	49	61	23			
Water Equivalent (in)		14.0	15.6	18.5	23.3			
MAP (in)		20	30	45	45			
Sub-basin 8								
Area (mi^2)		151	160	232	121	41	35	22
Water Equivalent (in)		14.0	15.6	18.5	23.3	29.5	34.9	38.6
MAP (in)		30	40	45	50	55	60	70
Sub-basin 9								
Area (mi^2)		153	177	5				
Water Equivalent (in)		14.0	15.6	18.5				
MAP (in)		20	30	30				
Sub-basin 10								
Area (mi^2)			98	106	44	29	3	
Water Equivalent (in)			15.6	18.5	23.3	29.5	34.9	
MAP (in)			40	50	60	65	65	

Table 21

SELECTED FLOOD EVENTS

Station No. (1)	Station Name (2)	Drainage Area (mi^2) (3)	Flood Event (4)	Flood Peak (cfs) (5)
15277100	Eagle River at Eagle River	192	Sep. 15-25, 1967	5,890
			Sep. 11-15, 1972*	2,680
			Jul. 05-18, 1975	2,630
			Sep. 10-20, 1978*	3,420
15277410	Peters Creek nr. Birchwood	87.8	Jul. 25-31, 1980	773
15281000	Knick River nr. Palmer	1,180	Jul. 09-16, 1965	236,000
			Jun. 22-28, 1966	144,000
			Aug. 08-13, 1966	49,600
			Sep. 05-25, 1967	35,900
			Aug. 07-18, 1971	45,600
			Aug. 06-19, 1981	57,700
15282000	Caribou Creek nr. Sutton	289	Jul. 26-28, 1967*	1,800
			Aug. 09-12, 1971*	3,650
			Jun. 13-15, 1973*	4,330
			Jul. 13-15, 1975	8,600
			Jun. 05-15, 1978	2,400
15284000	Matanuska River at Palmer	2,070	Jun. 04-14, 1964	39,700
			Aug. 02-17, 1967	21,500
			Aug. 06-12, 1971	82,100
			Jun. 06-20, 1972	31,700
15290000	Little Susitna River nr. Palmer	61.9	Aug. 22-28, 1955	1,790
			Aug. 19-25, 1959	5,160
			Jul. 18-22, 1967*	2,550
			Aug. 13-16, 1967*	1,890
			Sep. 11-14, 1972*	2,560
			Aug. 20-23, 1973*	2,340
			Jul. 27-29, 1980*	2,530
			Jul. 09-12, 1981*	2,030

Table 21

SELECTED FLOOD EVENTS

Station No. (1)	Station Name (2)	Drainage Area (mi^2) (3)	Flood Event (4)	Flood Peak (cfs) (5)
15291000	Susitna River nr. Denali	950	Aug. 19-25, 1959	14,800
			Aug. 04-20, 1971	38,200
			Jun. 10-25, 1972	16,400
			Jul. 26-31, 1980*	23,900
			Jul. 09-13, 1981*	21,300
15291200	Maclaren River nr. Paxson	280	Jul. 27-31, 1958	5,700
			Aug. 09-13, 1971*	9,260
			Sep. 10-14, 1975*	5,700
			Jul. 27-31, 1980*	5,950
15291500	Susitna River nr. Cantwell	4,140	Aug. 02-17, 1967	38,800
			Jul. 25-31, 1980	28,500
			Sep. 13-21, 1980	18,000
15292000	Susitna River at Gold Creek	6,160	Jun. 04-10, 1964	90,700
			Aug. 04-20, 1971	87,400
			Jun. 10-22, 1972	82,600
			Sep. 10-17, 1975	31,800
			Jun. 17-27, 1980	43,500
			Jul. 25-31, 1980	51,700
			Jul. 09-15, 1981	65,300
15292400	Chulitna River nr. Talkeetna	2,570	Jul. 10-15, 1959	39,200
			Aug. 08-22, 1959	33,200
			Jun. 28- Jul. 03, 1967	61,800
			Jul. 15-24, 1967	76,200
			Jul. 25-31, 1980	59,000
			Jul. 31- Aug. 06, 1981	62,700
			Aug. 12-19, 1981	62,000

Table 21

SELECTED FLOOD EVENTS

Station No. (1)	Station Name (2)	Drainage Area (mi^2) (3)	Flood Event (4)	Flood Peak (cfs) (5)
15292700	Talkeetna River nr. Talkeetna	2,006	Aug. 12-15, 1967*	38,100
			May 19-29, 1969	16,800
			Jul. 14-17, 1979	32,000
			Jul. 23-29, 1979	23,500
			Jul. 27- Aug. 01, 1980*	36,500
			Jul. 09-14, 1981*	45,700
			Jul. 31- Aug. 05, 1981	40,900
15294005	Willow Creek nr. Willow	166	Jul. 27-29, 1980*	4,550
			Jul. 09-12, 1981*	2,040
15294100	Deshka River nr. Willow	592	Nov. 07-15, 1979	9,900
			Jun. 30- Jul. 05, 1980	3,470
			Jul. 10-16, 1980	4,890
			Jul. 25-31, 1980	1,990
			Sep. 13-20, 1980*	2,620
			Aug. 01-07, 1981*	4,380
			Aug. 10-22, 1981	8,140
15294300	Skwentna River nr. Skwentna	2,250	Aug. 13-20, 1967	31,000
			Aug. 05-17, 1971	32,000
			Jul. 10-18, 1980	46,000
			Aug. 06-11, 1981	33,500
15294345	Yentna River nr. Susitna Station	6,180	Jul. 09-20, 1981	100,000
			Aug. 01-09, 1981	85,000
15294350	Susitna River at Susitna Station	19,400	Jun. 23-30, 1975	167,000
			Jul. 25-31, 1980	230,000

EXHIBITS

Table 21

SELECTED FLOOD EVENTS

Station No. (1)	Station Name (2)	Drainage Area (mi^2) (3)	Flood Event (4)	Flood Peak (cfs) (5)
15294450	Chuitna River nr. Tyonek	131	Sep. 18-27, 1977	6,630
			Nov. 04-20, 1979	7,620
			Jul. 09-15, 1981	2,340
			Aug. 11-14, 1981	4,660
			Sep. 19-22, 1981	1,760
15294500	Chakachatna River nr. Tyonek	1,120	Aug. 04-20, 1967	22,200

* Flood events analysed for dimensionless graphs.

Table 22

WATERSHED PARAMETERS OF BASINS ABOVE SELECTED STREAM GAGING STATIONS

Gaging Station	Area A, mi^2	Length of Main Stream L, mi	Length to Centroid L_c, mi	Overall Slope S ft/mi	$LL_c \div \sqrt{S}$	Lag[1/]
Caribou Creek nr. Sutton	289	31.2	13.5	151	34	12
Little Susitna River nr. Palmer	62	16.2	7.3	366	6	15
Eagle River nr. Eagle	192	29.0	16.6	131	42	33
Talkeetna River nr. Talkeetna	2006	88.5	48.7	89	457	27
Willow Creek nr. Willow	166	19.8	9.3	280	11	16
Susitna River nr. Denali	950	58.8	24.5	109	138	39
Maclaren River nr. Paxson	280	31.7	17.9	155	46	27
Deshka River nr. Willow	592	69.3	33.9	288	533	57

[1/] assumed equal to time to peak.

Table 23

WATERSHED PARAMETERS OF SUB-BASINS UPSTREAM FROM GOLD CREEK

Sub-basin	Drainage Area (A, mi^2)	Length of Longest Watercourse (L, mi)	Length to Centroid of Sub-basin (L_c, mi)	Overall Slope of of Longest Watercourse (S, ft/mi)	$LL_c) \div \sqrt{S}$	Lag[1/] (hr)	Average Elevation (ft)
1	630	58.5	26.8	86	169	42	3,170
2	460	33.1	17.2	135	49	28	3,310
3	580	42.0	15.3	123	58	30	3,760
4	725	60.2	36.8	83	244	48	4,110
5	1,060	106.7	58.0	28	1174	79	2,710
6	790	63.3	18.1	29	213	46	3,290
7	188	19.8	3.8	115	12	18	3,800
8	762	50.9	21.5	125	98	36	4,300
9	335	42.7	22.7	35	163	42	3,080
10	280	31.7	17.9	155	46	28	4,400
11	350	41.9	19.4	101	81	33	

[1/] Lag = 8.2 $(LL_c \div \sqrt{S})^{0.32}$

EXHIBITS

Table 24

SOILS DESCRIPTION

Soil Number	Description[1]	Hydrologic[2] Group
EA2	Sandy, nearly level, major components poorly to to very poorly drained, water table near surface	D
IO1	Clayey, nearly level to rolling, major components poorly drained over shallow permafrost	D
IO2	Loamy, nearly level to rolling, major components poorly drained, shallow to moderately deep permafrost	D
IU2	Very gravelly, hilly to steep, major components well drained soils, permafrost many feet deep	B
IU3	Very gravelly, hilly to steep - rough mountainous land, major components (55%) well-drained soils, permafrost deep, other components contain areas of rock outcrop and poorly drained soils with shallow permafrost	C
RM1	Rough mountainous land, steep rocky slopes, icefields and glaciers.	D
5010	Very gravelly, hilly to steep, well drained	B
5015	Very gravelly, nearly level to rolling, well to very poorly drained, shallow to no permafrost	C
5016	Very gravelly, hilly to steep also loamy nearly level to rolling, well to poorly drained, shallow to deep permafrost	C
5017	Very gravelly, hilly to steep, rough mountainous, well to poorly drained, shallow to no permafrost	C

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[1] Source: Exploratory Soil Survey of Alaska, U.S. Department of Agriculture.

[2] Estimated from soil description.

Table 25

ADOPTED RETENTION RATES FOR SUB-BASINS

	Percent Hydrologic Soil Groups[1]				Initial[2]	Adopted
Sub-basin	A	B	C	D	Estimate	Rate[3]
1		6	74	20	.07	.03
2			94	6	.08	.03
3		22	59	19	.08	.03
4		36	19	45	.08	.04
5		13	23	64	.05	.04
6			82	18	.07	.04
7			98	2	.08	.04
8			27	73	.04	.03
9			34	66	.04	.04
10			56	44	.05	.04
11		5	58	37	.06	.03

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[1] See Exhibit 27.

[2] Based on lower limit of recommended rate due to distribution of permafrost in the Basins (20).

[3] Based on reconstitution of historic flood events.

Table 26

SUB-BASIN PRECIPITATION FOR RECONSTITUTION OF HISTORIC FLOODS

Sub-basin	Precipitation (inch) July 25-31, 1980	 July 4-15, 1981	 September 11-22, 1982
1	2.61	3.99	3.57
2	1.82	4.07	2.93
3	3.10	2.09	1.60
4	3.34	1.38	1.20
5	2.21	1.23	0.80
6	1.75	3.08	2.34
7	1.88	2.64	2.80
8	3.26	7.58	6.10
9	1.78	4.00	1.80
10	3.46	8.27	5.30
11	3.43	4.04	5.13

Table 27

RECONSTITUTION OF JULY 25-31, 1980 FLOOD USING THE HEC-1 COMPUTER PROGRAM

	Flood Volume				Flood Peak				Time to Peak		
Station Name	Obs. (cfs-3 hr)	Comp. (cfs-3 hr)	Diff. (cfs-3 hr)	Percent Diff.	Obs. (cfs)	Comp. (cfs)	Diff. (cfs)	Percent Diff.	Obs. (hr)	Comp. (hr)	Diff. (hr)
Susitna River near Denali	783,380	854,870	71,490	9.1	24,300	23,812	-488	-2.0	87	90	3
Maclaren River near Paxson	242,620	235,701	-6,919	-2.9	5,950	6,791	841	14.1	90	93	3
Susitna River at Cantwell	1,265,400	1,279,851	14,451	1.1	28,500	33,156	4,656	16.3	102	105	3
Susitna River at Gold Creek	2,095,435	2,037,564	-57,871	-2.8	50,600	58,700	8,109	16.0	108	114	6

Table 28

RECONSTITUTION OF JULY 4-15, 1981 FLOOD USING THE HEC-1 COMPUTER PROGRAM

	Flood Volume				Flood Peak				Time to Peak		
Station Name	Obs. (cfs-3 hr)	Comp. (cfs-3 hr)	Diff. (cfs-3 hr)	Percent Diff.	Obs. (cfs)	Comp. (cfs)	Diff. (cfs)	Percent Diff.	Obs. (hr)	Comp. (hr)	Diff. (hr)
Susitna River near Denali	1,068,132	886,187	-181,945	-17	21,300	20,709	-591	-2.78	183	192	9
Maclaren River near Paxson	-	-	-	-	-	-	-	-	-	-	-
Susitna River at Cantwell	-	-	-	-	-	-	-	-	-	-	-
Susitna River at Gold Creek	3,237,150	2,786,834	-450,316	-13.9	65,000	52,913	-12,087	-18.6	204	189	-15

Table 29

RECONSTITUTION OF SEPTEMBER 11-22, 1982 FLOOD USING THE HEC-1 COMPUTER PROGRAM

	Flood Volume				Flood Peak				Time to Peak		
Station Name	Obs. (cfs-3 hr)	Comp. (cfs-3 hr)	Diff. (cfs-3 hr)	Percent Diff.	Obs. (cfs)	Comp. (cfs)	Diff. (cfs)	Percent Diff.	Obs. (hr)	Comp. (hr)	Diff. (hr)
Susitna River near Denali	596,748	626,956	30,208	5.1	11,300	15,369	4,069	36.0	120	135	15
Maclaren River near Paxson	-	-	-	-	-	-	-	-	-	-	-
Susitna River at Cantwell	1,244,230	1,217,764	-26,466	-2.1	20,700	23,159	2,459	11.9	138	144	6
Susitna River at Gold Creek	2,214,400	2,037,160	-177,240	-8.0	33,300	34,746	1,446	4.3	132	153	21

Table 30

INITIAL LOSS AND INFILTRATION RATES BASED ON RECONSTITUTION OF HISTORIC FLOODS

Sub-basin	Initial Loss, (inch)			Infiltration Rate (inch/hr)
	July 1980 Flood	July 1981 Flood	September 1982 Flood	
1	0	0	0	.03
2	0	0	0	.03
3	0	0	0	.03
4	3.2	0	0.4	.04
5	2.1	0	1.1	.04
6	1.5	0	1.5	.04
7	0	0	0	.04
8	0	0	1.3	.03
9	1.7	0	1.2	.04
10	0.9	0	0.9	.04
11	0	0	0	.03

Table 31

SUMMARY OF PROBABLE MAXIMUM FLOOD

A. Flood based on all season PMP

	Direct Runoff			Baseflow and Snowmelt			Total Flood			
	Peak (cfs)	Volume (af)	Duration (day)	Discharge[1] (cfs)	Volume (af)	Duration (day)	Peak (cfs)	Volume (af)	Duration (day)	Creager's C
Watana	221,000	$1.22x10^6$	20	46,000	$1.35x10^6$	20	267,000	$2.57x10^6$	20	36
Devil Canyon	264,000	$1.47x10^6$	20	47,000	$1.43x10^6$	20	311,000	$2.90x10^6$	20	41

B. Flood based on May and June PMPs with snowmelt

	Direct Runoff			Baseflow			Total Flood			
	Peak (cfs)	Volume (af)	Duration (day)	Discharge[1] (cfs)	Volume (af)	Duration (day)	Peak (cfs)	Volume (af)	Duration (day)	Creager's C
1. Mid-May										
Watana	297,000	$3.80x10^6$	20	11,200	$0.44x10^6$	20	309,000	$4.24x10^6$	20	42
Devil Canyon	350,000	$4.36x10^6$	20	12,600	$0.50x10^6$	20	362,000	$4.86x10^6$	20	47
2. Mid-June										
Watana	231,000	$2.12x10^6$	20	23,500	$0.93x10^6$	20	254,000	$3.05x10^6$	20	34
Devil Canyon	273,000	$2.47x10^6$	20	26,300	$1.04x10^6$	20	299,000	$3.51x10^6$	20	39

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[1] Discharge Coincident with PMF.

Table 32

MAXIMUM INSTANTANEOUS HISTORICAL FLOOD PEAKS
South Central Alaska

No.	Stream Gaging Station	Drainage Area (mi^2)	Period of Record	Date	Max. Q (cfs)	cfs/mi^2
1	15195000 Dick Creek near Cordova	7.95	06/70-9/81	08-07-81	2,600	327
2	15208000 Tonsina River at Tonsina	420	10/55-9/81	06-17-62	8,490	20
3	15212000 Copper River near Chitina	20,600	10/55-9/81	08-08-81	380,000	18
4	15216000 Power Creek near Cordova	20.5	08/47-9/81	09-25-49	5,540	270
5	15219000 W. Fork Olsen Bay Creek nr. Cordova	4.78	09/64-1/81	09-12-72	1,030	215
6	15236900 Wolverine Creek near Lawing	9.51	10/66-9/81	08-21-81	1,810	190
7	15238820 Barbara Creek near Seldovia	20.7	06/72-9/81	10-22-80	1,310	63
8	15238990 Upper Bradley River near Homer	10.0	10/79-9/81	08-10-80	2,180	218
9	15239000 Bradley River near Homer	54.0	10/57-9/81	08-10-79	6,020	111
10	15239900 Anchor River near Anchor Point	137	06/64-9/81	10-22-80	4,680	34
11	15241600 Ninilchik River at Ninilchik	131	04/63-9/81	04-24-74	1,240	9
12	15258000 Kenai River at Cooper Landing	643	05/47-9/81	09-21-74	23,100	36
13	15266300 Kenai River at Soldotna	2,010	05/65-9/81	09-09-77	33,700	16
14	15267900 Resurrection Creek near Hope	149	10/67-9/81	07-12-80	3,380	23
15	15271000 Six Mile Creek near Hope	234	06/79-9/81	07-12-80	8,070	34
16	15273900 S.F. Campbell Creek near Anchorage	25.2	10/66-9/81	08-12-81	476	19
17	15274300 N.F. Campbell Creek near Anchorage	13.4	10/67-9/81	08-09-71	107	8
18	15274600 Campbell Creek near Spenard	69.7	06/66-9/81	08-13-81	451	6
19	15275100 Chester Cr. at Artic Bld. at Anchorage	27.2	06/66-9/81	09-24-81	198	7
20	15276000 Ship Creek near Anchorage	90.5	10/46-9/81	06-21-81	1,860	21
21	15276570 Ship Creek below Powerplant at Elmendorf	115	10/70-9/81	09-09-71	1,600	14
22	15277100 Eagle River at Eagle River	192	10/65-6/81	09-18-67	6,240	33
23	15277410 Peters Creek near Birchwood	87.8	08/73-9/81	09-16-80	1,200	14
24	15281000 Knik River near Palmer	1,180	10/59-9/81	07-26-61	355,000	301[1]
25	15290000 Little Susitna River near Palmer	61.9	07/48-9/81	08-10-71	7,840	127
26	15291000 Susitna River near Denali	950	05/57-9/81	08-10-71	38,200	40
27	15291200 Maclaren River near Paxson	280	06/58-9/81	08-11-71	9,260	33
28	15291500 Susitna River near Cantwell	4,140	05/61-9/72	08-10-71	55,000	13
29	15292000 Susitna River at Gold Creek	6,160	08/49-9/81	07-07-81	90,700	15
30	15292400 Chulitna River near Talkeetna	2,570	02/58-9/81	07-20-67	75,900	30
31	15292700 Talkeetna River near Talkeetna	2,006	06/64-9/81	08-10-71	67,400	34
32	15294005 Willow Creek near Willow	166	06/78-9/81	07-28-80	4,450	27
33	15294010 Deception Creek near Willow	48.0	05/78-9/81	06-21-80	751	16
34	15294100 Deshka River near Willow	592	10/78-9/81	11-13-79	9,920	17
35	15294300 Skwentna River near Skwentna	2,250	10/59-9/81	06-09-77	51,600	23
36	15294345 Yentna River near Susitna Station	6,180	10/80-9/81	08-13-81	116,000	19
37	15294350 Susitna River at Susitna Station	19,400	10/74-9/81	07-29-80	230,000	12
38	15294410 Capps Creek near Tyonek	10.5	07/79-9/81	06-25-80	710	68
39	15294450 Chuitna River near Tyonek	131	10/75 9/81	11-11-79	7,620	58
40	15295600 Terror River near Kodiak	15.0	06/62-9/81	10-21-80	3,400	227
41	15296550 Upper Thumb River near Larsen Bay	18.8	07/74-9/81	10-21-80	988	53
42	15296600 Karluk River at Outlet Near Larsen Bay	100	08/75-9/81	11-11-79	1,760	18
43	15297200 Myrtle Creek near Kodiak	4.74	05/63-9/81	01-03-77	1,350	285

[1] Caused by release of stored water behind Knik Glacier

Table 33

COMPARISON OF PMF STUDIES FOR WATANA DAM SITE

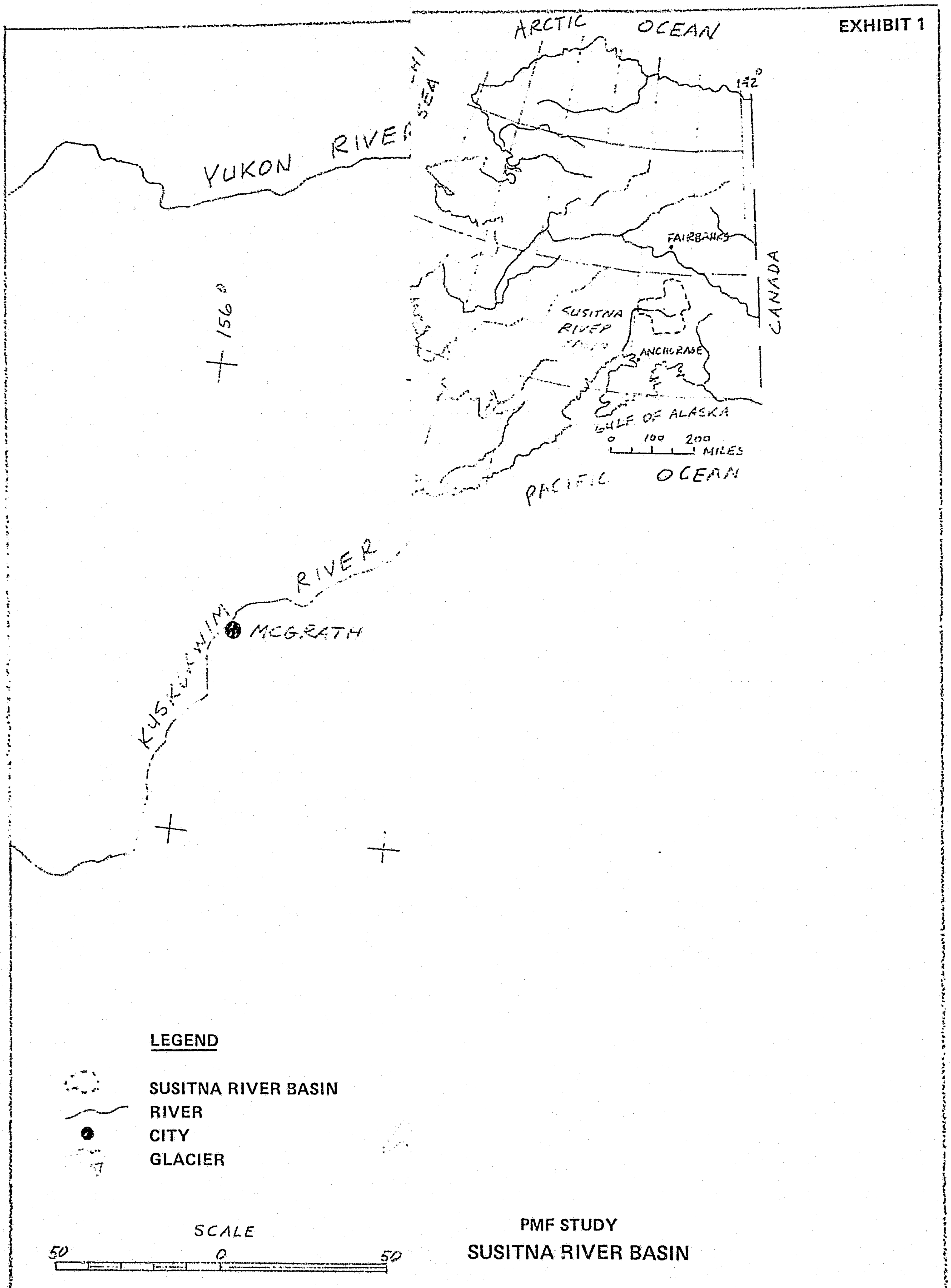
Agency Responsible for the Study	Probable Maximum Flood			
	Peak (cfs)	Volume (af)	Duration (day)	Creager's
Corps of Engineers	234,000	3.67×10^6	20	32
Acres American, Inc.	326,000	7.59×10^6	20	44
Harza Engineering Company				
May Flood	309,000	4.24×10^6	20	42
June Flood	254,000	3.05×10^6	20	34
July-August Flood	267,000	2.57×10^6	20	36

EXHIBITS

APPENDIX

EXHIBITS

EXHIBIT 1

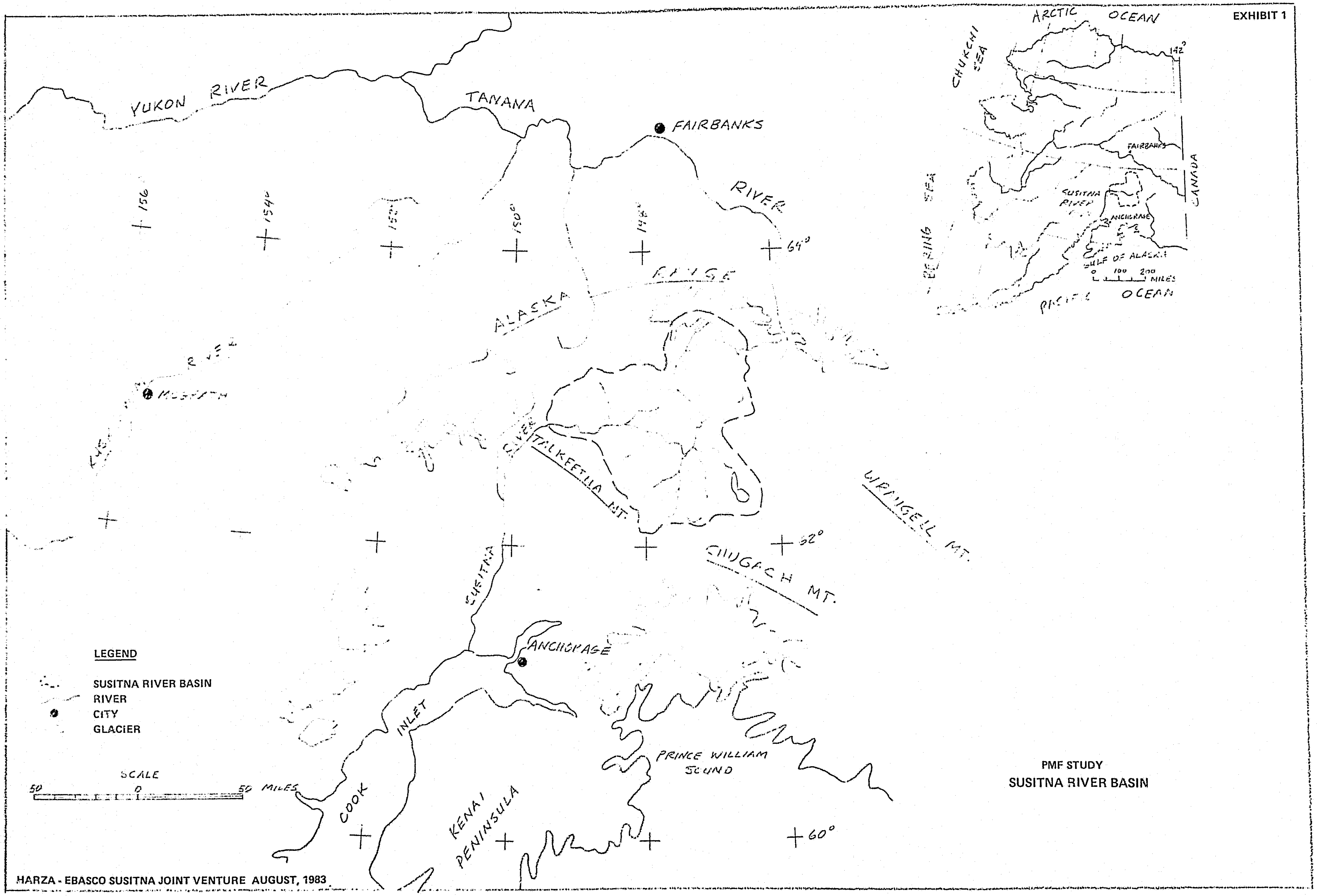


PMF STUDY

SUSITNA RIVER BASIN

HARZA - EBASCO SUSITNA JOINT VENTURE A

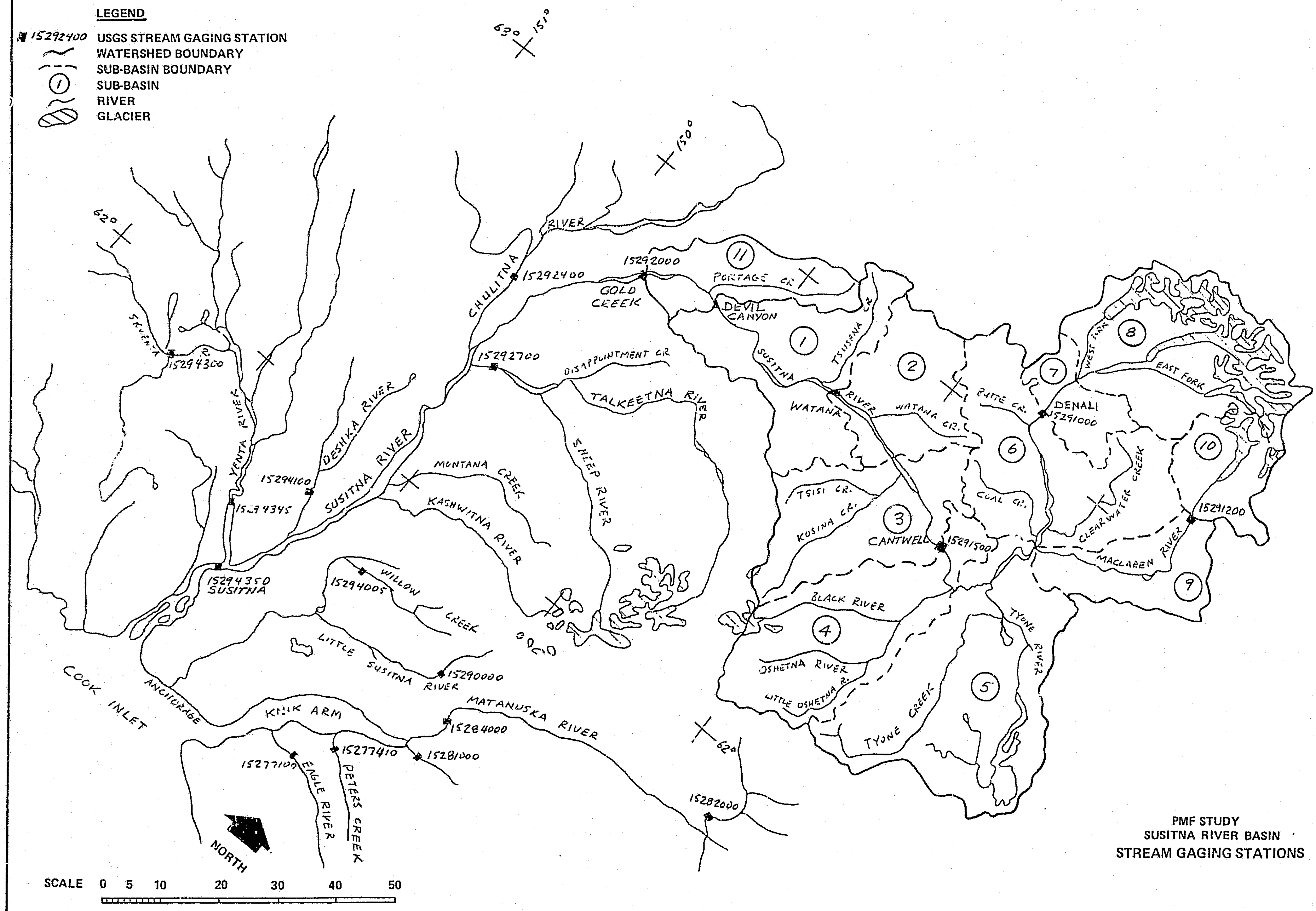
EXHIBIT 1



PMF STUDY
SUSITNA RIVER BASIN

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

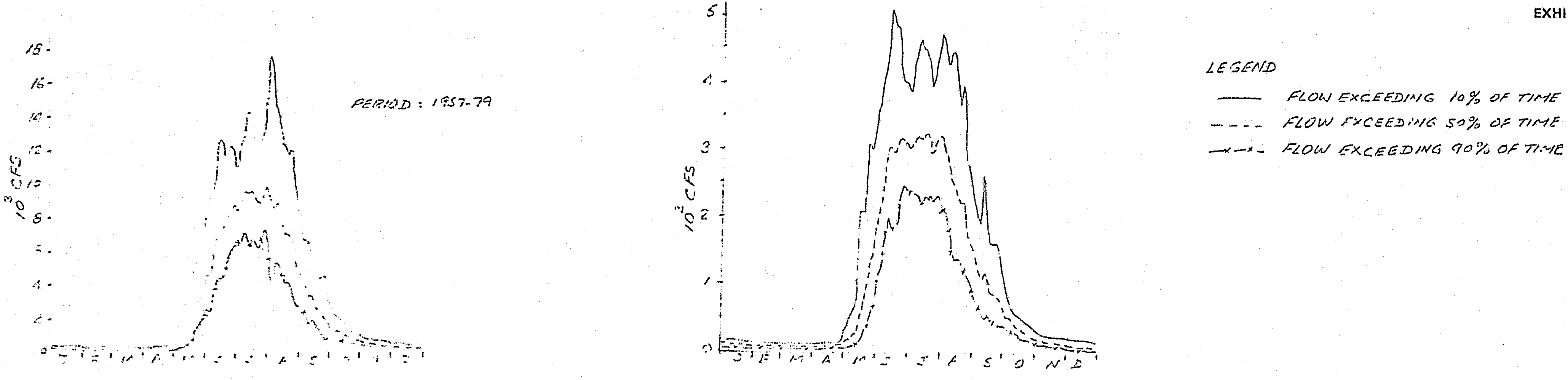
EXHIBIT 2



PMF STUDY
SUSITNA RIVER BASIN
STREAM GAGING STATIONS

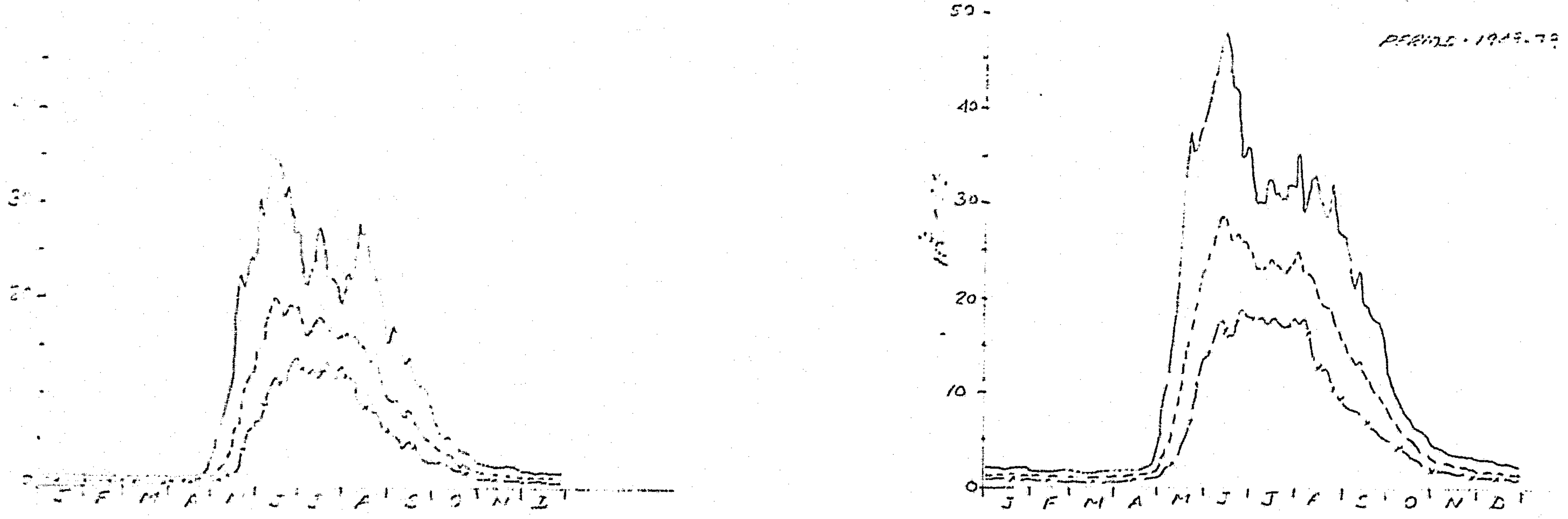
HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 3



