UNITED NATIONS

SURVEY OF THE HVÍTÁ AND THJÓRSÁ RIVER BASINS ICELAND

Preliminary Master Plan

NORENO Foundation
Oslo, Norway
July 1966

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THJÓRSÁ BASIN

CHAPTER 3, cont'd:

HVÍTÁ BASIN

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Synopsis of the expert reports.
Prepared by Mr. E. Wessel, Project Manager.

PREFACE

This is a report with Preliminary Master Plan for the development of the hydroelectric potentials of the Hvítá and Thjórsá river basins in Iceland, prepared under agreement CON 78/65 of 30th July, 1965 between United Nations and NORENO Foundation.

With the understanding of United Nations we have engaged the services of Norconsult A/S, Oslo for the preparation of the report.

For practical purposes drawings pertaining to the Preliminary Master Plan are not included in this volume, but presented separately.

As requested by the United Nations this report includes a synopsis prepared by the United Nations' project manager Mr. E. Wessel of the individual reports from the team of experts engaged by the United Nations.

We should like to express our gratitude that this assignment was awarded NORENO Foundation. The consultants and we have found it an interesting one. We also wish to express our appreciation of the cooperative spirit which we have met within the United Nations and the State Electricity Authority, Reykjavik.

I. INTRODUCTION

In the agreement the engineering services are specified as follows:

"a) The Preliminary Master Plan in 1 above shall include:

i) An assessment of the various possibilities for the development of the hydroelectric power in the river basins to arrive at a definite proposal for the best ultimate utilization of the potential of the two river basins as a whole.

ii) General layout drawings for selected alternatives. These general layout drawings shall show the main features of each project.

iii) Cost estimates for each project. These cost estimates shall provide the approximate cost of each main feature.

iv) Establishment of power production of each project.

v) The project which according to rough estimate prove not to be feasible shall be eliminated at an early stage and drawings and cost estimates for such projects shall not be supplied. These projects shall, however, be mentioned in the Preliminary Master Plan.

b) In preparing the report, the Contractor shall maintain a running contact with the work by an intimate liaison with the Project Manager and through visits to Iceland for discussions with the people concerned and inspection of relevant sites in the two basins."

Only the report from the experts on ice problems and the report from the expert on engineering geology have been available during the preparation of the Preliminary Master Plan.

It should be realised that it is not possible at this stage "To arrive at a definite proposal for the best ultimate utilization of the potential", as the Master Plan, owing to lack of more exact information, to a large extent will have to be based upon assumptions. We have, however, tried to specify relatively detailed the assumptions on which the Master Plan is based, so that the Master Plan and the cost estimates may be adjusted when more exact information, based upon further field investigation is available.

The following documents and other information received from SEA (partly through UN) and from the Project Manager form the basis for the work on the Preliminary Master Plan.

1. Some hydrological aspects. Thjórsá and Hvítá River Systems. By Sigurdjón Rist and Jacob Bjørnsson. Dated June 1959.

2. Hydrological data from SEA in the form of weekly volumes of discharge at:

   a) Gaging stations no. 000, 030, 043, 057, 068, 087, 095 (125), 096, 097 and 098 for periods ranging from 14 to 17 years. The data are partly produced by correlation.

   b) Gaging stations no. 094 and 099 for a period of 6 years.

3. Prognoses for determination of load factors (from SEA).

4. Information about labour wages and principal construction material in Iceland (from SEA). Dated October 1965.

5. Maps of the two river basins (from SEA):
   a) 1:50.000 maps over the entire area.

   b) Other map material as shown on dwg. 430-01.

6. Reports on the geology at some sites for potential hydro-power development in the Thjórsá and Hvítá River Systems. By Gudmundur Kjartanson.
Dated August 1959.

7. Preliminary appraisals of some potential hydro-electric power developments in the Thjórsá and Hvítá River Systems. By Sigurdur Thoroddsen.
Dated August 1959.

8. Advisory Report on the hydro-electric power resources, Hvítá and Thjórsá River Systems. By Harza Engineering Co. International. Dated March 1960.

9. Project Planning Report on the Burfell Project. By Harza Engineering Co. International. Dated February 1963.

10. Definite Project Report on the Burfell Project. By Harza Engineering Co. International. Dated April 1965.

11. Report on the geology of the Thjórsárver area (Nordlingaalda). By Tomas Tryggvason and Thorleifur Einarsson.
Dated March 1965.

12. Engineering geology of the Hvítá and Thjórsá Basins. By Allen H. Nicol. Dated October 1965.

13. a) Analysis and considerations of the ice conditions, Hvítá and Thjórsá River Systems. Final report by Olaf Devik and Edvigs V. Kanavin. Dated October 1965.
    b) Summary and recommendations based upon the above report. By the same authors. Dated March 1966.

14. Periodic reports on survey of hydro-electric power development in the Hvítá and Thjórsá River Basins.
By E. Wessel.

a) First report, dated July 1965.
b) Second " " October 1965.
c) Third " " April 1966.

2. GENERAL

Topography. Available Maps.

The Thjórsá and Hvítá basins are located in the south-west Iceland as shown on a small-scale map on drawing no. 430-02.

The area is slightly developed and the population, amounting to a few thousand is living in the lower parts of the basins.

The boundary of the drainage areas is shown on drawing no. 430-02. At Selfoss the Hvítá basin has a drainage area of 5760 km^2, and the drainage area of Thjórsá at Urridafoss is 7200 km^2.

The whole area is mapped in scale 1:50.000. A great part is mapped in scale 1:20.000 whereas smaller areas are covered by maps in scale 1:10.000, 1:5.000 and 1:2.000. The map coverage available for this report is shown on drawing no. 430-01. The scale of the available maps has been noted under the description of the various plants in chapter 3 of this report. The quality and accuracy of the master plan studies are, of course, to a great extent dependent upon the scale of the available maps. Where only maps to scale 1:20.000 are available, the master plan studies will, consequently, be correspondingly rough. In some cases where only maps to scale 1:50.000 exist, we have found it impossible to make studies.

Geology. Availability of Construction Materials.

The general geology of the area and the more detailed geology including some engineering geology aspects are excellently described in the report by Allen Nicol, dated October 1965.
The geology of the area is complex and the experience from an engineering point of view is confined to the area along the

Sog River. It appears that in great parts of the area the engineering geology problems that are to be encountered will be greater than those experienced during the construction of the plants along the Sog River, although the tunnel for Steingrímstød (Upper Sog Plant) was excavated in moberg.

The engineering considerations of major importance are:

1. Tunnelling conditions including temporary and permanent supports.
2. Conditions for excavation of rock cavities including temporary and permanent supports.
3. Seepage under dams etc.
4. Leakage from channels and tunnels.
5. Inflow into tunnels and cavities.
6. Leakage from reservoirs.

The problems are not listed in order of importance.

Items 1, 2, 4 and 5 may be substantially clarified when more investigations, such as core drillings, have been made. If exploratory tunnels are made, it may also be possible with reasonable accuracy to predict the cost of tunnelling and supporting, and also the demand for permanent lining.

Seepage under dams may be stopped or satisfactorily reduced by cement grouting.

From Mr. Nicols report it appears that some of the rocks in the area are very permeable and that some have very permeable interbeds between the different lava or basalt flows.

It is known that in several natural lakes there is considerable underground inflow of water and also extensive leakage from the lake. Some lakes have no visible outlet. Based upon some experience and some investigations it has been assumed by Icelandic engineers that leakage from artificial reservoirs will be sealed comparatively quickly by the silt and clay suspended in the water.

Although it may be reasonable to expect this natural sealing to be effective, the time element should be carefully considered. It is obvious that even if the leakage is stopped or satisfactorly reduced in, say, 10 to 20 years, the first years of possibly large leakage may affect the economy of the storage greatly.

We believe therefore that this problem should be extensively investigated at an early stage, as it may have bearing on several of the investigated dam sites.

The availability of construction materials has been investigated by Mr. Allen Nicol during his field survey in 1965 and the question has also been investigated by others previously.

Mr. Nicol has located quantities of moraine material which he states may be suitable as earth core in a fill dam along Hvítá, Thjórsá and the lower reaches of Tungnaá. Sand that may be suitable as concrete aggregate has also been located in a few places. The material has, to our knowledge, not been investigated in laboratory, nor has the quantity been estimated.

In our master plan studies we have assumed that it is generally more likely that suitable fill material can be found reasonably close to the sites, than that sand for concrete is available at short distances. We have therefore to the extent possible suggested rock and earth fill dams in order to limit the concrete material consumption.

The construction material situation is probably especially difficult in the upper reaches of Tungnaá (Storisjór and Langisjór). The moberg, which dominates this area, is probably not suitable for producing fill material or concrete aggregate of satisfactory quality.

Ice Problems

The problems of power development, resulting from the extensive ice production in the two rivers, are discussed in the report by Olav Devik and Edvigs V. Kanavin, dated Oslo October 1965, and in a Summary and Recommendations by the same authors dated Reykjavik March 4th, 1966.

The physical background for the ice production and also general methods to avoid or reduce the difficulties are discussed in the report and shall not be dealt with here. We shall, however, describe how and to what extent the recommendations made by Devik and Kanavin have influenced our master plan studies and discuss possible consequences of a hydro-electric development.

In their report on ice conditions the authors have suggested means of reducing the ice production and of controlling the ice difficulties for power development. It has been suggested:

1) to reduce effectively the open areas,
2) to establish reservoirs which can store floating ice, prevent step bursts and prevent the formation of ice bridges at critical places,
3) to ensure slow water flow and promote the formation of ice cover at the intakes of power plants.

Even if the river flow is more even than should be expected in the Icelandic climate (due to sub-surface water inflow), it is nevertheless necessary to regulate in order to increase the flow in the winter season when also the power demand is highest.

This will cause an increase in the total area of the river surface and also of the water velocity in the winter period. As discussed in the report by the experts, both factors will promote the production of ice. On the other hand, the discharge of comparatively warm water from storages will increase the temperature of the river water and thereby reduce the ice production in the river reaches a certain distance downstream of the storages. The effect on the ice production by the increased river flow in the winter period may in some cases have a bearing on the plans for the waterpower development of the two rivers.

In this report we have suggested storage reservoirs at Hvítárvatn, Nordlingaalda, Thórisvatn, Storisjór and Langisjór. Additional storages are provided by the various intake ponds. The increase in the river flow in periods of severe frost has not been investigated, but it will probably be more than 100% in some periods and the increase will probably be relatively greater in upper Thjórsá and upper Tungnaá than in upper Hvítá since this river has a more even natural waterflow. The effect on the ice problem of the increased winter riverflow should be investigated.

At the confluence of Thjórsá and Tungnaá (Sultartangí) a great deal of ice is produced, and the ice experts consider a dam here of great importance. The geologic conditions are, however, complicated and part of the dam will rest on Thjórsá lava. The Project Manager has suggested a dam site some 3 km upstream of the confluence, on account of the geologic conditions. We do not, however, find great difference in the foundation conditions as they appear from the investigations made so far, and have suggested a dam at the confluence. This site will in our opinion be preferable from a topographical point of view, and according to the ice experts, better with respect to ice production, as a greater part of the ice producing reaches are closed.

The Project Manager has also suggested a long tail race channel from the power station at the upper damsite on the left side of the river. This channel will reduce the ice production downstream of Sultartangí. We have, however, found that without more detailed geological investigations, it is not possible to calculate the cost for a channel and we have therefore in the Master Plan included a power station on the right bank which only utilizes the head at the dam. An investigation should be made to determine whether a reduction of the ice production downstream of Sultantangí is indispensable. In case it is, consideration should be given to the construction of either a plant on the right bank with a long tailrace tunnel closing a sufficient reach of the river and at the same time utilizing a higher head, or a tailrace channel at the left bank, more or less as indicated by the Project Manager.

Discharge the water from Thórisvatn reservoir via Kaldakvísl to Thjórsá upstream of Dynkur has been considered. Also considered has been the discharge of storage water from Thórisvatn through a channel or a tunnel in south-westerly direction into Tungnaá. These two alternatives will affect the ice conditions in different ways. We have not considered which of them will, as a whole, be preferable in this respect.

We have, however, found that the discharge through a channel in south-east direction into Tungnaá is preferable when the total construction cost in the two cases is compared with the power production.

Any provisions to promote the formation of ice cover by constructing stone fences from the banks towards the middle of the river have not been included in the Master Plan nor in the cost estimates. We assume that the necessity for such fences will be studied closer and that further investigations will also give information on the cost of such installations.

The intakes are in most cases located in reasonably large and deep intake ponds and it is assumed that it is possible to design the intake so that the pond will be ice covered.

The experts' report discusses how to design intakes and dams to allow for passing of drifting ice. For the Burfell project a quite complicated design has been chosen based upon extensive model tests. In a report on a preliminary master plan it is hardly possible to include the detailed arrangement of dam and intake. At any rate we feel that the ice problems with regard to the intakes and passing of drifting ice should be reviewed in light of the suggested Master Plan in order to decide where special provisions for the passing of ice is required.

Load Requirements and Production Prognosis. Installation Capacity. Hydrology.

Introduction:

The two river basins are both characterized as being high in runoff and, with the exception of the Upper Thjórsá tributary, as having a runoff that is more than ordinary evenly distributed over the year.

We have proposed storage reservoirs at Langisjór, Storisjór, Thórisvatn, Nordlingsalda and Hvítárvatn.

Definitions:

The following expressions and designations may require interpretation:

"Summer":	The period from May 1st to October 1st.
"Winter":	The period from October 1st to May 1st.
"Regulated river flow":	The rate of flow that could have been maintained without interruption during all except 2 out of the 14-17 years for which correlated flow data exist.
"Design flood":	The expected peak flow with 1000 years recurrence time, assuming all the proposed storage

reservoirs to be in effect.

"Annual load factor":	Ratio of the average load over a year to the highest peak load in a year.

Load Factor:

Our attempt in arriving at an annual load factor is based on the following items of information received from SEA:

1. A prognosis of the variations of the weekly demand over the year, comprising the total load.

2. A typical daily load curve for the general (domestic) load.

3. The general load shall be assumed to constitute 20% of the total system load.

4. As load curve for the remaining 80% shall be assumed a horizontal line (non-variable load).

Exhibit <u>2 - 1</u> shows the variation of weekly demand (total load) over the year. The corresponding annual load factor becomes 0.876. We have, however, in order to be on the safe side, based our studies on an annual load factor of <u>0.8</u>.

Installation Capacity:

Based on the above load factor, and with due regard to the advantage of operating the turbines in their best efficiency range under normal conditions, we have proposed that the installed capacity should correspond to $\frac{1.12}{0.8}$ = 1,4 times the regulated river flow. This figure includes, consequently, a

12% increase to permit the turbines to operate at a favourable efficiency.

Seasonal load variations:

The load curve on Exhibit <u>2 - 1</u> may be simplified as shown, to one constant load value during the summer and one during the winter. It appears that the average winter load is only about 6% higher than the average summer load.

From exhibit <u>3 - 3</u> it will be seen how this requirement has been met.

Hydrology:

Our estimates of regulated river flows, design floods etc., are based upon flow data obtained from gage readings at 10 different gaging stations in the Thjórsá-Hvítá basins over periods ranging from 3 to 14 years. By correlation computations executed by SEA, the periods have been extended to a minimum of 14 years duration at all gaging stations.

The correlated flow data should of course be regarded as being less reliable than the data obtained from gage readings. We have not, however, been able to distinguish between the two and have accepted all material submitted to us as being valid.

It should be noted that even reliable flow data for as short period as 14 years, is generally considered to be a meager hydrologic basis for a development of this order.

Our hydrologic studies are based on the following conditions and assumtions:

a) In accordance with the simplified load curve, exhibit 2 - 1, we have endevoured to obtain one constant flow value for the summer, and one for the winter season.

b) Only the storage reservoirs Langisjór, Storisjór, Thórisvatn, Nordlingaalda and Hvítárvatn are included in the study, and the intake reservoirs at the various power plants have not been regarded as seasonal storages.

c) The drawing from a storage reservoir is assumed to be governed by the demand at the nearest, downstream located, power plant of major size, aiming at an optimal production of energy in that plant. (The governing plants are: Tungnaár-krókur, Dynkur and Bláfell).

d) We have assumed that the release from the storage reservoirs, even the most remotely located ones, may be changed instantly, as if the gates of the outlet works were remote controlled, and that the travelling time for the water from a reservoir to the power plants is negligible.

e) The gross storage volume of a reservoir has been reduced with respect to ice, by subtracting a one meter thick sheet of ice of an area equal to the difference between the reservoir surface areas at max. and min. waterlevel.

The method applied in determining the storage and in estimating the regulated river flows at the pertinent stations is briefly described in the following:

1. A mass curve is prepared for each of the 10 gaging stations for which flow data are worked out by SEA.

2. For a given location of a power plant, the mass curve for the nearest gaging station is made applicable by a simple transformation.

3. For the assumed sizes of the pertinent storage reservoirs approximate values of the regulated river flows at the power plants during summer and winter are determined graphically by means of the mass curves.

4. An increase in the size (and cost) of the storage reservoirs will, up to a certain limit, result in an increased regulated river flow. For Nordlingaalda and Hvítárvatn we have tried to vary the storage volumes. By comparing the corresponding variations in the regulated flow and thereby the variations in production with the variations in total cost of storages and of power plants, we have tried to determine the storage volumes which, according to these simplified criteria, give the lowest cost per kWh.

5. The same has been tried for Storisjór, but the storage here is finally chosen with regard to geologic conditions (see page 3 - 3).

6. The cost of storage at Langisjór is more or less independent of the volume and may be used for long term regulation.

7. For Thórisvatn a discharge channel in the south-west end of the lake has been chosen provisionally, because we have found that according to the simplified criteria as described under item 4 above, a higher degree of regulation than can be obtained with a channel is not feasible. (A tunnel for the same draw-down level as suggested will result in a cost two times that of a channel). A closer study (power system analysis) may, however, prove that it is better to reduce the volume in other storages and increase correspondingly that in Thórisvatn even if this would mean a discharge tunnel instead of a channel.

Cost Estimates

All prices used in estimating the costs of the developments are referred to the price-level as of January 1966.

The following average unit prices have been used for estimating costs of civil engineering work for all projects, without regard to location. These prices are partly based on information received from SEA regarding imported construction materials such as timber, cement and reinforcing steel, and partly resulting from inquiries with Norwegian contractors, familiar with Icelandic construction costs:

		Unit:	US $
1.	Formwork	m^2	9.00
2.	Reinforcement	1.000 kg	400.00
3.	Concrete, in general	m^3	50.00
4.	Concrete, tunnel or shaft liner	m^3	55.00
5.	Excavation, common	m^3	1.50
6.	" rock, open cut	m^3	4.50
7.	" " subsurface	m^3	7.50
8.	" " weathered zone	m^3	8.00
9.	" " tunnel, see exhibit 2-2		
10.	Foundation grouting	m^2	15.00
11.	Guniting, d = 7 cm	m^2	8.50
12.	Shaft steel liner	1.000 kg	850.00
13:	Rock anchors, l = 3,5 m	each	15.00
14.	Concrete lined tunnel, see exhibit 2-3		
15.	Concrete and steel lined pressure shafts, see exhibit 2-4		
16.	Earthfill dam embankment, see exhibit 2-5		

Regarding mechanical and electrical equipment, the prices have been procured from Norwegian and Swedish suppliers of turbines, and from Norwegian suppliers of generators, transformers and gate structures. The prices, which are all quoted by the suppliers on a non-competitive basis, are cif Reykjavik and include complete erection at the site.

As we are to a large extent lacking information of the material situation, it has not been possible to present any considered recommendations regarding the **exact type of embankment dams** to be used. For the purpose of cost estimation we have therefore assumed that the main body of all the embankments will consist of compacted homogeneous moraine, with a crest width of 6 m and slopes 1 in 2.25. The average unit price is set according to item 16 above.

Cost estimates of each project have been made in accordance with the following cost summary:

1. Regulation and storage

   Include:

   Apportioned cost of all storage reservoirs situated upstream, each power project being charged in proportion to net head. See summary exhibit 2-6.

2. Power supply and communications

   Include:

   a) Cost of permanent and construction roads with bridges, as estimated by SEA.

   b) Expenses concerning power supply and telecommunications.

3. Civil engineering work

   Include:

   a) Cost of all excavation, embankments, concrete work, tunnel and shaft support or liner, miscellaneous interior and exterior work.

b) Rigging, assumed 10% of cost under a)

c) Contractors administration.

4. Mechanical and electrical equipment

Include:

a) Cost of turbines, gates, trashracks, powerhouse crane, auxilliary equipment.

b) Cost of generators, transformers and switchgear etc.

c) Local transport and handling, assumed 10% of cost under a) + b).

5. Owners general expenses

Include:

a) Administration, field explorations and design, assumed 10% of items 3 and 4.

b) Interest during construction, assumed 10% of items 2, 3 and 4.

6. Miscellaneous. Contingencies.

Assumed approx. 15% of items 2, 3 and 5.

It should be noted that the following items are not included:

a) Transmission lines.
b) Housing for operating personnel.
c) Damages.
d) Import duties.
e) Excise taxes.

In estimating the cost per kWh, we have applied an average rate of 9% of the total cost. This rate is meant to include:

A. Interest on invested capital.
B. Depreciation.
C. Maintenance and operational cost.

We have not been in the position to assess the contributions of the separate items, and the 9% rate should be regarded only as an assumed figure.

Depending upon whether a power plant is to be manually or remotely controlled, the item C, for instance, may vary somewhat.

3. TECHNICAL DESCRIPTIONS

THJÓRSÁ BASIN

LANGISJÓR RESERVOIR.
Dwg. 430 - 04.

GENERAL

Present outlet from Lake Langisjór to be closed with a small overflow weir, crest El. 666. Diversion to Lónakvísl Creek in the Storisjór watershed via tunnel. Cyclical storage volume between El. 655 and El. 666. Normal present water level assumed El. 661.

MAP COVERAGE

Topographic maps 1:20.000, contour interval 5 m. Maps incomplete with respect to contours along eastern shoreline, where contours largely have been assumed. Bottom contour map 1:20.000 available.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 26 - 27.

Late pleistocene moberg, breccia type with pillow lava at damsite, upper slopes of both banks covered with talus. Permeability of foundation presumed high.

Conditions considered acceptable for a concrete dam to El. 666.

Along the diversion tunnel alignment late pleistocene moberg of tuff-breccia type with pillow lava. A concrete lined tunnel with small cross-section assumed feasible.

