PRELIMINARY APPRAISALS OF SOME POTENTIAL HYDRO-ELECTRIC POWER DEVELOPMENTS IN THE ÞJÓRSÁ AND HVÍTÁ RIVER SYSTEMS, SOUTHERN ICELAND

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The State Electricity Authority
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C O N T E N T S

List of Abbreviations

kl	=	kilolitre (= 1 cu metre)
Gl	=	gigalitre (= 10^9 litres = 10^6 cu metres)
s	=	second
h	=	hour
a	=	year
kW	=	kilowatt
kWh	=	kilowatthour
GWh	=	gigawatthour (= 10^6 kWh)
Kr	=	Króna (1 Kr = 4 U.S. cents)
Mkr	=	million krónas
aur	=	aurar (1 Kr = 100 aurar)

Tabulation of Some Potential Power Sites in the Þjórsá and Hvítá River Systems and their Main Characteristics.

<u>Note</u>: All figures in the table are preliminary and are shown mainly for comparison between the various sites. This applies especially to the cost figures, which are taken from rough cost estimates, based on the 1955 price level and are not intended to show the power costs actually to be expected from these developments.

Name of Site	Watercourse	Develop-disch. at rated capacity m3/s	Gross head m	Installed capacity MW	Cost of civil eng. works Mkr	Cost of mech. and el. plant & equipment Mkr	Total construction cost Mkr	Cost pr kW of installed capacity kr/kW	Live storage of intake pond Gl	Live storage of separate storage works Gl	Annual primary output GWh	Cost pr kWh of annual primary output kr/kWh	Annual utilization time h
Bláfell	Hvítá	100	169-157	124	284	123	407	3280	590	0	660	0,62	5300
Gullfoss	Hvítá	200	147	215	346	244	590	2750	14	590	870	0,68	4050
Dynjandi	Brúará	65	10	5,5	18,7	8,3	27	4910	14	0	40	0,68	7300
Selfoss	Ölfusá	330	7	20	59	30	89	4450	0	0	125	0,71	6250
Urriðafoss	Þjórsá	300	33,5	80	160	96	256	3200	4,7	0	480	0,53	6000
Sultartangi	Þjórsá	340	130	330	450	370	320	2520	40	205 800	1620 1840	0,51 0,45	4900 5600
Fossá, Þjórsárdal	Fossá, St. Laxá	10,2	318	50	114	46	160	3200	100	0	250	0,64	5000
Þórisvatn	Kaldakv.-Þórisós	67	242-228	120	289	131	420	3500	800	0	720	0,59	6000
Hrauneyjafoss	Tungnaá	107	98-103	84	127	94	221	2630	35	35 205	445 505	0,50 0,44	5300 6000
Tungnaárkrókur	Tungnaá	98	55-75	52	112	55	167	3210	205	0	310	0,54	6000

A Preliminary Appraisal of the Hydro- electric Development of River Hvítá at Mt. Bláfell

C O N T E N T S

A Preliminary Appraisal of the Hydro-electric Development of River Hvítá at Mt. Bláfell

0 Introduction

In the following a preliminary appraisal will be given of the development of the section of river Hvítá between Lake Hvítárvatn (el. 419m) and the southern slope of Mt. Bláfell (river el. 263m).

1 Geographical Features and Local Conditions

River Hvítá originates in Lake Hvítárvatn, a lake of 30 km^2, with a drainage area at the outlet of 843 km^2, lying at the south-eastern margin of the Langjökull ice cap.

Several rivers discharge into the lake from the north, east and west. One of them, the glacial river Fúlakvísl, flowing from the east, has built up a delta (called Hvítárnes) of considerable size into the lake.

Some decades ago, the glaciers extending from the Langjökull ice cap down to the western shores of the lake reached the lake and icebergs broken off from them floated on the lake. Such icebergs are no longer to be seen, but if the water level is raised they will presumably appear again.

A short distance downstream of the lake, a glacial river, the Jökulfall, originating in the Hofsjökull ice cap, discharges into river Hvítá.

To the south-east of Mt. Lambafell, there is a low waterfall in river Hvítá, named Ábóti. The elevation of the ledge is 411 m.

Farther downstream, two bergvatnsá-rivers, Grjótá and Sandá, originating in Kerlingarfjöll and Bláfell, respectively, discharge into river Hvítá.

The fall of river Hvítá from the lake to the ledge of Ábóti is 8 m, as mentioned above. Downstream from Ábóti, the river has cut a deep canyon into the bedrock the whole way along the slopes of Mt. Bláfell.

The drainage area at the outlet from the lake is 843 km^2, as stated above; that of the Jökulfall river at the point of the proposed diversion into the lake is 380 km^2, making a total of 1223 km^2.

2 General Survey of Alternative Developments at Mt. Bláfell

In the following, three main alternatives of a full development of river Hvítá at Mt. Bláfell will be discussed.

2.1 Alternative I

Single-stage development of the whole fall with two variants, designated Bláfell Ia and Ib, differing only in the location

of the storage dam at the outlet; otherwise identical. A diversion dam to be built across river Jökulfall to lead it to the lake.

Developed discharge 100 m^3/s at a mean gross head of 164 m. Total installed capacity 124000 kW.

2.2 Alternative II

The fall developed in two stages. The upper stage, called Lambafell I has a developed discharge of 100 m^3/s; a mean gross head of 57 m; tailwater elevation 370 m and an installed capacity of 43000 kW. The storage- and intake dams for this stage will be identical with those in Alt. I.

The lower stage, called Bláfell II, has a developed discharge of 130 m^3/s, gross head of 107 m and an installed capacity of 104000 kW. The intake dam for this stage will be located ab. 2,2 km downstream of the confluence of river Grjótá with river Hvítá. River Sandá will be diverted to river Hvítá upstream of the intake dam by means of a diversion dam across river Sandá.

2.3 Alternative III

Two-stage development of the fall from the ledge of Ábóti, with a seperate storage dam at the outlet of Lake Hvítárvatn.

The upper stage, called Ábóti II, has an intake dam upstream of Ábóti and utilizes the fall from there down to el. 370 m. It will have a gross head of 50 m, a developed discharge of 100 m^3/s, and an installed capacity of 38000 kW. The lower stage is identical with that of Alt. II.

2.4 Summary of the Alternatives

Table 2.41 shows the main characteristics of the various developments and table 2.42 the various alternatives of a full development of the river at Mt. Bláfell. The prices shown are from rough cost- estimates based on a 1955 price level, and are shown for comparison only, but are not intended to show the power cost actually to be expected from these developments.

3 Storage and Stream-flow

3.1 Storage

As previously mentioned, it is proposed to divest river Jökulfall into Lake Hvítárvatn by means of a diversion dam across the former a short distance upstream from its confluence with river Hvítá, thereby enabling the storage facilities of Lake Hvítárvatn to be better utilized.

It is proposed to utilize a difference in water level of the Lake of 12 m, between el. 432 and 420 m, giving a live storage of 590 mill. m^3.

3.2 Stream-flow

Continuous stream-flow records are not available for river Hvítá above Gullfoss, where continuous records since 1949 are available.

In this appraisal, estimates of developable stream-flow at Mt. Bláfell are made from the Gullfoss records for the period 1949-1957, incl. by reducing the discharge in relation to the size of drainage area. The estimate is based on the most adverse water year of record, 1950/51.

4 Conclusion

As mentioned above this preliminary appraisal is made only for the purpose of comparing the various alternatives.

It has also been stated that the information and data on which such an appraisal must neccessarily be based are still inadequate in many respects. This will be further discussed in the next section, dealing with the site investigations which still have to be made.

A comparision of the various alternatives indicates that the fall available in river Hvítá at Mt. Bláfell should be developed in a single stage, although thereby loosing a power amounting to 140 GWh a year compared to a two-stage development, because the tributary rivers Grjótá, Sandá and Svíná cannot be utilized in the single-stage alternative.

This additional power will, however, be relatively expensive.

Of course, the single-stage development means a heavier financial burden but this aspect will not be discussed here.

At the moment, no estimate has been made of the construction time required for such a development as discussed here although this point certainly requires a study owing to the great amount of construction work involved, e.g. 820 000 m^3 of rock excavation; 320 000 m^3 of earth filling and 120 000 m^3 of concreting.

It might be pointed out here that the development of river Hvítá at Mt. Bláfell will be considerably more expensive than the development of the Gullfoss section, owing to the amount of storage facilities required to ensure an adequate regulation of the river, from which downstream power plants will also benefit.

5 Further Investigations

As mentioned above, there are no continuous stream-flow records available of river Hvítá at the outlet from the Lake or of river Jökulfall. The installation of a water level recorder at the two streams is now in preparation, so that this aspect of the matter will soon improve.

Measurements of the sediment load of river Jökulfall would be very valuable for being able to decide whether or not a bottom outlet would be required in a dam across the river for removing the precipitated sediment from the impounded water.

Depth soundings of Lake Hvítárvatn should be performed. (It has been decided that the SEA Hydrologic survey carry out these soundings the next summer (1958). Possibly, the results of these soundings might have an appreciable effect upon the location and arrangement of intake works at or in the lake.

The dam sites on river Hvítá and river Jökulfall, as well as sites for ancillary dams between the two, must be surveyed in greater detail than hitherto; enabling maps at scale 1:1000 or 1:2000 with 1 m contour intervals to be prepared. Further, the depression between Mt. Bláfell and Mt. Lambafell and the area around the proposed power house must also be surveyed. Finally, an assessment must be made of the geological conditions at all these sites and on the tunnel route through Mt. Bláfell.

