SUSITNA HYDROELECTRIC PROJECT

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

FINAL REPORT

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SUSITNA JOINT VENTURE

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Report by

Harza-Ebasco Susitna Joint Venture

Prepared for
Alaska Power Authority

Final Report
November 1985

NOTICE

ANY QUESTIONS OR COMMENTS CONCERNING THIS REPORT SHOULD BE DIRECTED TO THE ALASKA POWER AUTHORITY SUSITNA PROJECT OFFICE

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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 (channel segments about 1 to 3 miles in length) 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 (Exhibit 1). 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 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 at the study sites was investigated in qualitative terms. Under with-project conditions, an approximate 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 Games; 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, average depths and channel widths at each site. The size distribution representative of the bed material at each site was derived from the analysis of samples collected by Harza-Ebasco.

The sizes of armoring bed material corresponding to selected ranges of discharges were estimated as averages of the five sizes estimated 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 armoring 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 96 percent of the suspended sediment load carried by the river under natural conditions is finer than 0.5 millimeters (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, due to 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 all sediment except the smaller particle sizes including fine silt and clay size material. The river will strive to adjust itself for 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 degradation in the study reach.

An accurate estimate of actual degradation is difficult because of many unquantifiable parameters such as the sediment contribution from tributaries, bank erosion, the degree of armoring of the river bed under natural conditions and the actual streamflow and floods which would occur during early stages of the project. However, based on available data and using empirical relationships, it is estimated that degradation in the main channel would be approximately in the range of 1.0 to 1.5 feet corresponding to a dominant discharge of about 28,000 cfs, estimated as the average of maximum weekly discharges during Stage II of the project. The larger amount of this degradation would occur immediately downstream of the Devil Canyon dam and would decrease with distance downstream. In the sloughs and side channels, the degradation would be about 0 to 0.3 feet.

The estimated degradations in the main channel are based on the assumption that there would 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 degradations would be less than those estimated.

The estimated degradations in the main channel also depend upon the bed material size gradations which were determined using a limited number of samples. The bed material samples were taken from the river bed by reaching out into the river as far as feasible during low flow periods. Thus, the samples represented bed material near the banks. The near bank size gradation is likely to be finer than that in the middle of the river. Therefore, the estimated degradations could be an upper limit.

Using the adopted bed material size gradations at the main channel locations, the mainstem discharges ranging approximately between 10,000 and 20,000 cfs would cause movement of gravel sizes between 25 and 50 mm. Since about 40 percent of the bed material at these locations is finer than 25 mm, the degradation could start at lower discharges.

When the system hydropower demand increases as in late Stage III, the maximum reservoir releases would be significantly reduced. Therefore, the armoring layer developed earlier would be more stable than under natural conditions. However, infrequent flood events would not be controlled to as great an extent as the smaller floods and this could disturb the armor layer and cause bed degradation. Reservoir operation studies indicate that floods up to the 50-year event will be reduced by about 50 percent at Gold Creek for projected energy demands under late Stage III conditions. Control of less frequent flood events also will be improved by that time and the potential for further bed degradation would, therefore, be reduced.

Because of the many variables involved it is not possible to precisely predict degradation of these small amounts accurately. Therefore, monitoring of water levels near habitat areas is recommended. This will allow modification of habitat areas if any significant changes occur in the channel.

If degradation of the estimated amount occurs in the mainstem, discharges higher than those under natural conditions would be required to overtop the berms at the heads of the sloughs and side channels. If the river bed at the entrances is lowered by about one foot due to the degradation, the with-project discharges that would overtop the sloughs and side channels are estimated to range between 4,000 and 12,000 cfs higher than those under natural conditions.

The analysis indicated that whenever the sloughs or side channels are overtopped during floods, the velocities would be sufficiently high to carry out the fine sediment of sizes .004 millimeter and less. However, any coarse silt and fine sand picked up from the river bed and entering the sloughs or side channels would have the tendency to settle out in pools and backwater areas. Mechanical devices such as "gravel gerties" can be used to flush these materials from sloughs. Alternately, project discharges can be raised to overtop those slough berms that are not expected to be overtopped under normal project operations, 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 the 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 problem of sediment accumulation in the Watana and Devil Canyon reservoirs and the 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 armoring 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 were based on a limited number of samples taken from the 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 documents channel stability analyses 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 analyses are based on bed material samples taken from surface and subsurface material at or near the selected sites.

The draft of this report was issued in March 1985 when the with-project flow conditions were based on the analysis conducted for a two-dam, two-stage development. The Watana Reservoir was assumed to be operative by 1996, followed by the Devil Canyon Reservoir by 2002. The dominant discharges

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1/ Indicates reference at the end of text.

under with-project conditions for the draft report, were determined for the energy demands for the years 1996, 2001, 2002 and 2020.

As of April 1985, the project is being considered to be a two-dam, three-stage development. Stage I would be a low Watana (normal pool elevation = 2000 ft) development, Stage II would be a low Watana-Devil Canyon (normal pool elevation = 1455 ft) development and Stage III would be a high Watana (normal pool elevation = 2,185 ft) - Devil Canyon development. Stage III is further classified as early Stage III and late Stage III. The dominant discharges under with-project conditions used in this report are derived from the weekly reservoir operation studies for various stages of development (H-E December 1985a).

3.0 SCOPE OF STUDY

This study is made to provide input to the instream flow relationship studies, which will provide a quantitative assessment of potential effects on fish habitat because of with-project changes in streamflow, stream temperature, suspended sediments, channel regime 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 the 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 analyses, a stable channel means that its shape, slope and bed material size distribution do not change significantly on a long term basis. The major tasks are:

1. to evaluate sedimentation processes under natural conditions;

2. to estimate potential degradation or aggradation under with-project conditions;

3. to estimate discharge rates at which the mainstem flows are likely to overtop the entrances to 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 to estimate the flow rates required 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 the 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 the 12-mile reach between the entrance and the mouth (outlet) of Devil Canyon (ACRES, 1982). The river gradients between the 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 June through September and starts falling rapidly in October as the freeze-up occurs. The mean annual flows 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 scour and deposition have been observed (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 the 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 Sloughs
   - Slough 8A, RM 126.2
   - Slough 9, RM 128.3
   - Slough 11, RM 135.4
   - Slough 21, RM 142.2

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 the 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 (about 3,000 to 50,000 cfs).

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 and 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 long, between RM 113.6 and 114.2. The Lane Creek Slough is on the 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 islands 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 the 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 the left bank at 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 and 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 upstream 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). 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 reach selected 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 from 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 the Alaska Power Authority by the Alaska Department of Fish and Game, Susitna Hydro Aquatic Studies Team (ADF&G), R & M Consultants, Incorporated (R&M) and Harza-Ebasco Susitna Joint Venture (H-E). Discharge and sediment data also were taken from the publications of the U.S. Geological Survey, Water Resources Division (USGS) prepared in co-operation with the 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 a previous report by Harza-Ebasco (January 1984). 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 a previous report by Harza-Ebasco (January 1984).

Bed material samples were collected by USGS and Harza-Ebasco personnel for this study. The results of these samples are given in previous reports by Harza-Ebasco (April 1984) and the USGS (Knott-Lipscomb, 1983). 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 processes 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 is the intrusion of fine sediment into the gravel bed and its subsequent entrapment. In case of fine sediment deposition on the gravel bed, appropriate measures may be required to flush out the sediments so that the bed can be kept clean.

To provide some background for analyzing the specific problems under study, a 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 1 to 15 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 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 including Lane (1955), Leopold and Maddock (1953), Schumm (1971) and Santos and Simons (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 discharge 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 a qualitative approach provide understanding of the methods required to quantify the changes in the system. Mathematical modeling can help to study many factors simultaneously. Recent work by Simons and Li (1978) and others indicates that physical process computer modeling may provide a reliable methodology for analyzing the impacts and for 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 the 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 other information which are generally not readily available. The data of primary need include hydrologic and topographic maps and charts, large scale aerial and other photos of the river and surrounding terrain, existing river conditions (roughness coefficient, aggradation, degradation and 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, and size distribution of bank and bed materials and suspended sediments), and size and operation of anticipated reservoir(s) on the river system.

The information on sediment, particularly bank and mid-channel bed material sizes, bed-load estimates and sediment injected by tributaries, is not sufficient to calibrate a more quantitative mathematical model. Therefore, a water-sediment-routing mathematical model has not been developed for the study reach. The predictions of potential aggradation or degradation at the study sites were based on morphological concepts and empirical relationships.

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. Irregularities in the river bed,
5. Geometric and hydraulic characteristics of the 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, H-E December 1985b). The sediment passing through the reservoir would be about

15 percent of sediment inflow (APA, November 1985, H-E December 1985b);

2. Irregularities in the river and channel 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 and/or as suspended bed material load;
5. Sediment injections by tributaries is carried downstream without significant deposition in the channel segments under study;
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 armoring bed material size 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 (Simons, Li and Associates, 1982). Each of these methods is discussed below.

7.1.1 Competent Bottom Velocity

The velocity near the bed at which a sediment particle starts to move is defined as the competent bottom velocity (Mavis and Laushey, 1948). This velocity is approximately 0.7 times the corresponding mean channel velocity. Exhibit 17 shows a relationship between the competent bottom velocity and armoring size (Figure H-13, Design of Small Dams). This relationship was used in this 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:

$$\text{Tractive force} = \gamma \, d \, S \text{ (pounds/square feet, lbs/ft}^2\text{)}$$

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 determined as $Dm = \Sigma \, p_i \, d_{si}$, where p_i is the fraction by weight of that fraction of the bed sediment with mean size d_{si}.

d = mean water depth, feet

S = hydraulic gradient.

For no bed scour and assuming $Q = Q_B$, the armoring size (D) 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):

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

in which:

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

S = hydraulic gradient, ft/ft.

If B is the width of a 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 (Simons, Li and Associates 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 (armoring size), ft.

Shields determined a graphical relationship between F* and the 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 ranges 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 armoring size is given by the following relationship:

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

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

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

$$= 3944\ d\ S$$

in which:

D = armoring 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 the original streambed to the top of the amoring 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 armoring size or 0.5 ft whichever is smaller,

Δp = decimal percentage of material larger than the armoring size.

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

7.2 AGGRADATION

Potential aggradations in the mainstem at the heads of sloughs and side channels were estimated by comparing the armoring sizes for the flow in the mainstem before diversion into the slough or side channel and the armoring sizes corresponding to the remaining flow in the main channel after diversion into the side channel or slough. If the two sizes were significantly different, it was concluded aggradation would occur 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 armoring 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 Harza-Ebasco, as discussed 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). The dominant discharge at Gold Creek is estimated to be about 48,000 cfs.

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 maximum discharge over a reasonably long period in the release pattern 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 more representative of the dominant discharge. For the Middle Susitna River under study, the dominant discharge was derived based on weekly reservoir operation studies for Stages I, II and III of the project and is discussed under Section 9.2.2.

The dominant discharges for side channels and sloughs will depend upon the frequency of overtopping of the berms of the side channels and sloughs and on the magnitude and duration of the overtopped flows. The side channels and sloughs under study are currently overtopped 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 channels remain unchanged, the frequency of overtopping will be greatly reduced as also discussed under Section 9.2.2.

Relationships were developed between a range of dominant discharges and corresponding armoring sizes and between a range of dominant discharges and corresponding depths of degradation. The computations were made by using data for the individual locations and the discharges at a given location were referenced to the corresponding discharges at the Gold Creek stream gaging station. The computations cover a range of discharges 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 a previous report, (H-E, January 1984). The data representative of 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, and data received through correspondence from R&M and ADF&G. The same data were also used in determining the relationships between the slough or side channel discharges and average channel widths, 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 discharges at Gold Creek at which various sloughs and side channels are overtopped (Table 1). It also determined that the discharge entering a slough or side channel can be expressed as a function of the discharge at Gold Creek in the following form:

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

The relationships were derived based on the data collected in 1982 through 1984. These data correspond to discharges of 12,000 to 32,000 cfs at Gold Creek. The relationships provided a reasonably good comparison between the observed and computed discharges in the sloughs and side channels for the observed range of the data. However, they were 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 on Exhibit 19. The extension of these relationships for higher discharges is somewhat arbitrary but they represent the best relationships that can be established using the available date.

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 velocity 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 at gages (staff gage or recorder) near discharge measurement sites in selected sloughs and side channels. The discharge measurement sites 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 section and also the 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 the lack of additional data for a detailed analysis at the other cross sections. Therefore, the stage-discharge relationships developed for the stream gaging stations and the channel cross sections 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 a previous report (H-E, January 1984).

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 (ADF&G, 1983 and May 1984).

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 affects the evaluation of the sedimentation process. Therefore, representative bed material size distribution data were considered essential for the study. Thirty six sediment samples were taken (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. Because of limited data, the surface and sub-surface samples at a given site (main channel, slough or side channel) 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 would 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 every 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 flows entering these sloughs and side channels are from the upper layer of the flow in the main channel and do not carry coarse material. This relatively sediment free flow picks up finer bed material at the heads, thereby, leaving coarser material.

A report was prepared by Arctic Environmental Information and Data Center (AEIDC) on historical morphological changes in the Susitna River (AEIDC, June 1985). 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 may be indicative of river degradation over the 35-year period or deposition of material at the boundaries of the gravel bars. 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 armoring 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 armoring sizes for all study sites.

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

1. For all the study sites in the main channel, the armoring 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 undoubtedly has caused temporal deposition and scour in the past and the river bed likely exhibits similar behaviors at present. The extent of the deposition or scour can not be predicted with any degree of certainty because it depends on many factors such as the flow, sediment loads and ice jams all of which are highly unpredictable.

2. In the Northeast and Northwest Forks of Mainstem 2 Channel, the armoring 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, for the channel downstream from the confluence of these sub-channels, the analysis indicates that the armoring size is 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 staging and overtopping or breaching of an ice jam.

3. For Sloughs 8A and 11 and Side Channel 21, the armoring sizes corresponding to flows up to 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 up to a flow of about 55,000 cfs at Gold Creek. However, much larger floods or higher river flows caused by activities of ice jams can cause deposition and/or scour.

4. For Slough 9, the armoring 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 during flows higher than 45,000 cfs, 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 activities of ice jams) and the characteristics of the 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 the 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 96 percent of the suspended load is finer than 0.5 mm. Thus, there is a high probability of fine sediments depositing on the 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 indicate that at low velocities deposition occurs 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 degradation in a river reach some distance downstream from Devil Canyon Dam. The modified discharges downstream from the dams, however, will have reduced competence to transport bed material especially those added by the tributary flows. These two factors will tend to compensate with each other, resulting in the overall effects discussed below.

Lane's relationship discussed under Section 7.0, "General Approach", is based on the 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 gradient and particle sizes of the bed material. Previous studies (Hey, et al 1982) have indicated that the new median diameter of bed material downstream of a large reservoir 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 Consultants (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 degradations at the selected sites were estimated for various discharges using the procedures discussed under "General Approach". The relationships between the index discharge at Gold Creek and estimated degradations 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 the bed material injected by the tributaries and also the bed material eroded from the upstream main channel would not be deposited in the downstream reaches.

Table 7 shows average weekly flows at Gold Creek for four project operation scenarios of Stages I, II and III and for natural conditions. These data were obtained from recent studies reported in the License Application (APA 1985) and in a report by Harza-Ebasco (H-E December 1985a). These data indicate about a 40 to 60 percent reduction in flows during the late May through August period, about a 3 to 7 times increase in flows during the November through April period and nearly equal or slightly reduced flows in other months during the year. Table 8 shows annual maximum weekly flows at Gold Creek for natural and with-project conditions. Under with-project conditions, the maximum weekly flows generally would occur under Stage II load conditions. Using the mean of Stage II annual maximum weekly flows as the dominant discharge (about 28,000 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. As discussed previously, these estimates assume that the bed material injected by the tributary flows and also eroded from the upstream channel would not deposit at the study sites. In actual situations, some of the sediments carried down by the tributary flows would be deposited in the main river. Redeposition of some sediment eroded from the upstream channel also would occur and actual degradation at the main channel sites would be less than that estimated.

Table 3 shows that the flows entering at the heads of the sloughs and side channels are small compared to the corresponding flows at Gold Creek and therefore, these flows will not significantly reduce the discharge rates in the main channel. Thus, 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 confined within 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 the sloughs and side channels to become less effective for passing flow, but some new sloughs or side channels would 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 prior to spawning, unless other means such as "Gravel Gerties" are employed to flush out the fine sediment deposition.

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TABLES

Table 1

CHARACTERISTICS OF STUDY SITES
ON MIDDLE SUSITNA RIVER[1/]

	Approx. River Miles	Overall Slope of Study Site	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
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	,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 Percent Finer Than											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}
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

ARMORING 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
	Armoring 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)

Week[1/]	Natural Flow (cfs)	With-Project Flows[2/] Stage I (cfs)	Stage II (cfs)	Early Stage III (cfs)	Late Stage III (cfs)
(1)	(2)	(3)	(4)	(5)	(6)
1	1607	8795	8043	8319	10323
2	1554	8416	8054	8286	10300
3	1512	7920	8062	8250	10285
4	1494	7786	8067	8218	10201
5	1427	7596	7932	8177	10225
6	1354	7623	7889	8186	10262
7	1300	7569	7570	8129	10141
8	1258	7584	7182	8074	10082
9	1204	7358	6833	7959	9957
10	1152	6425	6468	7556	9448
11	1149	5753	6306	7305	9117
12	1157	5186	6129	7054	8781
13	1167	4785	6157	6910	8581
14	1216	4726	6256	6895	8500
15	1240	4323	6068	6703	8246
16	1408	3943	5990	6545	7999
17	1667	3593	5808	6402	7644
18	3654	3399	5859	6409	7532
19	7914	4530	6197	6824	7932
20	13466	6393	7217	7551	9067
21	18715	7650	7930	8340	9896
22	23556	10009	8465	9148	10782
23	27284	11410	9101	9280	10250
24	29369	13951	9069	9267	10452
25	27860	14405	9078	9227	10322
26	26313	14059	9741	9104	10112
27	23987	13108	10446	9918	9317
28	24491	13611	12880	10705	9383
29	24708	14285	15259	13793	9460
30	24031	15458	17866	15444	9355
31	25294	17428	20649	18343	9613
32	23320	18167	19882	18164	9415
33	22387	18880	20671	18566	10756
34	20411	18358	20803	18536	11875
35	18377	17249	18400	17381	11281
36	15621	15594	15546	15492	11772
37	14039	14308	14071	13859	10998
38	12871	13793	12897	12662	10211
39	10663	12582	10778	10611	9649
40	8102	10618	8471	8511	8812
41	6782	7641	7638	7747	8695
42	5348	6819	7211	7356	8557
43	4303	6973	7309	7491	8514
44	3332	7262	7422	7574	8461
45	2861	7635	7679	7928	8908
46	2562	7829	7896	8196	9554
47	2358	8079	8089	8585	10122
48	2204	8284	8328	8823	10603
49	1978	8947	8662	9179	11108
50	1886	9578	8853	9349	11474
51	1785	9394	8643	9070	11162
52	1739	8943	8288	8590	10590

1/ First week is the first week of January.
2/ Based on environmental constraints, E-VI.
Stage I: Low Watana
Stage II: Low Watana and Devil Canyon
Early Stage III: High Watana and Devil Canyon
Late Stage III: High Watana and Devil Canyon, increased power demand

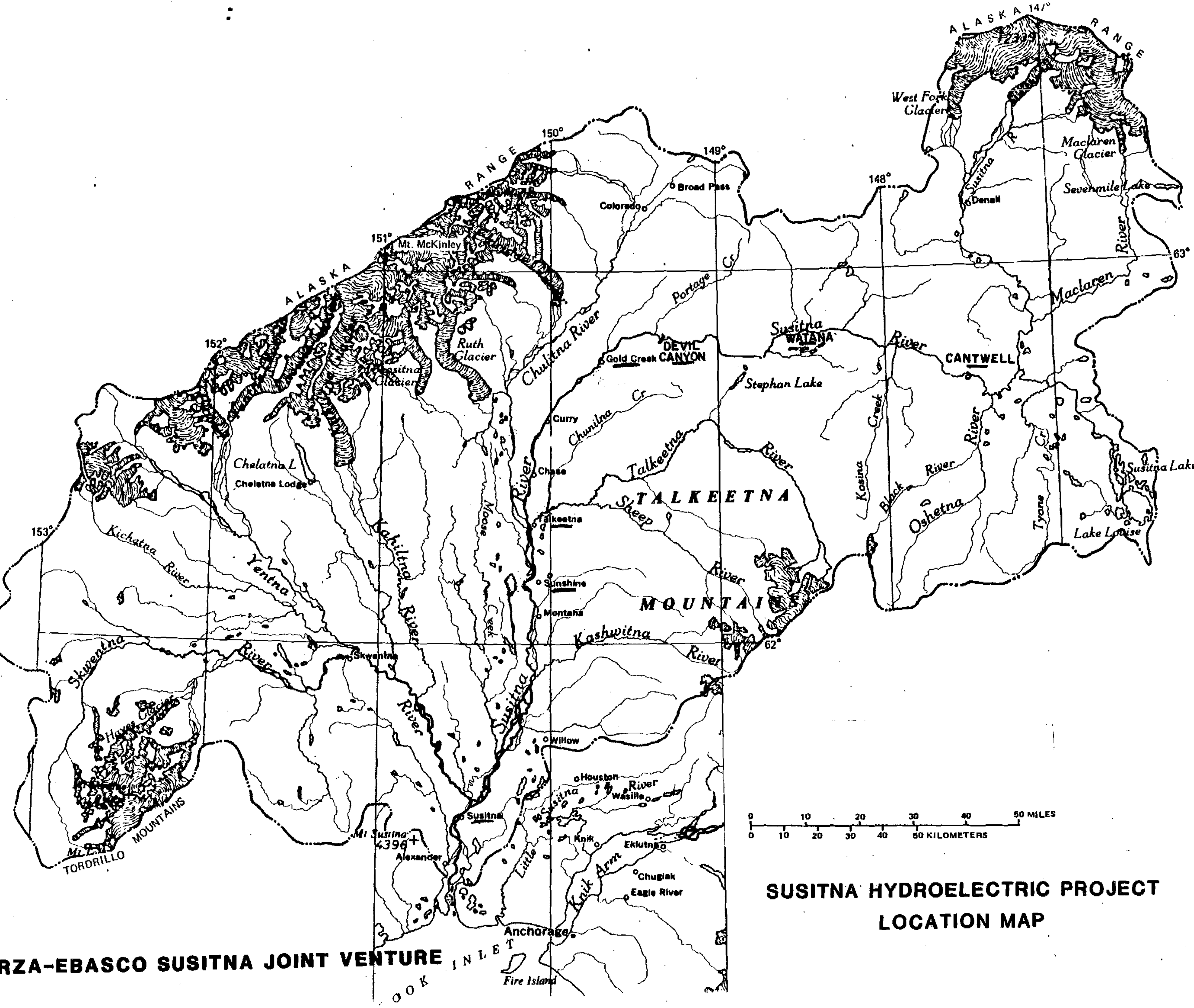
Table 8

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

		With Project Flow			
Year[1]	Natural Flow (cfs)	Stage I (cfs)	Stage II (cfs)	Early Stage III (cfs)	Late Stage III (cfs)
(1)	(2)	(3)	(4)	(5)	(6)
1950	26171	13197	17434	9255	10327
51	30057	27200	30057	27777	11856
52	38114	19629	37243	25071	12721
53	35114	21500	25643	24224	12698
54	31143	20276	24000	24000	12664
55	37243	36658	37243	33410	18572
56	43543	31429	32000	31429	26000
57	37443	21143	23915	21143	13414
58	38686	20443	29726	30896	11817
59	44171	43171	41845	41453	14829
60	32043	23487	28943	28943	12203
61	38714	25132	25900	26000	13787
62	58743	27186	27186	27186	23571
63	40257	32571	38143	35862	22106
64	75029	26143	26143	24671	14941
65	33643	30386	30386	30386	19812
66	47686	18816	22914	22829	14719
67	54871	43711	41589	40403	30600
68	37343	22214	25857	25857	12551
69	18114	9235	8000	8398	10228
70	26429	13743	19971	9699	10026
71	47186	38282	39737	22857	22857
72	44243	22318	25371	25357	18029
73	36443	14229	23171	13128	10293
74	31357	13950	12385	9355	10828
75	36400	24200	28343	25929	19886
76	29843	14066	20507	9611	11530
77	46300	22286	25514	22286	14420
78	22786	13194	14829	14829	11685
79	32457	12514	32457	26514	12927
80	33557	32093	33557	33014	13304
81	46729	40936	39877	37603	37029
82	28857	15725	26557	26557	11895
83	27343	13767	26586	26529	12875
Mean	37900	24100	27700	24800	15800

1/ Calendar Year.

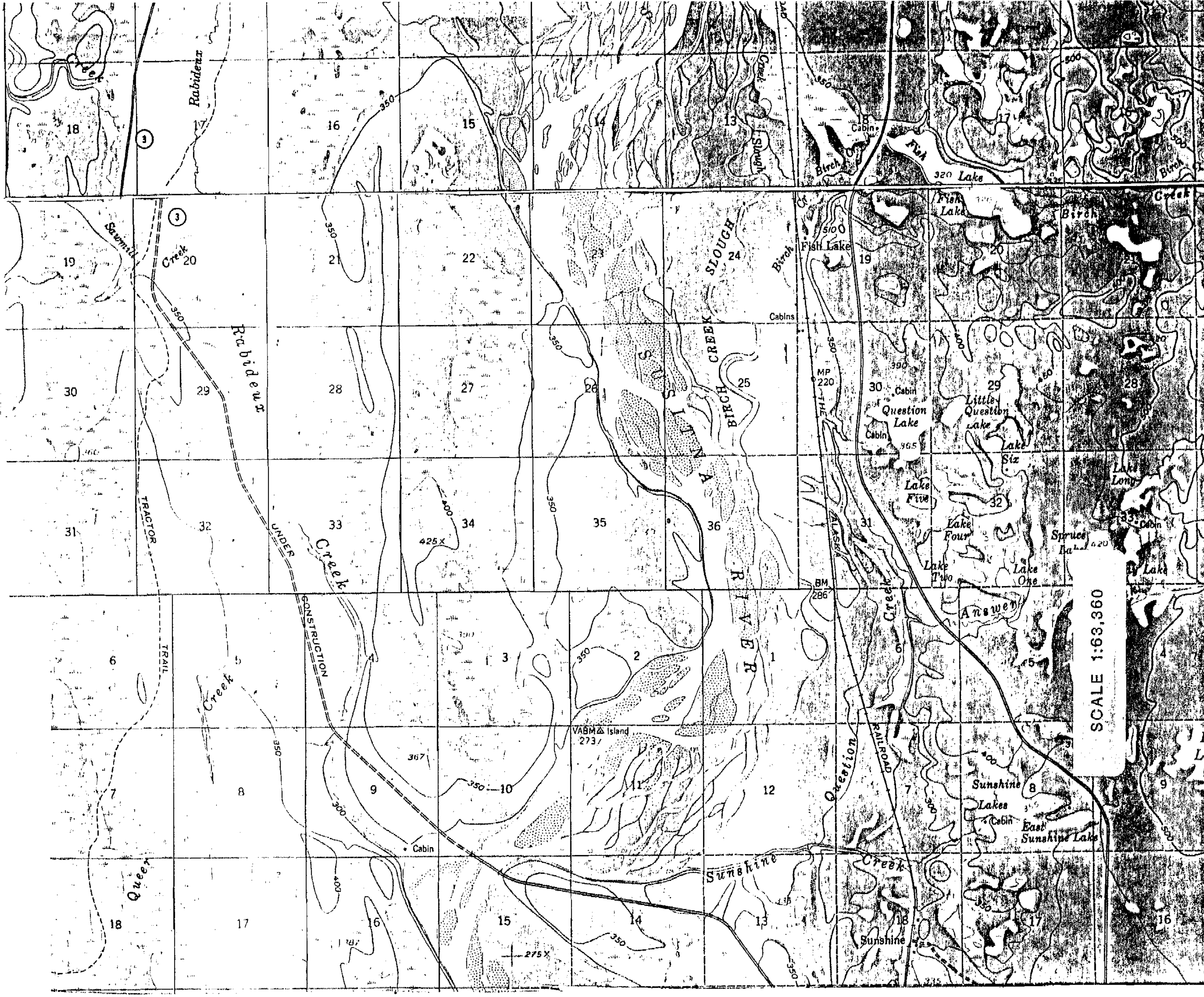
EXHIBITS



SUSITNA HYDROELECTRIC PROJECT LOCATION MAP

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 1



HARZA-EBASCO SUSITNA JOINT VENTURE

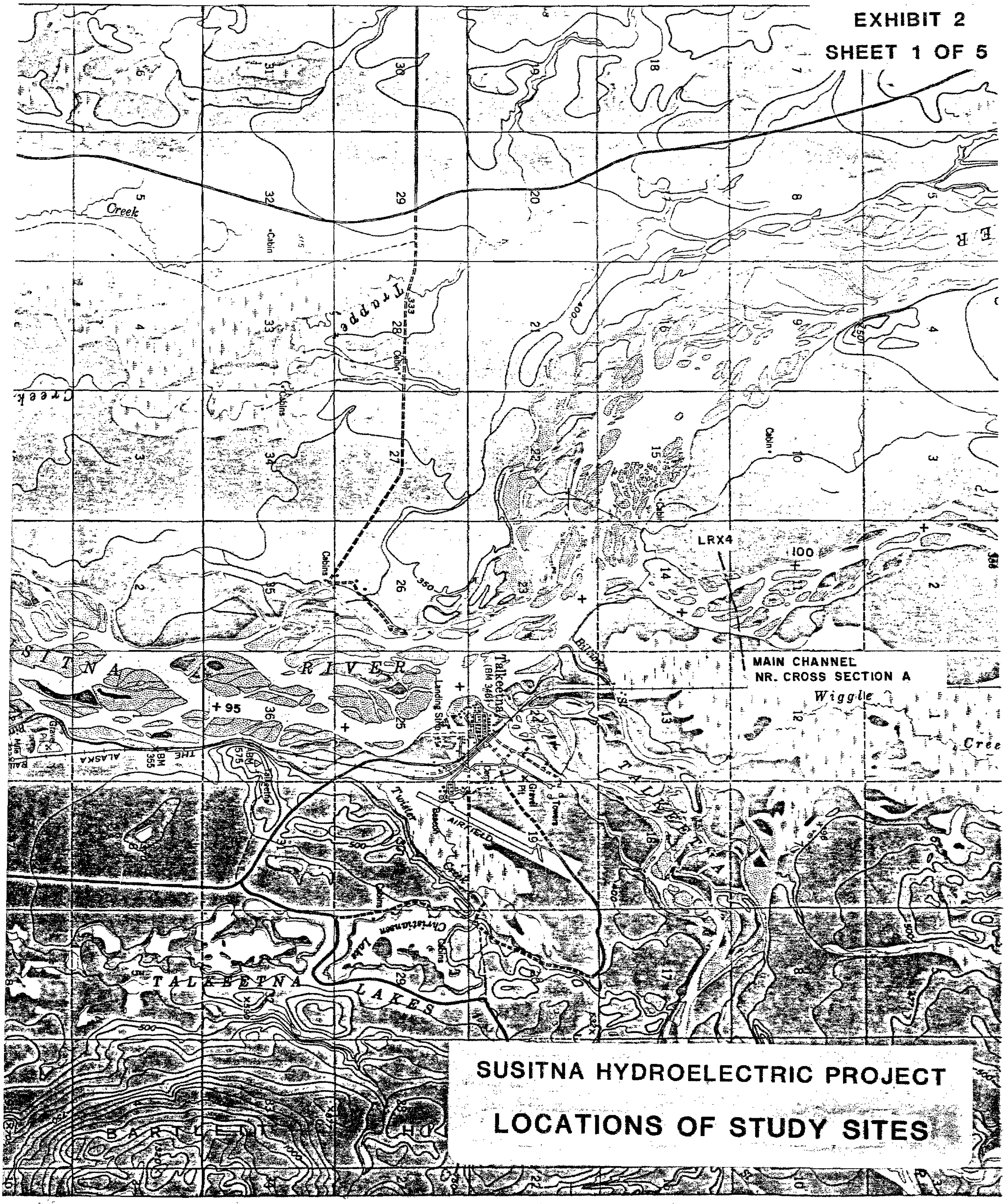
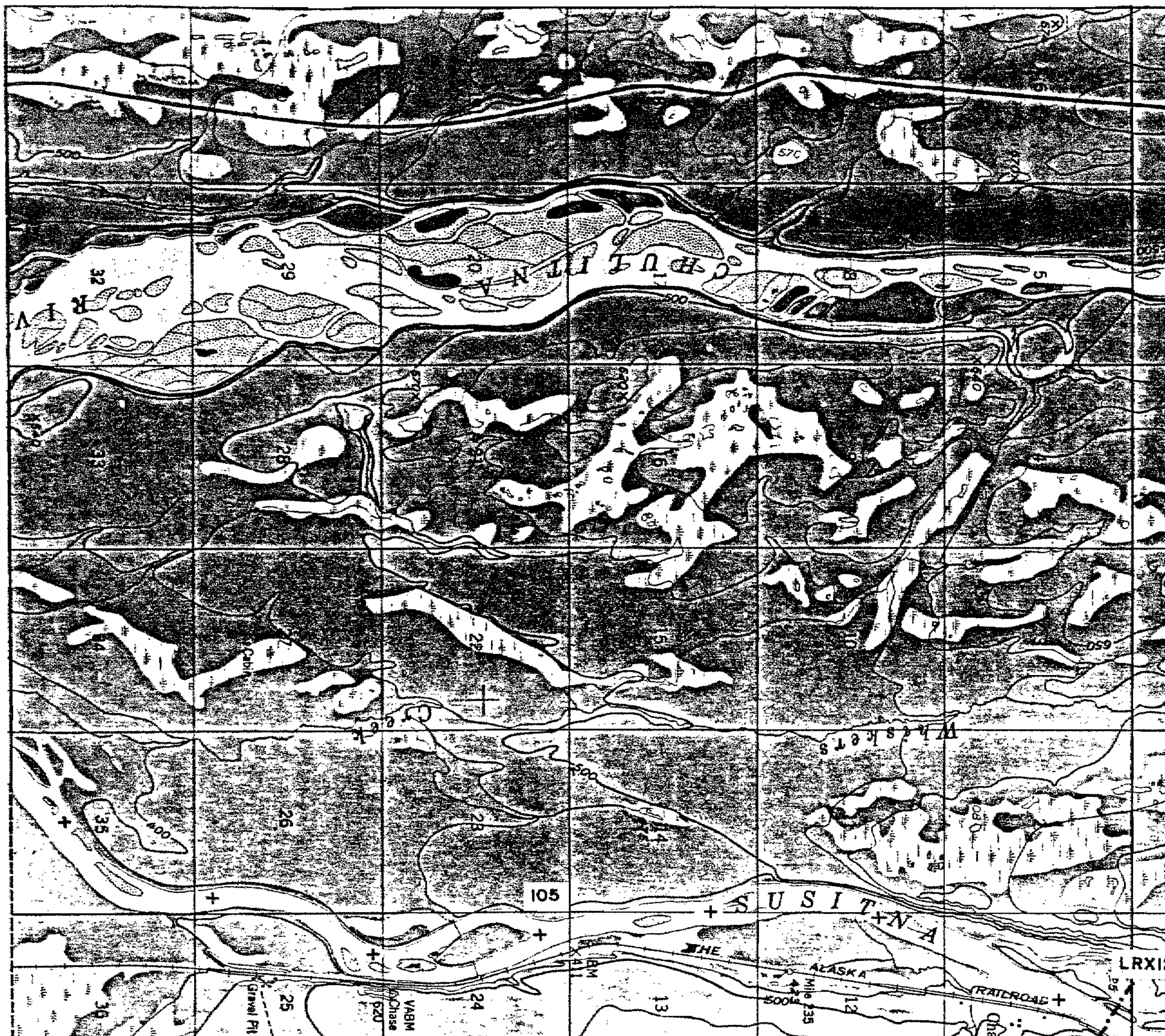