The suggested raising of the lake-level to El. 666, is dependent on such topographic and geologic conditions at the north-east end of the lake, that water from the reservoir will not spill over the saddle here.

HYDROLOGY

No runoff-data from Lake Langisjór available. Average annual runoff per km^2 assumed as 90% of that of the Upper Tungnaá River, gage no. 096. North-east boundary of watershed, on Vatnajøkull Glacier, is somewhat vague.

Estimated size of watershed:	100 km^2
Assumed average annual runoff:	190 mill. m^3
Estimated storage capacity:	
1) Between El. 655 and 666:	285 "
2) " El. 660 and 666:	150 "

MAIN FEATURES

1. Outlet Works.

Concrete lined diversion tunnel, length 2.700 m, net cross-sectional area 4 m^2, capable of drawing down reservoir to El. 655 at the rate of Q = 10 m^3/sec. Control gate near the intake.

2. Dam.

Concrete dam, partly gravity and partly flat-slab buttress type. Total length of crest at El. 666 assumed 125 m, max. height assumed 7 m. Since the construction of a road to the damsite is expected to become prohibitively expensive, most of the construction materials and supplies will be transported across the lake from the roadhead at the diversion tunnel intake.

COSTS

2.	Power supply, communications:		1.10 mill. $
3.	Civil engineering work:		
	Outlet works	2.20 mill. $	
	Dam	0.10 "	
	Rigging etc.	0.40 "	2.70 "
4.	Control gate:		0.05 "
5.	Owners general expenses:		0.65 "
6.	Miscellaneous. Contingencies:		0.70 "
		Total cost	5.2 mill. $

THJÓRSÁ BASIN

STORISJÓR (SNJÓALDA) RESERVOIR.

Dwg. 430 - 04.

GENERAL

Storage dam on the upper Tungnaá River at river level approx. El. 581, forming an artificial lake with its storage volume between El. 610 and El. 590.

MAP COVERAGE

Topographic maps 1:20.000, contour interval 5 m. Maps incomplete with respect to contours along eastern shoreline, where contours largely have been assumed.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 26. Description of damsite only.

Late pleistocene moberg of the tuff-breccia type, characterized as friable and fairly permeable. The site is described as suitable for a moderately high rockfill dam.

We conclude that the damsite is insufficiently explored, since no borings exist and the depth and character of the overburden of the valley floor is not investigated. Whether and to what extent the saddle at the extreme right bank is made up of earth material is not known.

Judging from the map, the neighboring Lake Litlisjór, less than 1 km to the west and with waterlevel approx. at El. 557, has no visible outlet. Provided this should be verified as a fact, it seems to indicate highly permeable bedrock in the vicinity, possibly also in the ridge separating the two lakes, thus presenting a weighty argument against anything but a low dam for the Storisjór Reservoir.

Future exploring of the depth and permeability of the soil deposits at the damsite may, however, prove even a low dam impracticable. Topographic conditions may, in our opinion indicate great depths to rock below the river bottom. It should be noted that the assumed bedrock line shown on the drawing represents the view expressed by Nicol.

HYDROLOGY

Evaluations mainly guided by river flow data obtained from gage readings over a period of 5 years at Hofsvad (Vatnaöldur), gage no. 096, Tungnaá River. By correlation methods the period has been extended to 14 years.

Evaluated watershed and runoff-data at Storisjór damsite, Langisjór Diversion included:

	Watershed, km^2:	Average annual runoff, million m3:
Upper Tungnaá	570	1.200
Langisjór Diversion	100	190
	670	1.390

Evaluated design flood flow:	1.200 m3/sec.
" max. flow, construction period	200 "

Estimated storage capacity between El. 590 and El. 610: 450 million m3

MAIN FEATURES

1. Spillway

An ungated overflow spillway, top El. 610, length approx. 350 m is proposed in the saddle on the right bank, provided suitable foundation conditions. The reinforced concrete structure, partly gravity and partly buttress type, is capable of passing the design flood with 1.5 m head on the crest.

For quantity estimate, depth of excavation from ground line to dam foundation assumed 2 m. A grout curtain, average depth 6 m, is assumed under the dam.

2. Main Dam.

An approx. 500 m long and 35 m high earth- or rockfill embankment is proposed. A cutoff-trench to the assumed bedrock-line is included in the cost.

3. Outlet Works.

To bypass the river during construction of the main dam, and later to serve as outlet works, a 300 m long lined tunnel is proposed under the left abutment. The tunnel, with a net cross-sectional area of 25 m^2, will be gate controlled.

COSTS	2. Power supply, communications:		0.60 million $
	3. Civil engineering work:		
	Spillway	0.35 million $	
	Main Dam	4.00 "	
	Outlet Works	0.45 "	
	Rigging etc.	0.80 "	5.60 "
	4. Control gate:		0.05 "
	5. Owners general expenses:		1.20 "
	6. Miscellaneous. Contingencies:		1.15 "
		Total cost	8.6 million $

THJÓRSÁ BASIN

THÓRISVATN RESERVOIR
Dwgs. 430-05 and -06

GENERAL Present outlet to be closed, and Kaldakvísl River to be intercepted and diverted into Thórisvatn Reservoir. Diversion of the reservoir to Tungnaá River via canal from the south-west end of Lake Thórisvatn. Storage volume between El. 564, and El. 571, which is also the present highest water level.

MAP COVERAGE Topographic maps 1:20.000, contour interval 5 m, lake-bottom contour interval 10 m. Topographic maps 1:5.000, contour interval 2 m, of damsites on Thórisós and Kaldakvísl.

GEOLOGY Based on the report of October 1965 by A.H. Nicol, page 22. Only damsites described. No sketch prepared, leaving room for misinterpreting the description.

At the lower damsite (Alt. "A), the left bank of Thórisós is moraine-capped andesite. Depth of overburden in the saddle where the concrete spillway is to be placed, is not quoted. The area between Thórisós and Kaldakvísl is Thjórsá lava (basalt) with scoria in the surface. Below the scoria which may be removed by bulldozer, firm basalt presents an excellent although permeable foundation. The right bank of Kaldakvísl is capped by moraine, probably underlain by andesite, resting on tillite and breccia, presumed to be fairly impermeable.

The site appears favorable for a 25 - 30 m high earthfill dam, but leakage may be excessive unless sealing by sediment carried by the river becomes effective.

At the upper damsites (Alt. "B"), both banks of Thórisós are capped by moraine, probably underlain by andesite on the left and Thjorsá lava on the right bank. This site may be considered acceptable for a low concrete weir. The upper site on Kaldakvísl consists of platy andesite. Foundation conditions described as very favorable, but leakage a possibility here as at the lower site.

HYDROLOGY

Based on river flow data obtained from gage readings over a period of 6 years at Vad, gage no. 094, Thórisós River, and gage readings over a period of 4 years at Saudafell, gage no. 095, Kaldakvísl River. By correlation methods the period has been extended to 14 years (The total flow from both gages are presented in the tabulation received frm SEA. It is believed that the correct gage number of this tabulation should be 125, not 095).

Watershed and runoff-data immediately below the confluence of Thórisós and Kaldakvísl:

	Watershed, km2	Average annual runoff, million m3
Thórisós	330	418 ±
Kaldakvísl	1120	994 ±
	1450	1412

Evaluated design flood flow, after regulation:	750 m3/sec.
Evaluated max. flow, construction period:	200 "
(Kaldakvísl only	170 ")
Estimated storage capacity between El. 564 and 571:	420 million m3.

MAIN FEATURES

1. Outlet Works.

Diversion canal as shown on Exhibit D-3 in the Burfell Project of February 1963 (Harza Engineering Co.), but bottom lowered 2 m in order to permit release of approx. 70 m3/sec. with the reservoir level approaching El. 564. Also, top of control structure raised 1 m to permit rise in water level to El. 572 (flood stage).

2. Dam Alt. "A" (lower site)

An approx. 370 m long ungated overflow spillway, crest El. 571, is proposed in the saddle in the left bank, provided suitable foundation conditions. The concrete gravity structure is capable of passing the design flood with 1.0 m head on the crest.

Depth of excavation from ground line to dam foundation assumed 1.5 m.

An approx. 850 m long earth- or rockfill embankment, max. height 28 m, is proposed for the main dam. Average depth of excavation from ground line to dam foundation assumed 1.0 m.

To bypass river flow during construction, a joint diversion tunnel, 250 m long, is proposed under the right abutment. The tunnel, concrete lined with 25 m2 net cross-sectional area, will be gate controlled.

3. Dam Alt. "B" (upper site)

At the left bank of Kaldakvísl, an approx. 300 m wide plateau will be levelled out by a low concrete sill and will serve as ungated overflow spillway, crest El. 576. No appreciable overburden assumed in this area. A 480 m long earth- or rockfill embankment, max. height 25 m, crest El. 580, is proposed for the main dam. Depth of excavation from ground line to dam foundation assumed

1.0 m. A concrete lined tunnel for construction diversion, similar to that of alt. "A", will be placed in the left bank.

From the diversion pool formed by this dam on Kaldakvísl, an excavated canal, 1600 m long, will convey the water into Thórisvatn Reservoir.

At the upper Thórisós site, an ungated overflow spillway of the concrete gravity type, total length 300 m, and crest El. 571, will be placed at river level approx. El. 563. Assume here 1.5 m depth of excavation from ground line to dam foundation.

COSTS

Alternative "A"

2. Power supply, communications:		0.90 million $
3. Civil engineering work:		
Outlet works	1.90 million $	
Spillway	0.45 "	
Main dam	2.00 "	
Diversion tunnel	0.45 "	
Rigging etc.	1.00 "	5.80 "
4. Control gates:		0.05 "
5. Owners general expenses:		1.25 "
6. Miscellaneous. Contingencies:		1.20 "
Total cost alternative "A"		9.2 million $

Alternative "B"

2. Power supply, communications:		1.00 million $
3. Civil engineering work:		
Outlet works	1.90 million $	
Main dam	0.75 "	
Diversion tunnel	0.45 "	
Diversion canal	1.35 "	
Dam Thórisós	0.35 "	
Rigging etc.	1.00 "	5.80 "

4. Control gates:	0.05 million $
5. Owners general expenses:	1.25 "
6. Miscellaneous. Contingencies:	1.20 "
Total cost alternative "B"	9.3 million $

THJÓRSÁ BASIN

NORDLINGAALDA RESERVOIR
Dwg. 430 - 07

GENERAL Storage dam on the upper Thjórsá River at river level approx. El. 554, forming an artificial lake with its storage volume between El. 592 and El. 565.

MAP COVERAGE Topographic maps 1:20.000 with contour interval 5 m.

GEOLOGY Based on the report of October 1965 by A.H. Nicol, page 20. (Only the damsite on the river is described).

Moraine containing soft sandstone lenses covers a basalt layer and volcanic breccia. The basalt and the breccia are underlain by conglomerate which forms the river bed.

All present types of materials (except the soft sandstone lenses and possibly the upper few meters of moraine) are suitable as foundation support for dams.

Due to the seepage in the contact zone breccia/conglomerate and to the very permeable breccia, grouting will be required.

HYDROLOGY Evaluated by river flow data for gage no. 000, based on the correlation method for a period of 14 years.

Evaluated	watershed	2.060 km2
"	average annual runoff	3.150 million m3
"	design flood flow	3.000 m3/sec.
"	max. flow, construction period	200 "

Estimated storage capacity between El. 565 and 592	1.560 million m3

(This value is based on the elevation-storage curve received from SEA. The selection of dam sites for this curve is not known. A comparison between this curve and a relatively rough one based on the dam locations as shown on dwg. 430 - 07 shows a minor deviation).

MAIN FEATURES

1. Dam.

The reservoir requires a total of 8 dams, the length and maximum height varying from 200 to 2.700 meters and from 6 to 43 meters respectively. With exception of the overflow spillway section which is of the concrete gravity type (alternatively flat-slab buttress type) the dams are all proposed as earth- or rock-fill embankments. Depth of excavation from original ground line to dam foundation assumed 1 m. The total embankment quantity amounts to approx. 2.875.000 m3. A grout curtain, average depth 4 m, is assumed under all dams.

2. Spillway.

An ungated overflow spillway, crest elevation 592, length approx. 700 m is proposed in dam marked no. 2 on the dwg. Depth of excavation from original ground line to the foundation of the concrete structure assumed 2 m. The spillway, together with the outlet works, is capable of passing the design flood with 1.5 m head on the crest.

3. Outlet works.

To bypass the river during construction of the main dam and later to serve as outlet works, a 400 m long concrete culvert is proposed in the right embankment. The culvert will be equipped with a gate and will require approx. 50.000 m3 of excavation and approx. 4.000 m3 of reinforced concrete.

COSTS

2. Power supply, communications: 0.7 million $

3. Civil engineering work:

Dams 9.7 million $

Grouting	0.4 million $	
Outlet works	0.6 "	
Rigging etc.	1.6 "	12.3 million $
4. Control gate:		0.2 "
5. Owners general expenses:		2.6 "
6. Miscellaneous. Contingencies:		2.3 "
	Total cost	18.1 million $

ALTERNATIVE

The alternative of lowering the normal maximum water level 5 m to El. 587 has been investigated.

The overflow spillway is in that case assumed divided into 2 parts with an approx. 200 m long section in dam no. 1 and another section approx. 500 m long in dam no. 2. Dam no. 1 will be designed as a flat-slab buttress type with the spillway crest on El. 587 and the crest for the remaining parts on El. 589. The spillway section of dam no. 2 is proposed as a concrete gravity type while the adjoining parts are assumed as earth- or rock-fill embankments with the crest at El. 590.

By lowering all embankments 5 m the moraine mass quantity will be reduced to 1.720.000 m3. The alternative will amount to a total cost of 12.9 million $.

The storage capacity is for this case estimated to 840 million m3. Judging from the mass diagram for gage no. 000 it seems reasonable to reduce the flow by approx. 15 m3/sec., resulting in a reduction of the power production of approx. 450 million kWh. The alternative with max. waterlevel at El. 592 appears consequently most attractive, according to the simplified criteria applied.

For cost estimates for alternative storage volumes see also Exhibit 3 - 1.

THJÓRSÁ BASIN

BJALLAR PROJECT
Dwg. 430 - 08

GENERAL

Intake dam crossing Tungnaá at river level approx. El. 543. Intake, powerstation and tailrace tunnel in the right bank. Suggested normal HW El. 563, TW El. 505.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 26 (only the damsite is described).

At both abutments of the proposed dam late pleistocene moberg is exposed. The area between,covered by postglacial lava flows, assumed to be highly permeable. Late pleistocene moberg assumed along the entire proposed waterway.

We conclude that the lava is suitable as foundation for the dam, but its permeability will necessitate grouting in the entire length. Tunnels require lining.

HYDROLOGY

Based mainly on river flow data obtained from gage readings over a period of 5 years at gage no. 096, Vatnaøldur, Tungnaá River. By correlation methods the period has been extended to 14 years.

Evaluated regulated river flows based on reservoirs at Storisjór and Langisjór. (Drawing on the reservoir in Storisjór will be governed by the demand at Tungnaákrókur).

Summer: Q_s = 68 m3/sec.
Winter: Q_w = 85 "

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways	90 m3/sec.
2. Installed capacity	105 "

Estimated hydrologic data at intake dam:

Watershed:	1.350 + 100 = 1.450 km2
Average annual runoff	3.045 million m3
Design flood flow	2.700 m3/sec.
Max. flow, construction period	400 m3/sec.

MAIN FEATURES

1. Intake dam.

Flat-slab buttress dam of total length 1.150 m and max. height 26 m with a 700 m long ungated overflow spillway section. The spillway with its crest on El. 563, is capable of passing the design flood with 1.5 m rise in water level.

For quantity estimate depth from original ground line to dam foundation is assumed 2 m.

A dam of the embankment type, necessitating a diversion tunnel, has been studied. This dam will require 5 gated spillways, each 15 m long and 7 m deep. This alternative does not appear competitive in cost with the concrete type dam.

2. Power Plant.

2 steel-lined pressure shafts, length 70 m, net cross-sectional area 11.5 m2. Subsurface powerstation with 2 vertical Francis units of 35.000 metric HP each, at Q = 52.5 m3/sec. and net head 55 m. 2.5 km long lined tailrace tunnel, net cross-section 30 m2. The same cross-

section for the adit and the access tunnel, totalling 600 m.

POWER PRODUCTION Utilized runoff, annual average 2.460 million m3, generating 315 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Langisjór and Storisjór		1.6 million $
2. Power supply, communications:		0.4 "
3. Civil engineering work:		
Intake dam	3.75 million $	
Intake, shafts	0.30 "	
Power house	1.00 "	
Tailrace tunnel	4.75 "	
Rigging etc.	1.50 "	11.3 "
4. Mechanical and electrical equipment:		
Turbines	0.85 million $	
Gates, misc.	0.25 "	
Generators	0.75 "	
Transformers	0.15 "	
Switchgear	0.45 "	
Local transport	0.25 "	2.7 "
5. Owners general expenses:		2.8 "
6. Miscellaneous. Contingencies:		2.2 "
	Total cost	21.0 million $

Total cost of energy per kWh: $\frac{21.0}{315}$ = 0.0667 $

Cost of energy per kWh (9%): 0.00600 $

THJÓRSÁ BASIN

TUNGNAÁRKRÓKUR PROJECT

Dwg. 430-09

GENERAL

Intake dam crossing Tungnaá at river level approx. El. 466. Intake, supply tunnel, power house and tailrace tunnel in the right bank, cutting across the bend formed by the river.

Suggested normal HW El. 500, TW El. 425.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m, and 1:5.000 with contour interval 2 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 24, with map figure 13.

At the right bank of the damsite late pleistocene moberg pillow lava and tuff-breccia. At the left bank several separate flows of Thjórsá lava underlain by moberg tuff-breccia; the contact zone being highly permeable. With the water level raised to El. 500, leakage in this zone may become serious. Placing of an impermeable blanket on the left bank extending upstream from the dam to contact with some alluvial deposits, assumed to be an ancient lake-bottom, is suggested as a solution to this problem. We have made no attempt, however, to estimate the extent and cost of such a blanket, as the boundaries of the deposits are rather vague.

Aside from the envisioned leakage problem, we assume the foundation conditions to be acceptable for a relatively high embankment.

The tunnels and the powerhouse will be located entirely in late pleistocene moberg tuff-breccia and pillow lava, characterized as weak, stratified, and very blocky and seamy.

We assume poor conditions for tunnelling, requiring concrete liner throughout. As the tailrace tunnel almost certainly will be located below the groundwater table and possibly in rock with permeable zones, the inflow of groundwater may become severe. The driving of a test tunnel will to some extent clarify this problem.

HYDROLOGY

Based on riverflow data obtained from gage readings over a period of 4 - 6 years at:

1. Hofsvad (Vatnaøldur), gage no. 096, Tungnaá River
2. Saudafell, gage no. 095, Kaldakvísl River
3. Vad, gage no. 094, Thórisós River

By correlation methods the period has been extended to 14 years.

Estimated regulated river flow in m3/sec. at the intake dam, with Langisjór and Thórisvatn (incl. Kaldakvísl) diverted to Tungnaá; with 450 million m3 storage capacity in Storisjór, 420 million m3 in Thórisvatn and 285 million m3 in Langisjór (without taking advantage of the Tungnaárkrókur intake storage):

	Summer:	Winter:
Tungnaá	Q = 102	Q = 93
Langisjór	Q = 0	Q = 10
Thórisvatn	Q = 37	Q = 50
	Q_s = 139	Q_w = 153

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways:	160 m3/sec.
2. Installed capacity:	200 "

Estimated watershed and run-off data at the intake dam:

	Watershed, km2:	Average annual runoff, million m3:
Tungnaá	1.500	3.173
Langisjór	100	190
Thórisvatn	1.450	1.412
	3.050	4.775

Estimated design flood flow	3.000 m3/sec.
Estimated max. flow, construction period:	450 "
Estimated intake storage capacity, between El. 480 and El. 500:	200 million m3

MAIN FEATURES

1. Intake dam

From the left abutment, an ungated concrete gravity spillway extends 650 m along the almost level lava field. Assume 2 m depth of excavation from ground line to base of dam.

An earth- or rockfill embankment is proposed between the end of the spillway and the right bank. Assume 1 m depth of excavation under base of dam.

A gated and concrete lined diversion tunnel, net cross-section 55 m2, length 180 m, will be placed under the right abutment.

A grout curtain, average depth 4 m, is assumed under the entire dam.

2. Power plant.

Concrete lined supply tunnel, length 1000 m, net cross-section 53 m2. 2 steel-lined pressure shafts, length 75 m, net cross-section 20 m2.

Subsurface powerhouse with two Francis units of 89.000 metric HP each at Q = 100 m3/sec. and net head 73 m. 200 m long concrete lined access tunnel, net cross-section 30 m2. 550 m long tailrace tunnel, lining and cross-section as for supply tunnel.

POWER PRODUCTION

Utilized runoff, annual average: 4635 million m3, generating 785 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Storisjór storage	1.65 million $	
Langisjór storage	1.00 "	
Thórisvatn storage	1.75 "	4.40 million $
2. Power supply, communications:		0.30 "
3. Civil engineering work:		
Concrete dam	0.70 million $	
Earthfill dam	1.75 "	
Diversion tunnel	0.35 "	
Supply tunnel	3.10 "	
Power house	1.10 "	
Tailrace tunnel	1.00 "	
Rigging etc.	1.30 "	9.30 "
4. Mechanical and electrical equipment:		
Turbines	1.30 million $	
Generators	1.60 "	
Transformers	0.35 "	
To be transferred	3.25	14.o million $

Transferred	3.25 million $	14.0 million $
Switchgear etc.	0.65 "	
Gates, misc.	0.40 "	
Local transport	0.40 "	4.70 "
5. Owners general expenses:		2.85 "
6. Miscellaneous. Contingencies:		1.85 "
Total cost		23.4 million $

Total cost of energy per kWh: $\frac{23.4}{785}$ = 0.0298 $

Cost of energy per kWh (9%): 0.00268 $

THJÓRSÁ BASIN

HRAUNEYJAFOSS PROJECT

Dwg. 430 - 10

GENERAL

Intake dam crossing TUNGNAÁ (main fork) at river level approx. El. 408. Intake, pressure shafts, powerhouse and tailrace tunnel in the right bank. Suggested normal HW El. 425, TW El. 320.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m, and 1:5.000 with contour interval 2 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 23 - 24, with map fig. 12.

