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SUSITNA HYDROELECTRIC PROJECT

LOWER SUSITNA RIVER SEDIMENTATION STUDY
PROJECT EFFECTS ON
SUSPENDED SEDIMENT CONCENTRATION

Report by
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Prepared for
Alaska Power Authority

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF EXHIBITS

1.0 SUMMARY

The concentration and particle size distribution of suspended sediment are determined for natural conditions at various locations on the Susitna River based on the data collected by the United States Geological Survey. Under with-project conditions, the concentrations are estimated for reservoir releases and at Gold Creek and Sunshine.

It is estimated that the average suspended sediment concentration of all flows entering Watana Reservoir will be about 830 milligram per litre (mg/l). The reservoir will trap about 82 percent of the sediment. Particle sizes of about .003 and .004 mm will pass through. The concentration in the releases will vary from about 55 mg/l in the winter to about 250 mg/l in the summer.

The estimated monthly suspended sediment concentrations at Gold Creek and Sunshine are shown on Exhibits 11 and 12. The project operation would increase the concentration during winter and decrease that during summer. At Gold Creek, November through March concentration would increase from aobut 5 to 60 mg/l. The increase at Sunshine also would be about the same. The concentrations in the months of April and October also will increase compared to that under natural conditions (Exhibits 11 and 12). The concentration during May through September will decrease (Exhibits 11 and 12).

2.0 SCOPE OF THE STUDY

The scope of this study includes the analysis of suspended sediment concentration under natural conditions and changes in the concentration due to the project operation. The analysis is made for the Susitna River at Gold Creek and at Sunshine stream gaging stations (see Exhibit 1 for the locations). The major tasks are:

1. to define the characteristics of suspended sediment at selected locations upstream of Sunshine stream gaging station (Sunshine gage);

2. to define the characteristics of suspended sediment entering Watana Reservoir;

3. to estimate probable suspended sediment concentration of water released from the reservoir;

4. to evaluate effects on suspended sediment concentration in the mainstem due to major tributaries entering the Susitna River above Sunshine gage; and

5. to provide a comparison of monthly suspended sediment concentrations at Gold Creek stream gaging station (Gold Creek gage) and at Sunshine gage for natural and with-project conditions.

3.0 SETTING

The Susitna River drains an area of about 19,600 square miles (mi^2) in the south central region of Alaska. The major tributaries include the Chulitna, Talkeetna and Yentna rivers with drainage areas of about 2,650, 2,040 and 6,200 mi^2 respectively.

The Susitna River originates in the West Fork and Maclaren glaciers of Alaska Range (Exhibit 1) and traverses a distance of about 320 miles to its mouth at the Cook Inlet. The Chulitna River originates in the glaciers on the south slopes of Mount McKinley and joins the Susitna River from the West near Talkeetna at river mile 98 (river miles referenced from the Cook Inlet). The Talkeetna River originates in the Talkeetna Mountain and joins the Susitna River from the east near Talkeetna at river miles 97. The Yentna River originates in the Alaska Range and enters the Susitna River from the west at river mile 28.

The Susitna Hydroelectric Project will include two dams, Watana and Devil Canyon, located at river miles 184 and 152, respectively. The drainage areas at the two sites are about 5,180 and 5,810 mi^2, respectively.

Susitna streamflow is characterized by turbid high flows in May through September and clear low flows from October through April. High spring and summer flows are caused by snowmelt, glacial melt and storm rainfall.

4.0 SUSPENDED SEDIMENT

4.1 DATA SOURCE

Suspended sediment samples have been collected at a number of stream gaging stations in the Susitna River basin by the United States Geological Survey (USGS). These samples have been analysed for total suspended sediment concentration in milligram per litre (mg/l). A number of samples also have been analysed for particle size distribution. Exhibit 1 shows the sampling stations for which the suspended sediment data are available. The number of samples collected at selected stations during the period of record are given in Table 1.

4.2 CHARACTERISTICS OF SUSPENDED SEDIMENT

Sediment is transported in suspension, as bed load rolling or sliding along the bed and interchangeably by suspension and bed load. The nature of movement depends on the particle size, shape and specific gravity in respect to the associated velocity and turbulence. Under some conditions of high velocity and turbulence (high flows in steep-gradient mountain streams) cobles (64 to 256 mm size) can be carried intermittently in suspension. Conversely, silt size particles (.004 to .062 mm) may move as bed load in low-gradient, low-velocity channels.

4.2.1 At Selected Locations

Suspended sediment is the sediment that is transported outside of the bed layer in suspension by the turbulent components of the flowing water. In the Susitna River, fine material (silt and clays finer than 0.062 mm) and fine to medium sand particles (sizes between 0.062 mm and upto 1.00 mm) have been observed in suspension.

The five material, also known as wash load, are derived from sheet erosion, glacier melt and bank erosion. The quantity of wash load being transported depends upon its availability because the Susitna River can transport much larger quantities of wash load for the observed range of flow. The sand particles are derived either from river bed erosion or from glacier melt and other erosion processes. The maximum quantity of sand being transported depends upon the magnitude of flow.

Suspended sediment samples generally have been collected during the months of May through October (Table 1). A few samples are available for some stations for the period from December through April but no sample was collected in November at any station.

Since the suspended sediment consists of wash load and sand particle, its concentration varies both with the availablity of wash load and the capacity of flow to transport sand particles. Available data did not allow to define a clear relationship between water discharge and suspended sediment concentration (Exhibits 2 and 3) which can be used to determine the monthly variation of suspended sediment based on mean monthly discharges. Therefore, to provide some idea of monthly variation, the maximum, minimum and median concentrations measured at various locations are listed in Table 2. The maximum and minimum concentrations are not provided for the months for which only one or two samples are available. The median values in such cases are the average of the two or the single value.

The size distributions of suspended sediment at various stations are given in Table 3. Size distributions are available for the samples collected during the months of May through October. A few samples collected during the other months were not analysed for size distribution probably because of insufficient sediment quantity. The size distribution curves based on Table 3 are shown on Exhibit 7 through 11. The percentages of fine material and sand particles at various locations are given below.

PERCENTAGES OF FINE MATERIAL AND SAND
IN SUSPENDED SEDIMENT

Station	Fine Material (< .062 mm)	Sand (> .062 mm)	Median Dia. (mm)
Susitna R. nr. Denali	52	48	.056
Susitna R. nr. Cantwell	54	46	.049
Susitna R. at Gold Creek	61	39	.038
Susitna R. nr. Talkeetna (above confluence)	70	30	.015
Chulitna R. nr. Talkeetna	62	38	.024
Talkeetna R. nr. Talkeetna	51	49	.060
Susitna R. at Sunshine	69	31	.014
Susitna R. at Susitna Station	61	39	.030

The above table indicates, on the average, an increase in the percentages of fine material from Denali to above the confluence of the Susitna and Chulitna rivers. Only limited number of samples are available for Susitna River near Talkeetna and at Sunshine.

Sufficient number of samples are not available to precisely define the concentration for each month. However, by comparing the data for various stations, some indicative values of monthly concentrations for the Susitna River at Gold Creek and at Sunshine were estimated and are shown on Exhibits 12 and 13, respectively. The values indicated on the exhibits are not related to specific discharges and approximately represent the median values from the range of observed concentrations under natural flow conditions.

4.2.2 Suspending Sediment Entering Watana Reservoir

The characteristics of the suspended sediment entering Watana Reservoir are best represented by those measured at the Cantwell station. This indicates that, on the average, the suspended sediment concentrations vary approximately between 2 to 20 mg/l during November through April and between 80 to 3,000 mg/l during May through October. The average size distribution based on the samples collected during May through October is shown on Exhibit 4. This indicates that about 18 percent of sediment is less than .004 mm (clay sizes), about 36 percent is between .004 and .062 (silt sizes) and about 46 percent is larger than .062 mm (sand sizes). The average annual streamflow at Watana is about 8,000 cubic feet per second (cfs) (1)[1/]. The suspended sediment inflow is estimated to be about 6,530,000 tons per year (ton/yr) (2). This gives an average concentration of about 830 mg/l for the flow entering the reservoir. The winter concentration may be about 0 to 10 mg/l mg/l (Table 2).

4.3 EFFECTS OF ICE COVER ON SEDIMENT TRANSPORT

A study made by W.W. Sayre and G.B. Song (3) to evaluate the effects of ice-cover on alluvial channel flow and sediments transport processes indicated that ice causes a number of changes in alluvial channel flows by approximately doubling the wetted perimeter and thereby producing a redistribution of the boundary and internal shear stresses. The total depth of flow in the channel with a given unit discharge and slope is significantly increased (about 20 to 30 percent for a smooth cover and from 30 to 80 percent for rough cover, relative to the depth for a free surface condition). Due mainly to the lower velocities, sediment discharge is significantly reduced.

1/ Indicate reference at the end of text

The above conclusions are applicable to the Susitna River.

