SUSITNA HYDROELECTRIC PROJECT

ACRES SPECIALIST CONSULTANTS PANEL

REPORT

NOVEMBER 18, 1981

Prepared by:

ACRES

ALASKA POWER AUTHORITY

SUSITNA HYDROELECTRIC PROJECT

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Meeting No. 4

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SPECIALISTS CONSULTANTS PANEL MEETING NO. 4
BUFFALO, NEW YORK - NOVEMBER 18, 1981

1. INTRODUCTION

Acres Specialists Consultants Panel Meeting No. 3 took place October 6-8, 1981 in Buffalo in conjunction with the APA External Review Board Meeting No. 3. The meeting was attended by Dr. A. Hendron, Dr. L. Sykes and Mr. M. Copen representing Acres Specialists Consultants Panel. Dr. R. Peck was unable to attend. The current meeting has been convened to review further work undertaken by Acres in the interim period.

2. AGENDA

08:30 - Meeting objectives and study status - J. Lawrence
08:45 - Update on seismic studies - V. Singh
09:15 - Update on geotechnical field work - S. Thompson
09:45 - Discussion
10:15 - Coffee
10:30 - Dam lowering - update on economic studies - J. Lawrence
11:00 - Relict channel treatment - D. W. Lamb
11:30 - Discussion
12:00 - Lunch (brought in)
13:00 - Relict channel discussion (cont'd)
13:45 - Watana dam materials - D. W. Lamb
14:15 - Discussion
14:45 - Watana dam design - D. W. Lamb
15:15 - Coffee
15:30 - Other dams - D. W. Lamb (saddle/cofferdam designs, construction materials, foundation treatment)
16:15 - Discussion

3. LIST OF ATTENDEES

Acres External Panel Members

Dr. R. Peck
Dr. A. Hendron
(Dr. L. Sykes and Mr. M. Copen were unable to attend)

3. LIST OF ATTENDEES (Cont'd)

Acres

Dr. D. H. MacDonald	)	
J. MacPherson	)	Internal Review Panel
L. Wolofsky	)	
A. H. Tawil	)	
J. D. Lawrence	)	
S. N. Thompson	)	Participants
D. W. Lamb	)	
V. Singh	)	

N. Bond/D. Peck - Recorders

G. Krishnan (part-time)	)	
J. Plummer (part-time)	)	
R. Miller	)	Observers
L. Duncan	)	
R. Ibbotson	)	

4. MEETING OBJECTIVES AND STUDY STATUS (Speaker: J. D. Lawrence)

After general introductory remarks, the last APA external panel meeting on October 6-8 was briefly summarized.

The main points raised by the APA panel were that there are no active faults of any concern at the project site. A magnitude of 6.5 floating earthquake at 5 km from project site should be considered. Woodward-Clyde reported that the location of the 1943 event lines up with the extension of the Talkeetna fault and this was a matter to be further resolved.

The APA panel were concerned about the excavation slopes associated with the Watana diversion tunnel portals. This problem has been addressed in design.

A hydrothermally altered zone in the Watana powerhouse cavern area was noted and as a result the powerhouse has been moved away from this zone.

At Devil Canyon the slopes associated with the spillway excavation gave some concern. These slopes have now been flattened and follow the dip of the bedding plane. To avoid these flat slopes a tunnel spillway was studied but not considered practical or economic.

Because of the relict channel, the APA panel had suggested lowering the main dam height at Watana.

Questions were asked about the core material for Watana dam which had been further studied and the results were included in later presentation. The panel also questioned the results of dam stability analyses under seismic conditions, suggested the adoption of an inclined core, and expressed concern about permafrost under the saddle dam.

Fixed cone valves were now proposed for spillway discharge of up to 24,000 cfs at Watana and Devil Canyon. These valves have the advantage of not causing nitrogen supersaturation of the water which is harmful to fish.

The panel suggested lowering the height of the fuse plug embankments for the emergency spillways and widening the spillway channels. This has been put into effect.

5. UPDATE OF SEISMIC STUDIES (Speaker: V. Singh)

Of the 13 features in the study area, only five have been identified as faults. There is a good degree of confidence that these faults are not active.

Woodward-Clyde have proposed an earthquake magnitude of 6 or less for both sites.

More work is being done on the floating earthquake criteria. A meeting was planned on 23 November with Dr. Sykes to discuss this.

It is thought that a magnitude of 6.0 at 4 to 5 km distance should be adopted.

Dr. Sykes' recent work puts the 1943 event to within 25 km of the Talkeetna thrust extension with an epicentral accuracy of ± 20 km. Therefore, in the worst case scenario the event could be as close as 5 km from the Talkeetna thrust fault.

So far the Talkeetna thrust has been considered inactive but the question should be asked "what happens if it is active?" This question is being addressed. Woodward-Clyde are continuing work on analysis of the likelihood of an earthquake occurring at the site and reservoir-induced seismicity.

6. UPDATE ON GEOTECHNICAL FIELD WORK (Speaker: S. Thompson)

A brief summary of exploration by others since the conception of the project was presented.

Locations of boreholes, seismic lines, borrow areas and details of testing carried out for Watana and Devil Canyon site were shown.

The main features were identified on an overall geologic map. At Watana the main rock types are granodiorite and andesite. The andesite is an extrusive material. Where drilled, the contact between the andesite and granodiorite is weathered. This weathered zone has been found to be on the order of several feet of thickness. No evidence for a thick paleosoil zone has been found. A major shear zone, "The Fins", on the north bank has affected the location of upstream diversion portals.

Boreholes 3 and 4 have been drilled recently into powerhouse area and have encountered an altered soft zone of rock 5 feet to 10 feet in thickness. Although this is not considered to be a feature that would affect the feasibility of the underground powerhouse, it has been considered in relocating the powerhouse slightly upstream.

Photographs of typical altered rock, major features and rock jointing were presented. A composite joint plot of several thousand joints was shown and major trends identified. Various sections through the site were discussed and borrow and quarry areas described.

The location and nature of the buried channel was described in detail. Further investigations have now shown that for a pool elevation of 2215 feet, the width of the channel is 1600 feet and has a maximum depth of 450 feet. Nine boreholes have been drilled in the area by the Corps of Engineers. The material in the channel consists of sand, gravel, and clays in a complex stratified sequence. At this time it was noted that there is not enough data to analyze flow paths.

At Devil Canyon a brief description of the geology was given and the main features were pointed out. The rock was described as good quality with high RQD's. The rock type is greywacke and argillite. The dip of the bedding being a controlling influence. A series of dikes and associated shears trend approximately north-south across the river.

Joint plots were presented together with sections showing major features. The area of open jointing on the south bank explored by BH3 was identified as an area requiring further investigation.

7. <u>DAM LOWERING - UPDATE ON ECONOMIC STUDIES</u> (Speaker: J. Lawrence)

As general background present layouts of both Watana and Devil Canyon dams were described.

It was noted that the way in which the reservoirs will be operated is still being refined. There were three factors to be considered:

(1) environmental
(2) energy
(3) cost

A major factor to be considered in the dam lowering study is that if the dam is lowered by more than 50 feet, an emergency spillway cannot be provided. The main spillway would have to be designed to handle the PMF.

It was noted that there was concern by the APA panel about the saddle dam stability under seismic loading and the relict channel treatment. The panel at the last meeting suggested lowering the dam to reduce or eliminate these problems. Preservation of ideal downstream flow for the fish is not compatible with production of maximum usable energy. Any attempt to compromise on these conditions will require the reservoirs to be fluctuated, and this will limit their recreational use and could cause problems with caribou crossing the river in winter.

Two years were considered for the study:

(1) 2010 - Watana and Devil Canyon operational
(2) 1994 - Watana only operational

Four operating conditions were considered:

(A) Meeting demand - producing maximum winter energy
Summer flow restricted
Uniform thermal load

(B) Constant thermal/hydro ratio (not now considered)

(C) Compromise between (A) and (D)

(D) Unrestricted summer flows
Reduced usable energy

Dam elevations:

(1) 2215 feet
(2) 2165 feet
(3) 2115 feet were considered

Cases analyzed:

Elevation	A	B	C	D
2215	X		X	X
2165	X		X	
2115	X		X	

It was noted that the flow requirements for fish are all based on flows at Gold Creek.

Graphs were shown illustrating the flows available downstream, the amounts of usable hydro energy produced and amounts of thermal energy required to meet total demand (see Section 11).

In Case C, 13,000 cfs are spilled downstream against the 20,000 cfs minimum requirement for fish considerations. Dr. Peck asked what the lowest summer flows were, suggesting that if this were tolerable for one season, maybe it would be tolerated every year.

Acres produced flow records to show that the lowest summer flow recorded is 8,900 cfs, whereas Case C gives a flow of 12,000 cfs under average annual flow conditions.

In Case D, not all the energy available is usable.

In Case C, based on an approximate rule of thumb in which 1 GWhr = $1 million dollars, the energy lost by lowering the dam 50 feet is equivalent to $220 million dollars. Therefore, if there is a savings less than this amount by lowering the dam, then this may be the optimum solution.

.t was noted that predicted energy demand growth curve is based on present conditions and forecasts and does not reflect the possibility that the existence of the Susitna project could stimulate demand.

It was noted that the drawdown of reservoirs will be considerable. Preliminary estimates are as follows:

For Case D: Watana drawdown - 172 feet
Devil Canyon drawdown - 398 feet (for maximum pool elevation 2215 feet)

For Case C: Watana drawdown - 202 feet
Devil Canyon drawdown - 228 feet

The possibility of pumped storage from one reservoir to the other was briefly discussed. Acres pointed out that they had considered this earlier and found it impractical.

8. RELICT CHANNEL TREATMENT (Speaker: D. W. Lamb)

Slides and sections were presented showing the general layout of the channel. The section of reservoir boundary where bedrock is below 2215 elevation was indicated to be 16,000 feet wide. The channel is 7,000 feet long from Susitna River to Tsusena Creek. Information about the channel is available from seismic lines, borings, some of which extended to rock, and some sampling and testing. It was stressed that the geology of the channel is very complicated and a typical borehole log was presented to illustrate this. It was pointed out that there are surface lakes in the area, artesian pressure had been noted in some boreholes, drill water circulation lost and permafrost encountered. It is likely that perched water tables exist in the channel. The channel is 450 feet maximum depth and has a hydraulic gradient of about 10 percent. Dr. Hendron said that he had calculated the gradient to be about 6%. Acres confirmed that their figure of 10% was for the critical thalweg.

Four major considerations were listed:

(1) Leakage
(2) Piping
(3) Permafrost
(4) Liquefaction

From leakage studies so far carried out assuming 10^{-2} cm/sec material, the average water loss is about 85 cfs varying very little drop within pool elevation. This represents a capital loss of about $40 million.

Since the actual gradient in the channel is uncertain, there may be concentrated flows which may cause piping. Possible solutions of an upstream blanket and downstream filter were discussed.

Both Dr. Peck and Dr. Hendron agreed that the upstream blanket should be ruled out. The cost would be excessive, in the region of $500 million, and the stability of the material on the steep slopes cannot be assured.

The positive seepage cutoff by slurry wall and cement grouting at present proposed by Acres was discussed. Dr. Hendron suggested that the slurry wall at shallow depth was of doubtful value. Dr. Peck suggested that the slurry trench wall be made deeper, if cheaper than grouting. Acres replied that the depth had been limited by precedent considerations. Dr. Peck noted that the reservoir will take three years to fill over the depth of the relict channel. If only the minimum treatment in the form of a downstream filter blanket was carried out at dam construction stage, then observations could be made and further treatment carried out only if necessary.

Both members of the panel thought that the channel is unlikely to be a problem if treated in this manner. They considered that the downstream filter to be just as effective a method as the slurry wall and grouted cutoff.

The downstream blanket, according to Acres' preliminary design, will be 7 feet thick with a potential cost of $100 million if required to cover the whole of the downstream slopes.

Dr. Peck said that if the material in the channel is horizontally stratified, then the maximum area of blanket will be required, but then added that a few vertical relief wells might well solve the problem. The effect of thawing of the permafrost is unknown, but increases in leakage could be handled by the filter.

J. Lawrence asked the panel if they envisaged problems with the relict channel that could not be dealt with. Dr. Peck thought that the filter could be placed quickly at the toe of the channel, in fact quicker than the dam could be lowered. Dr. Peck said that generally buried channels in fact turn out to be less of a problem then anticipated during preliminary design phases of a project.

Dr. Hendron could not see liquefaction being a problem except in isolated zones which might lead to settlement of the saddle dam. J. Lawrence stressed that only 15 feet of water were retained by the dam, and suggested that an allowance for settlement could be built into the dam.

Dr. Hendron said that the liquefaction will not be regular and therefore the settlement will lead to cracking. Acres said that only an 1,100-foot length of the saddle dam is normally wetted.

The panel considered that formation of a new channel by settlement due to liquefaction was very remote. Dr. Peck considered a downstream filter to be most effective since the area can be treated where necessary. The upstream blanket solution requires all treatment done in advance of filling the reservoir and considerable surface treatment before placing the blanket.

The amount of further investigations required for the relict channel was discussed but the panel noted that the need for investigations depended greatly on the method of treatment proposed.

Dr. Peck considered the efficiency of cutoff grouting to 400 foot depth to be uncertain.

Dr. MacDonald quoted examples of similar channels with gradients of 1:15 and 1:20. The Peace River project with a gradient of 1:20 was mentioned. All these examples have not given any problems.

Dr. MacDonald said that a downstream filter will be required in any case. He suggested that observations be taken over a 15-to-20 year period and only do work where required. He felt that the downstream filter was just as positive as a cutoff.

It was noted that piezometers located downstream in the channel will indicate seepage before effects were noticed at Tsusena Creek. Acres noted that the source of filter material is located less than one mile away in Tsusena Creek, and this area will not be flooded by the Devil Canyon Reservoir. The possibility of raising the tailwater level in Tsusena Creek to reduce the hydraulic gradient in the relict channel was discussed but was not considered viable.

The panel concluded that there was no urgent reason for doing anything in advance but stressed the need for continual observations.

9. <u>WATANA DAM MATERIAL</u> (Speaker: D. W. Lamb)

Grading curves for core materials from Areas D and H were presented and discussed.

It was noted that although the materials are classified as SM, they are quite well graded. Dr. Peck said that the curve for Mica dam core material falls in the middle of range of curves for Watana material and that Mica was good core material. Acres noted that the surface layer of fine material Area H would be wasted.

The modified proctor compaction curves were presented and it was noted that the natural moisture content of the material was 2 percent to 3 percent higher than optimum.

Area H core material is 10 miles from the dam, contains extensive permafrost, and is similar to the deeper materials from Area D. Ten or twelve tests have been done with PI values ranging between 2.5 and 9.2 percent.

For Area D at depth, the PI value is up to 40 percent, LL up to 65 percent. Samples from twelve auger holes are being tested now giving PI results of 5 percent to 9 percent, but tests are being done with gradation cutoff above 2 inches because of sampling method.

Gradation curves for filters were presented and it was noted that 13 percent was passing 200 sieve. Acres said that this material may be worked under water and may lose some of the fines.

The filters fit into preferred filter envelopes, but the top end is still a little uncertain because of the sampling methods. Dr. Hendron suggested that the filter design incorporate current thought as described in Lowe's paper on Tarbela presented in Mexico. At Devil Canyon there is no till suitable for core material for the embankment dam. The manufacture of core material using bentonite was considered and found to be uneconomic. At present, the plan is to transport material from Area H.

There was general discussion about the variability of material from Area D and H sources. The curves were displayed overlain and looked very similar. Dr. Hendron thought the grading curve of Area H looked better than Area D. Dr. Peck was surprised at the increase shown of PI with depth in Area D.

Dr. MacDonald asked about the extent of permafrost in borrow areas. In reply Acres said that it was thought that Area D is less frozen than Area H but there was not enough data to be more exact.

Dr. Peck could see no compelling reason to use Area H for Watana and considered that it would be better to use the faster draining materials if, as results show, the natural water content is slightly above optimum.

Dr. Peck said that generally lodgement tills are naturally close to optimum moisture content. He did not consider that even 3 percent above optimum would be a problem as long as placing traffic could run over it, even if major rutting did occur. T. Tawil pointed out that the compaction tests were done on material less than 3/4 inch. If less than No. 4 sieve had been used, the optimum moisture content would have been higher. Also, he felt that the standard Proctor test would have been more suitable and would have given an optimum closer to the nature moisture content and closer to the plastic limit of the material.

10. <u>WATANA DAM DESIGN</u> (Speaker: D. W. Lamb)

The arrangement of the dam was briefly described.

All overburden and weathered rock under the dam is to be removed and under the core and filters excavation to sound rock required. Sketches of grouting and drainage layouts were presented and discussed. The advantages of the grouting/drainage galleries were highlighted. The galleries will run the entire length of the dam. They will provide flexibility of working with the embankment being constructed at the same time, permanent inspection, facilities to perform remedial grouting when permafrost completely thaws, access to instrumentation, positive drainage and protection against freezing of drain holes. The question of piping of fines from rock into drain holes was raised. S. Thompson replied that he did not expect any problem with piping. If some piping in shear zones did occur, holes could easily be cleaned or filters provided.

The latest dam cross section was presented showing the free draining rock fill upstream shell and river gravel downstream shell.

Dr. Peck was concerned about the use of compacted rock fill for the upstream shell. He would expect such material to settle 3 feet to 4 feet on saturation during filling and this could give rise to a longitudinal crack in the crest of the dam.

Acres explained that the present cross section was based on suggestions from the last panel meeting when Dr. Seed was concerned about the drainage characteristics of the gravel. The pore water pressure buildup under seismic loading was a major design factor and clean processed rock fill was chosen for the upstream shell for this reason. The unprocessed gravel for the downstream shell was chosen mainly on a cost basis.

Dr. Peck was somewhat sceptical about the method of calculation of pore pressures within the dam. He stressed that there is no experience on rock fill behavior under seismic conditions. Dr. Peck expressed his fears that compaction of rock fill would result in crushing and breakage of the rock leading to an increase in fine material and a decrease in permeability.

The analysis of pore pressures at Oroville dam was discussed. Acres said that first analysis had assumed rock fill properties equivalent to those for the Oroville dam gravels. Dr. Peck said that assumed permeabilities for rock fill could be misleading. He commented that the difference between rock fill and gravel were not significant for earthquake design. Dr. Peck was also concerned about the buildup of fines in the rock fill even after processing. Acres did not think this would be a problem bearing in mind the strength of the rock.

Dr. Hendron preferred a gravel material for the upstream shell because under earthquake loading the rock fill tends to be compressible and gravel with high cobble content tends to dilate.

Lamb outlined the preliminary dynamic analysis done so far, which was based on properties of fill material from Oroville dam. Dr. Peck questioned the basic material properties used and was concerned that such an analysis should not control the design of the Watana dam.

Dr. Hendron advised doing laboratory tests on gravels to obtain more reliable properties. Acres explained that this was planned but not in this phase of the work.

The analysis of Boruca dam in Costa Rica was discussed. Dr. Peck advised that this might be helpful. Dr. MacDonald said he would look this up.

Dr. Hendron suggested that zones of processed rock within the gravel upstream shell might be a cost effective compromise. Lamb stressed Acres' concern in design for safety against earthquake effects.

The geometry of the dam was outlined with 2.25:1 upstream slope and 2:1 downstream slope for purposes of analyses. However, a 2.4:1 upstream slope was being used for layout studies. There followed much discussion on the relative merits of sloping the core. Tawil pointed out that slightly inclined cores appear to be favored on a number of large dams. This arrangement is believed to give better compressive stresses in the core and less potential for cracking.

Theoretical analysis shows that for a symmetrical core, tensile stresses are produced on the downstream edge. An inclination upstream will prevent this. Tawil quoted Mica and LG2 as examples of this.

Dr. Peck did not agree that inclined cores were selected for these reasons and explained that the location of the core at Mica was for reasons other than stress distribution in the core. The location of the core of Infernillo dam was also discussed.

Dr. Hendron said that during shaking by an earthquake the shells will tend to settle more than the core. With a central core, the shells will not tend to settle away from the core which could lead to cracking of the core.

A multiple plot of dam shapes constructed worldwide was tabled.

In conclusion it was generally agreed that symmetrical core is the most suitable arrangement for Watana dam.

The detail at the dam crest was presented and discussed. Dr. Peck said that even if a crack opened up 6 inches wide the whole length of the dam, this would not be a major problem. Lamb said that post-construction settlement of 1 percent for static and 0.5 percent (5 feet) for earthquake conditions, had been allowed. Dr. Peck thought that 1 percent was probably too much for the gravel fill downstream and not enough for the rockfill upstream.

It was noted that it had been suggested that the settlement of rock fill would be very small, in the order of 0.1 percent. Dr. Peck did not think that this was an appropriate figure to use.

Dr. Hendron suggested that a 25-foot to 50-foot wide zone be constructed next to the coarse filter in layers with half the normal thickness to provide a well compacted transition zone.

A brief description of the dynamic analysis of the dam section was presented. Lamb stated that at the previous panel meeting Dr. Seed was not happy about the size of the finite element mesh used for the analysis. Acres was intending to rerun the analysis using a smaller mesh.

The properties used were discussed and Dr. Peck stressed that whenever possible a range of properties should be used in analysis. Both Dr. Peck and Dr. Hendron agreed that finding background information on this type of material was very difficult.

The material properties used in the dynamic analysis, the earthquake 25 cycle history, accelerations and shear stresses in the dam were displayed.

The panel generally concluded that there was a need to firm up on material properties and geometry and then do further dynamic analysis.

11. OTHER DAMS (Speaker: D. W. Lamb)

Devil Canyon Saddle Dam

It is proposed to use the same cross section as at Watana. All overburden will be removed. The core material is not available locally and will be imported from Area H.

Dr. Hendron suggested that a concrete-faced rockfill dam be considered at this location. Acres said that this had been considered but thought that there might be a concrete aggregate freeze-thaw problem with the thin concrete slab. The possibility of using rollcrete was also discussed but Acres said this should be rejected because it was susceptible to freeze-thaw damage.

It was pointed out that the grouting/drainage gallery would be extended from the main dam under the whole length of the saddle dam. In response to Dr. Hendron, Acres stated that no evidence of permafrost had been found.

Coffferdams

The cofferdam sections were reviewed. Dr. Peck questioned the proximity of the cofferdam to the main dam excavation. Acres replied that the final excavation for the toe of the dam could be done at low river flow and the cofferdam reduced temporarily if found to be necessary.

The program for construction of the slurry wall cutoff was discussed. Acres explained that they had ruled out a sheet pile cutoff because of boulders.