The depth to a sound bedrock on the dam sites and in the depression between Mt. Bláfell and Mt. Lambafell must be explored.

A survey must be made of construction materials available in the vicinity of the development, both materials for earth-fill dams and concrete aggregates. In this preliminary appraisal, dams of the earth-fill type have been assumed and it is, therefore, essential to find out whether or not the moraine present at the dam site in a great abundance is a suitable material for an earth-fill dam.

A survey must be made of possible routes for an access road to the site, both from the point of view of construction materials for the road and that of its location in relation to snow deposits in order to ensure that the road is passable for as long a time of the winter as possible. This is essential both during construction and for the operation of the power plant.

These were the investigations required at the site before a detailed project can be made.

6. Description of the Various Alternatives

Above, the general features and main characteristics of the various alternatives have been given. Below, each alternative will be described in more detail.

6.1 Alternative; Variant a

6.11 Bláfell Ia

Max. developed discharge:	100 m^3/s.
Gross head:	169-157 m
Net head:	149 m

Installed capacity: 124 000 kW
(See drwgs. A-1650 and A-1652)

A concrete gravity dam is proposed across river Hvítá, ab. 470 m upstream from the bridge across the outlet.

The dam is a spillway dam, 145 m long and equipped with four bottom outlets.

Spillway crest level is 432 m above MSL. Max. height of dam is 17 m. A road bridge above the dam is envisaged at el. 435,5 m.

An earth-fill dam, without a spillway, will be built across river Jökulfall ab. 1800 in upstream from the confluence with river Hvítá, thereby diverting the Jökulfall into Lake Hvítárvatn. Bottom outlets for the removal of sediment are not envisaged here, but this point requires a further study before the final design is made.

Several smaller ancillary dams will be built between the two main dams, and one on the western side of river Hvítá. They will all be of the earth-fill type and withour a spillway. It is here assumed that the dams may be constructed from the local moraine deposits, using the hydraulic-fill method. Spoil from the tunnels would also be used to some extent.

Total length of the dams is ab. 2200 m. Max. height of dam above the Hvítá riverbed will be ab. 17 m, as mentioned above; that of the Jökulfall dam ab. 15 m. Crest level of non-spillway dams will be at el. 435 m, viz. 3 m above the spillway crest level, making an ample allowance for wave action.

The intake is located a short distance upstream from the dam, in the riverbed of Hvítá. It will be circular in shape and separated structurally from the dam, except for a connecting bridge.

The headrace tunnel will have a length of 10800 m from the intake to a surge basin excavated into the southern slope of Mt. Bláfell. The tunnel is lined with concrete and has a cross section area of 32 m^2.

From the surge basin, two vertical penstock shafts of a circular cross section lead to the power house. They are lined with concrete and steel, with an inside diameter of 4,3 m and are separated from the surge basin by valves.

The power house is wholly underground. Two units are envisaged, each rated 62000 kW. An access tunnel, containing ducts for ventilation and cables leads to the power house.

From the power house, a 2500 m tailrace tunnel leads to river Hvítá at el. 263 m. It is unlined, with a cross section area of 79 m^2.

6.2 Alternative I, Variant b

6.21 Bláfell Ib

Max. developed discharge:	100 m^3/s
Gross head:	169-157 m
Net head:	149 m
Installed capacity:	124 000 kW

(See drwgs. A-1650; A-1651; and A-1652)

In this variant, a gravity dam is proposed across the Hvítá riverbed ab. 300 m downstream from the bridge.

The dam has a spillway section of 144 m length. Spillway crest level at el. 432 m. There are two bottom outlets on the western side of the spillway.

A road bridge is envisaged at el. 435 m.

Max height of dam: 18 m

The headrace tunnel will be 200 m shorter than in variant a.

Otherwise, the two variants are identical.

6.3 Alternative II, Variant a

6.31 Lambafell Ia

Max developed discharge:	100 m^3/s
Gross head:	50-62 m
Average net head:	52 m
Installed capacity:	43 000 kW

(See drwgs. A-1650; A-1653; A-1654)

A dam across river Hvítá, ab. 300 m downstream from the bridge, and a dam across river Jökulfall ab. 1800 m above its confluence with river Hvítá is contemplated, with some ancillary dams between them. All the dams will be of the earthfill type and it is proposed to construct them from the local moraine deposits by the hydraulic-fill method. Tunnel spoil would also be used to some extent.

The total length of the dams is ab. 1500 m. Max. dam height is ab. 17 m in the Hvítá river channel and 15 m in the Jökulfall. Flood control is effected partly by a shaft spillway ab. 400 m long blasted into the eastern river bank, and partly by a spillway channel constructed in the depression between Mt. Bláfell and Mt. Lambafell. The shaft spillway has a cross section area of ab. 130 m^2, and is lined with concrete.

A circular intake is constructed in the river channel, a short distance upstream from the dam. It is structurally separated from the latter, but connected with it by a bridge.

From the intake, a headrace tunnel leads to a surge basin blasted into the southern slope of Mt. Lambafell. The tunnel is concrete lined and has a cross section area of 32 m^2.

A vertical penstock shaft, of circular cross section, having an inside diameter of 6 m leads from the surge basin to the power house, which is entirely underground. The penstock is lined with concrete and steel.

The tailrace tunnel has a length of 2300 m and a cross section area of 82 m^2. It is unlined. The tunnel mouth at river Hvítá is at el. 370 m.

The power house is wholly underground, as mentioned above. A single unit, rated 43 000 kW is proposed. An access tunnel. containing ducts for ventilation and cables leads to the power house.

6.32 Bláfell II

Max. developed discharge:	130 m^3/s
Gross head:	107 m
Net head:	96 5 m
Installed capacity:	104 000 kW

(See drwgs. A-1650: A-1655: A-1656)

A dam across river Hvítá is contemplated ab. 2,2 km downstream from the Grjótá confluence. The dam site is in a canyon, and as the dam crest will lie considerably below the canyon banks, an accress road tunnel to the dam will be excavated into the rock on both sides of the river. The dam crest level is at el. 372,5 m; the water surface at el. 370 m. The dam will be ab. 25 m high and 40 m long and will have 4 flood gates; two crest gates 40 m^2 each and two bottom gates, 40 m^2 each.

It is proposed to dam river Sandá ab. 800 m below its confluence with river Svíná, and divert it into river Hvítá by means of a canal.

The intake will be excavated into the western river bank. The valve chamber is underground and the valves are of the vertical-lift type.

The headrace tunnel is ab. 6400 long and leads to a surge basin excavated into the southern slope of Mt. Bláfell. The tunnel has a cross section area of 41 m^2 and is concrete lined.

Behind the surge basin is a valve chamber, from which a vertical penstock shaft leads to the underground power house. The penstock is circular in shape, with an inside diameter of 7 m. It is lined with concrete and steel.

A tailrace tunnel will lead from the power house to river Hvítá at el. 363 m approx. It will have a cross section area of 108 m^2, and be unlined. The section next to the river will consist of an open canal.

A single unit, rated 104 000 kW, is contemplated.

An access tunnel containing ducts for ventilation and cables will connect the power house with the ground surface.

6.4 Alternative II, Variant b

6.41 Lambafell Ib

Max. developed discharge:	100 m^3/s
Gross head:	50-62 m
Net head:	52 m
Installed capacity:	43 000 kW

(See drwgs. A-1650; A-1651; A-1653; A-1654)

This variant is identical with variant a, except that the earth-fill dam across river Hvítá is replaced by a concrete gravity dam of a type similar to that of Alt. I, var. b (6.21) Spillways in the dam, both of the weir and the shaft type, will replace the separate spillway channel of variant a.

6.42 Bláfell II.

This variant is identical with variant a of Alt. II. described above.

6.5 Alternative II, Variant c

6.51 Lambafell Ic

Max. developed discharge:	100 m^3/s
Gross head:	50-62 m
Net head:	52 m
Installed capacity:	43 000 kW

(See drwgs. A-1650; A-1653; A-1654; A-1196)

In this variant, a dam across river Hvítá ab. 470 m upstream of the bridge is contemplated. The dam will be identical with the dam in Alt. I, var. a, previously described (6.11) The concrete section of the dam, across the channel of river Hvítá has a weir spillway with a road bridge over it, and four bottom gates. Otherwise, the dam is of the earth-fill type.

Owing to the changed dam location, the location of the tunnels and the power house will be different from that of Alt II. var. a and b. The headrace tunnel will be 700 m longer, but the cross section area will remain unchanged. Otherwise, the variant is identical with Alt. II, var. a and b.

6.52 Bláfell II

This variant is identical with variant a of Alt. II, decribed above.

6.6 Alternative III

6.61 Storage Dam at the Outlet of Lake Hvítárvatn

The storage dam of this alternative is identical with the intake dams of Alt. I, var a. (6.11) and Alt. II. var c (6.51) described above.

6.62 Ábóti II

Max. developed discharge:	100 m^3/s
Net head :	46 m
installed capacity:	38 000 kW
(See drwgs. A-1650:	A-1189)

A dam across river Hvítá a short distance upstream of the waterfall is contemplated. Dam crest to be at el. 422 m. The length of the dam. excluding low embankments at both ends is 470 m including a spillway section of 250 m length. On the eastern river bank, an earth-fill embankment with a concrete cut-off will be coustructed. Max. height of dam in the river channel is ab. 13 m; that of the earth-fill section ab. 8 m. The power house is located below the western river bank. Total length of main water conduits is 2800 m.