4.4 SEDIMENT TRANSPORT DURING FREEZEUP

Field observations on the Susitna River show that freeze-up generally begins in October with some processes continuing until break-up. The beginning of frazil ice (a spongy or slushy accumulation of ice crystals which form in supercooled water that is too turbulent to permit coagulation of the crystals into sheet ice) is marked by a rapid reduction in suspended sediment concentration. As the process continues, the river becomes clear within a day or two. Since more contribution of fine sediment from erosion process is stopped due to frozen ground and also there is no glacier melt, the river remain practically clear until breakup.

The frazil crystals often flocculate into larger clusters having porosity of about 60 percent. Since water can permeate through these clusters, they filter out the sediment particles which remain entrapped. During breakup, significant quantity of sediment, mostly silt and clay, is observed to be mixed with ice. The sediment is concentrated at places rathern than distributed over the whole mass.

Anchor ice, similar to slush ice but adhering temporily to the river bottom, also has been observed to be mixed with sediment. The anchor ice probably catches sediment moving as bed load as well as suspended load. The anchor ice is generally formed at night and released during the day and then drifts downstream.

4.5 PROJECT EFFECT

4.5.1 Suspended Sediments Concentrations at Watana Reservoir Outlet

Peratrovich, Nottingham and Drage, Inc.; (PND), (4) made analysis of turbidity levels in Watana Reservoir using a computer model DEPOSITS. The major conclusions made by PND that are pertinent to this study are given below.

1. It is likely that sediment particles less than .003 and .004 mm will remain in suspension;

2. Maximum turbidity levels at the outlet will be on the order of 50 NTU's, which corresponds to a sediment concentration of 200 to 400 mg/l;

3. Minimum turbidity level will be in the order of 10 NTU's which corresponds to a sediment concentration of 30 to 70 mg/l;

4. Turbidity levels at the reservoir outlet during each month appear to primarily dependent upon the travel time for sediment slugs delivered to the reservoir during previous summers to reach the reservoir outlet; and

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

Harza-Ebasco plans to study the turbidity level in Watana reservoir and in the outflow from the reservoir. The dynamic reservoir simulation model DYRESM (5), currently being used for the reservoir temperature and ice study, will be enhanced to include a sub-routine for predicting turbidity levels under various flow conditions. This study will include the effect of ice cover on turbidity which was not considered in PND's study. The prupose of Harza-Ebasco study will be to confirm or refine analysis made by PND. For the purpose of this study, the results provided by PND have been used to estimate suspended sediment concentrations under with-project conditions.

PND's analysis show that sediment particles less than about .003 and .004 mm will remain in suspension and pass through the reservoir. Using size distribution curve shown on Exhibit 4, about 18 percent of the sediment is finer than .004 mm. Therefore, it can be expected that about 18 percent of the inflowing sediment will pass through the reservoir.

Turbidity level at the outlet is estimated to be about 10 to 50 NTU's by PND. Using Exhibit 14, this corresponds to about 55 to 250 mg/l. These values are slightly different than those reported by PND.

From the above discussion, it can be concluded that the operation of Watana reservoir would increase the suspended sediment concentration in winter from about 5 to about 55 mg/l. The summer concentrations would be significantly reduced. The extents of reductions would depend on the month.

4.5.2 River Temperatures

Harza-Ebasco is conducting a temperature and ice study for Watana Reservoir. The preliminary simulation computer runs indicate that the outflow temperatures will be about 1° to 3°C higher than those under natural conditions. The Arctic Environmental Information and Data Center (AEIDC), Alaska, is conducting a river temperature study to investigate with-project temperatures at various locations in the reach below Watana and Devil Canyon. The results of this study are not yet available. However, based on reservoir outflow temperatures, it can be assumed that the river reach between Watana and the confluence of the Susitna and Chulitna river would be ice free during the winter period, especially when Devil Canyon reservoir also will become operational.

4.5.3 Suspended Sediment Concentration between Watana and the Confluence

The suspended sediment concentration in this reach will be controlled by the concentration in the reservoir releases and any sediment contribution from the reach. During summer, the concentration will be somewhat higher than 250 mg/l because of intervening flows but much less than those observed under natural conditions.

During freeze-up and winter, formation of frazil ice or anchor ice will be practically eliminated because of above freezing water temperatures. The river will not clear up as rapidly as noticed under natural conditions. The sediment concentration will be nearly same as in the releases because intervening area will not contribute sediment because of frozen ground. However, the higher winter flow may tend to pick-up sand particles from the river bed, thereby slightly increasing the suspended concentration. The monthly distribution of suspended sediment concentration can be approximately represented as shown on Exhibit 12.

4.5.4 Suspended Sediment Concentration between the Confluence and Sunshine

In this reach two major tributaries, the Chulitna and the Talkeetna river joins the Susitna River. These river carry little sediments during winter (Table 2). The concentration during winter will, therefore, be controlled by the concentration in the Susitna River above the confluence. During summer months, low concentration in the Susitna above the confluence, will decrease the concentration at Sunshine compared to the natural conditions. Pro-rating the concentrations with discharges, the estimated concentrations at Sunshine are shown on Exhibit 13. The monthly discharges used for the Susitna River, were those for with-project and scenario 'C' of License Application. The monthly discharges for the Chuletna and Talkeetna rivers were for the period of record.

REFERENCES

1. Harza-Ebasco Susitna Joint Venture, Susitna Hydroelectric Project, January 1984: Susitna River at Watana and Devil Canyon, Streamflow Time Series, Draft Report, Document No. 460, prepared for Alaska Power Authority.

2. Harza-Ebasco Susitna Joint Venture, Susitna Hydroelectric Project, April 1984: Reservoir and River Sedimentation, Final Report, Document No. 475, prepared for Alaska Power Authority.

3. Sayre, W.W; and G.B. Song, February 1979: Effects of Ice Covers on Alluvial Channel Flow and Sediment Transport Processes, prepared for U.S. Geological Survey, IIHR Report No. 21S, Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa.

4. Peratrovich, Nottingham and Drage, Inc.; November 1982: Susitna Reservoir Sedimentation and Water Clarity Study, prepared for Acres American Inc.

5. Imberger, J., and J.C. Patterson, 1981: A Dynamic Reservoir Simulation Model. DYRESM: 5, Transport Models for Inland and Coastal Waters, Chapter 9, Academic Press.

Table 1

SUSPENDED SEDIMENT SAMPLES

Stream Gaging Stations	Period	J	F	M	A	M	J	J	A	S	O	N	D
		No. of Samples											
Susitna River nr. Denali	1961-62; 1964-66 1968; 1974-75; 1977; 1979-82	-	-	1	1	7	8	12	9	8	3	-	-
Susitna River nr. Cantwell	1962-72; 1980-82	1	-	1	-	3	11	14	9	12	3	-	-
Susitna River at Gold Creek	1962; 1974-82	3	1	4	-	9	7	9	9	8	5	-	-
Susitna River nr. Talkeetna	1982	-	-	-	-	-	5	4	5	1	-	-	-
Chulitna River nr. Talkeetna	1967-72, 1980-82	1	1	4	2	4	10	10	8	9	2	-	-
Talkeetna River nr. Talkeetna	1966-82	8	1	7	7	12	13	16	23	12	7	-	-
Susitna River at Sunshine	1971; 1977; 1981-82	-	-	2	-	1	7	7	8	3	1	-	-
Susitna River at Susitna Station	1975-81	2	-	3	2	3	4	6	4	1	2	-	2

Table 2

SUSPENDED SEDIMENT CONCENTRATIONS

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Months							
Susitna R. nr. Denali												
Max.	-	-	-	-	1190	1600	2770	5690	3600	1400	-	-
Min.	-	-	-	-	102	302	886	350	124	85	-	-
Median	-	-	8	5	570	840	1350	890	293	104	-	-
Susitna R. nr. Cantwell												
Max.	-	-	-	-	726	1860	2790	1040	770	140	-	-
Min.	-	-	-	-	132	172	632	380	34	6	-	-
Median	1	-	14	-	661	417	1090	755	138	84	-	-
Susitna R. at Gold Creek												
Max.	8	-	3	-	1110	1400	130	938	812	22	-	-
Min.	<1	-	1	-	65	151	100	158	23	7	-	-
Median	2	2	2	-	498	574	394	420	68	10	-	-
Susitna R. nr. Talkeetna												
Max.	-	-	-	-	-	769	768	341	-	-	-	-
Min.	-	-	-	-	-	181	145	219	-	-	-	-
Median	-	-	-	-	-	438	422	285	-	-	-	-
Chulitna R. nr. Talkeetna												
Max.	-	-	21	-	1040	1600	2200	1260	1680	-	-	-
Min.	-	-	4	-	500	90	717	694	129	-	-	-
Median	3	5	12	206	675	820	1165	817	396	105	-	-
Talkeetna R. nr. Talkeetna												
Max.	15	-	11	48	503	1340	1160	3530	310	29	-	-
Min.	2	-	1	2	21	171	90	38	13	8	-	-
Median	8	2	3	8	123	309	359	466	80	16	-	-
Susitna R. at Sunshine												
Max.	-	-	-	-	-	1630	1430	3510	1620	-	-	-
Min.	-	-	-	-	-	360	503	424	76	-	-	-
Median	-	-	2	-	508	702	713	715	-	288	-	-
Susitna R. at Susitna Station												
Max.	-	-	5	-	572	918	1490	1490	-	-	-	-
Min.	-	-	3	-	378	326	561	483	-	-	-	-
Median	4	-	3	3	417	503	852	943	235	175	-	7

Table 3

PARTICLE SIZE DISTRIBUTION OF SUSPENDED SEDIMENT

Stream Gaging Station	No. of [1/] Sample	.002	.004	.008	.016	.031	.062	.125	.250	.500	1.000
				Particle Size (mm) Percent Finer Than —							
Susitna River nr. Denali	34	12	16	23	31	41	53	64	81	96	100
Susitna River nr. Cantwell	27	12	18	25	33	43	54	67	86	97	100
Susitna River at Gold Creek	24	15	19	27	35	47	61	75	86	98	100
Susitna River nr. Talkeetna	13	29	35		53		72	79	90	100	
Chulitna River nr. Talkeetna	36	21	31	37	46	55	62	72	85	99	100
Talkeetna River nr. Talkeetna	16	9	16	22	31	41	53	65	85	99	100
Susitna River at Sunshine	17	22	33	43	53	62	67	79	90	100	
Susitna River at Susitna Station	9	16	23	33	43	52	60	82	94	100	

1/ Samples for which full range of size distributions were analyzed.