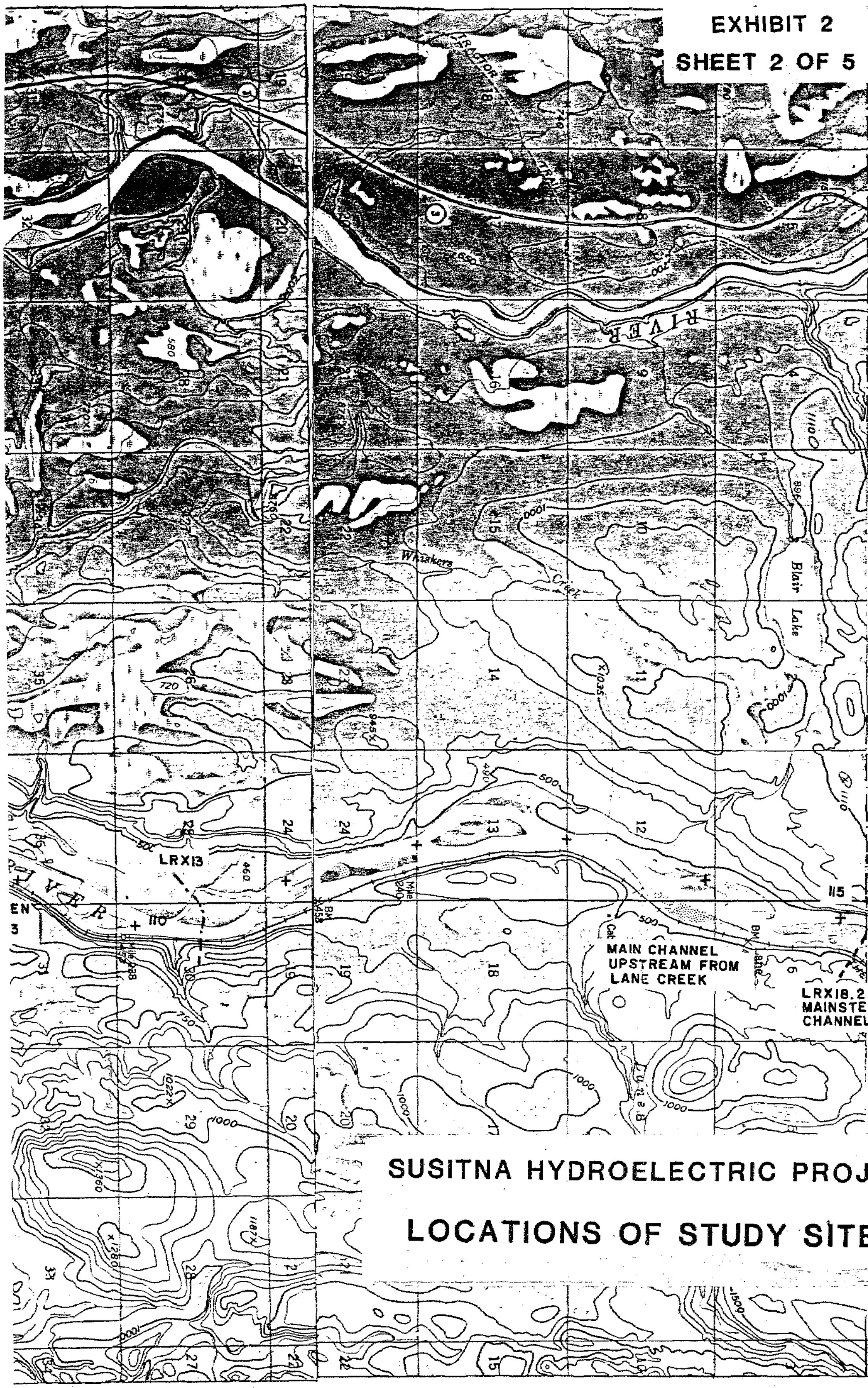
EXHIBIT 2
SHEET 1 OF 5
LRX4
MAIN CHANNEL
NR. CROSS SECTION A
Talkeetna
AIRFIELD
SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF STUDY SITES



HARZA-EBASCO SUSITNA JOINT VENTURE

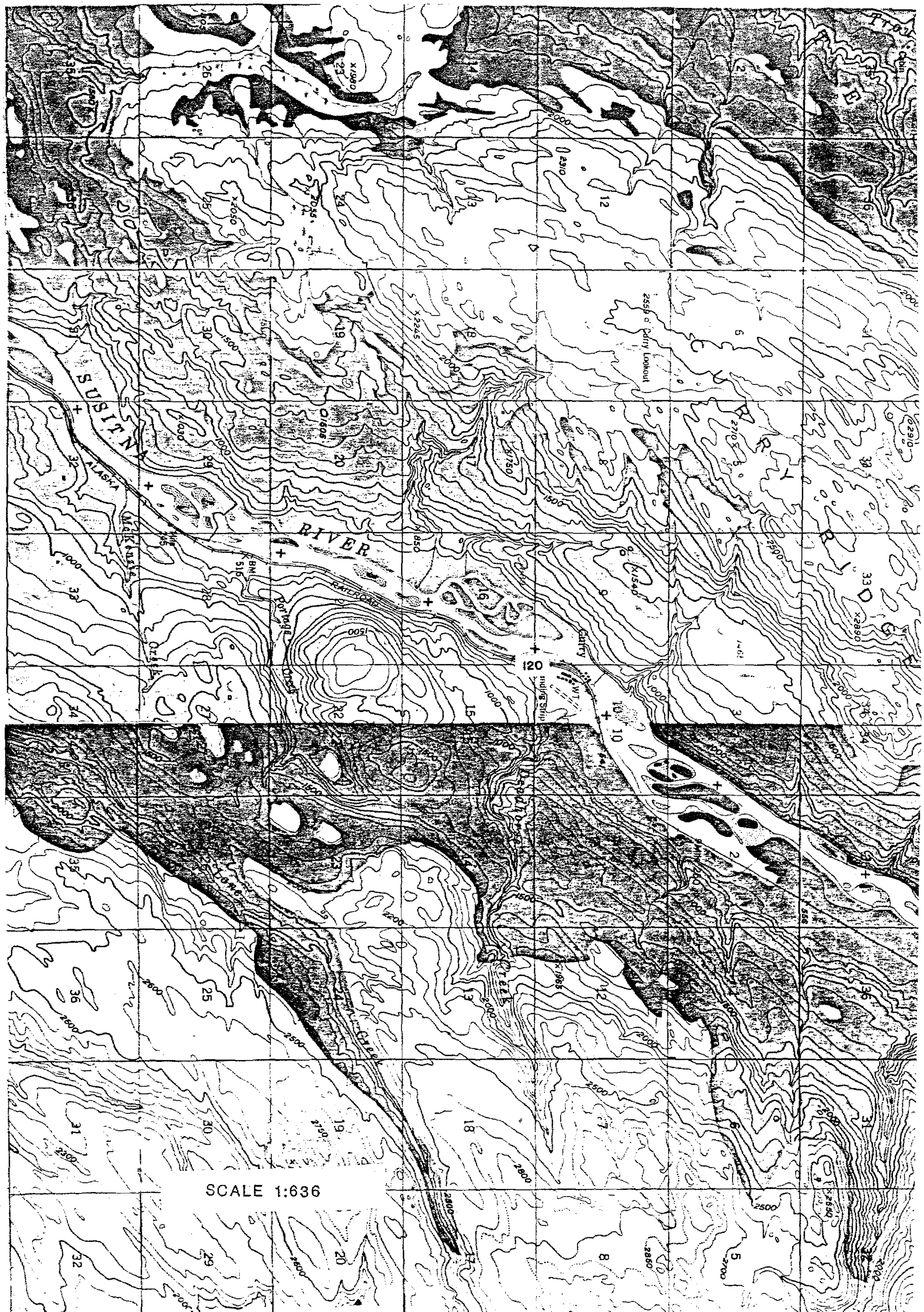
EXHIBIT 2

SHEET 2 OF 5



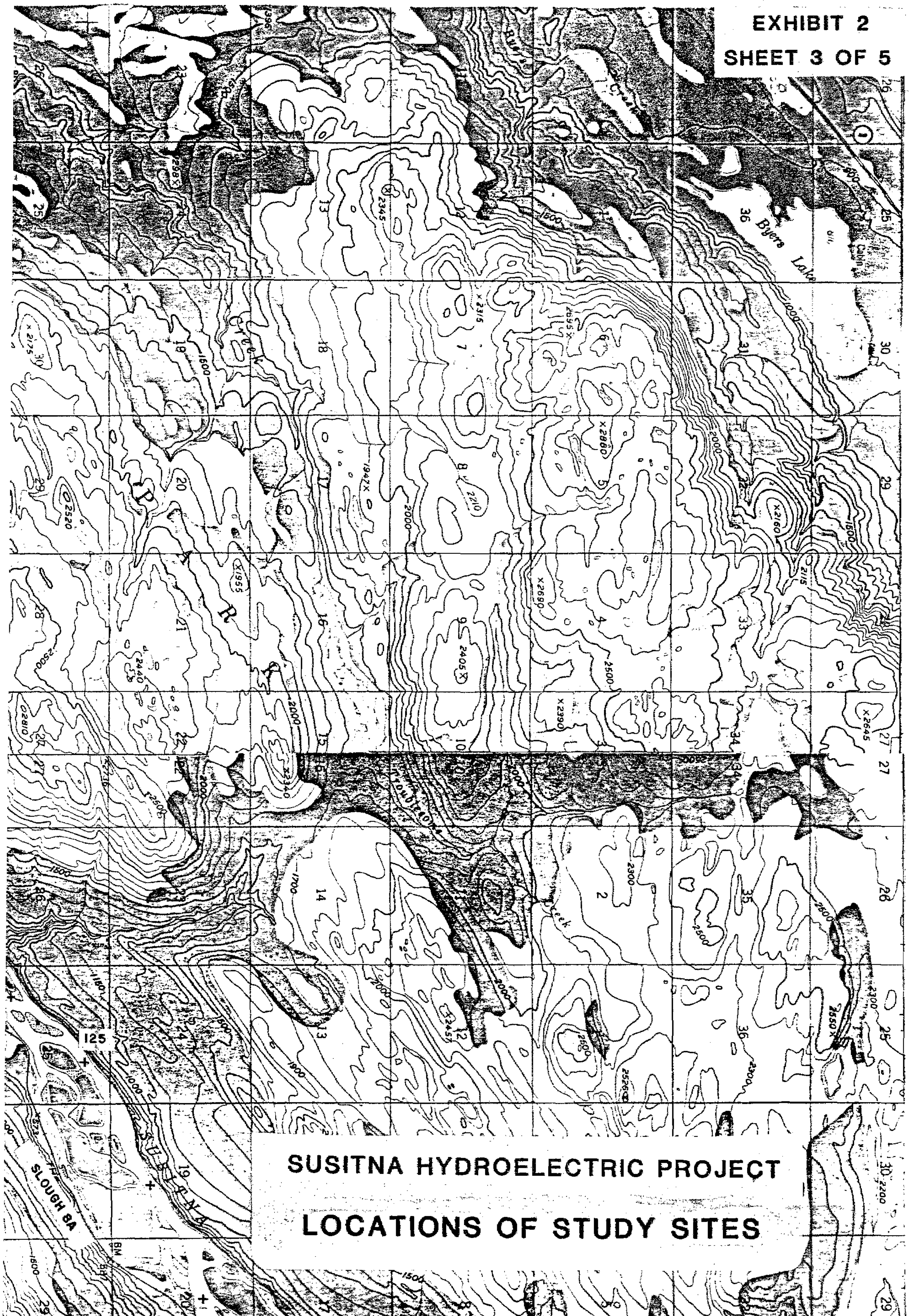
SUSITNA HYDROELECTRIC PROJECT

LOCATIONS OF STUDY SITES



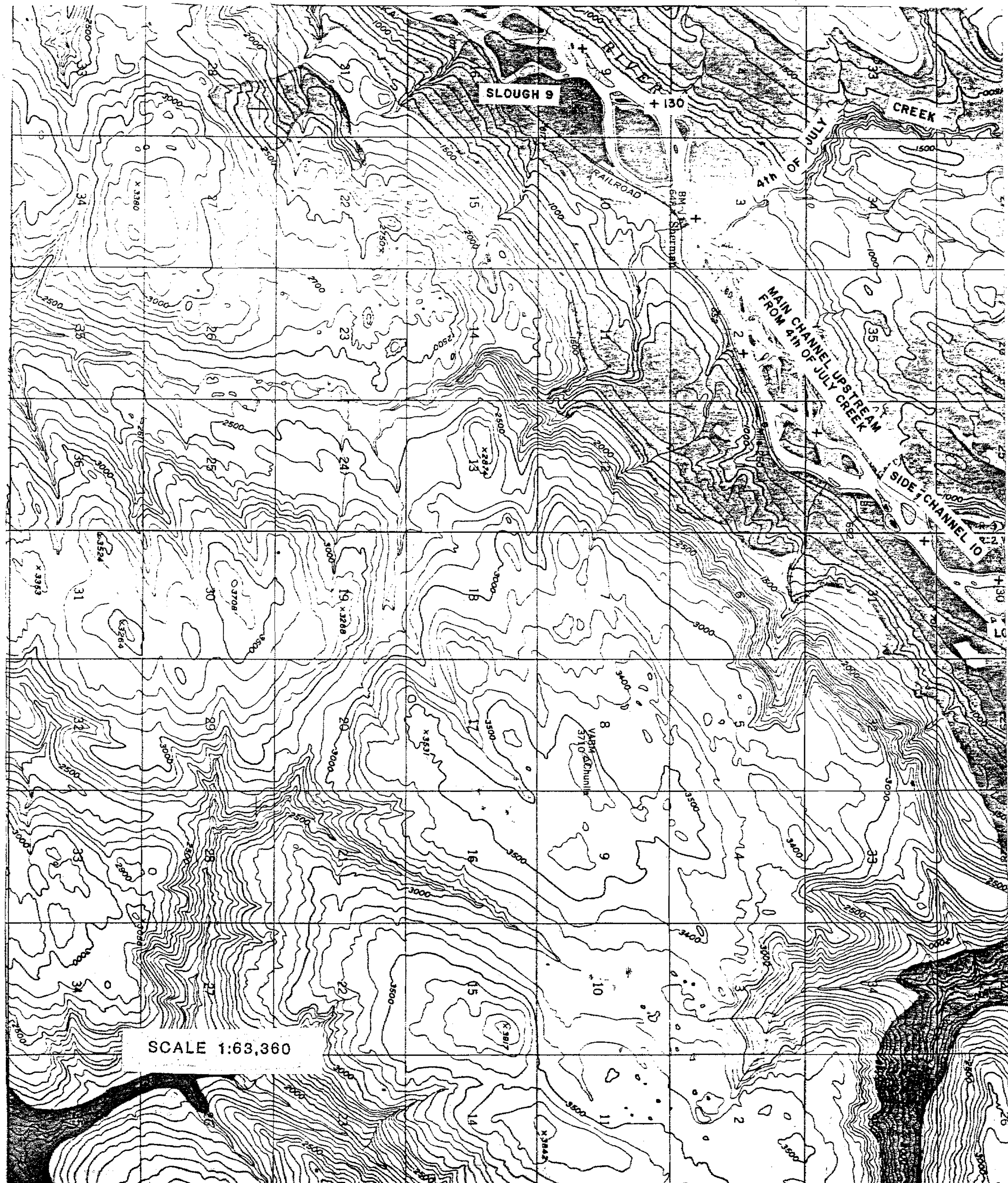
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 2
SHEET 3 OF 5



SUSITNA HYDROELECTRIC PROJECT

LOCATIONS OF STUDY SITES



HARZA-EBASCO SUSITNA JOINT VENTURE

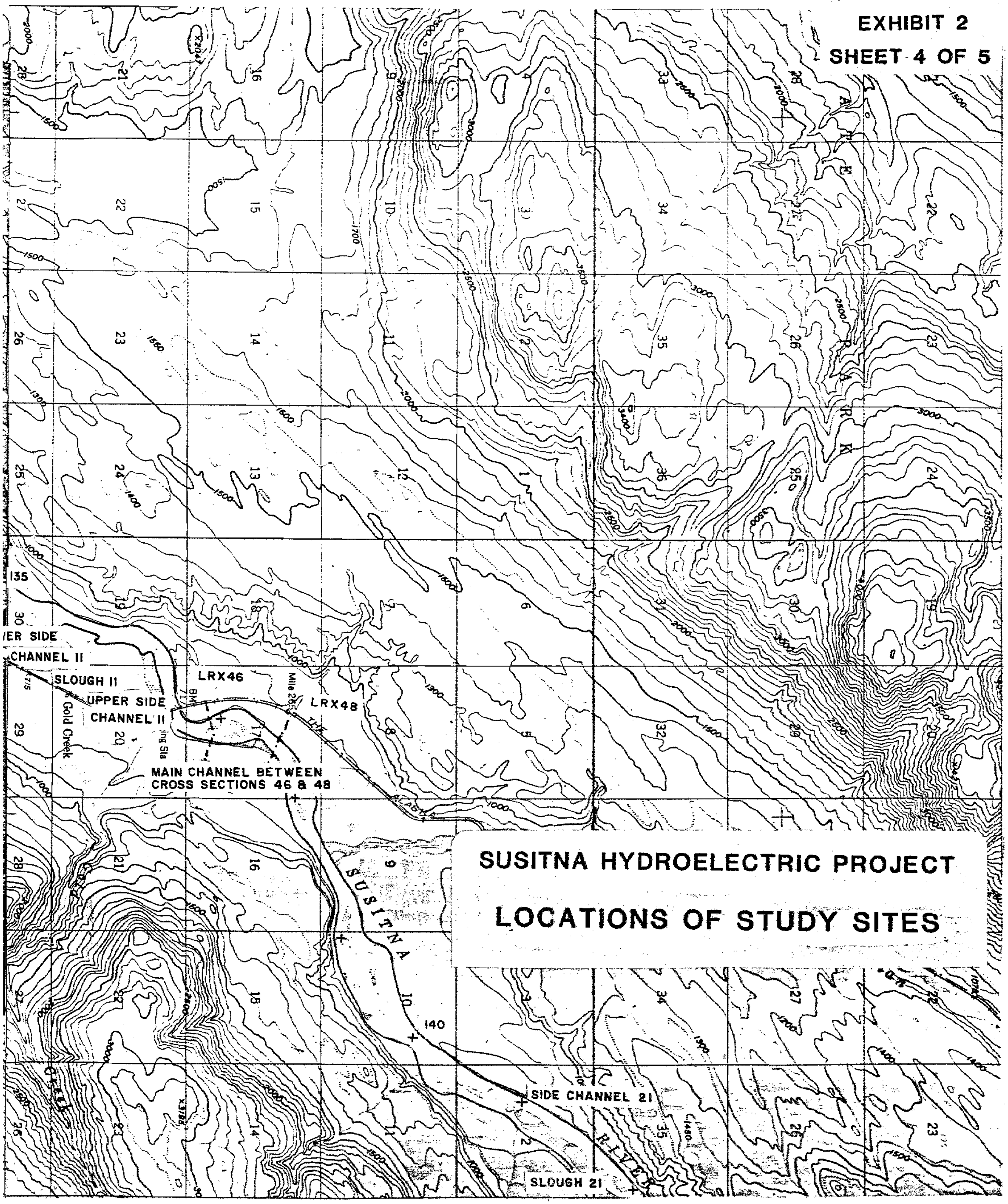
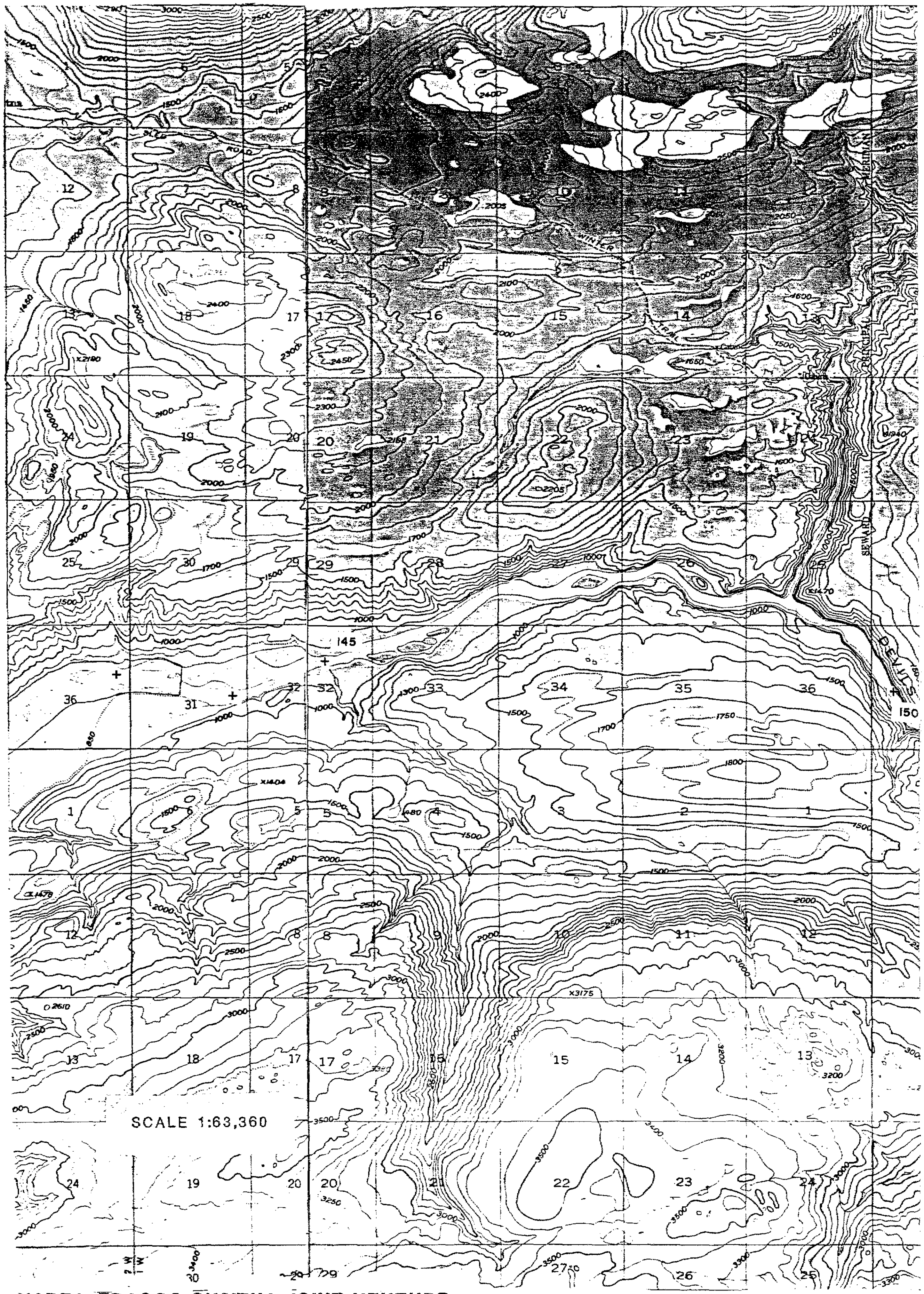


EXHIBIT 2
SHEET 4 OF 5
SUSITNA HYDROELECTRIC PROJECT
LOCATIONS OF STUDY SITES
CHANNEL II
SLOUGH II
UPPER SIDE CHANNEL II
LRX46
LRX48
Gold Creek
MAIN CHANNEL BETWEEN CROSS SECTIONS 46 & 48
SUSITNA
RIVER
140
135
SIDE CHANNEL 21
SLOUGH 21



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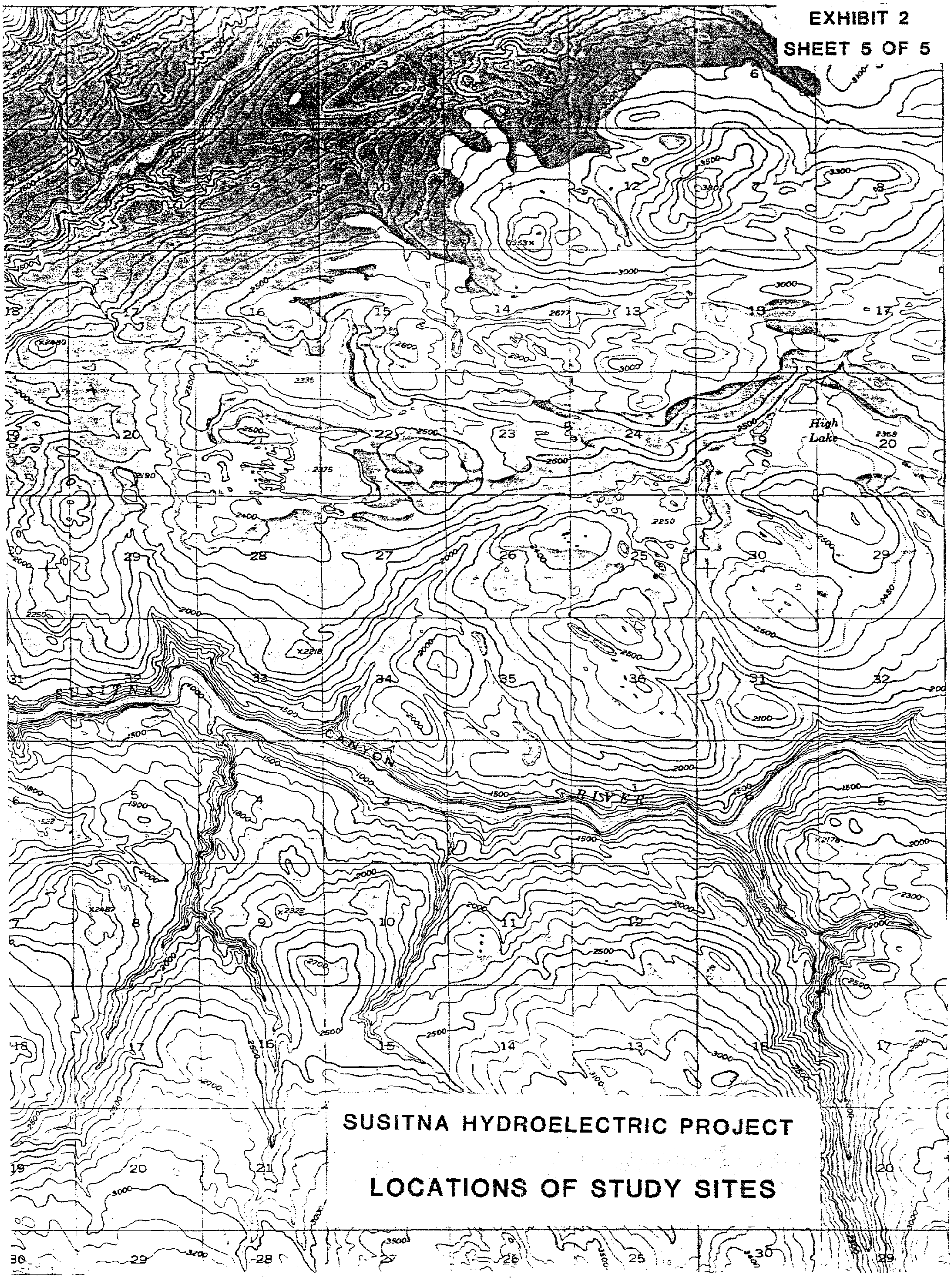
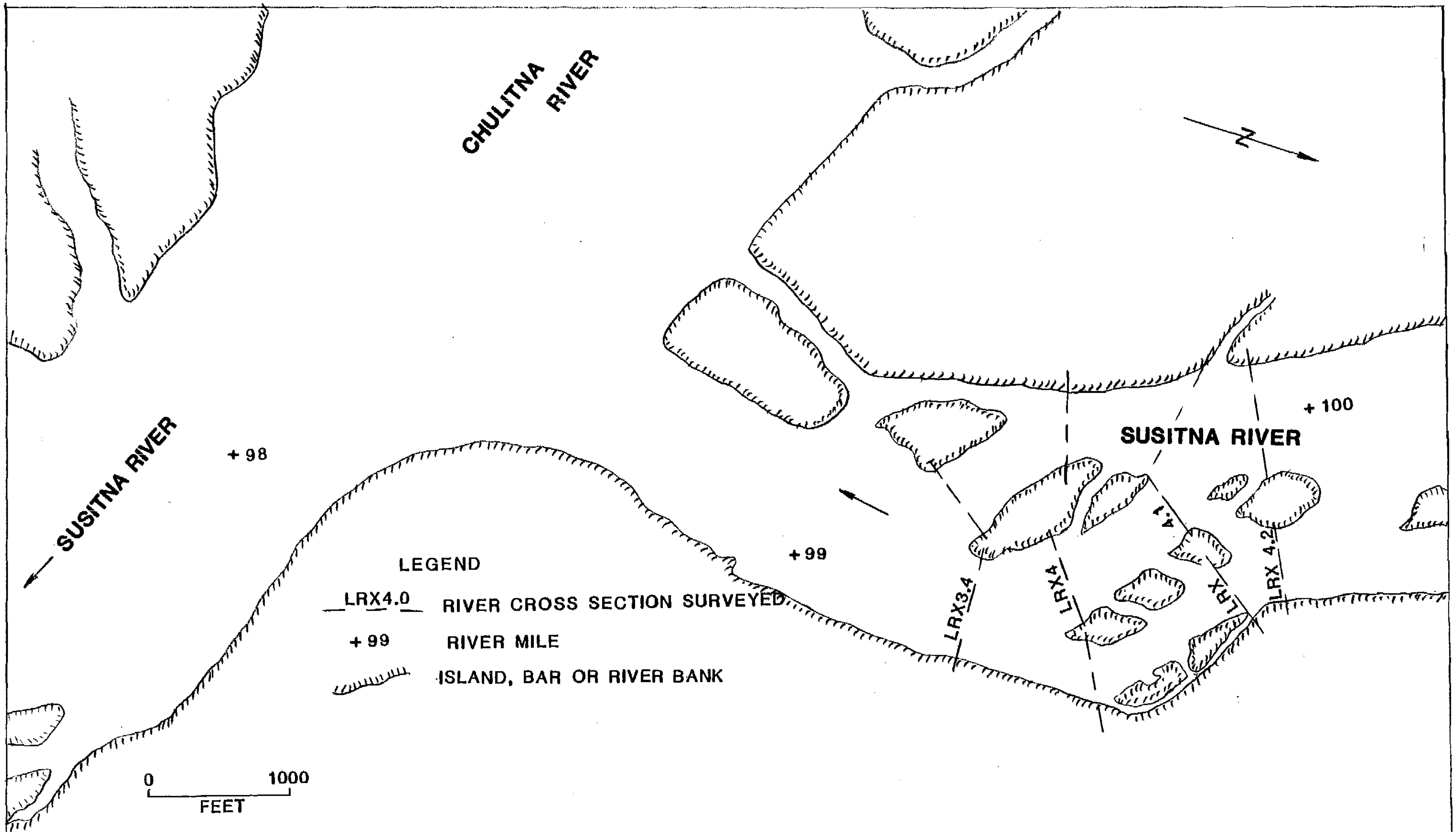


