SUSITNA HYDROELECTRIC PROJECT

MIDDLE SUSITNA RIVER SEDIMENTATION STUDY STREAM CHANNEL STABILITY ANALYSIS OF SELECTED SLOUGHS, SIDE CHANNELS AND MAIN CHANNEL LOCATIONS

Report by
Harza-Ebasco Susitna Joint Venture

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Alaska Power Authority

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1.0 SUMMARY

This study was conducted to evaluate potential effects of the Susitna Hydroelectric Project on channel stability at selected sites in the mainstem and at selected sloughs and side channels. The sedimentation process in the Susitna River under natural conditions also is discussed. The study reach includes the Susitna River between Devil Canyon and the confluence of the Susitna and Chulitna rivers. The selected sites (shown on Exhibit 2) are:

1. Mainstem Sites: near river Cross Section 4, river miles 99.0 to 100.0; between river cross sections 12 and 13, river miles 108.5 to 110.0; upstream from Lane Creek, river miles 113.6 to 114.2; upstream from 4th of July Creek, river miles 131.2 to 132.2 and between river cross sections 46 and 48, river miles 136.9 to 137.4.

2. Side Channels: Mainstem 2 Side Channel, Side Channel 10, Lower and Upper Side Channels 11 and Side Channel 21.

3. Sloughs: 8A, 9, 11 and 21.

For natural conditions, temporal deposition and/or scour was studied at the sites in qualitative terms. Under with-project conditions, a more quantitative estimate of potential degradation and/or aggradation was made for each study site. Intrusion of fine sediment into the gravel bed and its subsequent entrapment also were studied.

The hydraulic and sediment data required for the study were derived from various reports prepared by the Alaska Department of Fish and Game, Susitna Hydro Aquatic Studies Team; R&M Consultants, Incorporated; U.S. Geological Survey, Water Resources Division, Anchorage; and Harza-Ebasco Susitna Joint Venture during 1983 and 1984. The data were used to develop relationships

between the discharge rates at Gold Creek stream gaging station and corresponding flows at the mainstem sites and the flows entering the sloughs and side channels. These data also were used to estimate mean velocities, coverage depths and channel widths at each site. The bed material size distribution representative for the material at each site was derived from the analysis of the bed material samples collected by Harza-Ebasco.

The sizes of transportable bed material corresponding to a selected range of discharges were estimated as the average of the five sizes computed using the methods of competent bottom velocity; tractive force; Meyer-Peter, Muller formula; Schoklitsch formula and Shields criteria. A comparison of median bed material size and the transportable size at each site indicated that under natural conditions, most of the selected sites are subject to temporal scour and/or deposition depending upon the magnitude and characteristics of the sediment load and high flows caused by floods or breaching of ice jams.

About 56 percent of the suspended sediment load carried by the river, under natural conditions, is finer than 0.5 millimeter (medium to fine sand, silt and clay). This fine sediment has been observed to deposit in side channels and sloughs. However, many of these deposits are re-suspended and removed during high flows, probably because of disturbances of the surface bed material layer.

Under with-project conditions, the flow regime of the Susitna River will be modified and the reservoirs will trap most sediment except the smaller particle sizes including fine silt and clay size material. The river will strive to adjust itself to a new equilibrium. The main channel will have the tendency to be more confined with a narrower channel. This may cause the main channel to recede from the heads of some sloughs and side channels. There also will be some streambed degradation in the study reach.

At the selected sites in the mainstem, the potential degradation would be in the range of about 1.0 to 1.5 feet corresponding to a dominant discharge of about 30,000 cfs. Flows of this magnitude would be expected in the early years of Watana and Devil Canyon operation; presently projected for 2002. An armor layer will develop as the degradation takes place and the riverbed will become more stable. In the sloughs and side channels, the degradation would be about 0 to 0.3 feet.

The estimated degradations are based on the assuption that there will not be any deposition of sediments at the study sites. However, in the actual situation, some of the bed material eroded from upstream reaches and sediment injected by the tributaries or bank erosion would be deposited at these sites. Therefore, the actual degradation will likely be less than those estimated.

It is not possible to accurately estimate the actual degradation since there are many unquantifiable parameters. These include bed material transport from tributaries and bank erosion, the degree of armoring by the present bed and the actual streamflows and floods which will occur for the first few years of Devil Canyon operation. However, based on many samples of bed material and visual inspection it is believed that degradation in the main channel will not exceed approximately one foot, on the average. The amount of this degradation may be greatest near the Devil Canyon Dam face and decrease with distance downstream.

When the system energy demand increases (as in 2010), and less flow is discharged in July and August, the armoring layer developed earlier will be stable, more so than under natural conditions. Infrequent flood events will not be controlled to as great an extent as smaller floods, and will still have the ability to remove the armor layer and cause bed degradation. Reservoir operation studies indicate that floods up to the 50-year event will be controlled for projected energy demands in 2002. Control of infrequent flood events will be improved as energy demand increases, and the potential for bed degradation will therefore be reduced.

Because of the inability to predict degradation of these small amounts it will be necessary to monitor water levels. This will allow modification of habitat areas if and when degradation occurs.

Because of degradation in the mainstem, the discharges higher than those under natural conditions would be required to overtop the berms at the heads of the sloughs and side channels. Assuming that the river bed at the entrances would be lowered by about one foot due to the degradation, the with-project discharges that would overtop the sloughs and side channels were estimated to be between 4000 and 12000 cfs higher than those under natural conditions with an average value of approximately 8000 cfs.

The analysis indicated that if the sloughs or side channels were overtopped, the velocities would be sufficiently high to carry our the fine sediment of sizes .004 millimeter and less. However, any coarse silt and fine sand picked up from the river bed would have the tendency to settle out in pools ansd backwater areas. With project flows will still be sufficient to overtop these slough berms and therefore, some deposition of such material can be expected. Mechanical devices such as "gravel gerties" have been developed to flush these materials from sloughs. Alternately project discharges can be raised to overtop the slough berms and flush the sands from the sloughs. Spiking discharges in this manner may tend to destabilize the main channel streambed and result in additional degradation.

2.0 BACKGROUND

This is a third report by Harza-Ebasco Susitna Joint Venture on the evaluation of potential effects of the proposed Susitna Hydroelectric project on sediment transport in the Susitna River. The first report entitled "Reservoir and River Sedimentation" (H-E, April 1984)1/ addressed the sediment accumulation in the Watana and Devil Canyon reservoirs and potential aggradation and degradation in the river reach between Devil Canyon and the Sunshine stream gaging station. That study provided estimates of degradation and/or aggradation within the study reach in a general sense without any specific reference to side sloughs or side channels. The transportable sizes under natural and with-project conditions were computed based on dominant discharges taken to be the mean annual floods in both cases. The bed material size distributions at various locations in the reach was based on limited number of samples taken from surface layer material.

The second report entitled "Lower Susitna River Sedimentation Study, Project Effects on Suspended Sediment Concentration" (H-E, November 1984) provided a comparison of monthly suspended sediment concentrations at Gold Creek and Sunshine stream gaging stations for natural and with-project conditions.

The present report provides channel stability analysis for specific sites in the mainstem of the Susitna River and in the selected sloughs and side channels between Devil Canyon and the confluence of the Susitna and Chulitna Rivers. The analysis are based on bed material samples taken from surface and subsurface material at or near the selected sites.

3.0 SCOPE OF STUDY

This study is made to provide input to the instream flow relationship studies which will provide quantitative assessment of potential effects on fish habitat because of with-project changes in streamflow, stream temperature,

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1/ Indicated reference at the end of text.

suspended sediments, channel degradation or aggradation and water quality. A number of side sloughs, side channels and main channel sites were identified in the study reach where potential project impacts on the fish habitat would likely be significant.

The scope of this study includes the analysis of sedimentation process to evaluate stream channel stability under natural and with-project conditions for the study sites in the mainstem and in selected sloughs and side channels. For these analysis, a stable channel means that its shape, slope and bed material size distribution do not change significantly with time. The major tasks are:

1. to evaluate sedimentation process under natural conditions;
2. to estimate potential degradation or aggradation under with-project conditions;
3. to determine discharge rates at which the mainstem flows are likely to overtop the entrances of the sloughs and side channels under natural and with-project conditions; and
4. to estimate discharge rates for the sloughs and side channels at which their beds will be unstable and also the rates to flush out fine sediment deposits.

4.0 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, Susitna, East Fork and Maclaren glaciers of the Alaska Range (Exhibit 1) and travels 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 (RM, river miles referenced from the Cook Inlet). The Talkeetna River originates in the Talkeetna Mountains and joins the Susitna River from the east near Talkeetna at RM 97. The Yentna River originates in the Alaska Range and enters the Susitna River from the west at RM 28.

The Susitna River gradients average about 14 feet per mile (ft/mi) in a 54-mile reach immediately upstream of Watana, about 10.4 ft/mi from Watana to the entrance of Devil Canyon and about 31 ft/mi in a 12-mile reach between the entrance and the mouth of Devil Canyon (ACRES, 1982). The river gradients between mouth of Devil Canyon and the confluence of the Chulitna and Susitna Rivers, and between the confluence and Susitna Station (Exhibit 1) average about 10 and 4 ft/mi, respectively, as estimated from the United States Geological Survey (USGS) topographic maps of 1:63,360 scale.

The Susitna River is a typical natural glacial river with high turbid summer flow and low, clear winter flow. The river generally starts rising in early May, sustains high flow during July through September and starts falling rapidly in November or December as the freeze-up occurs. The mean annual flow of the Susitna River at Cantwell, Gold Creek and Susitna Station (See Exhibit 1 for locations) are about 6,400 (13 years, 1962-72, 81-82), 9,720 (33 years, 1950-82) and 50,700 (8 years, 1974-82) cubic feet per second (cfs), respectively.

The river carries a significant amount of suspended sediments during flood season. Bedload movement also occurs and fairly large scale aggradation or degradation have been observed (H-E, April 1984). The bed load and suspended sediment discharges during the water year 1982, were estimated to be about 423,000 and 13,330,000 tons, respectively for the Susitna River at Sunshine (H.E. April 1984).

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

5.0 STUDY SITES

The channel stability analysis was limited to the Middle Susitna River, from mouth of Devil Canyon to just upstream from the confluence of the Susitna and Chulitna Rivers. The specific sites for which the analysis was made include;

1. Mainstem Locations:
   - Near river cross section 4, RM 99.0-100.0
   - Between river cross sections 12 and 13, RM 108.5-110.0
   - Upstream from Lane Creek, RM 113.6-114.2
   - Upstream from 4th of July Creek, RM 131.2-132.2
   - Between river cross sections 46 and 48, RM 136.9-137.4
2. Side Channels
   - Mainstem 2 Side Channels at river cross section 18.2, RM 114.4;115.5
   - Side Channel 10, RM 134.2
   - Lower Side Channel 11, RM 135.0
   - Upper Side Channel 11, RM 136.2
   - Side Channel 21, RM 140.6
3. Side Slough
   - Slough 8A
   - Slough 9
   - Slough 11
   - Slough 21

The above locations, are shown on Exhibit 2. A brief description of each site is given below.

5.1 MAIN CHANNEL NEAR RIVER CROSS SECTION 4

Exhibit 3 shows a sketch of channel pattern at this location. The study reach is about one mile long (RM 99.0 to 100.0). A number of small islands (gravel bars with or without vegetation) are present in the reach. Most of these islands are submerged during medium to high flows.

5.2 MAIN CHANNEL BETWEEN RIVER CROSS SECTIONS 12 and 13

Exhibit 4 shows the channel configuration at this site. The study reach is about 1.5 miles long (RM 108.5 to 110.0). A few gravel bars with or without vegetation exist in the reach. Some of these are submerged during medium to high flows.

5.3 MAIN CHANNEL UPSTREAM FROM LANE CREEK

Exhibit 5 shows the channel configuration at this site. The study reach is about 0.6 mile, between RM 113.6 and 114.2. The Lane Creek Slough is on left bank of the river (left bank looking downstream). A number of small gravel bars are visible during low flow.

5.4 MAINSTEM 2 SIDE CHANNELS AT RIVER CROSS SECTION 18.2

Exhibit 6 shows the configuration of the main and side channels, and island or gravel bars near river cross section 18.2. A side channel is located on the left bank of the river. At the upstream end, the channel is divided into sub-channels. Measured along the main channel and the northwest sub-channel, the study site is about one mile long (between RM 114.4 and 115.4). The northeast sub-channel is about 0.4 mile in length (between RM 115.2 and 115.6).

5.5 SLOUGH 8A

The slough is located on the left bank of the river approximately at river mile 126.2 (Exhibit 7). It is about 2 miles in length and is separated from the main river by a large vegetated island. The main slough channel branches into two sub-channels approximately 2,500 feet upstream of the mouth of the slough. Two beaver dams, one downstream of the confluence of two sub-channels and one in the northeast sub-channel, exist in the slough.

5.6 SLOUGH 9

Exhibit 8 shows the location of Slough 9 with respect to main river and side channels. The slough is about 1.2 miles in length and is separated from the main river by a large vegetated island. Two small tributaries, designated as A and B (Exhibit 8) enter the slough from left bank at respectively about 500 and 3,000 feet upstream from the mouth of the slough.

5.7 MAIN CHANNEL UPSTREAM FROM 4TH OF JULY CREEK

Exhibit 9 shows the general configuration of the main river, side channels and the mouth of 4th of July Creek. The main river channel considered in this study is about one mile in length (between RM 131.2 and 132.2, river cross sections 36 and 37). A number of small and large-size islands or gravel bars exist in the reach which separate the side channels from the main river.

5.8 SIDE CHANNEL 10

The general configuration of the main river, Side Channel 10 and Slough 10 is shown on Exhibit 10. The side channel is about 0.5 mile in length (between RM 133.8 and 134.2). It confluences with Slough 10 before rejoining the main river. A large gravel bar separates the channel from the main river.

5.9 LOWER SIDE CHANNEL 11

The side channel is located on the left bank of the river approximately between RM 134.6 and 135.3 and is separated from the main river by a well vegetated island (Exhibit 11). At the upstream end, the channel has two forks which join at the confluence with Slough 11.

5.10 SLOUGH 11

The slough is located on the left bank of the river approximately between RM 135.4 and 136.4 (about 1.0 mile in length) and is separated from the main river by a large vegetated island (Exhibit 12). The downstream end confluences with the Lower Side Channel 11. The upstrame end joins with the Upper Side Channel 11. The slough runs almost parallel to the main river.

5.11 UPPER SIDE CHANNEL 11

The channel is located on the left bank approximately at RM 136.2 and is about 0.4 mile in length (Exhibit 13). The Slough 11 starts from the channel approximately 800 feet downstream of the head of the channel. The channel is separated from the main river by a vegetated island.

5.12 MAIN CHANNEL BETWEEN RIVER CROSS SECTIONS 46 AND 48

Exhibit 14 shows a sketch of the main channel. The selected reach for study is between RM 136.9 and 137.4. A large gravel bar divides the river into two channels at this location (Exhibit 14).

5.13 SIDE CHANNEL 21

Exhibit 15 shows the location of Side Channel 21. The channel is located approximately at RM 140.6 on the left bank of the river and is separated from the main river by a series of well vegetated islands and gravel bars.

The length of the channel is about 1.0 mile. Slough 21 joins the channel at about 800 feet downstream of the head of the channel.

5.14 SLOUGH 21

A general sketch of Slough 21 is shown on Exhibit 16. The slough is located on the left bank of the river, approximately at RM 141.8. It is about 0.5 mile long (between RM 141.8 and 142.3) and is separated from the main river by a large vegetated island. At about 1500 feet upstream from the mouth, the slough is divided into two sub-channels.

6.0 DATA SOURCES

The basic data used in this study were taken from various reports prepared for Alaska Power Authority by the Alaska Department of Fish and Games, Susitna Hydro Aquatic Studies Team (ADF&G), R and M Consultant, Incorporated (R&M) and Harza-Ebasco Susitna Joint Venture (H-E). Discharge and sediment data also were taken from the publications of U.S. Geological Survey, Water Resources Division (USGS) prepared in co-operation with Alaska Power Authority.

Hydraulic parameters such as stage-discharge relationships, channel widths, average channel depths, measured velocities and bed slopes of selected side channels and sloughs, were taken from various reports of R&M (R&M, February 1982 and December 1982) and ADF&G (ADF&G, 1983 and 1984). The hydraulic parameters for the main channel reaches were derived from the data given in H-E, January 1984 Report. Some unpublished data were obtained from USGS, R&M and ADF&G through correspondences.

The Manning's roughness coefficients for various main channel reaches, side channels and sloughs were estimated based on field reconnaissances made in 1983 and 1984 and also based on the analysis presented in the H-E, January 1984 report.

Bed material samples were collected by USGS and Harza-Ebasco personnel for this study. The results of these samples are given in the H-E, April 1984 and Knott-Lipscomb, 1983 reports. Data for samples collected by USGS in 1984 were obtained from the USGS office, Anchorage.

7.0 GENERAL APPROACH

As discussed under Section 3.0, "Scope of the Study", the purpose of the present analyses is to evaluate sedimentation process under natural and with-project conditions in the Susitna River at the study sites (Table 1 and Exhibit 2). Of major concern are potential aggradation or degradation in the sloughs and side channels and at their entrances, and at the sites in the main channel. Also of concern are intrusion of fine sediment into gravel bed and its subsequent entrapments. In case of fine sediment deposition on the gravel bed, appropriate measures will have to be taken to flush out the sediments so that the bed can be kept clean.

To provide some background for analyzing the specific problems under study, brief description of sediment transport in a river is given below. Some of the terminologies used are defined in Appendix A.

Sediment particles are transported by the flow as bedload and suspended load. The suspended load consists of wash load and bed-material load. In large rivers, the amount of bedload generally varies between about 3 to 25 percent of the suspended load. Although the amount of bedload is generally small compared to the suspended load, it is important because it shapes the bed and affects the channel stability.

The amount of material transported or deposited in a stream under a given set of conditions depends upon the interaction between variables representing the characteristics of the sediment being transported and the capacity of the stream to transport the sediment. A list of these variables is given below (Simons, Li and Associates, 1982).

Sediment Characteristics:

Quality: Size, settling velocity, specific gravity, shape, resistance to wear, state of dispersion and cohesiveness.

Quantity: Geology and topography of watershed, magnitude, intensity, duration, distribution and season of rainfall, soil condition, vegetal cover, cultivation and grazing, surface erosion and bank cutting.

Capacity of Stream:

Geometric shape: Depth, width, form and alignment.

Hydraulic Properties: Slope, roughness, hydraulic radius, discharge, velocity, velocity distribution, turbulence, tractive force, fluid properties and uniformity of discharge.

The above variables are not independent and in some cases the effect of a variable is not definitely known. However, the response of channel pattern and longitudinal gradient to variation in the variables have been studied by various investigators, Lane (1955), Leopold and Maddock (1953), Schumm (1971) and Santos and Simmons (1972). The studies by these investigators support the following general relationships (Simons and Senturk, 1977):

(i) depth of flow is directly proportional to water discharge;

(ii) channel width is directly proportional to both water discharge and sediment discharge;

(iii) channel shape expressed as width to depth ratio is directly related to sediment discharge;

(iv) channel slope is inversely proportional to water discharge and directly proportional to both sediment diacharge and grain size;

(v) sinuosity is directly proportional to valley slope and inversely proportional to sediment discharge, and

(vi) transport of bed material is directly related to streampower (defined as product of bed shear and cross-sectional average velocity), and concentration of fine material and inversely related to bed material sizes.

Because of the complexity of interaction between various variables, the river response to natural or man-made changes is generally studied by (i) qualitative analysis, involving morphological concepts, (ii) quantitative analysis involving application of morphological concepts and various empirical or experimental relationships, and (iii) quantitative analysis using mathematical models. The insights to the problems obtained through qualitative approach, provides understanding of the methods required to quantify the changes in the system. Mathematical modeling can help to study many fctors simultaneously. Recent work by Simons and Li (1978) and others indicates that physical process computer modeling provides a reliable methodology for analysing the impacts and developing solutions to complex problems of aggradation, degradation and river response to engineering activities.

For river channels of non-cohesive sediment, qualitative prediction of river response have been made using Lane's relationship (Lane, 1955):

$$QS \sim G_s d_s$$

in which

Q = stream discharge

S = longitudinal slope of stream channel

G_s = bed material discharge

d_s = particle size of bed material, generally represented by d_{50} (median diameter).

The use of above relationship to predict potential responses of the Susitna River under the natural and with-project conditions, is discussed under Section 9.0.

Prediction of quantitative changes in a river system requires geomorphic and hydraulic data or information which are generally not readily available. Considerable efforts, time and money are required to collect such information. The data of primary needs includes hydrologic and topographic maps and charts, large acale aerial and other photos of the river and surrounding terrain, existing river conditions (roughness coefficient, aggradation, degradation, local scour near structures), discharge and stage data (under natural and with-project conditions), existing channel geometry (main channel, side channels, islands); sediment data (suspended load and bed-load, size distribution of bank and bed material and suspended sediment), and size and operation of anticipated reservoir(s) on the river system.

Because of the available data and time did not permit a meaningful mathematical modeling using computer techniques, the morphological concepts and empirical relationships were used to predict potential aggradation or degradation at the study sites.

7.1 DEGRADATION

Generally, river bed degradation occurs downstream of newly constructed diversion and storage structures. The rate of degradation is rapid at the beginning, but is checked because of the development of a stable channel slope or formation of an armor layer if sufficient coarse sediment particles are available in the bed. The important variables affecting the degradation process are:

1. Characteristics of the flow released from the reservoir,
2. Sediment concentration of the flow released from the reservoir,
3. Characteristics of the bed material,
4. Irregularies in the river bed,
5. Geometric and hydraulic characteristics of river channel;
6. Existence and location of controls in the downstream channel.

The assumptions used in the present analysis include:

1. Bedload is completely trapped by the reservoir but suspended sediment particles of about .004 mm and less will remain in suspension and pass through the reservoir (PND, 1982). The sediment passing

through the reservoir would be about 18 percent of sediment inflow (Harza-Ebasco, November 1984);

2. Irregularities in the river and channels configurations remain unchanged;
3. Sediment supply due to bank erosion is negligible.
4. Sediment eroded from the river bed is carried downstream as bed-load.
5. Sediment injections by tributaries is carried downstream without significant deposition;
6. Size distribution of bed material is constant throughout the depth at each study site; and
7. Sufficient coarse material exists in the river bed to form an armoring layer which prevents further degradation.

The size of transportable bed material was estimated using (i) competent bottom velocity concept of Mavis and Laushey (1948) given in Design of Small Dams (1974), (ii) Tractive force versus transportable size relationship derived by Lane (1953) (iii) Meyer-Peter, Muller formula (Design of Small Dams, 1974), (iv) Schoklitsch formula (Design of Small Dams, 1974) and (v) Shields criteria (Simon and Li, 1982). Each of these methods is discussed below.

7.1.1 Competent Bottom Velocity

The velocity at which a sediment particle starts to move is defined as the competent bottom velocity (Mavis and Laushey, 1948). This velocity has been found to be approximately 0.7 times the mean channel velocity. Exhibit 17 shows a relationship between the competent bottom velocity and transportable sediment size (Figure H-13, Design of Small Dams) which was used in the study.

7.1.2 Tractive Force

The tractive force is defined as the drag or shear acting on the wetted area of the channel bed for a given discharge rate (Design of Small Dams) and can be expressed as:

Tractive force = γ d S (pounds/square feet, lbs/ft^2)

in which:

γ = unit weight of water (62.4 lbs/ft^3)

d = average water depth, ft

S = stream slope, ft/ft

Exhibit 18 shows empirical relationships between tractive force and transportable size (Lane 1953 and , Figure H-14, Design of Small Dams). The average relationship also shown in the exhibit was used in the study.

7.1.3 Meyer - Peter, Muller Formula

The Meyer - Peter, Muller formula for bedload transport can be written in the following form (Design of Small Dams):

$$G = 1.606B \left[3.306 \left(\frac{Q_B}{Q}\right) \left(\frac{D_{90}^{1/6}}{n_s}\right)^{3/2} d\ S - 0.627\ Dm\right]^{3/2}$$

in which:

G = bedload, tons/day

B = stream width, feet

Q_B = water discharge quantity directly over the area of bedload transport, cubic feet per second (cfs).

Q = total water discharge, cfs

D_{90} = particle size in millimeters (mm) at which 90 percent of bed material is finer,

n_s = Manning's 'n' value for the bed of the stream,

D_m = effective size of bed material in mm usually determine as Dm = Σ pi dsi, pi is fraction by weight of that fraction of the bed sediment with mean size dsi

d = mean water depth, feet

S = hydraulic gradient

For no bed load transport and assuming $Q = Q_B$, the transportable size is given by:

$$D = (5.26\ Sd)/(n_s/D_{90}^{\ 1/6})^{3/2}$$

7.1.4 Schoklitsch Formula

The Schoklitsch formula for initiation of transport can be expressed as (Design of Small Dams):

$$q_i = \frac{.00021\ Di}{S^{4/3}}$$

in which:

q_i = unit discharge in cfs/foot width to initiate motion of size Di in mm;

S = hydraulic gradient ft/ft

If B is width of stream in feet and Q is total discharge then

$$D = \frac{4762\ S^{4/3}\ Q}{B}$$

7.1.5 Shields Criteria

According to the Shields criteria, the beginning of motion of bed material can be expressed as (Simon and Li 1982):

$$F^* = \frac{\tau_c}{(\gamma_s - \gamma)\ D}$$

in which:

F^* = dimensionless number, referred to as the shields parameter;

τ_c = critical boundary shear stress, lbs/ft^2

γ_s = specific weight of sediment particles lbs/ft^3

γ = specific weight of water (62.4 lbs/ft^3)

D = diameter of sediment particle, ft

Shields determined a graphical relationship between F^* and shear velocity Reynolds number R^* to define initiation of motion. In the region where R^* is between 70 and 500, the boundary is completely rough, the F^* is considered independent of R^*. The value of F^* in this region range from 0.047 to 0.060.

A value of F^* equal to 0.047 was assumed for this study. Using a specific weight of about 165 lbs/ft^3 for the bed material and shear stress equal to "γ d S", the transportable size is given by the following relationship:

$$D = \frac{\tau_c}{(\gamma_s - \gamma)\, F^*} \quad \text{(ft)}$$

$$= \frac{\tau_c}{(165 - 62.4)\,(0.047)} \times 12 \times 25.4 \quad \text{(mm)}$$

$$= 0.207\ (12 \times 25.4)\ \tau_c$$

$$= 3944\ d\ \ S$$

in which

D = transportable size, mm

d = mean water depth, ft

S = hydraulic gradient, ft/ft

7.1.6 Depth of Degradation

The depth of degradation or the depth from original streambed to top of armoring layer was computed by the following relationship given in Design of Small Dams:

$$Y_d = Y_a \left(\frac{1}{\Delta p} - 1\right)$$

in which

Y_d = depth of degradation, ft

Y_a = thickness of armoring layer, assumed as 3 times transportable size or 0.5 ft whichever is smaller,

Δp = decimal percentage of material larger than the transportable size

The transportable size for a given discharge was the average of the five sizes estimated by using the five methods discussed above.

7.2 AGGRADATION

Potential aggradation at the entrances of sloughs and side channels were estimated by comparing the transportable size of the flow in the mainstem before diversion into the slough or side channel and the transportable size of the remaining flow in the main channel after diversion into side channel or slough. If the two sizes were significantly different, it was concluded that some of the bedload being transported would be deposited near the entrance.

8.0 HYDRAULIC DATA USED IN THE ANALYSES

Based on the procedures, described in the previous section, the hydraulic data required to estimate depths of degradation at the study sites include:

1. Dominant discharges based on which transportable sizes are computed;
2. Mean velocities, average depths, and channel widths corresponding to various discharge rates;
3. Channel bed slopes;
4. Manning's roughness coefficients ('n' values); and
5. Bed material size distributions.

These data were derived from various reports prepared by ADF&G, R&M and H-E, as dicussed below.

8.1 DOMINANT DISCHARGE

Generally, the estimation of depths of degradation is based on 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. The dominant discharge for an uncontrolled stream is usually considered to be either the bank-full discharge or the peak discharge having a recurrence interval of about 2 years (Design of Small Dams).

With regulation of streamflow by an upstream reservoir, the definition of dominant discharge would depend on the degree of regulation and the magnitude of flow from the area intervening between the dam site and the point of interest. If the reservoir releases follow a certain pattern without much deviation due to floods and flood flows from the intervening area are not significant, the higher discharge in the release pattern probably can be used as the dominant discharge. If the reservoir releases are subject to considerable fluctuations due to power demands or due to floods, the peak discharge having a 2-year recurrence interval would be a better representative of the dominant discharge. For the Middle Susitna River under study, the dominant discharge was derived based on weekly reservoir operation studies for the 1996, 2001, 2002 and 2020 energy demands and is discussed under Section 9.2.2.

The dominant discharges for side channels and sloughs will depend upon the frequency of overtopping the side channels and sloughs and on the magnitude and duration of the overtopped flows. The side channels and sloughs under study are overtopped currently at different mainstem discharges as shown in Table 1. Under with-project conditions, the high flows at Gold Creek will be greatly reduced unless the spiking release (being considered for flushing out fine sediments) is made from the reservoirs. Therefore, assuming that the entrances to the sloughs and side channel remain unchanged, the frequency of overtopping will be greatly reduced as also discussed under Section 9.2.2.

The relationships were developed between dominant discharge and transportable size and between dominant discharge and depth of degradation. The computation were made by using data of the individual locations but the discharges at a given location are referenced to the corresponding discharges at the Gold Creek stream gaging station. The computations cover a range of discharge between 5,000 and 50,000 cfs at Gold Creek.

8.2 MEAN VELOCITIES, AVERAGE DEPTHS AND CHANNEL WIDTHS

For the sites on the main channel, the mean velocities, average depths and channel widths corresponding to various discharges were derived from the H-E January 1984 report. The data representative for the study sites are given in Table 2.

The discharges entering the sloughs and side channels at various discharges at Gold Creek were estimated using data available in ADF&G and R&M reports, data received with R&M letter no. 452403 dated December 6, 1984 and ADF&G letter no. 02-84-13.06 dated December 13, 1984, and additional discharge, depth, velocity and width data, observed by ADF&G at various transects in

Sloughs 8A, 9, 11 and 21, and Side Channels 10, 11 and 21. The same data were also used in determining the relationships between the slough or side channel discharges and average channel width, depths and velocities.

Generally, flows enter the sloughs or side channels during medium to high river stages depending upon the elevations of channel inverts at the heads of the sloughs or side channels. For stages lower than these, the flows in the sloughs and side channels are either from ground water seepage or local runoff. Based on detailed field investigations, ADF&G determined the dis charges at Gold Creek at which various sloughs and side channels are overtopped (Table 1). It also determined that the discharge entering a sloughs or side channel can be expressed as a function of the discharge at Gold Creek in the following form:

$$Q_{\text{slough or side channel}} = 10^{A} \, (Q_{\text{Gold Creek}})^{B}$$

The relationship was derived based on the data collected in 1982 through 1984. These data correspond to discharges at Gold Creek of 12,000 to 32,000 cfs. The relationships provided reasonably good comparison between the observed and computed discharges in the sloughs and side channels for the observed range of the data. However, it was found to provide unrealistically high slough and side channel discharges for flows higher than 32,000 cfs at Gold Creek. Therefore, new relationships were developed by visually fitting curves to observed data. Typical relationships for Slough 9 and Side Channel 10 are shown Exhibit 19. The extension of these relationships for higher discharges is somewhat arbitrary but they represent the best relationships that can be established before additional observations are made for such discharges.

After the estimation of slough and side channel discharges for a given flow at Gold Creek, the next step was to derive the corresponding channel width, average depth and mean velocity data at the sloughs and side channels. For the cases where depth and velocities data for a given discharge were available at a number of transects in a slough or side channel, the average of these data over the transects were used to represent the slough or side channel.

ADF&G also has developed stage discharge relationships for sloughs and side channels at selected locations. These locations are shown on Exhibits 6, 7, 8, 10, 11, 12, 13, 15 and 16. Additional cross sections also have been observed on some sloughs and side channels.

The hydraulic parameters generally change along the channel length because of changes in the cross sectional shape and also because of presence of riffles and pools (changes in stream bed slope). Attempts were made to use the additional channel cross sections to derive representative width, average depth and mean velocity corresponding to a given discharge in a slough or side channel. However, in most cases, the discharge measuring station was assumed to represent the study reach because of lack of additional data for a detailed analysis. Therefore, the stage-discharge relationships developed for the stream gaging stations and the channel cross sectional at the same locations were used to determine the representative width, average depth and mean velocity data. Typical depth-discharge and velocity- discharge relationships are shown on Exhibits 20 and 21.

8.3 CHANNEL BED SLOPES

The bed slopes of the reaches of the main channel were determined from the river thalweg profiles given in the H-E January 1984 report.

ADF&G developed thalweg profiles for sloughs and side channels from field survey data (ADF&G, 1984). Alternate riffles and pools exist in nearly all sloughs and side channels. The bed slope changes significantly from one sub-reach to the other along the length of the sloughs and side channels. For the purpose of the present analysis, the overall slopes were used.

Table 1 shows the overall slopes for the sloughs and side channels along with the slopes of the adjacent mainstem. These data were derived from various reports of ADF&G.

The bed slopes of Side Channel 10, Upper Side Channel 11 and Slough 21 are steeper than those of other sites. This, probably, is the reason for the higher velocities as shown in Table 3.

8.4 MANNING'S ROUGHNESS COEFFICIENTS

The Manning's roughness coefficients ("n" values) for the sloughs and side channels were estimated based on field reconnaissance. The "n" values for the sites on the mainstem were based on the data and analysis presented in the Harza-Ebasco report on water surface profiles (H-E, January 1984). The estimated "n" values are given in Table 1.

8.5 BED MATERIAL SIZE DISTRIBUTION

Bed materials of the Susitna River consist mostly of gravel and cobbles with some percentage of sand. The substrate in the sloughs and side channels vary significantly along the channel length. Moderate to heavy deposits of silt and sand over gravel and cobbles are visible in the pool areas. The substrates at riffles are generally of clean gravel, cobbles or sometimes boulders. Near the head of the sloughs, the substrates are clean with little deposition of fine material. In backwater areas near the mouths, some deposition of silt and sand occurs over gravel and boulders.

The size distribution of bed material greatly affect the evaluation of sedimentation process. Therefore, representative bed material size distribution data was considered essential for the study. Harza-Ebasco took about 36 sediment samples (see footnotes on Table 4) at the selected locations in the mainstem, sloughs and side channels. The samples were taken both from surface and sub-surface layers.

In the mainstem of the Susitna River, the surface material is generally coarser compared to the sub-surface material. The bed material samples collected in the sloughs and side channels, however, did not show any distinct difference between the surface and sub-surface materials. The surface and sub-surface samples at a given site were combined to determine the size distribution.

The adopted size distributions are given in Table 4 and shown on Exhibits 22 to 33. These are considered only indicative of the bed material at the specific sites because many additional samples will be required to determine a representative size distribution for the whole length of the study reach.

9.0 SEDIMENTATION PROCESS

9.1 NATURAL CONDITIONS

9.1.1 River Morphology

The Susitna River between Devil Canyon and above the confluence of the Susitna and Chulitna Rivers, has a single channel or a split channel configuration. A number of barren gravel bars or moderately to heavily vegetated islands exist in the river. The mid-channel gravel bars appear to be mobile during moderate to high floods (R&M, January 1982). A number of tributaries including Portage Creek, Indian River, 4th of July Creek and Lane Creek join the main river in this reach. Almost each tributary has built an alluvial fan into the river valley. Due to relatively steep gradients of some of these tributaries, the deposited material is somewhat coarser than that normally carried by the Susitna River.

Vegetated islands generally separate the main channel from side channels and sloughs. These sloughs and side channels exist on one bank of the river at locations where the main river channel is confined towards the opposite bank. The flows enter into these sloughs and side channels depending upon the elevations of the berms at their heads, relative to the mainstem river stages (see Table 1). Coarser bed materials are generally found at the heads of sloughs and side channels. This is because the flow enters these sloughs and side channels is from the upper layer of the flow in the main channel and does not carry coarse material. This relatively sediment free flow picks up finer bed material at the heads, thereby, leaving coarser material.