2/ Median value for a give size.

EXHIBIT 2

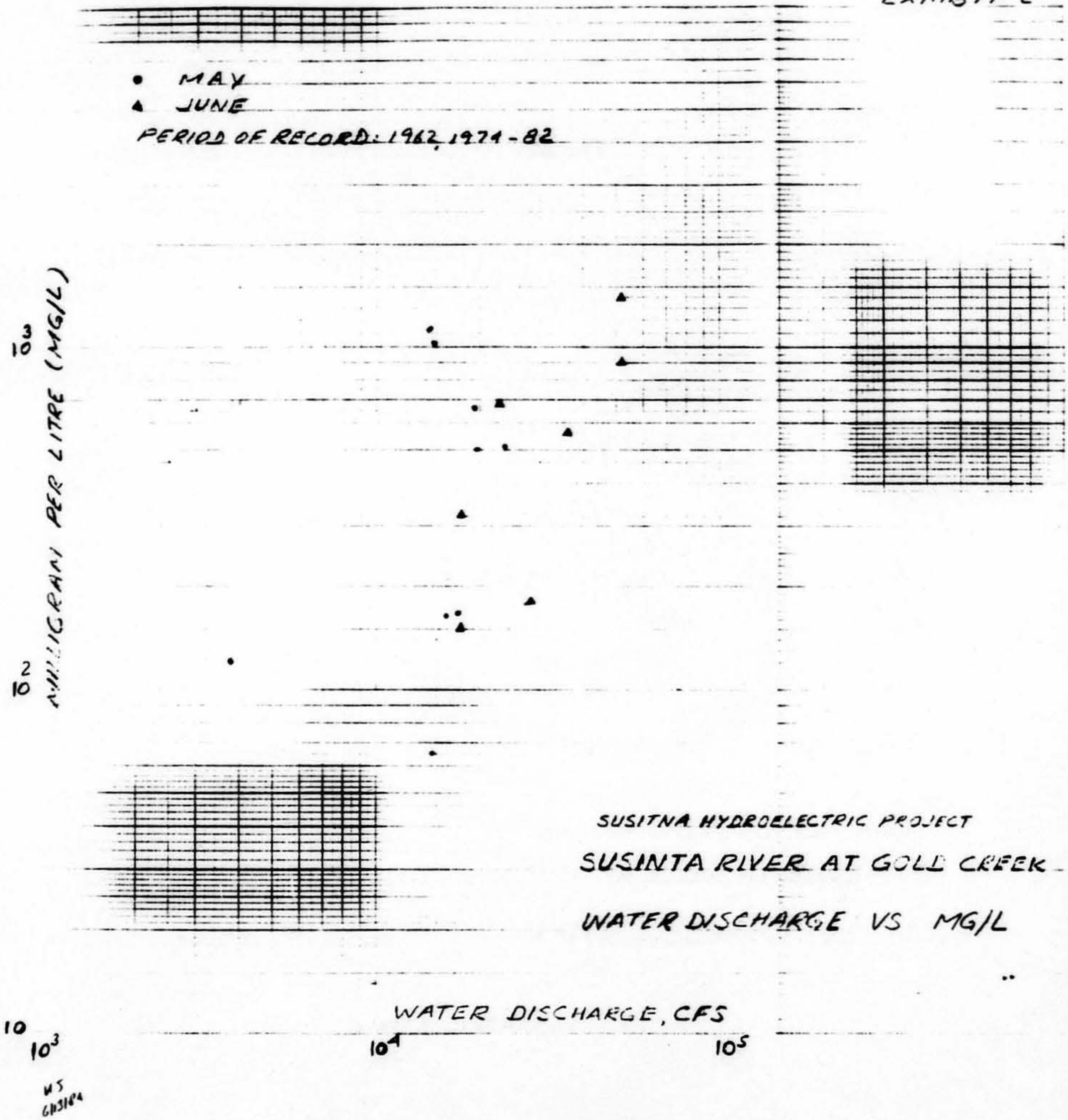
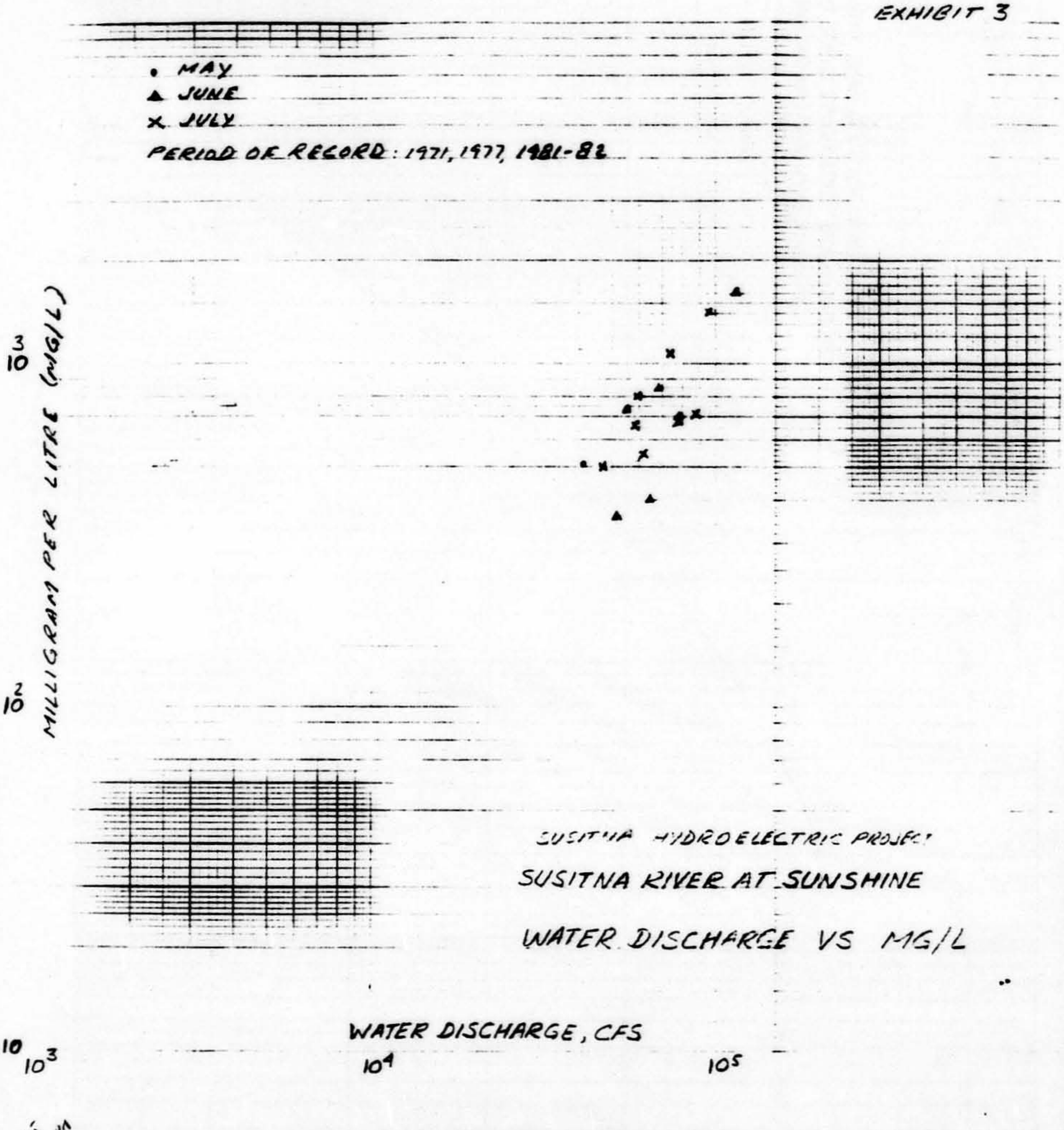
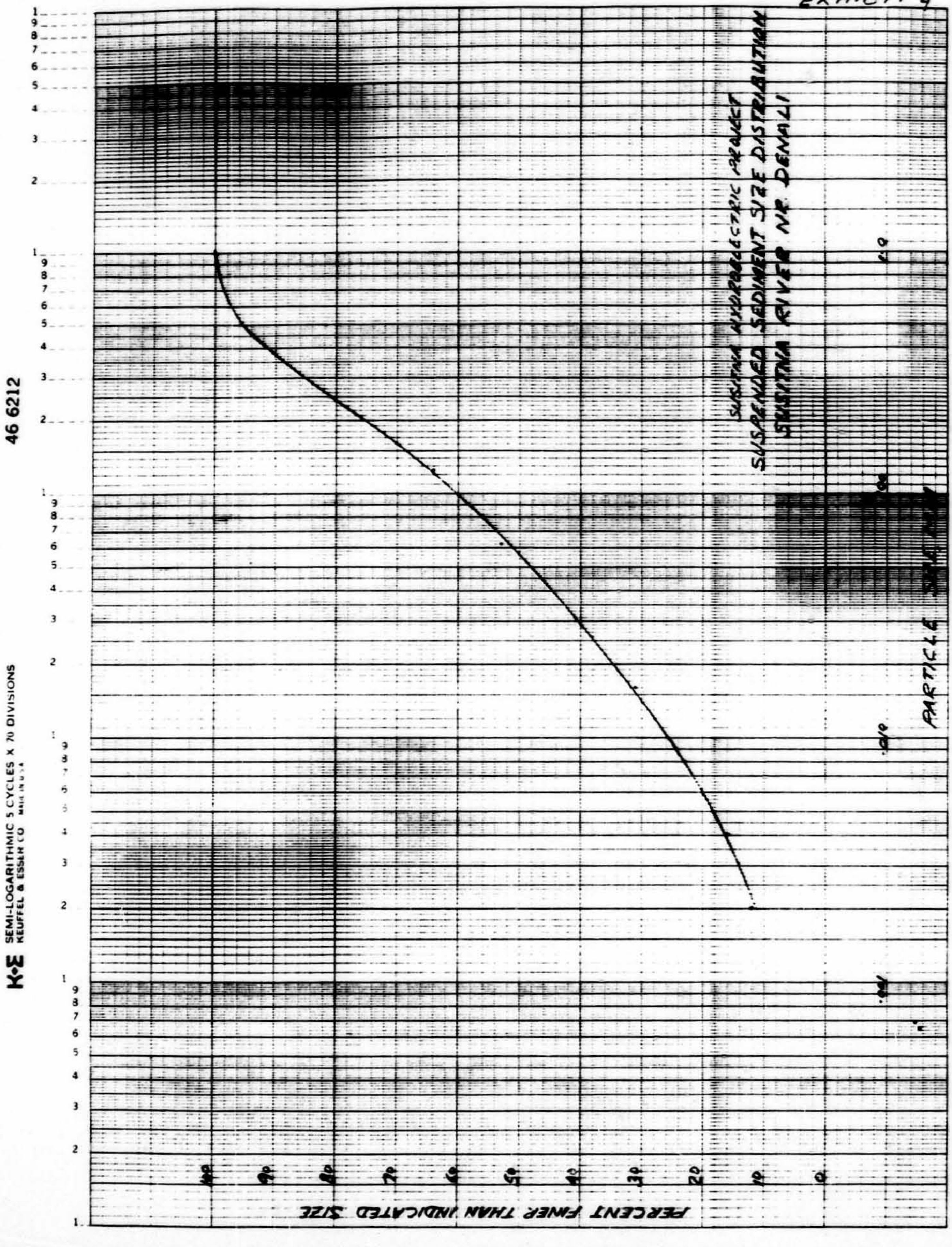