SUSITNA RIVER NR DENALI

MACLAREN RIVER NR PAXSON



SUSITNA RIVER NR CANTWELL

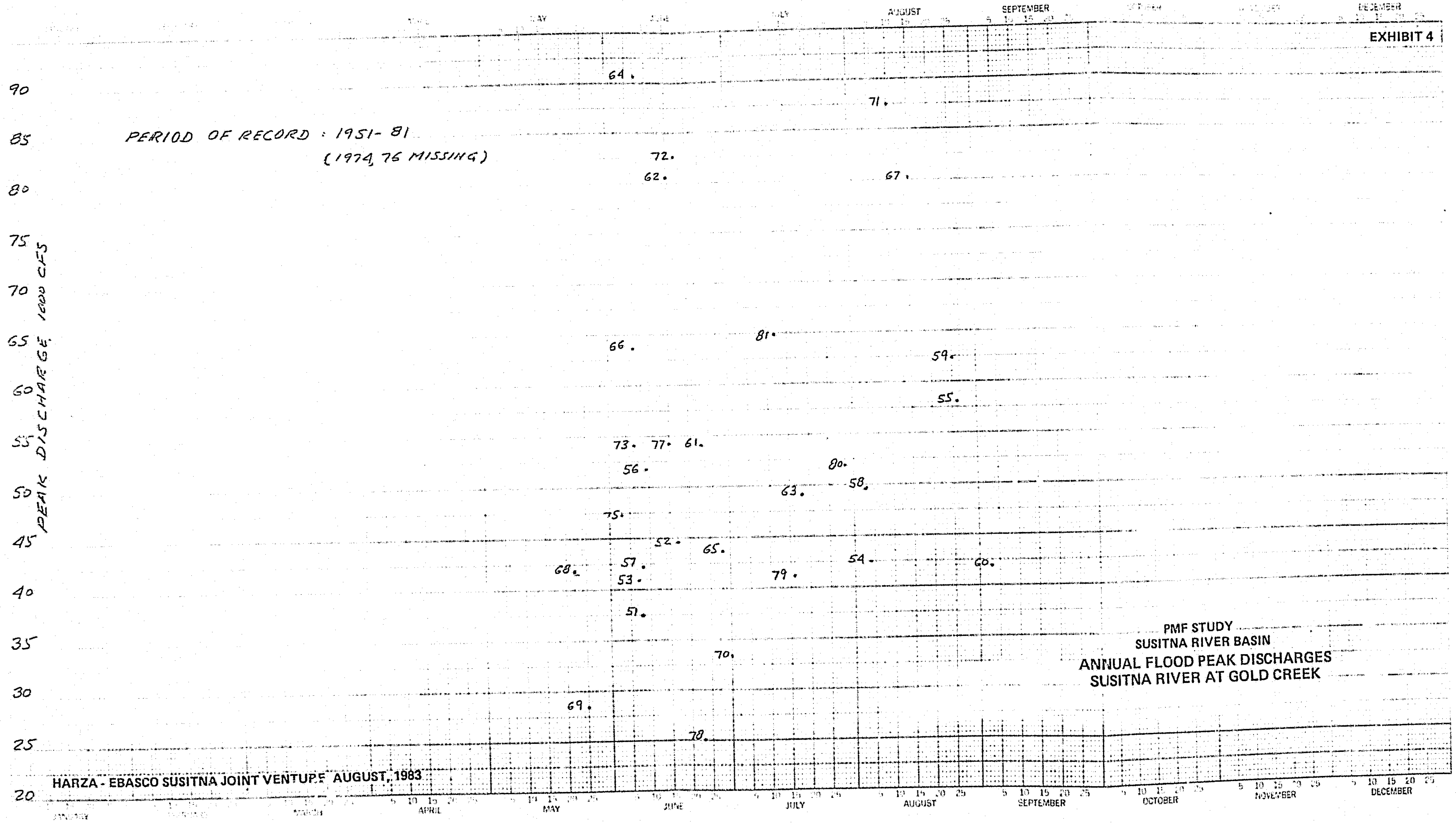
SUSITNA RIVER AT GOLD CREEK

PMF STUDY
SUSITNA RIVER BASIN

STREAMFLOW CHARACTERISTICS OF SUSITNA RIVER ABOVE GOLD CREEK STATION

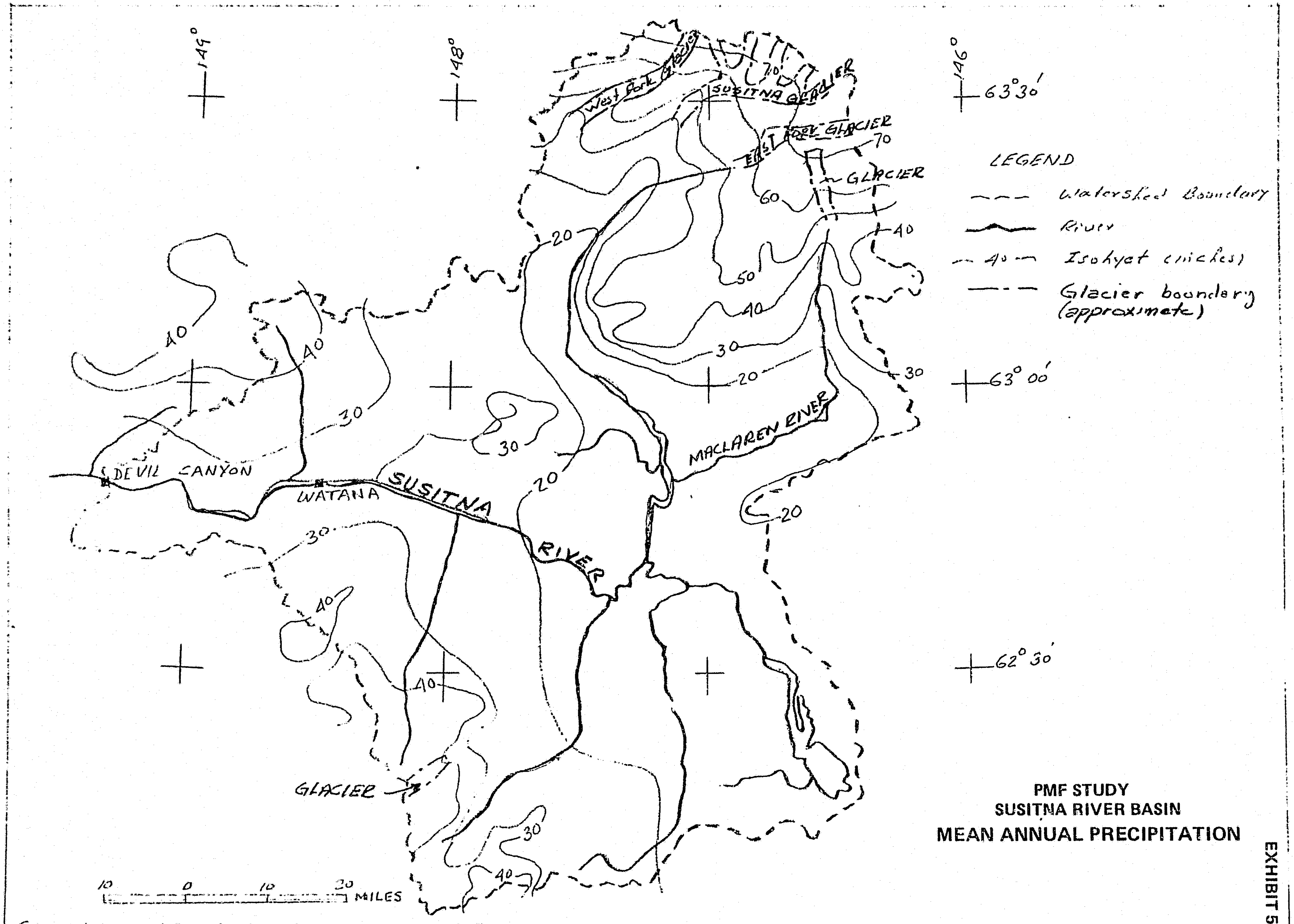
HARZA- EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 4



PMF STUDY
SUSITNA RIVER BASIN
ANNUAL FLOOD PEAK DISCHARGES
SUSITNA RIVER AT GOLD CREEK

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



PMF STUDY
SUSITNA RIVER BASIN
MEAN ANNUAL PRECIPITATION

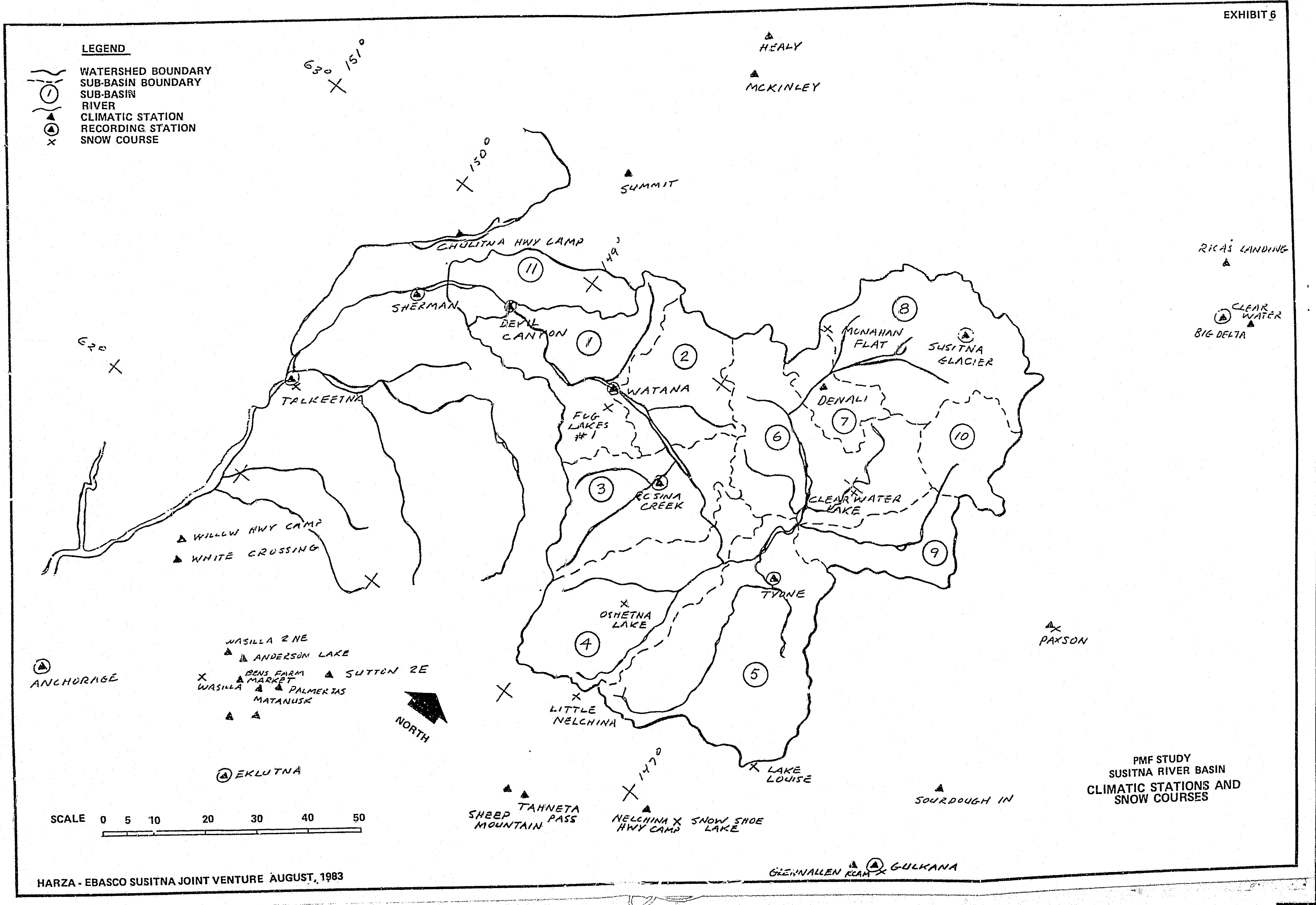
EXHIBIT 5

SOURCE SCS, ALASKA DEC. FEB. 1982

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

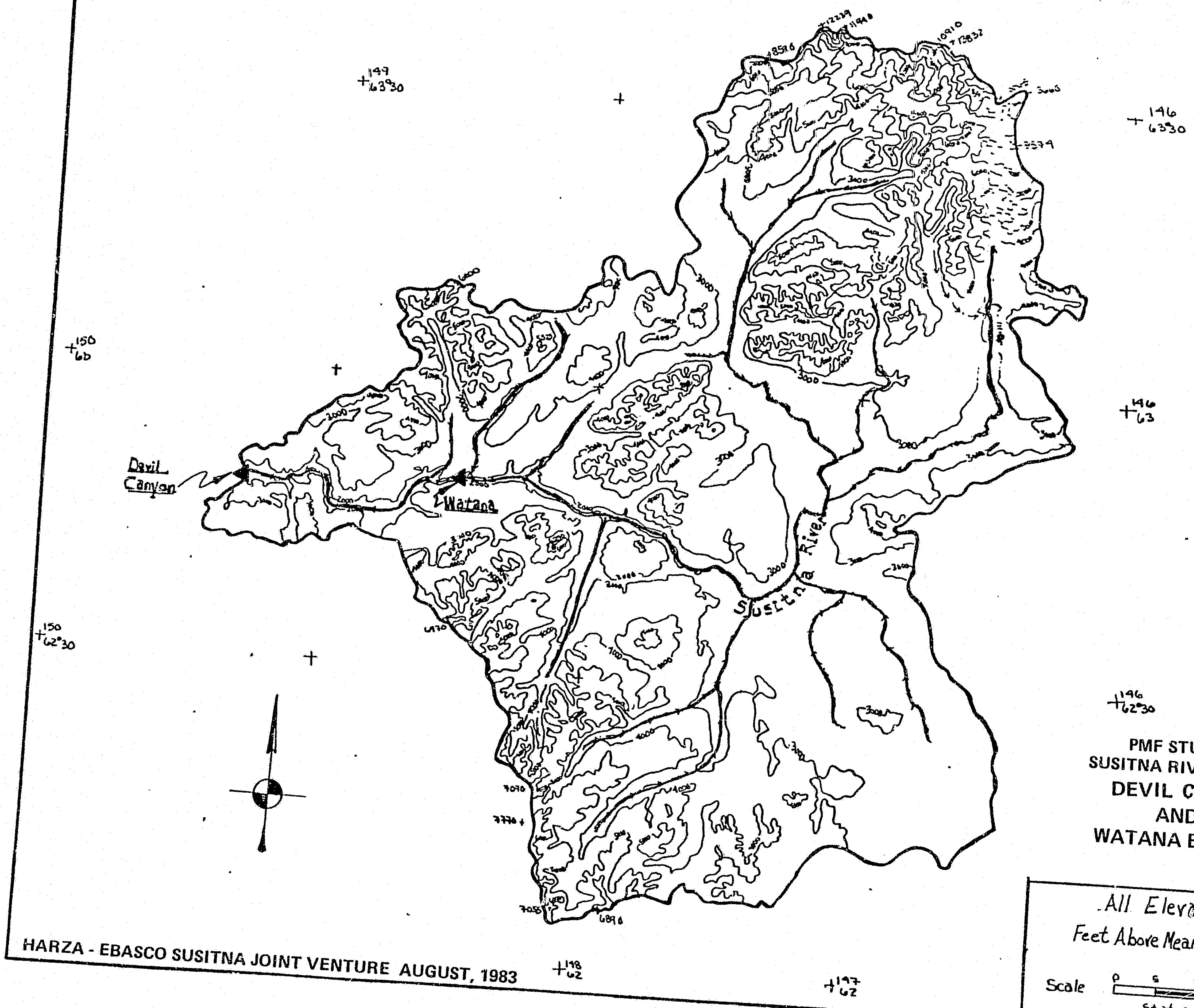
APPENDIX

EXHIBIT 6



PMF STUDY
SUSITNA RIVER BASIN
CLIMATIC STATIONS AND
SNOW COURSES

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



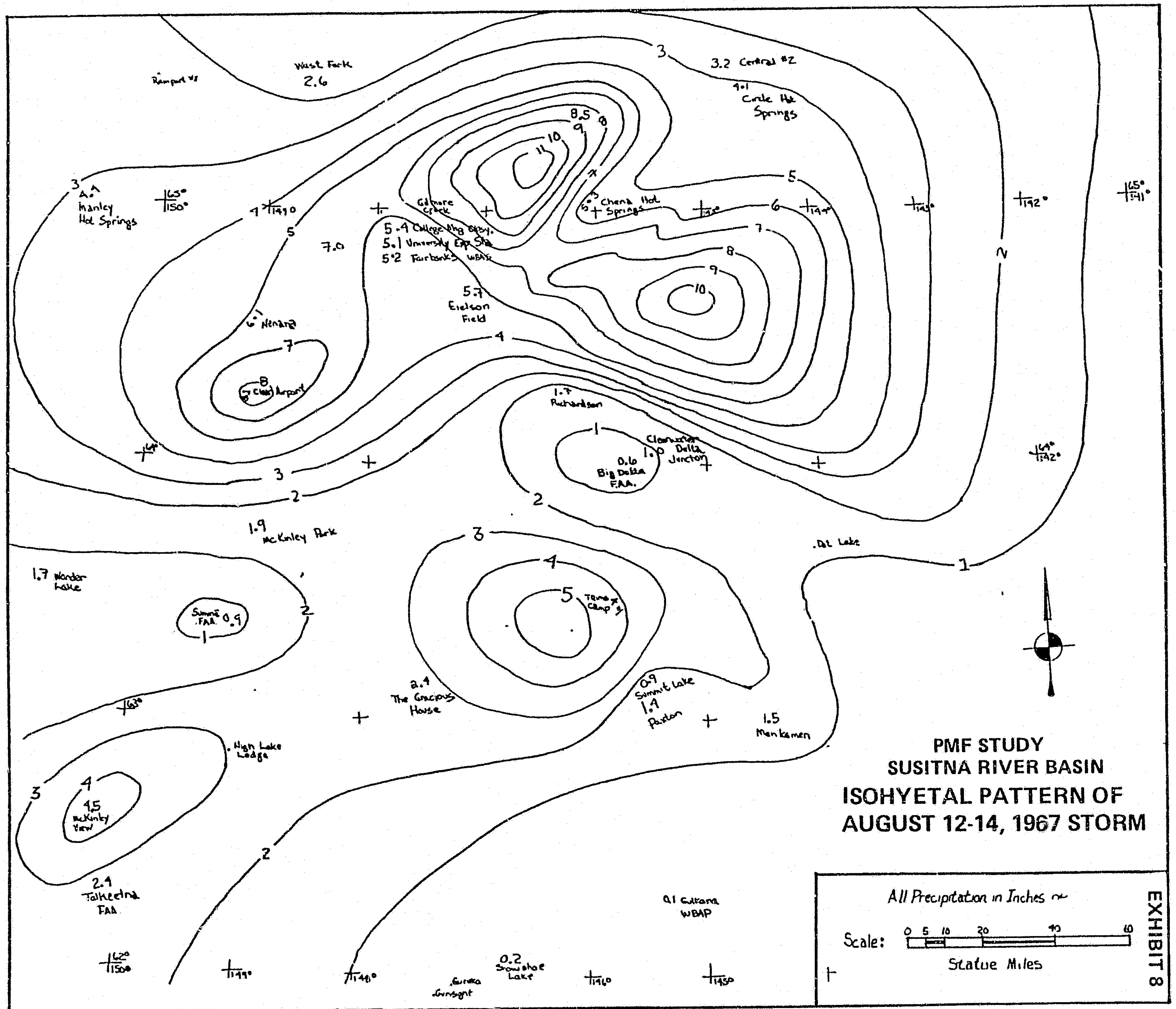
PMF STUDY
SUSITNA RIVER BASIN
DEVIL CANYON
AND
WATANA BASINS

All Elevations,
Feet Above Mean Sea Level

Scale 0 5 10 20
Statue Miles

EXHIBIT 7

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



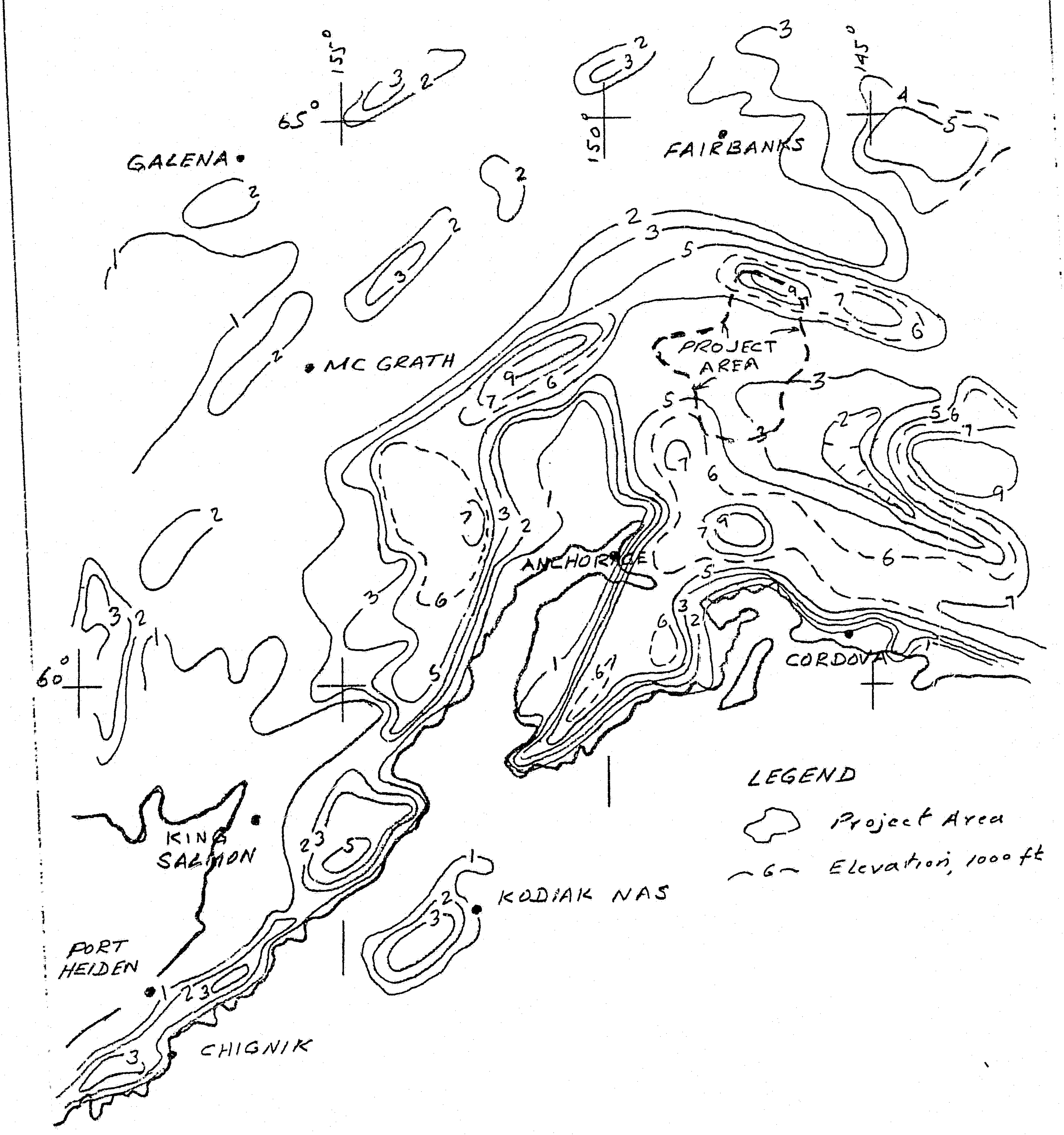
PMF STUDY
SUSITNA RIVER BASIN
ISOHYETAL PATTERN OF
AUGUST 12-14, 1967 STORM

All Precipitation in Inches ~

EXHIBIT 8

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 9



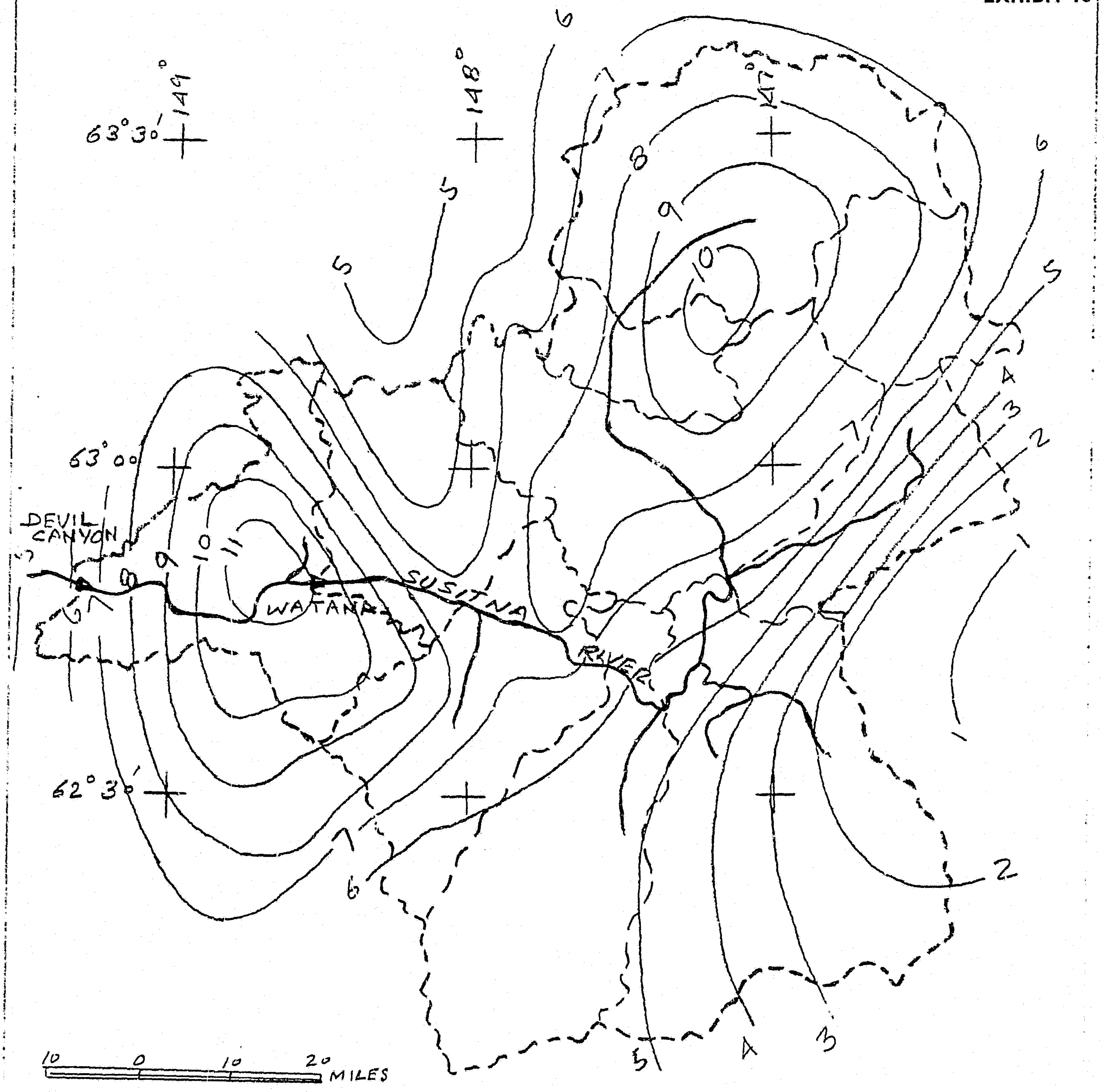
PMF STUDY
SUSITNA RIVER BASIN

ELEVATIONS OF MOISTURE INFLOW BARRIERS

SOURCE: USWB, TP NO. 47, 1963

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 10



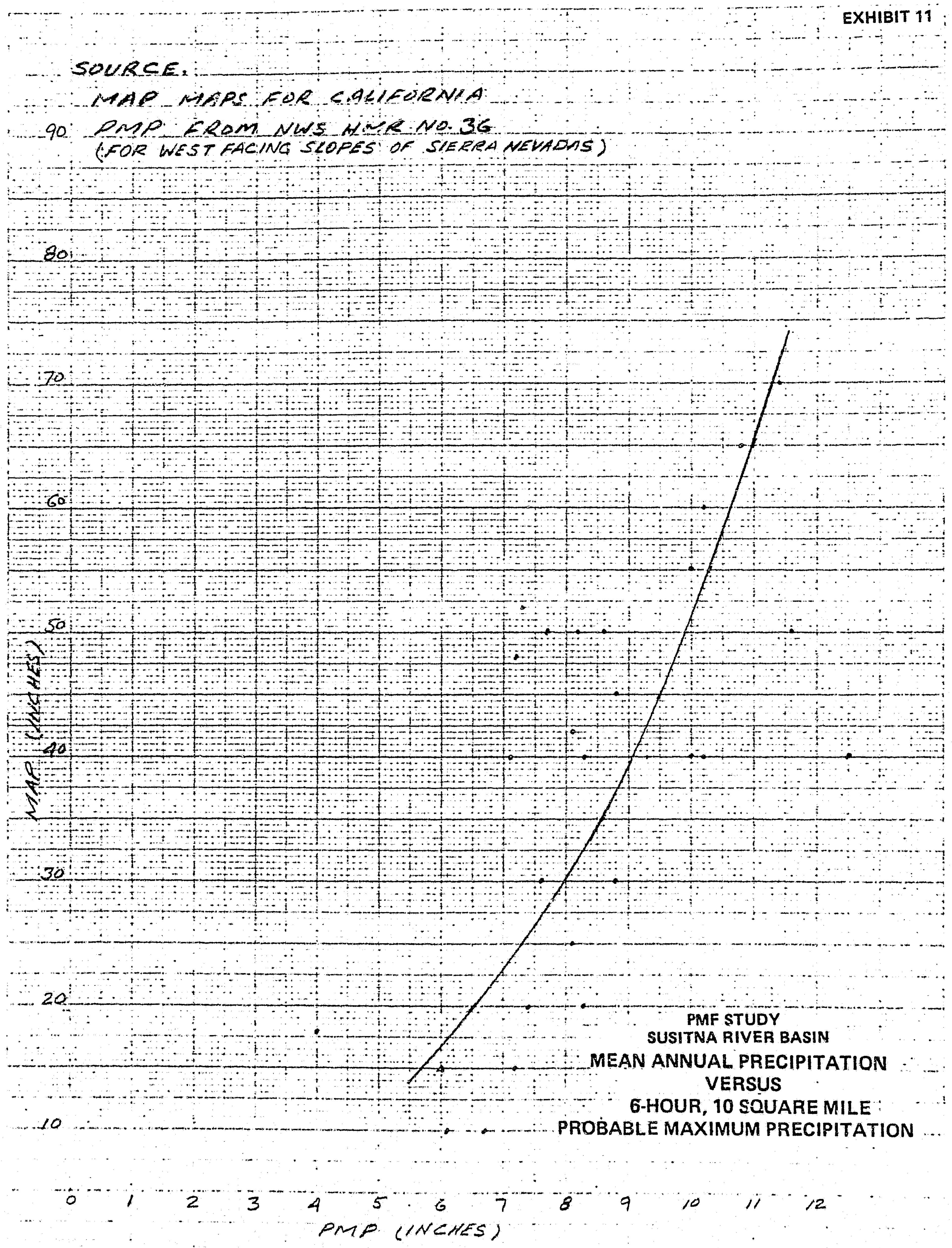
NOTE: PMP = PRECIPITATION REPRESENTED BY THE ABOVE STORM ISOHYETS MULTIPLIED BY THE COMBINED MOISTURE MAXIMIZATION AND BARRIER REDUCTION FACTOR OF 1.07

