SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

WINTER 1983 GEOTECHNICAL EXPLORATION PROJECT

VOLUME 1

MAIN REPORT

Prepared for the

ALASKA POWER AUTHORITY

BY

HARZA-EBASCO Susitna Joint Venture

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1.0 INTRODUCTION

The work described in this report was completed by the Harza-Ebasco Susitna Joint Venture under contract to the Alaska Power Authority.

1.1 PROJECT DESCRIPTION

The Susitna Hydroelectric Project consists of the Watana and Devil Canyon developments and is located in the Upper Susitna River Basin of South-Central Alaska, approximately midway between Anchorage and Fairbanks (Figure 1-1). The Watana Damsite, which this report addresses, is the upstream development, and is located on the Susitna River at about river mile 184, between two small tributaries, Tsusena and Deadman Creeks.

The conceptual Watana project plan as depicted in the Federal Energy Regulatory Commission license application and used to guide the exploration program, consists of an 885 foot high embankment dam impounding a reservoir more than 40 miles long. The dam is roughly 4,000 feet long at the crest, narrowing to 400 feet at the river bottom (Figure 1-2). The base width of the dam exceeds 3,900 feet. Spillway and power intake structures would be located immediately upstream of the dam, with an underground powerstation located downstream of the dam in the right bank. Construction of the dam will require upstream and downstream cofferdams and the excavation of two diversion tunnels. The materials required for construction of the cofferdams and main dam will be acquired from borrow or quarry areas in proximity to the site and from required excavation to the extent possible.

1.2 SITE DESCRIPTION

The Watana Damsite is located within a V-shaped canyon incised into a broad, glaciated upland plateau. The canyon is over 900 feet deep at the damsite, and more than one mile wide at the top. The lower portions of the canyon consist of steep slopes, while the upper portions flatten becoming more gentle near the top. During the summer, the Susitna River flows are high, filling the river channel to a width of 400 feet. During the winter, the flow is reduced, and extensive gravel bars are exposed in the valley bottom. The bedrock in the area consists of Tertiary igneous rocks, chiefly diorite and andesite.

The area has undergone several geologically recent periods of glaciation with attendant erosion and deposition. The Watana relict channel area, northeast of the site, consists of one main channel and other secondary tributary channels. The channels are filled with fluvio-glacial, and related lacustrine deposits.

1.3 PREVIOUS INVESTIGATIONS

The Susitna Project Damsites (Figure 1-2) at Watana and Devil Canyon were investigated intermittently betwen 1952 and 1979 by the U. S. Bureau of Reclamation and the U. S. Army Corps of Engineers. At the Watana site, these investigations consisted of geologic mapping, seismic refraction surveys, and several boreholes within the river channel, abutments, and the surrounding area. A total of six potential borrow and quarry sites were identified. Four of the borrow sites were explored with test pits and auger borings. The Corps of Engineers also installed ten stand-pipe piezometers and thirteen thermal probe stand-pipes in boreholes.

From 1980 to 1982, the Alaska Power Authority commissioned Acres American, Inc. to conduct more extensive studies at both sites. These studies at the Watana site, aimed at developing the feasibility of the hydroelectric project, further identified and characterized the geologic conditions of the dam abutments, the potential borrow and quarry areas, and the relict channels. The results of these studies, presented in the 1980-81 Geotechnical Report and the 1982 Supplement, concluded that there was nothing to impair the technical feasibility of the Watana Project.

2.0 PURPOSE AND SCOPE

The purpose of this report is to present the results obtained during the Winter 1983 Explorations Program which will be used for the geotechnical design of the Watana Dam Project. The report is comprised of two volumes. Volume 1, Main Report, summarizes the results of the exploration program. Volume 2, Appendices, contains details of the geophysical exploration methods, drilling and sampling methods, borehole logs and laboratory test results.

Discussed herein are geological conditions in the main river valley at the damsite, cofferdams and in the adjacent relict channel. Emphasis is given to geophysical exploration, drilling and sampling, field permeability testing in overburden and pressure testing in bedrock, laboratory testing and instrumentation.

The exploration program was executed during January-April, 1983. The Harza-Ebasco Susitna Joint Venture, carried out this program under interim contracts with the Alaska Power Authority, and the participation by Acres American during a transition period which ended in mid-February. Subcontracted technical and logistical support was provided by Denali Drilling, Inc., Harding-Lawson Associates, R&M Consultants, Air Logistics, Inc., Alyeska Air Service, and Cook Inlet Region, Incorporated.

2.1 RIVER CHANNEL

In general the exploration program in the river channel was designed to delineate subsurface conditions at selected project features including the upstream and downstream cofferdams, the dam axis, and the diversion tunnel portals. The exploration program was designed to:

- o determine the distribution and physical properties of the channel deposits.

- o to assess the suitability of the channel deposits as a foundation for the main dam.

- o to provide data for cofferdam design.

- o to estimate the potential quantities of material to be excavated in the dam foundation

- o to determine the characteristics of the underlying bedrock for assessing dam foundation suitability and treatment.

The program was implemented by reviewing previous work, performing further geophysical surveys and by drilling boreholes using both hammer and rotary equipment. Geophysical surveys, using ground penetrating radar, seismic refraction, and downhole gamma logging, were designed to locate the top of the alluvium and bedrock, to identify bedrock surface anomalies, and to aid in stratigraphic correlations.

2.2 RELICT CHANNEL

The relict channel exploration program was designed to supplement previous work by further characterizing the lithology and stratigraphy of the Watana relict channels. The overall purpose of the investigation was to provide further assessment of the geohydrologic properties of the Watana relict channel area and to supplement preliminary data on liquefaction potential of the glacial and fluvial deposits. Assessment of the channel deposits was made by boreholes, geophysical monitoring and installation of piezometers.

3.0 SUMMARY AND CONCLUSIONS

3.1 RIVER CHANNEL

The river channel exploration program provided new information regarding the channel deposits and bedrock relative to the dam foundation. The following conclusions and observations have been drawn from the exploration data:

* The bedrock channel is generally symmetrical in cross-section about the river centerline. The channel bottom is nearly flat with the exception of two pronounced depressions in the area between the dam axis and upstream toe.

* The bedrock underlying the river channel alluvium ranges from altered to fresh, hard, diorite. Areas of moderately to closely fractured rock were found as were a few shear zones containing fine-grained gouge material. Water takės from pressure testing within these zones were low.

* Although sections of closely spaced fractures were found within the bedrock, pressure testing indicated low water losses.

* Alluvial deposits overlying the bedrock channel are typically less than 80 feet thick, although two bedrock depressions upstream of center line contain deposits over 140 feet thick.

* The deposits within the river channel are comprised primarily of coarse-grained gravels, sandy gravels, and gravelly sands. These materials are generally well-graded.

* The distribution of the overburden materials within the river channel is related to the geometry and characteristics of the river flow, with the locations of identifiable buried gravel bars and boulder and cobble concentrations related to flow energy gradients.

* Permeability of the river deposits is variable. Evaluations of grain size and drilling operations indicate the majority of the materials are very pervious.

* Downhole gamma logs of the river boreholes, in general, reflect the lack of continuous clay layers in the river alluvium. Further, local high gamma counts in the channel deposits appear to coincide with accumulations of boulders which yield gamma signatures similar to fresh unweathered diorite.

3.2 RELICT CHANNEL

The results of the winter exploration program of the relict channel generally support and correlate with previous results and interpretations of geologic conditions in the relict channel area. No major variances in subsurface conditions from those previous exploration results were obtained in these relict channel explorations. The following conclusions are made relative to subsurface conditions explored.

* The borings along seismic Survey Line SW-3 confirm the existence of the two bedrock channel thalwegs delineated from refraction survey interpretation. The borings partially define the cross-section of the channels and provide new data on the stratigraphy and material properties of deep outwash and alluvium deposits.

* The borings along seismic Survey Line DM-A define the surface of the compact, Unit G/G' till and lacustrine deposits.

* The density of Unit E/F outwash deposits and overlying units varies from medium dense to very dense beneath the active or seasonal frost zone, which is of about 15 feet below the ground surface. Unit G/G' lacustrine and till deposits and all underlying units are generally dense to very dense.

* Portions of the permeable outwash and alluvium deposits are not saturated. Groundwater is present in local areas of outwash and alluvium deposits, generally above till and lacustrine aquicludes and possibly where horizontal groundwater movement is retarded by the presence of permafrost or the surface of the underlying aquiclude. Surface infiltration into glacial deposits below Unit G/G' is retarded over much of the area by the lower permeability of Unit G/G'.

* The entrance and exit conditions for potential seepage flow through outwash and alluvium Units H, I and K are poorly defined. Future shallow explorations by seismic refraction, trenching, test pitting, augering, and possibly by aditing should be conducted at these areas. In addition, the planned deep pumping tests in Unit K material, at and near the "bottleneck" in the deep channel in the center of the relict channel area, should be carried forward if any uncertainty about the through-going nature of Unit K remains after near--surface investigations are completed.

4.0 EXPLORATION METHODS

4.1 GEOPHYSICAL EXPLORATION

The winter exploration program utilized three geophysical investigation methods, the details of which are described below.

Ground Penetrating Radar

The ground penetrating radar was used as a rapid reconnaisance tool to locate areas of shallow bedrock, to determine the thickness of river ice, and to locate the top of river alluvium. The system produced a continuous profile of near surface materials. Fourteen radar profiles were run for a total coverage of 8,490 lineal feet as shown on Table 4-1.

Seismic Refraction

The results of seismic refraction surveys were incorporated into the bedrock drilling program by providing indications on the depth to bedrock throughout the river channel. Since the higher velocity ice layer masked the underlying lower velocity alluvium, the offset between the shot and geophone spread had to be long enough to detect the first arrival signals from the bedrock. Consequently, refraction profiles were run parallel or oblique to the river channel to take advantage of the long offset. Ten reversed refraction lines were run; totaling 8,785 lineal feet of geophone coverage as shown in Table 4-1.

Borehole Gamma Logs

The borehole gamma logs assisted in stratigraphic correlation of the river channel deposits and the glacial/fluvial deposits in the relict channels. Natural gamma logs were run in 22 river channel boreholes as shown in Table 4-2 and in 8 relict channel holes as shown in Table 4-3.

Details of the geophysical exploration program, tables, figures, and gamma logs are presented in Volume 2, Appendix A.

4.2 DRILLING AND SAMPLING

The damsite exploration drilling program, performed along and adjacent to the river channel is shown on Figure 5-1; exploration in the relict channel area is shown on Figure 6-1.

A hammer drill rig, Becker Model AP-1000, using a percussive hammer, drilled most of the boreholes, switching to a rotary attachment with roller cone drill bits when drilling conditions became difficult at depth. The percussive hammer system used a diesel pile hammer to drive a 5-1/2-inch or 9-inch O.D. double-wall pipe while a reverse air circulation system removed the cuttings as the pipe advanced. The sample cuttings were recovered from an energy dissipating cyclone. Specially designed tooth bits were used to penetrate the soil formations and to direct the soil into the inner pipe. A diamond drill rotary head was used with an NX-size core barrel to core inside the drive pipe whenever bedrock or refusal was encountered.

A geologist or geotechnical engineer continuously monitored the drilling operations. Usually at five foot intervals, a composite sample was collected, logged, and placed in a canvas bag for transportation to the field laboratory. Samples for moisture determination were sealed in plastic bags. A split-spoon drive sampler was passed inside the drive pipe as necessary to recover intermittent samples. Blow counts for driving the split spoon sampler were taken for estimating relative densities.

Blow counts recorded during driving of the double-wall drive pipe were used only as a relative indication of density. The energy delivered by the diesel hammer was not always constant because the driller adjusted the fuel injection to control pipe penetration rate. Also, the resistance to penetration, due to pipe wall skin friction, increased with depth thereby absorbing an increasing amount of the hammer's energy.

Fourteen boreholes were drilled in the relict channel area for a total of 1,927 lineal feet plus a boring for a potential water well boring WW-3 as shown in Table 4-4. A total of 43 borings were drilled in the river channel for a total of 3710 lineal feet including five 45-degree angle holes as shown in Table 4-5. A lightweight rotary core drill rig with an NX-size core barrel was mobilized late in the program for the river areas where ice conditions prohibited the use of the heavier hammer drill rig.

A detailed discussion of the drilling and sampling methods can be found in Volume 2, Appendix B.

4.3 IN SITU PERMEABILITY AND PRESSURE TESTING

Constant head tests and hydraulic pressure tests (using a mechanical packer) were conducted in the river channel boreholes to determine information in regard to the overburden permeability and potential for water loss in the bedrock.

During the performance of constant head tests in the river overburden, water was added to the open drive pipe at a rate sufficient to maintain a constant water level at or near the top of the pipe for a period of not less than 10 minutes. The positive displacement piston beam pump on the drill rig had a capacity limited to 18 gpm. Therefore, only sections of alluvium anticipated to have the lowest permeability were tested. Ten constant head tests were conducted in six boreholes.

For the performance of hydraulic pressure tests in the bedrock, 19-foot intervals of the borehole were isolated using mechanical packers. For each test interval, water was injected in steps by increasing and decreasing pressures, and flow rates were measured at each pressure increment. Nine hydraulic pressure tests were conducted in four boreholes.

The formulas used to compute the approximate coefficient of permeability for both the constant head tests and hydraulic pressure tests are from The Earth Manual, U. S. Bureau of Reclamation (1974).

4.4 LABORATORY TESTING

As part of the Winter 1983 Field Drilling Program a field soils laboratory was established and operated at the Watana site The various types of soil encountered in the river and relict channels were classified in accordance with the Unified Soil Classification System and tested in accordance with the following ASTM Procedures:

a)	Particle Size Analysis	ASTM D 422-62 (modified)
b)	Atterberg Limits	ASTM D 423-66, ASTM D 424-59
c)	Moisture Content	ASTM D 7126-71
d)	Organic Content	Standard Method
e)	Specific Gravity	ASTM D 854-58

f) Compaction ASTM D 698, ASTM D 1557-78

g) Visual Classification ASTM D 2488-69

During the winter program, a total of 1,421 index property tests were performed on 838 samples. The types and quantities of tests performed during the winter program are tabulated in Tables 4-6 through 4-8, inclusive. The results of these tests are summarized on the test summary forms presented in Volume 2, Appendix D

4.5 RELICT CHANNEL INSTRUMENTATION

Piezometers and thermal probes were installed in selected boreholes to monitor the groundwater and thermal regimes in the overburden deposits in the relict channel areas as indicated in Table 4-9. Pneumatic piezometers were chosen for installation to allow groundwater monitoring during freezing conditions which exist at the site area during much of the year. To facilitate monitoring the thermal regime of the materials, 1 or 2-inch I.D. capped PVC pipes filled with ethylene glycol were installed. Readings are taken at five foot intervals using a portable thermistor cable, lowered into the PVC pipe. Both the piezometers and thermal probes are scheduled to be read bi-monthly.

4.6 PERMITS AND ENVIRONMENTAL PROTECTION

The winter geotechnical program was conducted with land use authorizations and permits obtained before and during the program. Permit stipulations and control of exploration activities resulted in the program being executed with minimal damage to the environment.

U. S. Bureau of Land Management (BLM) temporary use permit number AA44409 and Alaska Department of Natural Resources (ADNR) land use permit number LVP SCM 82-036 were obtained to mobilize and demobilize drilling and support equipment to and from the Watana site over a winter access trail across federal and state lands. This was the same trail used by the Corps of Engineers in 1978, and by the Alaska Power Authority in 1980. Permit stipulations were complied with during the mobilization in January, and the demobilization in April. BLM representatives observed a portion of the mobilization, provided authorization to use the trail for demobilization, and observed the demobilization.

Other land use permits and authorizations consisted of BLM permit number AK0170096 for conducting field explorations on federal lands; an agreement between the APA, Cook Inlet Village Corporations and CIRI for activities on lands conveyed and managed by these native organizations; and letter of non-objection from CIRI, Knikatna, Inc., Tyonek Native Corporation, Inc., and the State of Alaska for land access and exploration activities on lands selected by these agencies but managed by BLM. A letter of non-objection for construction and use of an access trail from Watana Field Camp to the Susitna River channel was obtained from Knikatna, Inc.

Other types of permits obtained were a temporary water use permit from the ADNR for pumping water from test wells or surface waters. Archaeological clearances of borehole locations were obtained from a University of Alaska archaeologist acting for the ADNR. Authorizations were obtained from the ADNR and BLM for use of Miller Lake as a temporary ice airstrip.

Restoration work was intiated at the access trail from Watana Field Camp to the Susitna River channel. Terracing and grading of the trail was performed at several locations to assure that erosion of the tundra did not occur during spring break-up and carry sediment into the river.

5.0 RIVER CHANNEL INVESTIGATIONS

Discussion of the findings and results of the river channel exploration program are presented below. The work area extends from the upstream diversion tunnel portals to the downstream outlets, a distance of approximately 6,000 feet as shown in Figure 5-1. Within this area, geophysical and drilling explorations were conducted to develop topographic information, characterize overburden depths and physical characteristics, and establish the depth to bedrock and the bedrock properties. Also determined were permeability and pressure test information in overburden and bedrock respectively. The discussion below is divided into the following sections: overburden and bedrock subsurface conditions at the cofferdams, main dam, and diversion tunnel portal areas.

5.1 OVERBURDEN (ALLUVIUM)

5.1.1 Surface Morphology and Thickness

The distribution of gravel bars along the edge of the Susitna River was mapped prior to the winter exploration program. This data was combined with ground penetrating radar profiles and borehole results to develop a topographic map of the surface of the river bottom presented as Figure 5-2. Topographic relief is nominally 10 feet, but locally exceeds 20 feet in the area of the upstream cofferdam. Over most of this stretch of river, the stream bed gradient is relatively flat.

The thickness of the overburden deposits within the river channel ranges to over 140 feet as shown on Figure 5-2. Along the centerlines of the main dam and cofferdams, the overburden reaches a average thickness of 80 feet. The alluvial deposits are thickest within the two bedrock depressions located approximately 900 and 1,900 feet upstream of the main dam centerline.

5.1.2 Classification and Distribution

A wide range of soil types and mixtures exist in the river channel. The results of the drilling and sampling program indicate that the river alluvium is mostly sandy gravels, with materials ranging from cobbles and boulders to small amounts of sand. The finer-grained materials were found to be a part of the matrix of the coarser materials rather than being a distinct layer or lense.

The coarseness of the river channel materials was evidenced on several occasions by deflection of the drive pipe. Coring beneath the refusal point of the drive pipe frequently revealed the presence of boulders which were estimated to range in diameter from less than 1 foot to over 5 feet. An isolated pocket of clay-rich peat was found in one angle-hole (HD83-46) drilled into the left bank, main dam centerline.

The lithology of the gravels sampled in the river channel include diorite, andesite, gneiss, granodiorite, argillite, and minor amounts of granite. Cobbles, gravel, and sand particles are generally sub-round to round, with the larger particles having smooth, unweathered surfaces.

Laboratory analyses of the hammer drill samples indicate that there are generally four types of material in the river channel. Table 5-1 summarizes the percentage distribution and gradation of each of the four major types. Almost 67% of the materials sampled in the river channel are classified as well-graded sandy gravel, with about 21% classified as poorly-graded gravelly sand. About 10% of the materials are classified as well-graded gravel, and less than 2% are poorly-graded sands.

Figure 5-3 presents a summary of the grain size distributions for the four primary materials. Note that the apparent convergence of the gravel, sandy gravel, and gravelly sand curves near the 3-inch size range reflects the size limitation of the drilling and sampling equipment, and does not represent the coarsest fraction of the in-situ materials. Further the coarser fractions of the gradations are subject to additional intrepretation as the hammering action of the drill bit fractured a certain amount of the coarse gravel, cobbles, and boulders. The percentage of the total sample represented by broken fragments retained on the 3/4-inch sieve was recorded as part of the classification as noted on the table. Fine fraction material occurs in samples of all four primary materials, but rarely exceeds 10% of the total sample. Details of the distribution and characteristics of each of these primary material types is presented below.

5.1.2.1 Gravel (GW)

The gravel deposits show a remarkable similarity throughout the dam foundation area. Figure 5-4 presents the weighted average and upper and lower limits of the gradation based on 21 samples representing 76 feet of sampled interval. An average of 37% of the sampled materials on the 3/4 sieve are broken fragments, indicating that the in-situ material contains an abundance of coarser material not properly reflected in the sample.

As expected, the gravel materials encountered are located on or near the large gravel bars. These bars are on the inside part of curves in the river channel, and represent deposition on the low-velocity side of the channel during periods of high flow. The gravel layers occur primarily in the top 30 to 40 feet.

Downhole gamma logging of borings were completed for most of the river channel holes. Gamma logging of the bedrock portions of the borings indicate that fresh, unaltered diorite yields the highest of the primary recorded gamma counts. Within the river channel fill materials, the exposed and buried gravel bars and the deposits mantling the channel bottom also yield similarly high gamma counts, perhaps reflecting the abundance of fresh diorite cobbles and boulders.

5.1.2.2 Sandy Gravel (GW-GM)

Figure 5-5 presents the high and low range, and average gradation curves for this material, based on 150 samples covering 524 feet of sampled interval. The materials are generally well-graded, although some of the medium sand fraction is missing . The mean grain size of these materials is fine to coarse gravel. The upper limit of particle size, shown as roughly 3 inches, represents limitations of the drilling and sampling techniques. On the average, 20% of the material retained on the 3/4" sieve sampled consisted of broken fragments of larger particles, indicating that the in-situ materials are somewhat coarser than the laboratory data indicate.

The sandy gravel materials represent typical lenticular river channel sediment deposits. Variations in grain size and gradation are noted, with concentrations of large cobbles distributed as pockets and limited strata.

The downhole gamma logs of these materials are characterized by variations in emission levels over vertical distances ranging from several inches to over one foot. Although these variations may reflect stratification or bedding of the deposits, it is also possible that the gamma peaks in part reflect distribution of fresh diorite cobbles and boulders.

5.1.2.3 Gravelly Sand (SP-SW)

Figure 5-6 presents the high and low ranges, and average gradation curves based on 50 samples representing 166 feet of sampled interval. The median grain size of the sampled materials is a medium to coarse sand, and the material is poorly-graded. Some of the samples are skip-graded, with much of the medium sand-sized fraction missing. An average of 11.5% of the material retained on the 3/4" sieve consisted of broken fragments.

The gravelly sand materials seem to occur primarily within the central part of the channel, or along the outside section of the major curves in the river. This distribution is consistent with the observed course of the river during low-flow periods. Since these materials represent deposition during low-flow periods, they "meander" within the coarser river channel deposits. The meandering pattern results in extensive inter-fingering with the coarser deposits formed during the periods of high flow.

The downhole gamma signature of the gravelly sands is in general less intense than those of the gravels or sandy gravels.

5.1.2.4 Sand (SP-SM)

The sand materials comprise less than 2% of the total material sampled. Figure 5-7 presents the high and low range, and average gradation curves for the material, based on 6 samples representing 10 feet of sampled interval. Most of the samples are classified as fine sands, and are poorly graded. Less than 4% of the material sampled contains broken fragments, indicating that the laboratory results are comparable to the gradation of the in-situ materials.

The sands occur within all of the coarser units, and probably represent deposition in very local, quiet water conditions, such as eddies and overbank ponds. Their minor quantity, thickness, and random distribution within the river channel precludes their consideration as an important part of the river channel stratigraphy.

The downhole gamma logs of these sand units is typified by very low counts.

5.1.3 Permeability

Constant head permeability tests were completed within the finer grained, less permeable units in the river channel. Testing of the more pervious gravels and sandy gravels was not possible due to limitations of the equipment. The results of the tests are presented on Table 5-2. The range of permeability values obtained (1.2×10^{-1} to

$1.5x10^{-3}$ cm/sec) are considered to be in the low range even for the finer materials tested.

In addition to the constant head tests, field observations during the drilling operation provided additional insight as to relative permeabilities. During the progress of the hammer drilling, it was evident that some intervals were much more permeable than others. While all the river channel deposits were saturated, penetration of some sands and gravels was accompanied by noticeably greater quantities of return water from the reverse air circulation system. For example, in borehole HD83-12 at the main dam centerline, large quantities of water were reported for virtually the entire 70 feet of alluvium. Borehole HD83-10, also along the main dam centerline, reported high water returns coincident with a gravel layer, then reduced water return after passing through the gravel. At borehole HD83-37, about 800 feet upstream of the main dam centerline, several discrete, 1 to 5-foot intervals of high permeability material were reported in the top 100 feet of the boring based upon water returns.

These observations coupled with the test data indicate that the alluvium in the river channel is generally very pervious. Permeability will vary greatly over short lateral and vertical distances due to the lenticularity of the alluvium.

5.2 BEDROCK

5.2.1 Channel Configuration

The configuration of the bedrock channel was investigated using a combination of seismic refraction surveys and borehole data. A topographic map of the top of the bedrock surface is shown on Figure 5-8. Bedrock elevations beneath the river bed range from 1,450 to 1,310 feet. The sidewall slopes of the buried bedrock channel are similar to those of the exposed canyon walls in most areas.

The base of the bedrock channel ranges in width from about 100 to over 300 feet. With the exception of two isolated bedrock depressions, the bedrock surface along the axis of the river is near level, with a drop of less than 20 feet over the 6,000 feet of river run between the upstream and downstream portal locations.

Two apparently isolated bedrock depressions occur about 900 and 1,900 feet upstream of the main dam centerline as seen in Figure 5-8. These low areas were first indicated by the seismic refraction work and were later verified by drilling. Overburden depths in these two depressions are 50 to 70 feet greater than the average channel bottom. Although their origin is unknown, it is likely the depressions result either from erosion during very high flows of the river or differential erosion of a shear or fracture zone which crosses the river.

5.2.2 Lithology

Bedrock encountered beneath the channel overburden is predominantly fine to medium-grained diorite, with some monzonite and granodiorite. One borehole, (HD83-27), near the downstream cofferdam encountered an 11-foot section of fine-grained andesite. Core recovery within the bedrock generally ranged from 90 to 100%, with RQD values typically above 50%. With the exception of local shear zones and altered rock all of the cored bedrock is fresh, and hard.

5.2.3 Structure

Structures revealed during the drilling program were primarily joints and shear zones. Joints are generally vertical, and joint spacing varies from less than an inch to several feet. Most joint surfaces are fresh or slightly weathered, and generally rough. Calcite deposits are found as joint fillings or as light coatings on joint surfaces. The quantity of drilling water lost through joints varies from 0 to 100%.

A few of the boreholes encountered zones of moderately to severely fractured and jointed rock, for example Borings HD83-10, 43 and 44. Core recovery in the fractured areas is usually high, although RQD values are low. Some areas are associated with loss of drilling water, although many are not. In general, the closely fractured sections of the borings appear to be localized and represent a small portion of the recovered cores.

Evidence of local shear zones and gouge was encountered near the Fingerbuster shear zone near the downstream cofferdam (Hole HD83-27). A possible shear zone was encountered in Boring DH83-4 on the right abutment,near the main dam centerline. This zone may be correlated with GF-5 as defined in the 1982 supplement (Figure 5.2). The orientation and extent of the zone is unknown. Coring within the shear zones is usually characterized by both poor core recovery and low RQD values. No significant drilling water loss was associated with these zones.

5.2.4 Weathering and Alteration Zones

Typical surface weathering of diorite produces a rust-brown, iron oxide staining. Weathering is usually developed to a slight or moderate degree in the bedrock cores. However, such weathering is usually surficial, and restricted to the top of rock surfaces or along some joint faces. Penetrative weathering occurs in zones, a foot or more thick, indicated by decomposed feldspars and oxidized iron-magnesium minerals. Such penetrative weathering was encountered near the right abutment of the main dam in hole DH83-4.

Evidence of hydrothermal alteration of the diorite was more common than typical surface weathering. The alteration involves a hydrothermal chemical process which accelerates the decomposition of the rock as the feldspar minerals are altered to clay minerals. Such processes result in a bleached rock of variable strength dependent on the degree of alteration. Most of the altered diorite sampled appears to be only mildly altered. More extensive alteration appears to be associated with shear zones and zones of extensive fracturing. As discussed above, such zones form a minor percentage of the bedrock sampled.

5.2.5 Pressure Testing

Hydraulic pressure testing in the bedrock was accomplished using mechanical packers. A total of nine tests were run, and yielded Lugeon values ranging between zero and 1×10^{-3} cm/sec. Table 5-3 summarizes the pressure test results. There is no apparent correlation between the observed severity of fracturing and the measured water loss. Although loss of return water was reported in over half of the borings, none of the measured Lugeon values are sufficiently high to have caused complete water loss.

5.3 FOUNDATION CONDITIONS

The following sections describe the specific foundation condition of bedrock and alluvium encountered at the proposed locations of the major project features, including the main dam, upstream and downstream cofferdams, and at the diversion tunnel portals.

5.3.1 Main Dam

The evaluation of the main dam subsurface conditions has been divided into three study areas covering the main dam centerline, the areas between the upstream toe, and between the downstream toe and the dam centerline.

5.3.1.1 Main Dam Centerline. Ten boreholes were drilled along the proposed centerline of the main dam. Seven of the boreholes were drilled vertically, while three, near the channel sidewalls, were drilled at a 45 degree angle. The location of these boreholes is presented in Figure 5-1. Downhole gamma surveys were completed in six of the boreholes. Hydraulic pressure tests were run in 3 of the borings and laboratory testing was performed on selected overburden samples from each hole. Figure 5-9 presents the geologic profile of the river channel at the main dam centerline along with borehole logs, gamma logs and pressure test results.

The bedrock channel is generally symmetrical in cross-section, with sidewall slopes of approximately 40 to 50 degrees. The base of the bedrock channel is about 300 feet wide and ranges in elevation from about 1370 feet to about 1400 feet. The channel is deepest along the north side.

The bedrock core from boreholes along the centerline consist primarily of fresh and altered diorite. The rock varies from moderately to closely fractured. Local zones of deeply weathered or altered diorite were encountered, primarily in the boreholes on the north side of the channel. Core recovery averages 90%, although recovery in the weathered or altered material ranged as low as 25%. In areas of good core recovery, RQD values average 80% on the south side of the channel, dropping to about 50% on the north side in the vicinity of the bedrock depression. Only one zone of low RQD was encountered, located near the middle of the channel. The distribution of RQD and core recovery values suggest that the rock materials on the north side of the channel are, in general, more fractured or altered than those on the south side. The more extensive erosion evidenced by the deeper bedrock in this area may reflect differences in rock strength or fracture frequency.