Dr. Peck was not happy about the proposed grouted cutoff at Devil Canyon cofferdam and the slurry cutoff at the Watana upstream cofferdam. He suggested the use of upstream impervious blankets and provision of extra dewatering in place of grouting. Lamb noted that an upstream blanket was not possible at Devil Canyon cofferdam because of the geometrical arrangement. The schedule of construction of the Watana cofferdam slurry wall was discussed. The closure in September would be followed by construction of the slurry trench. The embankment would not be placed during winter months. The cofferdam is required to full height by May 1.

The slurry wall is to a maximum depth of 80 feet.

Emergency Spillway

It was explained that there will be water against the fuse plug frequently but the plug is required to fail only at PMF. Dr. Peck was concerned that the plug might be frozen when PMF occurs. Acres said that PMF always occurs in summer months.

Fog Lakes Relict Channel

This is a similar channel to the relict channel near the main dam but recent investigations show a maximum hydraulic gradient of 0.3 percent with expected flows of less than 4 cfs. Acres said this is not now considered a problem.

The rest of the Watana reservoir is surrounded by a 20-mile band of mountains. At Devil Canyon the reservoir is surrounded totally by rock.

Concluding Remarks

Dr. Hendron asked what Acres was going to do about the dam lowering at Watana. Acres said they were carrying out studies to determine the optimum pool level.

Dr. Peck was not happy about the Watana saddle dam, even 10 feet high, and did not think that the slurry wall and grouted cutoff of the relict channel could be justified. He thought that the height of the main dam should be fixed on overall economic grounds.

Dr. Hendron said that Acres should make sure that if a saddle dam was required, then sufficient costs should be allowed for the preculiarities of the foundation. He also suggested that it might be possible to build the dam up to lower elevation with a wide crest and increase the height later if desired. J. Lawrence did not think this would be acceptable to FERC for granting the license.

The panel recommended that the reservoir level be adjusted to eliminate the need for a saddle dam. The PMF water level would then be fixed by the lowest ground level in the relict channel area with suitable freeboard allowance.

Dr. Peck quoted the example of the James Bay project where the rock foundation was very irregular and was expensive to prepare. Acres should make sure they have sufficient cost for foundation preparation.

NB/rmr

Prepared by: N A J Bond

12. PRESENTATION BY J. D. LAWRENCE

DAM ELEVATION

TRADE-OFFS :

- ENVIRONMENTAL
- ENERGY
- COST

SAFETY CONSIDERATIONS :

- EMERGENCY SPILLWAY
- SADDLE DAM
- RELICT CHANNEL
- PERMAFROST/SEEPAGE
- LIQUEFACTION

ENVIRONMENTAL TRADE-OFFS

- RESERVOIR LEVEL FLUCTUATIONS
- MULTI-LEVEL INTAKES (WATER QUALITY)
- DOWNSTREAM FLOW VARIATIONS

ENERGY PRODUCTION

- YEAR 2010 (WATANA/DEVIL CAN.)
- YEAR 1994 (WATANA ALONE)
- RESERVOIR OPERATION:

Ⓐ
- MAXIMUM WINTER ENERGY
- UNIFORM THERMAL LOAD
- SUMMER FLOWS RESTRICTED

Ⓑ
- CONSTANT RATIO HYDRO: THERMAL (INITIAL APPROXIMATION)

Ⓒ
- COMPROMISE BETWEEN Ⓐ AND Ⓓ:
  - WINTER ENERGY REDUCED
  - SUMMER FLOWS INCREASED

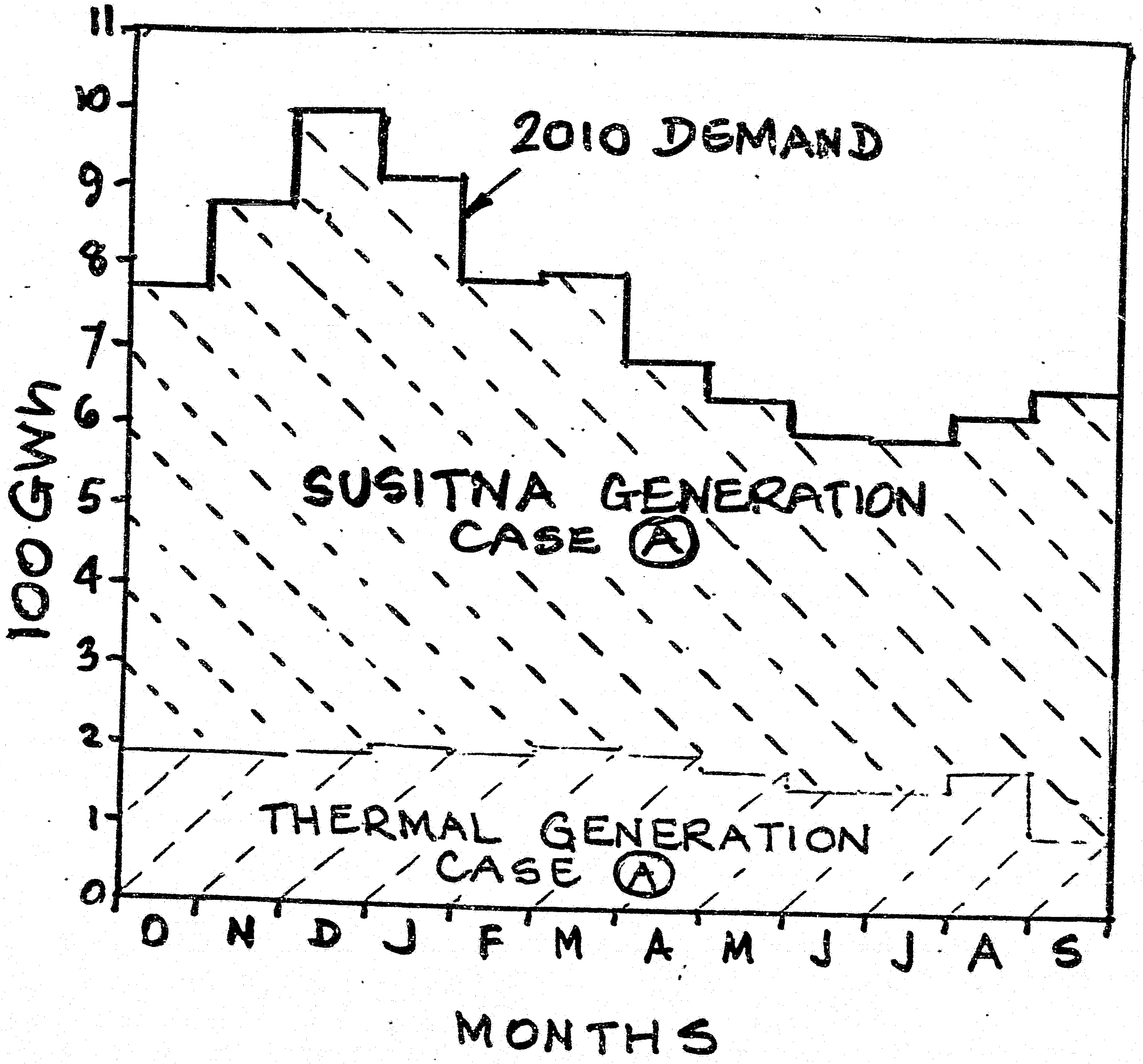
Ⓓ
- UNRESTRICTED SUMMER FLOWS
- REDUCED USABLE ENERGY

- RESERVOIR ELEVATIONS:
  1. 2215 (ORIGINAL)
  2. 2165
  3. 2115

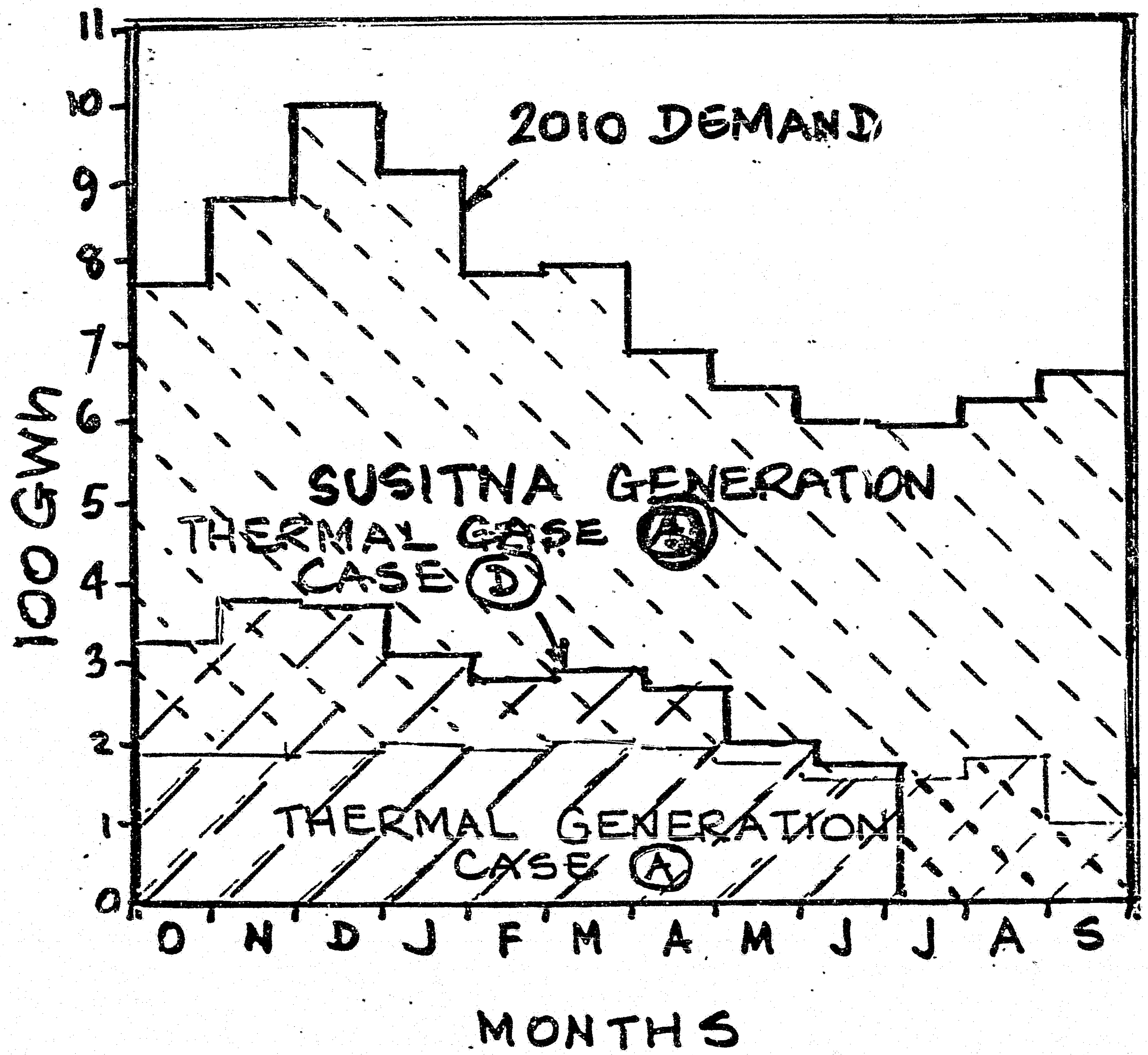
CASES ANALYSED

W.S. ELEVATION	OPERATION CASE (A)	(B)	(C)	(D)
2215	X		X	X
2165	X		X	
2115	X		X	

AVGE. MONTHLY ENERGY GENERATION



AVGE. MONTHLY ENERGY GENERATION



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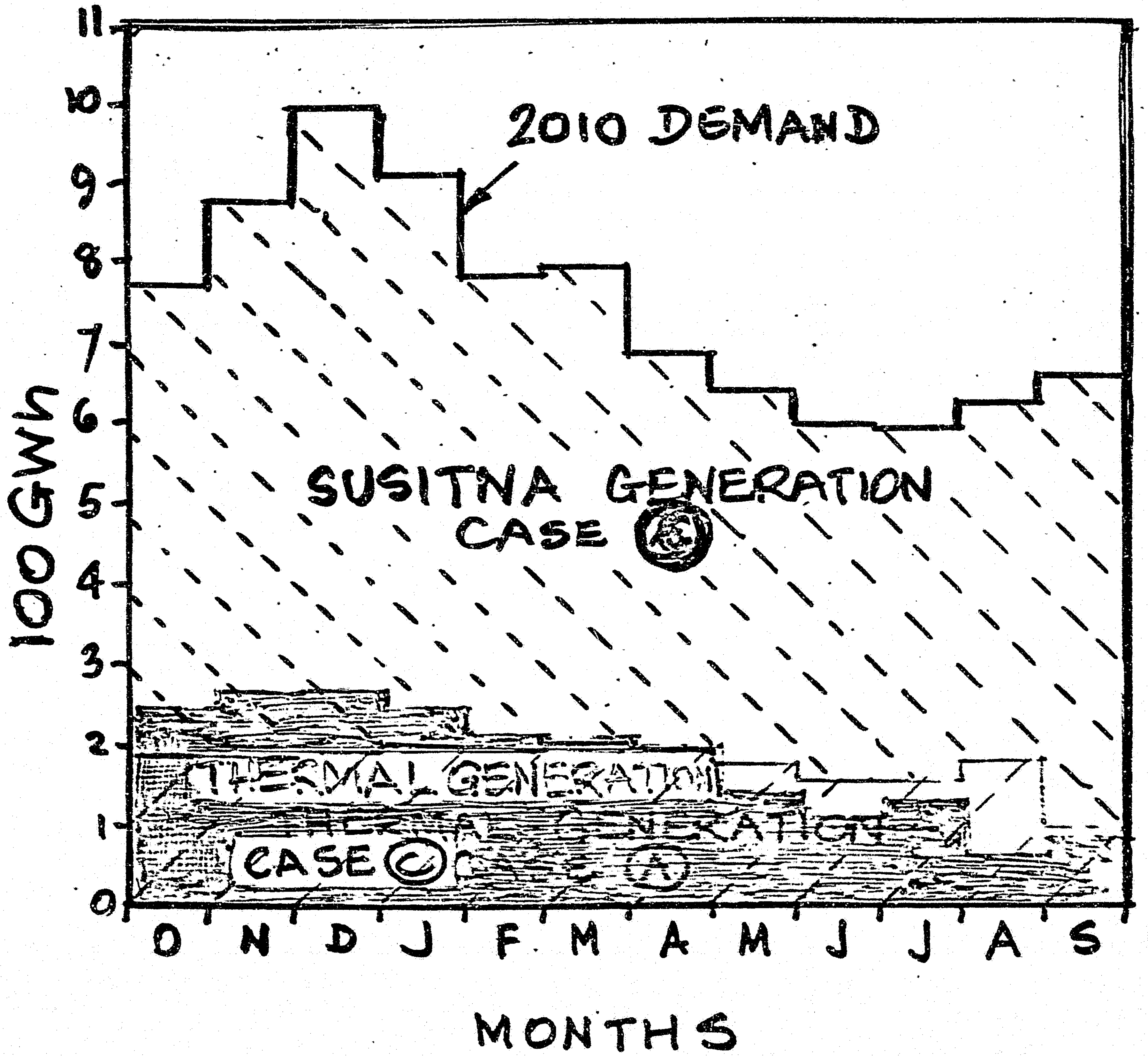
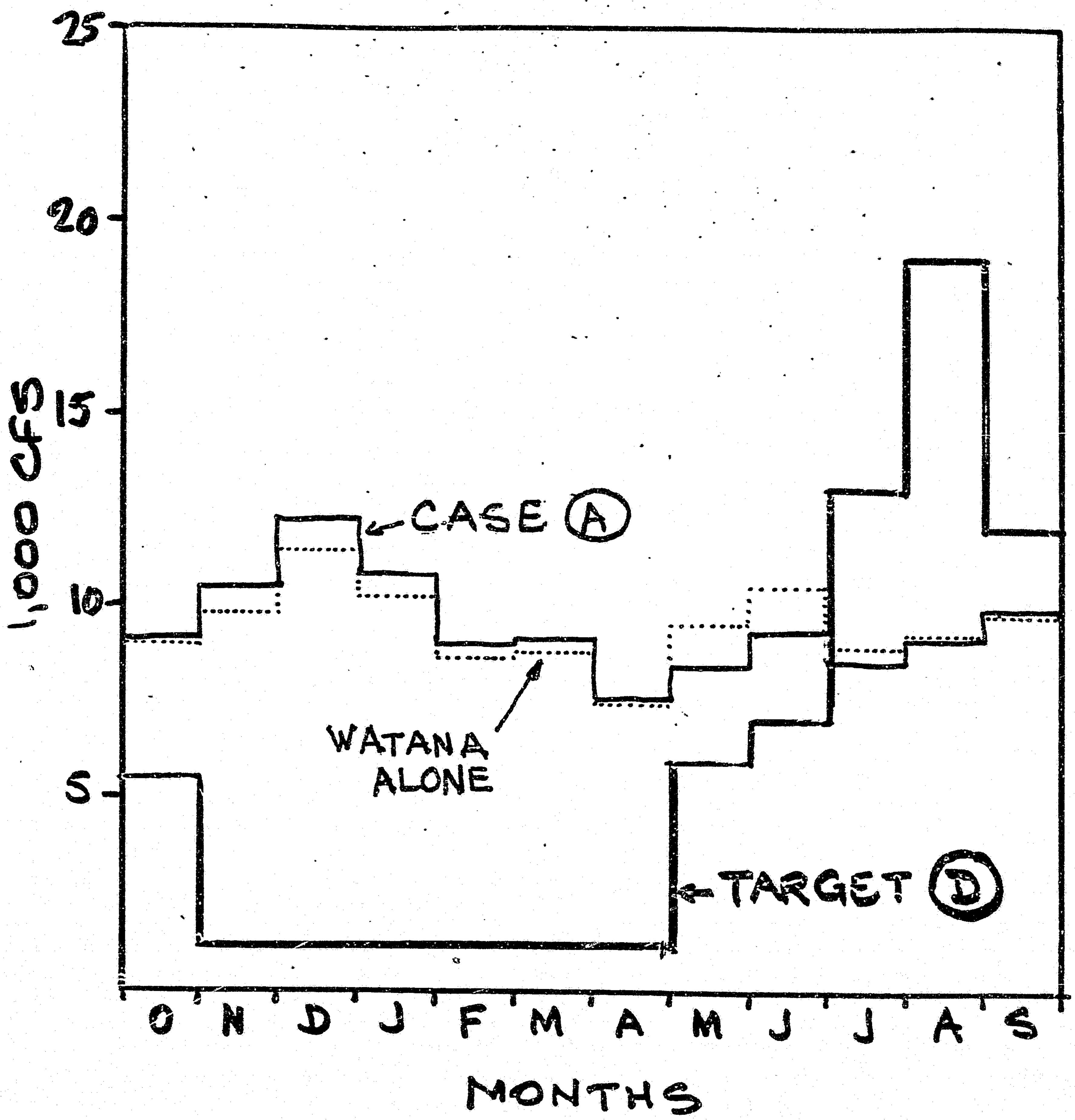


AVGE. MONTHLY FLOW AT GOLD CREEK



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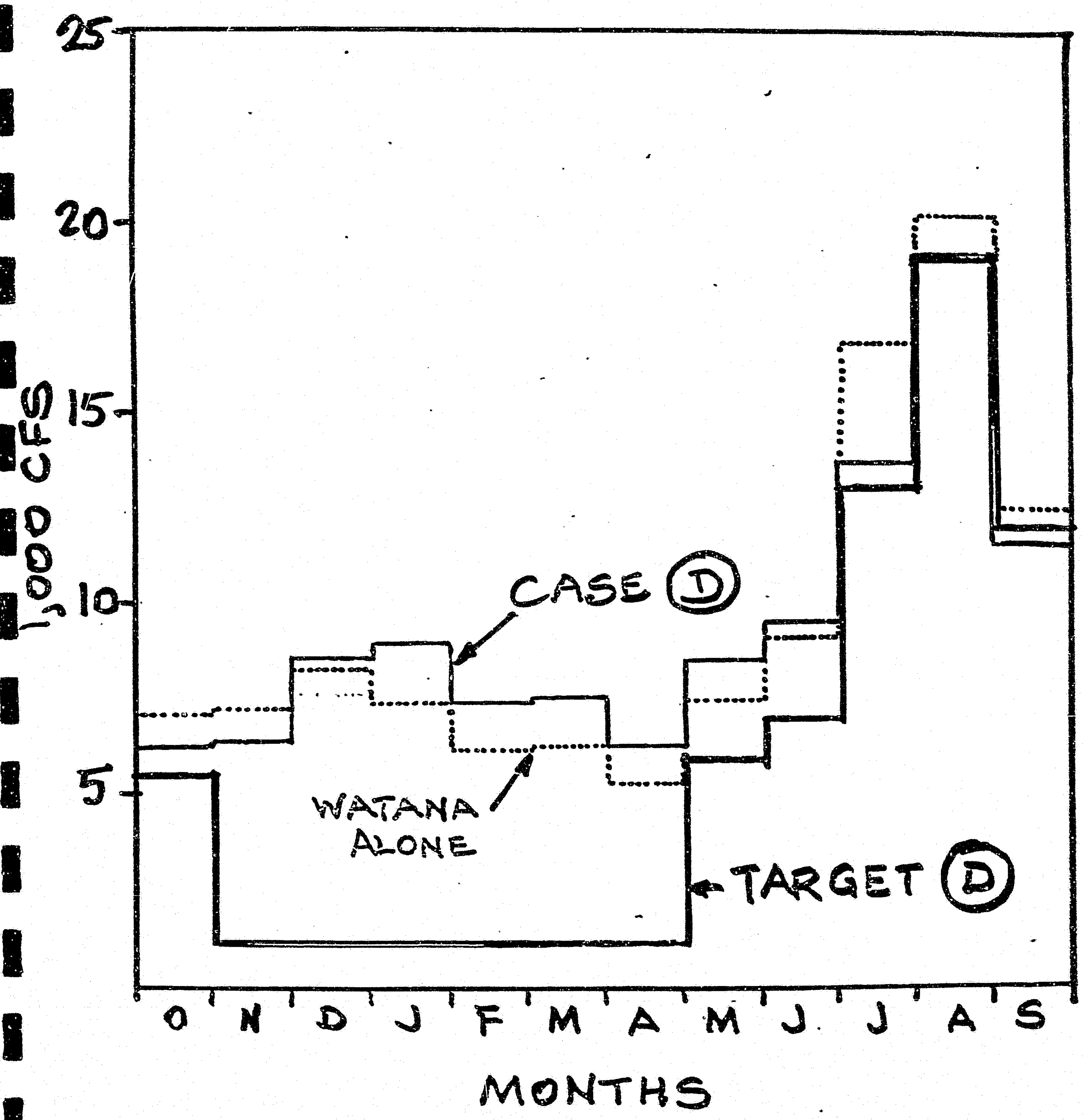
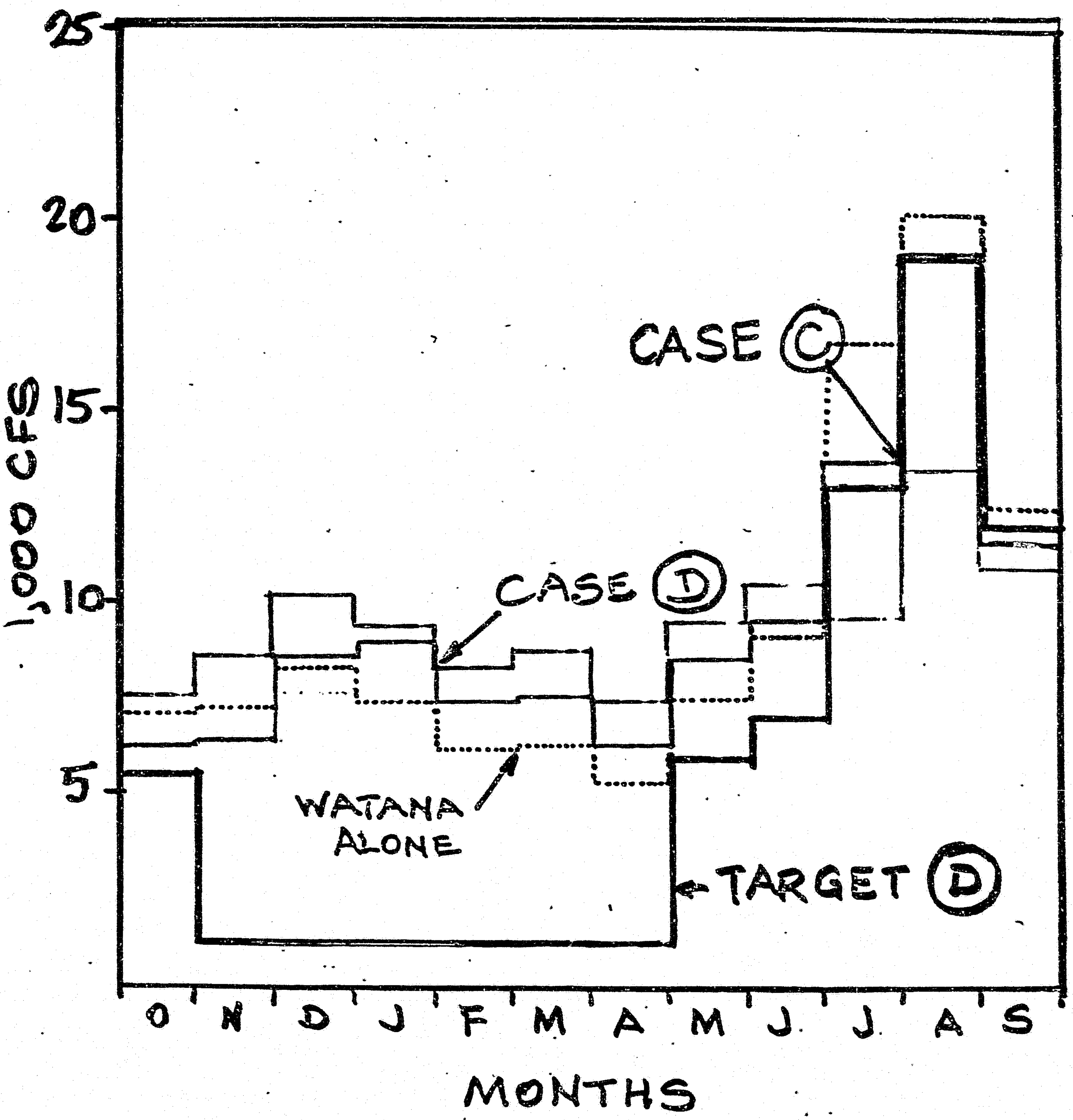


