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Susitna Hydroelectric Project

Reservoir and River Sedimentation

Prepared by

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for the

Alaska Power Authority

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1.0 SCOPE OF THE STUDY

The scope of the present study includes a reservoir sedimentation analysis for Watana and Devil Canyon Reservoirs, and a river sediment transport study for the Susitna River between the Devil Canyon dam site and the Sunshine stream gaging station (see Exhibit 1 for the locations). The major tasks are:

1. to review available relevant reports,

2. to estimate sediment inflow to the reservoirs and sediment deposit in the reservoirs for 50 and 100 years of reservoir operation,

3. to conduct a preliminary assessment of aggradation and degradation of the Susitna River below the dams especially near the mouths of the tributaries and sloughs;

4. to recommend areas of concern for further study; and

5. to recommend a program of data collection required for further study.

2.0 SUMMARY AND CONCLUSIONS

Sediment inflow to Watana and Devil Canyon Reservoirs were estimated by transposing sediment discharge data for the Susitna River near Cantwell and at Gold Creek. Suspended-sediment discharges at the gaging stations were computed by the sediment rating-flow duration curve method. Bedload discharges were estimated as a percentage of suspended-sediment discharges. Sediment deposits in the reservoirs were estimated by assuming 100 percent trap efficiency.

Sediment deposit in the Watana Reservoir was estimated to be 6,730,000 tons per year (tons/yr) or 210,000 acre-feet (af) for a 50-year period, which is about 2.2 percent of the gross reservoir volume of 9,470,000 af. The 100-year deposit would be about 410,000 af.

Sediment deposit in the Devil Canyon Reservoir was estimated to be 7,240,000 tons/yr or 226,000 af for a 50-year period assuming without Watana Reservoir. The 50-year sediment deposit would occupy about 21 percent of the gross reservoir volume of 1,090,000 af. The 100-year deposit would be about 442,000 af.

With Watana Reservoir in operation, sediment deposit in the Devil Canyon Reservoir would be about 515,000 tons/yr or 16,100 af for a 50-year period assuming that Watana Reservoir would trap all sediment inflow except insignificant amount of very fine material. The 50-year sediment deposit is about 1.8 percent of the gross reservoir volume. The 100-year deposit would be about 31,400 af.

The river sedimentation studies below Devil Canyon Dam cover the Susitna River from its confluence with Portage Creek to the Sunshine gage. This river segment was divided into the Middle and Lower reaches for analysis. The Middle reach runs from the confluence with Portage Creek to the confluence with the Chulitna River and the Lower reach from the confluence with the Chulitna River to the Sunshine gage.

The Middle reach was divided further into 12 subreaches for estimating post-project degradation. The degradation for each subreach was computed by assuming no bedload inflow to the subreach and assuming that bed armoring will develop as small particles are sorted out and transported downstream.

Table 1 lists the estimated degradations along with armoring sizes under pre- and post-project conditions, and bed material size distributions. The armoring sizes for post-project conditions are considerably smaller than those for pre-project conditions because of the smaller dominent discharge (1)[1/] due to reservoir regulation. The dominant discharges were taken as the mean annual flood under the respective conditions. The channel degradation was computed using the procedures given in "Design of Small Dams" (1) and ranges between zero to 0.3 ft in various subreaches. Since bedload from tributaries and upstream subreaches could deposit in a subreach, the net degradation would be smaller.

River bed aggradation near the mouths of some tributaries appears to be likely under post-project conditions. This conclusion is based on a comparison of sediment size transportable by the Susitna River under post-project conditions with the bed material size distribution near the mouth of the tributaries.

The sediment transportable under post-project condition were assumed to be equal to or smaller than the corresponding armoring size shown in Table 1. The median sizes (D_{50}) of bed material at the mouths of Indian River and Sherman Creek are greater than the transportable sizes. Thus, coarser material brought by these tributaries will have the tendency to accumulate in the mainstem of the river near the confluences.

1/ See list of references at the end of the text.

The size distributions of bed material for other tributaries (Table 1) indicate D_{50} smaller than the transportable size, and there would be less aggradation near the mouth of these tributaries. However, because only a few bed material samples were collected in the study reach as discussed under section entitled "Bed Material", additional data will have to be collected and anlayzed to confirm or revise this assessment.

Currently, data are not available to quantify the extent of potential aggradation in the mainstem near the mouths of the tributaries. A sediment data collection program has been proposed by the U.S. Geological Survey (USGS) which includes sediment measurements on Indian River and Portage Creek. When data collected under this program become available, a quantitative estimation may become feasible. However, severe aggradations at the mouths of tributaries are not expected which will require substantial mitigative measures. Most of the tributaries will adjust to new flow regime without detrimental effects on fish access, bridge or railroad. The adjustment will depend upon a number of factors such as the shape of a tributary cross section, size of bed material, increase in the hydraulic gradient due to lowering of water surface elevation in the mainstem under post-project conditions, magnitude and frequency of high flows in a tributary and the size of sediment transportable by the mainstem flow. The interaction of these factors is not completely understood. Therefore, depending upon these factors, a tributary may adjust to new regime over a period of time, one wet season or a number of years.

Slough berms

Bed material samples collected by Harza-Ebasco in side channels and on slough berms indicate that under the pre-project conditions, erosion of the berms at the entrance of sloughs and the erosion of side channels occur during high flows. Under post-project conditions, the erosion will be less and some aggradation at the entrance of the sloughs and side channels may be expected. This is because the main river channel will become more confined and any occasional higher flows may deposit bedload near the entrance. This in conjunction with attenuation of high flows by the reservoir will reduce the frequency of mainstem flows overtopping the berms.

Project effect on sediment transport in the Lower reach will depend primarily on the change in the bedload transporting capacity of the Susitna River below its confluence with the Chulitna and Talkeetna Rivers.

The sum of bedload discharges estimated for the Susitna River near Talkeetna (about 5 miles above the confluence with the Chulitna River), the Chulitna River near Talkeetna (about 17 miles above the confluence) and the Talkeetna River near Talkeetna (about 4 miles above the confluence) in water year 1982 was about 1,460,000 tons. The Susitna River contributes 3 percent of the total bedload, the Chulitna River 83 percent, and the Talkeetna River 14 percent. In the same year, bedload passing Sunshine (about 14 miles downstream from the confluence) was estimated to be 423,000 tons. BEDLOAD

The bedload discharges were computed by the sediment rating-flow duration curve method. The sediment rating curves at the gaging stations were developed using bedload samples collected by the USGS during the summer months of 1981 and 1982 (Exhibits 16,17, 18,and 19). The sediment-rating curves are not well defined, especially the curve for the Chulitna River, because of large scattering of the data points. This introduces some degree of uncertainty in the above estimated rates. a large degree!

suspended load

The sum of suspended sediment discharges for the Susitna River near Talkeetna, the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna was estimated to be about 11,660,000 tons in water year 1982. The suspended sediment discharge for the Susitna River near Sunshine was estimated to be about 13,330,000 tons for the corresponding period. Therefore, the total sediment loads (suspended sediment load + bedload) entering and leaving the Lower reach were about 13,120,000 and 13,753,000 tons, respectively.

The river cross sections (Exhibit 9 through 15) indicate periodic scour and deposition. Based on field reconnaissance, the Lower reach apears to be in a long-term stable regime. Therefore, the imbalance of 633,000 tons indicated in water year 1982 is likely to be because of contribution of sediment

∴ on Chulitna Bedload : Susp. Sed. is 1:10 (?) ← How did I find this?

from intervening area between the sediment measuring stations or because of error in the estimation of sediment discharge at the gaging stations.

* Computations show that the total sediment discharge capacity at Sunshine under post-project conditions would be about 55 percent of that under present conditions. Therefore, with 79 percent of the total load coming from the Chulitna and Talkeetna Rivers, long-term aggradation in the Lower reach can be expected because of regulation of flood and high flows by the reservoirs. The magnitude of the aggradation and its location cannot be properly predicted with the available data. However, it is expected that the aggradation will start at the mouth of the Chulitna River. Existing delta formation will further develop and extend towards the left bank below the confluence but the river channel will become better defined compared to existing conditions. This is because the flow in the river will be much more stable under post-project conditions than under the present condition.

Although the eventual magnitude of aggradation cannot be predicted with the available data, the aggradation is unlikely to cause severe navigational or fish access problems in the reach below the confluence. This is because of better defined channel with major flow contribution (average flows at Sunshine and Susitna Station are about 2.5 and 5 times that at Gold Creek) from the drainage basin below the confluence.

The USGS has collected more data on bedload discharge during 1983 and also will collect data during 1984. When these data become available, a better estimation of potential aggradation may become possible.

1. They conclude that long-term lower ~~river~~ reach is in equilibrium presently

2. Post-project aggradation in lower reach

3.0 RECOMMENDATION

As indicated previously, a precise estimation of aggradation or degradation in the Susitna River below Devil Canyon Dam can not be made at present because insufficient data are available.

The 1983-84 sediment sampling program of the USGS includes a new bedload measurement station on the Susitna River below the confluence of the Chulitna and Susitna rivers. This will permit refinement in the analysis of bedload transport in the Chulitna River and also will help to identify the location of sediment deposits in the Lower reach.

The USGS also will conduct a bedload and bed material sampling program for the Indian River and Portage Creek. This will help in evaluating the aggradation, if any, near the mouth of these tributaries.

For each major tributary of concern, about 5 cross sections on the tributary (at the confluence and upstream from the confluence) and two cross sections (upstream and downstream from the confluence) on the mainstream should be surveyed to determine the gradient of the tributary. This will help in the computations of aggradation or degradation in the tributries near their confluence with the main stream.

The USGS sediment sampling program should be continued for a period of at least 3 to 5 years. The size distribution of bed material used in this analysis is based on small number of samples taken near the surface and may not represent the sub-pavement materials. Therefore, bed material samples in the twelve subreaches identified in this study should be taken both for pavement and sub-pavement.

Streamflow data of the tributaries are not available and hence the estimates of bedload transported by the tributaries could not be made. A stage recorder and periodic discharge measurements are recommended for the Indian

River. These data can be used with results of the USGS sampling program to estimate the bedload transported by the river. The information obtained from these data also can be transposed to other tributaries to estimate amount of bedload brought into the Susitna River.

4.0 PROJECT SETTING

The Susitna River drains about 19,600 square miles (sq mi) in the southcentral region of Alaska. Major tributaries include the Chulitna, Talkeeta, and Yentna rivers. Glaciers in the headwaters contribute substantial sediment during summer months. Streamflow is characterized by turbid high flows from ice breakup in May to September and clear low flows from October to April. High summer flows are caused by glacial melt, snowmelt, and storm rainfall.

The Susitna River is about 320 mile (mi) long. The Watana and Devil Canyon damsites are located at river miles 184 and 152, respectively. The drainage areas at the two dams are about 5180 sq mi and 5810 sq mi, respectively.

The Chulitna River originates in the glaciers on the south slopes of Mount McKinley and enters the Susitna River from the west near Talkeetna at river mile 98. The Talkeetna River originates in the Talkeetna Mountain and enters the Susitna River from the east near Talkeetna at river mile 97. The Yentna River originates in the glaciers of the Alaska range and enters the Susitna River from the west at river mile 28.

The Susitna River falls from elevation (El.) 850 ft at the Devil Canyon damsite to El. 260 ft at the Sunshine gage (Exhibit 2). The average slope in this reach is about 0.0017.

The Susitna River between the Devil Canyon damsite and the Susitna-Chulitna confluence has many side channels, sloughs, and islands, while most length of the river below the confluence is highly braided.

5.0 REVIEW OF PREVIOUS STUDIES

Reports of previous studies related to reservoir sedimentation, turbidity and channel stability were reviewed. The studies from which the basic data and results were used in the present study include the following:

1. R&M Consultant, Inc. "Susitna Hydroelectric Project, River Morphology," prepared for Acres American Inc. January 1982 (2).

This study provides an overview of the climate, topography, geology, soils, vegetation and available water resources in the Susitna River basin. Potential changes in the present river morphology under post-project conditions also are discussed.

Estimates of available streamflow are provided as monthly flow duration curves under pre- and post-project conditions. Flow variability is discussed by presenting 1-, 3-, 7- and 15- day high and low flow values for May through October period. Mean annual floods are estimated for all major tributaries. Discharge and stage frequency curves are given for key locations on the Susitna River under pre- and post-project conditions.

Sediment characteristics of the Susitna River are discussed and sediment rating curves are provided for the stream gaging stations on the Susitna, Talkeetna, Chulitna and Maclaren rivers. Bedload of the Susitna River at Denali is reported to be about 1,588,000 tons per year.

Size distribution of bed material at various cross sections are provided. The movable particle sizes for various discharges are computed for a number of cross sections.

2. R&M Consultants, Inc. "Susitna Hydroelectric Project, Reservoir Sedimentation," prepared for Acres American Inc., January 1982 (3).

This report presents estimates of sedimentation in the Watana and Devil Canyon reservoirs. The trap efficiencies of the reservoirs were estimated to vary between 80 and 100 percent. Specific weights of 97, 71.6 and 72.8 pounds per cubic foot (lbs/ft^3) were used for the bedload, suspended sediment deposit after 50 years and suspended sediment deposit after 100 years, respectively. The derived sediment rates are given below:

	50-year	100-year
Watana		
100 percent trap efficiency	240,000 af	472,500 af
70 percent trap efficiency	170,000 af	334,000 af
Devil Canyon with 70 percent trap efficiency of Watana		
100 percent trap efficiency	79,000 af	155,000 af
70 percent trap efficiency	55,000 af	109,000 af
Devil Canyon with 100 percent trap efficiency of Watana		
100 percent trap efficiency	8,600 af	16,800 af
70 percent trap efficiency	6,100 af	-

Turbidity of water released from the reservoirs also is discussed based on the data collected by the USGS in 1974-76 and by R&M in 1980-81. It is concluded that the turbidity during the summer months will sharply decrease due to sediment trapping characteristics of the reservoirs. The turbidity during the winter months will be near natural conditions as suspended sediment in near-surface waters will rapidly settle once the reservoir ice cover forms and essentially quiescent conditions occur.

3. Peratovich, Nottingham & Drage, Inc. "Susitna Reservoir Sedimentation and Water Clarity Study," prepared for Acres American Inc., November 1982 (4).

This report presents the analysis of turbidity levels in Watana Reservoir. A computer model "DEPOSITS" was used to compute the turbidity at various levels in the reservoir. The major conclusions of the report are given below:

a. It is likely that sediment particles less than 3 to 4 microns will remain in suspension. This constitutes up to 20 percent of the summer sediment input. Maximum turbidity levels at the outlet are on the order of 50 NTU's, which corresponds to a sediment concentration of 200 to 400 milligram per litre (mg/l). Minimum turbidity levels will be in the order of 10 NTU's. This corresponds to a sediment concentration of 30 to 70 mg/l.

b. Turbidity levels at the reservoir outlet during each month appear to be primarily dependent upon the travel time for sediment slugs, delivered to the reservoir during previous summers, to reach the reservoir outlet. Longitudinal mixing, primarily induced by wind turbulence, will tend to mask the near surface sediment slugs. Quantification of longitudinal mixing has not been directly addressed within the scope of this task.

c. Wind mixing is significant in retaining sediments of less than about 12 microns in suspension for the upper 50-foot layer of water.

d. Reintrainment of sediment from the shallow depth along the reservoir periphery during severe storms will result in short-term high turbidity levels. This will be particularly evident during the summer refilling process when water levels will rise, resubmerging sediment deposited along the shoreline during the winter.

e. In spite of some limitations, the data gathered from outside sources supports the conclusion that Watana reservoir turbidity levels will be in the range of 10-50 NTU's.

f. Preliminary results from the Eklutna Lake study show summer turbidity levels in the near surface layers to be in the range of 20-40 NTU's.

This generally agress with the range of turbidity values predicted for the Watana reservoir.

4. R&M Consultants, Inc., "Susitna Hydroelectric Project, Tributary Stability Analysis," prepared for Acres American Inc., December 1982 (5).

This report presents field data collected in various tributaries. It also provides a quantitative discussion of potential project impact on channel stability near the mouth of tributaries. Nineteen tributaries are selected for the study. Three creeks (Jack Long, Sherman and Deadhorse) are estimated to aggrade and to likely restrict the access by fishes. The tributaries at river miles 127.3 and 110.1, and Skull Creek are estimated to degrade and to affect the railroad bridges. The other tributaries will either degrade or aggrade but without effects on fish access or railroad.

5. Trihey, E. Woody, "Preliminary Assessment of Access by Spawning Salmon into Portage Creek and Indian River," prepared for Alaska Power Authority March 1983 (6).

This report is based on field data collected during the summer and fall of 1982 by ADF&G Su-Hydro Aquatic Studies Group and R&M.

Entrance conditions at the mouths of Portage Creek and Indian River are calculated for mainstem discharges of 8,000 13,400, 21,500 and 34,500 cfs at the Gold Creek gaging station.

Average monthly post-project streamflow at Gold Creek are estimated to be in the range of 7,000 to 11,000 cfs. A controlled flow of 12,000 cfs is assumed from mid-August to mid-September.

The analysis indicates that fish access to Portage Creek and the Indian River has not been a problem and is unlikely to be a problem under post-project conditions. These creeks will adjust streambed gradient and will re-establish entrace conditions.

6.0 DATA SOURCES

6.1 STREAMFLOW

Streaflow records collected by the USGS for the Susitna River near Cantwell, at Gold Creek and at Sunshine; the Chulitna River near Talkeetna; and the Talkeetna River near Talkeetna were used in this study. The periods of record available are shown below. The stream gaging stations are shown on Exhibit 1.

STREAM GAGING STATIONS
PERIOD OF RECORD

Gaging Station	USGS Gage No.	Drainage Area, sq mi	Period of Record
Susitna River near Cantwell	15291500	4,140	May 1961 - Sep 1972 May 1980 - Present
at Gold Creek	15292000	6,160	Aug 1949 - Present
at Sunshine	15292780	11,100	May 1981 - Present
Chulitna River near Talkeetna	15292400	2,570	Feb 1958 - Sep 1972 May 1980 - Present
Talkeetna River near Talkeetna	15292700	2,006	Oct 1974 - Present

6.2 RIVER CROSS SECTIONS

Cross sections of the Susitna River have been surveyed at 99 locations between river mile 94.6 near Talkeenta and river mile 150.2, about 1.3 mile upstream from the confluence with Portage Creek (7, 8). Cross sections at 23 locations also are available between river mile 162.1 at Devil Creek and river mile 186.8 at Deadman Creek (9).

6.3 BEDLOAD AND BED MATERIAL

Bedload discharge data have been collected by the USGS in the Susitna, Chulitna, and Talkeetna rivers starting in 1981 as shown below.

BEDLOAD DISCHARGE DATA
SUSITNA RIVER BASIN

Station	USGS Gage No.	Period of Record	No. of Samples
Susitna River at			
at Gold Creek	15292000	Jul - Sep 1981	3
near Talkeetna	15292100	Jun - Sep 1982	15
at Sunshine	15292780	Jul - Sep 1981	3
		Jun - Sep 1982	15
Chulitna River near Talkeetna	15292400	Jul - Sep 1981	3
		Jun - Sep 1982	15
Talkeetna River near Talkeetna	15292700	Jul - Sep 1981	3
		Jun - Sep 1982	15

Additional measurements of bedload discharge have been made by the USGS in 1983 at the last four stations listed in the above table but were not available for this study.

Harza-Ebasco collected 17 bed material samples from the mainstem of the Susitna River and 2 samples from the Chulitna River. Additional 29 samples were collected in the side channels of the Susitna River upstream from the confluence with the Chulitna River. Size distributions of these samples were determined by sieve analysis. Exhibit 3 shows the locations at which the samples were taken. Bed material size distributions for the Susitna River also have been estimated by R&M (5) using grid sampling techniques at 38 locations between cross section 4 at river mile 99.58 and cross section 59 at river mile 144.83. Bed material size distributions at the mouths of

11 tributaries also have been estimated by R&M using the same method. These tributaries join the Susitna River between river mile 113.6 at Lane Creek and river mile 148.9 at Portage Creek.

6.4 SUSPENDED SEDIMENT

Suspended sediment data are available from the USGS at five sampling stations as listed below.

SUSPENDED SEDIMENT DISCHARGE DATA
SUSITNA RIVER BASIN

Station	USGS Gage No.	No. of Samples	Period of Record water year
Susitna River near Cantwell	15291500	43	1962-1972, 1982
at Gold Creek	15292000	370	1949, 1951-1958, 1962, 1967-1968, 1974-1982
at Sunshine	15292780	32	1971, 1977, 1981-1982
Chulitna River near Talkeetna	15292400	51	1958-1959, 1967-1972 1970-1982
Talkeetna River near Talkeetna	15292700	116	1966-1982

7.0 RESERVOIR SEDIMENTATION

7.1 GENERAL APPROACH

Suspended-sediment loads at the Watana and Devil Canyon dam sites were estimated by interpolating the loads at the Cantwell and Gold Creek gages on the Susitna River. Sediment trap efficiencies of the reservoirs were estimated by the Brune's and Churchill's curves.

Sediment deposits in Devil Canyon Reservoir were estimated for with- and without-Watana Reservoir conditions.

Bedloads were estimated as percentages of suspended- sediment loads using available data at the Gold Creek, Talkeetna, and Sunshine gages on the Susitna River. All bedloads were assumed to be trapped by the reservoirs. Bedloads at Devil Canyon Reservoir were computed for with- and without-Watana Reservoir conditions.

7.2 SEDIMENT LOAD

Sediment discharges at the Cantwell and Gold Creek gages were computed by the sediment rating- flow duration curves method. Suspended sediment discharges and the corresponding water discharges for the Cantwell gage are shown on Exhibit 4. The data points were grouped into three groups each corresponding to the period from June to October, November to April, and May. Only one sample was available for the November-April period and two samples for the May period. These data are insufficient to develop separate curves. Therefore, one sediment rating curve was fitted visually to all data points.

A flow-duration curve for the Cantwell gage is shown on Exhibit 5. The curve is based on 13 years (1962-1972, and 1981-1982) of available daily flow data.

Using the suspended-sediment rating curve on Exhibit 4 and the flow-duration curve on Exhibit 5, the mean annual suspended-sediment discharge at the Cantwell gage was computed to be about 5,660,000 tons/yr.

Suspended-sediment discharges and the corresponding water discharges for the Gold Creek gage are shown on Exhibit 6. The samples, collected in the period from 1949 to 1982, were divided into three groups correspnding to June-October, November-April, and May periods. The points for the latter two periods appear to constitute a trend line and were fitted with a curve. The points for the first period constitute a different trend line and were fitted with a separate curve.

The daily flow duration curves for the Gold Creek gage for the June-October and November-May periods were divided using the 1950-1982 flow data and are shown on Exhibit 5. The mean annual suspended-sediment discharge at the Gold Creek gage was computed to be about 7,260,000 tons/yr, using the sediment rating curves on Exhibit 6 and the flow duration curves on Exhibit 5.

see p 8-12, much higher than at confluence

7.3 RESERVOIR SEDIMENT INFLOW

Suspended-sediment inflows to Watana and Devil Canyon Reservoir were computed by transposing sediment discharges at the Cantwell and Gold Creek gages, whose locations bracket the two reservoirs. Sediment discharges at the two gages were assumed to follow the following exponential relationship:

$$\frac{q_{s_2}}{q_{s_1}} = \left(\frac{A_2}{A_1}\right)^n$$

reference?

in which

q_{s_1} = sediment discharge per unit drainage area (unit sediment discharge) at point 1

q_{s_2} = unit sediment discharge at point 2

A_1 = drainage area for point 1

A_2 = drainage area for point 2

n = exponent

Using the unit sediment discharges at the Cantwell and Gold Creek gages, exponent "n" in the above equation was computed to be -0.376. Thus, suspended-sediment discharge at the Watana damsite was computed to be 6,530,000 tons/yr for the drainage area of 5180 sq mi.

Assuming no Watana Reservoir, the suspended-sediment discharge at the Devil Canyon damsite was computed to be 7,030,000 tons/yr using drainage area of 5810 sq mi.

Bedload discharge was estimated to be three percent of suspended-sediment discharge based on the following analysis.

Bedload and suspended sediment discharges for the Susitna River near Talkeetna was estimated to be 43,400 and 2,610,000 tons/yr, respectively, as presented later in this report. Thus, the bedload discharge is about 1.6 percent of suspended-sediment discharge. For the Sunshine gage, this percentage is about 3.2 based on the bedload and suspended sediment discharges of 423,000 and 13,330,000 tons/yr, respectively. A value of 3 percent was used in the analysis.

7.4 SEDIMENT TRPA EFFICIENCY

Sediment trap efficiencies of Watana and Devil Canyon Reservoirs were estimated by the Brune's and Churchill's curves (1). The trap efficiency of Watana was also estimated by Peratrovich, Nottingham and Drage (4) using a sedimentation model. Similar modeling is not available for Devil Canyon Reservoir.

A comparison of the trap efficiencies of Watana and Devil Canyon Reservoirs estimated by the three methods is shown in the following table.

COMPARISON OF TRAP EFFICIENCIES ESTIMATED BY
BRUNE'S CURVES, CHURCHILL'S CURVE, AND SEDIMENTATION MODEL

Method	Trap Efficiency, %	
	Watana	Devil Canyon
Brune's Curves		
Coarse Sediment	100	98
Median Curve	99	94
Fine Sediment	96	86
Churchill's Curve		
Local Silt	100	95
Fine Silt	-	88
DEPOSITS Model		
Quiescent	94 to 96*	-
Minimum Mixing	86 to 93*	-
Maximum Mixing	78 to 90*	-

* Corresponding to dead storage volumes from 5,340,000 acre- feet to 900,000 acre-feet (reservoir capacity = 9,470,000 acre-feet at normal maximum pool).

The Watana trap efficiency ranges from 96 to 100 percent based on the Brune's curves. The trap efficiency is about 100 percent based on the Churchill's curve for local silt. The trap efficiency computed by a reservoir sedimentation model, DEPOSITS, ranges from 78 to 96 percent depending on reservoir mixing and dead storage volume.

The trap efficiency of Devil Canyon Reservoir ranges from 86 to 98 percent based on the Brune's curves. The trap efficiency estimated with the Churchill's curves is 95 percent for local silt and 88 percent for fine silt, the latter case being for sediment discharged from an upstream reservoir.

Table 2 and 3 show the estimation of the trap efficiencies by the Brune's curve and the churchill's curve.

7.5 SEDIMENT DEPOSIT

Based on the estimated trap efficiences shown in the above table, the Watana Reservoir was assumed conservatively to trap all sediment inflow to the reservoir. The resulting sediment deposits over a 50- and 100-year period will be about 210,000 and 410,000 af, which are about 2.2 and 4.3 percent of the gross reservoir volume, respectively.

Without Watana Reservoir, the 50- and 100-year sediment deposits in the Devil Canyon Reservoir would be about 226,000 and 442,000 af respectively also assuming a trap efficiency of 100 percent. These are about 21 and 41 percent of the gross reservoir volume, respectively.

Compare to previous work, p 5-2

With Watana Reservoir, the 50- and 100-year sediment deposits in Devil Canyon Reservoir would be about 16,100 and 31,400 af respectively or 1.5 and 2.9 percent respectively of the gross reservoir volume assuming 100 percent trap efficiency for sediments from the intervening drainage area. Any suspended sediment passed through Watana Reservoir was assumed to also pass through Devil Canyon Reservoir.