The alluvium along the main dam centerline varies in thickness from a maximum of about 93 feet on the north side of the channel to an average thickness of 70 feet across the remainder of the channel. Two of the four primary types of materials identified in the river channel are present in this area. Well-graded alluvial sandy gravel (GW-GM) accounts for 67% of the total materials sampled, and a poorly-graded gravelly sand (SP-SM) account for the remaining 33%. The average gradations are shown on Figure 5-10. An average of 21% of the sandy gravel sampled consist of +3/4" fragments broken by the drilling operation. Similarly, an average of 13% of the gravelly sand samples consist of broken fragments. Gradation curves showing observed ranges in gradation are presented in Volume 2, Appendix D, Figures D-1 and D-2.

The alluvial sandy gravels and gravelly sands deposits are lenticular. Grain size and gamma log data indicate that the gravelly sands are generally found in the central part of the channel, while the coarser sandy gravels are located along the outer perimeter. The single exception is a buried gravel lens located in the center of the channel, about 25 feet below the river level.

Boulders and cobbles were encountered along much of the bedrock alluvium interface.

The alluvial material is expected to be very pervious. Partial or complete water loss from the drilling was noted in several sections of the bedrock, although pressure tests in bedrock in both the north and south abutments did not indicate appreciable water loss.

5.3.1.2 Upstream Area. Four vertical holes were drilled in the area upstream of the dam centerline, three of which were drilled in the exposed gravel bar on the north side of the channel, and one hole in the center of the channel, as shown on Figure 5-1. Downhole gamma logging was completed in two of the boreholes, and laboratory testing was performed on selected samples from each hole. Figure 5-11 presents summary borehole logs, gamma log curves and results of permeability tests.

The bedrock floor, in this portion of the river channel drops in elevation from 1450 feet along the margins of the channel to less than 1,310 feet within two apparently closed bedrock depressions shown on Figure 5-8. The bedrock samples recovered from these depressions are closely-fractured, fresh and altered, friable diorite. The percent recovery and RQD values of core taken in this area were less than the typical values for much of the river channel bedrock, and average about 80% and 35%, respectively. The upstream most depression may correlate with geologic feature GF-2 as mapped previously on the abutments (See Acres American, 1982; Figure 5.2).

Three types of overburden material are present in this section of the river. The average gradation of each of the materials is shown on Figure 5-12. Gradation curves showing the range of materials encountered are presented in Chapter 2, Appendix D, Figures D-3 through D-5.

Well-graded sandy gravel (GW-GM) account for 66% of the total materials sampled. An average of 24% of the samples retained on the 3/4" sieve consisted of fragments broken during drilling.

Well-graded gravel (GW) accounts for 25% of the material. Almost 40% of the samples retained on the 3/4" sieve consisted of fractured particles.

Gravelly sand accounts for the remaining 9% of the sampled material. An average of 15% of the sampled material consists of broken fragments.

The coarse, well-graded gravel and sandy gravel sampled in this area represent a large buried gravel bar, deposited on the inside of the curve in the river. This buried bar is part of the gravel bar exposed at the surface, and extends vertically to a depth of over 140 feet as indicated in HD83-37.

The permeability of the alluvial materials is expected to be high as evidenced by Boring HD83-39, which repeatedly encountered 1 to 5 foot intervals of materials yielding relatively high amounts of water in the return air circulation system. Water pressure testing in boring HD83-3 yielded moderate water losses in the bedrock.

5.1.3.3 Downstream Area. The area downstream of the main dam centerline was investigated previously by the U.S. Army Corps of Engineers in 1978. Their Boreholes DH-4 and DH-5 are located approximately 800 feet downstream of the main dam centerline. These holes encountered 65 and 51 feet, respectively, of river gravels, cobbles and boulders and some sand. The bedrock section of borehole DH-5 encountered a shear zone (with slickensides and gouge) and alteration roughly 22 feet below rock line. Loss of drilling water was experienced in the upper part of this zone.

Farther downstream, the USCE drilled three boreholes about 1,700 feet downstream of the main dam centerline. Because of equipment difficulties, alluvial deposits were difficult to penetrate. USCE borehole DH-1 encountered boulders up to 3.7 feet in diameter. Borehole DH-3 encountered boulders to 3.5 feet in diameter from a depth of 64 feet to the top of rock at a depth of 78 feet. Borehole DH-2 did not penetrate beyond 29 feet of alluvium in four attempts.

Two new boreholes were drilled during the Winter 1983 program in the area between the dam axis and the downstream toe. Figure 5-11 presents boring logs, gamma log curves and permeability test results for the borings in the downstream area. The two holes, HD83-35 and 36, are approximately 1,500 feet downstream of the main dam centerline, as shown in Figure 5-8. The holes were drilled in an exposed gravel bar, and the materials recovered are all classified as well-graded sandy gravel (GW-GM). The average gradation and envelope of gradations of the material are presented on Figure 5-13.

The sandy gravels in the downstream area represent a gravel bar on the inside bank of a curve in the river. The material is presumed to have a high degree of permeability.

The bedrock in the downstream area is intensely to moderately fractured, slightly altered diorite. Core recovery was approximately

90 percent, while RQD values were much lower, ranging from 80 percent in one borehole to less than 40 percent in the other boreholes.

5.3.2 Upstream Cofferdam

Eight vertical boreholes and one angle hole were drilled along the proposed axis of the upstream cofferdam, as shown on Figure 5-8, Profile C-C. Downhole gamma surveys were completed in five of the borings, and several permeability and bedrock hydraulic pressure tests were run. A geologic cross- section at the upstream cofferdam showing boring logs, gamma curves, permeability and pressure test results is presented on Figure 5-14.

The bedrock channel is generally symmetrical in cross-section, with sidewall slopes of ranging from 30 degrees to 70 degrees. The base of the bedrock channel is roughly 300 feet wide, with an average elevation of about 1385 feet. The base of the channel is relatively flat, with the exception of a bedrock knoll near the south side of the channel.

Bedrock sampled in this area is generally unweathered, hard diorite, although some altered diorite was encountered in the mid-river boreholes (HD83-19 and 20, and in angle Hole HD83-41 on the south side of the channel. Core recovery was the highest of any section drilled in the river, averaging over 95% recovery. RQD values were found to be slightly higher than average, ranging from 30% to 85%.

The alluvium in the foundation area of the upstream cofferdam varies in thickness from 85 feet in a slight bedrock depression (Boring HD83-22) to 66 feet at the adjacent Boring HD83-21). All of the four primary types of material identified in the river channel are present in the area of the upstream cofferdam. Well-graded sandy gravel (GW-GM) accounts for 57% of the total materials sampled. Poorly-graded gravelly sand (SP-SM) accounts for an additional 26%, while the remainder of the materials are a well-graded gravel (GW) and a poorly-graded sand, accounting for 13% and 4%, respectively. The average gradation of each of these materials is shown in Figure 5-15. The percentage of broken fragments in the recovered samples ranges from over 30% in the gravels to less than 4% in the sands. More detailed gradation curves showing the range of gradations measured are presented in Chapter 2, Appendix D, Figures D-6 through D-9.

The distribution of materials within this section of the river is related to the "S" shaped geometry of the canyon in this stretch of the river. The coarsest materials containing boulders and cobbles occur at the extreme outside of the curves in the river. On the inside portion of the curves, large gravel bars have formed, consisting primarily of the coarse gravels and sandy gravels. The gravelly sands and sands, which comprise the finest materials sampled, are generally found within the central parts of the channel, and along part of the outside curves.

The permeability of the alluvium is estimated to be high. Permeability tests in the finer materials indicates values in the range of 2×10^{-2} to 1×10^{-1} cm/sec, while Boring HD83-22 recorded large volumes of excess water in the return circulation throughout most of its length.

5.3.3 Downstream Cofferdam

Eight vertical boreholes and one abutment angle hole were drilled along the foundation for the proposed axis of the downstream cofferdam, as shown on Figure 5-8, Profile A-A. Downhole gamma surveys were completed in six of the holes, and labortory testing was performed on selected soil samples from each hole. Figure 5-16 presents the geologic profile of the river channel at the downstream cofferdam, including summary boring logs, gamma curves, and permeability test results.

The bedrock channel is generally symmetrical in cross-section, with both sidewalls showing a significant break in slope. The upper channel sidewalls apparently slope at about 70 to 80 degrees, while the lower sidewalls slope at 35 to 40 degress. The base of the bedrock channel is about 300 feet wide. The bottom of the channel is gently undulating, with a total relief of about 30 feet. The average elevation of the base of the bedrock channel is about 1380 feet.

Bedrock in the downstream cofferdam foundation area is generally fresh or altered diorite. Core recovery values, with a few exceptions, were very high. RQD values typically ranged from zero in the shear zone in HDB3-27 to 80% in the altered diorite. One six-foot interval of altered and sheared diorite was encountered in borehole HD83-27 underlying 12 feet of fresh, hard, andesite. On the south side of the channel, Boring HD83-24 encountered a 14-foot thick interval of hard, fresh diorite above a four-foot section of alluvium. This interval of diorite may represent an overhang in the bedrock channel wall, or a large slide block in the channel alluvium.

The thickness of overburden in this area ranges from 73 feet (HD83-26) in the middle of the section to 59 feet (Boring HD83-31) on the north side of the channel. All four of the material types identified in the river channel occur in the downstream cofferdam area. Well-graded sandy gravel (GW-GM) accounts for 75% of the total materials sampled. Poorly-graded gravelly sand (SP-SM) accounts for an additional 20%. The remaining 5% of the materials are a well-graded gravel (GW) and a poorly-graded sand. The average gradation of each of the sediments is shown in Figure 5-17. The percentage of broken fragments in the samples range from an average of 38% in the gravels to 4% in the sands.

More detailed gradation curves showing the range of gradations sampled are presented in Chapter 2, Appendix D, Figures D-10 through D-14.

The coarsest of the materials sampled occur at the base of the channel and in the shallow gravel bar on the south side of the channel. The sandy gravels and gravelly sands are distributed throughout the section, although some concentration of the finer materials occurs with depth along the north side of the channel.

The permeability of the overburden will vary significantly based on the wide range of gradations. Relatively large amounts of water in return circulation was reported from a sand layer at a depth of 48 feet in borehole HD83-25, within a short sand interval at 40 feet in HD83-26, and locally in HD83-29 and HD83-27.

5.3.4 Diversion Tunnel Portals

The exploration of the diversion tunnel portal area was primarily designed to develop the characteristics and topography of the bedrock in the threshold area of both the upstream and downstream portal areas. A discussion of the findings in each of these two areas is presented below.

5.3.4.1 Upstream Portal. Four vertical holes were drilled near the upstream portals. Three were drilled adjacent to the north bank of the river channel (DH83-14, 15, and 16) and one was drilled approximately 900 feet upstream of the upstream cofferdam axis (HD83-2), as shown in Figure 5-1 and 5-11.

The very coarse alluvium and talus blocks from the adjacent rock cliffs on the north bank vary in thickness from 11 feet (HD83-16) to 29 feet (HD83-14). HD83-15 and 16 both required 3 attempts to reach bedrock because of the very coarse overburden materials. Another nearby borehole, HD83-40, required 5 attempts and did not reach bedrock. Although the size of material deflecting the drive pipe is not known, it can be expected that boulders in the 2 to 5-foot diameter range are present.

The majority of samples from this area classified as well-graded sandy gravels (GW), with 25% fractured material remaining on the 3/4-inch sieve, as shown in Figure 5-18. Approximately 60% of the material is classified as gravel, with 35% sand and 5% fines.

Bedrock in all four boreholes was fresh, moderately fractured diorite. Bedrock elevation varies from 1446 (Boring HD83-16) to elevation 1424 (Boring HD83-2). Percent recoveries ranged from 90 to 100%, while RQD values ranged between 70% and 100%.

5.3.4.2 Downstream Portal. Three verical boreholes were drilled in the area of the downstream portal area in the gravel bar adjacent to the north bank of the channel as shown in Figure 5-1 and 5-11. The alluvium in this area varies in thickness from 7 feet (Boring HD83-34) to 22.5 feet (HD83-32), becoming shallower downstream along the north bank of the river channel.

Two types of materials are present in this section of the river. Well-graded sandy gravel (GW) accounts for 84% of the total materials sampled. Well-graded gravel (GW) accounts for the remaining 16% of the material mix. The average gradation of the two main material types is shown on Figure 5-19. An average of 20% to 30% of the material sampled contained broken fragments. More detailed gradation curves showing the range of gradations encountered are presented in Chapter 2, Appendix D, Figures D-14 and D-15.

The elevation of bedrock rises in the downstream direction from an elevation of 1425 feet (HD83-32) to elevation 1445 (HD83-34). The bedrock sampled was found to be slightly weathered diorite with high percentage recovery and low RQD values due primarily to zones of closely fractured rock. The bedrock was found to be hard and moderately strong even in zones of low RQD.

6.0 RELICT CHANNEL INVESTIGATIONS

6.1 - GENERAL

The existence of relict channels in the bedrock topography between the Susitna River valley and the tributary valley of Tsusena Creek near the Watana Dam site was originally indentified by the U.S. Army Corps of Engineers explorations at the Watana site (Corps of Engineers, 1979). Feasibility stage explorations of the relict channel from 1980 through 1982 by Acres American Inc. have developed detailed information on the bedrock topography, glacial stratigraphy and properties of the glacial/fluvial deposits (Acres American Inc., 1982).

The results of the winter program supplemented the previous stratigraphic interpretation and evaluation of engineering properties of the glacial deposits in the relict channels at three locations defined as being of primary interest from previous exploration results. The locations explored are shown on the Exploration Map, Figure 6-1.

6.1.1 Relict Channel Morphology

The winter drilling results did not change significantly the interpretation of the bedrock topography in the area of the Watana Relict Channel. Figure 6.2 shows the configuration of the bedrock surface as interpreted from the seismic refraction lines and boreholes which also are shown. Geologic profiles on Figures 6-3, 6-4, and 6-5 show the interpreted bedrock surface and present summary boring logs, gamma curves and field and laboratory test results.

Watana Relict Channel is the term used in previous studies to denote a number of buried bedrock paleo-channels, ancestral to the present Susitna drainage. They are located in the area on the north side of the Susitna valley between the mouth of Deadman Creek and a point about 1,000 feet upstream from the proposed dam axis and thence extending northwesterly to Tsusena Creek. The development of the channels has been postulated (Acres American Inc., 1982) to have occured during pre-Wisconsinian time with modifications occuring during Wisconsinian interglacial stages.

The thalweg of the deepest channel trends westerly for about 5,000 feet commencing at a breach in the bedrock of the Susitna valley north wall just downstream of the Deadman Creek confluence. The thalweg then turns and trends northwest for about 7,000 feet to Tsusena Creek. The bedrock floor of this deepest channel is about elevation 1825 over most of its westerly reach and is deeper both upstream and downstream. Two secondary channels in the north bedrock valley rim have been interpreted about 2,000 feet and 4,000 feet upstream of the dam axis and these have been cut to elevations of 2,050 feet and 1,950 feet respectively. During subsequent development of Susitna drainage, the present main Susitna valley has cut its bedrock channel to elevation 1380.

The relict channels have been found to be backfilled with fluvial and glacial deposits which are described and discussed in Section 6.2.2.

6.1.2 Bedrock Exploration and Lithology

The exploration program completed at Watana relict channels consisted of 15 boreholes and a total of 2,140.5 feet of drilling as listed in Table 4-4 and at locations shown on Figure 6-1. Four piezometers and nine thermal probes were installed in borings as shown in Table 4-9.

Rock was encountered in five of 15 borings and bedrock verified in three of those borings. In HD83-52, the bedrock was cored and found to be fresh, unweathered diorite. In HD83-2, -6, and -8, bedrock appeared to be weathered but the drilling method precluded identification of the rock lithology. In HD83-6, from 114.0 to 116.5, a white to yellowish brown clayey sand material was penetrated that resembles gouge previously observed in outcrop in the damsite area.

Bedrock surface elevations which are reasonably close to the bedrock elevation contours presented in the 1982 Supplement Report are presented in Figure 6-2. The deepest boring, HD83-52, encountered bedrock very close to that predicted by previous contour mapping. Bedrock in other borings was within 10 to 30 feet and in WW-3 bedrock was about 50 feet higher then shown by contour maps. Seismic refraction data, which formed the basis for most of the bedrock surface topography, has not yet been reinterpretated using the new bedrock surface data for correlation. Borings HD83-2 and HD83-8, did partially confirm the depth and limits of a secondary channel. An intermediate boring, planned to confirm the approximate depth at the deepest part of this channel, could not be drilled because of equipment limitations.

6.2 OVERBURDEN STRATIGRAPHY

The topography of the upper Susitna River Basin has been modified by repeated glaciations as coalescing ice masses from both the Talkeetna Mountains and the Alaska Range merged and filled the broad plain of the Watana dam site area (Karlstrom 1964; Pewe, 1975). As a consequence of these glaciations, the overburden deposits filling and overlying the Relict Channel on the north abutment at the Watana site are comprised of a sequence of glacial and fluvial materials.

Five basic deposits have been differentiated based on their mode of deposition: ice disintegration, outwash, lacustrine, till, and alluvium. The system of identification of these deposits, originally by Acres Amrican Incorporated (1982) and further developed in this investigation, are based on samples collected in drilling, mapping of outcrop exposures, in-hole testing and geomorphology. Although not always clearly defined, 12 stratigraphic units (designated A through K) have been delineated within these deposits and are shown in Table 6-1.

6.2.1 Classification Criteria

The physical properties used to distinguish the units are color, grain size, roundness of coarse particles, striations and polish, compactness, imbrication, structure, lithology, sorting and weathering. The main criteria used in distinguishing between the various deposits are as follows:

Alluvium	roundness of the coarse fraction, the general absence of fine material, i.e., clean, and well sorted
Ice Disintegration	morphology
Lacustrine	structure; grain size - high percentage of fines, absence of coarser particles
Outwash	roundness of the coarse fraction, grain size, generally the material gets coarser with depth
Till	striations, polish and roundness of the coarse fraction, grain size, density

None of the individual properties listed above, by themselves, are indicative of the type of deposit. Due to the complexity of the erosional and depositional processes associated with glacial environments, the variation in physical and material properties between units was, in many instances, most difficult to ascertain.

6.2.2 Stratigraphic Units

The descriptions of the stratigraphic units, particularly the upper units as defined by Acres American Incorporated (1982), have been modified as a result of using the Becker Hammer Drill during the winter 1983 program and is reflected in the descriptions of the units in Table 6-1. The drilling equipment and method of sampling as discussed earlier in Section 4.2 and in Appendix B, enabled recovery of coarser material than that which had been recovered previously. Brief descriptions of the overburden stratigraphic units which have been delineated in the Relict Channel/Borrow Site D area are as follows:

UNIT A/B - Surfical Deposits - is the uppermost material and consists primarily of organic silts, peat and cobbles and boulders which have been brought to the surface through frost heaving. Within this thin (0-8 feet) nearly continuous material, thin volcanic ash layers have been delineated (University of Alaska Museum, 1982). Post glacial erosion of this material has resulted in soil formation, organic decomposition and frost heaving. In poorly drained or undrained areas, peat and organic silt deposits have formed. In low depressions usually occupied by small ponds and lakes, boulder fields are found where cobbles and boulders have been heaved to the surface by frost action.

UNIT C - Ice Disintegration Deposit - is characterized by a hummocky, knob and kettle topography which forms a discontinuous mantle across the area. It is found predominantly in the northern and northwestern portions of the Relict Channel/Borrow Site D area. The unit is composed of a brownish grey to greyish brown, gravelly sand to silty sand with little to some subangular to subrounded gravels and cobbles. It is usually poorly sorted, but in a few local areas is well sorted. The degree of compaction is variable, though density tends to increase with depth.

UNIT M - Basal Till - Found near the Susitna River is a basal till ranging in thickness up to 79 feet. It is a brownish grey to dark grey, silty sand to clay with angular to subrounded striated gravels, and some cobbles and boulders. It is dense to very dense, moist, poorly sorted, and occasionally frozen.

UNIT D - Alluvium - is a local alluvium found within channels in the underlying outwash surface, Unit E/F. Where erosion of the overlying ice disintegration deposit has occured, this unit is found near the surface.

The unit is composed of grey stratified sands and silts, with subrounded to rounded gravels and cobbles. It is generally sorted, medium dense to very dense, moist, and its thickness ranges up to 40 feet.

UNIT D' - Lacustrine - is a discontinuous lacustrine unit. It is generally found in local depressions on top of the underlying outwash unit (E/F). The unit is composed of a grey to very dark greyish brown, laminated clayey silt to clayey, silty sand with small amounts of angular to subangular gravel. It is moist to wet, dense to very dense and frozen in some areas. Its maximum thickness is in the range of 23 feet.

UNIT E/F - Outwash - forms a thick continuous mantle over the Relict Channel/Borrow Site D area. In areas not overlain by ice disintegration material, this unit is exposed at the surface and is characterized by a relatively flat, poorly drained surface. It averages 40 feet thick but ranges to a maximum of 131 feet in the northeastern portion of the area, near Deadman Creek.

It is composed of an olive brown to greyish brown matrix with varying amounts of silt, sand, gravel, cobbles, and boulders. The percentage of coarse material ranges from 5 to 60 percent, resulting in a material which ranges from a well graded silty sand with little gravel and cobbles to a well graded sandy gravel with occasional cobbles and boulders. The coarse particles are subangular to subrounded and in general, the size and percentage of coarse material increases with depth. The material is dense to very dense, moist to wet, poorly sorted and frozen in some areas.

UNIT G - Lacustrine - is a relatively continuous lacustrine and/or till deposit with minor gaps in the strata. This unit together with the underlying till deposit, Unit G', forms a continuous, easily identifiable marker strata across the area. It ranges in thickness up to 74 feet, averaging approximately 30 feet.

The unit is composed of blue grey to dark grey, laminated sandy silt to silty clay material with small amounts of gravel. The laminated lacustrine material consists of rhythmic interbeds of clay and fine silt. The unit is dense to very dense, moist to wet, locally frozen, containing trace amounts of organics and is poorly sorted. The coarse particles are subanglar to rounded, and occasionally striated.

UNIT G' - Basal Till - is a basal till found in isolated patches in the eastern and western portion of the Borrow Site and in the Relict Channel areas. It has a maximum thickness of 231 feet.

The unit ranges from an olive grey to very dark grey clayey, silty sand with minor amounts of gravel, to a gravelly, silty or clayey sand.

The coarse particles, which include occasional cobbles and boulders are subangular to subrounded with striations and polish. The material is dense to very dense, moist, occasionally frozen and poorly sorted.

UNIT H - Alluvium - is local alluvium found in channels on the upper surface of the underlying outwash, Unit I. The maximum thickness is in the order of 42 feet. The unit is composed of greyish brown to olive grey well graded silty sands and sands with minor amounts of well graded sandy gravels. The coarse material is generally slightly oxidized and rounded but subangular to subrounded particles. The unit is stratified, sorted and contains trace amounts of organics. It is moist to wet, very dense, and a relatively clean material.

UNIT I - Outwash Deposit - is nearly continuous stratum found over much of the Relict Channel/Borrow Site D area. It ranges in thickness up to 81 feet. The unit ranges from an olive to olive grey, well graded silty sand with minor amounts of gravel and cobbles. The cobbles are slightly weathered, with limonite and some hematite staining. The coarse material is primarily subangular to subrounded with a trace of rounded particles, some particles are striated. The unit is moist to wet, very dense and sometimes sorted.

UNIT J' - Lacustrine and/or Stratified Deposits - is a localized fluvial and/or lacustrine deposit found in the northern and southwestern portions of the Relict Channel/Borrow Site D area. It is found overlying bedrock and in topographic lows on the surface of the underlying till, Unit J. It ranges in thickness up to 58 feet. The unit is composed of olive grey to olive brown, silty sand with a trace of subangular to rounded gravel to a sandy gravel. It is very dense and moderately weathered, with limonite staining and is well sorted to partly sorted.

UNIT J - Basal Till Deposit - Maximum thickness of the basal till found in the relict channels is in the order of 62 feet. It is an olive grey to dark grey, clayey sand to clay with small amounts of gravel. The gravel is rounded to angular, slightly weathered with some limonite staining, striated and polished. There is a possible change at the bottom of the unit to a lacustrine or waterlain till deposit. It is very dense and poorly sorted.

UNIT K - Alluvium - is the oldest and deepest unit in the Relict Channel/Borrow Site D area. It is found in the deepest part of the V-shaped valley comprising the main Relict Channel.

The unit is composed of very dense olive grey, silty sandy gravel and a poorly graded sandy gravel. The coarse fraction which includes cobbles and boulders, is subangular to rounded, slightly weathered and well sorted.

6.2.3 Stratigraphic Correlation

The overburden materials as classified above have been delineated and correlated across the Relict Channel/Borrow Site D area (Figure 6-3 through 6-5). In general, the outwash strata (Units E/F and I) and the marker bed strata, (the lacustrine and till deposit; Unit G and G'), are continuous across the relict channel and borrow area. The exception to this is adjacent to the southwestern portion of Borrow Site D where in HD83-2 and 8, where no lacustrine or basal till were encountered.

Correlation of the stratigraphic units was attempted through the use of natural-gamma, borehole geophysical logging. The complex stratigraphy and the variations of the materials within each stratum precludes the identification of stratigraphic boundaries with any reasonable level of confidence. The natural gamma log profiles are presented in Volume 2 Appendix A.

Based on the geotechnical investigation, to date, the overburden deposits beneath and including the lacustrine/waterlain till and the basal till strata (Unit G and G') are generally dense and overconsolidated. A contour map of the top surface of the relatively impervious marker bed strata (Unit G/G') is shown in Figure 6-6. It appears that the surface of the strata forms a northeast-southwest topographic ridge that approximately coincides with seismic line DM-A (Note, the borings are also concentrated along this trend).

Boring HD83-49 is about in the middle of the topographic low and is the low point in the surface of Unit G/G' at elevation 2187 (Figure 6-4). The other topographic low in the surface elevation of Unit G/G' occurs in the vicinity of boring HD83-4 at elevation 2200. The thickness of overlying Units C, and E/F varies from 10 to 70 feet along Profile B-B, Figure 6-4.

The existence of the deep Unit K alluvium was further verified with boring HD83-1, which penetrated the top part of Unit K about 34 feet higher than it was encountered in Corps of Engineers boring DR-22, located about 700 feet to the north towards Tsusena Creek. Although only 35 feet of the unit was penetrated, the bedrock contours suggest a unit thickness of about 130 feet at this location. The extent of Unit K along the deepest part of the main channel can be reasonably well estimated in the bedrock control section, but as is the case with all the lower units, it remains undefined at the entrance and exit areas of the relict channel.

Unit I outwash was present in all borings drilled through the overlying Unit G/G' except where G/G' was absent at boring HD83-2. Unit H alluvium was often present as a more permeable unit on the surface of the Unit I outwash. Thus, the relatively more permeable Units I and H are present throughout much of the area of relict channel investigation in the winter program.

The winter program results add valuable information to the data base for borrow materials above Unit G/G'. The six borings drilled along or near the limits of Borrow Site D add to the data on volume of borrow materials evaluated in the 1982 Supplement Report. No significant variations in stratigraphy affecting borrow quantities were determined during the winter program.

The soil property data for units above G/G' provide additional information to add to that summarized in the 1982 Supplement Report. The grain size curves, Atterberg Limits, and moisture contents for units correlate well with the results of previous explorations as shown in Appendix D, figures D-22 and D-23, D-34 and D-35, and D-37 through D-40.

6.3 OVERBURDEN PHYSICAL PROPERTIES

6.3.1 Soil Types

The various types of soils encountered in the glacial deposits were classified in accordance with the Unified Soil Classification System, The soil descriptions are based on field and laboratory visual examination, on results of laboratory and field testing and on observations of drilling behavior. Typical group classifications for each geologic unit of the glacial deposits are provided on Table 6-1.

The soil type (SM) is typical for glacial till Units M, G', and J', and is common in the outwash deposits E/F and I as shown on Table 6-1.

Some silty sand (SM) is encountered in alluvial deposits D and H. Clayey sand (SC) soils are also common to many geologic units, particularly the glacial lacustrine and till deposits. These soils are generally absent in the outwash, Unit I, and in all the alluvial deposits. Cohesive clayey and silty (CL, ML) soils are generally limited to lacustrine and till deposits. Gravelly materials (GM, GP, GW) are found in the alluvium of Unit K, and to a lesser extent, the outwash of Units J. and E/F. The coarseness of the outwash/alluvial deposits generally increases with depth. Unit K is coarser than Units J and H, which are coarser than E/F and D. Soil types with low fine contents (GW, GP, SW, SP) are limited to outwash Units E/F and I, and alluvial Units D, H, and K.

6.3.2 Texture and Plasticity

Laboratory tests for soil grain size and plasticity were anaylzed for each geologic unit (C through K) tested in the winter program. Weighted average and upper and lower limits of the grain size distribution of all samples were determined for the various units. The average and range of soil types in each unit were compared with previous grain size distributions presented in the 1982 Supplement Report. When possible the summarized weighted averages and ranges for each unit were then compared by mode of deposition, (till, outwash, alluvium, lacustrine). Unit C, an ice disintegration deposit, was categorized with the outwash because of similar texture. A summary of the analyses or grain size distribution by geologic units is presented in Table 6-3.

Till Units M, G', and the basal till deposit J had average grain size distributions and a gradation envelope as shown in Figure 6-7. With the exception of clay materials in J, the deposits exhibit very similar average grain size characteristics and are predominantly silty, clayey sand to sandy clay with little gravel. The upper and lower gradation limits of the till deposits include a wide variety of soil types from clay to gravel. However, the weighted average distribution for each unit is very similar to previous results as shown in Appendix D, Figures D-16 through D-20. Each of the units is classified as low plastic with the Atterberg limits of the materials ranging from cohesionless to a plasticity index of approximately 10 and a liquid limit of 25 as shown in Appendix D, Figures D-37 through D-40. The limits disclosed in samples of winter program sampling were well within the range previously found in each unit.