● MAY
▲ JUNE
PERIOD OF RECORD: 1962, 1974 - 82
MILLIGRAM PER LITRE (MG/L)
10
10^2
10^3
WATER DISCHARGE, CFS
10^3
10^4
10^5
SUSITNA HYDROELECTRIC PROJECT
SUSINTA RIVER AT GOLD CREEK
WATER DISCHARGE VS MG/L

EXHIBIT 3



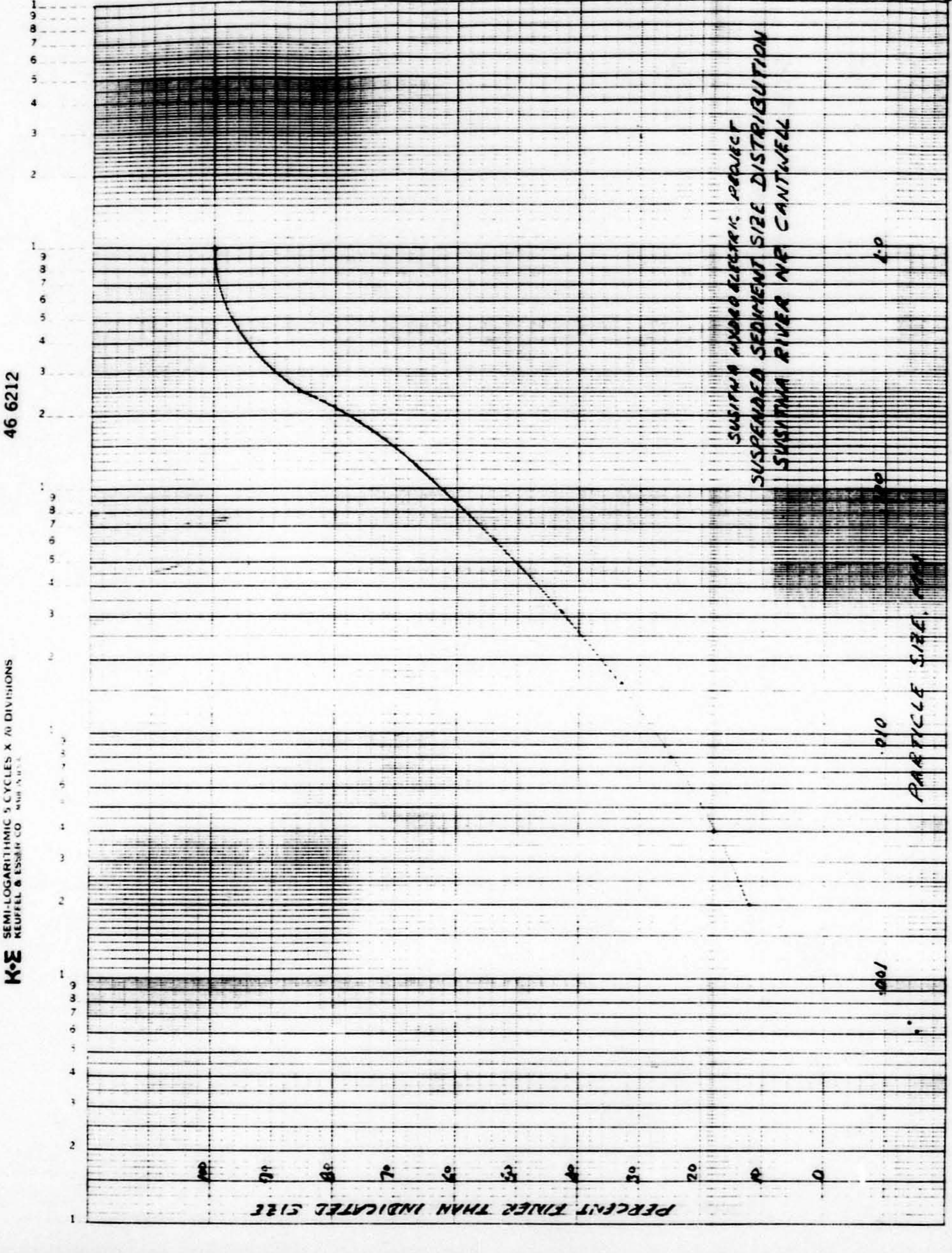
KS
6/13/84

EXHIBIT 4



SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER NR. DENALI
PARTICLE SIZE
PERCENT FINER THAN INDICATED SIZE
100
90
80
70
60
50
40
30
20
10
0
46 6212
K·E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT 5


SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER NR CANTWELL
PERCENT FINER THAN INDICATED SIZE
PARTICLE SIZE, mm
.001
.010
.10
1.0
100
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80
70
60
50
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30
20
10
0
46 6212
K·E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO

EXHIBIT 6

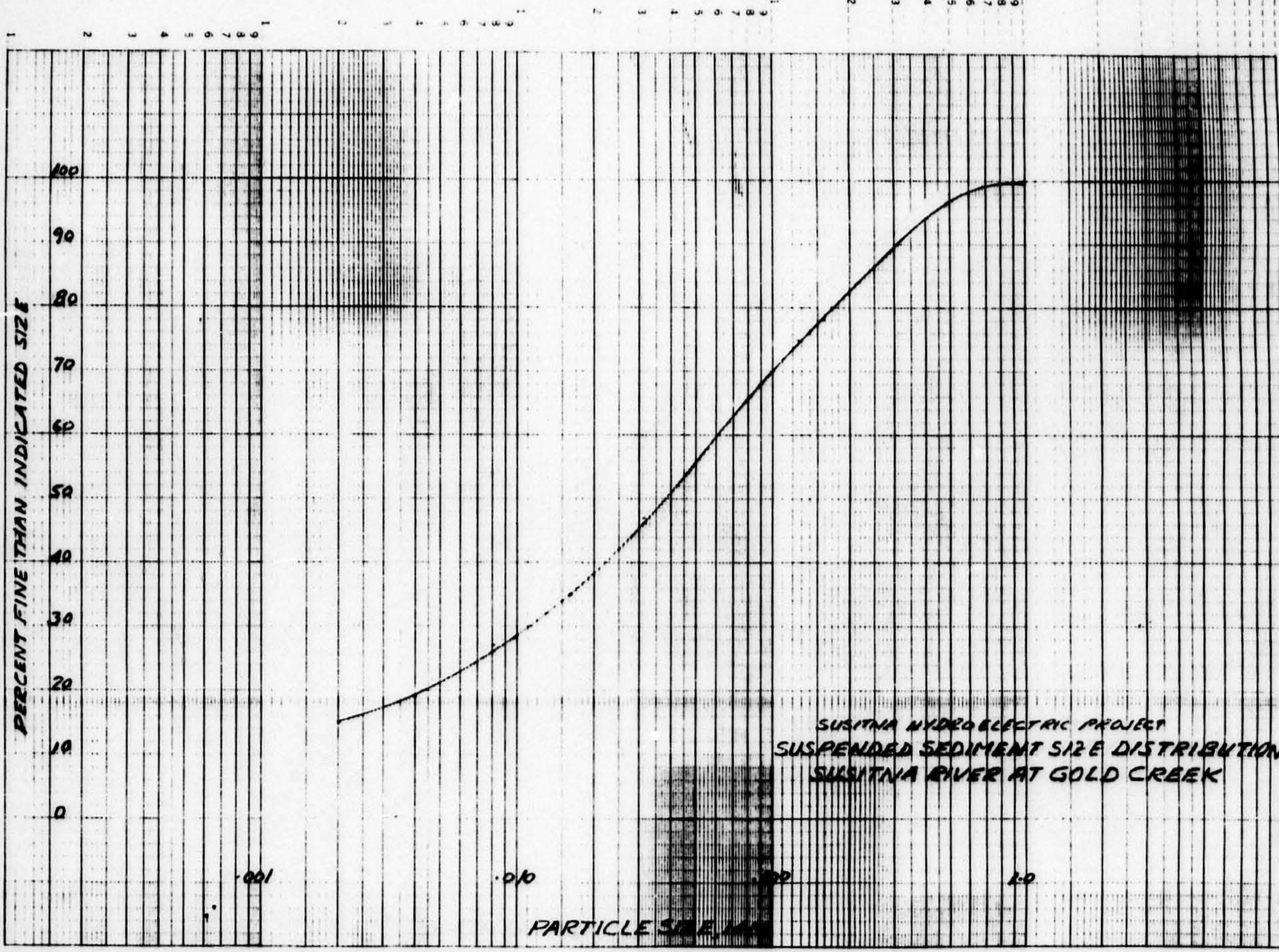
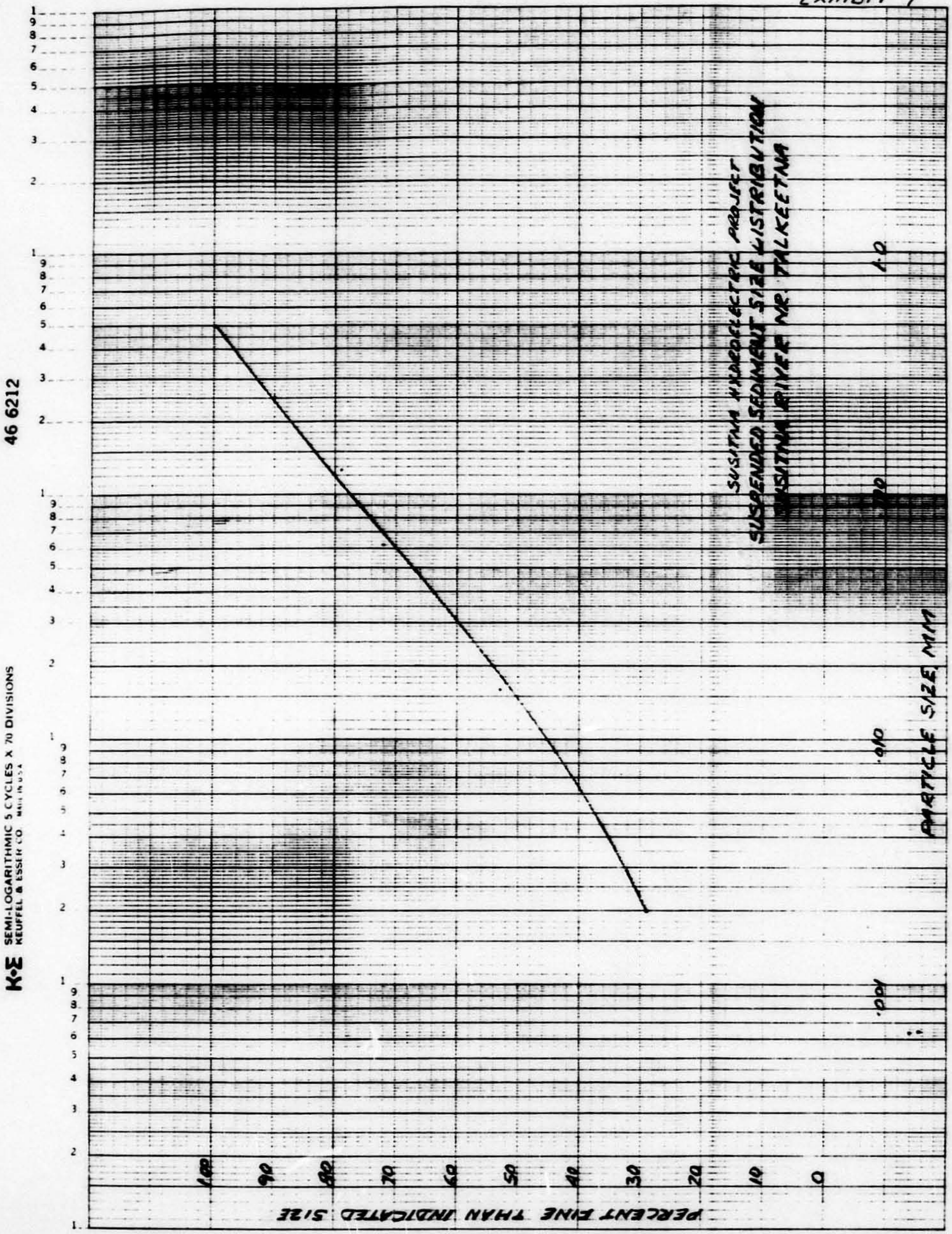

SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER AT GOLD CREEK
PERCENT FINE THAN INDICATED SIZE
100
90
80
70
60
50
40
30
20
10
0
.001
.010
.100
1.0
PARTICLE SIZE, MM

EXHIBIT 7


SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER NR. TALKEETNA
PARTICLE SIZE, MM
PERCENT FINE THAN INDICATED SIZE
100
90
80
70
60
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40
30
20
10
0
1.0
.10
.010
.001
46 6212
K+E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