The sediment volumes presented above were computed using the procedures of the U.S. Bureau of Reclamation (1). Percentages of clay, silt, and sand of the incoming suspended sediment were estimated to be 20, 38, and 42, respectively, using sediment data for the Cantwell and Gold Crek gages. Using the unit weights of clay, silt and sand as 26, 70, and 97 lb/ft^3, respectively, the unit weights of the suspended sediment deposit after 50 and 100 years were estimated to be about 80 and 82 lbs/ft^3, respectively. The unit weight of bedload was estimated to be 120 lb/ft^3.

7.6 TURBIDITY

Since the studies made by R&M (3) and Peratrovich, Nottingham & Drage, Inc. (4), no additional data have been collected on turbidity in the Susitna River. These studies were reviewed as discussed under the section entitled "Review of Previous Studies". The conclusion arrived in these studies are reasonable and can be used to estimate the turbidity of the reservoirs and their outflows.

8.0 DOWNSTREAM AGGRADATION AND DEGRADATION

The operation of the Susitna Project will reduce flood flows and consequently sediment transport capacities of the river downstream from the dams. However, most of the suspended sediments and all bedloads from upstream will be trapped in the reservoirs. The combined effects on the river downstream from the dams would be aggradation in some river reaches and degradation in other reaches. A preliminary assessment of these effects were made using available data.

8.1 GENERAL APPROACH

The channel aggradation and degradation study covers the Susitna River from its confluence with Portage Creek to the Sunshine gage. This river segment was divided into two reaches -the Middle and Lower reaches- for analysis. Because of the difference in the nature of the problem and data availability for the two reaches, different study approaches were used.

The Middle reach runs from the confluence with Portage Creek to the confluence with the Chulitna River. The Lower reach runs from the confluence with the Chulitna River to the Sunshine gage. The Middle reach was further divided into 12 subreaches, as shown in Table 1 and Exhibit 7. The subreaches were selected such that, in general, a major tributary is located near its upstream end. Also, each subreach was sufficiently short such that the average flow depth, velocity, and slope in the subreach would be representative throughout the entire subreach.

River beds below a dam often degrade if the reservoir traps a large portion of the sediment and release clear water which is capable of picking up bed materials. Under such conditions, smaller particles in the riverbed are picked up and transported downstream by river flow. Large particles, however, will remain on the river bed and gradually form an armoring layer, which will stop further degradation.

The degradation computation for each subreach was based on assumption that bedload inflow to the subreach is carried through and no deposition occurs. When there is a tributary entering the subreach, its bedload is also assumed to be carried through although some deposition of the bedload can be expected under actual conditions. Therefore, the computed degradation represents a conservative estimate. ← Sounds wrong; I think the reverse.

The larger particles brought to the mainstream by a tributary may be too large for the mainstem to transport under post-project conditions. The likelihood that a part of the tributary bedload may accumulate near its mouth was evaluated by comparing the armoring size in the mainstem under post project conditions with the size of bed materials near the tributary mouth.

Project effects on sediment transport in the Lower reach was evaluated based on a sediment balance analysis. The bedload discharge data at four stream gaging stations: the Susitna River near Talkeetna and at Sunshine, the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna, were used in the analysis.

8.2 MIDDLE REACH

8.2.1 Dominant Discharge

The dominant discharge is defined as the discharge which, if allowed to flow constantly, would have the same overall channel shaping effect as the natural fluctuating discharges would (1). The dominant discharge used in computing channel degradation or aggradation is usually considered to be either the bankfall discharge or the mean annual flood.

The mean annual flood for the Susitna River at Gold Creek was estimated to be 52,000 cfs under pre-project conditions and 13,400 cfs under post-project conditions (5). The mean annual flood for pre-project conditions increases from 51,100 cfs in subreach 1 to 53,600 cfs in subreach 12. The mean annual flood for post-project conditions increases from 12,500 cfs in subreach 1 to 15,000 cfs in subreach 12.

8.2.2 Bed Material

Bed materials of the Susitna River consist mostly of gravel and cobble with a small percentage of sand. Size distribution of the bed materials have been analyzed by Harza-Ebasco, R&M, and the USGS. Harza-Ebasco collected and analyzed 46 bed material samples from the mainstem and side channels of the Susitna River. Of these samples 40 are from the Middle reach. Samples from under water were collected either with a pipe dredge of six-inch diameter in the middle of the river or with a shovel near the banks where water depth was about 1 to 1.5 feet. Samples from gravel bars in the river and berms near the head of the sloughs were collected by a shovel. The size distributions of all samples were determined by sieving.

The samples collected by Harza-Ebasco from under water are considered representative of bed material subject to transport. The median diameters of the samples collated in the mainstream are generally larger than those of the samples collected in the side channels (Table 4).

R&M (5) determined the size distrubution of bed material by the grid-by-number method at 38 locations in the Middle reach between cross sections 4 and 79. Most samples were taken near the river banks. Comparing to the samples collected from the channel, the particle sizes of bed material collected near the banks are generally larger.

The USGS collected bed material samples at two gaging stations in the Middle reach: the Susitna River at Gold Creek and near Talkeetna. The samples were collected by the pipe dredge of six-inch diameter.

In some of the subreaches more than one smaples were available while in other either only one or no samples were collected. Because of the limited number of the samples the bed material data used in the degradation computation were judiciously selected from all available bed material data. The size distribution used for each subreach is shown on Exhibit 8. Some size distribution are the average of two or more samples.

8.2.3 Tributaries and Sloughs

Portage > 2x Indian for both Q + Area

The Middle reach has 19 major tributaries. The two largest tributaries are Portage Creek in Subreach 1 and the Indian River in Subreach 3, with a drainage area of about 176 sq mi and about 82 sq mi, respectively. The mean annual flood is estimated to be 1680 cfs for Portage Creek and 786 cfs for Indian River (5). The other tributaries have drainage areas ranging from 24 sq mi to 0.4 sq mi. The mean annual floods are estimated to range from 260 cfs to 4 cfs (5). Table 5 lists drainage areas, mean annual floods and bed material sizes of the tributaries.

Sloughs are side channels which are not hydraulically connected with the Susitna River flow until the berms at the upstream end of the sloughs are overtopped. A slough, when its berm is not overtopped, usually carries a small flow (3 to 20 cfs) from its drainage area or seepage. Major sloughs include Sloughs 22, 21, 20, 9, and 8 (Exhibit 7).

8.2.4 Degradation Limited by Armoring

Degradation limited by armoring in each subreach was computed using the procedures in "Design of Small Dams"(1). The armoring particle size was estimated for the post-project dominant discharge by four methods: competent bottom velocity, critical tractive force, Meyer-Peter and Muller formula, and the Schoklitsch formula. The average of the four armoring sizes computed is taken as the armoring size in the subreach, as listed in Table 1. The flow velocity, depth, bed slope, channel width, and roughness coefficient used were there obtained from a hydraulic study made by Harza-Ebasco (10). The pre-project armoring sizes also were computed, using the pre-project dominant discharges, and are listed in Table 1 for comparison.

The depth of post-project degradation required to form an armor layer was then computed using the armoring size and bed material size distribution described earlier. The bed material size distributions are summarized in Table 1 by their D_{16}, D_{50}, and D_{90} sizes, which, respectively, are the sizes at which 16, 50 and 90 percent (by weight) of the bed material particles are finer.

Table 1 shows that the post-project armoring size ranges from 40 mm in sub-reach 1 to 21 mm in Subreach 12. The size generally decreases in downstream direction. The estimated degradation ranges from zero to 0.3 ft. The degradation for each subreach was computed by assuming no bedload inflow.

8.2.5 Aggradation Near Tributary Mouths

The transportable size under pre-project conditions is considerably greater than D_{50} of bed material for all tributaries as shown in Table 1. Thus most bedload inflow from these tributaries are transported downstream by the mainstem flow. This indicates that long-term accumulation at tribuary mouths is not likely to occur under pre-project conditions.

The transportable size of the Susitna River under post-project condition is either smaller or only slightly greater than D_{50} of bed material at the mouth of a tributary depending on the tributary (Table 1). Furthermore, study by Trihey (6) indicated that particle size of tributary bedload and bed material may coarsen due to lowering of the Susitna River stage under post-project conditions. Thus, part of bedload carried down by some tributaries may accumulate at the mouth of the tributaries and in the mainstem immediately downstream from the tributary. This will tend to compensate the

Because of steepened gradient?

minor degradation discussed in the previous section. The extent of further aggradation cannot be estimated at this stage because of non-availability of data. However, field investigations being made by USGS (1983-84 program) on the Indian River and Portage Creek would provide data to analyse aggradation or degradation problems.

Bed material data for some of the tributaries listed in Table 1 are not available. Assuming that their bed material are similar to those of nearby tributaries, a similar conclusion would be reached.

8.2.6 Other Project Effects

During a field reconnaissance in August, 1983, a sample of bed material was taken on the berm of Slough 21. This sample is believed to be fairly representative of bed material on most of the berms. The D_{50} of this sample is smaller than the armoring size corresponding to pre-project conditions (Table 1). Thus, under the present condition, erosions frequently occur on the berms. Field reconnaissances made during high and low flows indicate that deposition of fine sediment (silt and clay) occurs in the sloughs during low flows, which is flushed out during high flows.

Slough berms:

Under post-project conditions, the armoring size is smaller than the D_{50}. Thus, erosion of the berms would be much less under normal condition. Some aggradation near the berms could be expected because the main river channel would become more confined and any occassional higher flows would push the moving bedload near the entrance of sloughs. This would tend to close the entrance to the sloughs and there will be less frequent over topping of the berms by the mainstem flows to flush out the fine sediment deposits in the sloughs.

8.3 LOWER REACH

The effect of the project on the river below the Chulitna-Susitna River confluence was evaluated by accounting total sediment inflow and outflow for the Lower reach.

8.3.1 Cross Sections

Exhibits 9 and 10 show two typical cross sections (Sections 1 and 2, Exhibit 7) of the Susitna River in the Lower reach. Exhibits 11 and 12 show the cross sections of the Susitna River near Talkeetna and Sunshine gages. Exhibit 13 shows Susitna River section at the upstream face of the Sunshine bridge and Exhibits 14 and 15 show the cross sections of the Chulitna River and Talkeetna River at the sediment measuring stations. All of the cross-sections were surveyed more than once during the period from 1980 to 1982 except those shown on Exhibit 13 which were surveyed in 1971. The cross sections indicate a fairly large seasonal aggradation or degradation. Exhibit 13 shows that scouring occurs in spring and summer during the high flow season, but deposition occurs in the fall during the low flow season.

The continuous changes in the cross sections (Exhibits 9 to 15) indicate that aggradation and degradation have occurred continuously in the Lower reach. However, results of field reconnaissances did not show any evidence of large long-term aggradation or degradation in the reach. Therefore, the reach can be assumed to be in equibrium under pre-project conditions on a long-term basis.

8.3.2 Bedload-Discharge Rating Curves

Bedload discharges measured by the USGS at two stations on the Susitna River near Talkeetna and at Sunshine and at two stations on the Chulitna and Talkeetna Rivers in 1981 and 1982 were used in this study. Additional bed-load discharge measurements at these four stations have been made by the

USGS in the summer of 1983. However, the results of these measurements were not available for the present study.

Bedload discharges for the Susitna River near Talkeetna and at Sunshine, the Chulitna River near Talkeetna, and the Talkeetna River near Talkeetna are presented in Tables 6 through 9. These were plotted, and a curve was fitted individually to the data points for the Susitna River near Talkeetna (Exhibit 16), the Talkeetna River near Talkeetna (Exhibit 17) and the Susitna River at Sunshine (Exhibit 18). The data points for the Chulitna River near Talkeetna indicated a wide scatter (Exhibit 19) and fitting of a curve to these points was considered inappropriate.

The Chulitna data ~~was~~ were carefully reviewed along with the daily discharges during the periods when the samples were taken. It was noticed that the early June flows bring heavy bedload which decreases with time probably, because of decrease in sediment supply from upstream. At that time, even higher flows transport relatively small amount of bedload. However, abrupt increase in bedload was noticed in the subsequent months because of slight increase in flows (see Table 7). Once this increase has occurred, the subsequent higher flows transport smaller amount. This clearly indicates that the bedload transport depends upon availability of material in addition to the magnitude of flows. However, this conclusion should be further confirmed in the future based on additional data.

To provide some estimate of annual bedload transport, the Chulitna data were grouped respectively for the months of June, July and August-September for deriving the bedload-discharge rating curves. This provided somewhat less scatter of the data for each period as shown on Exhibit 19.

A preliminary analysis was also made to develop a correlation between bedload and suspended sand transport for the Chulitna River. The analysis was made based on the assumption that coarse sand and very fine gravel moving as bedload during medium flows could become a part of suspended load during high flows. Because of limited number of data points, a well defined relationship was not discernable. As theoretically such a relationship is possible, the data will be re-analyzed when the results of 1983 and 1984 sampling become available.

8.3.3 Suspended Sediment Discharge Rating Curves

These curves were developed for the Susitna River near Talkeetna and at Sunshine, the Chulitna River near Talkeetna and the Talkeetna River near Talkeetna based on suspended sediment samples taken in 1982 and also in the preceeding years. The curves are shown on Exhibits 20 through 23. The period of record also is shown on each exhibit.

8.3.4 Particle Size of Bedload

Size distributions of particles contained in each bedload sample are shown in Tables 6 through 9 for the four stations.

These data were reviewed and it was noticed that the Susitna River near Talkeetna and the Talkeetna River near Talkeetna carry coarser material in June compared to that carried in July and August (Exhibits 24 and 26). This is probably due to availability of coarser material during early flood season and after breakup of ice. This also can be seen from Tables 6 and 8, which indicate lower bedload discharges in July and August compared to those in June for the same water discharges. The samples taken at the Talkeetna River near Talkeetna and the Susitna River at Sunshine in September after the flood of September 15, 1982, also indicate coarser material (Exhibits 24 and 27).

Average size distribution of bedload material for the Chulitna River and Susitna River at the Sunshine are shown on Exhibits 25 and 27. The Chulitna River does not show large variation in bedload sizes for different months. The Susitna River at Sunshine shows nearly the same characteristics as for the Susitna River and Talkeetna River near Talkeetna.

conditions as for the Susitna River near Talkeetna and Talkeetna River near Talkeetna.

Particle sizes also can be divided into three categories: Sand (0.064 mm to 2.0 mm), Gravel (2.0 mm to 64.0 mm), and Cobble (64.0 mm to 256.0 mm). Average percentages of sand, gravel, and cobble based on all bedload samples collected at the four stations are summarized below.

Gage	Size Distribution of Bedload Particles, %		
	Sand	Gravel	Cobble
Susitna River near Talkeetna	78	16	6
Chulitna River near Talkeetna	41	58	1
Talkeetna River near Talkeetna	75	23	2
Susitna River at Sunshine	56	42	2

Bedload for the Susitna River near Talkeetna contains 78 percent of sand, 22 percent of gravel and cobble. The Chulitna bedload contains a lower fraction (41 percent) of sand and a higher fraction (59 percent) of gravel and cobble. The Talkeetna River bedload size distribution is similar to that of the Susitna River near Talkeetna, with 75 percent sand and 25 percent gravel and cobble. The Size distribution of bedload for the Susitna River at Sunshine is about 56 percent sand and 44 percent gravel and cobble.

8.3.5 Bed Material

The size distributions of bed material at the four bedload stations also have been analyzed by the USGS. The resulting size distributions are listed in Tables 10 through 13. The samples were taken at different verticals across the sampling section. The average percentages of sand, gravel, and cobble for each station are as follows:

Gage	Size Distribution of Bedload Particles, %		
	Sand	Gravel	Cobble
Susitna River near Talkeetna	0	30	70
Chulitna River near Talkeetna	26	64	10
Talkeetna River near Talkeetna	5	52	43
Susitna River at Sunshine	5	66	29

8.3.6 Balance of Total Sediment Inflow and Outflow

For the water year 1982, the total sediment inflow in the study reach was taken as the sum of total loads measured on the Susitna, Chulitna, and Talkeetna Rivers above their confluence. The total sediment outflow from the reach was taken as the load measured at the Susitna River at Sunshine. The total load is the sum of bedload and suspended sediment discharges. The annual bedloads and suspended sediment discharge were computed by the sediment rating - flow duration curves method.

The sediment rating curves for the four gages are shown in Exhibits 16 through 23. The 1982 flow duration curves were developed from provisional daily flow data obtained from the USGS for the Susitna River at Sunshine, and the Talkeetna River near Talkeetna. The seasonal flow duration curves were developed for the Chulitna River near Talkeetna. Because no daily flow data are available for the Susitna River near Talkeetna, a flow duration curve for the Susitna River at Gold Creek gage was developed. For each duration point, the discharge near Talkeetna was estimated to be 103 percent of the corresponding discharge at Gold Creek, based on the drainage area ratio. Exhibits 28 and 29 show the daily flow duration curves for 1982.

Using the bedload discharge rating curve and the corresponding flow duration curve, the bedload discharge for the Susitna River near Talkeetna was computed to be about 43,400 tons for 1982. Similarly, the bedload discharges for the Chulitna River near Talkeetna and Talkeetna River near Talkeetna were calculated to be 1,220,000 and 197,000 tons respectively for 1982. The corresponding suspended sediment discharges are 2,610,000, 7,410,000 and 1,640,000 tons, respectively. Thus, the total sediment inflow to the Lower reach is about 13,120,000 tons.

The bedload discharge for the Susitna River at Sunshine was computed to be 423,000 tons for the same year. The suspended sediment discharge was 13,330,000 tons. This indicates that about 633,000 tons of total sediment were contributed from the reach between the three upstream gages and the Sunshine gage. This contribution appears to be somewhat higher probably because of some inaccuracy in the estimation of sediment discharges at the gaging stations.

8.3.7 Project Effect

Under post-project conditions, the total sediment discharge passing the confluence will not be significantly less than that under pre-project conditions because the Chulitna and Talkeetna rivers, which currently contribute a major portion (about 79 percent) of total load, will not be affected by the project. However, the total sediment discharge that can be carried by the Susitna River near Sunshine will be greatly reduced due to the attenuation of floods by the reservoirs. This indicates that aggradation is likely to occur below the confluence of the Susitna River with Chulitna and Talkeetna.

Daily flow duration curves for post-project conditions are not yet available. Therefore, the effect of the project on bedload discharge passing the Sunshine gage was computed with the monthly flow duration curves presented in the License Application Exhibit E, Figure E.2. 161 for Watana operation (11). The computation shows that the mean annual bedload discharge would be about 252,000 tons/yr and the suspended sediment discharge would be about 7,380,000 tons/yr under post-project conditions. This sediment discharge capacity is considerably smaller than that under pre-project conditions as indicated by the total load of 13,753,000 tons estimated for water year 1982. Therefore, long term aggradation is likely to occur and the aggradation will start at the mouth of the Chulitna River. The eventual magnitude of aggradation can not be properly predicted with the available data, but it is likely that the existing delta of the Chulitna River will extend toward the left bank of the Susitna River. The extention of the delta formation, however, is unlikely to cause severe problem on flows in the Susitna River because much more stable flows under post-project conditions will eventually develop a river channel which is better defineed than under present conditions.

REFERENCES

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10. Harza-Ebasco Susitna Joint Venture, "Susitna Hydroelectric Project, Water Surface Profiles and Discharge Rating Curves for Middle and Lower Susitna River," Dec. 1983.

11. Acres American Inc. "Application for License for Major Project -Susitna Hydroelectric Project," Vol. 5A, Exhibit E, Chapter 2, "Water Use and Quality," for Alaska Power Authority, Feb. 1983.

Table 1

RIVER BED DEGRADATION,
ARMORING SIZE AND BED MATERIAL SIZE

Reach	Cross Section	Armoring Size, mm: Pre-Project	Armoring Size, mm: Post-Project	Post-Project Degradation, ft	Bed Material Size, mm: Mainstem D_{16}	Mainstem D_{50}	Mainstem D_{90}	Tributary or Slough: Creek or Slough	Tributary D_{16}	Tributary D_{50}	Tributary D_{90}
1	62-57	120	40	0.0	63	70	79	Portage Creek	14	33	100
								Jack Long Creek	-	-	-
								Slough 22	-	-	-
2	57-51	87	36	0.0	63	70	79	Slough 21	7	40	96
								Slough 20	-	-	-
3	51-45	95	46	0.2	39	62	82	Indian River	33	50	86
								Gold Creek	17	36	94
								RM 132.0 Creek	-	-	-
4	45-36	73	35	0.2	23	51	83	4th of July Creek	14	25	54
5	36-32	51	28	0.3	10	37	97	Sherman Creek	16	30	70
6	32-30	51	25	0.0	28	49	95	Slough 9	-	-	-
								RM 128.5 Creek	-	-	-
7	30-26	61	28	0.2	13	31	80	RM 127.3 Creek	-	-	-
								Skull Creek	10	20	47
								Slough 8	-	-	-
								RM 123.9 Creek	-	-	-
8	26-24.1	53	27	0.2	12	37	75	RM 121.0 Creek	7	20	65
								Deadhorse Creek	8	19	55
9	24.1-19	58	30	0.1	21	45	110	Little Portage	13	26	63
								McKenzie Creek	9	18	45
10	19-18	52	23	0.2	5	36	118	Lane Creek	5	13	47
								Lane Slough	-	-	-
11	18-7	57	26	0.1	21	44	70	Gash Creek	-	-	-
								RM 110.0 Creek	-	-	-
12	7-3	30	21	0.1	17	40	68	Whiskers Creek	-	-	-

Table 2

RESERVOIR TRAP EFFICIENCY
BY BRUNE'S CURVES

Reservoir	Storage Capacity af	Average Annual Inflow af	Capacity ÷ Inflow	Trap Efficiency Max.	Median	Min.
Watana	9,470,000 1/	5,780,000 3/	1.64	100	99	96
Devil Canyon	1,090,000 2/	6,580,000 4/	0.17	98	94	86

1/ At normal maximum pool elevaton 2185 feet above mean sea level. From License Application, Exhibit E, Chapter 2, page E-2-55 (11).

2/ At normal maximum pool elevation 1455 feet above mean sea level. From License Application, Exhibit E, Chapter 2, page E-2-55 (11).

3/ Converted from average annual flow of 7990 cfs at Watana, as shown in License Application, Exhibit E, Chapter 2, Table E.2.4 (11).

4/ Converted from average annual flow of 9080 cfs, as shown in License Application, Exhibit E, Cnapter 2, Table E.2.4 (11).

Table 3

RESERVOIR TRAP EFFICIENCY
BY CHURCHILL'S CURVES

(1) Reservoir	(2) Storage 1/ Capacity	(3) Average 2/ Inflow	(4) Retention 3/ Period	(5) Reservoir 4/ Length	(6) Average 5/ Cross-Sectional Area	(7) Mean 6/ Velocity	(8) Retention Period ÷ Velocity	(9) % of Silt Passing	(10) Trap Efficiency
	ft^3	cfs	sec	ft	ft^2	ft/sec	sec^2/ft		%
Watana	$4.13x10^{11}$	7990	$5.17x10^7$	$2.75x10^5$	$1.50x10^6$	$0.53x10^{-2}$	$9.70x10^9$	< 0.1	100
Devil Canyon (local silt)	$0.48x10^{11}$	9080	$0.52x10^7$	$1.69x10^5$	$0.28x10^6$	$3.23x10^{-2}$	$0.16x10^9$	5	95
Devil Canyon (fine silt)								12	88

1/ At normal maximum pool elevation 2185 ft for Watana and 1455 ft for Devil Canyon.
2/ From License Application, Exhibit E, Chapter 2, page E-2-55.
3/ From License Application, Exhibit E, Chapter 2, Table E.2.4.
4/ Col. (2) ÷ Col. (3).
5/ Converted from 52 reservoir miles for Watana and 32 reservoir miles for Devil Canyon.
5/ Col. (2) ÷ Col. (5).
6/ Col. (3) ÷ Col. (6).

Table 4

BED MATERIAL SIZE DISTRIBUTION
SAMPLES COLLECTED BY HARZA-EBASCO

	Location	Date of Sampling	Bed Material Size, MM		
			D_{16}	D_{50}	D_{90}
1.	LRX-1.0, left channel, left bank	08-25-83	0.4	0.7	28
2.	LRX-1.0, left channel, center	08-25-83	30	70	76
3.	LRX-1.0, left channel, right bank	08-25-83	54	62	75
4.	LRX-1.0, right channel, center	08-25-83	30	50	90
5.	LRX-2.3, on a bar in the middle of the river	08-25-83	1.7	20	62
6.	LRX-2.3, near left bank	08-25-83	5	24	55
7.	LRX-3.3, near left bank	08-25-83	34	58	72
8.	LRX-3.3, near right bank	08-25-83	37	64	88
9.	LRX-7.0, right channel	08-25-83	30	50	72
10.	Near Talkeetna Camp, pavement (bar)	08-26-83	135	160	200
11.	Near Talkeetna Camp, sub-pavement (bar)	08-26-83	26	45	72
12.	LRX-42, center	08-25-83	38	52	65
14.	LRX-45, center	08-25-83	38	65	78
15.	LRX-51, center	08-25-83	63	70	78
16.	Near LRX-55, on the berm of slough 21	08-25-83	7	40	96
17.	LRX-61, center1/	08-25-83	20	30	36
18.	Chulitna River above confluence, bar	08-26-83	1.2	15	54
19.	Chulitna River above confluence, sub-pavement	08-26-83	8	30	70
20.	LRX-4, East bank, sub-pavement	10-06-83	2	36	60
21.	LRX-4, East bank, pavement	10-06-83	5	30	70
22.	LRX-4, East bank, large sizes	10-06-83	80	90	100
23.	LRX-4, Site 1, sub-pavement	10-06-83	1.2	12	36
24.	LRX-4, Site 1, pavement	10-06-83	5	30	70
25.	LRX-4, Site 1, large sizes2/	10-06-83			
26.	LRX-4, Site 2, sub-pavement	10-06-83	1.5	20	38
27.	LRX-4, Site 2, pavement	10-06-83	4	20	40
28.	LRX-4, Site 2, large sizes	10-06-83	38	70	95
29.	Near RM 109.3, pavement	10-06-83	26	65	97
30.	Near RM 109.3, sub-pavement	10-06-83	0.4	14	39
31.	Near LRX 18.2, Site 1, sub-pavement	10-06-83	2.4	50	130
32.	Near LRX 18.2, Site 2, sub-pavement	10-06-83	2	30	140
33.	Near LRX 18.2, lower end sample	10-06-83	6	54	130
34.	Near LRX 18.2, upper end pavement	10-06-83	0.4	10	50
35.	Upstream Lane Creek, pavement	10-06-83	24	58	94
36.	Upstream Lane Creek, sub-pavement	10-06-83	0.6	16	56
37.	Near 4th of July Creek, side channel, pavement	06-23-83	4.5	30	80
38.	Near 4th of July Creek, side channel, pavement	10-06-83	7	38	90
39.	Near 4th of July Creek, side channel, sub-pavement	10-06-83	0.8	13	67
40.	Near slough 10, pavement	06-22-83	0.7	20	70
41.	Near slough 10, sub-pavement	06-22-83	0.7	20	70
42.	Right channel slough 11, sub-pavement	06-22-83	2	32	90
43.	Right channel slough 11, pavement	06-24-83	13	60	110
44.	Side channel downstream slough 11, pavement	09-27-83	2.5	26	80
45.	Side channel downstream slough 11, sub-pavement	09-27-83	2.5	22	74
46.	Side channel between LRX 46-48, pavement	10-06-83	16	50	90
47.	Side channel between LRX 46-48, sub-pavement	10-06-83	0.8	17	40
48.	Side channel between LRX 46-48, large sizes3/	10-06-83			

1/ Sample not representative

2/ Sizes between 90 and 100 mm

3/ Sizes between 100 and 124 mm

Table 5

TRIBUTARY FLOODS AND BED MATERIAL SIZES

Tributary	River Mile	Mean[1/] Annual Flood, cfs	Drainage[1/] Area, sq mi	Bed Material Size[1/], mm		
				D_{16}	D_{50}	D_{84}
Portage Creek	148.9	1680	175.6	14	33	78
Jack Long Creek	144.9	181	18.0	-	-	-
Indian River	138.7	786	82.2	33	50	76
Gold Creek	136.7	260	24.1	17	36	76
RM 132.0 Creek	132.0	17	1.48	-	-	-
4th of July Creek	131.2	187	20.8	14	25	45
Sherman Creek	130.8	72	6.76	16	30	58
RM 128.5 Creek	128.5	14	1.03	-	-	-
RM 127.3 Creek	127.3	28	2.11	-	-	-
Skull Creek	124.3	51	4.49	10	20	39
RM 123.9 Creek	123.9	67	6.86	-	-	-
Deadhorse Creek	120.9	51	4.61	8	19	43
RM 121.0 Creek	121.0	16	1.52	7	20	50
Little Portage Creek	117.8	23	2.45	13	26	51
McKenzie Creek	116.8	21	2.07	9	18	37
Lane Creek	113.6	117	10.0	5	13	35
Gash Creek	111.6	4	0.43	-	-	-
RM 110.1 Creek	110.1	21	1.98	-	-	-
Whiskers Creek	101.2	114	15.4	-	-	-

1/ From R&M, "Tributary Stability Analysis," Tables 4.2 and 4.4.