Outwash Units C, E/F, and I, are predominately stratified silty sand (SM) with layers or lenses of sandy gravel (GM). The average grain size distribution is very similar for the two deposits as shown on Figure 6-8. In both Unit E/F, and I, two types of materials have been delineated which average gradations and envelopes very similar to the gradation trends from previous results as shown in Appendix D, Figures D-21 through D-26. Each of the units is classified as low plastic with the Atterberg limits of the materials ranging from cohesionless to a plasticity index less than 5 and a liquid limit less than 25 as shown in Appendix D, Figures D-37 through D-40. Upper and lower limits for winter program samples fall within the limits of previous results.

Clean, granular soils (GW, SW) are present in the lower I outwash deposit, but were not detected in Unit E/F.

Alluvium Units H and K are dissimilar in texture as shown on Figure 6-9. Unit H was predominantly a silty sand (SM) with layers or lenses of well graded sandy gravel (GW-GM) while Unit K was primarily a poorly graded sandy gravel (GP-GM) with layers or lenses of silty, sandy gravel (GM). Unit H sample test results from the winter program define a much coarser unit than samples from previous exploration as shown in Appendix D. The unit K data represents the only grain size distributions which have been completed in the deep alluvium based on a limited pentetration of the unit (35 feet) and limited sample recovery.

Lacustrine Units G, D', J' vary in texture from silty clay (CL) in G, sandy silty (ML) in D', to silty sand (SM) in J' as shown on figure 6-10. Unit J', a stratified silt and sand deposit was included for comparison purposes because of a similar mode of deposition. Comparison of winter program sample test results for each unit with results of previous explorations are provided in Appendix D, Figures D-34 through D-36. The winter program data correlate well with previous results.

6.3.3 Density

The density of in-situ soil is normally estimated by blow counts on split-spoon samples (SPT) or measured by density testing of representative undisturbed samples. The high content of gravel and coarser materials throughout the glacial deposits and the compactmess of the deposits beneath the upper Unit C outwash material make undisturbed sampling difficult if not impossible to accomplish. Undisturbed sampling was not included in the relict channels program due to experience from previous explorations and the priority objectives of obtaining glacial stratigraphy and soil texture. Although the finite values are suspect because of the presence of gravel, standard penetration resistance blow counts on split-spoon samplers were used to further evaluate the density of the geologic units. Blow counts of the hammer drill were also used during drilling to qualitatively evaluate density by degree of drilling difficulty.

The results of 71 penetration tests on split-spoon samples and hammer drill observations confirm previous exploration results. In general, glacial deposits beneath the Unit C ice disintegration deposits are generally dense to very dense. These deposits are overconsolidated by ice from the most recent major glacial advance over the area. The Unit A/B surficial deposits and Unit C ice disintegration deposits are not overconsolidated. These deposits are generally within the active/ seasonal frost zone. Previous blow count data indicates the Unit C material is dense to very dense below a depth of 15 feet. At some boring locations, the surface E/F deposit was medium dense to dense where it was within about 15 feet below the ground surface.

The blow count data is consistent with that presented in the 1982 Geotechnical Report. Of 38 data points in Unit G and G', 5 were less than 100 blows per foot and one was less than 50 blows per foot. Of 17 in Unit E/F, 4 were less than 50 blows per foot, 5 were from 50 to 100 blows per foot and 8 were greater than 100 blows per foot.

6.3.4 Permeability

Permeability of the glacial deposits varies significantly between the vertical and horizontal components of seepage due to the stratification and sorting of the soils during deposition. In addition to soil structure, the permeability of the relict channel soils is directly related to the grain size, density and particle shape of the deposits. All of the relict channel deposits below Units A/B, or C are evaluated to be dense to very dense.

The interstructure and grain size distribution of individual seams or lenses has not been accurately distinguished nor determined in the stratified relict channel deposits sampled by the hammer drill. The sampling method mixes the sample during retrieval, as a result the sample is a composite sample for the depth drilled, which varied from one to five feet.

The soils within all units of the glacial deposits are generally well graded and contain appreciable fines. These textures tend to reduce the porosity of the soils. The high density of the soils further reduces the permeability. However, pervious sand and gravel deposits are present, particularly in the alluvium deposits. However pervious, the 35 feet of Unit K penetrated in boring HD83-1 was not open work cobbles as postulated from the COE boring DR-22; rather it was silty gravel and sandy gravel, more similar in texture to the gravels in the present Susitna river channel.

The extensive data on soil texture presented in Volume 2, Appendix D correlates very well with previous data for each of the units. The variation of grain size distribution within stratified deposits is characterized in more detail from this data. This data provides a reasonable basis for estimating permeablility and soil structure characteristics in future engineering studies of seepage in the relict channel.

6.4 GROUNDWATER

The groundwater regime of the Relict Channel/Borrow Site D area is complex because of the variable characteristics of the various stratigraphic units identified and the presence of discontinuous or sporadic permafrost. In general, the overburden deposits can be divided into potential aquifers (ice disintegration deposits, outwash and alluvium) and into more impervious zones such as the dense lacustrine and basal till deposits. The existence of permafrost in potential aquifers may create blockage of groundwater flow and, therefore, portions of the stratum might respond as an aquiclude.

Limited information on the groundwater regime exists at the present time. During the winter drilling program, groundwater was detected primarily in the outwash strata (Units E/F and I) above and below and the alluvial deposit (Unit H) below the lacustrine and/or basal till deposits (Unit G/G'). Together, the lacustrine and basal till deposits form a continuous, thick impermeable strata across the Relict Channel/ Borrow Site D area, except for a small area near HD83-2 and 8 (Figure 6-6). It appears that surface recharge to the groundwater aquifers becomes trapped above this strata in the overlying materials and is generally very close to the ground surface.

Groundwater recharge of the deposits beneath the impermeable strata (Unit G/G') is believed to be from the bedrock high to the southwest of the relict channel, where groundwater can follow bedrock and enter into the underlying pervious strata and/or surface infiltration in areas not overlain by the impermeable strata (Figure 6-6). No ground water was detected in the top 35 feet of the preglacial alluvium, Unit K stratum.

The detection of groundwater at only intermittent locations in the outwash and alluvium units above the till and lacustrine units may indicate that these units have drained to the adjacent Susitna river and Tsusena creek valleys. An exception to this is where the permeable units fill lows in the underlying till and lacustrine units.

6.5 PERMAFROST

The Watana Dam site area lies within a zone of discontinuous permafrost and has a mean annual temperature very close to freezing, roughly -1.5°C. During the winter drilling program, permafrost in the form of ice lenses and visible ice were detected in HD83-3 and 5 to a depth of 38 and 50 feet, respectively. Thawing of ice lenses is indicated by abnormally high moisture contents at HD83-3. This is in good agreement with assumptions for permafrost resulting from borings during previous investigations (Corps of Engineers, 1979; Acres American Inc., 1982). Permafrost has been detected primarily in the horizons above and inclusive of the lacustrine and basal till strata (Units G/G'). The active layer in Relict Channel/Borrow Area D has been delineated and is generally from 5-15 feet deep where permafrost is found.

It appears, based on previous drilling information, that permafrost may locally reach depths of up to 110 feet below the ground surface.

Instrumentation readings to date are indicative of a thermal regime that may be in disequilibrium with the present climate. Only in 5 of 15 instrumented borings drilled prior to 1982, which detected permafrost, has freezeback occurred to temperatures at or below freezing, upon stabilization. Therefore, it appears that the growth or continued growth of permafrost is only marginal with the present climatic regime, however, this does not preclude its formation in localized areas.

REFERENCES

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TABLE 4-1
RIVER CHANNEL
SUBSURFACE GEOPHYSICAL PROFILES
FOOTAGE SUMMARY

SEISMIC REFRACTION

LINE NO.	LINE LENGTH, FEET
S83-1	430
S83-2	275
S83-3	500
S83-4	1080
S83-5	1100
S83-6	1550
S83-7	1100
S83-8	550
S83-9	1705
S83-10	1100

GROUND PENETRATING RADAR

LINE NO.	LINE LENGTH, FEET
R83-1	1200
R83-2	1600
R83-3	310
R83-4	800
R83-5	800
R83-6	1100
R83-7	288
R83-8	384
R83-9	384
R83-10	230
R83-11	377
R83-12	324
R83-13	380
R83-14	313

TABLE 4-2
RIVER CHANNEL
BOREHOLE GEOPHYSICAL LOGGING
FOOTAGE SUMMARY

BOREHOLE NUMBER	LENGTH LOGGED, FEET	TOTAL DEPTH, FEET	LOCATION
HD83-20	63.0	76.5	Upstream Cofferdam
HD83-21	65.5	86.5	Upstream Cofferdam
HD83-22	105.6	107.3	Upstream Coferdam
HD83-23	74.0	87.0	Upstream Cofferdam
HD83-24	40.4	57.0	Downstream Cofferdam
HD83-26	76.0	96.0	Downstream Cofferdam
HD83-28	86.1	88.5	Downstream Cofferdam
HD83-29	74.0	104.3	Downstream Cofferdam
HD83-30	67.5	75.6	Downstream Cofferdam
HD83-31	79.0	82.9	Downstream Cofferdam
HD83-34	14.0	32.4	Downstream Portal
HD83-35	51.9	71.5	Downstream Shell
HD83-36	42.5	43.6	Downstream Shell
HD83-37	123.0	155.0	Upstream Shell
HD83-39	166.3	168.0	Upstream Shell
HD83-42	126.0	127.8	Dam Centerline
HD83-43	52.0	107.7	Dam Centerline
HD83-44	66.0	118.0	Dam Centerline
HD83-45	43.9	80.0	Dam Centerline
HD83-46	53.5	98.2	Dam Centerline
HD83-48	107.0	108.0	Downstream Cofferdam
DH83-4	114.5	116.5	Dam Centerline

TABLE 4-3
RELICT CHANNEL
BOREHOLE GEOPHYSICAL LOGGING
FOOTAGE SUMMARY

BOREHOLE NUMBER	LENGTH LOGGED, FEET	TOTAL DEPTH, FEET	LOCATION
HD83-4	58.7	94.0	Seismic Line DM-A
HD83-5	78.0	138.0	Seismic Line DM-A
HD83-6	91.5	126.5	Seismic Line DM-A
HD83-7	80.3	82.0	Seismic Line SL82-18
HD83-8	78.0	78.0	Seismic Line SW-3
HD83-9	106.0	110.0	Seismic Line DM-A
HD83-49	37.0	38.0	Seismic Line DM-A
HD83-50	118.0	119.5	Seismic Line DM-A
HD83-51	94.0	98.5	Seismic Line DM-A

TABLE 4-4
RIVER CHANNEL
1983 WINTER DRILLING PROGRAM
DATA SUMMARY

BOREHOLE NUMBER(1)	SURFACE ELEVATION ICE	OVERBURDEN	INCLINATION	AZIMUTH	DEPTH TO BEDROCK(2) FEET	BEDROCK ELEVATION	TOTAL DEPTH FEET
DH83-1	1,464.4	1,386.4	Vert.	----	78.0	1,386.4	91.0
DH83-2	1,470.6	1,466.1	"	----	46.0	1,424.6	64.0
DH83-3	1,460.4	1,450.6	"	----	92.9	1,367.5	126.5
DH83-4	1,475.2	1,473.8	45°	350°	22.0	1,459.6	116.5
HD83-10	1,459.4	1,455.9	Vert.	----	96.0	1,363.4	119.5
HD83-11	1,459.1	1,451.1	"	----	73.2	1,385.9	89.4
HD83-12	1,459.0	1,451.5	"	----	77.0	1,382.0	87.5
HD83-13	1,458.5	1,449.5	"	----	84.0	1,374.5	89.5
HD83-14	1,464.8	1,459.8	"	----	34.0	1,430.8	57.5
HD83-15	1,465.1	1,460.1	"	----	29.5	1,435.6	46.0
HD83-16	1,465.5	1,457.5	"	----	19.0	1,466.5	39.5
HD83-17	1,464.4	1,449.4	"	----	63.0	1,401.4	77.5
HD83-18	1,465.7	1,461.2	"	----	30.0	1,435.7	39.0
HD83-19	1,463.5	1,453.0	"	----	80.0	1,383.5	98.0
HD83-20	1,464.9	1,455.4	"	----	---	----	76.5(3)
HD83-21	1,467.7	1,467.7	"	----	66.0	1,401.7	86.5
HD83-22	1,467.6	1,464.6	"	----	87.0	1,380.3	107.3
HD83-23	1,468.0	1,468.0	"	----	71.0	1,397.0	87.0
HD83-24	1,453.8	1,448.3	"	----	44.0	1,409.8	57.0
HD83-25	1,454.4	1,446.4	"	----	75.0	1,379.4	95.9
HD83-26	1,453.8	1,445.8	"	----	81.0	1,372.8	96.0
HD83-27	1,453.7	1,445.8	"	----	70.0	1,383.7	98.5
HD83-28	1,453.6	1,443.6	"	----	72.0	1,381.6	88.5
HD83-29	1,453.8	1,444.8	"	----	79.0	1,374.8	104.3
HD83-30	1,453.8	1,444.8	"	----	65.0	1,388.8	75.6
HD83-31	1,456.2	1,455.2	"	----	60.0	1,396.2	82.9
HD83-32	1,454.0	1,447.5	"	----	29.0	1,425.0	57.8
HD83-33	1,453.2	1,445.7	"	----	21.0	1,432.2	43.0
HD83-34	1,454.9	1,449.9	"	----	12.0	1,442.9	32.4

TABLE 4-4
RIVER CHANNEL
1983 WINTER DRILLING PROGRAM
DATA SUMMARY

BOREHOLE NUMBER(1)	SURFACE ELEVATION ICE	SURFACE ELEVATION OVERBURDEN	INCLINATION	AZIMUTH	DEPTH TO BEDROCK(2) FEET	BEDROCK ELEVATION	TOTAL DEPTH FEET
HD83-35	1,458.4	1,455.9	Vert.	----	51.5	1,406.9	71.5
HD83-36	1,456.8	1,453.9	"	----	24.0	1,432.8	43.6
HD83-37	1,464.3	1,463.3	"	----	153.5	1,310.8	155.0
HD83-38	1,463.6	1,461.1	"	----	----	-----	94.5(3)
HD83-39	1,467.2	1,462.2	"	----	152.0	1,315.2	168.0
HD83-40	1,470.6	1,468.6	"	----	----	-----	38.0
HD83-41	1,471.9	1,470.5	"	098°	83.0	1,413.2	104.5
HD83-42	1,462.1	1,451.1	Vert.	----	70.0	1,392.1	127.8
HD83-43	1,461.1	1,451.1	"	----	75.4	1,385.7	107.7
HD83-44	1,459.9	1,449.9	"	----	67.5	1,392.4	118.0
HD83-45	1,463.5	1,462.8	"	328°	56.0	1,423.9	80.0
HD83-46	1,461.5	1,460.1	"	155°	55.5	1,422.3	98.2
HD83-47	1,459.6	1,458.2	"	010°	----	----	65.0(3)
HD83-48	1,455.6	1,447.6	Vert.	----	88.0	1,367.6	108.0
						TOTAL	3,710.4

(1) Longyear boring, DH83-1. Hammer boring, HD83-10
(2) Depth to bedrock is along the hole axis
(3) Refusal while drilling, (cobble/boulder or bedrock)

TABLE 4-5
RELICT CHANNEL
1983 WINTER DRILLING PROGRAM
DATA SUMMARY

BOREHOLE NUMBER	SURFACE(1) ELEVATION	DEPTH TO(2) BEDROCK FEET	BEDROCK ELEVATION	TOTAL DEPTH FEET
HD83-1	2,246.2	----	----	328.0
HD83-2	2,147.1	77.5	2,069.6	87.0
HD883-3	2,220.0	----	----	82.5
HD83-4	2,246.7	----	----	94.0
HD83-5	2,283.7	----	----	138.0
HD83-6	2,211.2	----	----	126.5(2)
HD83-7	2,095.5	----	----	82.0
HD83-8	2,217.2	----	----	78.0R
HD83-9	2,237.6	----	----	110.0
HD83-49	2,205.5	----	----	38.0
HD83-50	2,289.0	----	----	119.5
HD83-51	2,234.9	----	----	98.5
HD83-52	2,249.1	320.0	1,929(1)	333.0
HD83-53	2,248.0	----	----	212.0
WW-3	2,267.0	206.5	----	214.5
			TOTAL	2,141.5

(1) Surface Elevation is approximate
(2) Refusal while drilling, (cobble/boulder or bedrock)

TABLE 4-6
SUMMARY OF 1983 WINTER PROGRAM LABORATORY TESTING
NUMBER OF SAMPLES AND TEST TYPE

		River Channel	Relict Channel	Test Totals
1.	Number of Samples:	409	429	838
2.	Laboratory Tests			
	a. Particle Size	258	270	528
	b. Hydrometer	6	74	80
	c. Atterberg Limits	7	120	127
	d. Moisture Content	0	106	106
	e. Organic Content	2	4	6
	f. Specific Gravity	16	17	33
	g. Compaction	2	1	3
	h. Visual Classification All Samples	258	280	538
	Total Number of Tests	549	872	1,421

TABLE 4-7
RIVER CHANNEL
SUMMARY OF 1983 PROGRAM LABORATORY TESTING
NUMBER OF SAMPLES AND SPECIFIC TESTS

Boring No. HD83	No. of Samples	Visual Class.	Grain Size	Hydrometer	Atterberg Limits	Moisture Content	Organic Content	Specific Gravity	Compaction
10	18	13	13	0	0	0	0	0	0
11	9	3	3	0	0	0	0	0	0
12	13	4	4	0	0	0	0	0	0
13	13	5	5	0	0	0	0	0	0
14	5	3	3	0	0	0	0	0	0
15	5	3	3	0	0	0	0	0	0
16	3	1	1	0	0	0	0	0	0
17	9	6	6	0	0	0	0	0	0
18	5	5	5	0	0	0	0	0	0
19	15	8	8	0	0	0	0	0	0
20	12	8	8	0	0	0	0	0	0
21	13	9	9	0	0	0	0	0	0
22	17	11	11	0	0	0	0	0	0
23	13	8	8	0	0	0	0	0	0
24	3	3	3	0	0	0	0	0	0
25	8	7	7	0	0	0	0	0	0
26	13	7	0	0	0	0	0	0	0
27	12	8	8	0	0	0	0	0	0

TABLE 4-7
RIVER CHANNEL
SUMMARY OF 1983 PROGRAM LABORATORY TESTING
NUMBER OF SAMPLES AND SPECIFIC TESTS

Boring No. HD83	No. of Samples	Visual Class.	Grain Size	Hydrometer	Atterberg Limits	Moisture Content	Organic Content	Specific Gravity	Compaction
28	10	8	8	2	1	0	0	2	0
29	11	6	6	0	0	0	0	0	0
30	10	6	6	0	0	0	0	0	0
31	11	6	6	0	0	0	0	0	0
32	5	3	3	0	0	0	0	0	0
33	3	2	2	0	0	0	0	0	0
34	2	1	1	0	0	0	0	0	0
35	10	6	6	0	0	0	0	0	0
36	4	2	2	0	0	0	0	0	0
37	26	14	14	0	0	0	0	0	0
38	19	10	10	0	0	0	0	0	0
39	26	14	14	0	0	0	0	6	0
40	6	3	3	0	0	0	0	1	0
41	16	9	9	0	0	0	0	4	0
42	11	8	8	0	0	0	0	2	0
43	12	9	9	0	0	0	0	0	1
44	11	8	8	0	0	0	1	0	1
45	11	5	5	3	1	0	0	0	0
46	11	6	6	0	0	0	0	0	0
47	12	7	7	0	2	0	0	0	0
48	15	9	9	1	3	0	0	0	0
Subtotal	409	258	258	6	7	0	2	16	2

Total: 549 Tests

TABLE 4-8
RELICT CHANNEL
SUMMARY OF 1983 PROGRAM LABORATORY TESTING
NUMBER OF SAMPLES AND SPECIFIC TESTS

Boring No. HD83	No. of Samples	Visual Class.	Grain Size	Hydrometer	Atterberg Limits	Moisture Content	Organic Content	Specific Gravity	Compaction
1	58	50	48	11	11	23	2	0	0
2	23	17	17	0	6	16	0	0	0
3	13	6	5	2	6	13	0	0	0
4	14	12	12	3	9	6	0	0	0
5	20	14	12	7	7	9	0	2	0
6	21	16	16	7	7	2	0	2	0
7	9	7	7	3	2	6	0	0	0
8	16	8	8	2	3	0	0	0	0
9	21	12	11	4	5	0	0	0	0
49	10	7	5	2	4	1	1	0	0
50	28	15	15	11	3	0	0	4	0
51	35	15	14	1	11	13	1	1	1
52	93	52	50	14	28	16	0	4	0
53	24	16	16	6	14	1	0	3	0
Water Well No. 3	44	33	34	1	4	0	0	1	0
Subtotal	429	280	270	74	120	106	4	17	1

Total 872 Tests

TABLE 4-9
RELICT CHANNEL
SUMMARY OF INSTRUMENTATION INSTALLATION
TYPE, DEPTHS, AND ELEVATIONS

BORING NO.	SURFACE ELEVATION	DATE INSTALLED	PIEZOMETER POINT DEPTH	PIEZOMETER ELEVATION	PIEZOMETER READINGS, ELEVATION 3/83	4/83	5/83	THERMAL PROBE TOTAL DEPTH
HD83	2,246.2	2/18/83	225.0	2,021.2	2,147.0	2,059.3	2,060.4	230.0
HD83-2	2,147.1	2/07/83	75.5	2,071.6	2,162.8	2,127.0	2,127.0	
HD83-3	2,220.0	NOT INSTRUMENTED						
HD83-4	2,246.7	2/09/83	57.0	2,189.7	2,247.4	2,242.8	2,246.2	60.0
HD83-5	2,283.7	2/10/82	70.0	2,213.7	2,299.4	2,264.5	80.0	
HD83-6	2,211.2	2/12/83						125.0
HD83-7	2,095.5	2/12/83					82.0	
HD83-8	2,217.2	2/13/83					80.0	
HD83-9	2,237.6	2/13/83					110.0	
HD83-9	2,205.5	3/20/83					38.0	
HD83-50	2,289.0	3/21/83					119.5	
HD83-51	2,234.9	NOT INSTRUMENTED						
HD83-52	2,249.1	3/26/83					333.0	
HD83-53	2,248.0	NOT INSTRUMENTED						

TABLE 5-1
RIVER CHANNEL
SUMMARY OF MATERIAL CLASSIFICATIONS

MATERIAL	% OF TOTAL MATERIALS	NUMBER OF SAMPLES	FEET SAMPLED	% FRACTURED +3/4 INCH	GRADING	CLASSIFICATION
GRAVEL	9.8	21	76	36.7	WELL	GW
SANDY GRAVEL	67.6	150	524	18.9	WELL	GW-GM
GRAVELLY SAND	21.4	50	166	11.5	POOR	SP-SM
SAND	1.2	6	10	3.8	POOR	SP-SM
TOTALS	100.0	227	776			

TABLE 5-2
RIVER CHANNEL
IN-SITU OVERBURDEN PERMEABILITY TEST RESULTS

BOREHOLE NUMBER	DEPTH TESTED (FT.)	GEOLOGIC DESCRIPTION	DURATION OF TEST (MIN.)	TOTAL HEAD (FT)	PERMEABILITY (CM/SEC)
HD83-19	28	Fine to coarse sand and fine gravel trace silt, trace coarse gravel	19	3.5	$1.5x10^{-3}$
HD83-20	48	fine to coarse sand	30	5.0	$7.4x10^{-3}$
HD83-21	18	fine to coarse sand and fine gravel, trace silt/clay	30	8.0	$5.0x10^{-2}$
	38	Medium to coarse sand, some gravel, trace fine sand/silt	12	8.0	$1.2x10^{-1}$
	48	Fine to coarse sand, some fine to coarse gravel, trace silt/clay	20	8.0	$2.1x10^{-2}$
	58	Fine sand, trace medium sand, trace fine gravel, trace silt/clay	15	8.0	$2.6x10^{-2}$
HD83-22	28	Coarse sand, some fine to coarse gravel, trace fine sand/silt	12	9.0	$1.1x10^{-2}$
	58	Medium to coarse sand, some fine to coarse gravel	12	9.0	$1.1x10^{-2}$
HD83-28	28	Coarse sand and fine gravel, little fine sand and silt, trace to little coarse gravel.	20	3.0	$2.0x10^{-2}$
HD83-30	58	Coarse sand and fine gravel, some medium sand, little coarse gravel sub-rounded, grey saturated.	10	10.0	6.8x10-2

TABLE 5-3
RIVER CHANNEL
BEDROCK HYDRAULIC PRESSURE TEST RESULTS

INTERVAL TESTED (ft)	GEOLOGIC DESCRIPTION	DURATION OF TEST (min.)	PRESSURE (psi)	TOTAL HEAD (ft)	PERMEABILITY (cm/sec)
DH83-4 40-49	Diorite and altered diorite, closely to intensely fractured	5	10	27	
		5	10	50	
		8	10	27	

55-64	Diorite, little to closely fractured	5	15	39	3.6×10^{-5}
		5	30	73	3.0×10^{-5}
		5	45	108	1.5×10^{-5}
		5	30	73	2.5×10^{-5}
		5	15	39	2.9×10^{-5}
					2.7×10^{-5}
81-100	Diorite and altered diorite, moderately fractured	7	20	50	3.1×10^{-5}
		10	30	73	5.4×10^{-6}
		4	20	50	1.4×10^{-6}
		10	30	73	3.5×10^{-6}
					1.0×10^{-5}
97.5-116.5	Diorite and altered diorite, closely to intensely fractured	6	15	39	3.8×10^{-4}
		4	25	62	3.7×10^{-4}
		5	12.5	33	3.1×10^{-4}
					3.5×10^{-4}
DH83-3 105.3-114.3	Diorite, moderately to closely fractured	5	15	38	2.2×10^{-4}
		5	30	73	2.0×10^{-4}
		5	45	107	1.8×10^{-4}
		5	30	73	1.7×10^{-4}
		5	15	38	2.1 x 10-4
					2.0×10^{-4}

TABLE 5-3 Continued
RIVER CHANNEL
BEDROCK HYDRAULIC PRESSURE TEST RESULTS

INTERVAL TESTED (ft)	GEOLOGIC DESCRIPTION	DURATION OF TEST (min.)	PRESSURE (psi)	TOTAL HEAD (ft)	PERMEABILITY (cm/sec)
15-	Diroite moderately to or- closely fractured	5	20	49	8.6×10^{-4}
		6	10	26	1.5×10^{-4}
					5.1×10^{-4}
117.5 126.5	Diorite, moderately to closely fractured	10	15	38	9.2×10^{-4}
		10	30	72	9.0×10^{-4}
		7	45	107	1.0×10^{-3}
		10	30	72	1.2×10^{-3}
					1.0×10^{-3}
HD83-46 79.0- 88.2	Diorite and altered dior- ite, closely to intensely fractured	7	17	47	9.3×10^{-4}
		9	19	51	8.5×10^{-4}
		4	20	55	8.0×10^{-4}
		10	20	55	7.9×10^{-4}
		10	35	89	2.7×10^{-4}
		10	20	55	3.1×10^{-4}
					6.6×10^{-4}
HD83-48 89- 108	Diorite and altered dior- ite, moderately to very closely fractured	10	20	52	6.2×10^{-5}
		10	30	75	5.9×10^{-5}
		10	20	52	6.0×10^{-5}
					6.0×10^{-5}

TABLE 6-1 WATANA RELICT CHANNEL STRATIGRAPHY - GENERALIZED DESCRIPTION OF PROPERTIES[1]

GRAPHIC SYMBOL	UNIT	TYPE OF DEPOSIT	DESCRIPTION	GEOLOGICAL AND ENGINEERING REMARKS [2]	UNIFIED SOIL CLASSIFICATION [3]	THICKNESS RANGE IN FEET [4]
	A/B	Surficial Deposit	Organics, peat, silt and boulders raised by frost action.	Organic mat which includes localized boulder fields and bogs. Within the active layer/seasonal frost penetration zone.	OL, PT, SM	0.5 - 8.0
	C	Ice Disintegration	Grey brown, gravelly sand to silty sand with little to some gravel and cobbles. Coarse fraction subangular to subrounded.	Hummocky, knob and kettle topography. Variable density Permafrost detected in 1 out of 16 possible borings. No groundwater detected.	SM, SC	2.5 - 38.0
	M	Basal Till	Grey to dark grey silty sand to clay with little angular to subrounded gravel and cobbles, occasional boulder. Very dense, hard. Poorly sorted.	Gravel and cobbles are striated. Limited in areal extent to near the Susitna River Valley. Similar to unit G', it is overconsolidated. Permafrost detected in 1 out of 4 possible borings. No groundwater detected.	SM, SC, CL	14.5 - 79.0
	D	Alluvium	Grey stratified sand, gravel and cobbles. Very dense.	Localized fluvial event, reworking of the underlying outwash, unit E/F, found in topographic lows on top of outwash. No permafrost or groundwater detected.	SM, SP, SC	1.5 - 55.0
	D'	Lacustrine	Grey to dark greyish brown, laminated clayey silt to clayey silty sand. Very dense, hard. Sorted to partly sorted.	Thin laminated deposit, limited in areal extent. Permafrost detected in 1 out of 4 possible borings. No groundwater detected.	ML, CL, (SC, SM)	3.5 - 23.0
	E/F	Outwash	Olive brown to grey brown, silty sand with little gravel and cobbles to a silty sandy gravel with occasional cobbles and boulders. Coarse fraction subangular to subrounded. Dense to very dense. Poorly sorted.	In places the unit gets coarser with depth, higher energy environment. Thick continuous deposit. Density is loose to medium dense in active frost zone, up to 15 feet deep. Permafrost detected in 3 out of 31 borings. Groundwater detected in 4 out of 15 possible borings.	SM, GM, SC	10.0 - 131.0
	G	Lacustrine and/or Waterlain Till	Dark grey to olive grey, laminated, sandy silt to silty clay, little or no gravel, little to some sand. Very dense. Poorly sorted.	Thin clay, silt and sand interlaminations. Organics and wood present. Overconsolidated. Permafrost detected in 2 out of 17 possible borings. No groundwater was detected. Together with unit G', forms a prominent marker bed.	ML, CL, SM	8.3 - 73.5
	G'	Basal Till	Olive grey to very dark grey, clayey silty sand with trace to little gravel to gravelly silty or clayey sand. Coarse fraction subangular to subrounded and includes occasional cobbles and boulders. Very dense. Poorly sorted.	Gravels and cobbles are striated and polished. Overconsolidated. Permafrost detected in 1 out of 15 possible borings. Groundwater was detected in 1 out of 9 possible borings. Forms a marker bed with unit G.	SM, SC, (ML, CL, GC)	7.0 - 231.0
	H	Alluvium	Grey brown to olive grey, silty sand and sand with little or no gravel to sandy gravel. Coarse fraction subangular to rounded, slightly oxidized. Very dense. Sorted to partly sorted.	Rounded particles, sorted, relatively clean lenses or layers, possibly stratified. Localized fluvial event, reworking of the underlying outwash, found in topographic lows of unit I. Groundwater detected in 4 out of 6 possible borings. No permafrost detected.	SM, SP, GW-GM	2.0 - 41.0
	I	Outwash	Olive grey, silty sand with little gravel to sandy gravel with little fines. Coarse fraction subangular to subrounded trace rounded; some cobbles, particles oxidized. Very dense. Poorly sorted.	Oxidation on particles, indicative of age and weathering. Organics found in the upper horizon. Trace striations on gravel. Thick nearly continuous deposit. Groundwater detected in 3 out of 6 possible borings. No permafrost detected.	SM, GW-GM, SW, GM, (CL, ML)	6.0 - 77.0
	J'	Lacustrine and/or Stratified Deposits	Olive grey to olive brown, silty sand, trace subangular gravel with some sandy gravel (?). Oxidized and weathered particles, some cobbles and boulders(?). Very dense. Sorted to partly sorted.	Moderately oxidized and weathered, generally sorted, possibly stratified. Overconsolidated. Localized deposit. No permafrost or ground water detected. Mud loss of 50 gals/ft over 25 foot interval in DR-22.	SM, SW, SC	3.0 - 57.7
	J	Basal Till	Olive grey to dark grey, clay to clayey sand little to no subangular to subrounded oxidized(?) gravel. Dense, very hard. Poorly sorted.	Gravels are striated and polished. Overconsolidated. Probable lacustrine or waterlain till at base of unit. No permafrost or groundwater detected.	CL, SM, SC	6.0 - 62.0
	K	Alluvium	Olive grey, silty sandy gravel to sandy gravel with cobbles and boulders (?) Coarse fraction subangulars to rounded, oxidized. Very dense. Sorted.	Rounded particles, sorted, relatively clean. Found only along the main thalweg to date. No permafrost or groundwater detected. Mud loss of 14 gal/ft over an 85 foot interval in DR-22.	GM, GP, GW	36.0 - 161.0

[1] Modified After Acres American, Inc., 1982

[2] Remarks on permafrost are based on Acres Summer 1982 and Harza-Ebasco Winter 1983 Exploration. Remarks on groundwater are based on the 1983 Winter Exploration.