A preliminary report was prepared by Arctic Environmental Information and Data Center (AEIDC) on morphological changes in the Susitna River (AEIDC, May 1984). The changes are evaluated based on photographs taken during 1949 through 1951 and 1977 through 1980. Results of the evaluation indicate that some sloughs have come into existence since 1949-51, some have changed character and/or type significantly, and others have not yet changed enough to be noticeable. Many sloughs have evolved from side channels to side sloughs or from side sloughs to upland sloughs. Thus, they are now higher in elevation relative to the water surface in the mainstem at a given discharge. The perching of the sloughs and increased exposure of gravel bars above the water surface are indicative of river degradation over the 35-year period. However, the photographs presented in the report also show significant increase in the number and/or size of barren gravel bars which indicates that depositions also have occurred. Therefore, both aggradation and degradation can be expected to occur in the Susitna River under natural conditions depending upon the flows and sediment loads.

9.1.2 Channel Stability

The channel stability at each of the study sites was evaluated by comparing the median diameter of bed material (Table 4) with the transportable sizes under various discharges. These sizes were estimated using the procedures discussed in Section 7.0, "General Approach", and are listed in Table 5. Exhibits 34 through 47 show the relationships between discharges at Gold Creek and transportable sizes at the study sites.

A comparison of median diameters listed in Table 4 and transportable sizes listed in Table 5 shows that:

1. For all the study sites in the main channel, the transportable sizes for a flow of about 15,000 cfs or greater at Gold Creek are considerably larger than the median sizes (d_{50}) of the bed material. Therefore, for a discharge of this magnitude or greater, active exchange of particles occurs between the channel bed and the bedloads carried by the flow. This undoubtly has cuased temporal deposition and scour in the past and likely exhibits similar behavoirs at present. The extent of the deposition or scour can not be predicted with any degree of certainty because it depends on so many factors such as the flow, sediment loads and ice james all of which are highly unpredictable.

2. In North-east and North-west Forks of Mainstem 2 Channel, the transportable sizes corresponding to a flow of about 55,000 cfs at Gold Creek are smaller than the median size of the bed material. Therefore, these sub-channels are stable under the present conditions. However, the channel downstream from the confluence of these sub-channels, indicates the transportable sizes larger than the median size for flows of about 35,000 and above at Gold Creek. Thus, this channel likely exhibits temporal deposition and scour for flows larger than about 35,000 cfs at Gold Creek or equivalent river flow caused by breaching of an ice jam.

3. For Sloughs 8A and 11 and Side Channel 21, the transportable sizes corresponding to flows upto about 55,000 cfs at Gold Creek, are smaller than the median size of bed material at these sites. Therefore, appreciable changes in the channel cross-sections are not expected at these sites upto a flow of about 55,000 cfs at Gold Creek. However, much larger floods or higher river flows

caused by breaching of ice jams can cause deposition and/or scour.

4. For Slough 9, the transportable size corresponding to a flow of about 45,000 cfs at Gold Creek, is larger than the median bed material size. Therefore, active exchange of sediment particles is expected between the channel bed and bed load being carried, causing temporal scour and deposition.

5. Similar phenomenon (active exchange of sediment particles between the channel bed and bed load) causing temporal scour and/or deposition, exists in Side Channel 10, Upper and Lower Side Channels 11 and Slough 21 for flows corresponding to flows larger than about 30,000, 35,000, 25,000 and 45,000 cfs respectively, at Gold Creek.

Based on the above observations, it can be concluded that most of the selected sites are subject to temporal scour and/or deposition under natural conditions depending upon high flows (caused by flood or breaching of ice jams) and characteristics of sediment load being transported.

9.1.3 Intrusion of Fine Sediments

The fine sediments consisting of medium to fine sand, and silt (particle sizes between 0.50 to .004 mm) have been observed deposited on gravel bars and banks of the mainstem channel and side channels during low flows. In sloughs, the deposits have been observed in backwater areas and in pools. Field reconnaissances during 1983 and 1984 indicated that much of these deposits (except those in the pools of the sloughs) were removed during high flows. This was because of disturbances of surface bed material layer under high flows, which caused the fine sediment to be re-suspended.

The analysis of suspended sediment data collected at Gold Creek (H.E., November 1984) indicates that, on the average, about 56 percent of suspended load is finer than 0.5 mm. Thus, there is a high probability of fine sediments depositing on channel bed.

A number of laboratory studies are available to understand the process of the intrusion of fine sediments in a gravel bed (Carling, 1984; Einstein, 1968, Beschta and Jackson, 1979 and Cooper, 1965). These studies indicates that at low velocities, deposition occur on the surface of substrates while at high velocities the surface is flushed clean.

9.2 WITH-PROJECT CONDITIONS

9.2.1 River Morphology

The construction of the Susitna Hydroelectric Project will change the streamflow pattern and also will trap sediments. The essentially sediment-free flows from the reservoirs will have the tendency to pick-up bed material and cause degration. The modified discharges downstream from the dams, however, will have reduced compentence to transport sediment especially that brought by the tributaries. These two factors tend to compensate with each other, resulting in the overall effects discussed below.

The Lane's relationship discussed under Section 7.0, "General Approach", is based on equilibrium concept, that is, if any change occurs in one or two parameters of the water and sediment discharge relationships, the river will strive to compensate the other parameters so that a new equilibrium is attained. In the case of the Susitna River, both water discharge and bed load discharge will be modified by the reservoirs. Therefore, adjustments will occur in the river channel and particle sizes of the bed material. A number of studies (Hey, et al 1982) have indicated that the new median diameter under with-project conditions may correspond to the D_{90} or D_{95} of the original bed material.

The potential morphological changes of the Susitna River also were addressed qualitatively by R&M (January 1982). It was argued that the Susitna River between Devil Canyon and the confluence of the Susitna and Chulitna Rivers would tend to become more defined with a narrower channel. The main channel river pattern will strive for a tighter, better defined meander pattern within the existing banks. A trend of channel width reduction by encroachment of vegetation and sediment deposition near the banks would be expected.

9.2.2 Channel Stability

Potential degradation at the selected sites were estimated for various discharges using the procedure discussed under "General Approach". The relationships between the index discharge at Gold Creek and estimated degradation at various sites are shown on Exhibits 48 through 59. The potential degradation at each site estimated from these relationships is listed in Table 6. These estimates are based on the assumption that there would not be significant supply of coarse sediments by the tributaries and also there would not be redeposition of bed material eroded from upstream channel.

Table 7 shows average weekly flows at Gold Creek for four project operation scenarios and for natural conditions. These data were obtained from recent H-E studies (under preparation). These data indicate about 50 percent reduction in flows during May through September period and about 3 to 4 times increase in flows during October through April period. Table 8 shows annual maximum weekly flow at Gold Creek for natural and with-project conditions. Under with-project conditions, the maximum weekly flows occurs under 2002 load conditions. Using the average of these annual maximum weekly flows as the dominant discharge (about 30,000 cfs), the potential degradation at the main channel sites would be in the range of about 1.0 to 1.5 feet. In the sloughs and side channels, the degradation would be about 0 to 0.3 feet. These estimates, however, are based on the assumptions that there will not be significant injection of bedload by the tributarites and there would not be redeposition of sediment eroded from upstream channel. In actual situations, there will be sediments carried down by the tributaries and some of which will be deposited in the main river. Redeposition of some sediment eroded from upstream channel will occur. Therefore, actual degradation at the main channel sites would be less than those estimated.

Table 3 shows that bifurcation of flow at the heads of the sloughs and side channels will not significantly reduce the discharge rates in the main channel. Therefore, the competence of flow to transport bed material will not be affected due to bifurcation of flow and little aggradation should be expected in the main channel near the entrances to the sloughs and side channels.

As discussed above, the main channel will have the tendency to degrade and to be more confined with a narrower channel. This may cause the main channel to recede from the heads of sloughs and side channels. Therefore, the berms at the heads of the sloughs and side channels would be overtopped at higher discharges than those under natural conditions. Assuming that the river bed at the entrances would be lowered by about one foot due to the degradation, larger mainstem discharges would be required to overtop the sloughs and side channels. Thus, the overtopping of the sloughs and side channel will be less frequent, and the estimated 0 to 0.3 feet degradation for the sloughs and side channels would be smaller. This could cause some of sloughs and side channels to become less effective, but some new sloughs or side channels will likely be created by the new flow regime in the Susitna River.

9.2.3 Intrusion of Fine Sediments

As discussed under "General Approach", the reservoir will trap all sediment except particles sizes of .004 mm and less, which constitute about 18 percent of the suspended load. The velocities at the study sites (Table 2 and 3) would be sufficiently high to carry these fine particles in suspension, and the substrates would generally be cleaner. However, some coarse silt and fine sand might be picked up from the river bed which would have the tendency to settle out in pools and backwater areas. Therefore, some deposition of such silt and sand in the sloughs and side channel is possible, and it may be desirable to operate the project such that the sloughs and side channels are overtopped at least for a few days each year, unless other means such as "Gravel Gerties" are employed to flush out the fine sediment deposition.

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Cohesive Sediments: Sediments whose resistance to initial movement or erosion is affected mostly by cohesive bonds between particles.

Colloids: Finely divided suspended solids which do not settle in a liquid.

Concentration of Sediment (by weight): The ratio of the weight of dry sediment in a water-sediment mixture to the weight of the mixture. This concentration, determined as parts per million (ppm) can be converted to grams per cubic meter or milligram per litre.

Contact Load: Sediment particles that roll or slide along in almost continuous contact with the streambed.

Degradation: The process by which stream beds, flood plains and the bottoms of other water bodies are lowered in elevation by the removal of material from the boundary.

Density of Water-Sediment Mixture: Bulk density which is mass per unit volume including both water and sediments.

Deposition: The mechanical or chemical processes through which sediments accumulate in a resting place.

Discharge-weighted Concentration: Dry weight of sediment in a unit volume of stream discharge, or the ratio of discharge of dry weight of sediment to discharge by weight of water-sediment mixture.

Erosion: The wearing away of the land surface (including river beds, etc.) by detachment and movement of soil and rock fragments through the action of moving water and/or other geological agents.

Fine Material: Particles of size finer than the particles present in appreciable quantities in the bed material; normally silt and clay particles (particles finer than 0.062 mm). Scale of particle sizes for sediment is given below:

Class Name	Millimeters	Micrometers (microns)
Boulders	>256	
Cobbles	256 - 64	
Gravel	64 - 2	
Very coarse sand	2.0 - 1.0	2,000 - 1,000
Coarse sand	1.0 - 0.50	1,000 - 500
Medium sand	0.50 - 0.25	500 - 250
Fine sand	0.25 - 0.125	250 - 125
Very fine sand	0.125 - 0.062	125 - 62
Coarse silt	0.062 - 0.031	62 - 31
Medium silt	0.031 - 0.016	31 - 16
Fine silt	0.016 - 0.008	16 - 8
Very fine silt	0.008 - 0.004	8 - 4
Coarse clay		4 - 2
Medium clay		2 - 1
Fine clay		1 - 0.5
Very fine clay		0.5 0.24
Colloids		<0.24

Fine Material Load (or wash load): That part of the total sediment load that is composed of particle sizes finer than those represented in the bed. Normally the fine-sediment load is finer than 0.062 mm for a sand-bed channel. Silts, clays and sand could be considered as wash load in coarse gravel and cobble bed channels.

Load (or aediment load): Sediments that is being moved by a stream.

Measured Sediment Discharge: The quantity of sediment passing a cross section of a stream in a unit of time that is computed with information derived from sampling. Sampling with suspended-sediment samplers makes the measured sediment discharge the same as the measured suspended-sediment. This is generally computed as the product of: (1) the discharge weighted concentration from the suspended-sediment samples, (2) the total water discharge through the cross section, and (3) an appropriate units conversion constant. Thus, measured suspended-sediment discharge for the cross section includes all of the suspended-sediment moving in the sampled zone, but only part of the suspended sediment moving in the unsampled zone. This is because the water discharge in the unsampled zone was included with sediment concentration which is generally less than that in the unsampled zone (a concentration gradient exists).

Median Diameter: The size of sediment such that one-half of the mass of the material is composed of particles larger than the median diameter, and the other half is composed of particles smaller than the median diameter.

Noncohesive Sediments: Sediments consisting of discrete particles; for given erosive forces, the movement of such particles depends only on the properties of shape, size, and density and on the position of the particles with respect to surrounding particles.

Particle-Size Distribution: The frequency distribution of the relative amounts of particles in a sample that are within specified size ranges or a cumulative frequency distribution of the relative amounts of particles coarser or finer than specified sizes. Relative amounts are usually expressed as percentages by weight (mass).

Sediment (or fluvial sediment): Fragmental material that originates from weathering of rocks and is transported by, suspended in, or deposited by water.

Sedimentation: A broad term that pertains to the five fundamental processes responsible for the formation of sedimentary rocks: (1) weathering, (2) detachment, (3) transportation, (4) deposition, and diagenosis, also means the gravitational settling of suspended-sediment particles that are heavier than water.

Sediment Delivery Ratio: The ratio of sediment yield to gross erosion expressed in percent.

Sediment Discharge (or sediment load): Quantity of sediment that is carried past any cross section of a stream in a unit time. Discharge may be limited to certain sizes of sediment or to discharge through a specific part of the cross section.

Sediment Yield: Total sediment outflow from a watershed or a drainage area at a point of reference and in a specified time period. This is equal to the sediment discharge from the drainage area.

Spatial Concentration: Dry weight of sediment per unit volume of water-sediment mixture in place or the ratio of dry weight of sediment to total weight of water-sediment mixture in a sample taken from a place, or unit volume of the mixture at a place.

Suspended Load (or suspended sediment): Sediment that is supported by upward components of turbulent currents and stays in suspension for an appreciable length of time. Also quantity of suspended sediment passing through a stream cross section above the bed layer in a unit of time.

Total Sediment Load (or total sediment discharge or total load): Total sediment load (or discharge) of a stream, it is sum of suspended load (or discharge) and bedload (or bedload discharge) or the sum of bed-material load (or bed-material discharge) and wash load (or wash load discharge).

Velocity-Weighted Sediment Concentration: Dry weight of sediment discharged through a cross section during unit time.

Wash-load Discharge (wash load): That part of total sediment discharge that is composed of particle sizes finer than those represented in the bed and is determined by available bank and upslope supply rate.

Table 1

CHARACTERISTICS OF STUDY SITES
ON MIDDLE SUSITNA RIVER[1]

	Approx. River Miles	Overall Slope of Study Reach	Overall Slope of Main River	Observed Overtopping Discharge[2]	Estimated Bed Elev. at Head	Estimated Manning's Roughness
Main Channel Nr. River Cross Section 4	99.0 to 100.0	.0017	.0017	NA[3]	NA	.030
Main Channel Between River Cross Sections 12 and 13	108.5 to 110.0	.0012	.0012	NA	NA	.035
Main Channel Upstream from Lane Creek	113.6 to 114.2	.0017	.0017	NA	NA	.035
Mainstem 2 Side Channels at River Cross Section 18.2		.0030	.0017	12,000	476.3	.035
NW Channel	114.4	.0020	.0017	12,000	476.3	.035
NE Channel	115.5	.0024	.0017	23,000	484.6	.035
Slough 8A (main channel)		.0024	.0017	26,000		.032
NW Channel	126.2	.0024	.0017	26,000		.032
NE Channel	126.7	.0024	.0017	33,000	576.5	.032
Slough 9	128.3	.0026	.0016	16,000	604.6	.032
Main Channel Upstream From the 4th of July Creek	131.2 to 132.2	.0015	.0015	NA	NA	.035
Side Channel 10	134.2	.0039	.1017	19,000	656.6	.035
Lower Side Channel 11	135.0	.0024	.0020	5,000		.035
Slough 11	135.4	.0029	.0020	42,000	684.6	.032
Upper Side Channel 11	136.2	.0045	.0020	13,000	684.3	.035
Main Channel Between Cross Sections 46 and 48	136.9 to 137.4	.0017	.0017	NA	NA	.035
Side Channel 21		.0030	.0032			
Downstream from A5	140.6			12,000		.030
Upstream from A5	141.9			20,000		.030
Slough 21		.0043	.0023			.030
NW Channel	142.2			23,000	753.8	
NE Channel	142.3			26,000	756.9	

1/ Data taken from various reports of H-E; ADF&G and R&M.
2/ Discharges at Gold Creek Station
3/ Not applicable.

Table 2

HYDRAULIC PARAMETERS FOR MAINSTEM SITES

Location	Gold Creek Discharge (cfs)								
	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Near River Cross Section 4									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	650	750	860	1,010	1,200	1,380	1,640	2,060	2,680
Depth, ft	2.9	3.4	3.9	4.6	5.5	6.3	7.3	8.9	10.6
Velocity, ft/sec	2.7	3.4	3.8	4.4	4.4	4.3	4.2	4.6	4.9
~~Near~~ Between River Cross Sections 12 and 13									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	380	410	425	445	460	473	495	518	545
Depth, ft	5.6	6.6	7.6	8.0	9.2	9.9	11.2	13.1	16.0
Velocity, ft/sec	2.3	3.0	3.4	4.2	4.7	5.3	6.1	7.0	7.7
Upstream from Lane Creek									
Discharge, cfs	3,090	5,150	7,210	9,990	13,800	17,500	24,100	35,500	53,600
Width, ft	850	960	1,020	1,110	1,350	1,680	1,790	1,860	1,900
Depth, ft	5.9	6.8	7.4	8.2	8.5	9.3	10.0	11.0	12.9
Velocity, ft/sec	1.7	2.2	2.6	3.1	4.1	4.3	5.2	6.7	7.5
Upstream from 4th of July Creek									
Discharge, cfs	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Width, ft	250	340	430	580	800	970	1,150	1,250	1,380
Depth, ft	6.3	7.2	7.7	8.3	9.0	9.3	10.1	10.6	11.6
Velocity, ft/sec	2.1	2.7	3.3	4.0	4.9	5.8	6.2	7.4	8.8
Between River Cross Sections 46 and 48									
Discharge, cfs	3,000	5,000	7,000	9,700	13,400	17,000	23,400	34,500	52,000
Width, ft	305	385	465	545	600	650	710	800	920
Depth, ft	5.1	6.2	6.9	8.1	9.0	9.7	10.6	12.0	14.1
Velocity, ft/sec	3.6	4.1	4.6	4.9	5.7	6.4	6.8	8.2	9.4

Table 3

HYDRAULIC PARAMETERS FOR SIDE CHANNELS AND SLOUGHS

Location	Gold Creek Discharge (cfs)	Slough/Side Channel Discharge	Slough/Side Channel Width (ft)	Slough/Side Channel Depth (ft)	Slough/Side Channel Velocity (ft/sec)
(1)	(2)	(3)	(4)	(5)	(6)
Mainstem 2 Side Channel					
Northwest Channel	17,000	150	112	1.0	1.39
	23,400	940	117	1.9	2.78
	34,500	2,940	228	2.5	5.20
	52,000	6,700	264	2.9	8.75
Northeast Channel	34,500	650	111	3.4	1.71
	52,000	2,900	124	3.8	6.09
Main Channel Below Confluence	17,000	150	128	0.5	2.31
	23,400	940	250	1.4	3.78
	34,500	3,590	341	2.7	3.89
	52,000	9,600	366	4.4	6.00
Slough 8A					
Northwest Channel	30,000	19	45	0.7	0.62
	35,000	47	45	0.9	1.18
	40,000	98	45	1.0	2.21
	45,000	183	45	1.1	3.75
	52,000	383	46	1.3	6.58
Northeast Channel	30,000	17	70	1.0	.42
	35,000	26	71	1.1	.51
	40,000	37	73	1.2	.59
	45,000	51	75	1.4	.67
	52,000	74	78	1.6	.77
Main Channel Below Confluence	30,000	36	62	0.8	.72
	35,000	73	66	1.0	1.14
	40,000	135	70	1.1	1.74
	45,000	234	72	1.2	2.68
	52,000	457	78	1.5	3.96
Slough 9	23,400	80	73	1.3	0.82
	34,500	580	151	2.2	2.34
	45,000	1,600	156	3.0	4.03
	52,000	2,650	160	3.2	5.30

Table 3 (cont'd)

HYDRAULIC PARAMETERS FOR SIDE CHANNELS AND SLOUGHS

Location	Gold Creek Discharge (cfs)	Slough/Side Channel Discharge	Slough/Side Channel Width (ft)	Slough/Side Channel Depth (ft)	Slough/Side Channel Velocity (ft/sec)
(1)	(2)	(3)	(4)	(5)	(6)
Side Channel 10	21,000	30	38	0.8	1.00
	25,000	150	83	1.5	1.25
	30,000	430	102	2.1	2.05
	34,500	860	108	2.6	3.07
	45,000	2,800	119	3.7	6.36
	52,000	4,900	127	4.4	8.75
Lower Side Channel 1	7,000	520	275	0.9	1.75
	9,700	862	280	1.3	2.27
	13,400	1,420	285	1.8	2.96
	17,000	2,053	290	2.3	3.60
	23,400	3,365	295	3.2	4.64
	34,500	6,133	300	4.8	6.46
	45,000	9,248	300	6.3	7.87
	52,000	11,565	300	7.5	8.90
Upper Side Channel 11	17,000	38	101	0.5	.75
	23,400	170	117	1.0	1.52
	34,500	1,060	146	2.2	3.30
	45,000	3,900	155	4.0	6.70
	52,000	7,800	170	5.2	8.80
Slough 11	44,000	21	24	0.5	1.65
	46,000	33	30	0.6	1.80
	48,000	94	49	0.9	2.25
	50,000	176	64	1.1	2.60
	52,000	332	84	1.3	3.00
Side Channel 21	12,000	67	77	1.0	0.87
	16,000	205	105	1.4	1.40
	20,000	420	130	1.7	1.90
	25,000	810	162	2.0	2.50
	30,000	1,350	189	2.3	3.10
	40,000	2,900	260	2.7	4.15
	52,000	5,600	298	3.3	5.70
Slough 21	25,000	13	52	0.5	0.50
	30,000	39	72	0.9	0.60
	35,000	105	94	1.4	0.80
	40,000	235	98	2.0	1.20
	45,000	500	99	2.8	1.80
	50,000	970	99	3.9	2.52

Table 4

REPRESENTATIVE BED MATERIAL SIZE DISTRIBUTION
FOR SELECTED SLOUGHS, SIDE CHANNEL AND MAINSTEM SITES

	Particle Size, mm											Bed Material Sizes (mm) For Given Percentage		
	.062	.125	.250	.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	D_{16}	D_{50}	D_{90}
	Percent Finer Than													
Main Channel near Cross Section 4[1]	2	3	7	10	13	16	22	29	42	70	89	1.7	20	65
Main Channel between Cross Sections 12 and 13[2]	1	2	3	5	8	12	18	24	32	50	77	3.0	34	78
Main Channel upstream from Lane Creek[3]	2	3	5	7	9	10	14	21	32	48	77	5.0	35	84
Mainstem 2 Side Channels at Cross Section 18.2[4]	3	5	7	10	13	17	22	29	37	53	73	1.7	30	110
Slough 8A[5]	1	3	6	10	12	13	15	18	28	47	83	4.3	35	70
Slough 9[6]	1	2	7	15	18	20	23	30	41	63	93	0.5	22	58
Main Channel upstream from 4th of July Creek[7]	2	4	6	8	11	14	20	27	36	55	78	2.5	28	85
Side Channel 10[8]	1	3	6	12	17	20	25	34	44	62	82	0.8	20	80
Lower Side Channel 11, downstream from Slough 11[9]	1	2	5	7	10	14	19	30	41	58	84	2.6	25	72
Slough 11[10]	1	2	5	8	12	15	20	27	35	50	68	2.2	32	100
Upperside Channel 11, upstream from Slough 11[10]	1	2	5	8	12	15	20	27	35	50	68	2.2	32	100
Main Channel between Cross Section 46 and 48[11]	1	2	3	7	10	13	17	24	33	53	72	3.3	30	100
Side Channel 21, downstream from Slough 21[12]	0	0	1	4	6	8	12	17	23	40	62	7.5	46	96
Slough 21[12]	0	0	1	4	6	8	12	17	23	40	62	7.5	46	96

[1] Based on 6 samples taken at three locations near cross section 4.
[2] Based on 2 samples taken near river miles 109.3.
[3] Based on 2 samples taken in main channel upstream from Lane Creek.
[4] Based on 4 samples taken in the Mainstem 2 side channel, at four locations.
[5] Based on 6 samples taken near the slough in the main channel at RM 125.6.
[6] Based on 5 samples taken near the slough in the main channel at RM 128.7.
[7] Based on 3 samples taken in the main and side channels near 4th of July Creek.
[8] Based on 2 samples taken in Slough 10.
[9] Based on 2 samples taken in Side Channel 11, downstream from Slough 11.
[10] Based on one sample taken in Slough 11.
[11] Based on 2 samples taken between cross sections 46 and 48.
[12] Based on one sample taken near the upstream end of side channel.

Table 5

TRANSPORTABLE BED MATERIAL SIZES IN SELECTED
SLOUGHS, SIDE CHANNELS AND MAINSTEM SITES

Location	Discharge at Gold Creek (cfs)										
	5,000	7,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	55,000
	Transportable Bed Material Size (mm)										
Main Channel near Cross Section 4	18	21	24	29	33	36	38	41	43	44	48
Main Channel between Cross Sections 12 & 13	21	25	28	37	44	48	53	57	60	65	76
Main Channel upstream from Lane Creek	25	28	32	37	44	48	52	56	60	64	72
Mainstem 2 Side Channel at Cross Section 18.2											
Main Channel				6	11	18	25	31	37	43	56
North-east Fork				5	9	13	16	18	21	24	29
North-west Fork				5	9	13	16	17	19	21	24
Slough 8A							4	6	8	9	12
Slough 9						9	13	17	20	24	31
Main Channel upstream from 4th of July Creek	27	31	35	40	45	50	54	57	61	64	71
Side Channel 10					5	13	22	29	37	45	60
Lower Side Channel 11		5	9	16	22	28	34	39	45	50	61
Slough 11										5	17
Upper Side Channel 11					7	13	20	30	44	57	84
Main Channel between Cross Sections 46 and 48	30	35	41	49	56	62	68	73	79	84	94
Side Channel 21			6	10	15	18	22	25	28	31	37
Slough 21					3	5	9	14	21	30	58

Table 6

POTENTIAL DEGRADATION AT SELECTED SLOUGHS,
SIDE CHANNELS AND MAINSTEM SITES

Location	Discharge at Gold Creek (cfs)										
	5,000	7,000	10,000	15,000	20,000	25,000	30,000	35,000	40,000	45,000	55,000
	Estimated Degradation, ft										
Main Channel near Cross Section 4	0.1	0.2	0.3	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.4
Main Channel between Cross Sections 12 & 13	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.8	2.4	3.7
Main Channel upstream from Lane Creek	0.2	0.2	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.5
Mainstem 2 Side Channel at Cross Section 18.2											
Main Channel	0	0	0	0	0	0.1	0.2	0.3	0.5	0.7	1.2
North-east Fork	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2
North-west Fork	0	0	0	0	0	0	0	0.1	0.1	0.2	0.2
Slough 8A	0	0	0	0	0	0	0	0	0	0	0
Slough 9	0	0	0	0	0	0	0	0.1	0.2	0.3	0.5
Main Channel upstream from 4th of July Creek	0.3	0.3	0.4	0.6	0.8	1.1	1.3	1.5	1.7	2.0	2.5
Side Channel 10	0	0	0	0	0	0.1	0.2	0.4	0.6	1.0	2.0
Lower Side Channel 11	0	0	0	0.1	0.2	0.3	0.5	0.7	1.0	1.3	2.1
Slough 11	0	0	0	0	0	0	0	0	0	0	0.1
Upper Side Channel 11	0	0	0	0	0	0.1	0.2	0.3	0.6	0.9	1.8
Main Channel between Cross Sections 46 and 48	0.3	0.4	0.6	0.9	1.2	1.4	1.7	1.9	2.1	2.4	2.8
Side Channel 21	0	0	0	0	0	0	0.1	0.1	0.2	0.2	0.3
Slough 21	0	0	0	0	0	0	0	0	0.1	0.2	0.5

Table 7

NATURAL AND WITH-PROJECT AVERAGE WEEKLY FLOWS
OF SUSITNA RIVER AT GOLD CREEK
(1950-1983)

		With-Project Flows[2]			
Week[1]	Natural Flow	1996 Load Conditions[3]	2001 Load Conditions[3]	2002 Load Conditions[4]	2020 Load Conditions
(1)	(2)	(3)	(4)	(5)	(6)
1	1607	9552	9695	7027	10323
2	1554	9540	9679	6997	10300
3	1512	9526	9655	6965	10285
4	1494	9537	9666	6936	10201
5	1427	9518	9639	6897	10225
6	1354	9561	9789	6903	10262
7	1300	9603	9775	6851	10141
8	1258	9502	9669	6802	10082
9	1204	9357	9521	6709	9957
10	1152	8711	8971	6376	9448
11	1149	8338	8486	6167	9117
12	1157	7953	8093	5959	8781
13	1167	7715	7852	5840	8581
14	1216	7593	7682	5832	8500
15	1240	7260	7303	5670	8245
16	1408	7028	7028	5543	8000
17	1667	6765	6765	5534	7644
18	3654	6912	6875	5481	7532
19	7914	7449	7559	5910	7932
20	13466	8886	9001	6780	9067
21	18715	10440	10521	7434	9896
22	23556	11910	11953	8115	10782
23	27284	11367	11438	9014	10252
24	29369	11679	11741	8960	10452
25	27860	11415	11539	10227	10322
26	26313	10974	11142	11773	10112
27	23987	10006	10161	13951	9317
28	24491	10124	10254	16950	9383
29	24708	10153	10275	19797	9460
30	24031	10013	10204	20915	9355
31	25294	11002	11103	22285	9613
32	23320	10470	10629	21810	9415
33	22387	11770	11072	21224	10756
34	20411	12367	12177	20478	11875
35	18377	12280	11929	18366	11281
36	15621	12685	12088	15756	11772
37	14039	11783	11100	14030	10998
38	12871	11269	10790	12790	10211
39	10663	10304	10033	10750	9649
40	8102	8990	8726	8297	8812
41	6782	8384	8266	7258	8695
42	5348	8543	8374	6443	8557
43	4303	8636	8456	6531	8514
44	3332	8440	8345	6620	8461
45	2861	8792	8691	6824	8908
46	2562	9215	9165	7032	9554
47	2358	9727	9698	7255	10122
48	2204	10196	10195	7476	10603
49	1978	10892	11025	7775	11108
50	1886	11162	11312	7918	11474
51	1785	10796	10915	7675	11162
52	1739	10080	10142	7263	10590

1/ First week is the first week of month of January.
2/ Based on environmental constraints, E-6.
3/ Watana Operation.
4/ Watana - Devil Canyon operation.