Table 6

BEDLOAD DISCHARGE AND SIZE DISTRIBUTION
SUSITNA RIVER NEAR TALKEETNA, ALASKA[1/]

Date	Water Discharge, cfs	Bedload Discharge, tons/day	% Finer than Indicated Size in Millimeter										
			0.125	0.25	0.50	1.0	2.0	4.0	8.0	16	32	64	76
6/03/1982	35,800	2840	0	3	37	47	48	49	52	54	58	74	100
6/08/1982	44,400	1500	1	3	53	63	69	71	75	79	86	100	100
6/15/1982	24,200	831	0	0	24	32	32	33	35	38	44	76	100
6/22/1982	37,000	992	0	2	47	58	60	60	61	61	62	64	100
6/30/1982	30,200	442	0	1	33	39	40	41	43	46	84	100	100
7/08/1982	20,800	324	0	0	65	94	96	97	99	99	100	100	100
7/14/1982	30,800	906	0	1	51	71	74	75	77	81	90	100	100
7/21/1982	25,000	360	0	1	65	90	92	93	94	96	100	100	100
7/28/1982	30,800	600	0	1	70	85	86	88	91	93	100	100	100
8/04/1982	22,800	215	0	2	78	98	99	99	99	100	100	100	100
8/10/1982	20,200	282	0	1	66	94	96	96	96	97	100	100	100
8/18/1982	17,800	106	0	1	69	97	99	100	100	100	100	100	100
8/25/1982	16,900	110	0	1	69	97	99	100	100	100	100	100	100
8/31/1982	19,400	188	1	1	73	95	97	97	98	98	100	100	100
9/19/1982	28,900	372	0	2	63	78	80	80	82	84	91	100	100
	Average		0.1	1	58	76	78	79	80	82	88	94	100

1/ Source: U.S. Geological Survey

Table 7

BEDLOAD DISCHARGE AND SIZE DISTRIBUTION
CHULITNA RIVER NEAR TALKEETNA, ALASKA1/

Date	Water Discharge, cfs	Bedload Discharge, tons/day	% Finer than Indicated Size in Millimeter									
			0.25	0.50	1.0	2.0	4.0	8.0	16	32	64	76
7/22/1981	31,900	2,970	2	15	22	26	30	45	70	93	96	100
8/26/1981	22,500	3,870	1	12	19	27	40	56	73	89	97	100
9/29/1981	6,000	2,900	0	15	29	44	55	77	91	99	100	100
6/04/1982	12,500	11,400	1	14	28	35	54	74	90	99	100	100
6/09/1982	17,200	18,300	1	15	38	47	54	67	82	95	100	100
6/16/1982	14,600	11,400	1	11	40	52	63	74	83	93	100	100
6/22/1982	19,400	10,200	1	28	53	58	64	71	79	91	100	100
6/29/1982	28,900	13,000	2	26	38	45	57	74	87	98	100	100
7/07/1982	20,600	9,610	1	17	47	53	58	68	80	94	100	100
7/13/1982	22,800	9,110	0	11	20	24	34	50	69	88	99	100
7/20/1982	23,100	13,800	1	12	35	40	45	57	67	85	100	100
7/27/1982	33,400	6,900	1	15	28	35	42	53	63	84	100	100
8/03/1982	23,500	7,490	1	16	38	46	53	62	75	90	98	100
8/11/1982	21,700	9,670	0	13	30	35	41	51	67	90	100	100
8/17/1982	22,000	12,100	1	12	39	46	54	66	80	93	100	100
8/24/1982	17,900	7,560	1	12	25	29	37	52	70	91	100	100
9/01/1982	17,100	7,480	1	17	40	56	64	75	86	95	100	100
9/18/1982	29,600	2,560	1	22	36	41	45	53	64	82	100	100
	Average		0.9	16	34	41	49	62	76	92	99	100

1/ Source: U.S. Geological Survey

Table 8

BEDLOAD DISCHARGE AND SIZE DISTRIBUTION
TALKEETNA RIVER NEAR TALKEETNA, ALASKA 1/

Date	Water Discharge, cfs	Bedload Discharge, tons/day	% Finer than Indicated Size in Millimeter										
			0.125	0.25	0.50	1.0	2.0	4.0	8.0	16	32	64	76
7/21/1981	16,800	2340	1	12	46	54	56	57	59	64	78	97	100
8/25/1981	9,900	756	0	5	68	85	87	88	89	100	100	100	100
9/29/1981	2,910	25	0	6	86	99	100	100	100	100	100	100	100
6/02/1982	19,100	2800	1	3	35	90	94	96	97	100	100	100	100
6/09/1982	14,000	5790	0	1	12	30	34	36	41	56	85	100	100
6/16/1982	11,400	1630	0	0	13	31	35	38	41	46	59	86	100
6/23/1982	12,400	1410	0	1	32	60	64	66	71	82	98	100	100
6/29/1982	10,900	620	0	2	44	73	76	77	77	79	83	91	100
7/07/1982	6,840	1080	0	0	39	91	93	93	93	94	96	100	100
7/13/1982	9,020	243	0	18	66	89	91	92	93	95	96	100	100
7/20/1982	8,560	516	0	1	42	64	65	65	65	65	67	100	100
7/28/1982	14,300	885	0	3	52	81	85	88	90	92	95	100	100
8/03/1982	9,140	802	0	2	38	62	64	65	67	69	78	84	100
8/10/1982	7,070	2470	0	1	55	97	98	99	99	99	100	100	100
8/17/1982	6,260	2380	0	1	23	82	93	96	98	99	100	100	100
8/24/1982	5,960	1800	0	0	14	84	95	97	98	99	100	100	100
8/31/1982	9,200	1460	0	1	18	84	92	93	94	95	99	100	100
9/20/1982	14,600	2740	0	1	12	26	27	28	33	49	82	100	100
	Average		0.1	3	39	71	75	76	78	82	90	98	100

1/ Source: U.S. Geological Survey

Table 9

BEDLOAD DISCHARGE AND SIZE DISTRIBUTION
SUSITNA RIVER AT SUNSHINE, ALASKA[1/]

Date	Water Discharge, cfs	Bedload Discharge, tons/day	% Finer than Indicated Size in Millimeter 0.062	0.125	0.25	0.50	1.0	2.0	4.0	8.0	16	32	64	76
7/22/1981	89,000	3,540	0	1	13	42	47	49	54	60	70	85	100	100
8/26/1981	61,900	3,040	0	1	22	76	79	81	83	87	92	98	100	100
9/30/1981	19,100	385	0	0	7	62	70	70	72	73	77	83	100	100
6/03/1982	71,000	6,080	0	0	2	15	22	26	27	30	38	64	100	100
6/10/1982	64,700	13,600	0	0	2	12	17	17	18	20	29	54	96	100
6/17/1982	50,700	1,870	0	0	2	47	65	65	66	66	69	75	100	100
6/21/1982	78,900	2,510	0	1	12	18	50	51	53	57	62	70	95	100
6/28/1982	75,400	6,390	0	0	3	17	22	23	25	27	46	64	100	100
7/06/1982	46,700	6,020	0	0	2	35	46	47	49	57	71	86	100	100
7/12/1982	59,200	3,800	0	0	3	52	75	77	80	85	88	96	100	100
7/19/1982	61,500	3,960	0	0	2	40	54	58	62	69	75	84	87	100
7/26/1982	99,000	8,750	0	0	2	18	28	30	33	39	53	77	97	100
8/02/1982	63,600	3,480	0	0	4	60	73	74	74	75	78	93	97	100
8/09/1982	53,800	5,220	1	1	5	62	81	82	83	85	89	94	100	100
8/16/1982	48,100	2,740	0	0	2	61	83	84	85	86	92	98	100	100
8/23/1982	38,500	1,050	0	0	1	55	85	88	89	90	92	92	100	100
8/30/1982	39,200	1,480	1	2	4	44	63	64	64	65	66	70	100	100
9/17/1982	87,400	8,120	0	0	1	12	20	23	26	37	60	78	100	100
	Average		0.1	0.3	5	40	54	56	58	62	69	81	98	100

1/ Source: U.S. Geological Survey

Table 10

BED MATERIAL SIZE DISTRIBUTION
SUSITNA RIVER NEAR TALKEETNA, ALASKA[1/]

Date	Water Discharge, cfs	% Finer than Indicated Size in Millimeter 16	32	64	128
7/28/1982	30,800	0	0	0	100
		0	100	100	100
8/04/1982	22,800	0	7	53	100
		1	6	42	100
9/19/1982	28,700	0	0	18	100
		0	0	0	100
		0	4	30	100
		0	2	19	100
			0	5	100
	Average:	0.1	13	30	100

1/ Source: U.S. Geological Survey

Table 11

BED MATERIAL SIZE DISTRIBUTION
CHULITNA RIVER NEAR TALKEETNA, ALASKA[1/]

Date	Water Discharge, cfs	% Finer than Indicated Size in Millimeter										
		0.125	0.25	0.50	1.0	2.0	4.0	8.0	16	32	64	128
9/29/1981	6,000					0	7	52	81	94	100	100
			0	1	1	2	10	57	92	100	100	100
			0	2	10	18	30	59	83	98	100	100
			0	4	60	76	79	84	91	99	100	100
			0	1	26	47	53	65	78	94	100	100
		2	24	84	100	100	100	100	100	100	100	100
7/27/1962	30,600				0	1	3	15	46	71	89	100
					0	1	5	18	44	72	93	100
				5	29	34	36	42	52	67	100	100
									0	5	24	100
		—	—	2	5	6	6	8	13	36	87	100
	Average:	0.2	2	9	21	26	30	45	62	76	90	100

1/ Source: U.S. Geological Survey

Table 12

BED MATERIAL SIZE DISTRIBUTION
TALKEETNA RIVER NEAR TALKEETNA, ALASKA1/

Date	Water Discharge, cfs	% Finer than Indicated Size in Millimeter									
		0.25	0.5	1.0	2.0	4.0	8.0	16	32	64	128
9/29/1981	2,910									0	100
			0	3	8	8	8	8	8	13	100
								0	2	52	100
							0	1	3	100	100
								0	7	100	100
								0	2	18	100
									0	11	100
									0	45	100
									0	35	100
7/28/1982	14,000	1	7	50	74	84	91	95	100	100	100
							0	4	25	85	100
								0	7	100	100
									0	100	100
9/20/1982	14,600								0	6	100
						0	5	22	65	100	100
							0	4	38	80	100
							0	1	3	30	100
	Average:	0.1	0.4	3	5	5	6	8	15	57	100

1/ Source: U.S. Geological Survey

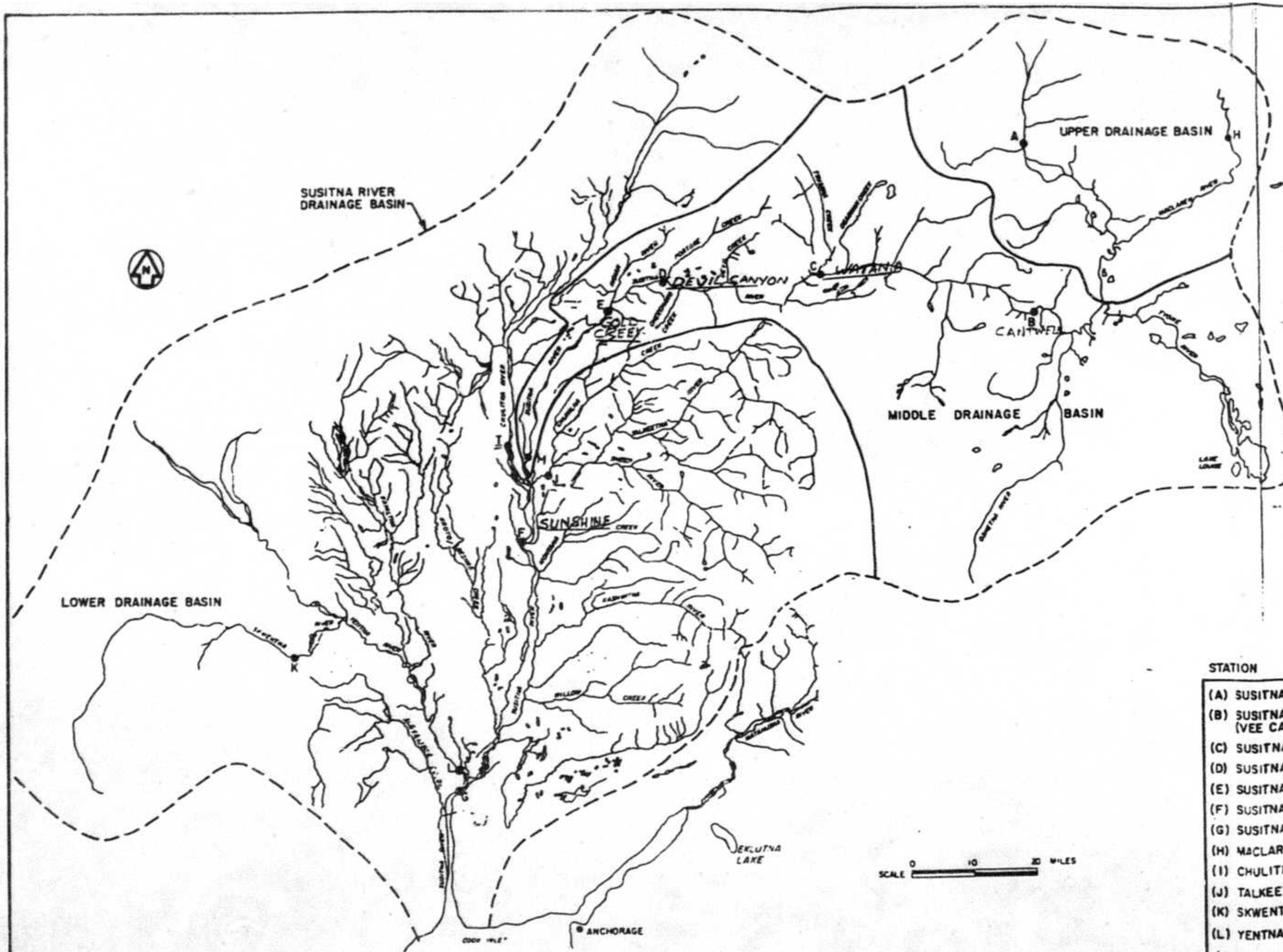
Table 13

BED MATERIAL SIZE DISTRIBUTION
SUSITNA RIVER AT SUNSHINE, ALASKA[1/]

Date	Water Discharge, cfs	% Finer than Indicated Size in Millimeter									
		0.25	0.5	1.0	2.0	4.0	8.0	16	32	64	128
9/30/1981	19,100									0	100
									0	58	100
									0	100	100
								0	18	100	100
								0	41	100	100
		2	47	64	67	69	74	86	96	100	100
									0	36	100
									0	52	100
7/26/1982	95,200						0	2	18	100	100
								0	8	54	100
								0	4	31	100
		0	1	3	5	11	23	38	53	62	100
							0	1	15	100	100
		—	0	2	4	6	12	23	64	100	100
	Average:	0.1	3	5	5	6	8	11	23	71	100

1/ Source: U.S. Geological Survey

EXHIBIT 1



NOTES:

1. CONTINUOUS WATER QUALITY MONITOR INSTALLED.
2. DATA COLLECTION (JUL-SEP 1981 AND JUN-SEP 1982.)
3. THE LETTER BEFORE EACH STATION NAME IN THE TABLE IS USED ON THE MAP TO MARK THE APPROXIMATE LOCATION OF THE STATIONS.

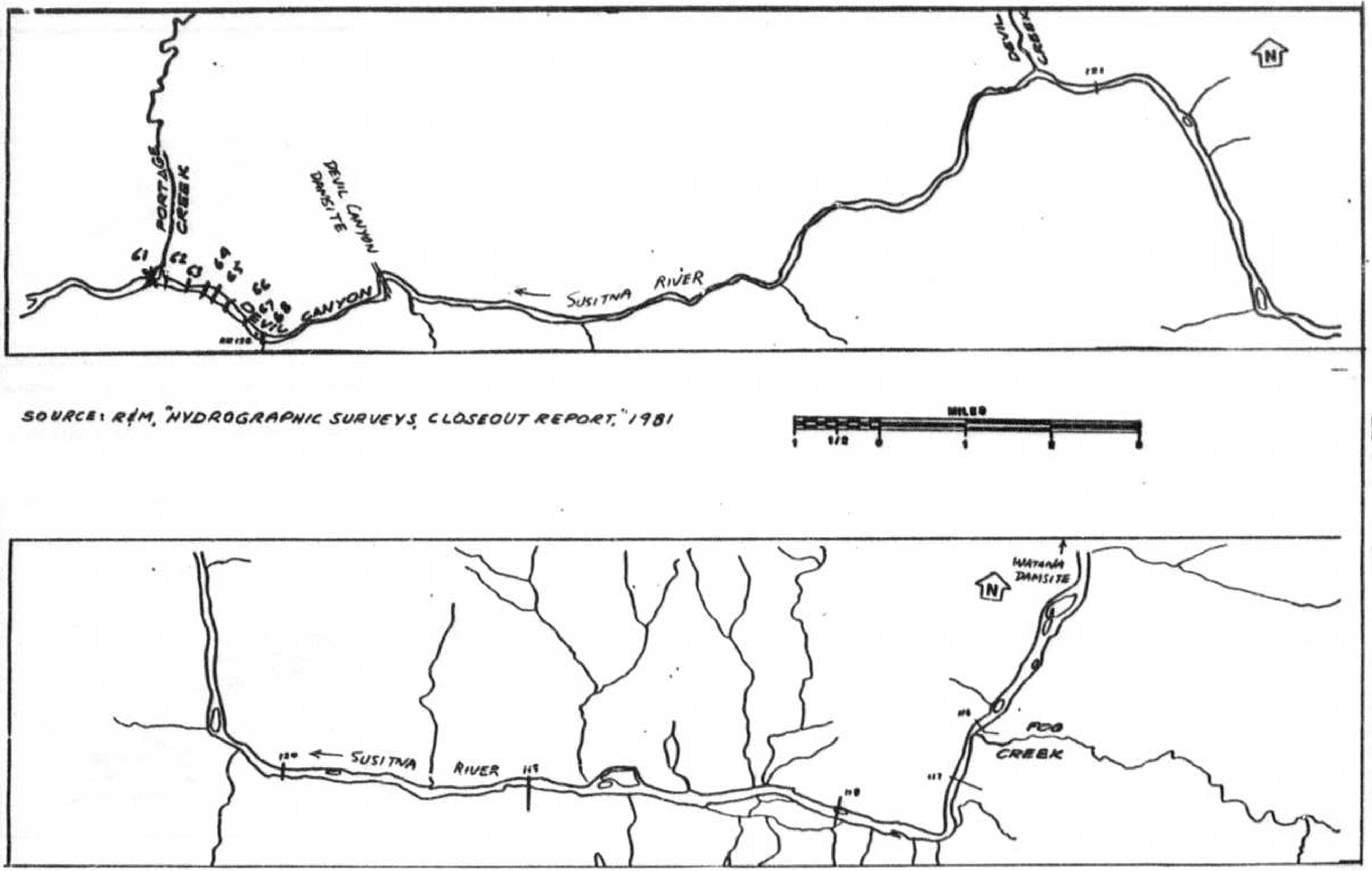
STATION	STREAMFLOW GAGING	CREST STAGE GAGE	STAFF GAGE	WATER QUALITY	WATER TEMPERATURE	SEDIMENT DISCHARGE	BEDLOAD SAMPLING[2]	CLIMATE
(A) SUSITNA RIVER NEAR DENALI	X		X		X	X		X
(B) SUSITNA RIVER NEAR CANTWELL (VEE CANYON)	X		X	X	X	X		
(C) SUSITNA RIVER NEAR WATANA DAMSITE	X	X		X[1]	X			X
(D) SUSITNA RIVER NEAR DEVIL CANYON		X	X					X
(E) SUSITNA RIVER AT GOLD CREEK	X			X	X	X	X	
(F) SUSITNA RIVER NEAR SUNSHINE	X				X	X	X	
(G) SUSITNA RIVER AT SUSITNA STATION	X			X	X	X		
(H) MACLAREN RIVER NEAR PAXSON	X							
(I) CHULITNA RIVER NEAR TALKEETNA	X				X	X	X	
(J) TALKEETNA RIVER NEAR TALKEETNA	X			X	X	X	X	
(K) SKWENTNA RIVER NEAR SKWENTNA	X			X	X	X		X
(L) YENTNA RIVER NEAR SUSITNA STATION	X				X	X		
(M) SUSITNA RIVER NEAR TALKEETNA						X	X	

SOURCE: SUSITNA HYDROELECTRIC PROJECT LICENSE APPLICATION, EXHIBIT E, FIGURE E.2.1

SUSITNA HYDROELECTRIC PROJECT

SUSITNA RIVER BASIN AND GAGING STATIONS

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 983



SOURCE: R&M, "HYDROGRAPHIC SURVEYS, CLOSEOUT REPORT," 1981

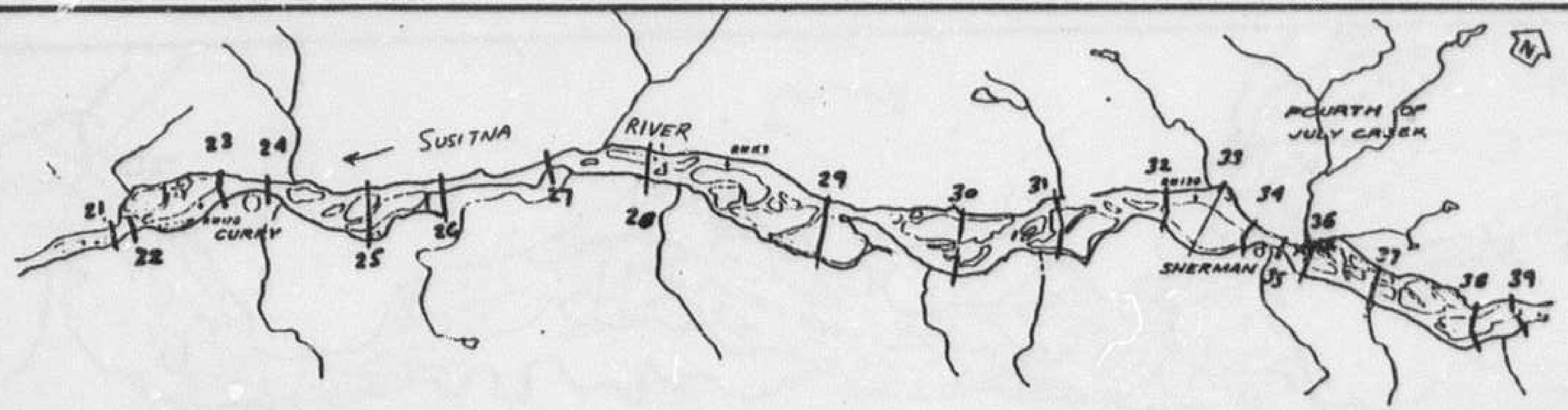
—— RIVER CROSS SECTION LOCATION

X BED MATERIAL SAMPLING LOCATION

SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF BED MATERIAL SAMPLES
COLLECTED BY HARZA-EBASCO

EXHIBIT 3
SHEET 3 OF 3

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983



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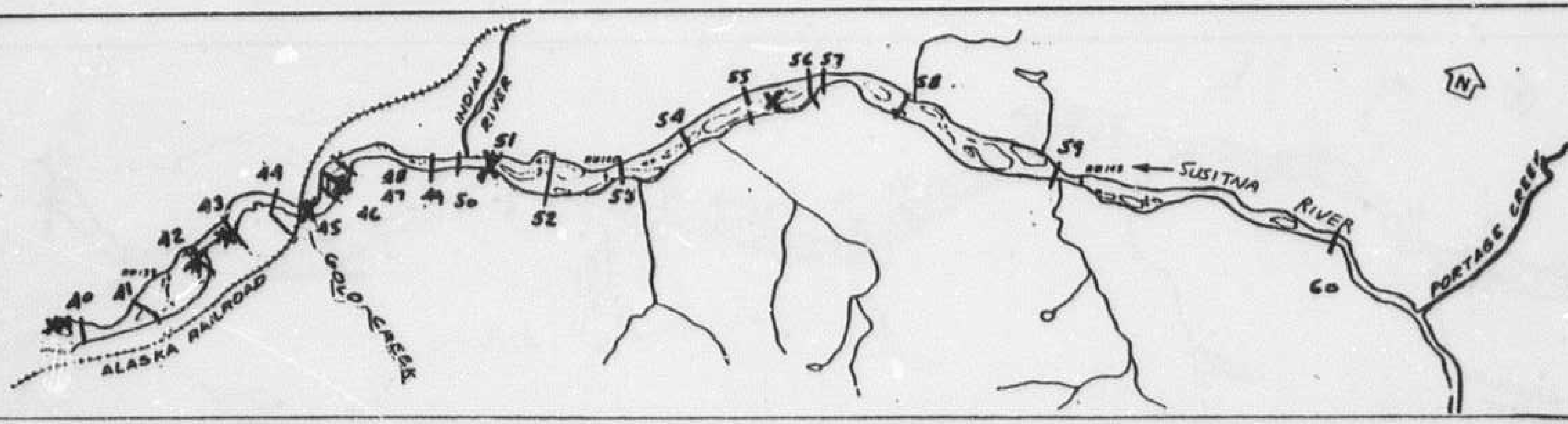
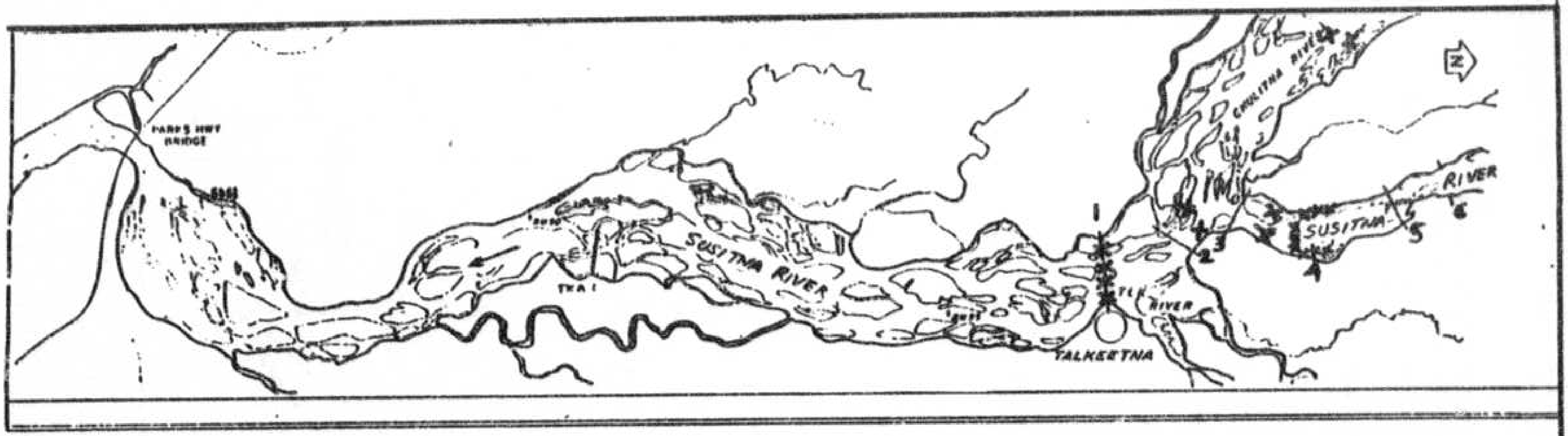