6.63 Bláfell II

This variant is identical with variant a of Alt II described above.

Preliminary Proposals for the Hydro- electric Development of River Hvítá at Gullfoss

CONTENTS

1 Introduction

Below, a brief description will be given of the proposed arrangement of the hydro- electric development of river Hvítá at Gullfoss. Two alternatives, I and II will be described. In one of them, a net head of 115 m will be utilized in an underground power plant located on the eastern side of the river. The total length of conduits will be 8.5 km approx. The plant will discharge into river Hvítá some distance downstream from the Gullfoss waterfall. Proposed installed capacity is 187 000 kW. The other alternative invisages a diversion of river Hvítá to the west, to river Tungufljót through an underground power plant. Net head would be 132 m in this case; total length of conduits ab. 11 km and the installed capacity 215 000 kW. The latter alternative appears to be more expensive, but it would facilitate developments farther downstream on the river.

2 Storage and Stream-flow

2.1 Storage

The best possibilities for the construction of a storage reservoir (seasonal storage) on river Hvítá is at Lake Hvítárvatn, where a live storage of 590 Gl may be obtained by raising the level of that lake by some 12 m. The Hvítárvatn storage scheme has been described to some detail in the appraisal of the Bláfell developments, and need not be repeated here.

Other storage possibilities in the part of the Hvítá basin lying upstream of Gullfoss are confined to Lake Sandvatn, where some storage may be obtained by damming the outlet of that lake, which now feeds the Tungufljót river, and divert the outlet river into river Hvítá upstream of the Gullfoss development.

2.2 Stream-flow

Continuous stream-flow records are available of river Hvítá at Gullfoss since 1950. Mean discharge for this period has been 118 m^3/s. For further information, the records of the S.E.A. Hydrologic Survey should be consulted.

3 Description of the General Arrangement of Development

3.1 Storage Dam at Lake Hvítárvatn

(See Preliminary Appraisal of the Hydro- electric Development of River Hvítá at Mt. Bláfell)

3.2 Gullfoss Development, Alternative I

Max. developed discharge	200 m^3/s
Net head (average)	115 m
Installed capacity	187 000 kW
(See drwgs. A-1204; A-1483;	A-1484)

A dam is contemplated across river Hvítá ab. 250 below the confluence of river Búðar with the Hvítá, or ab. 1500 m above the Illagil gorge.

A comparison has been made of this dam site with another one located ab 800 m downstream. In terms of cost, there does not appear to be any difference between the two sites, so that both of them should be studied further before selecting the site of the dam for this development.

Total length of dams is 1370 m approx., whereof ab. 1000 m consist of earth-fill embankments with a concrete cut-off. Max. height of these embankments is ab. 9 m. On each side of the riverbed, concrete spillways are envisaged, with a total length of ab. 200 m. In the riverbed a section with flood outlets will be constructed, plus a 120 m long section of the multiplearch type, with 6 sloping archs. Max. height of the dam is ab. 24 m.

A circular intake is constructed at the eastern river bank a short distance above the flood outlets section of the dam. Total length of the waterways is ab. 8.5 km.

The headrace tunnel is located east of the river. It is lined with concrete and has a cross section area of 54.3 m^3. It is ab. 6.9 km long from the intake to a surge basin excavated into the hill ab. el. 270 m, approx. above the Nautavík. Two circular penstocks, with an internal diameter of 6.o m excavated in rock and lined with concrete and steel, lead from the surge basin to the underground power house. The tailrace tunnel is ab. 900 m long from the turbine axis to the river bank of Hvítá at Nautavík. The tunnel is unlined and has a cross-section area of 133 m^2.

Two units are envisaged, each rated 93500 kW.

An access tunnel, containing ducts for ventilation and cables, connects the power house with the ground surface.

3.2 Gullfoss Development, Alternative II

Max. developed discharge	200 m^3/s
Average net head	132 m
Installed capacity	215 000 kW
(See drwg.	A-1506)

The proposed dam is identical with that of alt. I

Two intakes will be constructed at the western river bank a short distance above the gate section of the dam. From the intakes two circular penstocks with an internal diameter of 6.0 m lead to the underground power house. The penstocks are lined with concrete and steel. The tailrace tunnel is ab. 11 000 m long from the turbine axis to river Tungufljót at el. 95 m, i.e. about 1200 m above the confluence of the Kjósastaðalækur brook with that river. The tailrace tunnel will be unlined; it has a cross-section area of 137 m^2.

Two units, each rated 107 500 kW, are envisaged.

An elevator shaft containing ducts for ventilation and cables connects the underground power house with the ground surface.

Preliminary Appraisal for the Hydro- electric Development of River Brúará at Dynjandi

CONTENTS

1 Local Conditions

River Brúará is a lindá river, originating in the Brúarskörð gorge. It is a small stream only at the mouth of the gorge, but three other lindá rivers, the Innri Kálfá, the Fremri Kálfá and the Hrútá discharge into river Brúará some distance downstream from the Brúarskörð. A single discharge measurement exists of river Brúará downstream of its confluence with river Hrútá. The result was 20 m^3/s.

In the river section downstream from the Hrútá confluence are some low waterfalls and rapids.

Farther downstream, some smaller rivers and brooks discharge into river Brúará, among which is the Hagaás, the outlet river of the lakes Apavatn and Laugarvatn.

The Dynjandi is a rapid of river Brúará situated ab. 1.5 km upstream of the road bridge. The fall in the river is here ab. 3.5 m in a section of 150 m, but the river banks are so high that a head of 10 m may be obtained by damming the river. This would create a pond of an appreciable size above the dam. Further, the level of Lake Apavatn would rise a metre, while the level of Lake Laugarvatn would not be affected, as there is a difference in water level of 2.6 m between these two lakes.

2 Stream- flow

As mentioned above, river Brúará is a lindá river and besides, it receives a part of its water from lakes. Accordingly, the discharge is very uniform. For the 10 years period of record, the mean discharge has been ab. 66 m^3/s; min. discharge ab. 48 m^3/s and max. discharge ab. 194 m^3/s.

The size of the drainage area is 670 km^2 at the proposed site.

The area of Lake Apavatn is 14 km^2. Although accurate topographical maps are available of the dam site only, as the surrounding area is very flat, it may be concluded that an appreciable storage volume may be obtained above the dam. In Lake Apavatn alone, a storage of not less than 14 Gl may be obtained.

In this appraisal a max. developed discharge of 65 m^3/s has been assumed. The storage space available should allow 40 GWh of primary power to be produced annually in most years.

3 Geological conditions

An assessment has not been made of the geology at the site.

The riverbed and the banks consist of a solid rock, which may be seen cropping out on both sides of the river. Apparently, this is a sort of a clastic rock, in all probability belonging to the so-called Hreppar series and is presumably solid as foundations for a dam. It is not porous and reasonably watertight. Soil is overlying the bedrock; a dry meadow to the north, and a swamp to the south of the site.

Concrete aggregates may undoubtedly be found near the site.

4 Arrangement of the Development

Max. developed discharge	65 m^3/s
Gross head	10 m
Installed capacity	5500 kW
Annual production of primary power	40 GWh
(See drwg.	A-1777)

The proposed dam is located just above the rapids. It consists of several sections: (1) A concrete spillway section, ab. 7 m high and 48 m long, across the riverbed. (2) An outlet 10 m wide and 7 m high, equipped with gates, is located at the northern river bank. (3) Earthfill section with a timber cutoff and a riprap on the upstream face, on both sides of the river. Total length of these last sections is ab. 370 m; max. height ab. 5 m, near the river.

The intake is excavated into the northern river bank.

The power house is close to the intake.

A tailrace canal, ab 120 m long, leads from the power house to the river downstream of the plant.

One Kaplan unit 188 RPM, vertical shaft, with a generator rated 6900 kW at 0.8 power factor is contemplated.

Preliminary Proposals for the Hydro-electric Development of River Ölfusá at Selfoss

Max. developed discharge	330 m^3/s
Gross head	7 m
Installed capacity	20 000 kW
(See drwg.	A-1781)

The proposed dam across river Ölfusá is in the lowest part of the rapids above the Selfoss waterfall. The width of the river is 210 m at the site.

The power house will be located at the western river bank. It will be an integral part of the dam. The rest of the dam consists of a section of 7 gates, 20 m wide each, with [illegible] buttresses between them. This design was adopted for being able to discharge the floods occurring in river Hvítá without raising the level of the impounded water.

It is proposed to keep the headwater level at el. 14 m; the tailwater level is at el. 7 m, giving a gross head of 7 m, except during great floods, when the head may be greatly reduced.

At a headwater level at el. 17 m, parts of the eastern river bank will be flooded. It may thus be assumed that the sewage system of the village Selfoss may have to be altered substantially, as the sewage disposal is now directly into river Ölfusá partly above the proposed dam. The ground-water table in the village would also rise appreciably.

Considerable amount of money may have to be paid as compensations for damage of land caused by the proposed development.

Two Kaplan units are contemplated. Each alternator will be rated 12500 kWA at 0.8 power factor.