Table 8

MAXIMUM NATURAL AND WITH-PROJECT WEEKLY
FLOWS OF SUSITNA RIVER AT GOLD CREEK

Year	Natural Flow	1996 Load Conditions	2001 Load Conditions	2002 Load Conditions	2020 Load Conditions
1950	26171	10092	11534	21157	10327
51	30057	15024	11374	30057	11856
52	38114	14216	14216	37243	12721
53	35114	14356	15779	25643	11771
54	31143	13975	13975	31143	12664
55	37243	22402	19671	35236	18572
56	43543	25394	22429	32000	26000
57	37443	20071	19275	25943	13414
58	38686	12426	12426	37485	11817
59	44171	28700	16498	41415	14829
60	32043	13342	13914	28943	12203
61	38714	15622	15622	26000	13787
62	58743	26057	26057	35557	23571
63	40257	19900	19543	38549	22106
64	75029	18410	18410	29834	14941
65	33643	21913	21913	28514	19812
66	47686	17098	17098	28014	14719
67	54871	41459	29071	41589	30600
68	37343	14439	15125	29429	12551
69	18114	9861	8000	8000	10228
70	26429	9211	9409	8126	10226
71	47186	22857	22857	37427	22857
72	44243	18029	19488	33149	18029
73	36443	11756	11756	23171	10293
74	31357	11846	11846	16614	10828
75	36400	19886	18629	29900	19886
76	29843	11965	11965	25844	11530
77	46300	15438	15438	25514	14420
78	22786	11800	11921	20214	11685
79	32457	12955	13558	32457	12927
80	33557	13106	13264	33557	13304
81	46729	37029	37029	39966	37029
82	28857	12141	12145	27500	11895
83	27343	12683	13481	26586	12875

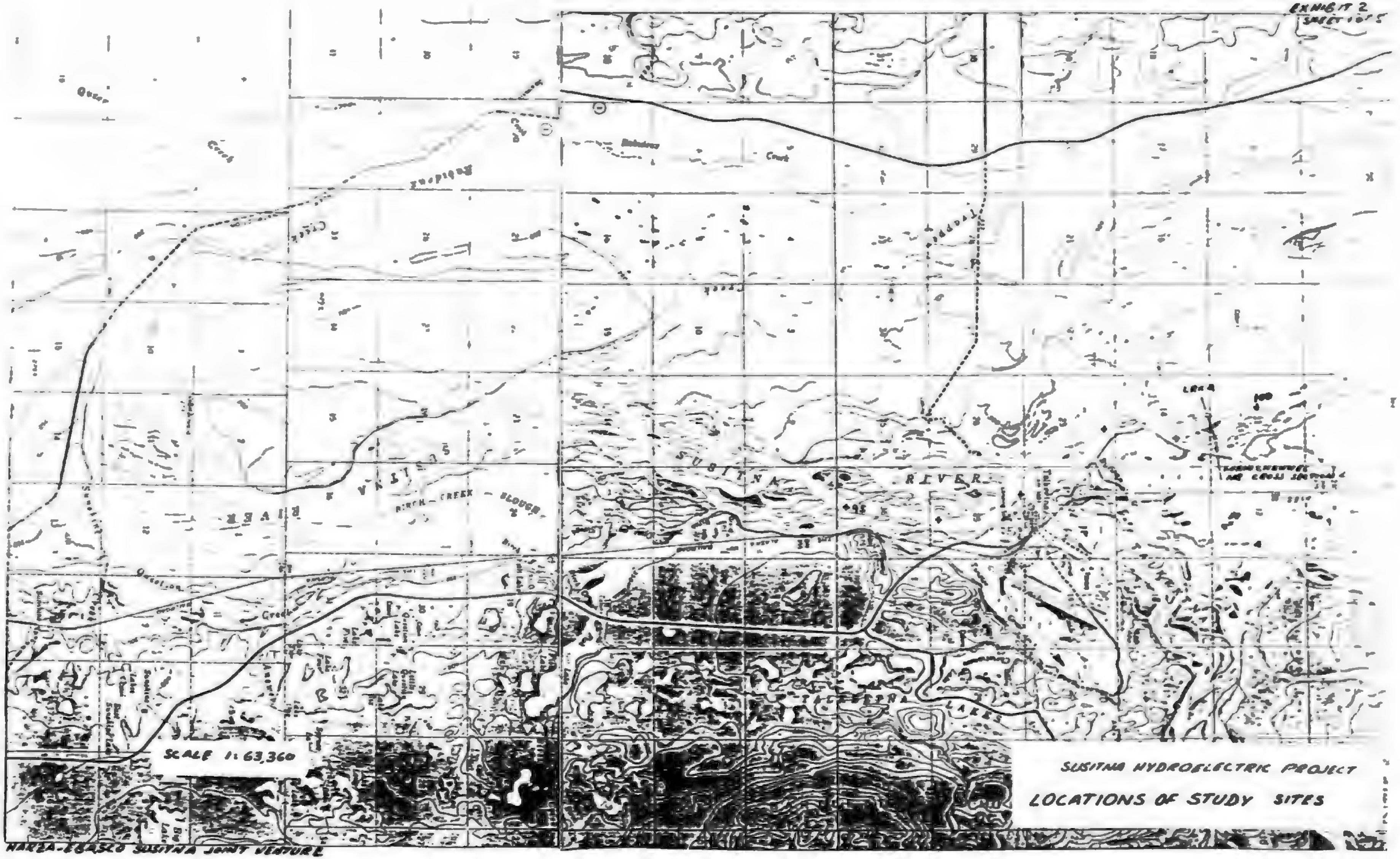
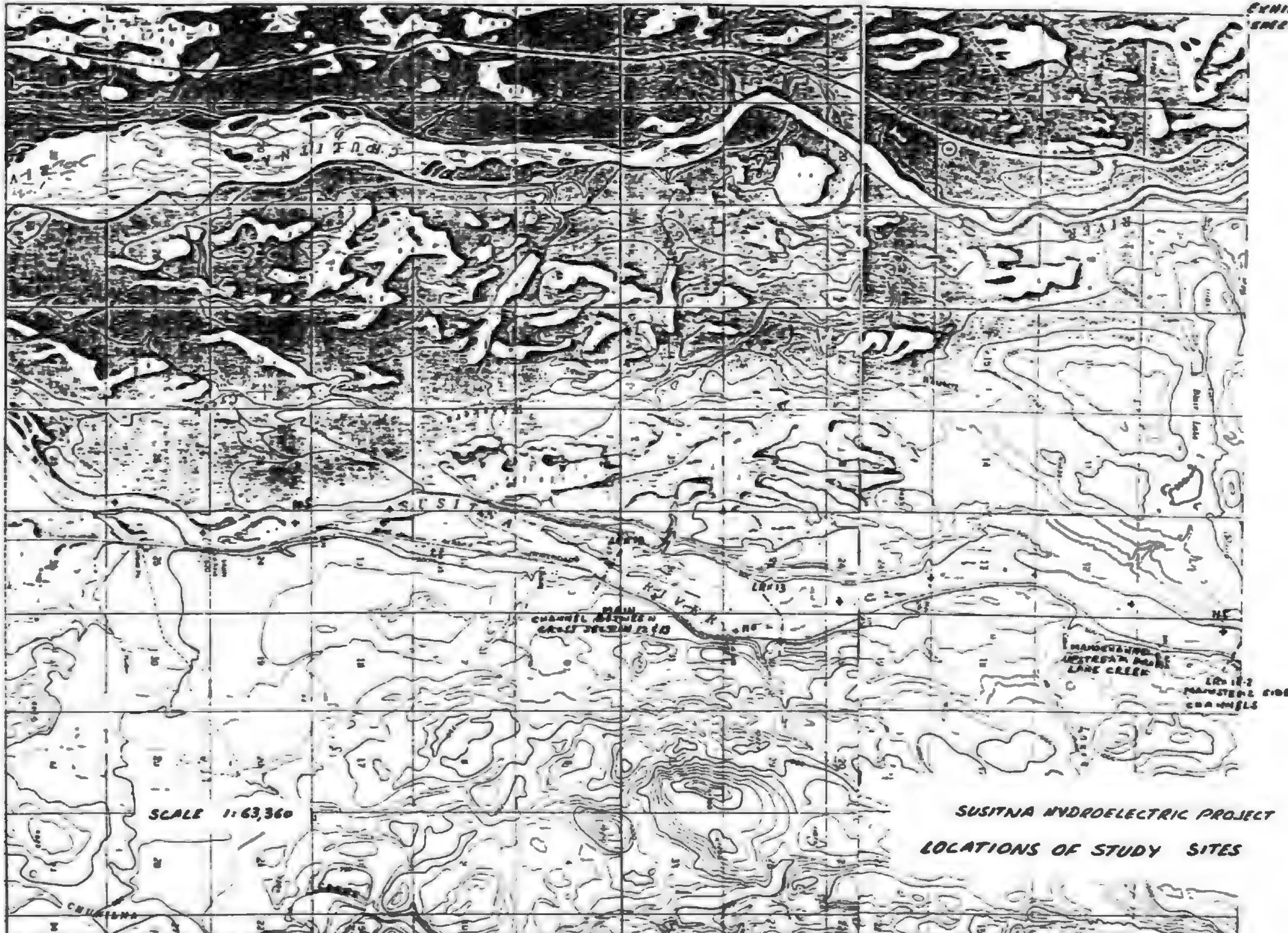


EXHIBIT 2
SHEET 1 OF 5
SUSITNA
RIVER
SCALE 1:63,360
SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF STUDY SITES
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 2
SHEET 2 OF 5



HARZA-EBASCO SUSITNA JOINT VENTURE

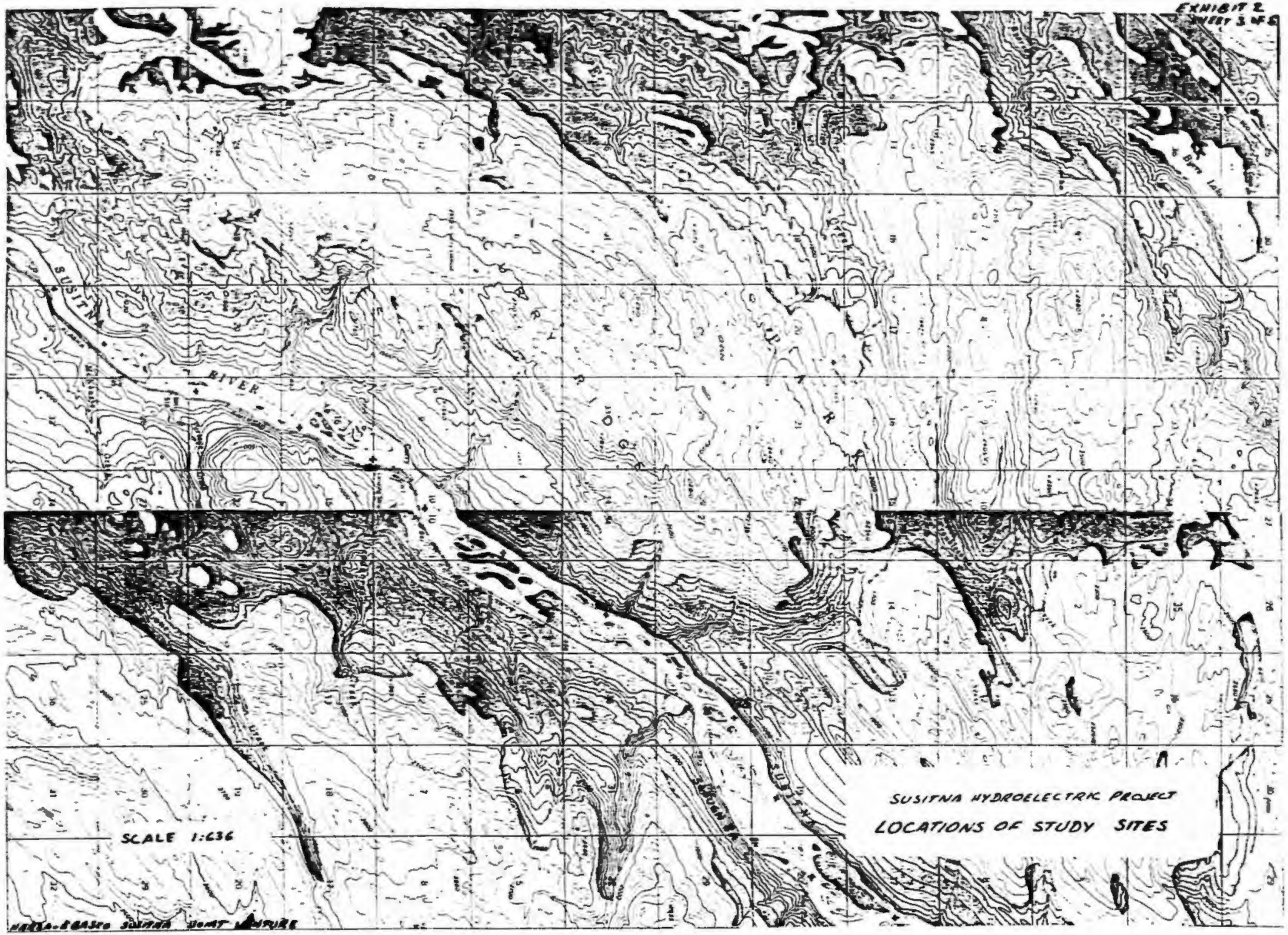
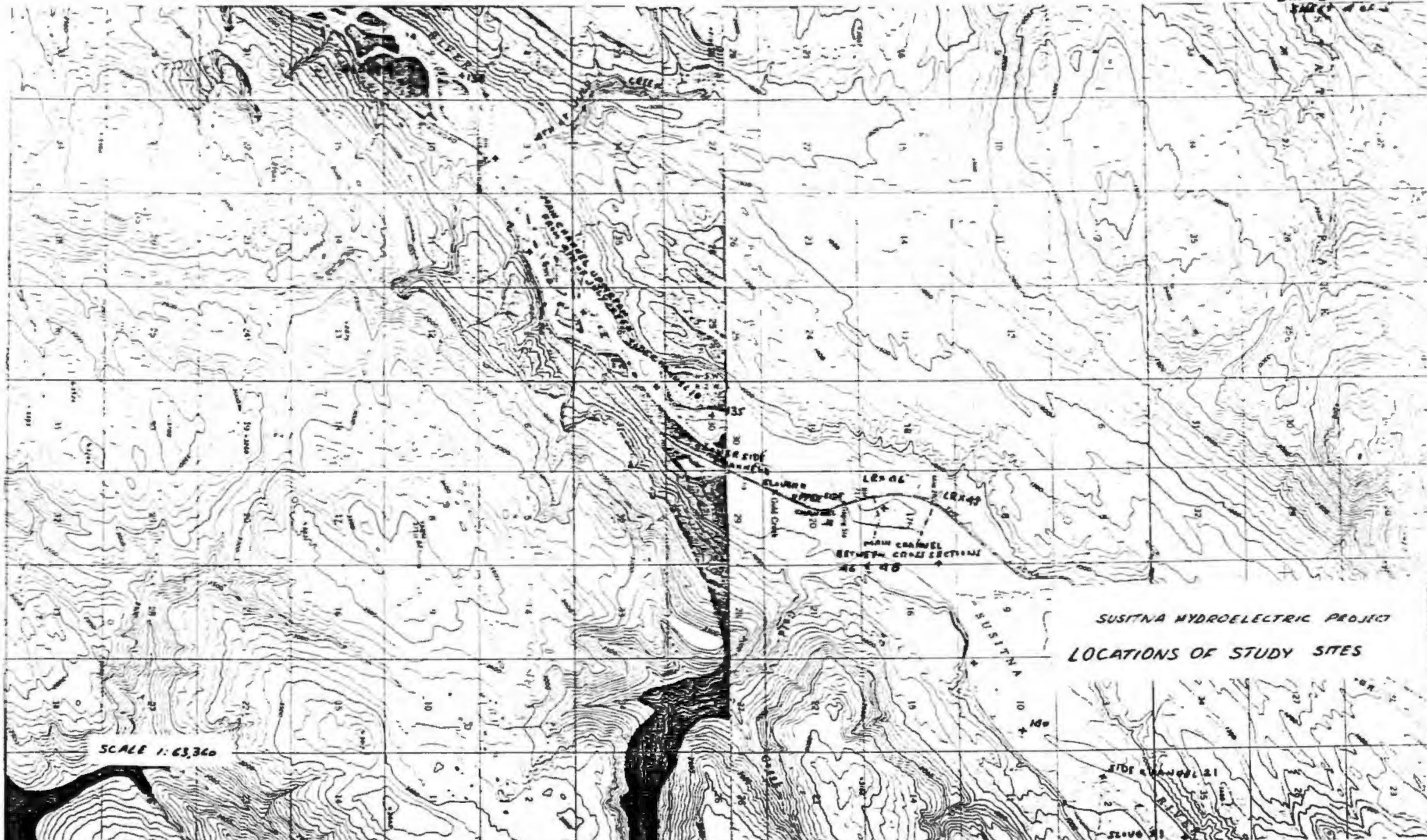
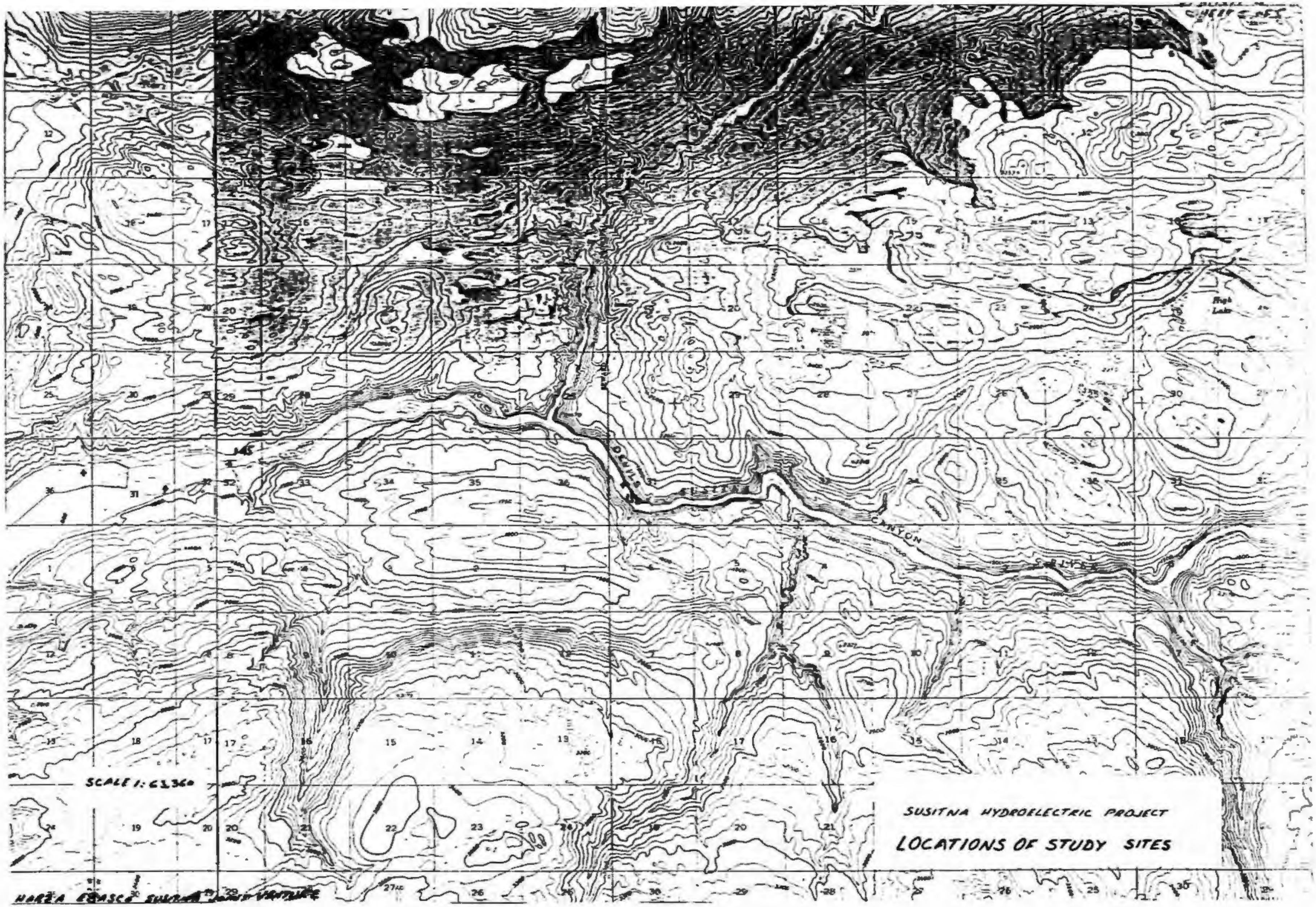


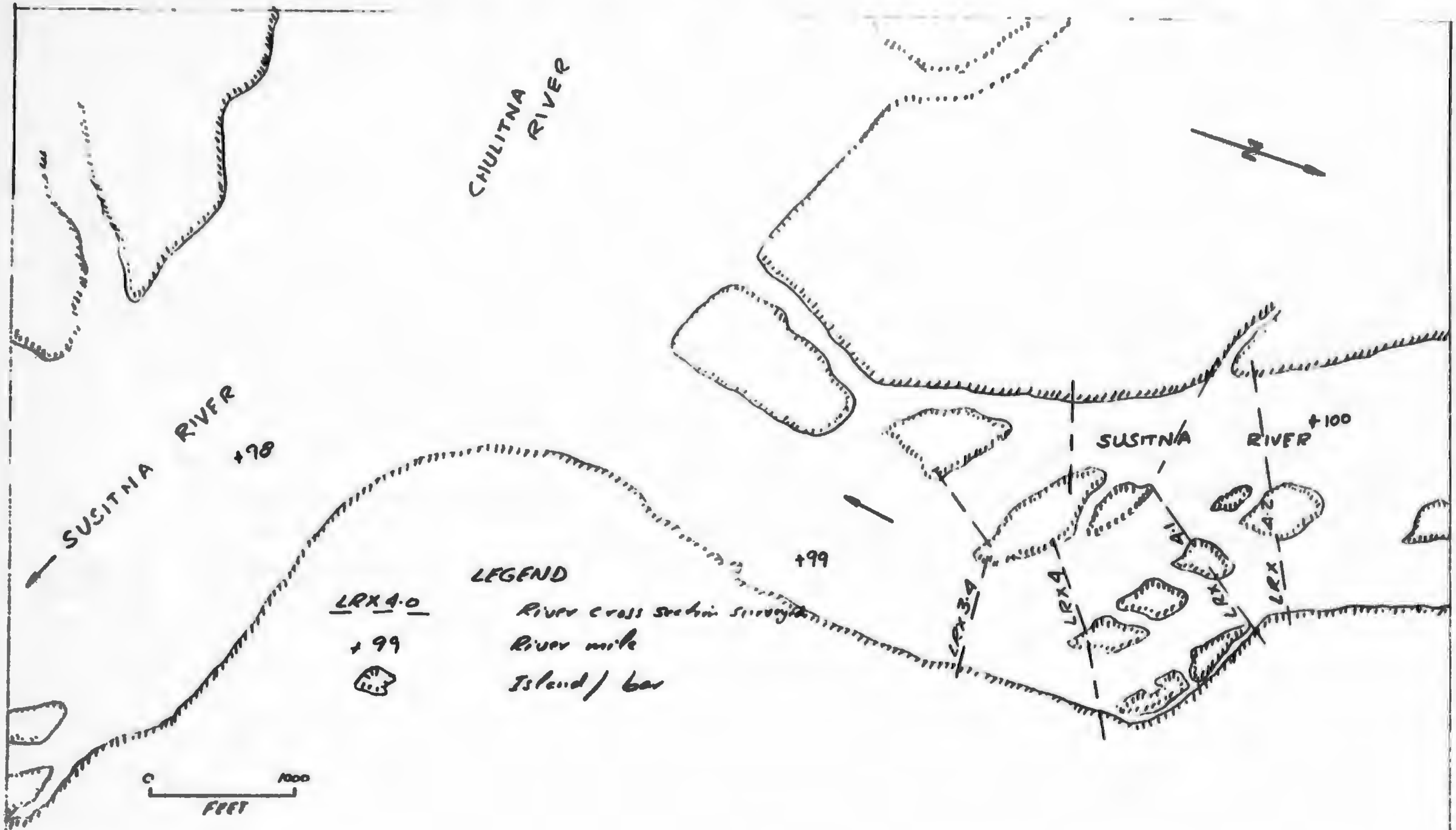
EXHIBIT 2
SHEET 3 OF 5
SUSITNA RIVER
SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF STUDY SITES
SCALE 1:636
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 2



HARZA-EBASCO SUSITNA JOINT VENTURE


SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF STUDY SITES
SCALE 1:63360
DEVILS
SUSITNA
CANYON
RIVER
High Lake
HARZA EBASCO SUSITNA JOINT VENTURE

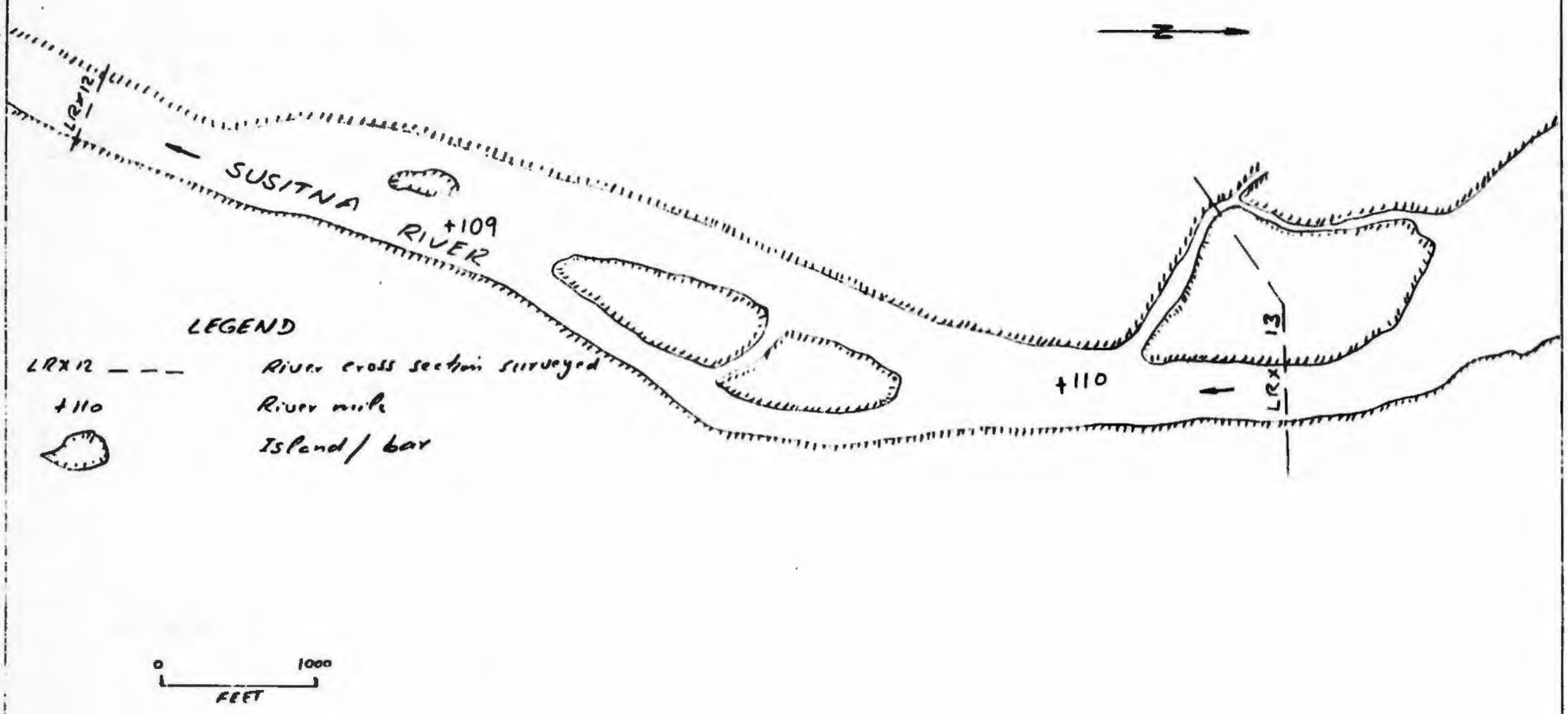


SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL NEAR CROSS
SECTION 1

SOURCE R&M/ADF&G

EXHIBIT 3

HARZA-EBASCO SUSITNA JOINT VENTURE

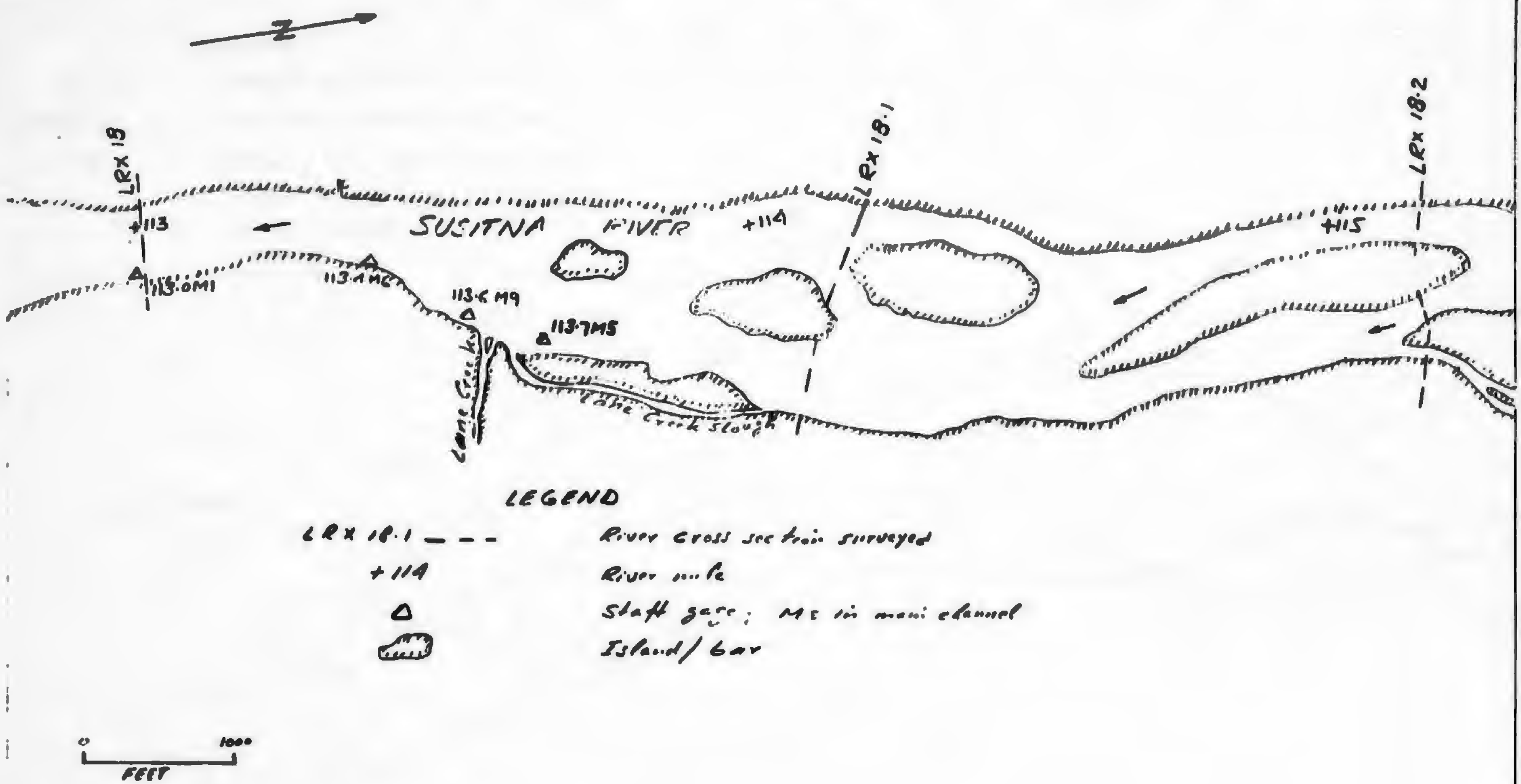


SOURCE RSM/ADF&G

SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL BETWEEN
CROSS SECTIONS 12 AND 13

EXHIBIT 4

HARZA-EBASCO SUSITNA JOINT VENTURE



SOURCE: R&M/ADF&G

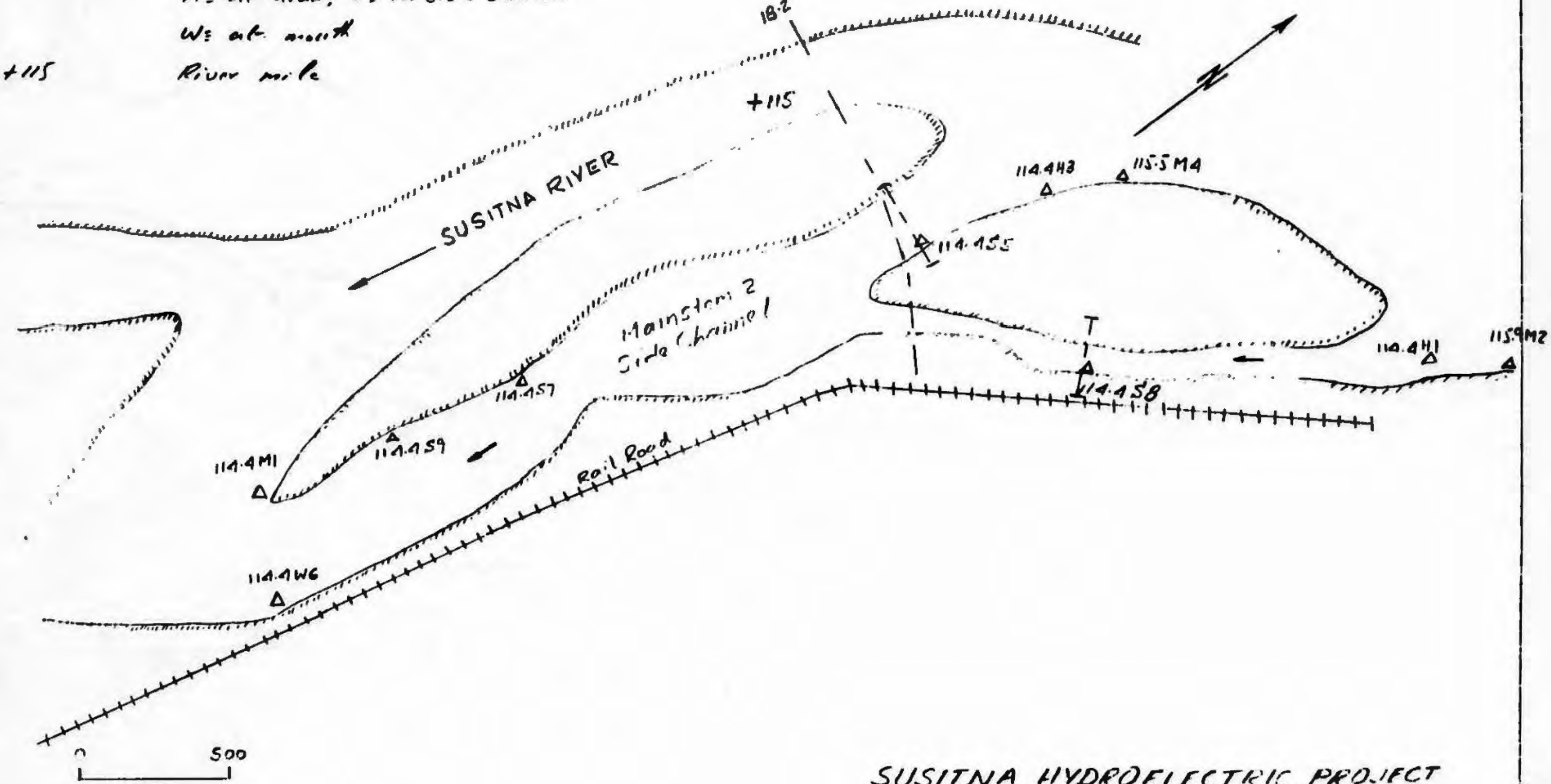
SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL UPSTREAM FROM
LANE CREEK

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 5

LEGEND

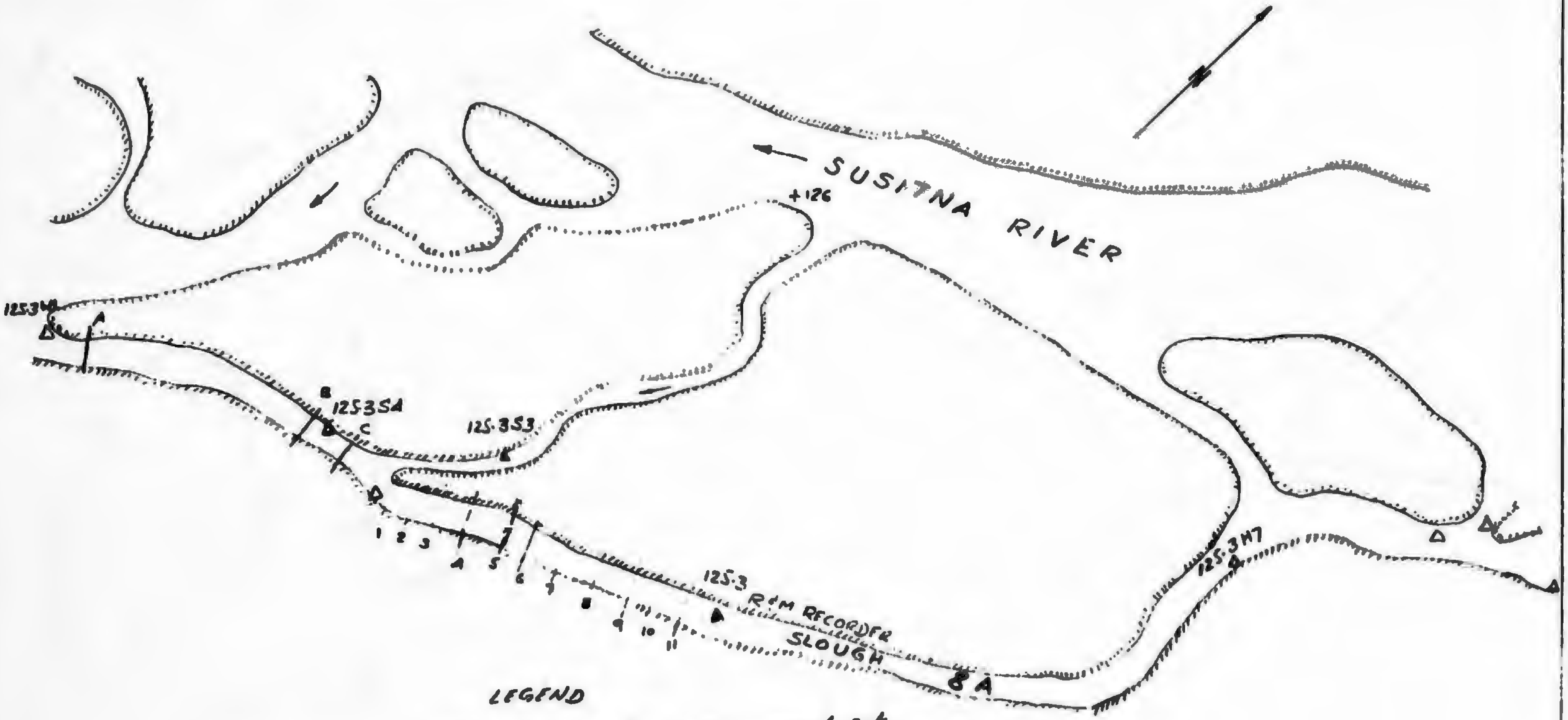
⊢ ⊣	Discharge Measurement Site
18.2 - · - · -	River cross section surveyed
Δ	Staff gage, M = in main channel
	H = at head; S = in side channel
	W = at mouth
+115	River mile



SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
MAINSTEM 2 SIDE CHANNELS AT
CROSS SECTION 18.[illegible]