—— RIVER CROSS SECTION LOCATION

X BED MATERIAL SAMPLING LOCATION

SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF BED MATERIAL SAMPLES
COLLECTED BY HARZA-EBASCO

EXHIBIT 3
SHEET 2 OF 3



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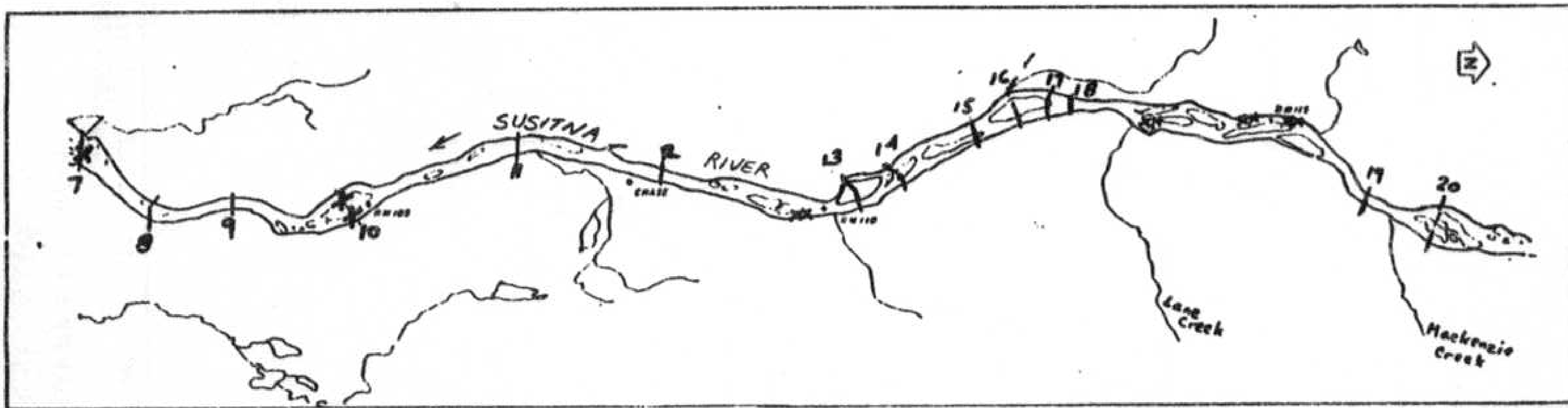


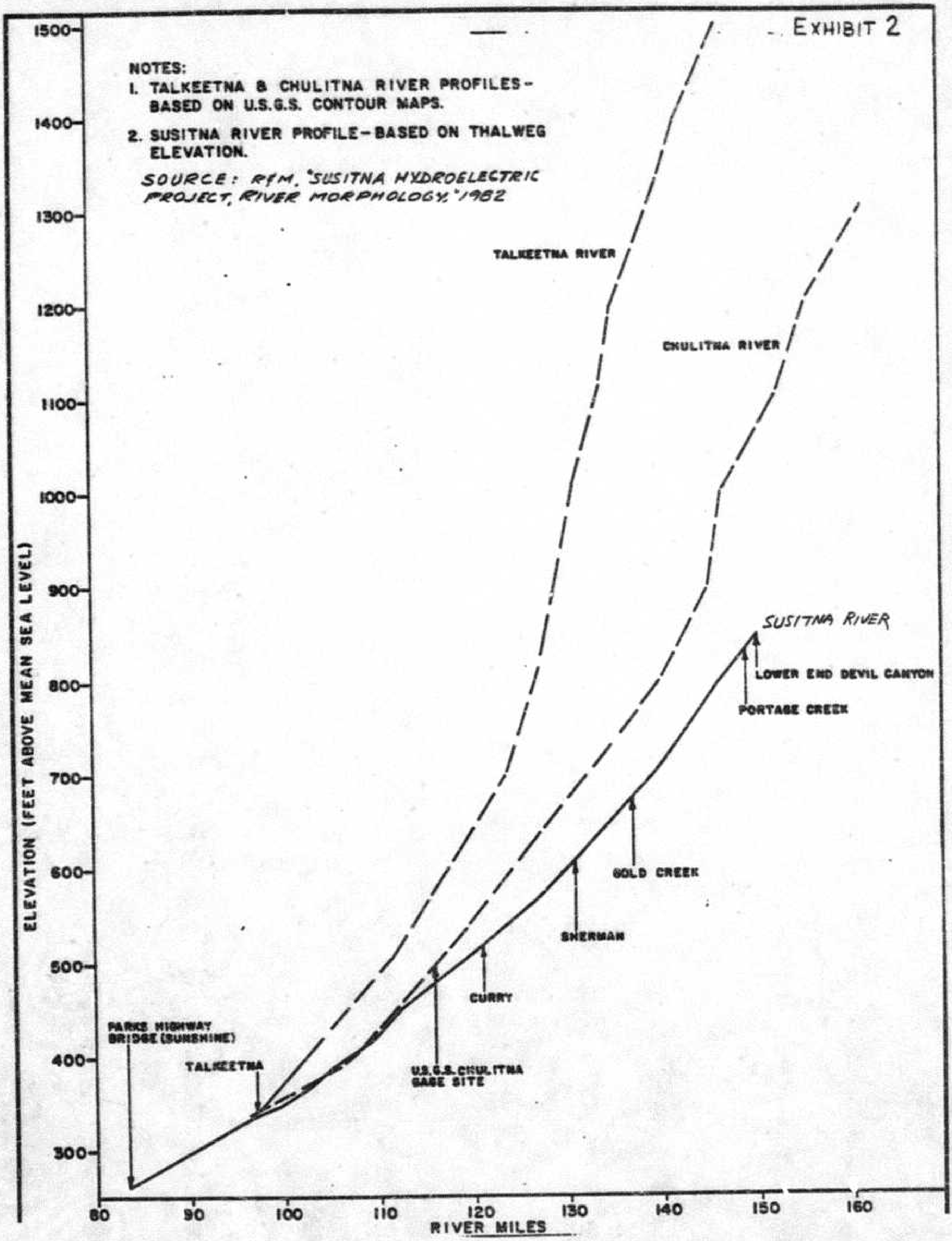
— RIVER CROSS SECTION LOCATION

X BED MATERIAL SAMPLING LOCATION

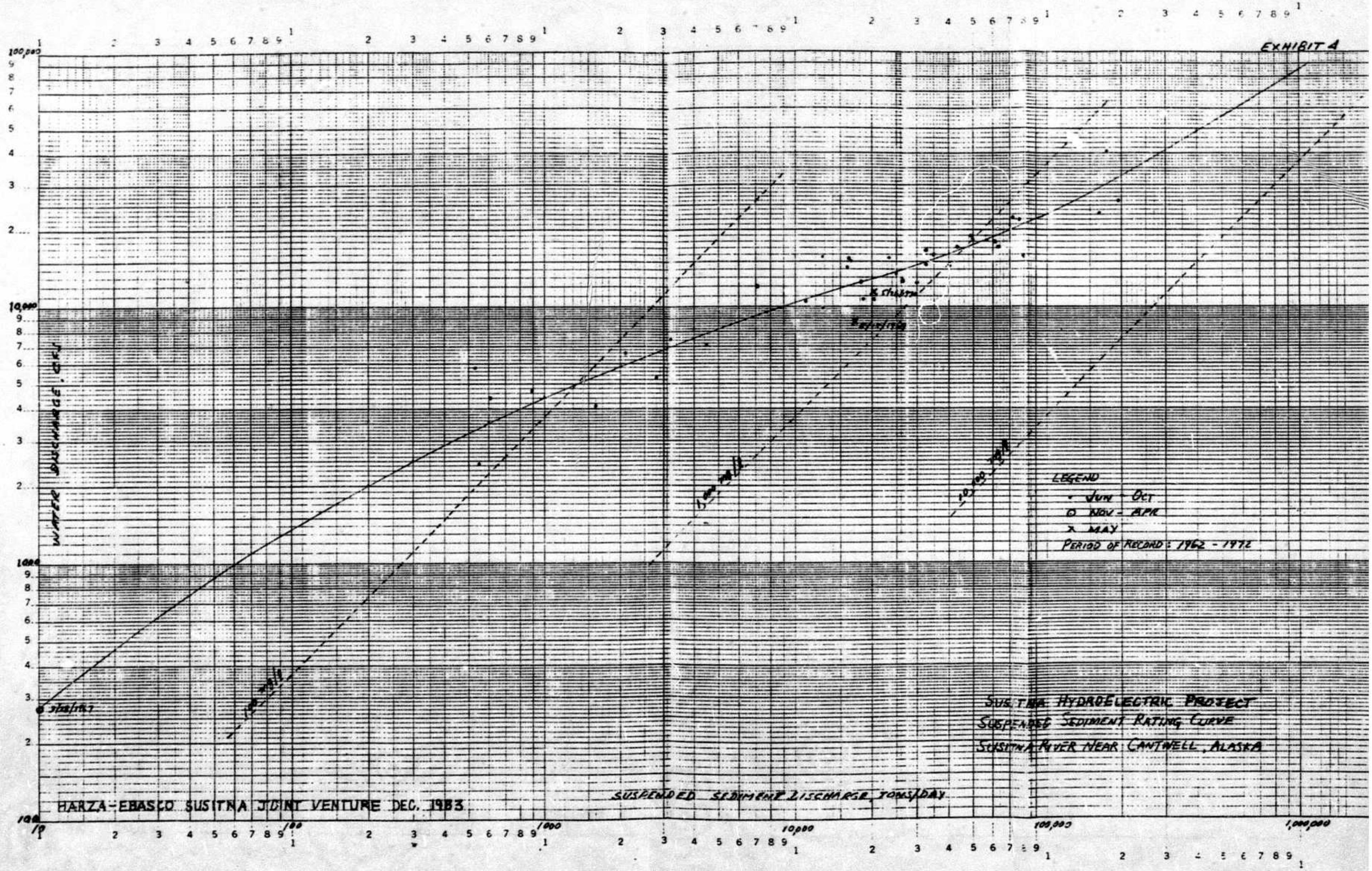
SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF BED MATERIAL SAMPLES
COLLECTED BY HARZA-EBASCO

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

EXHIBIT 2



SUSITNA HYDROELECTRIC PROJECT
RIVER PROFILES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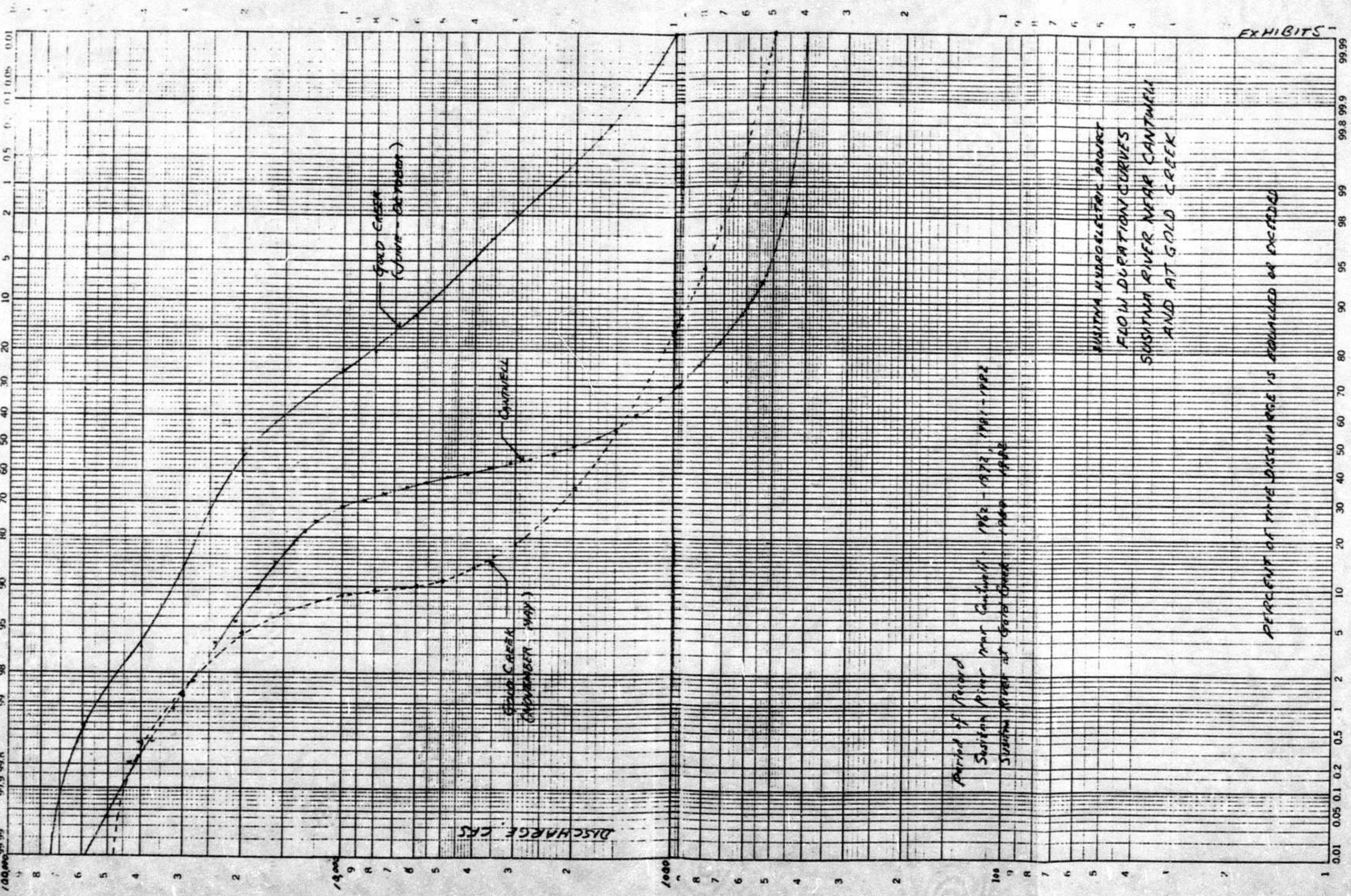
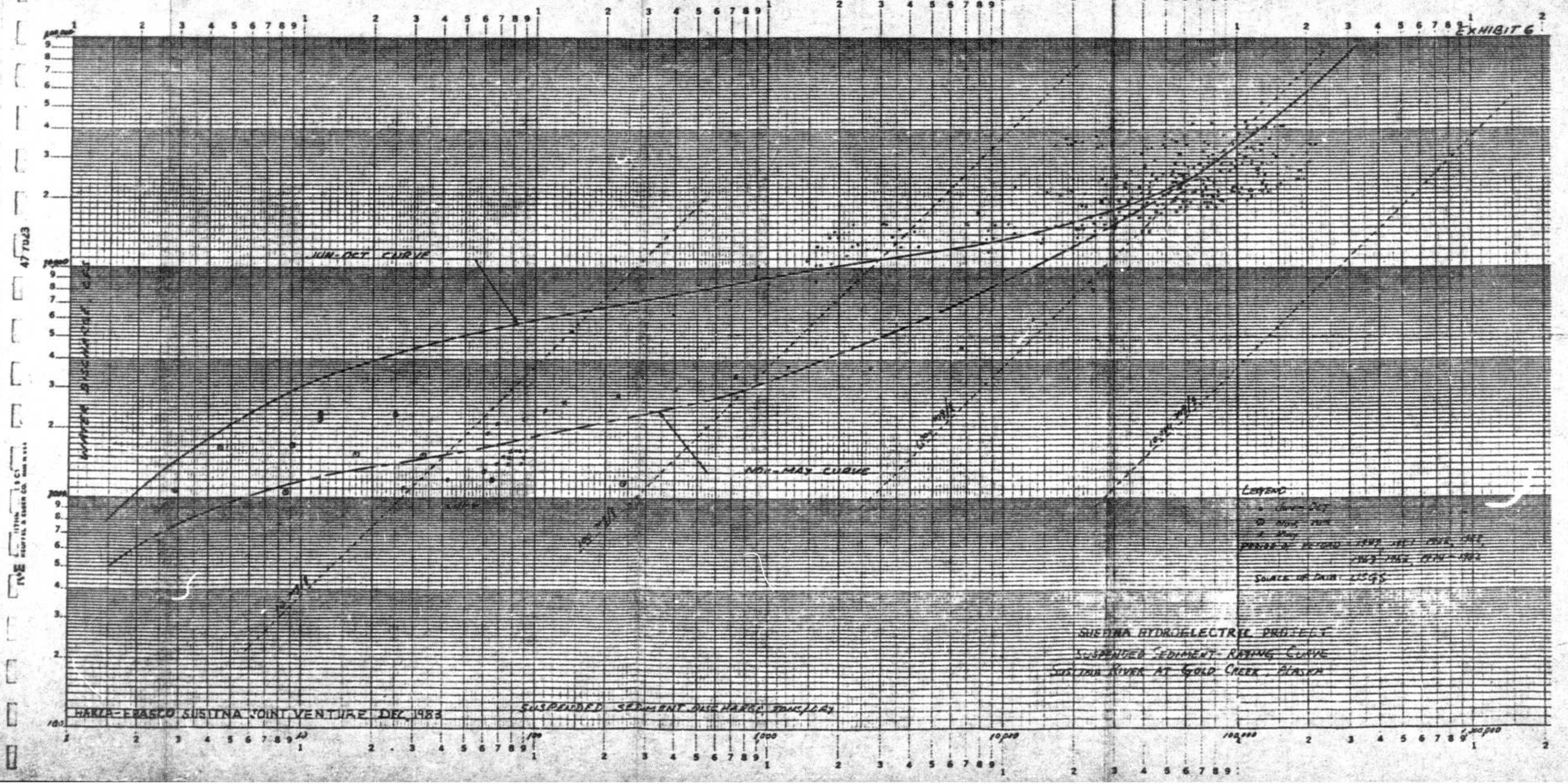
WATER DISCHARGE, CFS
100,000
10,000
1000
100
10
100
1000
10,000
100,000
1,000,000
LEGEND
• JUN - OCT
O NOV - APR
X MAY
PERIOD OF RECORD: 1962 - 1972
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT RATING CURVE
SUSITNA RIVER NEAR CANTWELL, ALASKA
SUSPENDED SEDIMENT DISCHARGE, TONS/DAY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
477523



HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983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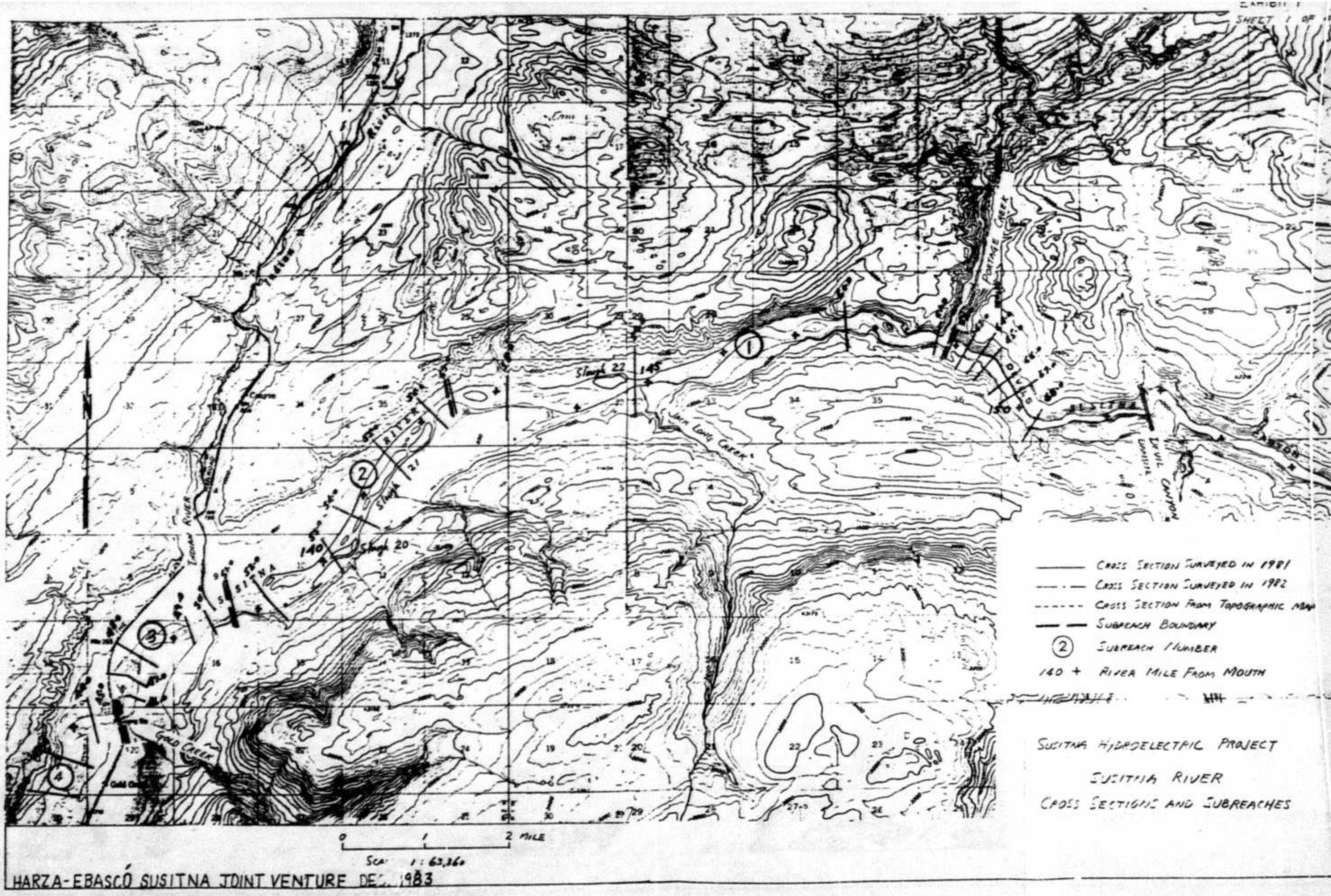
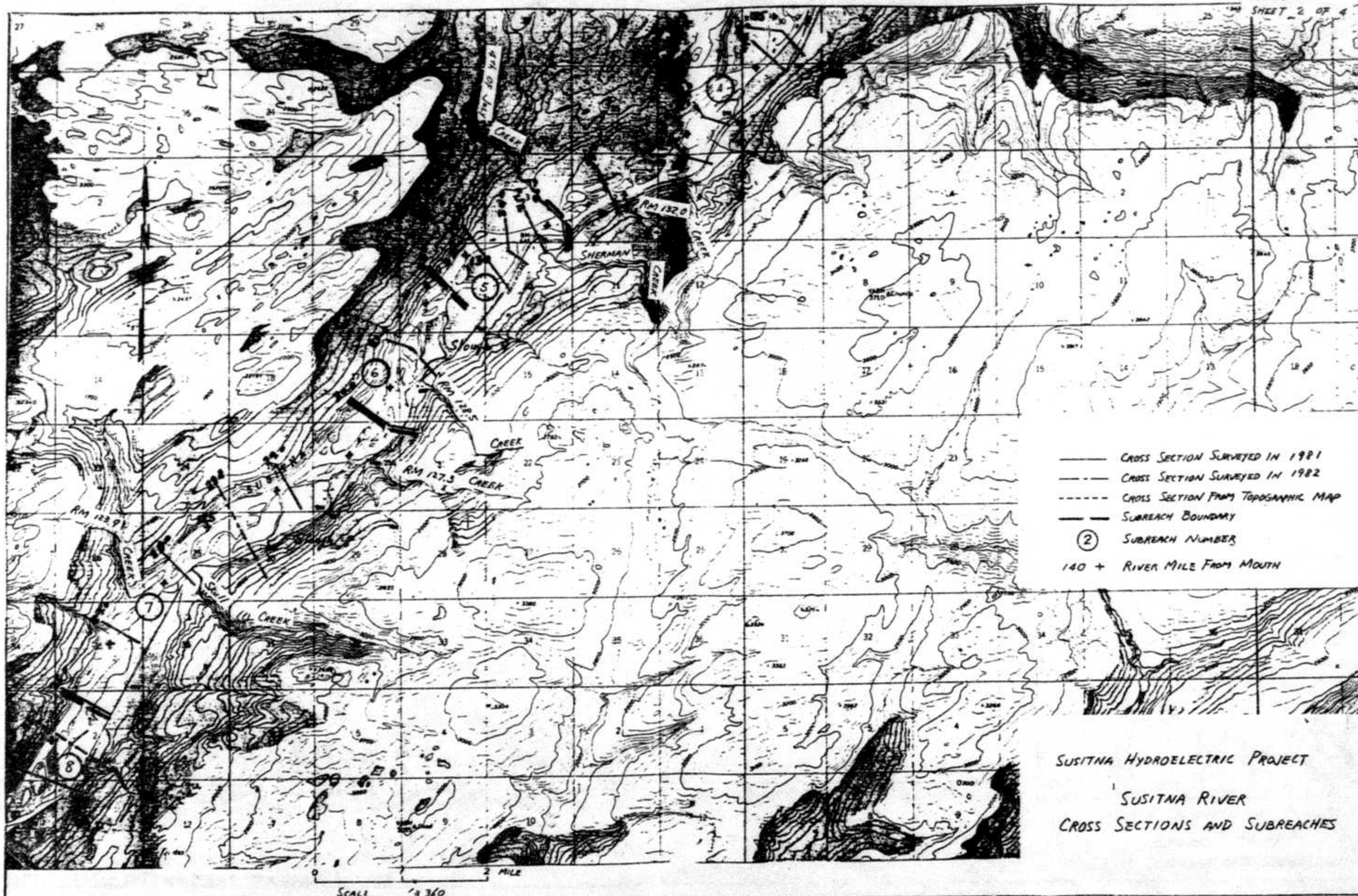
JUN-OCT CURVE
NOV-MAY CURVE
WATER DISCHARGE, CFS
LEGEND
SOURCE OF DATA: USGS
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT-RATING CURVE
SUSITNA RIVER AT GOLD CREEK, ALASKA
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
SUSPENDED SEDIMENT DISCHARGE, TONS/DAY