PMF STUDY
SUSITNA RIVER BASIN

LOCATION AND ORIENTATION OF AUGUST 12–14, 1967 CHENA STORM OVER SUSITNA BASIN

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 11

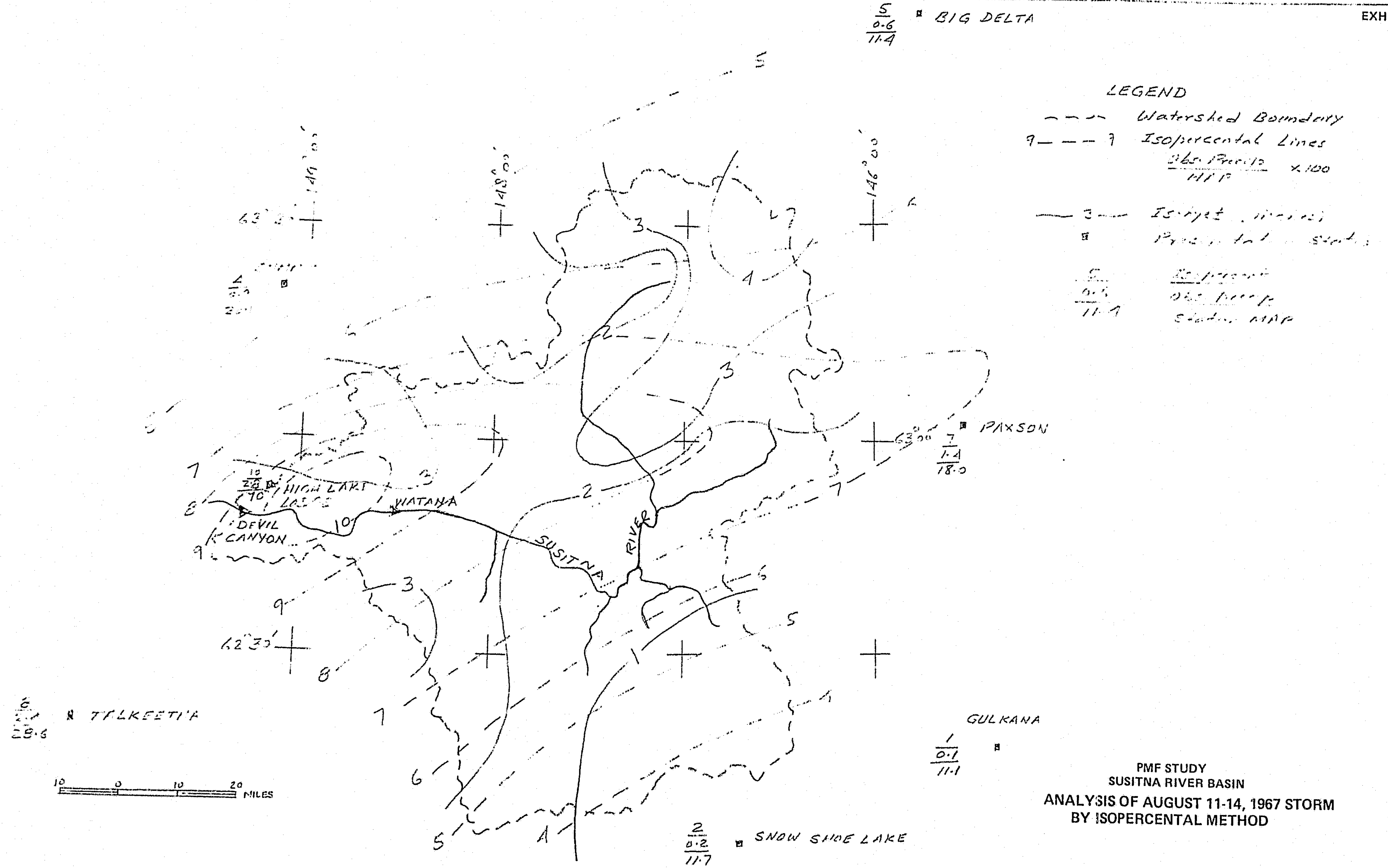


SOURCE:
MAP MAPS FOR CALIFORNIA
PMP FROM NWS HMR NO. 36
(FOR WEST FACING SLOPES OF SIERRA NEVADAS)

PMF STUDY
SUSITNA RIVER BASIN
MEAN ANNUAL PRECIPITATION
VERSUS
6-HOUR, 10 SQUARE MILE
PROBABLE MAXIMUM PRECIPITATION

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

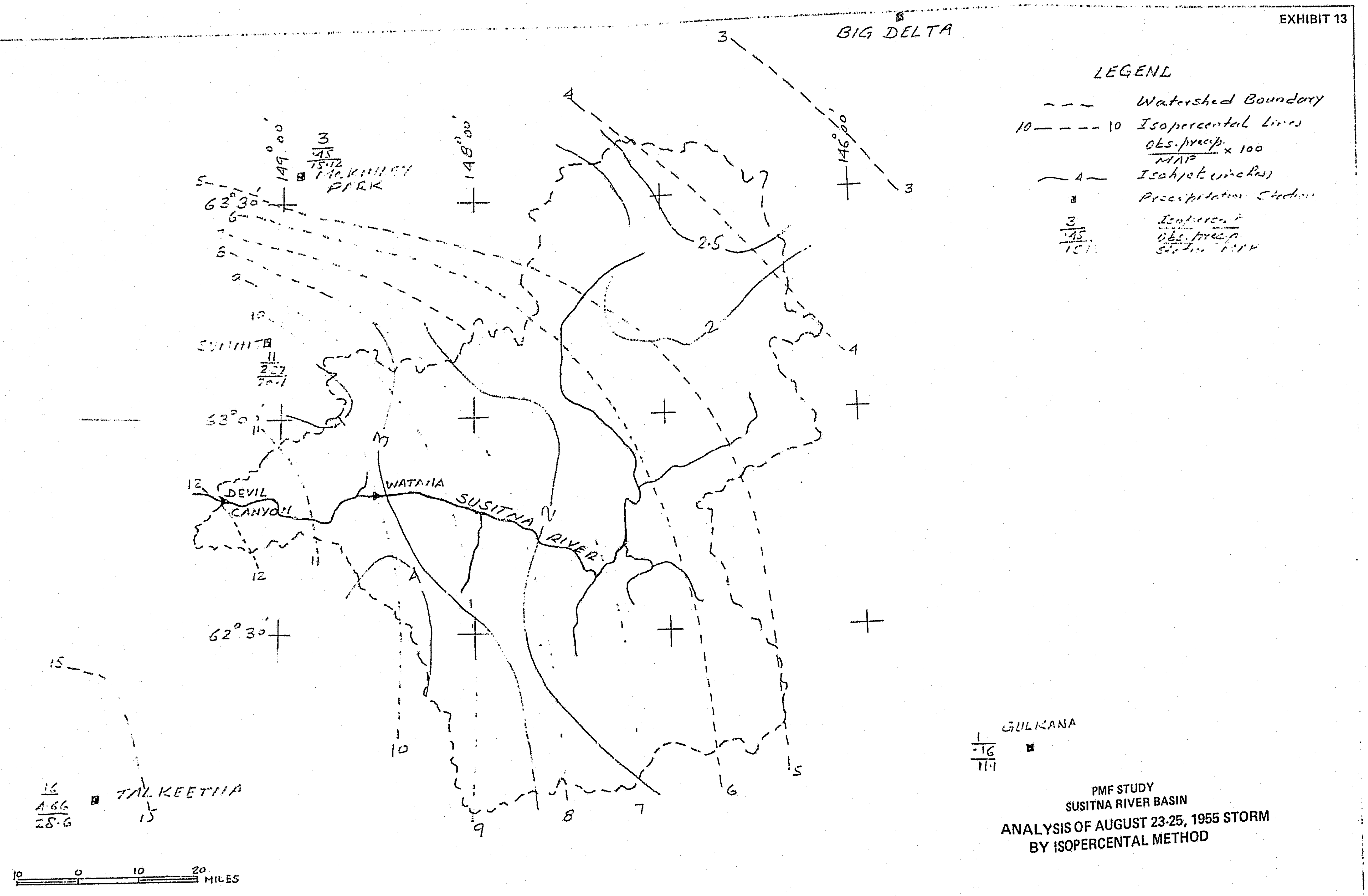
EXHIBIT 12



PMF STUDY
SUSITNA RIVER BASIN
ANALYSIS OF AUGUST 11-14, 1967 STORM
BY ISOPERCENTAL METHOD

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 13

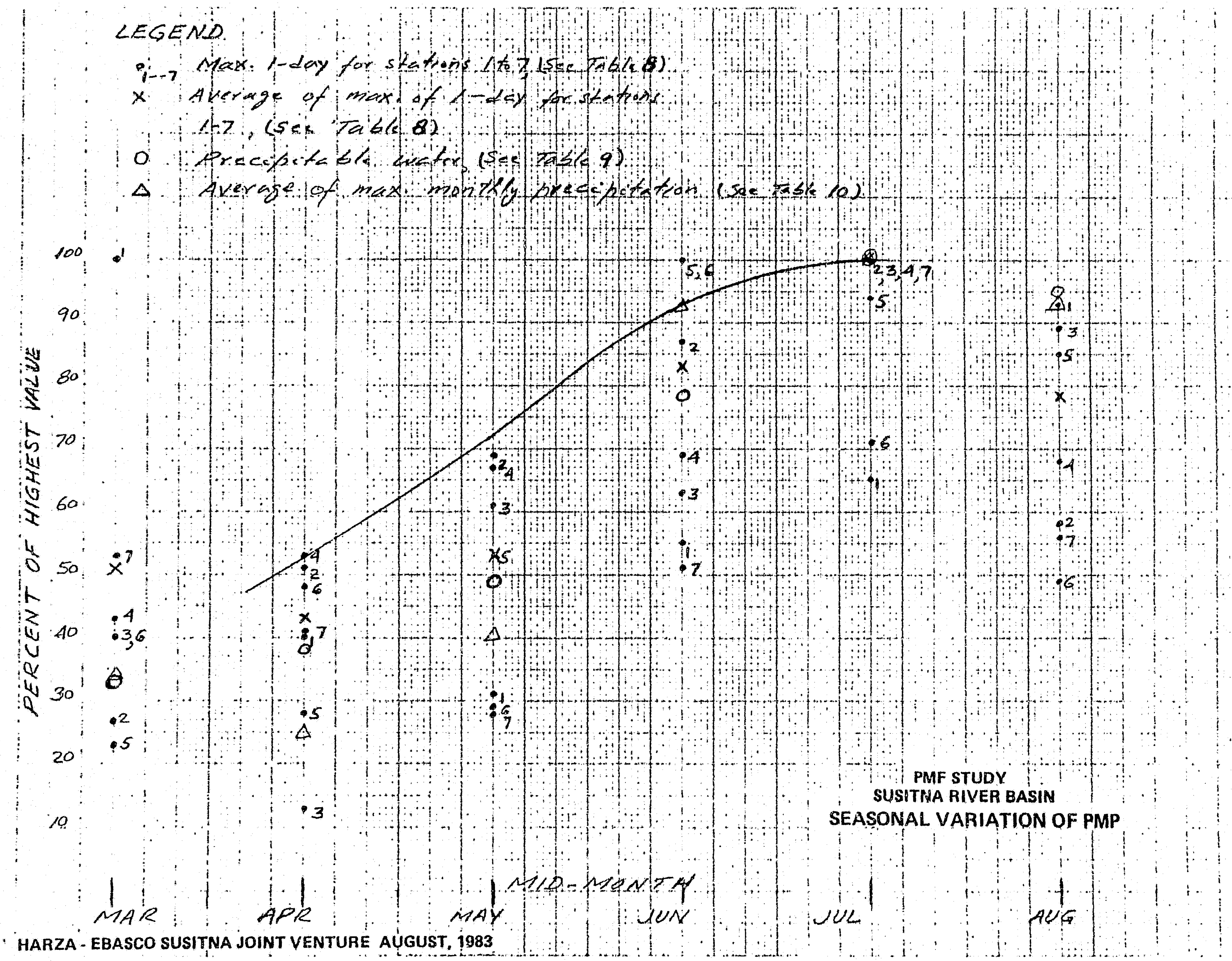


PMF STUDY
SUSITNA RIVER BASIN

ANALYSIS OF AUGUST 23-25, 1955 STORM
BY ISOPERCENTAL METHOD

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

FOLD LENGTH
— 12
— 11
— 8.5
— 8



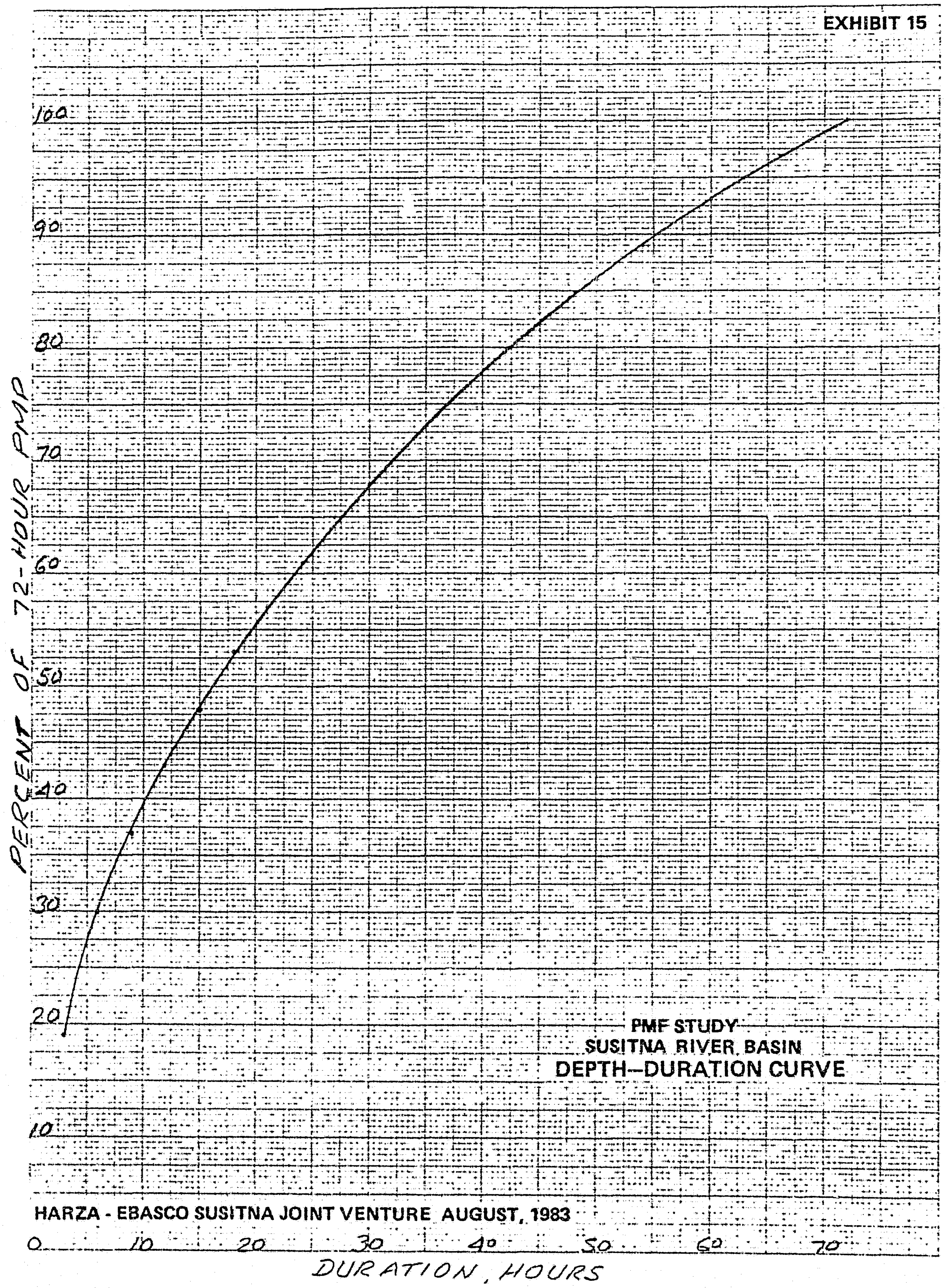
PMF STUDY
SUSITNA RIVER BASIN
SEASONAL VARIATION OF PMP

EXHIBIT 14

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

APPENDIX

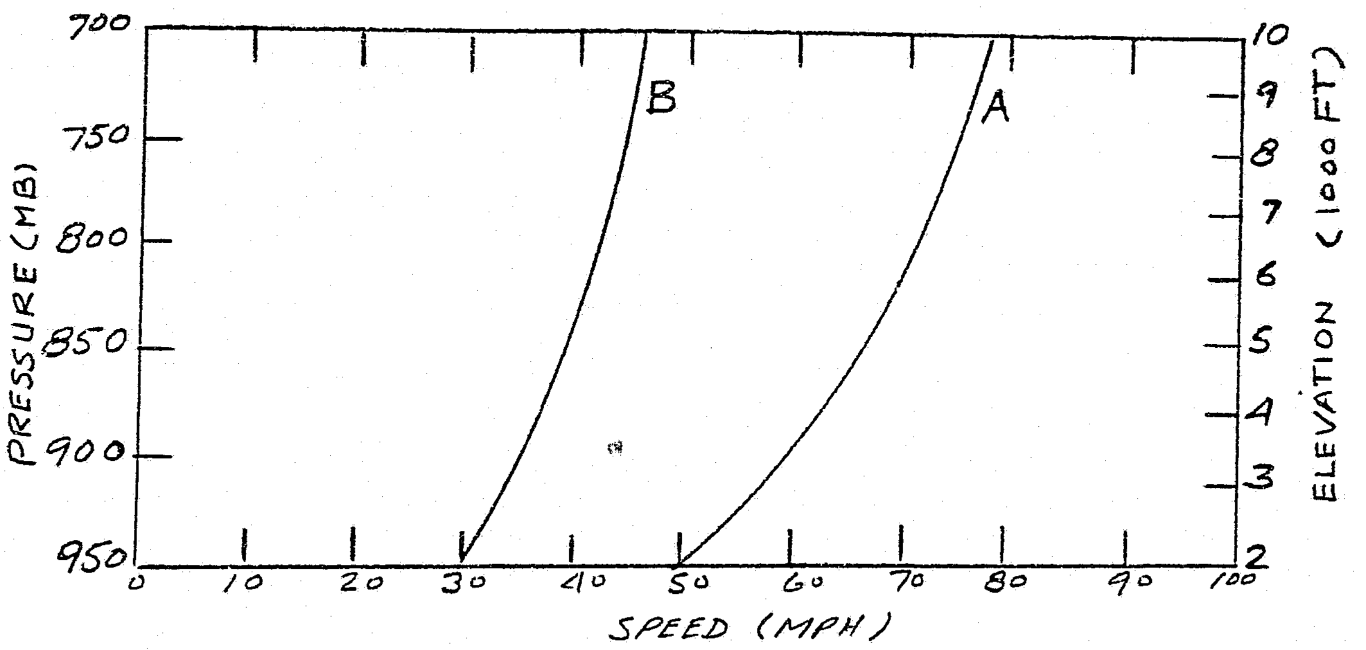
EXHIBIT 15



PMF STUDY
SUSITNA RIVER BASIN
DEPTH—DURATION CURVE

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 16



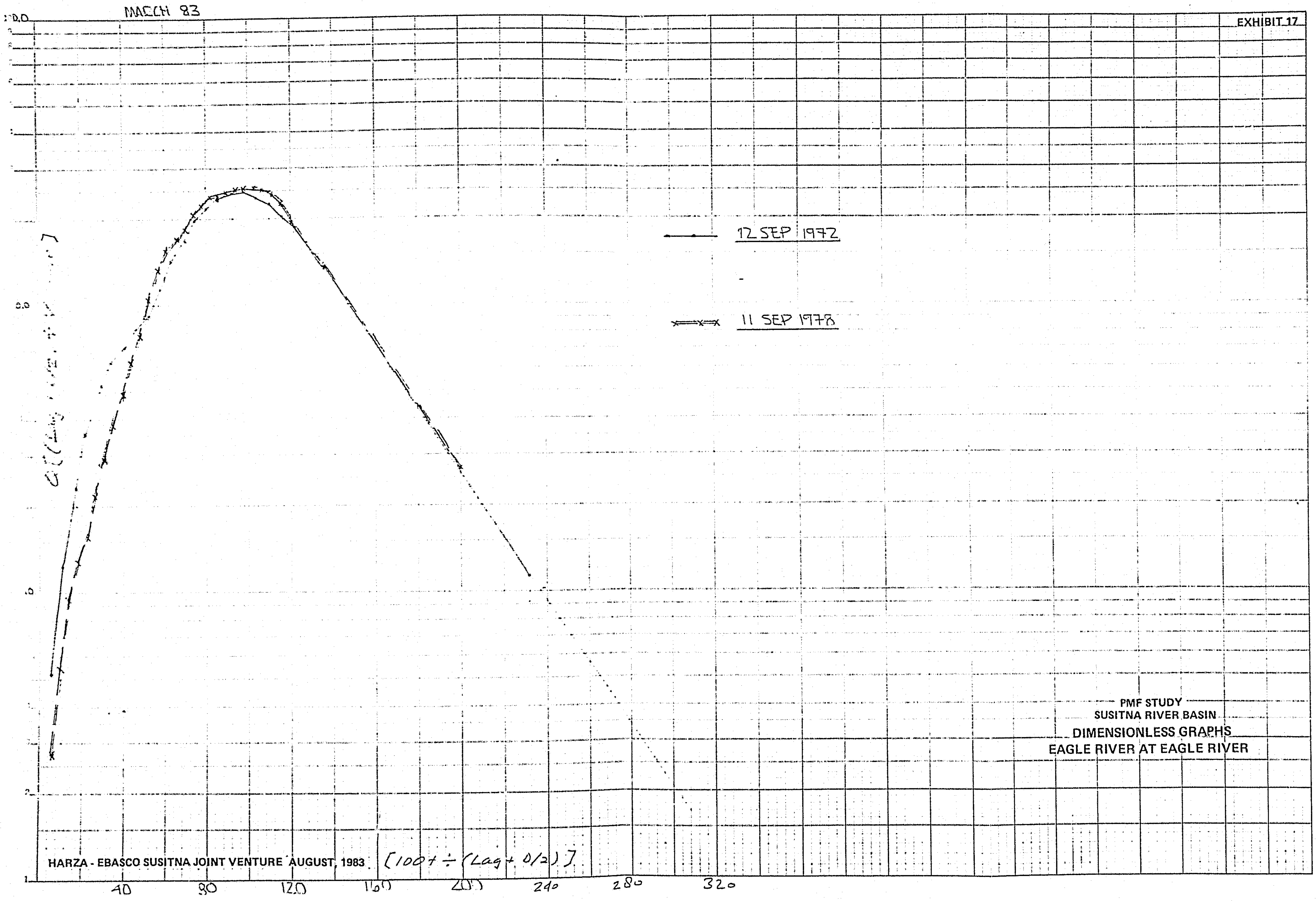
CURVE A : 100-YEAR, 24-HOUR FREE-AIR WIND SPEED, FAIRBANKS