EXHIBIT 6



LEGEND

0 — 2000
FEET

Discharge Measurement Site

Transect

▲ Water level recorder

△ Staff gage; H: at head
S: in slough; W: at mouth

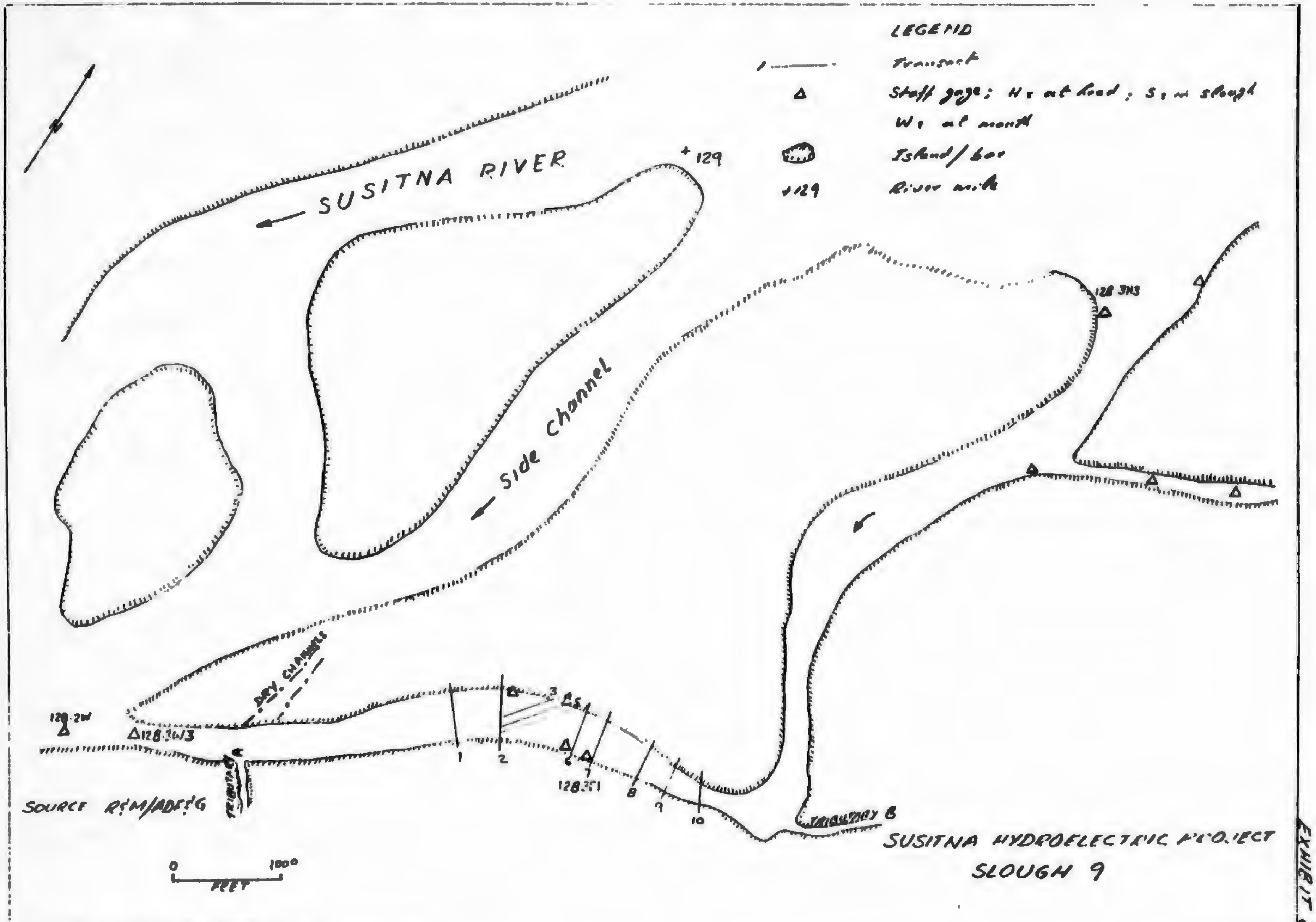
SOURCE: R&M/ADF&G

+126 River mile

SUSITNA HYDROELECTRIC PROJECT
SLOUGH 8A

EXHIBIT 7

HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

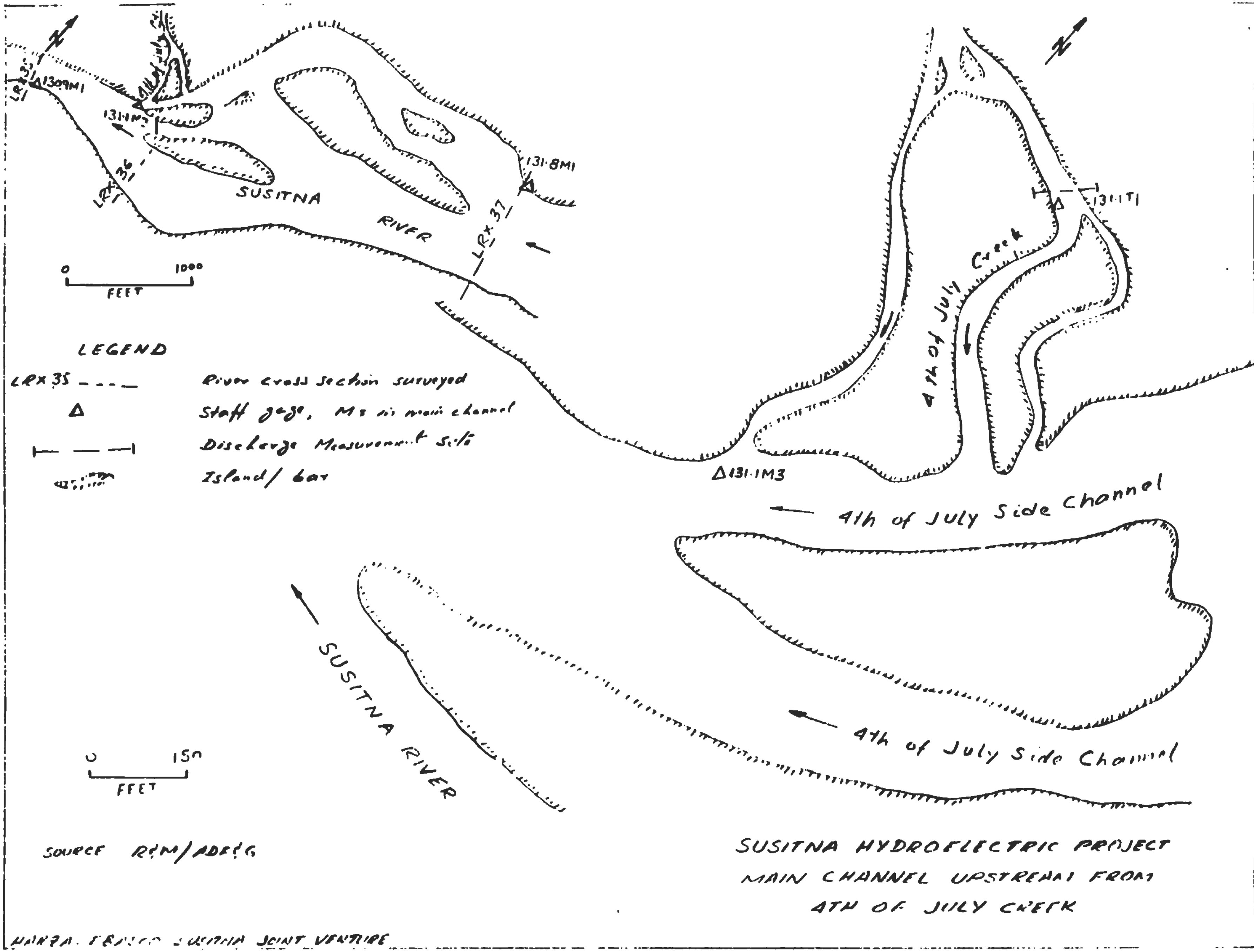
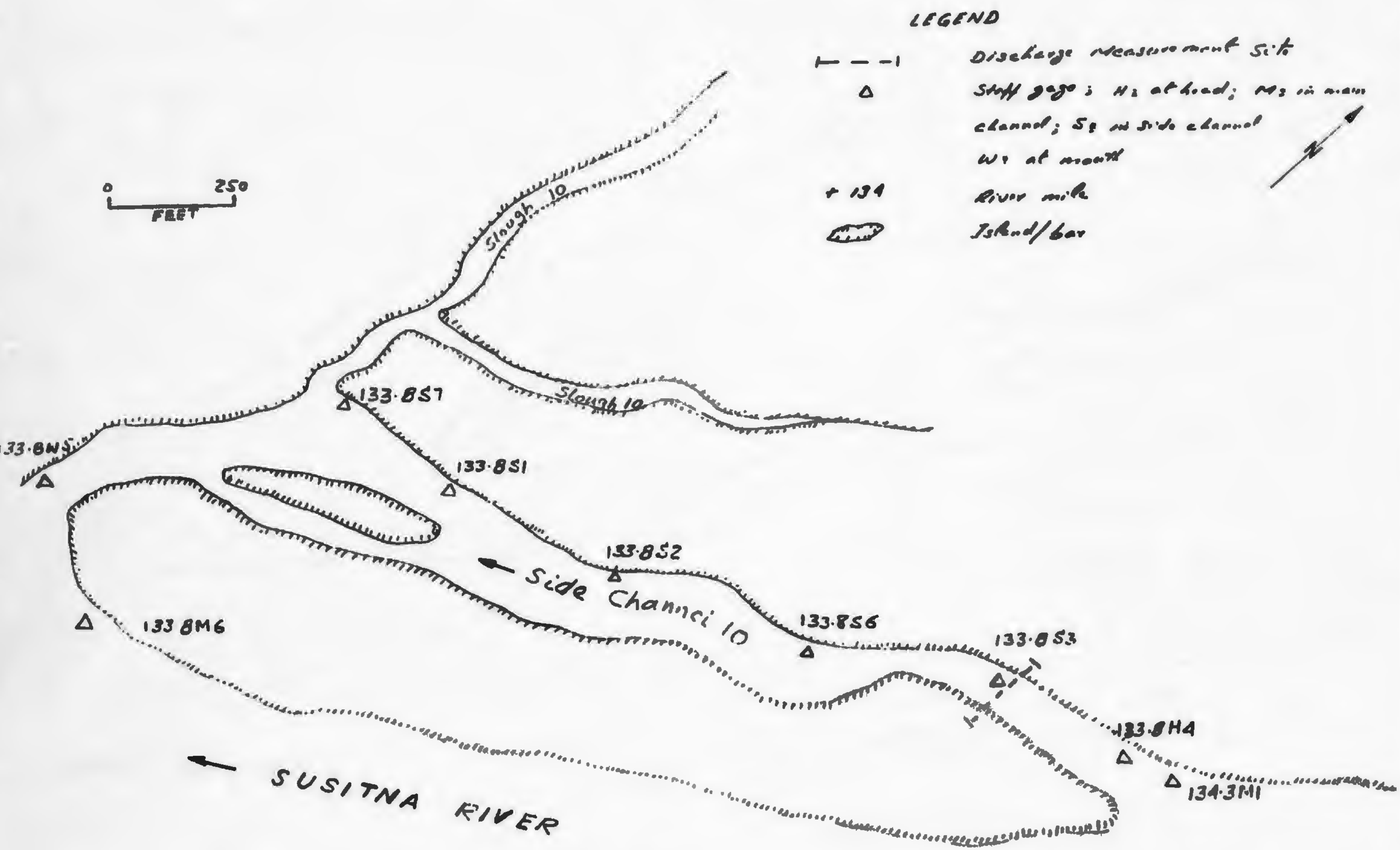


EXHIBIT 9

SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL UPSTREAM FROM
4TH OF JULY CREEK

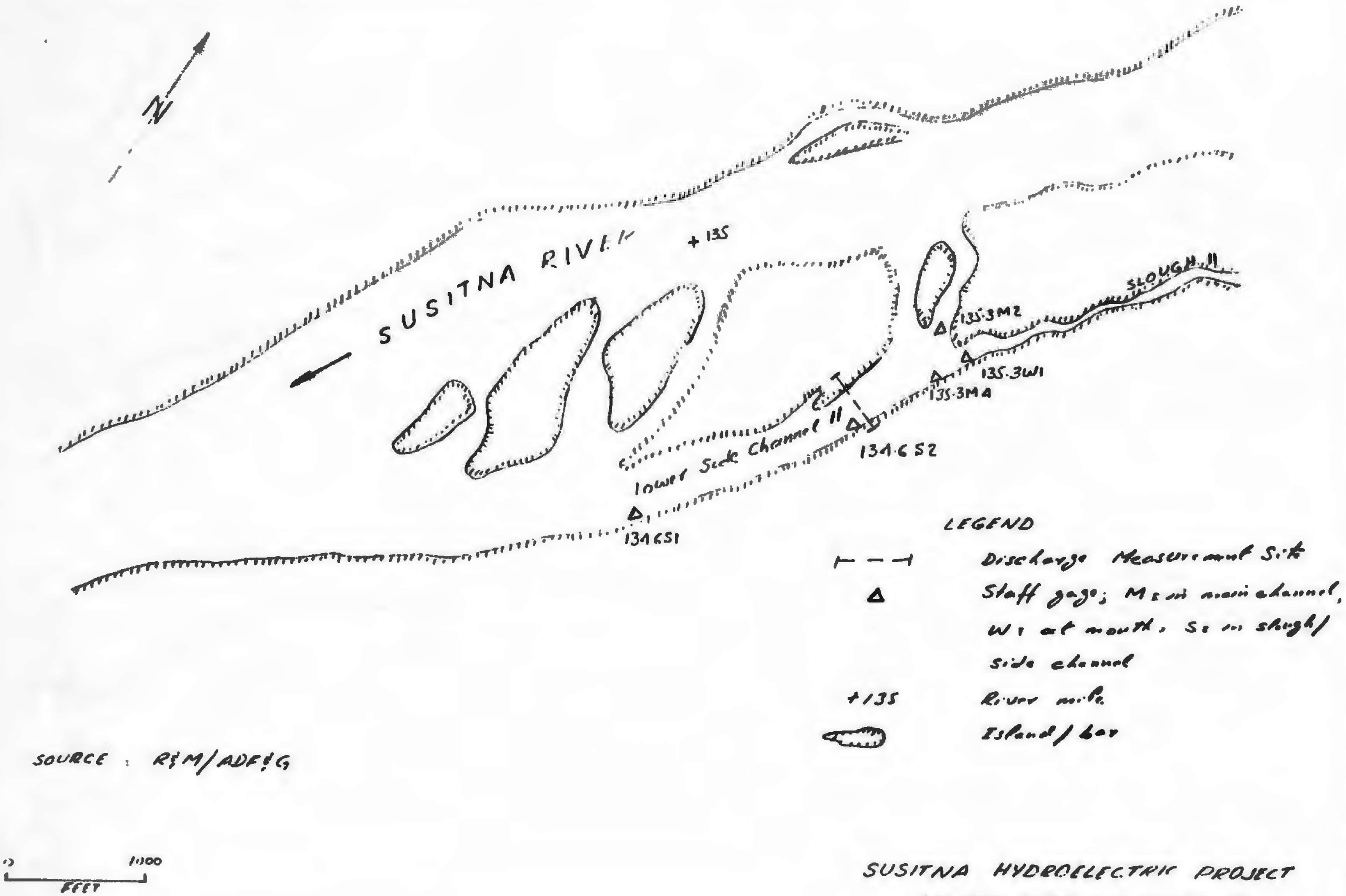


SOURCE R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
SIDE CHANNEL 10

EXHIBIT 10

HARZA- EBASCO SUSITNA JOINT VENTURE

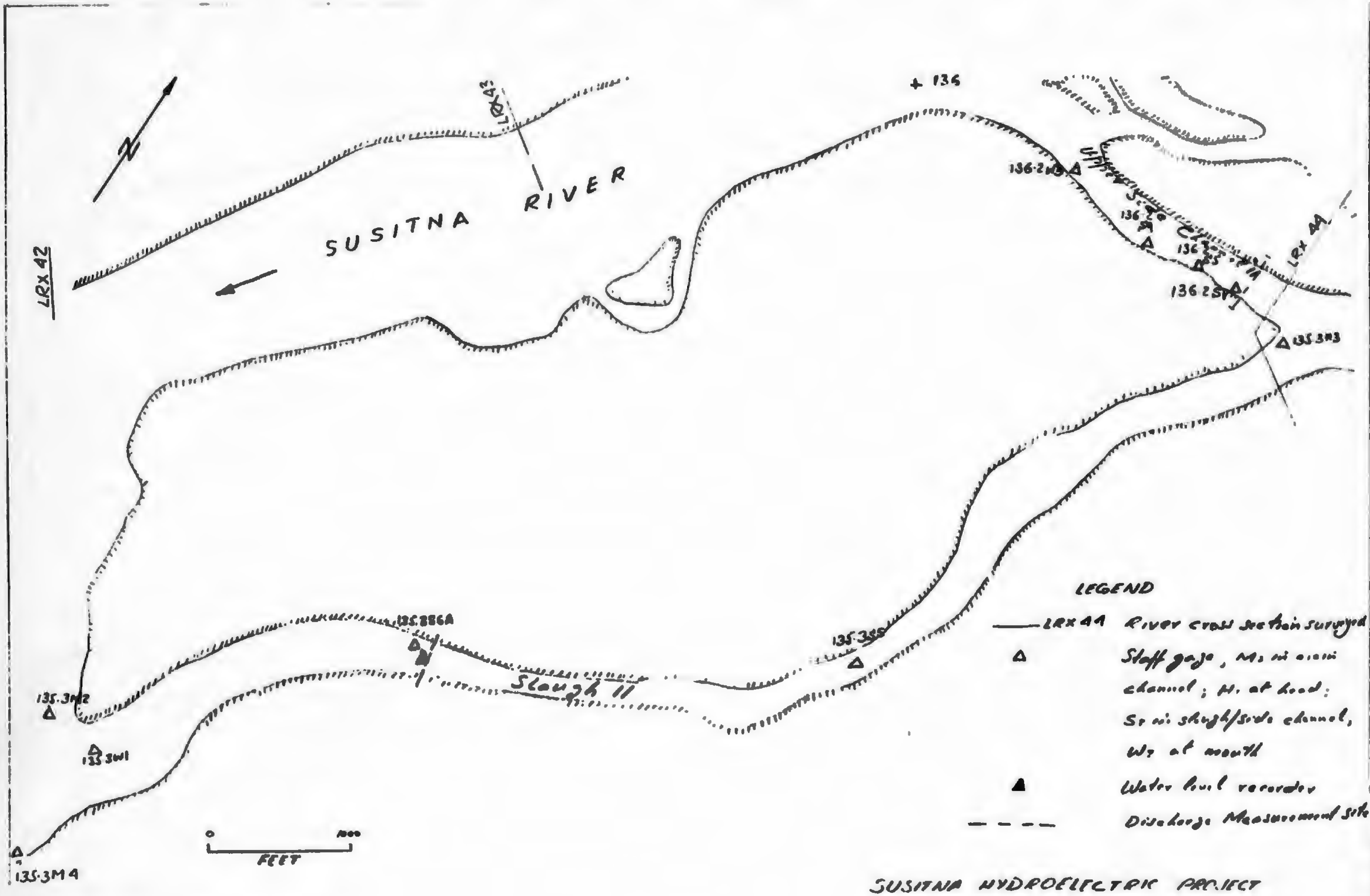


SOURCE : R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
LOWER SIDE CHANNEL 11

EXHIBIT 11

HARZA - EBASCO SUSITNA JOINT VENTURE

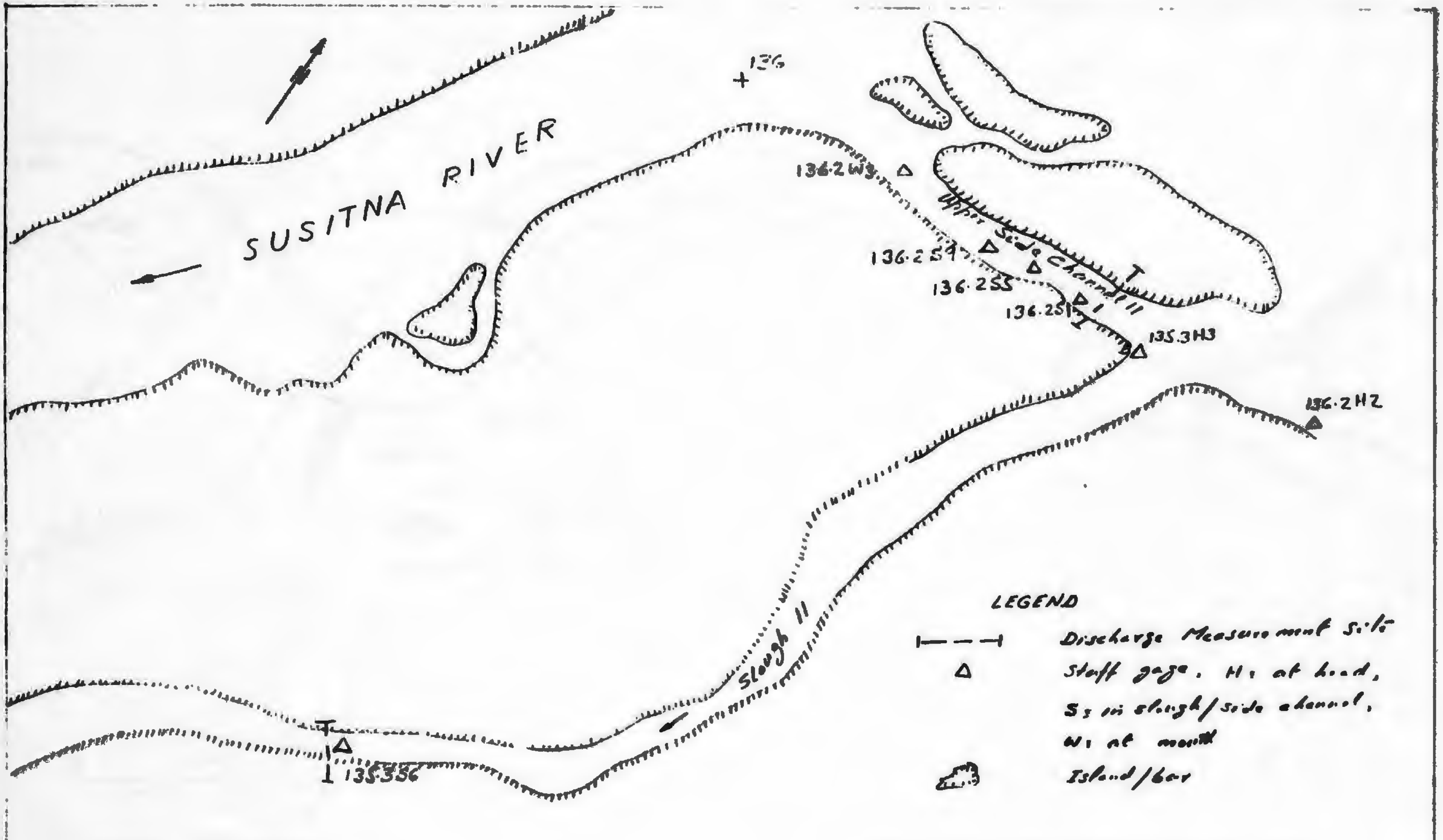


SUSITNA HYDROELECTRIC PROJECT
SLOUGH 11

SOURCE R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 12



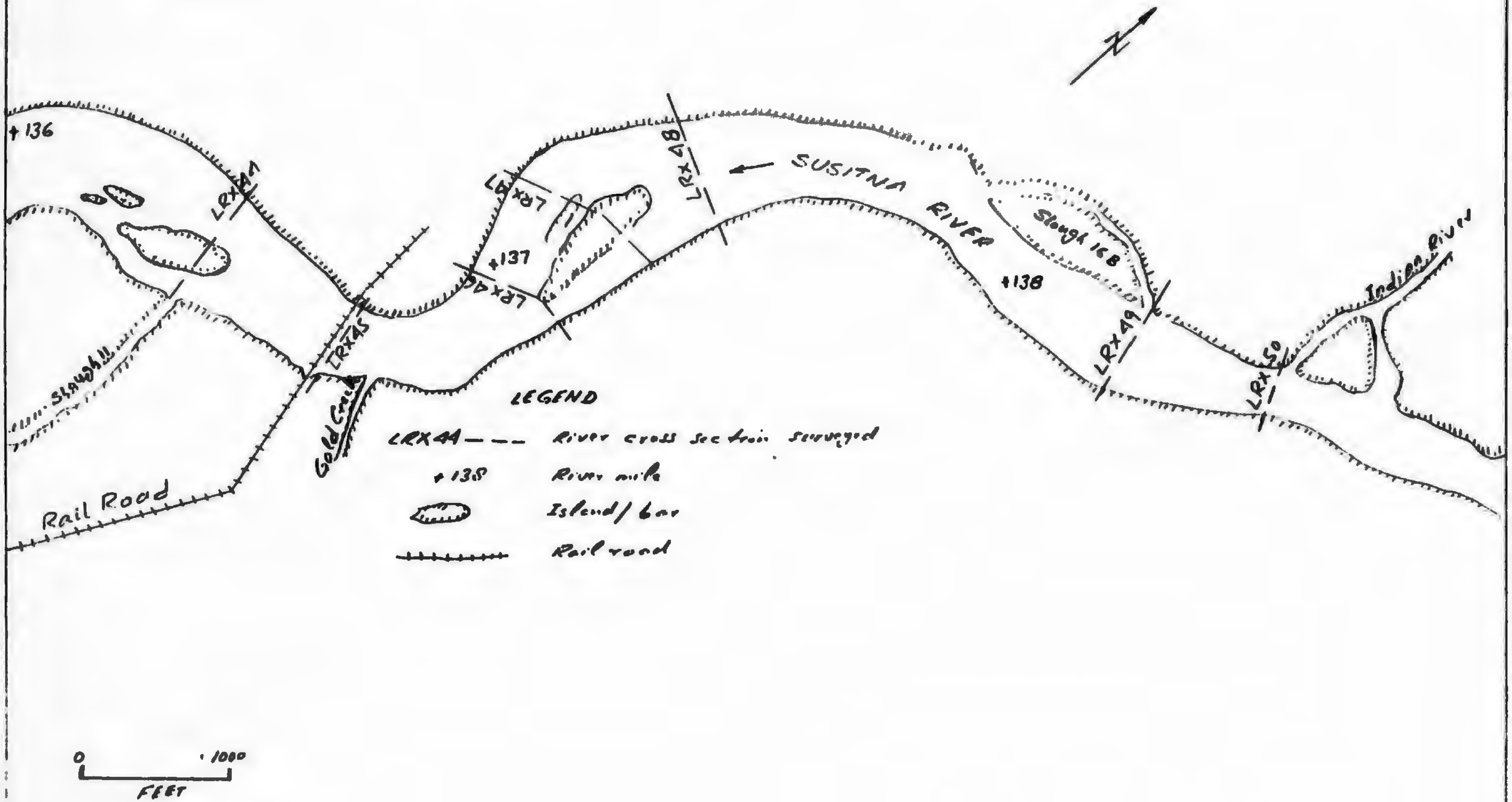
0 1000
FEET

SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
UPPER SIDE CHANNEL 11

EXHIBIT 13

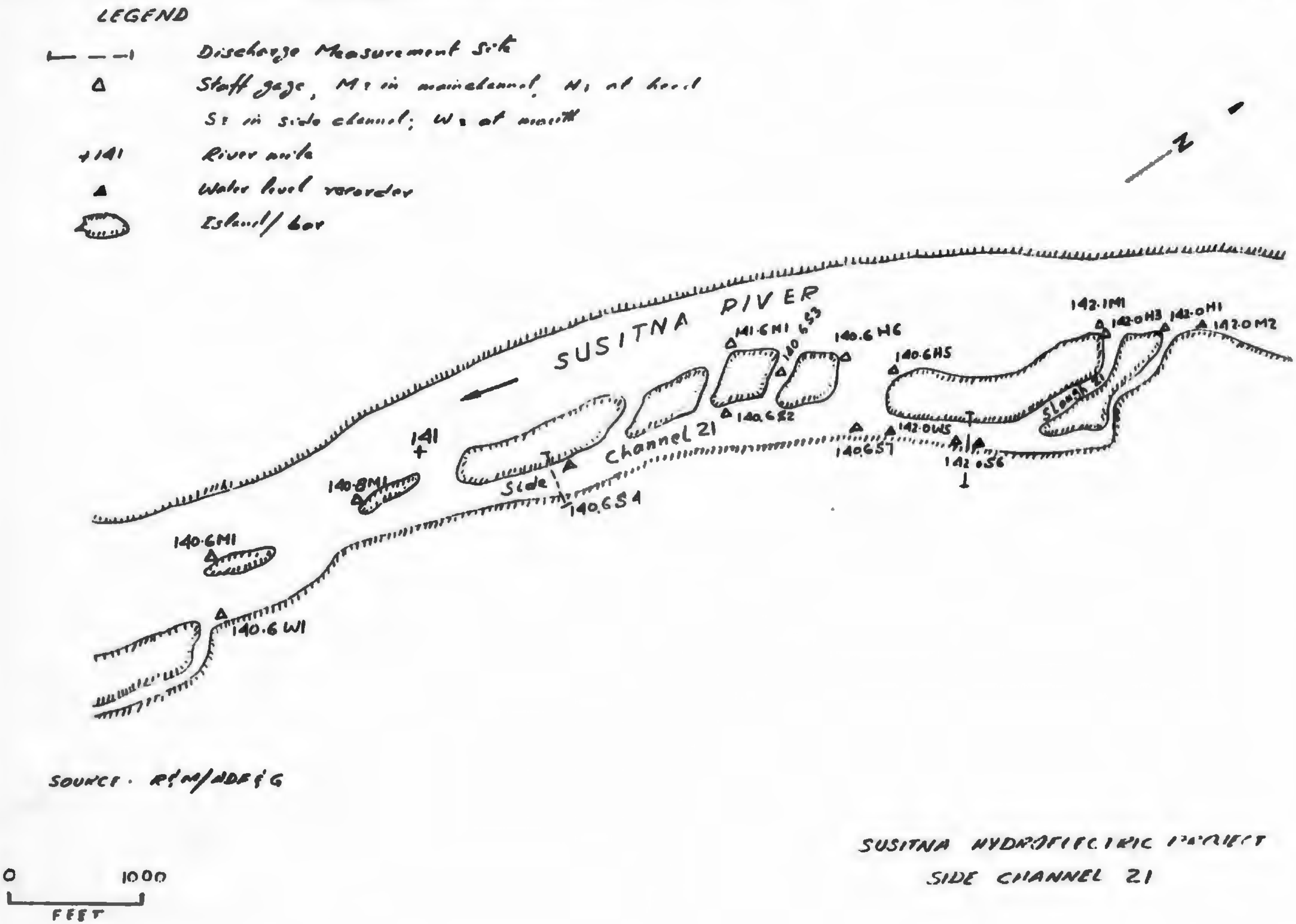
HARZA EBASCO SUSITNA JOINT VENTURE



SOURCE R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
MAINCHANNEL BETWEEN RIVER CROSS
SECTIONS 46 AND 48

EXHIBIT 14



SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT

SIDE CHANNEL 21

EXHIBIT 15

HARZA-EBASCO SUSITNA JOINT VENTURE

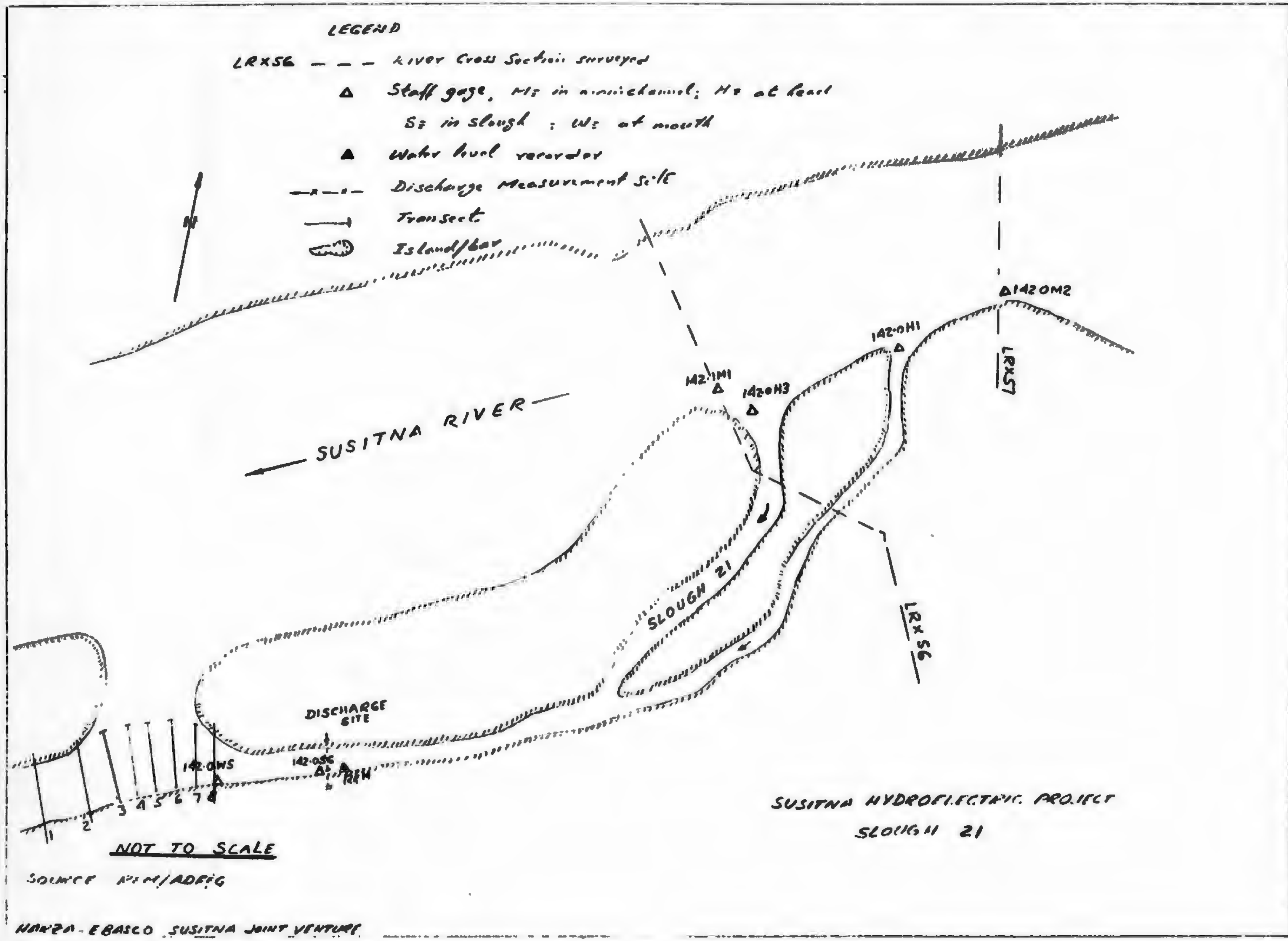
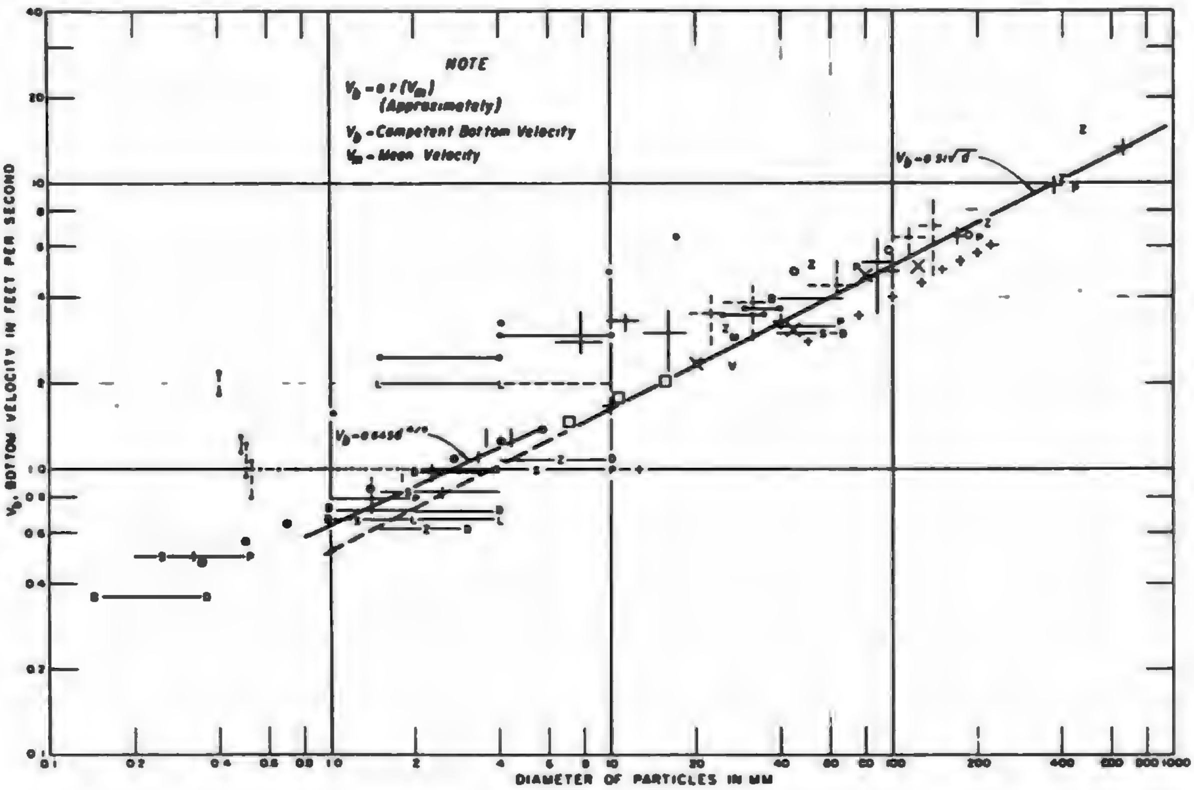