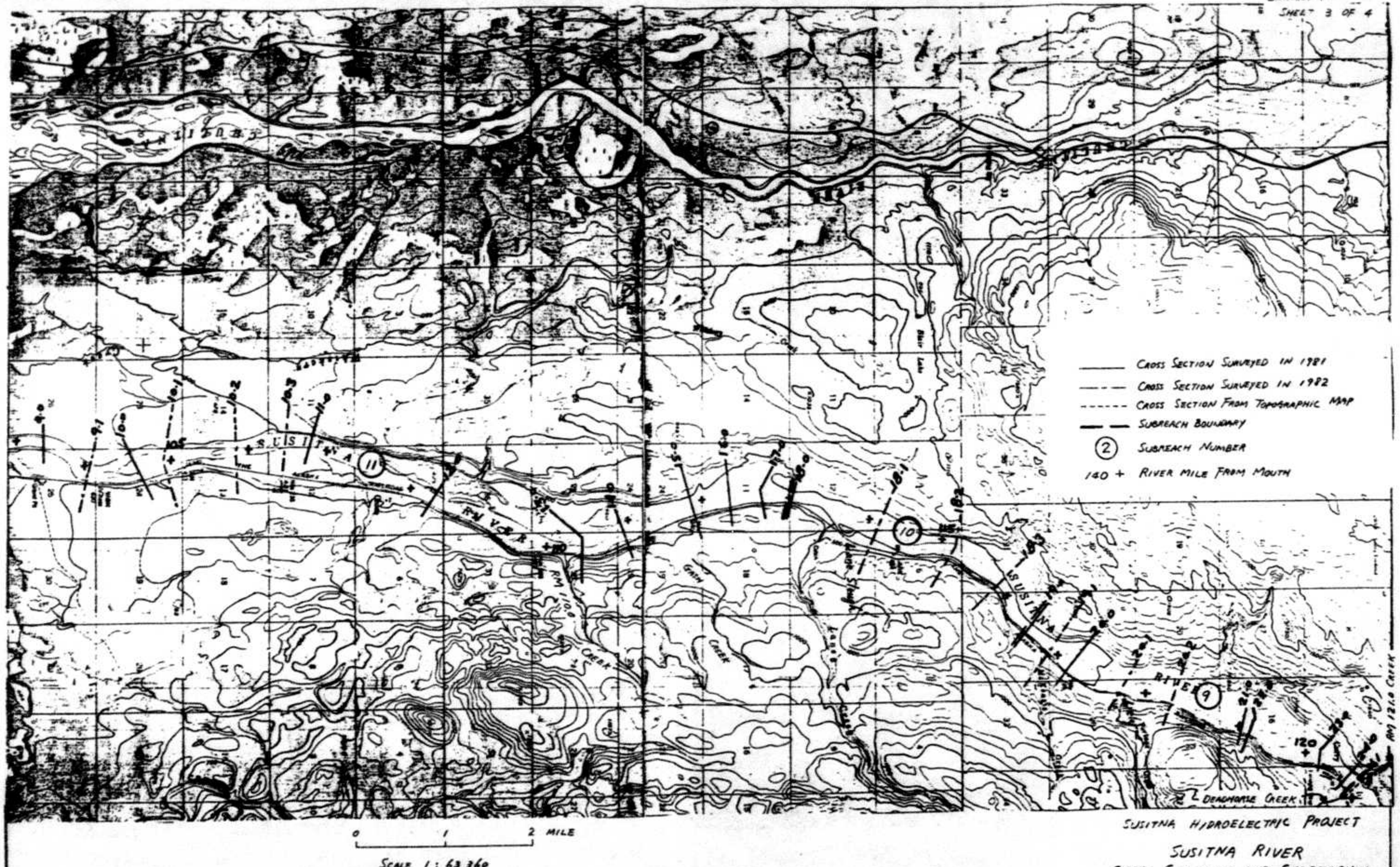

SHEET 1 OF
Slough 22
145
Slough 21
Slough 20
140
RIVER
SUSITNA
INDIAN RIVER
GOLD CREEK
JACK LONG CREEK
PORTAGE CREEK
DEVIL CANYON
CROSS SECTION SURVEYED IN 1981
CROSS SECTION SURVEYED IN 1982
CROSS SECTION FROM TOPOGRAPHIC MAP
SUBREACH BOUNDARY
② SUBREACH NUMBER
140 + RIVER MILE FROM MOUTH
SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER
CROSS SECTIONS AND SUBREACHES
0 1 2 MILE
SCALE 1:63,360
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983



Susitna Hydroelectric Project

Susitna River
Cross Sections and Subreaches

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983



SUSITNA HYDROELECTRIC PROJECT

SUSITNA RIVER
CROSS SECTIONS AND SUBREACHES

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

EXHIBIT 1
SHEET 4 OF 4

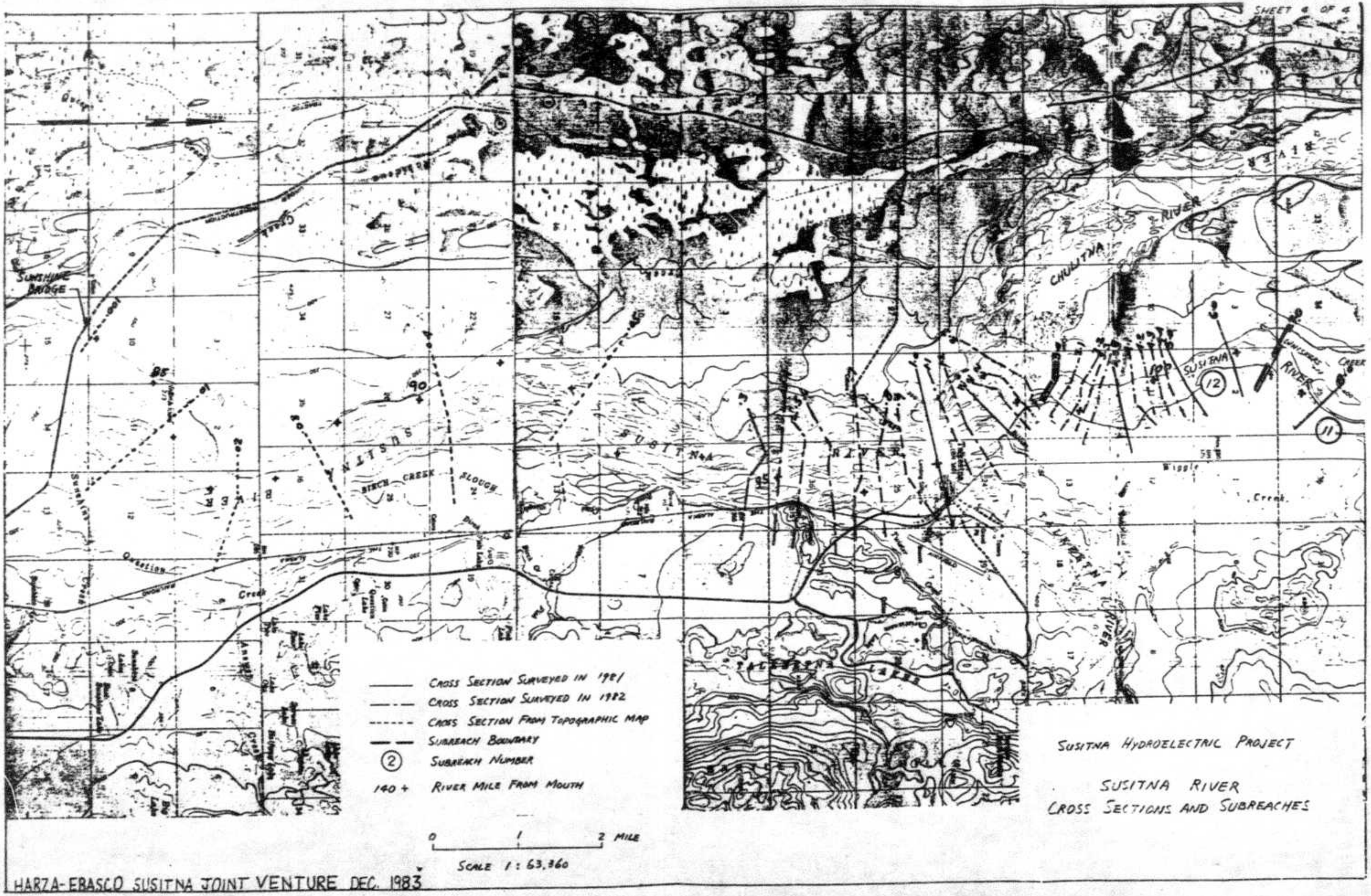
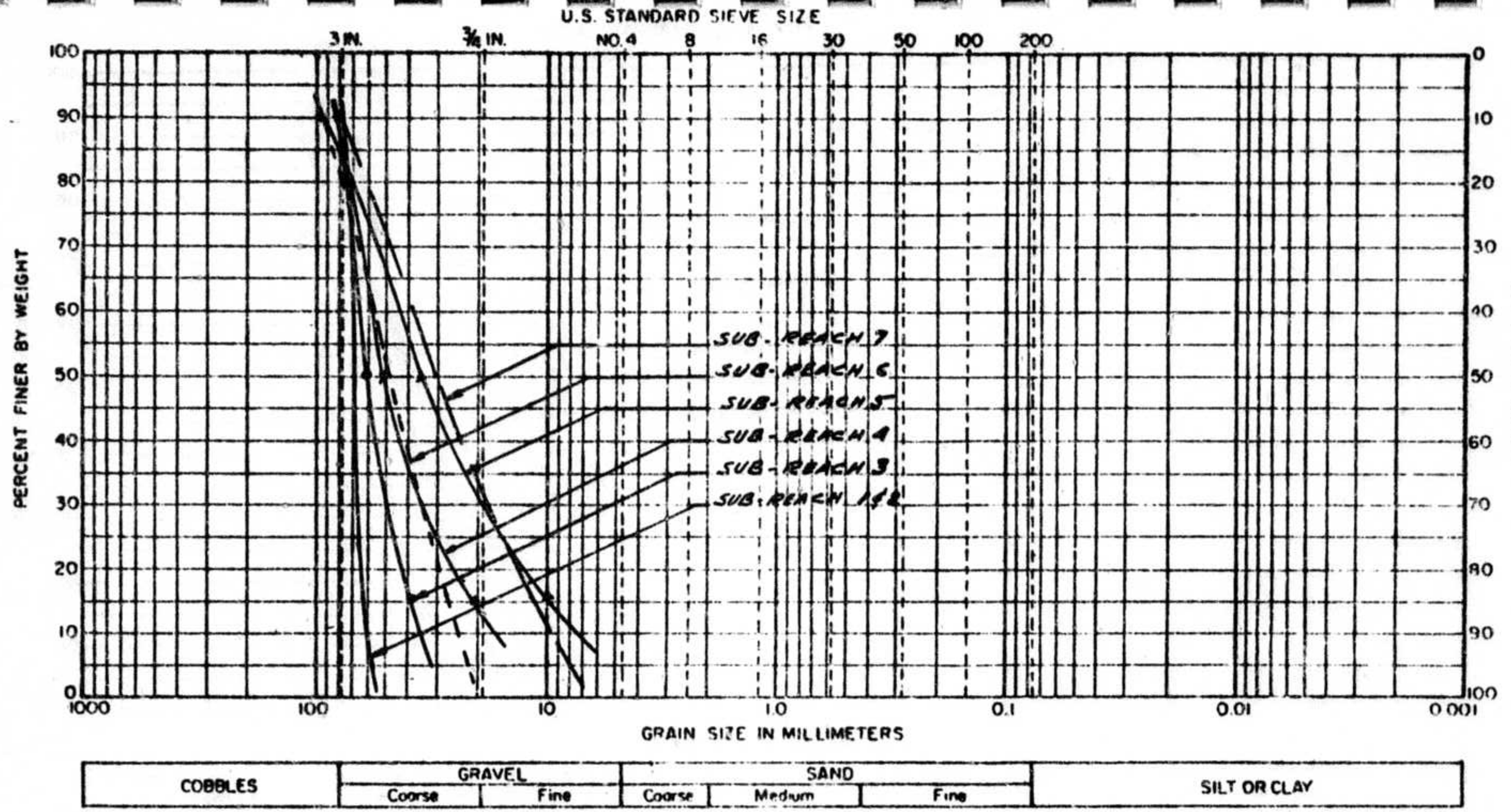


EXHIBIT 8
SHEET 1 of 2



Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

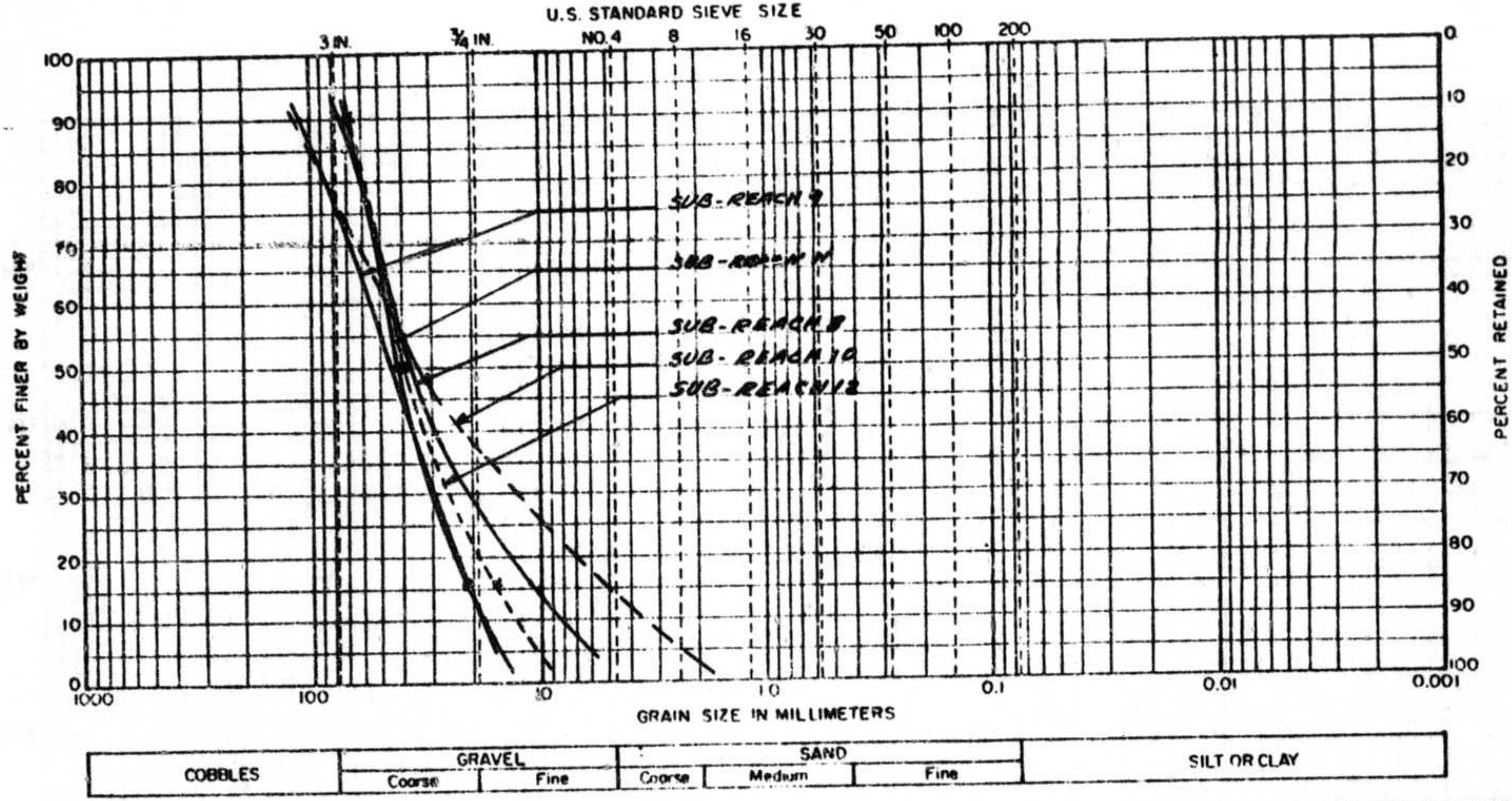
GRADATION CURVES

SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER
SIZE DISTRIBUTION OF BED MATERIAL

HARZA ENGINEERING CO., CHICAGO
APPROVED.......

DATE | DWG. NO.

HARZA - EBASCO SUSITNA JOINT VENTURE DEC. 1983



Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

GRADATION CURVES

SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER
SIZE DISTRIBUTION OF
BED MATERIAL

HARZA ENGINEERING CO., CHICAGO
APPROVED..........................

DATE	DWG. NO.

EXHIBIT B SHEET 2 of 2

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

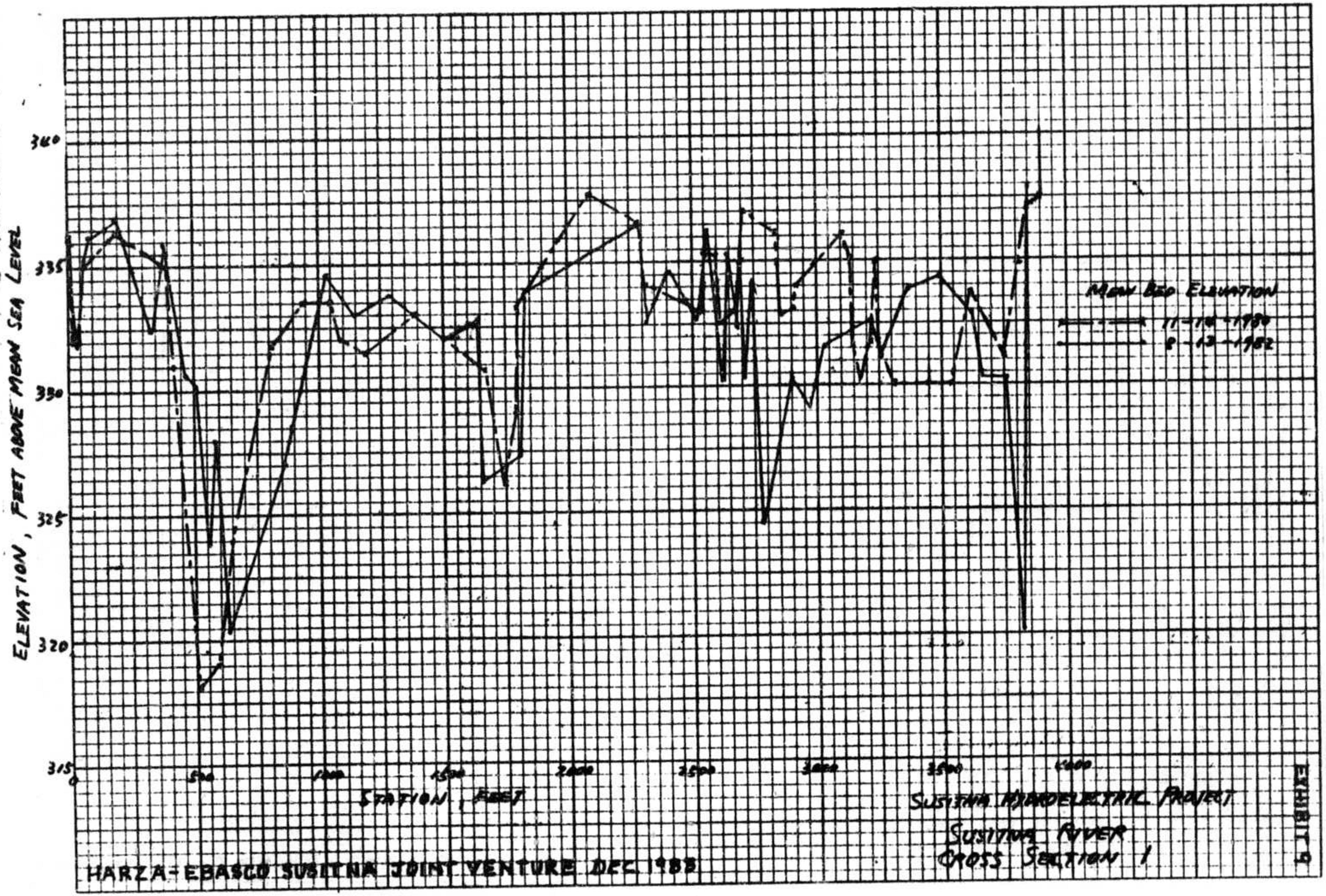
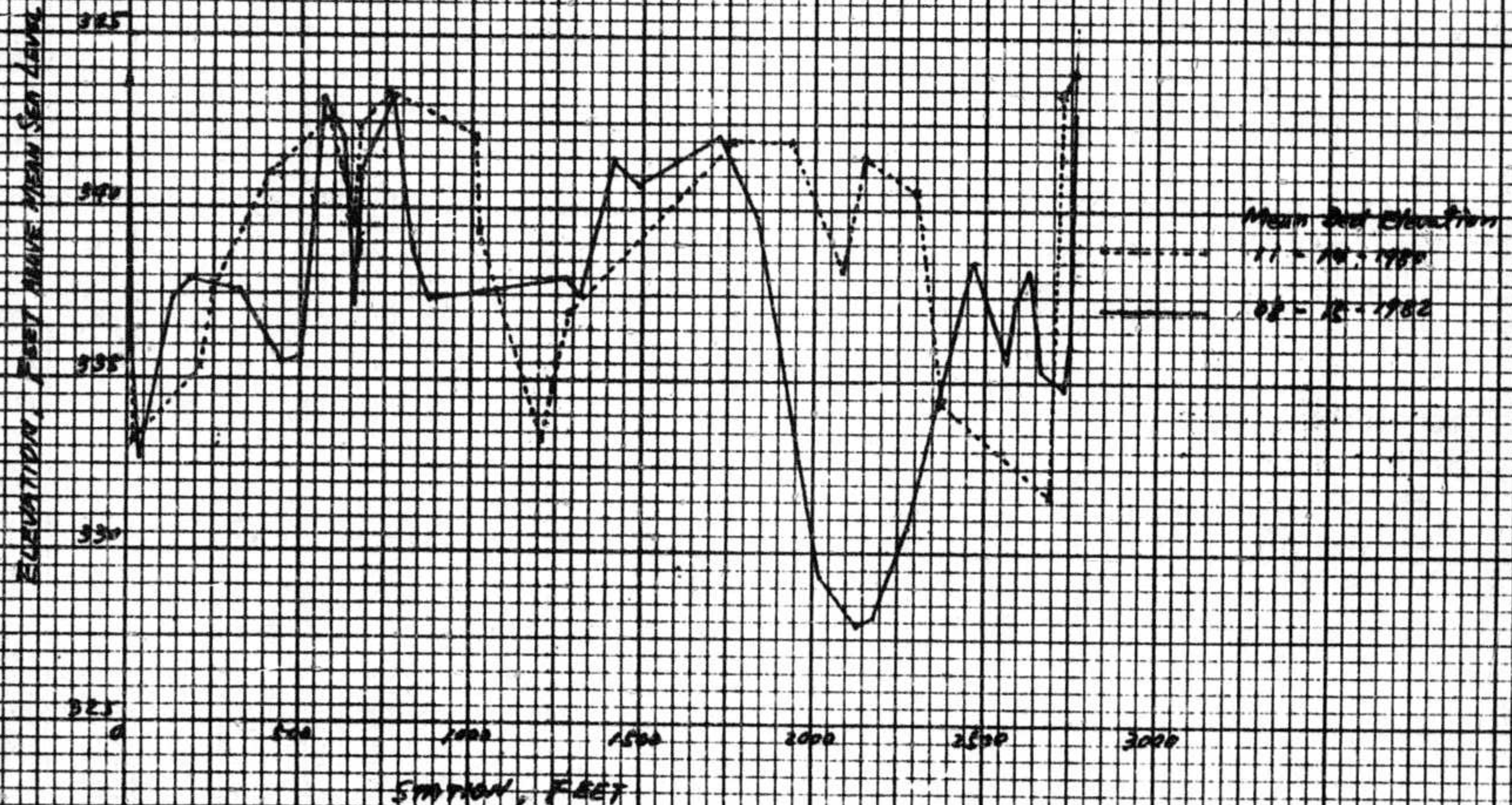


EXHIBIT 9
MEAN BED ELEVATION
11-18-1980
8-13-1982
ELEVATION, FEET ABOVE MEAN SEA LEVEL
340
335
330
325
320
315
0
500
1000
1500
2000
2500
3000
3500
4000
STATION, FEET
SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER
CROSS SECTION 1
HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1985



SUSITNA HYDROELECTRIC PROJECT

SUSITNA RIVER
CROSS SECTION 2

EXHIBIT 1D

HARZA - EBASCO SUSITNA JOINT VENTURE DEC. 1983

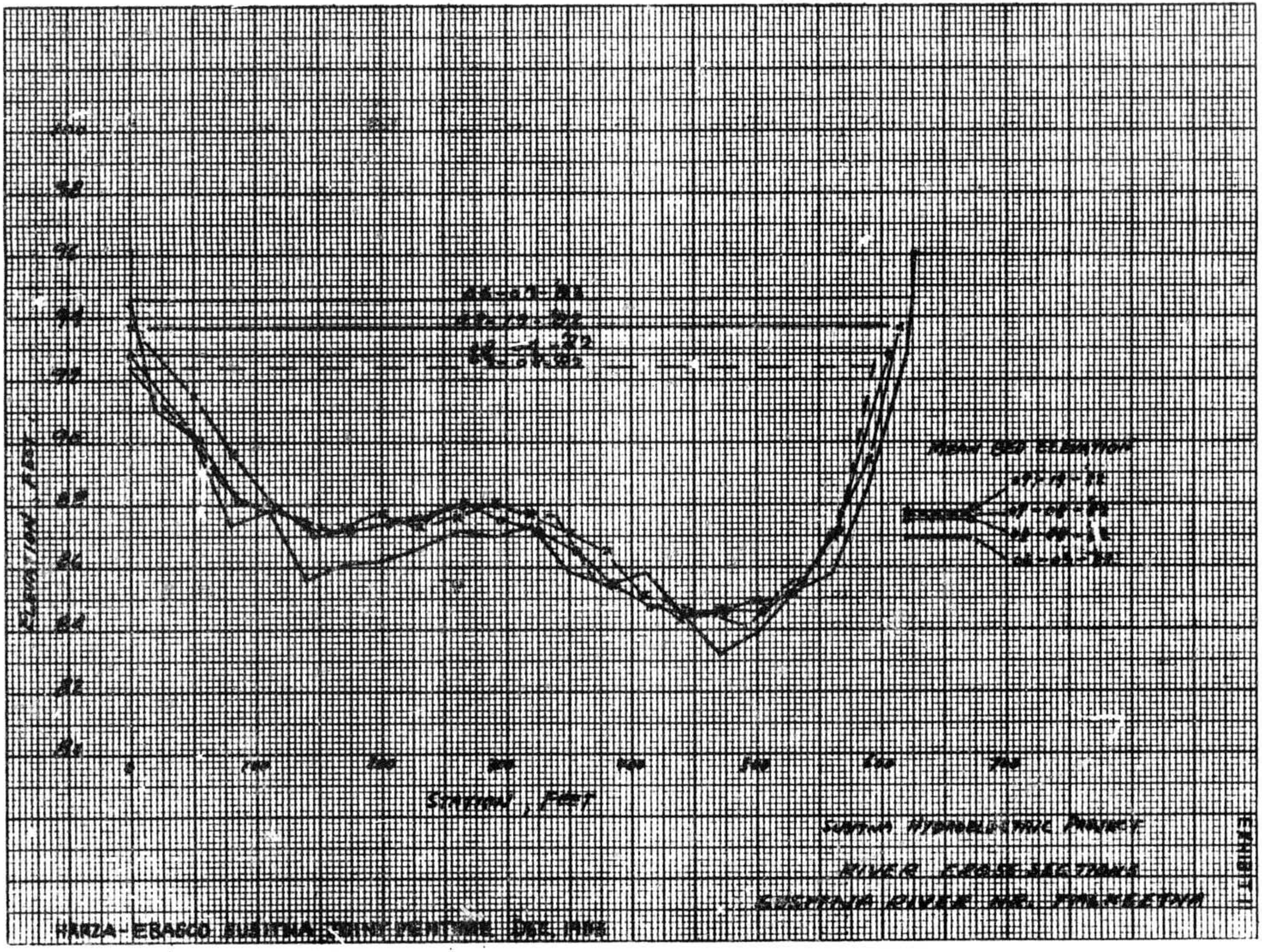


EXHIBIT 1
MEAN BED ELEVATION
ELEVATION, FEET
STATION, FEET
SUSITNA HYDROELECTRIC PROJECT
RIVER CROSS-SECTIONS
HARZA-EBASCO