Preliminary Appraisal for the Hydro- electric Development of River Þjórsá at Urriðafoss

CONTENTS

1 Introduction

The proposed scheme is located on river Þjórsá ab. 23 km above its mouth, or in the vicinity of the road bridge across the river. The river section to be developed lies between the Heiðartangi peninsula, ab. 1000 m above the bridge and the Urriðafoss waterfall, ab. 2000 m downstream from the bridge. The length of the section is thus ab. 3000 m; the total head available is ab. 35 m.

Four alternatives for the development of the river are put forward (see drwgs. A-1182 and A-1186). The main difference between the alternatives lies in the location of the dam and the length of the waterways. 80 000 kW of installed capacity has been assumed in all four alternatives, and there is only a slight difference between them in the gross head.

2 Local Conditions

The geology at the site of the scheme has been studied by Kjartansson, and described in his report. It will not be entered into here; it shall only be stated that, according to Kjartansson, the eastern river bank consists of the Hreppar series, but the western bank of a Þjórsá lava, except for a hill near the middle of the section which consists of the Hreppar series like the eastern bank. The same is true of the western river bank downstream of the Urriðafoss waterfall.

3 Stream-flow and Storage

Continuous stream-flow records are available of river Þjórsá at the site of this scheme since 1947. According to these records, the mean discharge of river Þjórsá over the period of record has been 383 m^3/s. Max. observed floods have been of the order of 3500 m^3/s. For further information on the stream-flow, the records of the S.E.A. Hydrologic Survey should be consulted.

The proposed dam would provide as daily pondage only, whereas storage reservoirs would have to be constructed farther up-stream, at Lake Þórisvatn, for instance (For the dams and conduits necessary for creating a storage reservoir at Lake Þórisvatn, as well as the amount of storage available there, see the preliminary appraisal of the Þórisvatn development). Unless such seperate storage works are created fasther upstream on river Þjórsá, the proposed scheme would be a pure run-of-river development.

4 Description of the Various Alternatives

4.1 Alternative I

Gross head	36.5 m
Installed capacity	80 000 kW
(See drwgs. A-1181; A-1182: A-1186)	

The dam would be located just downstream of the Heiðartangi peninsula.

The foundations of the dam consist of bedrock of the Hreppar series on the eastern river bank, and of a Þjórsá lava on the western bank.

The edge of the lava is presumably lying somewhat to the east of the middle of the riverbed. According to Kjartansson, an unsound sedimentary layer may be expected in the deepest part of the riverbed, at the boundary between the lava and the bedrock.

The dam consists of a concrete section, 100 m long and 15 m high, across the riverbed of Þjórsá and an earth-fill section with a cut-off on the western river bank. The concrete section would accommodate gater capable of discharging all surplus water, so that no overflow spillway is required. The earth-fill section will have to be founded on lava, but as it is rather low, mostly within 5 m in height, one might hope that the leakage through the lava beneath the dam would not be very great. Owing to lack of sufficiently accurate topographical maps of the area to the west of the river, the length of the earth-fill section is indeterminate.

The crest of the dam would be at el. 50.0 m; the level of the impounded water at el. 48.5. The purpose of selecting the dam as high as proposed here is to provide some daily pondage and a greater depth at the intake.

The intake is excavated into rock at the eastern abutment, at right angles to the concrete section of the dam.

The power house is also excavated into rock on the eastern river bank, but extends above ground level (semi- underground). It accommodates two Francis units; each alternator rated 40 000 kW at 0.8 power factor.

A surge chamber is provided for on the tailwater side of the power house. From there, a tailrace tunnel leads to river Þjórsá downstream of the Urriðafoss waterfall. The length of the tailrace tunnel is ab. 2200 m. An unlined tunnel is assumed here, although the relative merits of a lined and an unlined tunnel cannot be assessed at the present stage, owing to lack of data on the flow and water in unlined tunnels excavated in basalt.

The water level of the intake reservoir varies between al. 48.5 and 45.0 m.

4.2 Alternative 2

Gross head	33.5 m
Installed capacity	80 000 kW
(See drwgs.	A-1183 and A-1186)

The proposed dam is located at the downstream end of the hill Sandholt, where the dam would be founded solely on Hreppar rocks. A low ancillary dam is required on the lava to the west of the hill.

The main dam is of concrete, with a section of gates across the whole of the riverbed. The length of this section is ab. 80 m; its max. height ab. 24 m. All surplus water will be discharged through the gates (no owerflow spillway). The ancillary dam is of the earth-fill type.

The crest of the dam is at el. 47.0 m; the normal level of the reservoir at el. 45.5 m. Max. drawdown is 3.5 m.

The intake is located in the eastern river bank, beyond the gates section of the dam. The power house is constructed close to the intake.

A tailrace tunnel connects the power house with river Þjórsá downstream of the Urriðafoss waterfall.

4.3 Alternative 3

Gross head	33.5 m
Installed capacity	80 000 kW
(See drwgs.	A-1184 and A-1186)

The main dam is constructed across the riverbed of Þjórsá at the legde of the Urriðafoss waterfall, between the eastern bank and the Bæjarholt hill on the western bank. The length of this dam is ab. 500 m; its max. height ab. 24 m.

An acillary dam is constructed across the depression to the west of the Bæjarholt, between that hill and the Fossvirki. Its length is ab. 400 m; max. height ab. 18 m. This dam contains gates for discharging all surplus water. The power house is built into the southern end of this dam.

Both dams are founded solely on rocks of the Hreppar series.

The crest of both dams is at el. 45.0 m; the normal level of the reservoir is at el. 43.5 m. Max. drawdown is 3.5 m.

The length of the tailrace tunnel, including a surge chamber, is ab. 160 m.

4.4 Alternative 4

Gross head	33.5 m
Installed capacity	80 000 kW
(See drwgs.	A-1185 and A-1186)

The proposed dam is located in a narrow section of the Þjórsá gorge, ab. 1000 m downstream from the Urriðafoss. On the western river bank, the dam abutts against the hill Bæjarholt. An ancillary dam is constructed across the depression th the west of that hill, between it and the Fossvirki. The ancillary dam is of the earth-fill type, with a cut-off wall, whereas the main dam is of concrete.

Both dams are founded on rocks of the Hreppar series.

The crest of the dams is at el. 45.0; normal reservoir level is at el. 43.5 m. Max. drawdown is 3.5 m.

The power house is incorporated in the main dam.

5 Comparison of the alternatives

In comparing the alternatives, it should be borne in mind that the available data only permit the general features of design to be drawn up, and, therefore, any cost estimate based thereon must necessarily be rough. The costs shown in the following table are taken from such rough cost estimates, based on 1955 price level, and are shown for comparison only, but are not intended to show the power costs actually to be expected from the developments.

Alternative	Total cost Mkr.	Specific total cost, kr/kW	Relative total cost
1	291	3640	1.16
2	252	3150	1.00
3	308	3850	1.23
4	256	3200	1.02

It appears from the comparison that alt. 2 and alt. 4 are significantly cheaper than alt. 1 or 3. However, other aspects than total cost enter into comparison between the four alternatives:

(1) Geological considerations favour alt. 3 or 4, as the dam foundations in these two alternatives consist solely of old and sound rocks of the Hreppar series, whereas part of the dams in alt. 1 or 2 have to be founded on a Þjórsá lava.

(2) A greater amount of pondage may be obtained for the same drawdown in alt. 3 or 4 than in alt. 1 or 2.

(3) The construction of the plant would be easier if alt. 3 or 4 are selected than if alt. 1 or 2 are chosen.

(4) Possible interruptions in the operation of the plant due to ice jamming in the Þjórsá gorge near Urriðafoss would presumably be less severe the fasther downstream the dam is located, favouring alt. 3 or 4 in comparison to alt.

The net result, therefore, appears to be that alt. 4 is the most favourable alternative.

Regarding point (4) in the comparison, considerations should be given to the possibility of constructing the plant still fasther downstream, e.g. at the Egilsstaðir farm, where, according to local observers, no significant change in the water level of the river due to ice barriers have been observed. This would require a sufficiently detailed topographical mapping of the area involved and the collection of other basic data, for a development in this place.

Preliminary Appraisal for the Hydro- electric Development of River Þjórsá at Sultartangi

CONTENTS

1 Introduction

The proposed scheme envisages the construction of an intercepting dam at the toe of the Sultartangi peninsula, immediately upstream of the confluence of the rivers Þjórsá and Tungnaá, raising the water level to el. 290 m approx. The utilized water would be led through a tunnel to an underground power house excavated into the eastern slope of the Fossárdalur valley, and discharged into river Fossá at el. 160 m. The gross head will thus be ab. 130 m. Total installed capacity is 330 000 kW divided between 3 identical units.

2 Stream-flow and Storage

No stream-flow records are available at the site, but the S.E.A. Hydrologic Survey has estimated the mean discharge 334 m^3/s. Max. developed discharge is taken as 340 m^3/s.

By a drawdown of 10 m from el. 290 m at the dam, a live storage of ab. 40 Gl may be obtained. This is an ample daily pondage. However, as sufficiently accurate topographical maps of the reservoir site are not available, this figure may be somewhat in error.

There are several possibilities of a (seasonal) storage farther upstream on river Þjórsá and river Tungnaá. The most promising of them all is Lake Þórisvatn, where a live storage of ab. 2000 Gl may be obtained. (Regarding the dams and tunnels necessary for accomplishing this storage at Lake Þórisvatn, see the report on the preliminary appraisal of the Þórisvatn scheme).