[3] Classification is based on the primary soils types in decreasing order of occurence. Those in parentheses are key secondary types.

[4] Thickness ranges are based on outcrop exposures and drilled thicknesses.

HARZA-EBASCO
SUSITNA JOINT VENTURE

TABLE 6-2

RELICT CHANNEL
DEPTHS TO TOP OF INTERPRETED STRATIGRAPHIC UNITS

STRATIGRAPHIC UNITS

Boring	A/B	C	M	D	D'	E/F	G/G'	H	I	J'	J	K	Bedrock	Total Depth
HD83-1	---	---	---	---	---	0.0	18.0	174.0	194.0	---	243.0	292.0	---	328.0
HD83-2	---	---	---	---	---	0.0	---	---	---	20.0	---	---	77.7	87.0
HD83-3	---	---	---	---	---	0.0	14.0	---	---	---	---	---	---	87.0
HD83-4	0.0	8.0	---	---	---	17.0	60.0	---	---	---	---	---	---	138.0
HD83-5	---	---	---	---	---	0.0	10.0	44.0	86.0	115.0	---	---	---	138.0
HD83-6	---	---	---	---	---	0.0	11.0	---	50.5	86.0	---	---	126.5	126.5
HD83-7	---	---	---	---	---	0.0	14.0	61.5	---	---	---	---	---	82.0
HD83-8	---	---	---	---	---	0.0	---	51.5	56.0	---	---	---	76.5	78.0
HD83-9	---	---	---	---	---	0.0	40.0	---	---	---	---	---	---	110.0
HD83.49	---	---	---	---	---	0.0	19.0	---	---	---	---	---	---	38.0
HD83-50	---	---	---	---	---	0.0	25.0	---	---	---	---	---	---	119.5
HD83-51	---	---	---	---	---	0.0	30.0	---	---	---	---	---	---	98.5
FD83-52	---	0.0	---	---	---	8.5	32.0	208.0	229.0	---	310.0	---	320.0	333.0
HD83-53	---	0.0	---	---	---	20.0	30.0	Not Interpretated			---	---	---	212.0
WW#3	---	0.0	26.0	---	70.0	93.0	143.0	158.0	175.0	---	---	---	206.5	214.5

TABLE 6-3

RELICT CHANNEL - SUMMARY OF MATERIAL CLASSIFICATIONS BY UNITS

UNIT	MATERIAL	FIGURE No. 2	BORING NO.'s	NUMBER OF SAMPLES	FEET OF SAMPLES	APPROXIMATE COEFFICIENCY OF UNIFORMITY CU	APPROXIMATE COEFFICIENCY OF CURVATURE CU	GRADE	UNIFIED SOILS CLASSIFICATION	% OF MAT'L IN SECTION
C	Silty Sand	D-27	4, 52, 53 WW-3	8	27	50.0	1.25	Well	SM	100.0
M	Silty Clayey Sand	D-16	WW-3	8	13	60.0	.83	Poor	SM/SC	100.0
D'	Sandy Silt	D-34	WW-3	4	4	----	----	----	ML	100.0
E/F	Summary of Materials	D-21	1,2,4,5,8,9 49-52,WW-3	45	99	----	----	----	--	100.0
	Sandy Gravel	D-22	2,4,9,49,52 WW-3	10	26	180	1.0	Well	GM	26.3
	Silty Sand	D-23	2,4,9,49,52 WW-3	35	73	50	1.03	Well	SM	73.7
G	Silty Clay	D-35	4-6, 49 WW-3	9	17	----	----	----	CL/CL-ML	100.0
G'	Silty Gravelly	D-17	1,3,4,6,9	91	223	----	----	----	SM/SC/GC	100.0

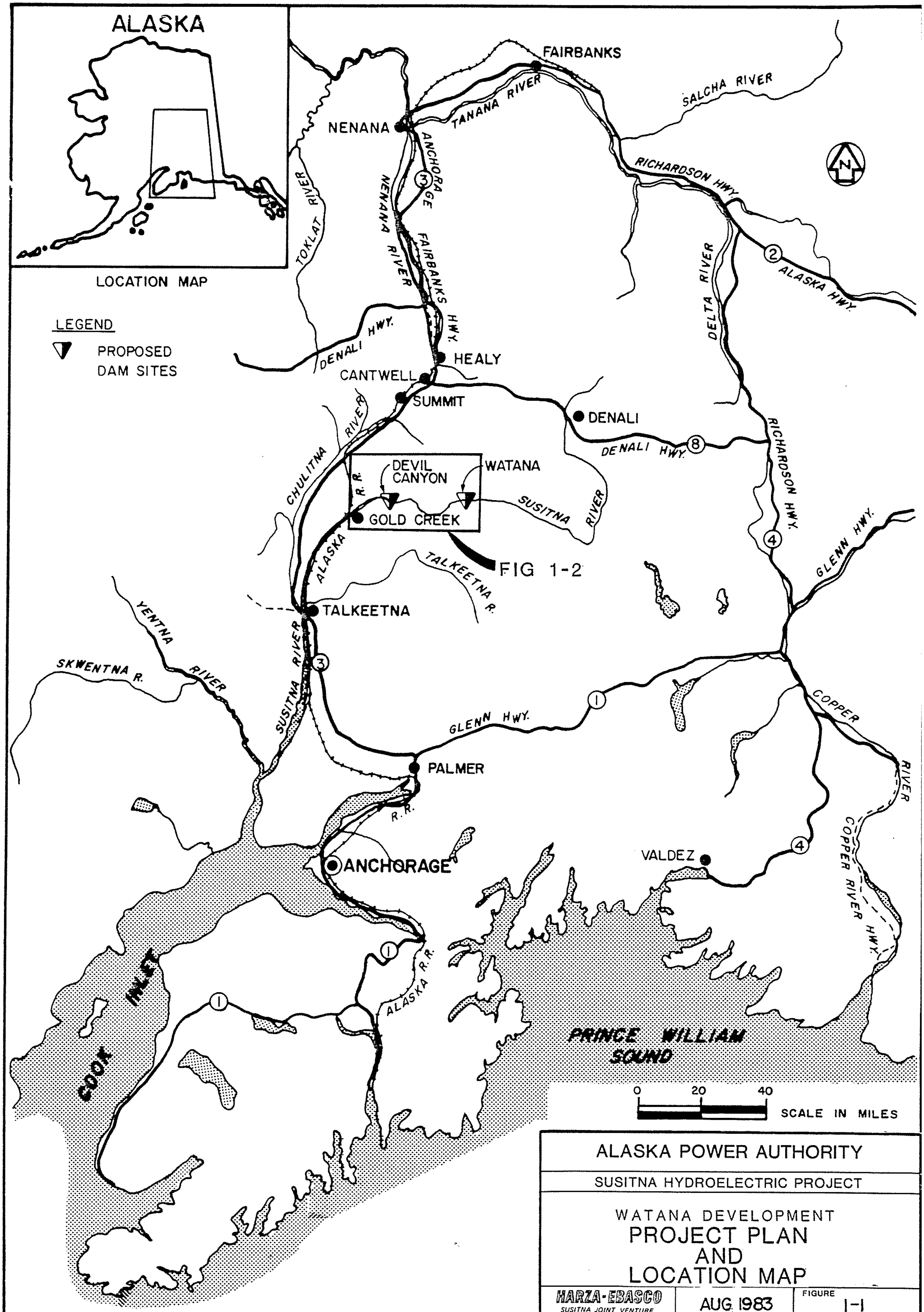
1 Based on the weighted average gradation of all samples tested.

2 Figures found in Appendix D

TABLE 6-3 Continued

RELICT CHANNEL - SUMMARY OF MATERIAL CLASSIFICATIONS BY UNITS

UNIT	MATERIAL	FIGURE No. 2	BORING NO.'s	NUMBER OF SAMPLES	FEET OF SAMPLES	APPROXIMATE COEFFICIENCY OF UNIFORMITY CU	APPROXIMATE COEFFICIENCY OF CURVATURE CU	GRADE	UNIFIED SOILS CLASSIFICATION	% OF MAT'L IN SECTION
H	Summary of Materials	D-28	1,3,4,8,52 WW-3	16	31	----	----	----	----	100.0
	Sandy Gravel	D-29	1,3,5	6	10	42.85	2.67	Well	GW-GM	32.3
	Silty Sand	D-30	1,8,52,WW-3	10	21	12.0	1.33	Well	SM	67.7
I	Summary of Materials	D-24	1,5,6,8,52	22	59	----	----	----	----	100.0
	Sandy Gravel	D-25	5,6,52	5	11	128.57	1.28	Well	GW-GM	18.7
	Silty Sand	D-26	1,5,6,8,52	17	48	50.0	1.45	Well	SM	81.3
J'	Silty Sand	D-36	2,5,6	18	23	33.3	1.33	Well	SM/SM-SC	100.0
J	Summary of Materials	D-18	1	8	12	----	----	----	----	100.0
	Sandy Silt	D-19	1	4	6	----	----	----	SM-SC	50.0
	Clay	D-20	1	4	6	----	----	----	CL	50.0
K	Summary of Materials	D-31	1	9	10	----	----	----	----	100.0
	Sandy Gravel	D-32	1	7	7	12.8	4.75	Poor	GP-GM	70.0
	Silty Sandy Gravel	D-33	1	2	3	----	----	----	GM	30.0

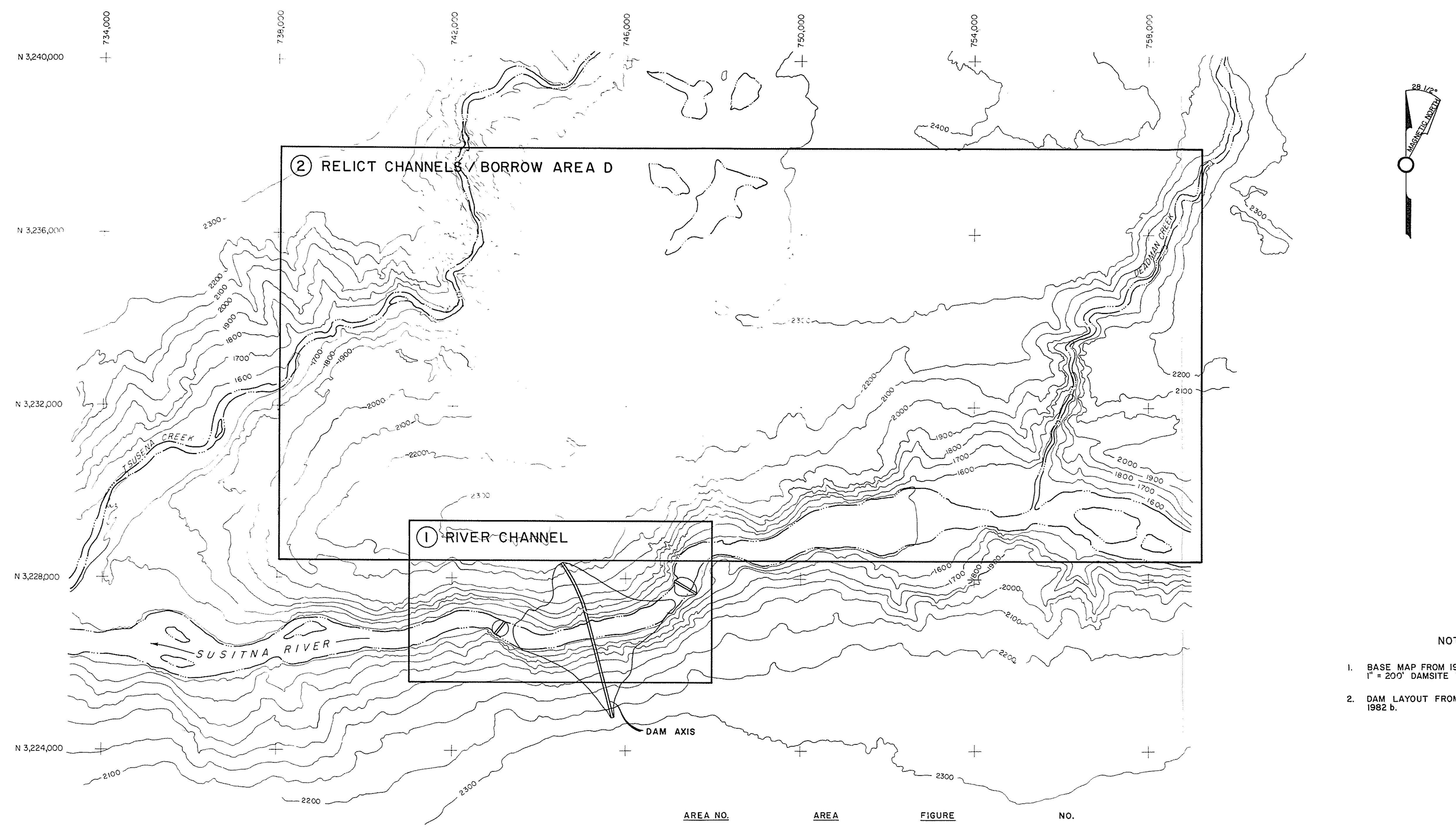


ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT
PROJECT PLAN AND LOCATION MAP

HARZA-EBASCO SUSITNA JOINT VENTURE	AUG 1983	FIGURE 1-1

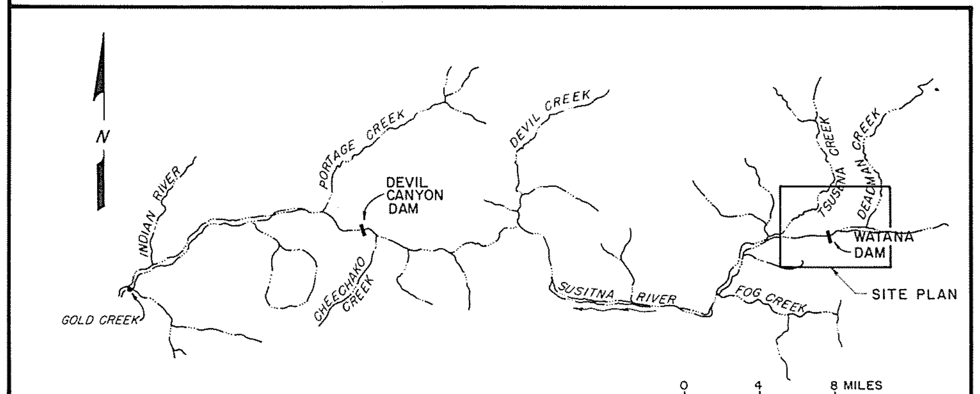


AREA NO.	AREA	FIGURE	NO.
①	SUSITNA RIVER		
		EXPLORATION MAP	5-1
		ALLUVIUM THICKNESS AND RIVER BED CONTOURS	5-2
		TOP OF BEDROCK	5-8
		MAIN DAM CROSSECTION B-B	5-9
		ADDITIONAL BORINGS	5-11
		UPSTREAM COFFERDAM CROSSECTION	5-14
		DOWNSTREAM COFFERDAM CROSSECTION	5-16
②	RELICT CHANNELS		
		EXPLORATION MAP	6-1
		TOP OF BEDROCK	6-2
		CROSSECTION A-A	6-3
		CROSSECTION B-B	6-4
		CROSSECTION C-C	6-5
		TOP OF UNIT 6/6'	6-6

NOTES

1. BASE MAP FROM 1978 CORPS OF ENGINEERS 1" = 200' DAMSITE TOPOGRAPHY.
2. DAM LAYOUT FROM ACRES AMERICAN, INC., 1982 b.

SCALE 0 1000 2000 FEET



VICINITY MAP
SUSITNA PROJECT DAMSITE

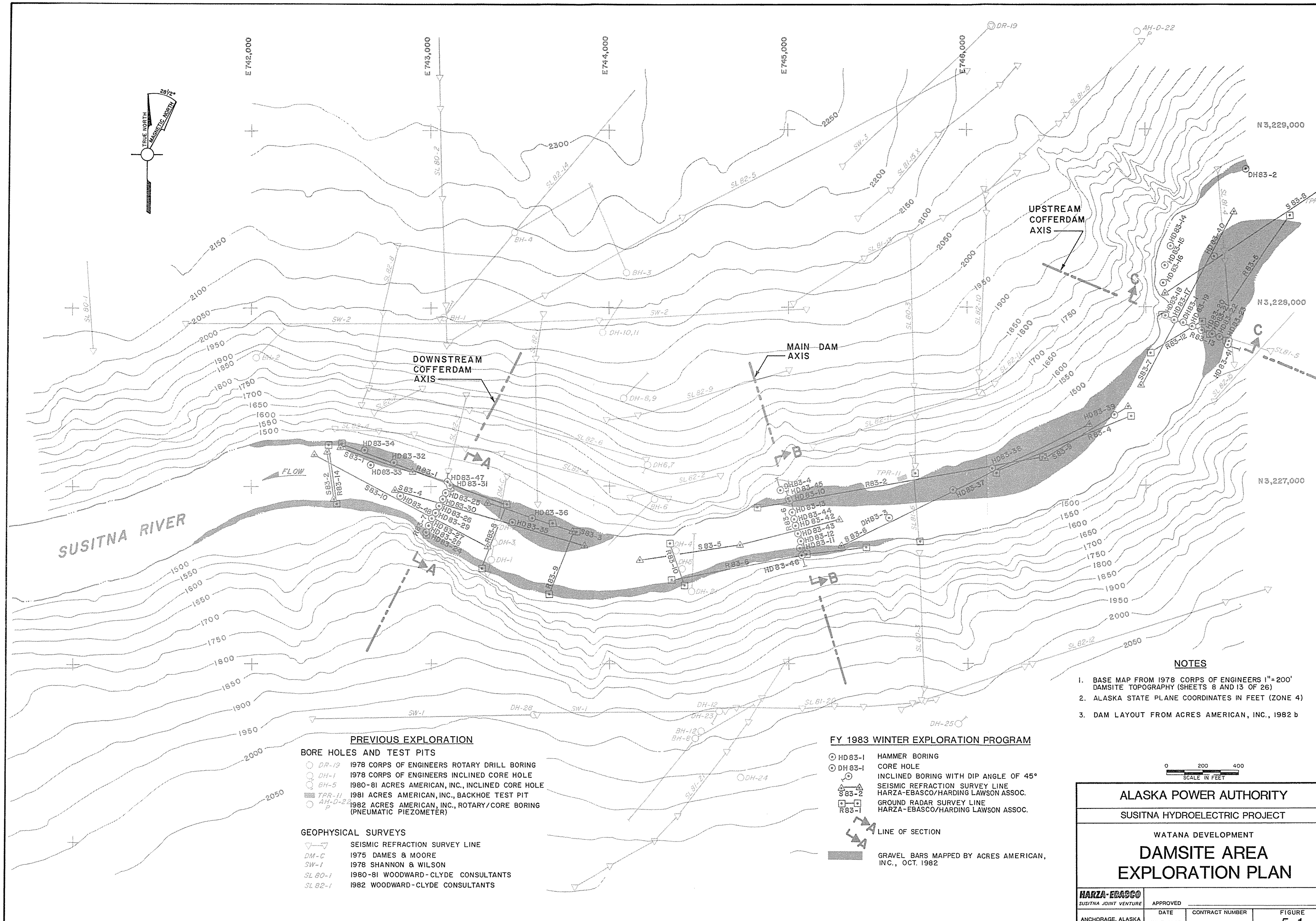
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

SITE PLAN AND VICINITY MAP

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUG 1983	CONTRACT NUMBER	FIGURE 1-2



NOTES

1. BASE MAP FROM 1978 CORPS OF ENGINEERS 1"=200' DAMSITE TOPOGRAPHY (SHEETS 8 AND 13 OF 26)
2. ALASKA STATE PLANE COORDINATES IN FEET (ZONE 4)
3. DAM LAYOUT FROM ACRES AMERICAN, INC., 1982 b

PREVIOUS EXPLORATION

BORE HOLES AND TEST PITS

- DR-19 — 1978 CORPS OF ENGINEERS ROTARY DRILL BORING
- DH-1 — 1978 CORPS OF ENGINEERS INCLINED CORE HOLE
- BH-5 — 1980-81 ACRES AMERICAN, INC., INCLINED CORE HOLE
- TPR-11 — 1981 ACRES AMERICAN, INC., BACKHOE TEST PIT
- AH-D-22 P — 1982 ACRES AMERICAN, INC., ROTARY/CORE BORING (PNEUMATIC PIEZOMETER)

GEOPHYSICAL SURVEYS

- SEISMIC REFRACTION SURVEY LINE
- DM-C — 1975 DAMES & MOORE
- SW-1 — 1978 SHANNON & WILSON
- SL 80-1 — 1980-81 WOODWARD-CLYDE CONSULTANTS
- SL 82-1 — 1982 WOODWARD-CLYDE CONSULTANTS

FY 1983 WINTER EXPLORATION PROGRAM

- HD83-1 — HAMMER BORING
- DH83-1 — CORE HOLE
- INCLINED BORING WITH DIP ANGLE OF 45°
- S83-2 — SEISMIC REFRACTION SURVEY LINE HARZA-EBASCO/HARDING LAWSON ASSOC.
- R83-1 — GROUND RADAR SURVEY LINE HARZA-EBASCO/HARDING LAWSON ASSOC.
- A — LINE OF SECTION
- GRAVEL BARS MAPPED BY ACRES AMERICAN, INC., OCT. 1982

0 200 400
SCALE IN FEET

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

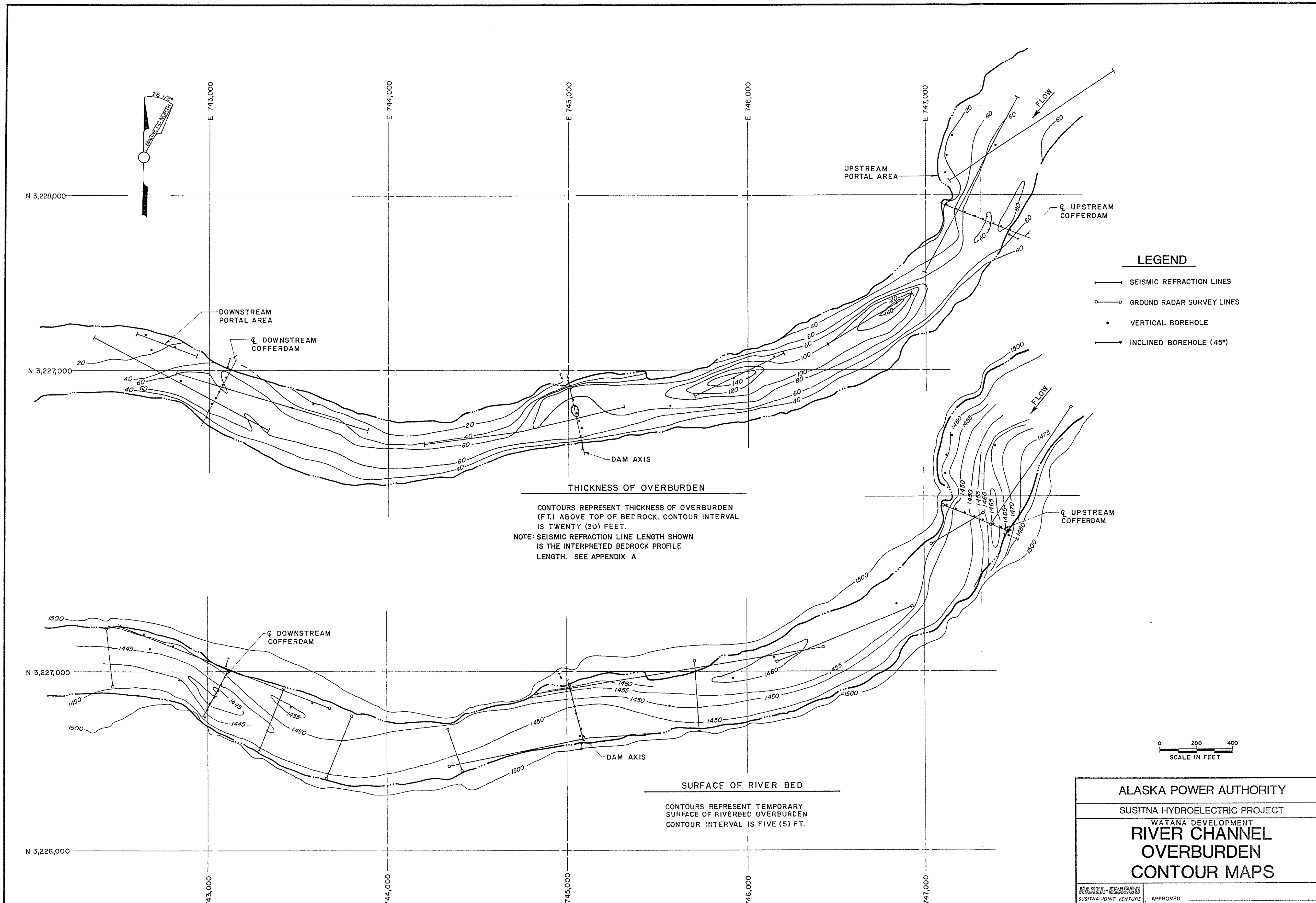
WATANA DEVELOPMENT

DAMSITE AREA EXPLORATION PLAN

HARZA-EBASCO
SUSITNA JOINT VENTURE

ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
JUNE 1983		5-1



ALASKA POWER AUTHORITY

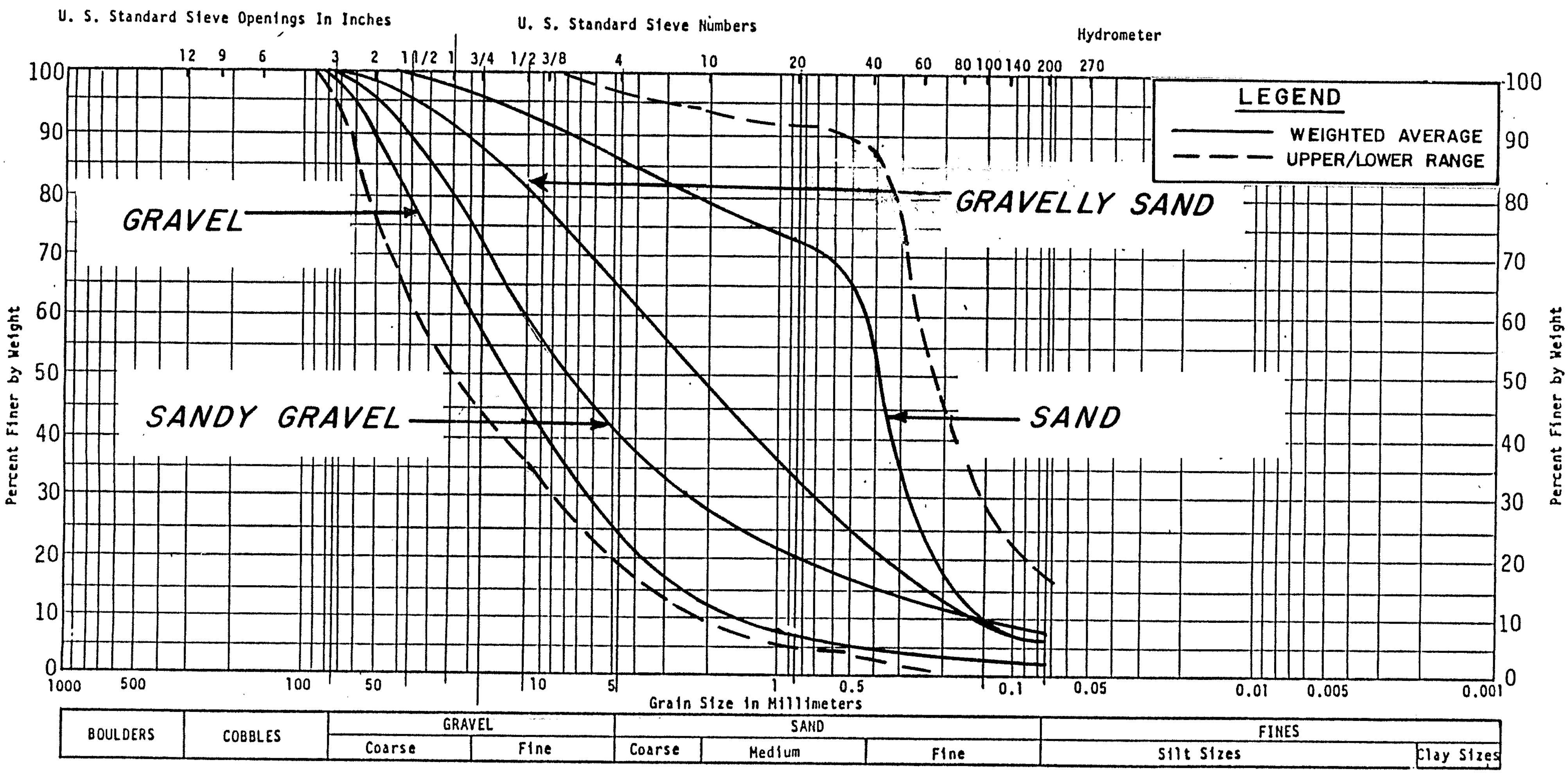
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL OVERBURDEN CONTOUR MAPS