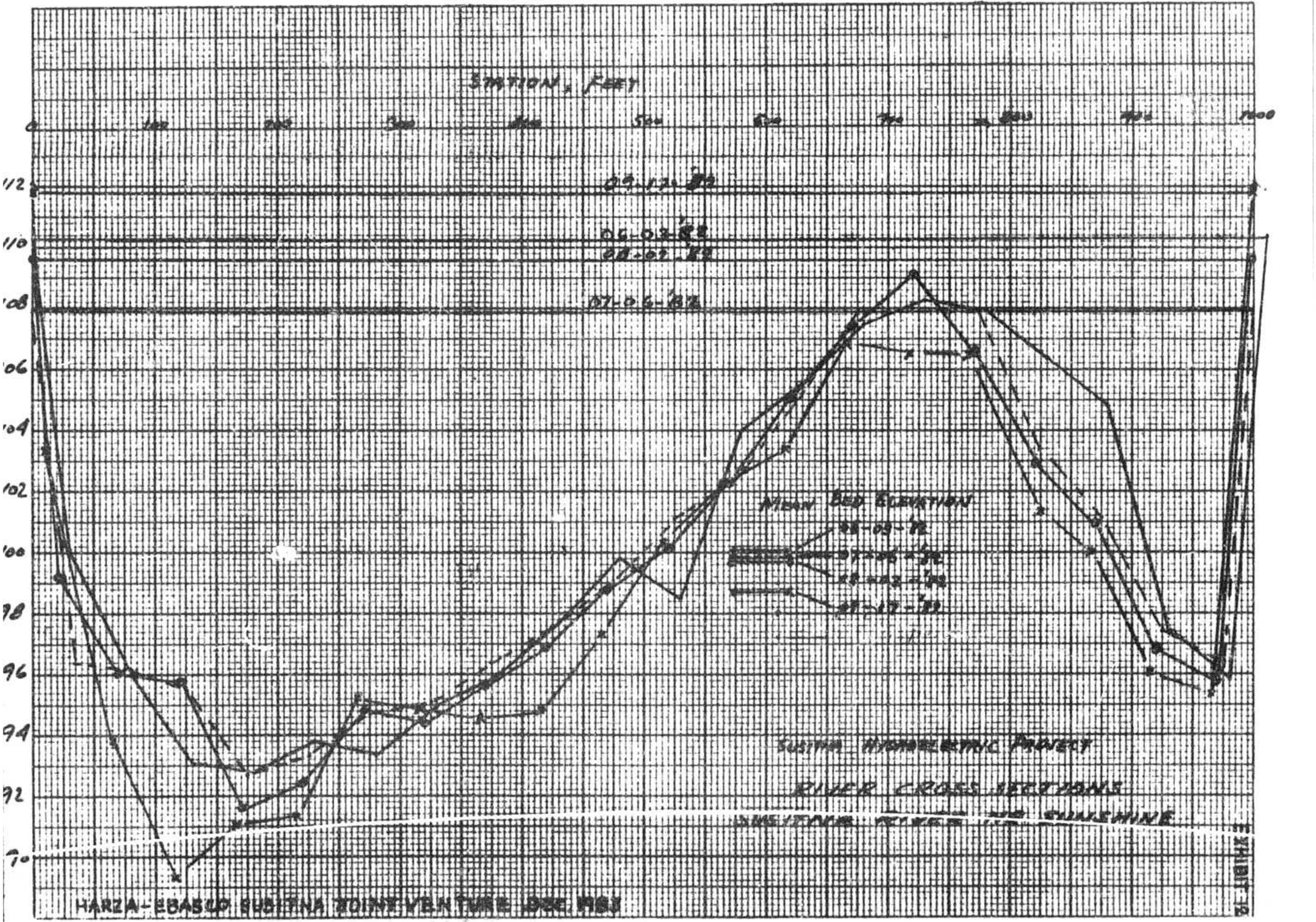
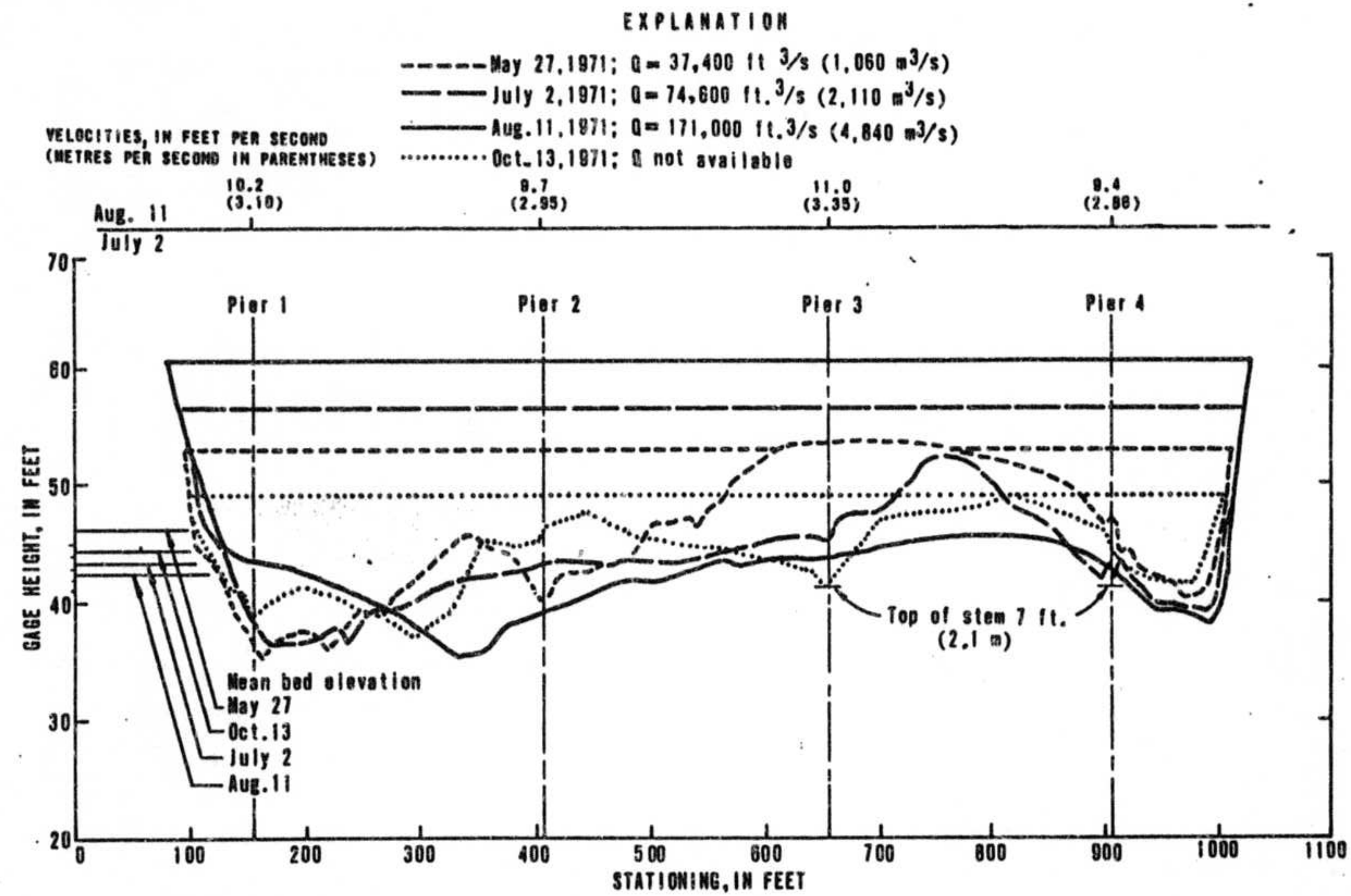

STATION, FEET
0
100
200
300
400
500
600
700
800
900
1000
112
110
108
106
104
102
100
98
96
94
92
90
07-06-82
MEAN BED ELEVATION
SUSITNA HYDROELECTRIC PROJECT
RIVER CROSS SECTIONS
HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1983
EXHIBIT 12

EXHIBIT 13



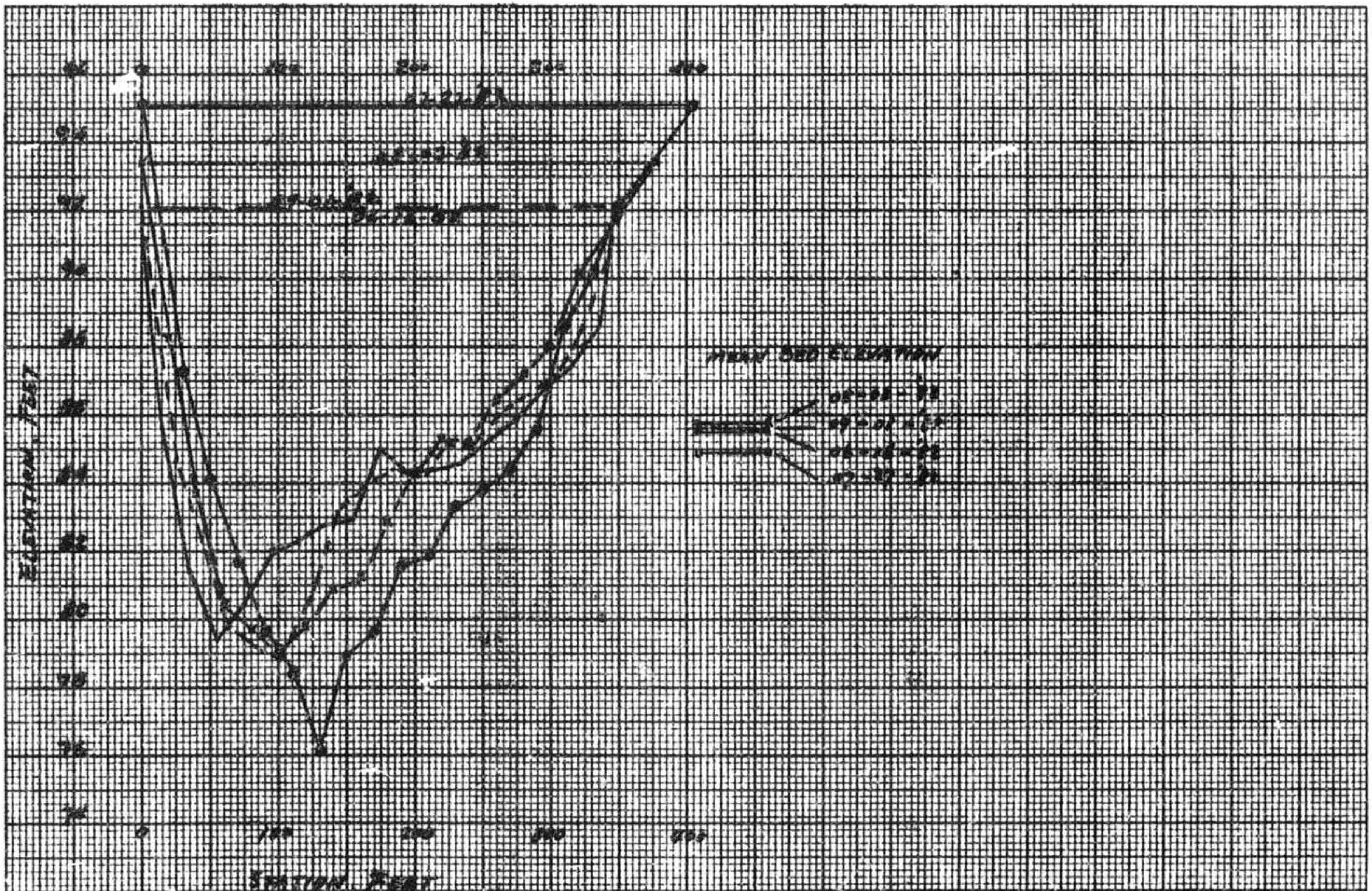
SOURCE: NORMAN, V.W., "SCOUR AT SELECTED BRIDGE SITES IN ALASKA," WATER RESOURCES INVESTIGATION 32-75, USGS, 1975.

SUSITNA HYDROELECTRIC PROJECT

RIVER CROSS SECTIONS
SUSITNA RIVER AT UPSTREAM FACE
OF SUNSHINE BRIDGE

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

EXHIBIT 14



SUSITNA HYDROELECTRIC PROJECT

RIVER CROSS SECTIONS

CHULITNA RIVER NR. TALKEETNA

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

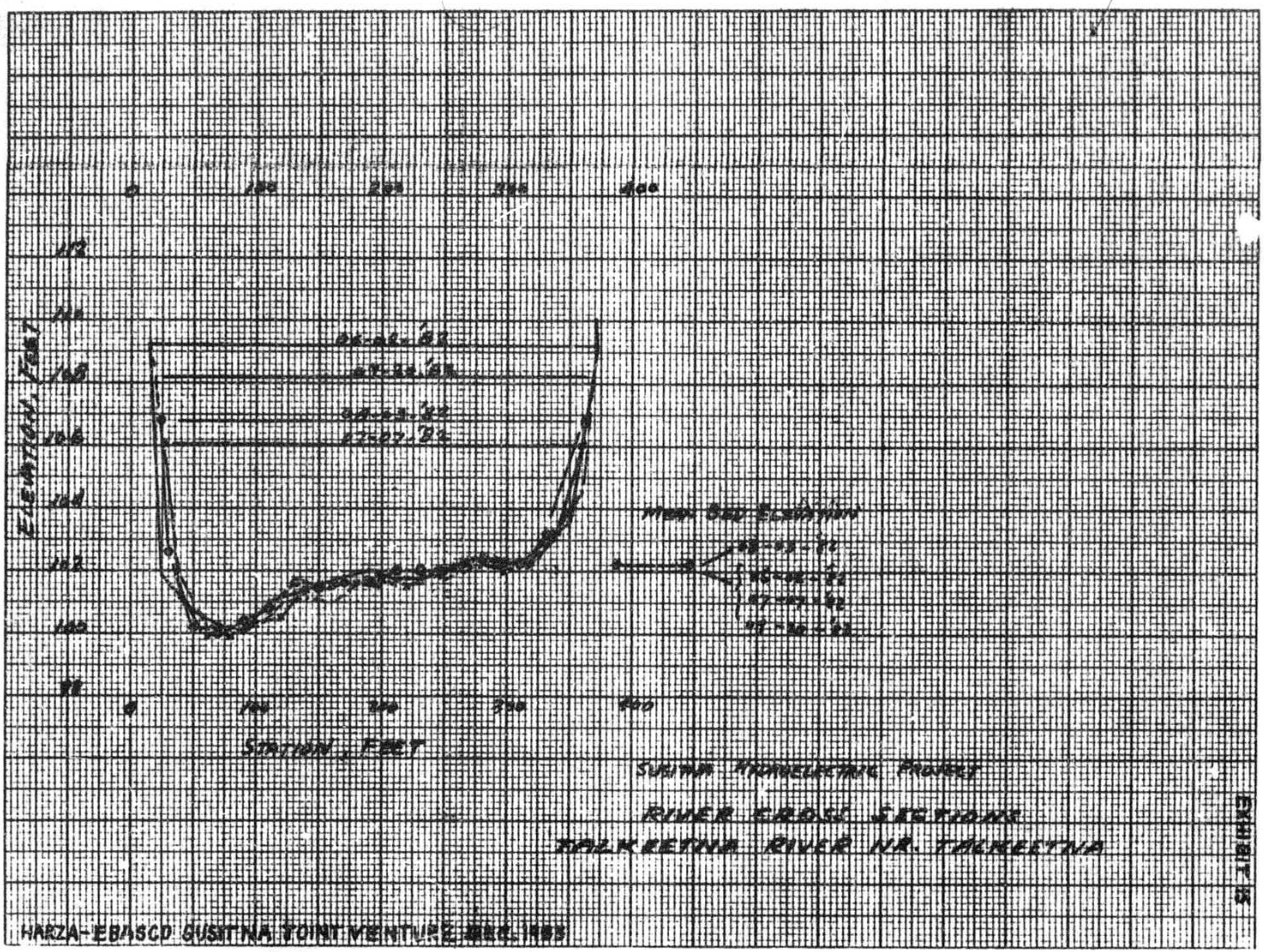


EXHIBIT 15
ELEVATION, FEET
112
110
108
106
104
102
100
98
0
100
200
300
400
STATION, FEET
MEAN BED ELEVATION
SUSITNA HYDROELECTRIC PROJECT
RIVER CROSS SECTIONS
TALKEETNA RIVER NR. TALKEETNA
HARZA-EBASCO SUSITNA JOINT VENTURE

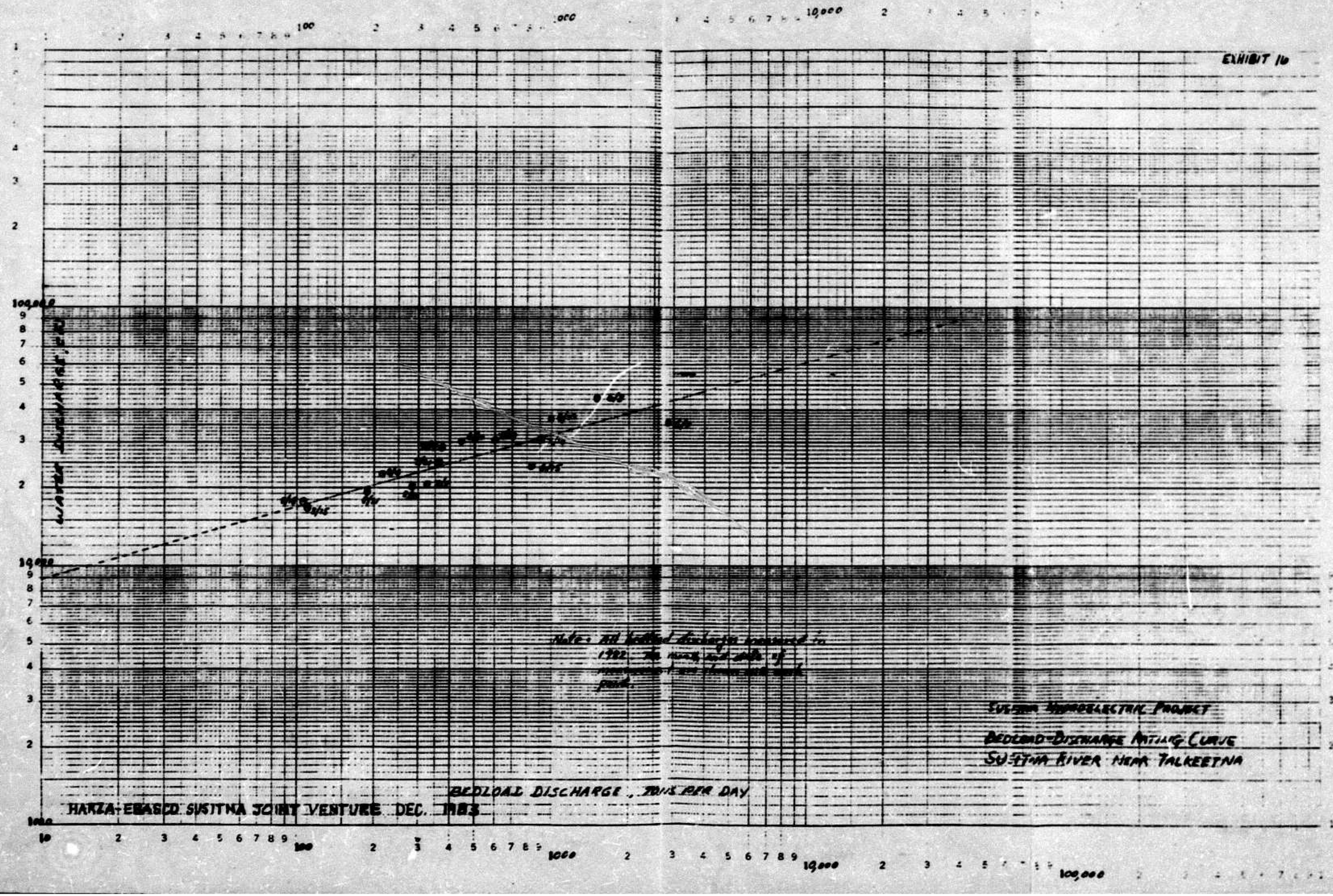


EXHIBIT 16
WATER DISCHARGE, CFS
BEDLOAD DISCHARGE, TONS PER DAY
SUSITNA HYDROELECTRIC PROJECT
BEDLOAD-DISCHARGE RATING CURVE
SUSITNA RIVER NEAR TALKEETNA
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

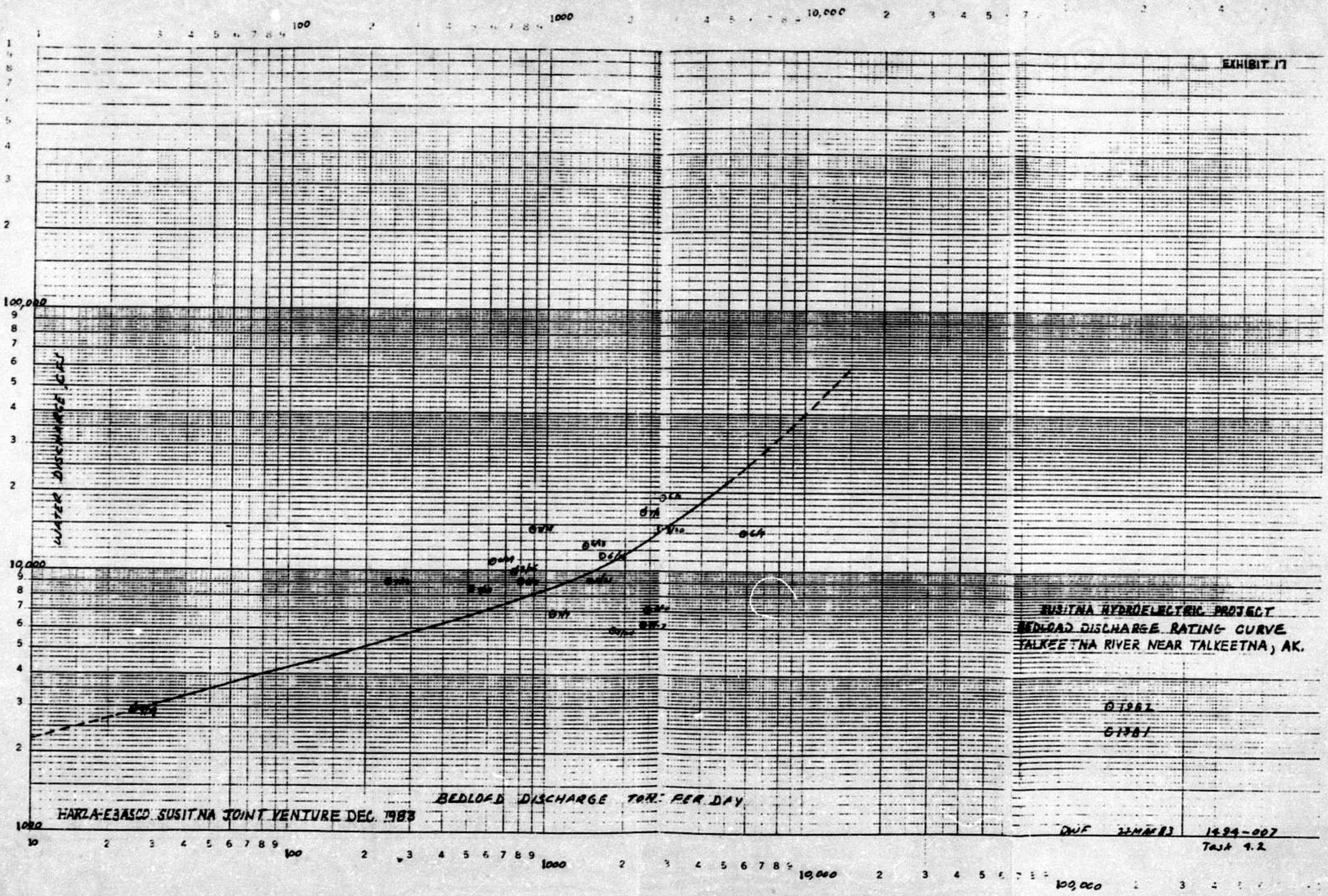


EXHIBIT 17
WATER DISCHARGE, CFS
BEDLOAD DISCHARGE TONS PER DAY
SUSITNA HYDROELECTRIC PROJECT
BEDLOAD DISCHARGE RATING CURVE
TALKEETNA RIVER NEAR TALKEETNA, AK.
○ 1982
○ 1981
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
DWF 22 MAR 83 1494-007
Task 4.2

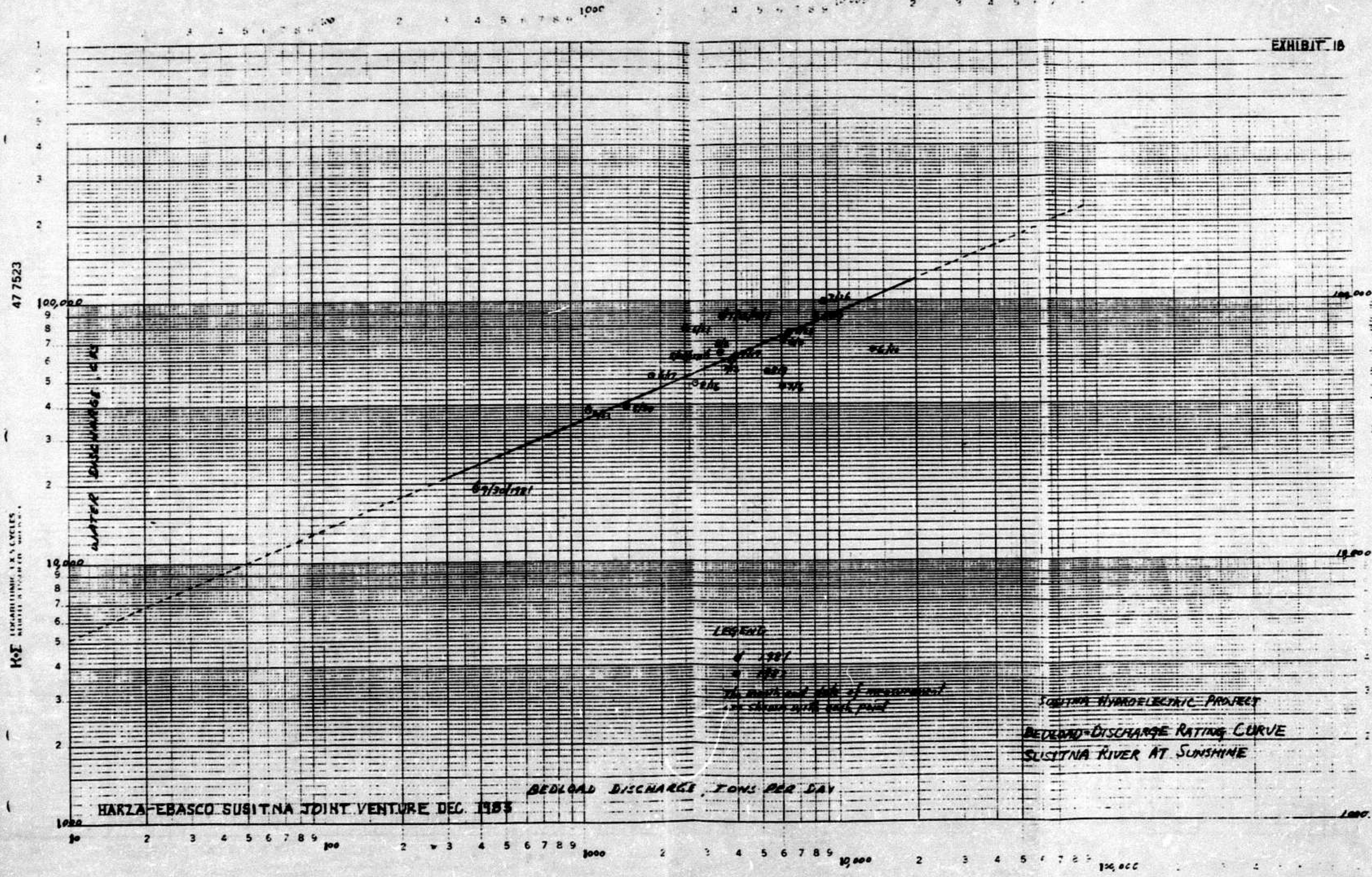


EXHIBIT 1B
WATER DISCHARGE, CFS
100,000
10,000
1000
BEDLOAD DISCHARGE, TONS PER DAY
LEGEND
1981
SUSITNA HYDROELECTRIC PROJECT
BEDLOAD-DISCHARGE RATING CURVE
SUSITNA RIVER AT SUNSHINE
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
K+E LOGARITHMIC 3 X 5 CYCLES
47 7523