AVGE. MONTHLY FLOW AT GOLD CREEK



ENERGY PRODUCTION

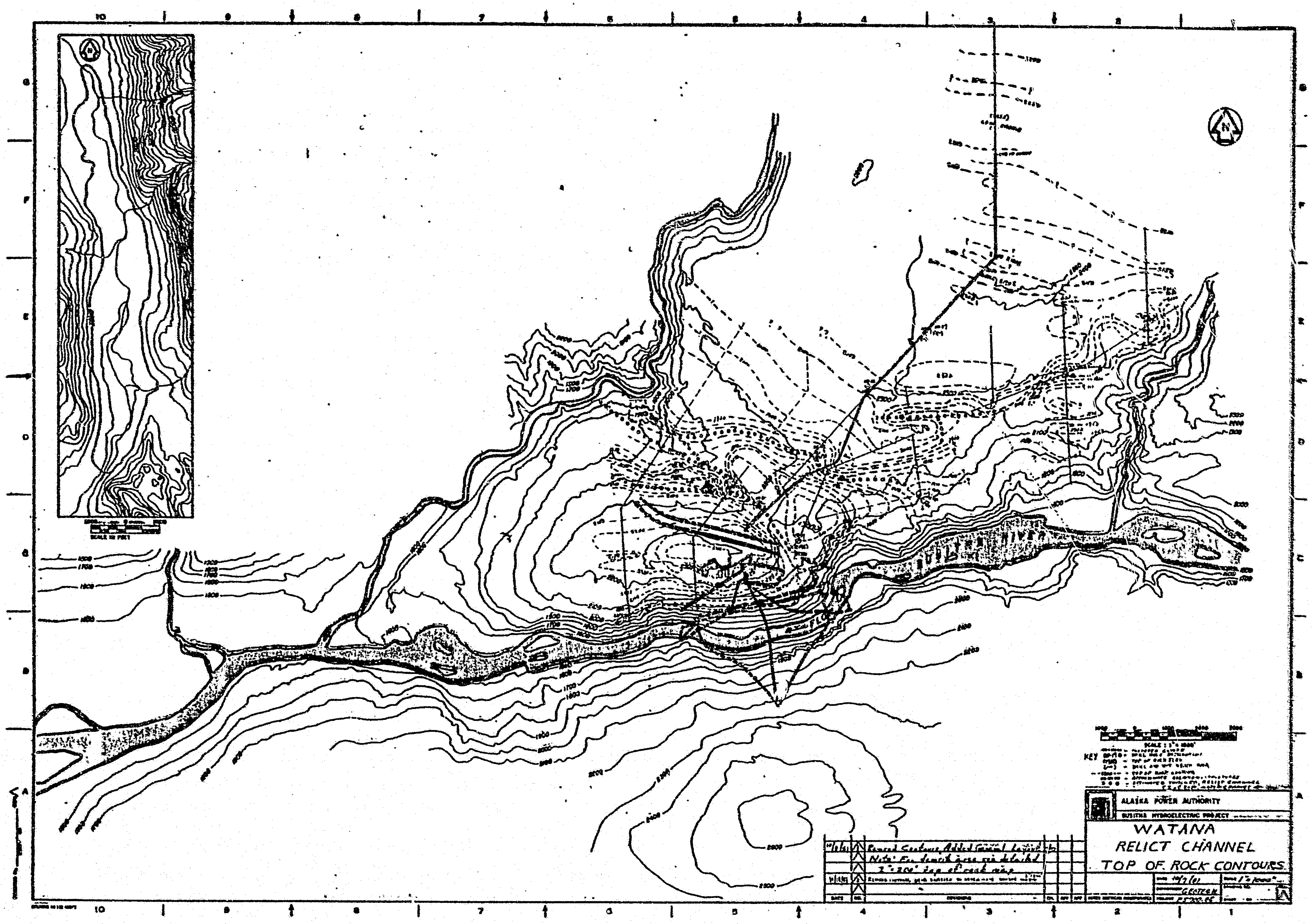
OPERATION CASE	GWh	RESERVOIR ELEV'N. 2215	2165	2115
A	WATANA	3513	3280	2977
	(MAX. D/D)	(194)	(234)	(280)
	DEVIL CAN.	3310	3279	3226
	(MAX. D/D)	(39)	(41)	(169)
	TOTAL	**6823**	**6559**	**6203**
C	WATANA	3513	3280	2977
	(MAX. D/D)	(170)	(194)	(239)
	DEVIL CAN.	3296	3306	3287
	(MAX. D/D)	(18)	(63)	(41)
	TOTAL	**6809**	**6586**	**6264**
D	WATANA	3557	–	–
	(MAX. D/D)	(120)		
	DEVIL CAN.	3266	–	–
	(MAX. D/D)	(38)		
	TOTAL	~~6823~~ 6389	–	–

(BASED ON AVGE. MONTHLY FLOWS)

PROJECT CONSTRUCTION COSTS
($ MILLIONS - 1982)

	2215	2165	2115
WATANA	3,672	3,305	2,963
TRANSM'N.	374	374	374
TOTAL	4,046	3,679	3,337
DEVIL CANYON	1,534	1,534	1,534
TRANSM'N.	93	93	93
TOTAL	1,627	1,627	1,627
TOTAL PROJECT:	5,673	5,306	4,964

13. PRESENTATION BY D. W. LAMB



KEY
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA
RELICT CHANNEL
TOP OF ROCK CONTOURS

WATANA DAM

RELICT CHANNEL

PROBLEMS

1. LEAKAGE

2. PIPING

3. PERMAFROST

3. LIQUEFACTION

WATANA DAM

RELICT CHANNEL

SOLUTIONS

1. SLURRY WALL - GROUTED CUT-OFF
2. MONITOR SEEPAGE THROUGH CUT-OFF
3. DAM CROSS SECTION
4. ?

(REJECTED:

- UPSTREAM IMPERVIOUS BLANKET
- DOWNSTREAM FILTER BLANKET)

WATANA RELICT CHANNEL
ESTIMATED COST/BENEFIT

	K (CM/SEC)		
	10^{-2}	10^{-4}	10^{-6}
POOL 2235' (MAX FLOOD)	86 CFS	0.86	.0086
POOL 2215' (MAX FLOOD)	83	.83	.0083
POOL 2160' (AVE POOL)	75	0.75	.0075

ANNUAL LOSS	$1.7-2 MILLION	$20K	$ 200
CAPITAL LOSS	$34-39 MILLION	$0.4 MILLION	$4000

(CAPITAL VALUE OF WATER - $450K/CFS)

(ANNUAL VALUE OF WATER - $22.4K/CFS)

WATANA RELICT CHANNEL
ESTIMATED QUANTITIES COMPARISON

	MARCH 81 EST	NOV 81 EST
MAX POOL	2225	2235 ft
OPER POOL	2205	2215 ft
MAX CHANNEL DEPTH	450 ft	410 ft
MAX CUTOFF DEPTH	430 ft (below max pool)	390 ft
AVG CUTOFF DEPTH	240 ft	131 ft
CUTOFF LENGTH	7500 ft	14275
SLURRY LENGTH (in total)	(7500 ft)	(7500 ft)
SF CUTOFF - SLURRY	.75 msf	0.525 msf
SF - GROUT	0.9 msf	1.38 msf
# GROUT HOLES	1830	4705
LF HOLES - DRILLED	507000	980000
- GROUTED	324000	677000
VOLUME - GROUTED	1.2 mcy	2.52 mcy
- SLURRY CUTOFF	0.05 mcy	0.05 mcy
EST TONS CEMENT	38000	400000
EST TONS BENTONITE	26400	4170
EST CY SAND	150000	630000
EST COST - SLURRY	11 million	15 million
- GROUTING	34 million	105 million
TOTAL	45 million	120 million

RESULTANT UNIT COSTS - SLURRY C/B CUTOFF - $35/SF USABLE, $29/SF TOTAL

- GROUT CUTOFF - $76/SF USABLE

WATANA RELICT CHANNEL
ESTIMATED QUANTITIES COMPARISON

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RESULTANT UNIT COSTS - SLURRY C/B CUTOFF - $35/SF USABLE, $29/SF TOTAL

- GROUT CUTOFF - $76/SF USABLE

DR-18

ELEV	DEPTH	GRAPHIC LOG	DESCRIPTION OF MATERIALS	SAMPLE NO.	REMARKS
2172.3	0		ML, Sandy silt, with boulders and cobbles. Brown, damp, nonplastic. (Outwash)	A 1	Sample A, 2.5'-3.5' Grab sample. 12'
2160	12'		ML, Sandy silt, gray-brown, damp, nonplastic. Occasional gravel and clay layers.		Sample 1, 12.5'-13.7' Drive sample, 279 blows 20'
2152	20'		CL-ML to ML, Sandy silt, damp, wet, dense, nonplastic. Frozen Natural moisture content 12.5% Liquid limit 21.7%	2 3	6 inch casing to 27' Sample 2, 23.1'-23.6' Drive sample, 59 blows Sample 3, 38.5'-39.7' Drive sample, 59 blows. No recovery. 48'
2124	50		SM, silty sand, gray, wet, dense, nonplastic. Frozen	4	Piezometer [illegible] to 65' Sample 4, 57'-65.1' Drive sample, 178 blows (2 inch spoon) 68'
2104	70		CM-ML, Sandy silt, gray, damp, dense, nonplastic. Minor subrounded coarse sand. Occasional, subrounded small gravel, below 97'	5 6	Sample 5, 72.7'-74.5' Drive sample, 88 blows. 5-5/8 inch tricone bit and mud, 0'-239.2' Sample 6, 97.8'-98.8' Drive sample, 30 blows
	100		CL-ML, Sandy silt, [illegible]		115'
2057	115		GP, Sandy, silty gravel with cobbles and boulders. Gray brown, damp, dense nonplastic. Gravel, rounded to subrounded; boulders to 1.5 feet in diameter. Occasional, weathered zones with iron staining. (Till)	7 8	Sample 7, 118.5'-122.3' NQ-3 core 5-5/8 inch tricone bit and mud, 0'-239.2' Sample 8, 158.5'-159.8' Drive Sample, 7 blows 170'
2002	170		Sandy silt with minor gravel, gray-brown, damp, dense to very dense, nonplastic. Boulders and cobbles absent. (Till)		200'
1972	200		ML Sandy silt interlayered with silty clay.		Sample 9, 199.1'-211.2' Drive sample, 193 blows.
	213		ML, Sandy silt, gray-brown, damp, very dense, plastic. Interlayered with silty clay, blue-gray, damp, very dense, plastic. Occasional, minor scattered gravel and cobbles. (Till) Top of Rock	9	5-5/8 inch tricone bit and mud, 0'-239.2' 231'
1941	231		Diorite, moderately hard, medium grained, altered, highly fractured, gray. Disseminated sulfides throughout.		4 inch casing to 239' 2-3/8 x 3-7/8 inch core 239.2'-248.5' 248.5'
1924	248.5		Bottom of Hole		3/4 inch galvanized pipe

DR-18

WATANA RELICT CHANNEL

TREATMENT POSSIBILITIES

UPSTREAM CLAY BLANKET: 850 ACRES (1.3 SQ MILES)

TASK: CLEAR & GRUB
SMOOTH SURFACE
10 FOOT CLAY BLANKET
2 FOOT FINE FILTER (MIN)
2 FOOT COARSE FILTER (MIN)
RIPRAP SURFACE

COST: (ROUGH ESTIMATE) $509 MILLION PLUS CONTINGENCY

DOWNSTREAM TOE FILTER/DRAIN: 460 ACRES (0.7 SQUARE MILES)

TASK: CLEAR & GRUB
SMOOTH SURFACE
7 FOOT FILTER

COST: (ROUGH ESTIMATE) $105 MILLION

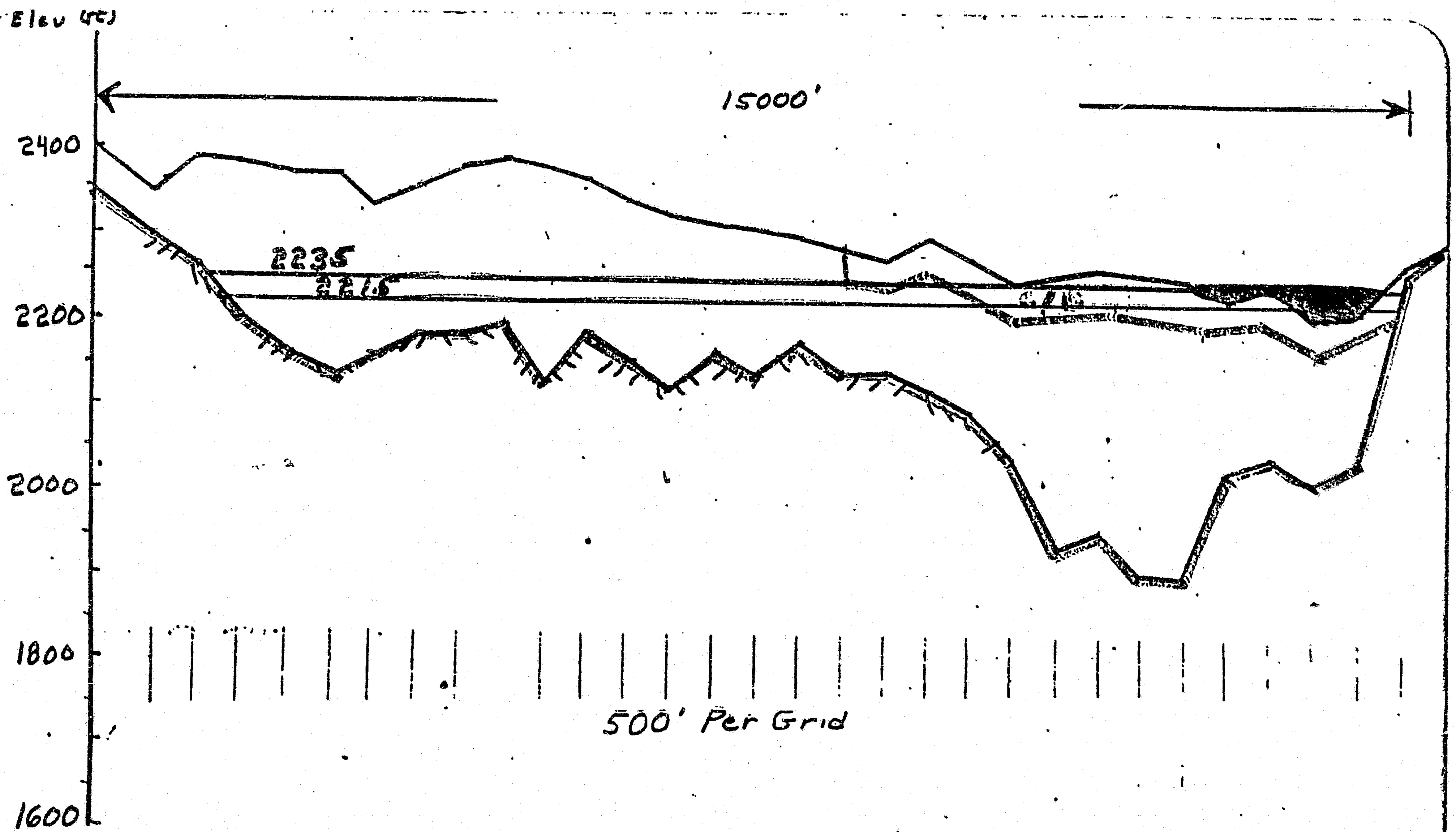
RELICT CHANNEL TREATMENT

1. FURTHER INVESTIGATION
   - REPRESENTATIVE SAMPLES
   - IN-SITU PERMEABILITY TESTS IN UNFROZEN GROUND
   - TEST TRENCHES AT CHANNEL OUTLET
   - IDENTIFY SOILS WHICH MAY LIQUEFY
   - EXTENT OF PERMAFROST
   - PIEZOMETER AND THERMISTER INSTALLATION

2. DESIGN
   - CUT-OFF V DOWNSTREAM BLANKET
   - PARTIAL CUT-OFF PLUS D/S BLANKET
   - DAM LOCATION AWAY FROM SHALLOW DEPOSITS WHICH MAY LIQUEFY
   - ASSESS RISK OF U/S AND D/S LIQUEFACTION
   - ASSESS SETTLEMENT ALLOWANCE FOR DAM TO COUNTER EFFECTS OF THAWING PERMAFROST

3. CONSTRUCTION

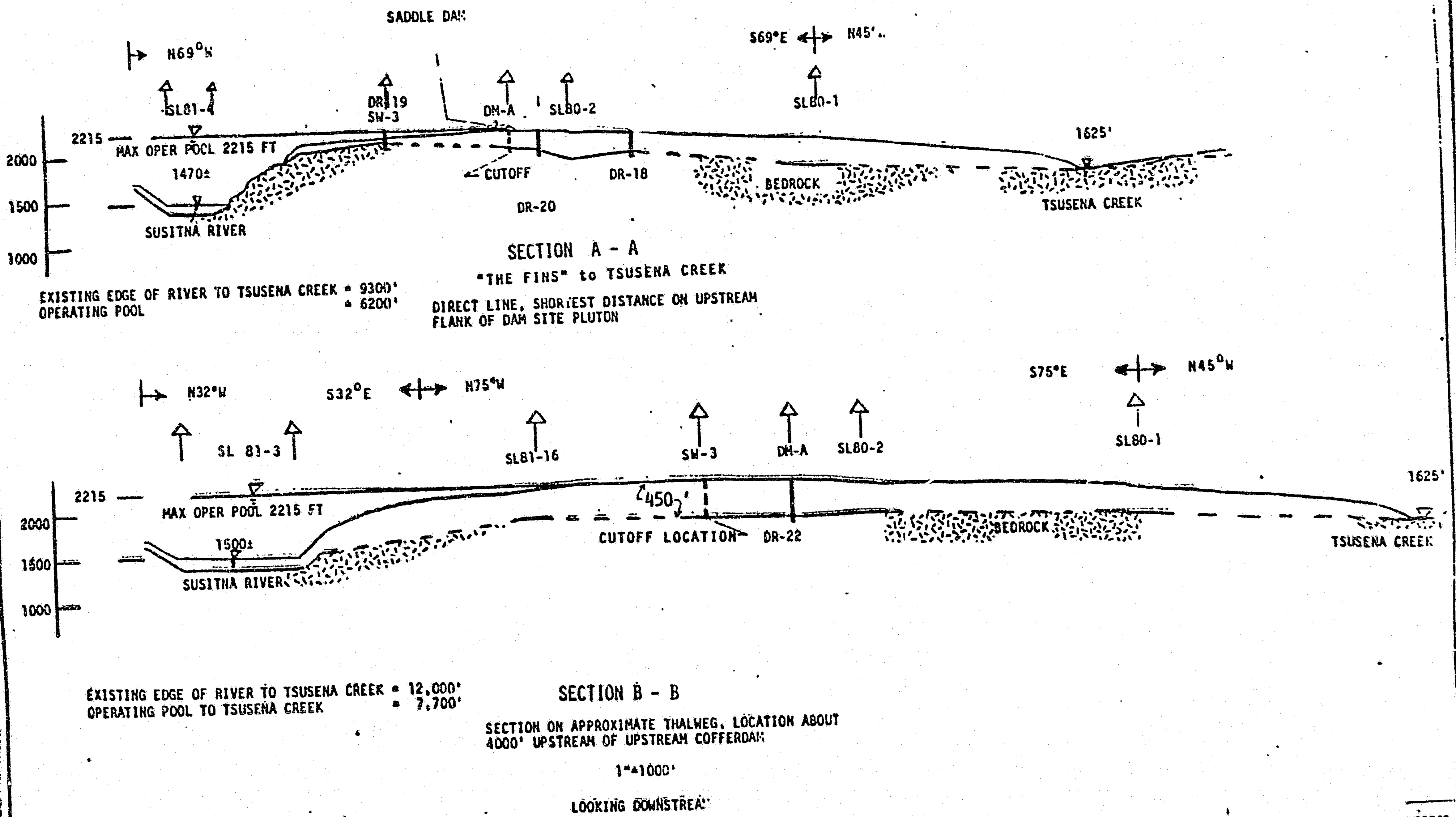
4. RESERVOIR FILLING AND OPERATION
   - MONITOR THAWING PERMAFROST
   - MONITOR PIEZOMETERS
   - MONITOR CHANNEL OUTLET FOR SEEPAGE
   - REMEDIAL WORK AS NECESSARY