LEGEND
LRXS6 — — — River Cross Section surveyed
Staff gage, M= in mainchannel; H= at head
S= in slough ; W= at mouth
Water level recorder
Discharge Measurement Site
Transect
Island/bar
N
142.0M2
142.0H1
142.1M1
142.0H3
LRX57
SUSITNA RIVER
SLOUGH 21
LRX56
DISCHARGE SITE
142.0W5
142.0S6
1 2 3 4 5 6 7 8
NOT TO SCALE
SOURCE R&M/ADF&G
SUSITNA HYDROELECTRIC PROJECT
SLOUGH 21
EXHIBIT 16
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 17

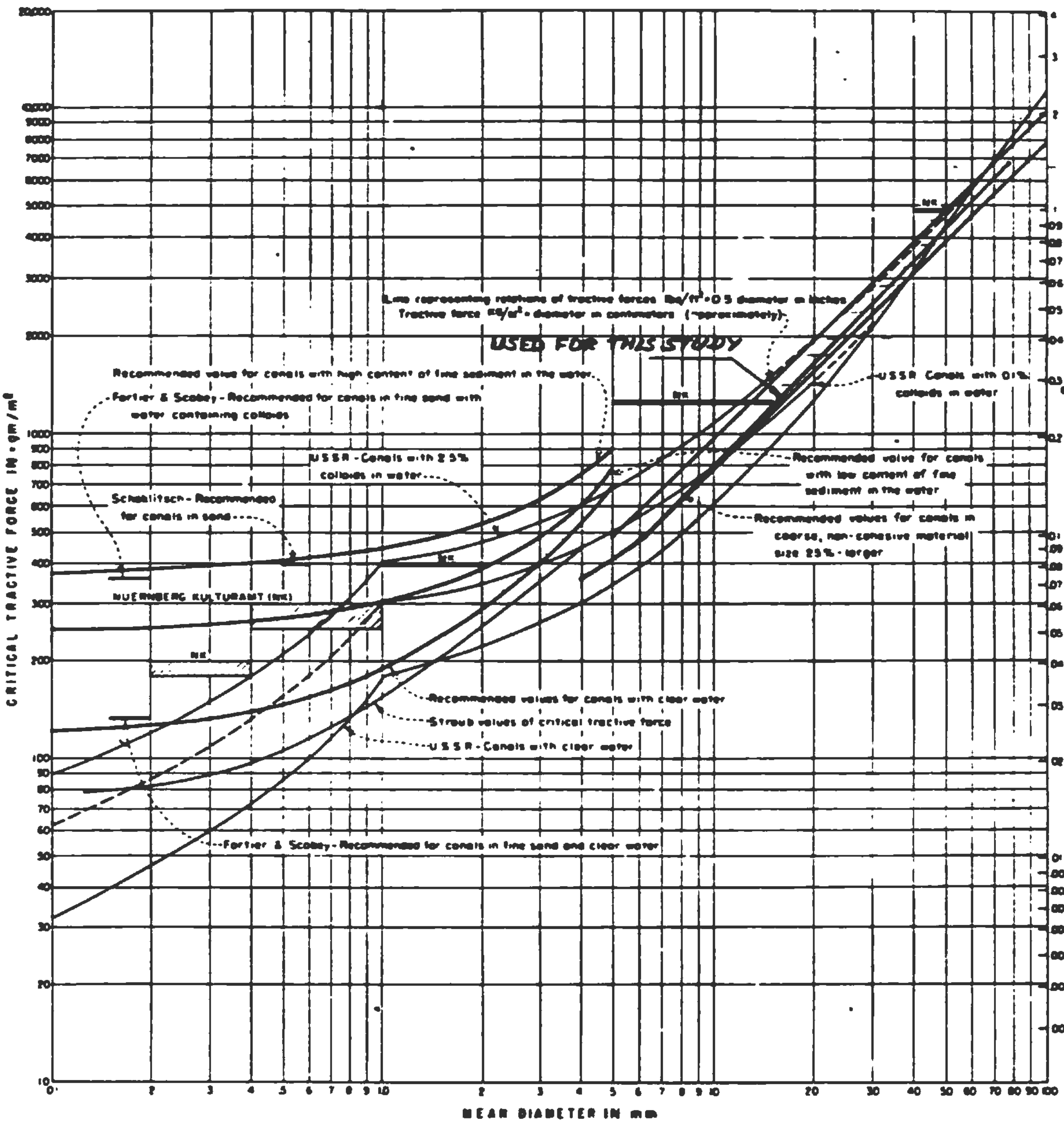


SUSITNA HYDROELECTRIC PROJECT

RELATIONSHIP BETWEEN PARTICLE SIZE AND BOTTOM VELOCITY

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 18



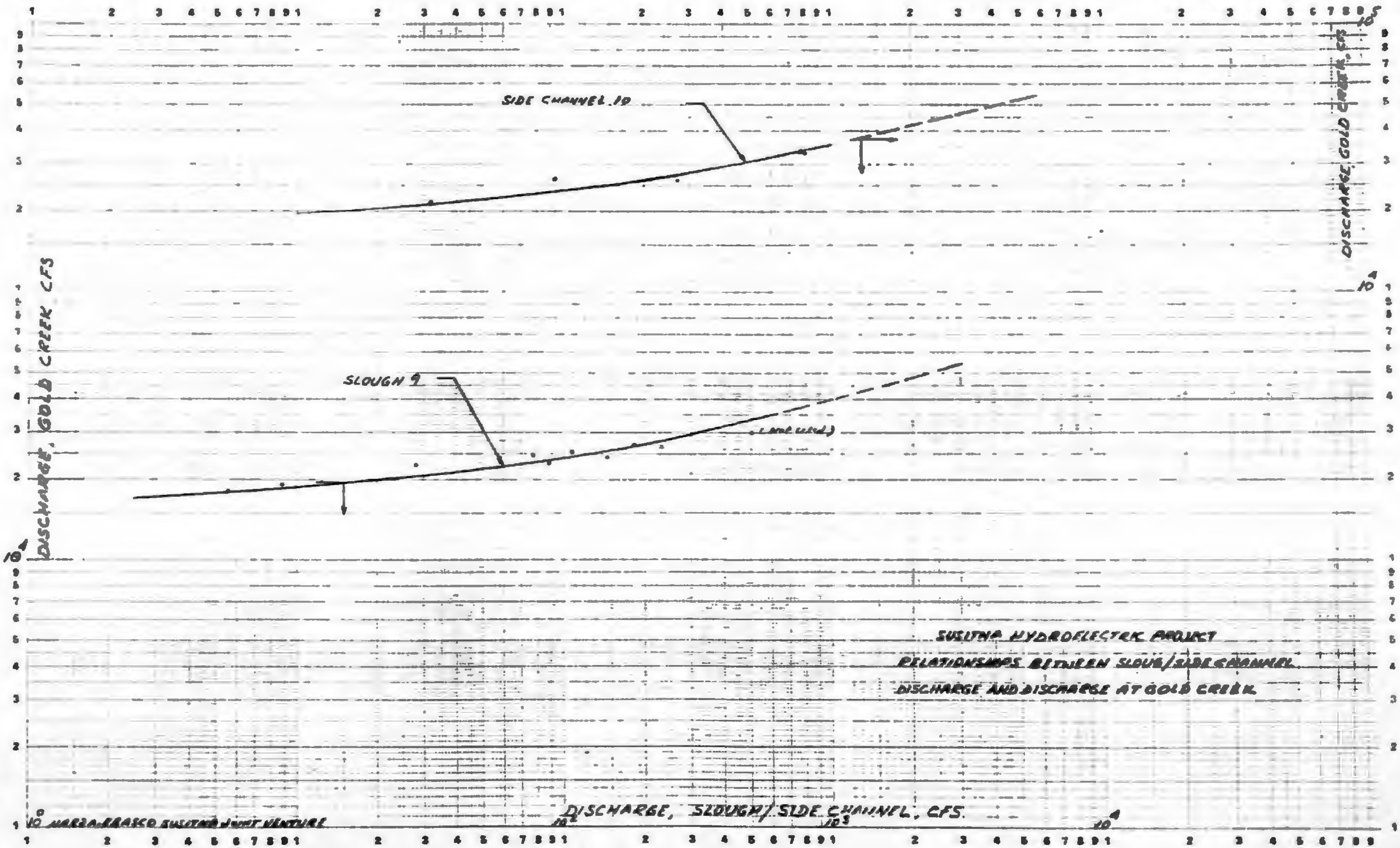
SUSITNA HYDROELECTRIC PROJECT

RELATIONSHIP BETWEEN MEAN DIAMETER AND CRITICAL TRACTIVE FORCE

(DESIGN OF SMALL DAMS)

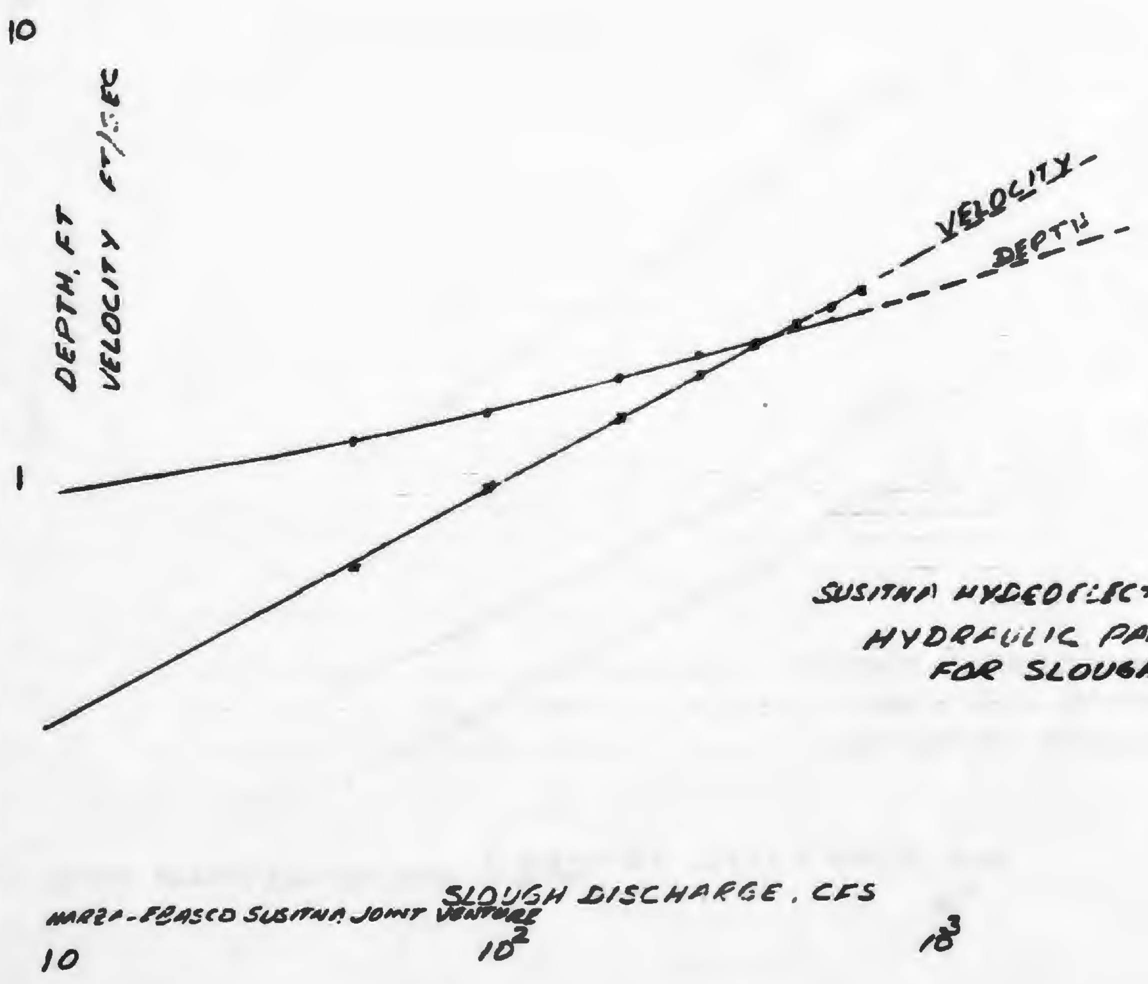
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 19



SIDE CHANNEL 19
SLOUGH 9
DISCHARGE, GOLD CREEK CFS
DISCHARGE, SLOUGH/SIDE CHANNEL, CFS.
SUSITNA HYDROELECTRIC PROJECT
RELATIONSHIPS BETWEEN SLOUGH/SIDE CHANNEL
DISCHARGE AND DISCHARGE AT GOLD CREEK
HARZA-EBASCO SUSITNA JOINT VENTURE

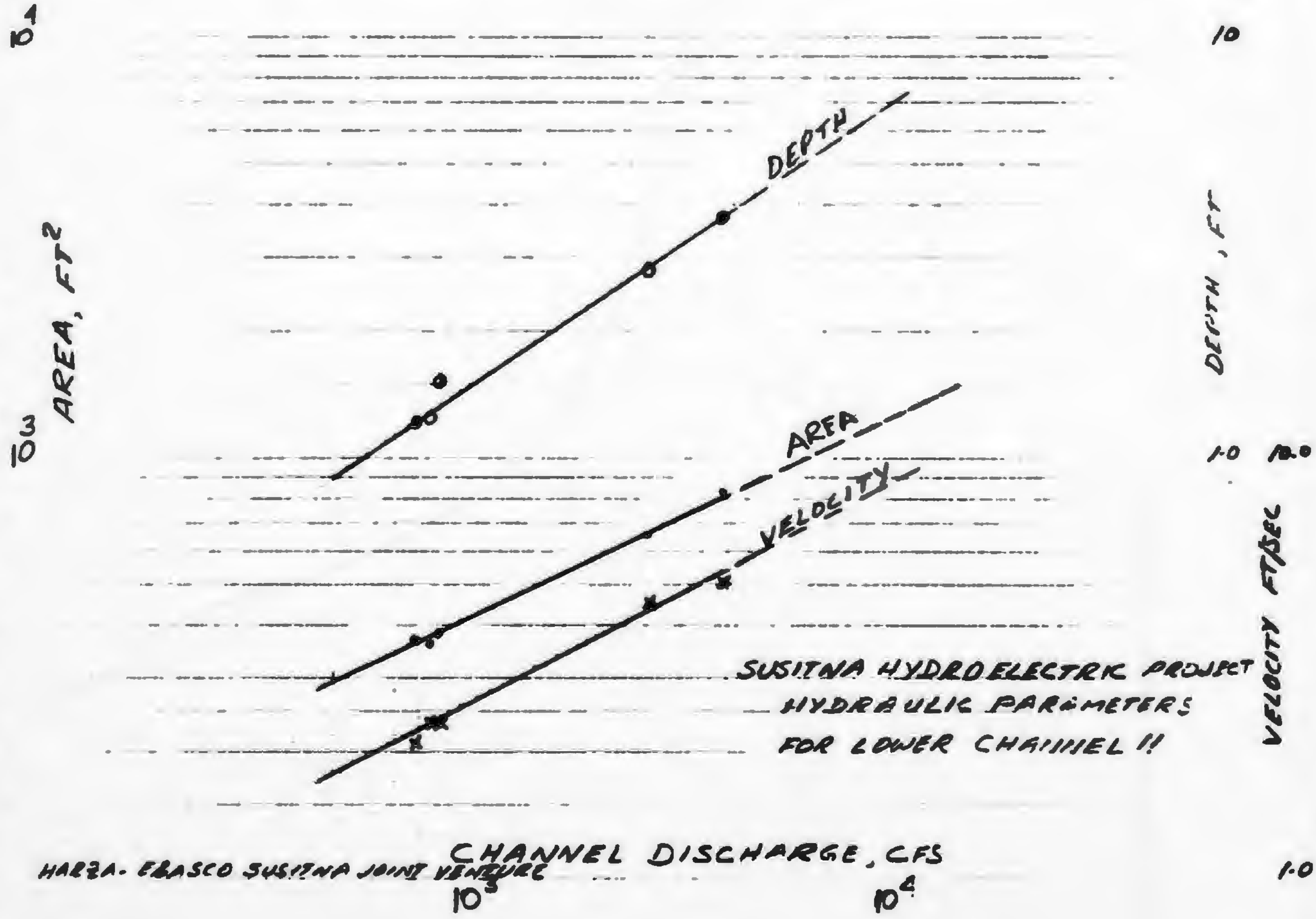
EXHIBIT 20



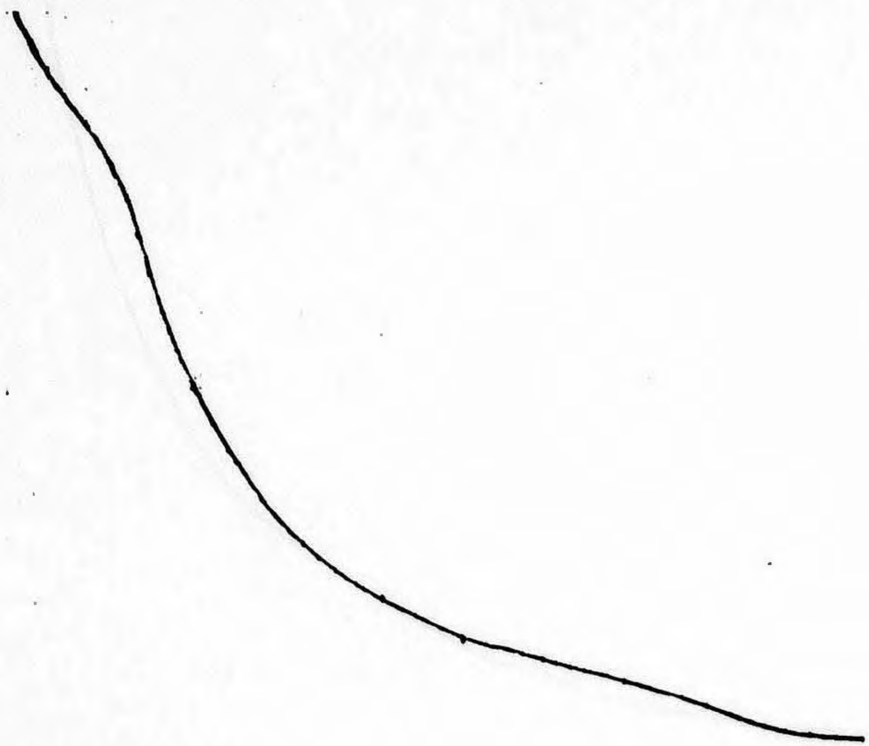
SUSITNA HYDROELECTRIC PROJECT
HYDRAULIC PARAMETERS
FOR SLOUGH 9

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 21



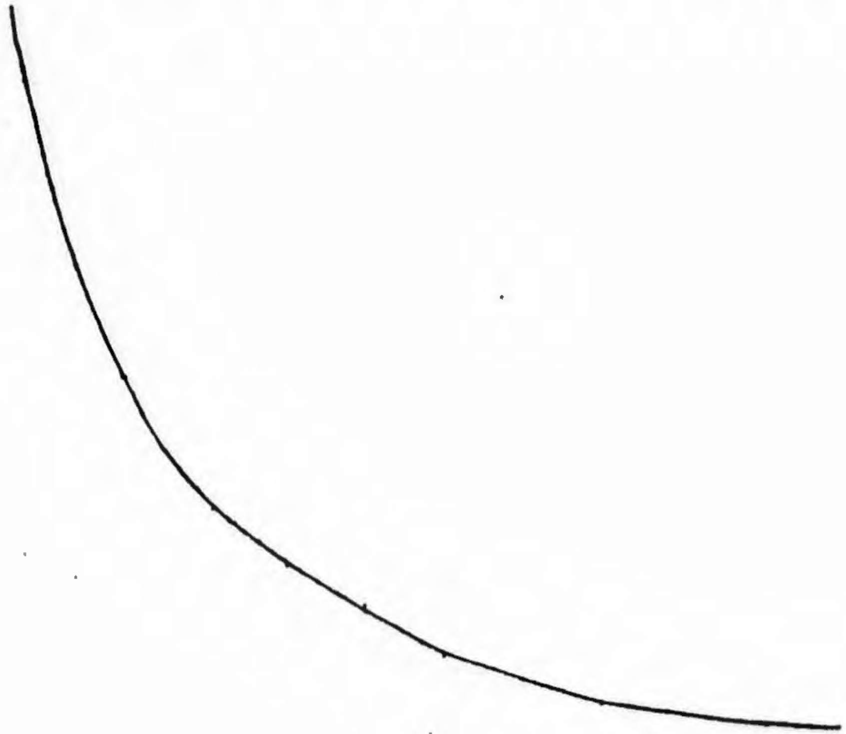
HARZA- EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED MATERIAL IN MAIN CHANNEL NR. CROSS SECTION 4.0

HARZA- EBASCO SUSITNA JOINT VENTURE

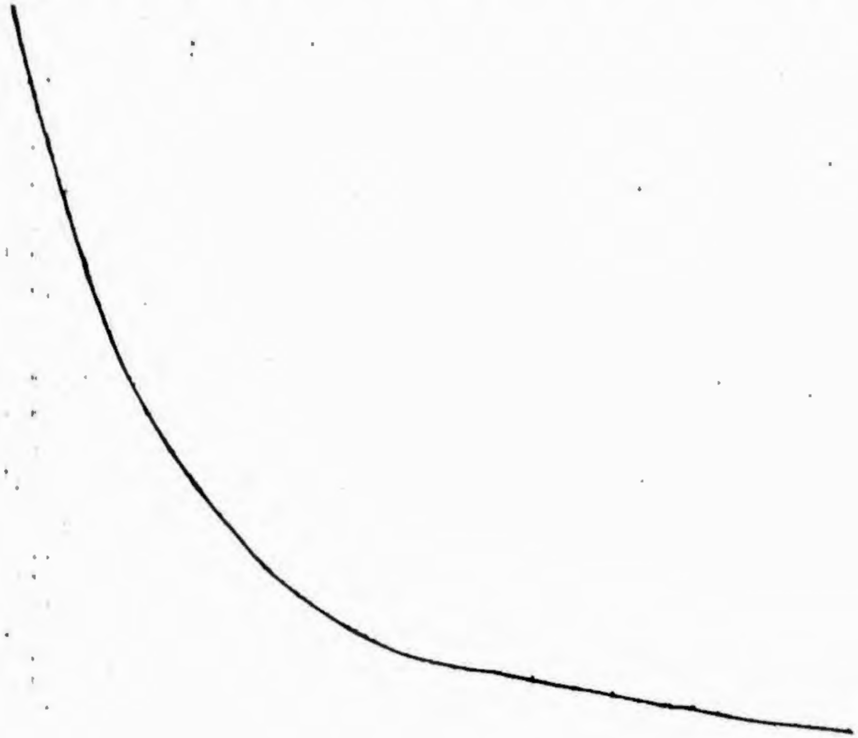
EXHIBIT 22



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN MAIN CHANNEL
BETWEEN CROSS SECTIONS 12 AND 13

EXHIBIT 23

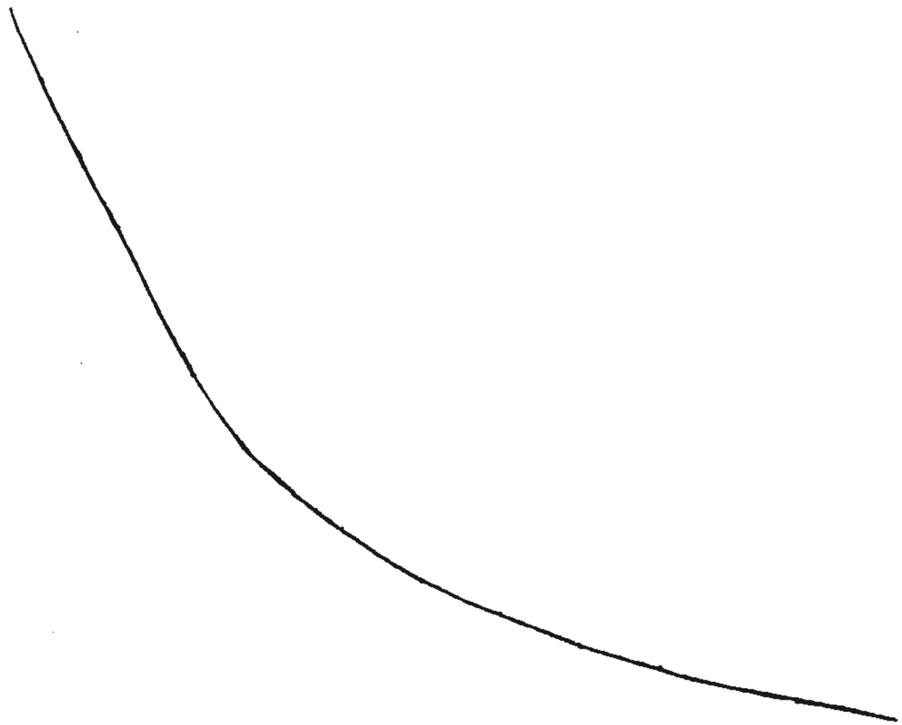
HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN MAIN CHANNEL
UPSTREAM FROM CANE CREEK

HARZA-EBASCO SUSITNA JOINT VENTURE

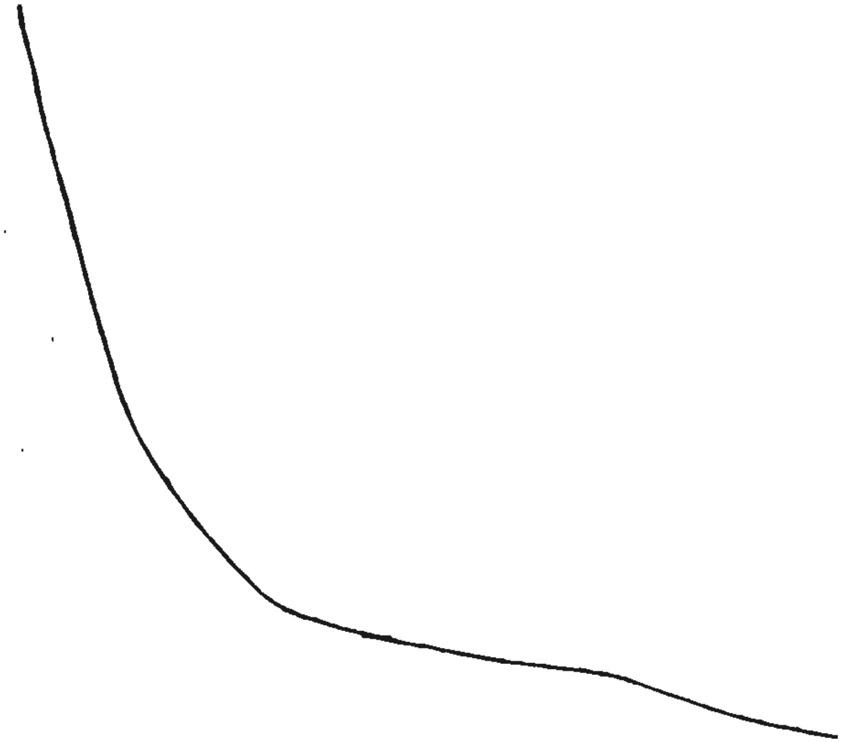
EXHIBIT 24



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN MAINSTEM &
SIDE CHANNELS AT CROSS SECTION 18-2

EXHIBIT 25

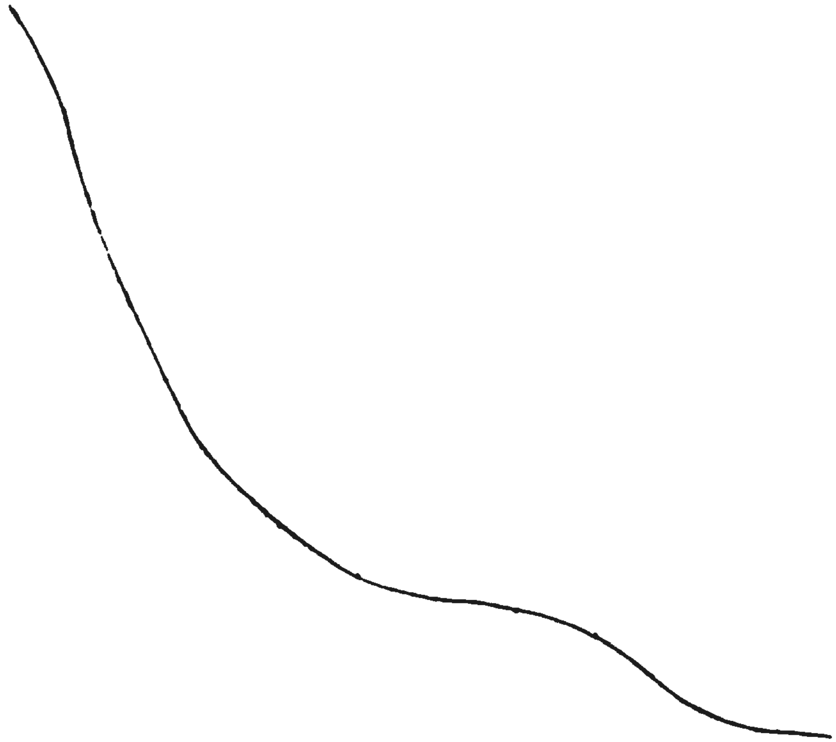
HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN SLOUGH 8A

HARZA-EBASCO SUSITNA JOINT VENTURE

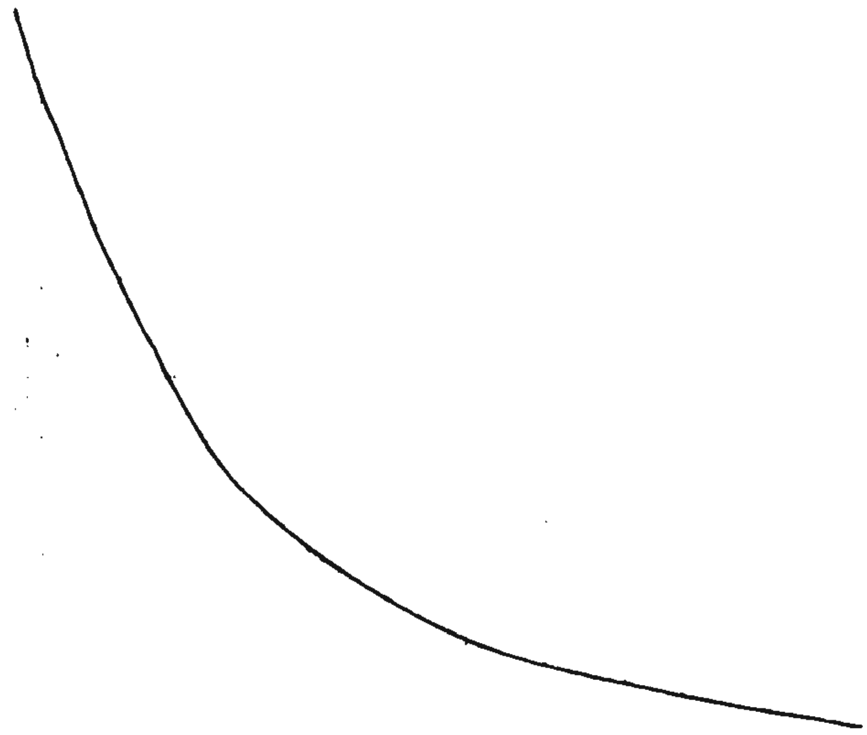
EXHIBIT 26



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED MATERIAL IN SLOUGH 9

EXHIBIT 27

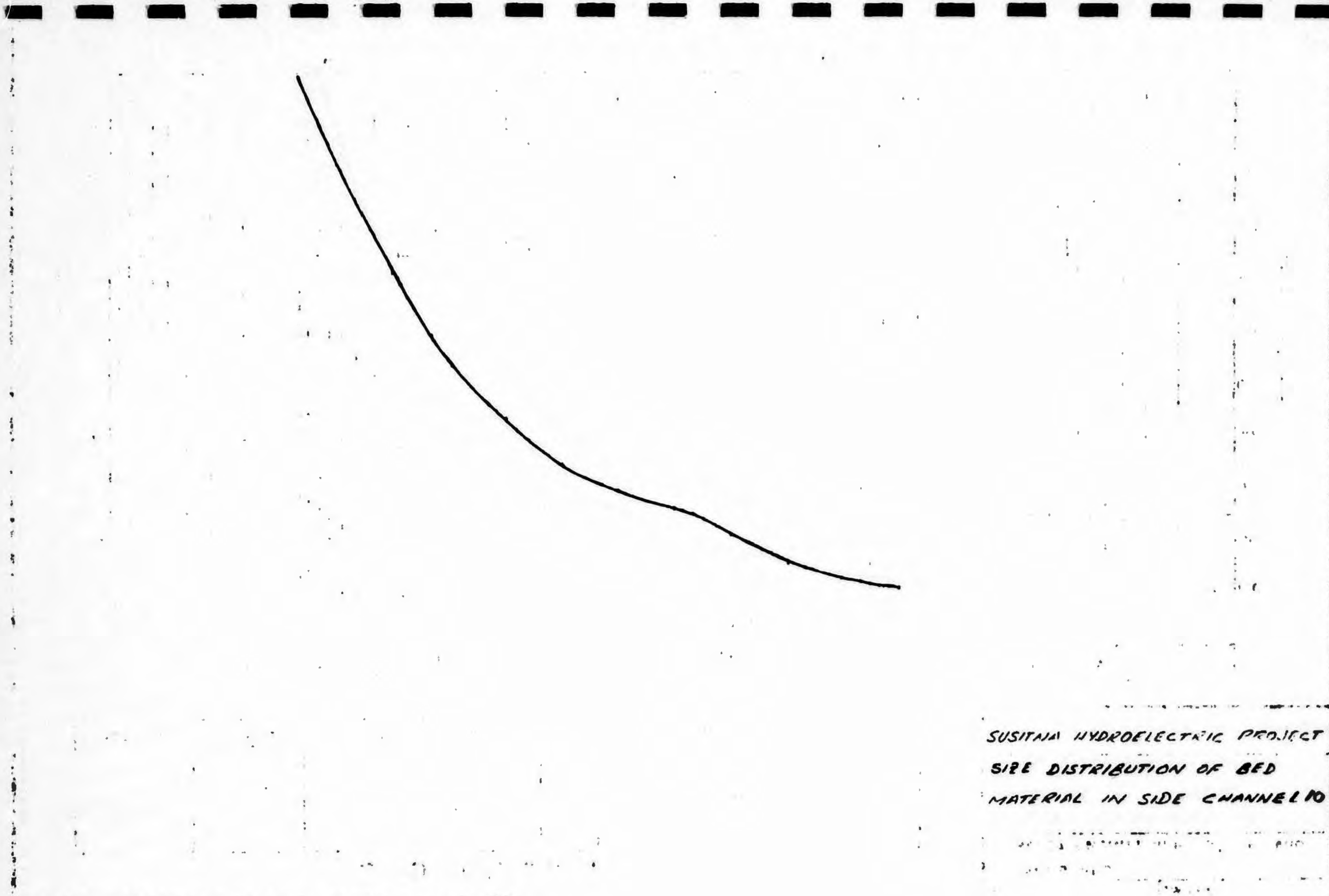
HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN MAIN CHANNEL
UPSTREAM FROM 4TH OF JULY CREEK