CURVE B: ESTIMATE OF 24-HOUR MAXIMUM SURFACE WIND SPEED (ANEMOMETER LEVEL) OVER UNFORESTED TERRAIN

PMF STUDY
SUSITNA RIVER BASIN
MAXIMUM 24-HOUR WINDS FOR
SNOWMELT SEASON

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

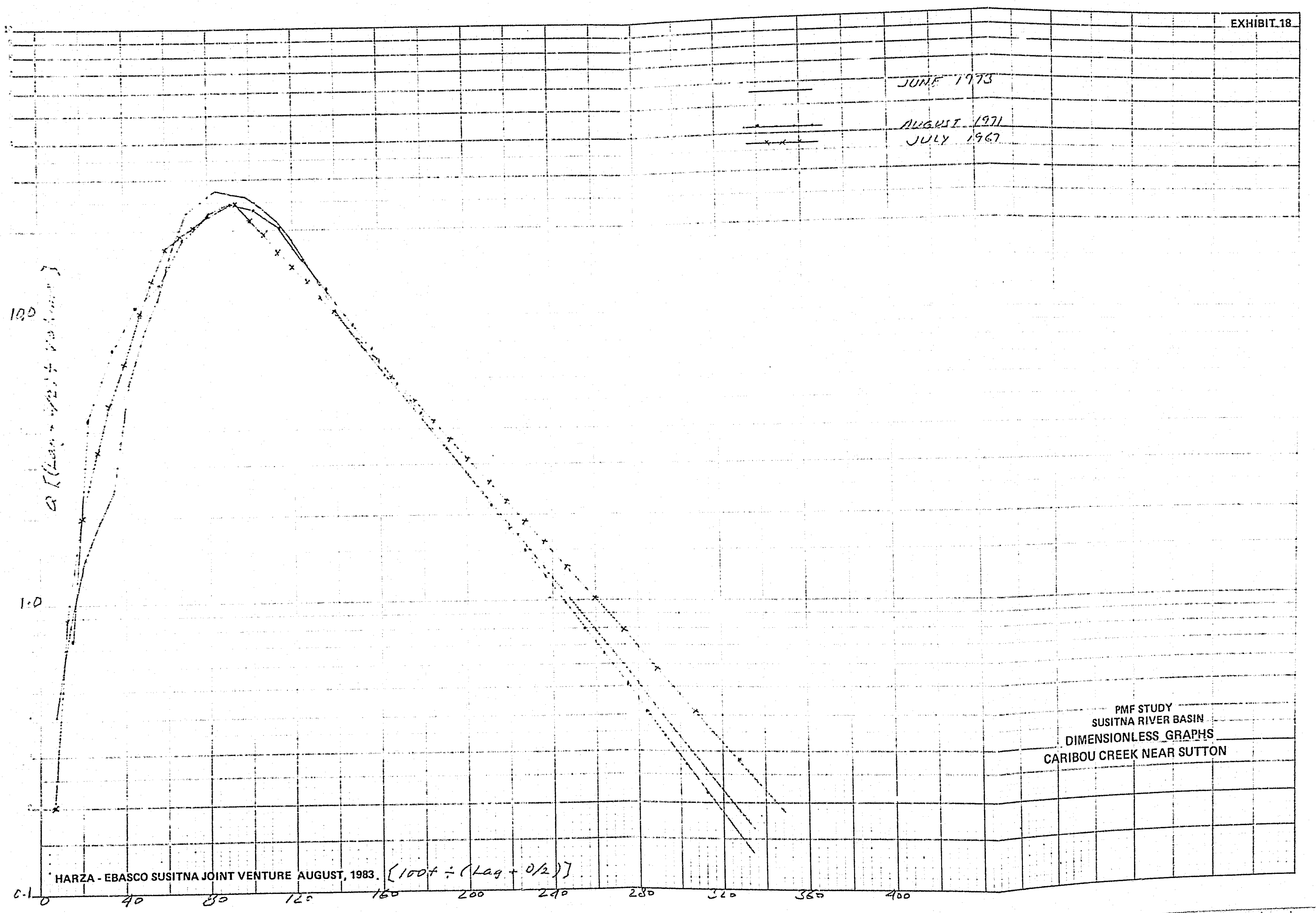
JTH
MARCH 83



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
EAGLE RIVER AT EAGLE RIVER

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

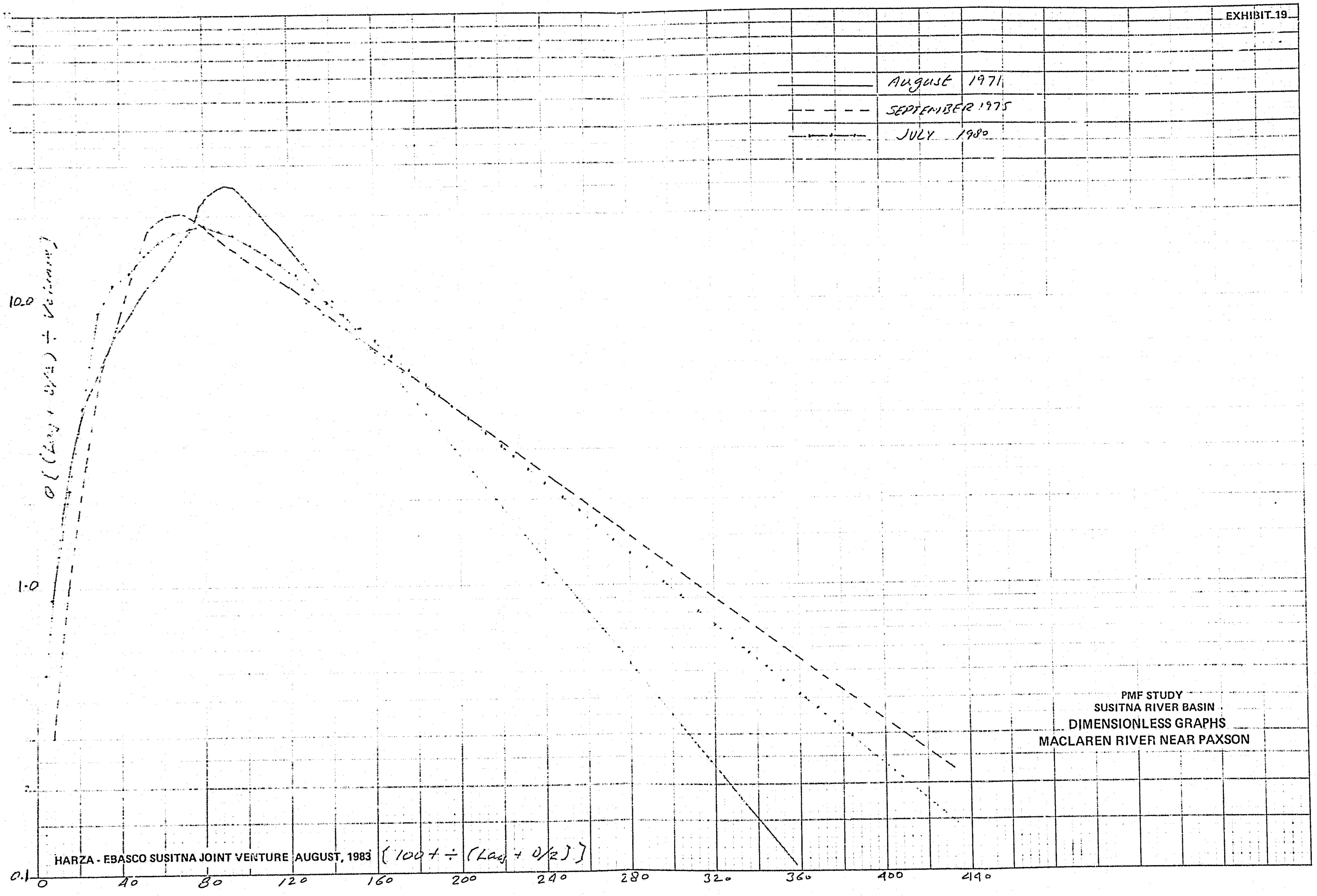
EXHIBIT 18



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
CARIBOU CREEK NEAR SUTTON

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

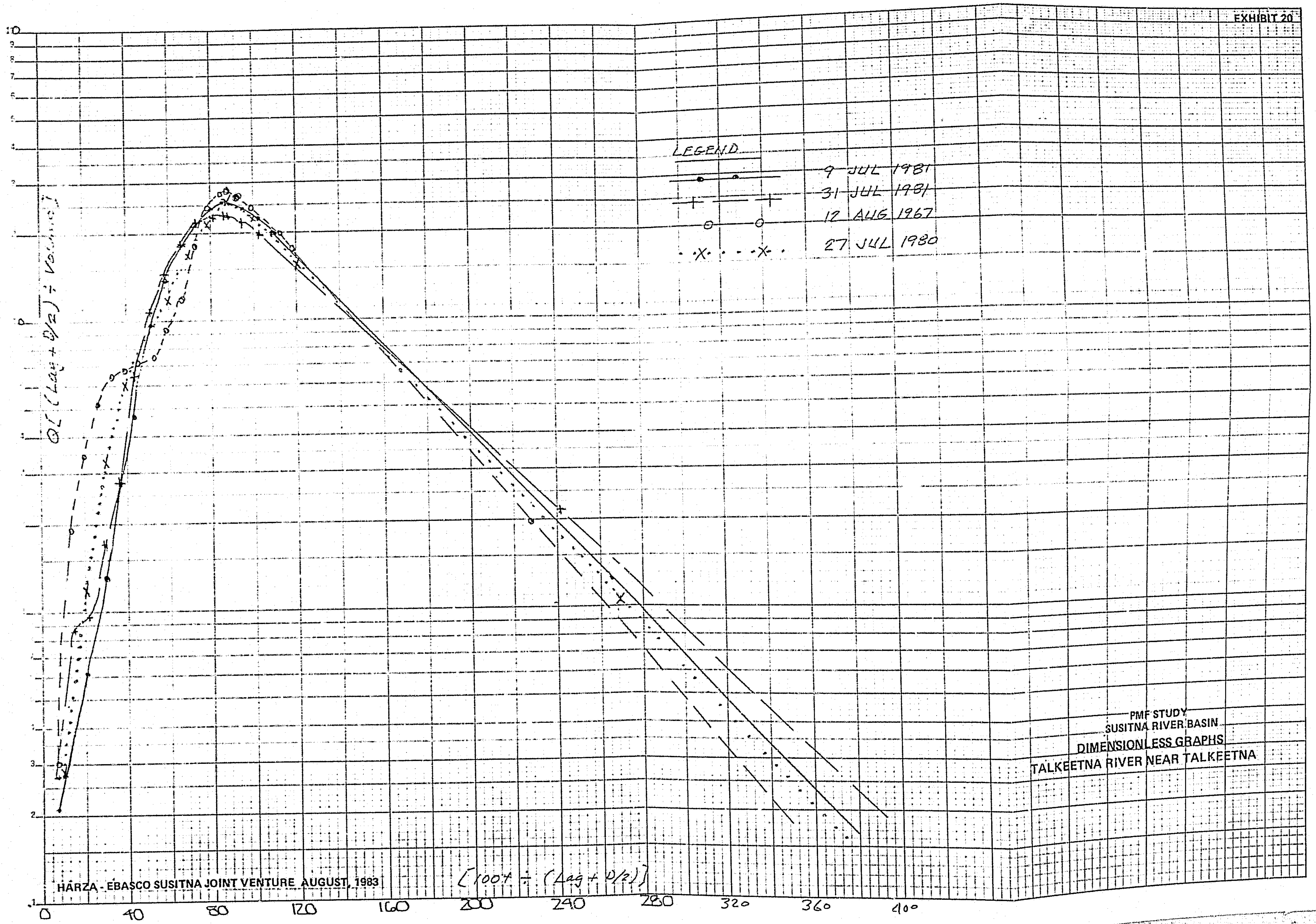
EXHIBIT 19



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
MACLAREN RIVER NEAR PAXSON

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

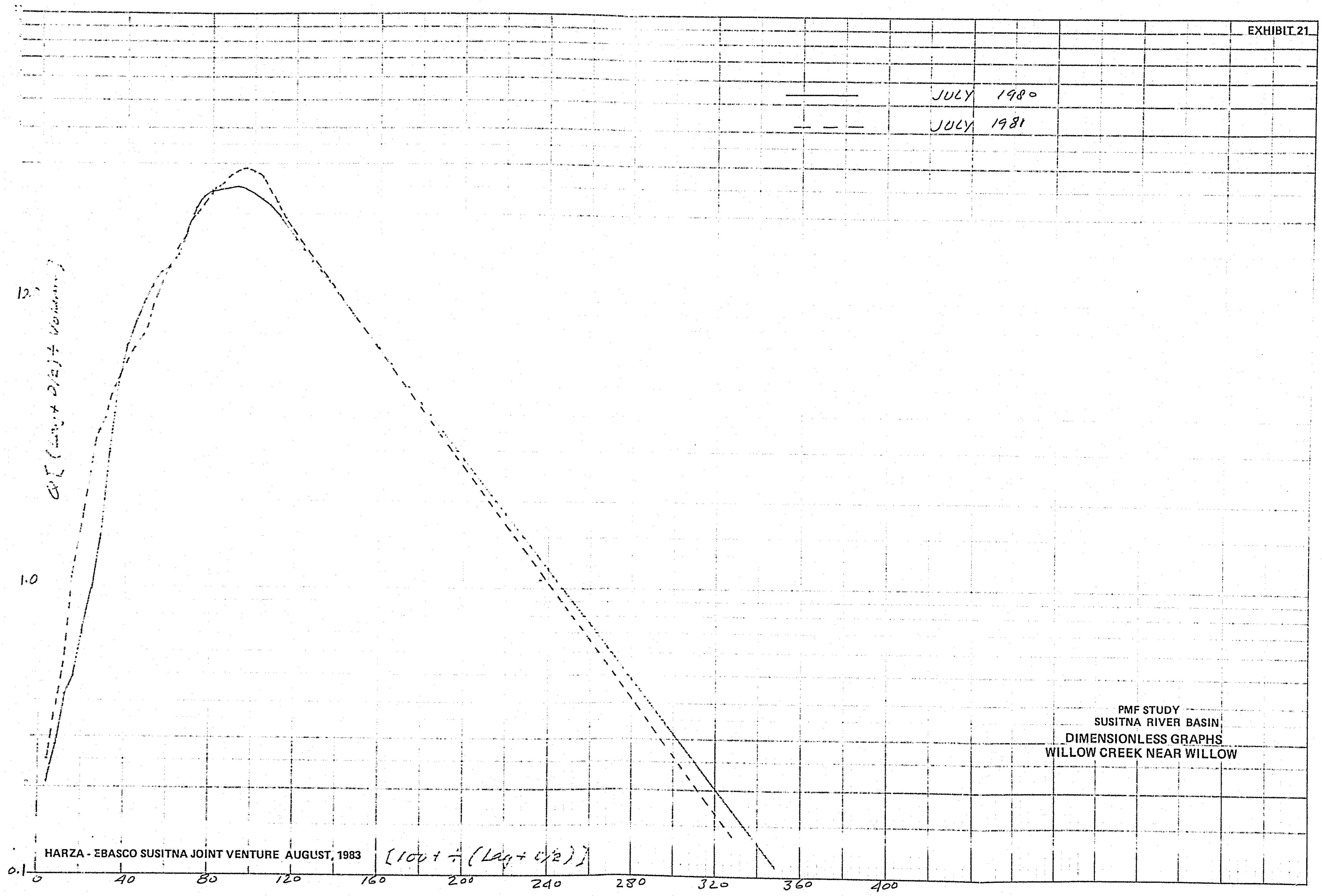
EXHIBIT 20



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
TALKEETNA RIVER NEAR TALKEETNA

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

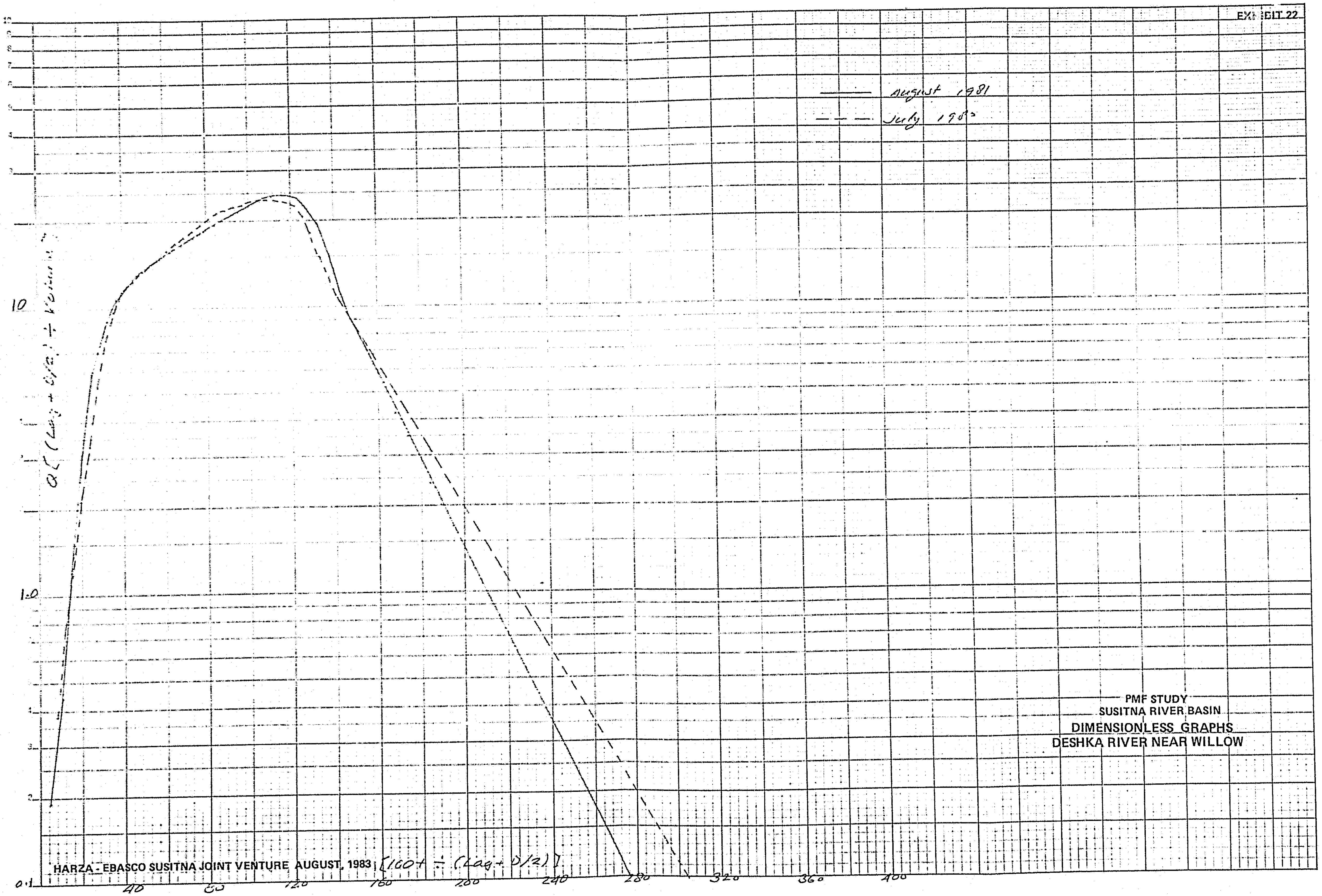
EXHIBIT 21



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
WILLOW CREEK NEAR WILLOW

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

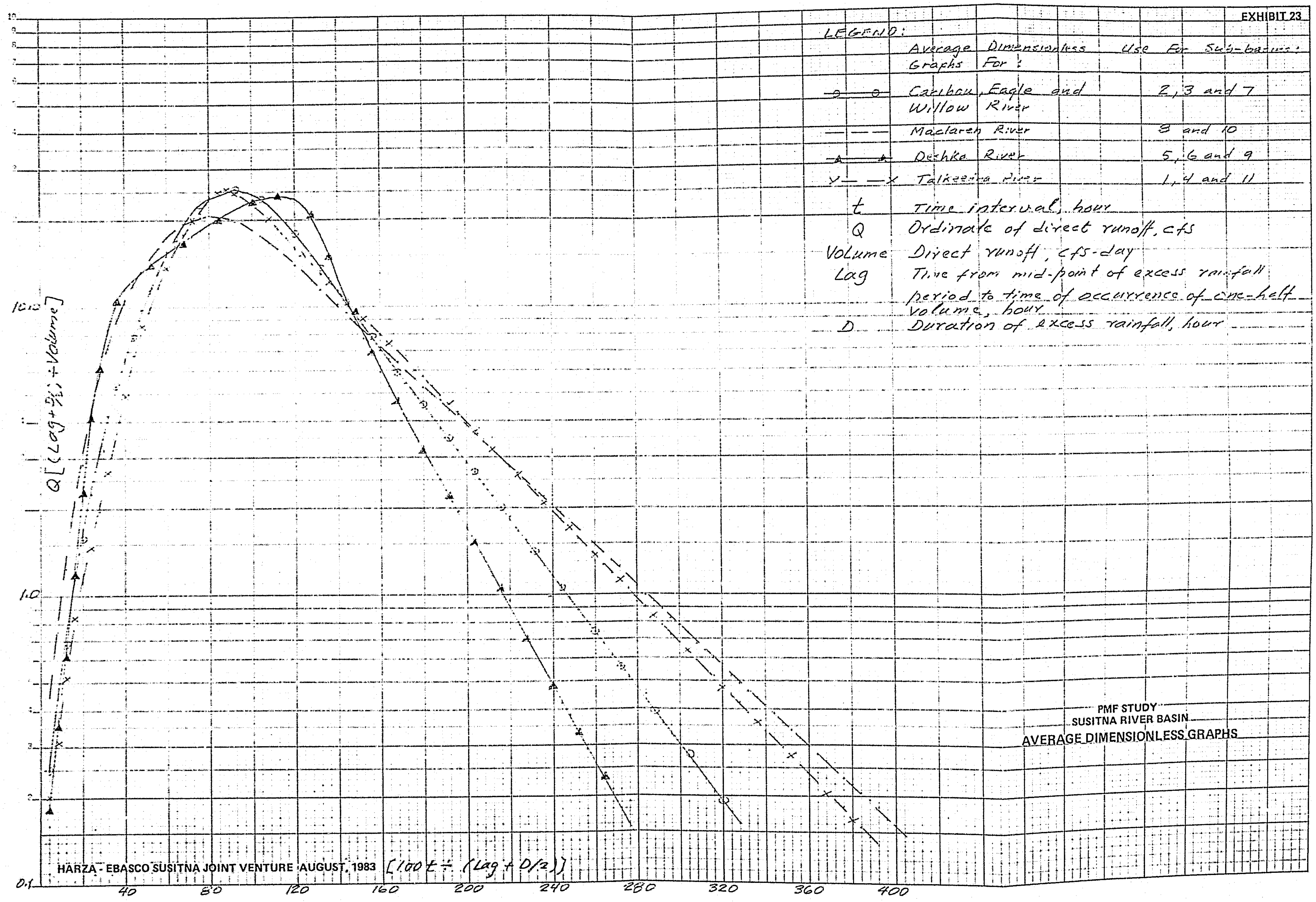
EXHIBIT 22



PMF STUDY
SUSITNA RIVER BASIN
DIMENSIONLESS GRAPHS
DESHKA RIVER NEAR WILLOW

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 23



PMF STUDY
SUSITNA RIVER BASIN
AVERAGE DIMENSIONLESS GRAPHS

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

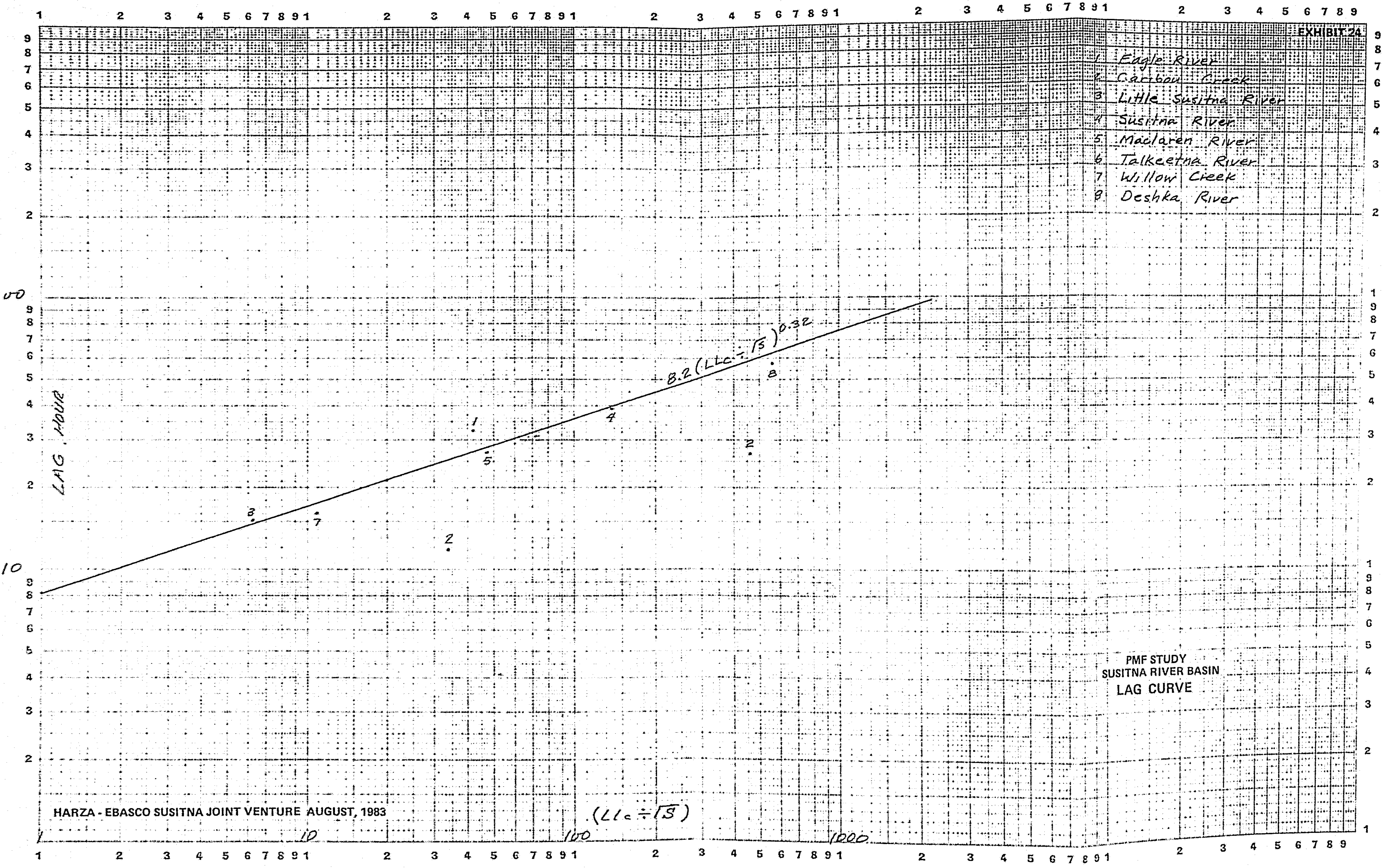


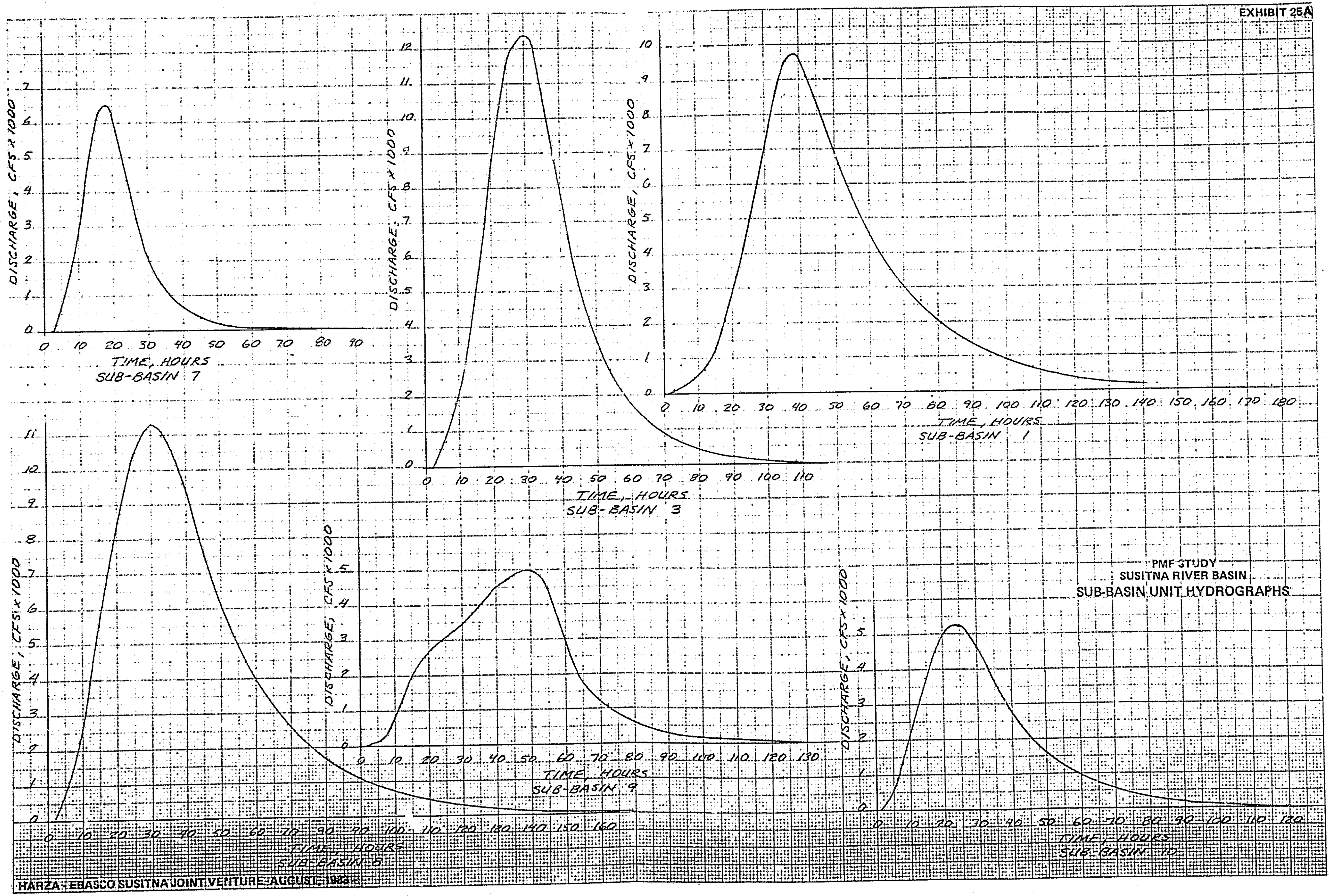
EXHIBIT 24

1 Eagle River
2 Caribou Creek
3 Little Susitna River
4 Susitna River
5 Maclaren River
6 Talkeetna River
7 Willow Creek
8 Deshka River