Watana Relict Channel
10:1 Vertical Exaggeration
Looking South

11/17/81 tb unchecked profile

WATANA - RELICT CHANNEL PROFILE



RELICT CHANNEL PROFILES

WATANA RELICT CHANNEL

TREATMENT POSSIBILITIES

SLURRY WALL & GROUT CURTAIN: 2.8 MSF OF SECTION
1.9 MSF OF CUTOFF

SLURRY WALL : CEMENT/BENTONITE (15% CEMENT)
5250 LF, 3' THICK, 100' DEEP
525000 SF @ $17/SF = $9 MILLION

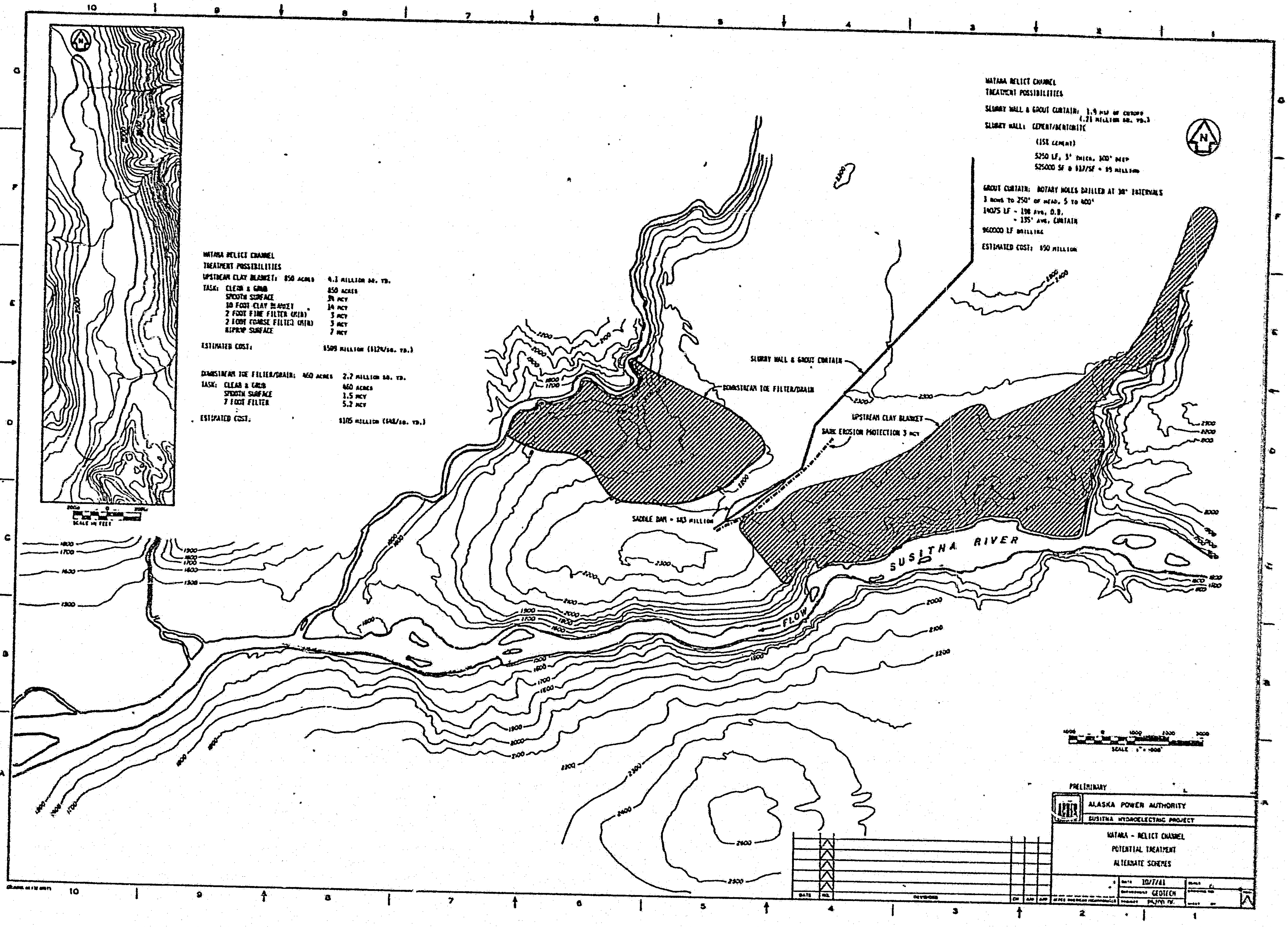
GROUT CURTAIN: ROTARY HOLES DRILLED AT 10' INTERVALS
3 ROWS TO 250' OF HEAD, 5 TO 400'
14075 LF - 198 AVG O.B.
- 135' AVG CURTAIN
960000LF DRILLING

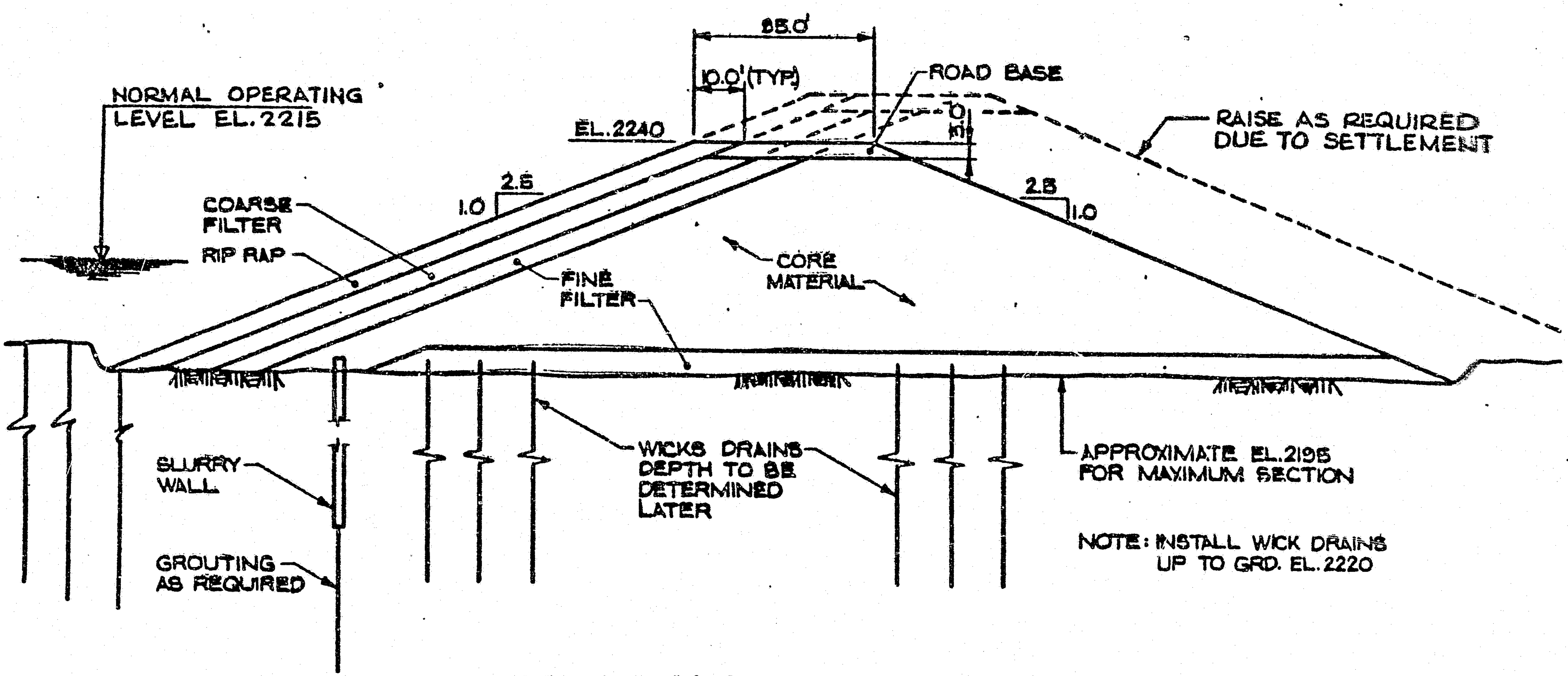
3600 HOLES TO 250' OF HEAD
1025 " OVER " " "

2.8 MSF DRILLED SECTION
1.4 " GROUTED "
0.55 MCY GROUT

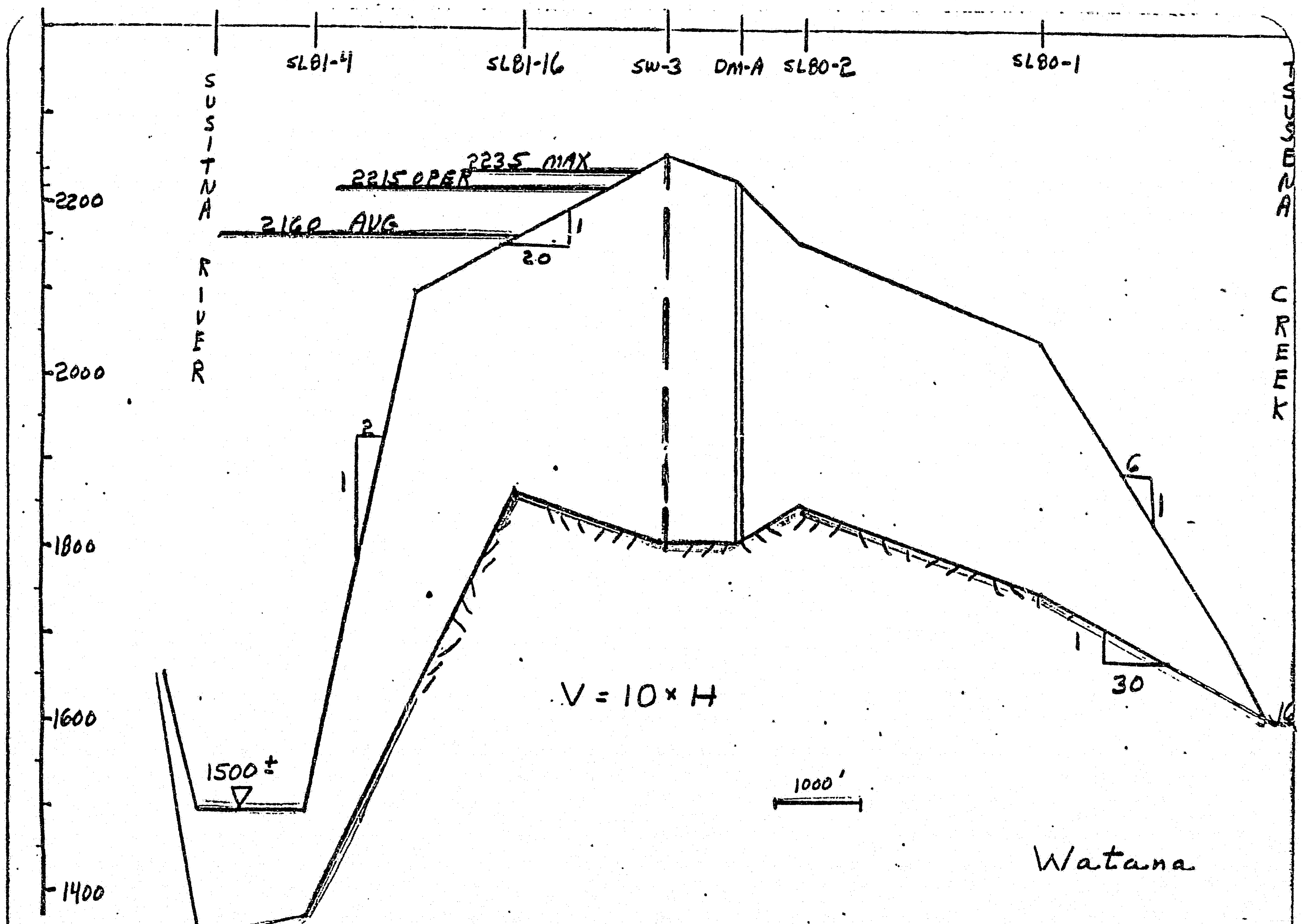
ROUGH COST:	ALL CEMENT GROUT	ALL CLAY GROUT
DRILLING	$48 MILLION	$48 MILLION
FLUID	54	11
PLANT (LS)	2	2
	$104	$61

TOTAL ESTIMATED CUTOFF	113	70


WATANA RELICT CHANNEL
TREATMENT POSSIBILITIES
UPSTREAM CLAY BLANKET: 850 ACRES 4.1 MILLION SQ. YD.
TASK: CLEAR & GRUB 850 ACRES
SMOOTH SURFACE 3? MCY
10 FOOT CLAY BLANKET 14 MCY
2 FOOT FINE FILTER (MIN) 3 MCY
2 FOOT COARSE FILTER (MIN) 3 MCY
RIPRAP SURFACE 7 MCY
ESTIMATED COST: $509 MILLION ($124/SQ. YD.)
DOWNSTREAM TOE FILTER/DRAIN: 460 ACRES 2.2 MILLION SQ. YD.
TASK: CLEAR & GRUB 460 ACRES
SMOOTH SURFACE 1.5 MCY
7 FOOT FILTER 5.2 MCY
ESTIMATED COST: $105 MILLION ($48/SQ. YD.)
WATANA RELICT CHANNEL
TREATMENT POSSIBILITIES
SLURRY WALL & GROUT CURTAIN: 1.9 MSF OF CUTOFF (.21 MILLION SQ. YD.)
SLURRY WALL: CEMENT/BENTONITE
(15% CEMENT)
5250 LF, 3' THICK, 100' DEEP
525000 SF @ $17/SF = $9 MILLION
GROUT CURTAIN: ROTARY HOLES DRILLED AT 10' INTERVALS
3 ROWS TO 250' OF HEAD, 5 TO 400'
14075 LF - 198 AVG. O.B.
= 135' AVG. CURTAIN
960000 LF DRILLING
ESTIMATED COST: $90 MILLION
N
SLURRY WALL & GROUT CURTAIN
DOWNSTREAM TOE FILTER/DRAIN
UPSTREAM CLAY BLANKET
BANK EROSION PROTECTION 3 MCY
SADDLE DAM = $43 MILLION
SUSITNA RIVER
FLOW
SCALE 1" = 1000'
PRELIMINARY
ALASKA POWER AUTHORITY
SUSITNA HYDROELECTRIC PROJECT
WATANA - RELICT CHANNEL
POTENTIAL TREATMENT
ALTERNATE SCHEMES
DATE 10/7/81
GEOTECH