Possibly, only two units would be installed first, and the plant operated as a run-of-river plant. However, some interruptions in the operation may always be expected until some storage has been provided.

3 Geological conditions

The geological formations of the area involved in this scheme have been thoroughly decribed by Kjartansson and will not be entered into here. Most of the dam is founded on a Þjórsá lava, which however, according to Kjartansson appears to be somewhat more sound and better watertight than lava flows in general. The bedrock is of the Hreppar series, consisting mostly of sound and tight rock types.

4 Arrangement of the development

Max. developed discharge	340 m^3/s
Gross head	130 m
Net head	118 m
Installed capacity	330 000 kW

(See drwgs: A-1536; A-1537; A-1538; A-1539)

A concrete dam is constructed across the rivers Þjórsá and Tungnaá just upstream of their confluence. A concrete dam has been selected with regard to the danger of piping due to leakage through the lava beneath the dam.

Total length of the dam is ab. 3.7 km, of which ab. 2.3 km is within 5 m in height. A spillway section, 600 m long, is constructed across the riverbed of the Tungnaá. The dam across the Þjórsá riverbed consists of flood gates section plus a multiple-arch section, 60 m in length. Apart from this latter section, the dam is of the gravity type.

The spillway crest is at el. 290 m; the rest of the dam at el. 293 m.

Max. height of the dam is in the Þjórsá riverbed, 20 m. The spillway section across the Tungnaá is 12 m high. Max. height outside the two riverbeds is 10 m.

Two circular intakes are constructed in the Þjórsá riverbed a whort distance above the gates section of the dam.

Two vertical shafts, circular, with an inside diameter of 700 cm connect the intakes with the (horizontal) headrace tunnel. The headrace tunnel is concrete-lined and has a cross-section area of 82 m^2. Its length from the intakes to a surge basin, excavated into the western slope of Mt. Stangarfjall, is ab. 8 km.

From the surge basin, three vertical penstocks lead to the underground power house. The penstocks, which are circular in shape, have an internal diameter of 640 cm. They are lined with concrete and steel.

A 400 m long tailrace tunnel conducts the water from the turbines to river Fossá at el. 160 m. The tunnel is lined with concrete and has a cross-section area of 82 m^2.

Total length of the waterways is ab. 8.6 km.

Three generating units are contemplated, each rated 110 000 kW.

An access tunnel, containing ducts for ventilation and cables, connects the underground power house with ground level.

Preliminary Appraisal for the Hydro- electric Development of River Fossá in Þjórsárdalur

CONTENTS

1 Introduction

The proposed scheme may be split up into three phases. The first phase consists of the development of river Fossá itself, the second in diverting the rivers Stóra-Laxá and Svartá to the intake reservoir of the Fossá development to increase the power generation, and the third phase consists in diverting still two other rivers, the Dalsá and the Kisa to river Fossá. The three phases may be carried out either simultaneously or successively, one at a time, as assumed in the following.

The section of river Fossá involved in the scheme lies between the Fossölduver and the Fossárdalur valley. The gross head of the development, as the latter is proposed here, is ab. 314 m and the total length of water conduits is ab. 5.1 km.

The power plant would have an installed capacity of 50 000 kW.

2 Geology of the Sites

A geological survey of the areas of interest for all three phases of the scheme has been performed by Kjartansson, and a geological map of it accompanies his report. According to that report, the bedrock is everywhere of the Hreppar series, mostly sound andtight rock types, and there does not appear to be any difficult geological problems involved in the scheme. The tunnels would lie safely within the bedrock, and although they may in some places cross faults, this is not considered a serious problem. At the site of the main dam, across river Fossá, the bedrock consists of basalt which crops out in the riverbed, but is overlain by moraine and alluvial sediments on the abutments. These deposits may reach a thickness of 5-10 metres in some places, but the lower part of the moraine has presumably acquired sufficient bearing strength and water-tightness to serve as foundation for the dam.

The proposed reservoir is everywhere, except at the dam site, contained within a basin in the Hreppar bedrock, and is accordingly, well watertight.

The geological conditions at the sites of the proposed diversion dams are similar to those at the site of the main dam, just described.

3 Stream- flow and Storage

No stream- flow records are available either of river Fossá or of the rivers to be diverted into that river.

The mean discharge of river Fossá at the dam site has been estimated 7.5 m^3/s by the S.E.A. Hydrologic Survey.

The main storage reservoir of the scheme is in Fossölduver, glacier- eroded basin just upstream from the dam site. The live storage available in this reservoir will be ab. 70 Gl in the first phase of the scheme, but may be increased to 100 Gl by the raising of the main dam envisaged in the second phase. In the third phase, a second reservoir with a live storage of 20 Gl is contemplated in the Fossárdrög, farther upstream on river Fossá.

4 Description of the Development

4.1 Phase 1

Max. developed discharge	20.8 m^3/s
Gross head	314 m
Net head	289 m
Installed capacity	50 000 kW
(Drwgs.	A-1482;A-1545)

The main dam on river Fossá is located at the outflow of the river from the Fossölduver. The dam consists mostly of an earth-fill section with a concrete cut-off. A 120 m buttress section, equipped with bottom outlets for the removal of sediment from the reservoir, is constructed across the river-bed, followed on the eastern river bank by a 100 m long over-flow spillway. Max. height of the dam is ab. 18 m. The crest of the spillway is at el. 494 m. The dam is so designed that it may be raised 4 m (spillway el. 498) in the second phase of the development.

The intake is constructed in the riverbed just upstream of the bottom gates.

From the intake, a horizontal headrace tunnel leads to a surge basin excavated into the slope of the Fossalda at el. 500 m approx. The tunnel is lined with concrete.

A vertical penstock shaft connects the surge basin with the underground power house. The penstock is lined with concrete and steel.

A tailrace tunnel conducts the water from the turbines to river Fossá at el. 180 m approx. It is concrete-lined.

4.2 Phase 2

Max. developed discharge	20.8 m^3
Gross head	318 m
Net head	293 m
Installed capacity	50 000 kW
(Drwgs.	A-1482; A-1545)

The dam on river Fossá below Fossölduver is raised 4 m so that the crest of the spillway is at el. 498 m.

A dam is constructed across river Stóra Laxá ab. 5 km west from the Fossölduver at river el. 508 m.

The site of the dam is in a canyon ab. 12 m deep and 6 m wide
The crest of the dam is at el. 524 m; its max. height is 16 m.

The water is conducted to the Fossölduver reservoir by a tunnel. The tunnel taps the river Svartá about midway between the Stóra Laxá and the reservoir. The tunnel is unlined.

4.3 Phase 3

Max. developed discharge head and installed capacity the same as in phase 2.
(Drwgs. A-1482; A-1545)

A dam is constructed on river Dalsá near Öræfahnúkur, impounding the water of the rivers Dalsá and Kisa. The rivers are diverted to the Fossárdrög by an unlined tunnel. A s parate storage dam is constructed in the Fossárdrög, creating a reservoir to supplement the main reservoir in the Fossölduver, farther downstream.

A Preliminary Appraisal of the Hydro- electric Development of Lake Þórisvatn

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A Preliminary Appraisal of the
Hydro- electric Development of
Lake Þórisvatn

1 Introduction

In the following the hydro- electric development of the Þórisós, the outlet river of Lake Þórisvatn, and the Kaldakvísl, a glacial river to the north of the lake, will be discussed.

The main features of the proposed scheme are as follows:

River Kaldakvísl is diverted into Lake Þórisvatn, either by two separate dams, one across the Kaldakvísl and the other across the Þórisós, with a tunnel or a canal connecting the impounded water bodies, or by a single dam extending across both rivers a short distance above their confluence. Two alternative developments of the Lake are suggested: Alt. 1: The head between Lake Þórisvatn and the lower part of the Þóristungur is utilized in a single development. The gross head would be ab. 240 m; the total length of the water conduits (headrace and tailrace tunnels combined) would be ab. 11.5 km. In the following, this alternative will be referred to as the Þórisvatn development. Alt. 2: The head between the Lake and el. 500 is utilized in a single development. The water is discharged into river Blautakvísl whence it flows into river Tungnaá upstream of the Tungnaárkrókur peninsula. The same water might thus be used again by the Tungnaárkrókur and Hrauneyjafoss plants (cfr. the preliminary appraisal of the hydro- electric development of river Tungnaá). The gross head would be ab. 70 m in this case, but the total gross head of all three staged (the Vatnsfell stage plus the two Tungnaá stages) would be ab. 245 m, or about the same as that of the first alternative. This second alternative will in the following be designated the Vatnsfell development.

Both alternatives will be discussed below.

2 Local Conditions

River Kaldakvísl originates in the Vatnajökull ice cap. Its drainage area at the confluence with river Þórisós is 1120 km^2. Extensive lava fields are present to the south of the river from which some amount of water from springs flows into the river. Dragá rivers also discharge into river Kaldakvísl.

River Þórisós originates in Lake Þórisvatn. It os a very short river, only 8 km long. The river derives part of its water from the lake, but it also recieves some large springs from the eastern river bank which is covered with lava throughout the whole length of the river. Thus, the discharge at the confluence with river Kaldakvísl is more than twice the discharge at the outlet from the lake. The topographical drainage area of river Þórisós at the motor ford is 330 km^2, but the area actually drained by the river cannot be determined accurately, owing to the very pervious rock formations covering most of the topographical drainage area.