Left bank made up of Thjórsá lava. The right bank consists of late pleistocene moberg, tuff-breccia or pillow lava type. Approx. 1 km length of the proposed tunnel alignment will be sedimentary rocks.

Conditions at damsite described as favorable for a rockfill dam, but with possibility of leakage in the left bank.

The moberg pillow lava is characterized as very blocky and seamy, and the tuff-breccia as weak tunnelling ground. We assume concrete lining throughout. As the tailrace tunnel almost certainly will be located below the groundwater table and possibly in rock with permeable zones, the inflow of groundwater way become severe. The driving of a test tunnel will to some extent clarify this problem.

HYDROLOGY

Based on the same data and conditions as Tungnaárkrókur.

Regulated river flow will increase by 4 m3/sec. in the summer and 2 m3/sec. in the winter, relative to Tungnaárkrókur:

Summer: Q_s = 143 m3/sec.
Winter: Q_w = 155 "

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways:	165 "
2. Installed capacity:	210 "

Estimated hydrologic data:

Watershed: (Incl. Langisjór and Thórisvatn)	3.120 km2
Average annual runoff:	4.900 million m3
Design flood flow:	3.000 m3/sec.
Max. flow, construction period:	500 "

MAIN FEATURES

1. Intake dam.

An ungated, flat-slab buttress type overflow spillway crest El. 425, extends from the left abutment for a length of 700 m. An embankment dam is proposed from the end of the spillway over to the right bank.

Depth of excavation, assumed 2 m under spillway and 1 m under embankment.

A gated and concrete lined diversion tunnel, net cross-section 80 m2, length 360 m, will be excavated in the right bank.

A grout curtain, average depth 4 m, is assumed under the entire dam.

2. Power Plant

2 steel-lined pressure shafts, length 155 m, net cross-section 20.5 m2. Subsurface powerhouse with 2 Francis units of 132.000 metric HP each at Q = 105 m3/sec. and net head 102 m. 700 m long concrete lined access tunnel, net cross-section 30 m2. 2.900 m long tailrace tunnel of 55 m2 net cross-section, concrete lined.

POWER PRODUCTION Utilized runoff, annual average: 4.725 million m3, generating 1.120 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Storisjór storage	2.3 million $	
Langisjór "	1.4 "	
Thórisvatn "	2.4 "	6.1 million $
2. Power supply, communications:		0.3 "
3. Civil engineering work:		
Concrete dam	1.25 million $	
Earthfill dam	1.15 "	
Diversion tunnel	0.80 "	
Intake, shafts	0.85 "	
Power house	2.10 "	
Tailrace tunnel	6.75 "	
Rigging etc.	1.80 "	14.7 "
4. Mechanical and electrical equipment:		
Turbines	1.55 million $	
Generators	0.65 "	
Transformers	0.45 "	
Switchgear etc.	1.25 "	
Gates, misc.	0.30 "	
Local transport	0.40 "	4.6 "
5. Owners general expenses:		3.9 "
6. Miscellaneous. Contingencies:		2.8 "
	Total cost	32.4 million $

Total cost of energy per kWh: $\frac{32.4}{1120}$ = 0.0289 $
========

Cost of energy per kWh (9%): 0.00260 $
=========

THJÓRSÁ BASIN

BUDARHALS PROJECT

Dwg. 430 - 11

GENERAL

Intake dam across Lower Tungnaá at river level approx. El. 296. Powerhouse incorporated in the dam. Suggested normal HW El. 320, TW El. 297.

MAP COVERAGE

Topographic maps 1:20.000 with 5 m contour interval.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 20.

The left bank consists of young Thjórsá lava (basalt) with no overburden, but with 1 or 2 m scoria in the surface. The rock is possibly permeable.

The right bank is composed of early and middle pleistocene moberg and basalt, covered by ground moraine of variable thickness.

The site is described as suitable for any type of dam.

HYDROLOGY

Based on the same data and conditions as Tungnaárkrókur, together with river flow data obtained from gage readings over a period of 3 years at gage no. 098, Hald, Tungnaá River (extended to 14 years by correlation). Regulated river flow will increase by 24 m3/sec. in the summer and 14 m3/sec. in the winter, relative to Tungnaárkrókur.

Summer: Q_s = 163 m3/sec.
Winter: Q_w = 167 "

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways: 180 m3/sec.
2. Installed capacity: 230 "

Estimated hydrologic data:

Watershed (incl. Langisjór)	3.490 km2
Average annual runoff:	5.580 million m3
Design flood flow:	4.000 m3/sec.
Max. flow, construction period:	800 "

MAIN FEATURES

1. Intake dam.

Concrete dam of the flat-slab buttress type, with 1050 m length of ungated overflow spillway between the river and the left abutment. Assume average depth of foundation excavation 1.5 m, depth of grout curtain 4 m.

2. Power house.

Intakes incorporated in dam. Above-surface powerhouse at toe of dam, with 2 Kaplan units of 32.000 metric HP each at 115 m3/sec. and net head 22.5 m, discharging directly into the riverbed.

POWER PRODUCTION

Utilized runoff, annual average: 5.205 million m3, generating 270 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Storisjór storage	0.40 million $	
Langisjór "	0.25 "	
Thórisvatn "	0.50 "	1.15 mill.$
2. Power supply, communications:		0.25 "
3. Civil engineering work:		
Intake dam	5.50 million $	
Powerhouse	1.10 "	
Rigging etc.	1.20 "	7.80 "
4. Mechanical and electrical equipment:		
Turbines	0.70 million $	
Generators	0.85 "	
Transformers	0.15 "	
Switchgear etc.	0.35 "	
Gates, misc.	0.30 "	
Local transport	0.25 "	2.60 "

5. Owners general expenses:	2.10 million $
6. Miscellaneous, contingencies:	1.50 "
Total cost	15.40 million $

Total cost of energy per kWh: $\frac{15.4}{270}$ = 0.0570 $

Cost of energy per kWh (9%): 0.00513 $

THJÓRSÁ BASIN

HVANNGILJAFOSS PROJECT
Dwg. 430 - 13

GENERAL

Intake dam crossing Thjórsá at river level approx. El. 507. Headrace canal, powerhouse and tailrace canal in the right bank.

Suggested normal HW El. 518, TW El. 493.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 19.

The report states that on the right bank there are sedimentary rocks covered by a thick layer of ground moraine. We assume similar conditions in the left bank.

The sedimentary rocks consist of well cemented conglomerate overlain by some very weak and friable sedimentary bed. The conglomerate, being fairly tight and impervious, is well adapted as foundation for different types of dams, while the overlying beds, being weak and permeable, will require strengthening.

We assume that the conglomerate is exposed only in the river bed.

HYDROLOGY

River flow data from gage no. 000.

Evaluated regulated river flows based on 1560 million m3 storage capacity in Nordlingaalda reservoir (Drawing on the Nordlingaalda reservoir will be governed by the demand at Dynkur):

Summer: Q_s = 95 m3/sec.
Winter: Q_w = 105 "

Corresponding rates of flow to govern:

1. Cross-sections of the waterways:	110 m3/sec.
2. Installed capacity:	140 "

Estimated watershed	2.240 km2
" average annual runoff	3.450 mill.m3
" design flood flow	3.300 m3/sec.
" max. flow, construction period	700 "

MAIN FEATURES

1. Intake dam.

A 500 m long concrete gravity dam of which 450 m is ungated overflow spillway, is placed on the gently sloping left bank.

On the right bank a 250 m long embankment type dam is proposed.

In the riverbed a flat-slab buttress dam with a section of four 12 by 4 meters gated overflow spillways is proposed. A 5 x 4 m bottom outlet together with two open bays serve as diversion during construction period.

The gated and ungated spillways are capable of passing the design flood with 1.5 m rise in waterlevel.

A secondary dam is required approx. 1 km north of the intake dam. The dam, 150m long and with average height 4 m, is assumed as an embankment.

For all dams a 2 m deep foundation excavation is assumed.

A 4 m deep grout curtain is proposed below the concrete gravity dam and all embankments, including the dikes for the headrace canal.

2. Power Plant.

Headrace canal, 600 m long, in which the water occupies a 185 m2 cross-sectional area for a flow of 110 m3/sec. Embankment type dikes along both sides of the canal. Above-surface powerhouse with two vertical Kaplan units of 20.500 metric HP each at Q = 70 m3/sec. and net head 24 m. Tailrace canal, 900 m long, partly following the course of an adjoining creek.

POWER PRODUCTION Utilized runoff, assumed annual average: 3.180 million m3, generating 175 million kWh of energy per year.

COSTS	1. Regulation and storage:		
	Dam Nordlingaalda:		1.0 million $
	2. Power supply, communications:		0.8 "
	3. Civil engineering work:		
	Intake dam	1.45 million $	
	Headrace canal	0.90 "	
	Powerhouse	0.65 "	
	Tailrace canal	1.60 "	
	Rigging etc.	1.00 "	5.6 "
	4. Mechanical and electrical equipment:		
	Turbines	0.50 million $	
	Generators	0.50 "	
	Transformers	0.10 "	
	Switchgear etc.	0.25 "	
	Gates, misc.	0.30 "	
	Local transport	0.15 "	1.8 "
	5. Owners general expenses:		1.6 "
	6. Miscellaneous. Contingencies:		1.2 "
	Total cost		12.0 million $

Total cost of energy per kWh: $\frac{12.0}{175}$ = 0.0686 $

Cost of energy per kWh (9%): 0.00617 $

THJÓRSÁ BASIN

DYNKUR PROJECT
Dwg. 430 - 14

GENERAL

Intake dam crossing Thjórsá at river level approx. El. 455. Intake supply tunnel, power station and tailrace tunnel in the left bank. Suggested normal HW El. 493, TW El. 305.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 18 with map fig. 11.

Exposed early and middle pleistocene basalt at the dam site, adequate to support a heavy concrete structure. Joints and interbeds may cause underseepage, and grouting is therefore assumed under the dam.

Along the proposed waterway partly moberg and partly basalt, both of the early and middle pleistocene type. Sedimentary beds, actually a part of the basalt, will require tunnel lining over considerable lenghts.

HYDROLOGY

Evaluated by river flow data for gage no. 000 based on the correlation method for a period of 14 years.

Estimated regulated river flows at the intake dam with 1560 million m3 storage capacity in Nordlingaalda reservoir:

Summer: Q_s = 125 m3/sec.
Winter: Q_w = 135 m3/sec.

Corresponding rates of flow to govern:

1. Cross-sections of the waterways:	140 m3/sec.
2. Installed capacity:	180 "
Estimated watershed	2.695 km2
" average annual runoff	4.160 million m3
" design flood flow	4.000 m3/sec.
" max. flow, construction period	750 "

MAIN FEATURES

1. Intake dam.
An embankment, a gated and an ungated spillway, and a gravity dam constitute the intake dam, of a total length of 1170 m, max. height 45 m. Depth of excavation from original ground line to base of dam assumed 1 m. A grout curtain, average depth 4 m, is assumed under the embankment and the gravity dam.

The 400 m long ungated overflow spillway and the 6 gated spillways each 12 m wide and 7 m deep, are capable of passing the design flood with 1.5 m rise in waterlevel.

Two unlined diversion tunnels, each 56 m2 in cross-section and with one of them gate controlled, are proposed in the right bank.

2. Power Plant.
Supply tunnel 7 km long of which 5 km is assumed concrete lined with a net cross-section of 47 m2, and 2 km unlined having a cross-section of 80 m2. Two steel-lined pressure shafts, length 270 m, net cross-section 17.5 m2. 2 adits each 200 m long, concrete lined with a net area of 30 m2. Subsurface powerstation with two vertical Francis units of 200.000 metric HP each at Q = 90 m3/sec. and net head 180 m. Access tunnel 1000 m long, net cross-section 30m2, half the length concrete lined. Tailrace tunnel 400 m long, unlined with a 80 m2 cross-section.

POWER PRODUCTION Utilized runoff, annual average 4125 million m3, generating 1730 million kWh of energy per year.

COSTS

1. Regulation and storage Nordlingaalda:		8.5 million $
2. Power supply, communications:		0.4 "
3. Civil engineering work:		
Dam	4.9 million $	
Diversion tunnels	0.4 "	
Supply tunnel	11.5 "	
Powerstation	1.9 "	
Tailrace tunnel	0.2 "	
Rigging etc.	2.4 "	21.3 "
4. Mechanical and electrical equipment:		
Turbines	1.55 million $	
Generators	2.50 "	
Transformers	0.60 "	
Switchgear etc.	1.35 "	
Gates, misc.	0.55 "	
Local transport	0.65 "	7.2 "
5. Owners general expenses:		5.7 "
6. Miscellaneous. Contingencies:		4.1 "
Total cost		47.2 million $

Total cost of energy per kWh: $\frac{47.2}{1730}$ = 0.0273 $

Cost of energy per kWh (9%): 0.00245 $

THJÓRSÁ BASIN

KALDAKVÍSL (THÓRISVATN) PROJECT
Dwg. 430 - 12

GENERAL

Diversion of Thórisvatn to Thjórsá at Dynkur via a power-station equipped with reversible pump-turbines.

Powerplant with head- and tailrace tunnels situated between Thórisvatn and Kaldakvísl, where a dam across the river forms a diversion pond. A tunnel diverts the flow from the pond over to the Dynkur intake reservoir. In periods of surplus river flow, Thjórsá water is diverted in the opposite direction and pumped into Thórisvatn.

MAP COVERAGE

Topographic maps 1:20.000 with 5 m contour interval.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 21 and 23 with maps fig. 11, sheet 2 and 3.

The damsite on Kaldakvísl will presumably be located in late pleistocene moberg or basalt. We assume foundation conditions acceptable for a small arch-dam.

The tunnel from Thórisvatn to Kaldakvísl will presumably pass mainly through early and middle pleistocene moberg, tuff and breccia type, but the intake in Thórisvatn will be in andesite, and the outlet in Kaldakvísl in late pleistocene basalt. We assume poor conditions for tunnelling.

The diversion tunnel from Kaldakvísl to Thjórsá may be located partly in pleistocene basalt of either the late or the early and middle type, but mainly in early and middle pleistocene moberg. We consider conditions for tunnelling somewhat dubious along a substantial part of the alignment.

HYDROLOGY

Evaluated on the basis of the same river flow data as Dynkur Project and Thórisvatn Reservoir.

For this alternative it is necessary to provide a large drawdown reservoir in Thórisvatn, while the storage volume of Nordlingaalda should be reduced. Assume the following size of the reservoirs:

1. Thórisvatn (El. 571 to El. 540): 1.600 million m3
2. Nordlingaalda (El. 587 to El. 565):840 "

The Kaldakvísl Diversion Pond fluctuates between El.502 and El. 490.

Estimated watershed, power plant:	1.450 km2
" " diversion:	1.570 "
" " pumping plant:	2.815 "
" annual average volume pumped into Thórisvatn: approx.	400 million m3

Assume the following flow data for Dynkur Project:

1. Normal flow, summer:	120 m3/sec.
2. " " winter: 120 + 90	210 "
3. Flow to govern cross-sections of waterways:	200 "
4. " " " installed capacity:	240 "

Assume the following flow data for Kaldakvísl Project:

1. Normal flow for generating, winter:	48 m3/sec.
2. " " bypassing turbine, winter:	42 "
3. " " for pumping, summer:	40 "
4. Flow to govern cross-sections of waterways:	85 "

MAIN FEATURES

1. Power plant:

Concrete lined supply tunnel, length 2.7 km with net cross-sectional area 28 m2. 2 steel-lined pressure shafts of length 80 m and 10.5 m2 area. Subsurface powerhouse with 2 reversible pump-turbine units generating 16.000 metric HP each at Q = 24 m3/sec. and net head 55 m, together with a bypass arrangement. Concrete lined tailrace tunnel of length 4 km.

2. Diversion dam:

A small arch-dam across the river gorge with adjoining earth- or rockfill embankments on both sides. An ungated overflow spillway, concrete gravity type, placed in a low saddle on the right bank of Kaldakvísl.

3. Diversion tunnel:

Total length 8 km of which approx. one half is assumed concrete lined, net cross-sectional area 28 m2, and the other half unlined with cross-section 48 m2.

POWER PRODUCTION

The average net gain in production by this diversion of Lake Thórisvatn, relative to the alternative diversion to Tungnaá, is difficult to estimate exactly with simple methods. We presume, however, that the net gain will hardly exceed 200 million kWh per year.

COSTS

Only the cost of the Kaldskvísl Project is included as the increase in cost of the Dynkur Project is assumed to be offset by a corresponding decrease in cost of the projects in Tungnaá.

2. Power supply, communications: 0.5 million $

3. Civil engineering work:

Power plant	13.4 million $	
Diversion dam	0.7 "	
Diversion tunnel	7.6 "	
Rigging etc.	2.7 "	24.4 "

4. Mechanical and electrical equipment:

Turbine/pumps	0.50 million $	
Generators	0.70 "	
Transformers	0.10 "	
Switchgear etc.	0.35 "	
Gates, misc.	0.25 "	
Local transport	0.20 "	2.1 "

5. Owners general expenses:	5.3 million $
6. Miscellaneous, contingencies:	4.5 "
Total cost	36.8 million $

Total cost of energy per kWh: $\frac{36.8}{200} = 0.1840$ $

Cost of energy per kWh (9%): 0.01655 $

THJÓRSÁ BASIN

SULTARTANGI PROJECT

Dwg. 430 - 15

GENERAL

Dual-purpose dam (ice prevention, power) across Thjórsá/ Tungnaá at river levels approx. El. 274 and El. 280 respectively, immediately upstream of the confluence. Powerhouse incorporated in the dam near the right bank of Thjórsá. Suggested normal HW El. 297, TW El. 273.

MAP COVERAGE

Topographic maps 1:20.000 with 5 m contour interval.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 16 - 17, with map fig. 10.

The damsite described in the report is located approx. 3 km upstream from the site proposed in this project, and our appraisal of the conditions is mainly guided by the geologic map.

The riverbed and the right bank of Thjórsá assumed to be early and middle pleistocene basalt, firm and tight, which also applies to low hill on the left bank of Thjórsá. The rest of the dam foundation will be Thjórsá lava, composed of several flows separated by permeable interbeds of loose sand and pumiceous gravel.

We expect favorable conditions for the dam across Thjórsá incl. the powerhouse. We assume acceptable conditions for the low overflow spillway, although leakage under the dam may be considerable. Foundation conditions for the main dam, however, are very dubious insofar as leakage through the interbeds may become uncontrollable.

While the Project Manager is advocating that the dam shall be placed approx. 3 km further upstream and that the power plant shall be placed in the left bank of Tungnaá, with the alignment of the extensive tailrace canal following an alluvium-filled depression in the lava field, we have prepared our project on the basis of the following conditions:

1. As no detailed map, with borings, of the tailrace canal alignment in the left bank is available, we are not able to present any reliable cost estimate for this major component.

2. By thus abandoning the attempt to install power in the left bank, the dual-purpose facet of the project seems to favor the lower damsite, as a powerhouse near the right bank in that case could eliminate tunnel--and canal projects.

3. There is apparently no essential difference in foundation conditions at the two damsites, except that leakage may become even more severe at the lower site, and that conditions at the right abutment may become adverse at the upper site.

4. From an ice condition standpoint, the lower damsite is apparently preferable to the upper one.

HYDROLOGY

Based on the same data as Tungnaárkrókur and Dynkur, and data obtained from gage readings at gage no. 098, Hald. Regulated river flow in m3/sec. will increase by 31 in the summer and 17 in the winter, relative to the sum of flow at Tungnaárkrókur and Dynkur:

	Summer:	Winter:
Tungnaárkrókur	139	153
Dynkur	125	135
Unregulated area:	31	17
	$Q_s = 295$	$Q_w = 305$

Corresponding rates of flow to govern:

1.	Cross-sectional area of waterways	330 m^3/sec.
2.	Installed capacity	420 "

Estimated hydrologic data:

Watershed (incl. Langisjór):	6.440 km^2
Average annual runoff: approx.	9.900 million m^3
Design flood flow:	6.000 m^3/sec.
Max.flow, construction period:	900 "

MAIN FEATURES

1. Dam.

Concrete dam of the flat-slab buttress type, length approx. 200 m, across the Thjórsá fork.

Earth of rockfill embankment, length approx. 1150 m, across the Tungnaá fork over to the left abutment.

The approx. 2000 m of ungated overflow spillway, partly flat-slab buttress and partly gravity type, is placed in the saddle in the left bank.

Depth of excavation from ground line to dam foundation assumed 1.5 m under the entire dam. Assume 7000 m^2 of grout curtain to be required.

2. Powerhouse.

Intakes incorporated in concrete dam across Thjórsá. Above-surface powerhouse at toe of dam, with 2 Kaplan units of 61.000 metric HP each at Q = 210 m^3/sec. and net head 23.5 m, discharging directly into the riverbed.

POWER PRODUCTION

Utilized runoff, annual average: 9.470 million m^3, generating 520 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Storisjór storage	0.55 million $	
Langisjór "	0.30 "	
Thórisvatn "	0.55 "	
Nordlingaalda "	1.10 "	2.5 million $
2. Power supply, communications:		0.2 "
3. Civil engineering work:		
Dam Thjórsá	0.8 million $	
Earthfill dam	2.6 "	
Spillway	1.7 "	
Cofferdams	0.3 "	
Powerhouse	2.5 "	
Rigging etc.	1.3 "	9.2 "
4. Mechanical and electrical equipment:		
Turbines	1.15 million $	
Generators	1.45 "	
Transformers	0.20 "	
Switchgear etc.	0.40 "	
Gates, misc.	0.50 "	
Local transport	0.40 "	4.1 "
5. Owners general expenses:		2.7 "
6. Miscellaneous. Contingencies:		1.80 "
	Total cost	20.5 million $

Total cost of energy per kWh: $\frac{20.5}{520}$ = 0.0394 $

Cost of energy per kWh (9%): 0.00355 $

THJÓRSÁ BASIN

HÁIFOSS PROJECT

Dwg. 430 - 16

GENERAL

Diversion dam crossing Stora Laxá at river level approx. El. 505. Tunnel conveying flow from diversion pool over to the river Eystri Svartá discharging into Fossá. Storage dam across Fossá at river level approx. El. 475. Intake, supply tunnel, penstocks and powerhouse in the right bank. Suggested max. HW. El. 500, TW. El. 225.