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUG. 1983	CONTRACT NUMBER	FIGURE 5-2

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED GRAVEL	21	76	36.7	10
WELL GRADED SANDY GRAVEL	150	524	18.9	68
POORLY GRADED GRAVELLY SAND	50	166	11.5	21
POORLY GRADED SAND	6	10	3.8	1
TOTALS	227	776	—	100

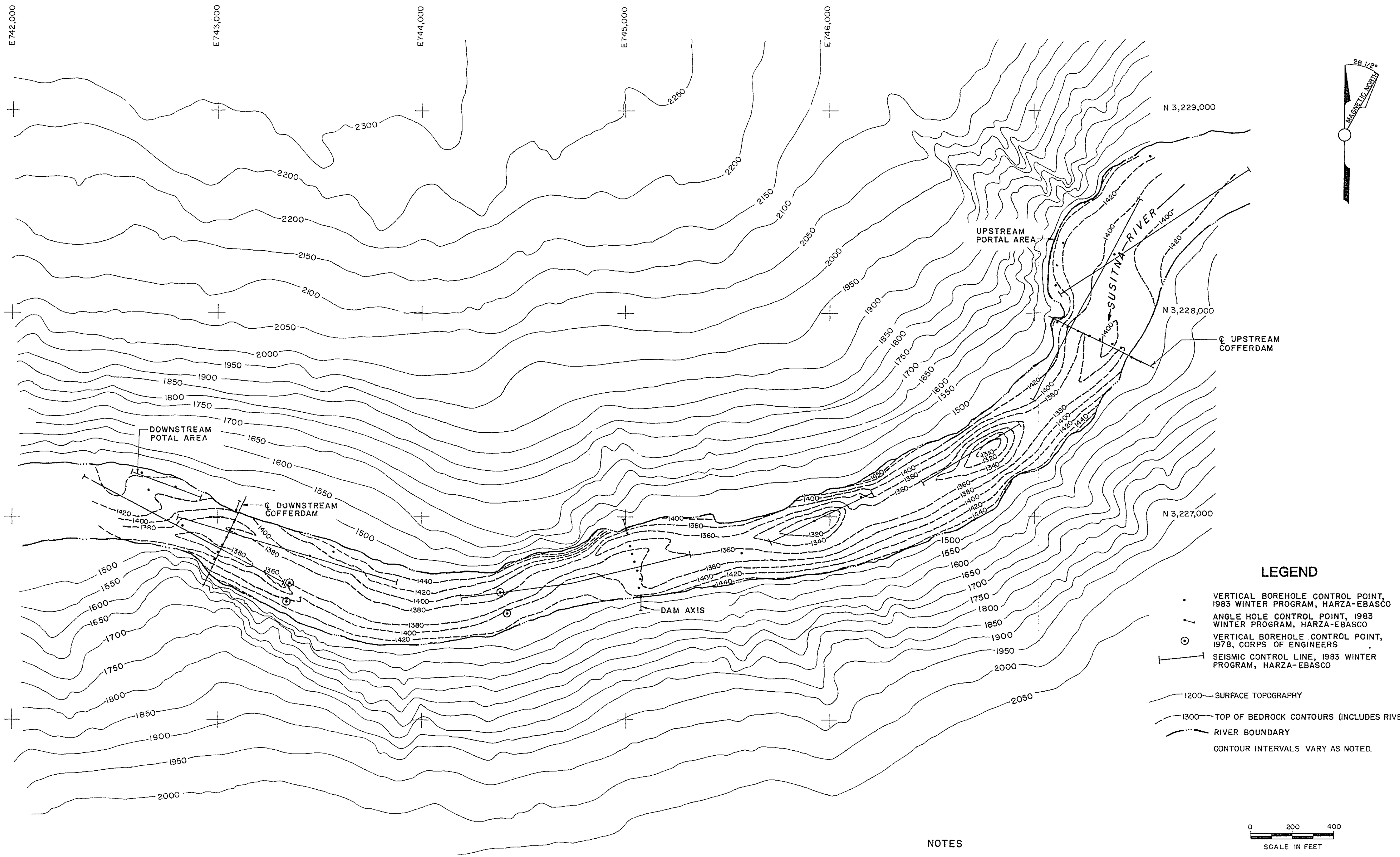
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL FOUNDATION MATERIALS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-3



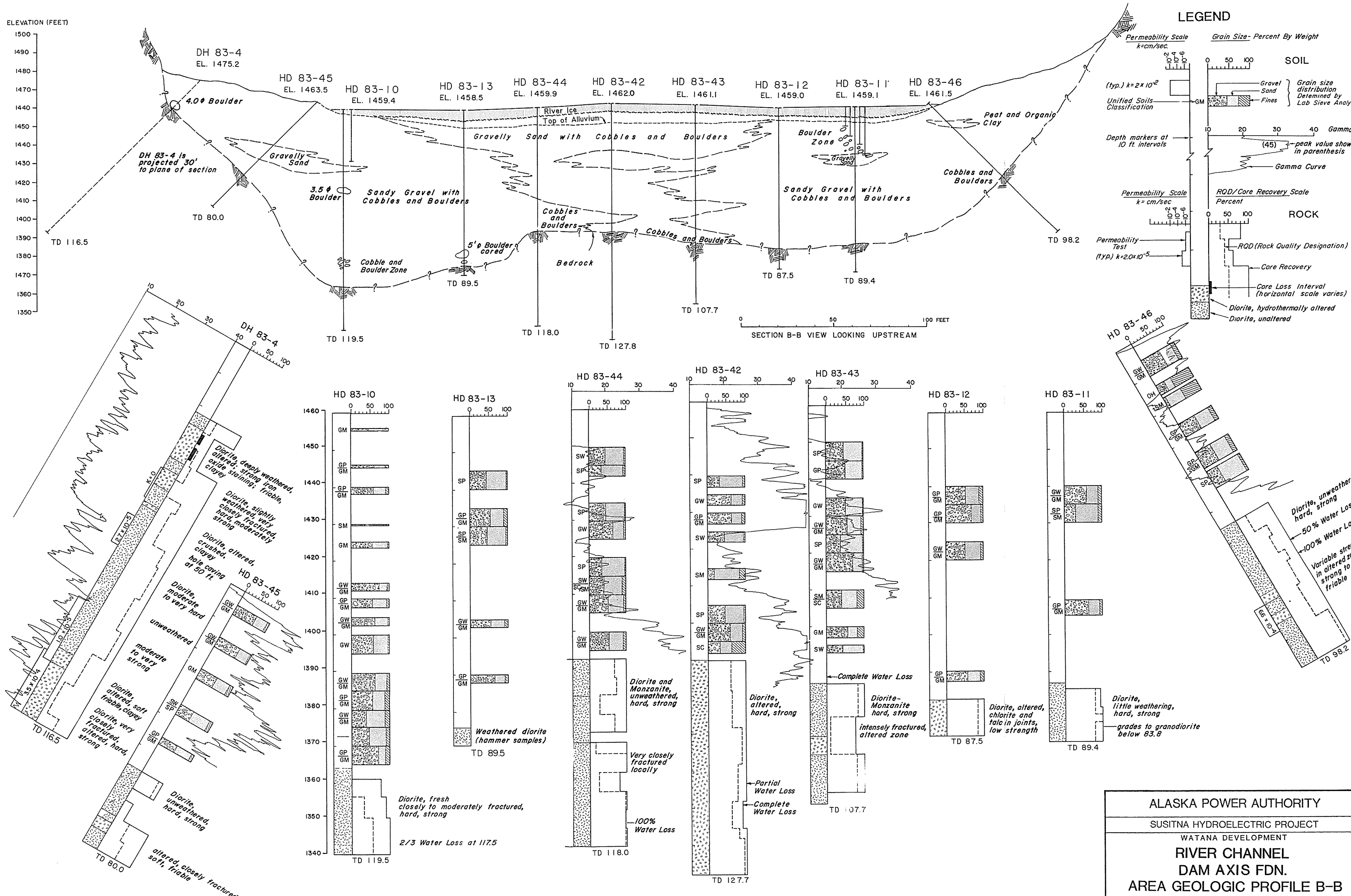
NOTES

1) TOPOGRAPHY FROM 1978 CORP OF ENGINEERS 1"=200' DAMSITE TOPOGRAPHY (SHEETS 8 & 13 OF 26)

2) BEDROCK CONTOURS AND OUTCROP DATA ABOVE RIVER BOUNDARY FROM ACRES AMERICAN, INC., 1982

3) BEDROCK CONTOURS WITHIN RIVER BOUNDARY FROM 1983 WINTER EXPLORATION PROGRAM.

ALASKA POWER AUTHORITY			
SUSITNA HYDROELECTRIC PROJECT			
DAMSITE AREA RIVER CHANNEL CONTOUR MAP TOP OF BEDROCK			
HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUG.1983	CONTRACT NUMBER	DRAWING NUMBER 5-8



ALASKA POWER AUTHORITY

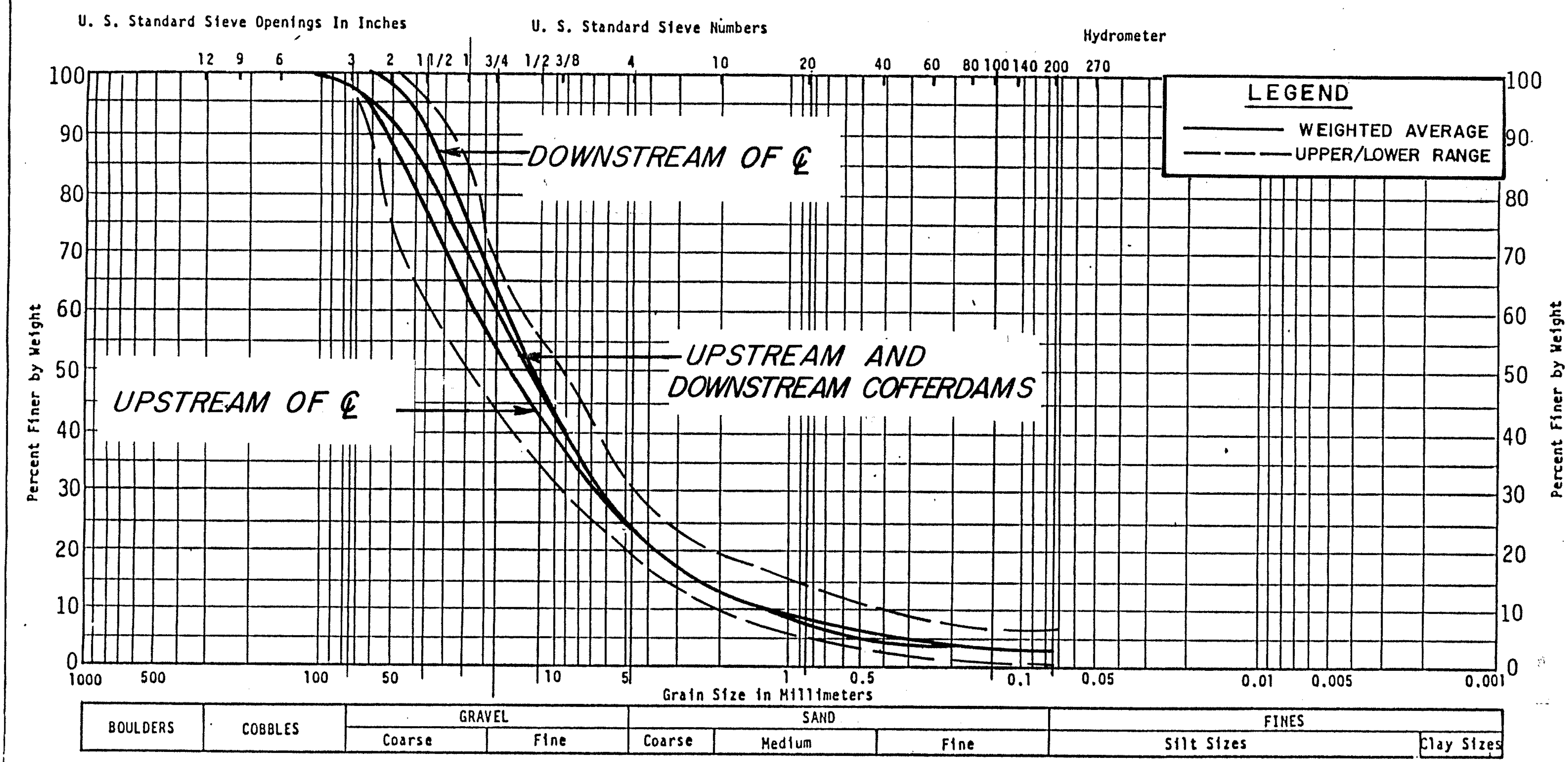
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL DAM AXIS FDN. AREA GEOLOGIC PROFILE B-B

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUGUST 1983	CONTRACT NUMBER	FIGURE 5-9

GRADATION SIZE ANALYSIS



LOCATION	NO. OF SAMPLES	% FRACTURE + 3/4	CLASSIFICATION (USC)
UPSTREAM COFFERDAM	*7*	*30.8*	*WELL GRADED GRAVEL (GW)*
DOWNSTREAM SHELL	*1*	*29.9*	
DOWNSTREAM COFFERDAM	*3*	*37.4*	
UPSTREAM SHELL	*10*	*39.4*	
	TOTAL 21	*WT. AVG. 35.8*	

ALASKA POWER AUTHORITY

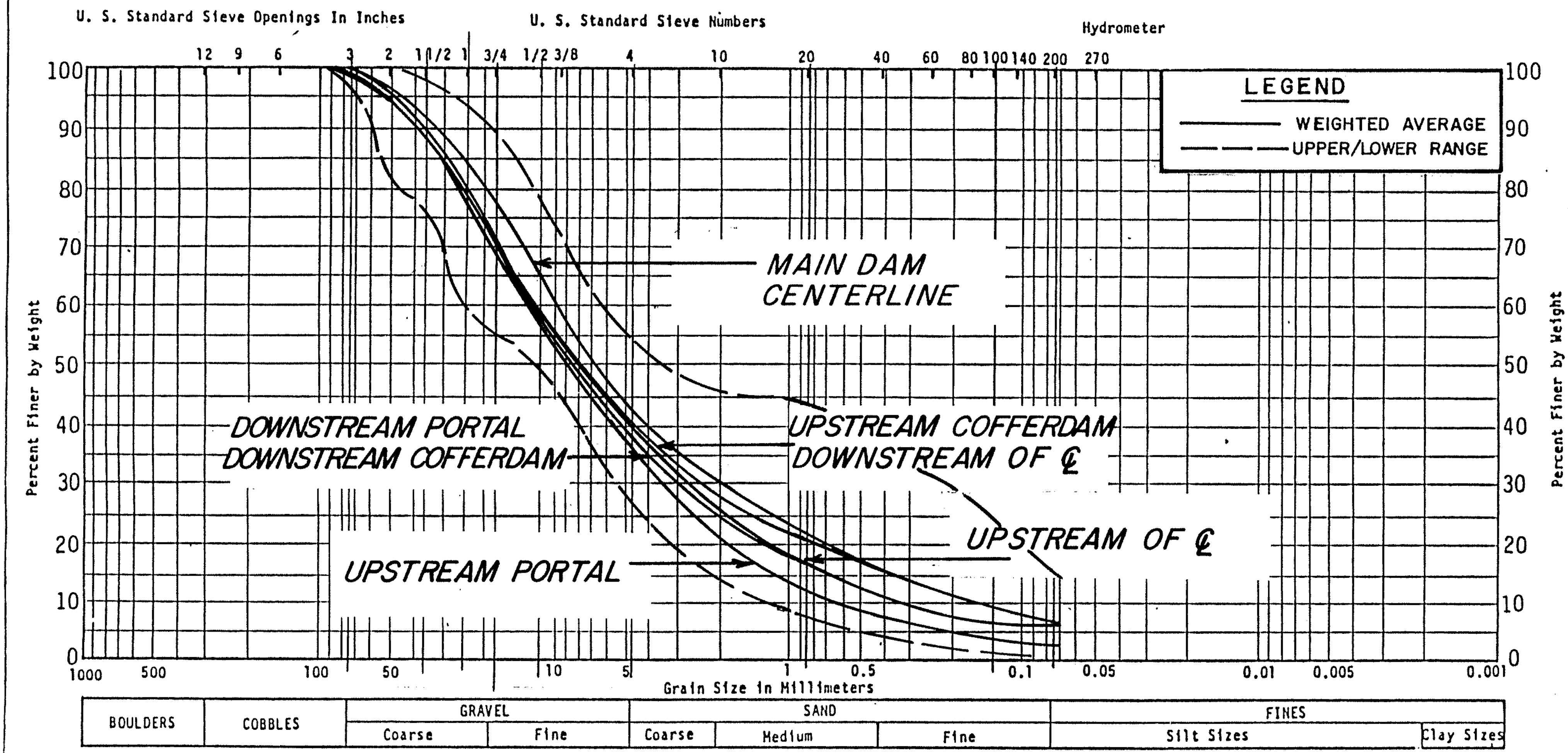
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL FOUNDATION GRAVELS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-4

GRADATION SIZE ANALYSIS



LOCATION	NO. OF SAMPLES	% FRACTURE + 3/4	CLASSIFICATION (USC)
UPSTREAM COFFERDAM	*32*	*25.1*	*WELL GRADED SANDY GRAVEL*
MAIN DAM CENTERLINE	*39*	*20.8*	*(GW-GM)*
DOWNSTREAM COFFERDAM	*40*	*28.0*	
UPSTREAM SHELL	*25*	*23.5*	
DOWNSTREAM SHELL	*2*	*21.2*	
DOWNSTREAM PORTAL	*5*	*21.5*	
UPSTREAM PORTAL	*7*	*25.5*	

ALASKA POWER AUTHORITY

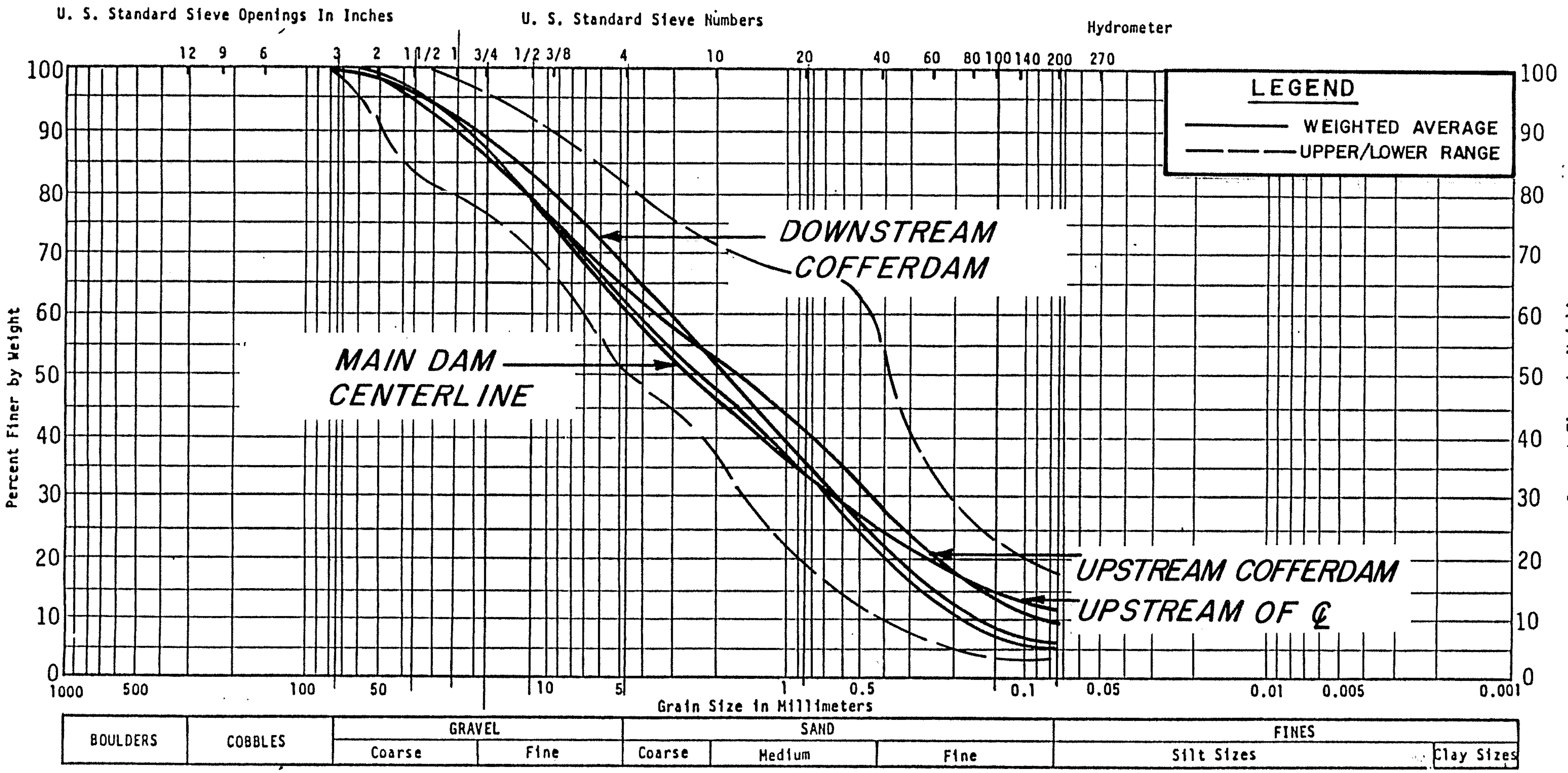
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL FDN. SANDY GRAVELS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE	DATE AUG 1983	FIGURE 5-5

GRADATION SIZE ANALYSIS



LOCATION	NO. OF SAMPLES	% FRACTURE + 3/4	CLASSIFICATION (USC)
UPSTREAM COFFERDAM	*18*	*11.2*	*POORLY GRADED GRAVELLY SAND*
MAIN DAM CENTERLINE	*18*	*12.8*	*(SP- SM)*
DOWNSTREAM COFFERDAM	*11*	*8.6*	
UPSTREAM SHELL	*3*	*15.6*	
	TOTAL 50	*WT. AVG. = 11.5*	

ALASKA POWER AUTHORITY

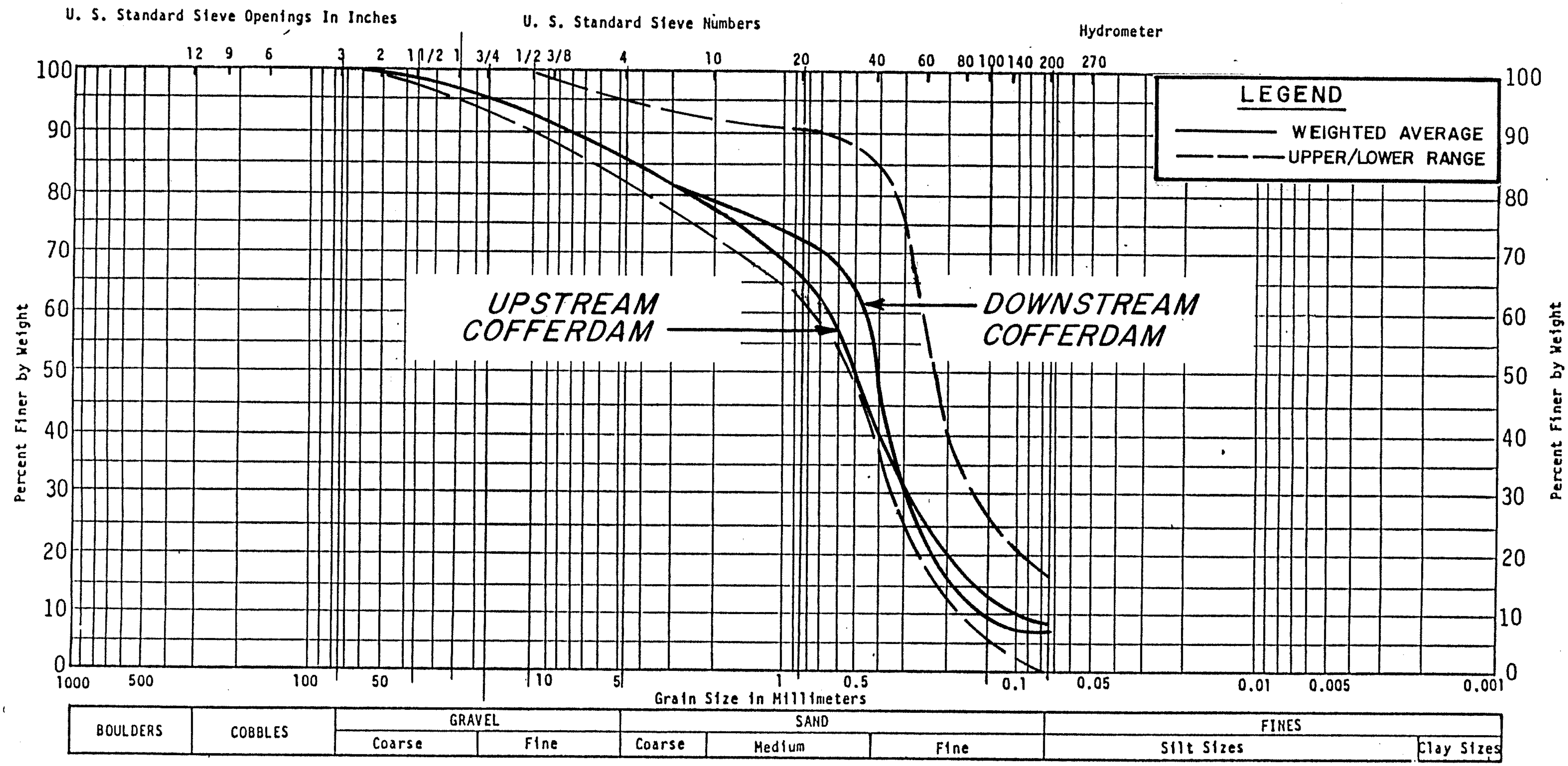
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL FDN. GRAVELLY SANDS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-6

GRADATION SIZE ANALYSIS



LOCATION	NO. OF SAMPLES	% FRACTURE + 3/4	CLASSIFICATION (USC)
UPSTREAM COFFERDAM	*4*	*3.7*	*POORLY GRADED SAND*
DOWNSTREAM COFFERDAM	*2*	*3.8*	*(SP - SM)*
	TOTAL 6	*WT. AVG. 3.7*	

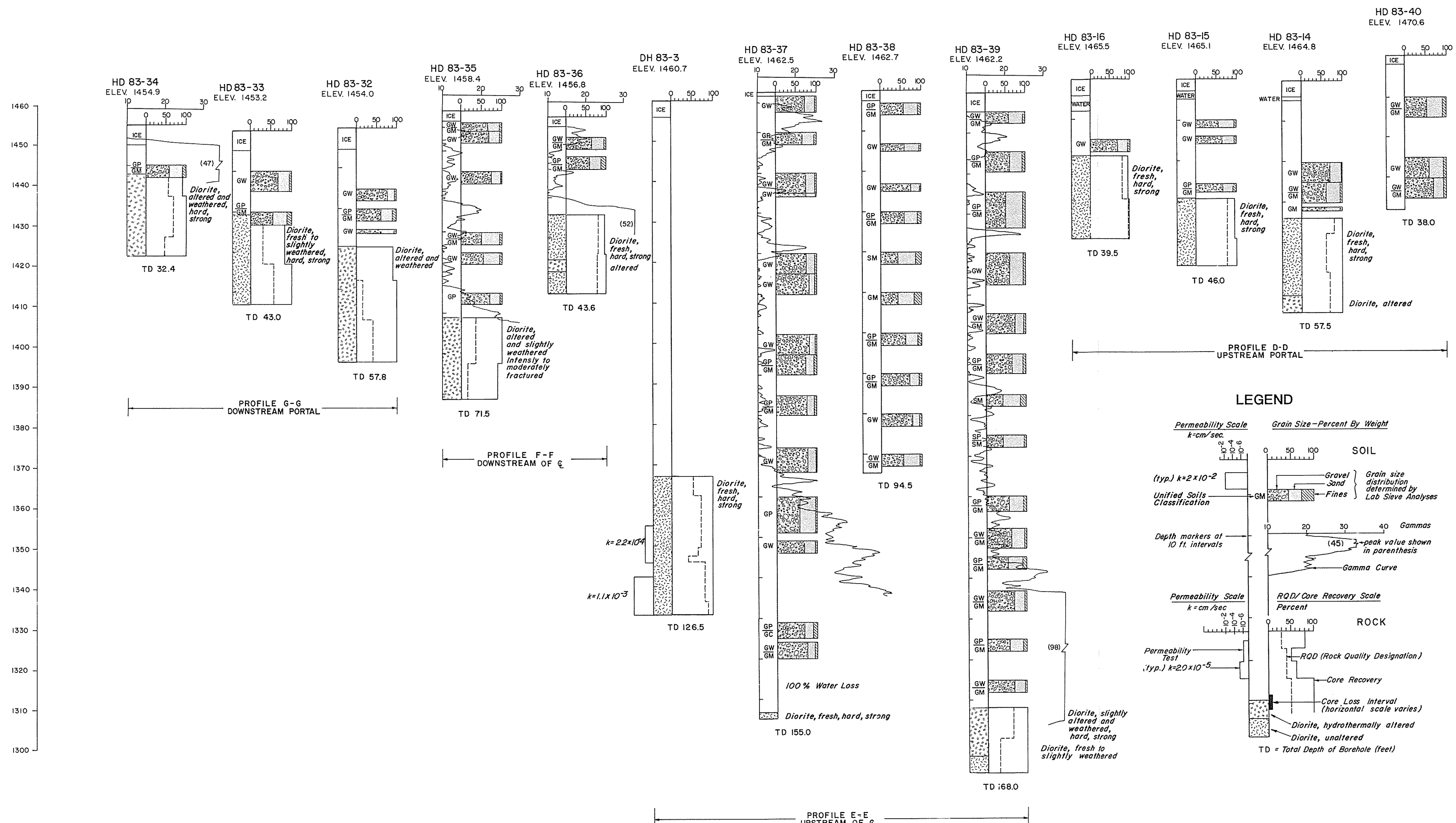
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL FOUNDATION SANDS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-7