The normal water level of Lake Þórisvatn is at el. 571 m. With an area of 70 km², Lake Þórisvatn is the second biggest lake in Iceland (exceeded only by Lake Þingvallavatn, which has an area of 83 km²).

The whole of Lake Þórisvatn has been sounded. Max. recorded depth is ab. 100 m; and most of the lake is rather deep, even close to the shore.

The rivers Kaldakvísl and Þórisós are lying at the boundary between the Palagonite series and the Hreppar series (cf. Mr. Kjartanssons report to the SEA on the geology of the Þórisvatn area). The details of the geology at the various sites in this scheme will not be discussed here, although some of the more important geological features will be mentioned below, when discussing further investigations which should be carried out at the sites. For further information on the local geology, Kjartanssons report should be consulted.

3 Summary of Alternative Developments

As mentioned in the introduction, two alternative developments of Lake Þórisvatn will be discussed. For one of them, two variants, differing in the location of the dam(s) on the Þórisós and the Kaldakvísl, will be put forward. However, as there obviously is an appreciable difference in the dam costs of the two variants, only the cheaper one is taken with the other alternative.

3.1 Alternative 1, variant a

A development in a single stage of the head between Lake Þórisvatn and the lower part of the Þóristungur. A seperate dam across each of the rivers Kaldakvísl and Þórisós.

3.2 Alternative 1, variant b

Same as above, except a single dam across the Kaldakvísl and the Þórisós a short distance above their point of convergence.

3.3 Alternative 2

A development of the head between Lake Þórisvatn and el. 500 m at a point near the river Blautakvísl, upstream of the proposed Tungnaárkrókur and Hrauneyjafoss developments on river Tungnaá.

3.4 Main Characteristics of the Various Alternatives

The following table shows the main characteristics of the alternatives mentioned above.
The cost figures are taken from rough cost-estimates based on

the 1955 price level and are shown for comparison only, but are not intended to show the power costs actually to be expected from the developments

Alternative	1.a	1.b	2	Unit
Installed capacity	120	119	33,5	MW
Annual production of primary power	720	714	201	GWh
Cost of civil engineering works	289	321	208	Mkr
Cost of mech. and el. plant & equipment	131	130	39	Mkr
Roads	10	10	8	Mkr
Total construction cost	430	461	255	Mkr
Total cost per kW of installed capacity	3580	3880	7610	kr/kW
Total cost per kWh of annual primary power	59.7	64.6	126.8	aur/kWh

4 Stream-flow and Storage

4.1 Stream-flow

As mentioned above, the drainage area of the Kaldakvísl and the Þórisós at the site(s) of the proposed dam(s) are ab. 1120 and 330 km², respectively.

Continuous stream-flow records of the two rivers are not available. Systematic gauging began last year, when a water level recorder was installed at each of the rivers. According to a SEA Hydrologic Survey estimate, the mean discharge of river Kaldakvísl at the site of the proposed dam is 30-35 m^3/s, that of river Þórisós 13-15 m^3/s , making a total of some 46 m^3/s .

In this appraisal, a full utilization of the annual run-off of the two rivers has been assumed. The max. developed discharge is taken as 67 m^3/s , corresponding to an annual utilization time of 6000 h (annual load factor ab. 70%).

4.2 Storage

Based on the flow-regulation curves for river Þjórsá at Urriðafoss, a storage amounting to 800 Gl or 55% of the mean annual run-off of the Þórisós and the Kaldakvísl combined would be required to ensure a uniform discharge equal to the mean discharge. A drawdown of Lake Þórisvatn to el. 560 m is required to obtain this storage. The design and location of the intake works is based on this drawdown, but the headrace tunnel is placed at a lower elevation in order to be able to obtain a greater storage space, by a lowering of the lake's water level later on.

5 Conclusions

The purpose of the present appraisal is to allow a comparison to be made between the various alternatives of the Þórisvatn scheme, and between this scheme and other ones. Further, the purpose is to point out what additional investigations must be performed at the site before a reasonably accurate design can be prepared for the development.

Although the data on the geology of the dam sites are still incomplete, as will be further discussed below, a comparison of the cost of a dam at the two alternative sites (var. a and b of Alt. 1) indicates that the two-dams variant (var. a) is so much cheaper that the other (lower) site may be abandoned without any further study.

There is a possibility of lowering the water level of Lake Þórisvatn by excavating a channel from the lake, deeper than the present outlet, thus reducing the necessary height of the dams and, accordingly, their cost. However, as adequate topographical maps of the site for the draining channel are not available, we have not included this alternative in the present appraisal.

There are still other ways of diverting river Kaldakvísl into Lake Þórisvatn, but they will not be discussed here.

Several routes are possible for the water conduits (tunnels) from Lake Þórisvatn to the Þóristungur. These routes are shown on drwg. A-1679. We have selected one of these routes for the present appraisal (shown more distinctly on the drawing). However, before some further investigations of the tunnel routes have been performed, it is not possible to say whether or not the route selected here has some advantages over the other routes.

In order to enable a comparison of the alternatives to be made, a rough estimate has been made of the cost of increasing the capacity and output of the Tungnaárkrókur and Hrauneyjafoss plants on the Tungnaá river.

The main features of each of the two alternatives are shown in the table below.

	Alt. 2 (Vatnsfell) + increased output of two Tungnaá plants	Alt. 1 a (Þórisvatn) + two Tungnaá plants
Installed capacity	223 MW	251 MW
Annual output of primary power	1640 GWh	1479 GWh
Cost of civil eng. works	480 Mkr	506 Mkr
Cost of mechanical and electrictal plant & equipment	250 Mkr	276 Mkr
Cost of roads	20 Mkr	22 Mkr
Total construction cost	750 Mkr	804 Mkr
Total cost per kW of installed capacity	3360 kr/kW	3200 kr/kW
Total cost per kWh of annual primary output	45.8 aur/kWh	54.4 aur/kWh

The first column in the table shows the figures for the Vatnsfell development (alt. 2) plus the two Tungnaá plants Tungnaárkrókur and Hrauneyjafoss at increased output and capacity.

The second column shows the corresponding figures for the Þórisvatn development plus the Tungnaá plants at the latter are described in the appraisal of the Tungnaá developments.

The table shows that there appears to be only a slight difference between the two schemes, so small, that it is within the limits of accuracy of the estimates. Therefore, not too much significance can be attributed to this difference at the present stage of the matter.

Besides, there may be some other considerations to be taken, such as financing of the scheme and so on.

6 Further Investigations

As previously mentioned, the investigations at the sites of the scheme are still incomplete.

In the following, the tasks which have to be performed before a reasonably accurate project can be drawn up of the present development will be discussed.

6.1 Topographical mapping

Adequate topograpical maps of the area involved in this scheme are either avilable or in preparation, so that they will be at hand when needed.

6.2 Hydrology

The available data on the hydrology of the scheme leave much to be desired as there is only one year since water level recorders were installed on the Þórisós and the Kaldakvísl.

In the present appraisal, the figures for stream-flow and storage are based on the records of Þjórsá at Urriðafoss, a great distance downstream from the present scheme and in a different topography (on the lowlands). Of course, matters will improve in the future in this respect, but temporarily, all the streamflow data required for this scheme must be estimated. The water level recorder on the Þórisós has been installed at the dam site but the Kaldakvísl recorder is located some distance upstream from the dam site on that river. Some springs issue into river Kaldakvísl between the recorder and the dam site.

Their discharge must be measured from time to time.

It would also be interesting to know the discharge of the springs issuing from beneath the lava sheet on the Þóriós dam site, both those issuing into river Þórisós and into river Kaldakvísl, and to compare the discharge of these springs with that of the Þórisós at or above the dam site.

6.3 Geology

6.31 Upper Dam Sites on the Þórisós and the Kaldakvísl

The geology at the dam sites has been investigated by Kjartansson and is described in his report. The main geological features will be discussed briefly in the following, but for further information, Kjartanssońs report is referred to.

The proposed dam across river Kaldakvísl is ab. 970 m long and ab. 20 m high, as a maximum, in the riverbed.

The description given in the report on the geology of this dam site does not require any comments except that it may be stated with certainty that a complete preliminary project for the dam can be prepared without any further site investigations other than the exploration of the depth of the overburden covering the basalt bedrock and of the moarine deposit at Mt. Sauðafell.

The same is not true of the dam site on the Þórisós. The proposed dam is ab. 1050 m long, with a max. height above the riverbed of 13 m approx. The western part of the dam has to be founded on moraine the eastern part on lava.

The following is a quotation from Kjartanssońs report on the moraine on the dam site:

"In the authoŕs opinion, there is every indication that this moraine is sufficiently indurated and tight to serve as foundations for a dam of the height in question here, with exception. however, of the surface layer, where the holes has to be lined".

We agree with Mr. Kjartansson on this point, although we are of the opinion that the properties of this moraine require further investigations.

Last summer (1958), some pits were dug into the moraine with a bulldozer. Owing to the high induration of the moraine, the pits could not penetrate deeper than ab. 1.3 m. At that depth. the bulldozer could no longer loosen the moraine.

Samples (disturbed).were taken from the moraine. In general, it appears to be well cemented, with rather few boulders at some depth, although its surface is owerstrewed with boulders.

A particle-size distribution analysis of the samples has been made. It shows that the moraine contains relatively little amount of fines. Liquid-limit, plastic-limit and optimum moisture content tests have also been performed on the samples.