PMF STUDY
SUSITNA RIVER BASIN
LAG CURVE

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

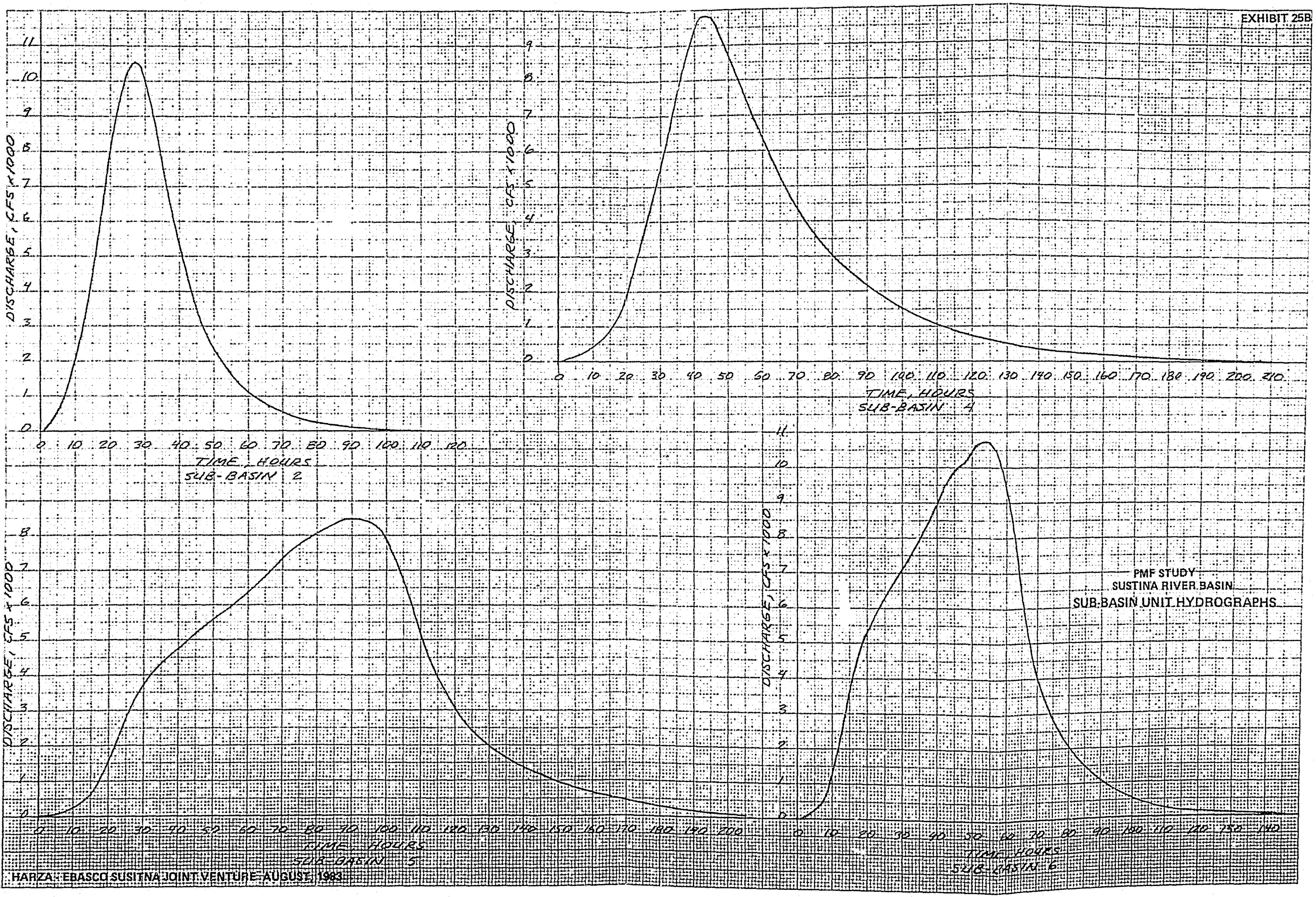
EXHIBIT 25A



PMF STUDY
SUSITNA RIVER BASIN
SUB-BASIN UNIT HYDROGRAPHS

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST 1983

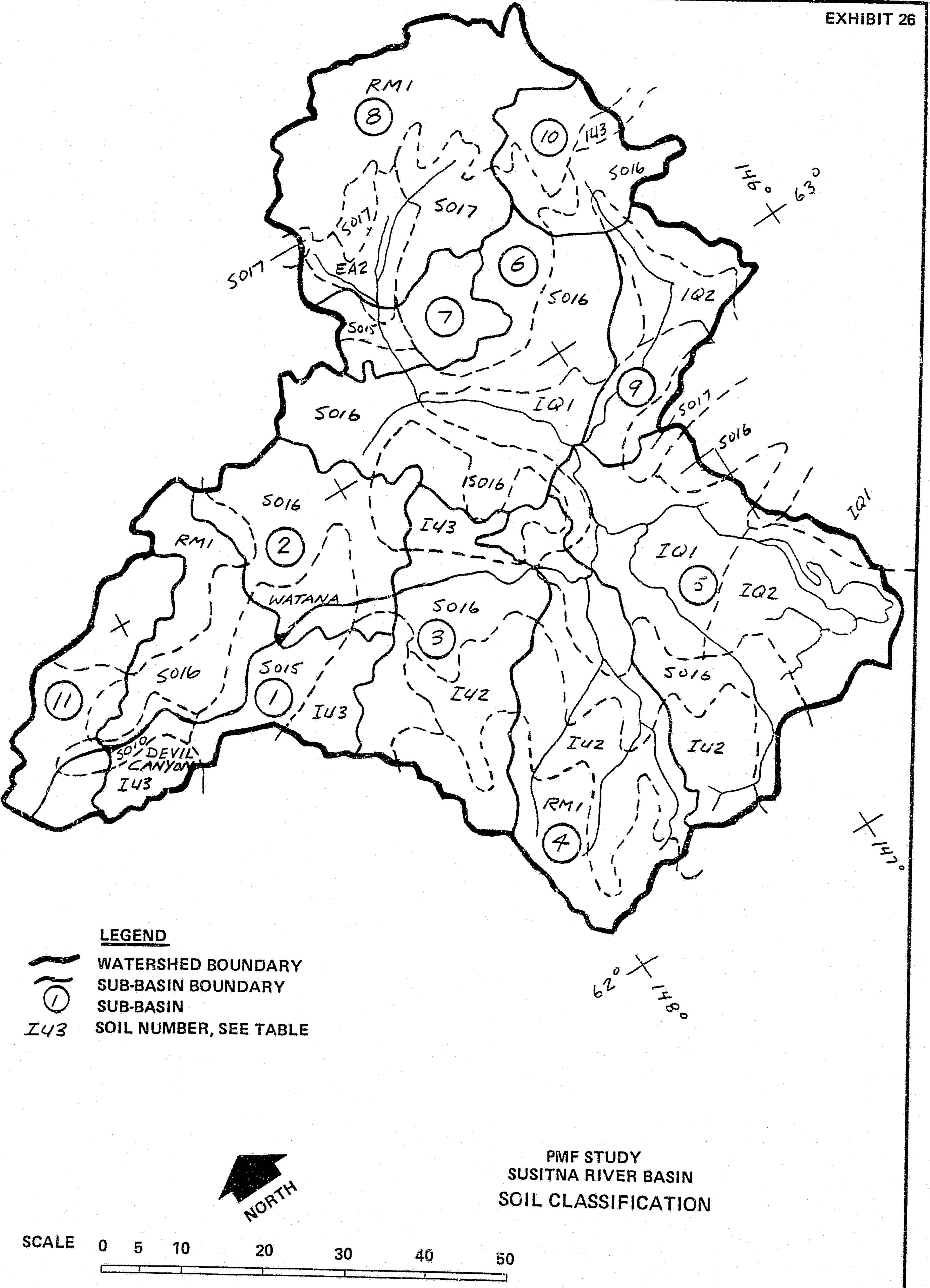
EXHIBIT 25B



PMF STUDY
SUSTINA RIVER BASIN
SUB-BASIN UNIT HYDROGRAPHS

HARZA - EBASCO SUSITNA JOINT VENTURE, AUGUST, 1983

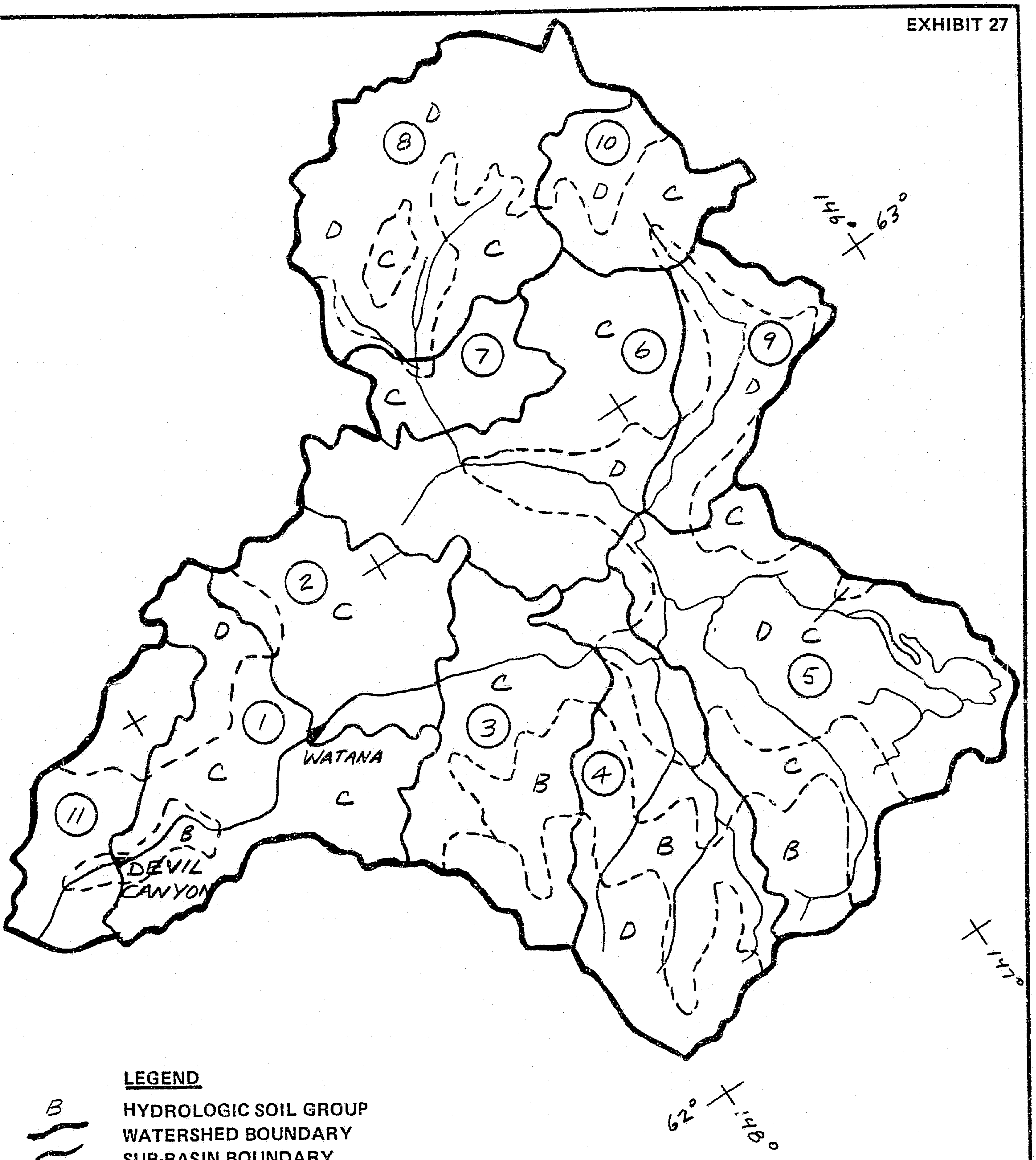
EXHIBIT 26



PMF STUDY
SUSITNA RIVER BASIN
SOIL CLASSIFICATION

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 27



LEGEND

- B HYDROLOGIC SOIL GROUP
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- ① SUB-BASIN
- SOIL CLASSIFICATION BOUNDARY
- RIVER

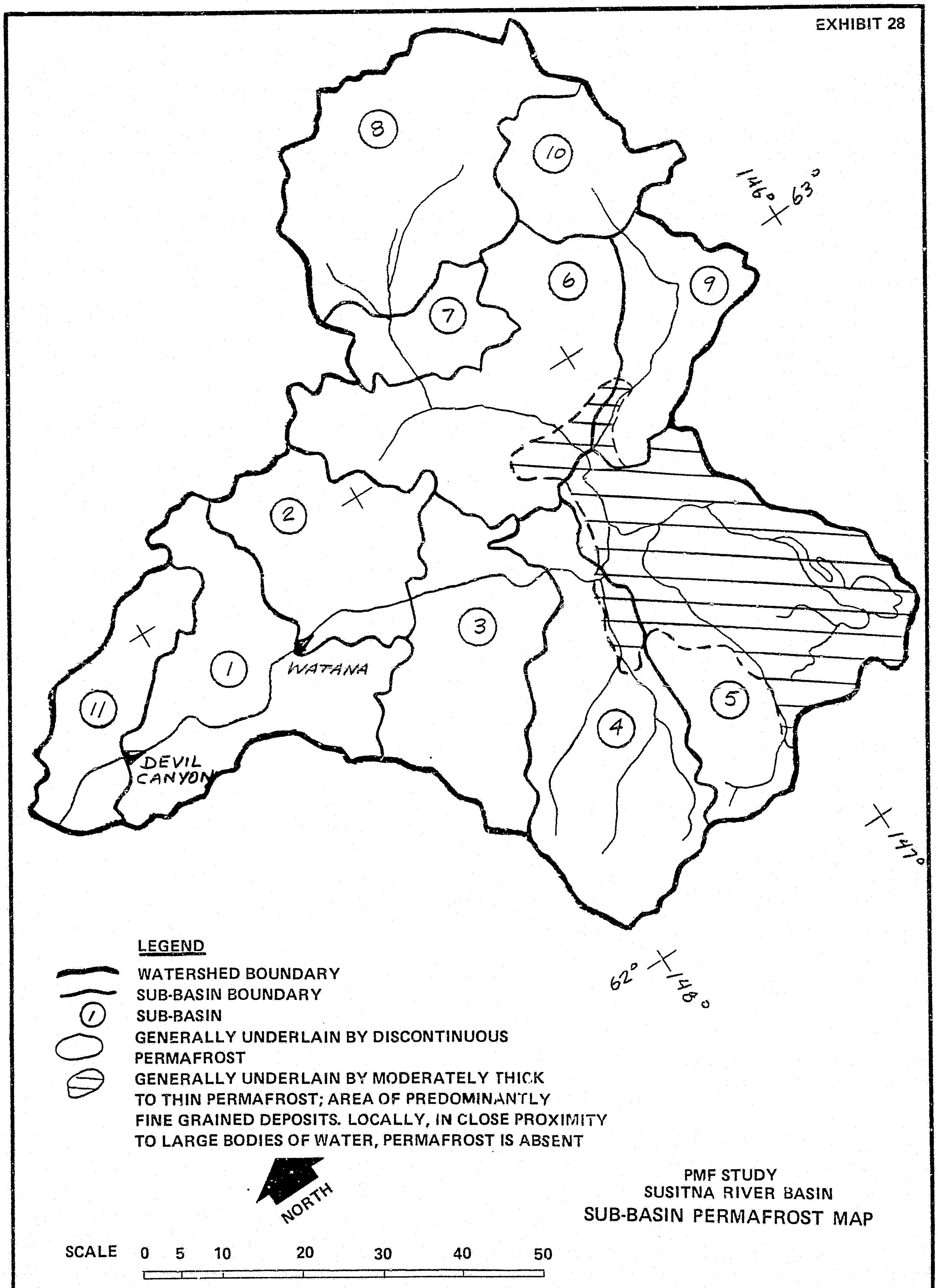
NORTH

PMF STUDY
SUSITNA RIVER BASIN
HYDROLOGIC SOIL GROUPS

SCALE 0 5 10 20 30 40 50

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 28



LEGEND

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

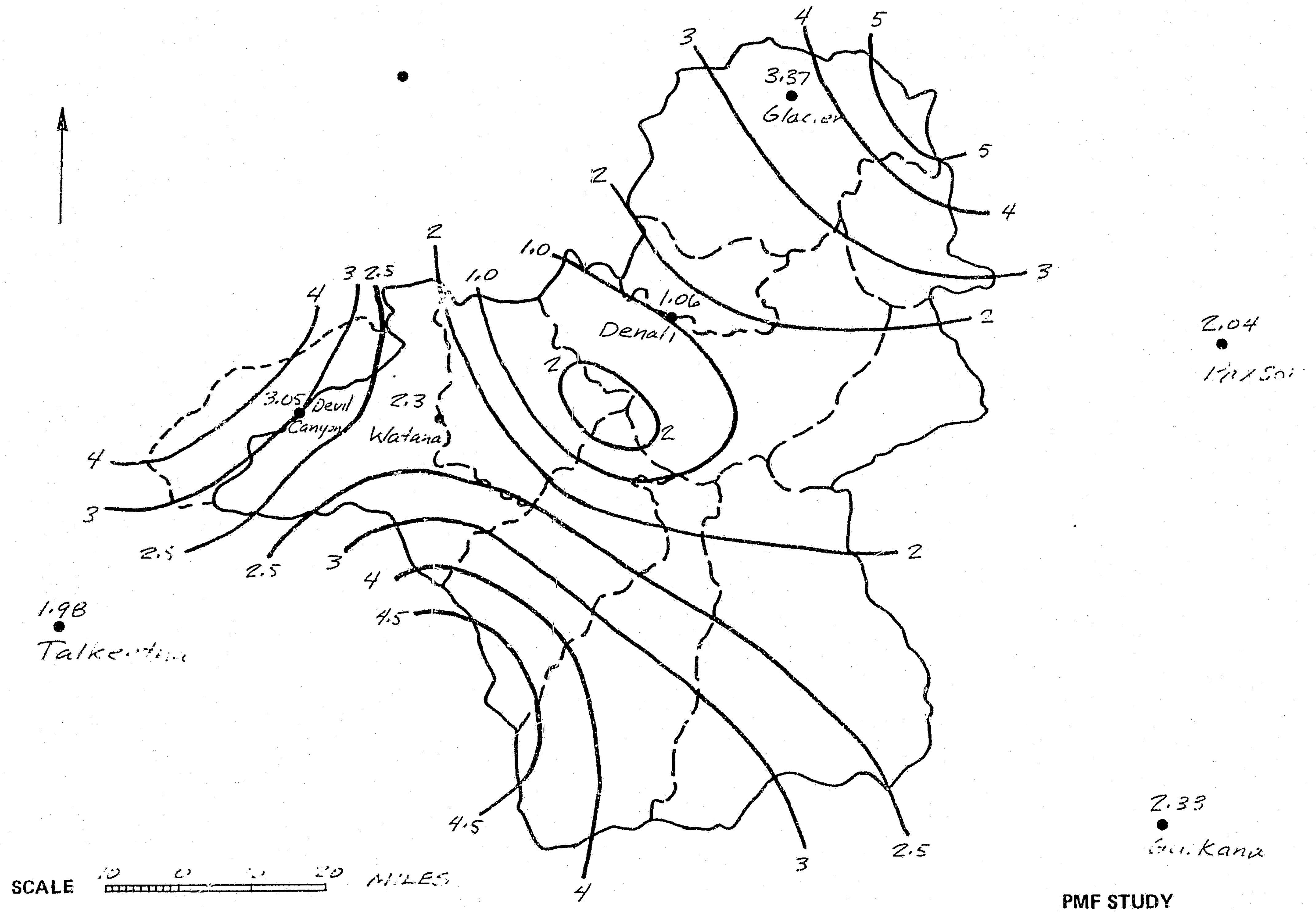
① SUB-BASIN

GENERALLY UNDERLAIN BY DISCONTINUOUS PERMAFROST

GENERALLY UNDERLAIN BY MODERATELY THICK TO THIN PERMAFROST; AREA OF PREDOMINANTLY FINE GRAINED DEPOSITS. LOCALLY, IN CLOSE PROXIMITY TO LARGE BODIES OF WATER, PERMAFROST IS ABSENT

PMF STUDY
SUSITNA RIVER BASIN
SUB-BASIN PERMAFROST MAP

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



LEGEND

● PRECIPITATION STATION

- - - DRAINAGE BASIN BOUNDARIES

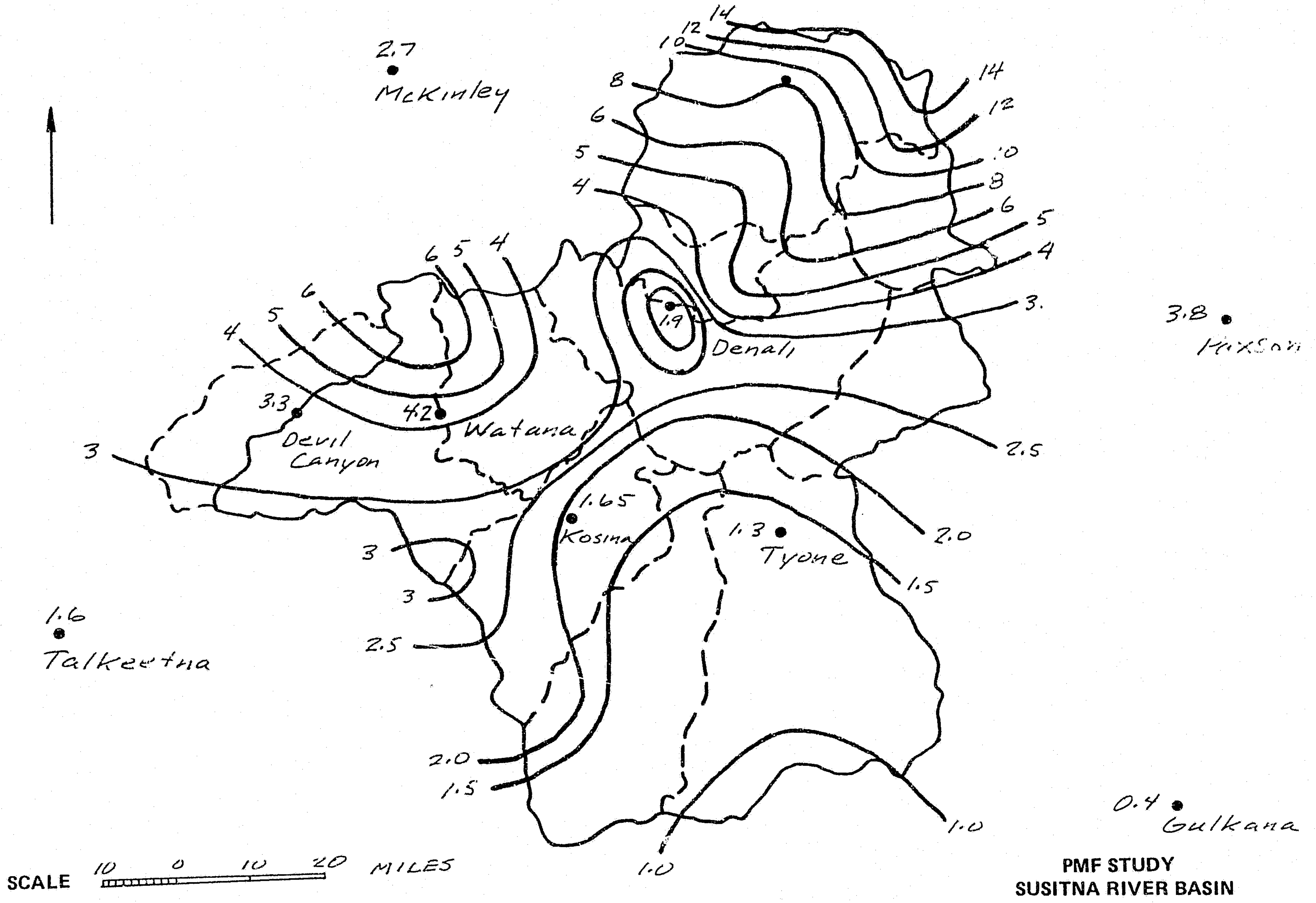
10 — 10 ISOHYETAL, INCHES

PMF STUDY
SUSITNA RIVER BASIN

ISOHYETAL MAP OF
JULY 25-31, 1980 STORM

EXHIBIT 29

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



PMF STUDY
SUSITNA RIVER BASIN
ISOHYETAL MAP OF JULY 4-15, 1981 STORM

LEGEND

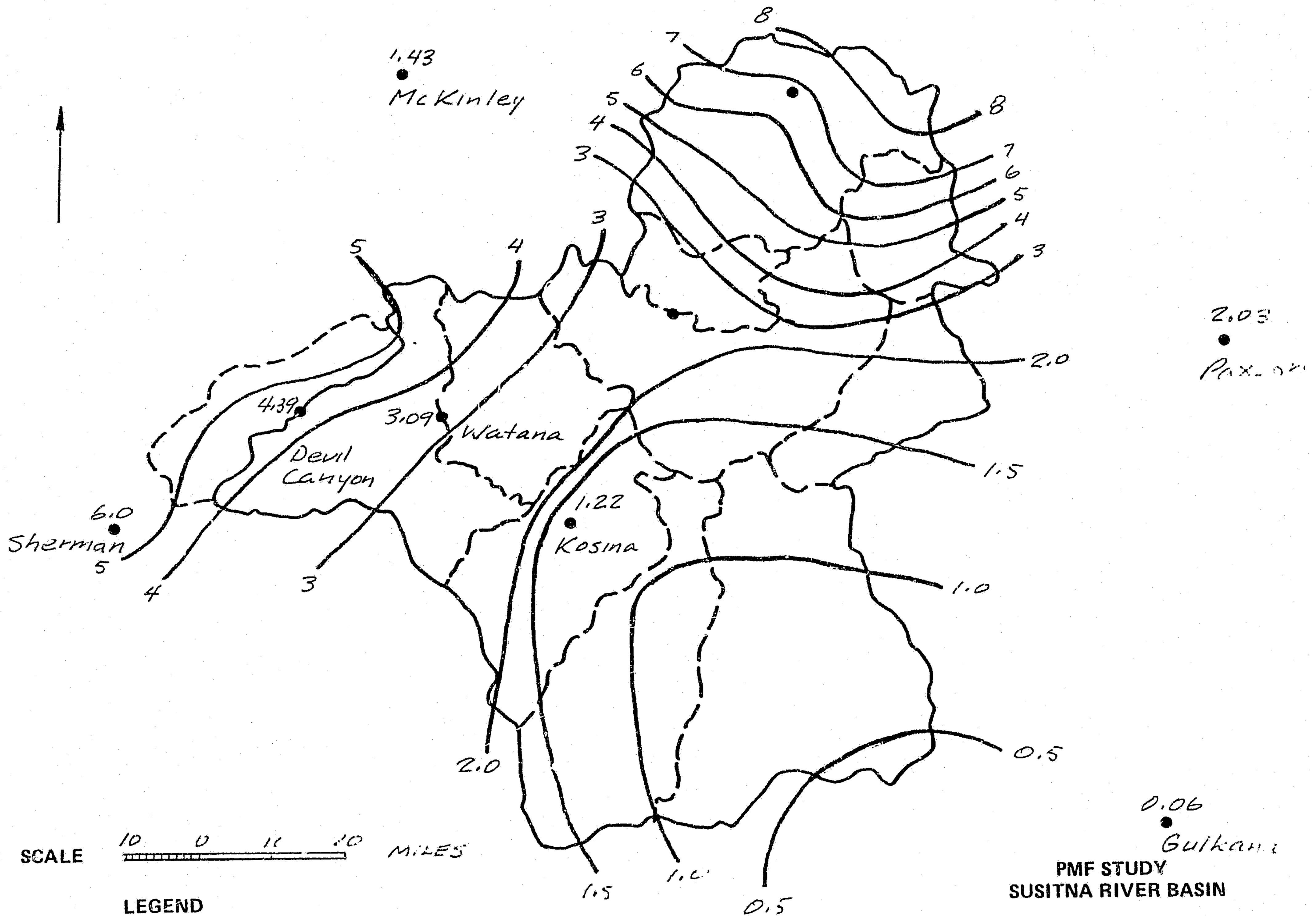
● PRECIPITATION STATION

— — DRAINAGE BASIN BOUNDARIES

10—10 ISOHYETAL, INCHES

EXHIBIT 30

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



LEGEND

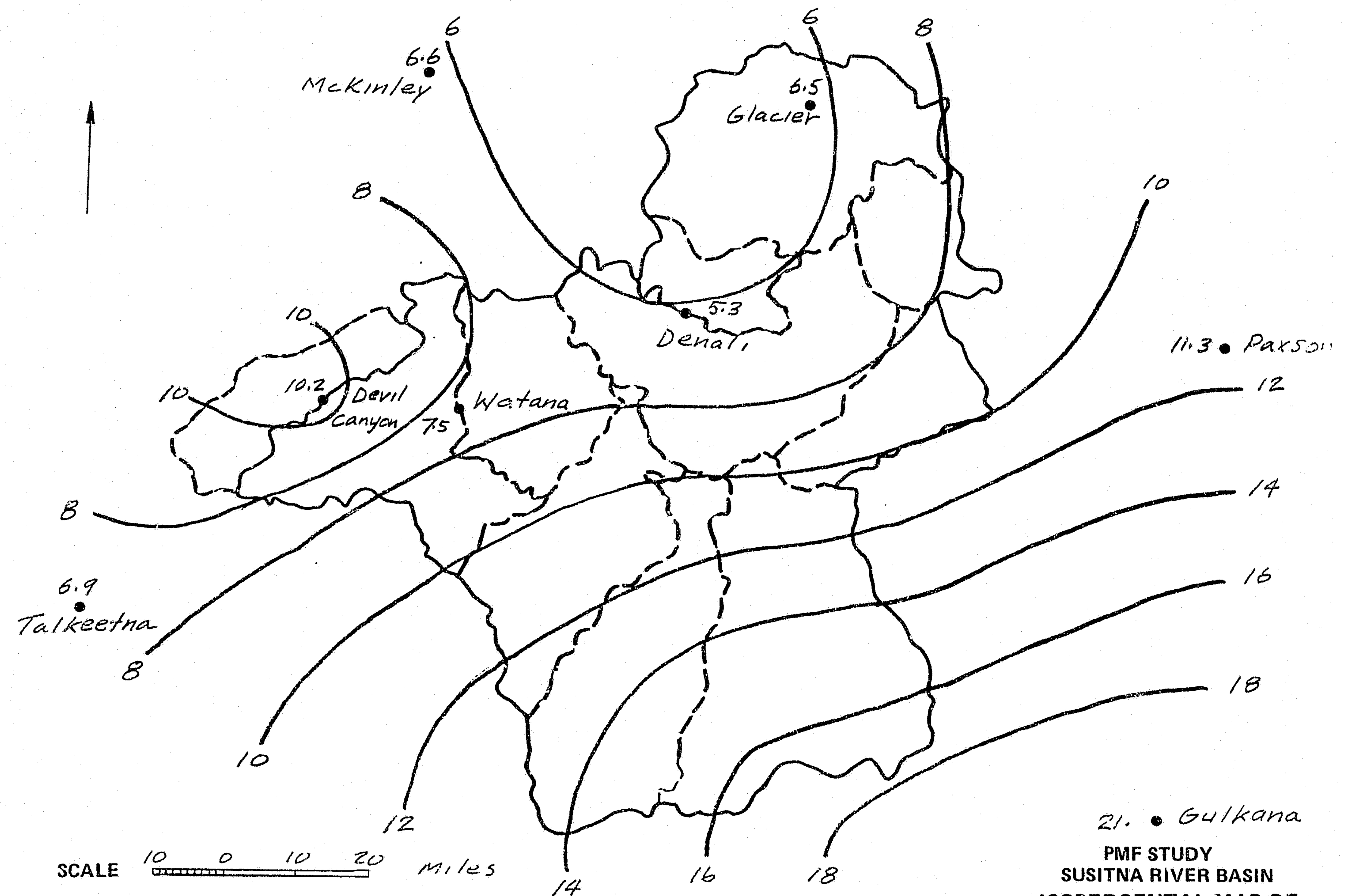
● PRECIPITATION STATION
– – – DRAINAGE BASIN BOUNDARIES
10 — 10 ISOHYETAL, INCHES

PMF STUDY
SUSITNA RIVER BASIN

ISOHYETAL MAP OF SEPTEMBER 11-22, 1982 STORM

EXHIBIT 31

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



PMF STUDY
SUSITNA RIVER BASIN

ISOPERCENTAL MAP OF JULY 25-31, 1980 STORM

LEGEND

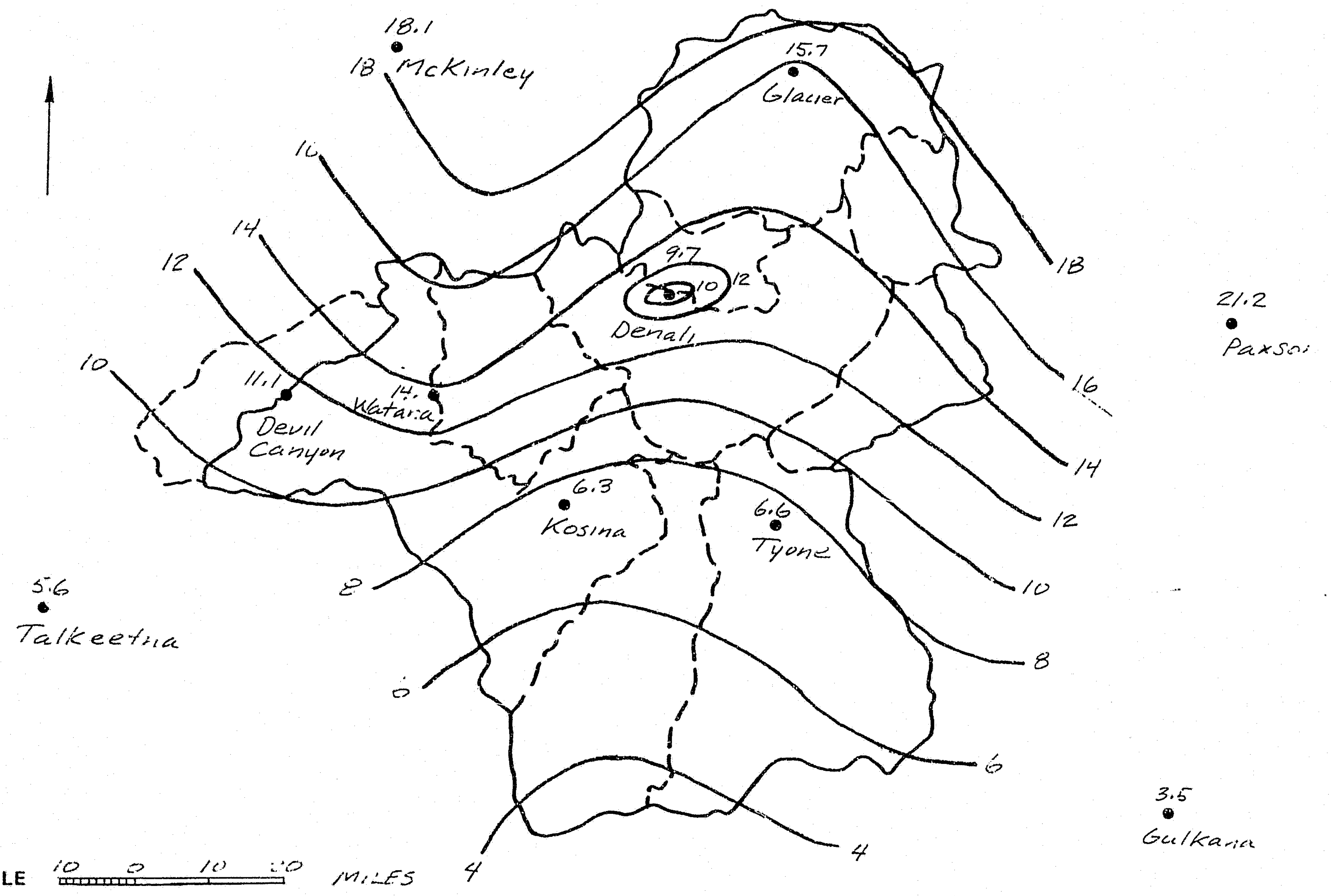
● PRECIPITATION STATION

– – – – DRAINAGE BASIN BOUNDARIES

10—10 ISOPERCENTAL , PERCENT

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 32



LEGEND

● PRECIPITATION STATION

- - - DRAINAGE BASIN BOUNDARIES

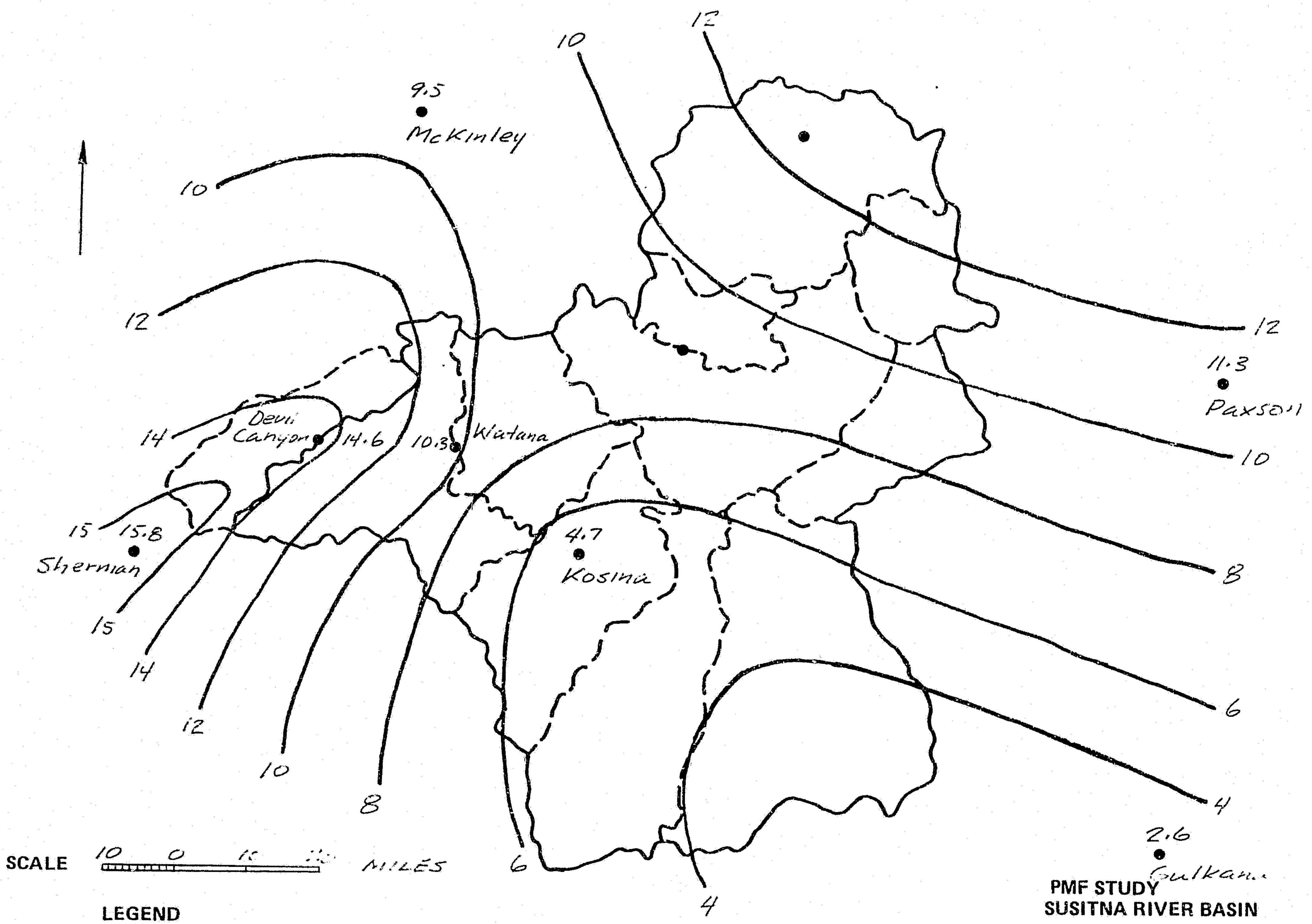
10 ISOPERCENTAL, PERCENT

PMF STUDY
SUSITNA RIVER BASIN

ISOPERCENTAL MAP OF
JULY 4-15, 1981 STORM

EXHIBIT 33

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



LEGEND

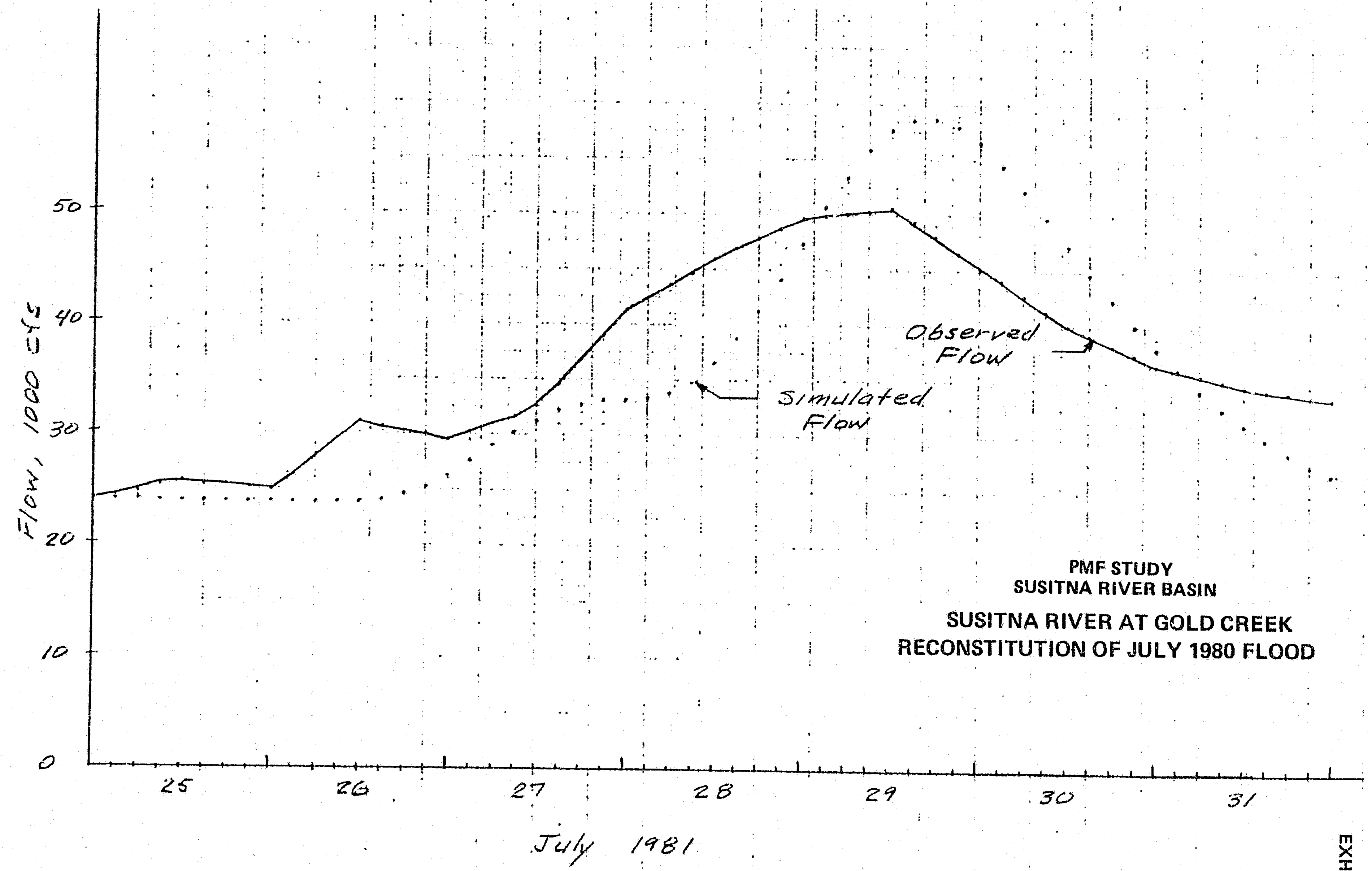
● PRECIPITATION STATION
— — — DRAINAGE BASIN BOUNDARIES
10 — 10 ISOPERCENTAL, PERCENT