EXHIBIT 28

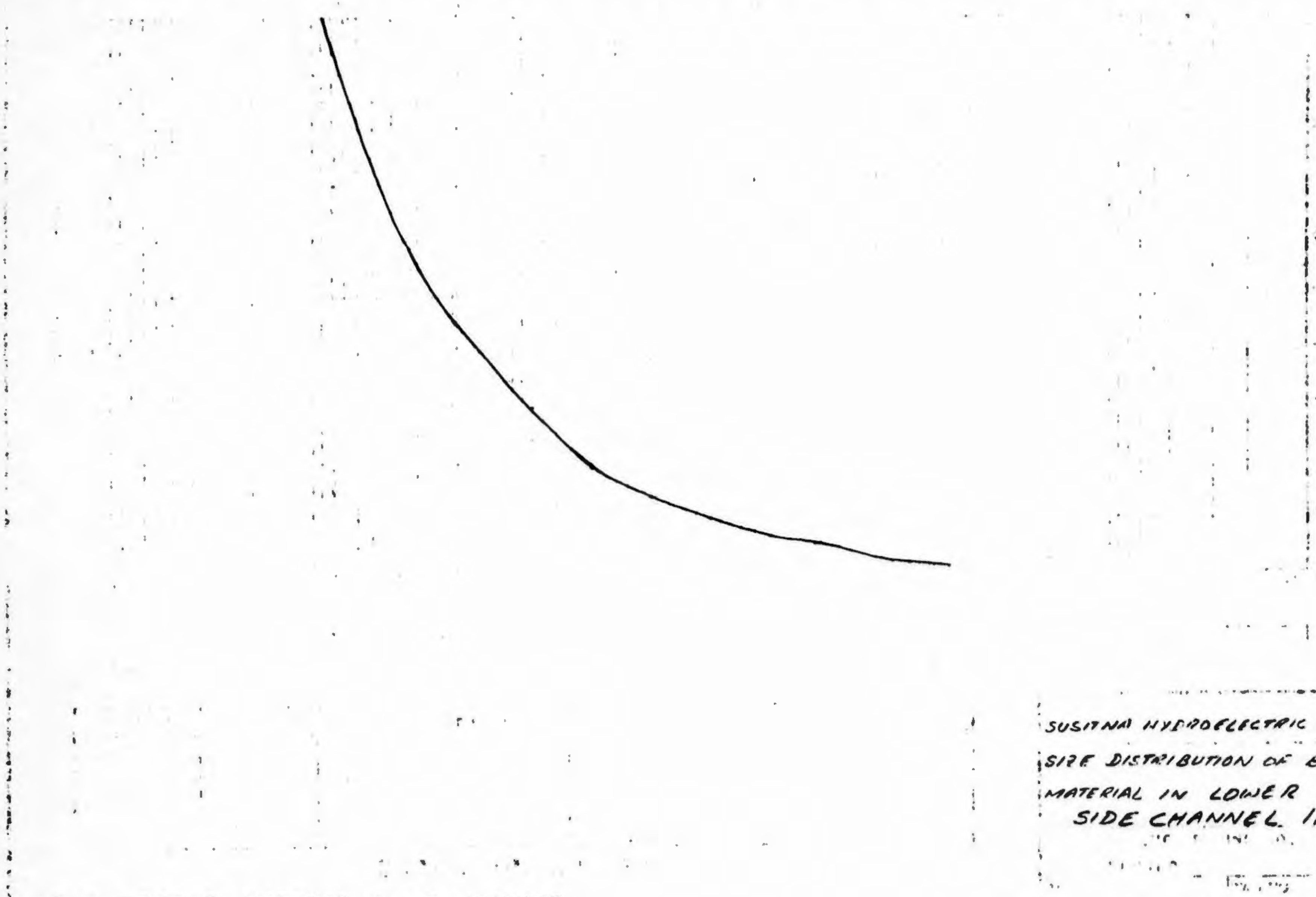
HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED MATERIAL IN SIDE CHANNEL 10

EXHIBIT 29

HARZA-EBASCO SUSITNA JOINT VENTURE

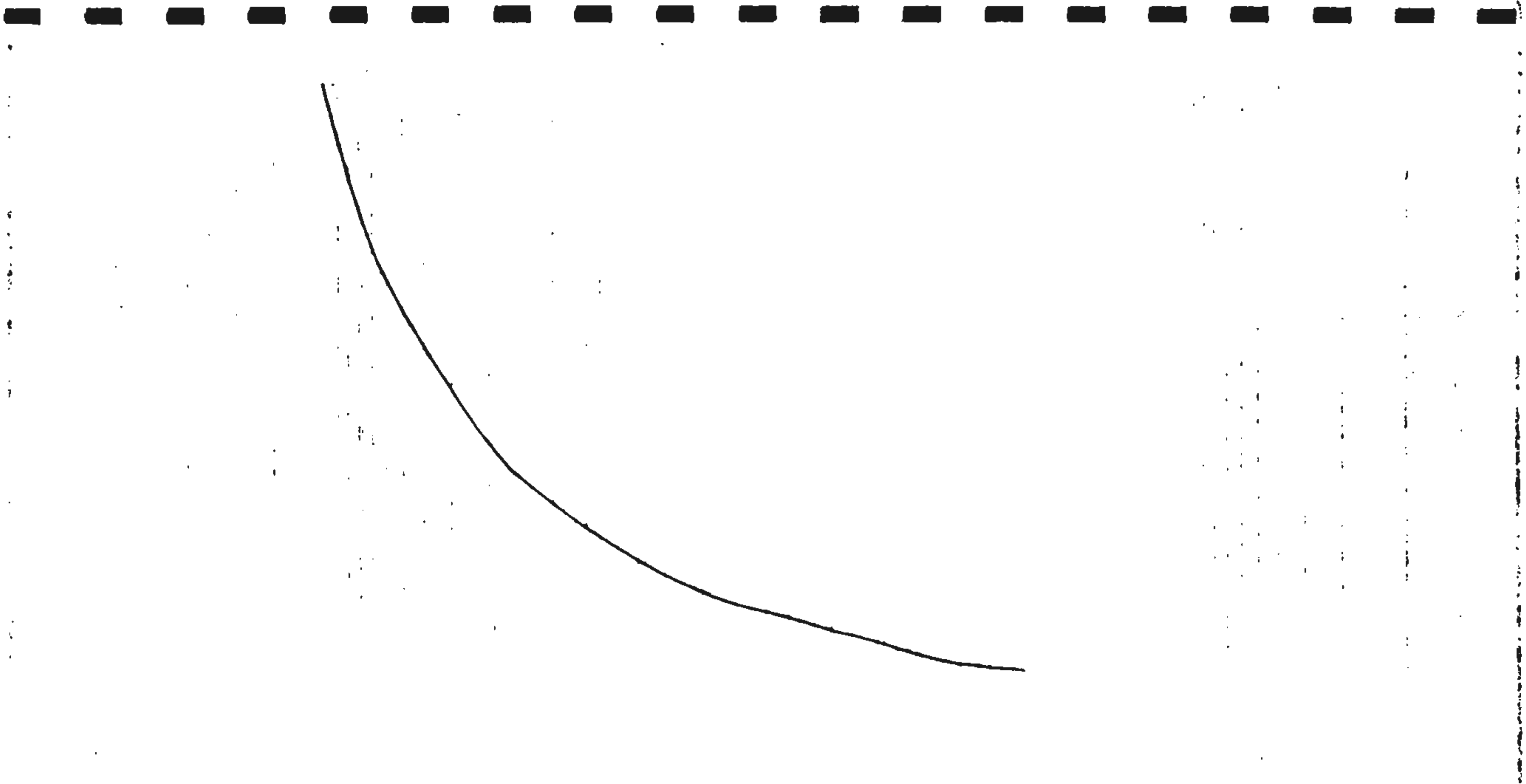


SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN LOWER SIDE CHANNEL 11

EXHIBIT 30

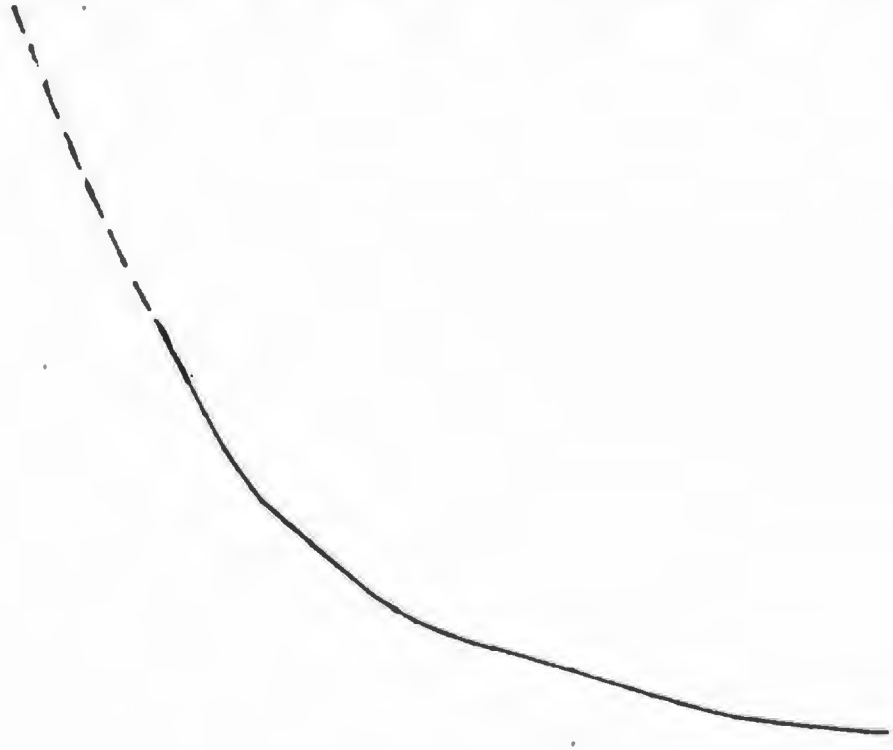
HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
SIZE DISTRIBUTION OF BED
MATERIAL IN SLOUGH 11 AND
UPPER SIDE CHANNEL 11

EXHIBIT 31

HARZA-EBASCO SUSITNA JOINT VENTURE

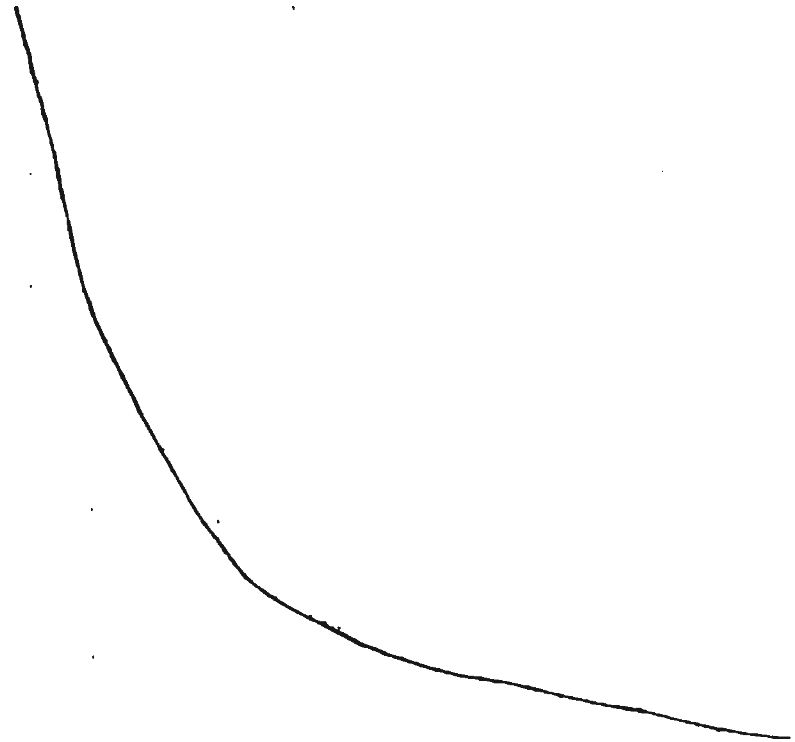


SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN MAIN CHANNEL BETWEEN CROSS SECTIONS 46 AND 48

EXHIBIT 32

HARZA-EBASCO SUSITNA JOINT VENTURE



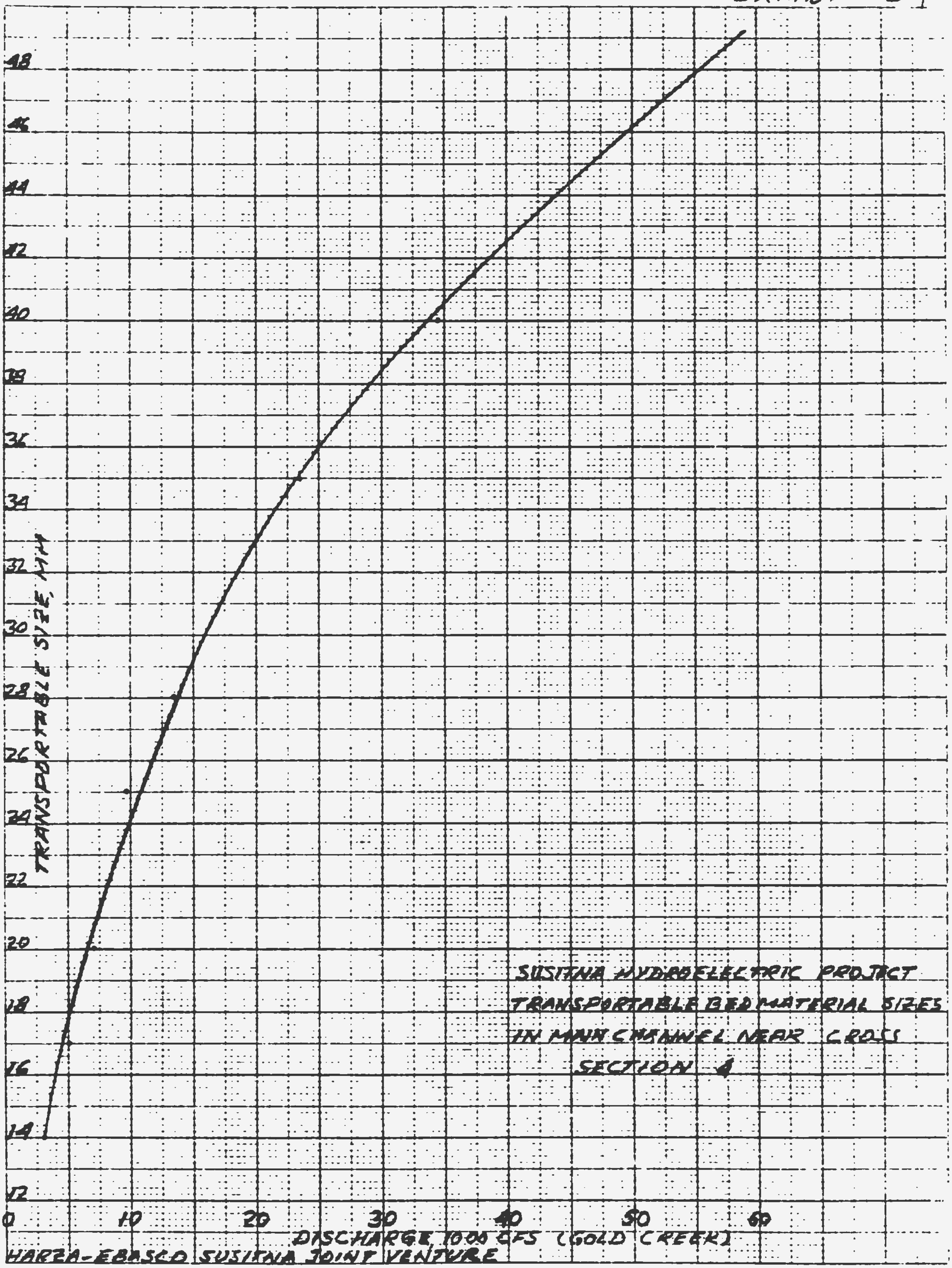
SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN SIDECHANNEL 21 AND SLOUGH 21

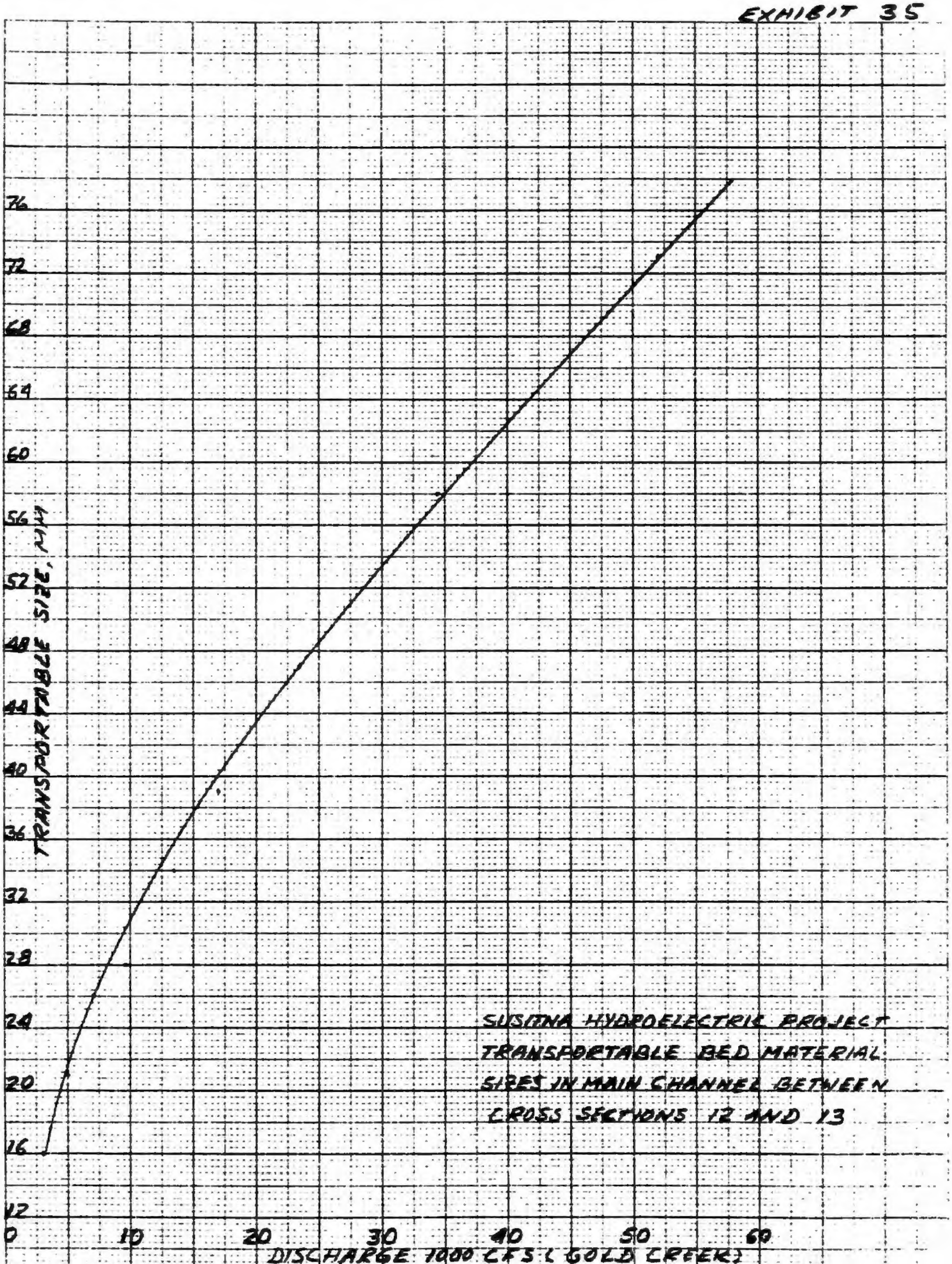
EXHIBIT 33

HARZA-EBASCO SUSITNA JOINT VENTURE

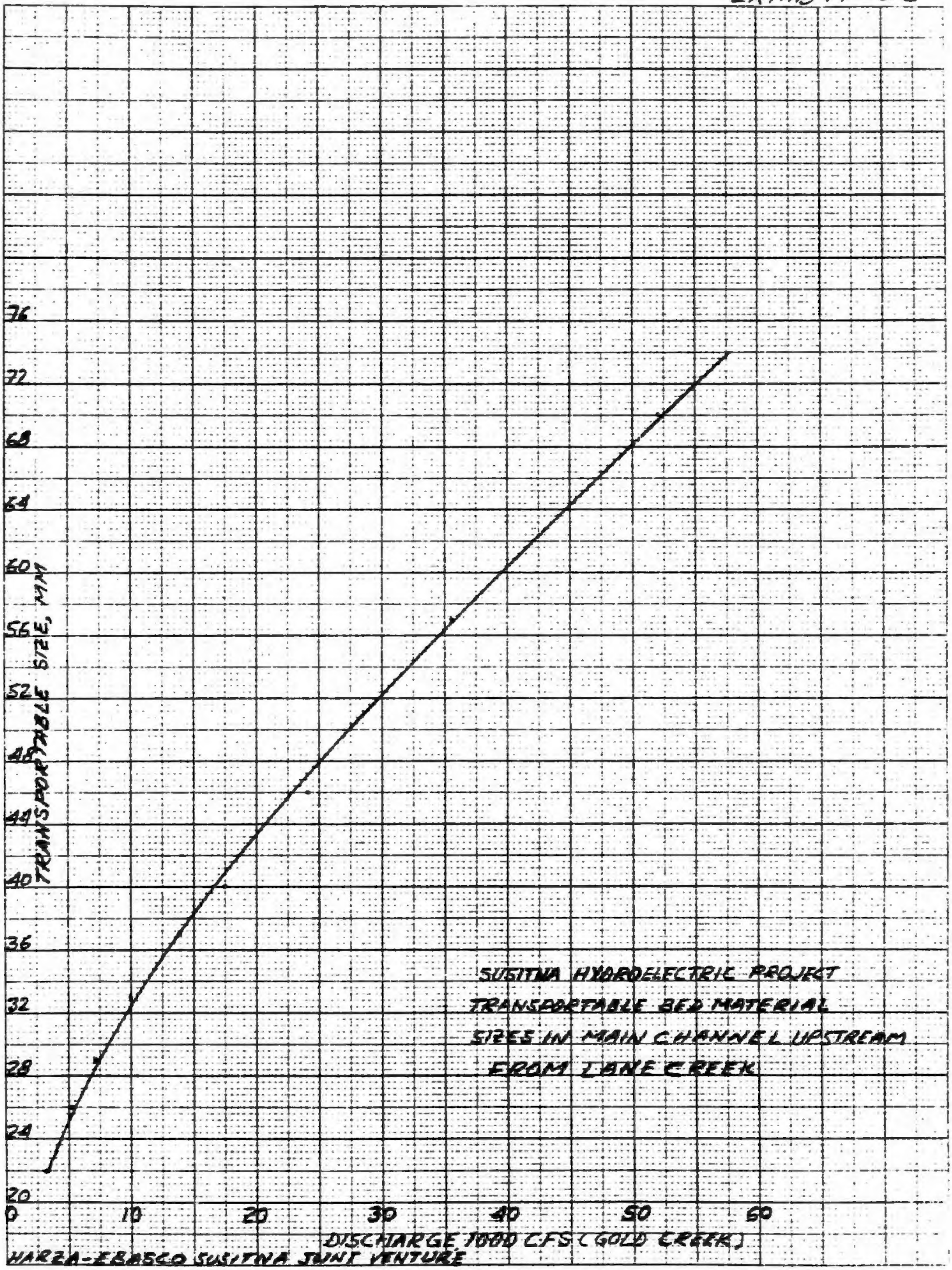
EXHIBIT 34

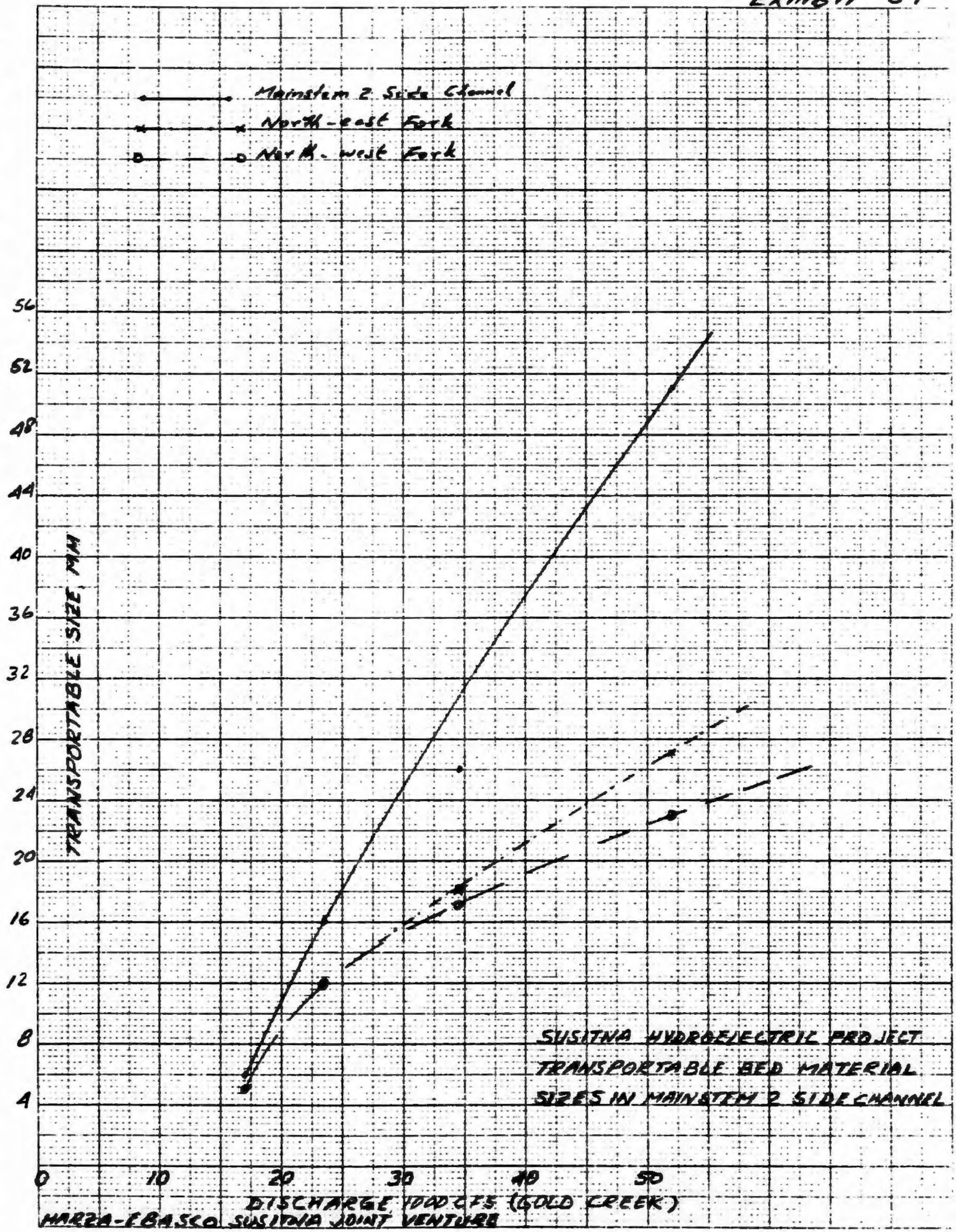


HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE


76
72
68
64
60
56
52
48
44
40
36
32
28
24
20
TRANSPORTABLE SIZE, MM
0
10
20
30
40
50
60
DISCHARGE 1000 CFS (GOLD CREEK)
SUSITNA HYDROELECTRIC PROJECT
TRANSPORTABLE BED MATERIAL
SIZES IN MAIN CHANNEL UPSTREAM
FROM LANE CREEK
HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 38

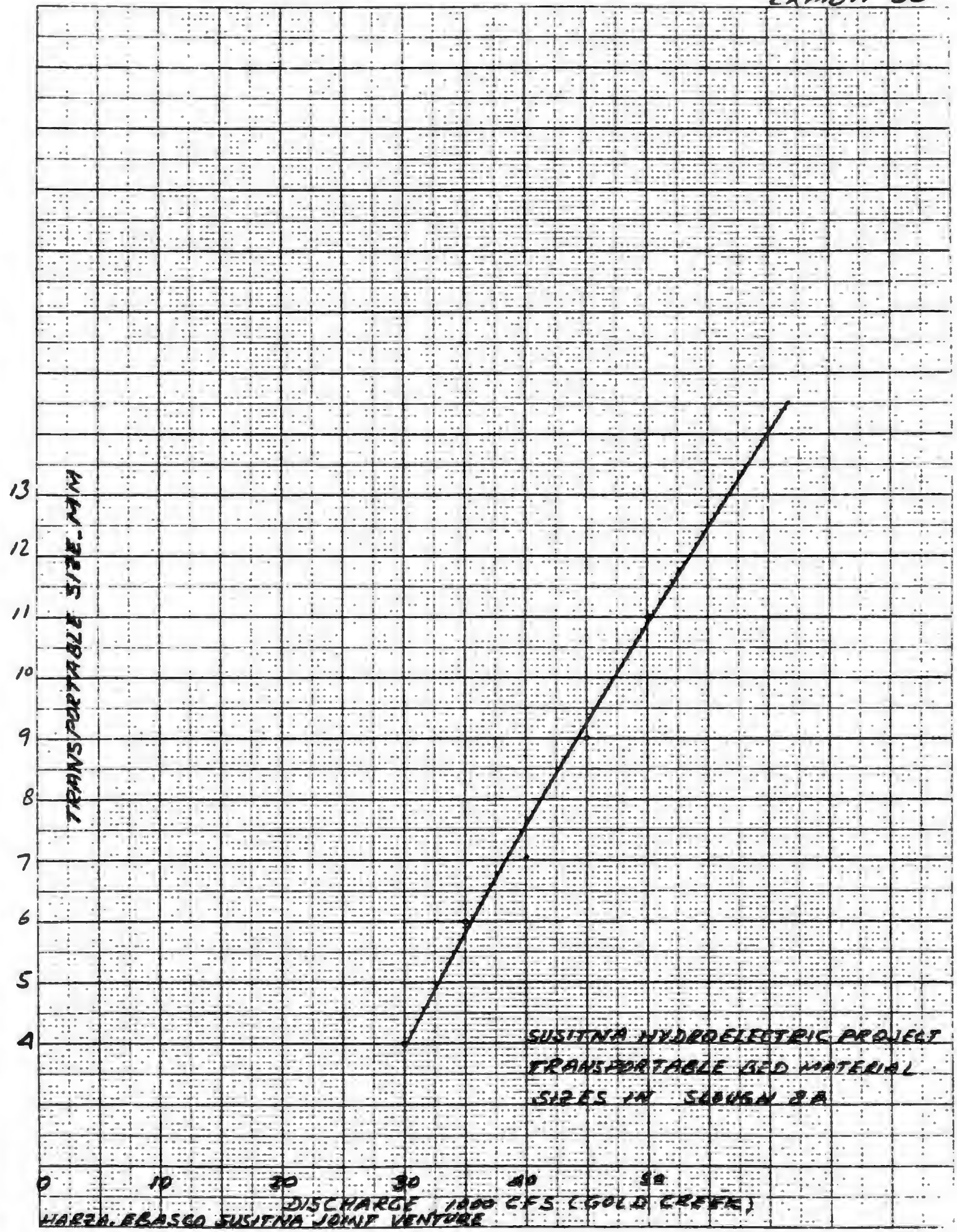
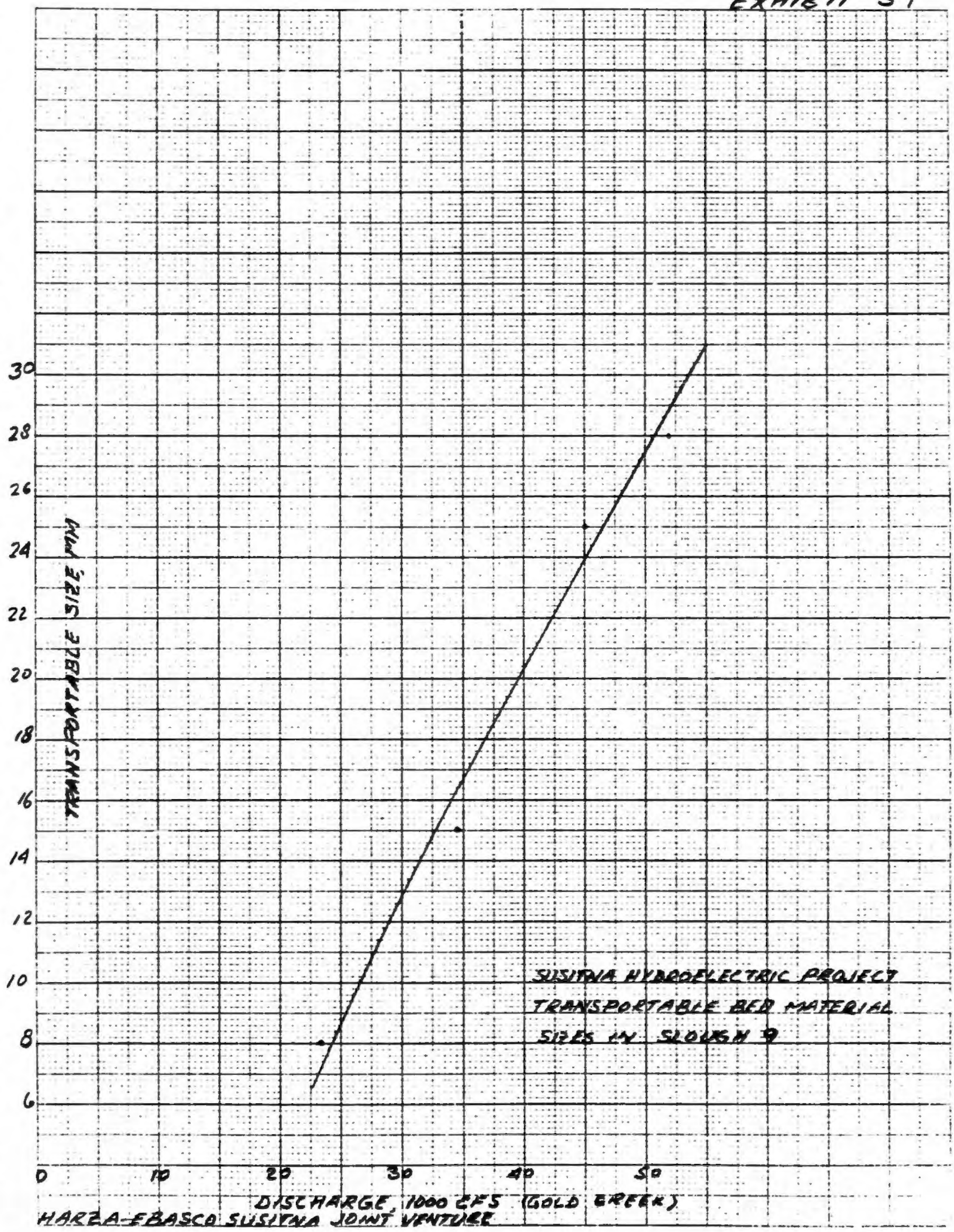
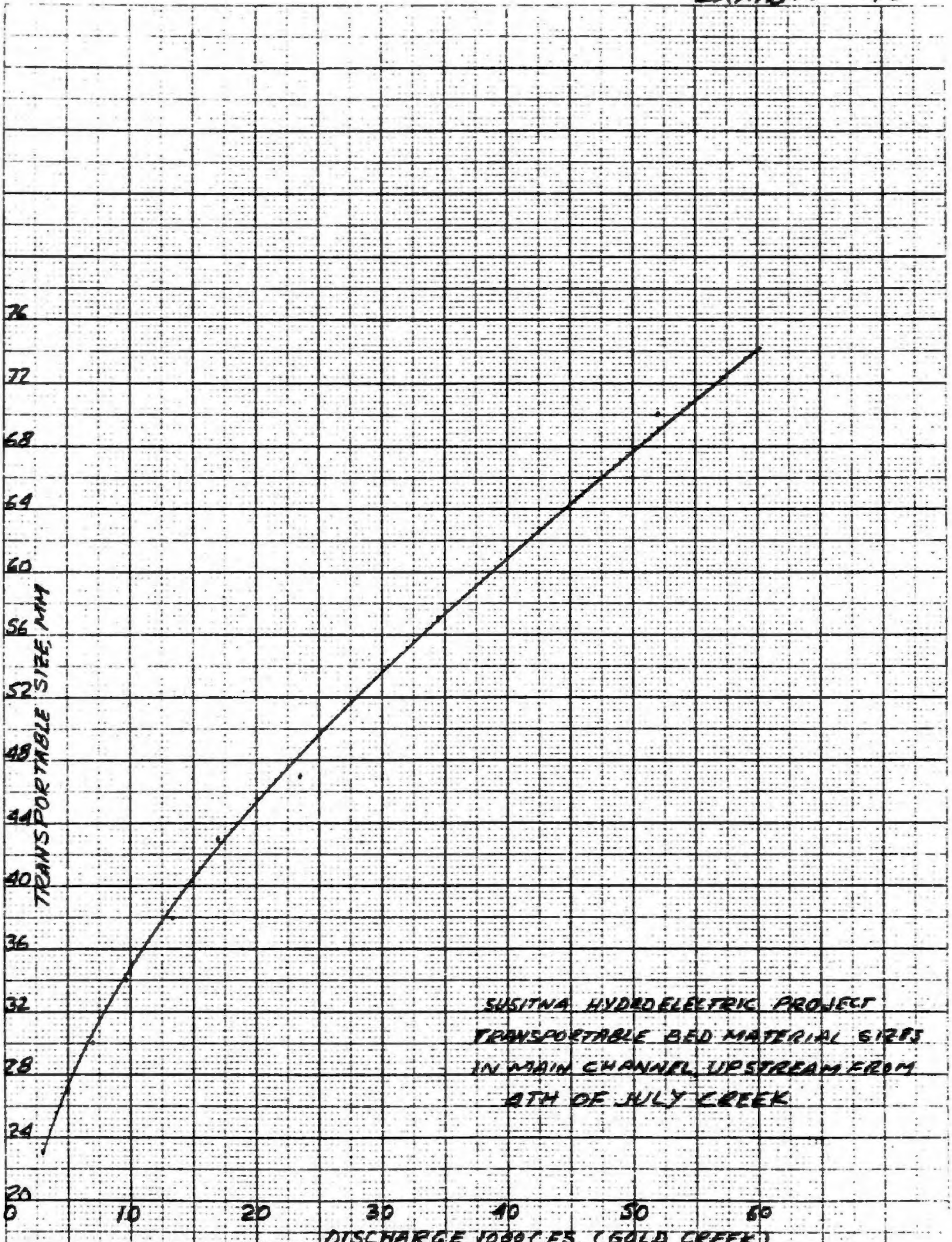