MAP COVERAGE

Topographic maps 1:20.000 with contour interval 5 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 15 (only the area from the Fossá damsite and downstream is described).

The damsite recommended by the Geologist has a thin overburden with firm andesite in both abutments, the andesite being exposed in the river bed.

The supply tunnel will probably in the northern part encounter firm andesite, but towards south it will run into altered rhyolite.

The cliffs, and the landslide areas will probably cause adverse conditions for penstock construction.

The foundation conditions for a power station are characterized as good.

HYDROLOGY

Evaluations guided by river flow data obtained from gage readings at Hàifoss, gage no. 099, over a period of 6 years.

Estimated regulated river flow at power intake, with 120 million m3 of storage volume:

Summer: Q_s = 11 m3/sec.
Winter: Q_w = 12 "

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways: 12 m3/sec.
2. Installed capacity: 15 "

Estimated hydrologic data:

	Watershed km2:	Average annual runoff, million m3:
Upper Fosså	125	192
Stora Laxå diversion	140	218
	265	410

	Design flood flow, m3/sec:	Max. flow, construction period m3/sec:
Stora Laxå dam	350	45
Fosså dam.	335	40

Estimated storage capacity in Fosså reservoir between El. 485 and El. 500: 120 million m3

MAIN FEATURES

1. Diversion dam, Stora Laxå.
A 450 m long embankment type dam with crest at El. 532 and max. height 28 m. Excavation for a 6 m wide and 2 m deep cut-off trench extended by a grout curtain of average depth 4 m.

A 300 m long concrete gravity saddle dam, parallel to the river, with its crest at El. 530 forms an ungated overflow spillway. 2 m deep foundation excavation. Discharge into a creek merging with Stora Laxá 2.5 km downstream. Construction flow bypassed through an unlined diversion tunnel, 300 m long, cross-section 10 m2.

3.800 m long unlined diversion tunnel, cross-section 10 m2, dimensioned for 21 m3/sec.

2. Storage dam, Fossá.
Ungated overflow spillway of flat slab buttress type in the right bank, crest El. 500. Assumed 2 m deep foundation excavation. The remainder of the dam is proposed as an embankment with crest at El. 502 and max. height 28 m. Assumed 4 m deep grout curtain under the entire dam. A 350 m long concrete lined diversion tunnel, net cross-section 6 m2, placed in the left bank.

3. Power plant.
Supply tunnel, concrete lined, net cross-section 4 m2, length 2.000 m. One steel penstock, 650 m long, net cross-section 3 m2. Above-surface powerhouse with 2 Pelton units of 23.500 HP each at Q = 7.5 m3/sec. and net head 270 m, discharging into the river.

POWER PRODUCTION

Utilized runoff, annual average 365 million m3, generating **230 million kWh** of energy per year.

COSTS

2. Power supply, communications: 0.5 million $

3. Civil engineering work:

Stora Laxá dams	1.00 million $		
Diversion tunnel	0.55 "		
Fossá storage dam	4.25 "		
Supply tunnel, penstocks	1.60 "		
Powerhouse	0.70 "		
Rigging etc.	1.30 "	9.4	"

4. Mechanical and electrical equipment:

Turbines	0.30 million $	
Generators	0.50 "	
Transformers	0.10 "	
Switchgear etc.	0.25 "	
Gates, misc.	0.10 "	
Local transport	0.15 "	1.4 million $

5. Owners general expenses:	2.2 "
6. Miscellaneous, contingencies:	1.8 "
Total cost	15.3 million $

Total cost of energy per kWh: $\frac{15.3}{230} =$ 0.0665 $

Cost of energy per kWh (9%): 0.00598 $

THJÓRSÁ BASIN

SKARD PROJECT

GENERAL

Due to insufficient map material only a rough outline is presented. For location of project see dwg. 430 - 03. Intake dam across Thjórsá. Intake, powerstation and tailrace tunnel in the right bank.

Suggested normal HW El. 120, TW El. 80.

MAP COVERAGE

Topographic maps 1:50.000 with contour interval 20 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 15 with accompanying Fig. 9, (only the dam site is described).

Post-glacial lava flows is exposed on the left bank and in the river bed, while the right bank is underlain by early and middle pleistocene basalt.

Adequate bearing capacity for any type of dam. However, leakage may be a problem, not only because of the lava, but also due to existing finiglacial beds.

HYDROLOGY

Regulated river flows based on the same data as Tungnaárkrókur and Dynkur. Relative to Sultartangi, the regulated river flow will increase by 27 m3/sec. in the summer and 6 m3/sec. in the winter.

Summer: $Q_s = 312$ m3/s
Winter: $Q_w = 311$ "

Corresponding rates of flow to govern:

1. Cross-sectional area of waterways: 340 m3/sec.
2. Installed capacity: 440 "

MAIN FEATURES

1. Intake dam.

Assumed same design as main dam Urridafoss, extended by embankments on both sides.

2. Power plant.

2 steel-lined pressure shafts, length 46 m, net cross-sectional area 42,5 m2. Subsurface powerstation with 2 Kaplan units of 97.000 metric HP each at Q = 220 m3/sec. and net head 36 m. 3.5 km long tailrace course divided into two parallel tunnels, half the lengths unlined the other half concrete lined. Cross-sections are 113 and 195 m2 for lined and unlined sections respectively.

POWER PRODUCTION

Utilized runoff, annual average 9.820 million m3, generating 820 million kWh of energy per year.

COSTS

1. Regulation and storage:

Nordlingaalda	1.7 million $	
Thórisvatn	0.9 "	
Langisjór	0.5 "	
Storisjór	0.8 "	3.9 million $

2. Power supply, communications:		0.2 "

3. Civil engineering work:

Dams	2.90 million $	
Powerstation	2.00 "	
Tailrace tunnels	9.00 "	
Rigging etc.	1.90 "	15.8 "

4. Mechanical and electrical equipment:

Turbines	1.20 million $	
Generators	1.90 "	
Transformers	0.35 "	
Switchgear etc.	1.35 "	
Gates, misc.	0.75 "	
Local transport	0.55 "	6.1 "

5. Owners general expenses: 4.4 million $

6. Miscellaneous, contingencies: 3.1 "

Total cost 33.5 million $

Total cost of energy per kWh: $\frac{33.5}{820} =$ 0.0409 $

Cost of energy per kWh (9%): 0.00368 $

THJÓRSÁ BASIN

URRIDAFOSS PROJECT. (Without diversion of Hvítá)

Dwg. 430 - 17

GENERAL

Intake dam across Thjórsá at river level approx. El. 27.5, approx. 600 m downstream from the bridge. Intake, power station and tailrace canal at left bank. Suggested normal HW El. 435, TW El. 10.5.

MAP COVERAGE

Topographic maps 1:5.000 with contour interval 2.5 m, and 1:2.000 with contour interval 1 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 13 with map Fig. 7.

The entire left bank exposes early and middle pleistocene basalt while the right bank is mainly post-glacial lava flows except a small area with the same conditions as at the left bank. The proposed dam located in the area where exposed early and middle pleistocene basalt forms both banks. Similar geological conditions are assumed along the entire proposed waterway.

Subsurface investigation is required to determine possible leakage and the method and extent of foundation treatment.

HYDROLOGY

River flow data from gage no. 030 with readings over a period of 17 years. Further based on the same data as Tungnaárkrókur and Dynkur.

Evaluated regulated river flows based on the Nordlingaalda, Thórisvatn and Storisjór/Langisjór reservoirs (drawing on the reservoirs governed by the demand at Dynkur and Tungnaárkrókur):

Summer: Q_s = 321 m3/sec.
Winter: Q_w = 315 "

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways: 350 m3/sec.
2. Installed capacity: 450 "

Estimated watershed	7.200 km2
" average annual runoff	11.730 mill.m3
" design flood flow	5.000 m3/sec.
" max. flow, construction period	1.500 m3/sec.

MAIN FEATURES 1. Intake dam.

The 200 m long main dam, of which approx. 135 m is reserved for spillways and bottom outlets, is a concrete structure with a max. height of 21 m.

The spillway section comprises seven 15 by 7 m gates while the bottom outlet section has two 5 by 5 m gates.

For diversion during construction period several weirs of the spillway section are to be left open temporarily.

2. Power plant.

2 steel-lined pressure shafts, length 40 m, net cross-sectional area 43.5 m2. Subsurface powerhouse with 2 Kaplan units of 85.000 metric HP each at Q = 225 m3/sec. and net head 31 m. Unlined access tunnel, length 800 m, cross-section 30 m2. Unlined tailrace tunnel 1.200 m long, cross-section 200 m2. One third of the tunnels are assumed gunited.

POWER PRODUCTION Utilized runoff, annual average 10.010 million m3, generating 725 million kWh of energy per year.

COSTS	1. Regulation and storage:		
	Nordlingaalda	1.45 million $	
	Thórisvatn	0.75 "	
	Langisjór	0.40 "	
	Storisjór	0.70 "	3.3 million $
	2. Power supply, communications:		0.1 "
	3. Civil engineering work:		
	Dams	1.65 million $	
	Powerstation	2.05 "	
	Tailrace tunnel	1.30 "	
	Rigging etc.	1.00 "	6.0 "
	4. Mechanical and electrical equipment:		
	Turbines	1.10 million $	
	Generators	1.65 "	
	Transformers	0.30 "	
	Switchgear etc.	1.20 "	
	Gates, misc.	0.65 "	
	Local transport	0.50 "	5.4 "
	5. Owners general expenses:		2.3 "
	6. Miscellaneous. Contingencies:		1.7 "
		Total cost	18.8 million $

Total cost of energy per kWh: $\frac{18.8}{725} =$ 0.0259 $

Cost of energy per kWh (9%): 0.00233 $

HVÍTÁ BASIN

HVÍTÁRVATN RESERVOIR

Dwg. 430 - 18

INTRODUCTION

Several potential damsites have previously been considered and described by Icelandic Engineers and Geologists (Thoroddsen, Kjartansson). We have therefore limited our investigation to one dam located upstream from the confluence of Hvítá and Jøkulfall Rivers (Midnes), and one dam located downstream from the confluence (Ábóti). Due to shortage of time only the latter alternative which was introduced by the Project Manager, has been shown on the drawing. Both alternatives will include Jøkulfalls flow into the reservoir, and will regulate Hvítárvatn between the limits El. 422 and 435. Attempts have been made to establish if installation of power may be economically justifiable for the two alternatives. However, since the drawing from the reservoir is governed by the demand of the major powerplants downstream, the power production at Hvítárvatn will become uneven, and the plant subjected to occasional shut-downs. It is therefore difficult to state both the size of the tentative installation and the amount and value of the annual power production.

Both alternatives will develop the head between HW. El. 435 (normal max) and TW. El. 386. Assume mean HW El. 432.

HYDROLOGY

Evaluations mainly guided by river flow data obtained from gage readings at:

1. Hvítárvatn outlet, gage no. 057, over a period of 5 years. Period extended to 14 years by correlation method.

2. Gullfoss, gage no. 087, Hvítá River, over a period of 14 years.

Evaluated hydrologic data:

Watershed:	1.230 km2
Average annual runoff:	2.400 million m3
Design flood flow:	1.200 m3/sec.
Max. flow, construction period:	400 "
Estimated storage capacity between El. 435 and 422:	690 million m3

(The latter value is based on the elevation-storage curve received from SEA. The dam site for which this curve is valid has not been stated, and may be different from the site shown on dwg. 430 - 18).

"Regulated" flow through the power plant is hard to assess. Use the following approximate data:

Summer: Q_s = 50 m3/sec. Winter: Q_w = 75 m3/sec.

Corresponding flows to govern:

1. Cross-sections of waterways	70 m3/sec.
2. Installed capacity	90 "

POWER PRODUCTION Utilized runoff, assumed annual average: 2.100 million m3, generating for alternative:

1. Midnes: 210 million kWh of energy per year.

2. Ábóti: 215 million kWh of energy per year.

I. Midnes Alternative.

GENERAL Storage dam across the Hvítá at river level approx. El.

419.5 (at the present bridge), extending along the ridge to cross Jøkulfall at river level approx. El. 422. Tentatively a power plant with intake, tunnels and powerhouse will be placed in the right bank of Hvítá.

MAP COVERAGE

Topographic maps 1:10.000 with contour interval 5 m, and 1:5.000 with 2 m contour interval. (Apparently map 3645, sheet no. 00, shall read no. 10, and its east-west coordinates shall be corrected).

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 12, with map fig. 6.

Except for the left bank of Jøkulfall, bedrock along the entire dam-site is late pleistocene basalt, covered by moraine of variable thickness. The moraine is hard and firm from 1 to 2 m below the surface. A certain amount of grouting may be required under dam.

The intake canal of the tentative powerplant to be excavated in late pleistocene basalt, the supply tunnel in early and middle pleistocene moberg, while the powerhouse and the tailrace canal will be located in early and middle pleistocene basalt. We assume no tunnel liner required.

MAIN FEATURES

1. Dam.

An earth- or rockfill embankment max. height approx. 20 m, is proposed for the main dam. Depth of excavation under dam assumed 1 m.

An ungated concrete gravity spillway, crest at El. 435, length approx. 300 m, will be placed in the saddle west of Lambafell, discharging into Lambafellkvísl. The spillway may pass the design flood with 1.5 m rise in water level.

For diversion during construction, later to serve as outlet works, a gated culvert is proposed under the main dam.

2. Power plant (tentative).

Headrace canal of length 450 m. 2 steel-lined pressure shafts, length 53 m, net cross-sectional area 9.5 m2. Subsurface powerhouse with 2 vertical Francis units of 24.000 metric HP each at Q = 45 m3/sec. and net head 43 m. Unlined access tunnel, length 500 m, cross-section 30 m2. The 100 m long supply tunnel and the 3000 m long tailrace tunnel are both unlined, cross-section 43 m2.

COSTS

Dam Midnes.

2. Power supply, communications:		0.80 million $
3. Civil engineering work:		
Main dam	2.10 million $	
Spillway dam	0.65 "	
Diversion arrangement	0.80 "	
Rigging etc.	0.85 "	4.40 "
4. Control gate:		0.05 "
5. Owners general expenses:		1.00 "
6. Miscellaneous. Contingencies:		0.95 "
Total cost		7.2 million $

Midnes Power Project.

1. Regulation and storage:	
Dam Midnes	0.9 million $

2. Power supply, communications:		0.2 million $
3. Civil engineering work:		
Intake, supply tunnel	0.4 million $	
Powerhouse	1.2 "	
Tailrace tunnel	1.3 "	
Rigging	0.3 "	3.2 "
4. Mechanical and electrical equipment:		
Turbines	1.8 million $	
Generators	0.65 "	
Transformers	0.15 "	
Switchgear etc.	0.45 "	
Gates, misc.	0.15 "	
Local transport	0.30 "	3.5 "
5. Owners general expenses:		1.0 "
6. Miscellaneous. Contingencies:		0.7 "
Total cost		9.5 million $

Total cost of energy per kWh: $\frac{9.5}{210}$ = 0.0452 $

Cost of energy per kWh (9%): 0.00407 $

II. Abóti Alternative.

GENERAL Storage dam across the Hvítá at river level approx. El. 415. Tentatively a power plant with intake, tunnels and powerhouse will be placed in the right bank.

MAP COVERAGE Topographic maps 1:10.000 with contour interval 5 m.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 12, with map fig. 6.

Early and middel pleistocene basalt in the entire area, covered by moraine or organic soil on both banks.

The site is described as suited for a low embankment or concrete dam. We conclude that neither grouting of foundation nor guniting of tunnels will become necessary.

MAIN FEATURES

1. Dam.

An earth- or rockfill embankment, max. height approx. 26 m, is proposed for the main dam. Assume same cross-section and foundation conditions as for the Midnes alternative. The spillway will be identical to that of the Midnes alternative, in outline and location.

For diversion during construction, later to serve as outlet works, an unlined tunnel of cross-section 57 m2, length 600 m, will be excavated in the right bank and equipped with a control gate.

2. Power plant (tentative).

Headrace canal of length 600 m, 2 steel-lined pressure shafts, length 53 m, net cross-section 9.5 m2. Sub-surface powerhouse with 2 vertical Francis units of 24.000 metric HP each at Q = 45 m3/sec. and net head 44 m. Unlined access tunnel, length 500 m, cross-section 30 m2. Total length of unlined supply- and tailrace tunnel 1.700 m, cross-section 43 m2.

COSTS

Dam Ábóti.

2. Power supply, communications:	0.80 million $

3. Civil engineering work:

Main dam	4.20 million $	
Spillway dam	0.65 "	
Diversion tunnel	0.30 "	
Rigging etc.	1.05	6.20 million $

4. Control gate:	0.05 "
5. Owners general expenses:	1.30 "
6. Miscellaneous. Contingencies:	1.25 " ä
Total cost	9.6 million $

Ábóti Power Project.

It appears that the cost of the dam has been increased by 2.4 million $ through the downstream relocation. Since this relocation of the dam will also serve to decrease the cost of the power tunnels considerably, the entire difference in dam costs is made chargeable to the Ábóti Power Project.

1. Regulation and storage:

Difference between dam Ábóti and dam Midnes 9.6 - 7.2 =	2.4 million $	
Dam Midnes	0.9 "	3.3 mill. $

2. Power supply, communications:	0.2 "

3. Civil engineering work:

Intake, supply tunnel	0.40 million $	
Powerhouse	1.20 "	
Tailrace tunnel	0.75 "	
Rigging	0.25 "	2.6 "

4. Mechanical and electrical equipment:
as Midnes Power Project 3.5 million $

5. Owners general expenses: 0.9 "

6. Miscellaneous. Contingencies: 0.6 "

Total cost 11.1 million $

Total cost of energy per kWh: $\frac{11.1}{215}$ = 0.0516 $

Cost of energy per kWh (9%): 0.00465 $

CONCLUSION The Midnes Project appears preferable to the Ábóti Project.

HVÍTÁ BASIN

SANDVATN DIVERSION

Dwgs. 430 - 02 and 03

GENERAL

Present outlets to be closed, partly with a low overflow weir and partly with low embankments. Water level of Lake Sandvatn to be raised enough for the water to spill over a saddle east of the lake and into a creek-bed leading down to Hvítá above Gullfoss.

MAP COVERAGE

Topographic map 1:20.000, contour interval 5 m (present lake-level not clearly recognizable, assume El. 273 as normal).

GEOLOGY

The area is not covered by the geologic report. Assume favorable conditions for low earth fill dams, and sound rock-foundation for concrete weir 2 m below ground-line.

HYDROLOGY

Based on river flow data obtained from gage readings over a period of 14 years at Faxi, gage no. 068, Tungufljót River.

It is assumed that by raising the normal water level approx. 2 m, and by constricting the new outlet to some extent, the selfregulating effect of Lake Sandvatn could be increased, producing a regulated flow into Hvítá of

$$\underline{\underline{Q_s = Q_w = 32 \text{ m3/sec.}}}$$

corresponding to a utilized runoff of 1.010 million m3 annually.

Estimated hydrologic data:

Watershed, at outlet Sandvatn: 560 km2

Average annual runoff, at outlet Sandvatn:	1.120 million m3
Design flood flow (assumed):	500 m3/sec.

assumed distributed with one half each to Hvítá and to Tungufljót via the spillway at the present outlet.

COSTS	2. Power supply, communications:	0.5 million $
	3. Civil engineering work:	0.3 "
	5. Owners general expenses:	0.1 "
	6. Miscellaneous, Contingencies:	0.1 "
	Total cost	1.0 million $

HVÍTÁ BASIN

BLÁFELL PROJECT

Dwgs. 430 - 19 and 20

GENERAL

Diversion dam crossing the Hvítá at river level approx. El. 348. Canal conveying flow from diversion pool over to Sandá. Intake dam across Sandá at river level approx. El. 367. Intake and powerhouse in the left bank of Sandá. Tailrace tunnel parallelling Hvítá at a distance of 0.5 - 2.0 km from left bank.

Suggested normal HW El. 385, TW El. 256.

MAP COVERAGE

Topographic map 1:10.000, contour interval 5 m, of entire area except end of tailrace tunnel which is covered by 1:20.000 map with 5 m contour interval. Spot-coverage on 1:5.000 topographic maps.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 10 - 12, with map fig. 5.

Bedrock at the site of the diversion dam (Hvítá) is pillow lava of fairly high permeability. Conditions may be acceptable for an arch dam, unless suitability of this type is ruled out by further investigations.

The diversion canal appears to be located mainly in basalt, according to fig. 5.

The site of the proposed intake dam (Sandá) is apparently located approx. 500 m upstream of the Sandártunga dam site described by Nicol, but conditions at the two sites are assumed to be similar: Under 1 - 2 m of overburden columnar basalt, blocky and vesicular. We consider conditions suitable for a concrete dam or an embankment.

Along pressure shafts, powerhouse and tailrace tunnel alignment presumably early and middle pleistocene basalt and moberg, according to fig. 5. We assume tunneling conditions to be favorable.

HYDROLOGY

Based on river flow data obtained from gage readings over a period of 14 years at Gullfoss, gage no. 087, Hvítá River.

Estimated regulated river flow in m3/sec. at intake dam Sandá, with 690 million m3 storage capacity in Hvítárvatn (no allowance made for the preservation of the scenic value of the Gullfoss Falls):

Summer: $Q_s = 86$ Winter: $Q_w = 101$

Corresponding rates of flow to govern:

1. Cross-sectional areas of water-ways:	100 m3/sec.
2. Installed capacity:	130 "

Estimated hydrologic data:

Watershed at intake dam:	1.660 km2
Average annual runoff at intake dam:	3.200 million m3
Design flood flow at diversion dam:	1.600 m3/sec.
Design flood flow at intake dam:	400 "
Max. flow, construction period, diversion dam:	500 "
Max. flow, construction period, intake dam:	100 "

MAIN FEATURES

1. Diversion dam, Hvítá.

A 45 m high arch is proposed to span the river gorge, with a concrete gravity section forming a trust-block for the left abutment. The spillway axis is placed parallel to the river in order to attain sufficient length of gated spillway.

To divert construction flow, a 50 m long tunnel of 75 m2 cross-sectional area, unlined but gunited, is proposed.

A grout curtain, average depth 4 m, has been assumed under the dam.

The velocity in the diversion canal is calculated at 0.6 m/sec. for max. winter flow, insuring the formation of an ice sheet.