The moraine should be subjected to all tests usually applied to sedimentary deposits, e.g. permeability tests; shearing-strength tests; moisture content tests and compaction tests.

Furthermore, before the scheme is finally decided upon, the thickness of the moraine should be explored. This can only be done by core drilling; the boreholes should extend well into the bedrock. The cores should be tested in accordance with standard practice.

A brief discussion of the lava on the dam site will now given.

Apparently, most of the springs which issue into river Þórisós from the lava on the eastern river bank are situated upstream of the dam site. In our opinion, this is a phenomenon deserving some further attention, as the ground-water table in postglacial lavas is, in general, at the bottom surface of the lava, except where local conditions cause a rise in the ground-water level. A study of the ground-water table at the Þórisós dam site reveals the following:

River Þórisós at the dam site is at el.	562.5 m
The ground-water table in borehole A in the moraine on the western river bank is at el.	563 m
The ground-water table in borehole D is at el.	565 m m
The ground-water table in borehole E the easternmost borehole in the lava is at el.	563.8 m
The surface of a small pond in the lava a short distance below the dam site is, according to the topographical map of the area, at el.	564 m

The springs at the dam site issue under an artesian head.

The lower boundary of the lava sheet is at el. 552 the rivers Þórisós and Kaldakvísl are at el. 550 m approx. downstream of the dam site, where they flow on each side of a narrow lava tongue.

Taking these facts into account, the rivers might be expected to drain the lava field appreciably, and large springs should issue into the rivers from beneath the lava downstream of the dam site. It may, therefore, be concluded either that the lava at the dam site is very impervious or that there is some hindrance to the ground-water flow at the dam site or downstream of it:

At the Þórisós dam site, the lava has filled a relatively narrow gorge. There is thus a possibility that the lava has been well compacted and acquired an intimate contact with the slopes of the gorge, although this accumpti is in a contradiction with the experience from the Laxá development in Northern Iceland, where a scoriaceous boundary between a lava flow and the gorge slopes was observed, extending as far down as the excavation for the main dam of that development.

A second possibility is the presence of two lava flows at the dam site (cf. Kjartanson's report), the lower one having been considerably tighted up for some reasons. This possibility is favoured by the presence of springs issuing into river Kaldakvísl apparently from the contact plane of two lava sheets. A possible reason for the tighting-up of the lower lava sheet is that the buried gorge might be an old riverbed of Kaldakvísl. The first lava flow might have dammed up the river, which subsequently might have flowed over the lava until the river was dammed again by the second lava, when it started cutting down its present bed at the slope of Mt. Sauðafell.

An evidence of two lava sheets is, in our opinion, the core loss in the boreholes, although only a few holes were sunk through the lava. The fact that the core loss was not observed at corresponding depths in the boreholes could be explained by the very uneven surface of a lava flow, as there is no reason to assume that the lower lava sheet was any more even than the upper one. The experience from boreholes in the Laxá gorge shows that the thickness of a lava sheet may vary considerably. In that place there are two sheets, one on top of the other. The thickness of the younger (upper) sheet was found to range from 5 to 10 m; that of the older (lower) one from 7 to 14 m.

A third possibility is that the lava has not filled a riverbed but an inlet of Lake Þórisvatn, and that an impervious threshold downstream of the site is holding up the ground water.

We think that investigations have to be performed with the aim of finding out whether or not any of the above hypothesis is true before a reasonably accurate cost estimate for the dam can be made. For instance, should there be two lava sheets at the site, a cut-off extending down through the upper sheet and a short distance into the lower one should be sufficient. However, at this stage of the matter there is no reasons for such speculations.

Wat is most important at the moment is to investigate the subsurface conditions at the site, especially the following:

1. Find out whether or not an impervious threshold is underlying the lava downstream of the dam site.

   This could possibly be accomplished by resistivity measurements, supplemented by borings if necessary.

2. If no such threshold is found, further investigations should be carried out to find out whether there are two lava flows or only one.

The core loss in the few existing boreholes at the site, as well as the ground-water level in the lava seems to indicate that the upper sheet- if there are in fact two lava sheets - is not very thick. A few additional boreholes and a thorough study of the cores from them might give a definite indication in this question. However, in the author's opinion, the safest way of acertaining this question beyond doubt would be to excavate a trench into the lava. Such a trench would at the same time give information on the consistency of the lava.

At the same time, detailed petrographical and chemical analysis of the lava above and below the springs issuing into river Kaldakvísl from the lava should be performed in order to detect possible differences in the physical characteristics of the rock which might answer the question of one or two sheets of lava. In the case of the Laxá development, however, such a study did not give a definite answer to the same question, as the difference in the physical characteristics was very small, almost undetectable.

Further, the water from the springs should be analysed chemically.

As to the dam site as a whole, we are of the opinion that there is no reason to abandon it and that the difficulties entailed by the rather unusual geological conditions may be overcome without unduly high costs.

In the rough cost estimates we have made of the dam, an earth dam with a concrete cut-off on the lava has been assumed.

6.3.2 Route for a Tunnel or a Canal Between the Reservoirs Above the Dams

A tunnel has been assumed in this appraisal to connect the impounded waters above the dams on the Þórisós and the Kaldakvísl, although a canal would also be a possibility. The choice is a matter of construction cost.

The proposed conduit has to run through a hill consisting of basalt, overlain by a thick moraine. In a borehole near the top of the hill, the thickness of the moraine was 15 m. A tunnel would have to lie entirely within the basalt and may thus have to be driven at a greater depth than would otherwise have been the case, which, however, would be well possible.

For a preliminary project of the scheme, no further investigations of the route appear to be required.

6.3.3 The Reservoir Area

According to Kjartansson (cf. his report on the Þórisvatn area), the watertightness of the proposed reservoir may safely be relied upon, except at the dam site on the Þórisós and to some extent along the western limit of Lake Þórisvatn, where some water leaks away from the lake to the Þóristungur.

6.3.4 The Lower Dam Site on the Þórisós and the Kaldakvísl; Single Dam Across Both Rivers

The proposed dam will be ab. 1300 m long and ab. 25-30 m high in the Kaldakvísl riverbed, and ab. 20 m high in the Þórisós riverbed.

The geology of the site is thoroughly described in Kjartansson's report.

The following investigations are required at the site:

(1) To find the thickness of the lava, either by drilling or by excavating test pits through the lava, which presumably is not very thick at the dam site. The boreholes should extend somewhat into the base of the lava, to furnish

information on the characteristics of the base. The resistivity measurements made at the dam site in the summer of 1958 were not considered conclusive. However, as these measurements were performed at one location only and no comparative measurements were made outside the lava, they should be repeated.

In the beginning, two boreholes or test pits would be sufficient.

(2) To explore the thickness of the moraine overlying the palagonite bedrock outside the lava at the dam site, and the physical characteristice of the moraine and the palagonite rock.

Or course, before constructing a dam at this site, extensive final investigations of the site must be carried out, as is usual in such cases. However, this alternative for the dam will presumably be so much more expensive than the other one that a dam will never be constructed at the site.

6.3.5 The Reservoir Area

The same comments apply here as in case of the reservoir area of the other alternative the upper dam sites.

6.3.6 Tunnel Routes from Lake Þórisvatn to the Þóristungur

The geological structure on the possible routes for the proposed tunnel is described in Kjartanssons report, mentioned above. His assessment is based solely on surface features. Obviously, a subsurface exploration by core drilling is required.

Last year, the present writer suggested ab. 10 boreholes along the possible tunnel routes in order to give a general picture of the subsurface conditions.

The depth of these boreholes would range from 40-320 m. The location of the suggested boreholes is shown on an accompanying drawing. It should be pointed out that permeability tests of the bedrock should be carried out, at least in some of the boreholes. The tests will presumably have to be performed as the drilling proceeds.

At the same time it should be noted that these tests may not be expected to give more than a qualitative indication of the permeability of the palagonite rock, owing to the variable structure of this rock type from one location to another.

As the tunnel will lie below the ground-water table for the most of its length and, accordingly, some leakage into it may be expected, the present writer has previously pointed at the possibility of lowering the water level of Lake Þórisvatn temporarily, while the construction work was in progress.

This might be accomplished by driving a temporary tunnel through the Ósöldur hill, which appear to consist of a much sounder rock than the surroundings. The length of such a tunnel would be 3.5 km approx.

The construction of the dams across the Þórisós and the Kaldakvísl would also be facilitated by the lowering of the water level of the lake.

At the present stage of the matter, a further discussion of the tunnel routes is not considered timely.

6.3.7 Sites for Tunnel and other Works of the Vatnsfell Development

The technical aspects of the local geology of this scheme have not yet been assessed. It may however, be stated already that most of the works will be in palagonite rock, similar to that on the upper part of the tunnel route from Lake Þórisvatn to the Þóristungur. The local conditions for this scheme will not be discussed further here.

7 Description of the Alternative Developments

At the beginning of this report, the main characteristics of the two alternative developments of Lake Þórisvatn were given In what follows, each alternative will be described in greater detail.

7.1 Alternative 1, variant a

Max. developed discharge	67 m^3/s
Gross head	242-238 m
Average net head	215 m
Installed capacity	120 000 kW

The dam designs adopted here were put forward in 1956 when no investigations had been carried out at the site. Since then, some boreholes have been sunk at the dam site on the Þórisós. There borings revealed that the lava is ab. 22.5 m thick as a maximum, instead of 10 m as assumed prior to the borings. A cut-off down through the lava might thus be much more expensive than originally assumed. However, as the porousity of the lava is very variable, it may possibly be tighted by injection grouting, so that a cut-off need only be carried through the scoriaceous top layer of the lava. For the present discussion, therefore, there are no reasons for changing the original designs.