TRANSPORTABLE SIZE, MM
13
12
11
10
9
8
7
6
5
4
0
10
20
30
40
50
DISCHARGE 1000 CFS (GOLD CREEK)
SUSITNA HYDROELECTRIC PROJECT
TRANSPORTABLE BED MATERIAL
SIZES IN SLOUGH 8A
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 39



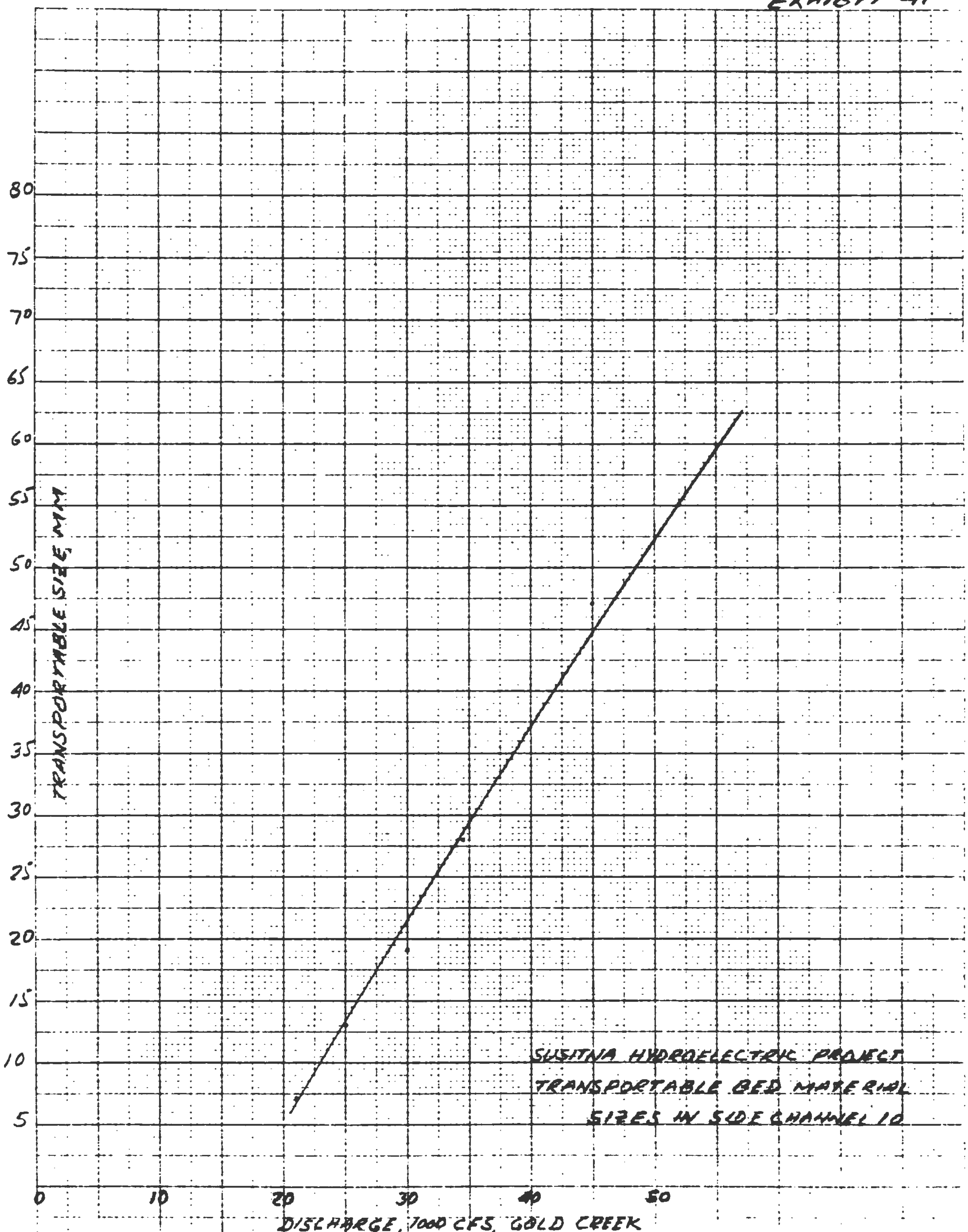
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 40



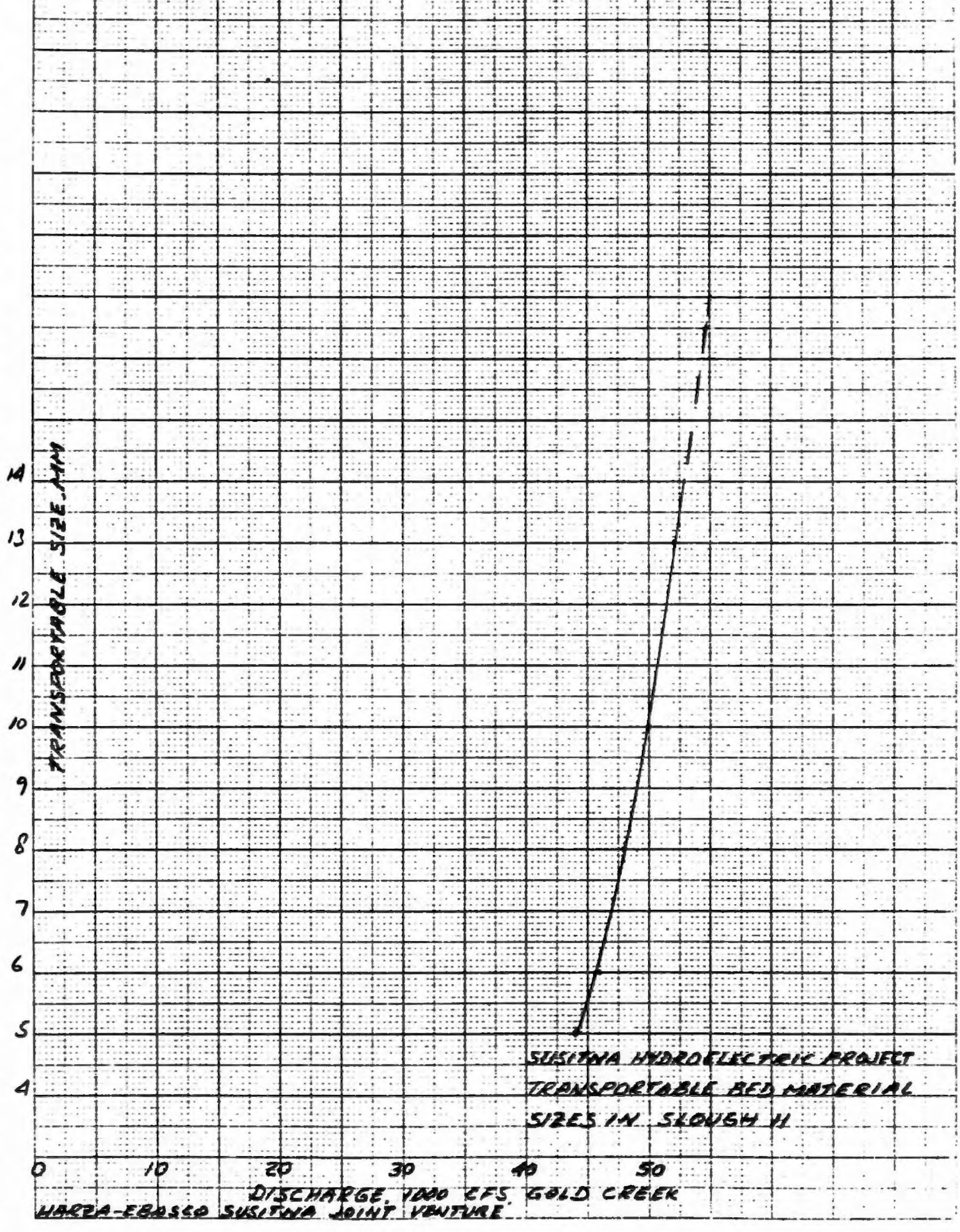
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 41



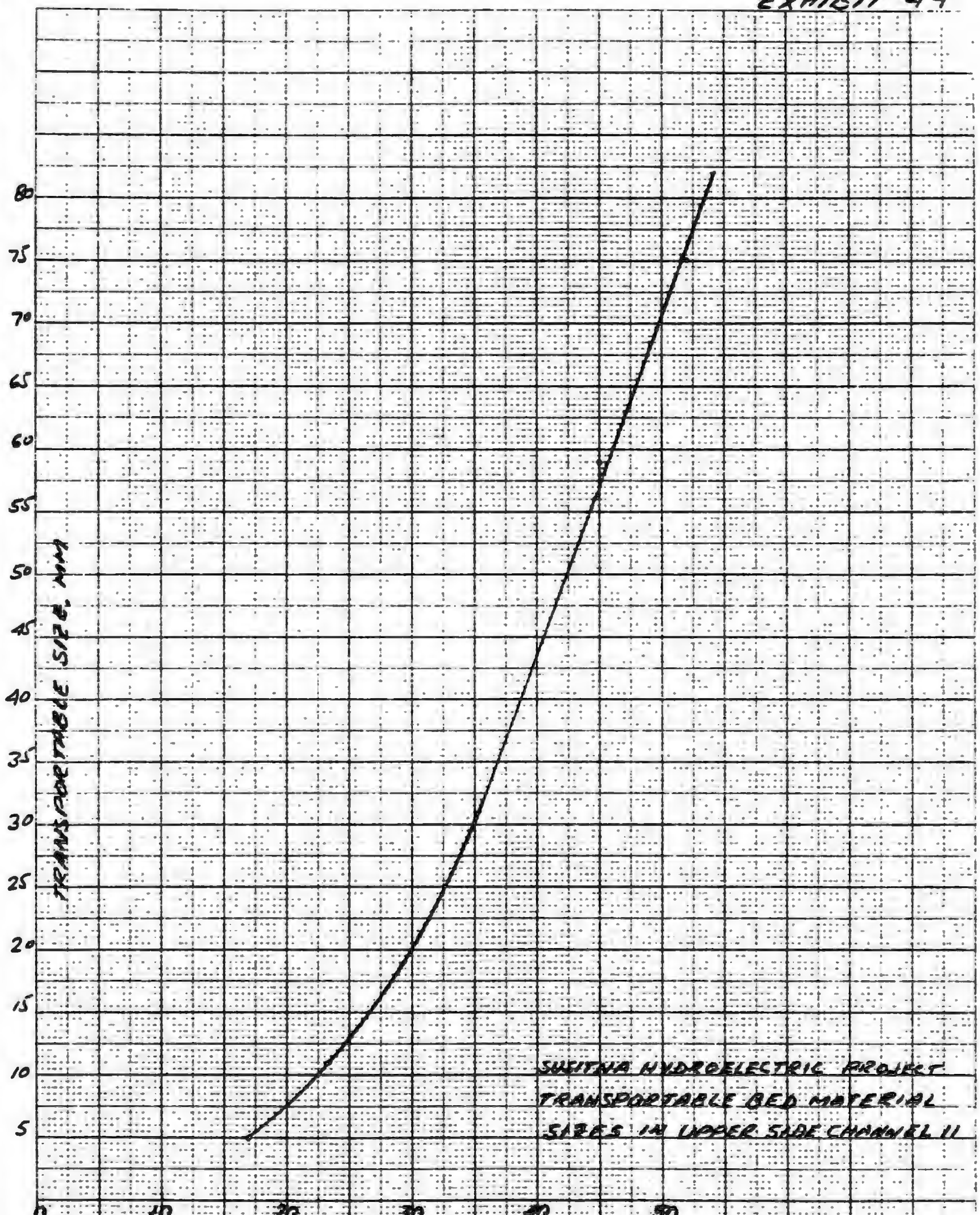
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 43



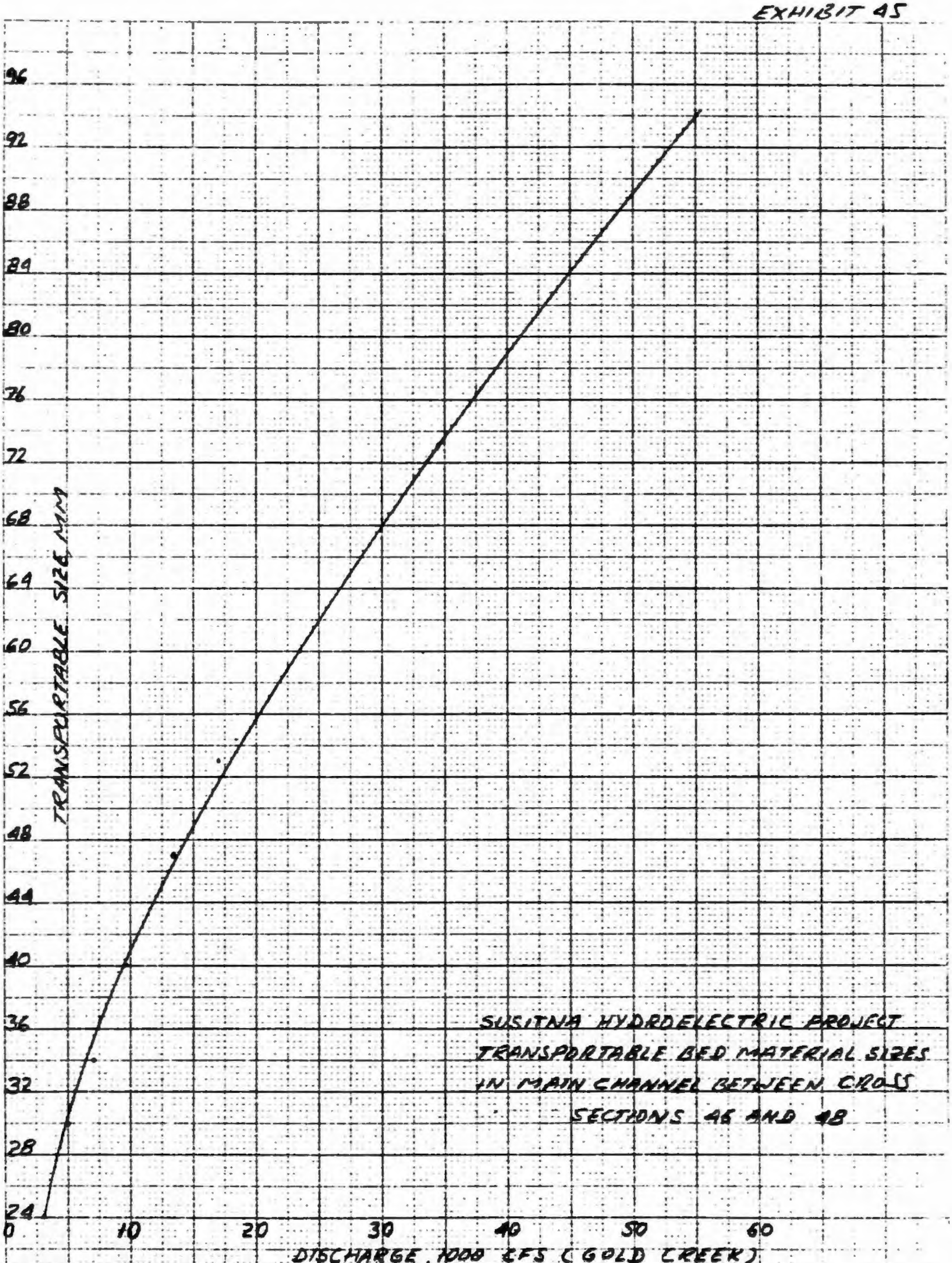
TRANSPORTABLE SIZE, MM
14
13
12
11
10
9
8
7
6
5
4
0
10
20
30
40
50
DISCHARGE, 1000 CFS, GOLD CREEK
SUSITNA HYDROELECTRIC PROJECT
TRANSPORTABLE BED MATERIAL
SIZES IN SLOUGH 11
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 44



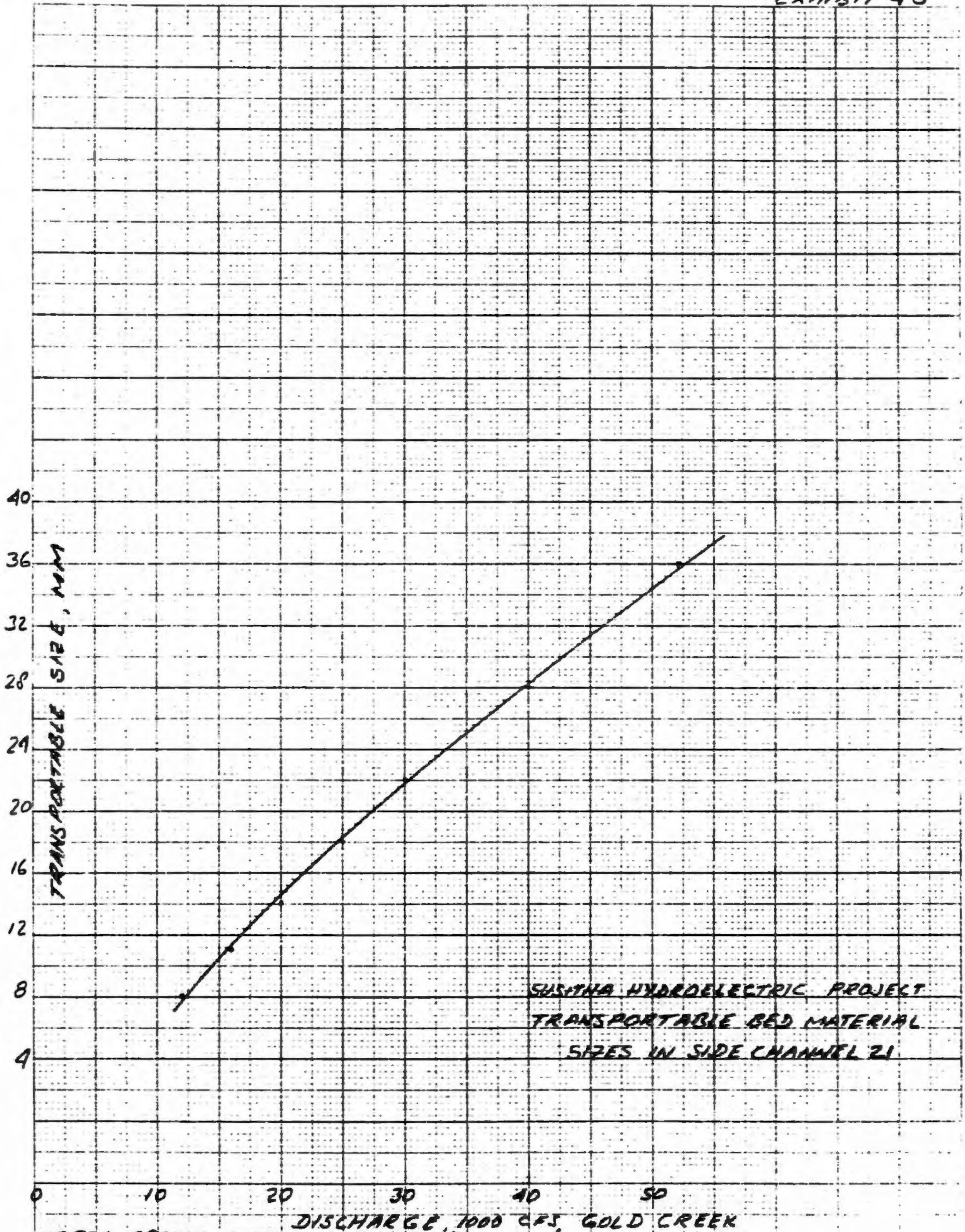
HARZA EBASCO SUSITNA JOINT VENTURE

EXHIBIT 45

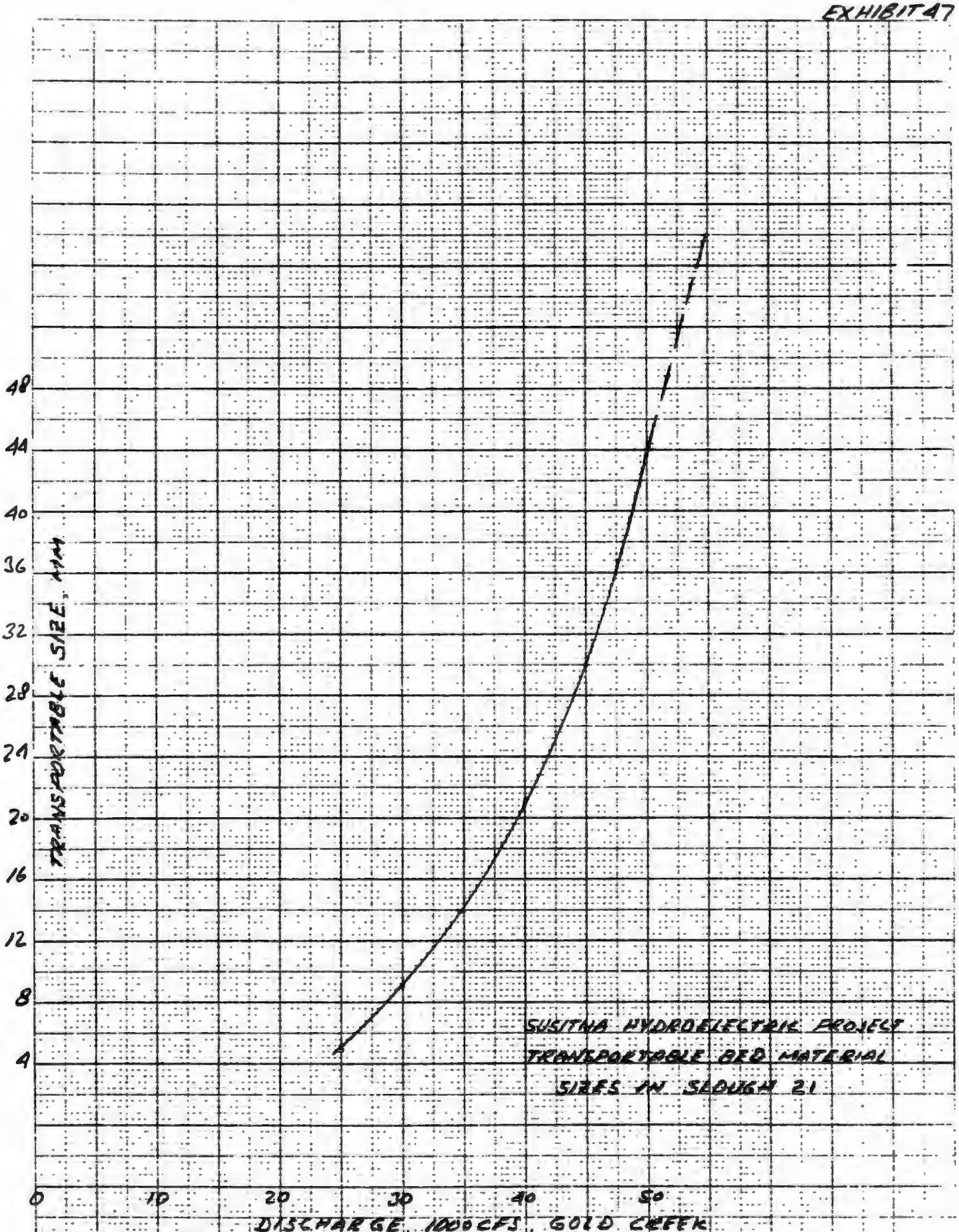


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 46

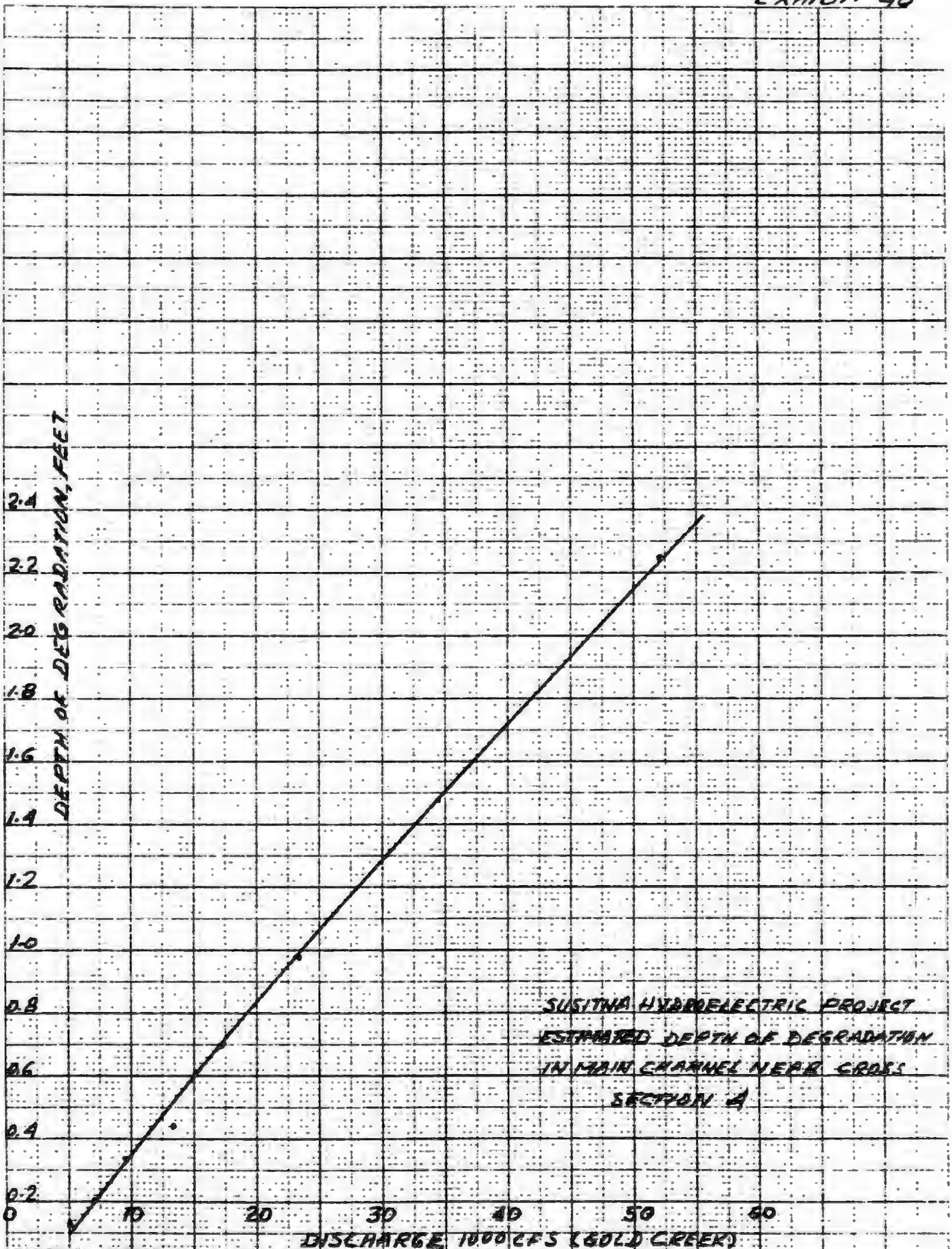


HARZA-EBASCO SUSITNA JOINT VENTURE



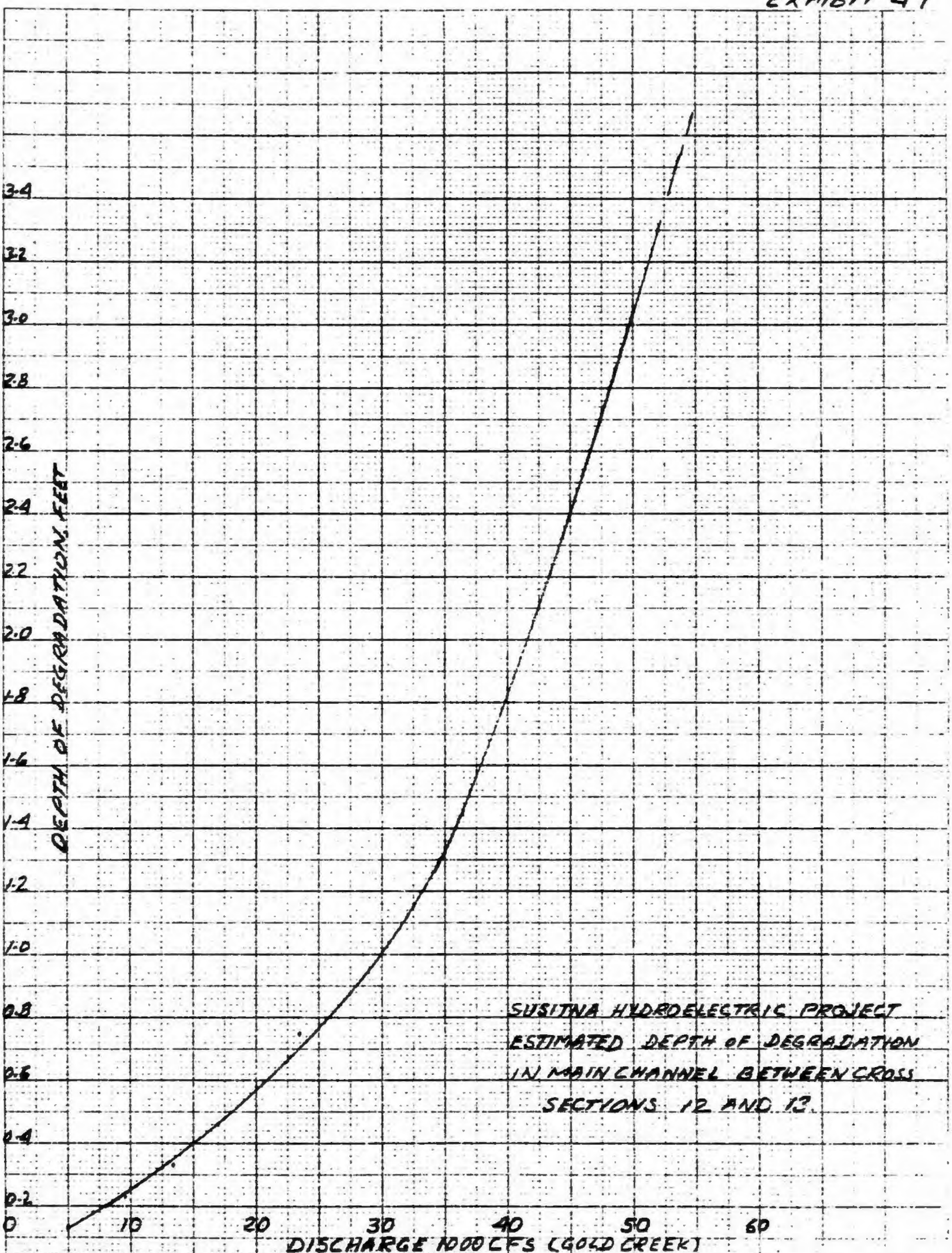
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 48