2. Intake dam Sandá.
Ungated overflow spillway of concrete gravity type in the left bank, crest El. 385. Assume 2 m deep excavation from ground line to dam foundation. For the remainder of the dam an earth- or rockfill embankment of max. height 24m is proposed.

3. Power plant.
2 steel lined pressure shafts, length 190 m,net cross-section 12.5 m2. Subsurface powerhouse with 2 Francis units of 95.000 metric HP each at Q = 65 m3/sec. and net head 119 m. Unlined access tunnel, length 1.100 m, cross-section 30 m2. 10.000 m length of unlined tailrace tunnel, cross-section 57 m2, assumed gunited along one half of the length.

POWER PRODUCTION Utilized runoff, annual average: 3.120 million m3, generating 860 million kWh of energy per year.

COSTS

1. Regulation and storage:	
Hvítárvatn storage:	3.1 million $
2. Power supply, communications:	0.8 "

3. Civil engineering work:

Diversion dam	1.50 million $	
Diversion canal	0.75 "	
Intake dam	0.80 "	
Intake shafts	0.50 "	
Powerhouse	0.70 "	
Tunnels	6.60 "	
Rigging etc.	1.45 "	11.7 mill. $

4. Mechanical and electrical equipment:

Turbines	1.15 million $	
Generators	1.55 "	
Transformers	0.35 "	
Switchgear etc.	0.90 "	
Gates, misc.	0.50 "	
Local transport	0.45 "	4.9 "

5. Owners general expenses:	3.4 "
6. Miscellaneous. Contingencies:	2.4 "
Total cost	26.3 mill. $

Total cost of energy per kWh: $\frac{26.3}{860}$ = 0.0306 $

Cost of energy per kWh (9%): 0.00275 $

HVÍTÁ BASIN

GULLFOSS (TUNGUFELL) PROJECT

Dwgs. 430 - 21 and 22

GENERAL

Intake dam crossing the Hvítá at river level approx. El. 212. Intake, supply tunnel, powerhouse and tailrace tunnel in the left bank.

Suggested normal HW El. 243, TW El. 102.

MAP COVERAGE

Topographic map 1:2.000, contour interval 2 m, of intake reservoir, damsite and powerhouse site, and of the tunnel alignment down to Nautavik. Topography (other than 1:50.000) of the downstream end of the tailrace tunnel alignment is lacking.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol page 10, with map fig. 4. (Only the damsite is described in the report).

At the damsite early and middle pleistocene basalt covered by moraine. We expect conditions to be favorable for dam foundation.

Along the supply tunnel including the pressure shafts and the powerhouse, early and middle pleistocene basalt, according to fig. 4. Tunneling conditions are assumed favorable by us.

Along the tailrace tunnel early and middle pleistocene moberg, except fini-glacial sediments along the downstream approx. 400 m, according to fig. 4. We expect conditions to be favorable in the moberg, but they may become adverse and prohibitively costly in the sediments.

The last 400 m of tailrace may therefore have to be omitted, moving the outlet 500 m upstream to TW El. 105.

HYDROLOGY

Based mainly on river flow data obtained from gage readings over a period of 14 years at:

1. Gullfoss, gage no. 087, Hvítá River.
2. Faxi, gage no. 068, Tungufljót River.

Estimated regulated river flow in m3/sec. at the intake dam, with 690 million m3 storage capacity in Hvítárvatn, and Sandvatn diverted to Hvítá above Gullfoss. No allowance made for the preservation of the scenic value of the Gullfoss Falls:

	Summer:	Winter:
Hvítá	Q = 97	Q = 107
Sandvatn	Q = 32	Q = 32
	Q_s = 129	Q_w = 139

Corresponding rates of flow to govern:

1. Cross-sectional areas of the waterways: 150 m3/sec.
2. Installed capacity: 190 "

Estimated watershed and runoff data at the intake dam:

	Watershed, km2:	Average annual runoff, million m3:
Hvítá	1.970	3.670
Sandvatn	560	1.120
Total	2.530	4.790

Estimated design flood flow: 3.250 m3/sec.

" max. flow, constr.period: 750 "

MAIN FEATURES

1. Intake dam.

From the power intake in the left abutment, a 350 m long concrete dam, mainly of the buttress type max. height 39 m, is proposed. A low earthfill embankment is proposed for the remaining 1.500 m of the dam. Normal HW level may possibly be raised one or two meters above the suggested El. 243, depending upon depth and permeability of overburden along right abutment.

For quantity estimate, depth of excavation from ground line to dam foundation assumed 2 m under concrete dam, 1 m under earthfill dam. A grout curtain, average depth 4 m, is assumed under the entire concrete dam.

During construction, the river flow is to be bypassed through one diversion tunnel, one bottom gate and one temporary opening between buttresses.

2. Power plant.

Unlined supply tunnel, length 6.000 m, cross-section 86 m2, assumed guniting along one half of the length. 2 steel-lined pressure shafts, length 175 m, net cross-section 19 m2. Subsurface powerhouse with 2 vertical Francis units of 155.000 metric HP each at Q = 95 m3/sec. and net head 132 m. Unlined access tunnel, length 350 m, cross-section 30 m2. 1.600 m length of tailrace of which 1.200 m is assumed unlined tunnel, cross-section 86 m2, and the remainder concrete lined tunnel of net cross-section 50 m2. Depending upon the topography, an open channel could possibly substitute the lined tunnel.

POWER PRODUCTION

Utilized runoff, annual average: 4.250 million m3, generating 1.310 million kWh per year.

COSTS

1. Regulation and storage:		
Hvítárvatn storage	3.4 million $	
Sandvatn diversion	0.8 "	4.2 million $
2. Power supply, communications:		0.2 "
3. Civil engineering work:		
Concrete dam	3.5 million $	
Earthfill dam	0.5 "	
Supply tunnel	5.1 "	
Powerhouse	1.0 "	
Tailrace tunnel	1.7 "	
Rigging etc.	1.7 "	13.5 "
4. Mechanical and electrical equipment:		
Turbines	1.70 million $	
Generators	2.15 "	
Transformers	0.50 "	
Switchgear etc.	1.20 "	
Gates, misc.	0.75 "	
Local transport	0.60 "	6.9 "
5. Owners general expenses:		4.1 "
6. Miscellaneous. Contingencies:		2.7 "
	Total cost	31.6 million $

Total cost of energy per kWh: $\frac{31.6}{1310}$ = 0.0241 $

Cost of energy per kWh (9%): 0.00217 $

HVÍTÁ BASIN

HAUKHOLT PROJECT

Dwg. 430 - 23

GENERAL

Intake dam crossing Hvítá at river level approx. El. 70. Power intake, pressure tunnel and powerhouse in the right bank.

Suggested normal HW El. 100, TW El. 69.5.

MAP COVERAGE

A 1:1000 sketch with contours at 5 m interval to El. 100 (Hvítárvatn Dam Site). No coverage for downstream portion of dam and for powerhouse.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 9 (it has not been clearly indicated that the described damsite is identical with the one for which the mapsketch is prepared).

Presumably early and middle pleistocene basalt in the right bank. Massive andesite with basalt layers below and above, and with one highly permeable breccia interbed in the left bank.

Further study may confirm that the site is suitable for a moderately high concrete buttress dam. Tunnelling operations in the right bank should not, in our opinion, encounter difficulties.

HYDROLOGY

Based on the same data as the Gullfoss Project immediately upstream.

Estimated regulated river flow in m3/sec. at intake dam Haukholt, with 690 million m3 storage capacity in Hvítárvatn, and Sandvatn diverted to Hvítá above Gullfoss (no allowance made for the preservation of the scenic value of the Gullfoss Falls):

Summer: Q_s = 133 Winter: Q_w = 141

Corresponding rates of flow to govern:

1. Cross-sectional areas of waterways:	150 m3/sec.
2. Installed capacity:	190 "

Estimated hydrologic data:

Watershed at intake dam:	2.605 km2
Average annual runoff at intake dam:	4.900 million m3
Design flood flow at intake dam:	3.500 m3/sec.
Max. flow, construction period, intake dam:	800 "

MAIN FEATURES

1. Intake dam.

50 m ungated concrete gravity spillway forms the left abutment, while the river gorge is spanned by a 120 m long buttress dam, partly a gated spillway and partly a non-overflow section. A gravity dam, with the power intake incorporated, forms the right abutment.

For quantity estimate, depth of excavation from groundline to dam foundation is assumed 1.5 m.

During construction, the river flow is to be bypassed through one bottom gate and one or two temporary openings between spillway buttresses.

2. Power plant.

Steel lined pressure shaft and tunnel of net cross-section 47 m2. Above-surface powerhouse with 2 Kaplan units of 35.000 metric HP each at Q = 95 m3/sec.and net head 30 m, discharging directly into the riverbed.

POWER PRODUCTION Utilized runoff, annual average: 4.330 million m3, generating 300 million kWh of energy per year.

COSTS

1. Regulation and storage:		
Hvítárvatn storage	0.80 million $	
Sandvatn diversion	0.20 "	1.0 million $
2. Power supply, communications:		0.2 "
3. Civil engineering work:		
Intake dam	2.0 million $	
Shaft and tunnel	0.5 "	
Powerhouse	1.5 "	
Rigging etc.	1.0 "	5.0 "
4. Mechanical and electrical equipment:		
Turbines	0.60 million $	
Generators	0.30 "	
Transformers	0.15 "	
Switchgear etc.	0.40 "	
Gates, misc.	0.60 "	
Local transport	0.25 "	2.8 "
5. Owners general expenses:		1.6 "
6. Miscellaneous. Contingencies:		1.0 "
	Total cost	11.6 million $

Total cost of energy per kWh: $\frac{11.6}{300}$ = 0.0387 $

Cost of energy per kWh (9%): 0.00348 $

HVÍTÁ BASIN

URRIDAFOSS DIVERSION

Dwg. 430 - 24

GENERAL

Diversion dam crossing Hvítá at river level approx. El. 46.5. Canal conveying flow from Hvítá to Thjórsá, discharging into Thjórsá approx. 2.5 km upstream from Urridafoss power intake. Power plant as outlined on page 3 - 50 "Urridafoss Project", the dimensions increased according to the increased regulated flows.

MAP COVERAGE

Topographic maps 1:5.000 with 1 m contour interval.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 14 with accompanying Fig. 8.

With exception of a one km long stretch of early and middle pleistocene basalt with a layer of finiglacial sediments, the excavation for the proposed canal will be in post-glacial lava flows. 3 m of overburden is assumed along the entire canal alignment.

HYDROLOGY

Based on the same data as Bláfell. Relative to Haukholt the regulated river flow will increase by 57 m3/sec. in the summer and 30 m3/sec. in the winter:

Summer: Q_s = 190 m3/sec.
Winter: Q_w = 171 "

Corresponding rates of flow to govern:

1. Cross-sectional area of waterways	200 m3/sec.
2. Installed capacity	220 "

Total governing rates of flow for the Urridafoss power plant will then be:

1. Cross-section area of waterways: 350 + 200 = 550 m3/sec.
2. Installed capacity: 445 + 220 = 665 "

Evaluated hydrologic data at Hvítá diversion dam:

Watershed	4.360 km2
Design flood flow	4.500 m3/sec.
Max. flow, construction period	1.000 "

MAIN FEATURES

1. Diversion dam.
The dam consists mainly of a 140 m long gated spillway capable of passing a flood of approx. 2.800 m3/sec. The largest floods will cause flooding of the land between Hvítá and Thjórsá and consequently of the proposed diversion structures. To minimize the damage, the gate houses and the bridge between piers are placed above max. flood stage.

2. Canal.
Total length 5.3 km of which approx. one tenth is assumed concrete lined. For the purpose of preventing ice production, the canal is dimensioned for a water velocity of 0.6 m/sec. and the outlet has been formed as an overflow weir.

3. Power plant.
As described previously for "Urridafoss". The dimensions are changed according to the increased regulated flows.

POWER PRODUCTION Utilized runoff, annual average 5.640 million m3, generating 405 million kWh of energy per year.

COSTS Urridafoss diversion project has been charged with the costs of the extension of the previously proposed power plant.

1. Regulation and storage:		
Hvítárvatn	0.65 million $	
Sandvatn	0.15 "	0.8 million $
2. Power supply, communications:		0.05 "
3. Civil engineering work:		
Diversion dam	0.35 million $	
Canal	6.90 "	
Power station	0.70 "	
Tailrace tunnel	0.90 "	
Rigging etc.	0.90 "	9.75 "
4. Mechanical and electrical equipment:		
Turbines	0.50 million $	
Generators, transformers, switchgear, etc.	2.10 "	
Gates, misc.	0.40 "	
Local transport	0.30 "	3.30 "
5. Owners general expenses:		2.60 "
6. Miscellaneous. Contingencies:		1.90 "
Total cost		18.4 million $

Total cost of energy per kWh: $\frac{18.4}{405}$ = 0.0454 $

Cost of energy per kWh (9%): 0.00409 $

HVÍTÁ BASIN

DYNJANDI PROJECT

Dwg. 430 - 25

GENERAL

Intake dam across the Brúará at river level approx. El. 53.5. Powerhouse incorporated in dam near the right bank.

Suggested HW El. 64 to El. 61, TW El. 54.

GEOLOGY

Based on the report of October 1965 by A.H. Nicol, page 8. (The location of the damsite is not described in the report. Assume same damsite as proposed by us).

Early and middle pleistocene basalt forms the entire dam foundation below less than 3 m of overburden.

We assume excellent foundation conditions for a low concrete dam.

HYDROLOGY

Based on river flow data from gage readings over a period of 13 years at Dynjandi, gage no. 043, Brúará River. Period extended to 16 years by correlation methods.

Storage reservoir (Apavatn):	55	million m3
Estimated river flow, summer:	56	m3/sec.
" " " winter:	53	"
Flow to govern sizing of waterways:	60	"
" " " installed capacity:	77	"
Estimated watershed:	670	km2
" average annual runoff:	2.020	million m3
" design flood flow:	1.000	m3/sec.
" max. flow, construction period:	200	"

MAIN FEATURES

1. Intake and storage dam.
Concrete dam of the buttress and the gravity types, length 700 m, max. height 15 m. Spillways, partly gated and partly ungated, are placed next to the left abutment.

Assume 3 m deep excavation from ground line to dam foundation.

2. Powerhouse.
Intakes incorporated in dam. Above-surface powerhouse at toe of the dam, with 2 Kaplan units of 4.000 metric HP each at Q = 38.5 m3/sec. and net head 8.5 m, discharging directly into the riverbed.

POWER PRODUCTION

Utilized runoff, annual average: 1.700 million m3, generating 34 million kWh of energy per year.

COSTS

1. Regulation and storage: Included in 3.

2. Power supply, communications:		0.2 million $
3. Civil engineering work:		
Intake dam	0.75 million $	
Powerhouse	0.30 "	
Rigging etc.	0.15 "	1.2 "
4. Mechanical and electrical equipment:		
Turbines	0.30 million $	
Generators	0.30 "	
Transformers	0.05 "	
Switchgear etc.	0.25 "	
Gates, misc.	0.20 "	
Local transport	0.10 "	1.2 "
5. Owners general expenses:		0.5 "
6. Miscellaneous. Contingencies:		0.3 "
Total cost		3.4 million $

Total cost of energy per kWh: $\frac{3.4}{34}$ = $\underline{\underline{0.1000\ \$}}$

Cost of energy per kWh (9%): $\underline{\underline{0.00900\ \$}}$

MISCELLANEOUS

Exhibit 3-2 and 3-3

The principal data from the preceding descriptions have been listed in the tables on exhibit 3-2 and 3-3. In table 1 the Burfell Project is entered with an installation of 210 MW. It should be noted that this installation would be approx. twice as large if it were to correspond to the regulated river flow at Burfell.

Other alternatives

The following two alternative developments have been investigated briefly, but have been abandoned as being infeasible economically:

> KALDAKVÍSL II. Diversion of Thórisvatn via tunnel from the south-western side of the lake to Kaldakvísl at river level approx. El. 335. Installed capacity approx. 150 MW. Length of concrete lined tunnels 12 km.
>
> HESTVATN. Diversion of Hvítá to Lake Hestvatn via canal at Hestfjell. Flow returned via canal and above surface powerhouse. Installed capacity approx. 35 MW. See table 1 (exhibit 3 - 3) for cost data.

SELFOSS is a low head alternative near the mouth of Hvítá. This project has not been investigated by us. From table 1, exhibit 3 - 3, it appears that the Hestvatn Project is less attractive than the Urridafoss Diversion Project. If the latter project should materialize the Hestvatn and Selfoss alternatives would both be abandoned.

An alternative development at Bláfell, designated the BLÁFELL DIVERSION PROJECT, has been proposed by the Project Manager. According to this alternative, the flow would be diverted from the dam on the Sandá over to a power intake near the creek Búdhará, approx. 11 km distant, partly via excavated canals and partly via low depressions, or plateaus. The flow would be returned to the Stangará River via pressure shafts, subsurface powerhouse and a tailrace tunnel.

Since the only available map of the diversion route is an 1:50.000 map with a contour interval of 20 m, and since the quantities - and cost estimates of such a diversion project including a number of dams or dikes may be strongly influenced by even minor irregularities in the topography, we have not found it possible to submit any recommendation as to the feasibility of this alternative.

4. CONCLUSIONS AND RECOMMENDATIONS

Based upon the mapping and other preliminary investigations made so far and upon the expert reports available at the present, we have presented a Preliminary Master Plan for the hydroelectric development of the two river basins.

As specified in the contract UN/NORENO FOUNDATION the Master Plan shall indicate the best ultimate utilization of the potential of the two river basins as a whole. During our work we have, consequently, visualized the storages and power plants to be developmed more or less at the same time.

It should be noted that the Preliminary Master Plan will give information on the feasibility of the various projects and the potential of the river basins as a whole. From this report it may further be derived:

a) The relative construction cost for the various projects.

b) The relative price of power from the various plants.

c) The order of magnitude of available power (kW) and energy (kWh).

d) To which extent topographic information and other physical data have been available for the study of the various sites.

The description of the various projects and the appurtenant drawings will also be of assistance for the planning of further field investigations.

It has, however, not been intended that the present Preliminary Master Plan without some supplementary studies should be used directly as the basis for a power system analysis. For such an analysis the costs of storage capacities, of installation and developed heads would be required in several alternatives.

It is, however, reasonably easy from the drawings and the cost estimates to assess the variations in cost of the separate power plants when the installation is varied.

In studying the regulation storages we have investigated the costs for several sizes of storage capacity and in Exhibit 3 - 1 we have quoted a few additional figures that may be of some interest for a power system analysis.

Our recommendations for the installation capacities, and storage volumes and also our evaluation of production are all based upon the assumption that the major part of the power (80%) is consumed by power consuming industries having a constant load throughout the year, whereas the balance covers domestic and ordinary industry demands.

The details of the Master Plan and the cost estimates are based upon certain assumptions which we have made, lacking exact information.

In describing the various projects included in the plan, we have mentioned the most important assumptions made, in order to facilitate adjustments to the plan when more exact information is available as a result of further investigation.

For cost estimations we have suggested unit prices for the various types of work. The unit prices are chosen after a preliminary study of Icelandic conditions. The unit prices are also listed in order to facilitate adjustments of estimates as required when more exact information is made available.

The storage capacities are chosen on the basis of very simplified criteria. We have tried to find the storage volume which would give the lowest price of energy for the power plants downstream of the storage, but have not tried to investigate all the consequences of a cooperation of all the storages and power plants in the two basins as this is regarded as a task for the power system analyst. A closer study may prove that the total storage volume shall be differently distributed between the storages and, of course, that the total storage capacity shall be increased or reduced from what has been indicated in this report.

As previously mentioned the plan is prepared under the assumption that the basins are fully developed more or less at the same time.

In reality the development will in any case have to take place over a considerable number of years. It will therefore be necessary to consider the sequence and also the speed of development.

In so far as the order in which the considered sites should be developed is only a question of size and cost, the present plan could be used for preliminary considerations. The unit prices used and the cost of machinery and equipment are to a very limited degree depending upon the sequence and rate of development (assuming the construction cost etc. to be constant in time). The transport roads and cost of regulation storages, however, which in the present estimates are distributed between all the plants which benefit from the roads, respectively from the regulation storages, will have to be carried by the first project or projects to be developed.

When the sequence shall be considered not only the size and cost should be considered. Even if the local geologic conditions, availability of materials etc. will be reflected on the cost estimates when more field investigations have been made, it will, of course, be advisable to start with a project where the local conditions are comparatively clear. When experience has been gained, one will be more prepared to meet the difficulties at the sites with more complex conditions.

On exhibit 3 - 3 two tables are presented. Table 1 shows the itemized and total cost for all the investigated projects, whereas table 2 shows the cost of the projects regarded as "feasible". We have here, somewhat arbitrarily, regarded projects yielding a kWh-price of US $ .004 or less as feasible. In the latter table the cost of storages has been distributed on a smaller total utilized head and the regulation and storage costs for the various projects are consequently higher than in table 1.

From table 2 it can be seen that in the Thjórsá basin the Urridafoss plant yields the lowest unit cost, or US $ .00228 per kWh. Number two is Dynkur with US $ .00241 per kWh. Hrauneyafoss and Tungnaárkrókur are more or less equal and Sultartangí and Skard comparatively costly.

In Hvítá basin Gullfoss is the most favourable project and in fact the cheapest in both basins with US $ .00212 per kWh. Bláfell is also on the cheaper side with US $ .00268 per kWh, whereas Haukholt is comparatively costly. Generally the bigger projects yield a lower unit price that the smaller, which of course is not surprising.

It is, however, not possible to discuss the sequence of development without knowing the increase in demand which is expected. It is assumed that if one want only to cover the increased domestic demand, one of the smaller projects, like for instance Haukholt, would be ample, although it is one of the more costly projects.

One could visualize Haukholt constructed for the full ultimate installation but with only one unit installed as the first stage. The next stage could be to divert Sandvatn and regulate Hvítárvatn and add one more unit. Before Hvítá is more developed, the Sandá diversion and regulation of Hvítárvatn will have to be carried by the one plant and the power will be costly.

It may also be investigated if stage number two could comprice diversion of Sandá only (plus addition of one unit). The installation will then, before Hvítárvatn is regulated, be relatively large, but for domestic supply a lower load factor must be taken into account.

If greater quantities of power are needed at the first stage of development, Urridafoss may be a suitable plant to start with. One has there also the great advantage that a subsequent regulation in Thjórsá basin will also be to the benefit of Burfell.