EXHIBIT B

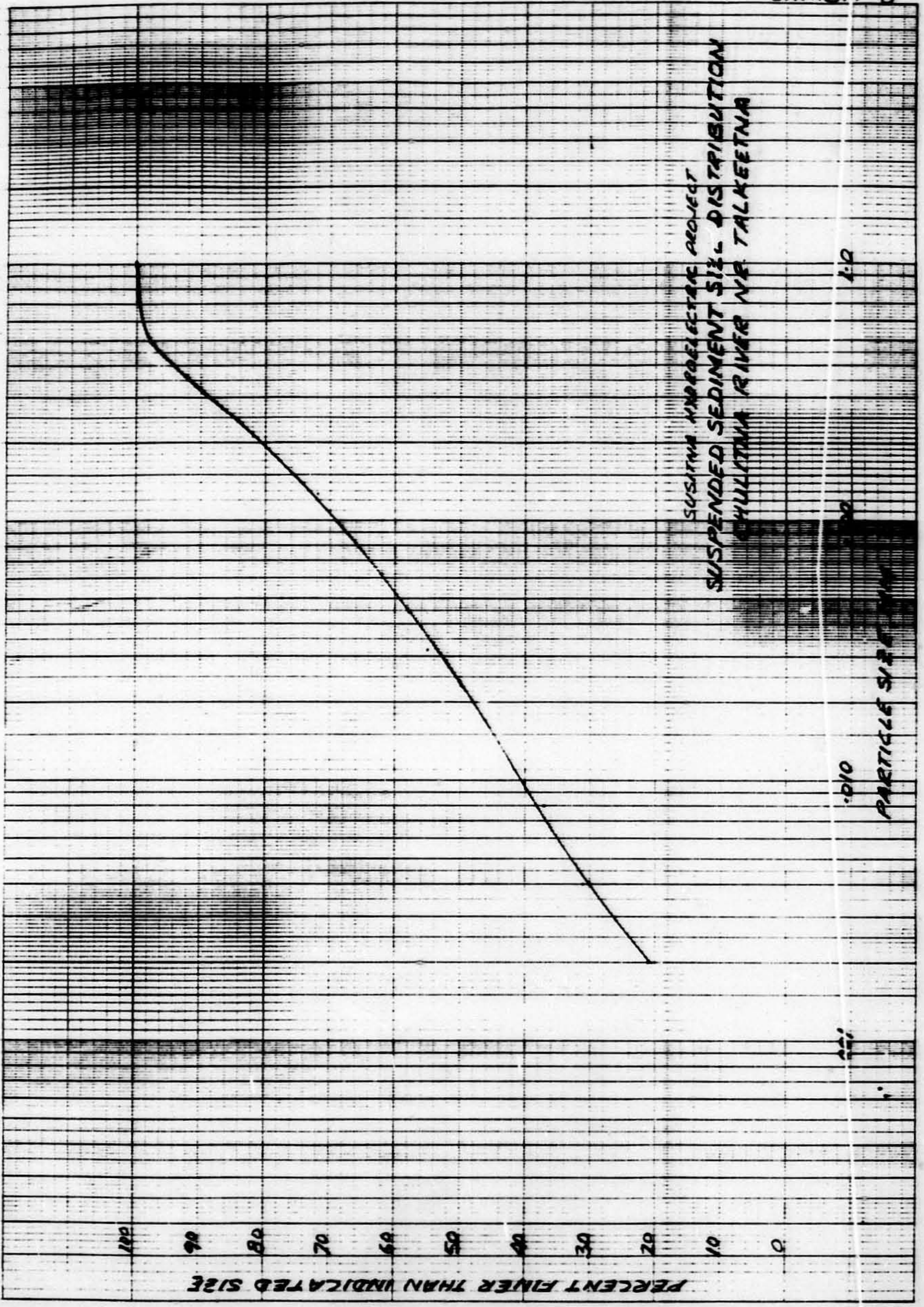

SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
CHULITNA RIVER NR TALKEETNA
1.0
.010
PARTICLE SIZE
100
90
80
70
60
50
40
30
20
10
0
PERCENT FINER THAN INDICATED SIZE

EXHIBIT 9

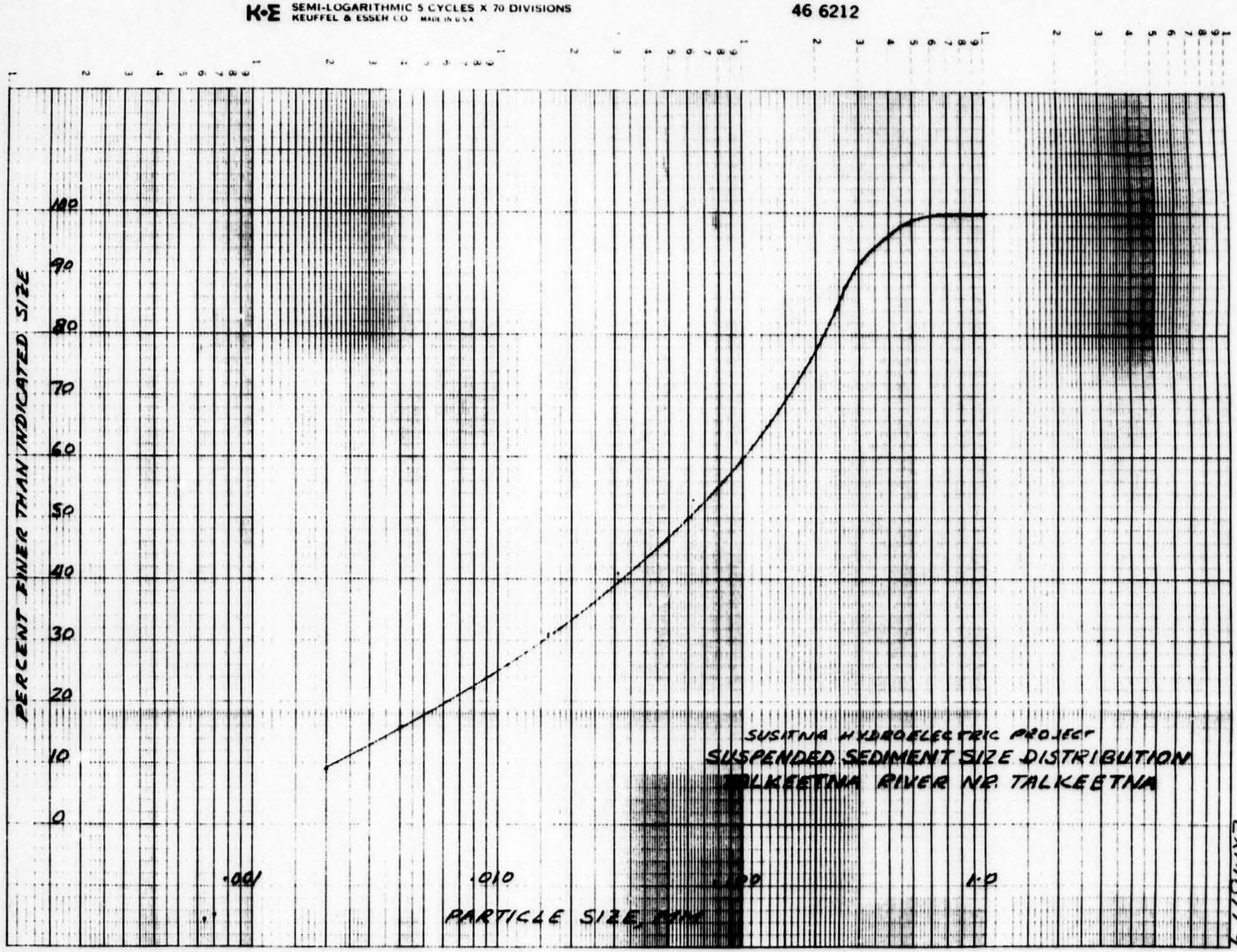

K·E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6212
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
TALKEETNA RIVER NR. TALKEETNA
PERCENT FINER THAN INDICATED SIZE
100
90
80
70
60
50
40
30
20
10
0
.001
.010
.100
1.0
PARTICLE SIZE, MM