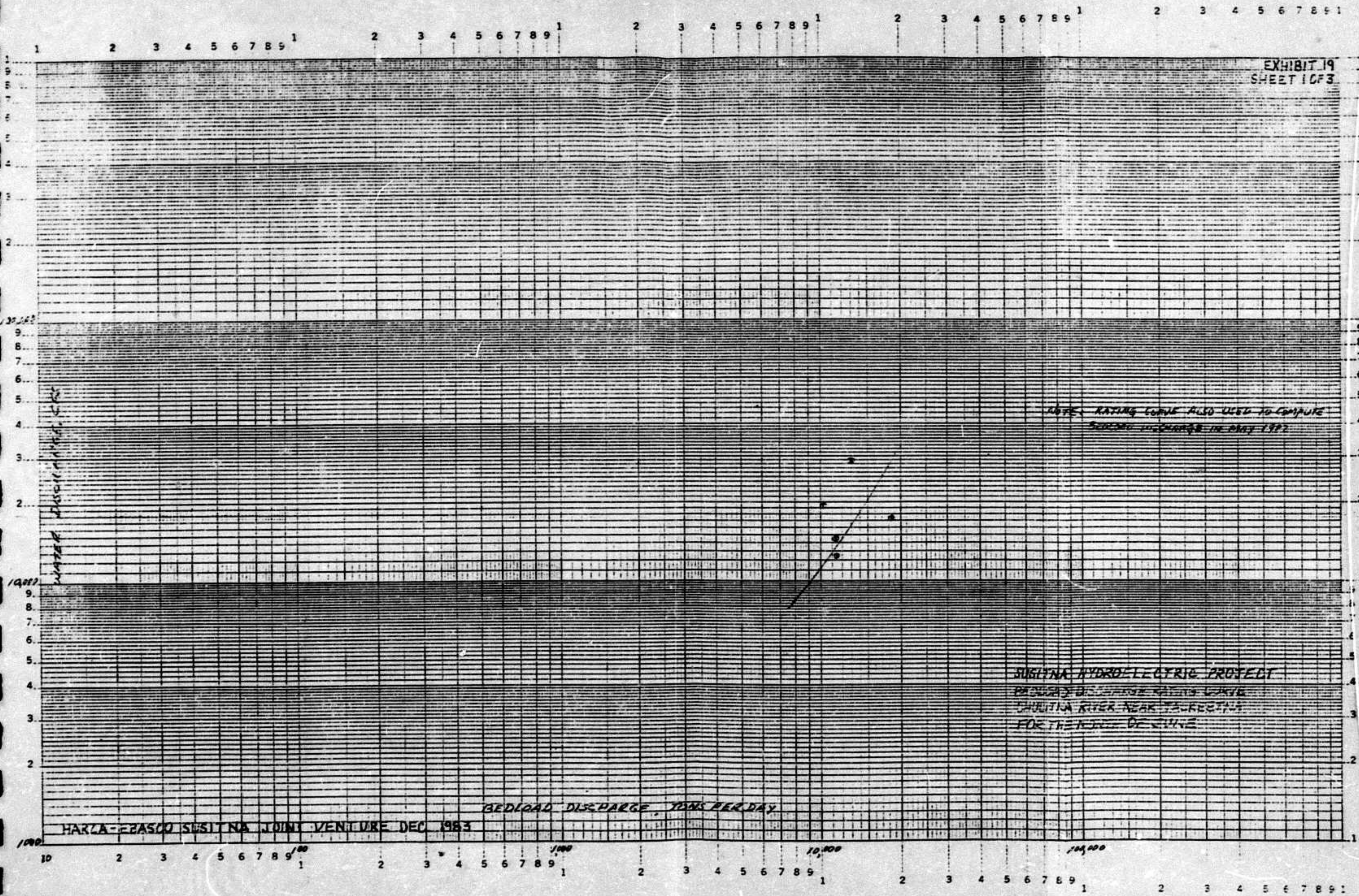
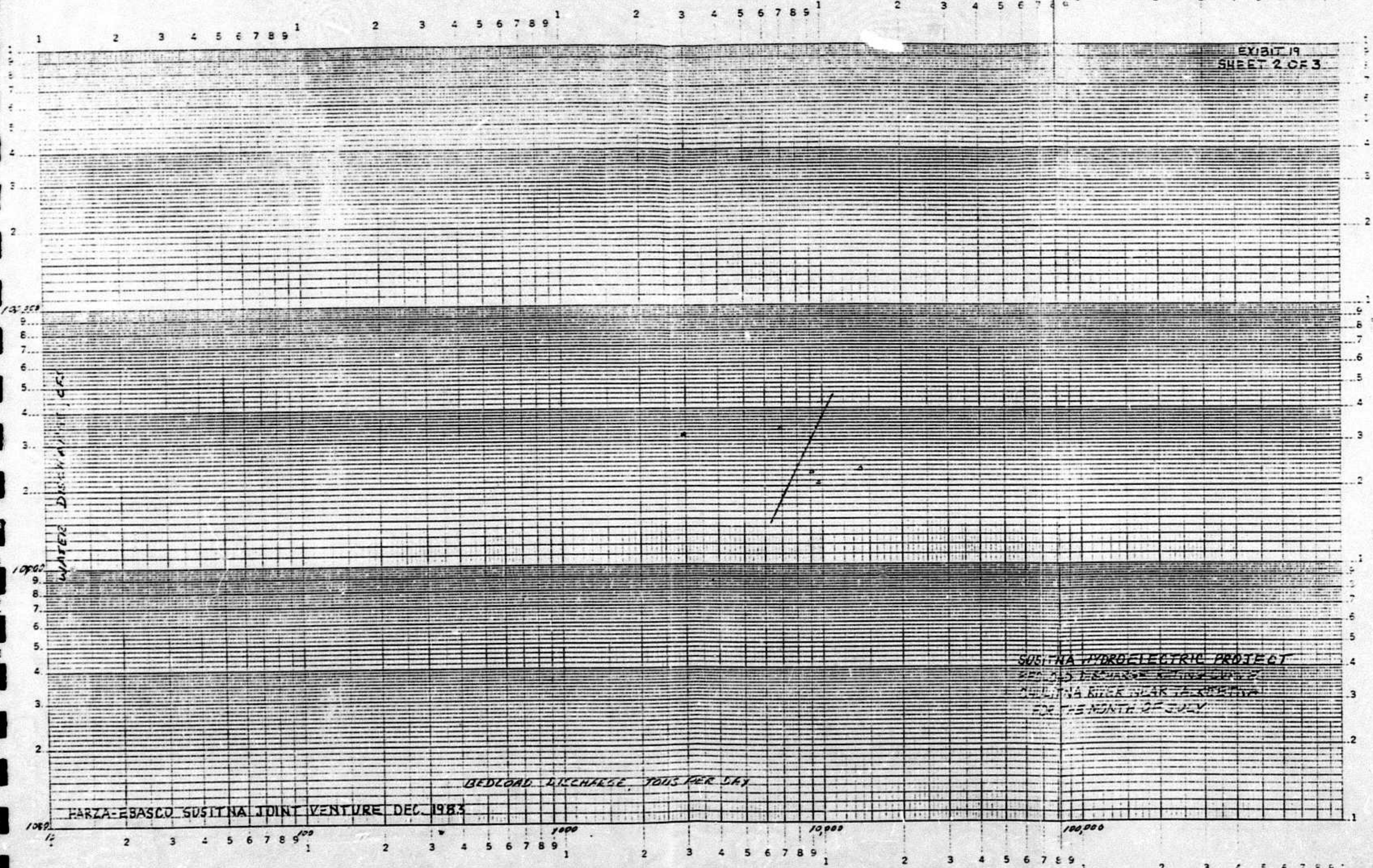


EXHIBIT 19
SHEET 1 OF 3
NOTE: RATING CURVE ALSO USED TO COMPUTE
SUSITNA HYDROELECTRIC PROJECT
WATER DISCHARGE, CFS
BEDLOAD DISCHARGE, TONS PER DAY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983


EXIBIT 19
SHEET 2 OF 3
WATER DISCHARGE CFS
BEDLOAD DISCHARGE, TONS PER DAY
SUSITNA HYDROELECTRIC PROJECT
FOR THE MONTH OF JULY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
1000
10,000
100,000
100
10

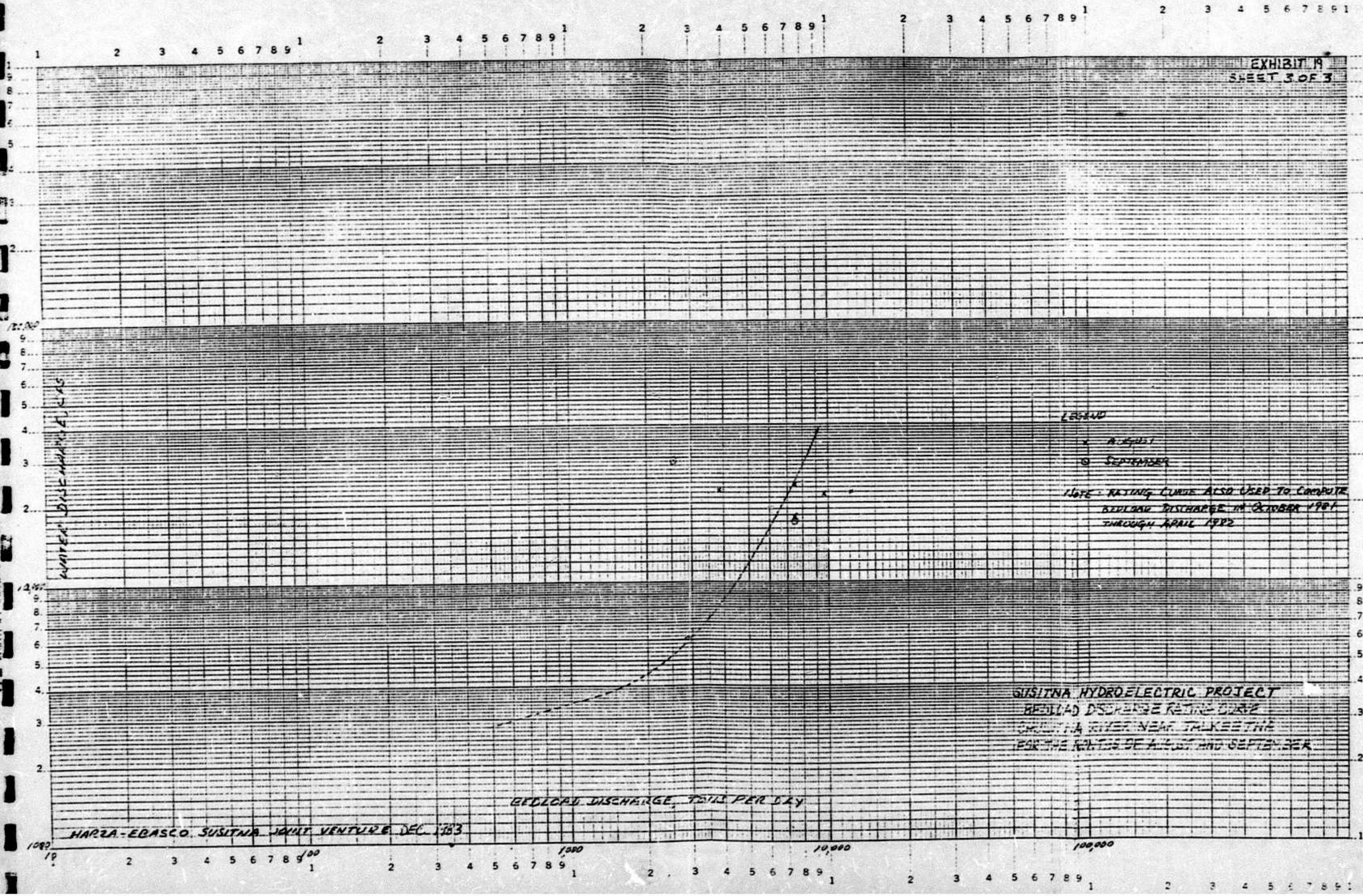


EXHIBIT 19
SHEET 3 OF 3
LEGEND
SEPTEMBER
NOTE: RATING CURVE ALSO USED TO COMPUTE BEDLOAD DISCHARGE IN OCTOBER 1981 THROUGH APRIL 1982
SUSITNA HYDROELECTRIC PROJECT
BEDLOAD DISCHARGE RATING CURVE
SUSITNA RIVER NEAR TALKEETNA
WATER DISCHARGE, CFS
BEDLOAD DISCHARGE, TONS PER DAY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
10
100
1000
10,000
100,000

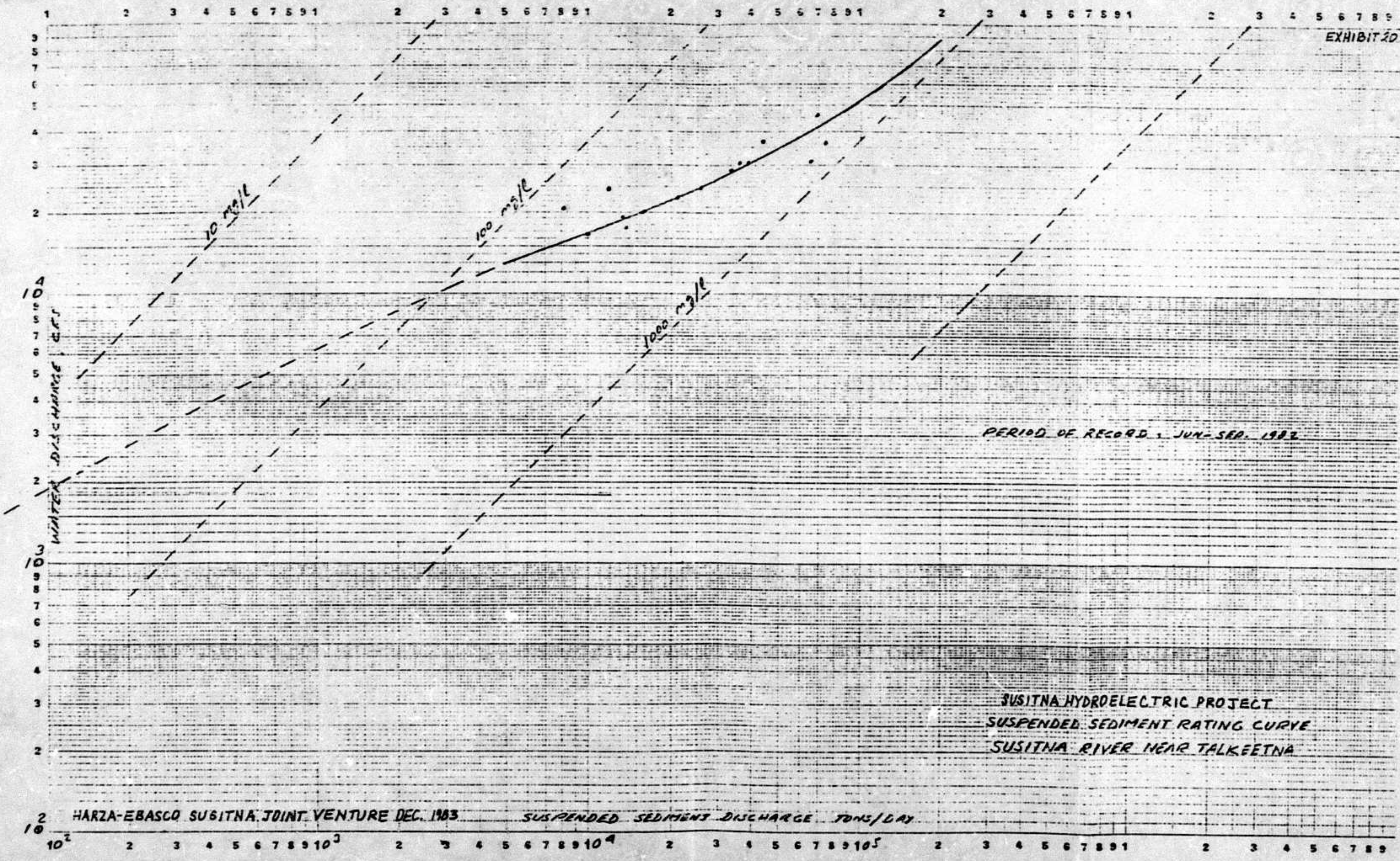


EXHIBIT 20
10 mg/l
100 mg/l
1000 mg/l
WATER DISCHARGE, CFS
PERIOD OF RECORD: JUN-SEP. 1982
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT RATING CURVE
SUSITNA RIVER NEAR TALKEETNA
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983
SUSPENDED SEDIMENT DISCHARGE TONS/DAY

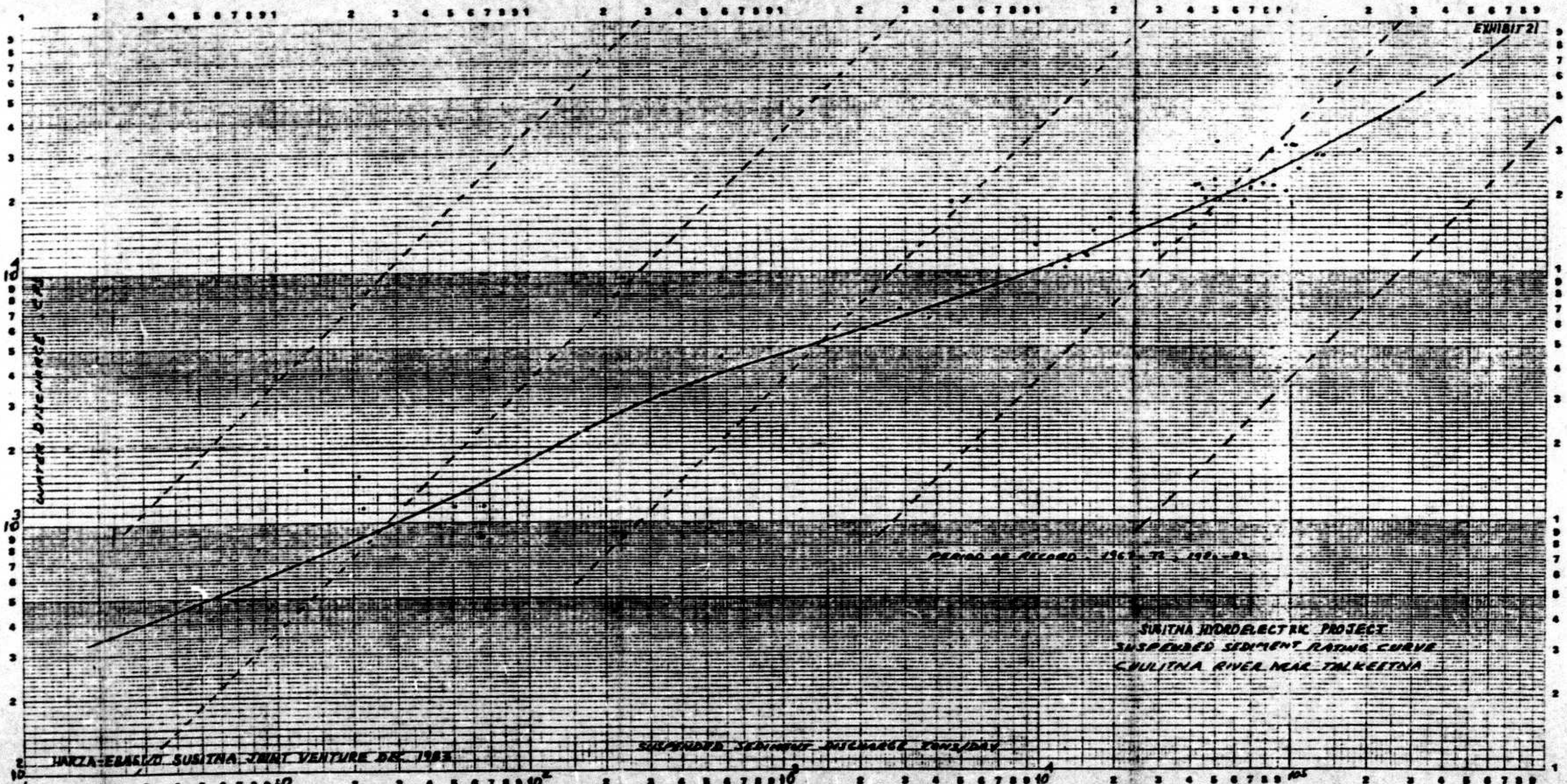
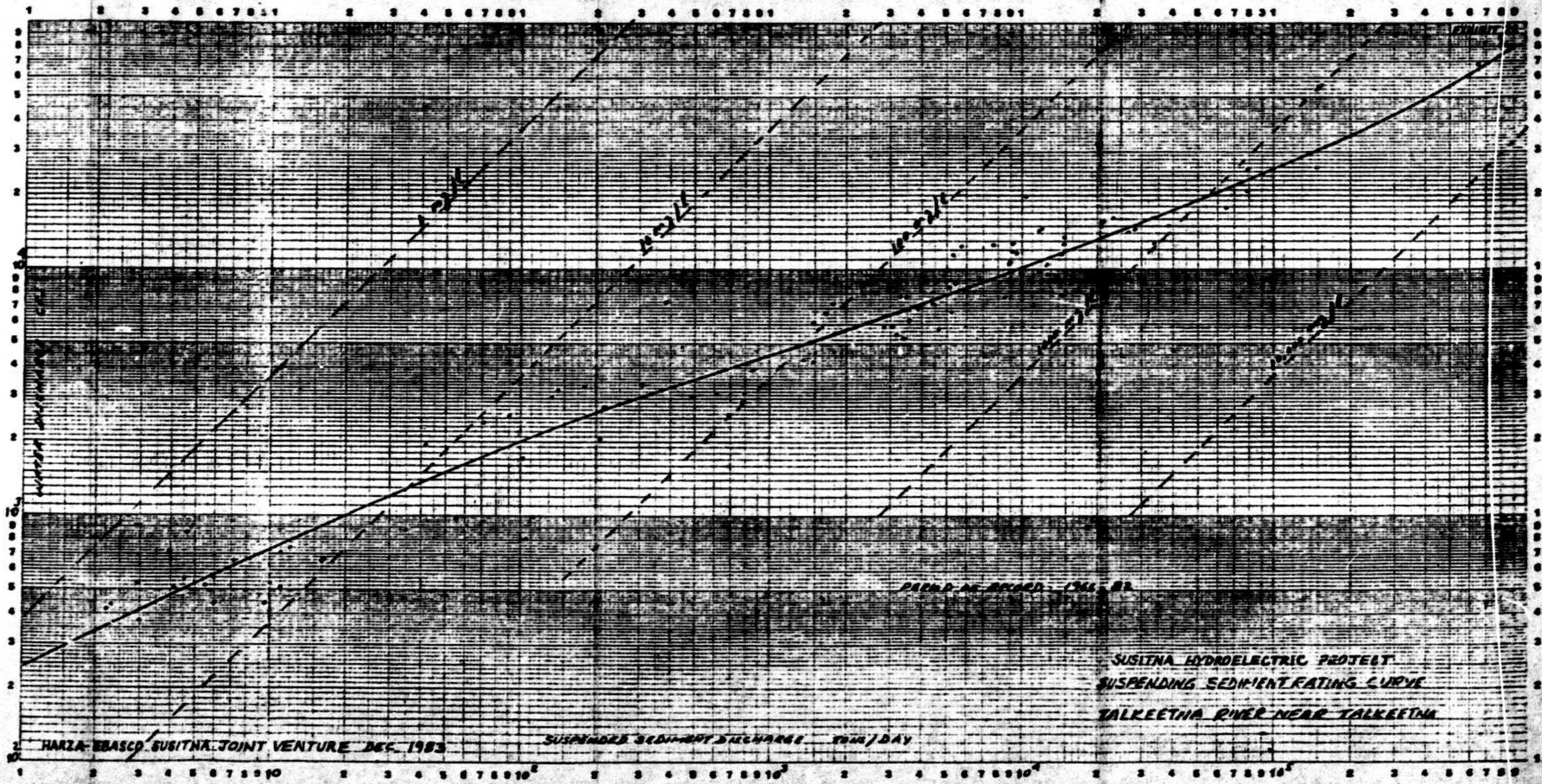


EXHIBIT 21
WATER DISCHARGE CFS
SUSPENDED SEDIMENT DISCHARGE TONS/DAY
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT RATING CURVE
CHULITNA RIVER NEAR TALKEETNA
HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1983



SUSITNA HYDROELECTRIC PROJECT
SUSPENDING SEDIMENT RATING CURVE
TALKEETNA RIVER NEAR TALKEETNA
PERIOD OF RECORD - 1966-82
SUSPENDED SEDIMENT DISCHARGE TONS/DAY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