SUSITNA HYDROELECTRIC PROJECT

LOCATIONS OF STUDY SITES

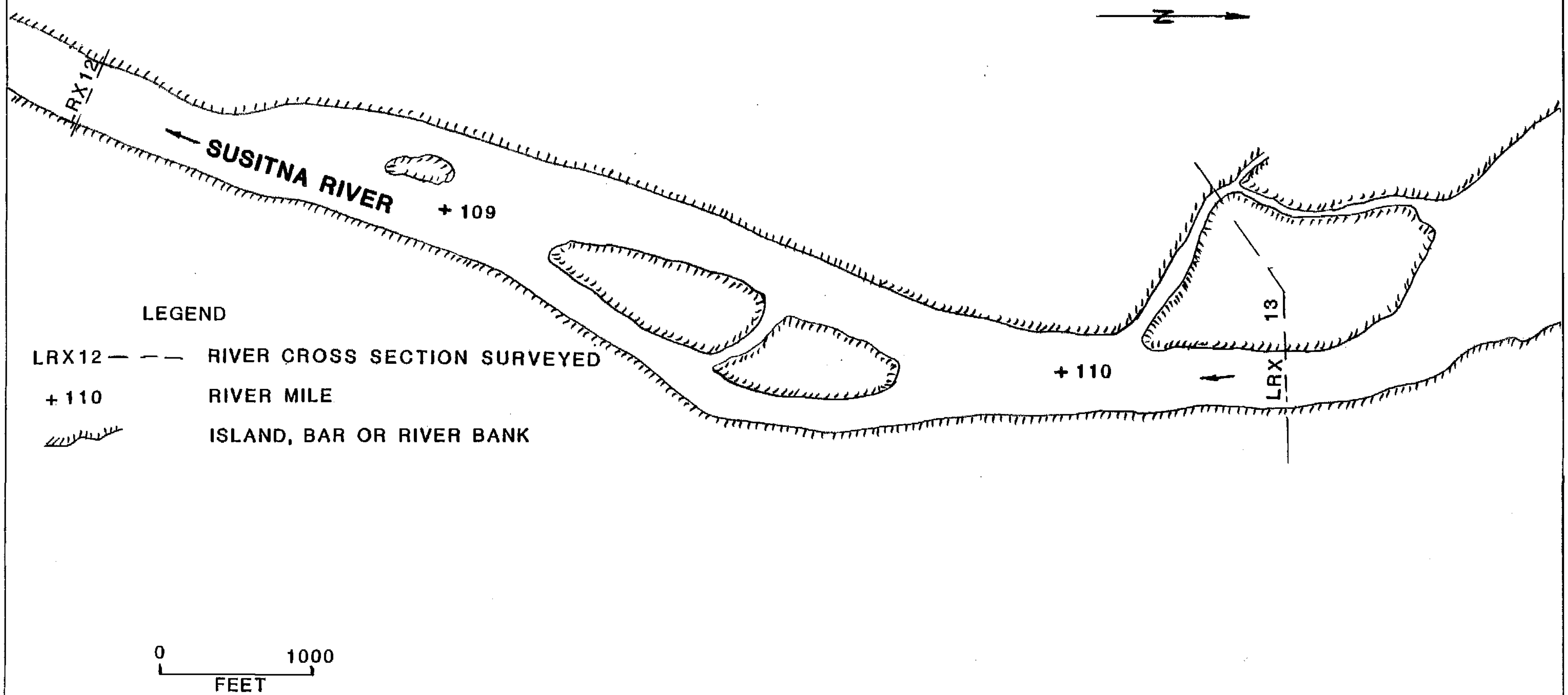


SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL NEAR CROSS
SECTION 4

EXHIBIT 3

HARZA-EBASCO SUSITNA JOINT VENTURE

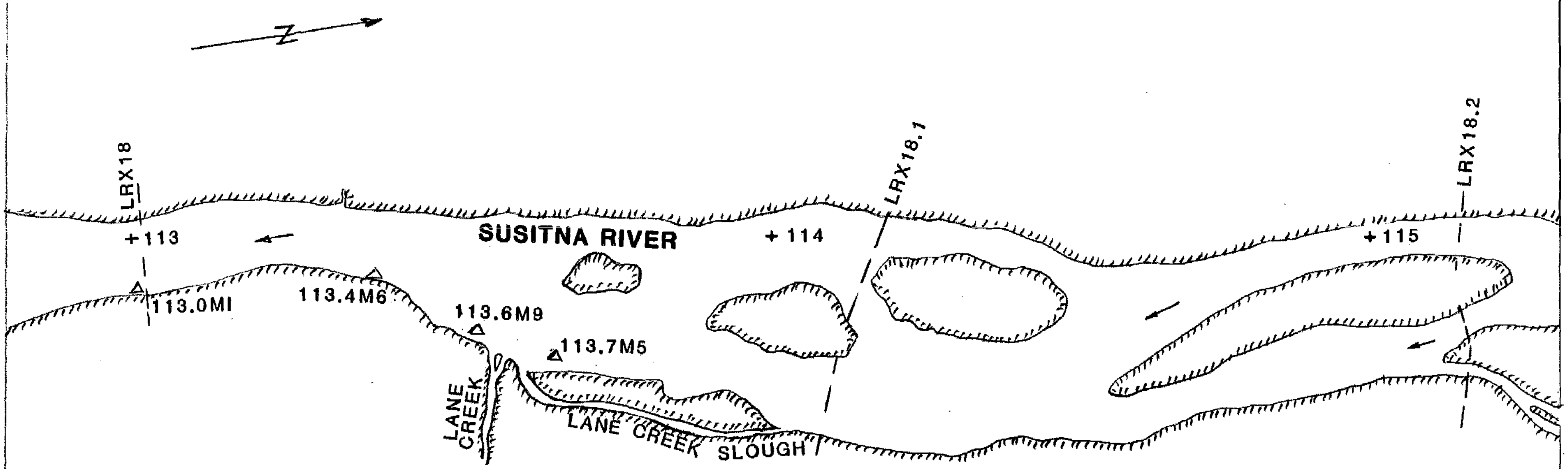


SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
MAIN CHANNEL BETWEEN RIVER
CROSS SECTIONS 12 AND 13

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 4



LEGEND

LRX18.1— — — RIVER CROSS SECTION SURVEYED

+114 RIVER MILE

△ STAFF GAGE; M≡IN MAIN CHANNEL

ISLAND, BAR OR RIVER BANK

0 1000
FEET

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, STAGE-DISCHARGE RELATION

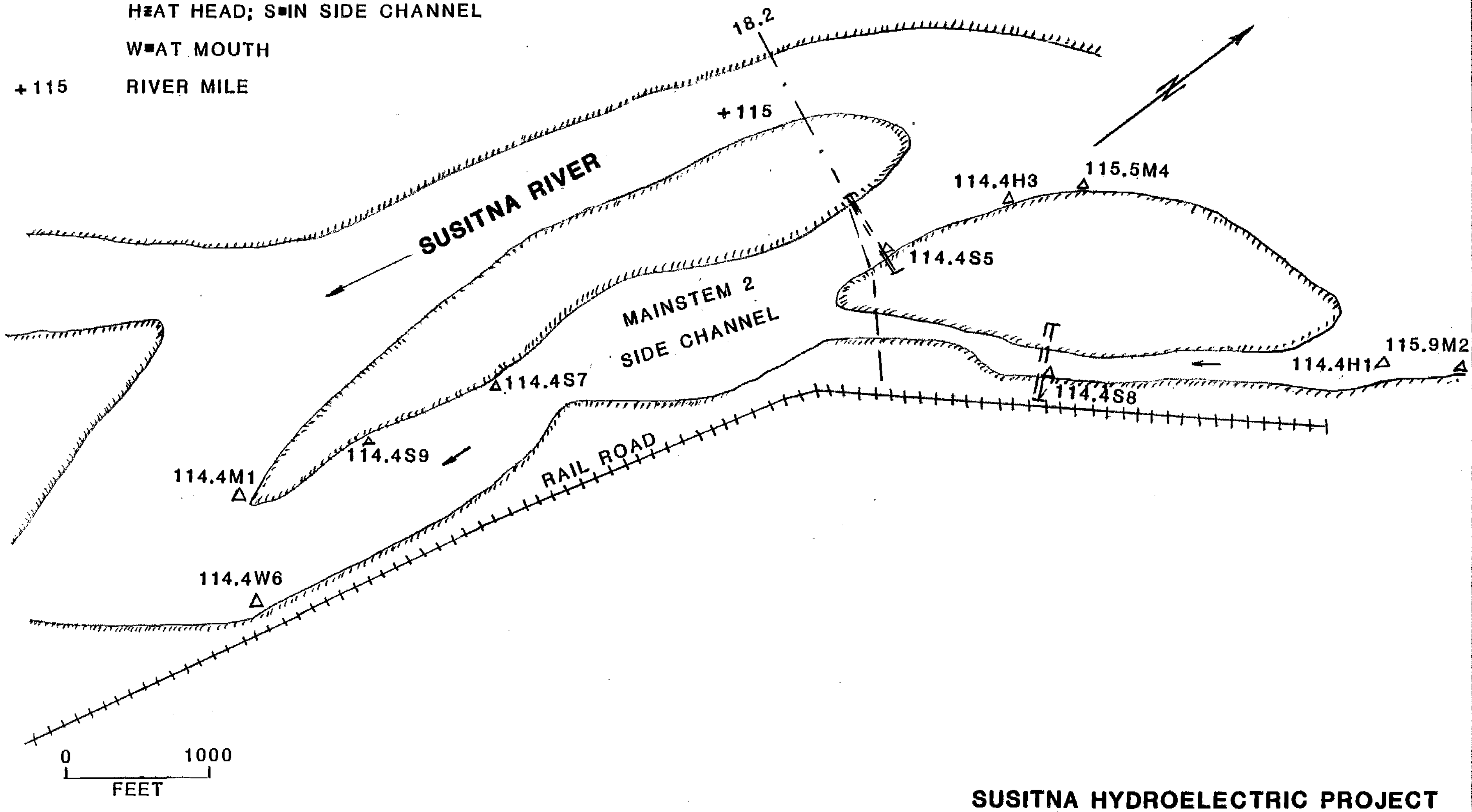
RIVER CROSS SECTION SURVEYED

STAFF GAGE; M=IN MAIN CHANNEL

H=AT HEAD; S=IN SIDE CHANNEL

W=AT MOUTH

+115 RIVER MILE

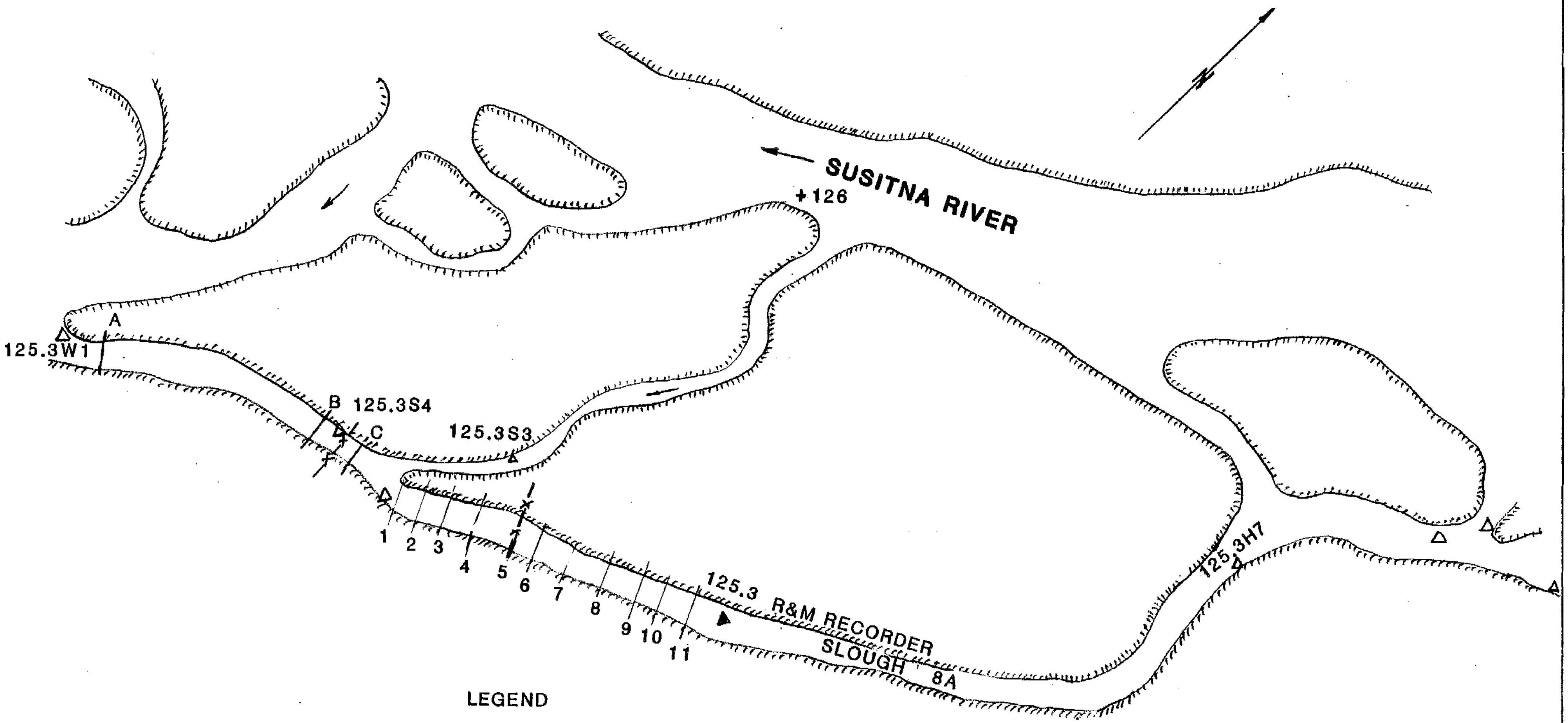


SOURCE: R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT
MAINSTEM 2 SIDE CHANNELS AT
RIVER CROSS SECTION 18.2

EXHIBIT 6



LEGEND

—x—x— DISCHARGE MEASUREMENT SITE, STAGE-DISCHARGE RELATION

——9 TRANSECT

▲ WATER LEVEL RECORDER

△ STAFF GAGE; H≡AT HEAD

S≡IN SLOUGH; W≡AT MOUTH

+126 RIVER MILE

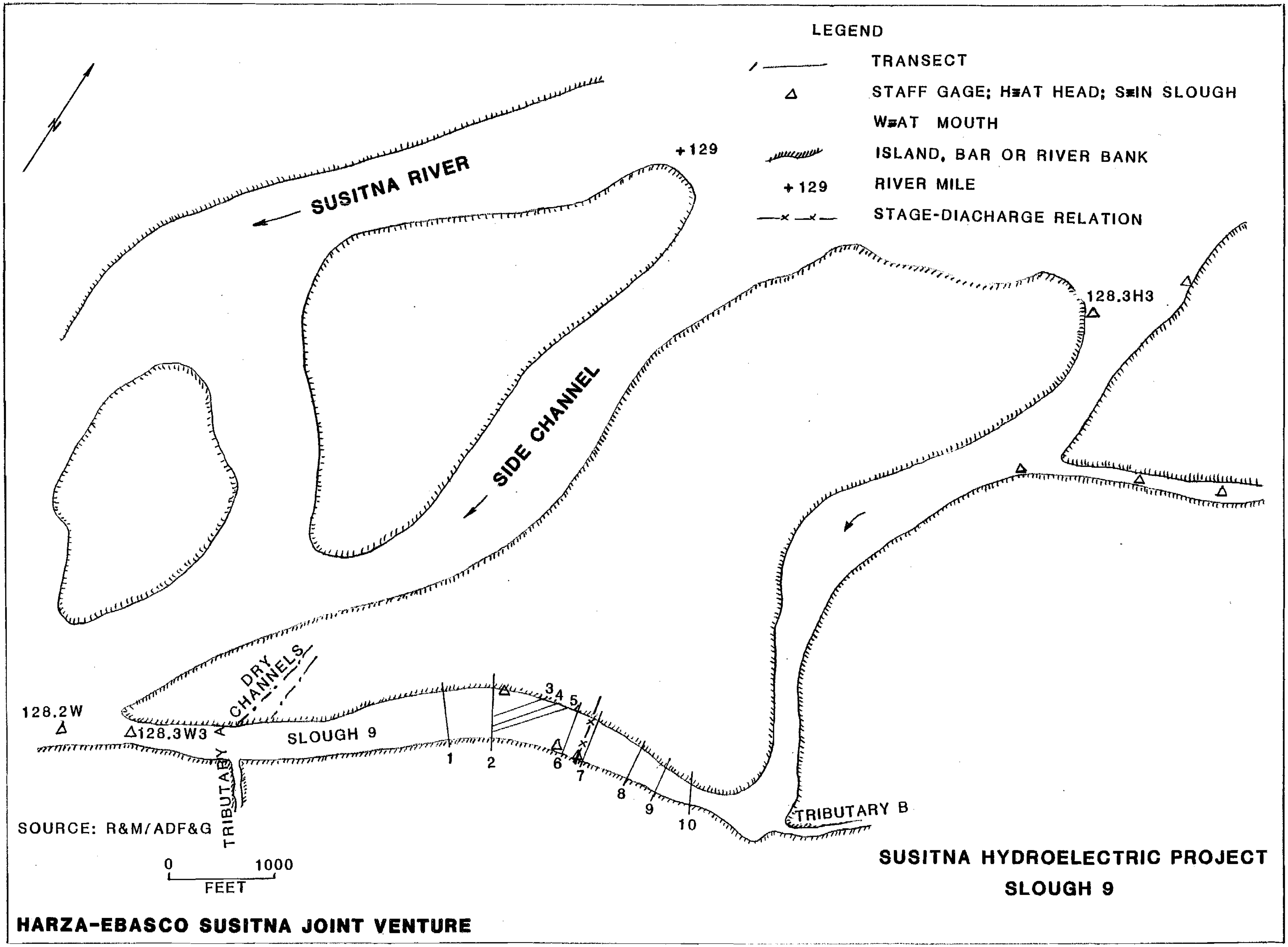
0 1000 FEET

SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
SLOUGH 8A

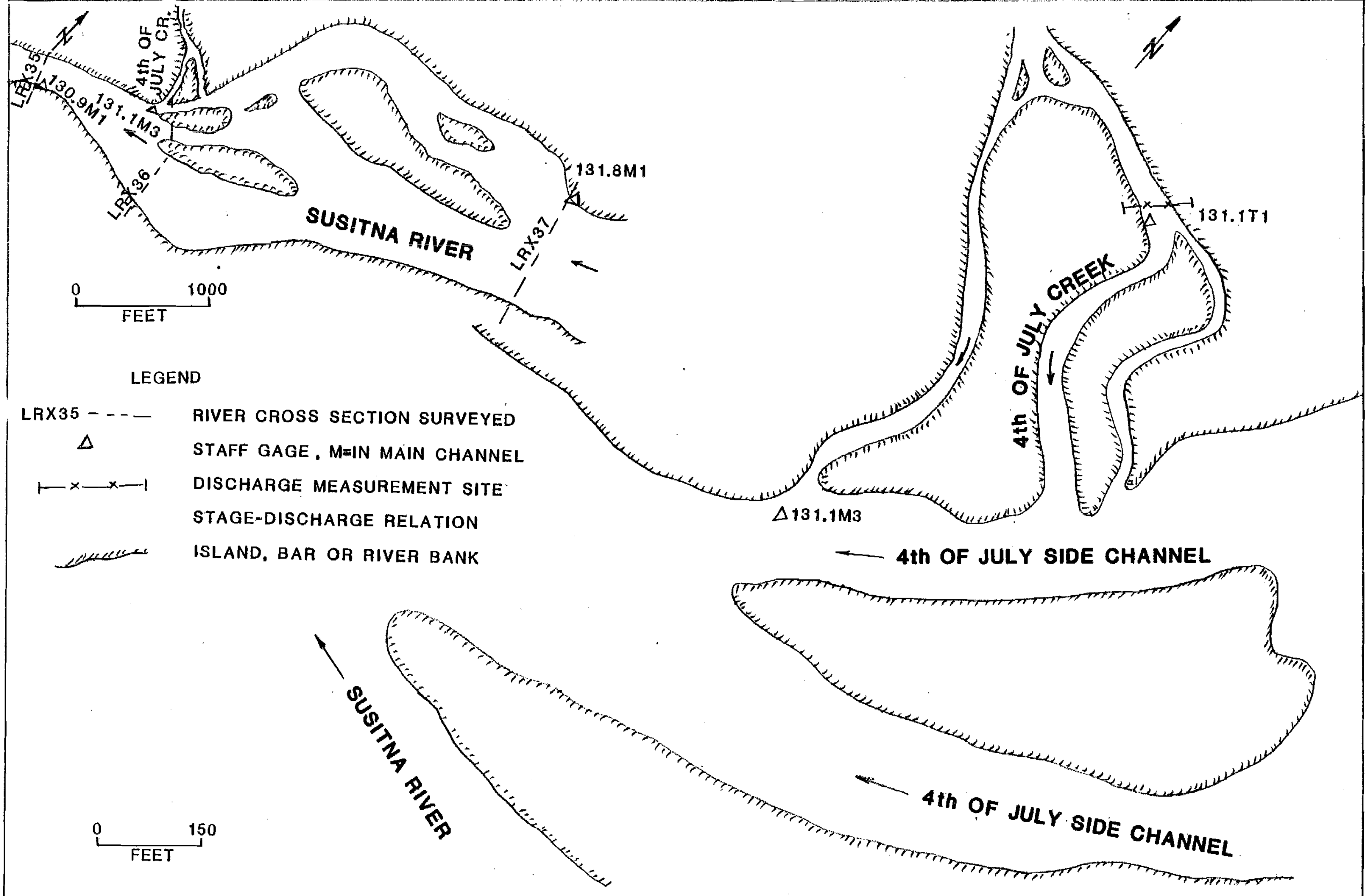
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 7



LEGEND
TRANSECT
STAFF GAGE; H=AT HEAD; S=IN SLOUGH
W=AT MOUTH
ISLAND, BAR OR RIVER BANK
+129 RIVER MILE
STAGE-DIACHARGE RELATION
N
SUSITNA RIVER
SIDE CHANNEL
+129
128.3H3
DRY CHANNELS
128.2W
128.3W3
SLOUGH 9
TRIBUTARY A
TRIBUTARY B
1
2
3
4
5
6
7
8
9
10
SOURCE: R&M/ADF&G
0
1000
FEET
SUSITNA HYDROELECTRIC PROJECT
SLOUGH 9
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 8

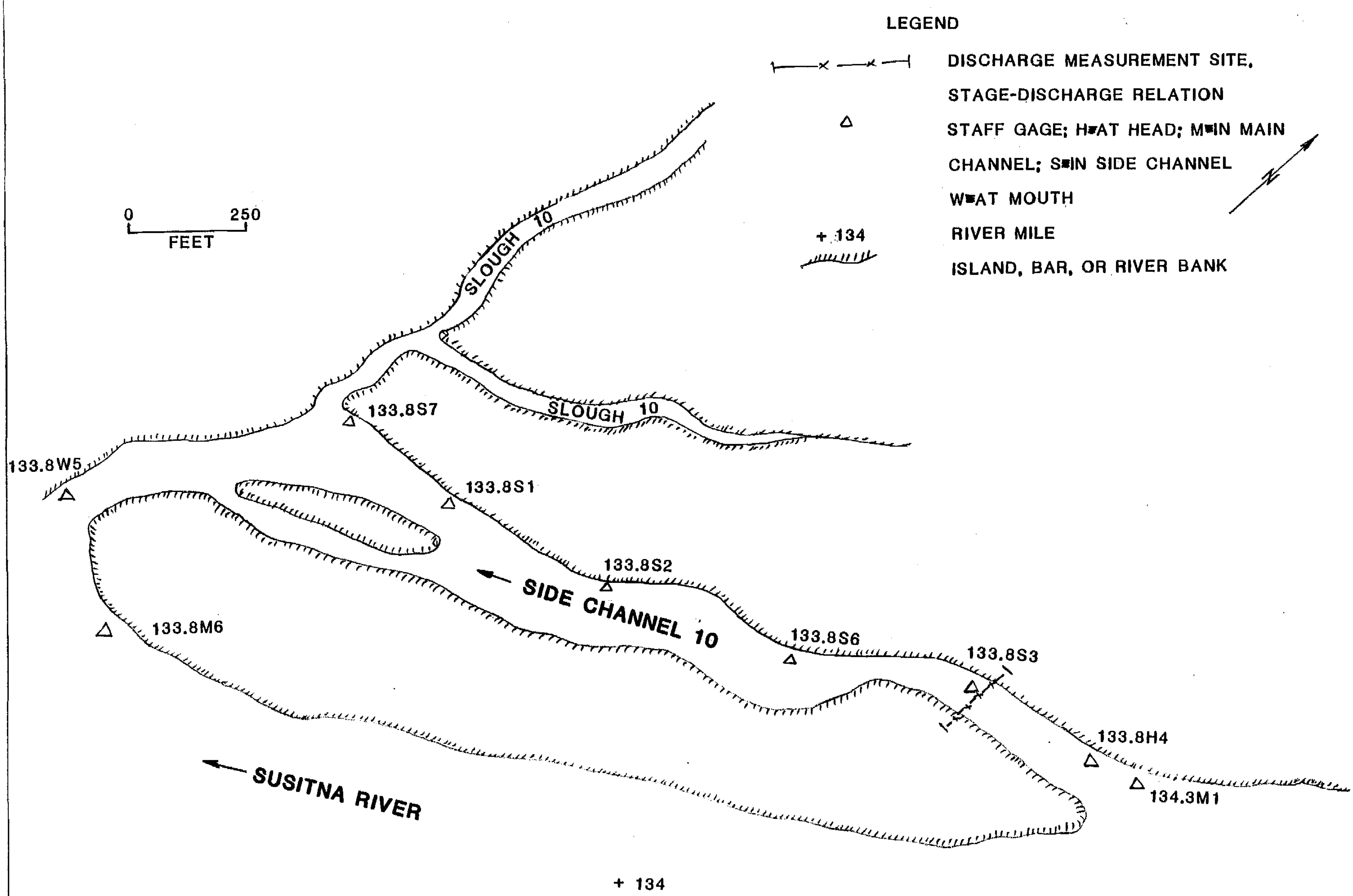


SOURCE: R&M/ADF&G

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

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 9

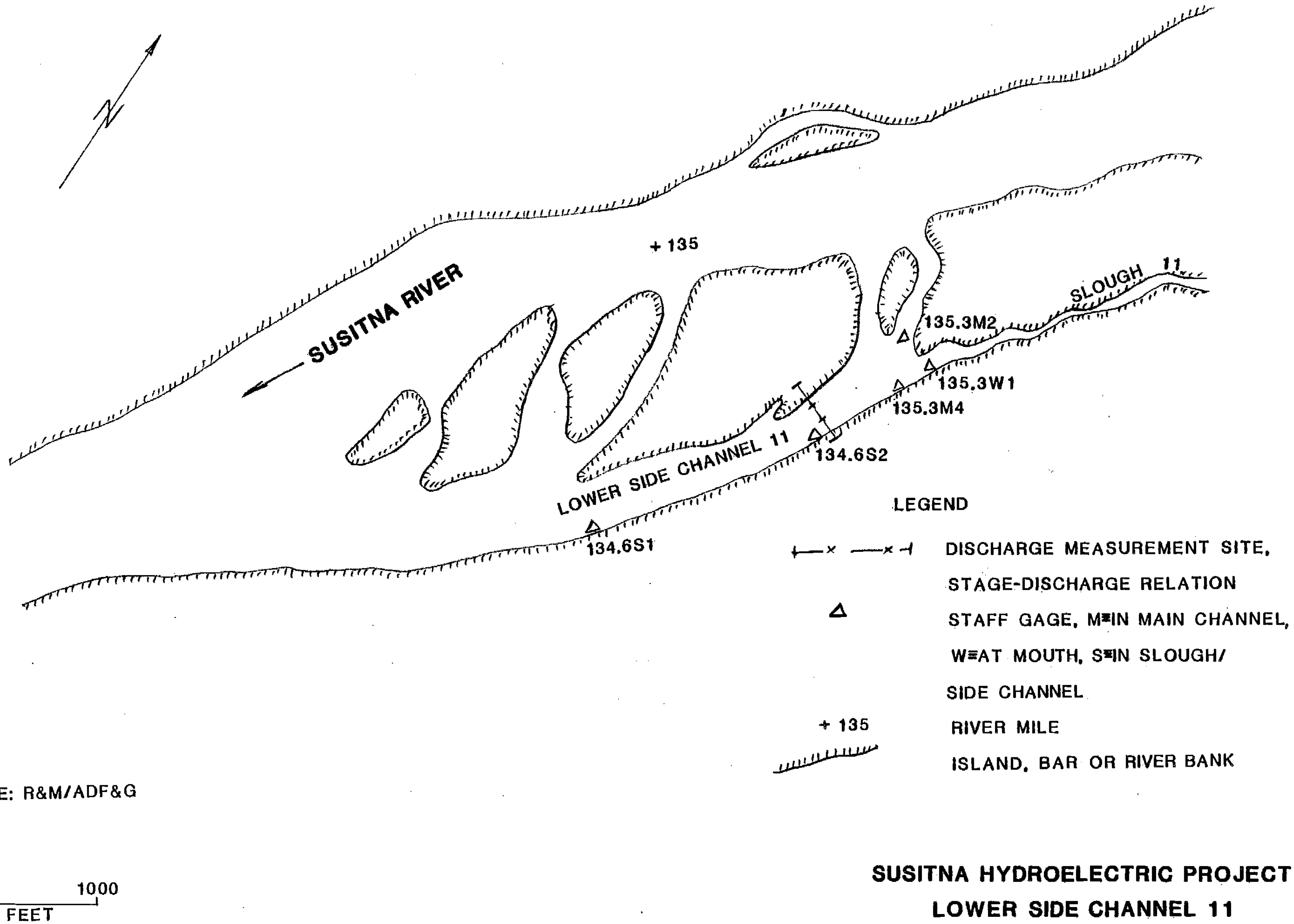


SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
SIDE CHANNEL 10

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 10

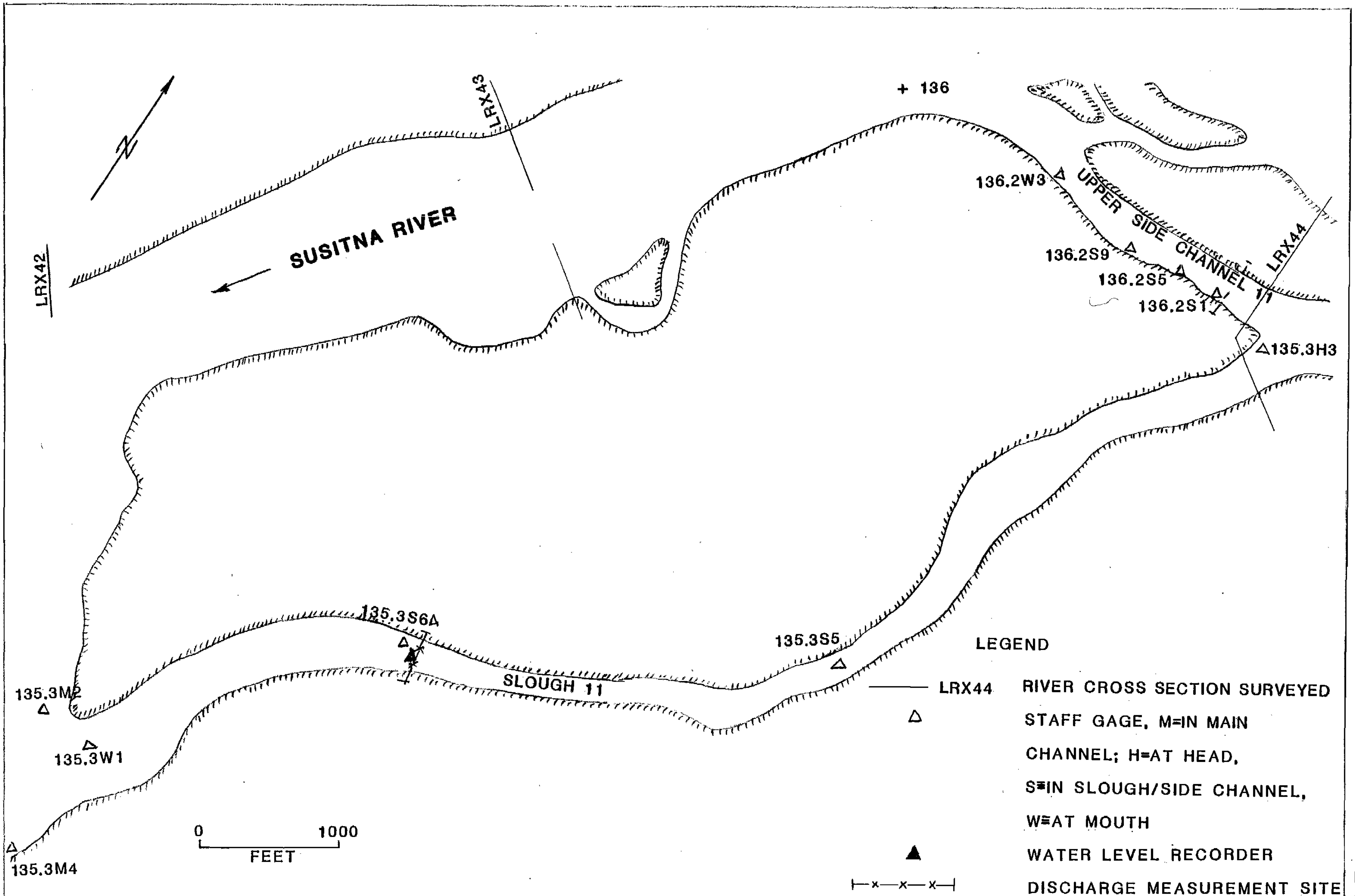


SOURCE: R&M/ADF&G

SUSITNA HYDROELECTRIC PROJECT
LOWER SIDE CHANNEL 11

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 11

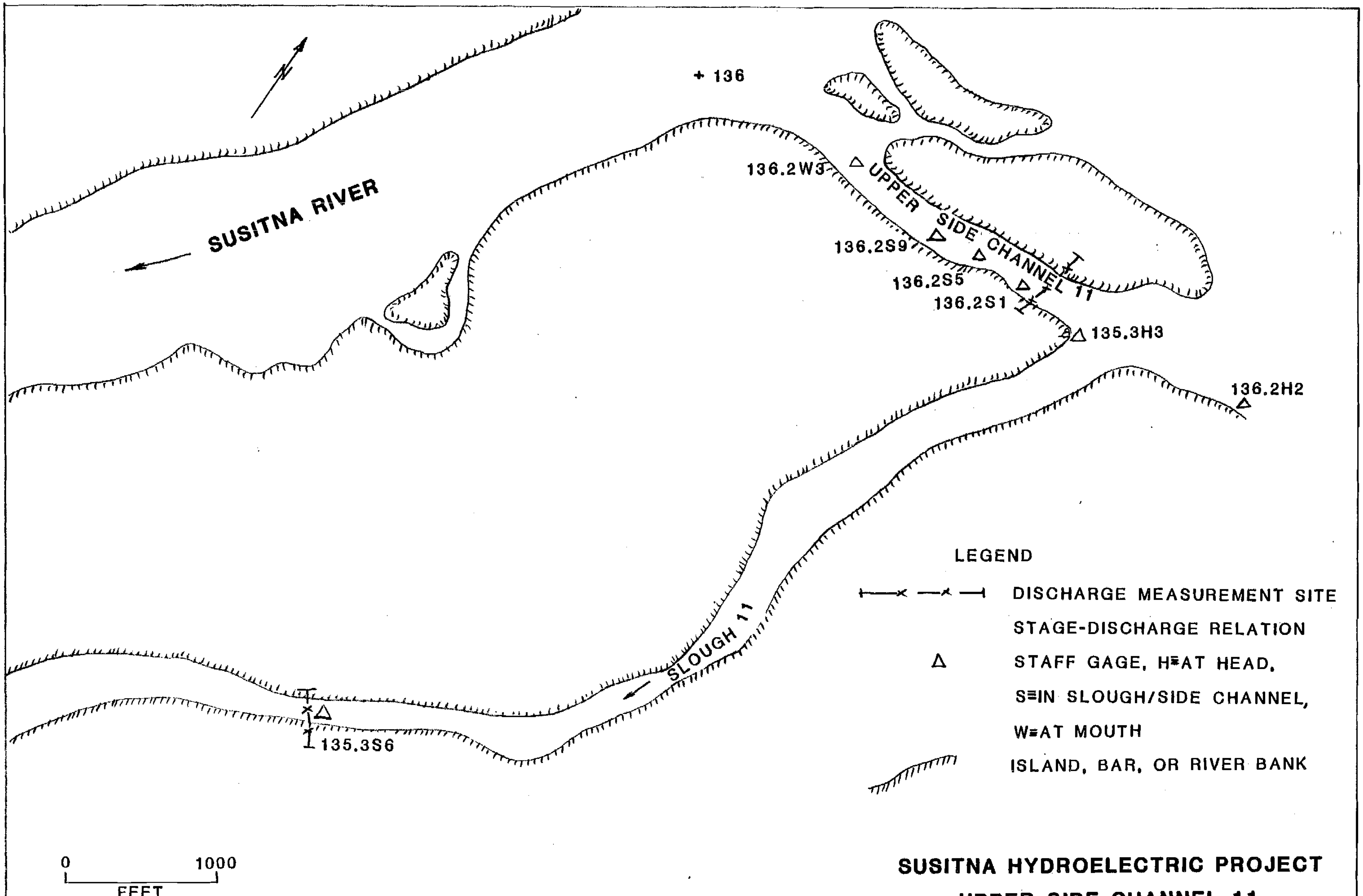


SOURCE: R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT
SLOUGH 11

EXHIBIT 12

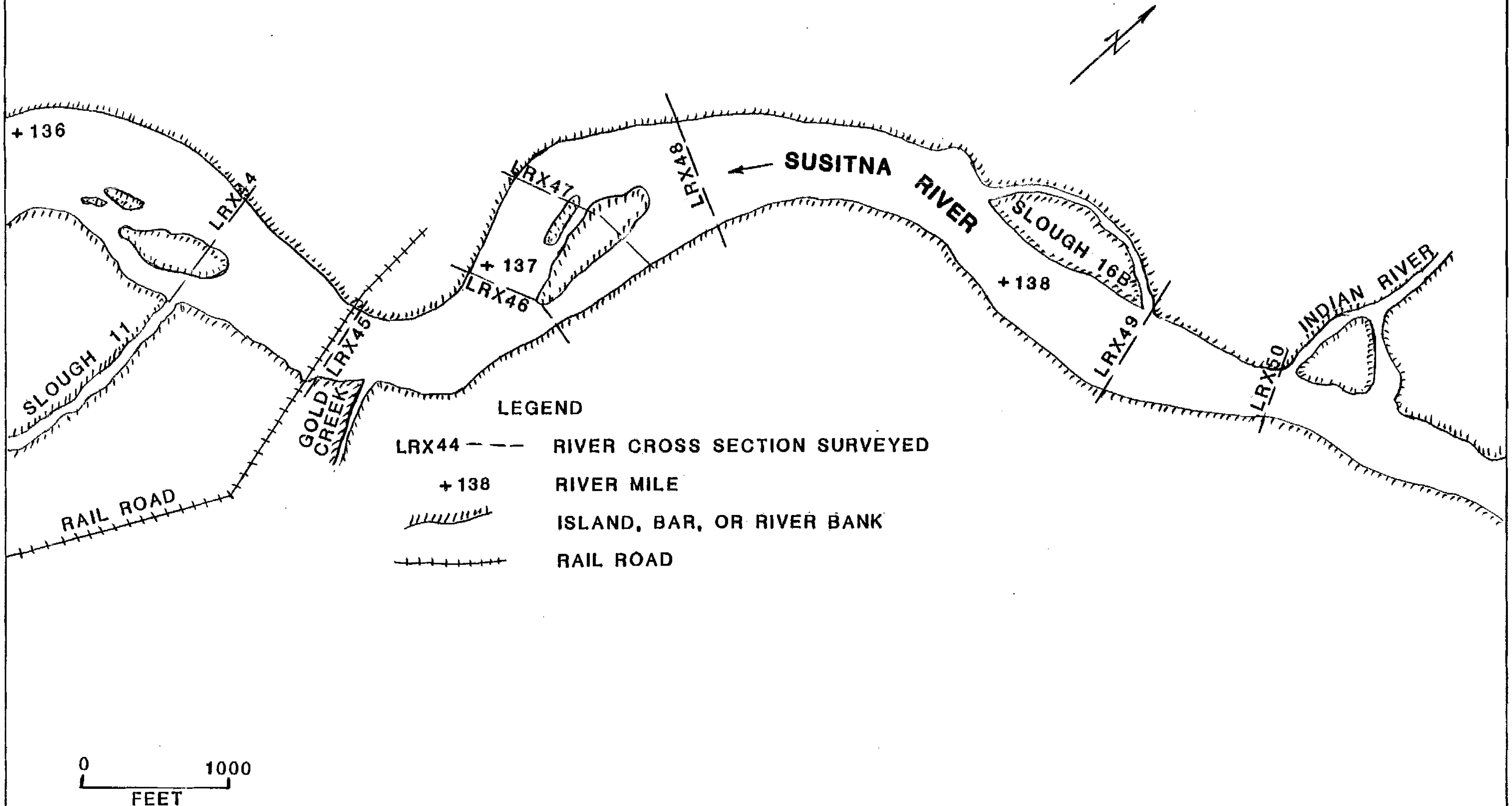


SOURCE: R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT
UPPER SIDE CHANNEL 11