NOTES

1. FOR LOCATION OF BORINGS SEE FIGURE 5-1

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

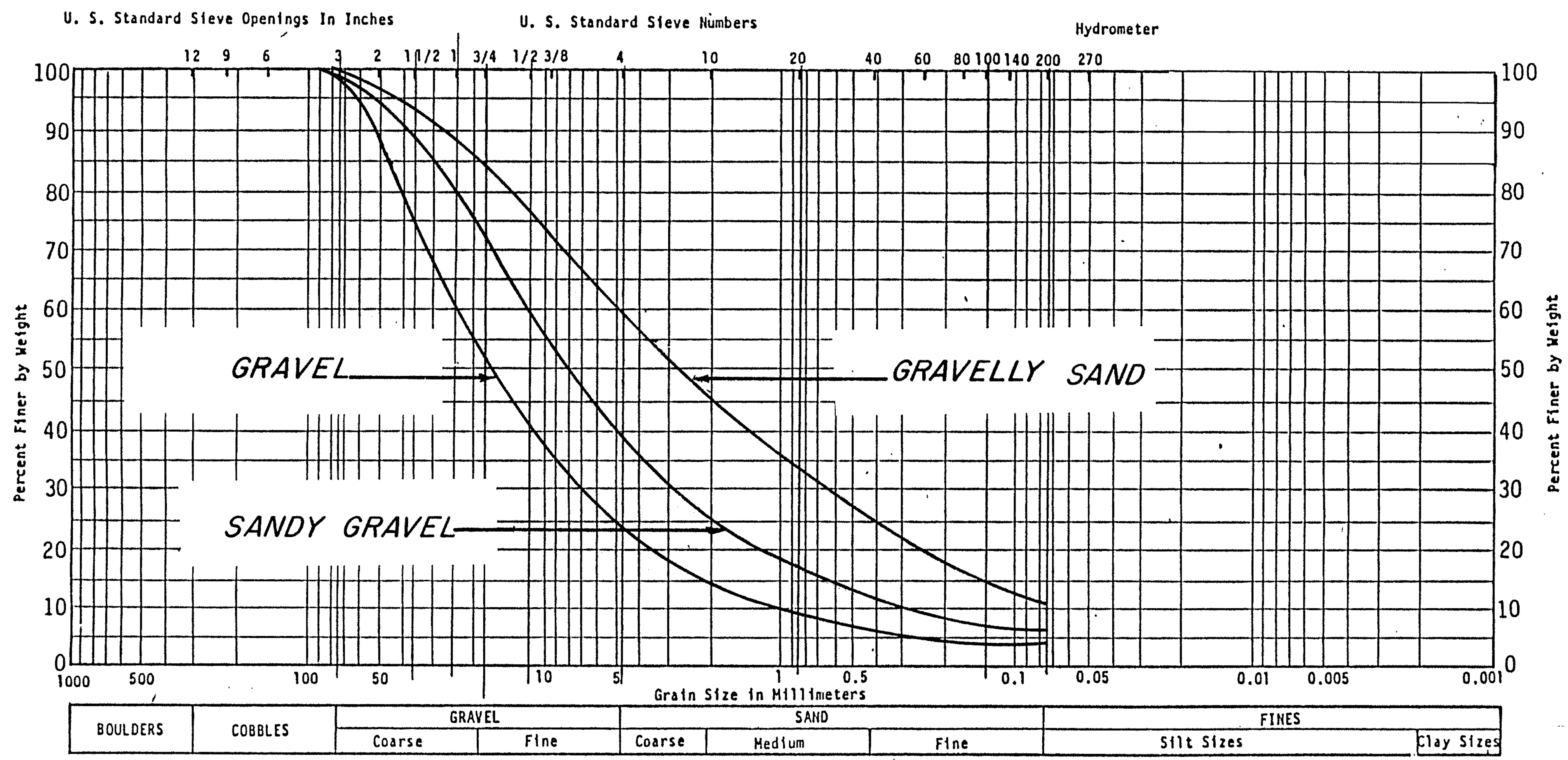
RIVER CHANNEL MISCELLANEOUS BORINGS

HARZA-EBASCO SUSITNA JOINT VENTURE

ANCHORAGE, ALASKA

APPROVED		
DATE AUG. 1983	CONTRACT NUMBER	FIGURE 5-11

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED GRAVEL	10	41	39.4	28
WELL GRADED SANDY GRAVEL	25	97	23.5	66
WELL GRADED GRAVELLY SAND	3	9	15.6	6
TOTALS	38	147	—	100

ALASKA POWER AUTHORITY

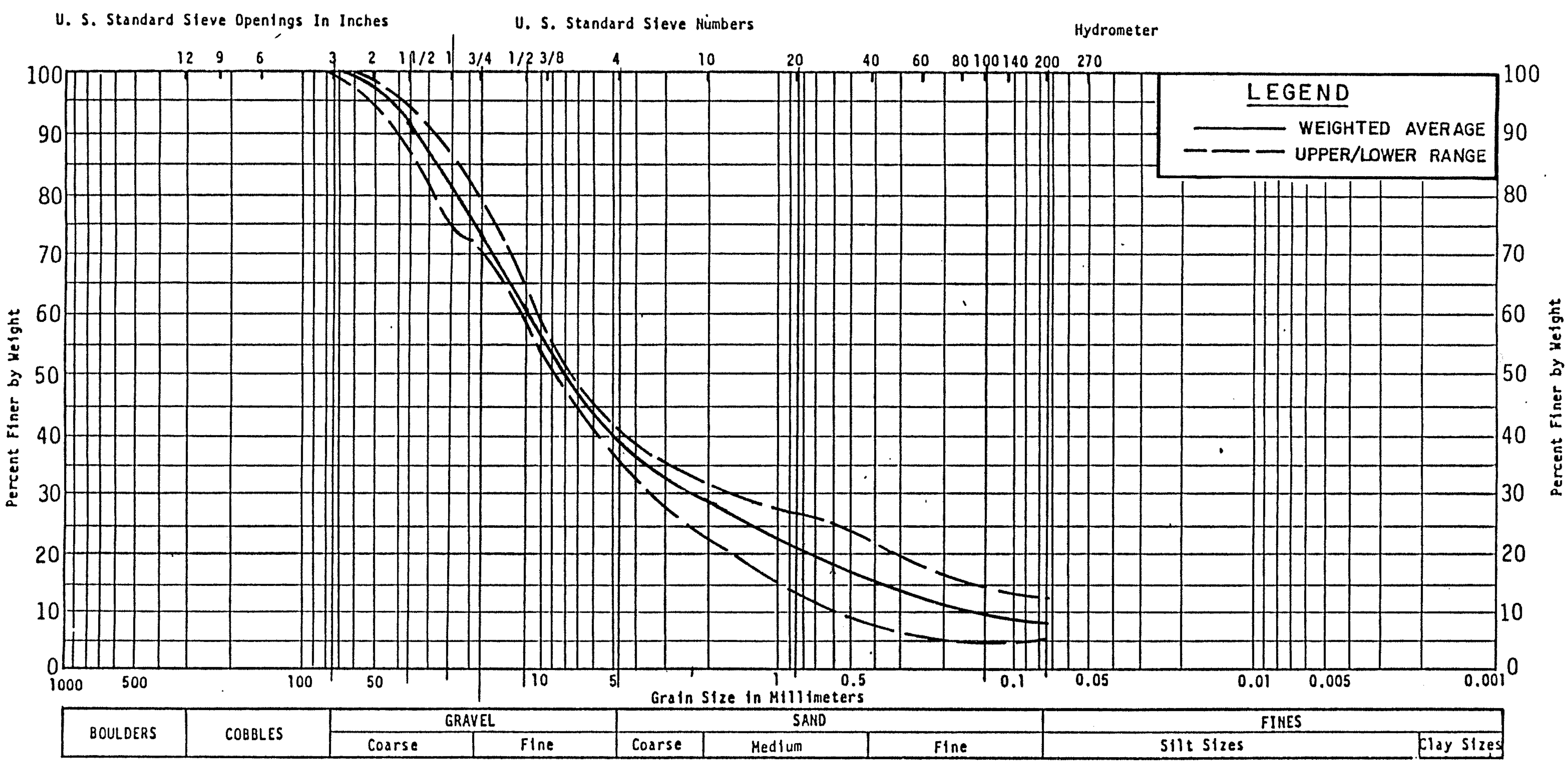
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL AREA U/S OF DAM AXIS GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-12

GRADATION SIZE ANALYSIS



LOCATION	BORING NO.	NO. OF SAMPLES	% FRACTURE + 3/4"	CLASSIFICATION (USC)
DOWNSTREAM	*HD 83-36*	*2*	*21.2*	*WELL GRADED SANDY GRAVEL,*
SHELL				*(GW-GM)*

COMMENT: *6' OF SAMPLE*

ALASKA POWER AUTHORITY

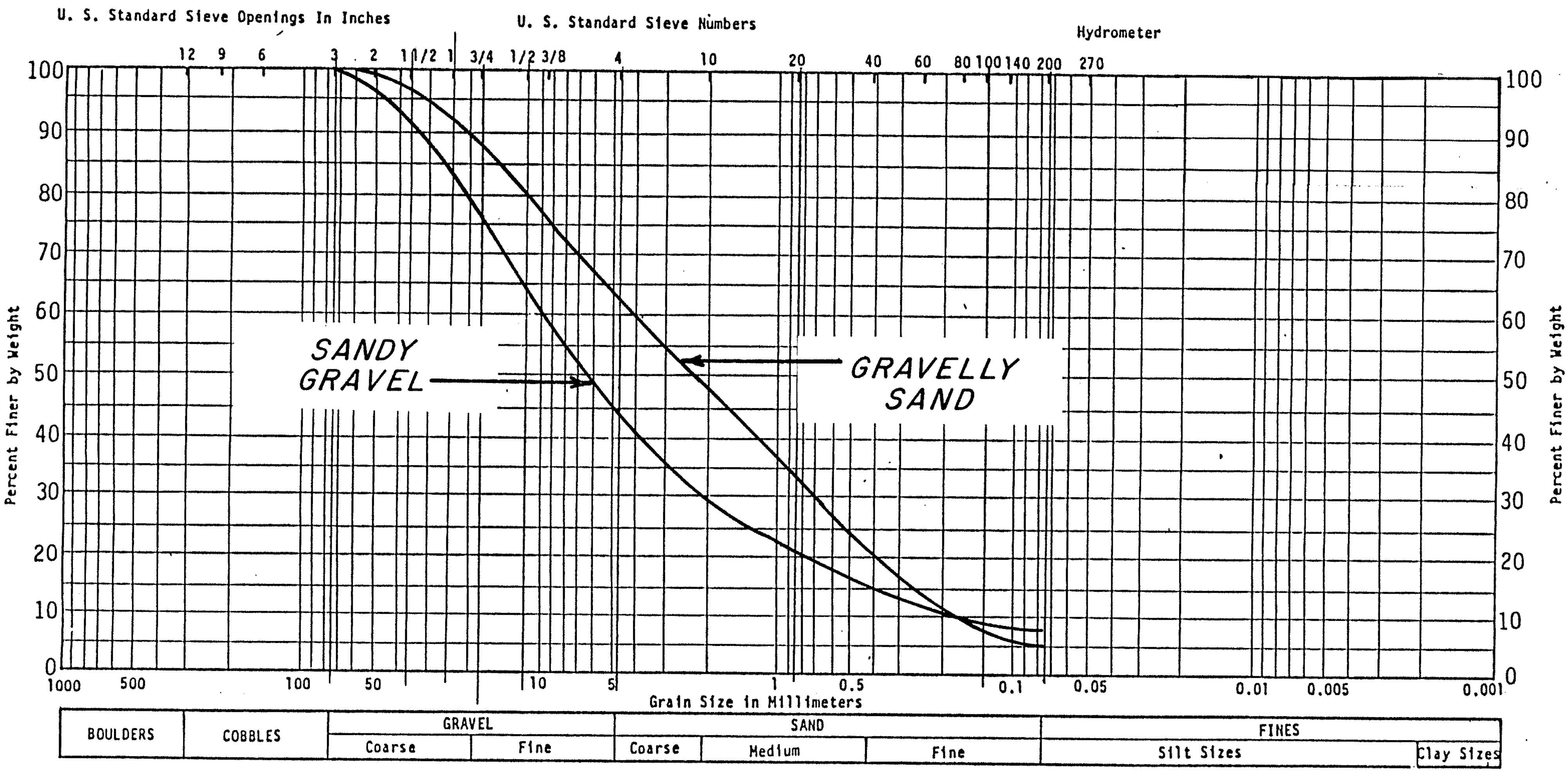
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL AREA D/S OF DAM AXIS SANDY GRAVEL GRAD.

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-13

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED SANDY GRAVEL	39	148	20.8	67
POORLY GRADED GRAVELLY SAND	18	72	12.8	33
TOTALS	57	220	—	100

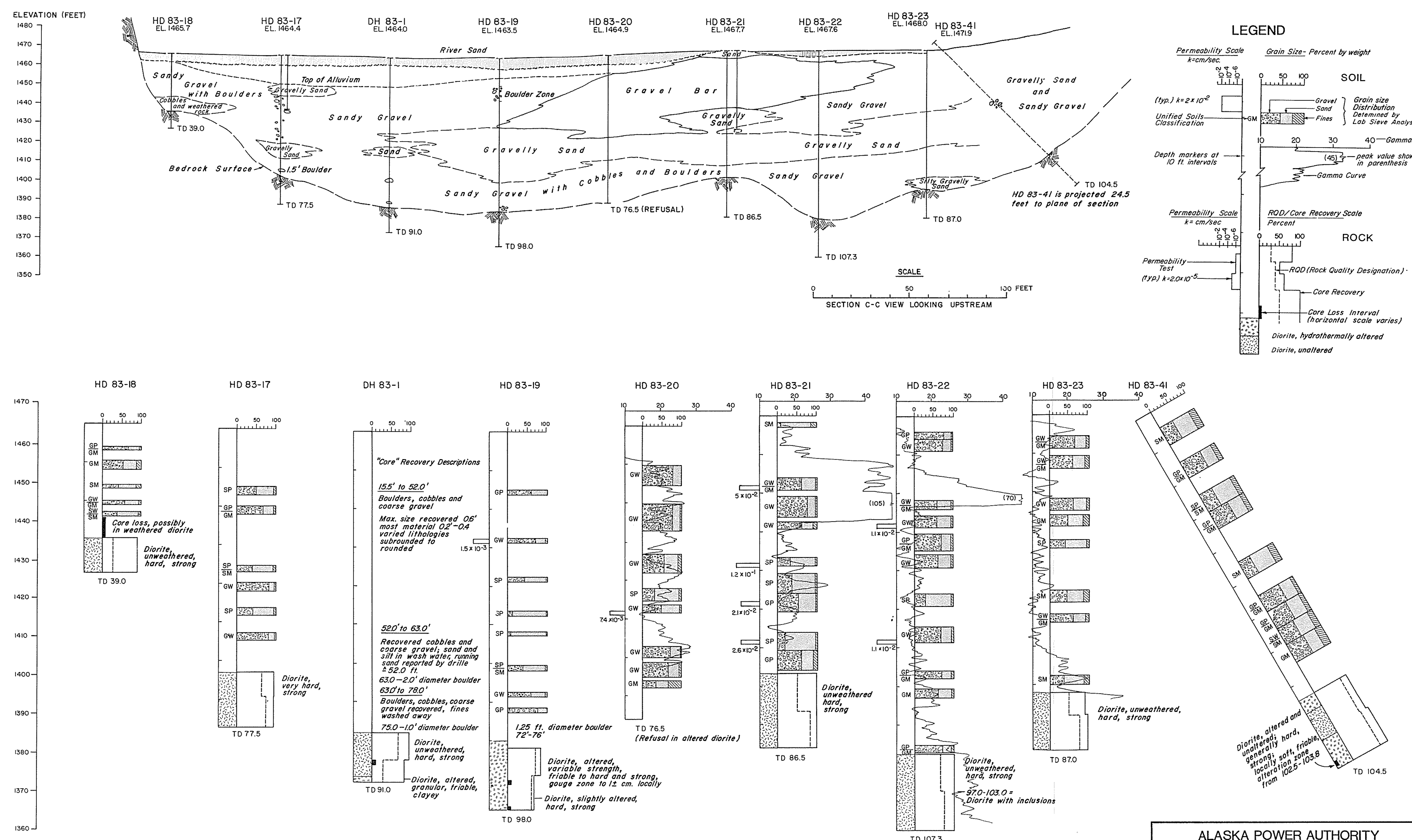
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL DAM AXIS FDN AREA GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-10



NOTE

1. FOR LOCATION OF PROFILE SEE FIGURE 5-1

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

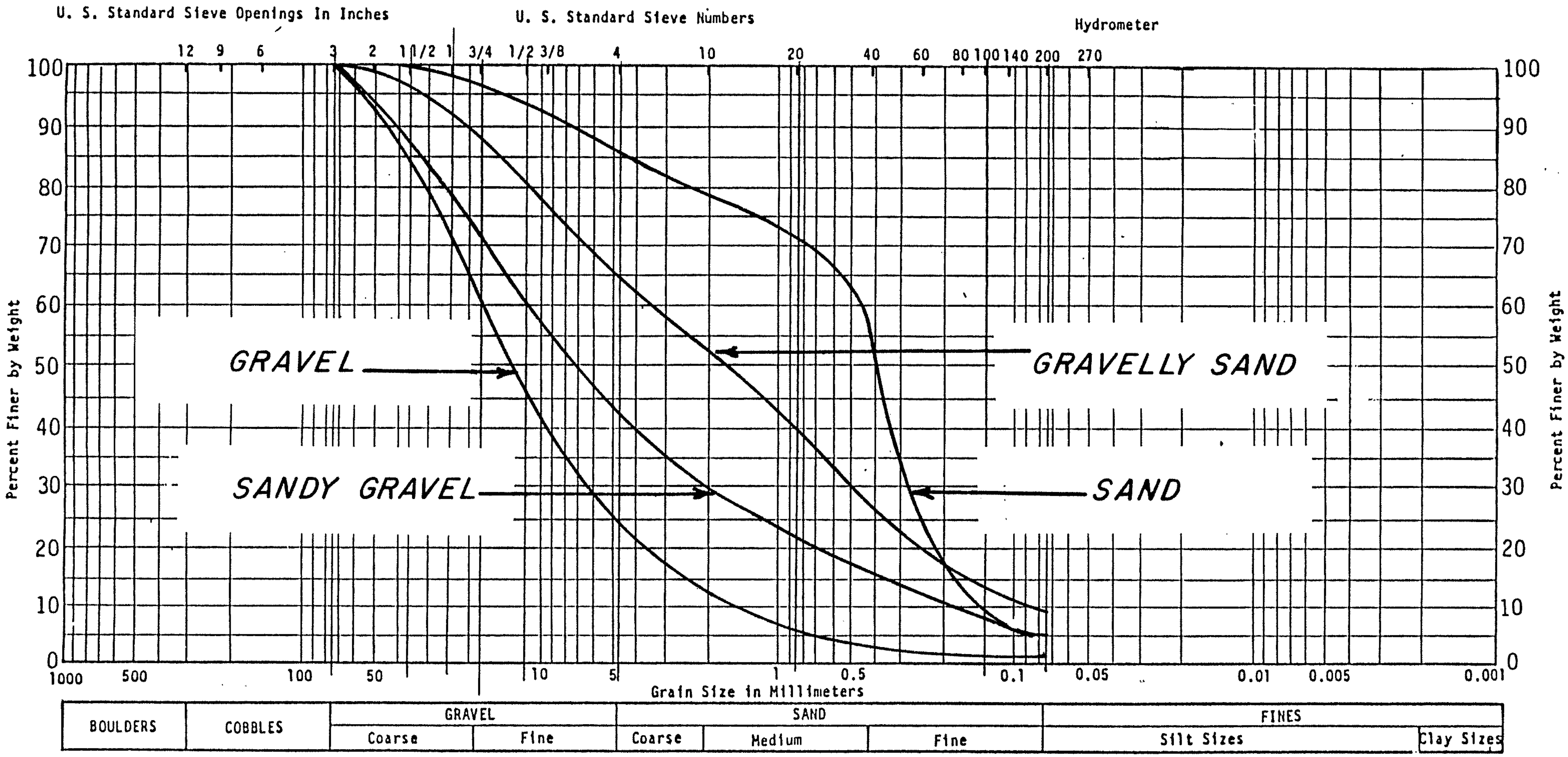
RIVER CHANNEL U/S COFFER DAM FDN. GEOLOGIC PROFILE C/C

HARZA-EBASCO SUSITNA JOINT VENTURE

ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
AUGUST 1983		5-14

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED GRAVEL	*7*	*24*	*30.8*	*13*
WELL GRADED SANDY GRAVEL	*32*	*99*	*25.1*	*57*
POORLY GRADED GRAVELLY SAND	*18*	*47*	*11.2*	*26*
POORLY GRADED SAND	*4*	*8*	*3.7*	*4*
TOTALS	*61*	*178*	*—*	*100*

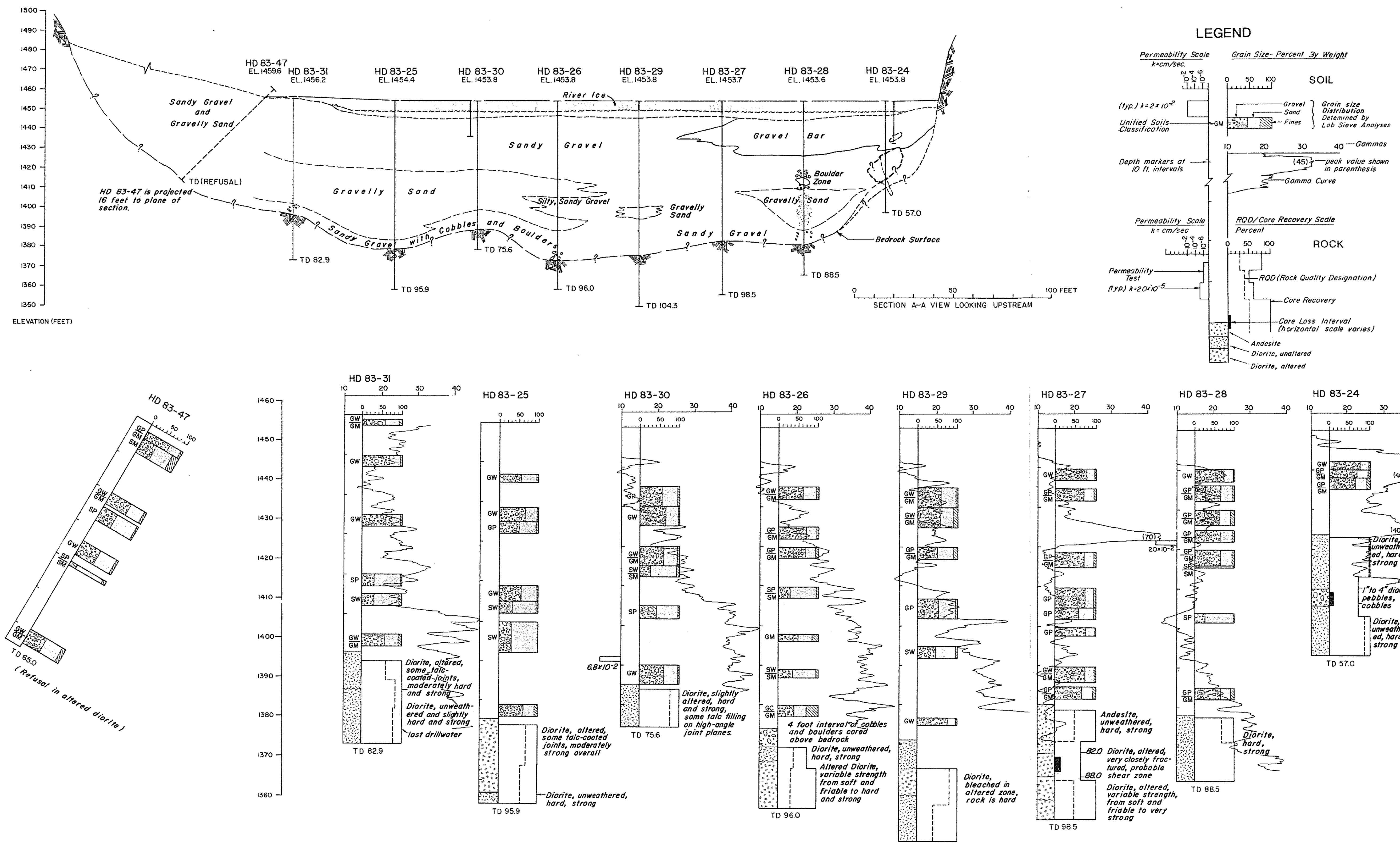
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL U/S COFFERDAM FDN. GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-15



NOTES

1. FOR LOCATION OF PROFILE SEE FIGURE 5-1.
2. UPPER PROFILE IS TRUE SCALE (NO VERTICAL OR HORIZONTAL EXAGGERATION). LOWER PROFILE IS EXPANDED WITH NO HORIZONTAL SCALE.