EXHIBIT 10

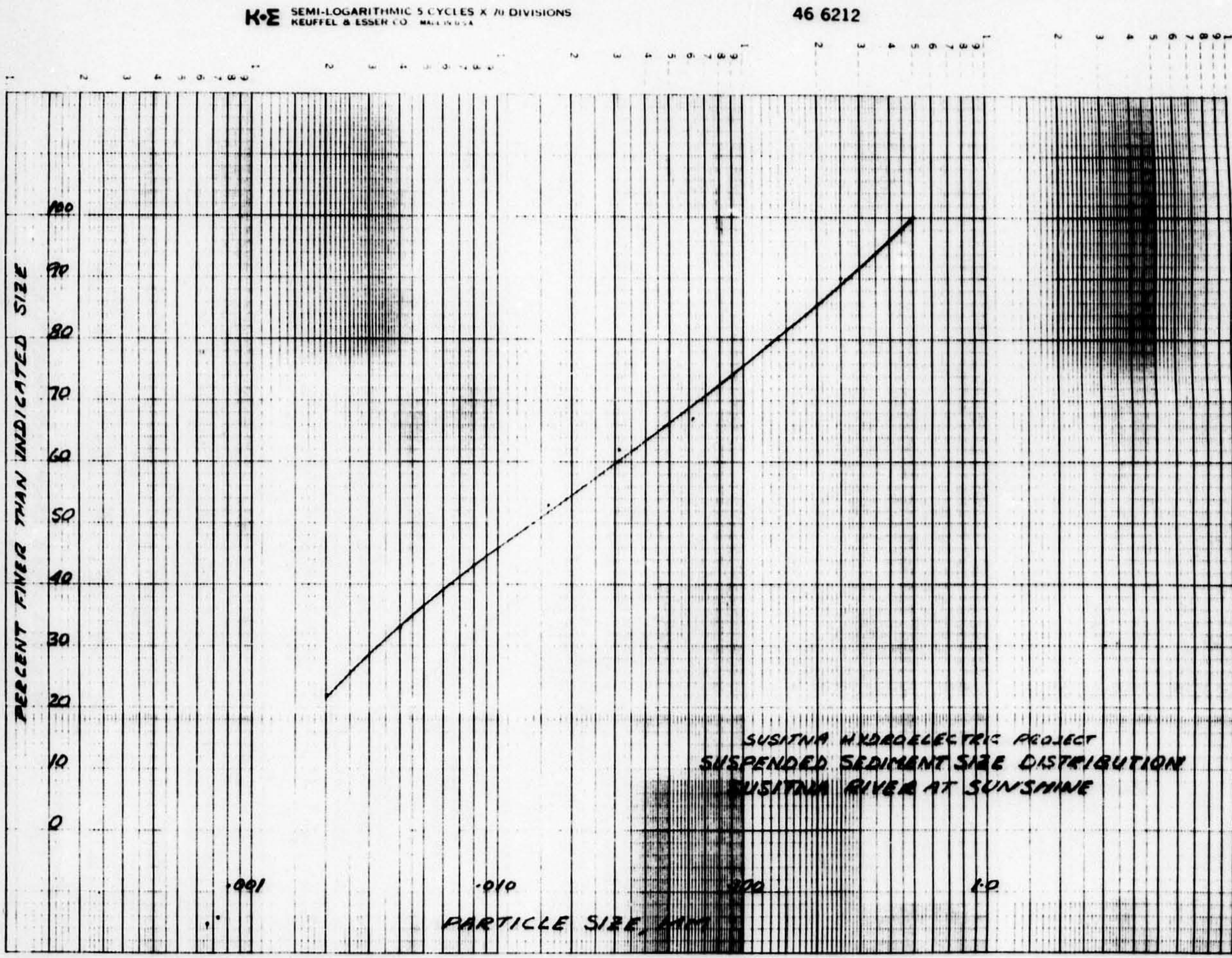

K·E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6212
PERCENT FINER THAN INDICATED SIZE
100
90
80
70
60
50
40
30
20
10
0
.001
.010
.100
1.0
PARTICLE SIZE, MM
SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER AT SUNSHINE

EXHIBIT 11

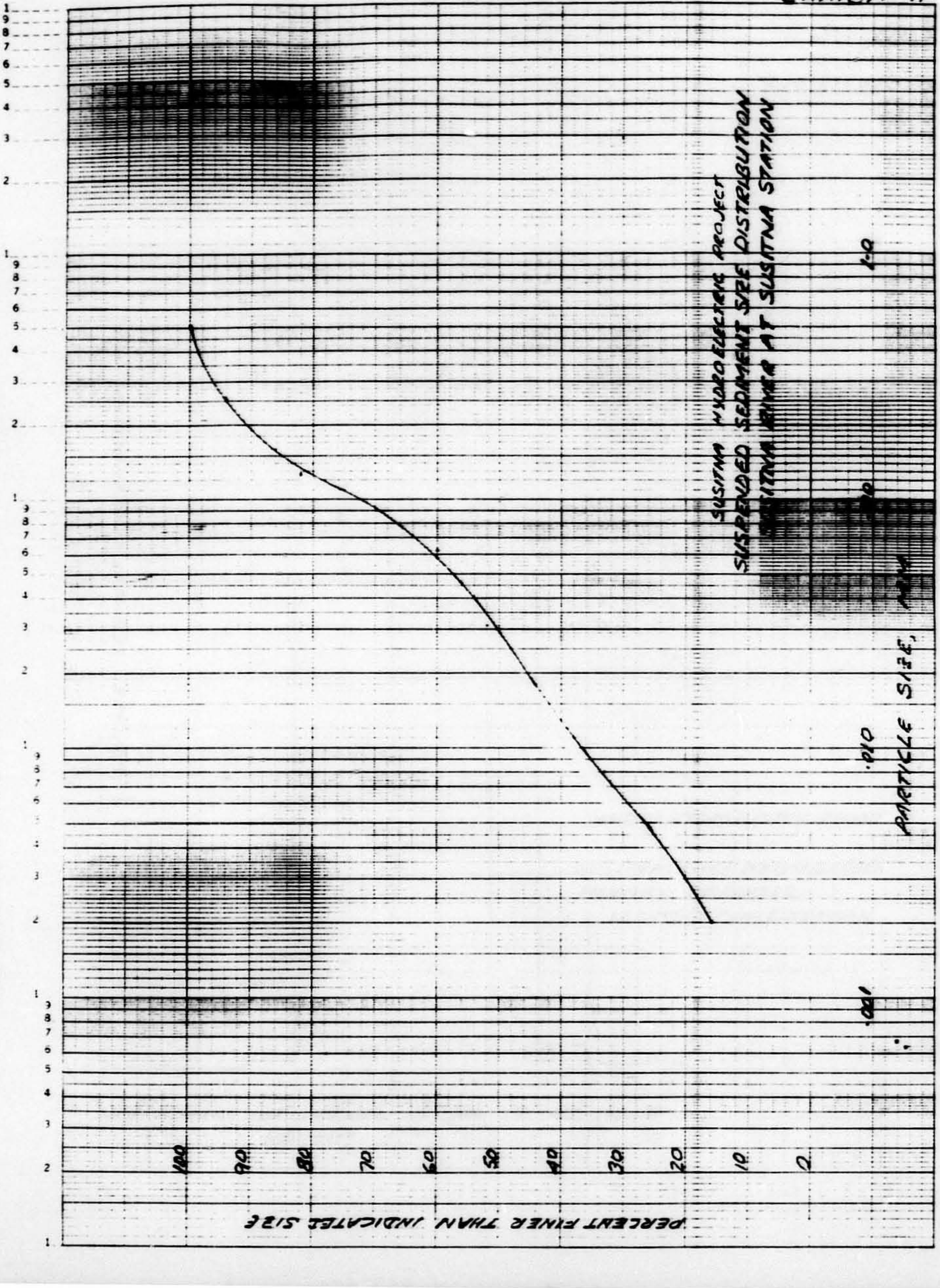

SUSITNA HYDROELECTRIC PROJECT
SUSPENDED SEDIMENT SIZE DISTRIBUTION
SUSITNA RIVER AT SUSITNA STATION
.001
.010
.10
1.0
PARTICLE SIZE, MM
100
90
80
70
60
50
40
30
20
10
0
PERCENT FINER THAN INDICATED SIZE