EXHIBIT 13

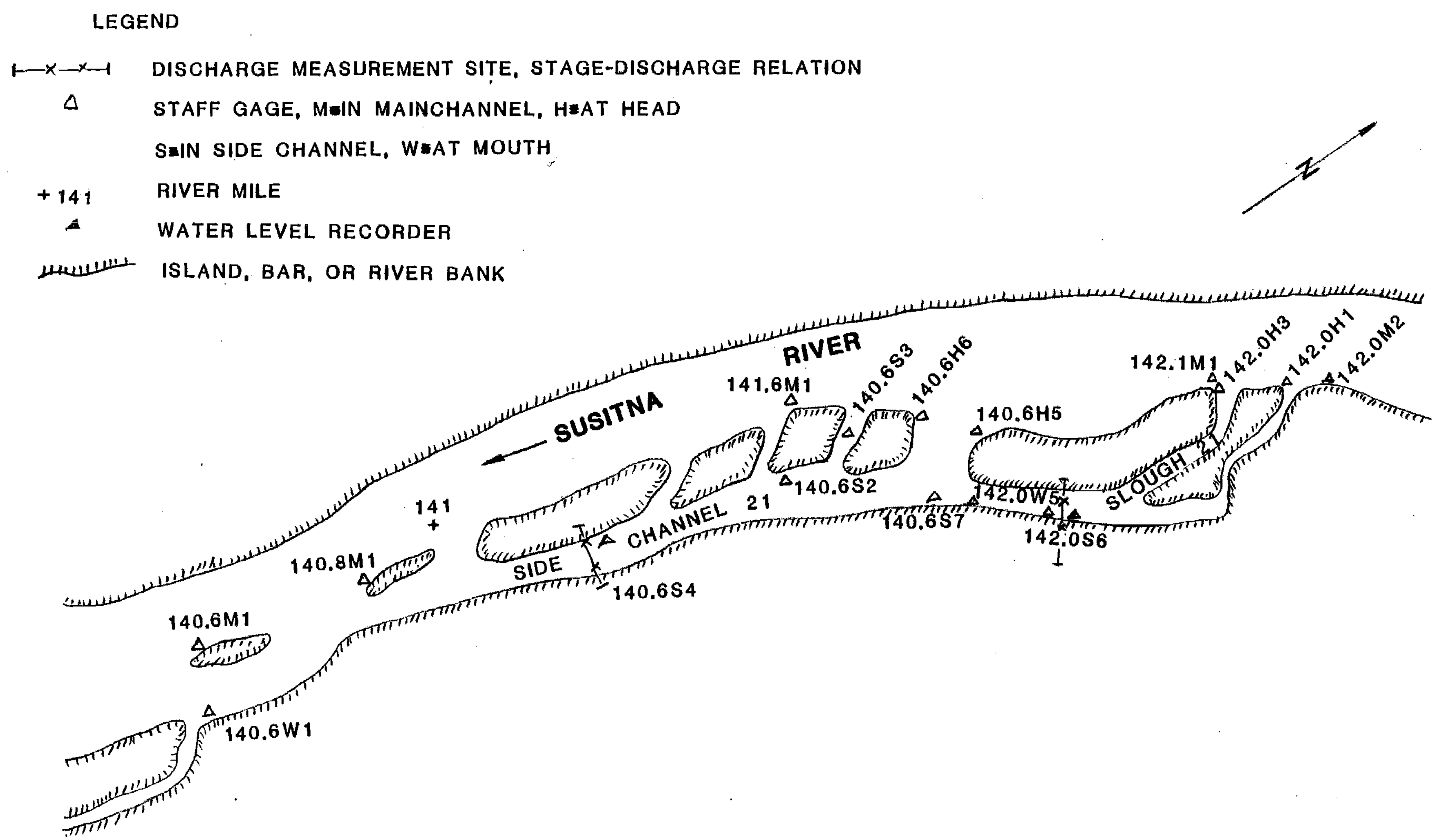


SOURCE: R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT
MAINCHANNEL BETWEEN RIVER CROSS SECTIONS 46 AND 48

EXHIBIT 14



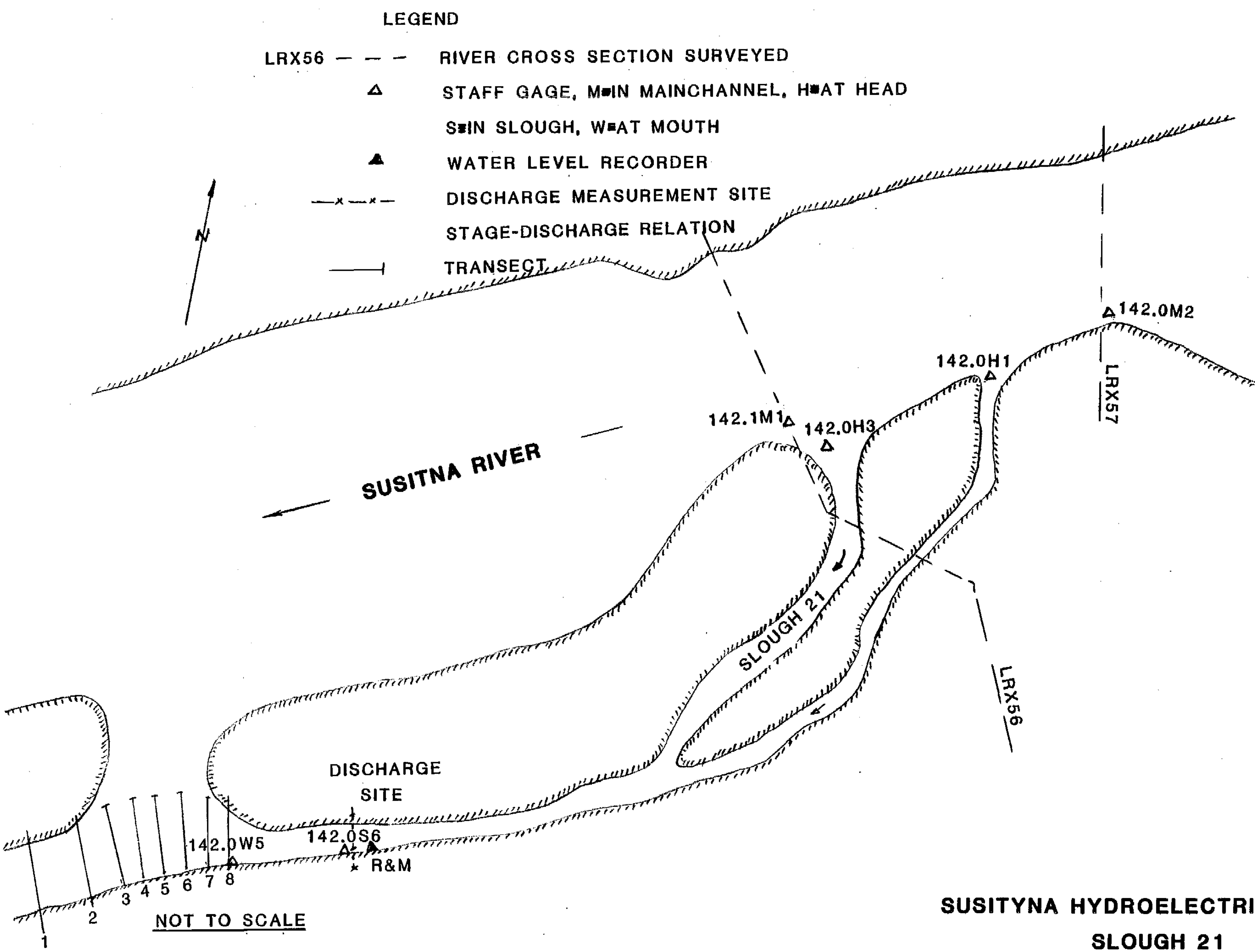
SOURCE: R&M/ADF&G

0 1000
FEET

SUSITNA HYDROELECTRIC PROJECT
SIDE CHANNEL 21

HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 15

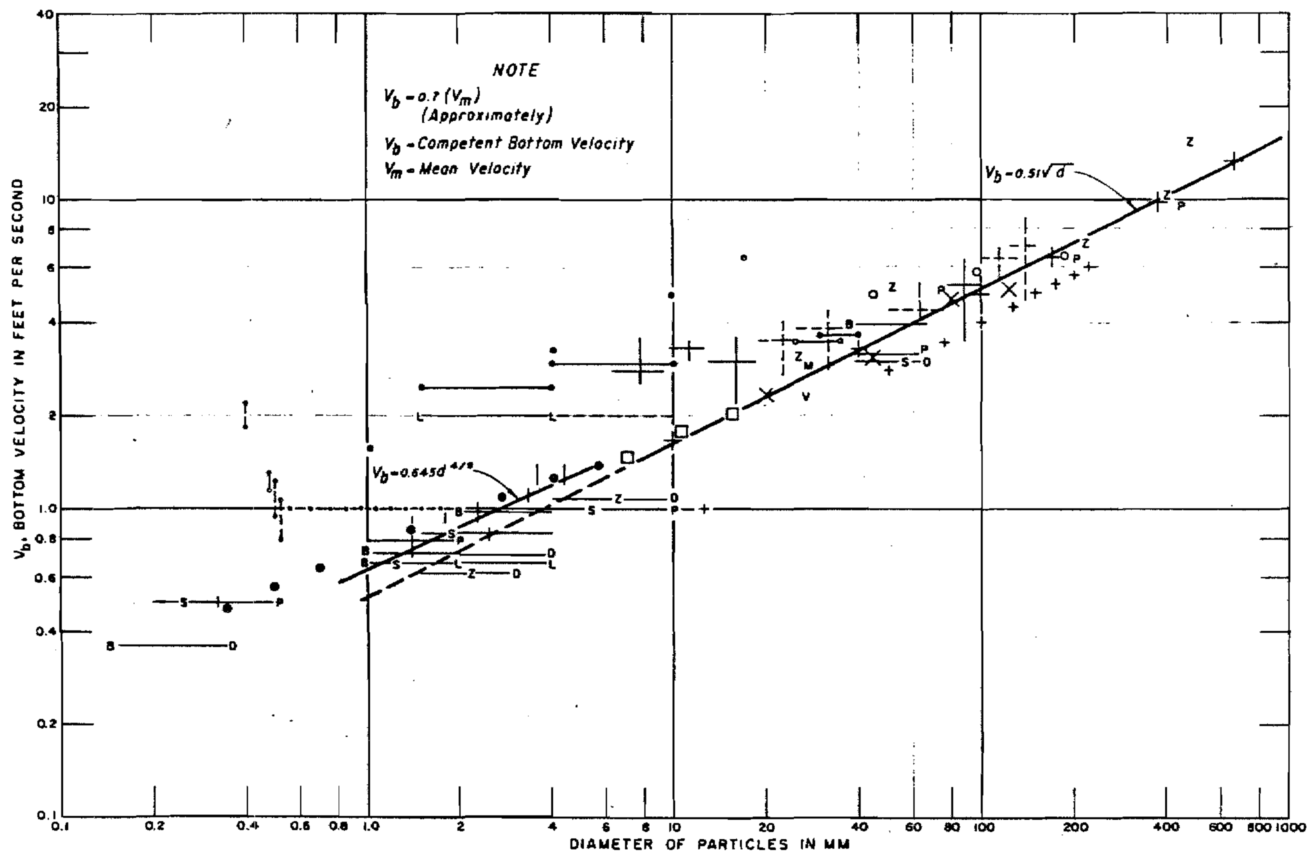


SOURCE: R&M/ADF&G

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITYNA HYDROELECTRIC PROJECT
SLOUGH 21

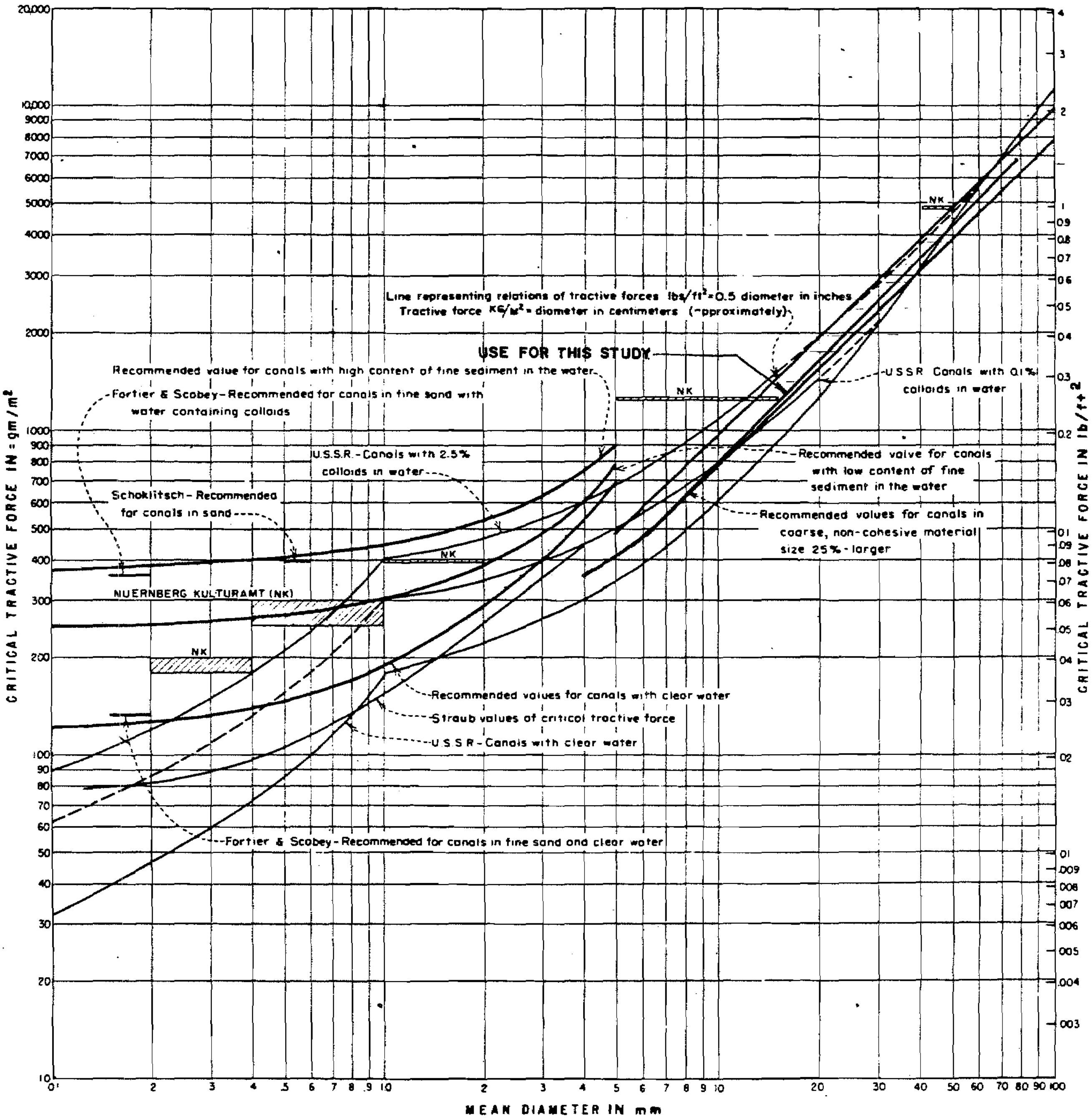
EXHIBIT 16



SOURCE: U.S. BUREAU OF RECLAMATION, "DESIGN OF SMALL DAMS", FIG. H-13

SUSITNA HYDROELECTRIC PROJECT
RELATIONSHIP BETWEEN PARTICLE SIZE AND BOTTOM VELOCITY

HARZA-EBASCO SUSITNA JOINT VENTURE



SOURCE: U.S. BUREAU OF RECLAMATION,
"DESIGN OF SMALL DAMS", FIGURE H-14

SUSITNA HYDROELECTRIC PROJECT
RELATIONSHIP BETWEEN MEAN DIAMETER AND CRITICAL TRACTIVE FORCE

HARZA-EBASCO SUSITNA JOINT VENTURE

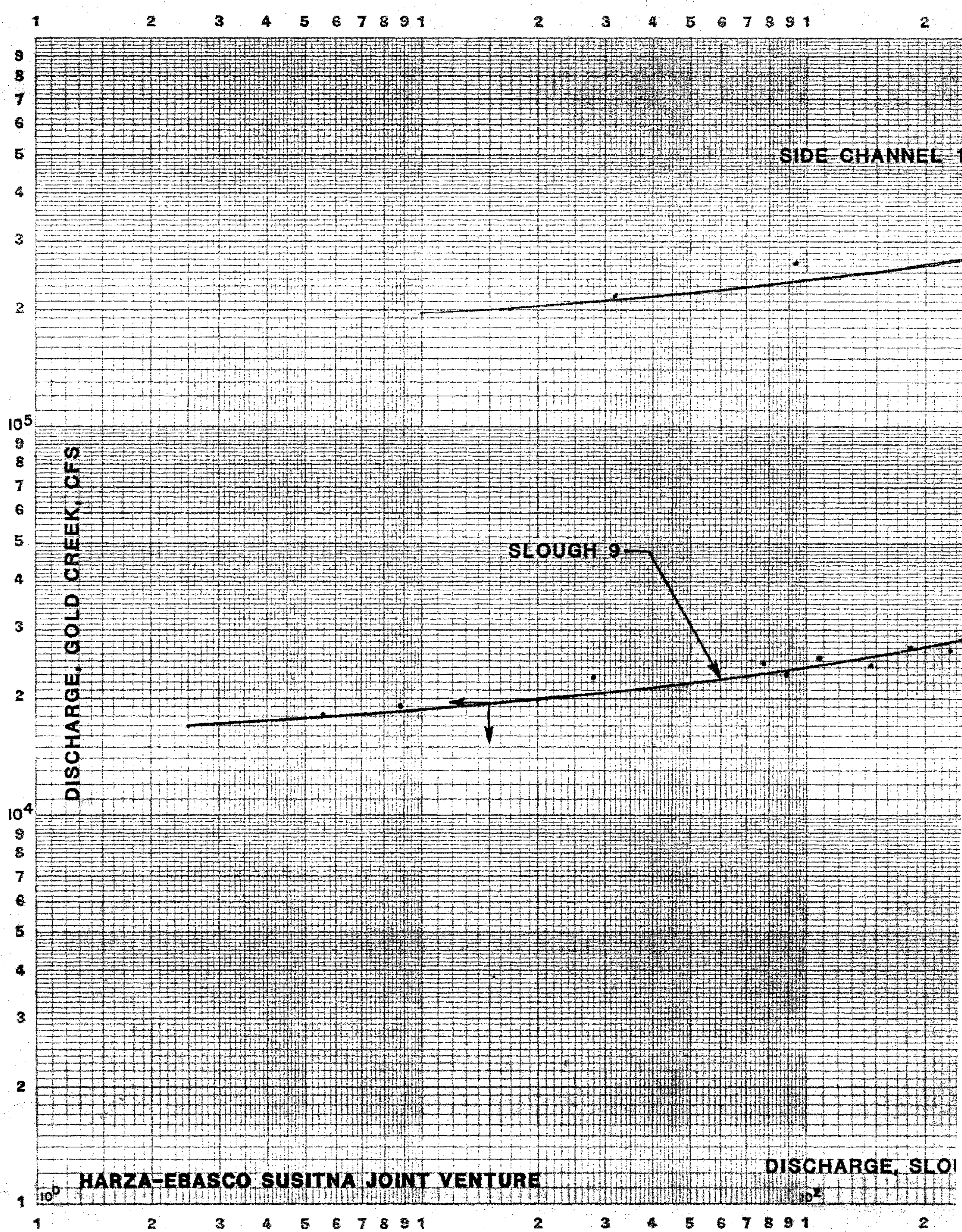
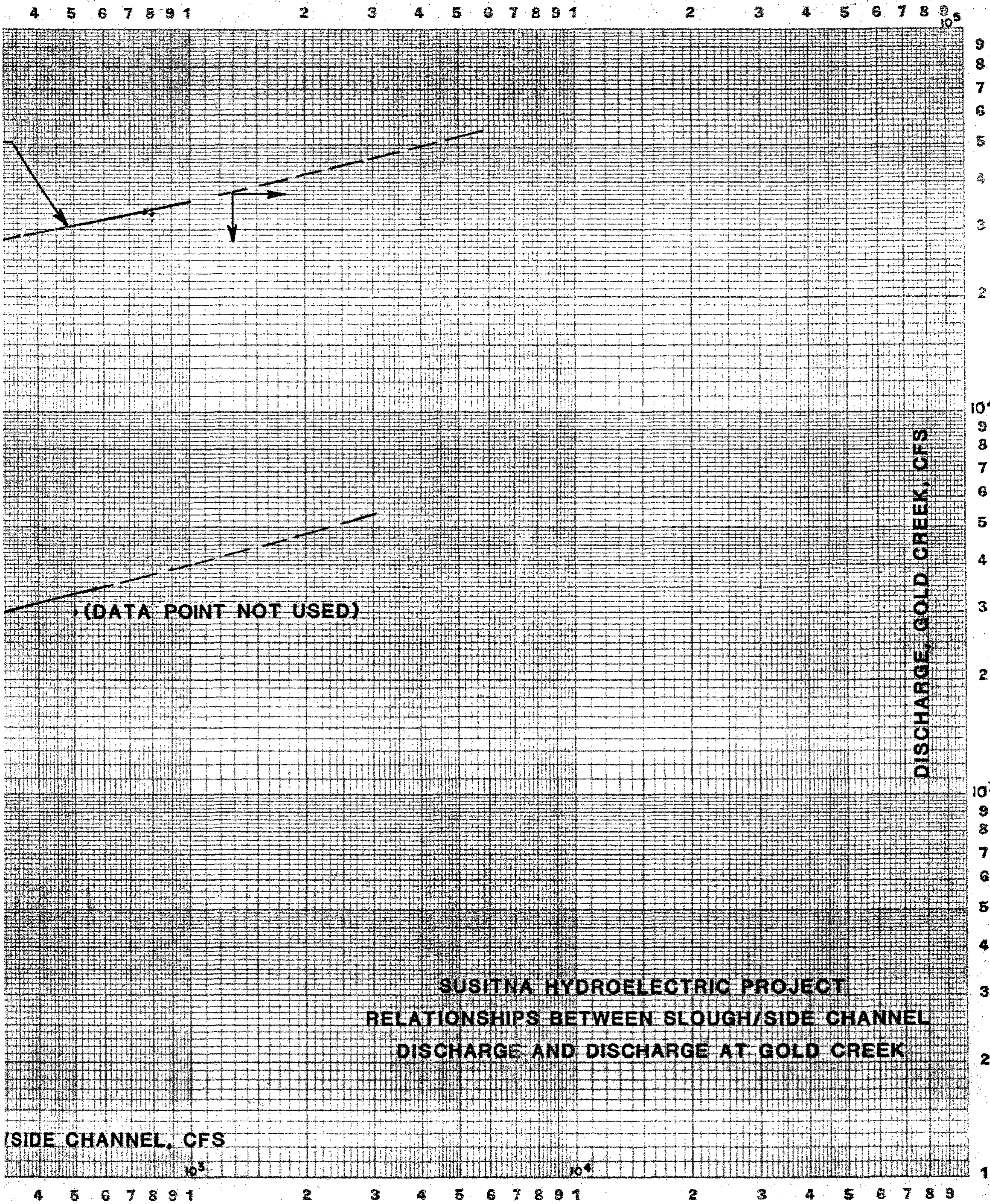
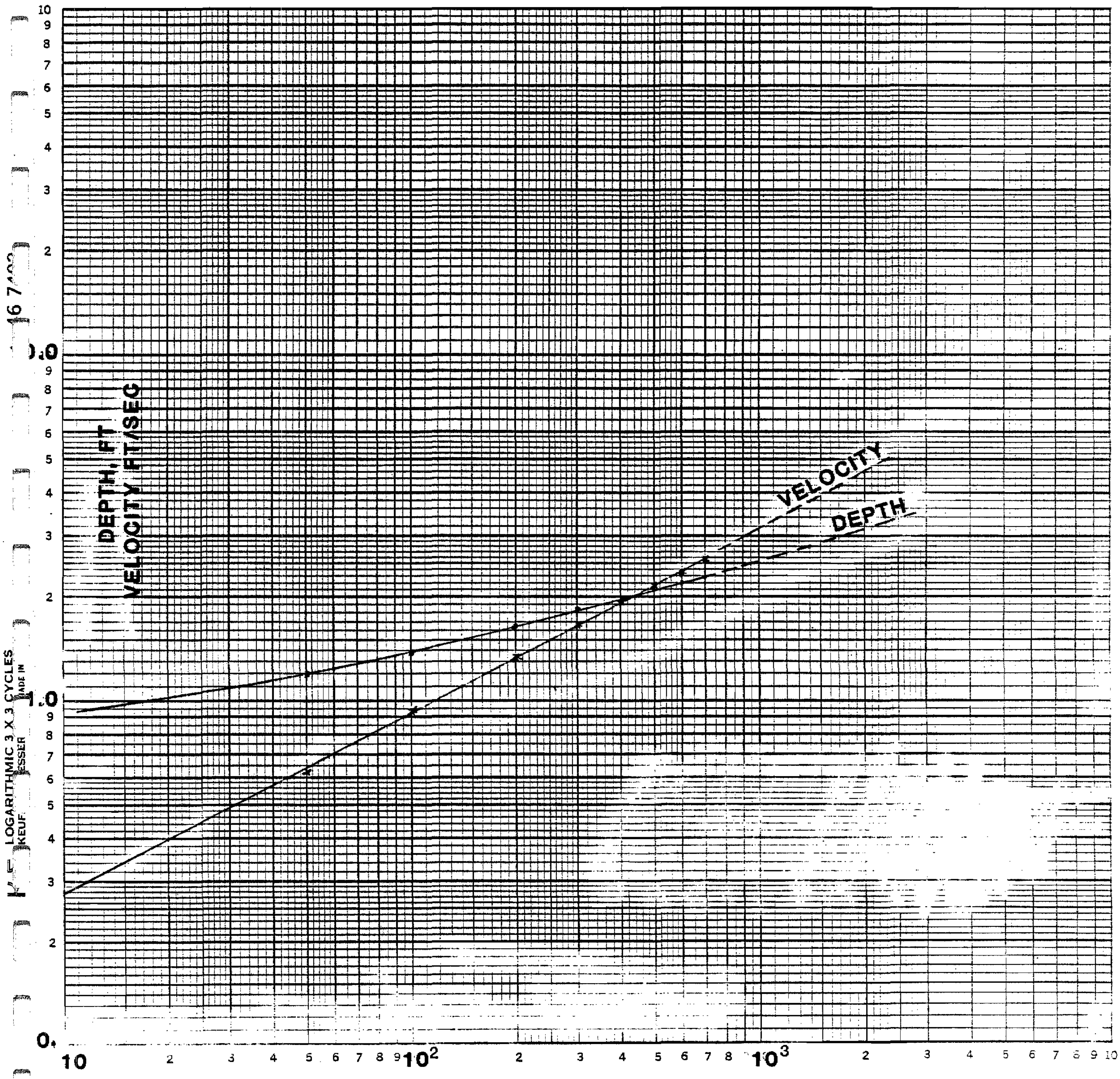

SIDE CHANNEL
SLOUGH 9
DISCHARGE, GOLD CREEK, CFS
10^5
10^4
HARZA-EBASCO SUSITNA JOINT VENTURE
DISCHARGE, SLO

EXHIBIT 19



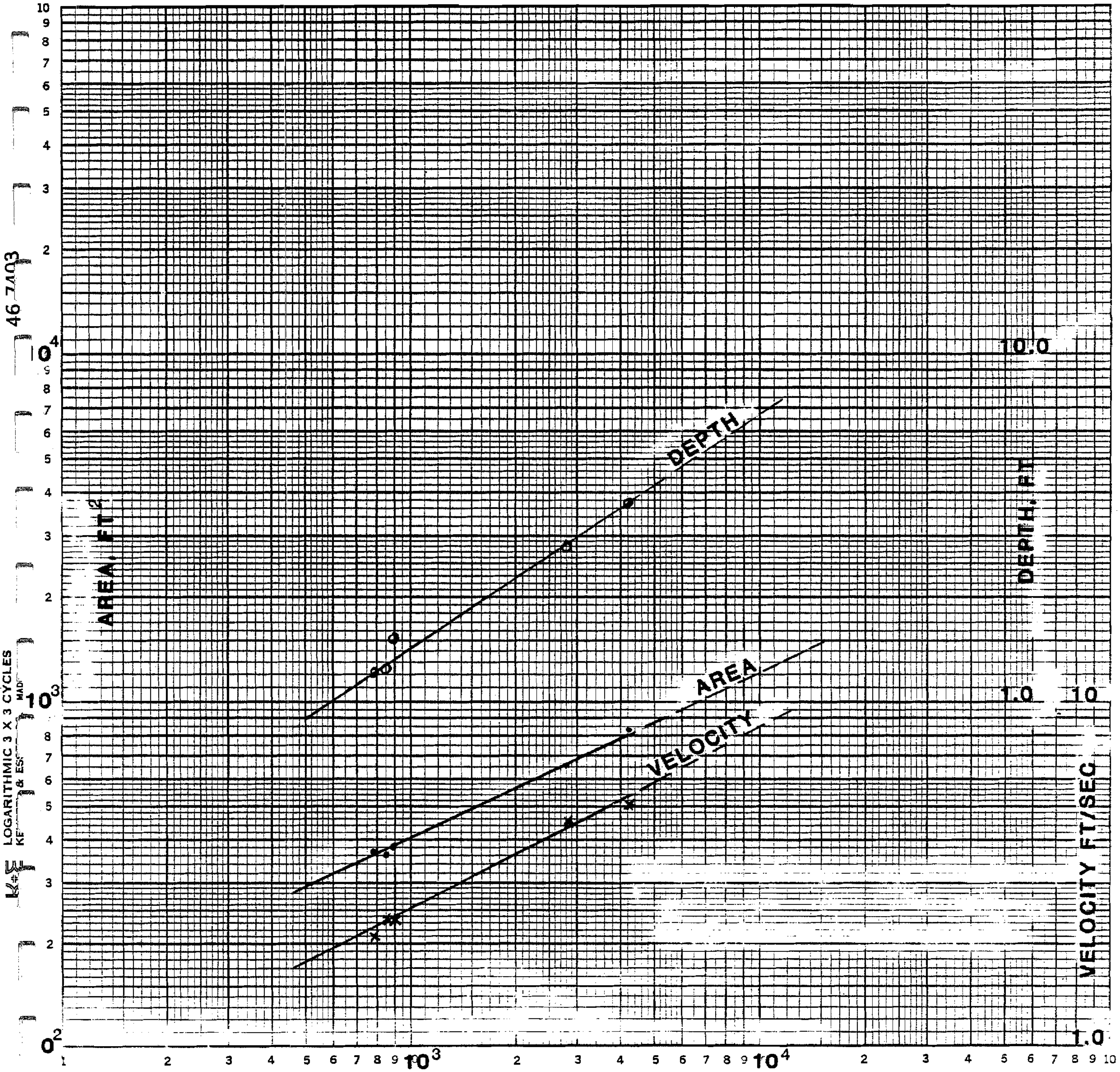
(DATA POINT NOT USED)
DISCHARGE, GOLD CREEK, CFS
/SIDE CHANNEL, CFS
SUSITNA HYDROELECTRIC PROJECT
RELATIONSHIPS BETWEEN SLOUGH/SIDE CHANNEL
DISCHARGE AND DISCHARGE AT GOLD CREEK