It should, however, be mentioned that an ultimate development of Thjórsá involves regulation at Nordlingaalda and/or Storisjór and we feel that especially these sites should be more investigated before any decision is taken as to the ultimate development of the Thjórsá basin. We are afraid that an investigation of the Storisjór site may reveal very difficult conditions both for the dam foundations and possibly also with regard to reservoir leakage.

As stated in the comments to the cost estimates, the cost of transmission lines are not included. The plans for transmission lines are to a great extent depending upon existing lines and on order of development. It is also very difficult to find a formula for distribution of cost of lines between the separate plants. As, however, it has been necessary to make some assumtions in order to evaluate the cost of electrical installations, we have prepared a single line diagram which is shown on drawing no. 430-26.

Where substations at the interconnection of the various lines are shown, the cost of electrical equipment has been included in the cost of the adjacent power plant. As a result an alteration of the transmission line system from the system shown will call for corresponding adjustment to the cost of the electrical installation for some of the power plants.

We have in this report discussed geologic conditions, ice questions ,hydrological investigations and also indicated the necessity of further field (and laboratory) investigations.

As the Icelandic engineers in charge of the field investigations are fully familiar with the methods, we shall not discuss, in detail, further field work.

In addition to the rock stability question in connection with tunnelling and other sub-surface work, we regard the problem of impervious rock (and soil) to be of vital importance both for sub-surface work and for dam foundations and with respect to reservoir leakage. It is assumed that the work in this field will be continued.

The ice problem should be reviewed in light of the present master plan and of subsequent investigations, so that the necessary measures to avoid or reduce the difficulties, can be incorporated.

The information on waterflow available at present is of course incomplete. We feel especially that more information on the run-off in the higher reaches of the basins is required, although it is realized that it will be difficult to obtain information from these areas due to climatic conditions.

Oslo, July 1966

NORENO FOUNDATION

Herman Christiansen

Herman Christiansen
Managing Director

NORCONSULT A/S

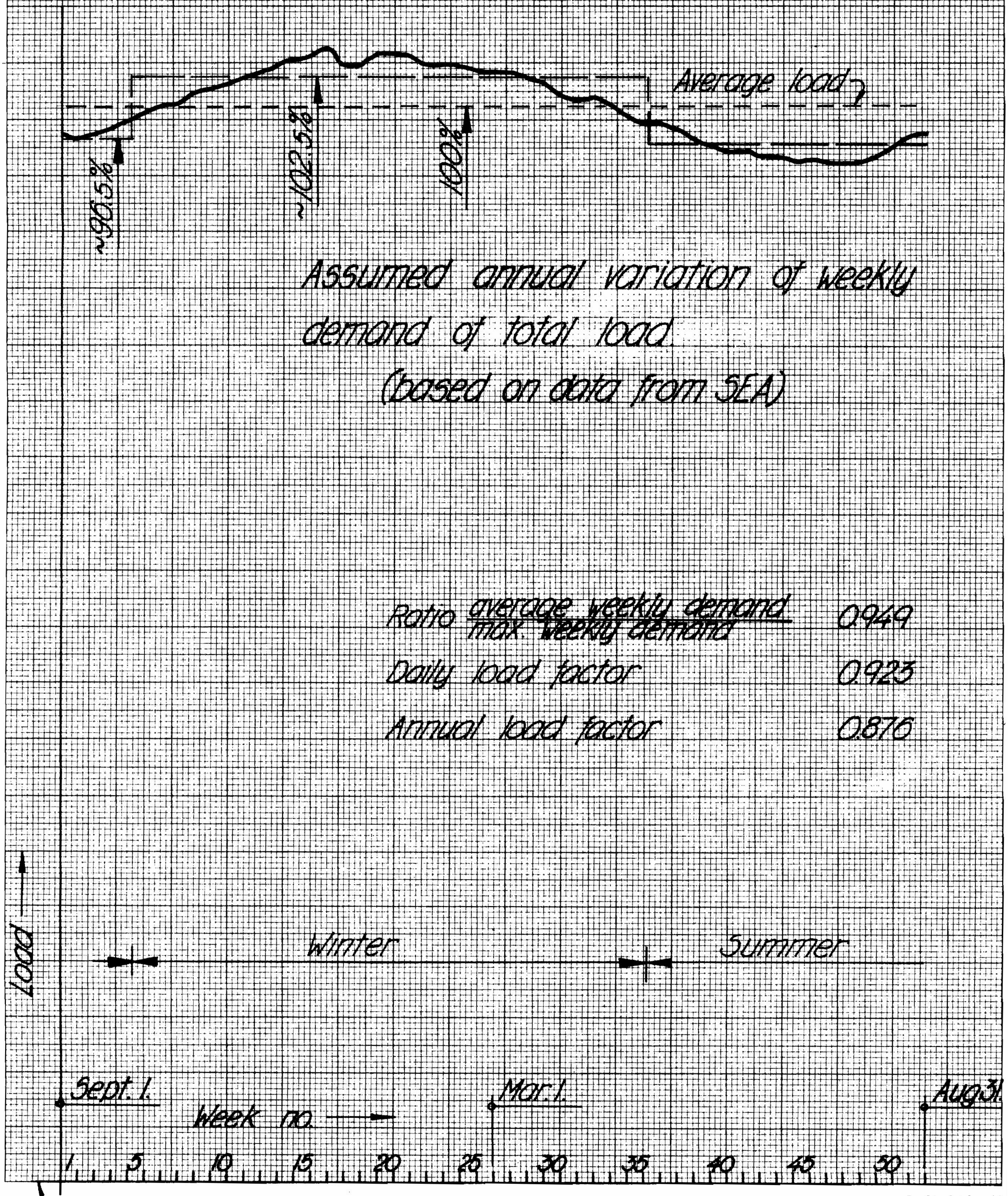
B.A. Berdal

B. A. Berdal
Partner of Norconsult A/S

EXHIBIT 2-1

HVÍTÁ-THJÓRSÁ

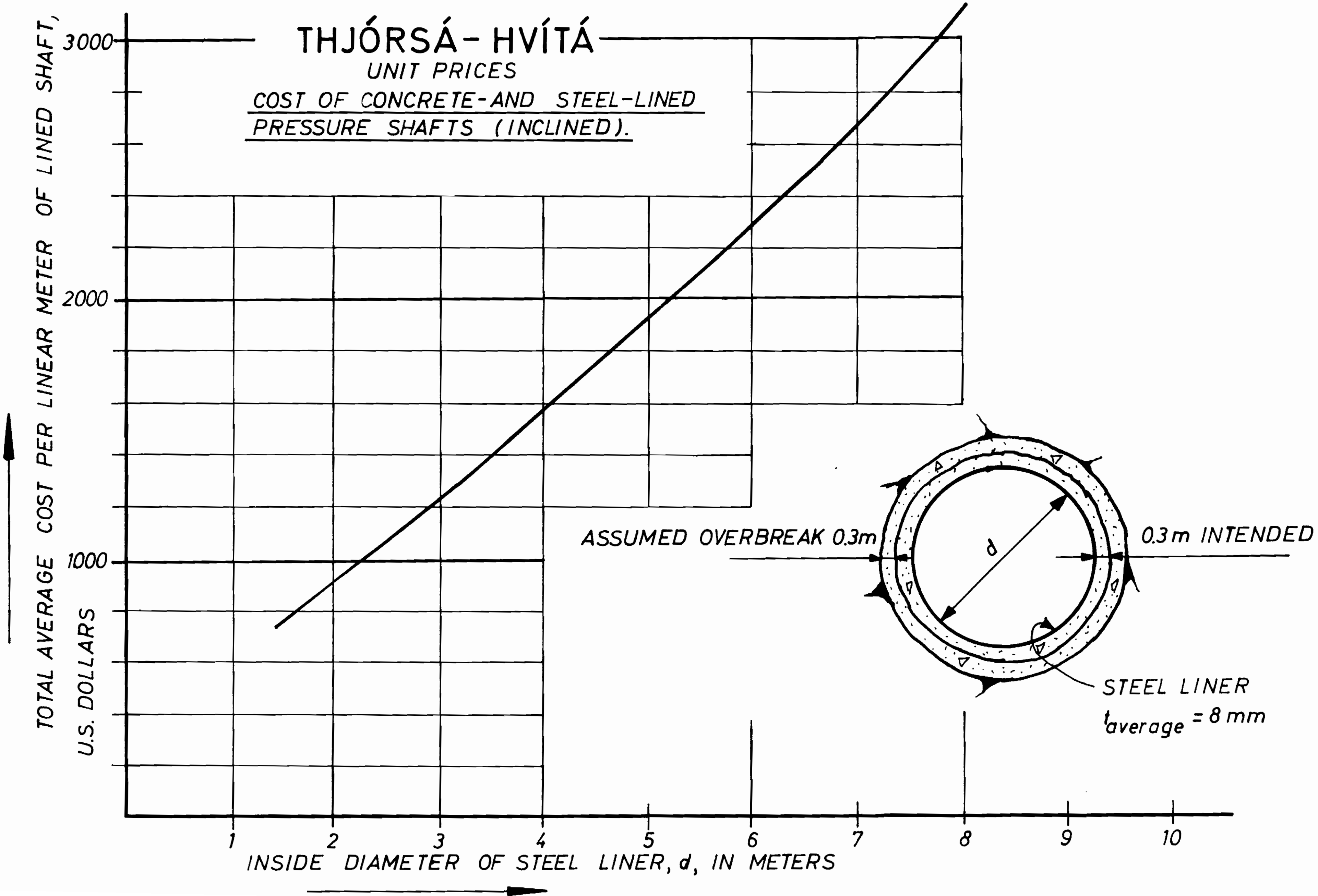
-ICELAND-



Assumed annual variation of weekly demand of total load.
(based on data from SEA)

Ratio $\frac{\text{average weekly demand}}{\text{max. weekly demand}}$	0.949
Daily load factor	0.923
Annual load factor	0.876

EXHIBIT 2-4



THJÓRSÁ - HVÍTÁ

UNIT PRICES

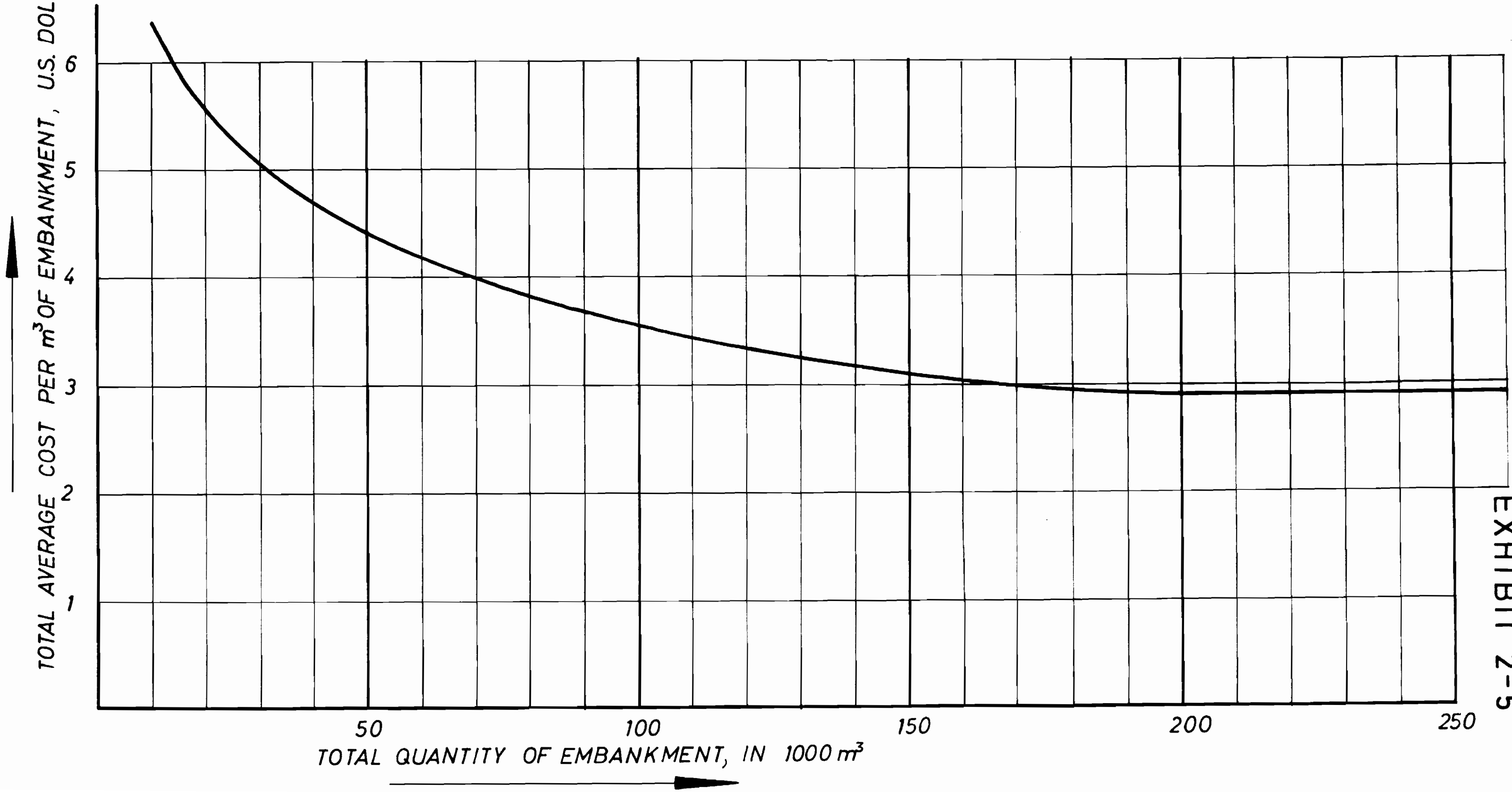
COST OF CONCRETE-AND STEEL-LINED PRESSURE SHAFTS (INCLINED).

EXHIBIT 2-5

THJÓRSÁ - HVÍTÁ

UNIT PRICES

COMPACTED EARTHFILL DAMS.
COST OF EMBANKMENT.



THJÓRSÁ BASIN

Distribution of storage costs in million $:

Each power project charged in proportion to its net head.

"1": Costs distributed between investigated projects.

"2": Costs distributed between "feasible projects" only.

Project		Thórisvatn Cost 9.2		Storisjór Cost 8.1		Langisjór Cost 4.9		Nordlingaalda Cost 18.1		Total	
Name	Net head	1	2	1	2	1	2	1	2	1	2
Bjallar	55	-	-	1.00	-	0.60	-	-	-	1.6	-
Tungnaárkrókur	73	1.60	1.75	1.30	1.65	0.80	1.00	-	-	3.7	4.4
Hrauneyjafoss	102	2.25	2.40	1.85	2.30	1.10	1.40	-	-	5.2	6.1
Budarhals	22.5	0.50	-	0.45	-	0.25	-	-	-	1.2	-
Hvanngiljafoss	24	-	-	-	-	-	-	1.00	-	1.0	-
Dynkur	180	-	-	-	-	-	-	7.70	8.5	7.7	8.5
Sultartangi	23.5	0.50	0.60	0.45	0.50	0.25	0.30	1.00	1.10	2.2	2.5
Burfell	116	2.55	2.80	2.10	2.60	1.30	1.60	4.95	5.40	10.9	12.4
Skard	35	0.80	0.90	0.65	0.80	0.40	0.50	1.55	1.70	3.4	3.9
Budafoss	13	0.30	-	0.20	-	0.15	-	0.55	-	1.2	-
Urridafoss	31	0.70	0.75	0.55	0.70	0.35	0.40	1.30	1.45	2.9	3.3

Exhibit 2 - 6a

Exhibit 2 - 6b

HVÍTÁ BASIN

Distribution of storage costs in million $

Each power project charged in proportion to its net head.
"1": Costs distributed between investigated projects.
"2": Costs distributed between "feasible projects" only.

Project		Hvítárvatn Cost 7.2		Sandvatn Cost 1.0		Total	
Name	Net head	1	2	1	2	1	2
Midnes (Aboti)	44	0.90	-	-	-	0.9	-
Bláfell	119	2.40	3.10	-	-	2.4	3.1
Gullfoss	132	2.70	3.40	0.70	0.80	3.4	4.2
Haukholt	30	0.60	0.80	0.15	0.20	0.80	1.0
Urridafoss Diversion	31	0.65	-	0.15	-	0.8	-
(Hestvatn)	(16)	(0.40)	(0.40)	(0.10)	(0.10)	(0.5)	-

Exhibit 3 - 1

COST OF TWO DIFFERENT STORAGE CAPACITIES AT:

HVÍTÁRVATN
NORDLINGAALDA
STORISJÓR

	HVÍTÁRVATN		NORDLINGAALDA		STORISJÓR	
Normal Max. WL El.	440	435	592	587	620	610
Storage capacity, million m3	1.050	690	1.560	840	825	450
Total cost, million $	10.9	7.2	18.1	12.9	12.1	8.6

EXHIBIT 3-2.

TABLE 3.

	POWER PROJECT	WATERSHED. km.^{2}	AVERAGE ANNUAL RUNOFF. million m.^{3}	AVERAGE FLOW. m^3/s.	DESIGN FLOOD FLOW. m^3/s.	STORAGE VOLUME. million m.^{3}	NORMAL H.W. EL. m.	NORMAL T.W. EL. m.	GROSS HEAD. m.	NET HEAD. m.	Q_{summer} m^3/s.	Q_{winter} m^3/s.	FLOW FOR SIZING OF WATERWAYS. m^3/s.	FLOW FOR INSTALLED CAPACITY. m^3/s.	AVERAGE ANNUAL ENERGY. million kWh.
THJÓRSÁ	TUNGNAÁRKRÓKUR.	3050	4775	152	3000	870 + Lanqisjór	500.0	425.0	75	73	139	153	160	200	785
	HRAUNEYJAFOSS.	3120	4900	155	3000	870 + Lanqisjór	425.0	320.0	105	102	143	155	165	210	1120
	DYNKUR.	2695	4160	132	4000	1750	493.0	305.0	188	180	125	135	140	180	1730
	SULTARTANGI.	6440	9900	314	6000	2620+ Lanqisjór	297	273	24	23.5	295	305	330	420	520
	SKARD.	6840	—	—	—	2620+ Lanqisjór	120.0	80.0	40	36	312	311	340	440	820
	URRIDAFOSS, without diversion.	7200	11730	374	5000	2620+ Lanqisjór	43.5	10.5	33	31	321	315	350	450	725
HVÍTÁ	BLÁFELL.	1660	3200	102	1600	690	385.0	256.0	129	119	86	101	100	130	860
	GULLFOSS.	2530	4790	152	3250	690	243.0	102.0	141	132	129	139	150	190	1310
	HAUKHOLT.	2605	4900	156	3500	690	100.0	69.5	30.5	30.0	133	141	150	190	300

TABLE 4.

	RESERVOIR	WATERSHED. km.^{2}	AVERAGE ANNUAL RUNOFF. million m.^{3}	AVERAGE FLOW. m^3/s.	DESIGN FLOOD FLOW. m^3/s.	STORAGE VOLUME. million m.^{3}	STORAGE AREA AT NORMAL MAX. W.L. km.^{2}	NORMAL MAX. W.L. EL. m.	NORMAL MIN. W.L. EL. m.	2. POWER SUPPLY, COMMUNICATIONS.	3. CIVIL ENGINEERING WORK.	4. MECHANICAL AND ELECTRICAL EQUIPMENT.	5. OWNERS GENERAL EXPENSES.	6. MISCELLANEOUS. CONTINGENCIES.	TOTAL COST.	COST IN U.S.$ PER m^3 OF STORAGE VOLUM.
THJÓRSÁ	LANGISJÓR.	100	190	6	—	in excess of 190	27	—	—	1.1	2.7	0.05	0.65	0.7	5.2	—
	STORISJÓR.	570	1200	38	1200	450	32	610	590	0.6	5.6	0.05	1.2	1.15	8.6	.019
	THÓRISVATN.	1450	1412	45	750	420	70	571	564	0.9	5.8	0.05	1.25	1.2	9.2	.022
	NORDLINGAALDA.	2060	3150	100	3000	1560	185	592	565	0.7	12.3	0.2	2.6	2.3	18.1	.012
HVÍTÁ	HVÍTÁRVATN. (MIDNES)	1230	2400	76	1200	690	65	435	422	0.8	4.4	0.05	1.0	0.95	7.2	.010
	SANDVATN, diversion.	560	1120	36	500	—	—	—	—	0.5	0.3	0	0.1	0.1	1.0	—

COST IN MILLION U.S.$.