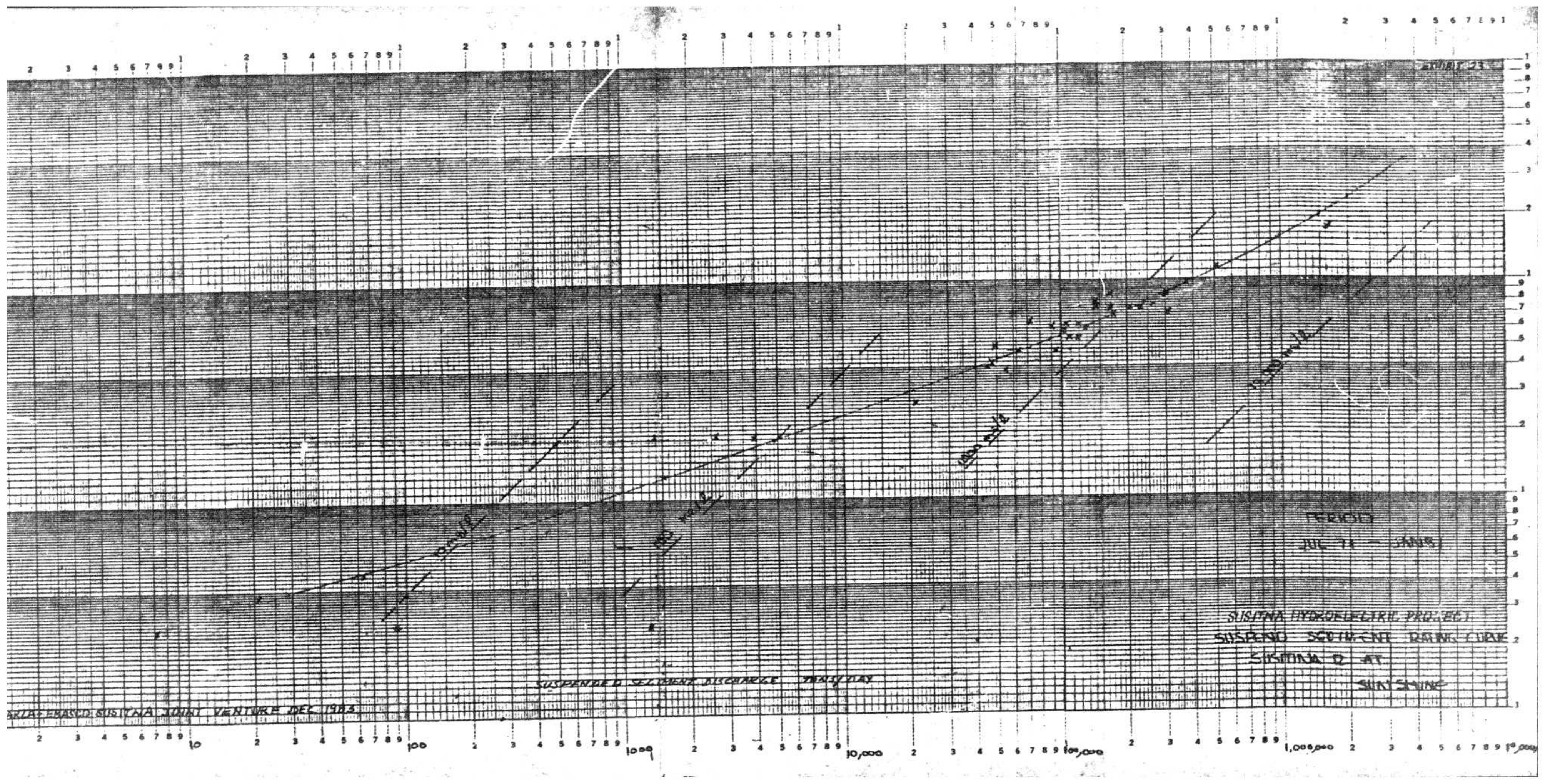
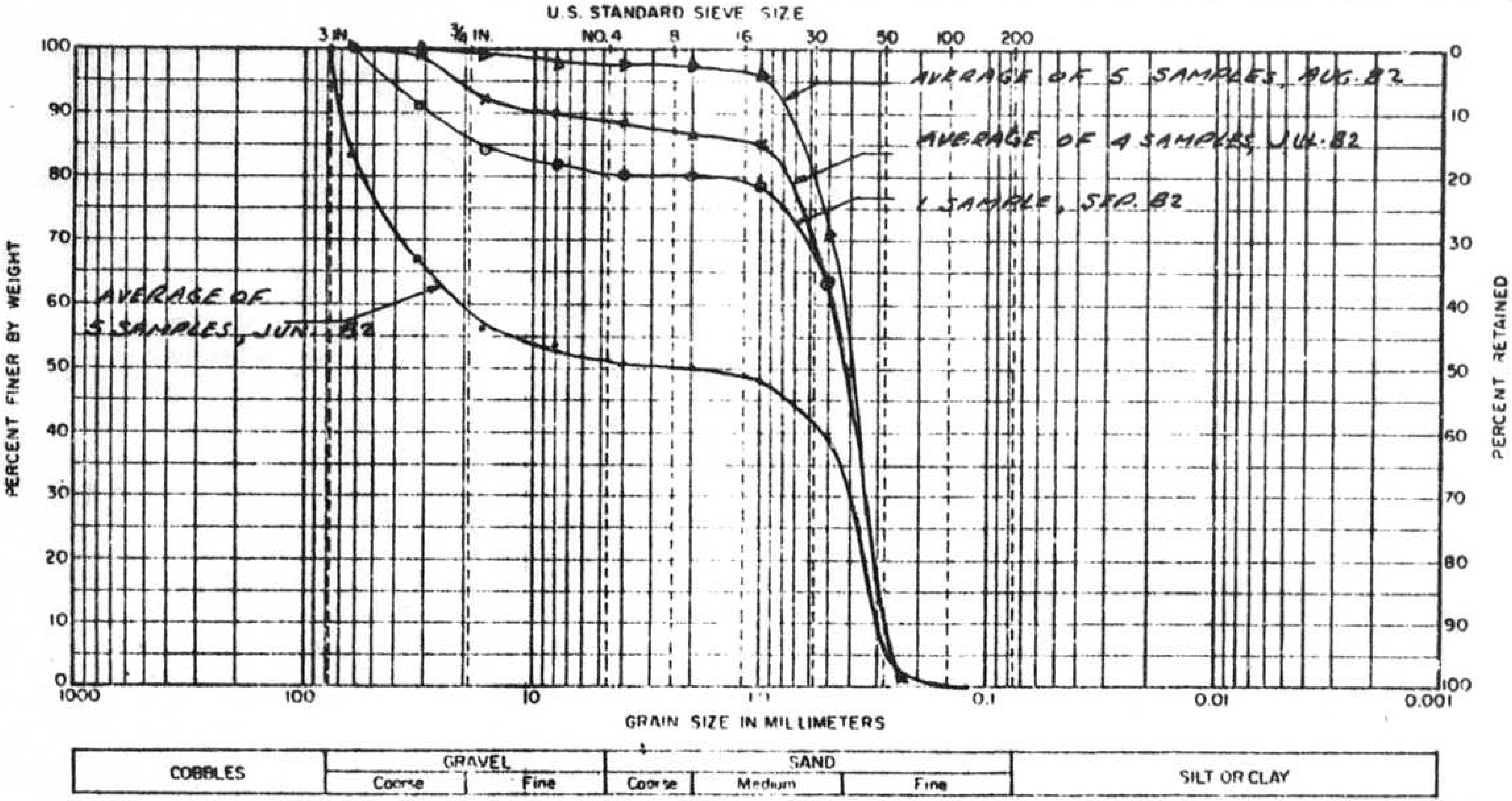


EXHIBIT 23
PERIOD
JUL 71 - JAN 81
SUSITNA HYDROELECTRIC PROJECT
SUSPEND SEDIMENT RATING CURVE
SUSITNA R AT
SUNSHINE
SUSPENDED SEDIMENT DISCHARGE TONS/DAY
HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1983
10
100
1000
10,000
100,000
1,000,000



Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

GRADATION CURVES

SUSITNA HYDROELECTRIC PROJECT

SUSITNA R. NR. TALKEETNA

SIZE DISTRIBUTION OF BED LOAD

HARZA ENGINEERING CO., CHICAGO

APPROVED ....

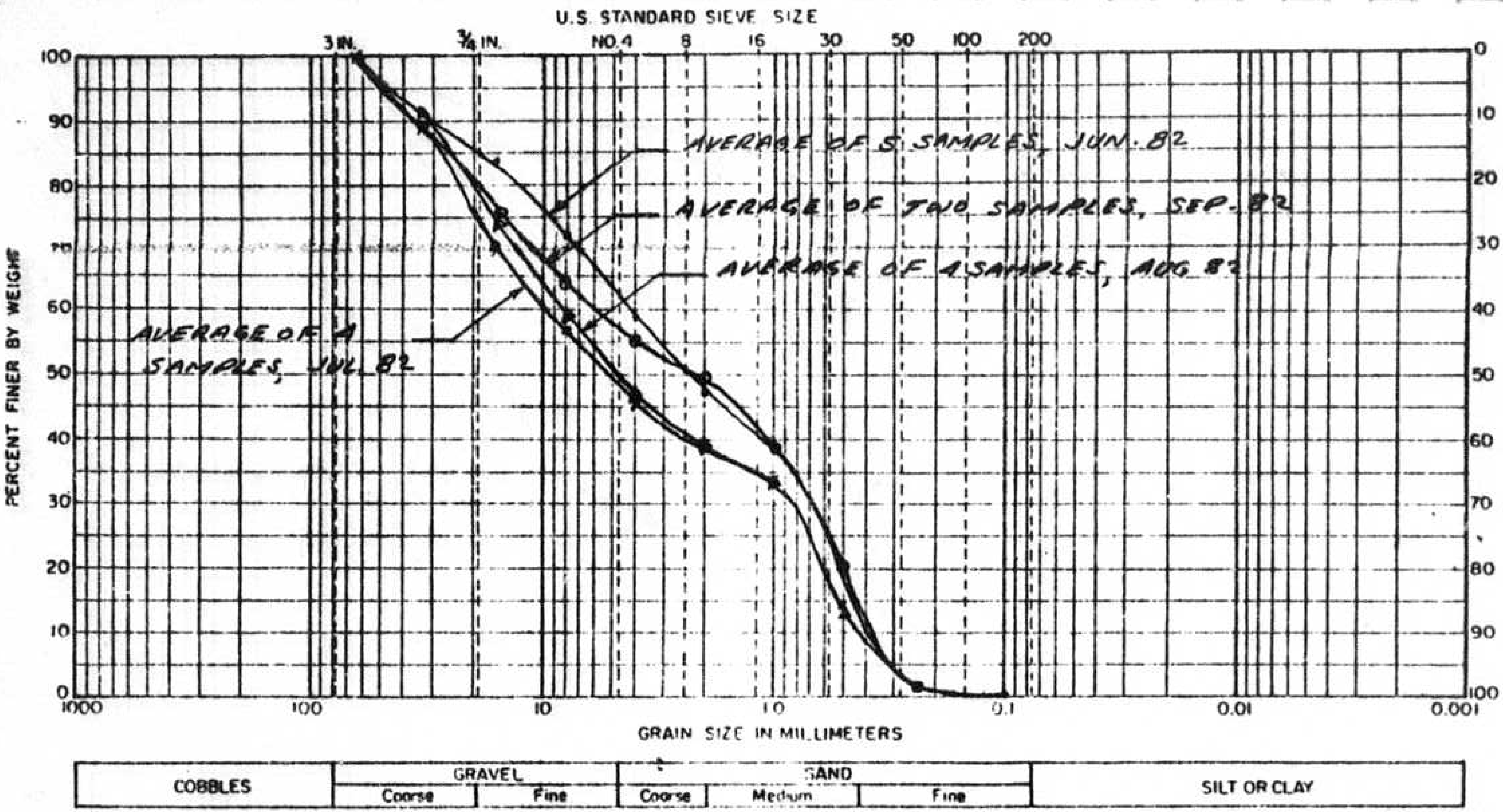
DATE

DWG. NO.

HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1983

EXHIBIT 24

EXHIBIT 25



Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

SUSITNA HYDROELECTRIC PROJECT

CHULITNA R. NR. TALKEETNA

SIZE DISTRIBUTION OF BED LOAD

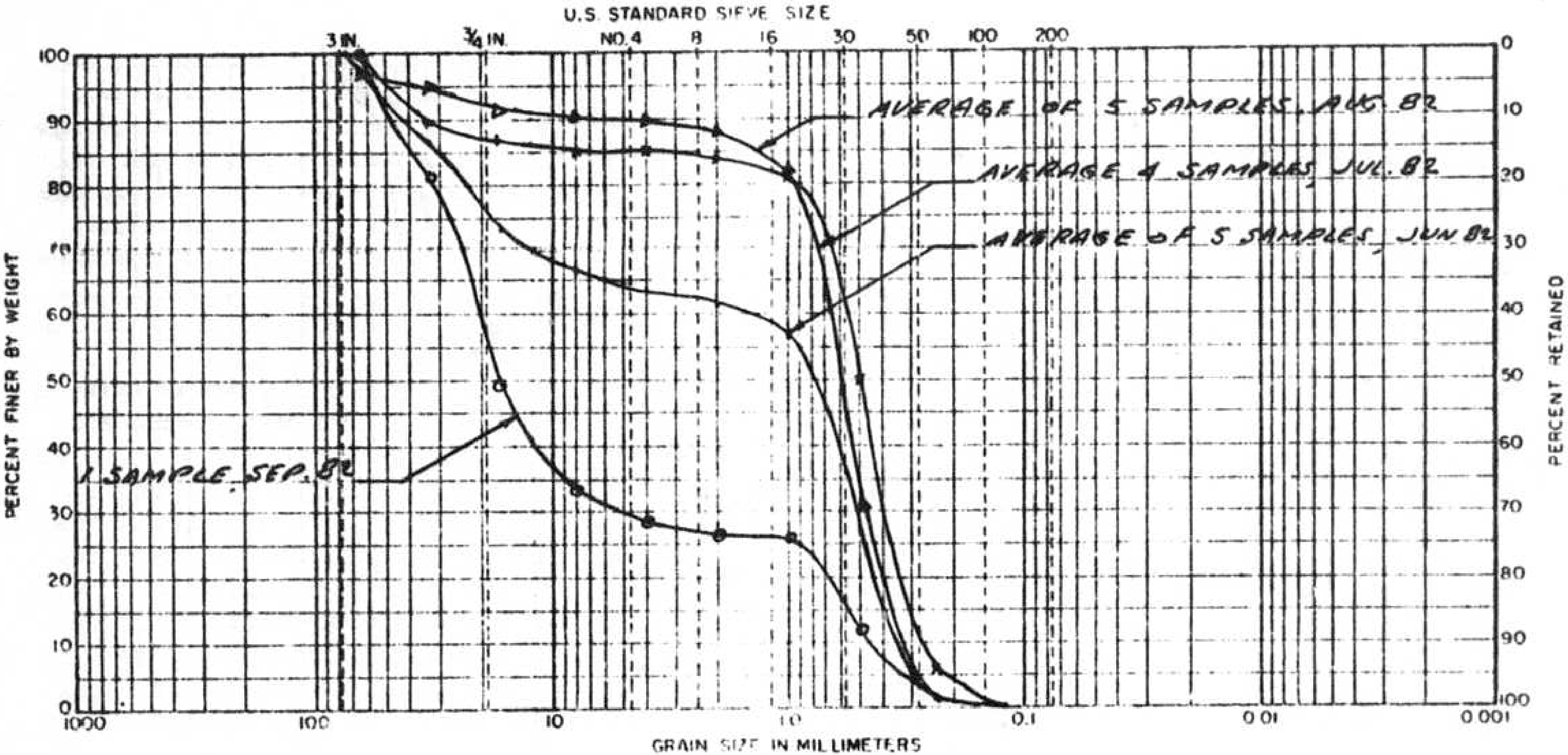
HARZA ENGINEERING CO., CHICAGO

APPROVED..........................

DATE

DWG.NO.

EXHIBIT 26



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE DEC. 1983

SUSITNA HYDROELECTRIC PROJECT

TALKEETNA R. NR. TALKEETNA

SIZE DISTRIBUTION OF BEDLOAD

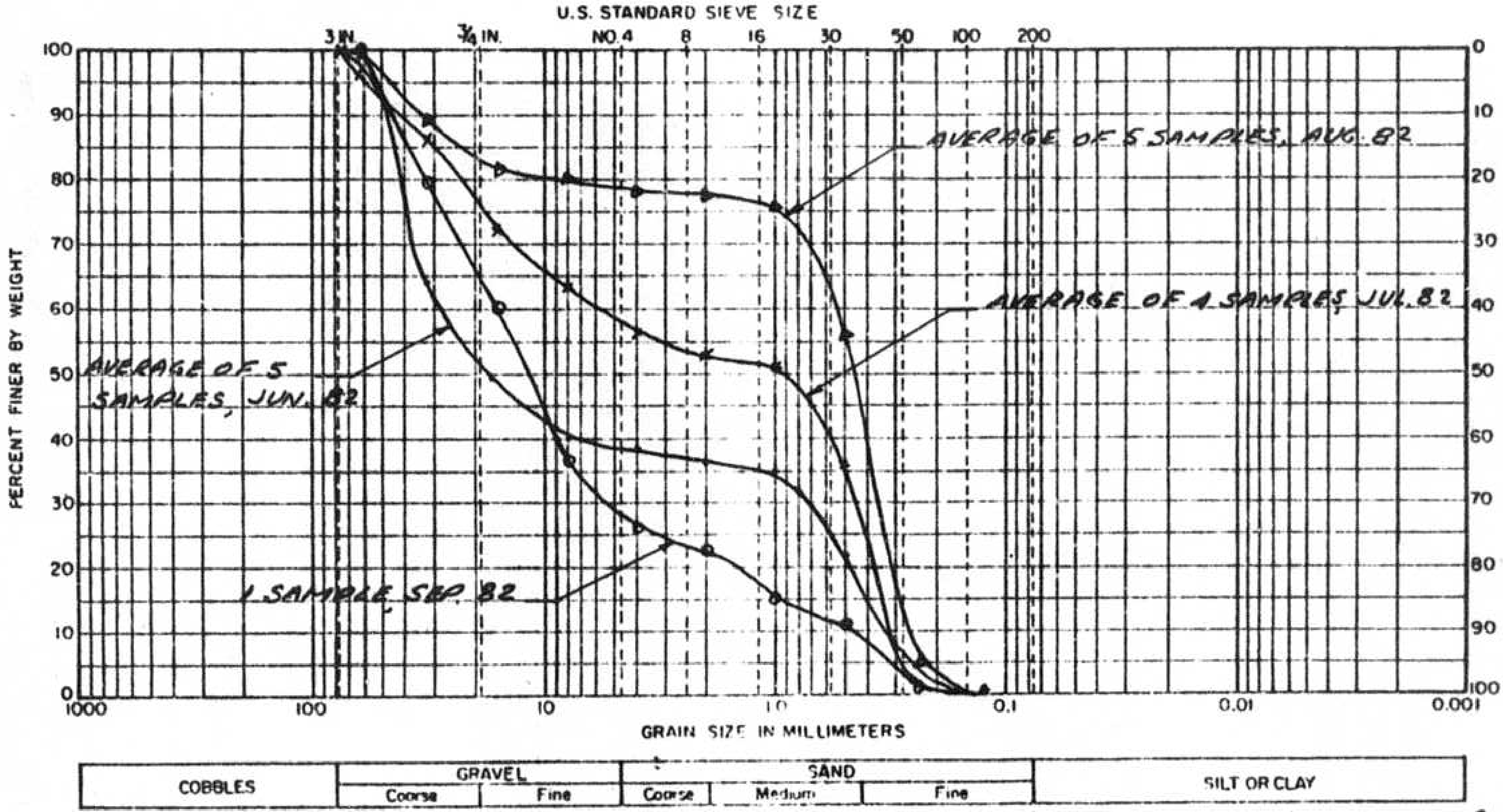
HARZA ENGINEERING CO., CHICAGO

APPROVED

DATE

DWG.NO.

EXHIBIT 27



Sample No.	Elev. or Depth	Classification	Nat WC	LL	PL	PI	

GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE DEC 1983

SUSITNA HYDROELECTRIC PROJECT

SUSITNA R. AT SUNSHINE

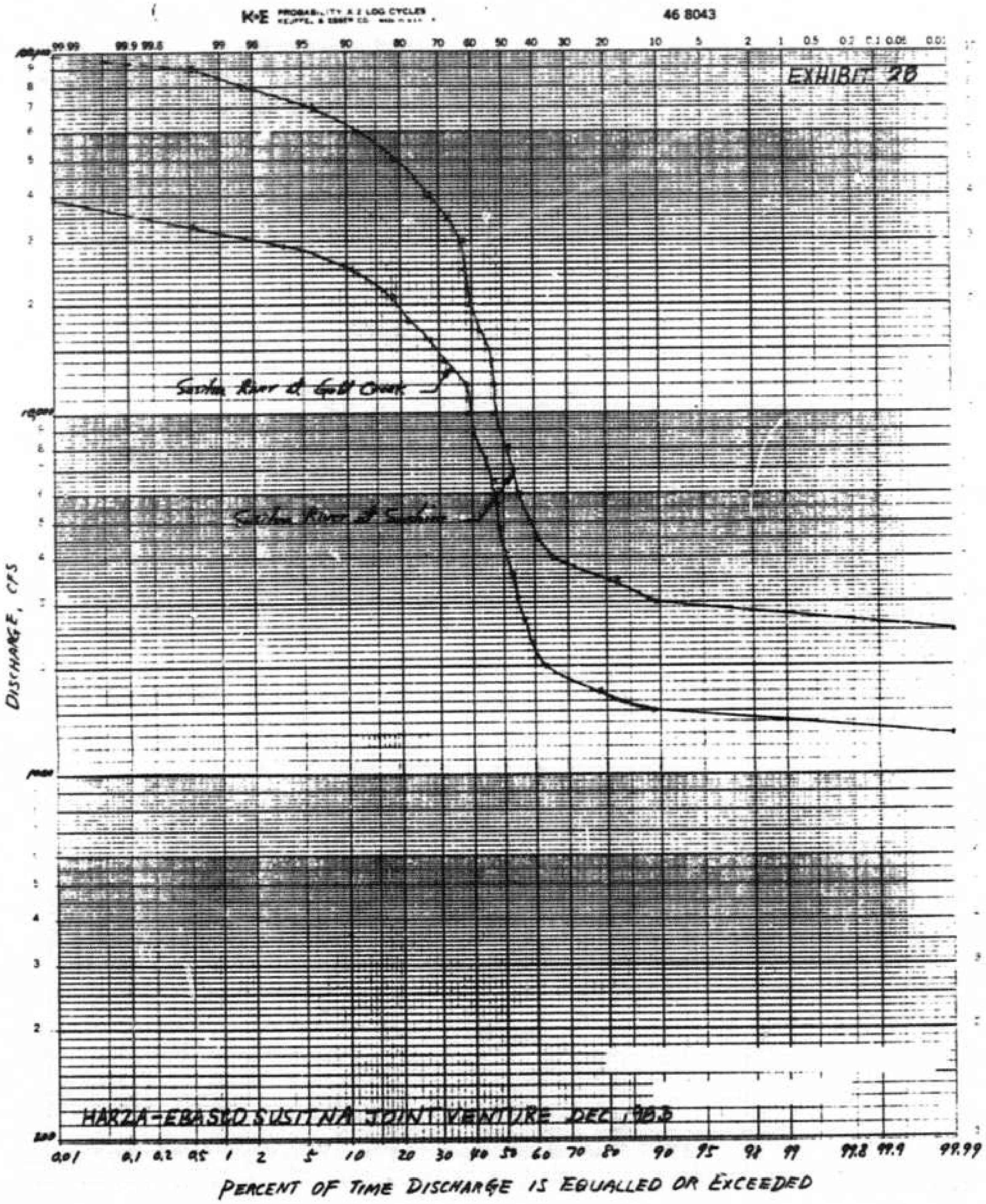
SIZE DISTRIBUTION OF BED LOAD

HARZA ENGINEERING CO., CHICAGO

APPROVED..........

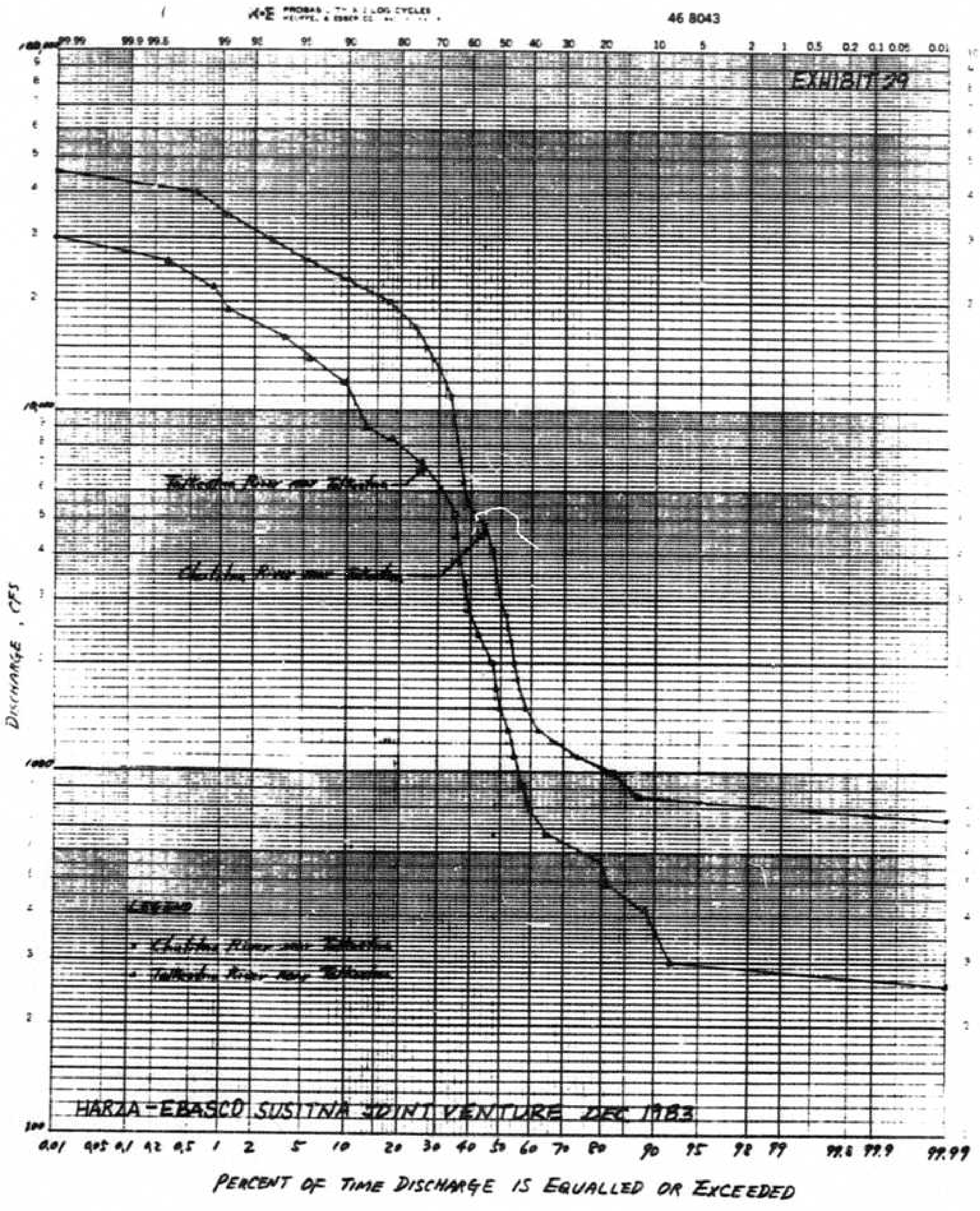
DATE

DWG. NO.



SUSITNA HYDROELECTRIC PROJECT
DURATION CURVES BASED ON DAILY FLOWS
WATER YEAR 1982
SUSITNA RIVER AT GOLD CREEK AND SUNSHINE

HARZA-EBASCO SUSITNA JOINT VENTURE, DEC. 1983



SUSITNA HYDROELECTRIC PROJECT

DURATION CURVES BASED ON DAILY FLOWS

WATER YEAR 1983

CHULITNA AND TALKEETNA RIVERS

HARZA-EBASCO SUSITNA JOINT VENTURE, DEC. 1983