EXHIBIT 20



SUSITNA HYDROELECTRIC PROJECT
HYDRAULIC PARAMETERS
FOR SLOUGH 9

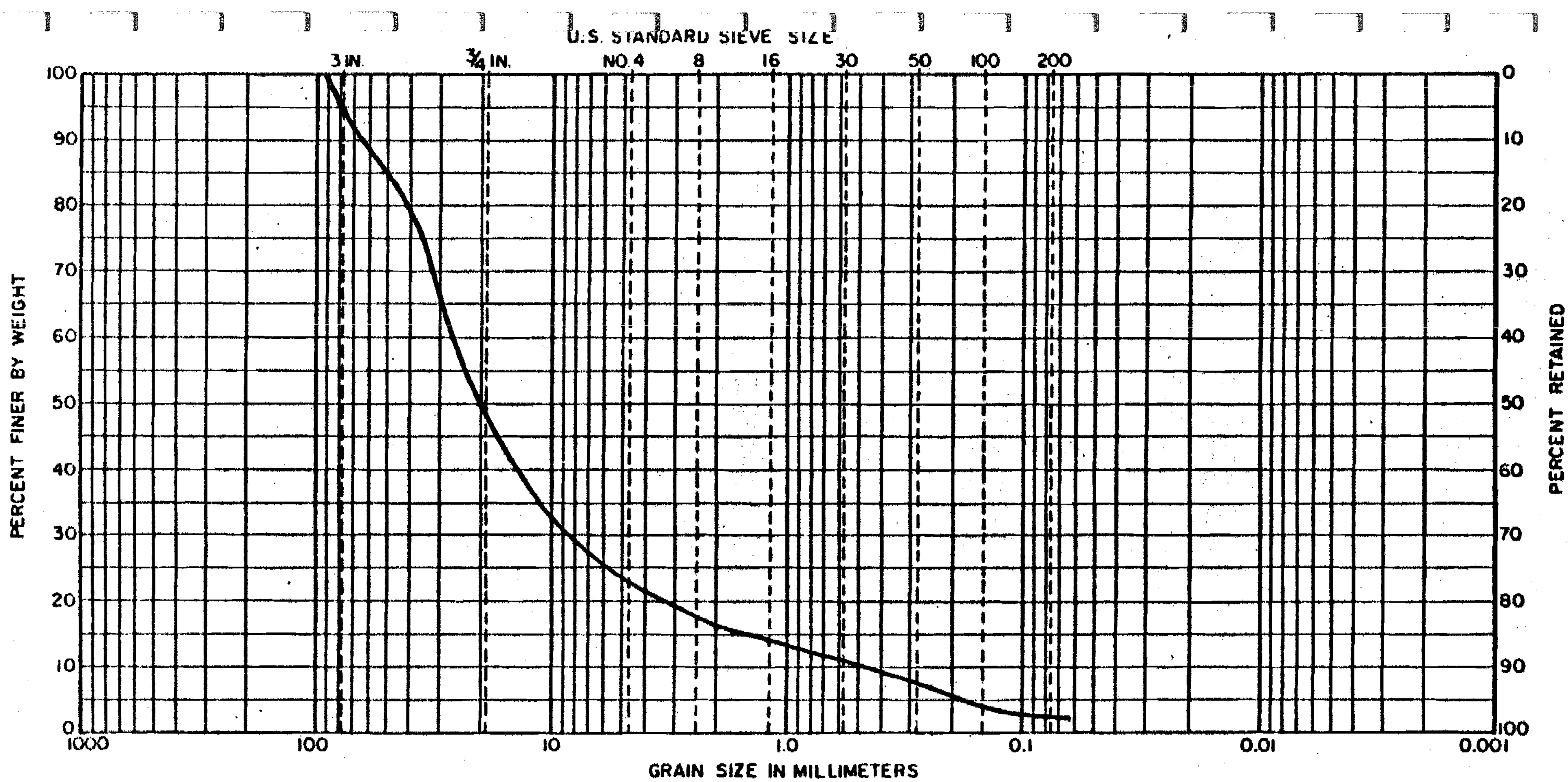
EXHIBIT 21



SUSITNA HYDROELECTRIC PROJECT

HYDRAULIC PARAMETERS

FOR LOWER SIDE CHANNEL 11



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

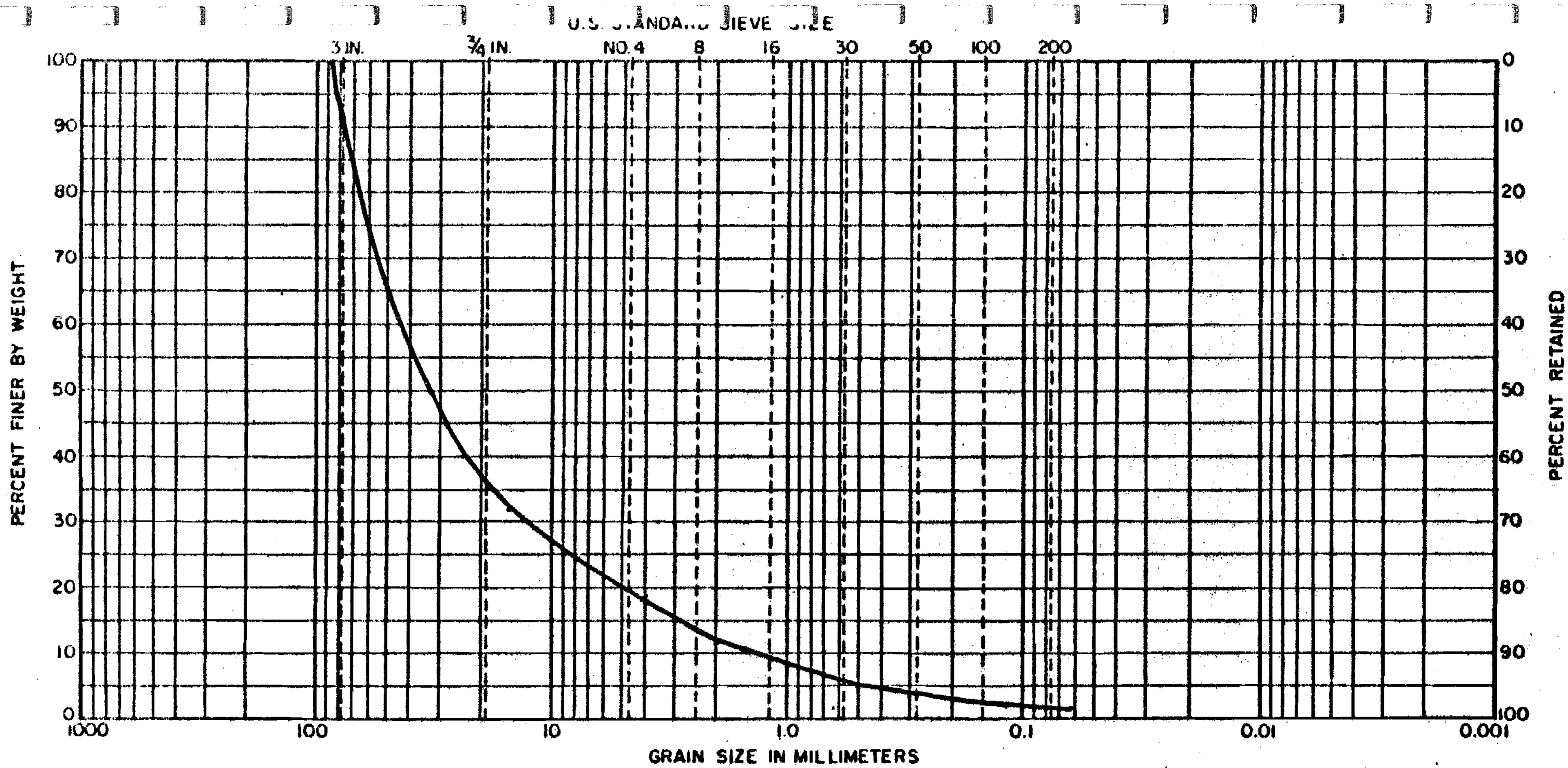
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

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

EXHIBIT 22



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

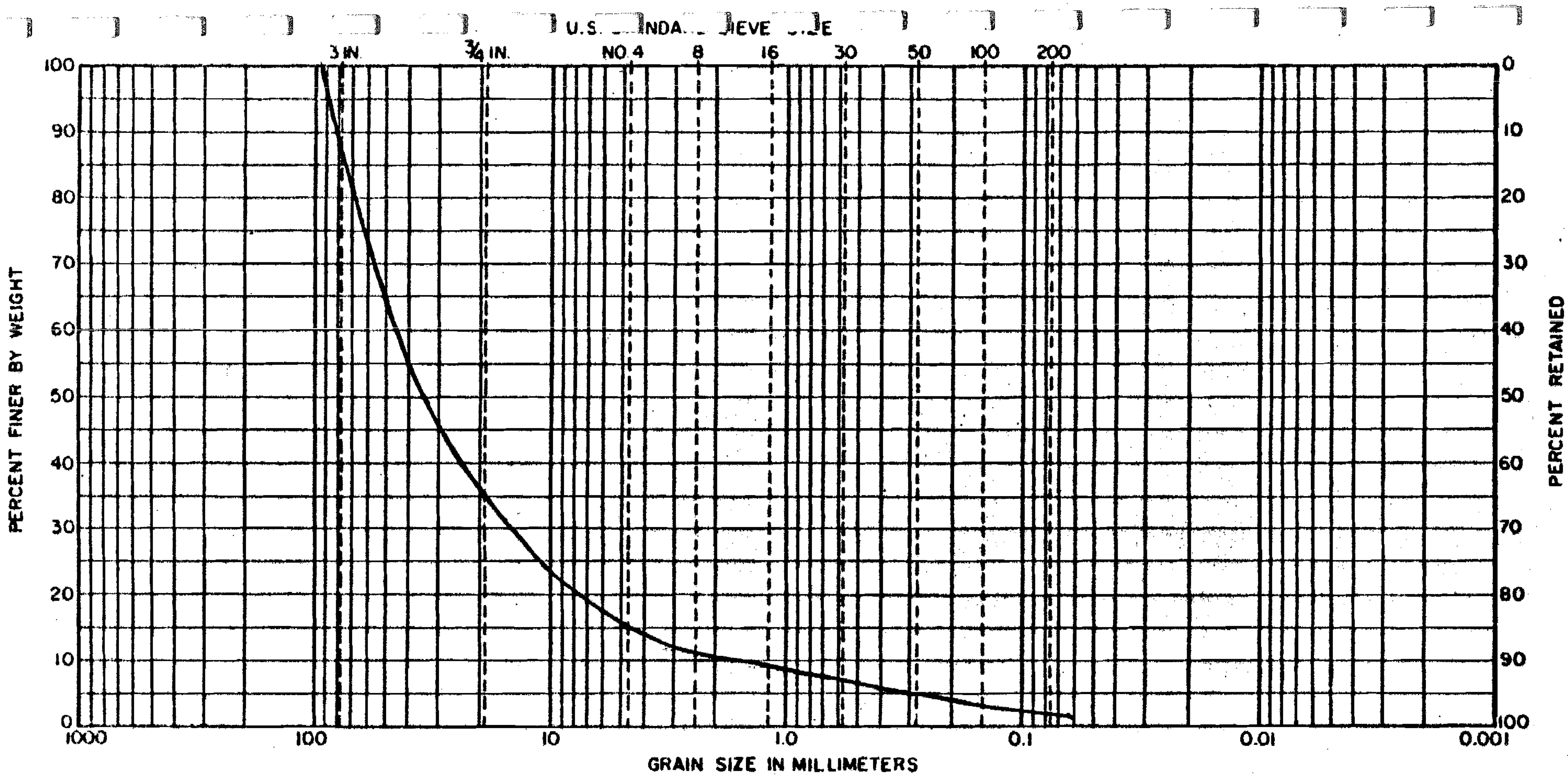
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

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

EXHIBIT 23



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

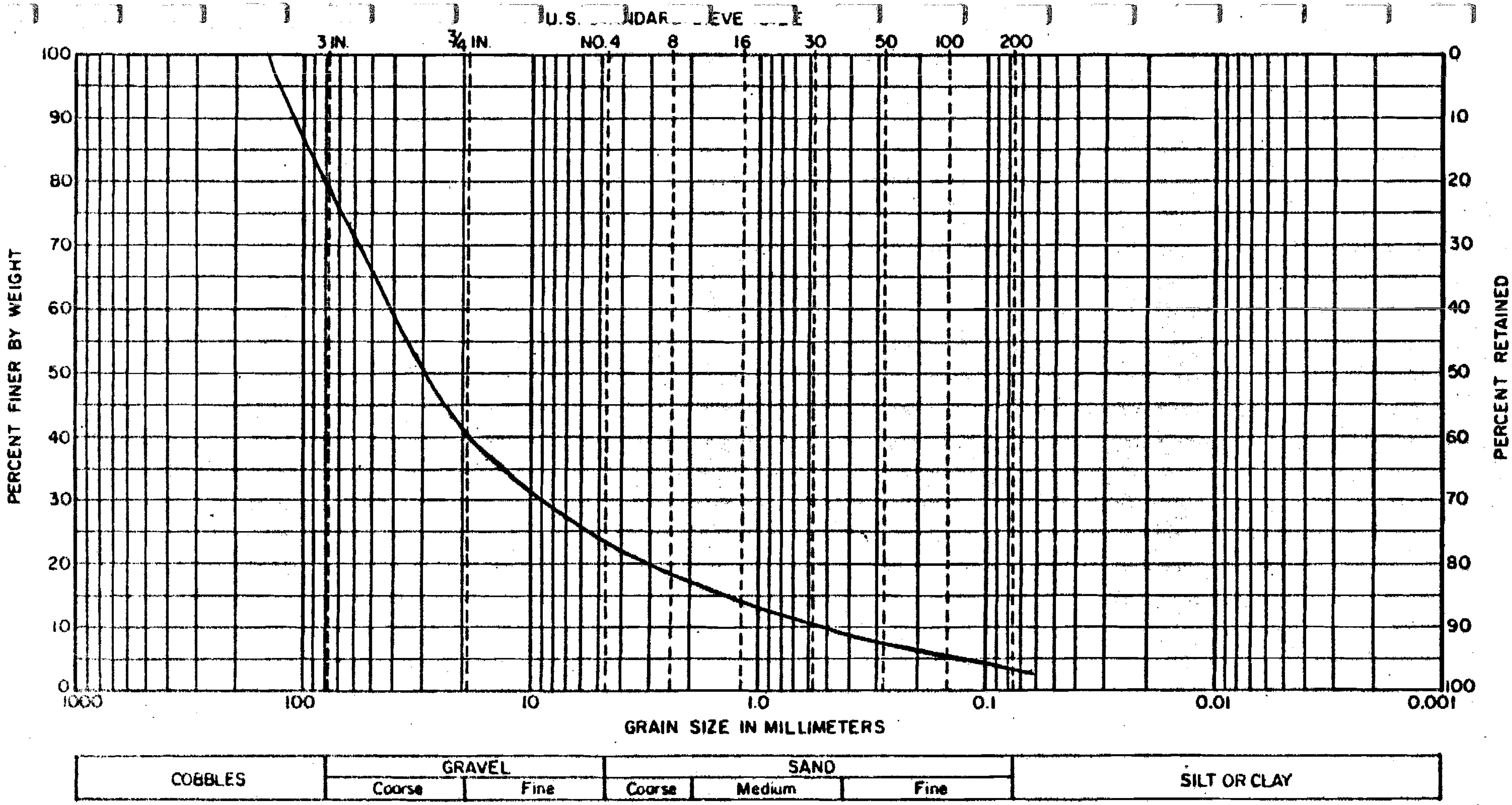
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN MAIN CHANNEL UPSTREAM FROM LANE CREEK

EXHIBIT 24



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

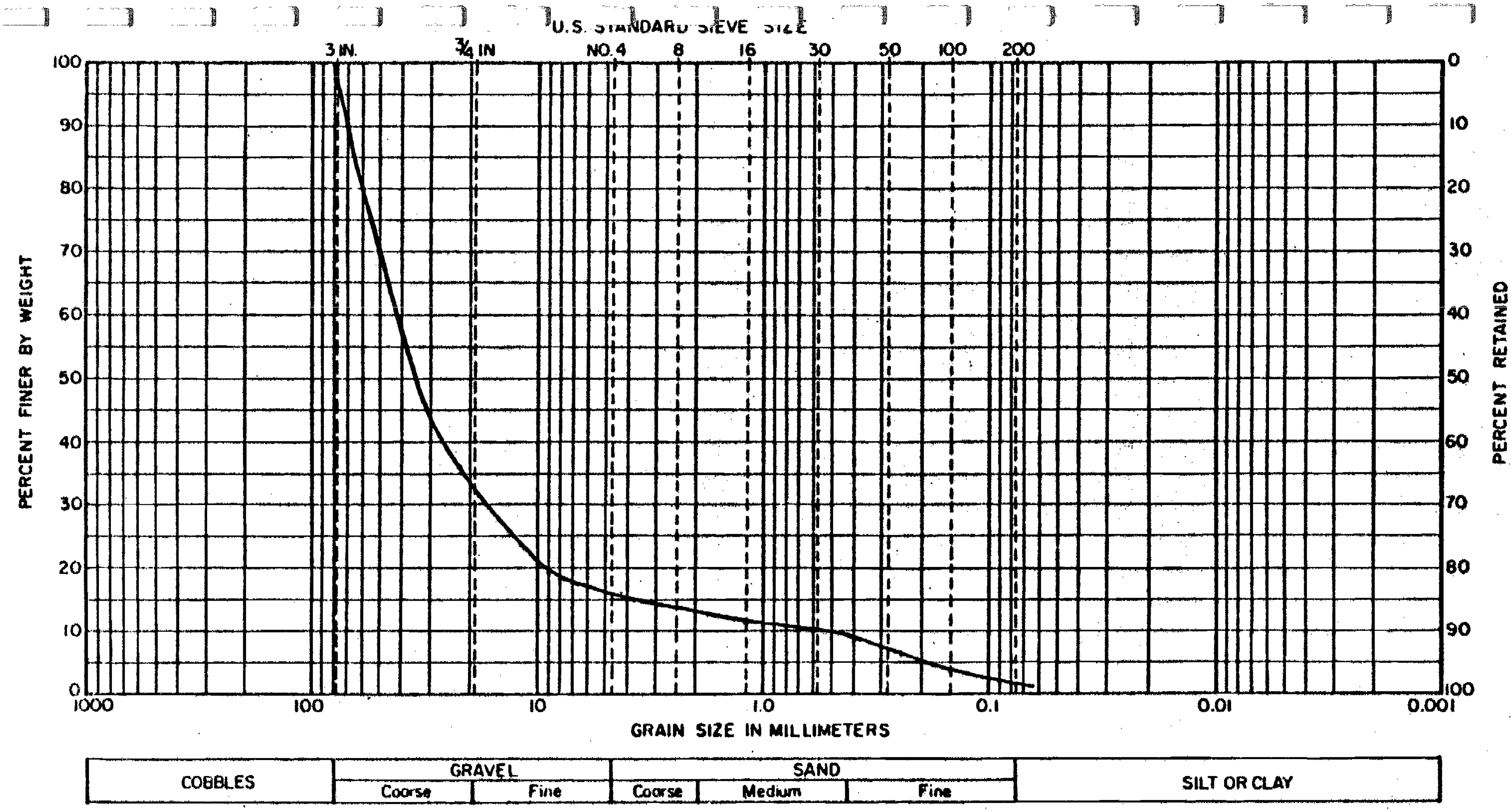
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN MAINSTEM 2 SIDE CHANNELS AT CROSS SECTION 18-2

EXHIBIT 25



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

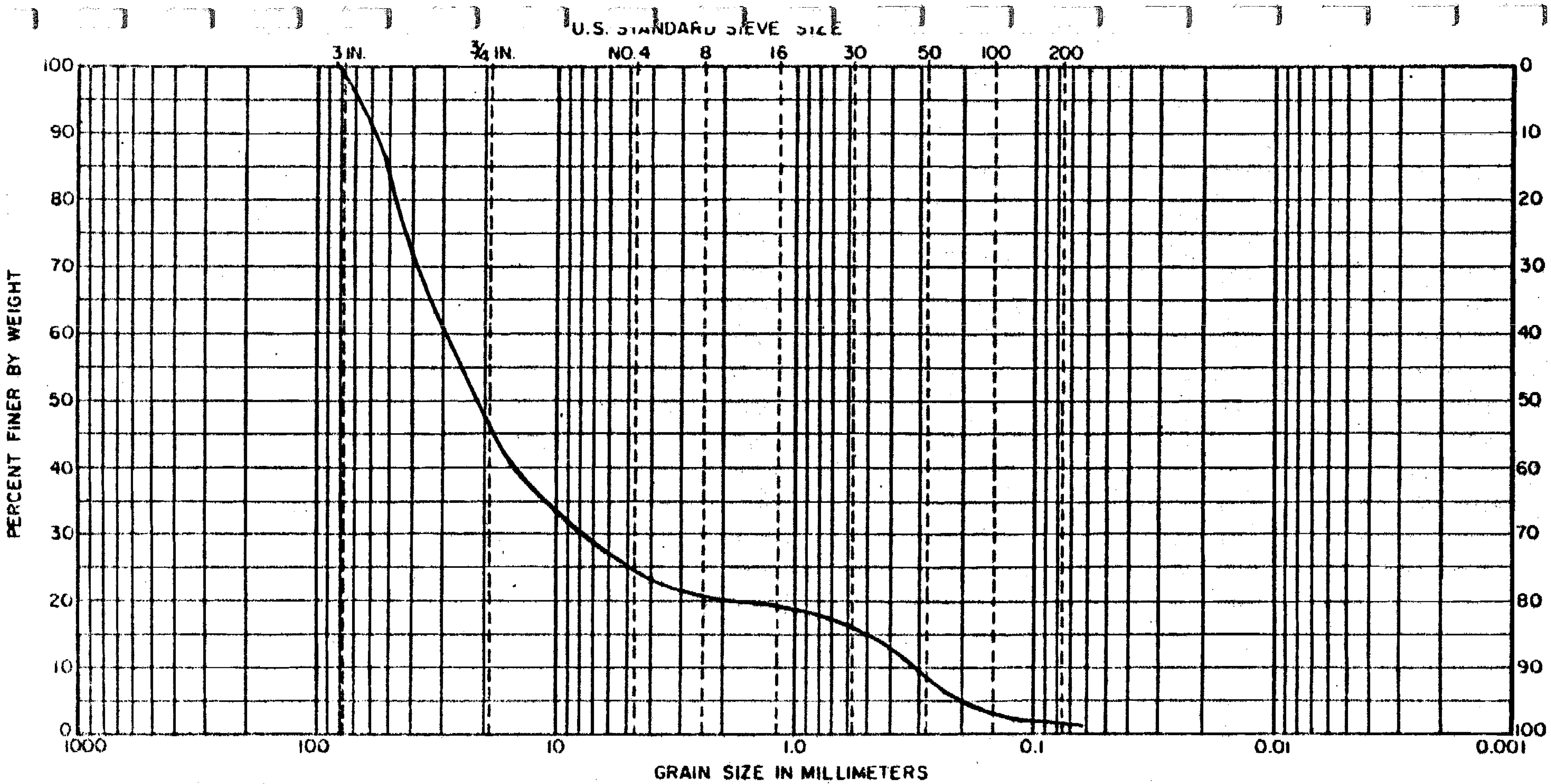
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN SLOUGH 8A

EXHIBIT 26



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

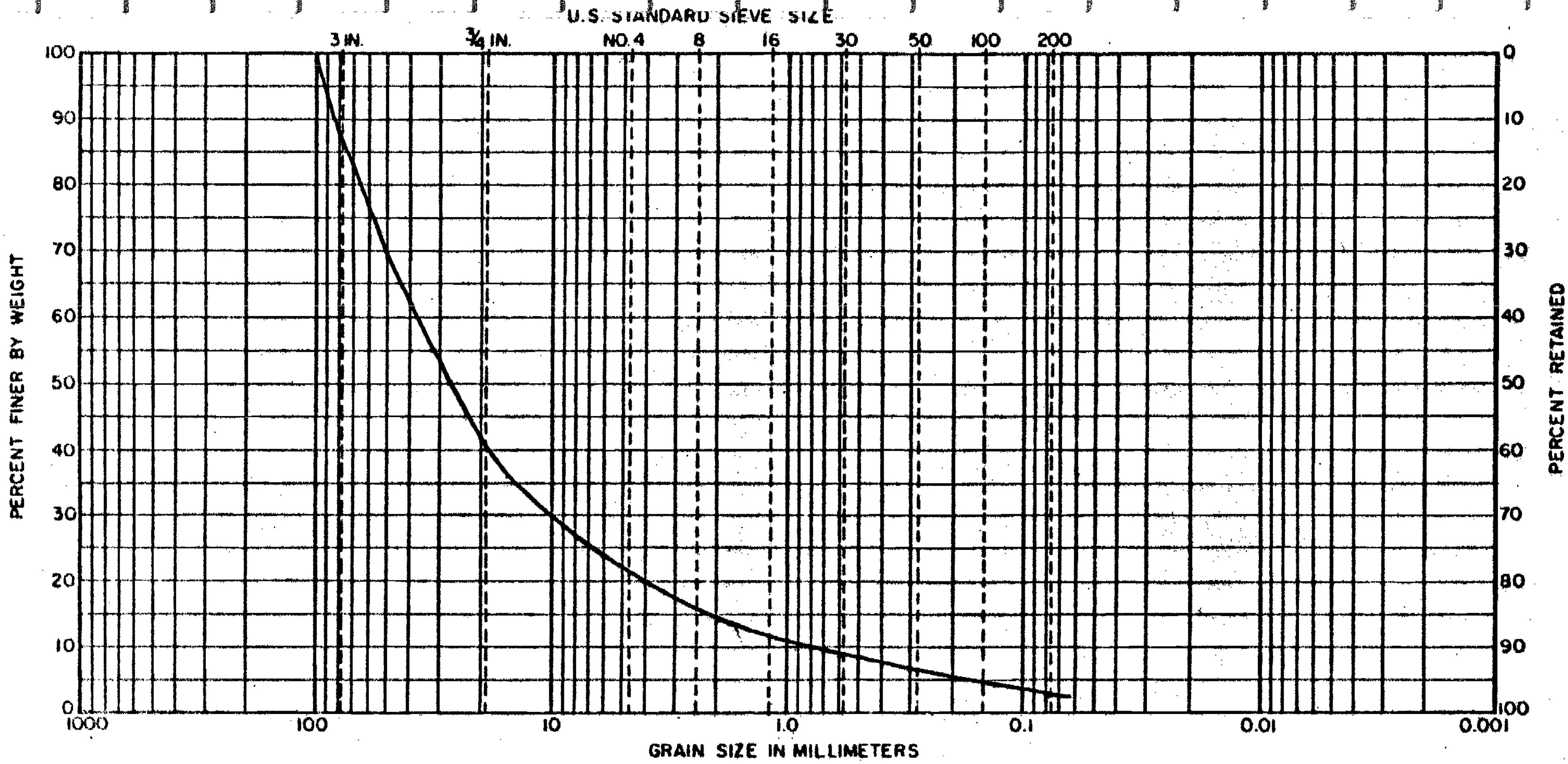
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN SLOUGH 9

EXHIBIT 27



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

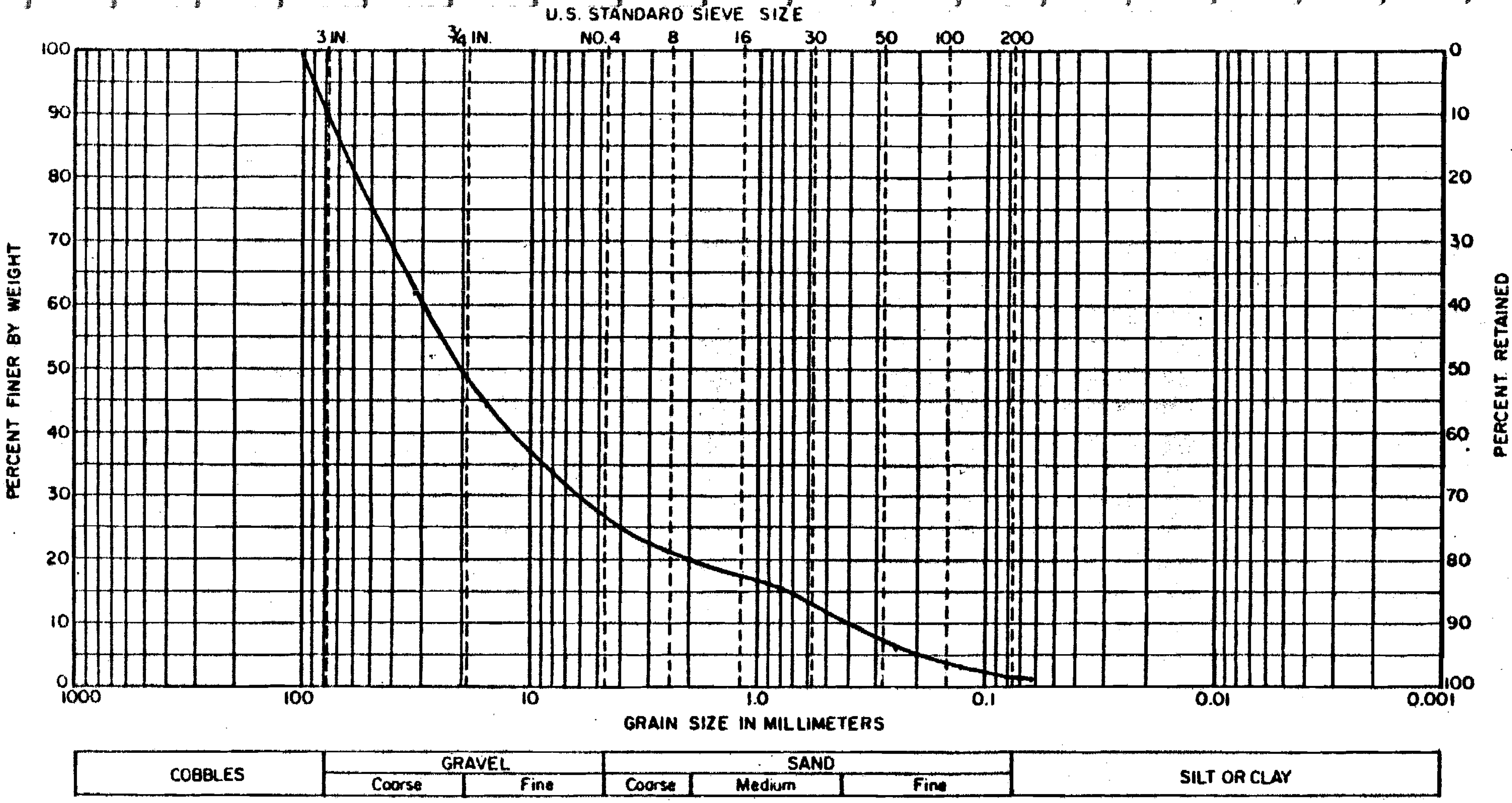
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN MAIN CHANNEL UPSTREAM FROM 4th OF JULY CREEK

EXHIBIT 28



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

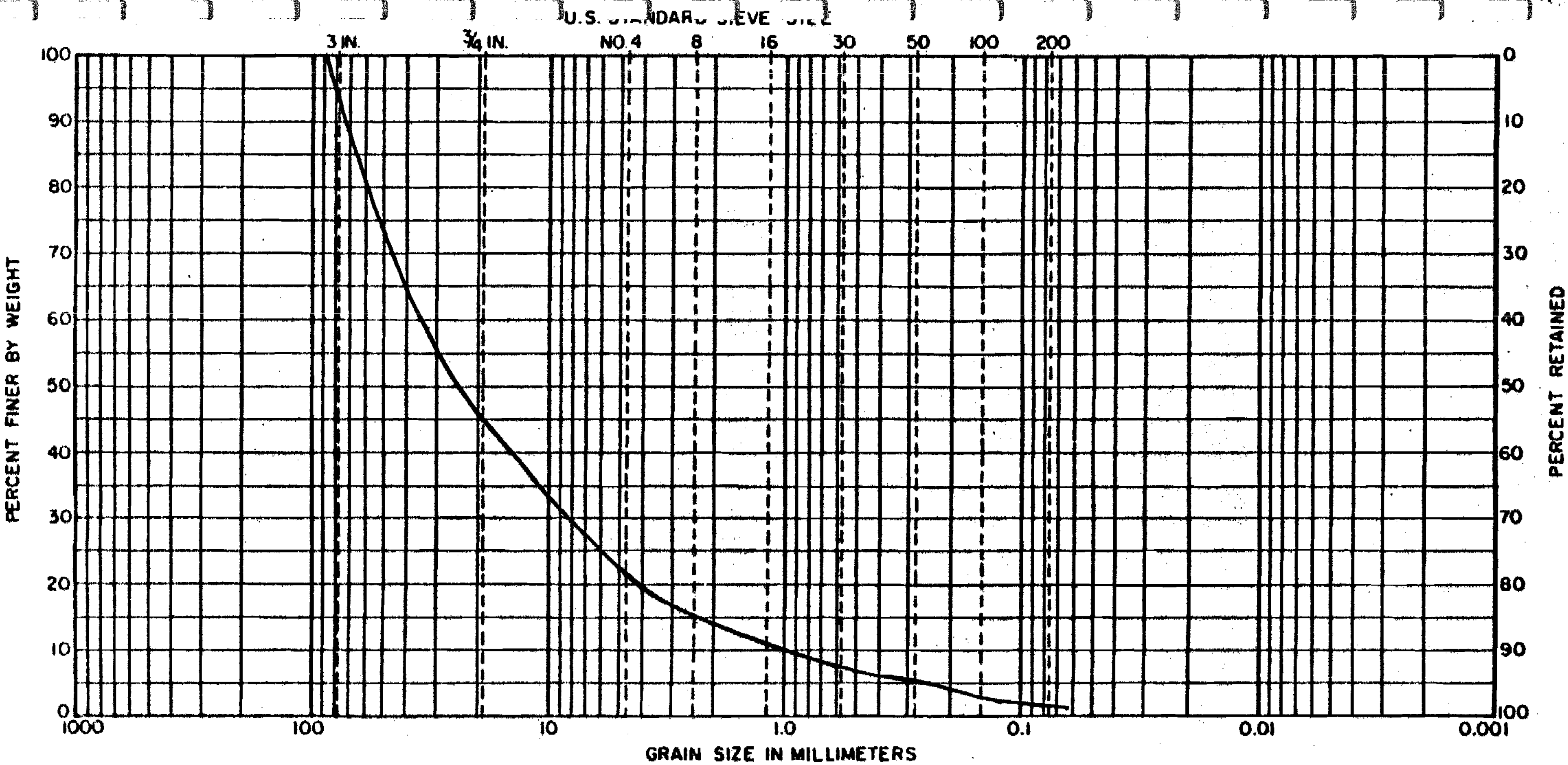
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN SIDE CHANNEL 10

EXHIBIT 29



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

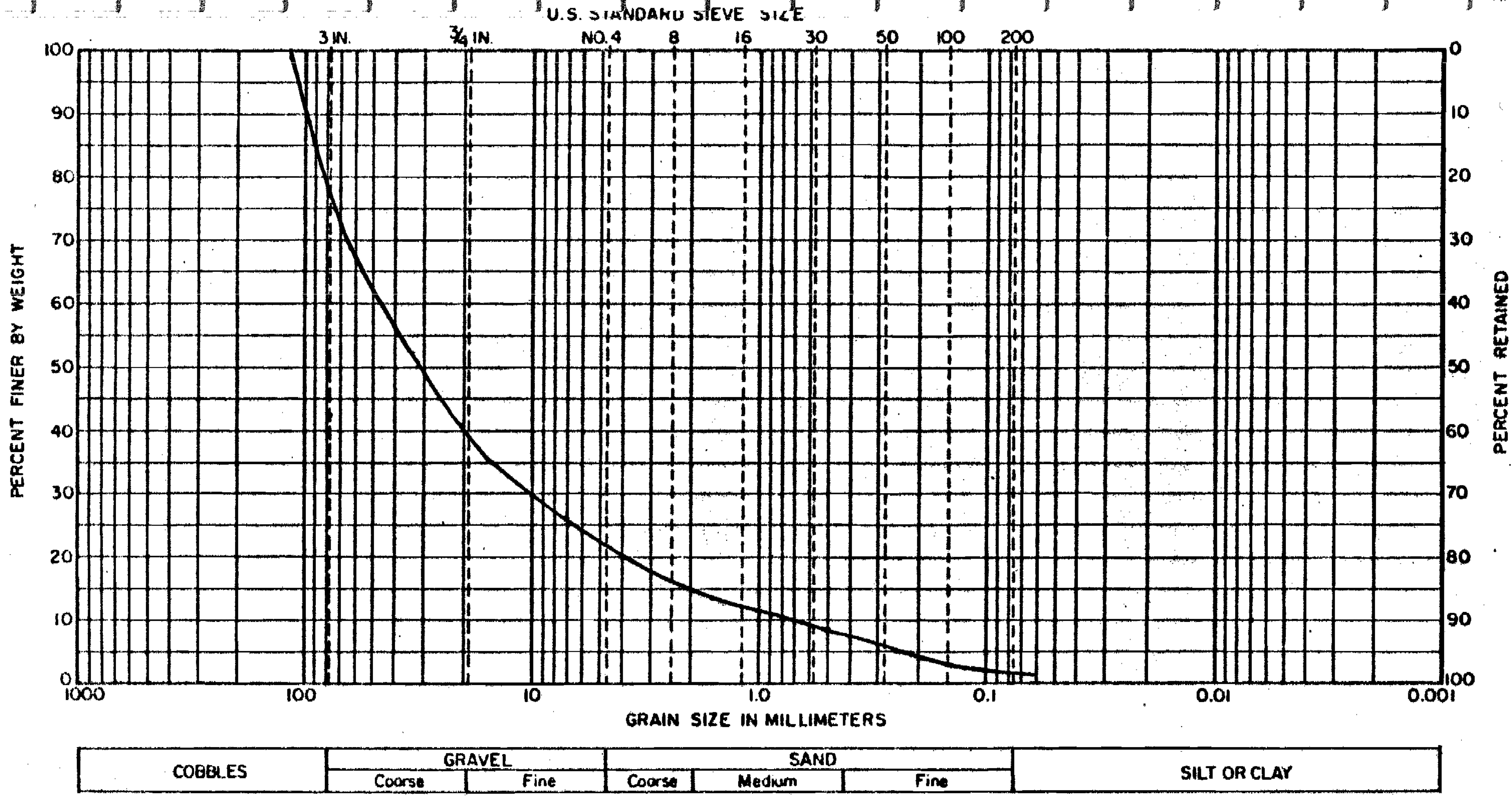
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