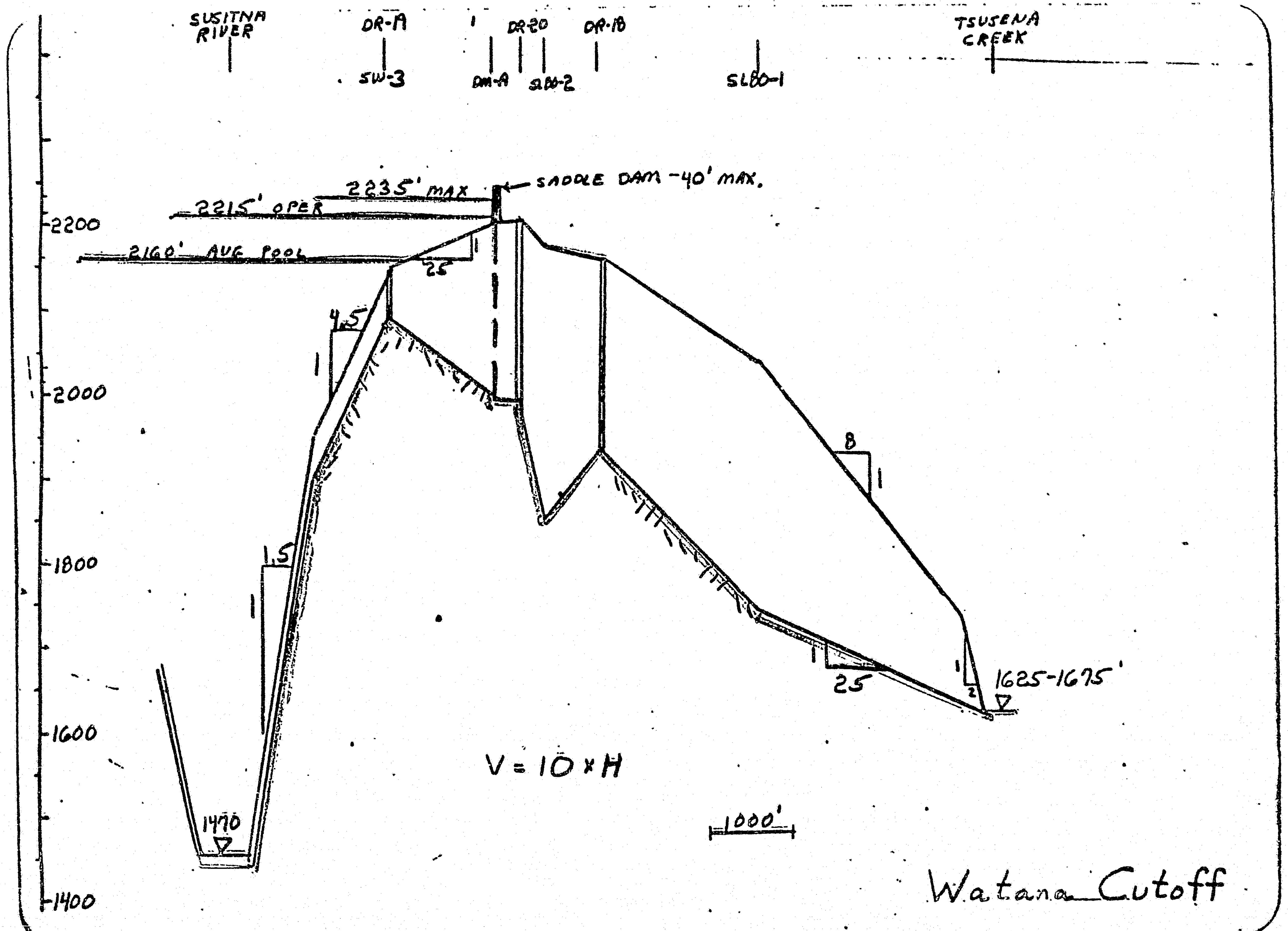


WATANA SADDLEDAM CROSS-SECTION

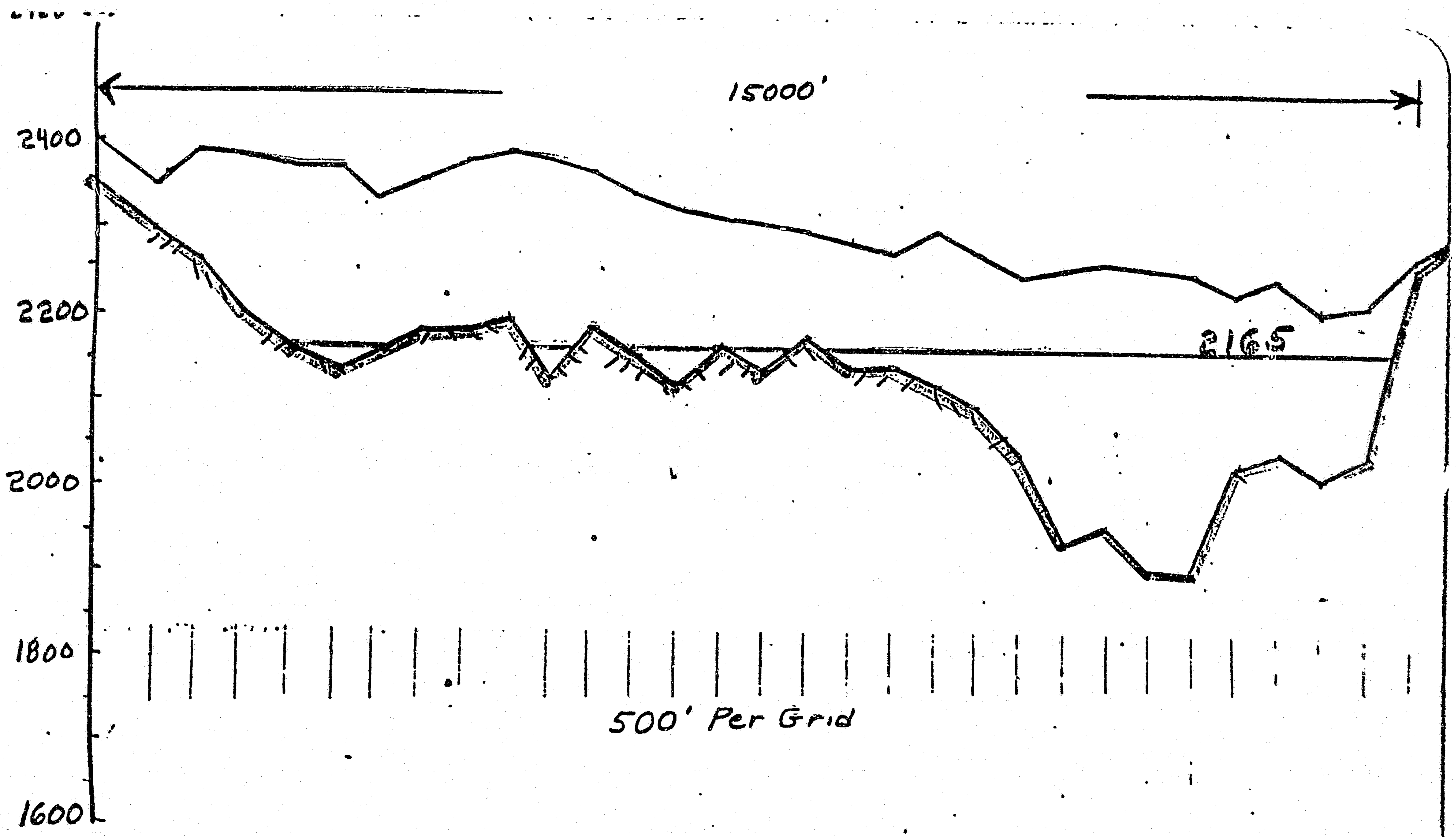


Relict Channel Thalweg

Section B-B

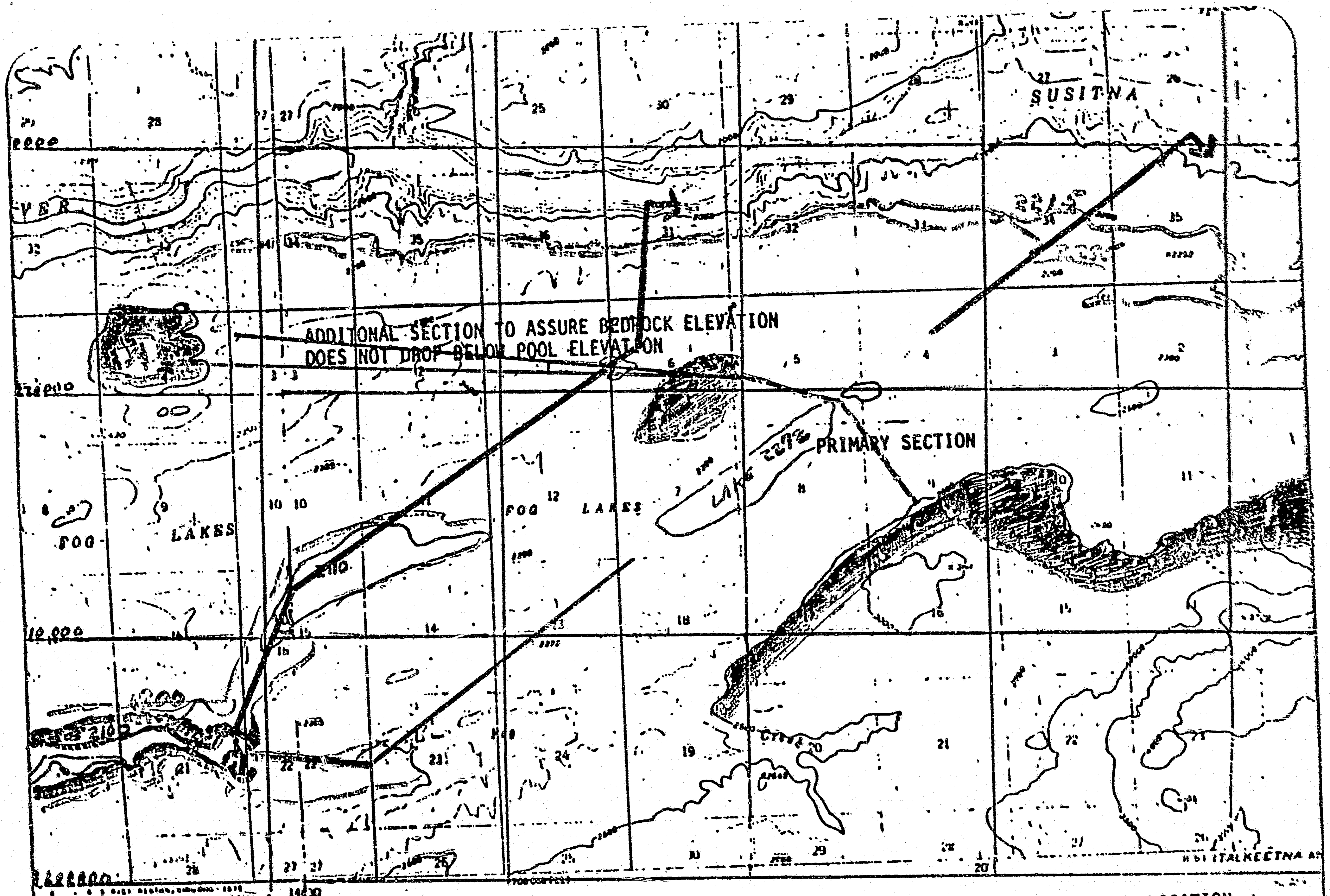


Watana Cutoff



Watana Relict Channel
10:1 Vertical Exaggeration
Looking South

11/17/81 unchecked profile



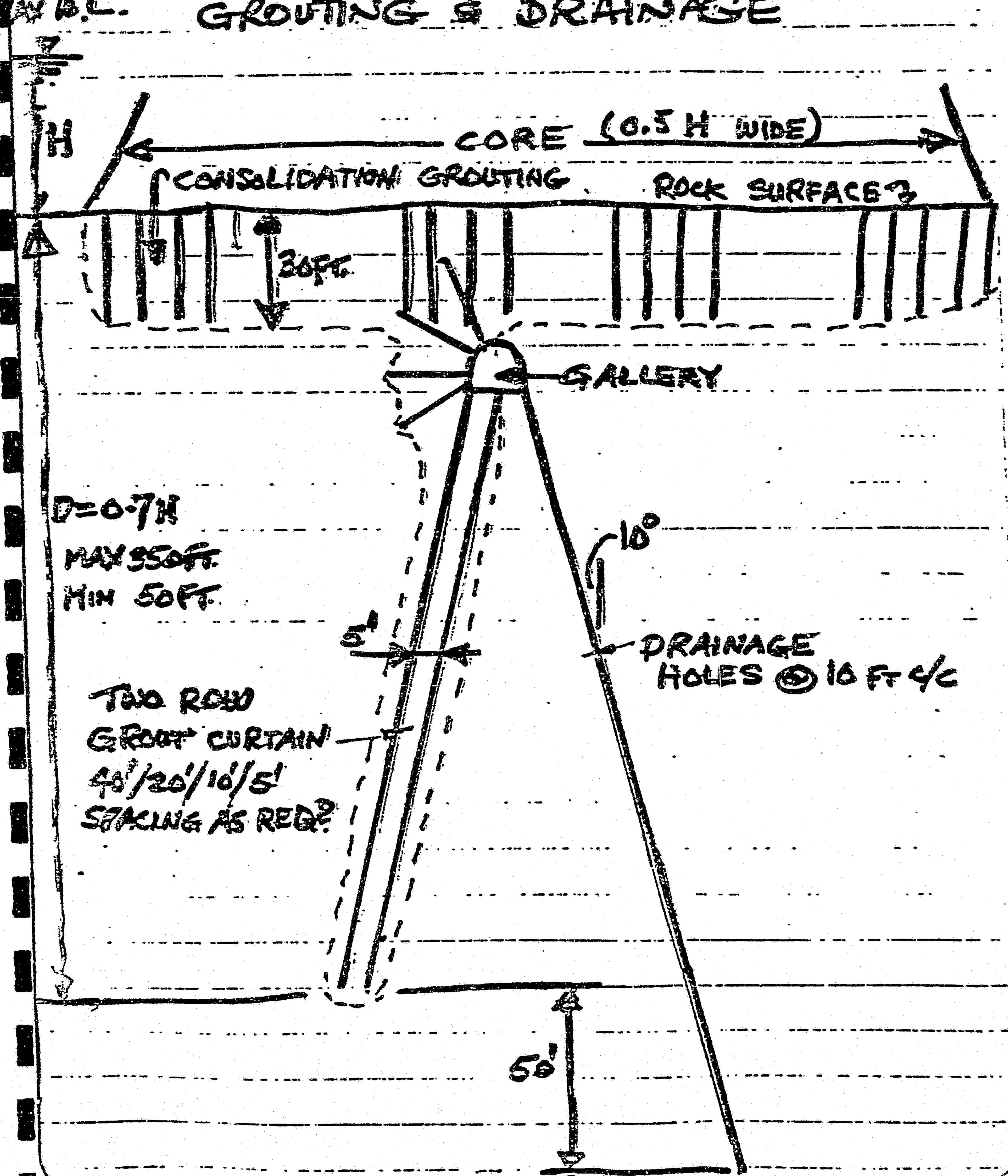
Mapped, edited, and published by the Geological Survey

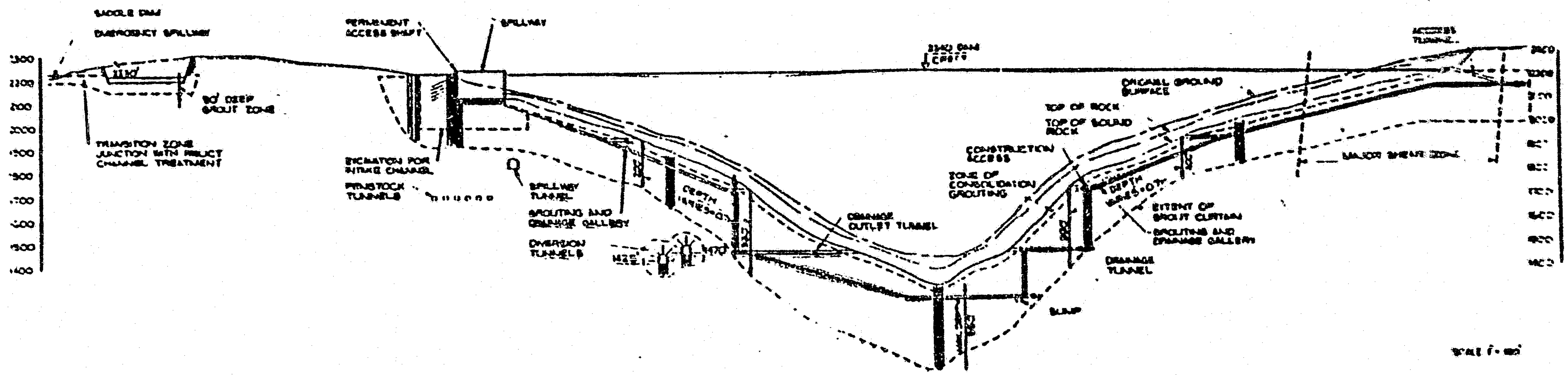
FOG LAKES SADDLE SEISMIC LINE - PREFERRED LOCATION

10/13/81 LCD

P5700.14.05.05

WATANA DAM
GROUTING & DRAINAGE





WATANA DAM
FOUNDATION TREATMENT

SUSITNA HYDROELECTRIC PROJECT

WATANA DAM

MAIN DAM

EXCAVATION

OVERBURDEN - AVERAGE 20 FEET DEPTH OVER ALL FOUNDATION AREA.

WEATHERED ROCK UNDER CORE AND FILTERS - 40' DEPTH.

WEATHERED ROCK UNDER SHELLS - 10' DEPTH.

MAXIMUM SLOPES - 1H:2V BELOW 1800' ELEVATION
1H:1V ABOVE 1800' ELEVATION

CONSOLIDATION GROUTING

10' X 10' GRID OF HOLES 30' DEEP OVER AREA OF CORE AND FILTERS.

SUSITNA HYDROELECTRIC PROJECT
WATANA DAM

CURTAIN GROUTING

DOUBLE ROW CURTAIN - VERTICAL.

350' MAXIMUM DEPTH (AT MAXIMUM HEAD).

50' MINIMUM DEPTH IN ABUTMENTS.

HOLE SPACING PRIMARY 40'.

SECONDARY	
TERTIARY	SPLIT SPACING TO GIVE
QUATERNARY	FINAL SPACING 5'.

GALLERIES FULL LENGTH OF DAM, APPROXIMATE SIZE 10' X 10'.

DRAINAGE

50' DEEPER THAN GROUT CURTAIN.

HOLE SPACING 10'.

DRILLED FROM GROUT GALLERIES.

FULL LENGTH OF DAM, EXTENDING 600' INTO LEFT ABUTMENT.

CONNECTING TO INTAKE AND SPILLWAY STRUCTURES RIGHT ABUTMENT.

HOLES INCLINED DOWNSTREAM 15° FROM VERTICAL.

Calculations	JOB NUMBER ____
SUBJECT: SUSITNA HYDROELECTRIC PROJECT	FILE NUMBER ____
DEVIL CANYON	SHEET ____ OF ____
GROUT / DRAINAGE GALLERY	BY ____ DATE ____
	APP ____ DATE ____

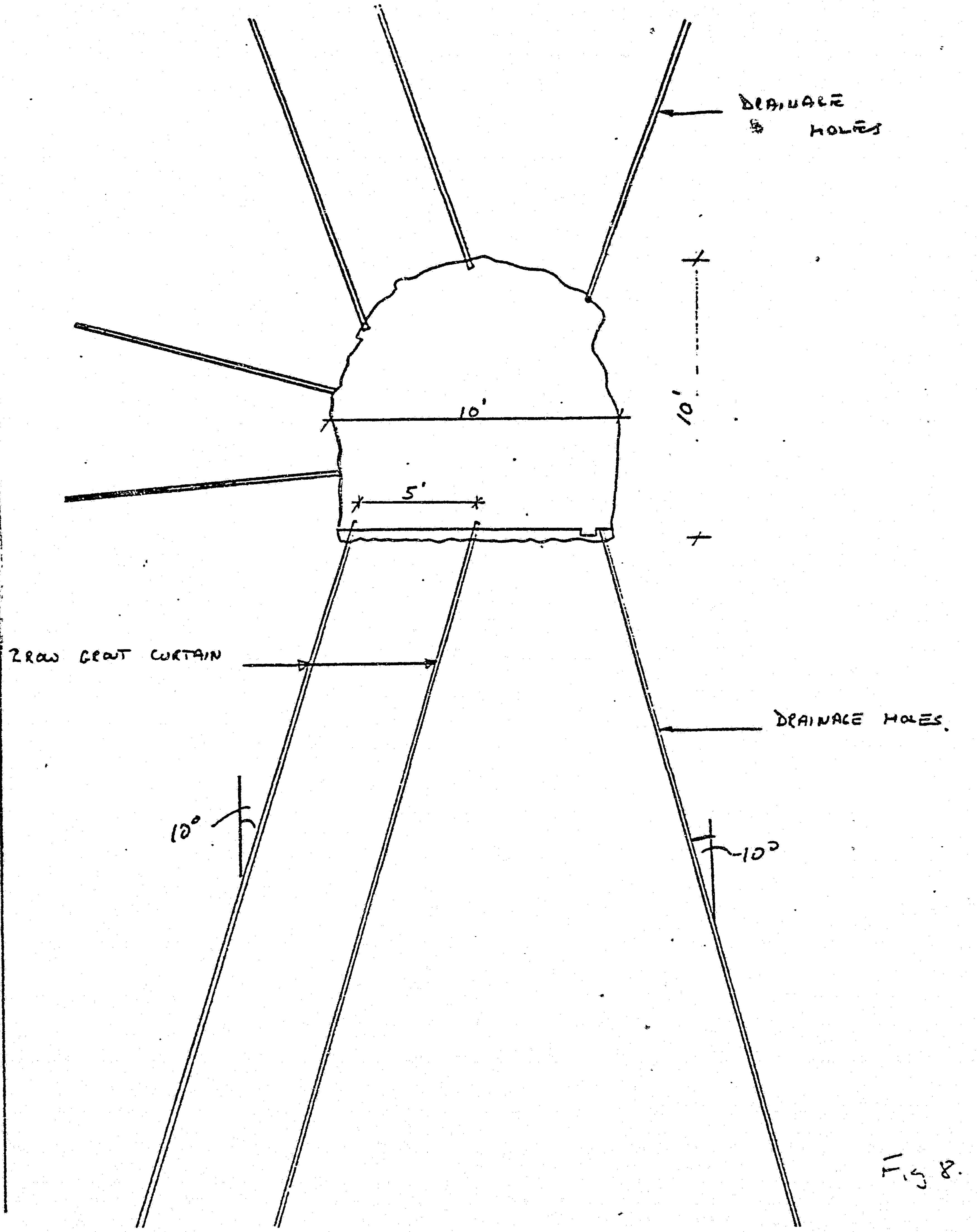


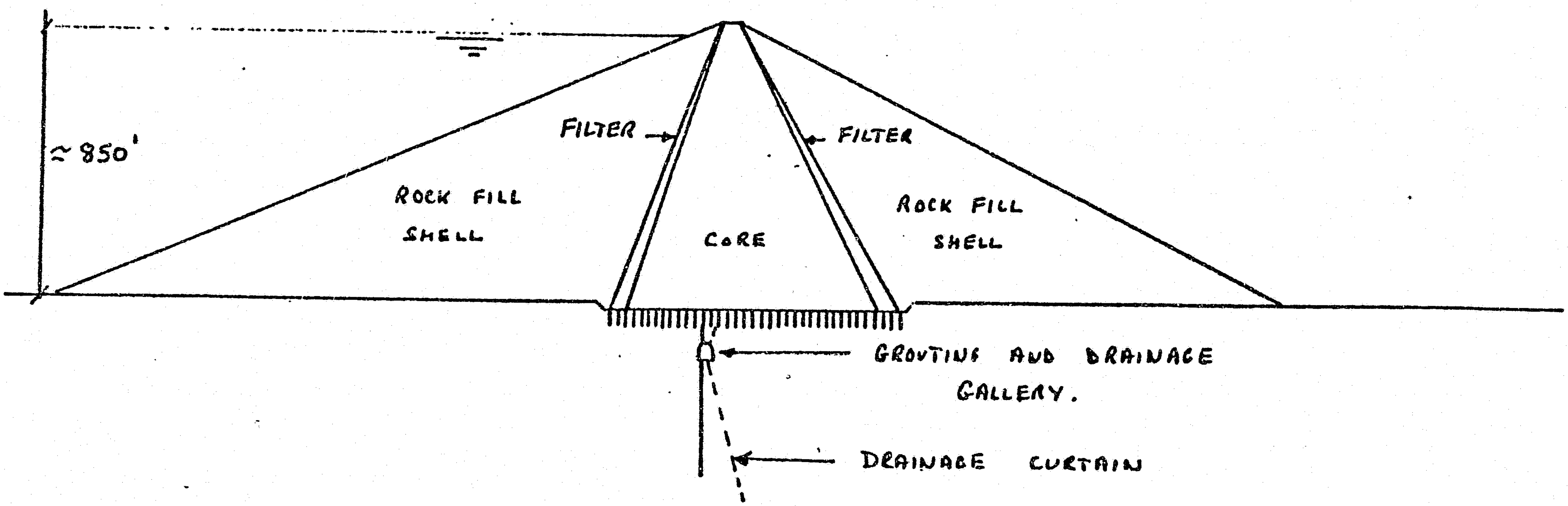
Fig 8.

FORM NO. 152 REV. 1

SUSITNA HYDROELECTRIC PROJECT

WATANA DAM

SECTION



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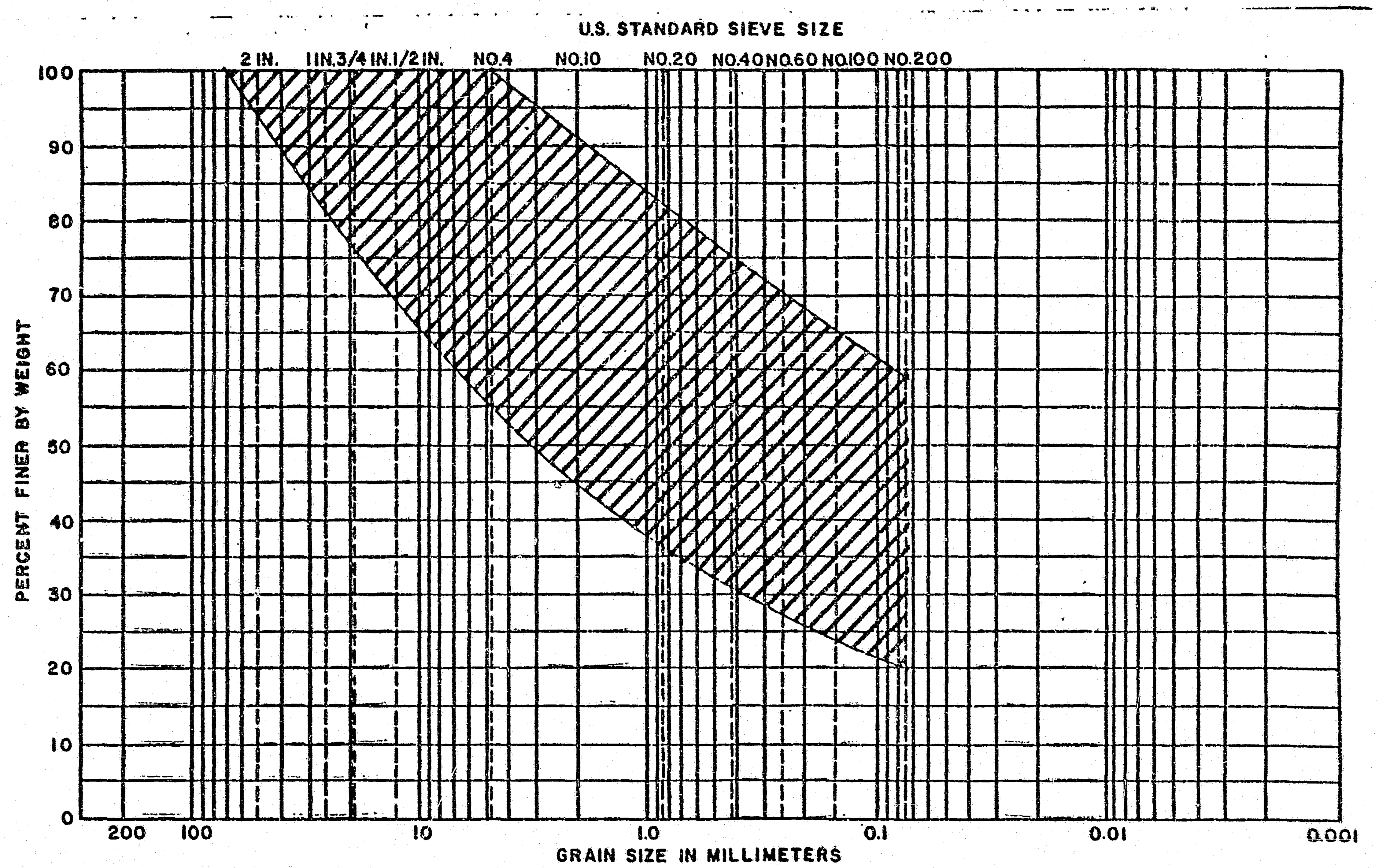


COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

UNIFIED SOIL CLASSIFICATION SYSTEM

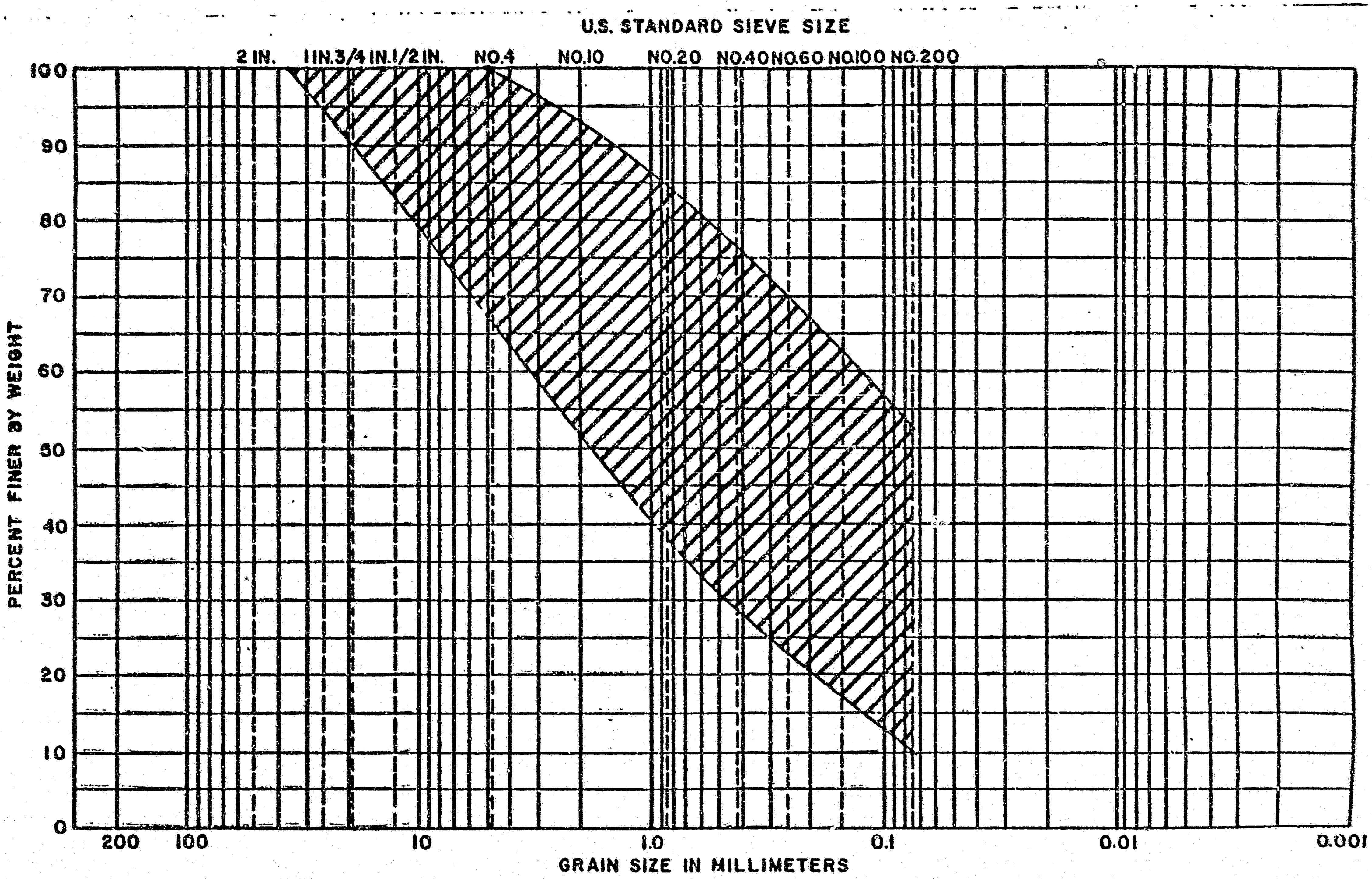
MMENTS

TURAL MOISTURE CONTENT RANGED FROM 6 TO 19% - AVERAGE OF 12%

ACRES AMERICAN INCORPORATED
BUFFALO, NEW YORK

COMPOSITE CURVES FOR H-1 THRU H-8

GRADATION ANALYSIS CURVES



COBBLES	GRAVEL		SAND			SILT OR CLAY	UNIFIED SOIL CLASSIFICATION SYSTEM
	COARSE	FINE	COARSE	MEDIUM	FINE		

MMENTS

NATURAL MOISTURE CONTENT RANGED FROM 6 TO 16% - AVERAGE OF 11%

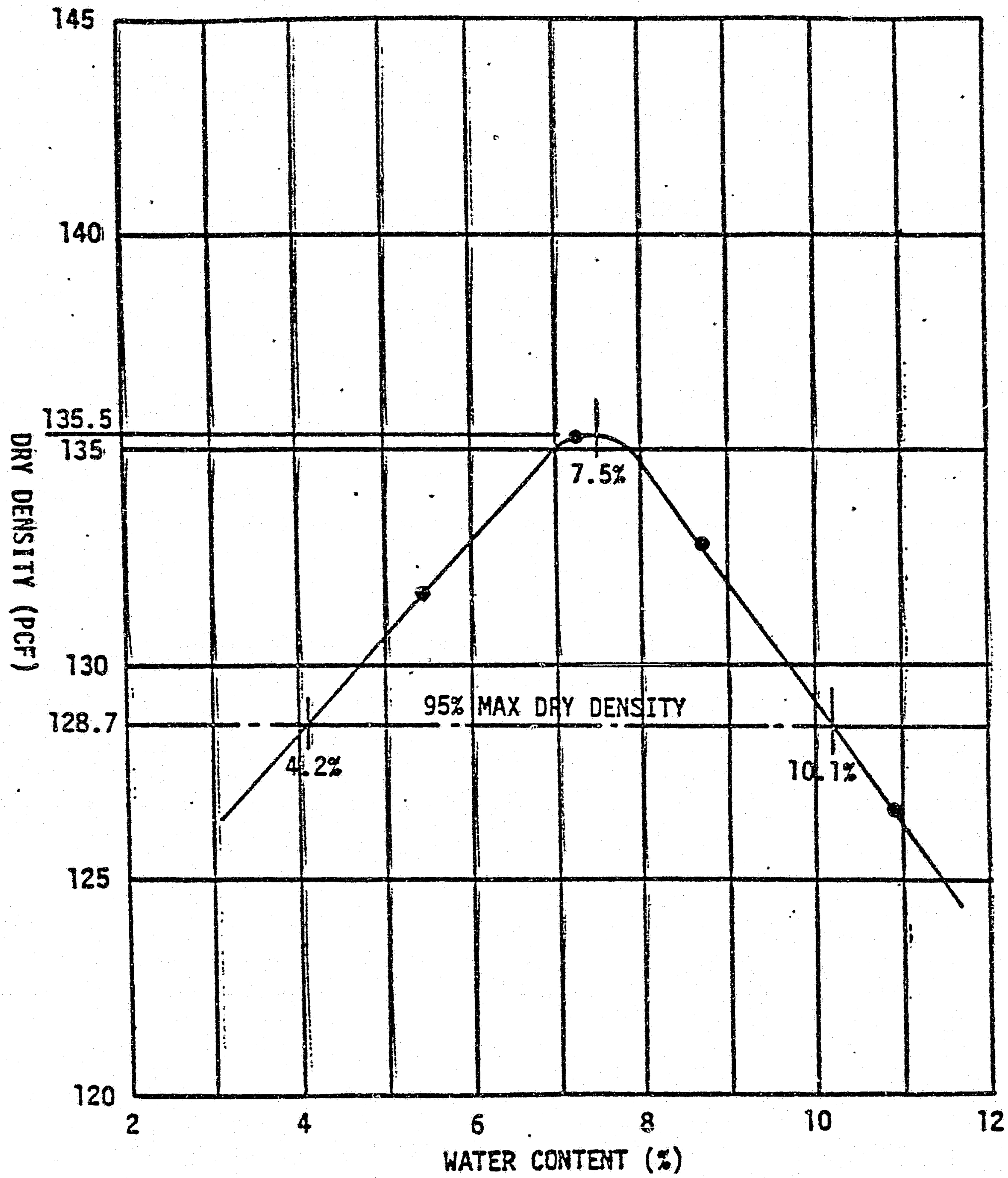
ACRES AMERICAN INCORPORATE

BUFFALO, NEW YORK

COMPOSITE CURVES FOR D-5 THRU D-9

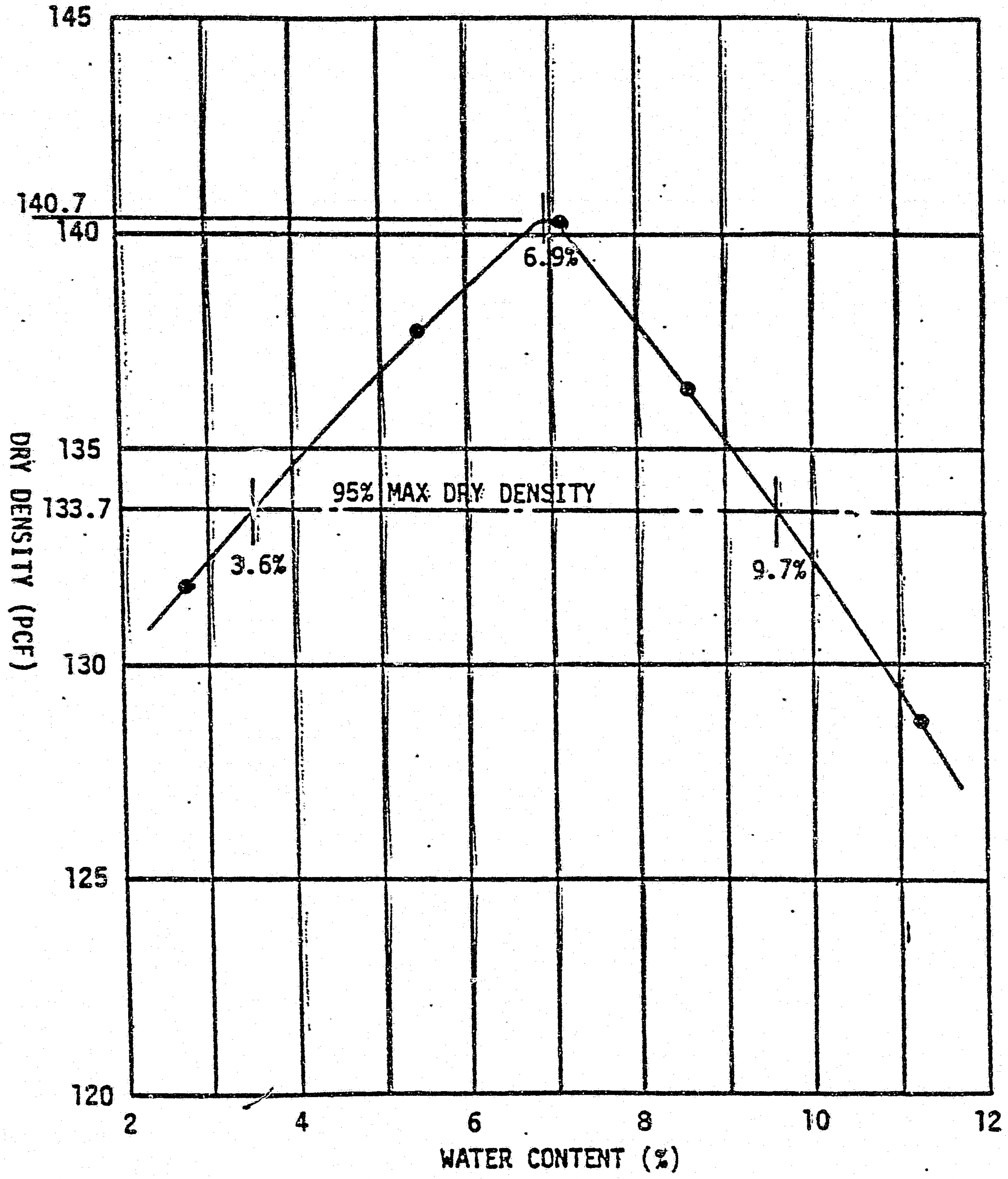
GRADATION ANALYSIS CURVES

FILE: DATE:



AREA D COMPOSITE
MINUS 3/4 INCH

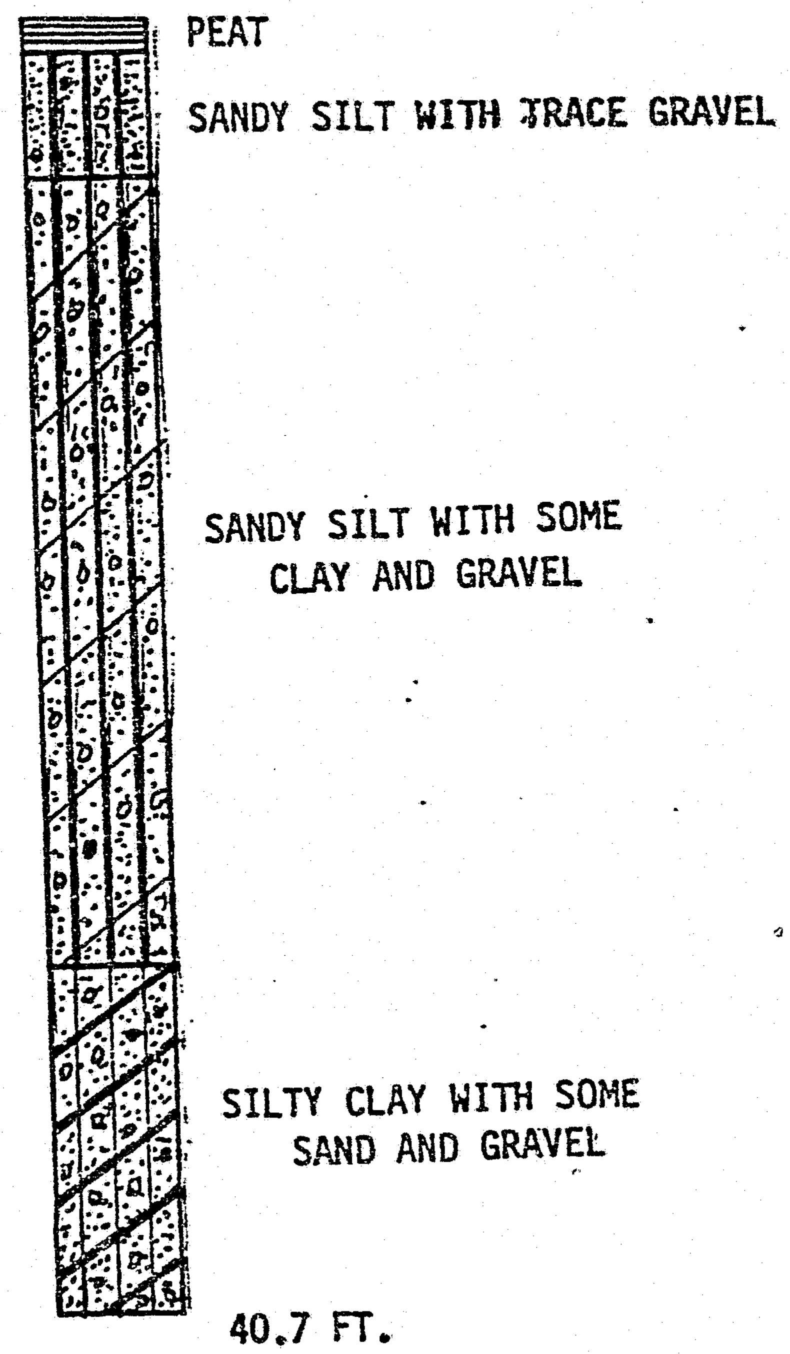
modified proctor



AREA H COMPOSITE
MINUS 3/4 INCH

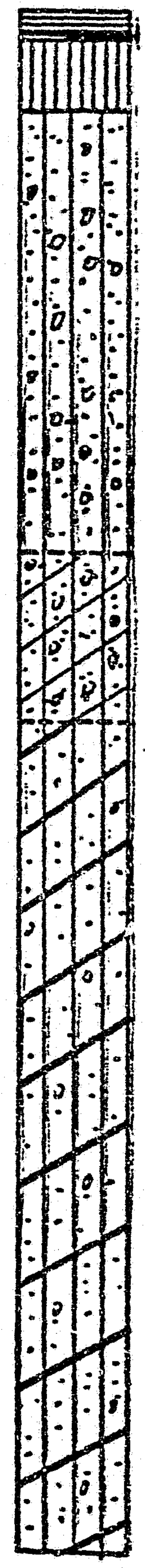
modified proctor
Area H

AH-H2

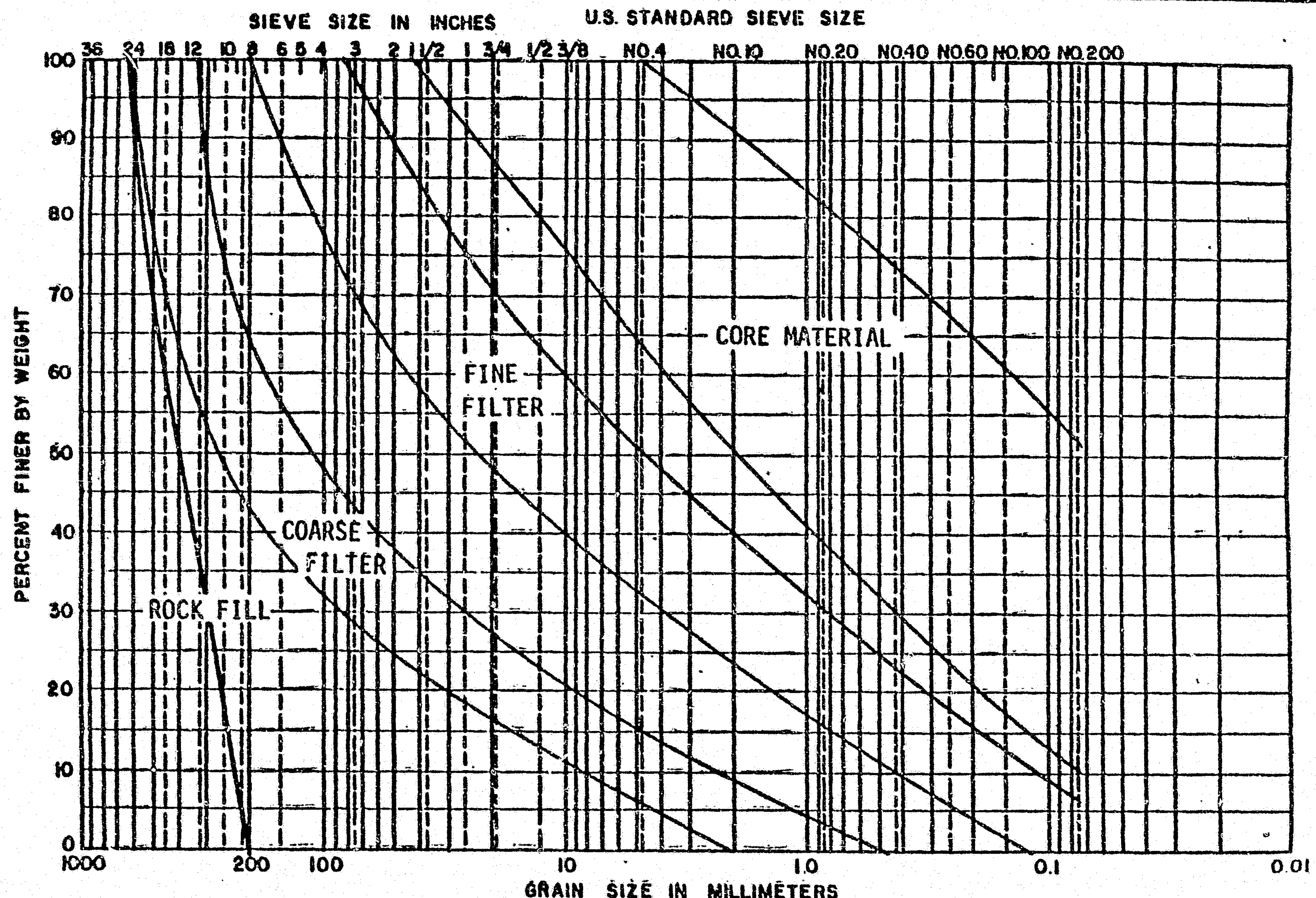


Typical Borelog Area H

AH-D11

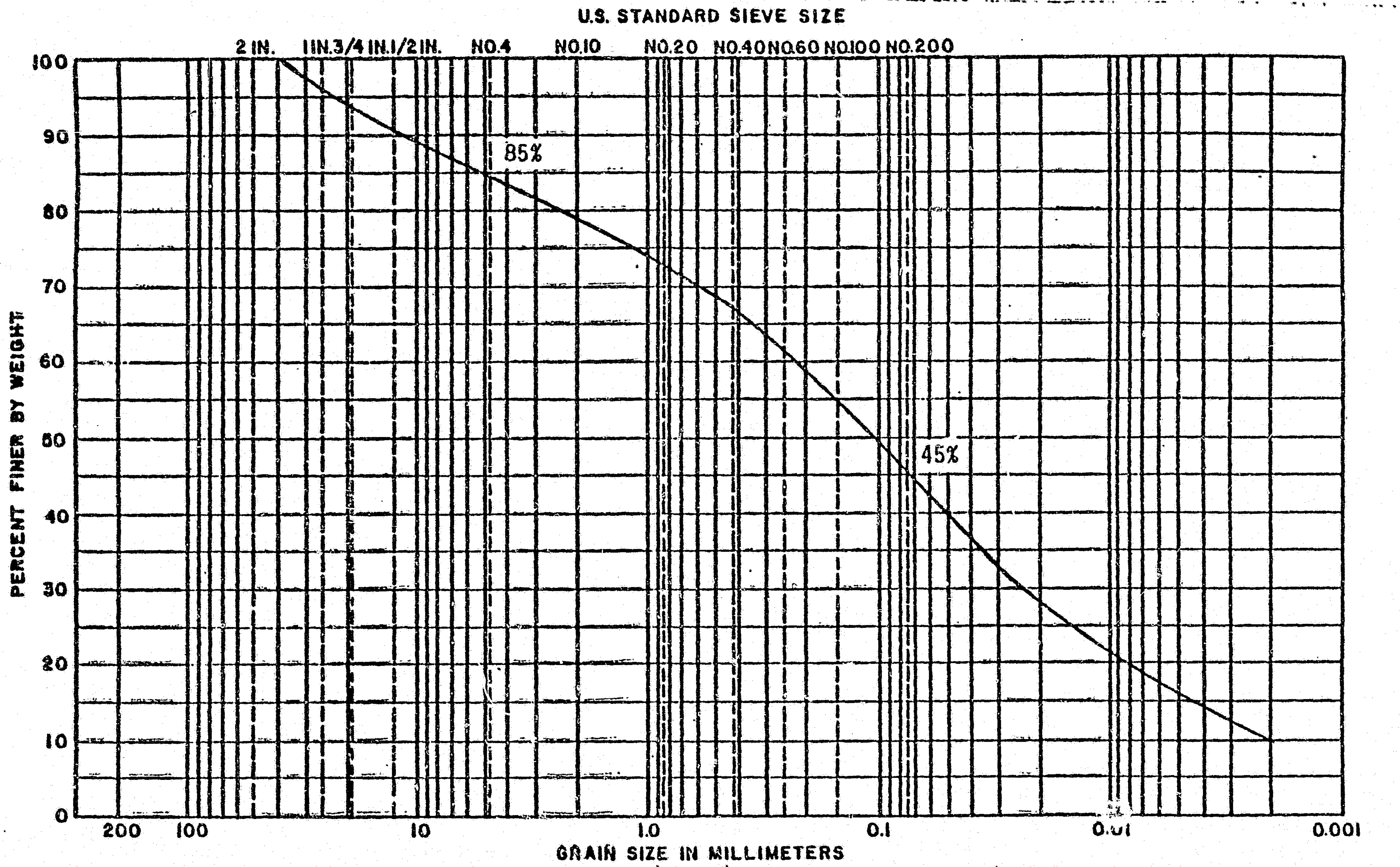


Typical Borelog Area D



COBBLES	GRAVEL		SAND			SILT OR CLAY	UNIFIED SOIL CLASSIFICATION SYSTEM
	COARSE	FINE	COARSE	MEDIUM	FINE		

LAB TEST NO.	BORING NO.	SAMPLE NO.	DEPTH	CURVE SYMBOL	CLASSIFICATION	ACRES AMERICAN INCORPORATED



COBBLES	GRAVEL		SAND			SILT OR CLAY	UNIFIED SOIL CLASSIFICATION SYSTEM
	COARSE	FINE	COARSE	MEDIUM	FINE		

G=2.71

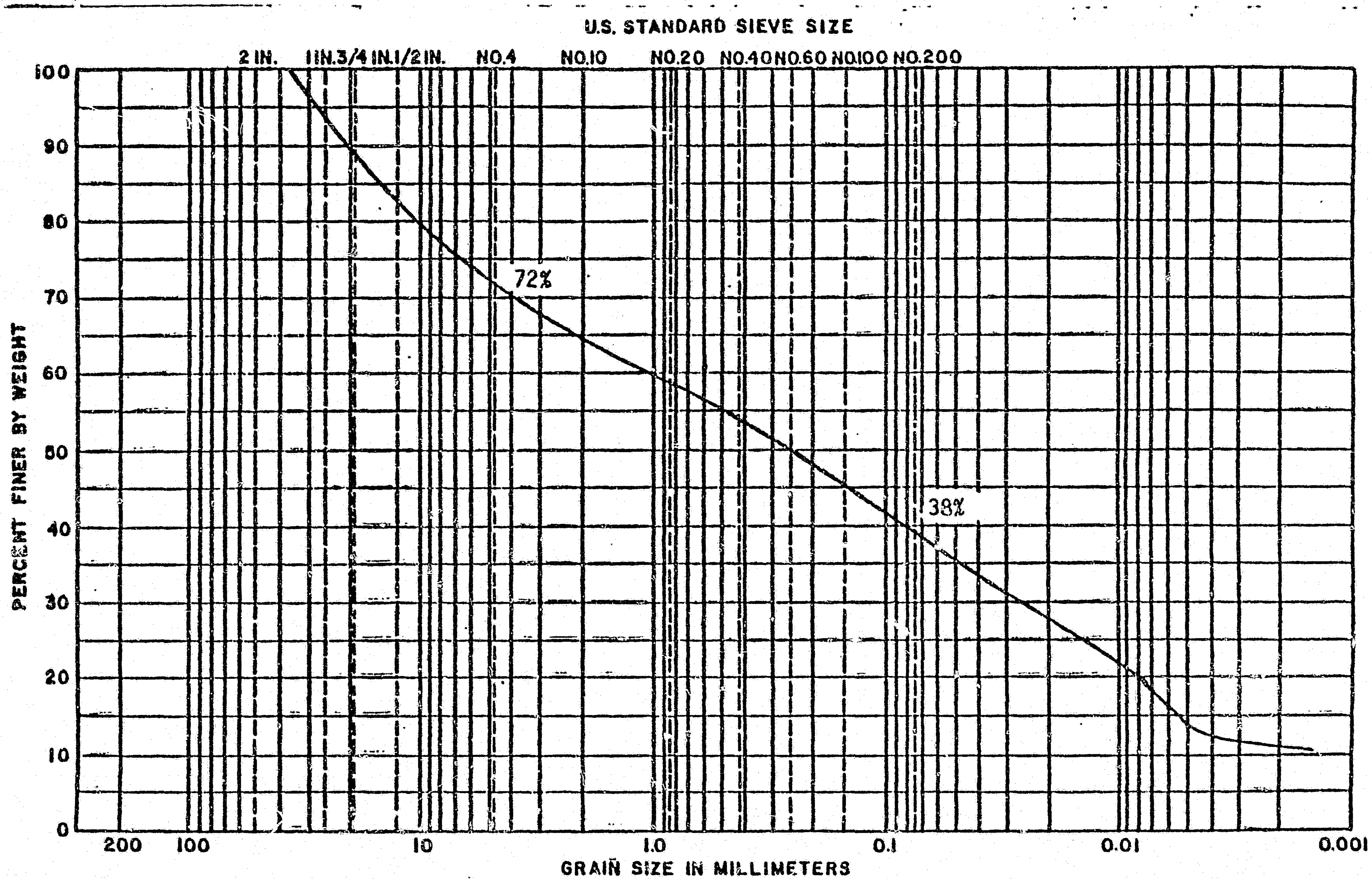
ACRES AMERICAN INCORPORATED

BUFFALO, NEW YORK

COMPOSITE CURVES FOR AREA D

GRADATION ANALYSIS CURVES

FILE: DATE: FIG.



COBBLES	GRAVEL		SAND			SILT OR CLAY	UNIFIED SOIL CLASSIFICATION SYSTEM
	COARSE	FINE	COARSE	MEDIUM	FINE		

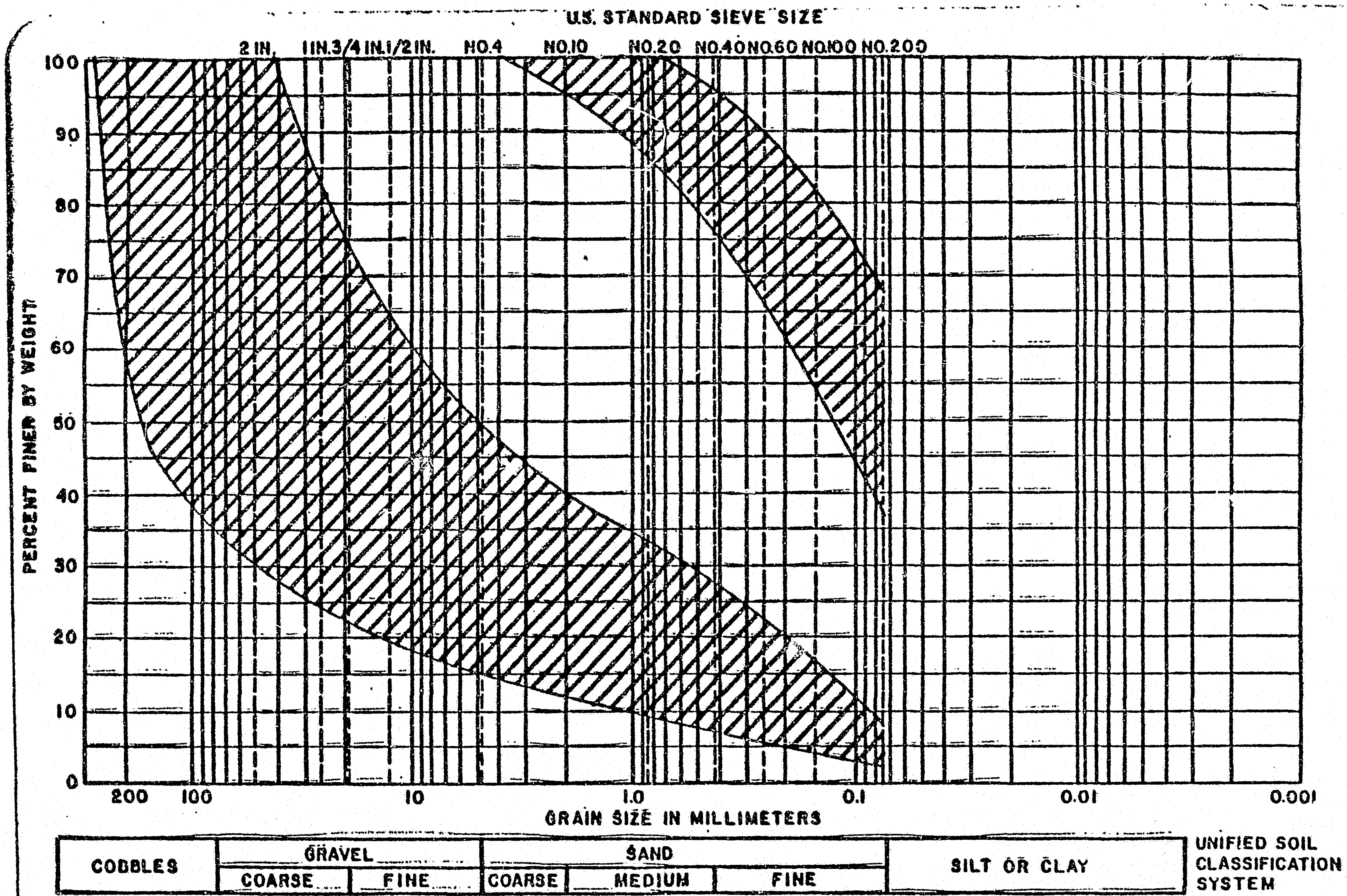
G=2.72

ACRES AMERICAN INCORPORATED
BUFFALO, NEW YORK

COMPOSITE CURVES FOR AREA II

GRADATION ANALYSIS CURVES

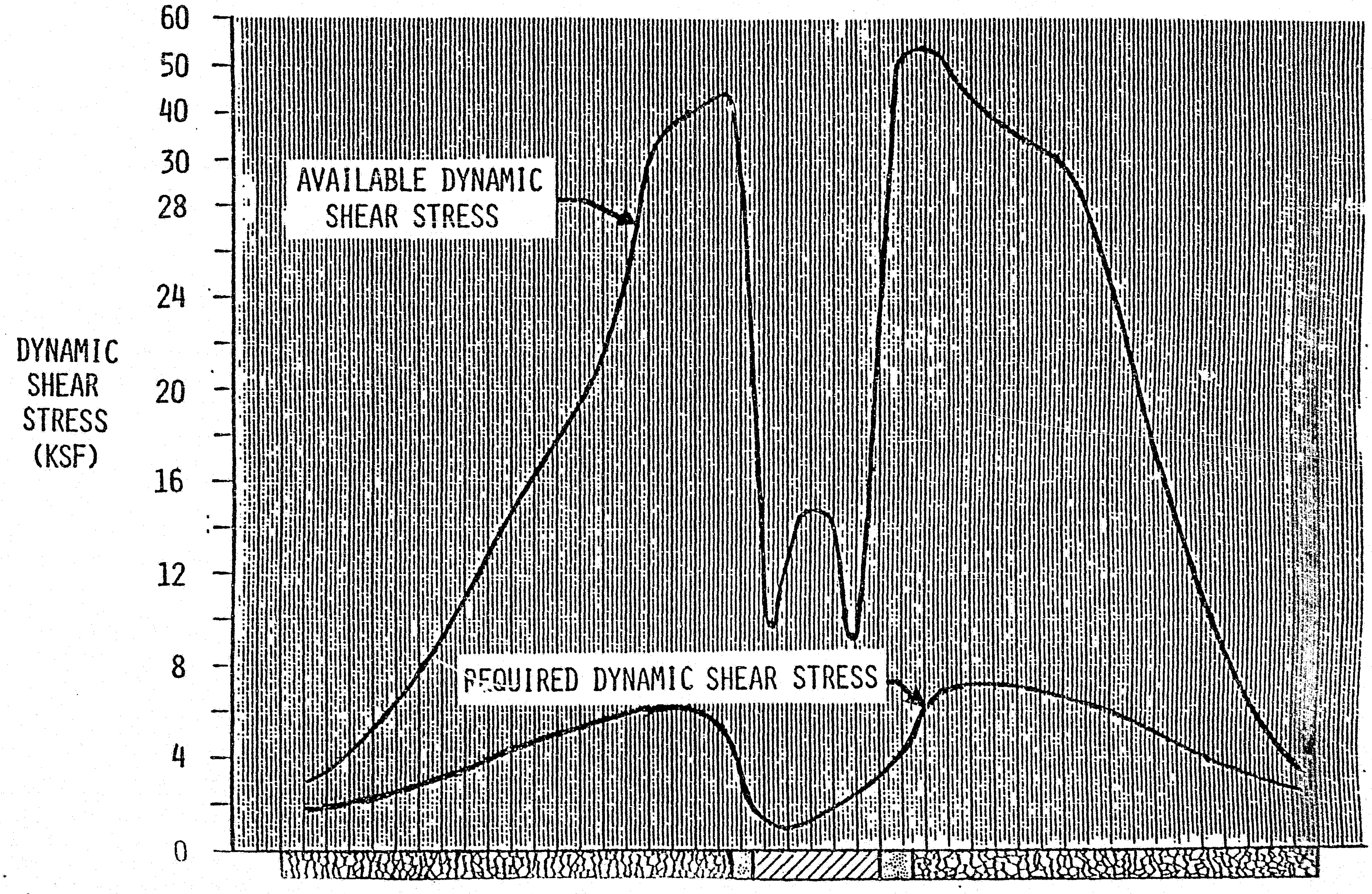
FILE: DATE: FIG.



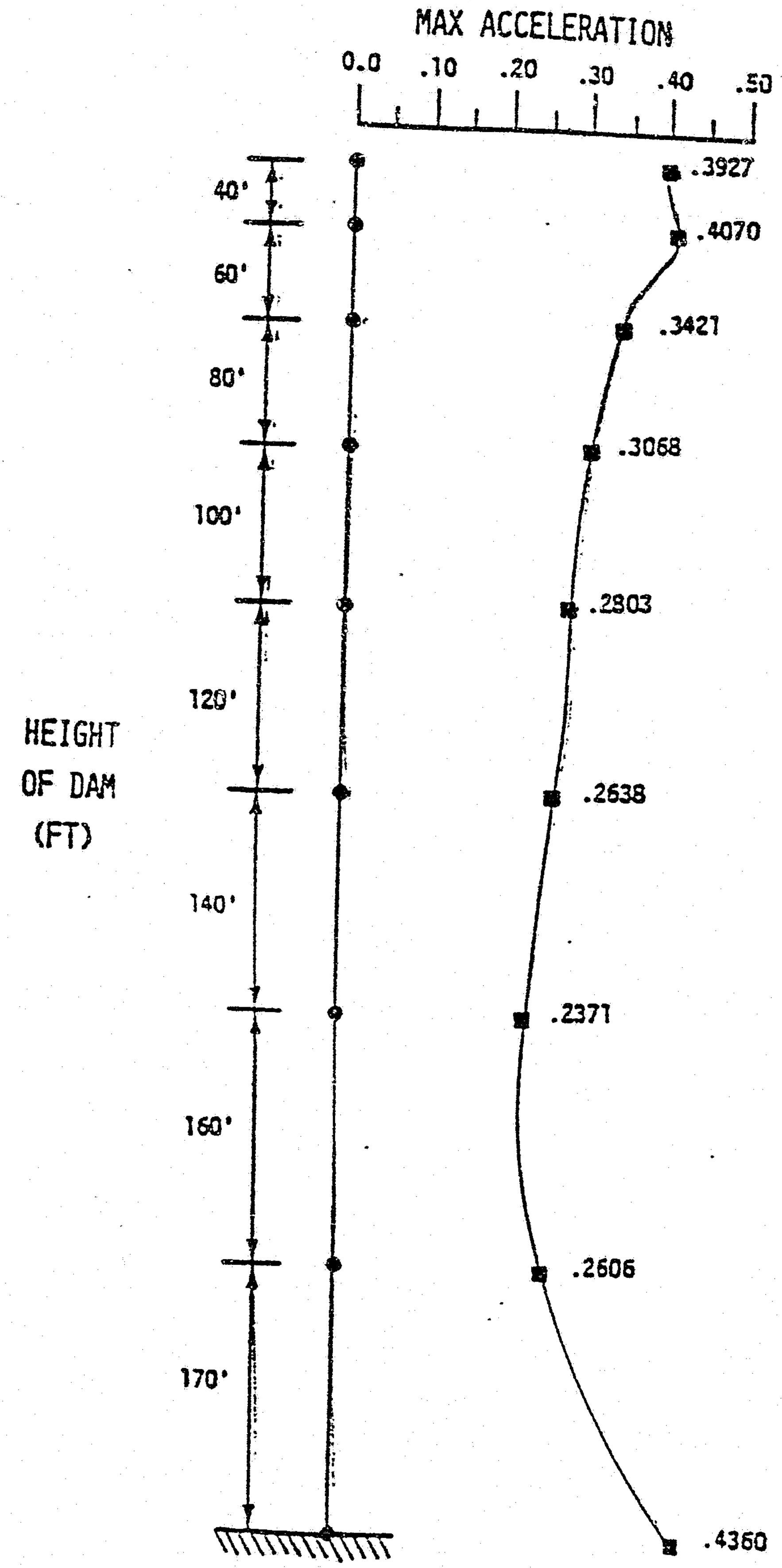
ACRES AMERICAN INCORPORATED

BUFFALO, NEW YORK

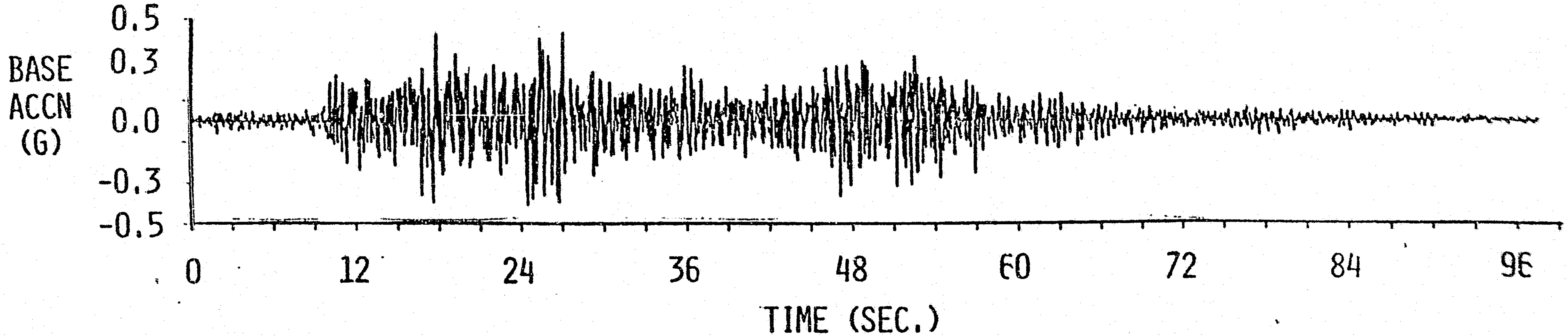
COMPOSITE CURVES FOR TP-E1 THROUGH TP-E21



HORIZONTAL SLICE B-B



ACCELERATION VS DEPTH AT CENTER OF DAM



DESIGN EARTHQUAKE TIME HISTORY

SOIL PROPERTIES

	G/S_u	K_2	DAMPING/SHEAR TYPE CURVE
CORE MATERIAL	2500	-	CLAY
FILTER MATERIAL	-	100	SAND
ROCK MATERIAL	-	180	SAND

DESIGN EARTHQUAKE

A) MAGNITUDE 8.5 RICHTER

B) LOCATION 40 KILOMETERS BELOW SITE (BENIOFF ZONE)

C) MAXIMUM ACCELERATION OF .436G

D) DURATION OF STRONG MOTION - 45 SEC.