PMF STUDY
SUSITNA RIVER BASIN

ISOPERCENTAL MAP OF SEPTEMBER 11-22, 1982 STORM

EXHIBIT 34

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

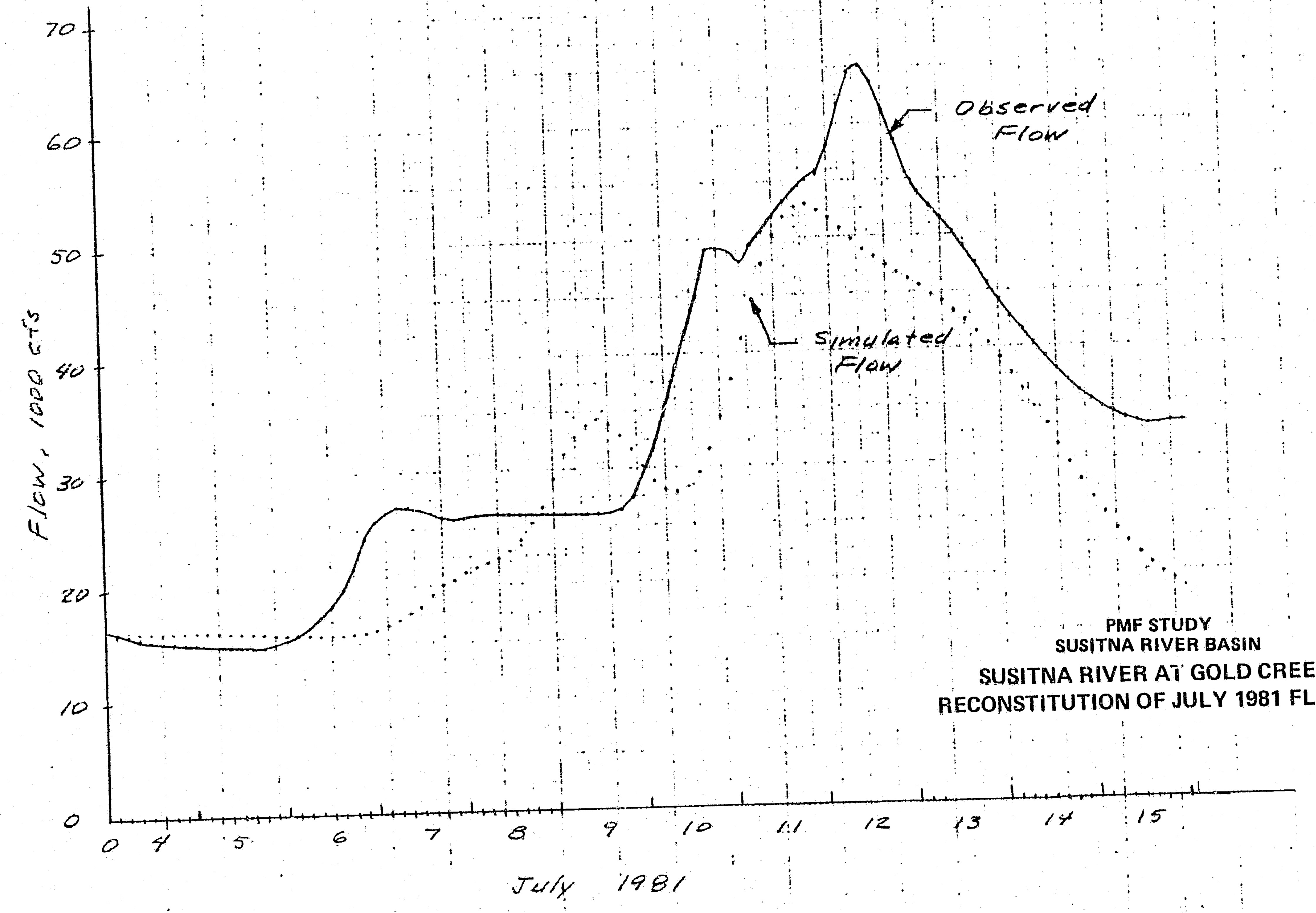


PMF STUDY
SUSITNA RIVER BASIN

SUSITNA RIVER AT GOLD CREEK
RECONSTITUTION OF JULY 1980 FLOOD

EXHIBIT 35

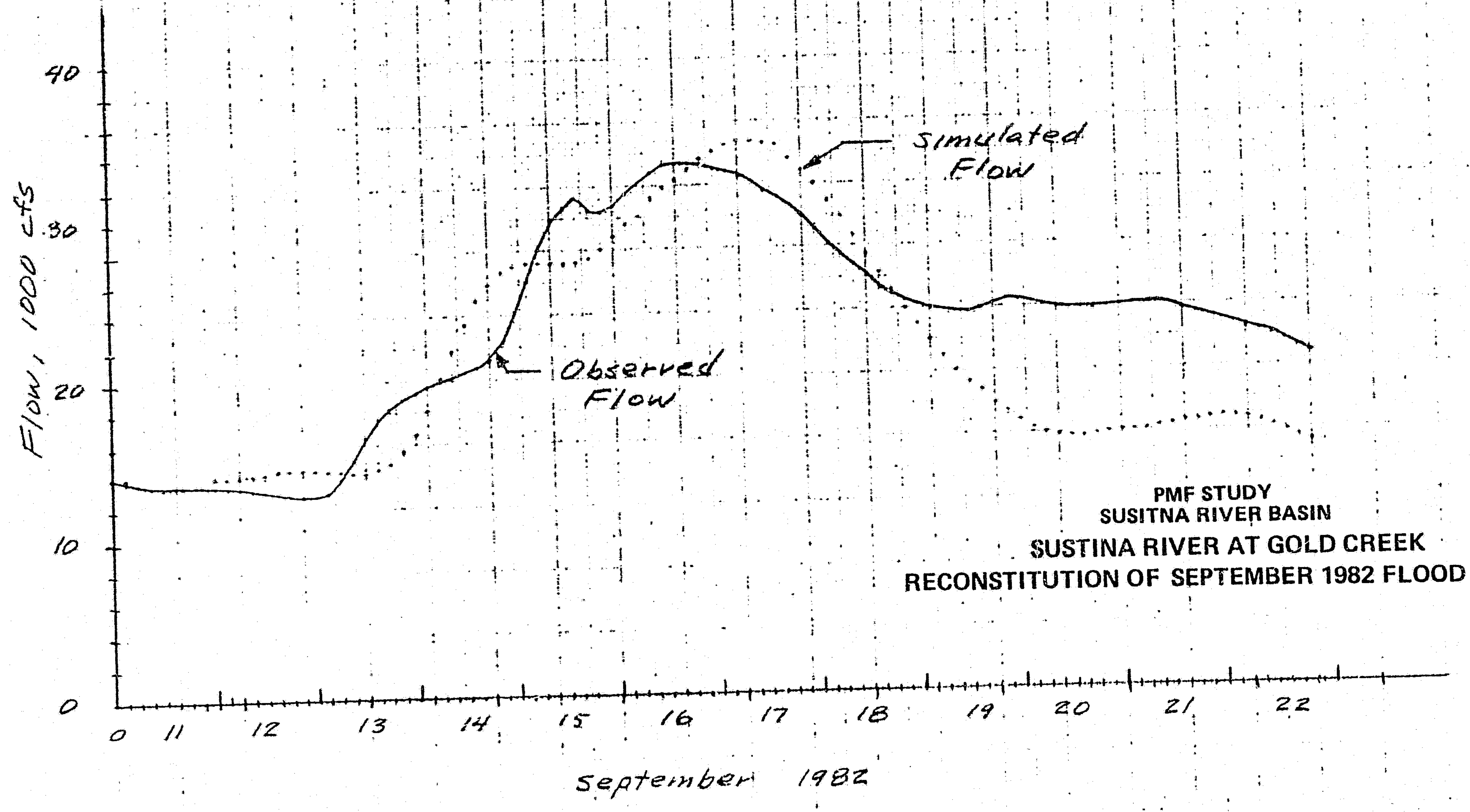
HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



PMF STUDY
SUSITNA RIVER BASIN
SUSITNA RIVER AT GOLD CREEK
RECONSTITUTION OF JULY 1981 FLOOD

EXHIBIT 36

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

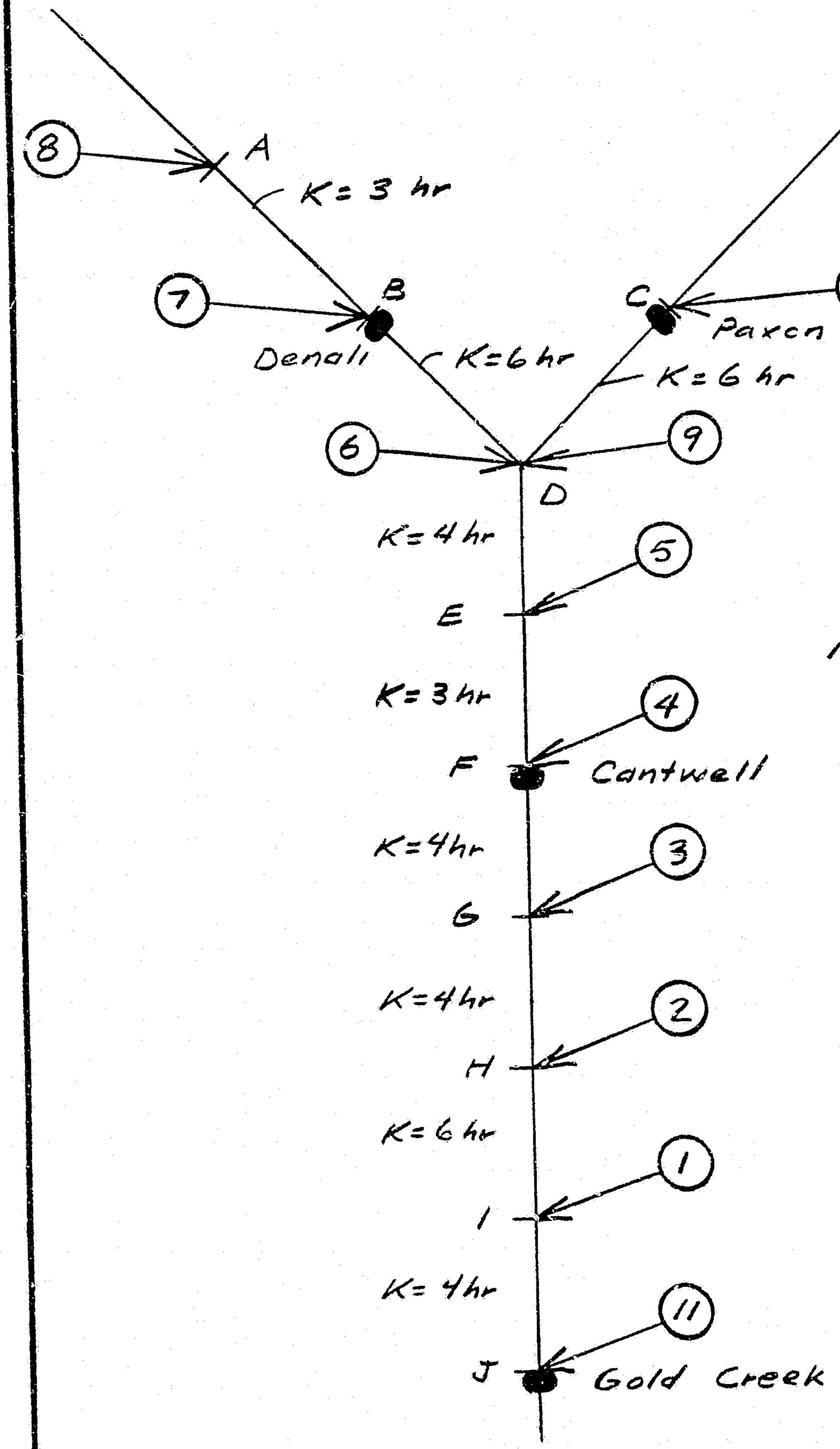


PMF STUDY
SUSITNA RIVER BASIN
SUSTINA RIVER AT GOLD CREEK
RECONSTITUTION OF SEPTEMBER 1982 FLOOD

EXHIBIT 37

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 38



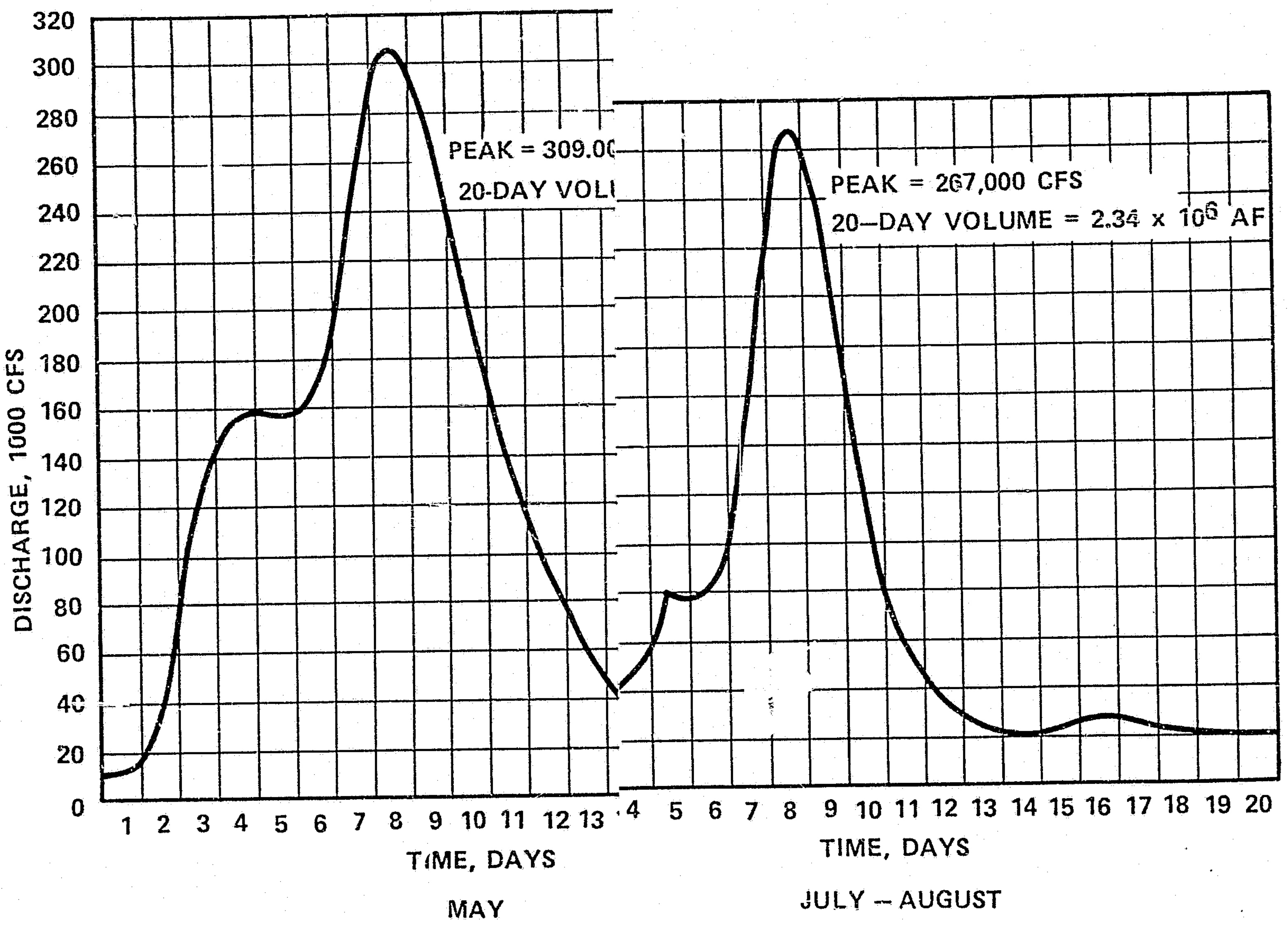
Note : Muskingum x equal to 0.2 for all basins. Muskingum K shown on diagram.

● Observed hydrograph available

PMF STUDY
SUSITNA RIVER BASIN
CHANNEL ROUTING SCHEME WITH
MUSKINGUM ROUTING COEFFICIENTS

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 39



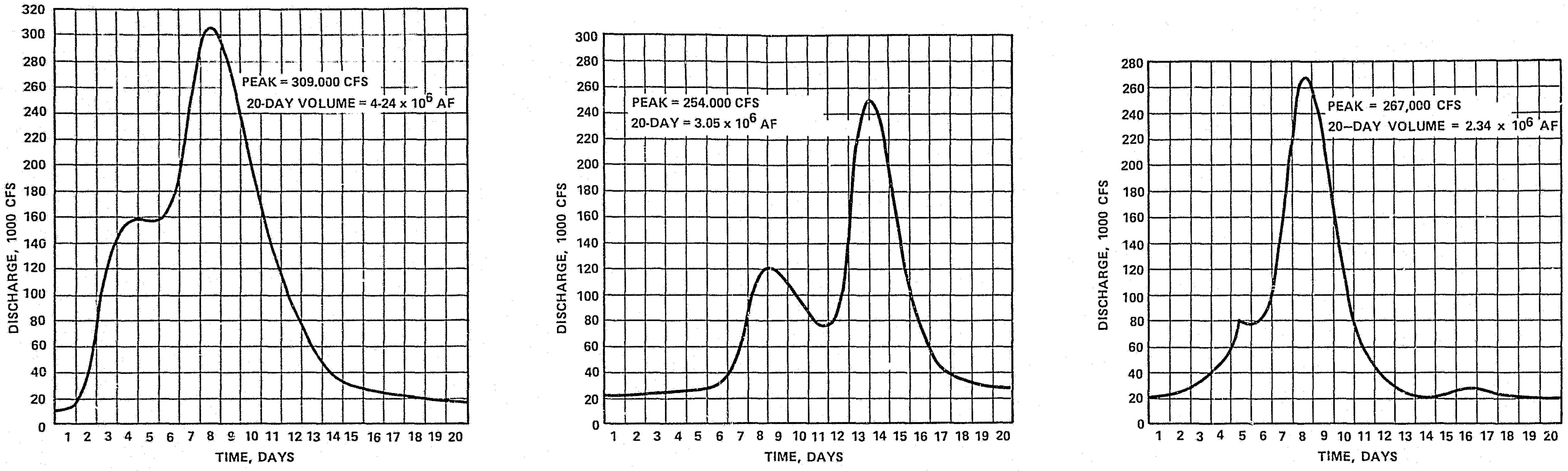
PMF STUDY
SUSITNA RIVER BASIN

PMF INFLOW HYDROGRAPHS AT WATANA

HARZA - EBASCO SUSITNA JOINT VENTURE AUGL

APPENDIX

EXHIBIT 39



MAY

JUNE

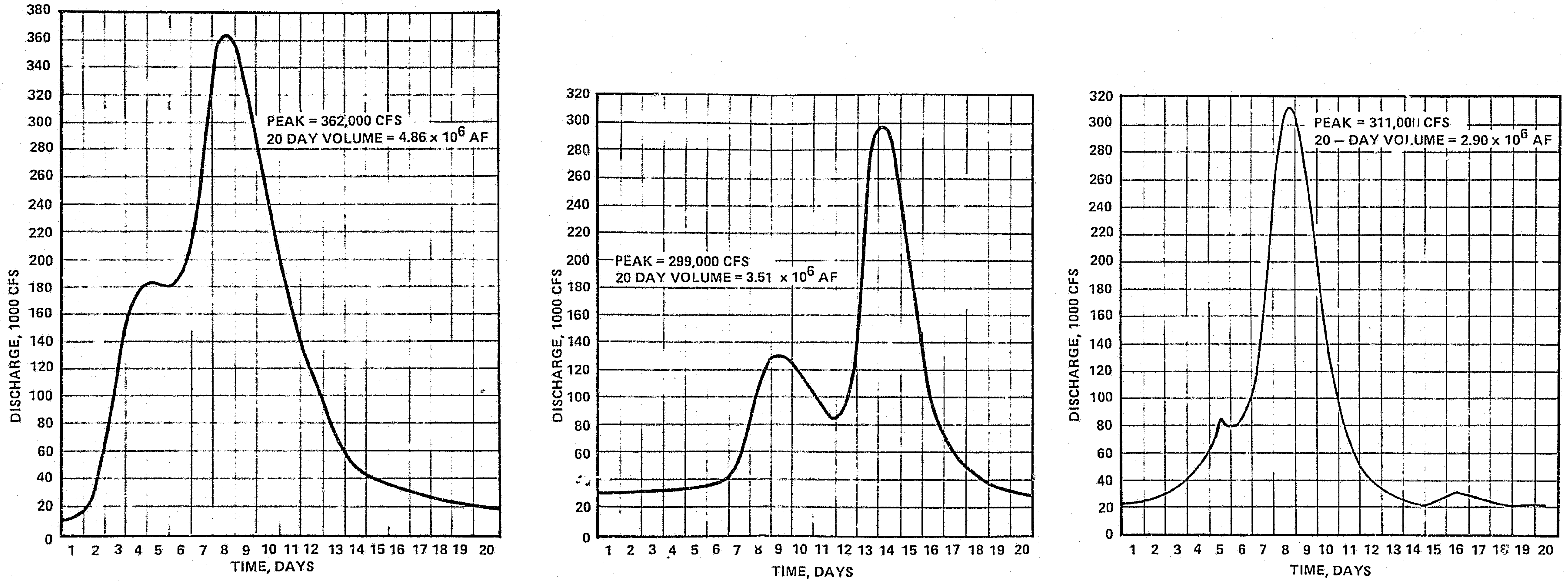
JULY – AUGUST

PMF STUDY
SUSITNA RIVER BASIN

PMF INFLOW HYDROGRAPHS AT WATANA

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 40



MAY

JUNE

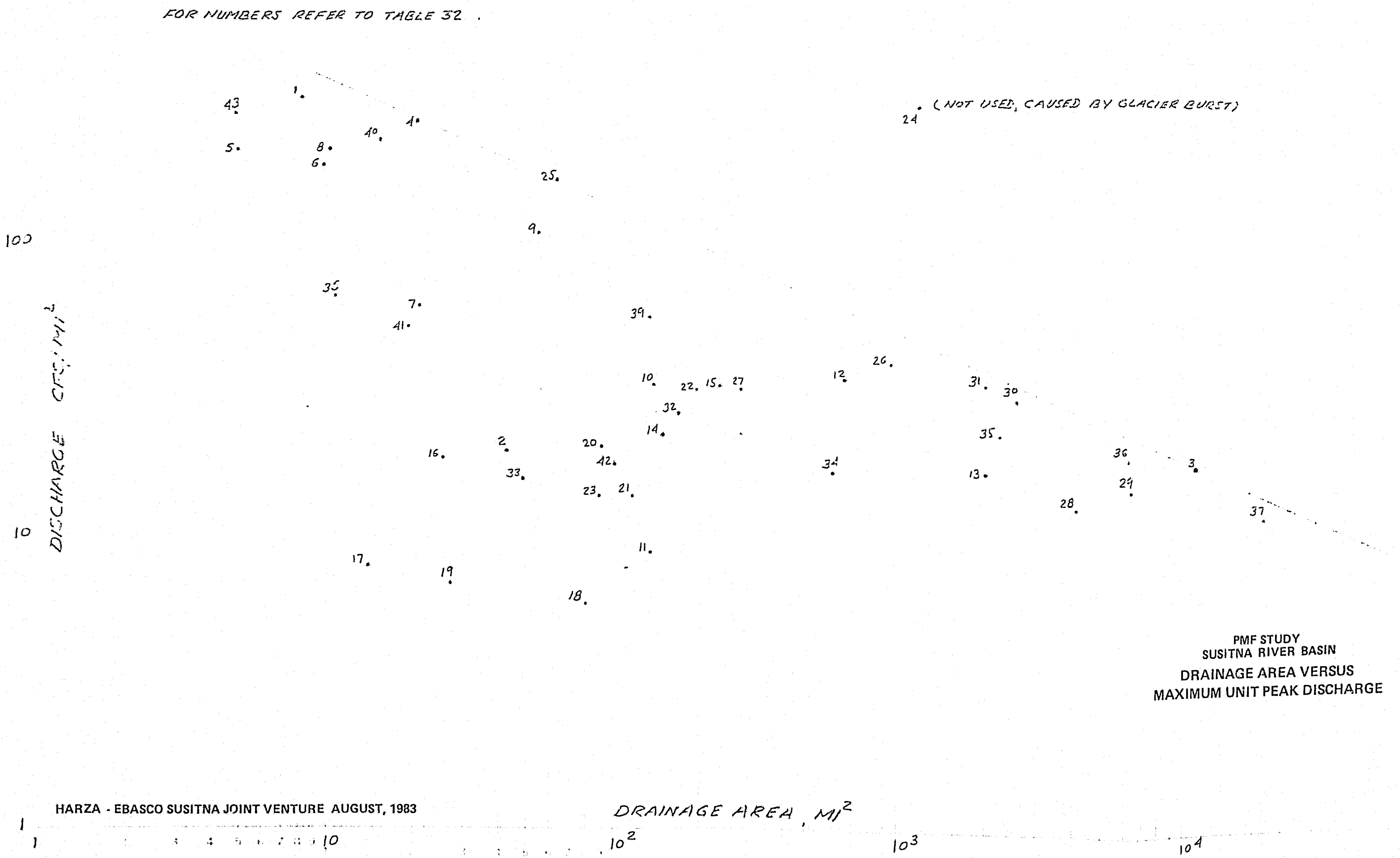
JULY – AUGUST

PMF STUDY
SUSTINA RIVER BASIN

PMF INFLOW HYDROGRAPHS
AT DEVIL CANYON

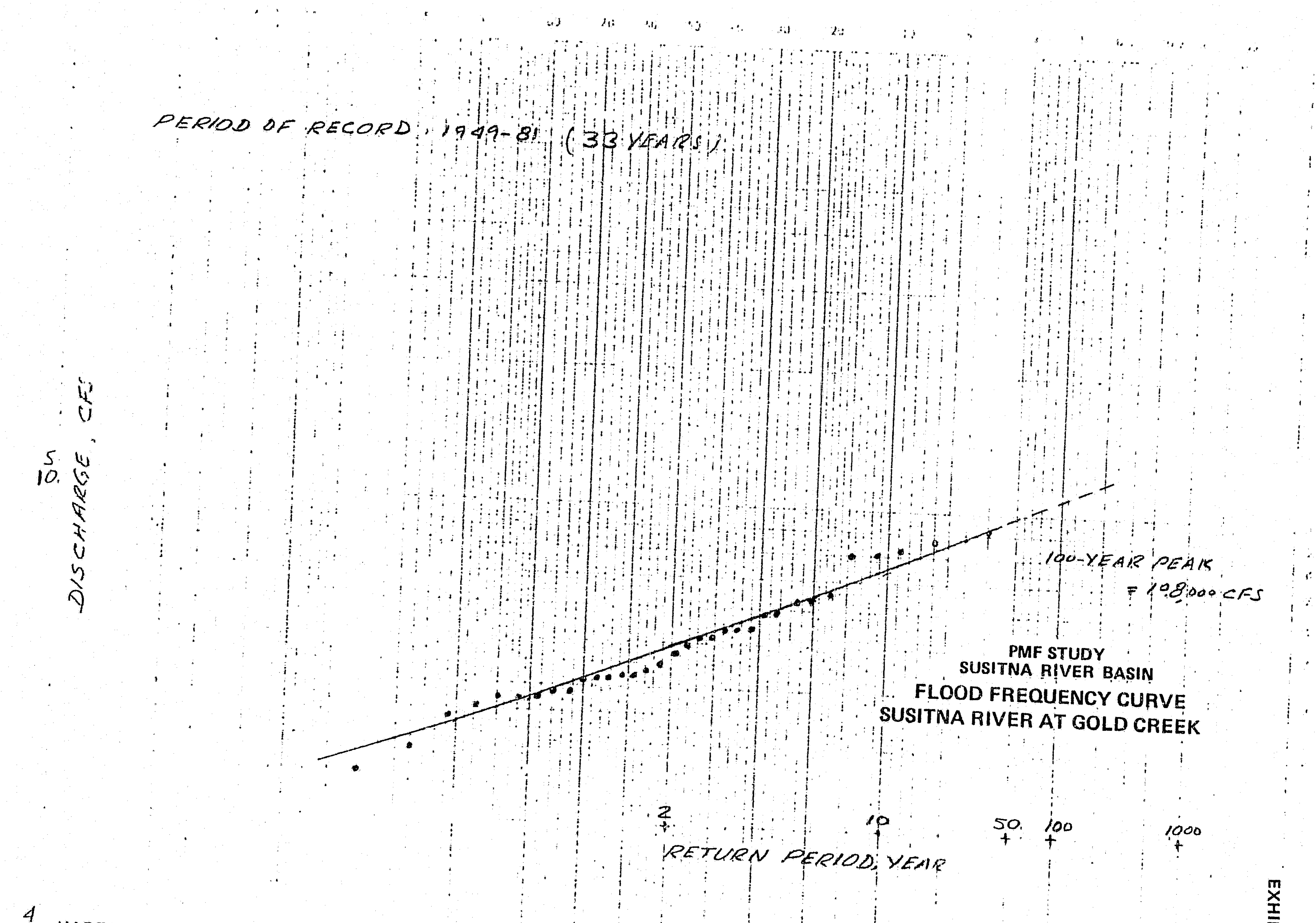
HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 41