SIZE DISTRIBUTION OF BED MATERIAL IN LOWER SIDE CHANNEL 11

EXHIBIT 30



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

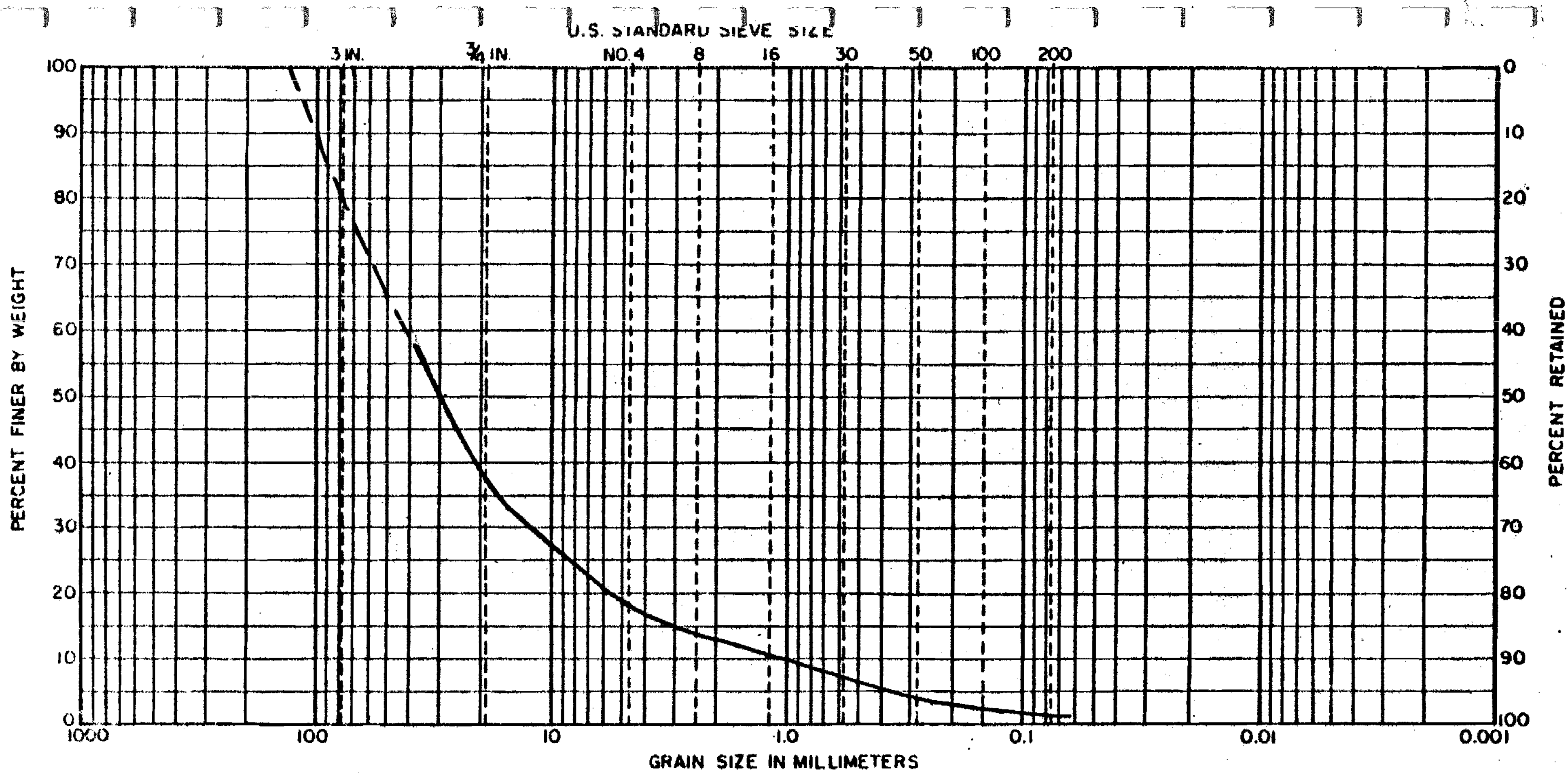
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

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

EXHIBIT 31



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

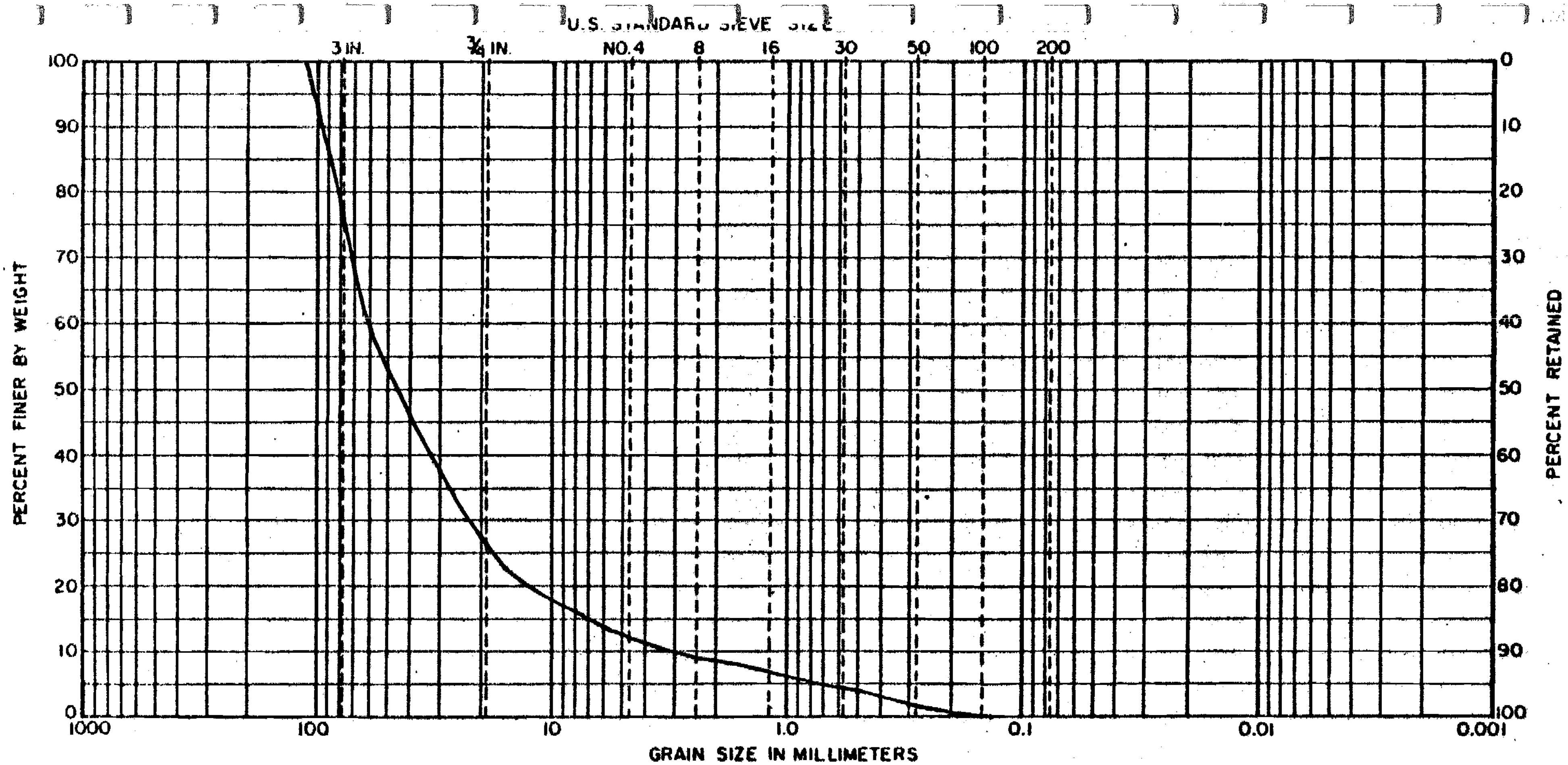
GRADATION CURVES

HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

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

EXHIBIT 32



COBBLES	GRAVEL		SAND			SILT OR CLAY
	Coarse	Fine	Coarse	Medium	Fine	

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

GRADATION CURVES

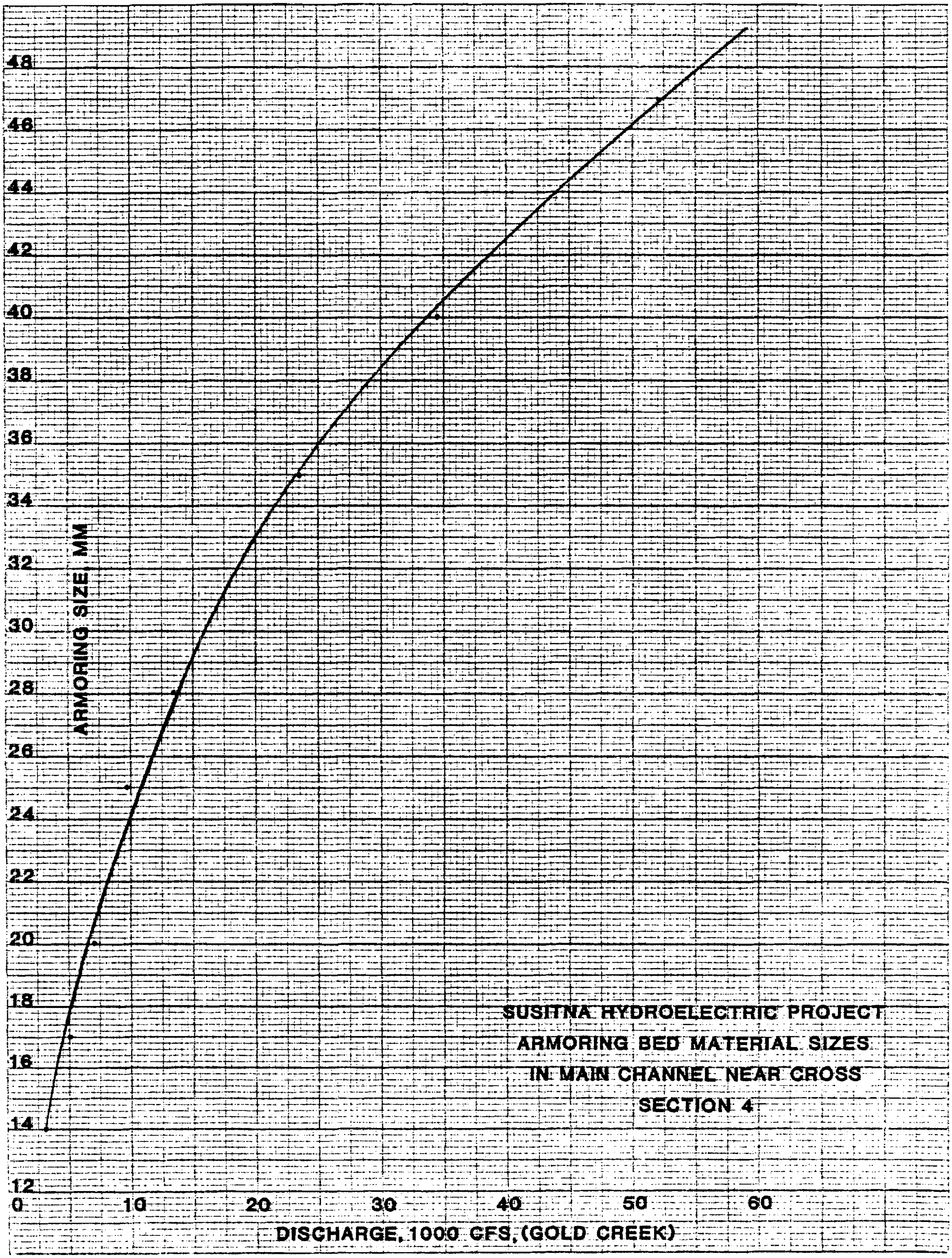
HARZA-EBASCO SUSITNA JOINT VENTURE

SUSITNA HYDROELECTRIC PROJECT

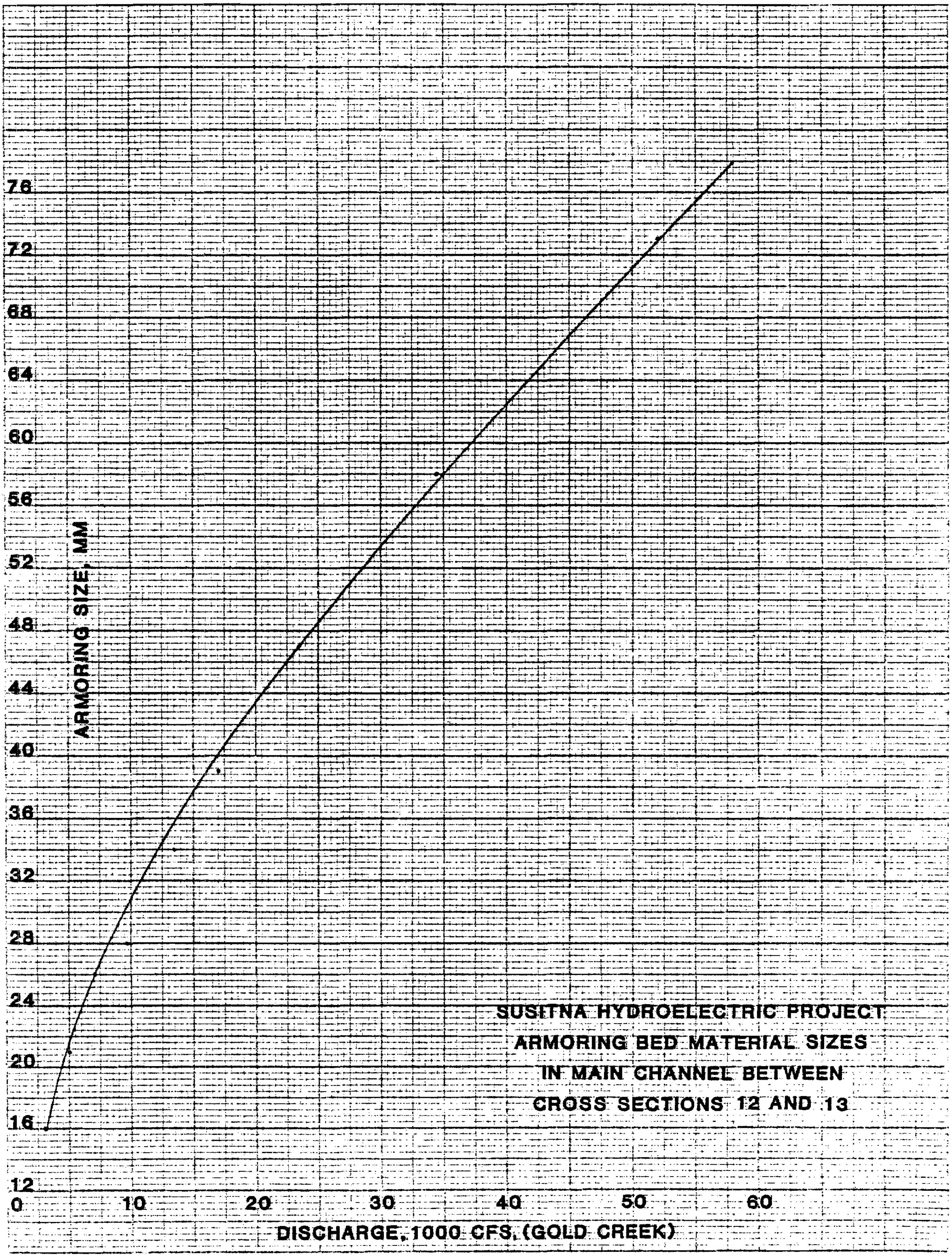
SIZE DISTRIBUTION OF BED MATERIAL IN SIDE CHANNEL 21 AND SLOUGH 21

EXHIBIT 33

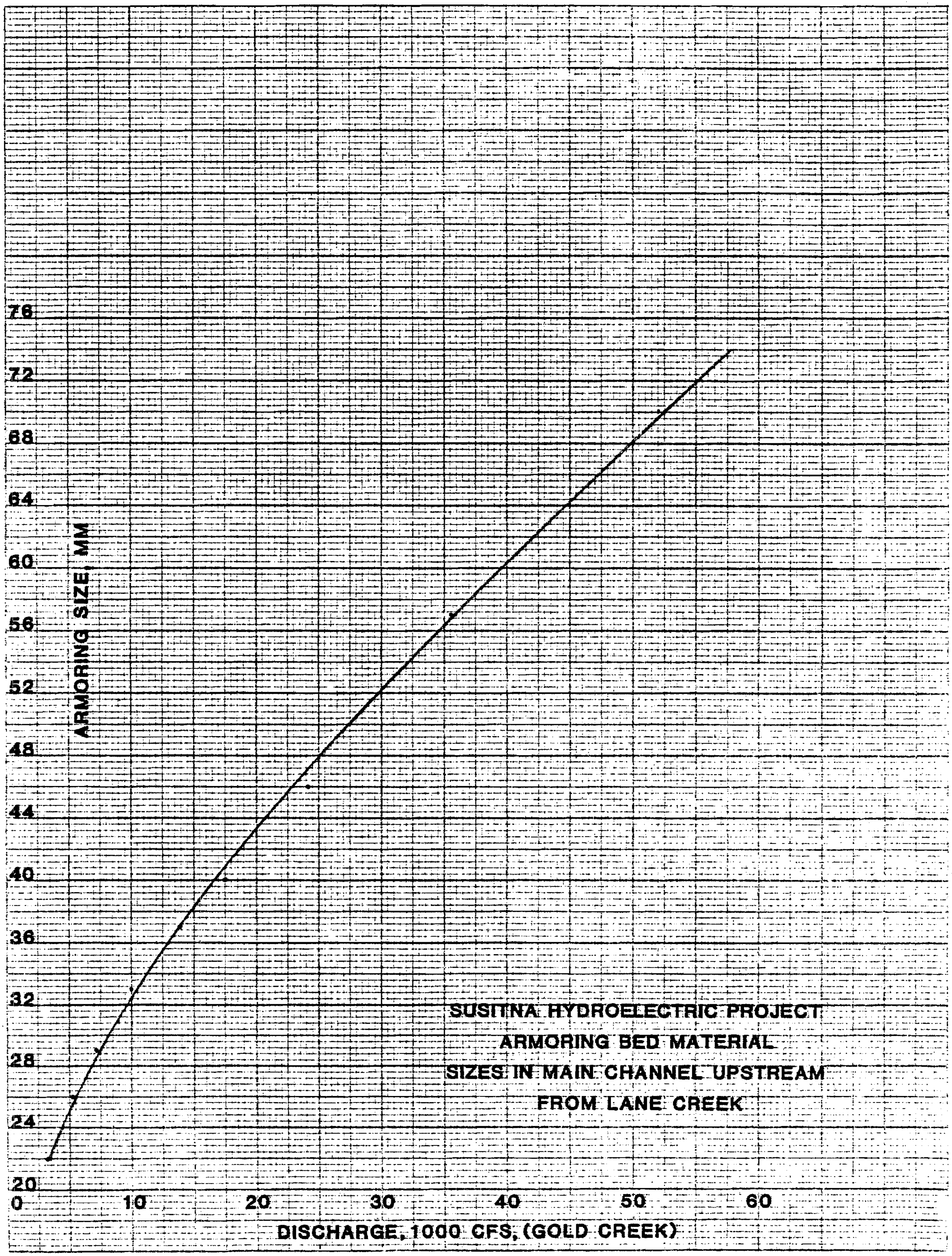
EXHIBIT 34



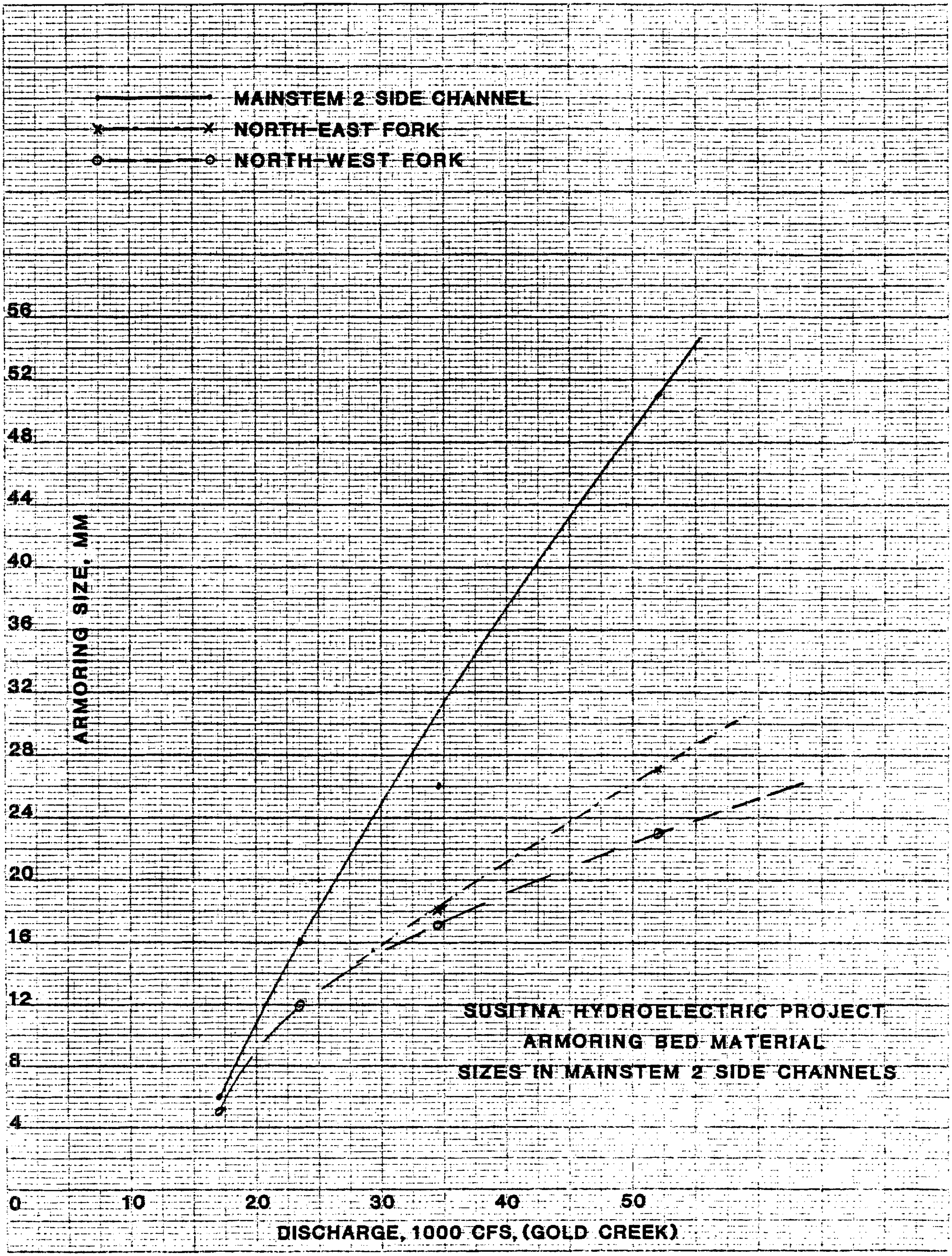
HARZA-EBASCO SUSITNA JOINT VENTURE

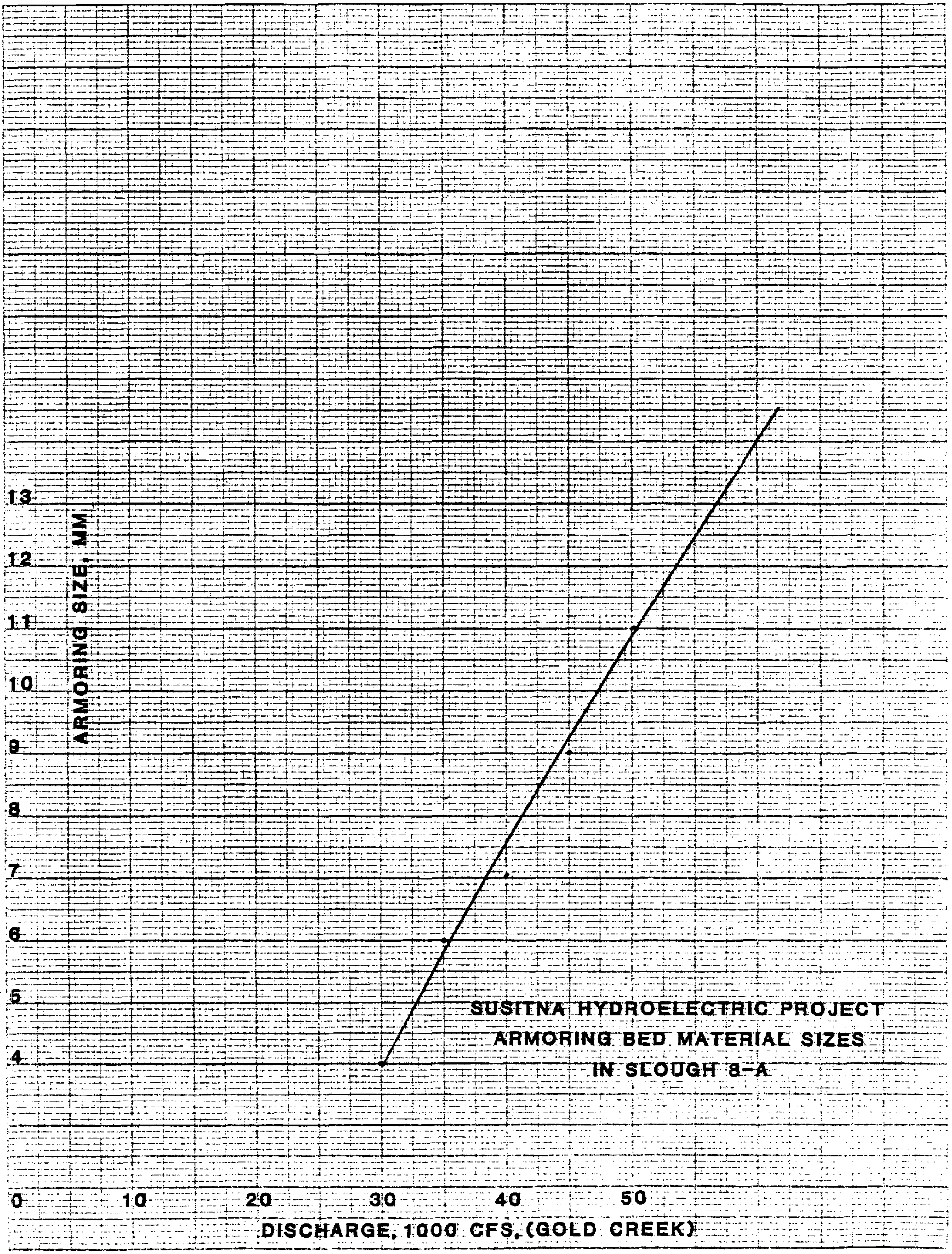


HARZA-EBASCO SUSITNA JOINT VENTURE



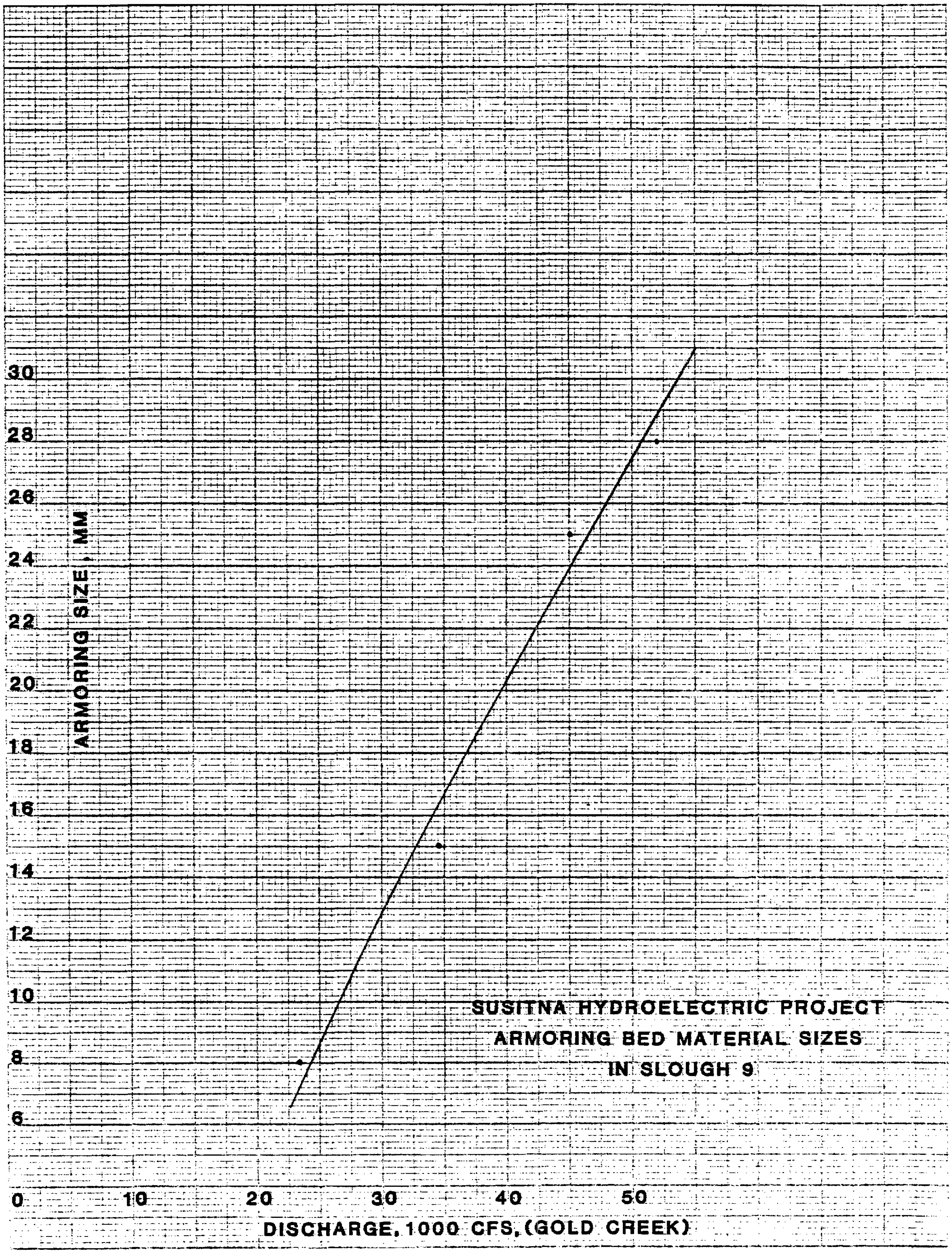
HARZA-EBASCO SUSITNA JOINT VENTURE


MAINSTEM 2 SIDE CHANNEL
NORTH-EAST FORK
NORTH-WEST FORK
ARMORING SIZE, MM
56
52
48
44
40
36
32
28
24
20
16
12
8
4
0
10
20
30
40
50
DISCHARGE, 1000 CFS, (GOLD CREEK)
SUSITNA HYDROELECTRIC PROJECT
ARMORING BED MATERIAL
SIZES IN MAINSTEM 2 SIDE CHANNELS