EXHIBIT 12

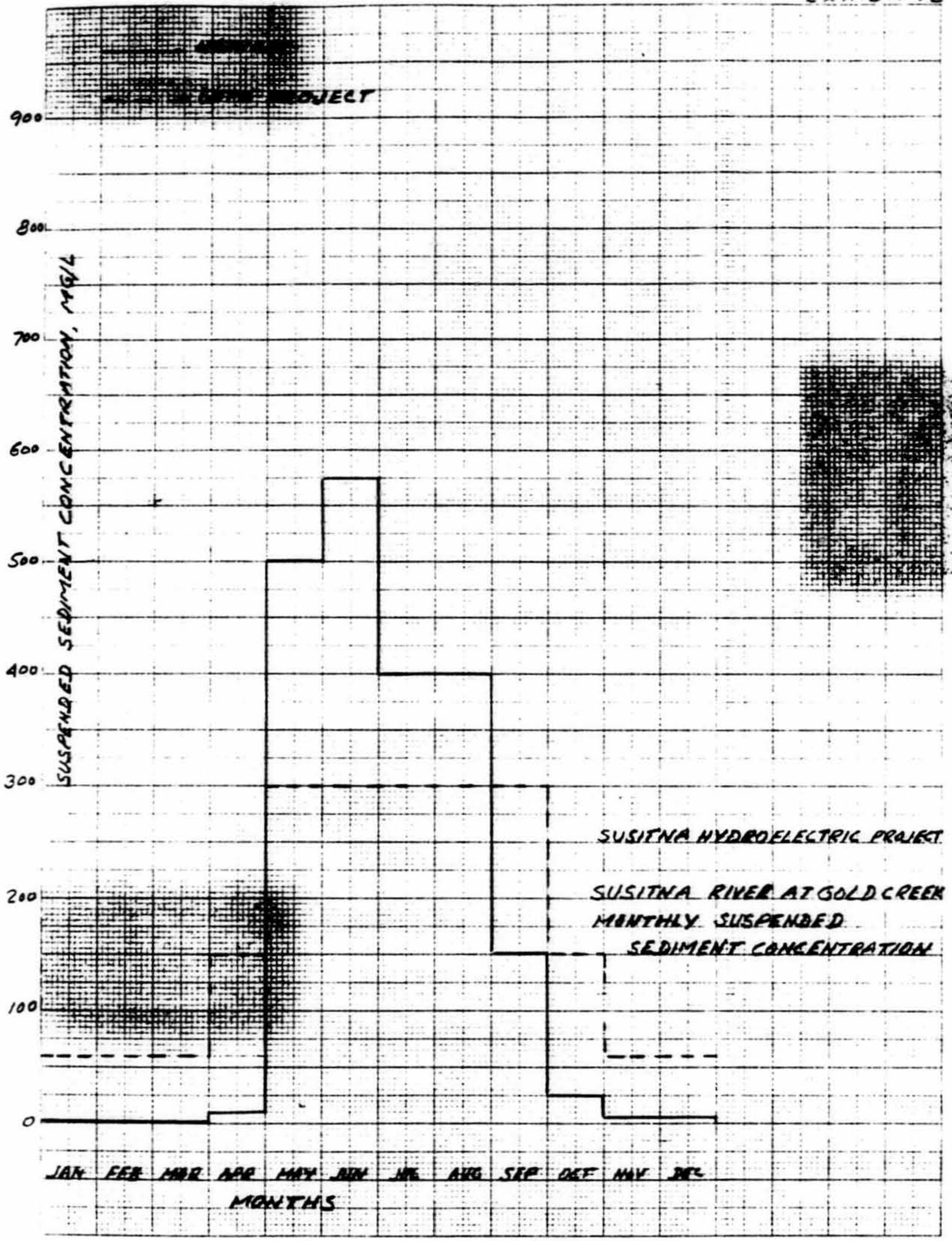
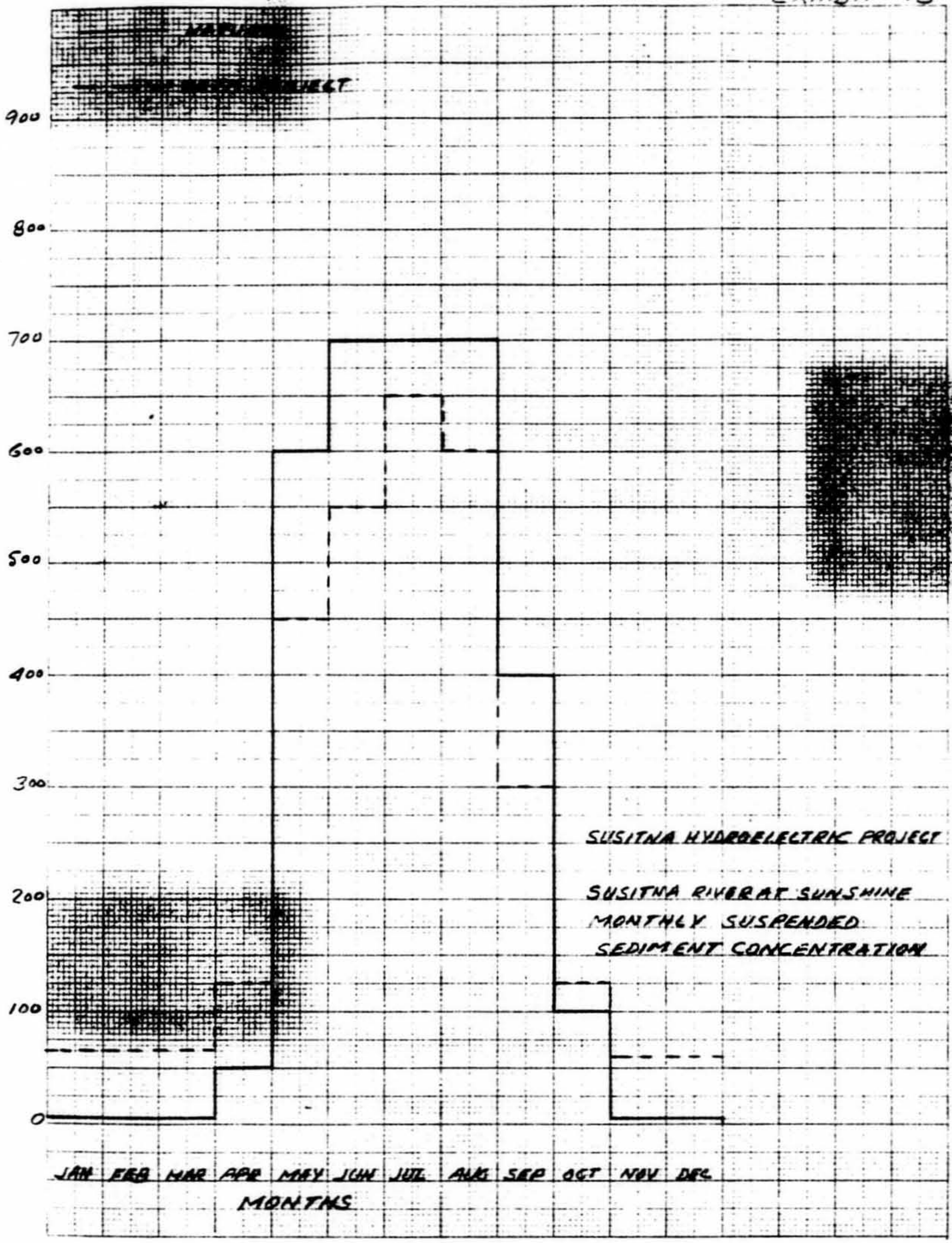
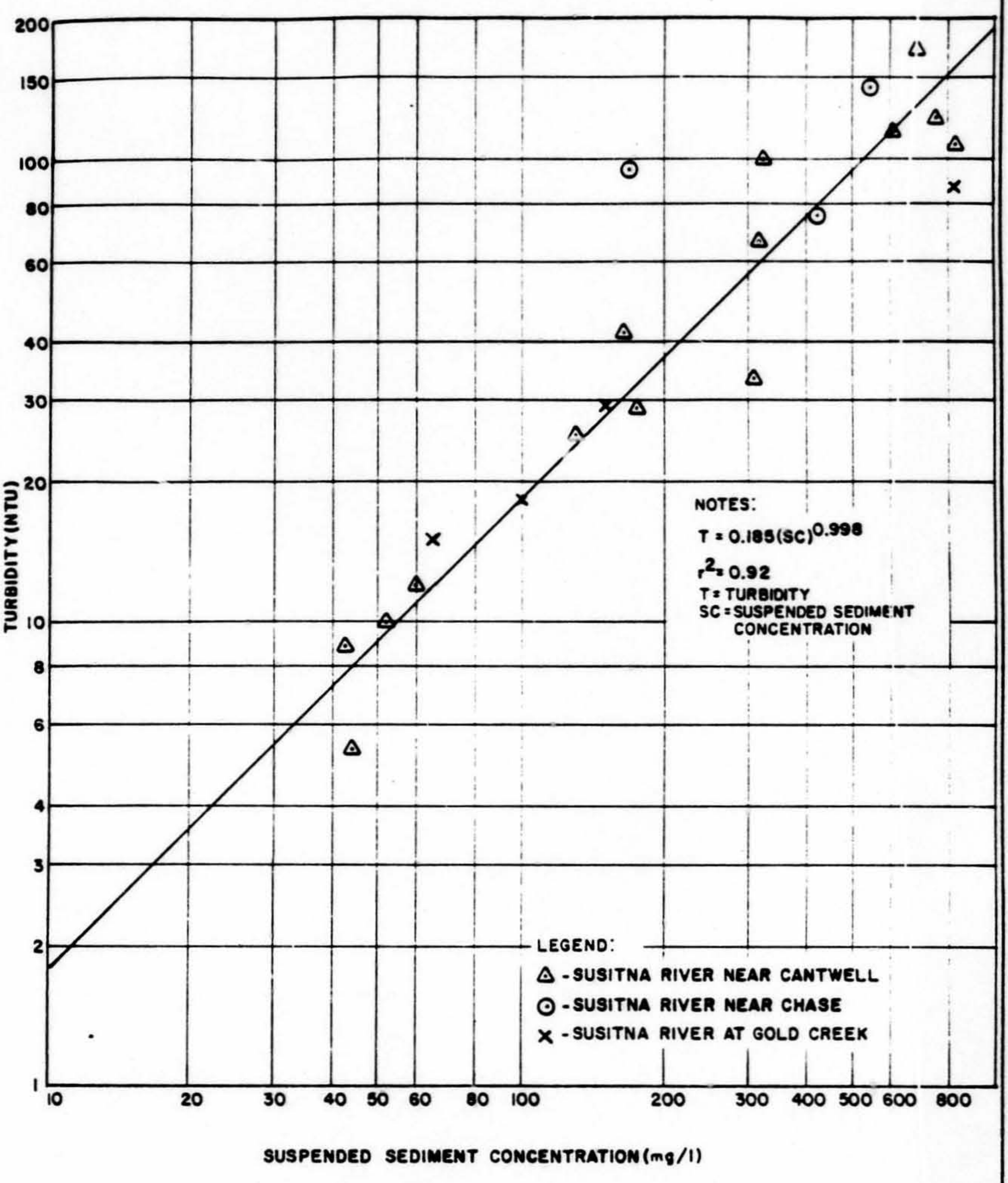

900
800
700
600
500
400
300
200
100
0
SUSPENDED SEDIMENT CONCENTRATION, MG/L
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER AT GOLD CREEK
MONTHLY SUSPENDED
SEDIMENT CONCENTRATION

EXHIBIT 13



900
800
700
600
500
400
300
200
100
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
SUSITNA HYDROELECTRIC PROJECT
SUSITNA RIVER AT SUNSHINE
MONTHLY SUSPENDED
SEDIMENT CONCENTRATION

EXHIBIT 14



TURBIDITY VS. SUSPENDED SEDIMENT CONCENTRATION

SOURCE: PERATROVICH, NOTTINGHAM AND DRAGE 1982

FIGURE E.2.82