EXHIBIT 3-3

TABLE 1: COST OF ENERGY. *STORAGE COSTS DISTRIBUTED BETWEEN INVESTIGATED PROJECTS.*

	PROJECT	THJÓRSÁ											HVÍTÁ								
		BJALLAR	TUNGNAÁRKRÓKUR	HRAUNEYJAFOSS	BUDARHALS	HVANNGILJAFOSS	DYNKUR	SULTARTANGI	HÁIFOSS	SKARD	BUDAFOSS	URRIDAFOSS	HVÍTÁRVATN (MIDNES)	BLÁFELL	GULLFOSS	HAUKHOLT	URRIDAFOSS DIVERSION	HESTVATN ALTERN.	DYNJANDI	BURFELL (THJÓRSÁ)	SUM
COST IN MILLION US.$	1. REGULATION AND STORAGE.	1.6	3.7	5.2	1.15	1.0	7.7	2.2	0	3.4	1.2	2.9	0.9	2.4	3.4	0.8	0.8	(0.5)	0	10.9	
	2. POWER SUPPLY AND COMMUNICATIONS.	0.4	0.3	0.3	0.25	0.8	0.4	0.2	0.5	0.2	0.2	0.1	0.2	0.8	0.2	0.2	0.05	(0.35)	0.2		
	3. CIVIL ENGINEERING WORK.	11.3	9.3	14.7	7.8	5.6	21.3	9.2	9.4	15.8	12.0	6.0	3.2	11.7	13.5	5.0	9.75	(5.0)	1.2		
	4. MECHANICAL AND ELECTRICAL EQUIPMENT.	2.7	4.7	4.6	2.6	1.8	7.2	4.1	1.4	6.1	4.0	5.4	3.5	4.9	6.9	2.8	3.3	(3.15)	1.2		
	5. OWNERS GENERAL EXPENSES.	2.8	2.85	3.9	2.1	1.6	5.7	2.7	2.2	4.4	3.2	2.3	1.0	3.4	4.1	1.6	2.6	(1.7)	0.5		
	6. MISCELLANEOUS. CONTINGENCIES.	2.2	1.85	2.8	1.5	1.2	4.1	1.8	1.8	3.1	2.3	1.7	0.7	2.4	2.7	1.0	1.9	(1.1)	0.3		
	TOTAL COST.	21.0	22.7	31.5	15.4	12.0	46.4	20.2	15.3	33.0	22.9	18.4	9.5	25.6	30.8	11.4	18.4	(11.8)	3.4		
SEASONAL EFFECT VALUES, IN MW.	SUMMER (1.MAY-1.OCT.)		85	122			189	58		94		84		86	143	34				210	1105 (100.0)
	WINTER (1.OCT.-1.MAY)		94	133			204	60		94		82		101	154	36				210	1168 (105.8)
POWER PRODUCTION IN MILLION kWh, TOTAL ANNUAL AVERAGE.		315	785	1120	270	175	1730	520	230	820	300	725	210	860	1310	300	405	(210)	34	1830	10 000
COST OF ENERGY PER kWh IN U.S.$ (9%).		.00600	.00260	.00253	.00513	.00617	.00241	.00350	.00598	.00362	.00686	.00228	.00407	.00268	.00212	.00342	.00409	(00505)	.00900		

TABLE 2: COST OF ENERGY. *STORAGE COSTS DISTRIBUTED BETWEEN "FEASIBLE PROJECTS"[x)] ONLY.*

		BJALLAR	TUNGNAÁRKRÓKUR	HRAUNEYJAFOSS	BUDARHALS	HVANNGILJAFOSS	DYNKUR	SULTARTANGI	HÁIFOSS	SKARD	BUDAFOSS	URRIDAFOSS	HVÍTÁRVATN (MIDNES)	BLÁFELL	GULLFOSS	HAUKHOLT	URRIDAFOSS DIVERSION	HESTVATN ALTERN.	DYNJANDI	BURFELL (THJÓRSÁ)	SUM
MILLION US.$	1. REGULATION AND STORAGE.		4.4	6.1			8.5	2.5		3.9		3.3		3.1	4.2	1.0				12.4	
	2.-6. SUM OF THE ITEMS 2.-6. AS LISTED IN TABLE 1.		19.0	26.3			38.7	18.0		29.6		15.5		23.2	27.4	10.6					
	TOTAL COST.		23.4	32.4			47.2	20.5		33.5		18.8		26.3	31.6	11.6					245.3
	COST OF ENERGY PER kWh IN U.S. $ (9%)		.00268	.00260			.00245	.00355		.00368		.00233		.00275	.00217	.00348					

x) PROJECTS WHERE COST OF ENERGY ACCORDING TO TABLE 1. IS LESS THAN .004 $ /kWh

SURVEY OF THE HVÍTÁ
AND THJÓRSÁ RIVER BASINS
ICELAND

SYNOPSIS OF THE
EXPERT REPORTS.

Prepared by
Mr. E. Wessel
Project Manager

INTRODUCTORY NOTE BY PROJECT MANAGER, MR. ERNST WESSEL

In July 1964 the United Nations, acting as Executing Agency for the United Nations Development Programme (Special Fund), signed an Agreement with the Government of Iceland for the purpose of a pre-investment survey of hydroelectric power development in the Hvítá and Thjórsá River Basins. A Plan of Operation which contains a detailed description of the arrangements for the execution of the Project constitutes the basic Agreement.

The engineering studies according to the provisions of the Plan of Operation concerning expert service were completed in May 1966. The Reports by the experts present the results of reconnaissance, engineering studies and analyses made with the basic aim of assisting in the preparation of the Preliminary Master Plan. A synopsis of these Reports is given below.

Plan of Operation

The concept of a master plan to serve as a guide for the water resources development of a river basin, or even an entire region is well recognized throughout the world, and was the policy of the State Electricity Authority with respect to the Hvítá-Thjórsá River Basins in Southwest Iceland.

The intention of the Special Fund project was to provide the Government with a Preliminary Master Plan for the overall hydroelectric development of the two rivers as far as data would permit. According to the Plan of Operation assistance would be given in the following fields:

a) Ice Hydrology and Studies of Ice Conditions
b) Engineering Geology Studies
c) Earth and Rockfill Dam Construction
d) River Forecasting Studies
e) Design of Hydraulic Laboratory
f) Power System Analysis
g) Final Report including Preliminary Master Plan

The Special Fund project required a professional study of the power resources and selection of the best possible design for individual projects to be integrated into an optimum plan of development for the two basins.

These services may be divided into the following four closely related phases:

A critical study of the preparatory work which has been carried out. It includes a study of all information and basic data available as well as preparing and completing this material for the purpose of the Preliminary Master Plan studies. A plan of development had to be indicated to establish a basis for field investigations.

Visits to the suggested power sites and a surface examination and engineering appraisal of the topographical, geological and hydrological conditions at each site, and of the natural construction materials available in the vicinity thereof.

General investigations and studies required for harnessing the water powers of the two river basins including a general layout and recommended solutions.

Preparing and printing the Final Report including the Preliminary Master Plan. This last phase is covered by the sub-contract work of NORENO Foundation, Oslo. The work comprises an assessment of the various possibilities for the development of the hydroelectric power in the river basins, general layout drawings for selected alternatives and cost estimates.

Delays in the recruitment of expert personnel resulted in the reports of some of the experts not being made available to NORENO. However, steps were taken to see that NORENO received sufficient information and data to enable them to prepare their Final Report.

SYNOPSIS OF THE EXPERTS'REPORTS

a) Ice Hydrology (Messrs. O. Devik and E. Kanavin)

One of the main problems to be solved by the Project is that created by the ice conditions that are in several respects peculiar to Iceland. The development of design to provide the most practicable solution to the severe ice problems in the Thjórsá and Hvítá river basins requires much study. The abnormal ice conditions must be given careful attention and thought in the design.of each project. Special provisions are needed to prevent waterways intakes and turbines as well to be clogged by ice. The magnitude of moving ice-masses and problems associated with the change of physical qualities at different stages of ice production, transportation and accumulation have made research and investigations necessary. The results obtained provided information of basic importance for the project design.

It is generally recognized that surface ice is formed on still or slow moving water by overcooling the top layer. When this sheet ice is formed on the water surface the heat loss is reduced.

Quite different is the formation of ice in a water flow with velocities higher than 0.5 m/s, and with turbulent motion.

Caused by the supercooling of a very thin water film on the water surface a transport takes place of slightly undercooled water, producing on the way immersed ice particles (frazil ice), and bottom ice on the river bed, building ice dams in the rapids and producing an increasing mass of floating sludge ice.

The floating ice masses which are very loose, may be compressed in narrow passages of the river, producing ice bridges, which may be broken and floated down the river. Such ice bridges do have a considerable strength as studies in Thjórsá have shown.

Another effect of the ice production in turbulent rivers is that the water level will rise, partly caused by the formation of a bottom ice layer, partly by the immersed ice particles and the floating sludge ice. The growth of ice dams from the river bed cause thresholds, which raise the water surface, thus forming a staircase. An important effect will further be the growth of rather solid shore ice which will grow as well in thickness as in width along the river beaches.

During a frost period when floating ice masses may encounter ice bridges, some parts will dive under the ice and other parts will be stopped and compressed, thus contributing to a belt of pack ice growing upstream from the ice bridge.

In frost periods of long duration, the pack ice may gradually cover long sections of the river. In the winter 1965-66, such pack ice covers have filled extraordinary long sections. The water is then finding its way under the pack ice, or the flow follows a narrow channel in the ice cover.

Transportation of frazil ice by the water stream under the pack ice cover is a regular process which is well known in Norwegian and Swedish rivers, where such transport may occur over distances of 10-50 km. In such a case there is no supercooling in the water stream.

The type of ice production which has been described above may be exposed to sudden disruption if the slope of the river bed is greater than a certain critical value, which according to observations in Norway and Sweden will be about 2 m/km if the river bed has a comparatively regular shape. In such cases the water velocity will be sufficient to propagate a flood-wave down the river, thereby releasing the water masses which have been stored by ice dams. It will be recognized that practically the whole section from Hvítárvatn to Haukholt has a slope which is steeper than the critical one. The bursting of an ice dam somewhere on this section would have a great probability of producing a step burst, and the same might happen through the action of a short-lived flood. In fact, step bursts are well known in this part of Hvítá.

There are also only few sections of Thjórsá, Tungnaa and Kaldakvísl which have a slope below the critical value. We may especially mention two sections namely the section of Tungnaa from the confluence with Kaldakvísl to the confluence with Thjórsá, and the adjacent section of Thjórsá to the broad river bed below Burfell at Hvassitangi.

Step bursts starting in the region of Hald will generally pass the whole section from Hald to Hvassitangi, and great ice masses will pile up there as a thick pack ice layer, growing upstream in the direction of Tjofafoss, some times even covering this waterfall. It is of importance to notice that these ice masses consist not only of compressed frazil ice and sludge ice, but are mixed with pieces and blocks of solid ice, having come from broken shore ice on the section from Hald to Thjofafoss.

During the 1965-66 winter, on 27.2.66., a step burst started about 1 km downwards of Klofaey, breaking up thick shore ice downstream, leaving multitudes of big ice blocks on the beaches which had been flooded. The step burst was released during cold weather, probably through a minor reduction of the heat loss from the water surface. This experience demonstrates that special provisions are needed to prevent waterways and intakes being clogged by ice.

The expert's Report contains a short survey of the ice production in rapid rivers and how the heat exchange between atmosphere and water surface may be calculated from meteorological observations. Examples are given of calculation of the ice masses which have been accumulated in the Hvassitangi field. The measurement of the deposited ice masses is rather difficult, and there are several sources of error, e.g. the passage of floating frazil ice and sludge ice underneath the pack ice cover. A satisfactory measurement of the increase in ice volume through a certain period has been obtained by using photogrammetric charts of the ice masses at the beginning and the end of the period. This has been done (for March 1965) and the result was in satisfactory accordance with the calculation of the ice production during this period, taking into account that the calculations have the limited accuracy of ± 20% in this case.

A production of e.g. 10 mill. m^3 ice during a month is small in comparison with the water volume which has passed the Thjórsá during the same period, as for instance

389 mill. m^3 at a discharge of 150 m^3/s. The direct loss of water which the ice represents is small, however, the indirect consequences on the discharge are by no means negligible.

It will be seen from the Report and from this summary that the ice problems are connected with different types of ice and ice transportation:

1. Drifting frazil ice and sludge ice
2. Stationary bottom ice and ice dams
3. Growing of shore ice
4. Production of ice bridges and pack ice layers
5. Temporary flood waves with step bursts, causing transportation of ice masses 2, 3 and 4 down the river to accumulation places.

Last, but not least, is the influence of the supercooling of open water to be taken into account.

The general conclusions are as follows:

The rivers Tungnaa and Thjórsá are extremely sensible to the variation of the heat exchange between river surface and the air, especially to the influence of air temperature and wind.

During frost periods the intensive ice production and the formation of local ice dams will cause temporary local increase of the water level. Thereby considerable water masses may be withheld and cause a corresponding reduction of the discharge further down in the river, lasting during the frost period. The only positive precaution to reduce this effect will be to reduce the open areas, which are the sources of ice productions.

The nature of the ice production has been treated in detail in the Report, and numerous photos illustrate the direct influence on the water flow. The fundamental importance of the supercooling associated with the formation of frazil ice and bottom ice, has emphasized the necessity of avoiding supercooled water and active frazil ice near the constructions of a plant. Formation of an ice cover on an intake reservoir must be promoted. The formation of ice bridges, associated with the accumulation of pack-ice masses produces a type of ice having a shear strength which may cause much greater practical difficulties than previously assumed. To avoid such complication the amount of drifting frazil ice and sludge ice must be reduced. The remedy will be to reduce the open areas and to establish reservoirs where floating ice may be retained. Such reservoirs will be necessary in order to prevent the passage of step bursts.

The analysis of the different ice problems points out the possibilities which exist to establish a control of the ice problem. The provisions recommended are:

1. To reduce the open water surface areas.
2. To establish reservoirs which can store floating ice, prevent step bursts and prevent the formation of ice bridges at critical places.
3. To secure slow water flow and promote the formation of an ice cover at the intake of a power plant.
4. The designs of intake structures must be adequate to assure passage of ice reaching the intake area.

As the rivers become more completely developed, approaching a series of ponds, which favour sheet-ice formation, ice troubles will tend to diminish.

b) Engineering Geology (Mr. A. Nicol)

(See exhibit 1)

Iceland is made up of volcanic products which are mainly of basaltic composition. The volcanism forming the country has proceeded since the earliest Tertiary age. The oldest rock is found near the east and northwest coast whereas the younger rock generally is located nearer the present volcanic belt of Iceland. This belt confined to two main zones which are connected in central Iceland near Hofsjøkull. The western zone is approximately 20-30 km wide and extends from the cape Reykjanes to the north side of the glacier Langjøkull. The eastern volcanic zone is about 30-50 km wide and extends from Vestmannaeyjar of the south cost to Melrakkaslétta in the north. The trend of the eruption fissures in both zones is from the north-east to the south-west except in the northern part of the eastern zone where it is north-south. Within the volcanic zones the rock is of late Pleistocene age and adjacent to and between of gradually higher Pleistocene age and late Tertiary age.

The volcanic products was during Tertiary mainly lava flows, but since Pleistocene much of the volcanic products are tuffs, breccias and pillow lavas, which have been formed through subglacial eruptions during several glacials in Pleistocene. These difference in products is also reflected in land forms. In Tertiary the volcanisms seemed to form lava plateau with small relief. But the subglacial volcanism forms ridges, fissure eruptions and table mountains in central eruptions. The ridges and the lower part of the table mountains, formed subglacially, consist of tuff, breccia and pillow lava, but the latter are capped by usual basalt lava flows which were formed when the Table mountain was high enough to produce through the glacier. Interglacial lava-flows tend to be confined to natural deepenings between the high ridges and Table mountains. There may also be accumulated sediments as the interglacial rivers were confined to these troughs. The drainage system is therefore parallel to the trend of the eruptions fissures and is mostly determined by constructive landforms.

The Thjórsá and Hvítá drainage basins are situated in this geologically young part of Iceland mainly between the two volcanic zones including the western and eastern margins. Tungnaá the main tributary river of Thjórsá is mainly within the eastern volcanic zone and the western tributary rivers of the river Hvítá are in the western volcanic zone. As a general rule of thumb it can be said that the older the rock formations are the farther away they are situated from the volcanic zones. The age of rock is of much importance when considering its engineering qualities. Permeability of all rock units decreases with age, and induration of móberg increases with growing age. In general it may be assumed that the older the rock the better the engineering geological properties.

On the engineering geological maps 11 units are marked. Many of these units are in reality the same type of material with difference only in age and consequently in engineering characteristics.

Unit 1, Recent Alluvium, and Unit 4, Fini-Glacial Sediments, as well as Unit 7, Sedimentary Rock, consist of the same material with only general difference in cementation due to age. Recent Alluvium is quite unconsolidated, Finiglacial Sediments have incipient induration, and sedimentary Rock is a real indurated rock. The source material for all these units are volcanic rocks and volcanic ash and it resembles therefore much the next group. The difference being mainly sorting and usually denser packing than in Móberg of similar age.

Unit 2, volcanic Ash, as well as Unit 5 and Unit 6 are Móberg of increasing age respectively. Unit 2 is quite unconsolidated. It corresponds to the Tuff in Móberg. Otherwise Móberg can be both Tuff, Breccia and Pillow Lavas and most commonly a mixture of all these which grade into one another without any sharp limits. But in most cases some sort of Tuff is the matrix, into which all the basalt fragments in the Breccia as well as the pillows of pillow lava, are inbedded. The induration of the tuff is the most important engineering property. In the Late Pleistocene Móberg this induration is usually not good, but better in the Early and Middle Pleistocene Móberg, and the better the older the Móberg is.

The units of basalt lava flows are unit 3, Post Glacial Lava Flows, as well as unit 8 and 9 which are correspondingly older. The difference concerns mainly the permeability of these rocks and the consolidation of the interbeds which belongs to them. These qualities are the same as in sedimentary units of the similar age. Unit 10 is Andesite and can in most respects be grouped with basalt of similar age.

Rhyolite, Unit 11, is highly heterogenous, but as fresh rock usually adequate for most engineering purposes. Commonly, however, it is much hydrothermally altered and in extreme cases it may result in alteration of the main part of the rock to clay substance.

Nordlingaalda dam site is situated on moraine which cover unit 8, and which is much brecciated due to influence from water. Móberg hills, probably unit 6, are also in the vicinity. A special problem is the high artesian pressure at the damsite indicated by springs through faults in the basalt. Hvanngiljafoss site is underlain by well cemented unit 7.

Kaldakvísl damsite at Thorisos consists of unit 10, but the Thorisos dam would be situated on unit 3, 6 and 10 capped by moraine.

The tunnel Thorisvatn-Kaldakvísl would probably pass through unit 10 at Thorisvatn, but elsewhere mainly through unit 6. Near Kaldakvísl it might enter unit 8.

At the lower damsite on Kaldakvísl unit 8 probably form the rocks, but it could also be unit 5 and 6.

The tunnel from Kaldakvísl to Thjorsa at Dynkur would probably pass through unit 6 and possibly through unit 8 at the Kaldakvísl entrance and unit 9 at the Dynkur end.

The Dynkur dam would be underlain by unit 9. The tunnel from Dynkur to below Gljúfurleitarfoss would pass unit 9 near Dynkur. Some part of it would enter unit 6, but the powerhouse at Gljúfurleitarfoss would be located in unit 9 which underlies the Móberg of unit 6.

The proposed structures at Langisjór will be situated on unit 5. This will also be the case for the dam construction at Snjóalda which besides will encounter thick layers of Alluvium in the river channel.

Tungnaárkrókur and Hrauneyjarfoss sites have identical geological condition with unit 3 on the left bank constituting the main foundations for the dams, while unit 5 on the right bank will make the tunnelling rock.

Budarháls dam site has unit 3 on one side and unit 9 on the right bank where tunnelling is proposed.

All structures for the Sultartangi project would be founded on unit 3. Some part of the excavations would, however, be unit 1.

At Skard the dam would be founded on unit 3, but tunnels are proposed in unit 9 covered by unit 3.

At Urridafoss all main structures would be founded on unit 9. Adjacent to the right bank is unit 3 which forms the bedrock. The Hvítá diversion would mainly pass unit 3, but the dam in Hvítá at Hestfjall would be founded on unit 3 and 5.

The Ábóti damsite in Hvítá is underlain by unit 9 on the highest part and by units 6 and 8 elsewhere.

Underground structures will probably be excavated in unit 9. Bláfell Hvítá dam would be founded on unit 6,all other dams and dikes in connection with this project belong to unit 9. Underground structures would either be excavated in unit 6 or 9.

At the Tungufell dam site and along the headrace tunnel the rock consists of unit 9. Powerhouse and tailrace would most likely be located in unit 6. Haukholt dam would be founded on units 9 and 10.

Permeability of the rock units is of two kinds, different for the bedded basalt formation and for the bulky Móberg formations. In the bedded basalt the permeability is much higher horizontally along contacts than vertically through the layers. The horizontal permeability for the Postglacial Lavas is very high. For Early and Middle Pleistocene basalt the permeability should not cause problems either for dam constructions or underground excavation. The permeability of the Móberg is more uniform in horizontal and vertical direction. Young Móberg is usually less permeable than the horizontal permeability of Postglacial lavas, but nevertheless highly permeable. In old Móberg the permeability should not be a problem. Generally the rock-units are adequate as foundation support for dams of moderate heights. At some places some groundwater problem might be encountered.

Tunnelling is difficult in young Móberg both because of lack of cementation and due to inflow of water if below the groundwatertable. These conditions become gradually better with increasing age. In basalt lavas strength of rock is adequate for tunnelling, but due to interbeds and enormous inflow of water below the groundwater table Postglacial Lavas may be almost impossible for economic tunnelling. The Early and Middle Pleistocene basalt is on the other hand excellent tunnelling rock.

c) Earth and Rockfill Dam Construction (Mr. V. Vutsel)

Among Icelandic natural peculiarities bearing upon the choice of type and design of dams the following may be enumerated: seismic conditions, relatively high precipitation and presence of volcanic rocks in foundations of dams.

The design value of seismic acceleration in Hvítá-Thjórsá river basins is taken as 0.1 g. An average annual precipitation is within the limits of 1000-2000 mm. Volcanic formations are mainly represented by postglacial basalt lava flows, palagonite tuffs and breccias and interglacial lava flows. Rather often the flows are interbedded with sedimentary interbeds. Post-glacial lava is characterized by high permeability especially in horizontal direction. The older rocks are often covered by glacial moraines.

Rivers run with considerable falls cutting deeply into streambed bedrocks and there are numerous waterfalls and rapids on them. Sedimentary intercalations intermittent with volcanic rocks, are exposed at bank slopes as a result of deep scouring. These intercalations are composed of conglomerate and sandstone. The contacts are frequently highly permeable and serve as the path to spring issues. The presence of sedimentary intercalations between lava flows may explain the less vertical permeability of lava flows when compared with horizontal one.

The Report gives recommendations on choice of type and design of dams in Hvítá and Thjórsá rivers and their tributaries.

Possible dam alternatives were considered in each case taking into account materials available in the vicinity of a site as well as amount of borrow pit materials and materials excavated from canals. However, in some cases only insufficient data were available on local materials, their general qualities and the approximate volumes of deposits.

Some additional design work has been done on other constructions closely related to dams (i.e. spillways, canals etc.) in order to define volumes of borrow pit materials that might be used for the body of a dam. After calculating volumes of construction work and costs of possible dam alternatives the most economical solutions were chosen. The natural conditions as well as methods of carrying out construction works were considered.

Appraisals are given for the following projects:

In Hvítá river
- Hvítarvatn
- Gullfoss

In Thjórsá river
- Nordlingaalda
- Hvanngiljafoss
- Dynkur
- Skard
- Urridafoss

In Thjórsá tributaries
- Thorisvatn (dams on Thorisos and Kaldakvísl rivers)
- Tungnaárkrókur
- Hrauneyjafoss
- Budahals
- Sultartangi (At confluence of the Thjórsá and Tungnaá rivers)

Rock-fill and earth dam alternatives were considered depending on the availability of construction materials in the vicinity of dam sites. When dam heights were some 10-15 meters maximum concrete gravity types may be advantageous.