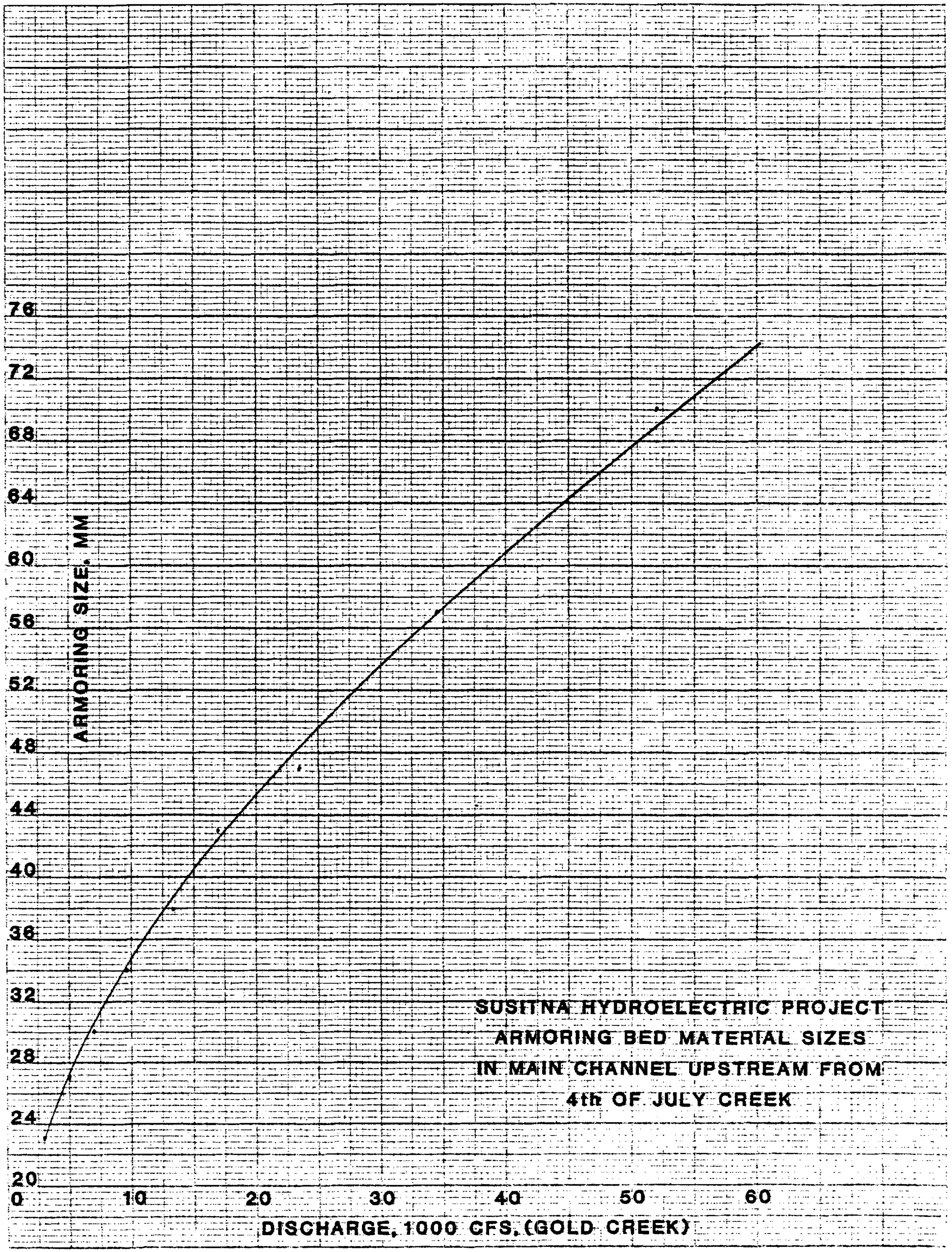


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 39

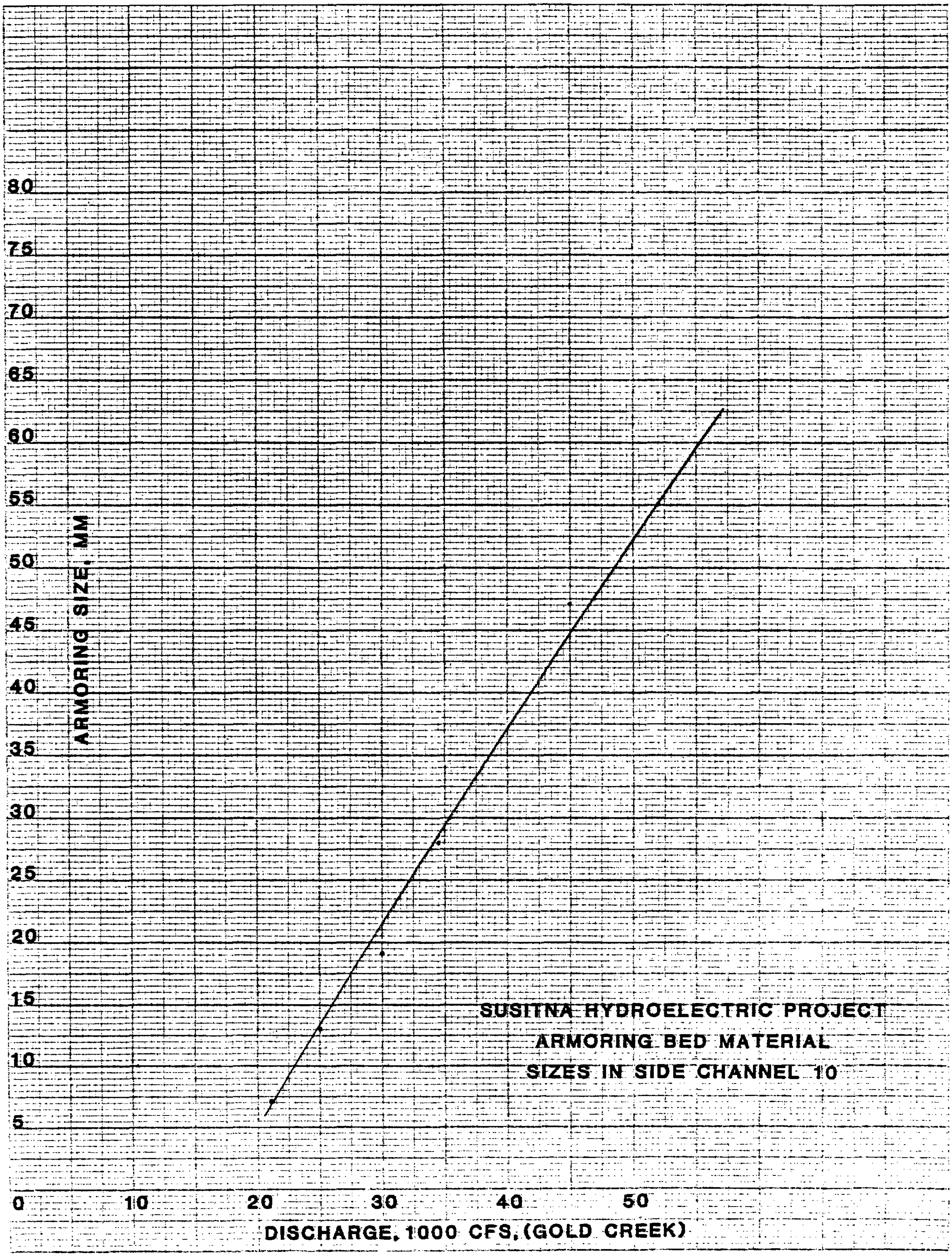


HARZA-EBASCO SUSITNA JOINT VENTURE

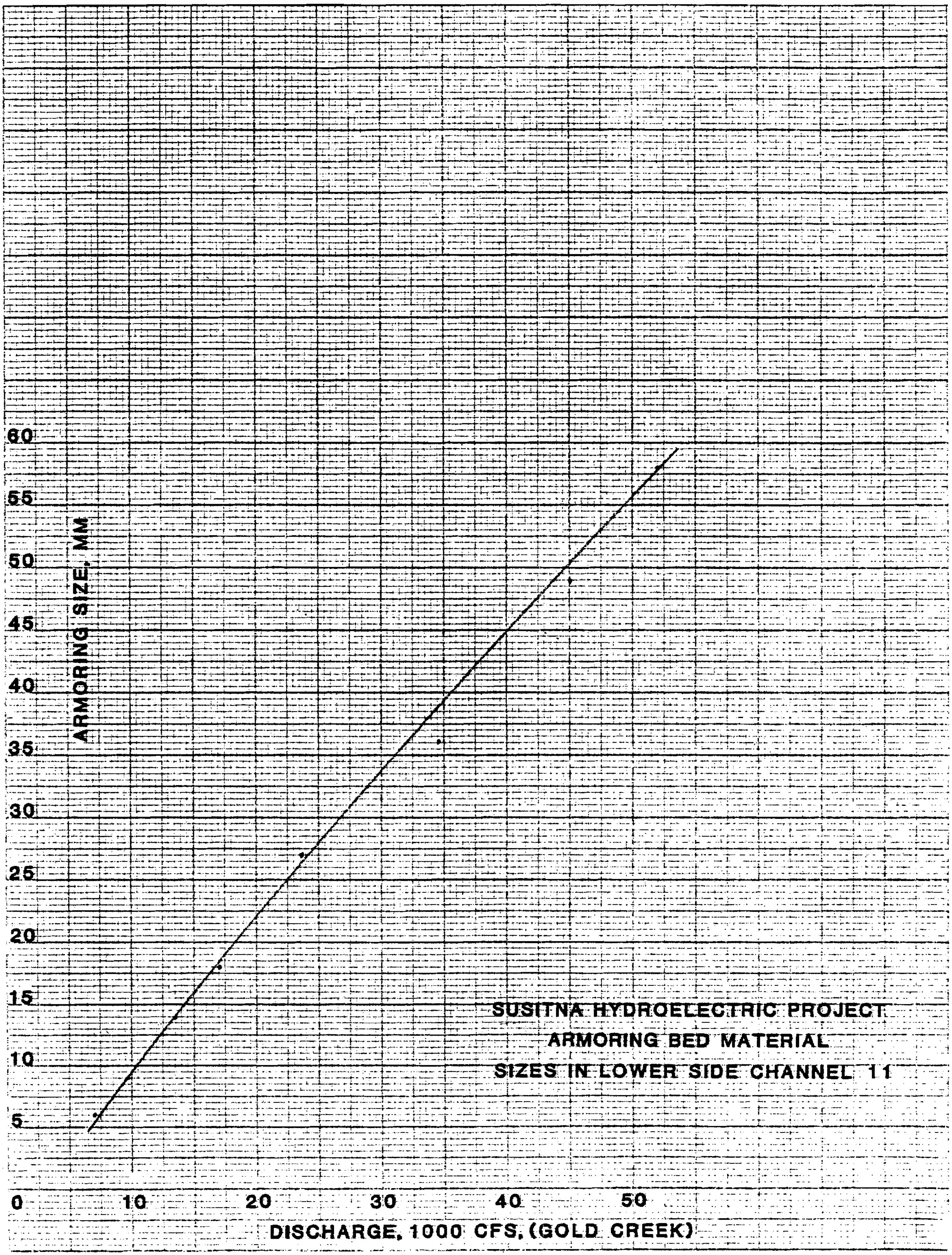


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 41

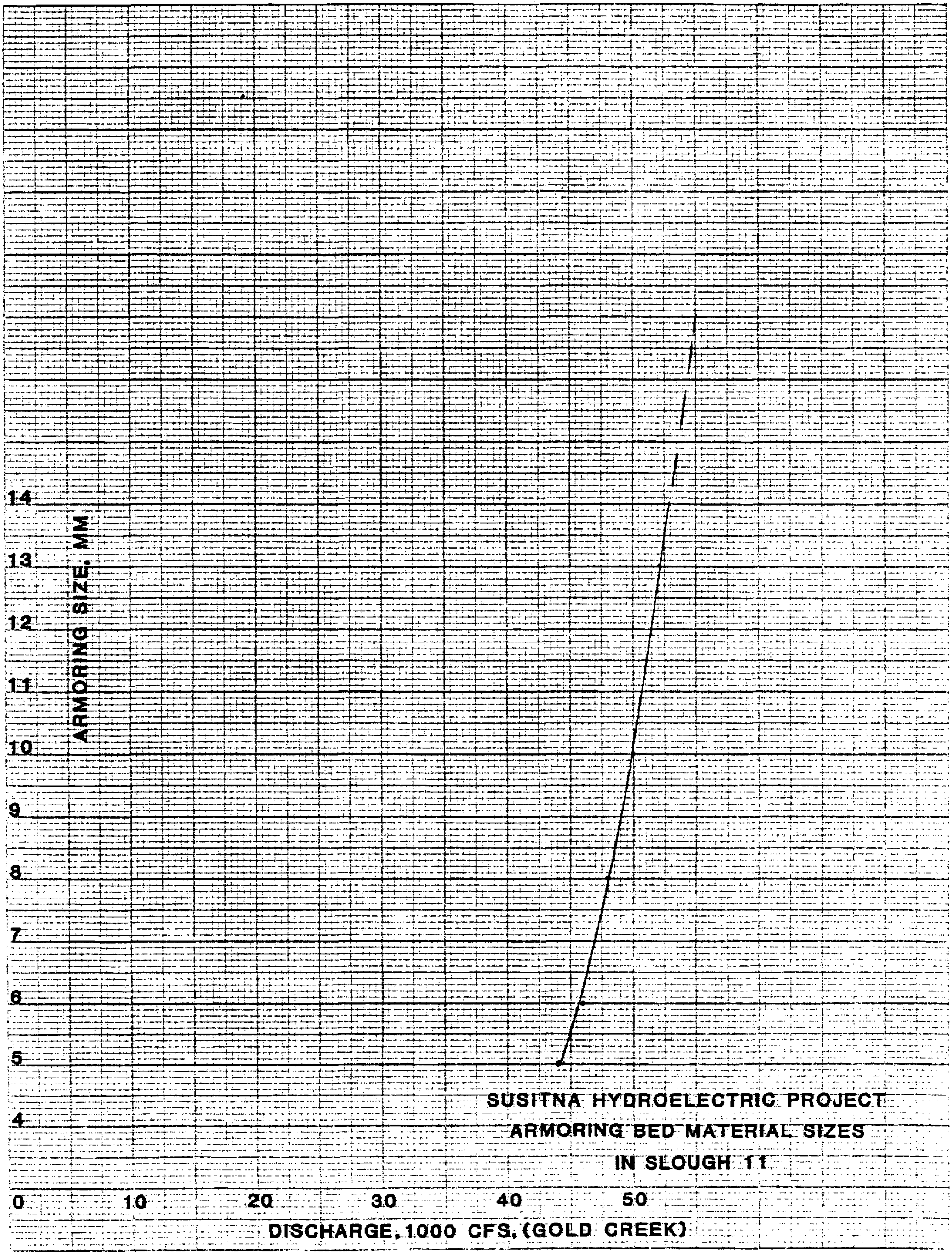


HARZA-EBASCO SUSITNA JOINT VENTURE



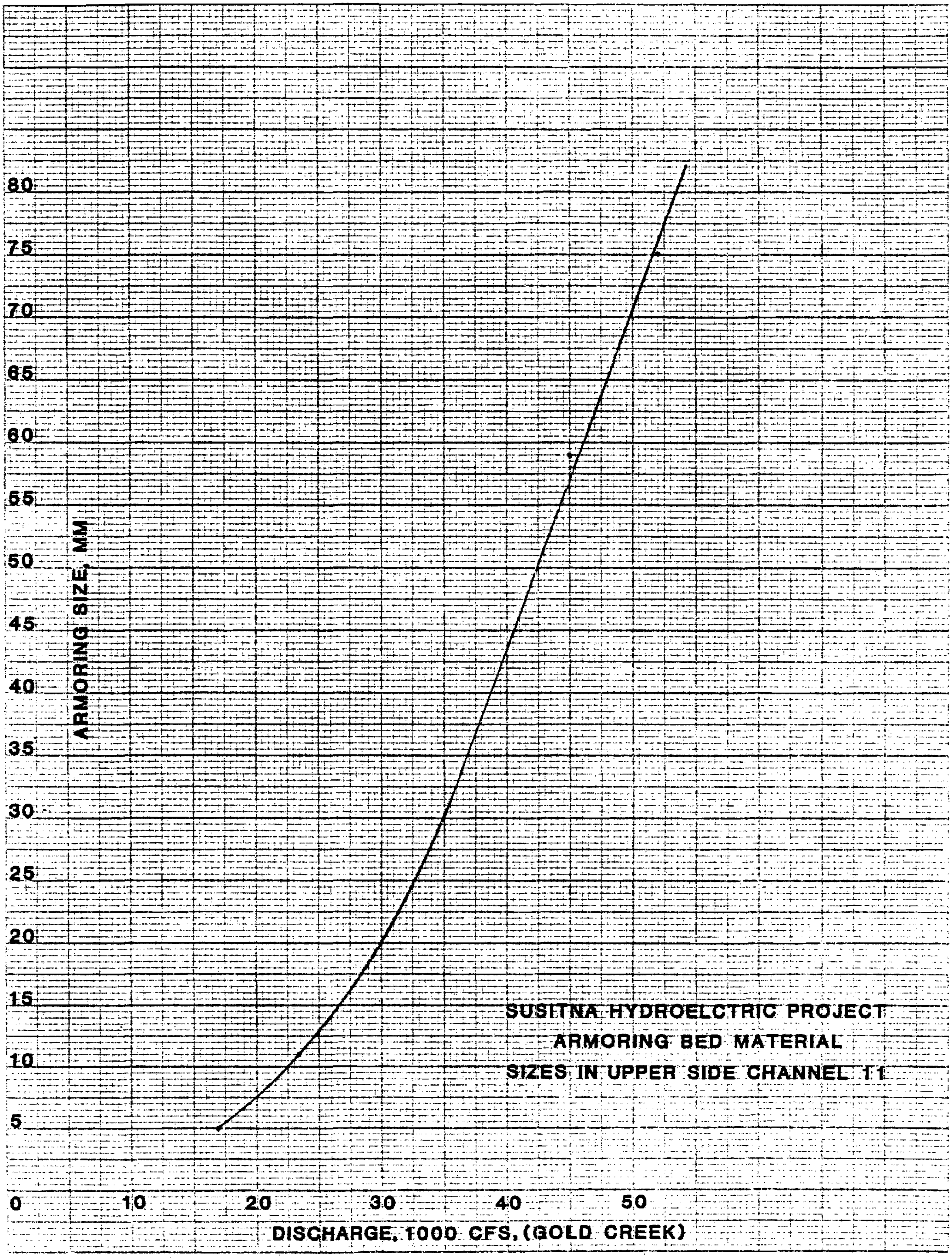
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 43

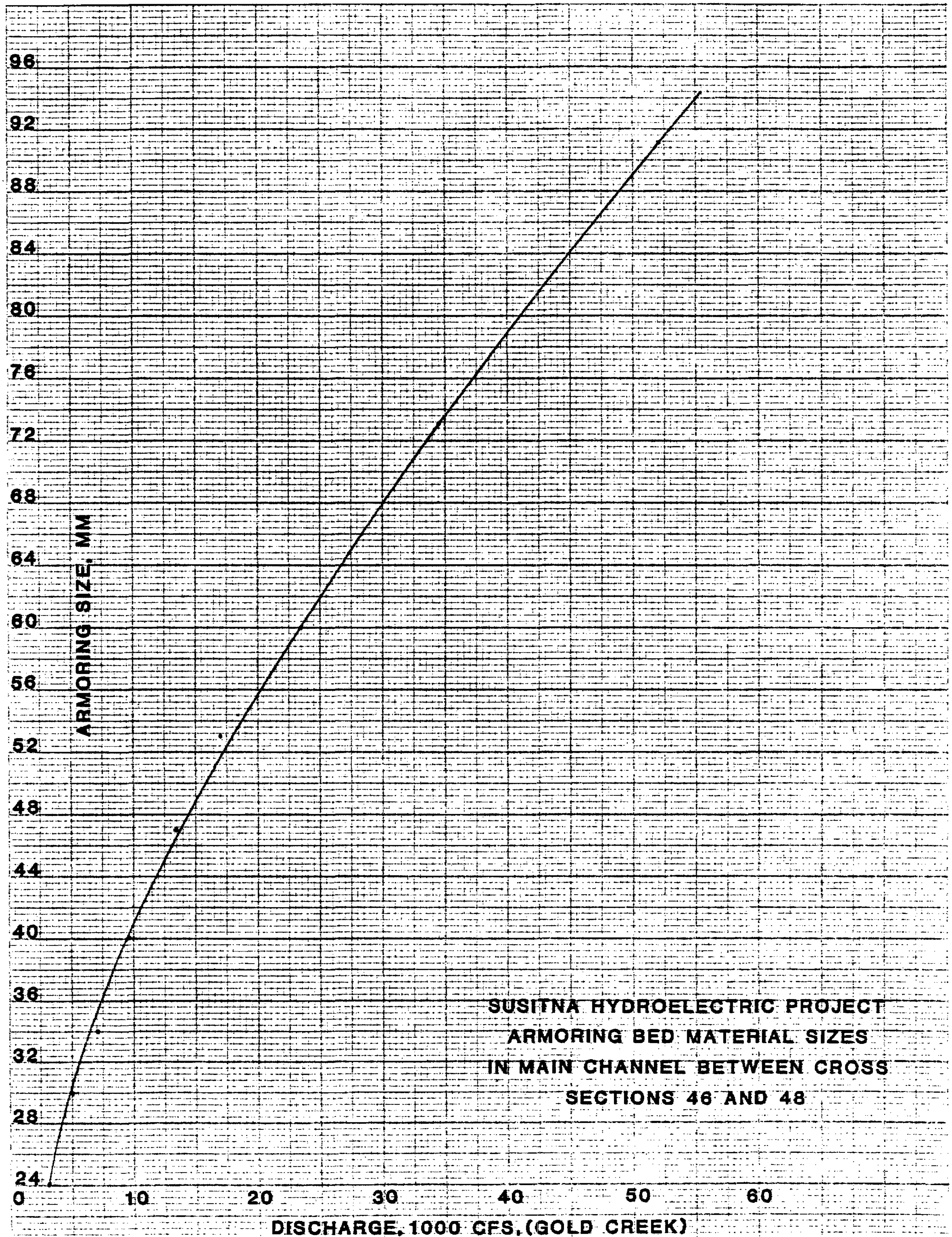


HARZA-EBASCO SUSITNA JOINT VENTURE

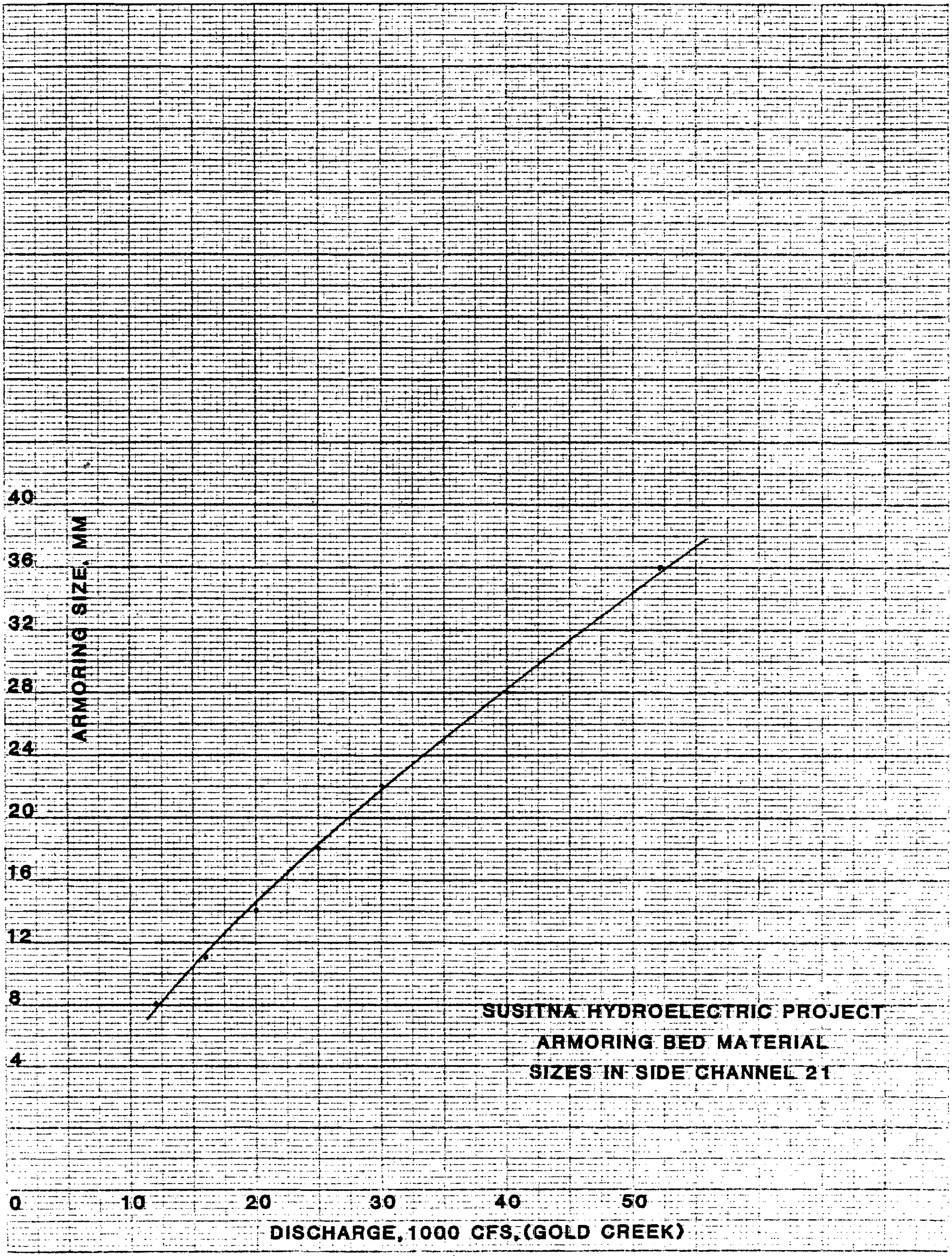
EXHIBIT 44



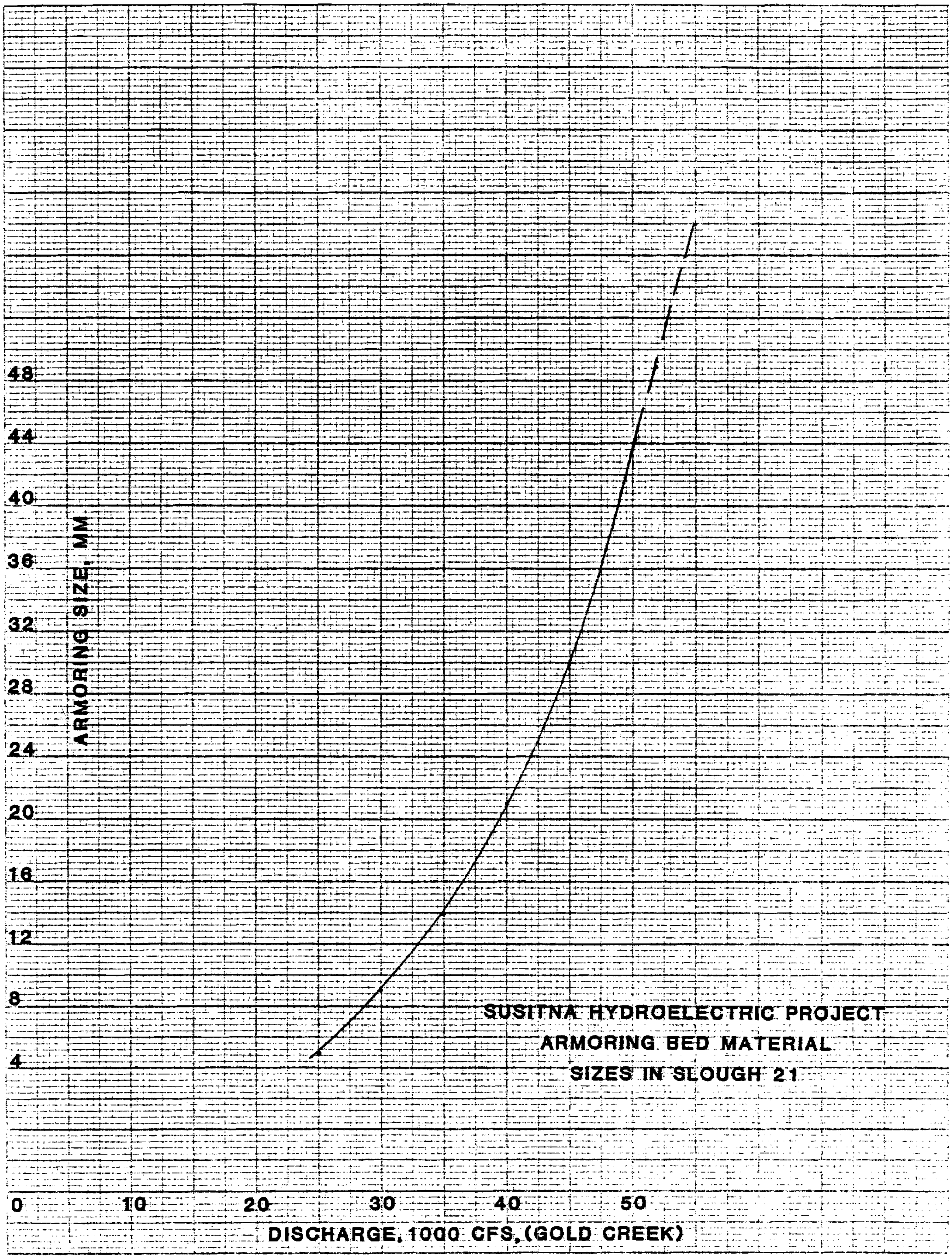
HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

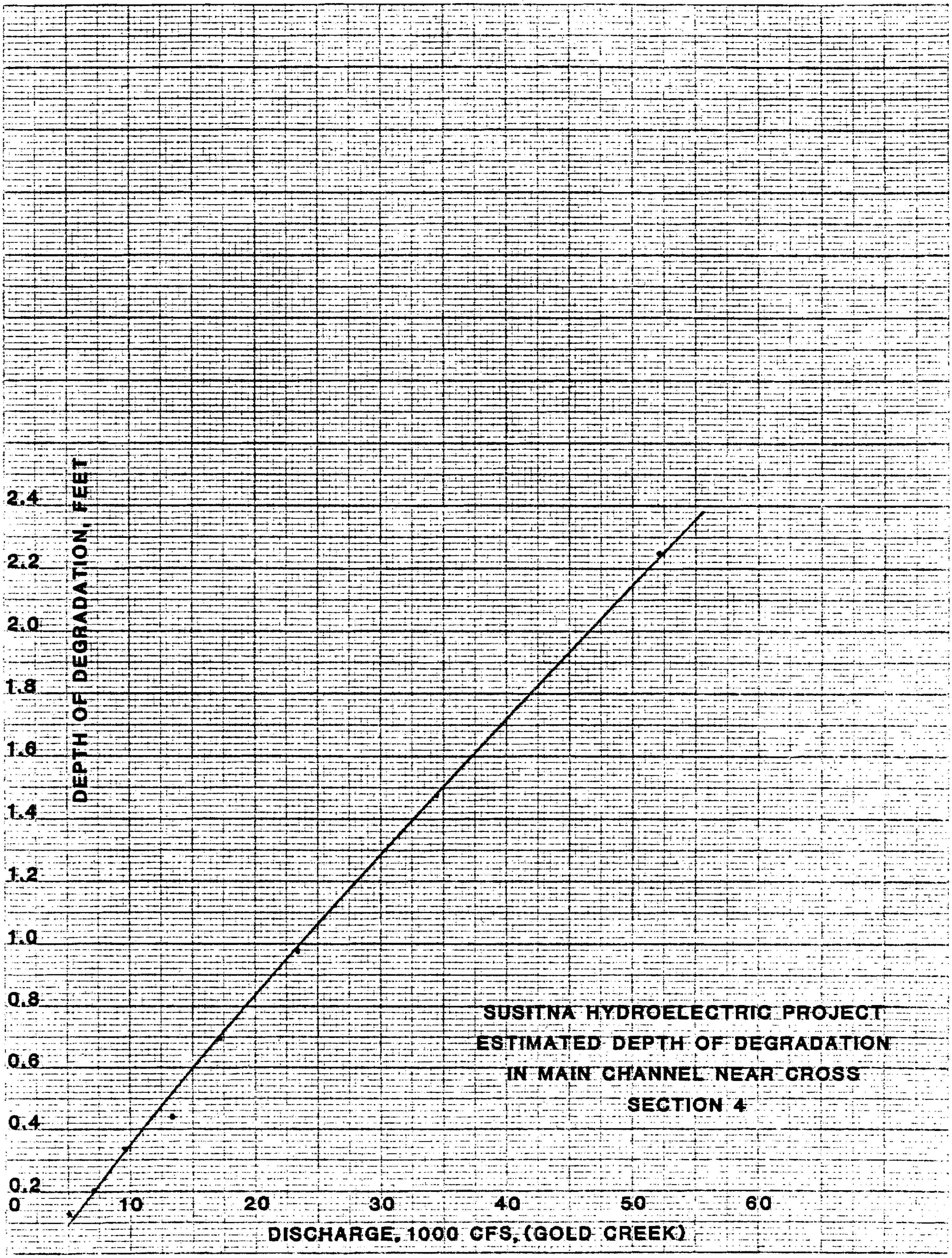


HARZA-EBASCO SUSITNA JOINT VENTURE



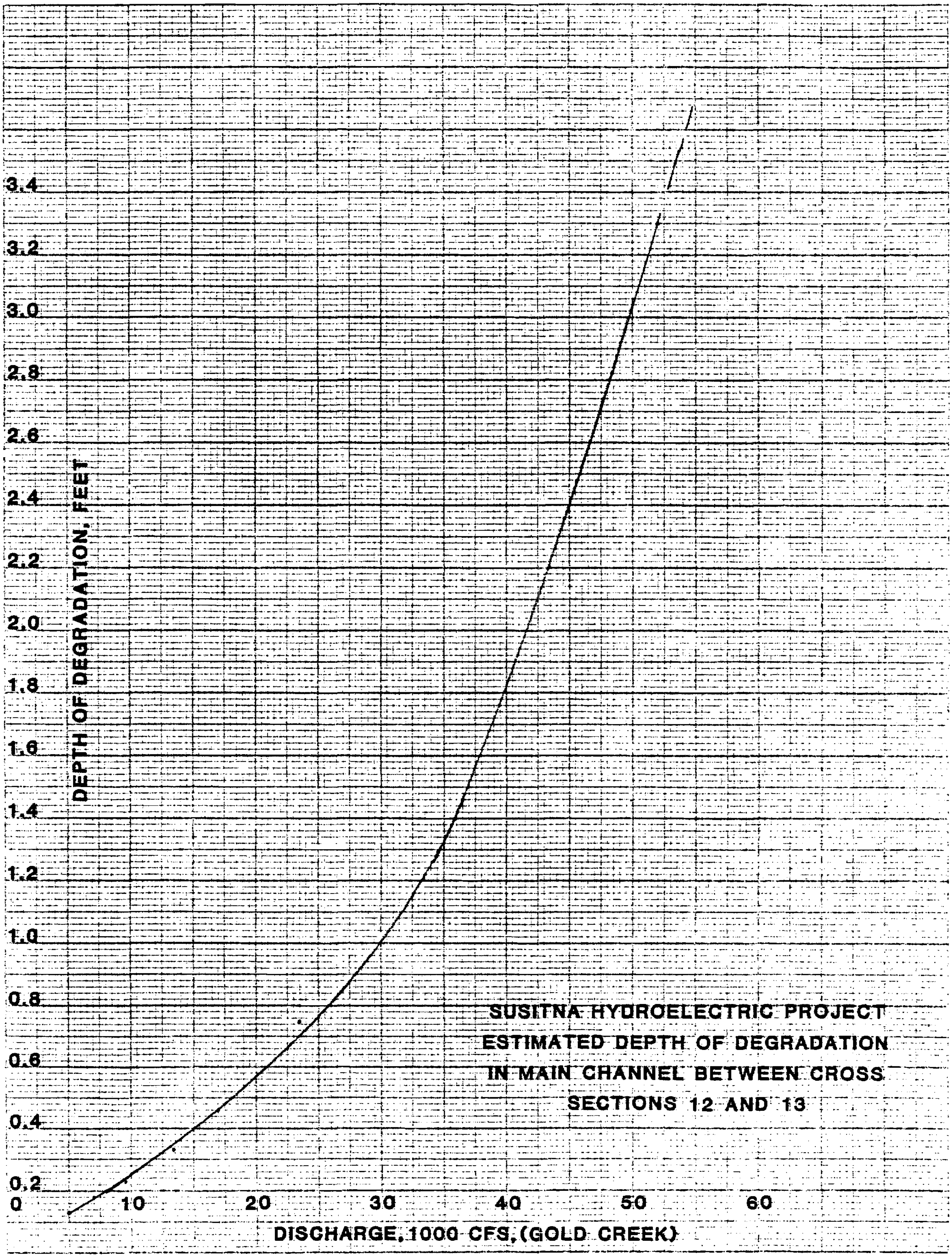
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 48



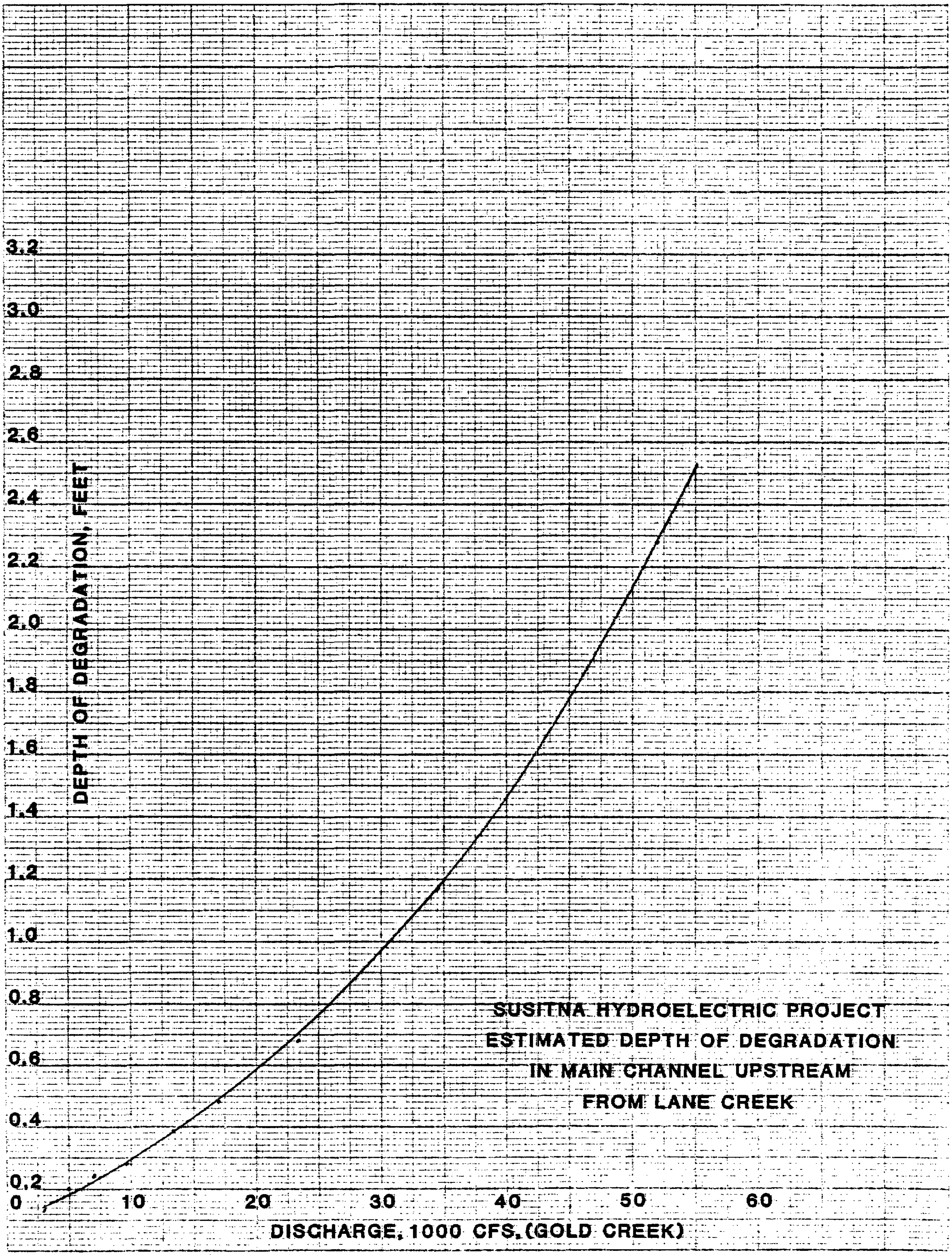
HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 49