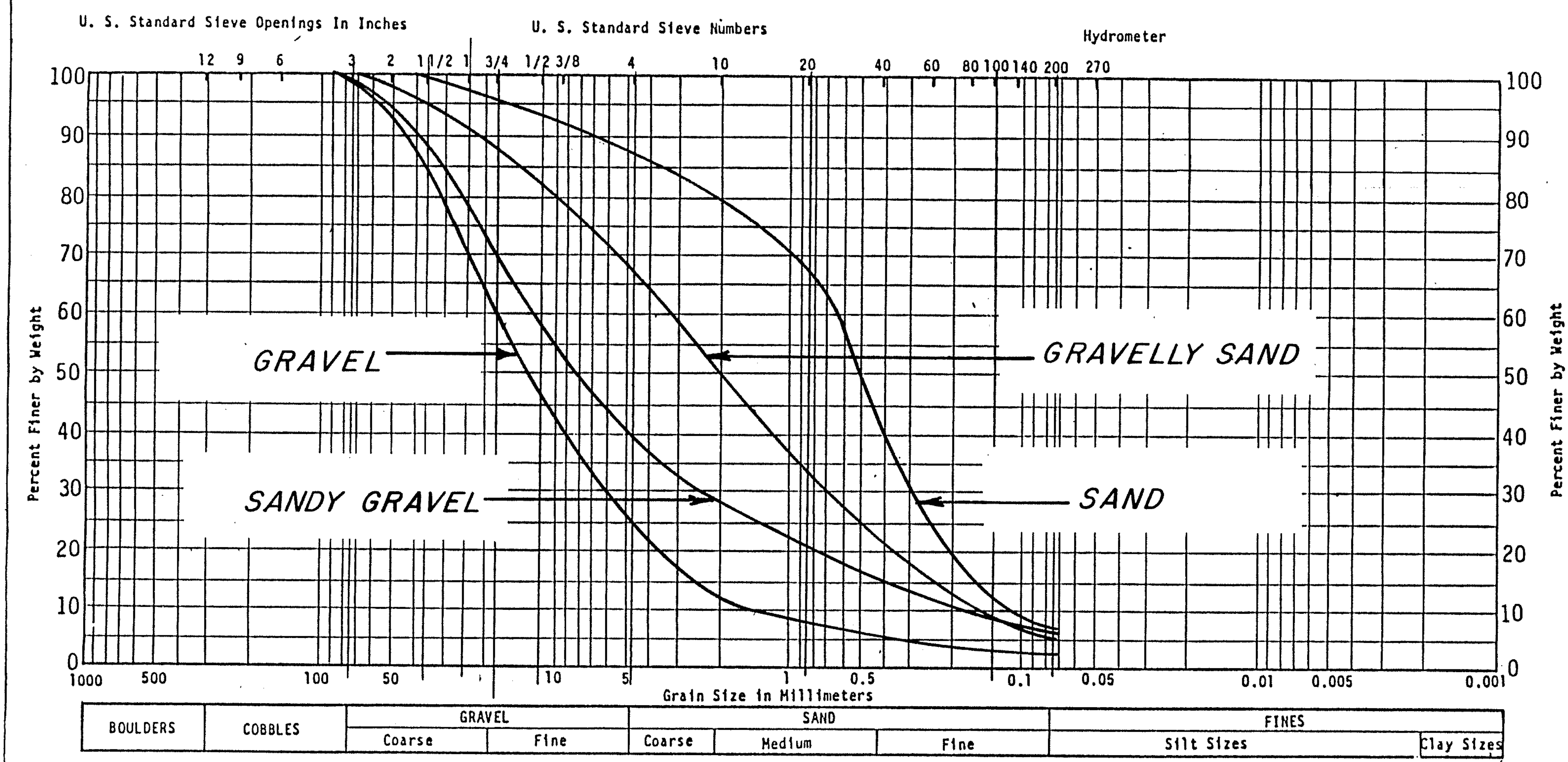
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

RIVER CHANNEL D/S COFFER DAM FDN. GEOLOGIC PROFILE A-A

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUGUST 1983	CONTRACT NUMBER	FIGURE 5-16

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED GRAVEL	3	8	37.4	4
WELL GRADED SANDY GRAVEL	40	138	28.0	75
POORLY GRADED GRAVELLY SAND	11	38	8.6	20
POORLY GRADED SAND	2	2	3.8	1
TOTALS	56	186	—	100

ALASKA POWER AUTHORITY

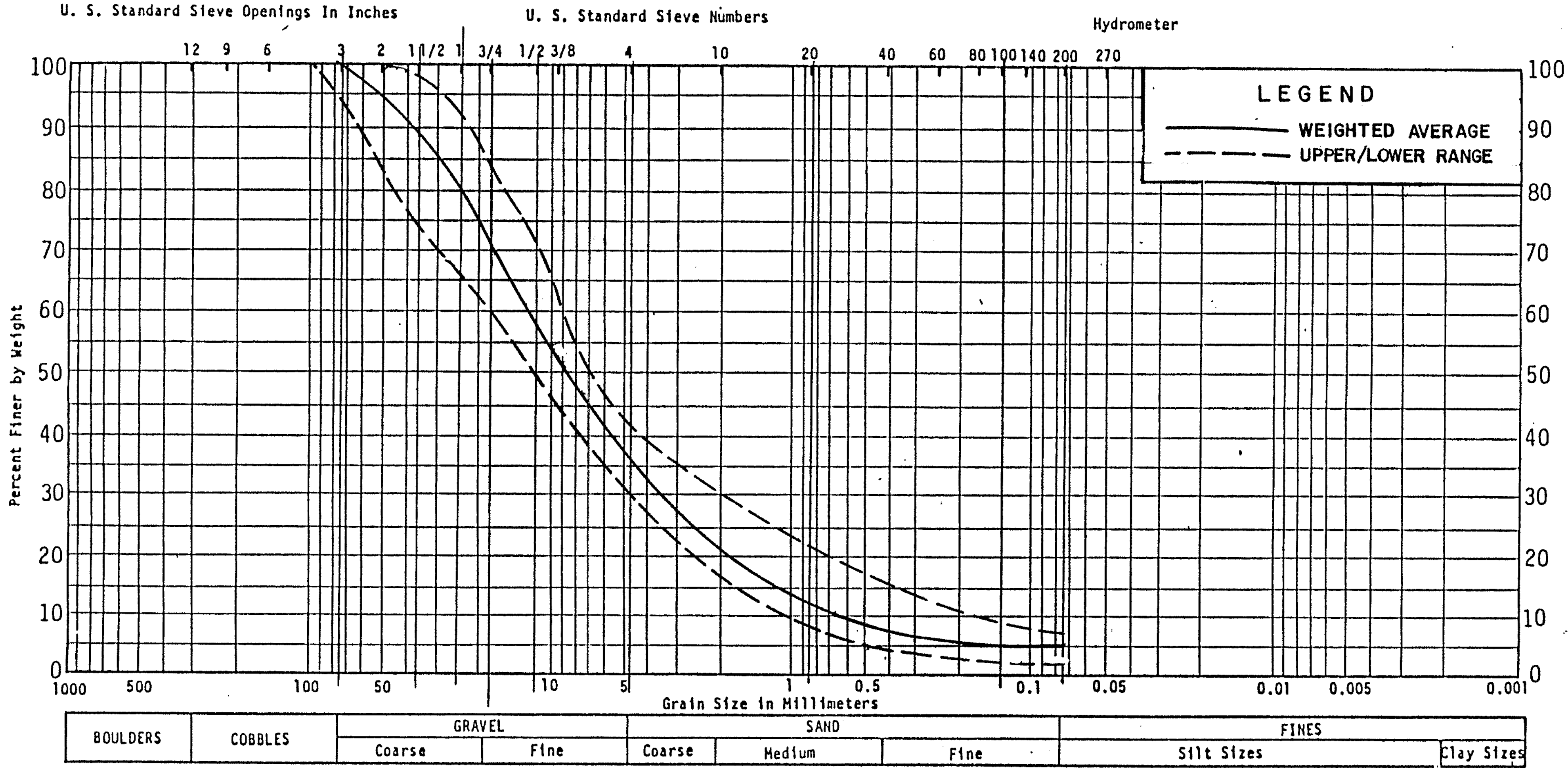
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL D/S COFFERDAM FDN. GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-17

GRADATION SIZE ANALYSIS



LOCATION	BORING NO.	NO. OF SAMPLES	% FRACTURE + 3/4"	CLASSIFICATION (USC)
UPSTREAM	HD 83–	7	25.5	WELL GRADED SANDY GRAVEL, (GW)
PORTAL	14-16			
AREA				

COMMENT: 20' OF SAMPLES

ALASKA POWER AUTHORITY

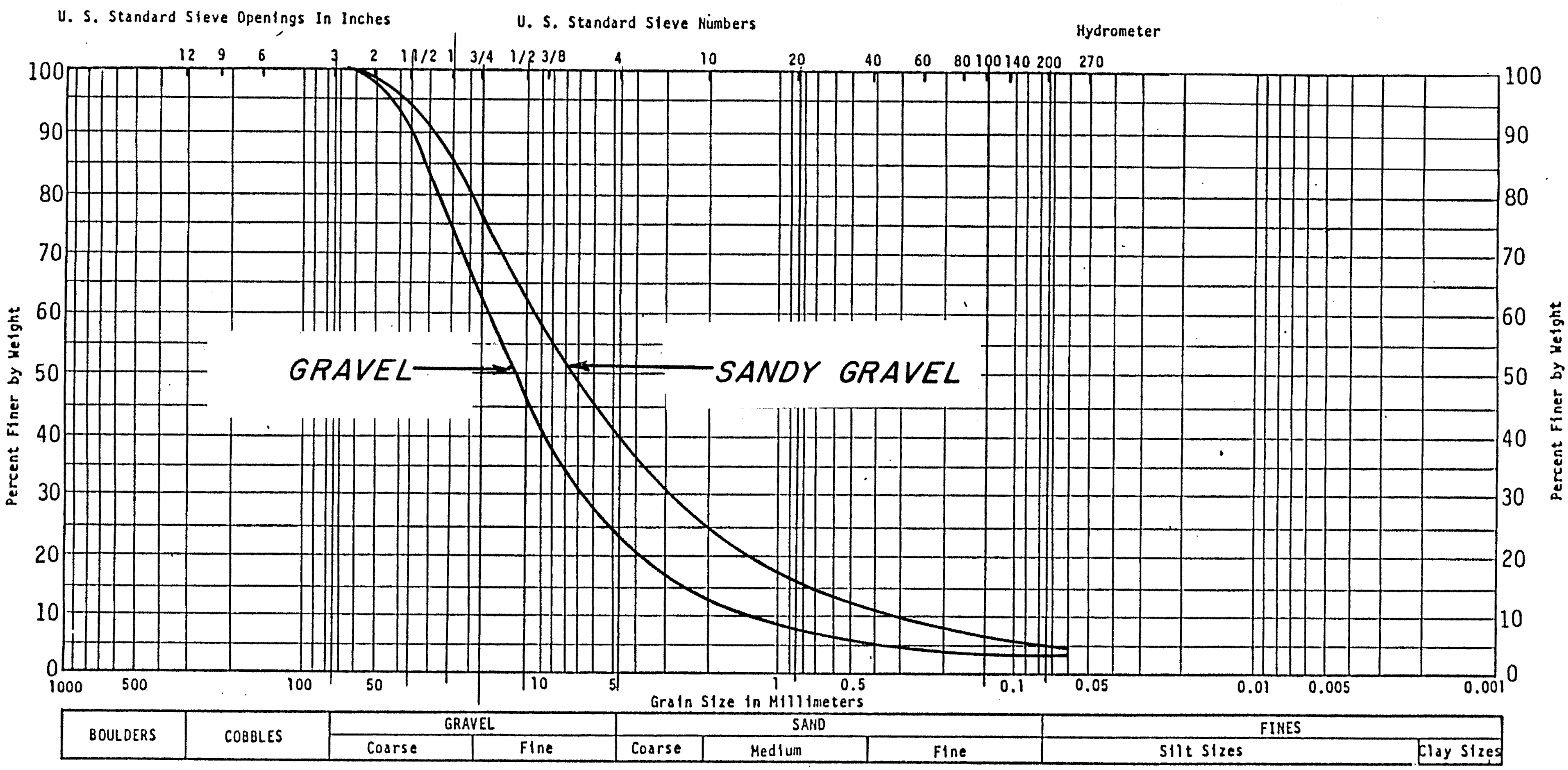
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RIVER CHANNEL U/S PORTAL AREA SANDY GRAVEL GRADATION

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 5-18

GRADATION SIZE ANALYSIS



MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% FRACTURE + 3/4	% MAT'L IN SECTION
WELL GRADED GRAVEL	1	3	29.9	16
WELL GRADED SANDY GRAVEL	5	16	21.5	84
TOTALS	6	19	—	100

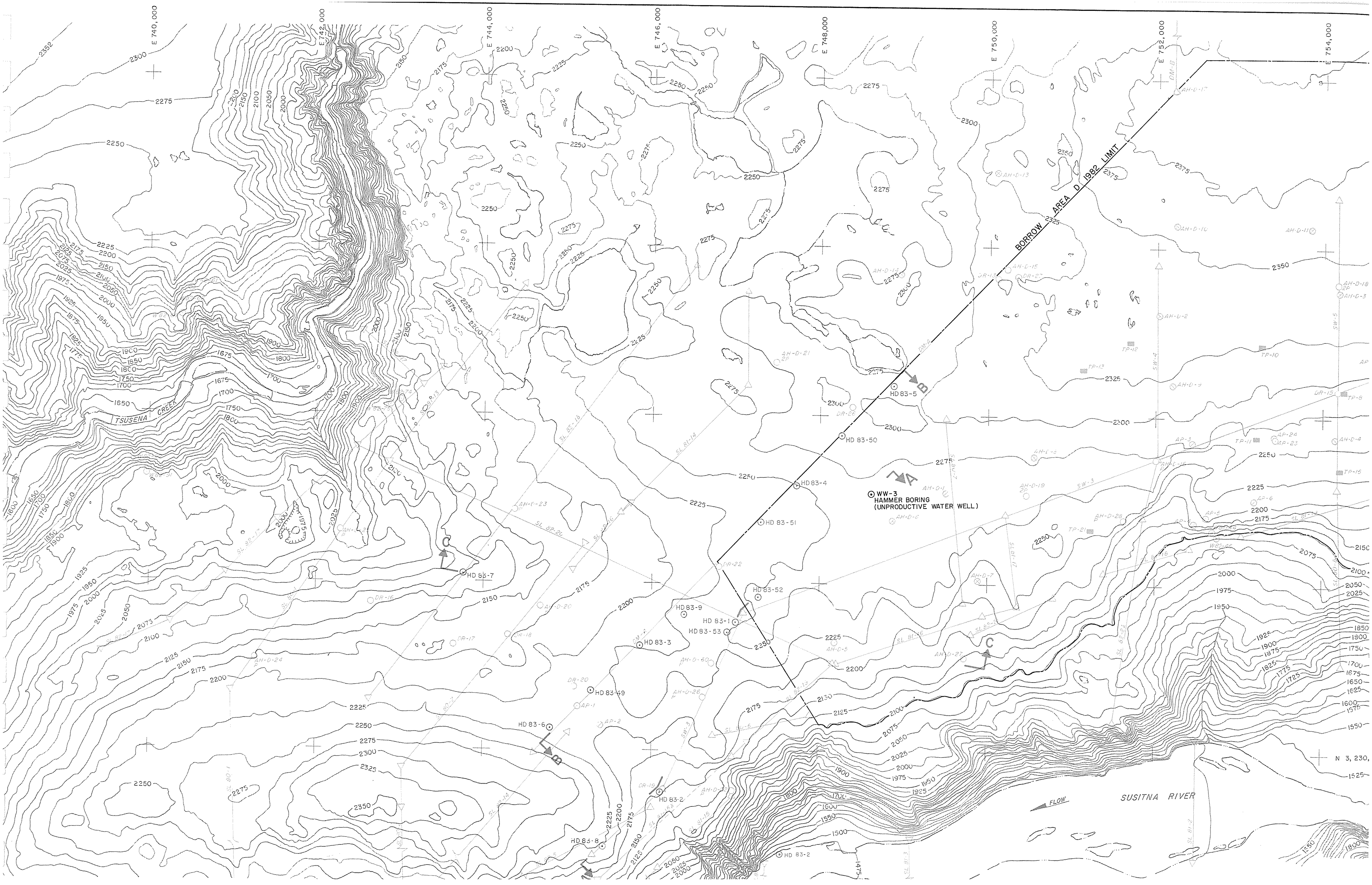
ALASKA POWER AUTHORITY

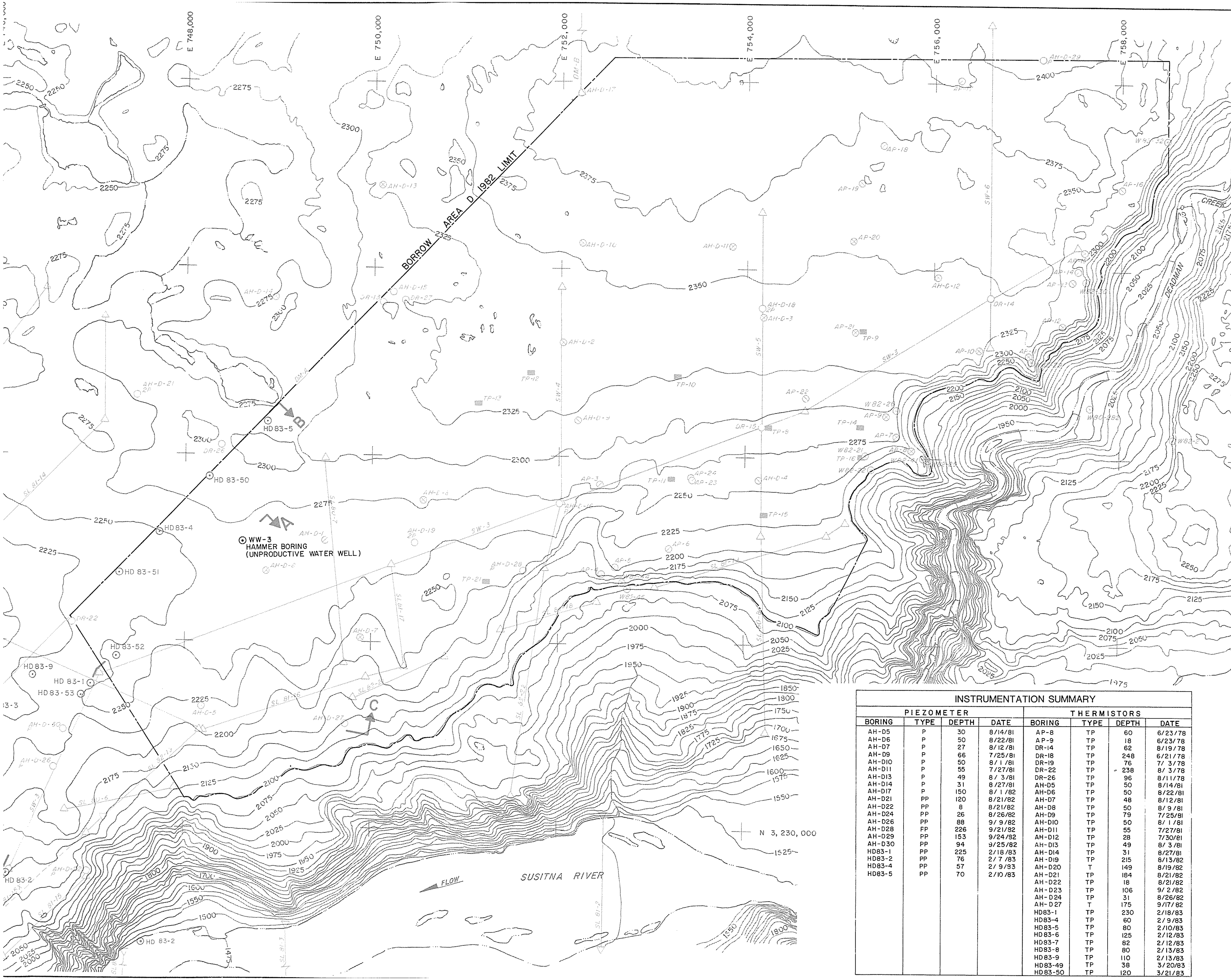
SUSITNA HYDROELECTRIC PROJECT

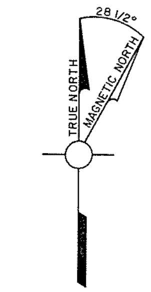
WATANA DEVELOPMENT

RIVER CHANNEL D/S PORTAL AREA GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE	DATE AUG 1983	FIGURE 5-19


E 740,000
E 742,000
E 744,000
E 746,000
E 748,000
E 750,000
E 752,000
E 754,000
N 3, 230,
TSUSENA CREEK
BORROW AREA D 1982 LIMIT
WW-3
HAMMER BORING
(UNPRODUCTIVE WATER WELL)
HD 83-5
HD 83-50
HD 83-4
HD 83-51
HD 83-7
HD 83-52
HD 83-9
HD 83-1
HD 83-53
HD 83-3
HD 83-49
HD 83-6
HD 83-2
HD 83-8
FLOW
SUSITNA RIVER





INSTRUMENTATION SUMMARY							
PIEZOMETER				THERMISTORS			
BORING	TYPE	DEPTH	DATE	BORING	TYPE	DEPTH	DATE
AH-D5	P	30	8/14/81	AP-8	TP	60	6/23/78
AH-D6	P	50	8/22/81	AP-9	TP	18	6/23/78
AH-D7	P	27	8/12/81	DR-14	TP	62	8/19/78
AH-D9	P	66	7/25/81	DR-18	TP	248	6/21/78
AH-D10	P	50	8/ 1 /81	DR-19	TP	76	7/ 3/78
AH-D11	P	55	7/27/81	DR-22	TP	238	8/ 3/78
AH-D13	P	49	8/ 3/81	DR-26	TP	96	8/11/78
AH-D14	P	31	8/27/81	AH-D5	TP	50	8/14/81
AH-D17	P	150	8/ 1 /82	AH-D6	TP	50	8/22/81
AH-D21	PP	120	8/21/82	AH-D7	TP	48	8/12/81
AH-D22	PP	8	8/21/82	AH-D8	TP	50	8/ 9 /81
AH-D24	PP	26	8/26/82	AH-D9	TP	79	7/25/81
AH-D26	PP	88	9/ 9/82	AH-D10	TP	50	8/ 1 /81
AH-D28	FP	226	9/21/82	AH-D11	TP	55	7/27/81
AH-D29	PP	153	9/24/82	AH-D12	TP	28	7/30/81
AH-D30	PP	94	9/25/82	AH-D13	TP	49	8/ 3/81
HD83-1	PP	225	2/18/83	AH-D14	TP	31	8/27/81
HD83-2	PP	76	2/ 7 /83	AH-D19	TP	215	8/13/82
HD83-4	PP	57	2/ 9/93	AH-D20	T	149	8/19/82
HD83-5	PP	70	2/10/83	AH-D21	TP	184	8/21/82
				AH-D22	TP	18	8/21/82
				AH-D23	TP	106	9/ 2/82
				AH-D24	TP	31	8/26/82
				AH-D27	T	175	9/17/82
				HD83-1	TP	230	2/18/83
				HD83-4	TP	60	2/ 9/83
				HD83-5	TP	80	2/10/83
				HD83-6	TP	125	2/12/83
				HD83-7	TP	82	2/12/83
				HD83-8	TP	80	2/13/83
				HD83-9	TP	110	2/13/83
				HD83-49	TP	38	3/20/83
				HD83-50	TP	120	3/21/83

FY 1983 WINTER EXPLORATION PROGRAM

- HD83-2 HAMMER BORING
- WW-3 WATER WELL BORING
- DH 83-2 CORE HOLE
- A A LINE OF PROFILE

PREVIOUS EXPLORATION

BOREHOLES AND TEST PITS

- DR-27 1978 CORPS OF ENGINEERS ROTARY DRILL BORING
- AP-21 1978 CORPS OF ENGINEERS AUGER BORING
- AH-D-12 1980 ACRES AMERICAN, INC., AUGER BORING
- AH-D-15 1982 ACRES AMERICAN, INC., AUGER/ROTARY/CORE BORING
- TP-11 1978 CORPS OF ENGINEERS BACKHOE TEST PIT
- W80-392 1980 ACRES AMERICAN, INC., BULK SAMPLE LOCATION
- W82-26 1982 ACRES AMERICAN, INC., BULK SAMPLE LOCATION

INSTRUMENTATION

- PP PNUEMATIC PIEZOMETER
- P PIPE PIEZOMETER
- T THERMISTOR
- TP THERMAL PROBE PIPE

GEOPHYSICAL SURVEYS

- SEISMIC REFRACTION SURVEY LINE
- DM-4 1975 DAMES & MOORE
- SW-3 1978 SHANNON & WILSON, INC.
- SL 80-5 1980-81 WOODWARD-CLYDE CONSULTANTS
- SL 82-16 1982 WOODWARD-CLYDE CONSULTANTS

NOTES

1. BASE MAP FROM 1978 CORPS OF ENGINEERS-1"-200' DAMSITE TOPOGRAPHY, SHEETS 7-9, 12-15, 17-20 OF 26
2. ALASKA STATE PLANE COORDINATES IN FEET (ZONE 4)

0 400 800
SCALE IN FEET

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL EXPLORATION PLAN

HARZA-EBASCO
SUSITNA JOINT VENTURE
ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
AUGUST 1983		6-1

LEGEND

SURFACE CONTOURS

BEDROCK OUTCROP, UNDIFFERENTIATED

TOP OF BEDROCK, CONTOUR INTERVAL 50 FEET

HD 83-6
WW-3
HAMMER BORING

AH-D-26
PREVIOUS BORING

SL 82-20
PREVIOUS SEISMIC REFRACTION SURVEY LINE

NOTES

1. MODIFIED AFTER ACRES AMERICAN, INC., 1982. SEE FIGURE 6.7
2. BASE MAP FROM 1978 CORPS OF ENGINEERS 1"=200' DAMSITE TOPOGRAPHY.
3. PREVIOUS BORINGS BY CORPS OF ENGINEERS, 1978 AND ACRES AMERICAN, INC., 1980-82.
4. PREVIOUS SEISMIC REFRACTION SURVEY LINES BY DAMES AND MOORE, 1975; SHANNON AND WILSON, 1978; AND WOODWARD-CLYDE CONSULTANTS, 1980-82.
5. DETAILED TOP OF BEDROCK IN DAMSITE AREA SHOWN IN FIGURE 5-8.
6. DAM LAYOUT FROM ACRES AMERICAN, INC., 1982.

SCALE 0 1000 2000 FEET

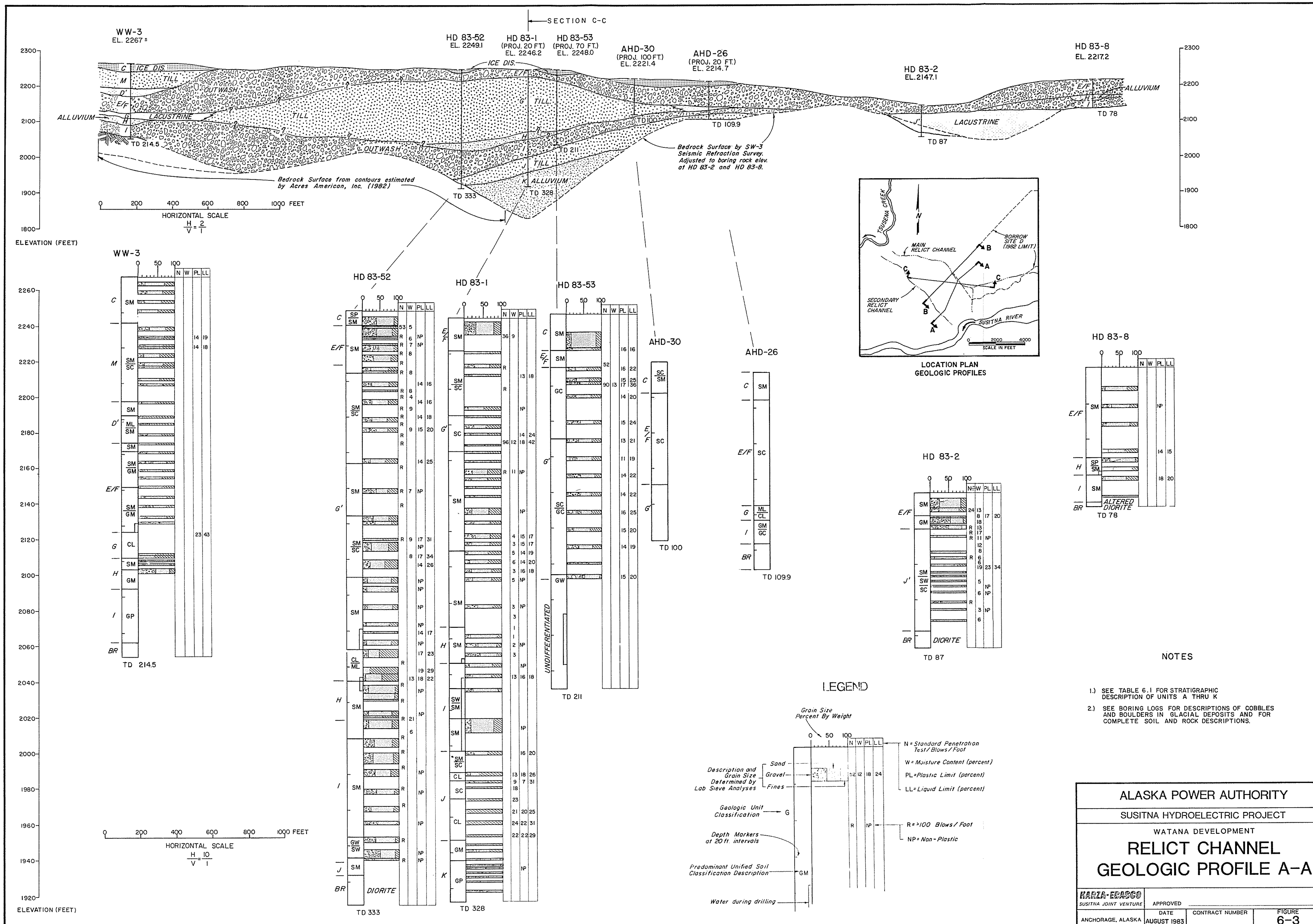
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL CONTOUR MAP TOP OF BEDROCK

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUG. 1983	CONTRACT NUMBER	FIGURE 6-2



NOTES

1.) SEE TABLE 6.1 FOR STRATIGRAPHIC DESCRIPTION OF UNITS A THRU K

2.) SEE BORING LOGS FOR DESCRIPTIONS OF COBBLES AND BOULDERS IN GLACIAL DEPOSITS AND FOR COMPLETE SOIL AND ROCK DESCRIPTIONS.