Cost of earth dams turned up to be higher than that of rock-fill ones since moraine is usually so strongly indurated that it may be costly to excavate and requires special procedures to place. Besides moraine fill compaction is more expensive than rock-fill compaction.

Rock-fill dams with reinforced concrete membrane are recommended for project when no suitable core material was suggested (e.g. Skard dam). However, in view of the small height of Hrauneyjafoss dam a concrete gravity dam was planned here.

For all other projects rock-fill construction with sloping or vertical core appear to be the most suitable and economical solution.

The former is probably also the safest structure considering seismic conditions. Dams with vertical core are recommended in the cases when dams are divided by spillways and it becomes necessary to secure the junction of spillway and abutments.

Location of spillways in the riverbed is caused by the necessity to pass the flow during construction period through an unfinished spillway. Excessively high discharge of flow may not be diverted through tunnels economically.

Seismic conditions were taken into account in rock-fill dam-design by the following measures:

Increasing dam's crest up to 6 meters. Making slopes more flat by some 10%. Thickening inverted filters near the core of the dam.

Depending on the height of the dam and foundation rocks it is recommended to make upstream slope approximately 1:2.0 to 1:2.3 and downstram slope 1:1.5 to 1:1.6. Such angles of slopes would certainly be less than angles of natural slopes of the rock-fill. Therefore berms on the slopes are required during construction period. Incline of an upstream face of a core is equal to an angle of natural slope of rock-fill which is approximately estimated at 37.5°.

Stone for the rock-fill of the majority of dams will be excavated from tunnels and canals. In case borrow-pit materials will not be sufficient quarry supply is required. It may be reasonable, however, in the latter case to consider rock and earth section type using loose materials available at site. The cost of excavation of such materials would in many cases be less costly than excavation of rock from a special quarry. Such possibility may exist for Hvítárvatn Project where moraine deposits can be found in the vicinity of the dam site. This type of materials is present in the construction area of some other dams too and can be used not only for filters, but also as fill materials in the central part of dams.

Moraine available almost at all dam sites can be used as core material. Dams of several projects are founded on adequate impermeable glacial moraine. To prevent washing of fines in such foundations inverted filters are established along contact zones of rock-fill.

The Report gives recommendations on dams foundation treatment. In most cases the proposed measures consist of constructing either ground cut-off or grouting curtain. Of great interest are the investigations reported by Haukur Tomasson on sediment load and seepage through postglacial lavas. Though more research and investigation of lava foundations for each particular object is required it is evident from the tests made that the sediment load of the rivers will tend to seal leakage from the reservoirs. Accordingly it was considered possible to recommend the construction of scattered grouting curtains or blankets to create favourable conditions for selfsealing of lava foundations. It appears quite safe to give the rivers opportunity to seal the leakage which might be very expensive to solve in another manner.

The construction of trench cut off is considered to be sufficient at low bank sections. The depth of a cut off is defined by allowable gradient of contact filtration.

Almost in all cases stone for rock-fill will be excavated from tunnels and canals. Such stone is usually not large. To avoid settlement of rock-fill the percent content of smallsize stone should be limited. Dams in Hvítá and Thjórsá rivers have relatively small heights along the greater part of their length and consequently it appears that truck transport would be sufficient for desired rock-fill compaction. Vibrocompacting will be required only for core materials. Watering is recommended when dumping rock-fill on the slope of a layer. Dumping of a core and filters should be carried out in thinner layers i.e. 0.5-1.0 meter with compaction up to 0.9 of the maximum value when using the modified Proctor compaction.

The sloped core allows dumping of rockfill independently of placing filters and a core that can be done only under favourable weather conditions. This feature is of considerable importance for Icelandic climatic conditions.

The Report contains recommendations on dumping of a moraine core of a sloping as well as vertical one by "wet" method which is extensively used in the Soviet dam construction practice. This method makes it possible according to the Report to carry out dumping under any weather conditions (heavy precipitation and frost).

Cost estimates for the 12 above-mentioned projects include direct dam costs, costs of spillways and appurtenant equipment as well as foundation treatment costs.

Unit costs are based on Icelandic pricelevel 1965. However, some uncertainty exists and the cost estimates should be regarded as preliminary only. Taxes and duties are not included.

The Report also contains recommendations on further research and directions of design work of general character and for particular objects based on the Soviet and foreign experience for dam designing and construction in conditions similar to that of Iceland.

d) <u>River Forecasting</u> (Mr. J. Prochazka)

As stated in the SEA report by S. Rist and J. Bjørnsson the drainage area of the Thjórsá and Hvítá river basins may be divided into three different types. Each has a runoff characteristic of its own. Depending principally on the sources and nature of the water supply the rivers are designated glacial, linda and draga.

The flow of the glacial rivers varies greatly. It increases in May-June then suddenly decreases in September and tends to be very low all throughout the winter.

Linda rivers are found in the permeable rock formations and maintain a fairly uniform discharge throughout the year.

Draga, the third type of river, receives the water from normal surface. Their discharge is influenced of natural valley storage, but depends mainly on the precipitation within a few proceeding weeks. The water temperatures varies with the airtemperature and discharge is reduced quickly when the air temperature falls below freezing.

By harnessing the power resources, the main part of the glacial run-off available during the summer season, would be retained in the great storage reservoirs for production of energy during the winter.

As a matter of fact the economic use of hydro is governed by the water level in the reservoirs and the expected river flows in future. Consideration must be given both to securing sufficient storage content for the energy demands during the low water period, and to drawing down the reservoir to catch flood water for building up the total generation.

Among the many factors involved in such planning of reservoir operation, forecasting may be of great importance. The better the prophecies made, the more closely the reservoirs can be operated to an economic optimum.

The variable time lag of discharge with respect to precipitation must be kept in mind in the preparation of a forecast. There is an enormous reservoir for absorbing rainfall in the permeable rocks of the two river basins. The water level in this reservoir can be approximately measured by weighting the amount of rainfall in the preceeding months. Thus relations exist between rainfall in the past months and the actual runoff, in particular where linda rivers contribute to the flow.

Especially during winter seasons the condition of the soil is of great significance as much of the precipitation is retained as snow and no melting of the glaciers takes place. The discharge from the subsurface is then an essential part of the runoff and consequently long term forecast can be determined more accurately during the winter.

The winter season is also the most critical one regarding power and energy yields. Due to these facts the main stress has been laid on winter runoff forecasting.

The forecast of waterflows is generally a problem of mathematical statistics which requires the seeking of correlations between the expected runoff on the one hand and historical precipitation, temperature and runoff on the other hand. Mathematical models may be used in connection with an electronic device. The mathematical expression of the flows must then take into account the present flow and its first and second derived functions, which determine the origin of the forecast. However, the errors increase rapidly with time except where subsurface discharge is concerned.

For illustrating purposes and for long term forecast graphical methods are quite suitable because they are easy to understand and simple to apply. Moreover, even if they are abandoned after a couple of years or so, the time spent on adjusting them will not be wasted as the curves can be used for checking exploitation.

Two graphical methods are illustrated in detail in the Report. One of the presented methods uses the discharge records only, whilst the second is based on meteorological and hydrological data as well.

The first method is based on the relation between the discharge from 1 July until the moment of forecast, and the successive winter discharge through April The couples of corresponding values were plotted, moving the moment of forecast from September through February. The curve connecting the lowest values of plotted winter discharges represents the most unfavourable observed relation between historical runoff and the expected flow during the remaining winter period.

This curve is therefore designated "the guaranteed discharge forecast".

The method is demonstrated by two examples from the Hvítá River basin. Good results were obtained, though the correlation between historical and future flows for long term forecast mainly depends on the amount of groundwater release into the river. Much better results are obtained in linda rivers than in draga rivers.

The second method is based on further graphical analysis in order to develop relations between precipitation, temperature and runoff. The studies carried out show that as soon as the number of parameters increase, the number of tests required in order to discover a certain relation also increase. Moreover, one may long be in doubt as to whether a valid relation has been rached.

The nature of the available data did not allow detailed investigations. As a general rule, however, the runoff in the anticedent period and the rainfall and runoff relation may be considered as the most important factors for obtaining an acceptable score.

According to the report precipitation and degree-days for the historical period as well as estimated values for the forecasting period may be helpfull in picturing the future flow.

Details concerning precipitation distribution, temperature gradient, altitude transformation of degree-days, and other noteworthy topics are discussed in the Report. Many illustrating exhibits are attached.

The establishment of meteorological stations in order to collect a sufficient amount of data for more precise forecast is recommended. Eight to fourteen stations are proposed equipped for recording temperature and rainfall, mainly in the higher parts of the river basins. Additional meteorological and hydrological stations should be established at all projects where operators will be stationed and beginning with initiation of construction. Snow measurement courses are not recommended to be carried out in a larger extent.

It is realized that it is impossible to work out results to a degree of accuracy greater than can be borne by the nature of the basic data. A considerable amount of additional meteorological and hydrological records are required to form the basis for more precise forecasting.

However, the magnitude of the benefit, which would result from better operating programme by means of forecast, calls for the most carefull attention of this question. The main task of the Report was to examine, analyse, classify and make use of the data available in order to establish estimates of flow volumes in advance. The theory has only been outlined to draw attention to the problems and demonstrate its usefulness. This is due to the fact that the subject is very extensive and a detailed treatment would cause the Report to exceed its bounds. It should also be realized that the full significance of forecasting can be grasped only when its applications are studied. This point of view underlies the use of illustrating graphical methods without advanced mathematical techniques.

e) Hydraulic Laboratory (Mr. S. Angelin)

Engineering hydraulics is not an exact science. Therefore experiments in the hydraulic laboratory has become one of the most useful resources in applied engineering hydraulics. Very often the hydraulic engineer meets problems which can not be solved by theory. He is thus forced to secure additional information by experiments.

It is quite clear that a competent designer would not take any risks of serious damage to such important structures that are involved in power plant development. Neither would he consciously suggest a design that could give future operation trouble.

Today, the hydraulic laboratory is a tool to ensure adequate, safe structures which are economical and represent the best engineering design.

The hydraulic laboratory in Iceland was originally planned in 1963, but withheld until it was taken up again in 1965 in econnection with the Special Fund Project.

A review of the plans was undertaken showing that some adjustment were necessary. A redesign was made by the United Nations expert in close cooperation with the State Electricity Authority, the consulting civil engineer and the architect. An estimate of construction costs was made in August 1965 showing that the cost would considerably exceed the amount mentioned in the Plan of Operation.

In view of this the Government decided to modify the plans in such a way that the laboratory could be built in stages. Somewhat lesser facilities than designed would be sufficient as an initial stage.

It was therefore agreed that the United Nations expert should modify his design according to the initial requirements.

Though the laboratory, planned for construction in the summer 1966, will be a smaller institution with a limited equipment, it will nevertheless be well suited to meet the immediate demand of hydraulic model studies. The first stage can easily be developed into a second stage wherein the size will be about doubled.

There are two requirements which must be met for the efficient operation of a hydraulic laboratory: adequate facilities and a qualified staff. The planning of the laboratory is based on analysis of requirements to be met. An exact prediction cannot be made because needs must always be tempered by finances, established priorities for developments as well as by the availability of trained manpower. The report indicates, however, the predominant types of problems which will be encountered.

It is presumed that the laboratory in Iceland in the first stage of development will not have sufficient experienced technical staff or laboratory facilities to carry out model tests for the largest and most difficult projects that can arise.

The general plan presented for development of the hydraulic laboratory is based on this assumption, but the plan is broad enough to permit flexibility to a great extent.

First of all power developments can be dealt with effectively by the new hydraulic laboratory at Reykjavík. Model studies of spillways, outlet works regulating works, measuring devices and the like are very necessary for the Master Plan developments and are among the most urgent needs. Consideration has also been given to facilities and equipment which can handle models dealing with ice-problems, river control, channels, diversion works and sediment aspects of development including erosion control structures. Closed-conduit studies of special components or equipment, where pressure distribution, hydraulic load, risk of vibration etc. is of decisive importance, have been regarded as well.

For Power plants it is often desirable to make a survey model in which the general layout can be studied. Different alternatives of intake spillway canals etc. can be compared and the best solution selected. Precaution for discharging ice, a suitable layout of energy dissipators, excavations, protecting walls and similar structures can also be studied in such a model. A scale 1:80 or 1:100 would usually be sufficient for a model of a plant of the Thjórsá and Hvítá rivers development.

For the more detailed designs, scale 1:40 or 1:50 usually is wanted. Practically all the main design problems, which are connected with flow problems can ordinarily be solved in models of this scale.

However, special components or parts of a plant may need to be studied carefully in an even still larger scale.

Iceland has a great number of harbours and the design of new ones as well as the demand for improving conditions in the existing harbours would need model tests. The hydraulic laboratory would also make it possible to study smaller projects in this domain.

In recent years testing of new equipment for seafishing has been carried out with good results in Norway and other countries. It would undoubtedly be of great advantage to be able to make such modeltests in Iceland and thereby contribute to the important trade of fishery.

Current problems connected with the great amount of hot water which is pumped from the underground may also be among the tasks which may be analysed with benefit in the laboratory.

A laboratory planned to cope with all problems which may arise in the field of hydraulics would be virtually impossible to design and construct. Even if this could be done, little would be gained because there is only a remote possibility of a need for the simultaneous study of many diversified problems. A flexible base which can readily be modified and expanded as needs arise has been preferred. Thus, it is avoided that major divisions of the laboratory would lie idle a great part of time initially. In specifying the measuring equipment, the water system, model construction, equipment and office rooms simplicity has been sought to the maximum extent possible.

The construction cost of the building is estimated to 3.3 million Isl. kronurs for the first stage. Additional 1.15 million Isl. kronurs for equipment gives a total cost of 4.45 million Isl. kronurs for the same stage.

The Report deals in one chapter with organization management and staff. How good the available laboratory ever may be, it will not be able to solve its important task if technical staff has not the necessary qualifications. On the other hand if the laboratory cannot offer interesting studies it will not be able to obtain and keep the qualified engineers it needs.

Although Icelandic engineers are aware that hydraulic models provide a very useful tool in the solution of design problems perhaps they do not realize the full potential of this aid in applied hydraulics. This is not unusual. Continued use of hydraulic models over a period of time increases confidence in the solutions obtained. This experience, coupled with increased familiarity of operation, leads to much wider use of models.

The laboratory is erected by the State Electricity Authority and will be managed by this authority at least for the first years. The laboratory could then, for purposes of supervision and reporting be placed under the chief of the water power development section. He is in a position to create a collaboration between the laboratory and other sections of the organization when needed. He should be capable of establishing priorities and would keep continuous contact with other companies and authorities from which the laboratory can get commissions.

General information of the practical procedure to be followed in model construction is also given in the Report. The reason for this is that the SEA-staff has little experience in the field of hydraulic model tests. However, theories and similarity laws that can be found in litterature are not treated. Finally the Report sums up the conclusions distributed throughout the text. Drawings showing the design of the hydraulic laboratory are attached.

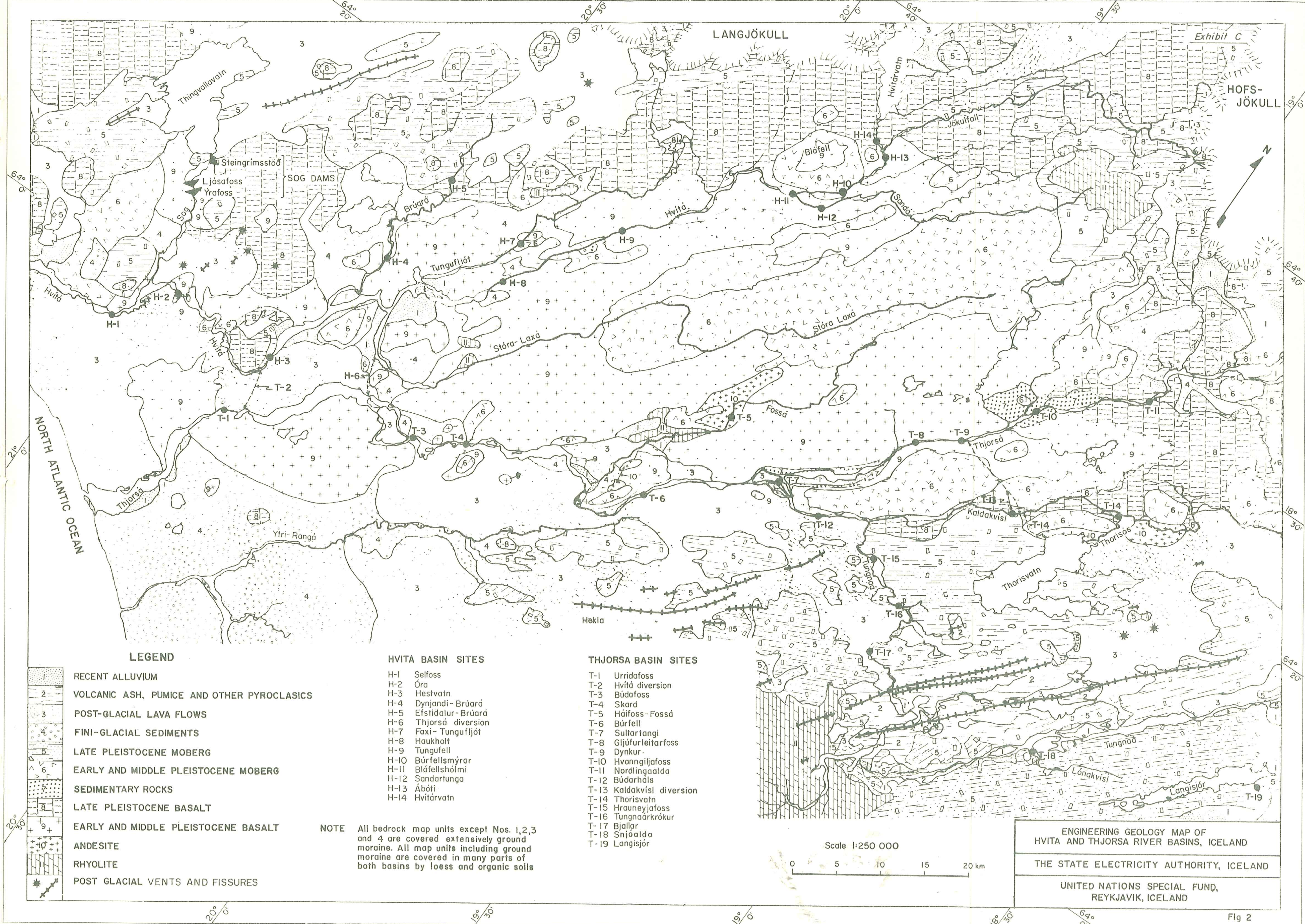
f) Power System Analyses (Prof. V. Hveding)

Professor V. Hveding, of A/S NORCONSULT, Oslo, working under a contract between UNSF and NORENO Foundation (contr. no. CON 78/65 amendment No. 2 of April 29th, 1966) has just started lectures in Iceland on methodology to Icelandic counterpart personnel, at the time this summary report is being written (May 1966). A separate report by Professor Hveding will be given upon conclusion of his studies, but his program is briefly as follows:

To arrive at optimal values of main design (or strategic parameters, such as storage volume), Prof. Hveding proposes a method involving simulation over an extended period of the economic operation of the combined power system, once for each plausible set of design parameters. The optimum (i.e. most favourable) set is then selected by systematically comparing the results obtained in terms of net economic output (value of power output over the period less real costs, including f.i. fuel used for supplementary steam power, as well as national costs attributed to possible rationing or curtailment of power). Prior to each simulation procedure, optimal procedures of operation (tactical operation rules) are established in terms of marginal values of stored energy as a function of time of the year and actual storage. During the (simulated) operation, storage will then be applied, withheld or replenished according the (simulated) storage position by adjusting power output so that the marginal value of a unit of output matches marginal value of a unit of storage. A pre-established scale of marginal values of output, at all levels of output and all times of the year, governs the whole system and is used for measuring the value of output. All relevant limitations (physical, in storage and power station capacities, as well as economic, such as demand limits) are embodied in the model.

The Icelandic counterpart staff are working out the computer programs needed, under guidance of Prof. Hveding. Prof. Hveding will return to Iceland first to discuss preliminary results as soon as they become available, and then, after possible supplementary runs have been carried out, to discuss and analyse final results.

Exhibit C



LEGEND

1	RECENT ALLUVIUM
2	VOLCANIC ASH, PUMICE AND OTHER PYROCLASICS
3	POST-GLACIAL LAVA FLOWS
4	FINI-GLACIAL SEDIMENTS
5	LATE PLEISTOCENE MOBERG
6	EARLY AND MIDDLE PLEISTOCENE MOBERG
7	SEDIMENTARY ROCKS
8	LATE PLEISTOCENE BASALT
9	EARLY AND MIDDLE PLEISTOCENE BASALT
10	ANDESITE
11	RHYOLITE
✱	POST GLACIAL VENTS AND FISSURES

HVITA BASIN SITES

H-1	Selfoss
H-2	Óra
H-3	Hestvatn
H-4	Dynjandi-Brúará
H-5	Efstidalur-Brúará
H-6	Thjorsá diversion
H-7	Faxi-Tungufljót
H-8	Haukholt
H-9	Tungufell
H-10	Búrfellsmýrar
H-11	Bláfellshólmi
H-12	Sandartunga
H-13	Ábóti
H-14	Hvítárvatn

NOTE All bedrock map units except Nos. 1,2,3 and 4 are covered extensively ground moraine. All map units including ground moraine are covered in many parts of both basins by loess and organic soils

THJORSA BASIN SITES

T-1	Urridafoss
T-2	Hvítá diversion
T-3	Búdafoss
T-4	Skard
T-5	Háifoss-Fossá
T-6	Búrfell
T-7	Sultartangi
T-8	Gljúfurleitarfoss
T-9	Dynkur
T-10	Hvanngiljafoss
T-11	Nordlingaalda
T-12	Búdarháls
T-13	Kaldakvísl diversion
T-14	Thorisvatn
T-15	Hrauneyjafoss
T-16	Tungnaárkrókur
T-17	Bjallar
T-18	Snjóalda
T-19	Langisjór

ENGINEERING GEOLOGY MAP OF
HVITA AND THJORSA RIVER BASINS, ICELAND

THE STATE ELECTRICITY AUTHORITY, ICELAND

UNITED NATIONS SPECIAL FUND,
REYKJAVIK, ICELAND

Fig 2