PMF STUDY
SUSITNA RIVER BASIN
DRAINAGE AREA VERSUS
MAXIMUM UNIT PEAK DISCHARGE

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983



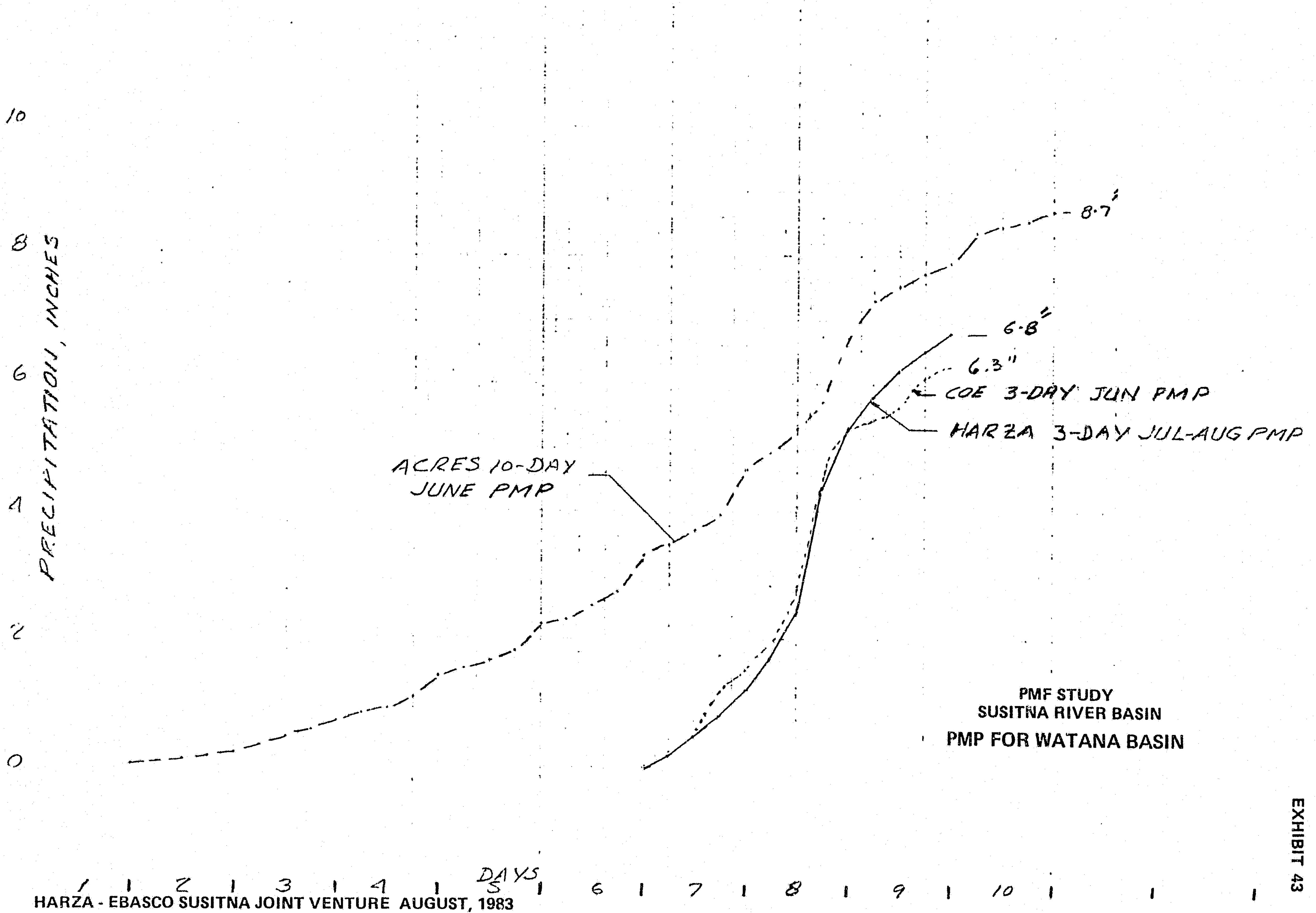
PMF STUDY
SUSITNA RIVER BASIN
FLOOD FREQUENCY CURVE
SUSITNA RIVER AT GOLD CREEK

EXHIBIT 42

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

APPENDIX



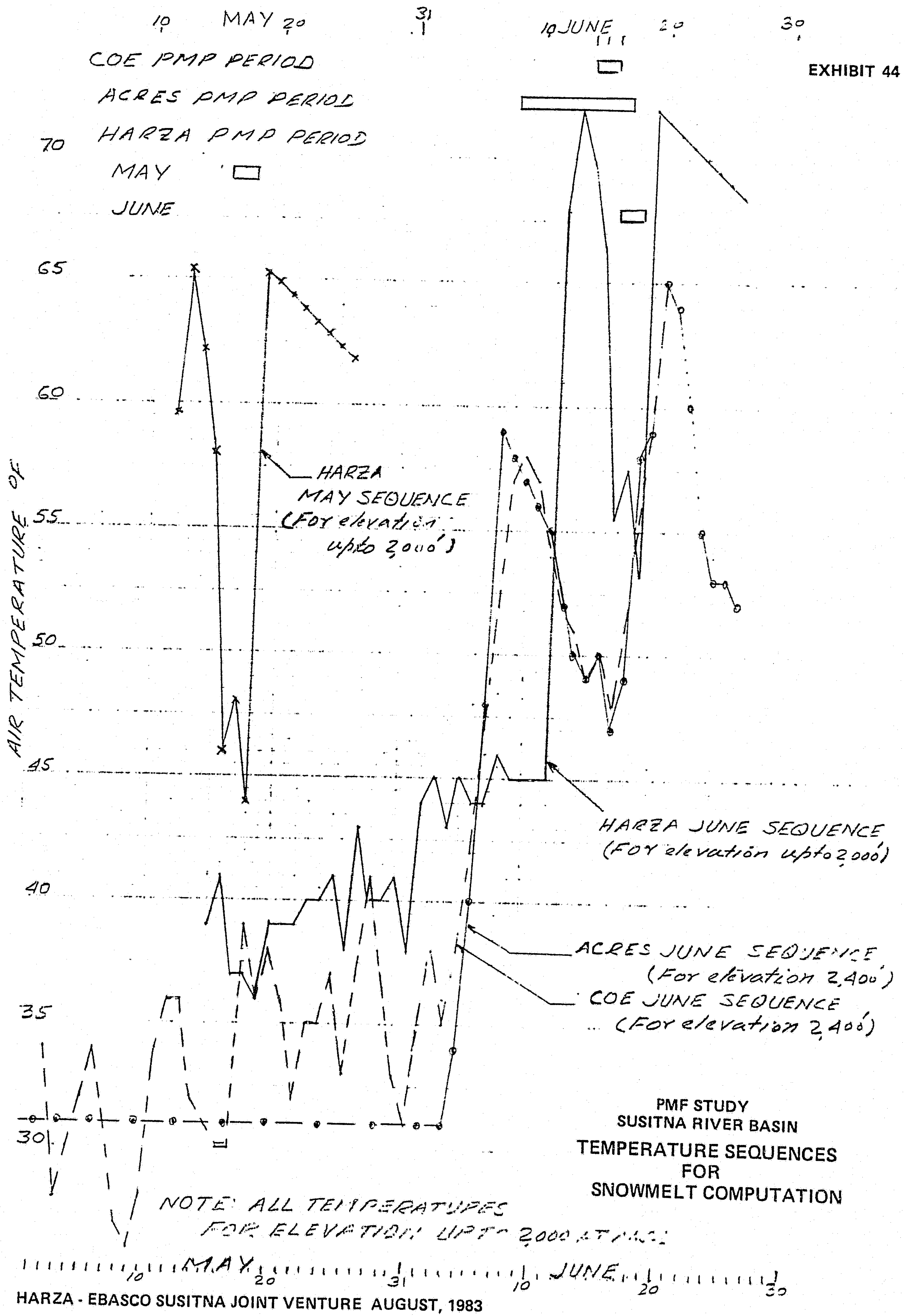
PMF STUDY
SUSITNA RIVER BASIN

PMP FOR WATANA BASIN

EXHIBIT 43

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

EXHIBIT 44



PMF STUDY
SUSITNA RIVER BASIN

TEMPERATURE SEQUENCES FOR SNOWMELT COMPUTATION

HARZA - EBASCO SUSITNA JOINT VENTURE AUGUST, 1983

APPENDIX

APPENDIX A

WEATHER FEATURES CONTRIBUTING TO THE FLOODS

By E. D. Diemer, U.S. Weather Bureau

INTRODUCTION

To completely describe the meteorological conditions involved in a rainstorm, it is necessary to describe weather features which occur on various scales. Large-scale phenomena controlling the east-central Alaska flood weather had an areal coverage ranging from the size of Alaska to that of most of the Northern Hemisphere. Such features can be described by using data obtained from the meteorological observation network. Small-scale features are just as significant and may range in size from a few hundred square miles to tens of thousands of square miles. A detailed analysis of rainfall from numerous surface observations combined with radar observations is one approach to describe the small-scale features of rainfall distribution. In general, owing to the lack of observations in the Alaska interior, discussion of small-scale weather phenomena will be limited to areas where small-scale features can be identified.

Two coincident factors are required for precipitation: moisture and upward vertical motion. Extremes of these factors occur as small-scale weather phenomena. The general synoptic patterns of large-scale weather systems, such as extensive high-pressure areas, low-pressure areas, and frontal zones, form an environment which is conducive to the development of the smaller scale features. The smaller features usually play the crucial role in extraordinary events and are actually responsible for much of the weather. This is particularly true for precipitation that may occur in a narrow band of cumulus clouds or that may be associated with a particular orographic feature.

CLIMATOLOGICAL BACKGROUND

A pronounced continental climate covers the area north of the Alaska Range. The heaviest precipitation at Fairbanks is generally from June through September: the average monthly totals are June, 1.39 inches; July, 1.84 inches; August, 2.20 inches; and September, 1.10 inches. In other months, less than 1 inch of precipitation (water equivalent) is received. The normal yearly total is 11.29 inches. Much summer precipitation is of the shower type. Fairbanks has an average of five thunderstorms from June through August, and showers and thunderstorms are quite common throughout the Alaska interior during these months.

Summer precipitation in the interior of Alaska is associated with a marked increase in both moisture and solar radiation. Much of the moisture originates from the Bering Sea and Northwest Pacific Ocean, which warm to 47°F and 51°F, respectively, by August. Surface dewpoints over the Bering Sea in August are in the mid-forties and in the Northwest Pacific reach the upper forties. Surface dewpoints in the forties are not uncommon in the Fairbanks area during July and August. Maximum dewpoints during August 1967 were in the low fifties. Evaporation supplies moisture that is necessary for shower formation, but the amount from this source is too small for consideration in the precipitation amounts recorded during the August flood. Fairbanks has about 22 hours of daylight per day in the latter part of June and about 16 hours during August. Normal daily maximum temperatures for June, July, and August are 71.1°F, 71.7°F and 65.3°F, respectively, with record highs near 80°F. The pronounced surface heating leads to upward vertical motion of the air by decreasing its stability, and thus summer shower activity increases.

Another feature which has a strong influence on summer precipitation is the annual migration of the Arctic Front, which separates the cold dry polar air from the warm moist maritime air of the Gulf of Alaska and Bering Sea. The mean position of the Arctic Front in January is along the North Gulf coast and Aleutian Chain. By July the Arctic Front has moved northward to a mean east-west position near 65° N. latitude, which is about the latitude of Fairbanks and the Chena River basin. A well-developed Arctic Front can increase precipitation along the frontal zone by increasing the upward vertical motion of warm moist air moving northeastward from the Bering Sea. Moist air moving northward from the Gulf of Alaska produces little precipitation at Fairbanks because the moisture is dropped as precipitation during the forced rise over the Alaska Range. Thus a large and continuous moisture supply for Fairbanks must occur as a strong northeastward flow from the Bering Sea area. Moisture from the Bering Sea and the position of the Arctic Front were of major importance among the synoptic features producing the rainfall leading to the Fairbanks flood.

The principal tracks of low-pressure centers are normally from the vicinity of Japan and the Kamchatka Peninsula (U.S.S.R.) northeastward into the Bering Sea. From the Bering Sea the storm tracks turn either eastward north of the Brooks Range into the Beaufort Sea or eastward across central Alaska between the Alaska Range and the Brooks Range. The low-pressure systems affecting Fairbanks during August followed the latter path.

Normal sea level pressures for August indicate that a low-pressure area in the North Bering Sea with northeastward flow across the Bering Sea into central Alaska is the average situation. The low-pressure area and northeastward flow are reflected in the upper airflow: a north-south layer occurs at 10,000 feet near 180° longitude, and southwesterly winds move from the central Bering Sea into central Alaska. The position of the trough and winds coincides with the principal storm tracks.

SYNOPTIC FEATURES

Rainfall started about August 8 and continued until about August 20 over a wide area in east-central Alaska. Figure 1 is an isohyetal map showing the distribution of rainfall during August. The area covered by heavy rainfall is enclosed by the 3-inch isohyetal and includes the lower Tanana River basin and adjacent basins to the north draining into the Yukon River.

August precipitation data for locations in east-central Alaska are given in table 1. Figure 1 shows the locations where the precipitation data were collected. U.S. Weather Bureau gages are in valleys and thus did not record the greater amounts of rain that fell in the mountains. Rainfall as high as 10 inches was unofficially reported in the Chatanika River basin 60 miles northeast of Fairbanks. For most of August the rainfall occurred during the same period over widely scattered locations. Figure 2 shows cumulative daily rainfall at Clear Airport, Nenana, and Chena Hot Springs from August 8–19. Clear Airport and Chena Hot Springs are about 100 miles

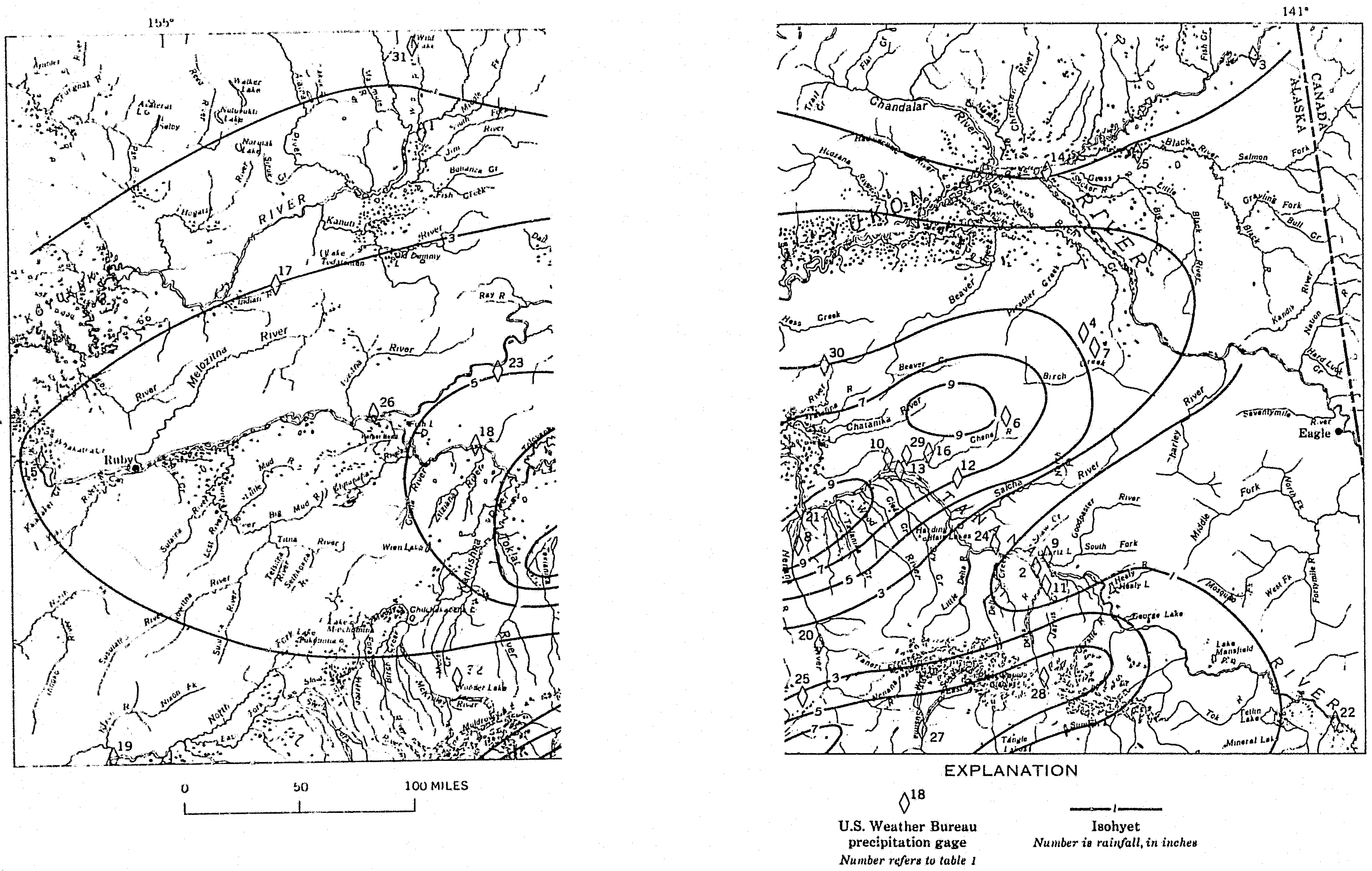


FIGURE 1.—Total rainfall distribution for August 1967, east-central Alaska.

apart. The cumulative daily rainfall curves at the three stations are very similar and indicate the general nature of this storm. Maximum daily rainfall of the storm period occurred on either August 12 or 13 at half of the locations given in table 1. Eight of the Weather Bureau stations reported an excess of 3 inches for the day of heaviest rainfall.

At the Fairbanks Airport, 6.15 inches of rain fell during the period August 8–15. The severity of the storms can be illustrated by

TABLE 1.—*Precipitation, in inches, during August 1967 in east-central Alaska*
[Adapted from U.S. Weather Bureau (1952)]

No. (fig. 1)	U.S. Weather Bureau station	Monthly total	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Bettles FAA Airport	2.17	Trace	---	---	---	---	---	---	Trace	0.18	0.24	0.22	0.12	---	0.14	0.01
2	Big Delta FAA	1.56	0.24	---	---	Trace	---	---	---	0.12	.09	.09	.04	.42	0.03	.02	Trace
3	Canyon Village	1.72	.69	---	---	---	---	---	---	.01	.03	.27	.04	.49	.03	---	---
4	Central No. 2	5.70	.23	0.09	---	---	---	---	---	---	.60	---	---	1.17	1.32	.73	.33
5	Chalkyitsik	1.37	.06	---	---	---	---	---	---	.09	.08	.33	.01	.59	---	.02	.03
6	Chena Hot Springs	7.74	.06	.02	---	---	0.05	---	---	.23	.50	.42	.18	3.13	1.50	.63	.34
7	Circle Hot Springs	5.75	.06	Trace	---	---	---	---	---	---	.34	.02	.01	1.66	1.62	.84	.17
8	Clear Airport	10.06	Trace	---	---	---	---	Trace	---	---	---	1.00	.70	1.70	4.58	1.20	.33
9	Clearwater	2.37	.02	.15	---	---	---	---	---	.05	.10	.05	---	.65	.15	.15	---
10	College Mag Obsy	7.36	.08	.05	---	---	---	---	---	---	.50	.21	.05	2.25	2.51	.65	.49
11	Delta Junction	2.48	.17	.05	---	Trace	---	---	---	.28	.09	.06	Trace	.48	.11	.10	Trace
12	Eielson	7.47	.09	---	---	0.02	---	---	---	Trace	.68	.29	.65	3.61	1.42	.38	.05
13	Fairbanks WB Airport	6.20	.02	---	---	---	---	---	---	.02	.56	.05	.87	3.42	.69	.47	.07
14	Fort Yukon	.35	.01	---	---	---	---	---	---	---	---	.10	.10	---	---	.05	.02
15	Galena	4.70	---	---	0.01	---	---	---	0.04	---	---	.01	.83	1.40	.49	.32	.18
16	Gilmore Creek	9.49	.09	.11	---	---	---	---	---	---	.67	.32	.04	3.38	2.80	.75	.70
17	Indian Mountain	3.44	---	---	---	Trace	---	---	---	.11	.16	.04	.41	.86	.02	.25	.11
18	Manley Hot Springs	6.89	.19	---	---	---	---	---	---	---	.08	.02	.14	3.33	.48	.54	.58
19	McGarth WB Airport	3.41	.07	---	Trace	---	Trace	---	---	Trace	---	.05	.07	.33	.22	.70	.41
20	McKinley Park	3.45	.26	---	---	---	---	---	---	---	.41	.25	---	1.86	.02	.32	.05
21	Nenana FAA	8.26	.08	---	---	---	---	---	---	.07	1.01	.06	.52	3.04	2.22	.80	.10
22	Northway FAA AP	1.85	.03	---	---	Trace	---	Trace	---	.28	---	.01	.07	Trace	.09	Trace	---
23	Rampart No. 2	6.08	.02	---	---	---	---	---	---	---	.28	.11	.98	2.00	.39	.32	.26
24	Richardson	2.87	---	.10	---	---	---	---	---	---	.15	.08	.14	1.07	.28	.36	.08
25	Summit FAA	3.52	.34	.12	.01	Trace	---	---	---	.30	.30	.48	.16	.18	.47	.28	.03
26	Tanana FAA	5.06	.02	---	---	Trace	---	---	---	---	.15	.10	.44	1.96	.13	.36	.07
27	The Gracious House	7.54	1.63	---	---	.05	---	0.02	.05	.02	.53	.75	.34	.50	1.08	.77	.77
28	Trims Camp	9.16	.85	.67	---	---	Trace	---	---	---	.37	.35	.40	.73	2.44	.91	.29
29	University Exp. Sta	6.57	.06	---	---	---	---	---	---	---	.50	.19	.17	3.28	1.15	.63	.31
30	West Fork	4.52	.54	Trace	---	---	---	---	.05	---	.28	.11	.21	1.78	.44	.35	.27
31	Wild Lake No. 2	2.00	---	---	---	---	---	---	---	---	.29	.17	.01	---	---	---	---
32	Wonder Lake	3.81	.63	---	---	---	---	---	---	---	.37	.36	.08	.49	.87	.30	.31

No. (fig. 1)	U.S. Weather Bureau station	Monthly total	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	Bettles FAA Airport	2.17	0.40	0.48	0.03	Trace	Trace	---	Trace	0.13	0.08	---	0.08	0.04	0.01	---	---	0.01
2	Big Delta FAA	1.56	---	---	---	Trace	Trace	0.25	0.12	Trace	---	---	Trace	.12	.02	---	---	---
3	Canyon Village	1.72	Trace	---	---	Trace	0.06	.04	---	---	---	0.06	---	---	---	---	Trace	---
4	Central No. 2	5.70	.02	.04	.04	0.10	---	.04	.02	---	---	.64	.01	.03	---	---	0.02	.27
5	Chalkyitsik	1.37	Trace	.08	Trace	Trace	---	---	---	---	---	.08	---	---	---	---	---	---
6	Chena Hot Springs	7.74	Trace	---	---	.27	Trace	Trace	.17	Trace	.03	---	---	.13	Trace	---	Trace	.08
7	Circle Hot Springs	5.75	.01	Trace	---	.19	Trace	---	---	---	.27	Trace	.03	Trace	.01	---	.25	.27
8	Clear Airport	10.06	.05	---	---	.04	---	---	.30	---	---	---	---	.16	Trace	---	---	---
9	Clearwater	2.37	---	---	---	---	.15	.05	.25	.40	---	---	---	.20	---	---	---	---
10	College Mag Obsy	7.36	.03	Trace	---	Trace	---	---	---	---	.06	---	---	.44	.04	---	---	---
11	Delta Junction	2.48	---	---	---	---	.07	Trace	.79	Trace	---	---	Trace	.09	.03	---	Trace	16
12	Eielson	7.47	.02	Trace	.02	.02	---	.22	Trace	Trace	---	---	Trace	Trace	Trace	Trace	Trace	Trace
13	Fairbanks WB Airport	6.20	Trace	---	---	Trace	---	Trace	.01	---	.01	---	.01	Trace	---	Trace	---	Trace
14	Fort Yukon	.35	---	---	---	---	---	---	---	---	---	.06	.01	---	---	---	---	---
15	Galena	4.70	.01	.40	---	.18	---	---	Trace	.10	.45	.18	.10	Trace	---	---	Trace	Trace
16	Gilmore Creek	9.49	---	---	---	---	.14	---	.15	.09	.08	---	---	.12	.05	---	---	---
17	Indian Mountain	3.44	.59	.37	.22	---	---	.04	.02	---	.03	---	---	.08	.09	---	---	.04
18	Manley Hot Springs	6.89	.63	.04	.15	---	.03	---	---	.30	.03	---	---	.06	---	---	.24	.05
19	McGrath WB Airport	3.41	.18	.41	.10	.18	.07	.49	.01	.01	---	Trace	.08	---	---	Trace	.03	---
20	McKinley Park	3.45	.01	.01	---	.05	.04	---	---	---	---	---	.05	.12	---	---	---	---
21	Nenana FAA	8.26	---	---	Trace	.04	---	.01	.02	.03	---	---	.26	Trace	---	---	---	---
22	Northway FAA AP	1.85	---	---	Trace	Trace	.90	.16	.09	.03	---	---	.06	Trace	---	---	.01	.12
23	Rampart No. 2	6.08	.38	.02	.02	Trace	---	---	---	.22	.08	---	---	---	---	---	.80	.20
24	Richardson	2.87	Trace	---	---	.07	---	Trace	.54	Trace	---	---	---	Trace	Trace	---	Trace	Trace
25	Summit FAA	3.52	.23	.04	Trace	.09	Trace	.10	.13	.22	Trace	Trace	.04	Trace	---	Trace	Trace	---
26	Tanana FAA	5.06	.09	.24	.02	Trace	Trace	---	.49	Trace	.03	---	.04	Trace	---	---	.31	---
27	The Gracious House	7.54	.25	---	---	.15	.02	---	---	Trace	---	.30	.05	---	---	0.08	.18	---
28	Trims Camp	9.16	.15	.31	.04	.03	.10	.13	.06	.09	.18	.09	.08	.06	.04	.03	.76	---
29	University Exp. Sta	6.57	Trace	Trace	---	---	---	---	Trace	Trace	Trace	---	.09	.19	Trace	Trace	---	---
30	West Fork	4.52	.29	---	Trace	---	---	---	---	---	---	---	.05	.01	---	---	.14	---
31	Wild Lake No. 2	2.00	.25	---	.81	---	---	---	---	.20	.22	.02	---	.03	---	---	---	---
32	Wonder Lake	3.81	Trace	---	Trace	.07	Trace	.03	.31	.03	---	.11	.05	Trace	---	---	Trace	---

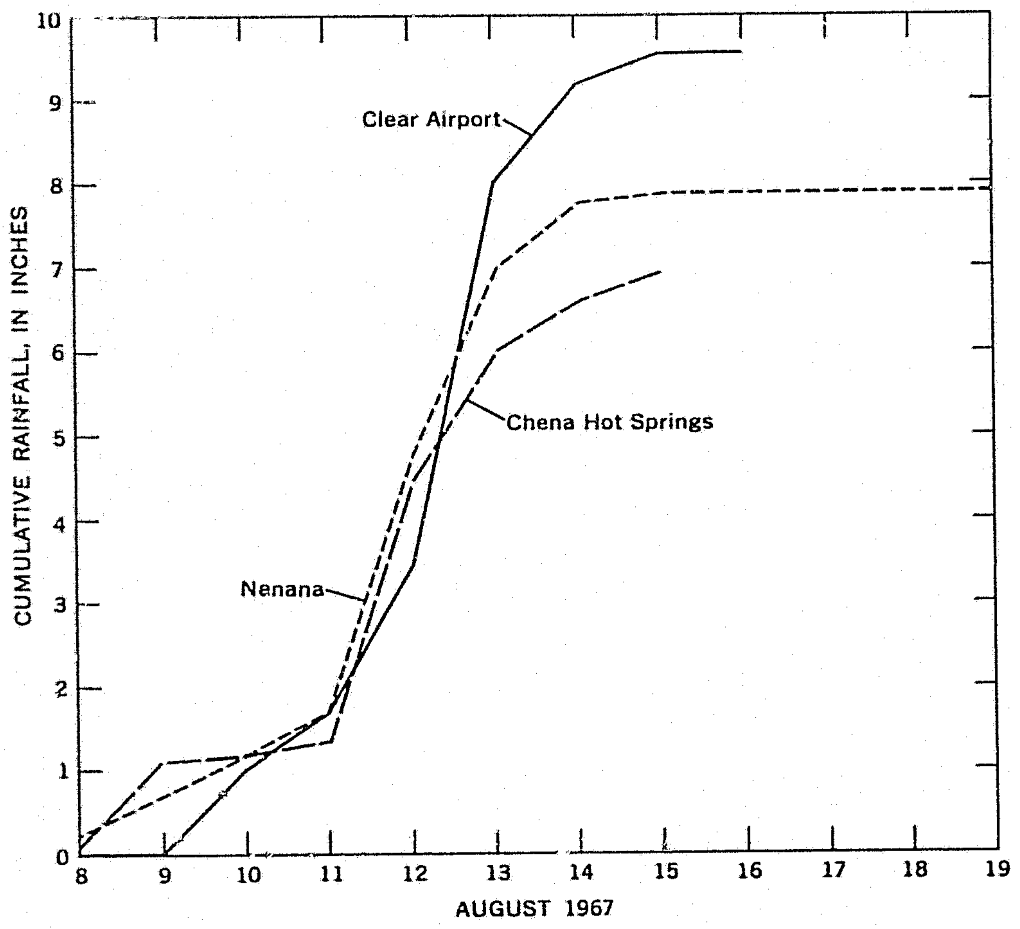


FIGURE 2.—Cumulative daily rainfall at Clear Airport, Nenana, and Chena Hot Springs, August 8–19.

several comparisons. The August 1967 rainstorm was the heaviest since records began in 1929 and exceeded the previous maximum amount by 31 percent. The storm precipitation of 6.15 inches is over half the normal annual precipitation at the airport. Comparison with the previous record storm, that of August 1930, is as follows:

	August 1930	*August 1967*
Total storm precipitation	4.69	6.15
Maximum daily precipitation	2.33	3.42

A series of storm systems accounted for such an extended period of rain. Thus, it is convenient to consider the rain period in four sections: the period prior to August 8, the period of August 8–11, the heavy rain of August 12, and the period of August 13–20.

CONDITIONS PRIOR TO AUGUST 8

The Weather Bureau airport station at Fairbanks recorded a total of 1.13 inches of precipitation during the month of June, 0.26 inches below normal. During July, precipitation was 1.50 inches above normal, and the total precipitation recorded was 3.34 inches. Of this total, 1.27 inches fell on July 24; this was the last heavy rain of the month. For the 14-day period July 25 through August 7, 0.39 inches of rain fell at Fairbanks, but of this amount only 0.02 inches fell during the first week of August.