ALASKA POWER AUTHORITY

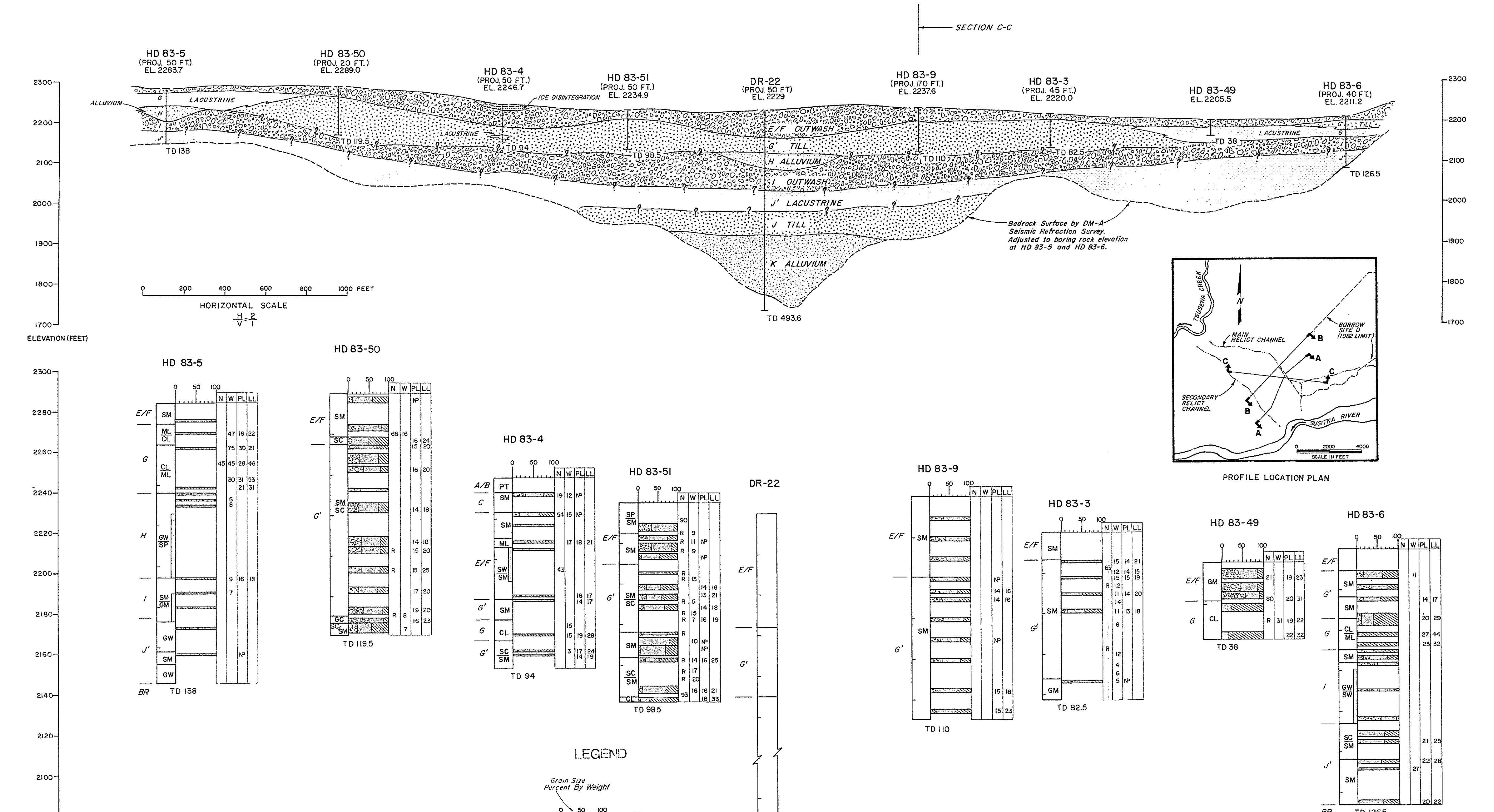
SUSITNA HYDROELECTRIC PROJECT

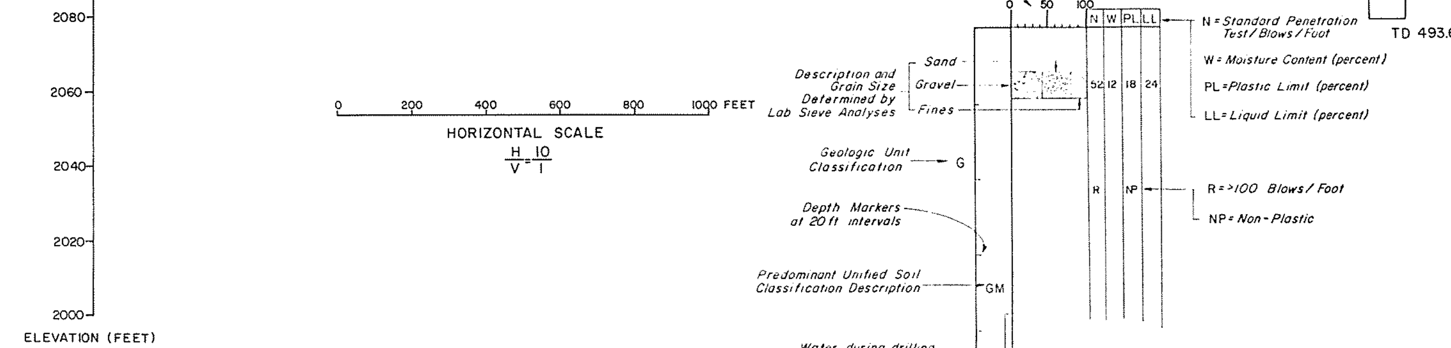
WATANA DEVELOPMENT

RELICT CHANNEL GEOLOGIC PROFILE A-A

HARZA-EBASCO
SUSITNA JOINT VENTURE
ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
AUGUST 1983		6-3





NOTES

1.) SEE TABLE 6.1 FOR STRATIGRAPHIC DESCRIPTION OF UNITS A THRU K.

2.) SEE BORING LOGS FOR DESCRIPTIONS OF COBBLES AND BOULDERS IN GLACIAL DEPOSITS AND FOR COMPLETE SOIL AND ROCK DESCRIPTIONS.

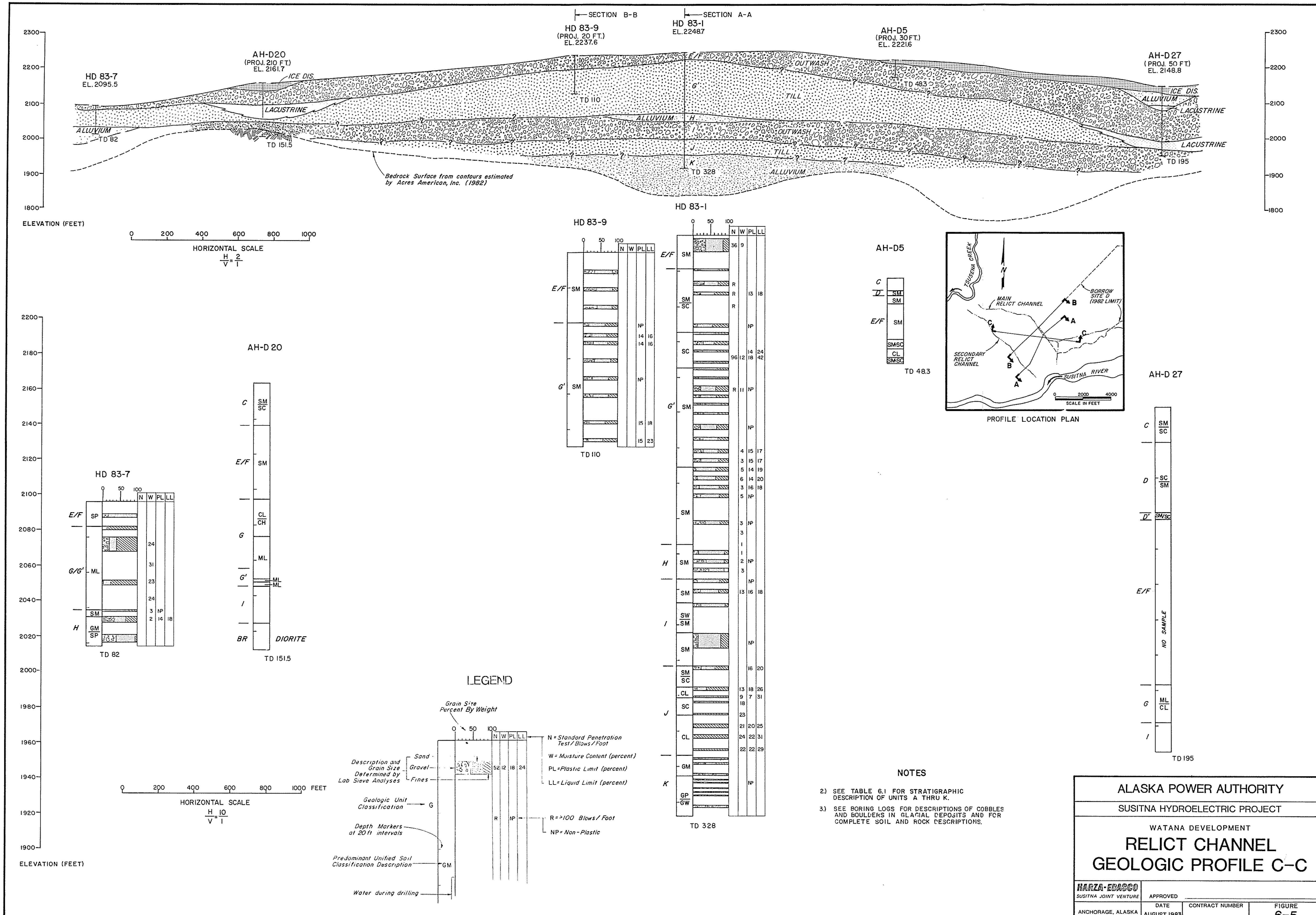
ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL GEOLOGIC PROFILE B–B

HARZA-EBASCO SUSITNA JOINT VENTURE	APPROVED		
ANCHORAGE, ALASKA	DATE AUGUST 1983	CONTRACT NUMBER	FIGURE 6-4



NOTES

2.) SEE TABLE 6.1 FOR STRATIGRAPHIC DESCRIPTION OF UNITS A THRU K.

3.) SEE BORING LOGS FOR DESCRIPTIONS OF COBBLES AND BOULDERS IN GLACIAL DEPOSITS AND FOR COMPLETE SOIL AND ROCK DESCRIPTIONS.

ALASKA POWER AUTHORITY

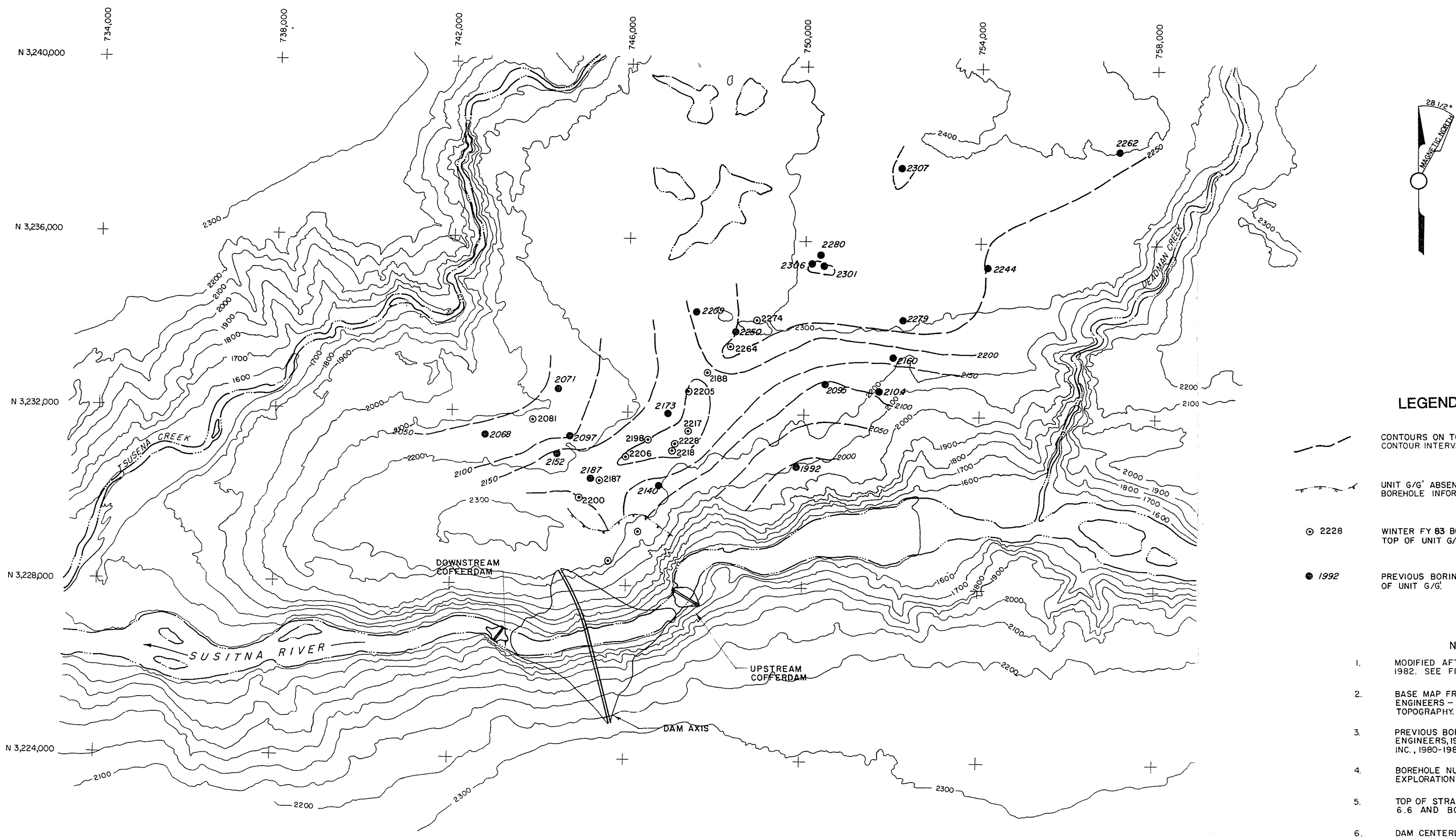
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL GEOLOGIC PROFILE C–C

HARZA-EBASCO
SUSITNA JOINT VENTURE
ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
AUGUST 1983		6–5



LEGEND

CONTOURS ON TOP OF UNIT G/G'. CONTOUR INTERVAL 50 FEET.

UNIT G/G' ABSENT LOCALLY, BASED ON BOREHOLE INFORMATION.

⊙ 2228 WINTER FY 83 BORING. ELEVATION OF TOP OF UNIT G/G'

● *1992* PREVIOUS BORING. ELEVATION OF TOP OF UNIT G/G'.

NOTES

1. MODIFIED AFTER ACRES AMERICAN, INC., 1982. SEE FIGURE 6.6.
2. BASE MAP FROM 1978 CORPS OF ENGINEERS – 1" = 200' DAMSITE TOPOGRAPHY.
3. PREVIOUS BORINGS BY CORPS OF ENGINEERS, 1978 AND ACRES AMERICAN INC., 1980-1982.
4. BOREHOLE NUMBERS ARE SHOWN ON THE EXPLORATION MAP, FIGURE 6-1.
5. TOP OF STRATIGRAPHIC UNIT FROM TABLE 6.6 AND BORING LOGS IN APPENDIX C
6. DAM CENTERLINE FROM ACRES AMERICAN INC., FY 83 PROPOSED GEOTECHNICAL EXPLORATION PROGRAM.

SCALE 0 1000 2000 FEET

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

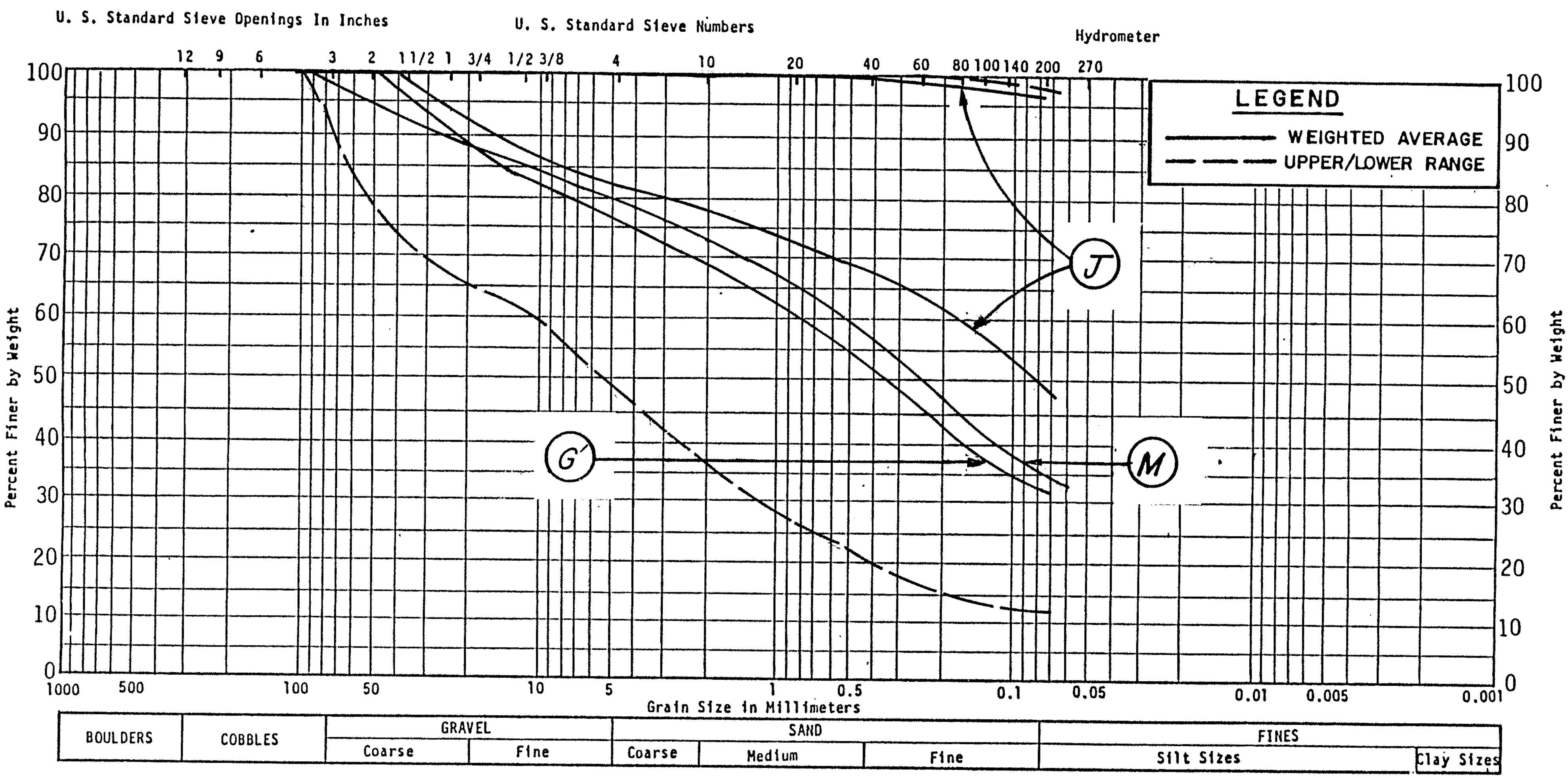
RELICT CHANNEL CONTOUR MAP TOP OF UNIT G/G'

HARZA-EBASCO
SUSITNA JOINT VENTURE

ANCHORAGE, ALASKA

APPROVED		
DATE	CONTRACT NUMBER	FIGURE
AUG 1983		6-6

GRADATION SIZE ANALYSIS



UNIT	MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% MAT'L IN SECTION
M	SILTY SAND, (SM/SC)	8	13	100
G'	SILTY GRAVELLY SAND, (SM/SC/GC)	91	233	100
J	SANDY SILT, (SM/SC)	4	6	50
J	CLAY, (CL)	4	6	50

ALASKA POWER AUTHORITY

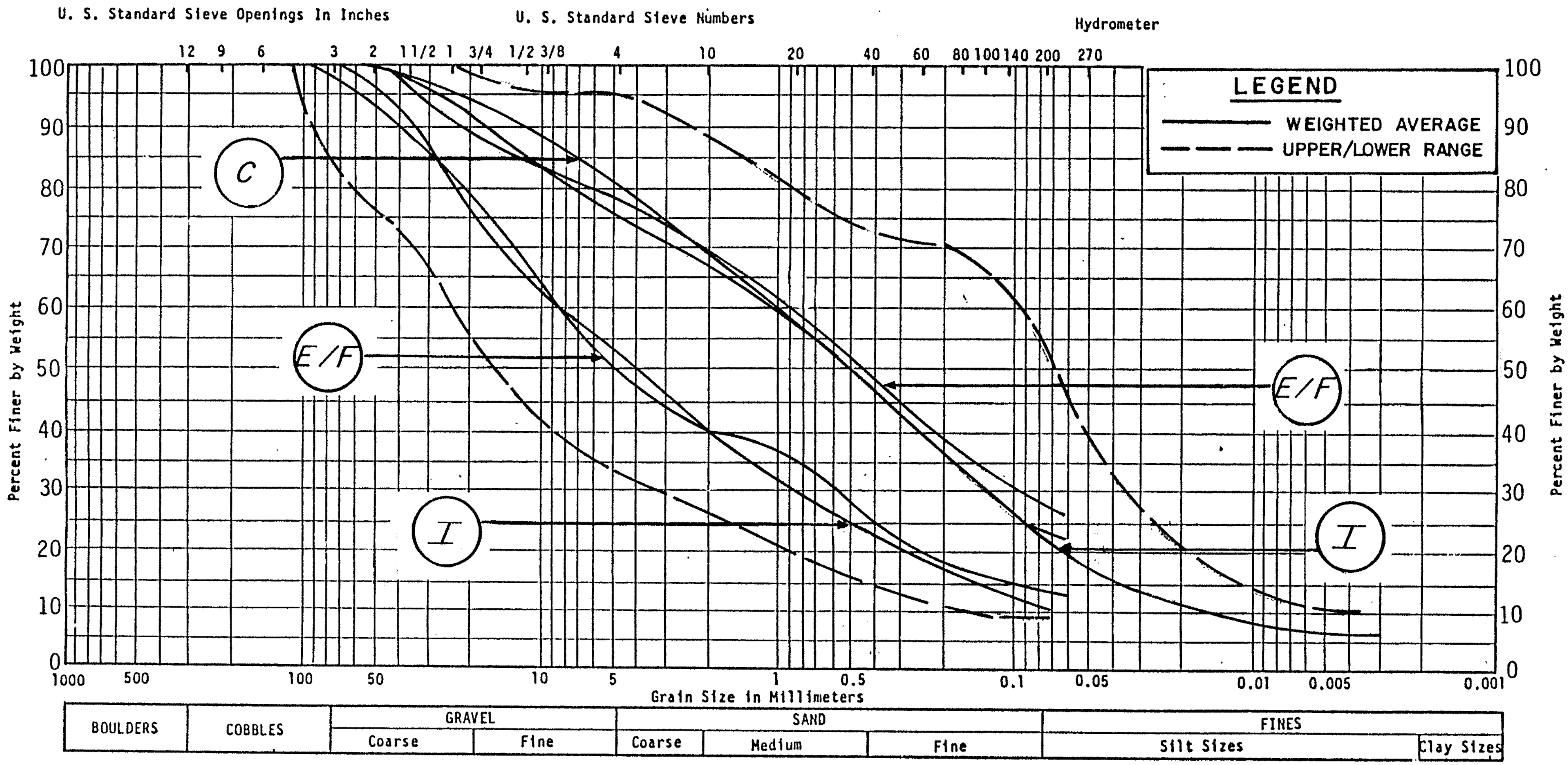
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL BASAL TILL GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 6-7

GRADATION SIZE ANALYSIS



UNIT	MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% MAT'L IN SECTION
E/F	SANDY GRAVEL, (GM)	10	26	26
E/F	SILTY SAND, (SM)	35	73	74
I	SANDY GRAVEL, (GW/GM)	5	11	19
I	SILTY SAND, (SM)	18	48	81
C	SILTY SAND, (SM)	8	27	100

ALASKA POWER AUTHORITY

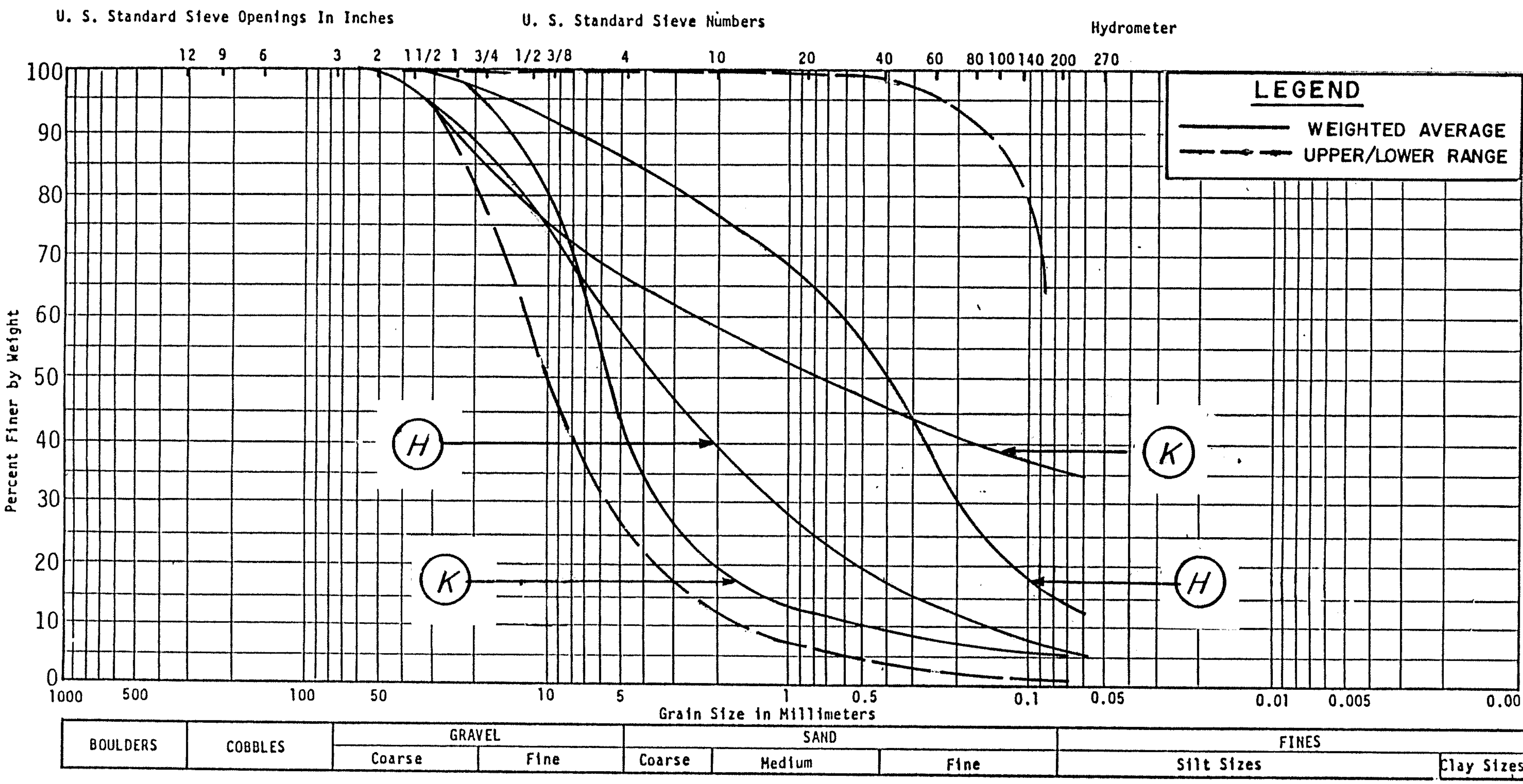
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL OUTWASH GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 6-8

GRADATION SIZE ANALYSIS



UNIT	MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% MAT'L IN SECTION
H	SANDY GRAVEL, (GW/GM)	6	10	32
H	SILTY SAND, (SM)	10	21	68
K	SANDY GRAVEL, (GP/GM)	7	7	70
K	SILTY SANDY, (GM)	2	3	30

ALASKA POWER AUTHORITY

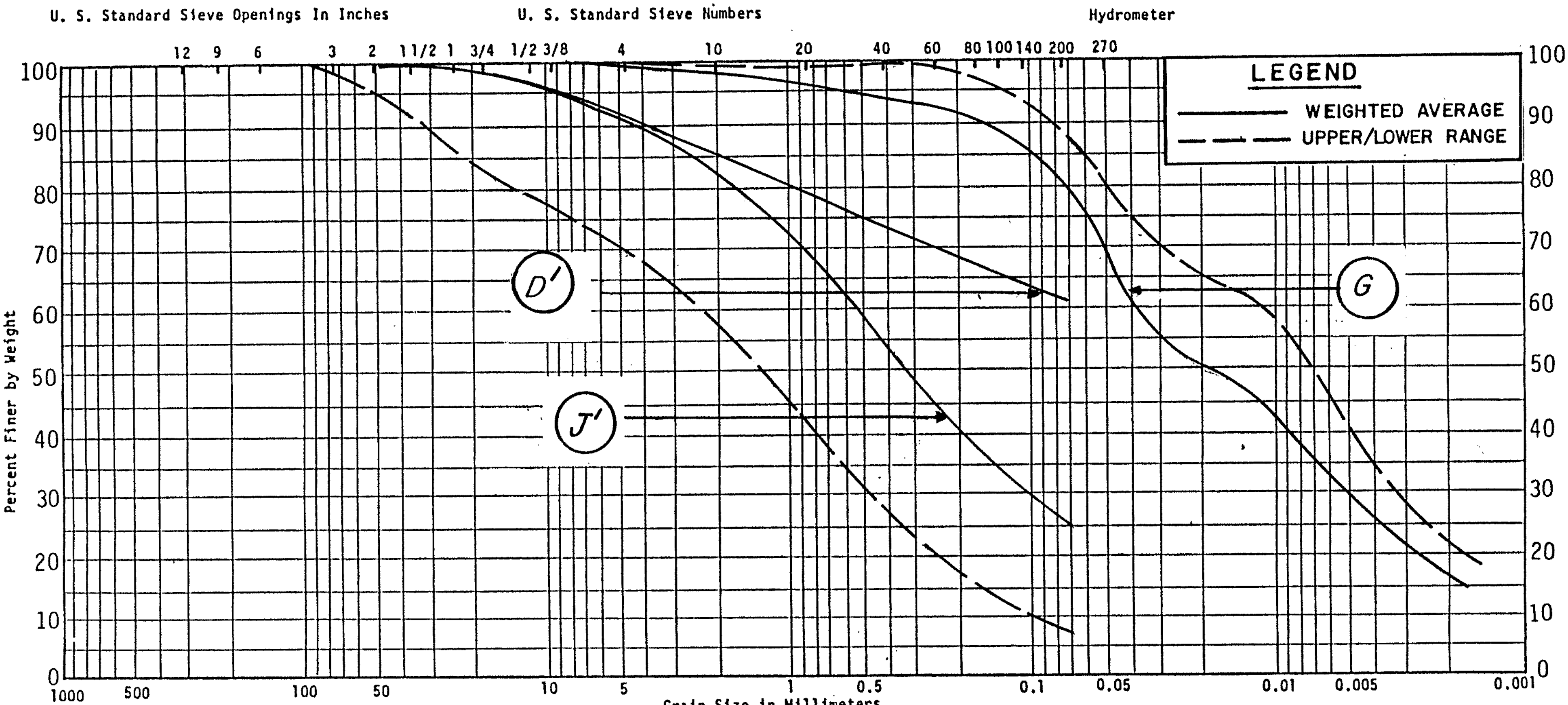
SUSITNA HYDROELECTRIC PROJECT

WATANA DEVELOPMENT

RELICT CHANNEL ALLUVIUM GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 6-9

GRADATION SIZE ANALYSIS



BOULDERS	COBBLES	GRAVEL		SAND			FINES	
		Coarse	Fine	Coarse	Medium	Fine	Silt Sizes	Clay Sizes

UNIT	MATERIAL	NO. OF SAMPLES	FEET OF SAMPLE	% MAT'L IN SECTION
G	SILTY CLAY, (CL/CL-ML)	9	17	100
D'	SANDY SILT, (ML)	4	4	100
J'	SILTY SAND, (SM/SM-SC)	18	23	100

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

IWATANA DEVELOPMENT

RELICT CHANNEL LACUSTRINE GRADATION SUMMARY

HARZA-EBASCO SUSITNA JOINT VENTURE | DATE AUG 1983 | FIGURE 6-10