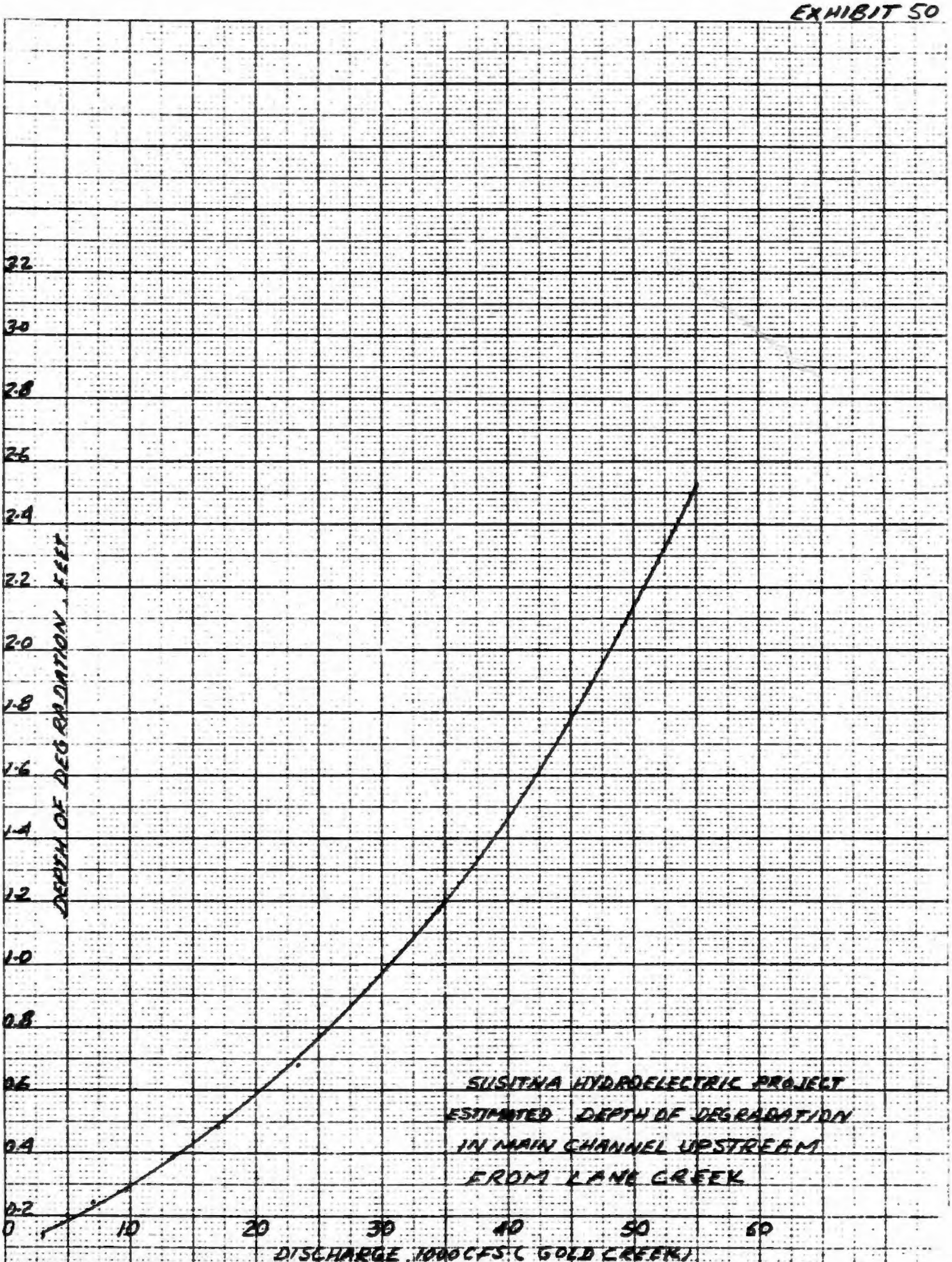
MARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 49



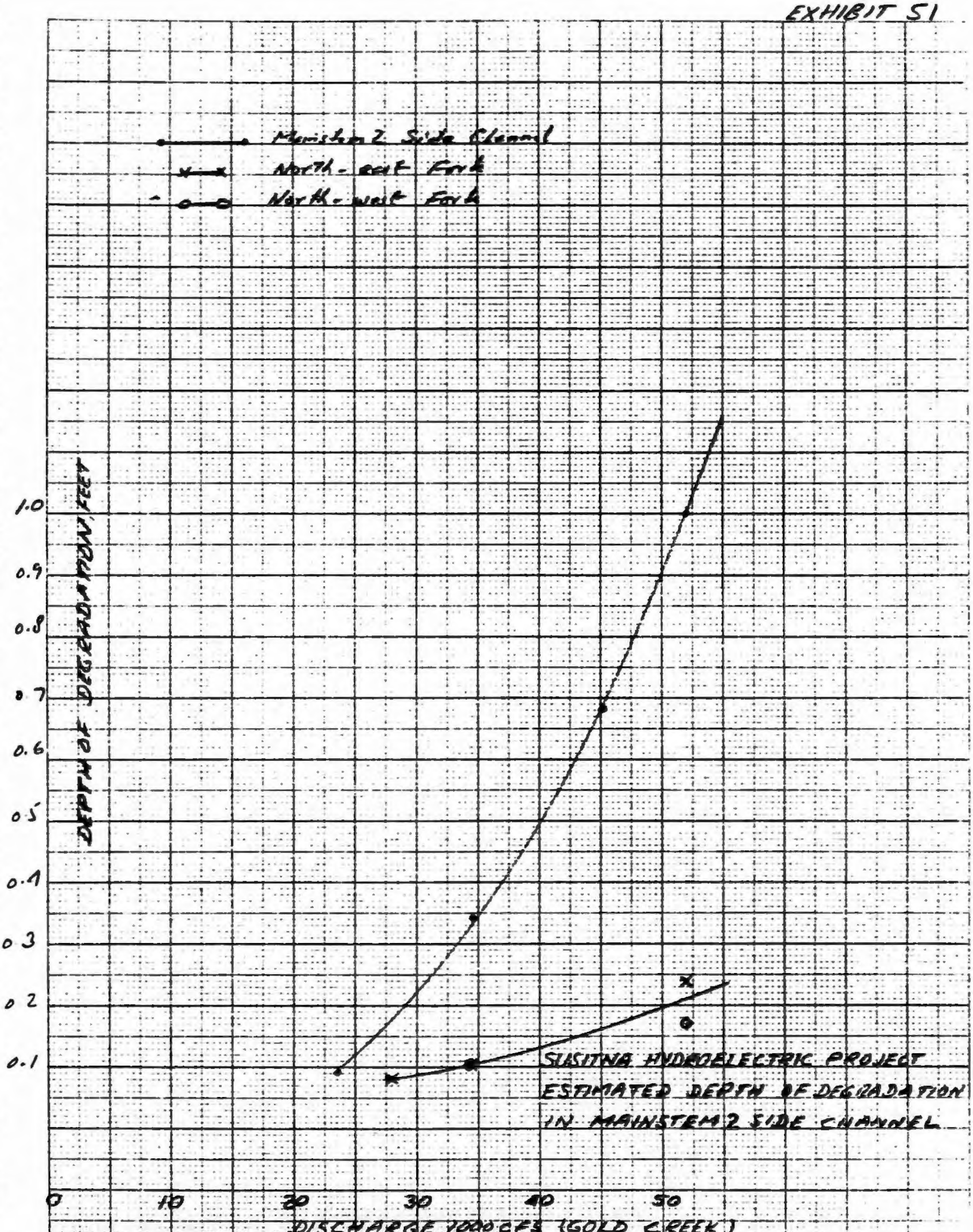
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 50

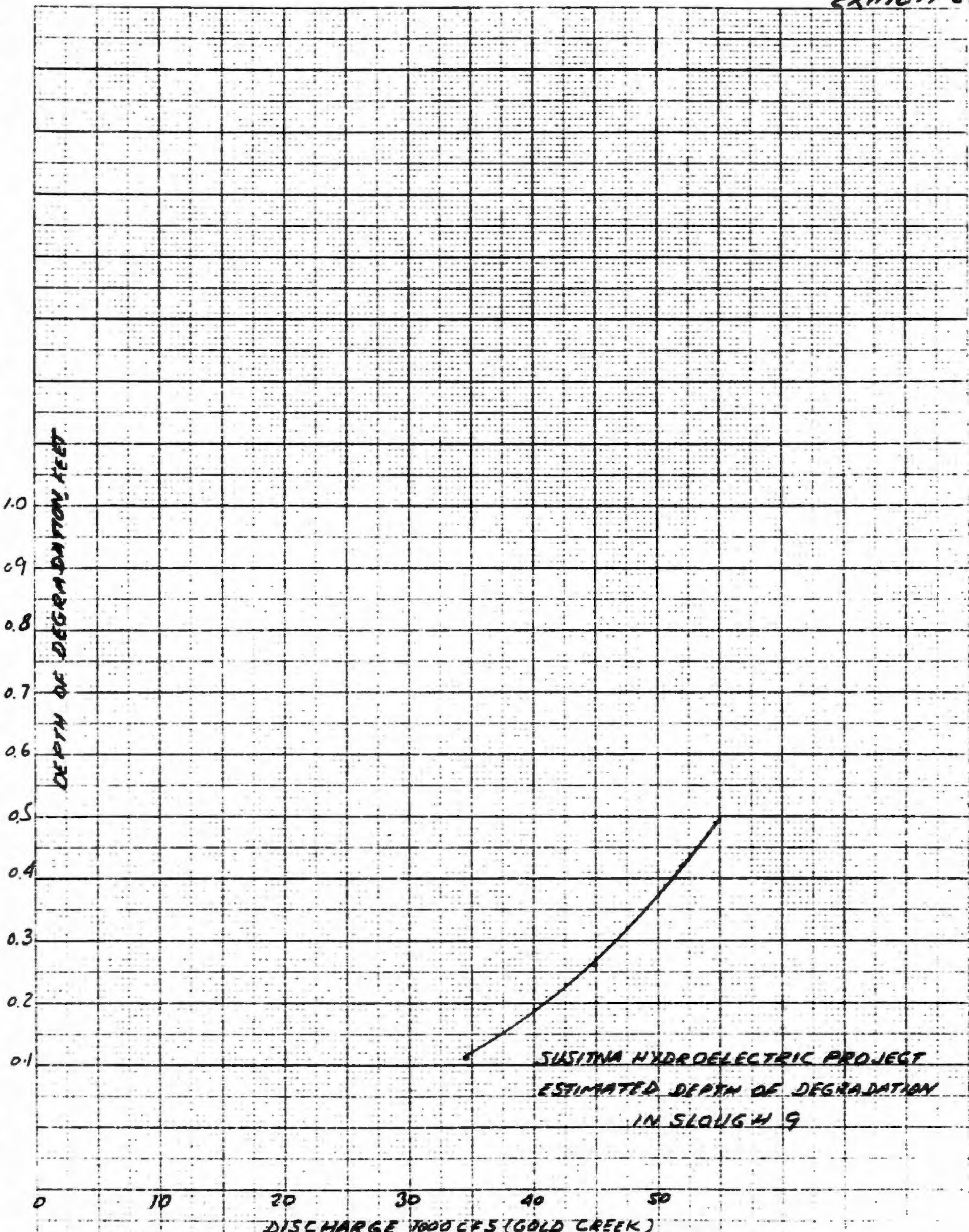


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 51

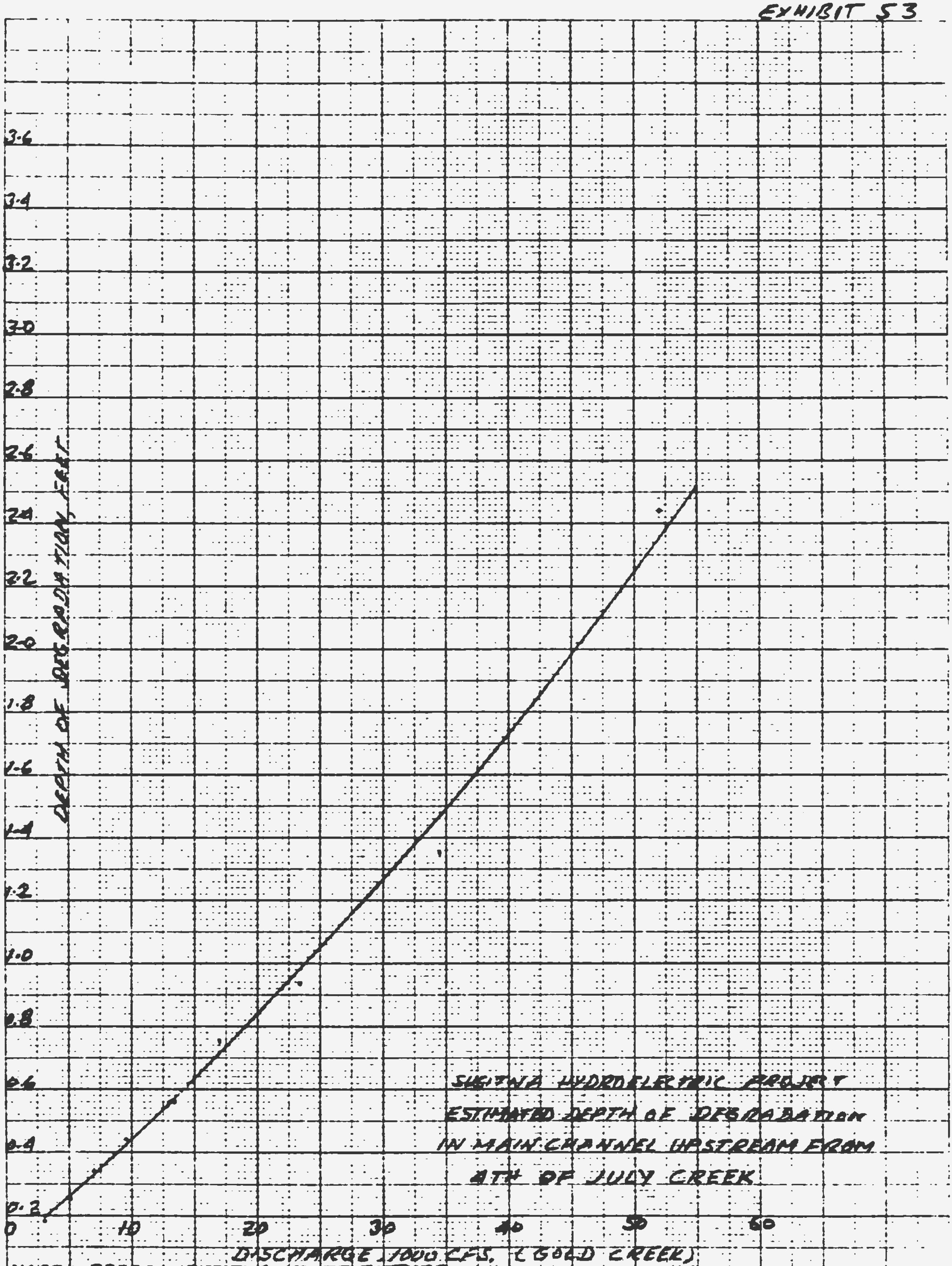


HARZA-EBASCO SUSITNA JOINT VENTURE

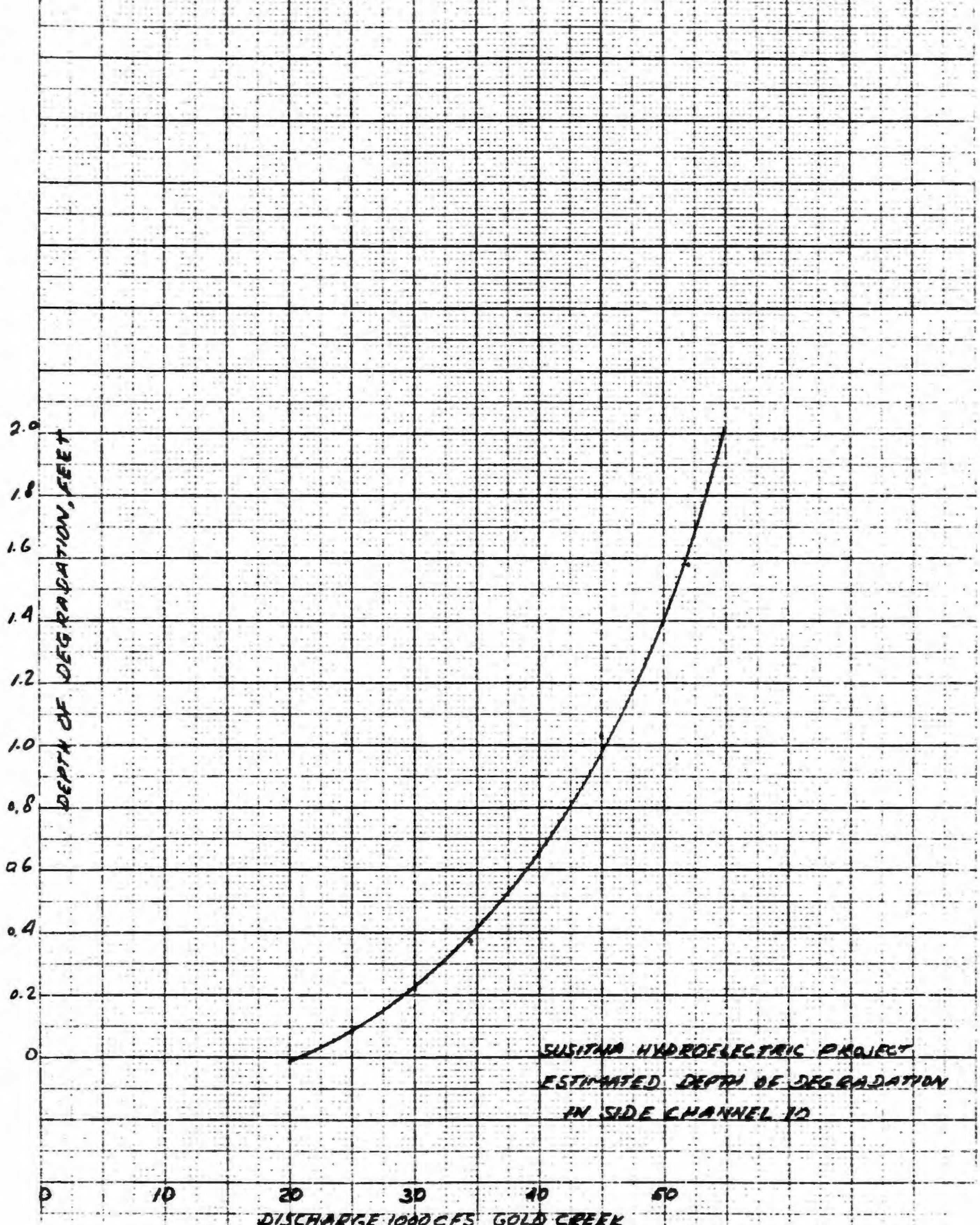


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 53

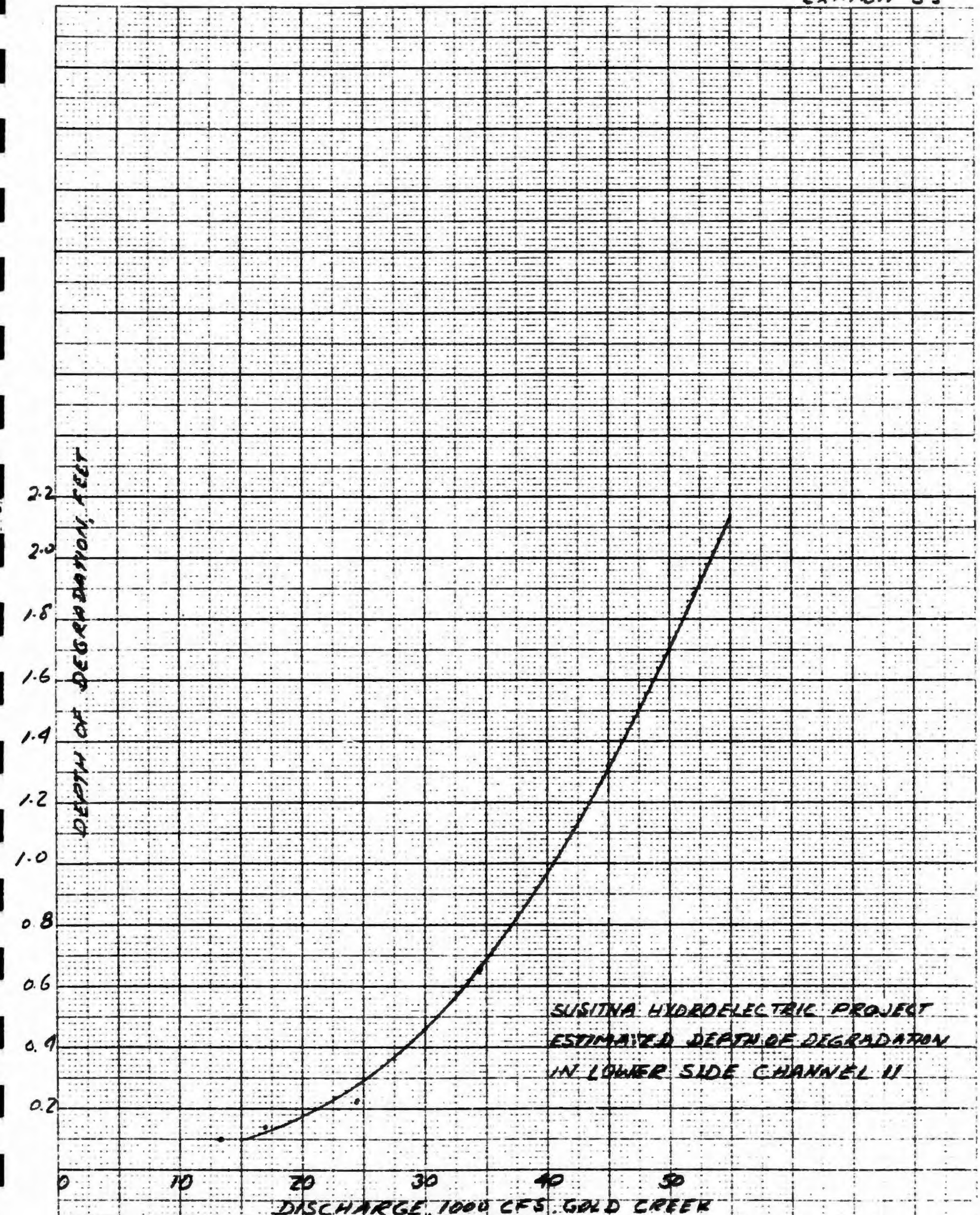


HARZA-EBASCO SUSITNA JOINT VENTURE



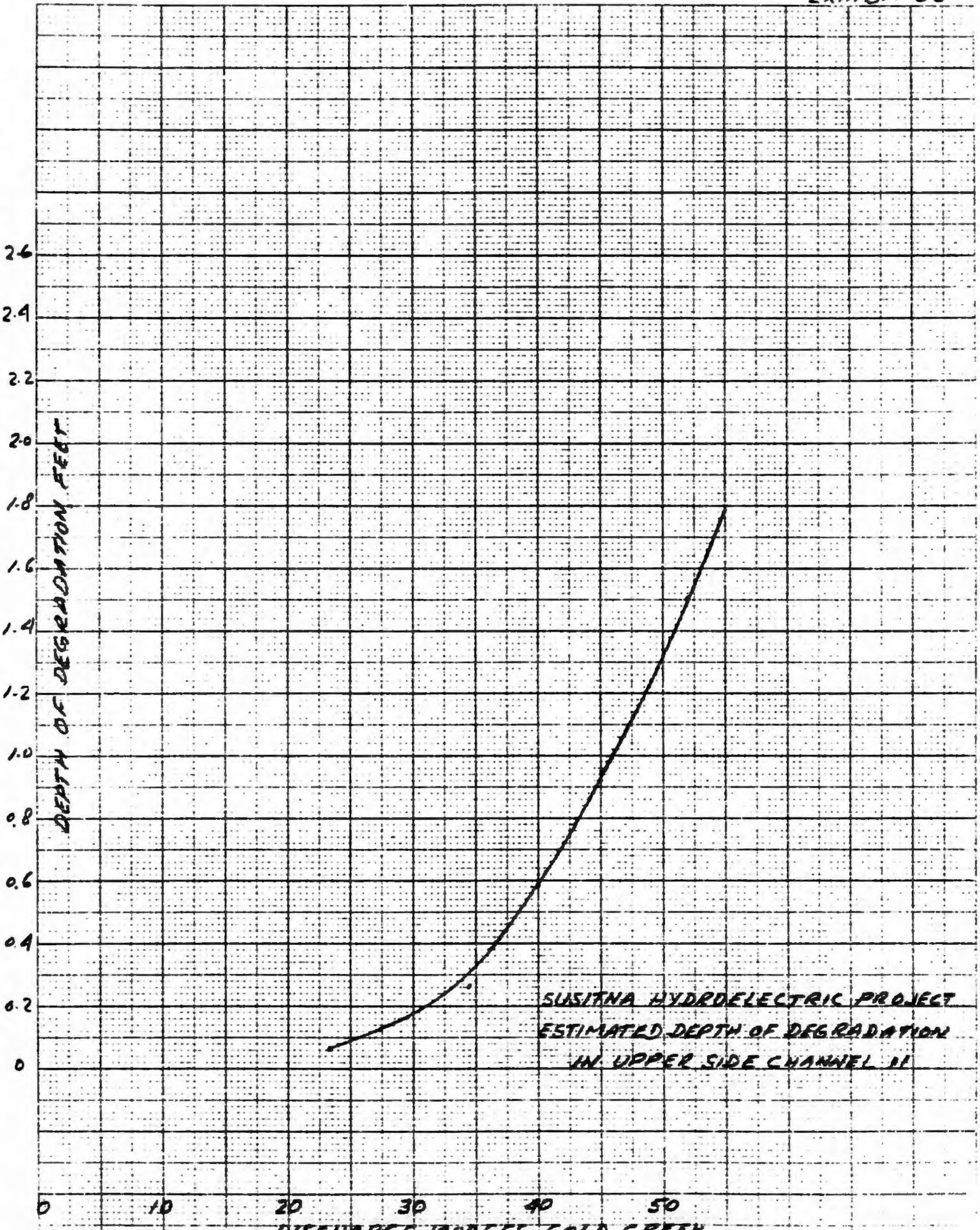
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 55

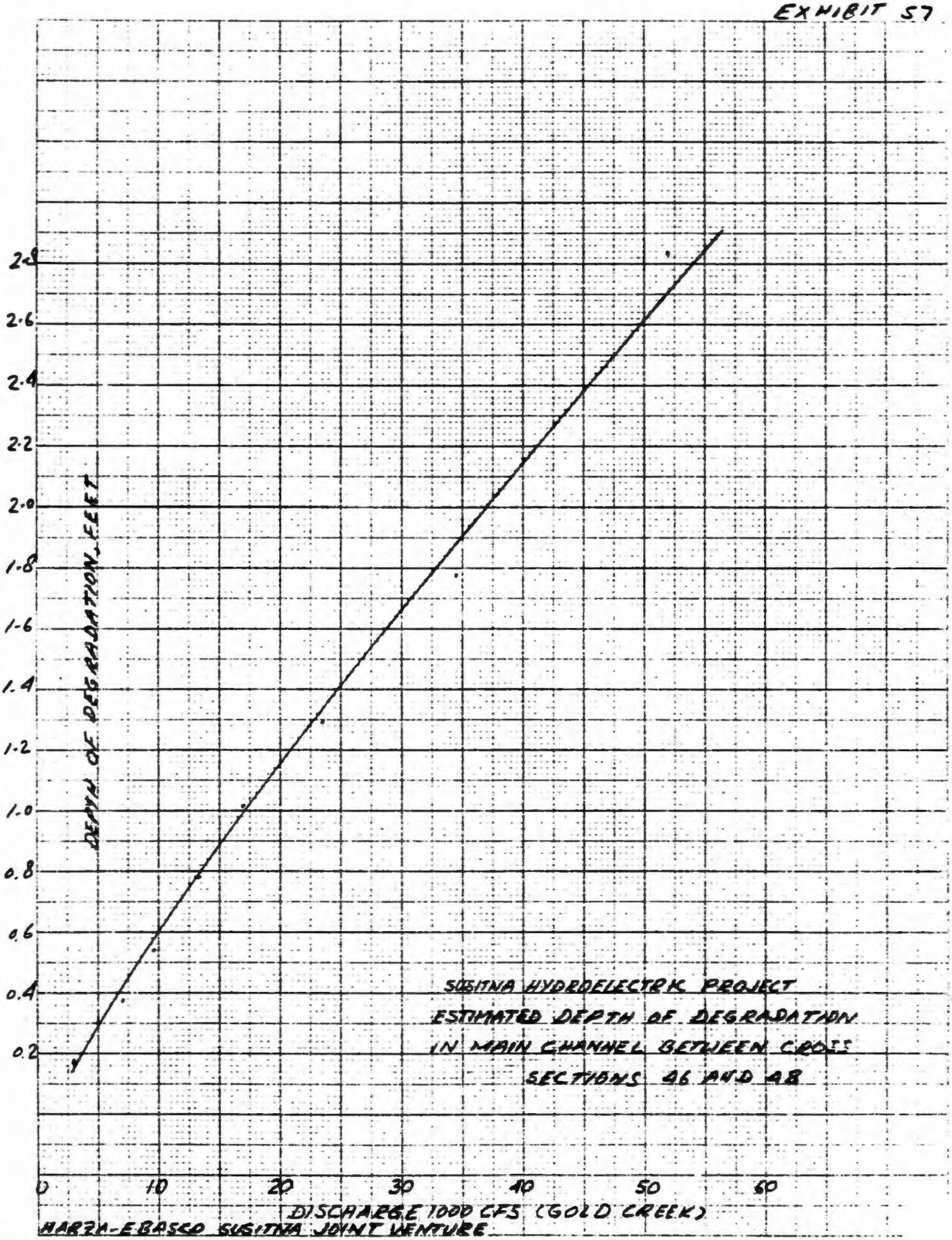


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 56



HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 58

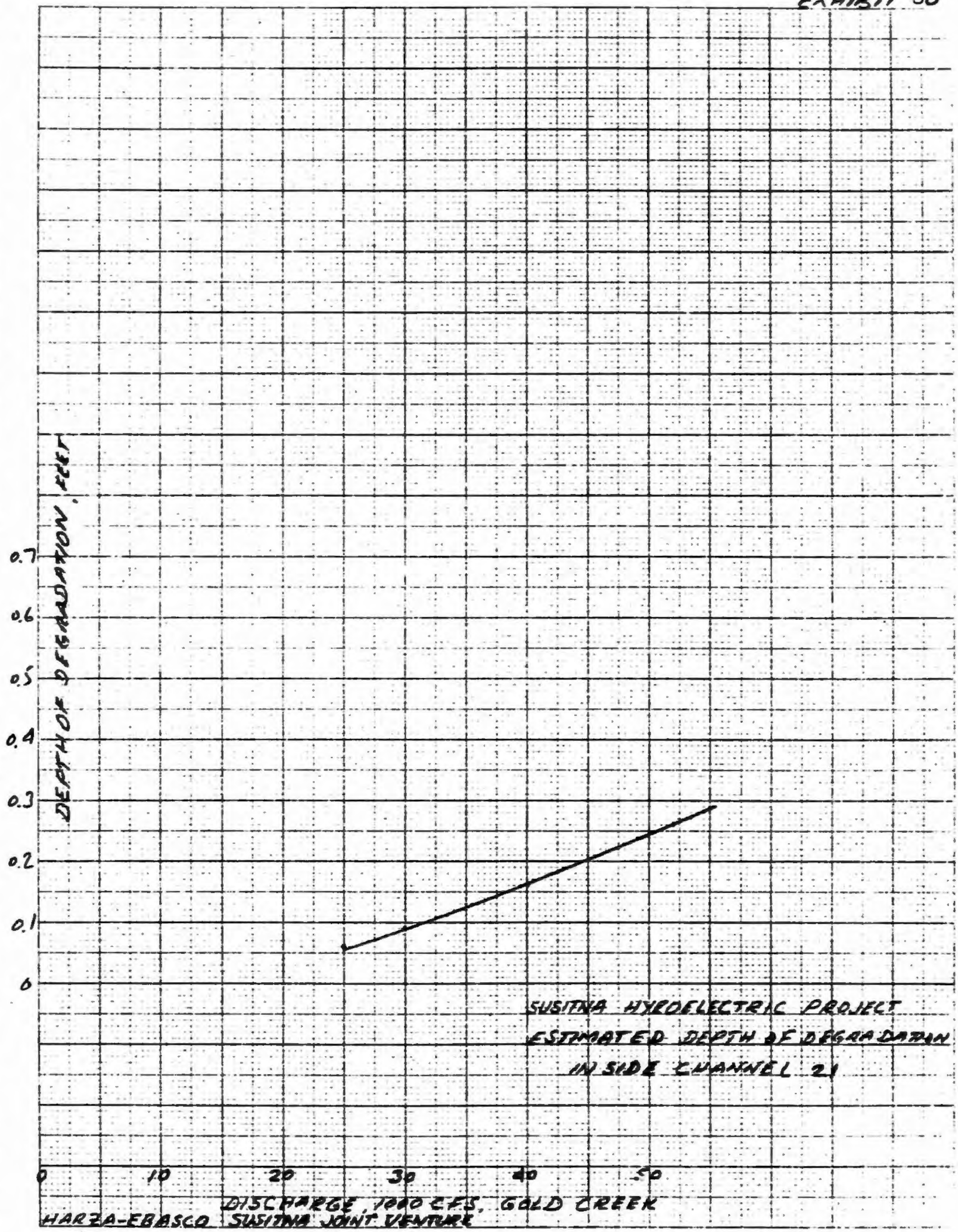
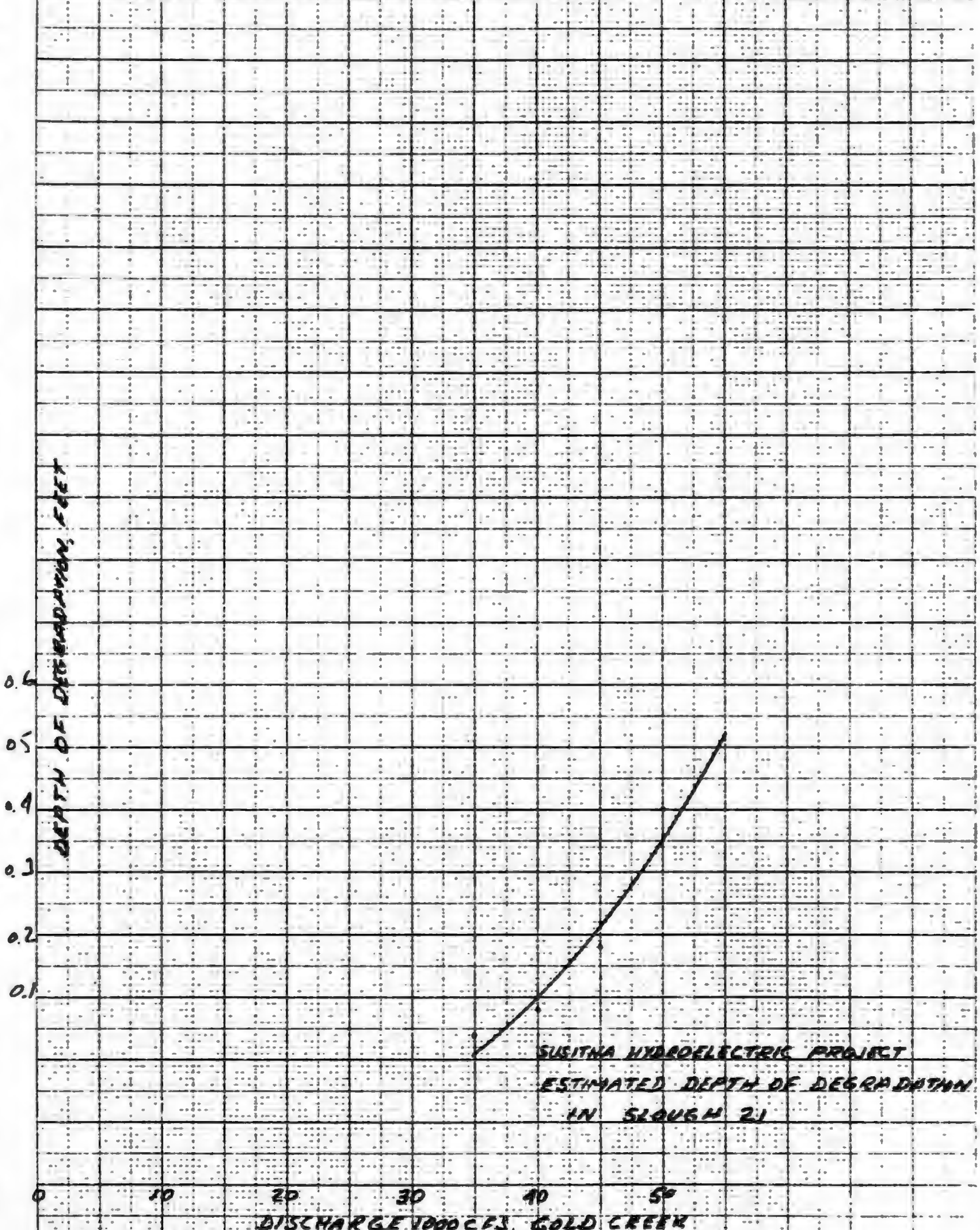

SUSITNA HYDROELECTRIC PROJECT
ESTIMATED DEPTH OF DEGRADATION
IN SIDE CHANNEL 21
DEPTH OF DEGRADATION, FEET
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
DISCHARGE, 1000 CFS, GOLD CREEK
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 59



HARZA-EBASCO SUSITNA JOINT VENTURE