Similar conditions prevailed upstream in the Chena River basin, judging from the precipitation record at Chena Hot Springs, the only observation station near the headwaters of the Chena River. Both the 1.46 inches of precipitation recorded during June and the 3.68 inches recorded during July are about one-third of an inch higher than the amounts recorded at Fairbanks. These are not significant differences considering that the usual amounts of precipitation differ and that Chena Hot Springs is at a higher elevation where the effects of nearby mountains are greater. On July 24, Chena Hot Springs received 0.54 inches of rain, compared with 1.27 inches at Fairbanks. During the 14-day period July 25 through August 7, 0.83 inches of rain fell at Chena Hot Springs, but only 0.13 inches of this amount fell during the first week in August. In general, conditions prior to August 8 were about normal.

CONDITIONS AUGUST 8–11

Rainfall of direct consequence to the flood began on August 8. Figure 3 presents the isohyets of total precipitation August 8 to 11, inclusive. The isohyets are a gross depiction of the rainfall distribution because there are only 32 precipitation records in about 80,000 square miles and these are in valleys or at mountain passes. During August 9, 10, and 11, the Chena River basin received about 1.5 inches of rain.

Two features of particular interest affected the rainstorms. The first feature was a tropical storm named Typhoon Hope, which had moved into midlatitudes and had become an extratropical low-pressure center near 40° N. latitude, 175° E. longitude, about 700 miles south of the Aleutian Islands, at 1800Z on August 9. (1800Z is 1800 hours Greenwich time, which is equivalent to 0800 hours Alaska standard time.) Typhoon Hope continued northward and by 1800Z on August 11 had formed the deep low-pressure system northwest of Shemya. Figure 4 shows the synoptic patterns at 1800Z on August 11.

The second feature was the Arctic Front in central Alaska near 65° N. latitude. A low-pressure center just west of Fairbanks at 1800Z on August 9 influenced the Fairbanks weather until about

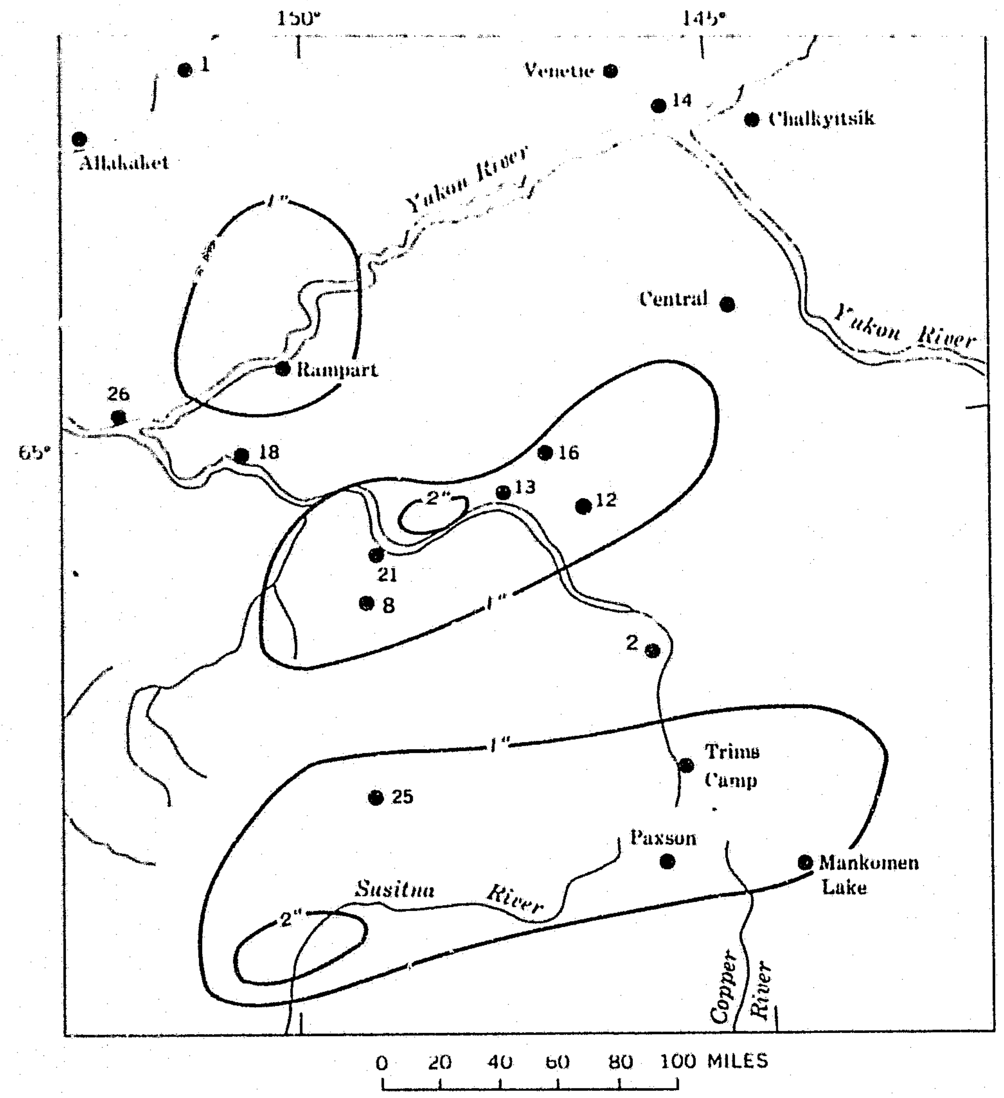


FIGURE 3.—Isohyets of total rainfall distribution, August 8–11. Numbered points are U.S. Weather Bureau precipitation gages identified in table 1.

0000Z August 11. By this time it had moved eastward into the Northwest Territories (Canada) near the mouth of the Mackenzie River, and the Arctic Front had moved to the south of Fairbanks. At about 0600Z on August 11 an open wave, or small low-pressure center, had formed on the Arctic Front south of Fairbanks causing the front to again move northward. Referring to figure 4, the effect on the front can be seen just north of Fairbanks. Another low-pressure center had moved eastward along the Arctic Front from 178° E. longitude to the North Bering Sea west of Nome. Note that the deep low pressure northwest of Shemya had set up a long southwest fetch for the Fairbanks area. Strong low-level winds began a renewed influx of moisture to central Alaska. The low pressure

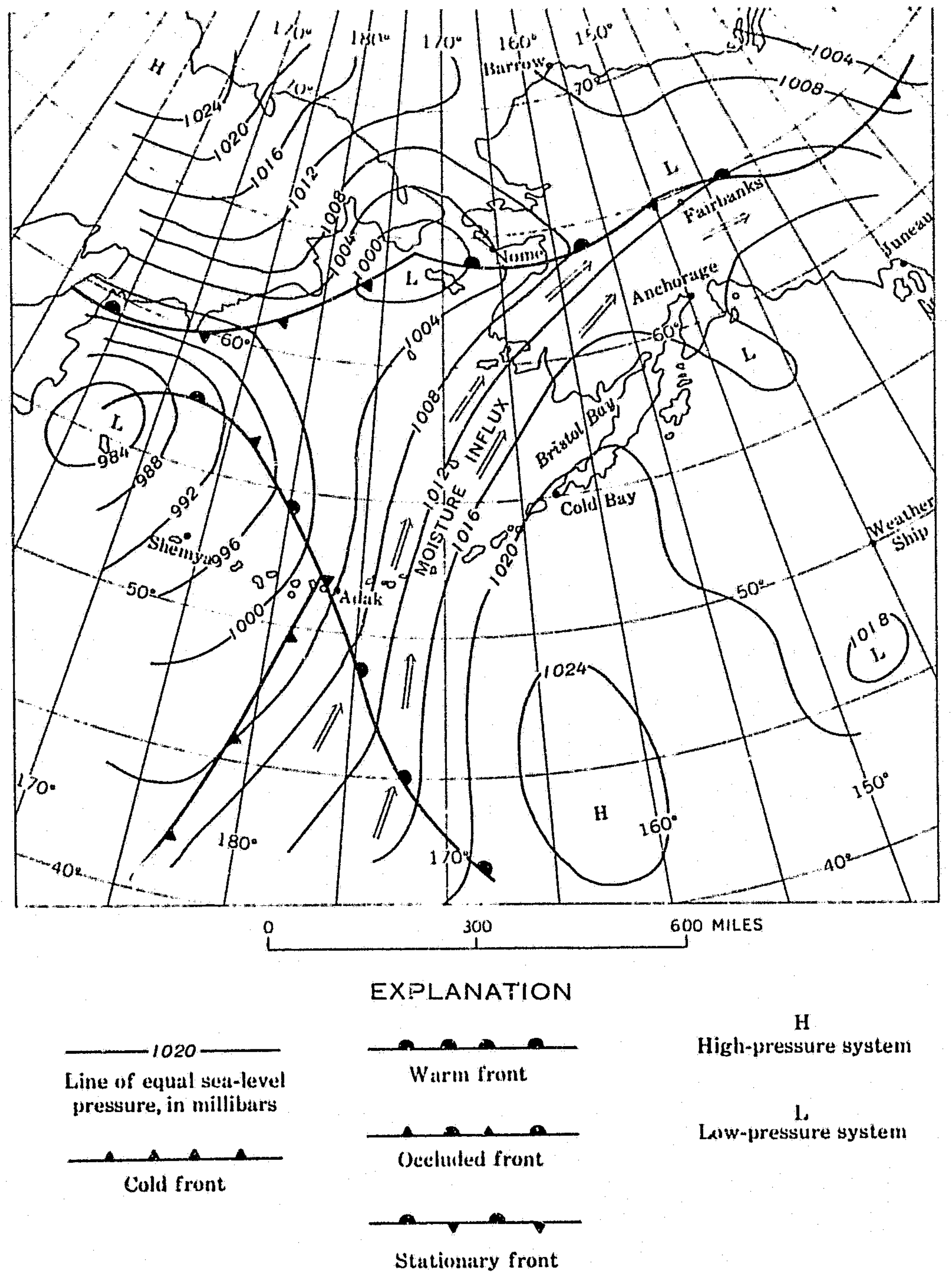


FIGURE 4.—Surface weather chart, 1800Z, August 11.

west of Nome continued rapidly eastward providing the vertical motion necessary for precipitation. About this time the low pressure in the Bering Sea, formed by the extratropical storm, began to play an important role in the Fairbanks and Chena River basin rainfall.

CONDITIONS AUGUST 12

Rain began falling again at Fairbanks about midafternoon on August 11 and continued until the early morning of August 15. On August 12 the heaviest rain fell: 3.42 inches at the Weather Bureau airport station at Fairbanks and 3.13 inches at Chena Hot Springs. Figure 5 depicts the isohyets for August 12. The 3-inch isohyet encloses an area about 180 miles long and 40 miles wide. The eastern extent of the 2-inch and the 3-inch isohyets was not defined, but was positioned to coincide with observed high water or flood conditions of the streams in that area.

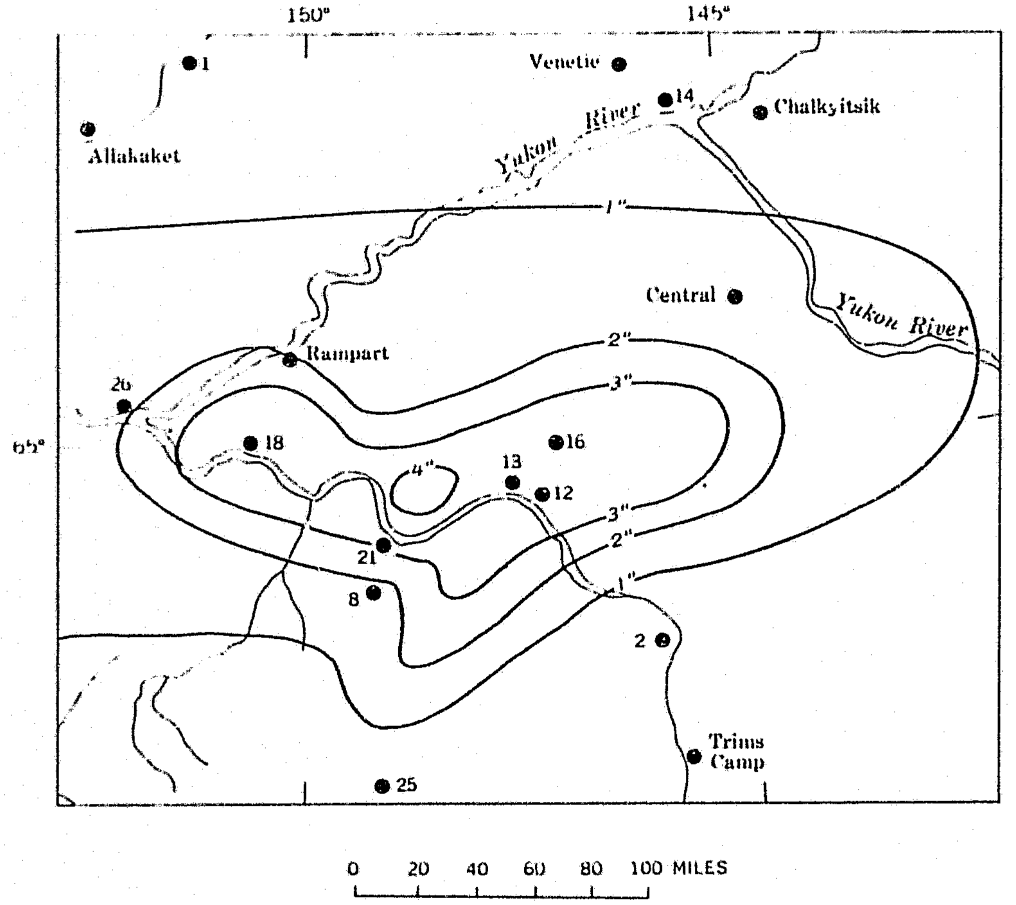


FIGURE 5.—Isohyets of total rainfall distribution, August 12. Numbered points are U.S. Weather Bureau precipitation gages identified in table 1.

There is a strong similarity between the weather systems that affected east-central Alaska, especially that of August 12, and a synoptic situation which leads to squall-line formation in the Great Plains of the United States. Strong low-level winds provided an intrusion of warm moist air, and a cross current of strong upper winds existed across the Arctic Front. Weak lows or open waves were moving along the frontal system. The degree of instability characteristic of a Great Plains squall line was lacking; however. the cumulus development must have been considerable to produce the rainfall amounts observed.

The low west of Nome moved rapidly eastward and decreased in intensity. By 1200Z on August 12 the remainder of this low appeared as just an open wave on the Arctic Front northeast of Fairbanks.

The frontal system in the Bering Sea began rapid eastward movement forming another low on the Arctic Front in the vicinity of Norton Sound south of Nome. The parent low remained north of Shemya.

By 1800Z on August 12 (fig. 6) this low had crossed Norton Sound and was about 250 miles west of Fairbanks. Moisture influx remained strong at low levels with the long southwest fetch extending from Fairbanks to the North Pacific south of Shemya, a distance of about 2,000 miles. At 0600Z August 13 (2000 hours August 12 local time) the low had passed Fairbanks and merged with the general trough of low pressure extending from Fairbanks eastward into Canada. The strong southwest flow of moist air continued into the Fairbanks area. The Arctic Front remained in almost the same position just to the north of Fairbanks. The parent low north of Shemya had decreased in intensity and began moving along the Arctic Front toward central Alaska.

CONDITIONS AUGUST 13–20

At 0000Z August 14 the Shemya low had moved to a position southwest of Norton Sound, and another low had formed in the Bristol Bay area (northeast of Cold Bay). By 1200Z August 14 (fig. 7) a series of low-pressure centers was evident. The Bristol Bay low extended northward from Cook Inlet (south of Anchorage) as a trough line, and the low to the north had moved into Norton Sound. An extensive area of low pressure in the South Bering Sea just to the north of the Aleutian Chain had become well formed.

At 0000Z August 15 several waves were still active along the Arctic Front. The last of these was located in eastern Norton Sound.

The low-pressure area moving into Bristol Bay continued eastward into southwestern Alaska. This was the last low-pressure system of this series of storms. Figure 8 shows the eastward movement of this low-pressure system. By 0000Z August 15 the winds at Fairbanks became southerly, a direction which is not conducive

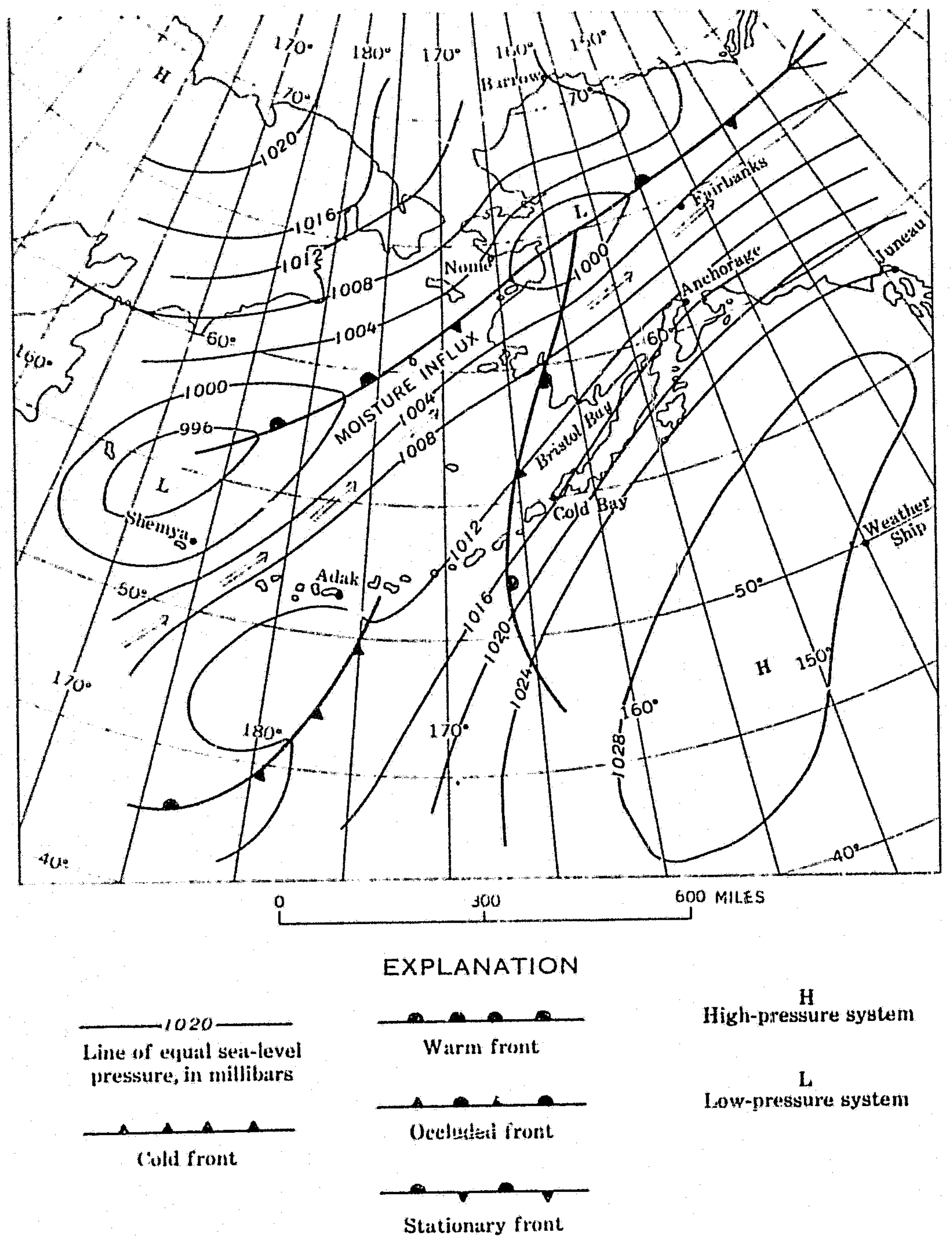


FIGURE 6.—Surface weather chart, 1800Z, August 12.

to precipitation at Fairbanks. Significant precipitation at Fairbanks ended early in the morning of August 15.

Precipitation during this period was highly variable, as indicated by the isohyets in figure 9. Several large centers stand out: Gilmore Creek, 4.39 inches; Clear, 6.46 inches; Trims Camp, 4.96 inches; and the area north of Talkeetna, 7.18 inches.

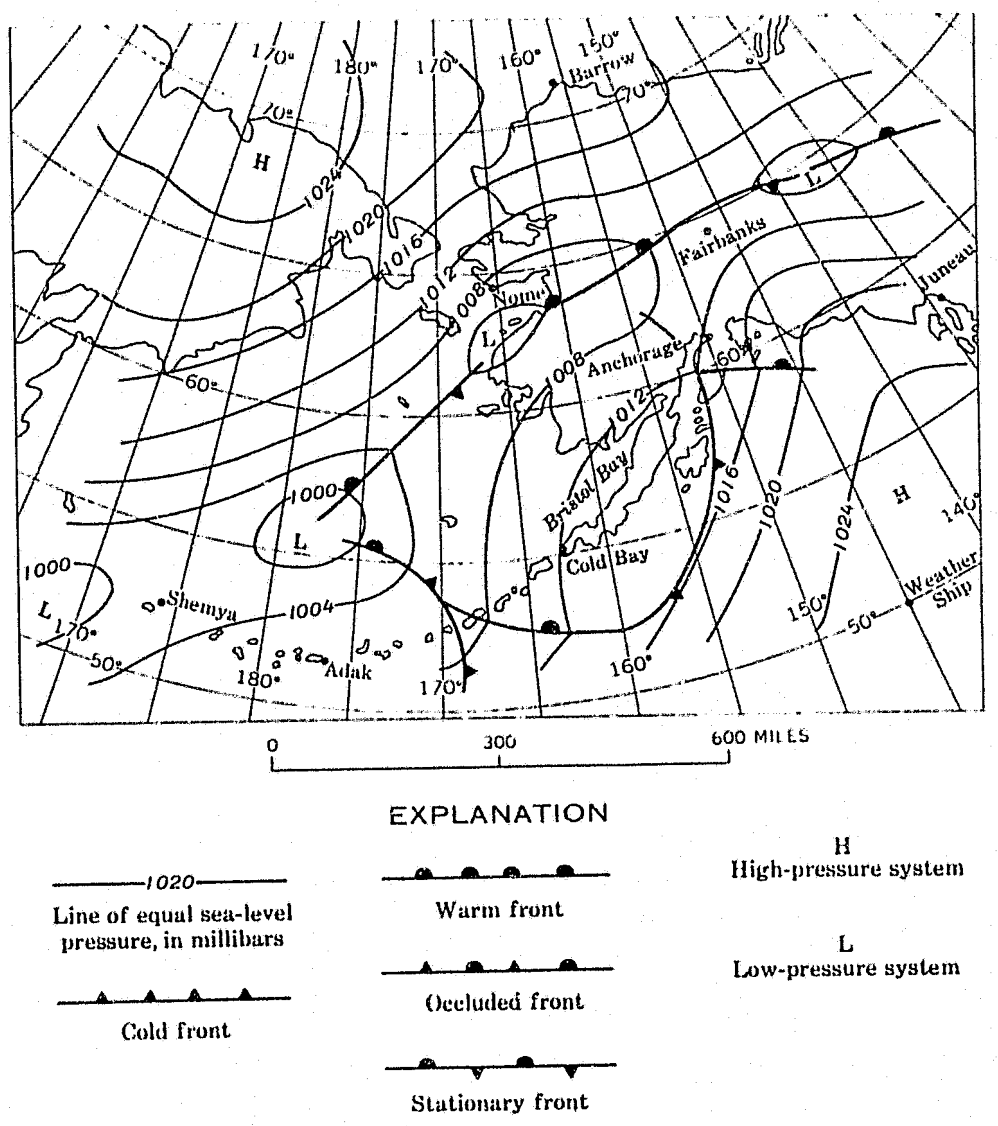


FIGURE 7.—Surface weather chart, 1200Z, August 14.

STORM SEQUENCE

One of the extraordinary aspects of the weather associated with the August 1967 floods in east-central Alaska was the rapid sequence of storms which traversed the area. Normally, low-pressure centers do not move through a specific area with such rapid succession. Also, when the interval between storms is brief, storm intensity usually decreases with succeeding storms of a series. This was not the case during August 1967, because on about August 12 the storm track into east-central Alaska changed from west to southwest as extratropical storm Typhoon Hope developed a deep low-pressure center in the Bering Sea. This change provided a new source of low-pressure centers and maintained the moisture influx to the Fairbanks area.

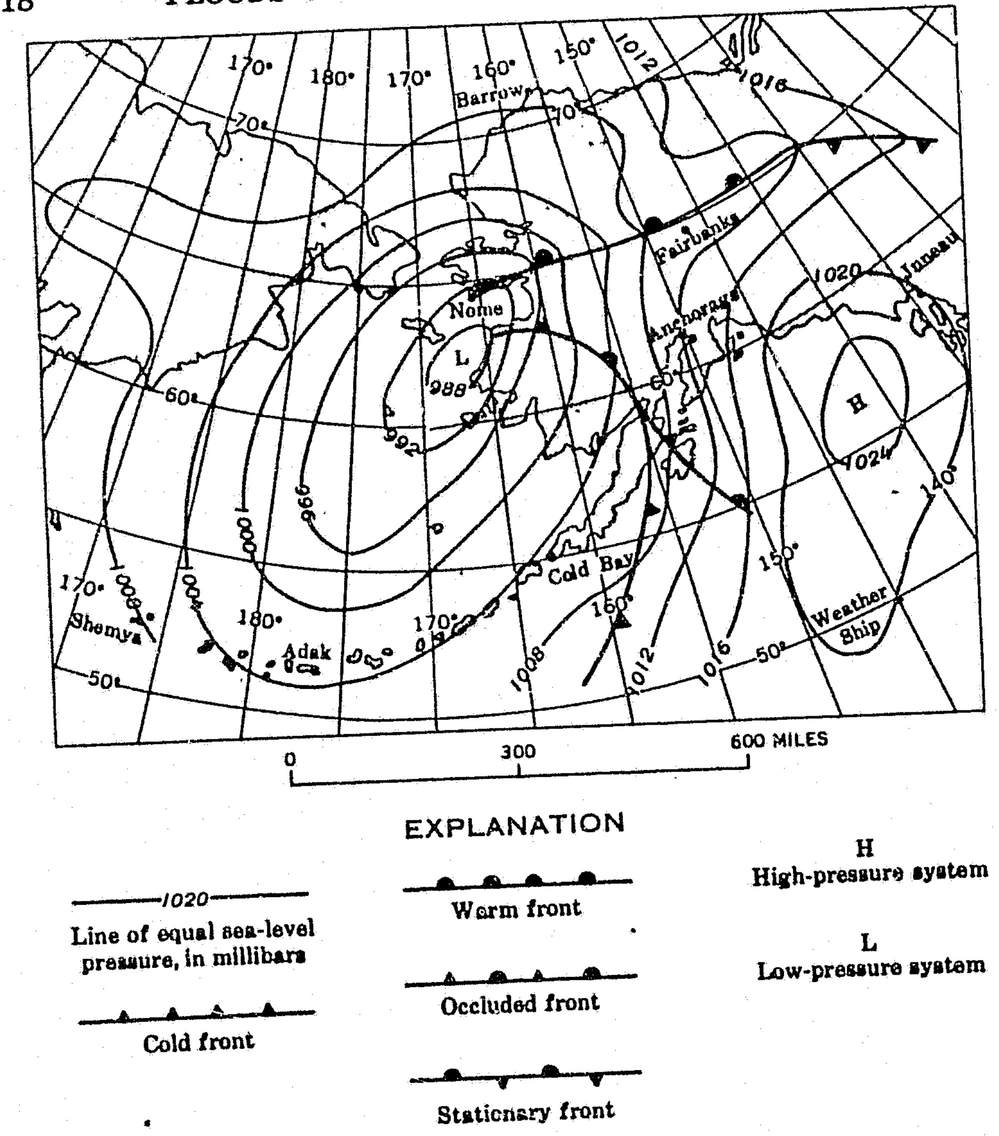


FIGURE 8.—Surface weather chart, 0600Z, August 16.

All the meteorological conditions required for rain were present over east-central Alaska during each storm passage; therefore, each storm dropped its maximum precipitation in the same general area. A small change in the development and movement of the low-pressure centers could have placed the vertical motion out of phase with the main moisture supply. For example, a slight shift in the low-level winds from the Bering Sea could have moved the moisture several hundred miles from east-central Alaska, or a slight fluctuation in the Arctic Front could have moved the area of maximum precipitation north or south.

Many floods, especially on small streams and rivers, result from exceptionally heavy rainfall from one storm. The August 1967 floods in east-central Alaska, however, resulted from an accumulation of rainfall events from a rapid sequence of storms over about a week's period. Only one of these rain periods, August 12, produced exceptionally heavy precipitation.

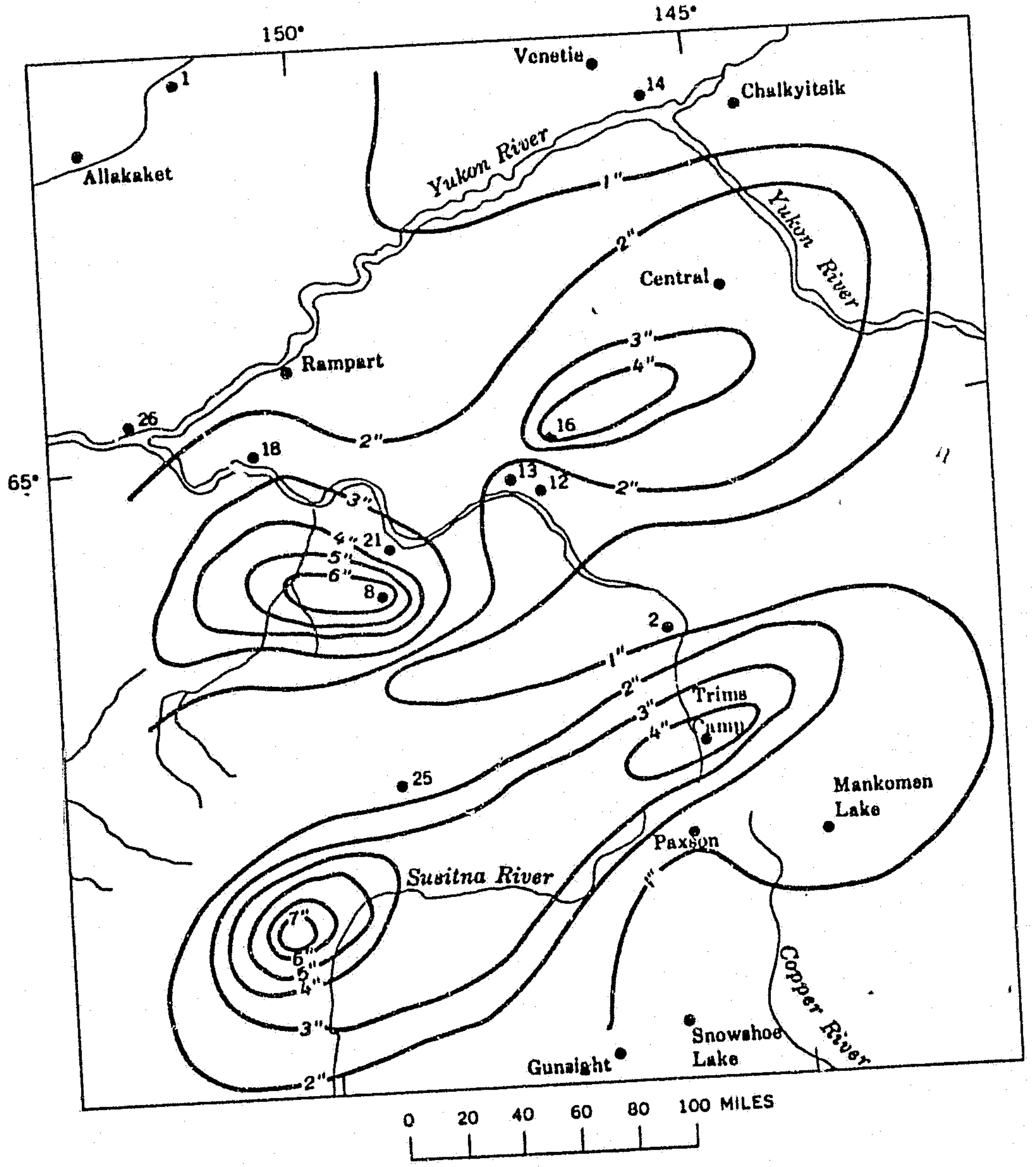


FIGURE 9.—Isohyets of total rainfall distribution, August 13–20. Numbered points are U.S. Weather Bureau precipitation gages identified in table 1.