E) SIGNIFICANT NUMBER OF CYCLES - 25

SAP IV ANALYSES

THE STATIC ANALYSES USING THE LINEAR ELASTIC FINITE ELEMENT PROGRAM (SAP IV) WERE DONE TO DETERMINE THE INITIAL STRESSES IN THE DAM DURING NORMAL OPERATING CONDITIONS. YOUNG'S MODULUS WAS DETERMINED FROM THE FOLLOWING RELATIONSHIP:

$$E = K P_A \frac{(\sigma_3)^N}{P_A}$$

WHERE: E = YOUNG'S MODUULUS

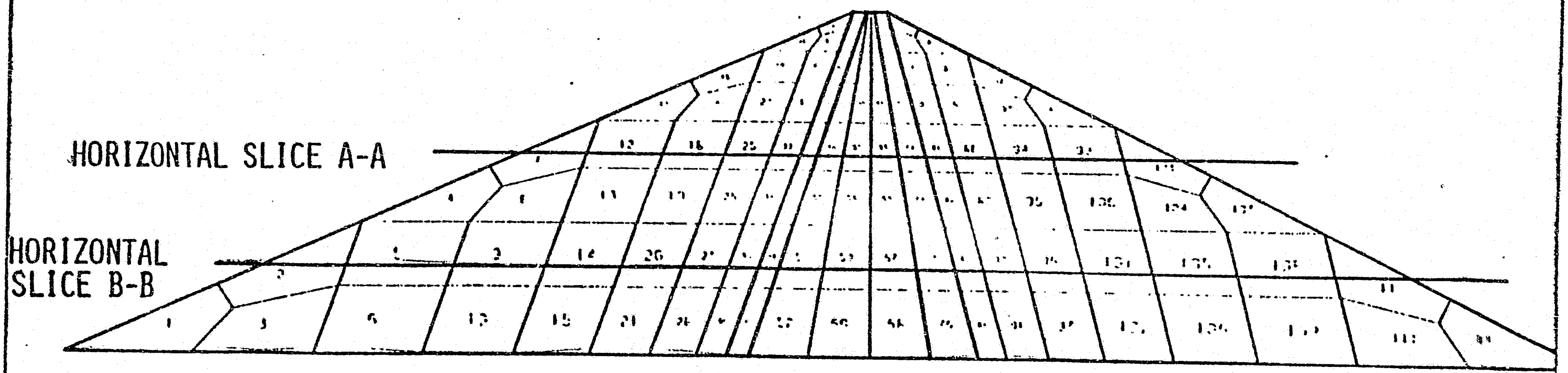
P_A = ATMOSPHERIC PRESSURE

σ_3 = CONFINING PRESSURE

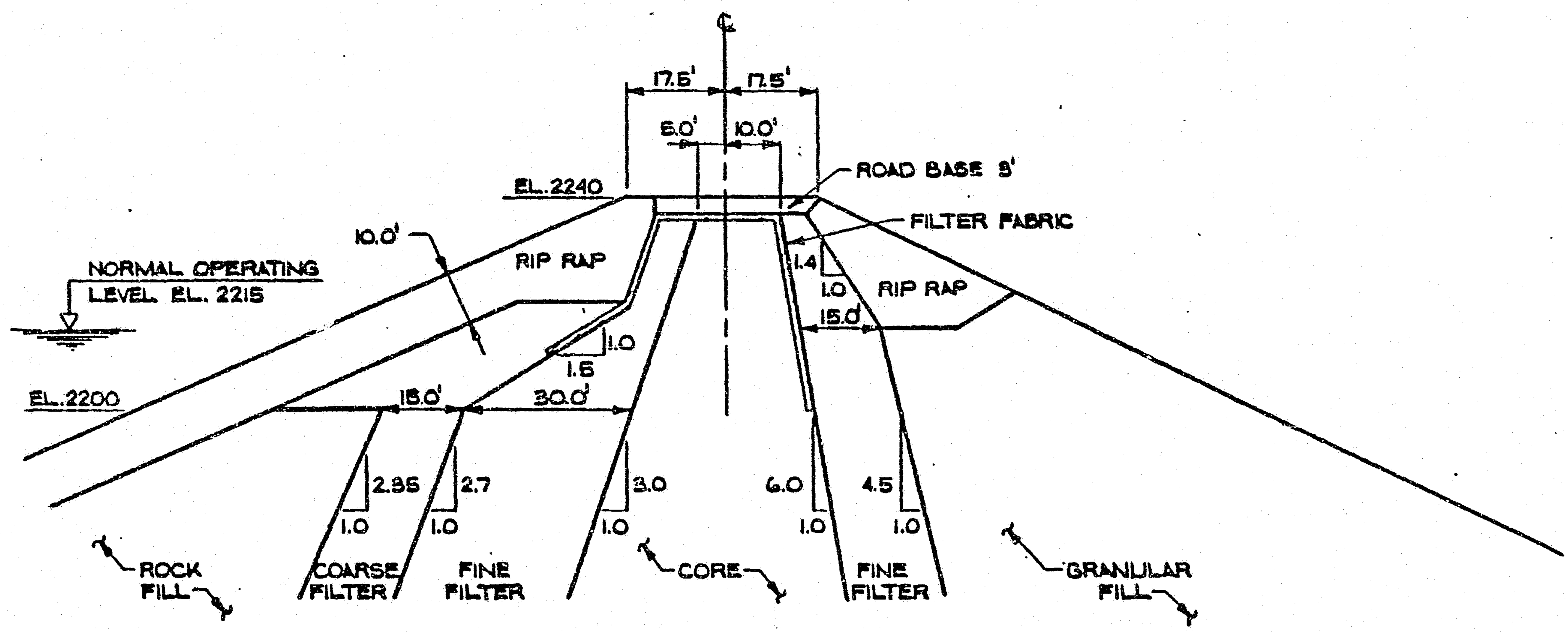
K, N = CONSTANTS

THE INITIAL VALUES OF THE PARAMETERS K AND N AND THE POISSON'S RATIO (ν) FOR THE VARIOUS DAM MATERIALS USED IN THE PROGRAM ARE AS FOLLOWS:

	K	N	ν
CORE MATERIAL	300	0.2	0.333
FILTER MATERIAL	2000	0.2	0.299
ROCKFILL MATERIAL	2000	0.3	0.263



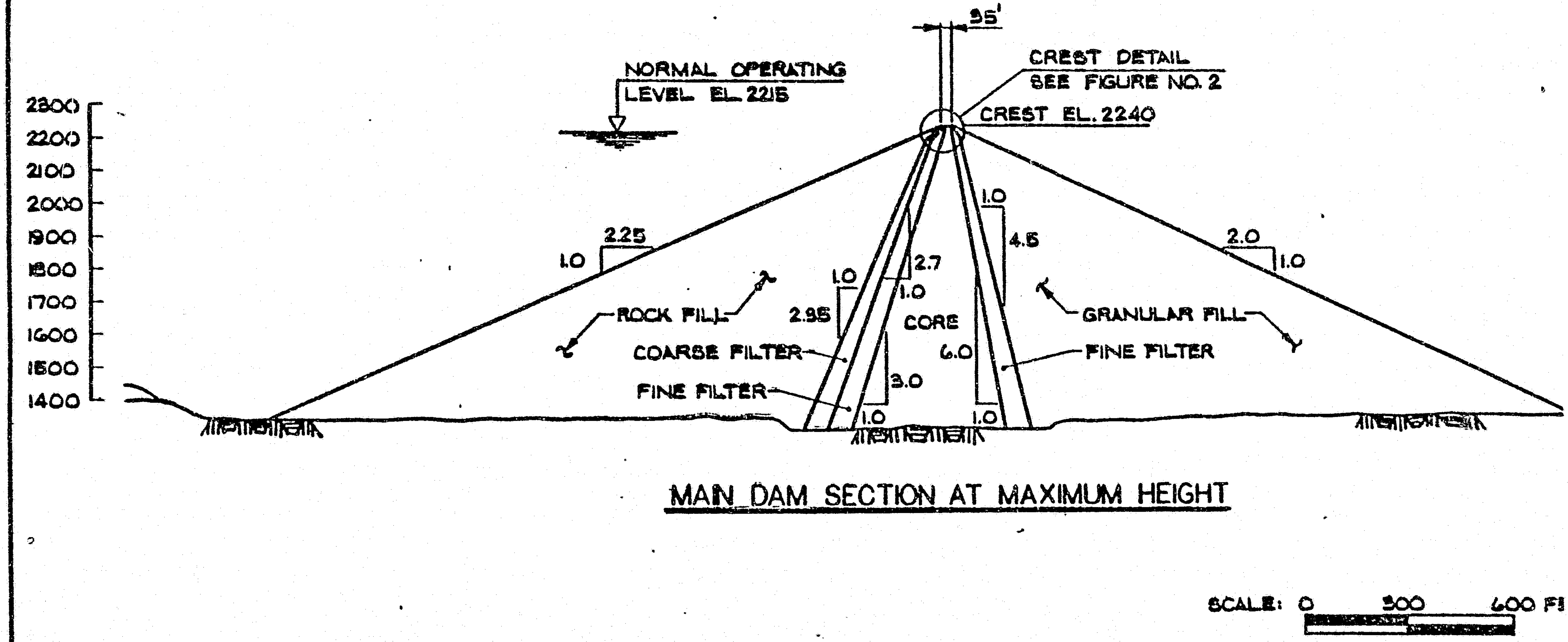
LOCATION OF HORIZONTAL SLICES



CREST DETAIL

SCALE: 0 20 40 FEET

FIGURE NO. 2



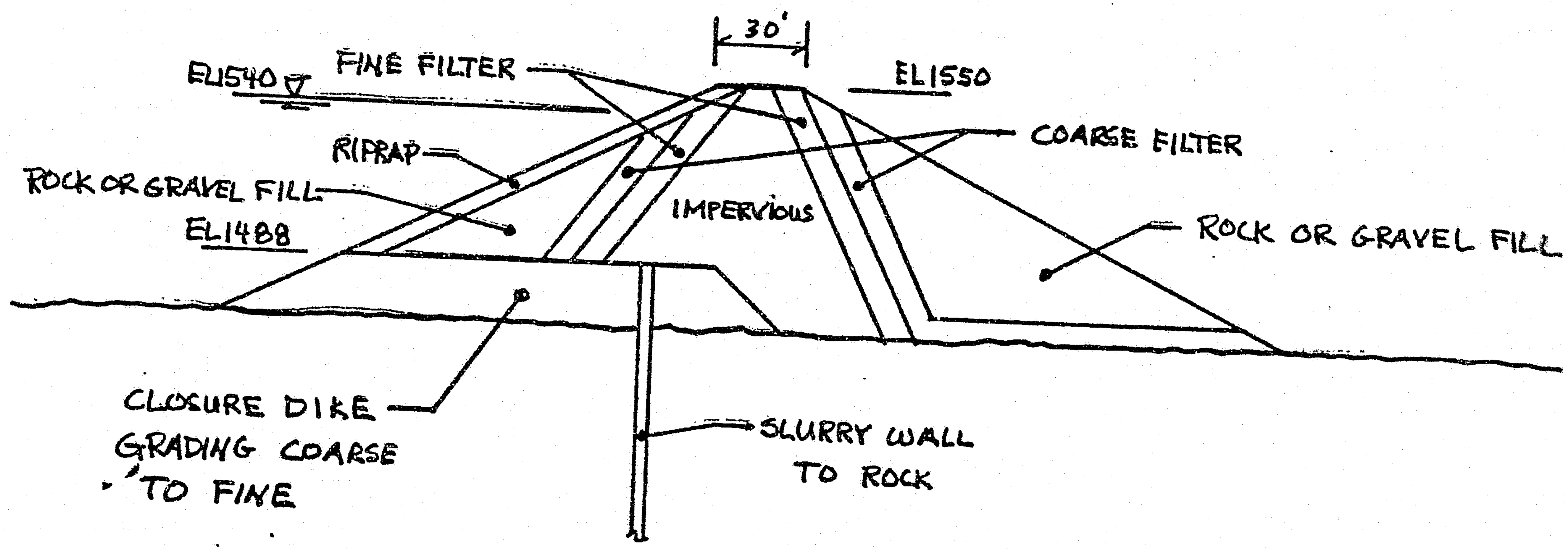
MAIN DAM SECTION AT MAXIMUM HEIGHT

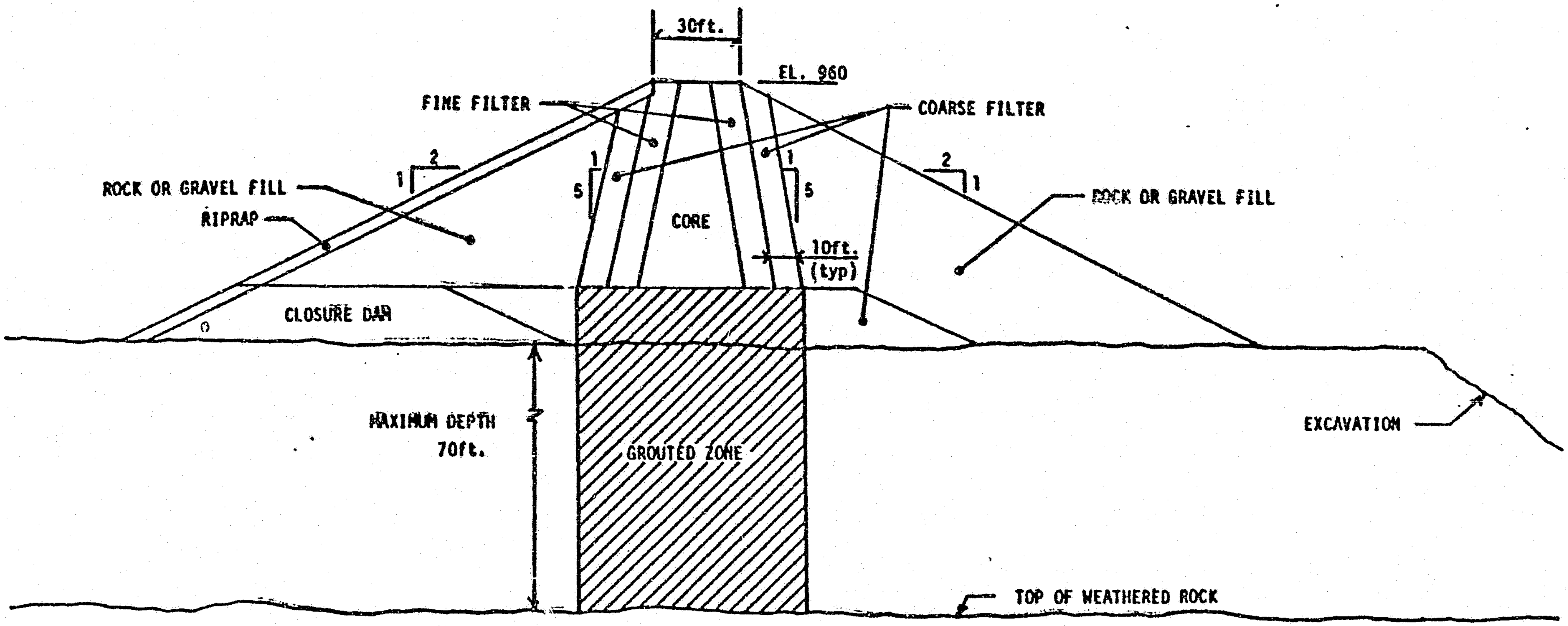
FIGURE NO. 1

WATANA DAM DESIGN

FOUNDATION

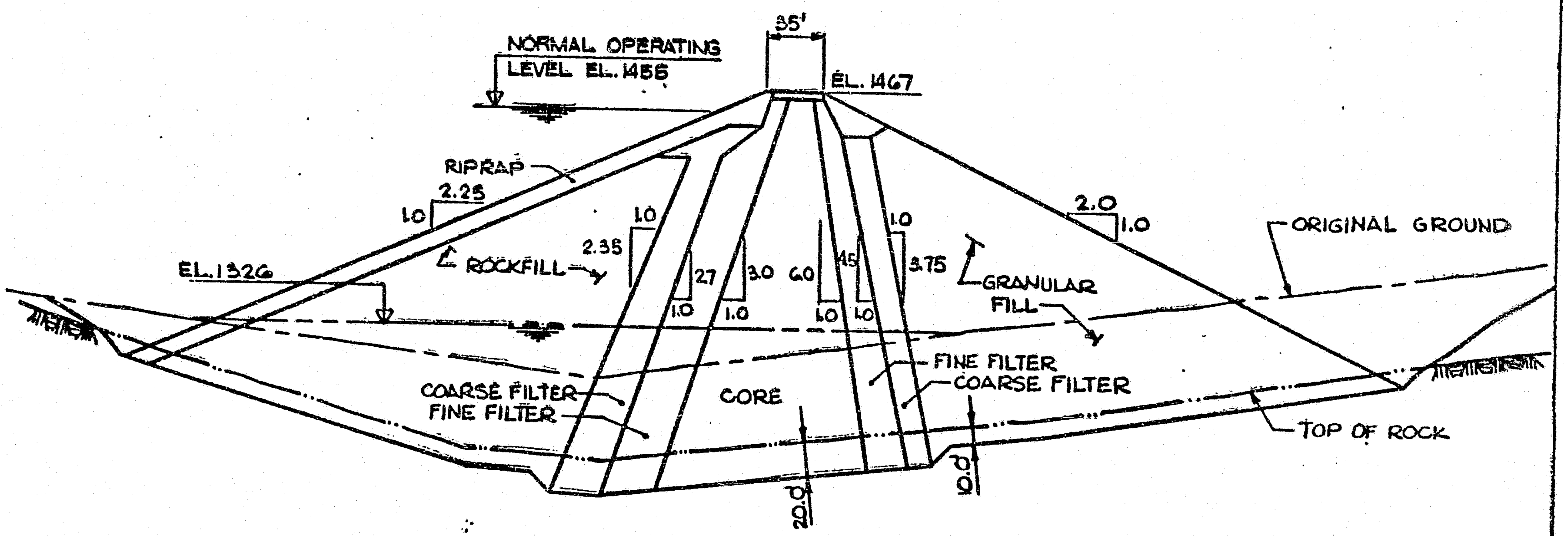
- STRIP WEATHERED ROCK & OVERBURDEN OVER WHOLE FOUNDATION
- EXCAVATE TO SOUND ROCK UNDER CORE
- CONSOLIDATION GROUTING/SLUSH GROUTING
- GROUT CURTAIN
- DRAINAGE HOLES - DOWNSTREAM DISCHARGE
- UNDER DAM TUNNEL SYSTEM
- INSTRUMENTATION & MONITORING


30'
EL1540
FINE FILTER
EL1550
COARSE FILTER
RIPRAP
ROCK OR GRAVEL FILL
IMPERVIOUS
EL1488
ROCK OR GRAVEL FILL
CLOSURE DIKE
GRADING COARSE
TO FINE
SLURRY WALL
TO ROCK



TYPICAL UPSTREAM COFFERDAM
CROSS SECTION

SCALE 1"=40'



DEVIL CANYON SADDLE DAM
MAXIMUM HEIGHT SECTION

SCALE: 0 60 120 FEET

14. REPORT BY SPECIALIST CONSULTANTS

18 November 1981

Mr. John Lawrence
Project Manager
Acres American Inc.
900 Liberty Bank Building
Buffalo NY 94202

Subject: Susitna Project
Specialist Consultants Panel Meeting No. 4
November 18, 1981

Dear Mr. Lawrence:

INTRODUCTION

On this date, Profs. Hendron and Peck met in Buffalo to discuss certain geotechnical features of the project. Briefing and discussions followed the attached agenda.

This letter was drafted in the Acres American office at the end of the meeting and was finalized by the undersigned shortly thereafter.

WATANA CORE MATERIALS

The well graded materials from borrow area D are suitable for use in the core of Watana Dam; current thought regarding filter requirements for well graded materials should be taken into account in the design of the filters (John Lowe III, 4th

Nabor Carrillo Lecture, 1979). The well graded materials from borrow area H are also suitable and have some plasticity which possibly makes them slightly more desirable when considering design against piping. However, the clayey materials may be more compressible than the materials from area D; also, they may exist at water contents too high to be placed at the desired densities and there will be little possibility of drying them during the construction season. In summary, both materials are acceptable on the basis of present information. More information is necessary on insitu water contents and desired densities in the dam before the final selection can be made properly.

WATANA DAM SHELL MATERIALS

We feel that the dam would perform better statically if river gravel and cobbles were used for the upstream shell, because rock fill dams over about 500 ft high usually develop longitudinal cracks upon first filling due to additional breakage at sharp contacts on saturation. Zones of processed gravel could be provided to eliminate the fines and assure higher permeabilities if excess pore pressures are thought to be a problem during earthquakes. It is possible that too low an assumed stiffness for the compacted river gravels may be a cause for the high pore pressures computed in dynamic analyses. Stiffness values for these materials could be approximated by back calculation from the observed settlement of Portage Mountain Dam in which both processed and pit-run compacted gravels were used.

WATANA CORE GEOMETRY

Although static analyses may indicate that a more favorable stress distribution is achieved if the core is sloped upstream (on the assumption that the core is more compressible than the shells), we feel that a central core is preferable under earthquake conditions because the shells will probably shake down more than the core. Thus the downdrag on the core will tend to produce higher vertical stresses in the core and so reduce the probability of cracking.

WATANA RELICT VALLEY

Control of seepage through this buried valley is required for safety; the cost of the lost water is of little import because the seepage loss merely offsets the requirement for a minimum downstream flow. Three alternatives have been considered:

1) An upstream blanket over the entire inflow area. This would be costly and, in fact, impractical because of the limitation on its extent imposed by the entrance to the diversion works.

2) A cutoff across the pervious channel. This would be extremely costly and probably ineffective. For practical reasons it would hardly be possible to construct a slurry wall deeper than 200 ft. Attempts to create a grouted alluvial cutoff between the bottom of the wall and bedrock would have small chance for success in view of the likelihood of encountering permafrost and in view of the great variation of permeability likely to exist. If such a cutoff were to be provided, it would be necessary to monitor points of possible emergence of seepage downstream in the Talkeetna* valley and, in all probability, to protect part of the area by filter blankets. In our judgment no further consideration should be given to the cutoff alternative.

3) Prevention of piping or backward erosion by providing suitable filters in the zone of seepage emergence in the Talkeetna* valley. This can be done, as the need is demonstrated, in the following steps:

*Note Tsusena valley - Casagrande 12.7.81

a) Establish the location and regime of springs that presently exist in the area of possible emergence, and install and observe piezometers at suitable locations prior to reservoir filling.

b) If discharges appear or increase during reservoir filling (or thereafter as permafrost zones melt), or if piezometric levels so indicate, cover the emergence areas with filter drains. If seepage emerges high above the Talkeetna* valley bottom, consideration can be given to directing the seepage into lower strata by means of filter wells and providing filter protection for the lower strata.

We consider this alternative to be the most positive control measure. It will, in addition, be the least costly. Similar treatment would be necessary to a lesser extent even if one of the other alternatives were adopted. The procedure requires a period of surveillance, adequately funded, for several years until conditions stabilize, including the melting of permafrost until thermal equilibrium develops. It also requires maintaining the ability at site to execute the measures that may be found necessary. It should be noted, however, that the requirements of surveillance and capability of

* Note: Tsusena valley – [illegible] 1/7/81

remedial work would exist in any event, in view of the remoteness and rigorous climatic conditions at the site.

SADDLE DIKE AT WATANA RELICT VALLEY

In view of our preference to eliminate the cutoff in the valley, the design of the saddle dike would not be premised on the incorporation of the cutoff in its foundation. The relatively low head across the dike would permit conventional seepage control. However, consideration must be given to the possible existence and thawing of permafrost zones in the foundation after the reservoir has risen and to the influence of liquefiable zones. Exploration is presently inadequate to determine if such zones exist. If the maximum reservoir level would be no higher than the natural saddle, these considerations would become insignificant. We believe the proposed studies of reservoir elevation will be useful to determine if there is an optimum level at which most of the project benefits may be retained while the problems of the dike can be substantially reduced.

WATANA UPSTREAM COFFERDAM

We are concerned about the space limitation that may require steepening the downstream slope of this cofferdam if the bedrock in the river should be lower than anticipated where the main-dam excavation would occur adjacent to the cofferdam. We also have concern that constructing the proposed cutoff to rock beneath the cofferdam may involve delays due to its depth and to obstructions in the alluvium. We suggest that the cofferdam design be studied further.

PERFORMANCE OF CONCRETE DAMS

We believe it would be pertinent to review the experience in arctic climates of concrete dams, including the long-time history of several dams in Norway. (For example, Heggstad and Myran, Investigations on 132 Norwegian Concrete Dams, 9th Congress Large Dams, Q34, R28, Istanbul 1967; Berdal and Kiel, Skogfoss Hydroelectric Power Station, Norway/USSR; Civil Engineering Works, Proc. Inst. CE, Vol. 30, pp. 271-290, Feb. 1965, discussion Vol. 33, pp. 481-491, March 1966.) This information would be pertinent to several features of the project, including possible consideration of a concrete-faced rockfill dike at the side channel to the left of the Devil Canyon site.

Yours sincerely,

Alfred J. Hendron Jr.

A. J. Hendron, Jr.

Ralph B Peck

Ralph B. Peck

RBP/ajj