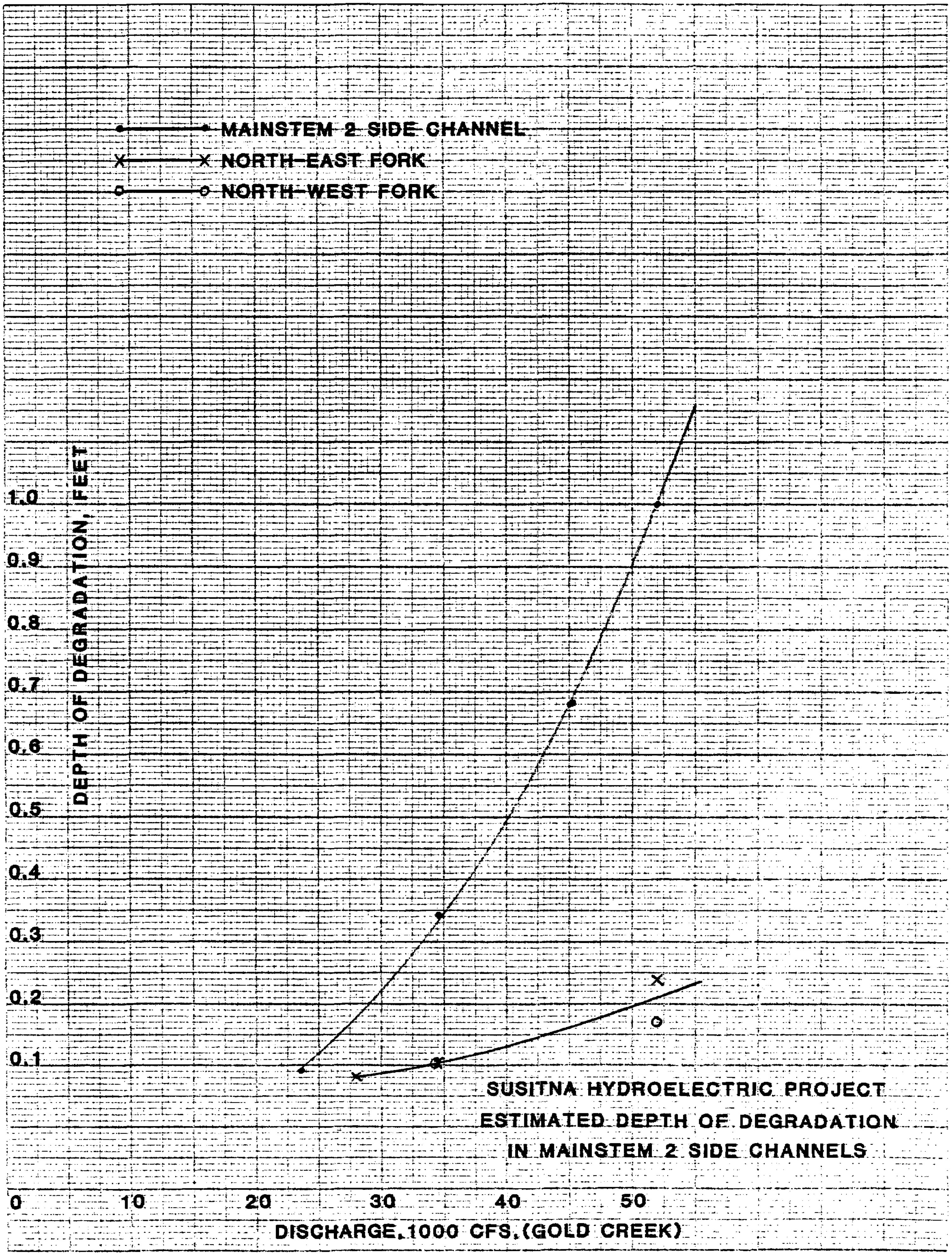


HARZA-EBASCO SUSITNA JOINT VENTURE

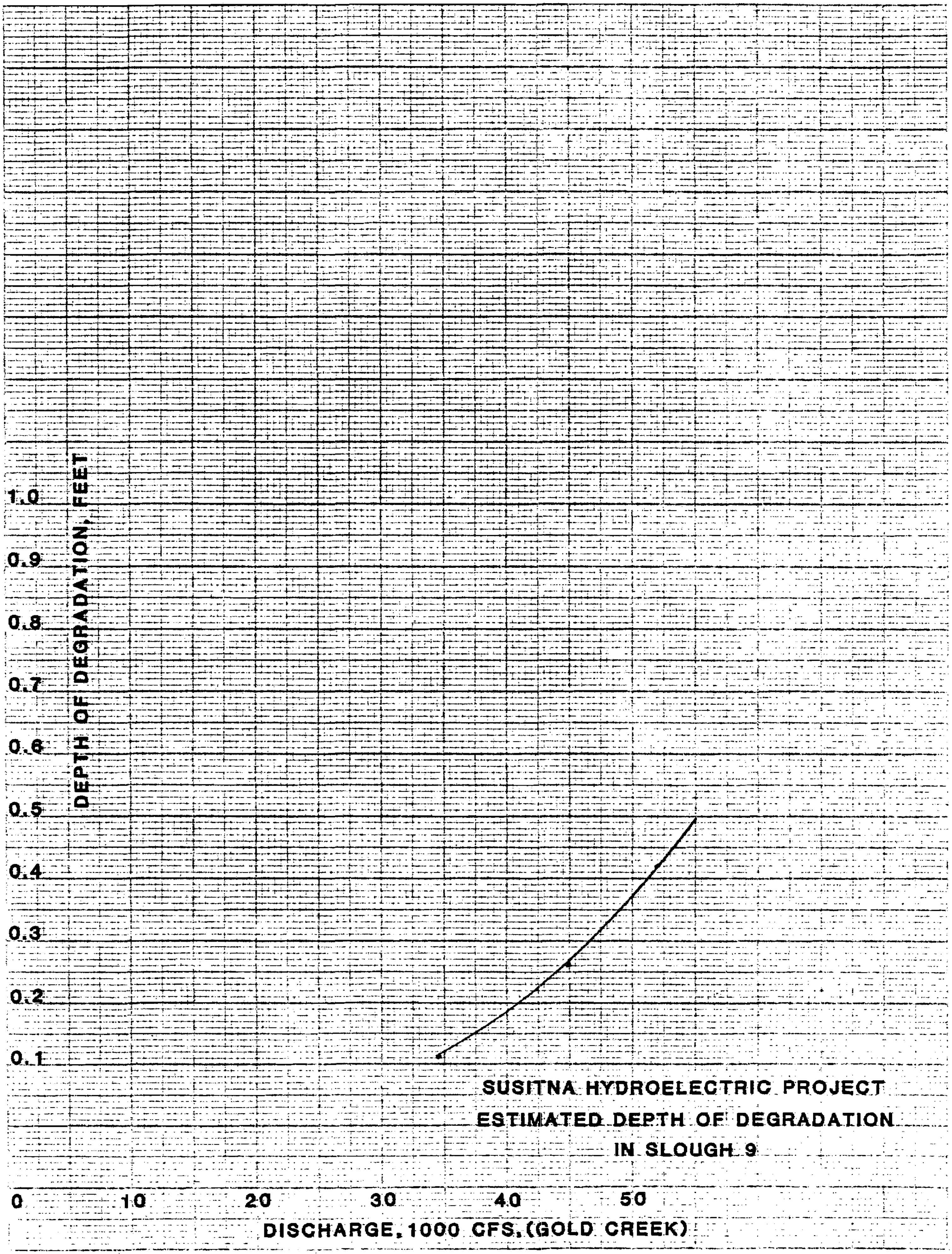
EXHIBIT 50



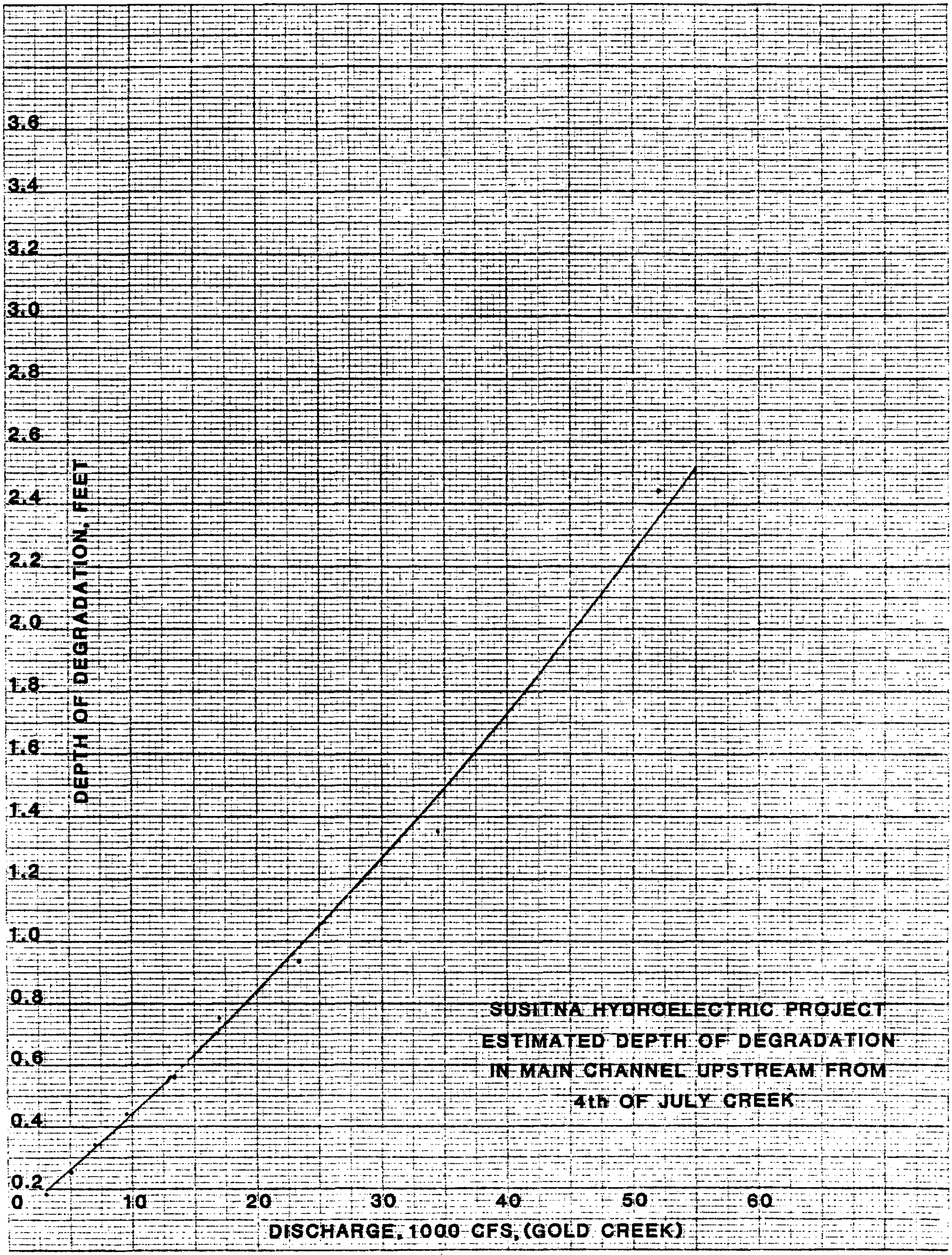
HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

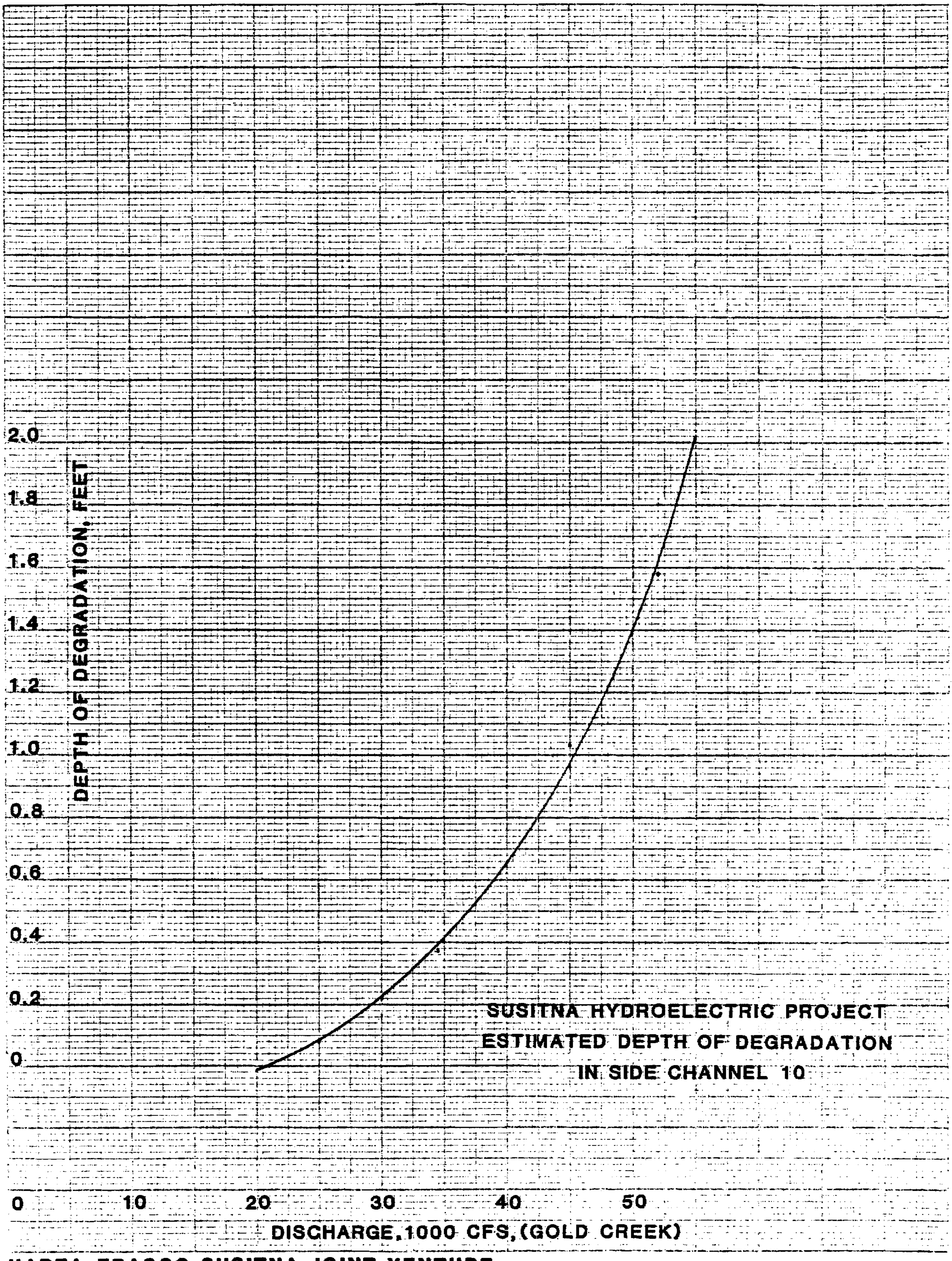


HARZA-EBASCO SUSITNA JOINT VENTURE

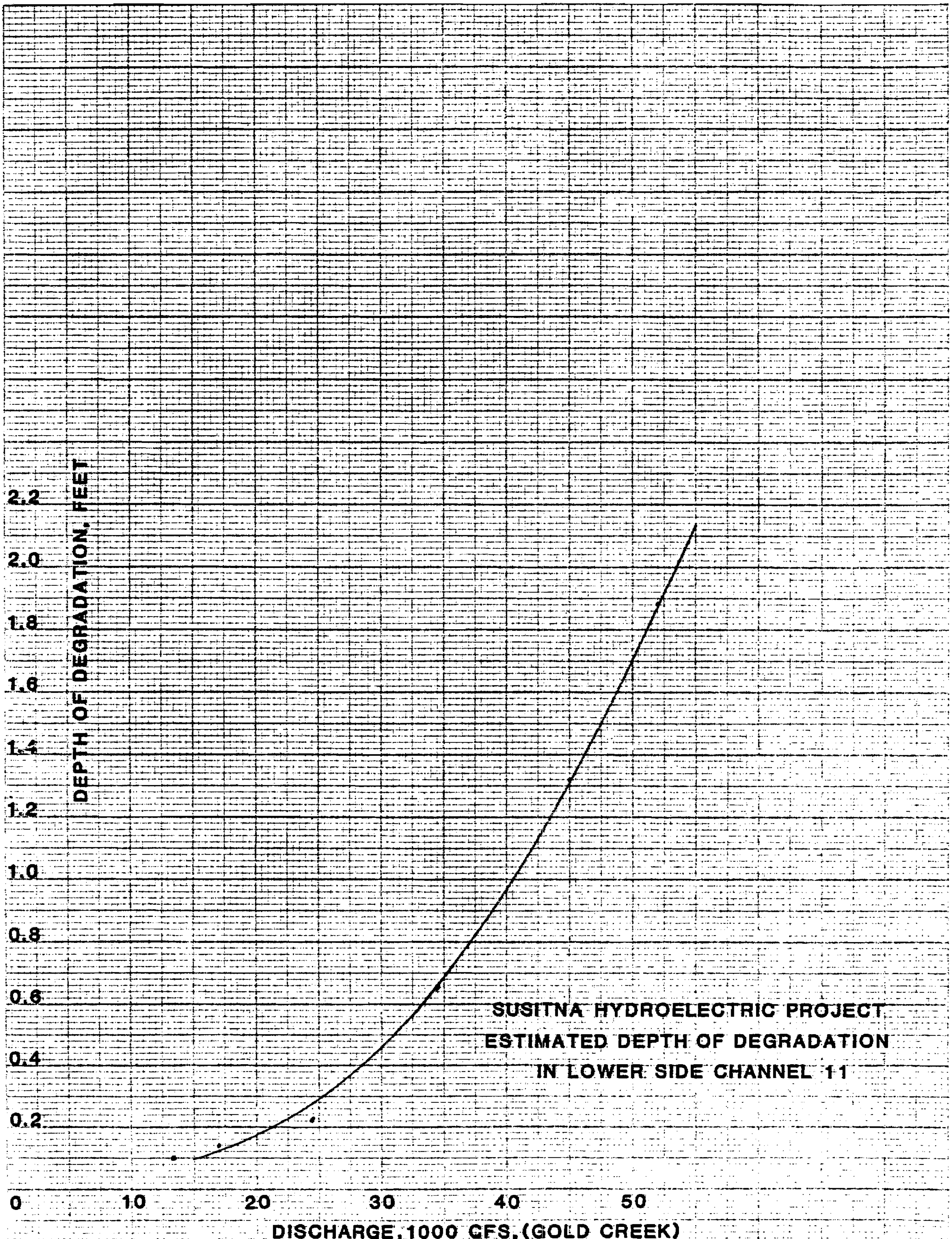


HARZA-EBASCO SUSITNA JOINT VENTURE

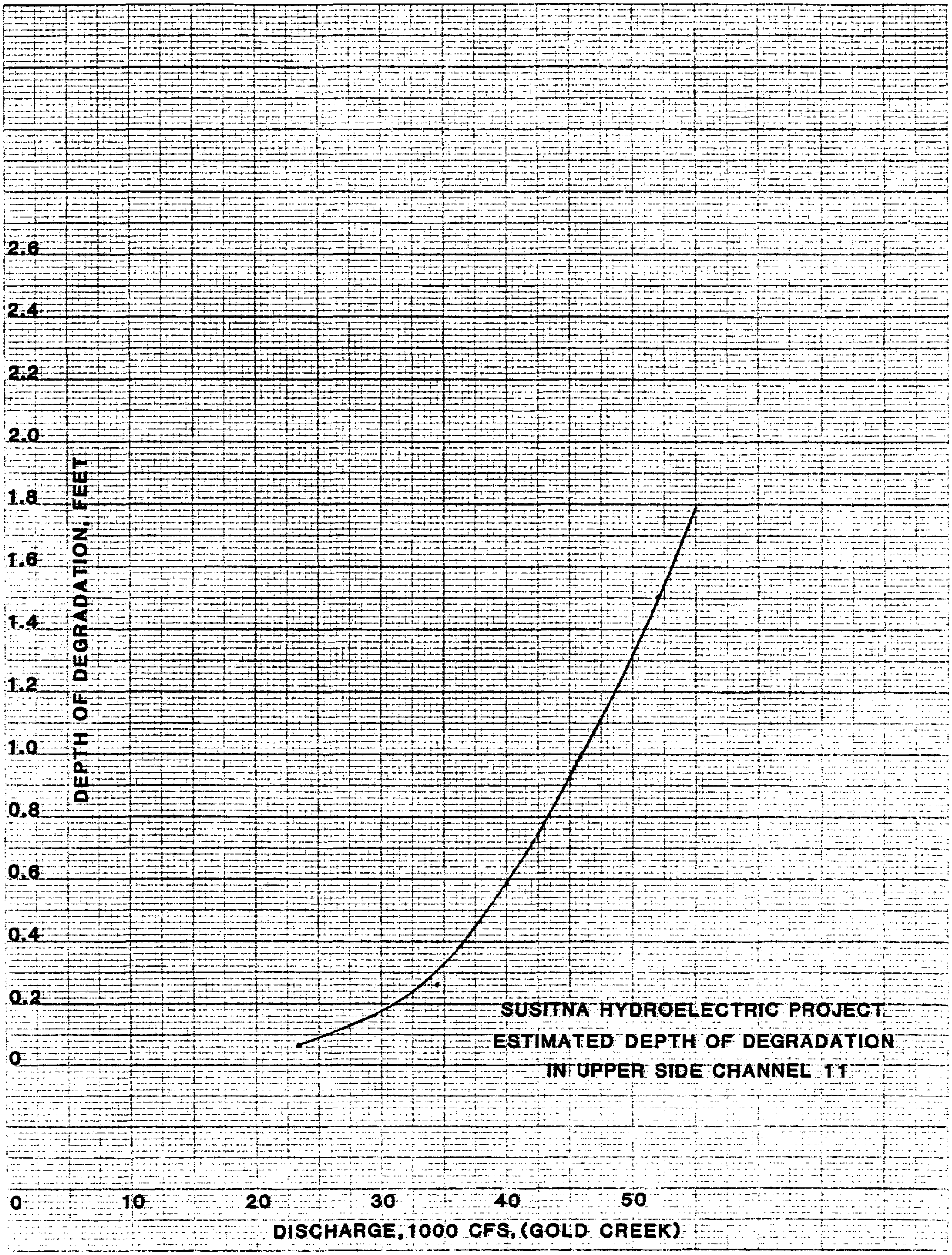
EXHIBIT 54



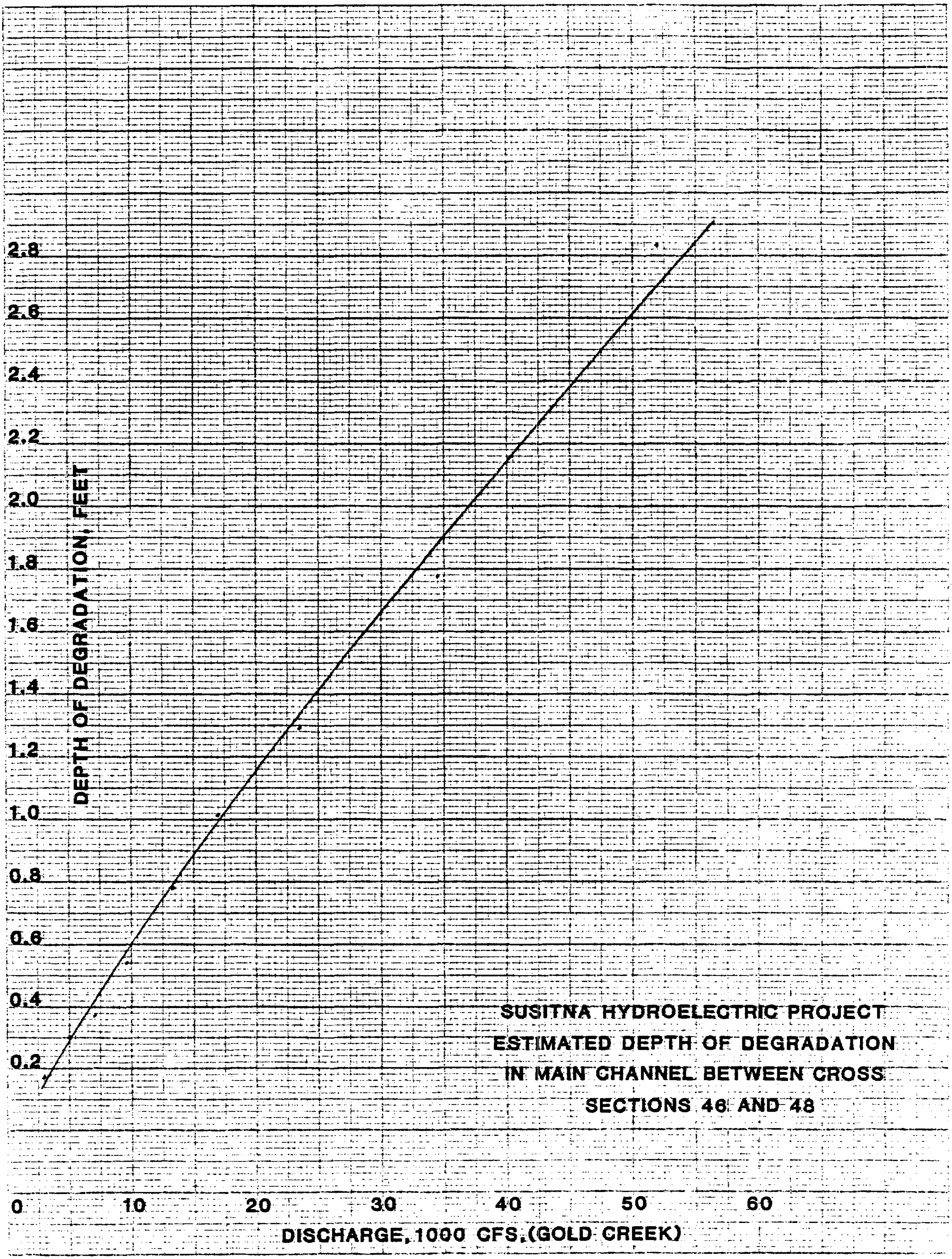
HARZA-EBASCO SUSITNA JOINT VENTURE



HARZA-EBASCO SUSITNA JOINT VENTURE

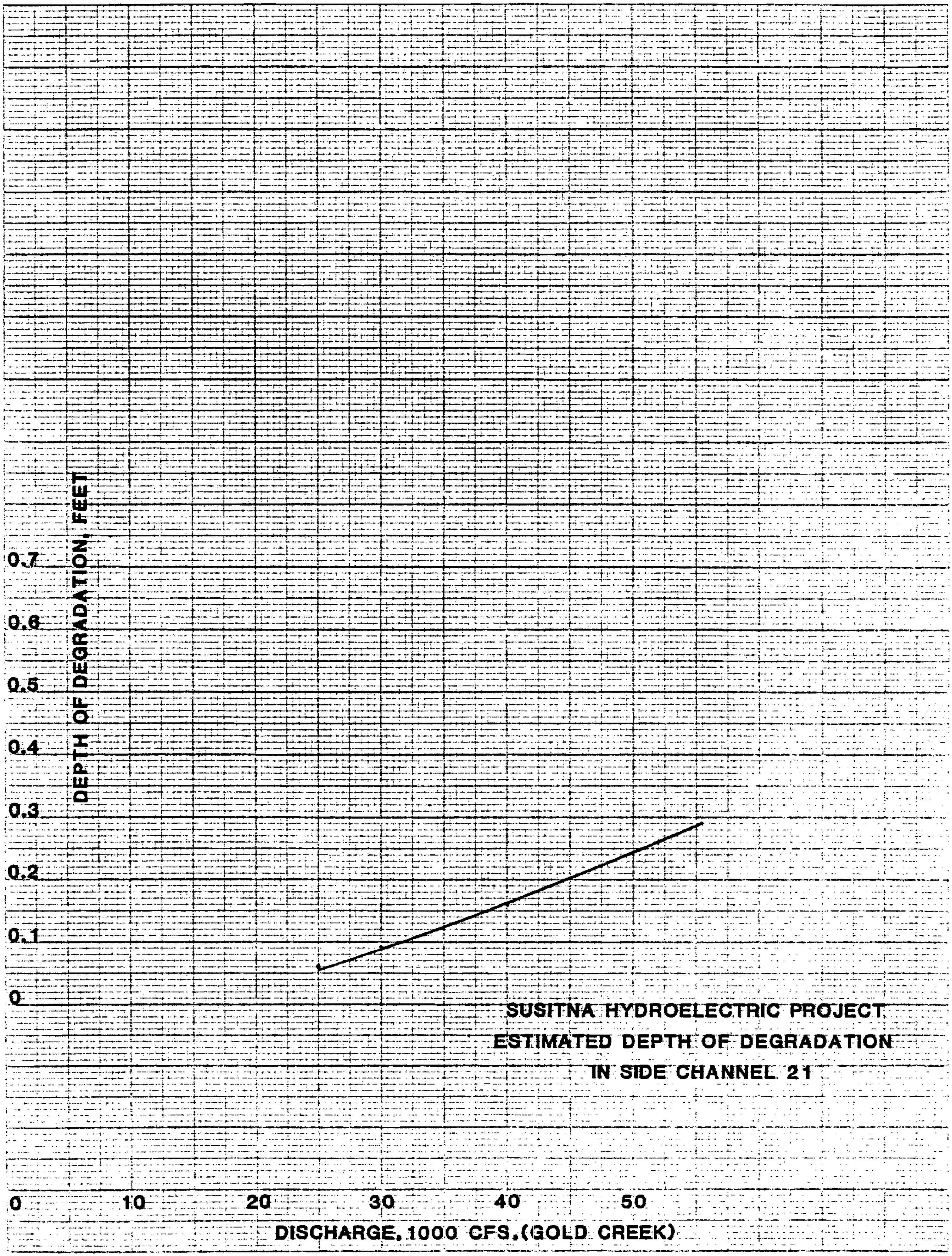


HARZA-EBASCO SUSITNA JOINT VENTURE

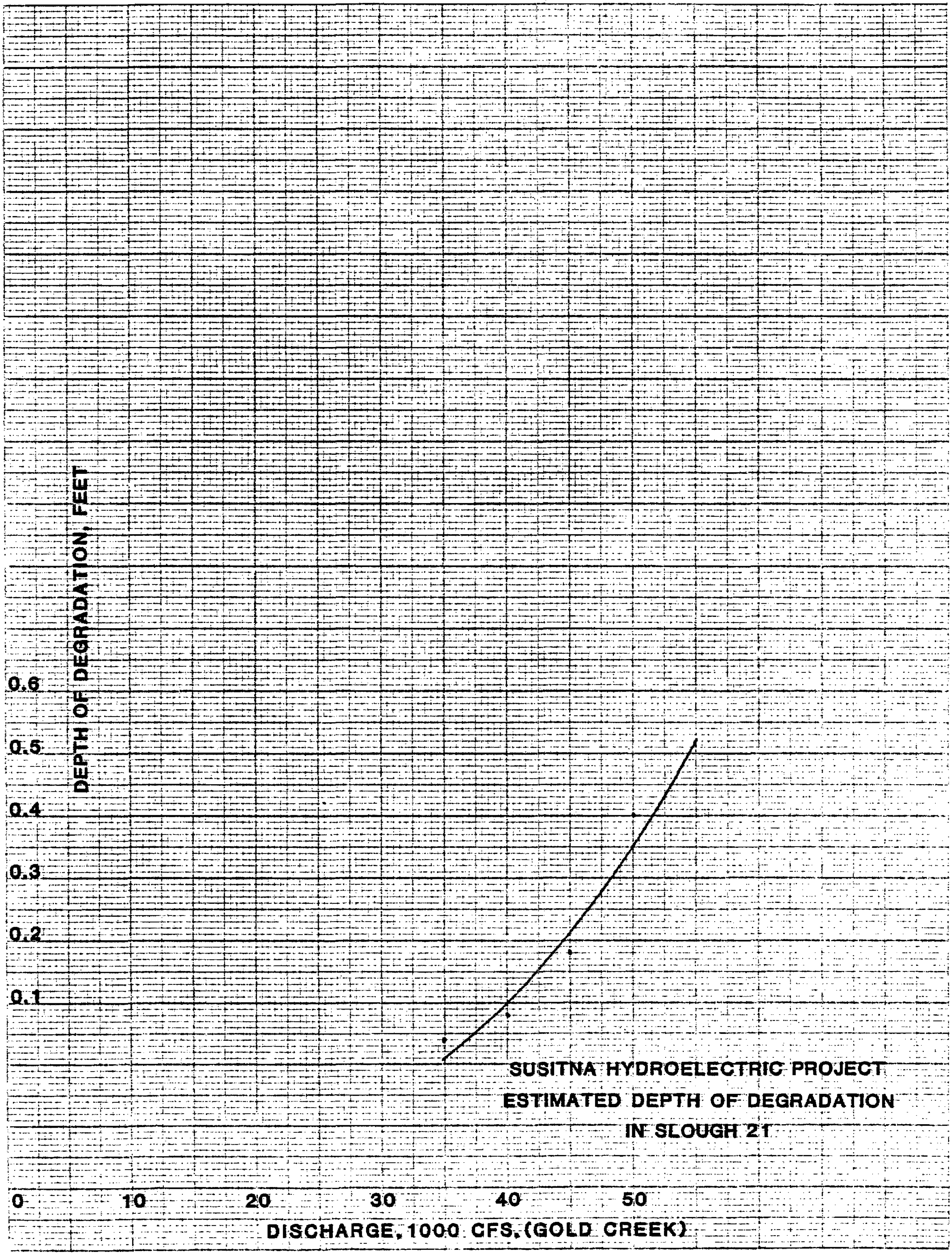


HARZA-EBASCO SUSITNA JOINT VENTURE

EXHIBIT 58



HARZA-EBASCO SUSITNA JOINT VENTURE



SUSITNA HYDROELECTRIC PROJECT
ESTIMATED DEPTH OF DEGRADATION
IN SLOUGH 21

HARZA-EBASCO SUSITNA JOINT VENTURE

APPENDIX

Appendix A
DEFINITION OF TERMS

Aggradation: The process by which stream beds, flood plains and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas.

Alluvial Deposit: Clay, silt, sand, gravel, or other sediment deposited by the action of running or receding water.

Alluvial Stream: A stream whose channel boundary is composed of appreciable quantities of sediments transported by the flow, and which generally changes its bed forms as the rate of flow changes.

Armoring: The formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion.

Bed Layer: A flow layer, several grain diameters thick (usually two grain diameters) immediately above the bed.

Bedload: Sediment that moves by saltation (jumping), rolling, or sliding in the bed layer.

Bedload discharge (or bedload): The quantity of bedload passing a cross section of a stream in a unit of time.

Bed material (or bed sediment): The sediment mixture of which the bed is composed. In alluvial streams, bed material particles are likely to be moved at any moment or during some future flow conditions.

Bed-material discharge (or bed-material load): That part of the total sediment quantity passing a cross section of a stream in a unit of time, that is composed of grain sizes found in the bed and is equal to the transport capability of the flow.

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 sediment 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 is the 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.