The dam across the Kaldakvísl consists of an earth-fill section, ab. 970 m long, with a concrete cut-off, and a spillway section ab. 200 m long, constructed as a concrete buttress dam. Max. height of the dam in the riverbed of Kaldakvísl is ab. 20 m. A bottom outlet for the removal of precipitated sediment is envisaged in the riverbed. The crest of the spillway is at el. 577.0 m, that of the earth dam at el. 580.0 m.

The Þórisós dam has a total length of 1050 m. It consists of an earth-fill dam with a concrete cut-off, except in the riverbed of Þórisós, where a 75 m long concrete spillway section is contemplated. Max. height of this section is 17 m. The crest of the spillway is at el. 574.0 m; that of the earth-fill section at el. 577.0 m.

From the Tangadjúp deep near the Grasatangi peninsula on the south-western side of Lake Þórisvatn, a 5100 m long headrace tunnel leads to a surge basin excavated into the western slope of the Stóragilsalda. The tunnel will be concrete-lined, with a cross section area of 21.4 m^2.

Two vertical penstock shafts, circular in shape with an internal diameter of 3.9 m and lined with concrete and steel, connect the surge basin with the underground power house.

A tailrace tunnel, concrete lined and having a cross section area of 21.4 m^2 leads from the power house to river Kaldakvísl at el. 332 m, a short distance downstream of the mouth of the Tjaldkvísl,

Two generating units are contemplated, each rated 60 000 kW.

A 900 m long access tunnel, with ducts for ventilation and cables connects the power house with the ground surface.

7.2 Alternative 1, variant b

Max. developed discharge	67 m^3/s
Average net head	213.5 m
Installed capacity	119 000 kW

A single dam across both river is contemplated ab. 2 km above their confluence.

The dam consists of an 1100 m long earth dam across the Kaldakvísl and the Þórisós and the lava tongue between the rivers, and a concrete spillway, 140 m long, across the trench in the basalt on the northern side of the Kaldakvísl. The trench has to be widened somewhat to acquire the required spillway length.

Max. height of the earth dam is 27 m, in the riverbed of Kaldakvísl.

A concrete cut-off through the lava tongue, the tickness of which is unknown, has been assumed.

On the southern abutement, the foundations consist of moraine. The moraine may be assumed to have reached sufficient watertightness below the weathered surface layer.

It is proposed to construct the earth dam from this moraine. The crest of the earth dam is at el. 575 m; that of the spillway at el. 572.5 m.

A diversion tunnel is driven through the basalt of the northern bank of the Kaldakvísl. It has a cross section area of 85,7 m^2 and is lined with concrete.

Alternative to the earth dam, a rock-fill dam may be constructed using basalt rock from borrow pits on the northern bank of the Kaldakvísl.

Waterways and power-house are identical with those in Alt. 1, var. a.

7.3 Alternative 2 (Vatnsfell Development)

Max. developed discharge	67 m^3
Gross head	74-60 m
Average net head	60.3 m
Installed capacity	33 500 kW

The dam in this alternative is identical with that of Alt. 1, var. a.

The intake will be located in Lake Þórisvatn near the hill Vatnsfell on the southern side of the lake.

A concrete lined headrace tunnel, 6100 m long with a cross section area of 26 m^2, leads to a surge basin excavated into a mountain slope ab. 2 km to the north from the Tungnaárkrókur.

The power house is wholly underground. It contains one generating unit, rated 33 500 kW.

A concrete lined tailrace tunnel, 200 m long with a cross section area of 26 m^2 leads from the power house to the intake reservoir of the proposed Tungnaárkrókur plant, at el. 500 m.

A Preliminary Appraisal of the Hydro- electric Development of River Tungnaá

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A Preliminary Appraisal of the Hydro-electric Development of River Tungnaá

0 Introduction

In the following, a preliminary appraisal will be given of the hydro-electric developments of river Tungnaá. This appraisal is a part of the appraisal study of the full development of the Þjórsá river system.

Three different sites on river Tungnaá will be discussed, viz. Hrauneyjarfoss, the lowest stage, Tungnaárkrókur, the middle stage and Bjallar, the uppmost stage.

The general conditions at each site are described and various alternatives of development are discussed and compared. Finally, some possible storage facilities on the river are mentioned.

At this stage of the matter, the basic data available are still incomplete, both as regards the discharge of the river at the sites and the geology of the surrounding area. Sufficiently accurate topographical maps are also not available of some of the sites.

The purpose of this appraisal is to endeavour, in spite of these shortcomings, to make a general survey of the condition for the development of the river, and to make a comparison, although incomplete, between possible sites on the river and between them and potential sites on other rivers which have previously been studied. Last, but not least, the purpose is to point out what kind of further investigations are required before a reasonably accurate project can be drawn up for these developments.

1 Geographical Features and Local Conditions

River Tungnaá originates in the Vatnajökull ice cap, the uppermost river sections at the margin of the glacier is at el. 700 - 900 m. From there, the river flows through a narrow gently sloping valley for ab. 50 km in direction southwest, where it turns sharply to the north and flows in that direction for ab. 9 km to Svartikrókur, where it turns to the north-west, keeping that direction except for some smaller turns, for the next 25-30 km of its course, until at the confluence with river Kaldakvísl, where it turns once more this time to the south-west, and retain that direction for a distance of ab. 15 km. to the confluence with river Þjórsá at Sultartangi. That confluence lies at el. 275 m. The total fall in river Tungnaá, from the glacier to river Þjórsá is thus ab. 425 m. The length is ab. 100 km, giving an average slope of 1 in 235. The main fall in the river is, however, confined to the section between the Kaldakvísl confluence and the Bjallar ford where the fall amounts to 230-240 m in ab. 30 km, giving an average slope for that section of 1 in 125. The sites discussed below are all located in this section of the river.

It is proposed to utilize a total head of 203-239 m, depending on the various alternatives, at the three sites under discussion here, or 80-100% of the fall in the river in this section.

The main tributary to river Tungnaá upstream of the proposed sites is the Jökulgilskvísl river, a glacial river originating in the Torfajökull ice cap, and discharging into river Tungnaá a short distance upstream of the Svartikrókur peninsula. This river carries great amount of sediment load during the summer months.

Near Svartikrókur, the Vatnakvísl a lindá river draining the Veiðivötn area, discharges into river Tungnaá.

Another lindá river, the Blautakvísl discharges into river Tungnaá upstream of Tungnaárkrókur.

Finally, river Kaldakvísl flows into river Tungnaá in the Þóristungur, below the river section considered here.

Besides these rivers, large springs issue into river Tungnaá from the lava fields on the western bank. They will be further described later.

1.1 Geological Conditions

Time has not yet allowed a geological survey to be made of the area of interest for the proposed power schemes.

The whole of the drainage area of river Tungnaá, all the way from the origin down to the confluence with river Kaldakvísl and the sites of the proposed schemes are lying within the area of the Palagonite series. The chief features of the Palagonite series are described in Kjartansson's report.

Postglacial lavas and pumice deposits cover extensive areas in the Tungnaá watershed. These formations are also of a great importance at the proposed sites, where the so-called Þjórsá lavas are forming the western river bank. They will be described in greater detail later, in the discussion of the various power sites.

1.2 Hydrological Conditions

As mentioned above, river Tungnaá originates in the Vatnajökull ice cap. The river is thus a glacial stream, and posesses the main characteristics of such streams in the section from the origin until downstream of the Svartikrókur.

Farther downstream, two lindá rivers the Vatnakvísl and the Blautakvísl discharge into river Tungnaá, and the river also receives numerous large springs from under the lava field forming the western bank in a long section of the river. This modifies river Tungnaá considerably giving the river some lindá characteristics, such as the absence of an ice cover during most part of the winter, and a relatively uniform discharge (much more uniform than that of river Þjórsá, for instance).

Continuous stream-flow records are not available for river Tungnaá. A water level recorder was installed at Vatnaöldur last autumn (1958), and the chart with the water stage graph was removed in March 1959 for the first time. In this appraisal, which was prepared before that time, the stream-flow figures are taken from an estimate of the discharge of river Tungnaá at various locations, made by the State Electricity Authority's Hydrologic Survey. The estimate was based on the stream-flow records of river Þjórsá at Urriðafoss for a period of 10 years, and on some comparative discharge measurements in river Tungnaá. It is unnecessary to state here that the preparatory work for the river's development is very incomplete in this respect.

In order to illustrate the flow patterns of river Tungnaá at Vatnaöldur and river Þjórsá at Urriðafoss, a graph of the discharge at these two locations for a part of the winter 1958/59 is reproduced below. It is evident from the graph that the flow patterns are in general similar, so that the method adopted in the estimate viz to correlate the discharge at the two locations appears to have some justification although various errors are, of course, introduced thereby.

There are several possibilities of constructing storage reservoirs in the Tungnaá drainage area. They will be described below, starting at Hreuneyjafoss and going upstream.

By constructing an intake dam of a suitable height upstream of Hrauneyjafoss, a storage (rather pondage) space of ab. 35 Gl (1 Gl = 1 million m^3) may be obtained.

At Tungnaárkrókur, a considerable amount of storage space, ab. 205 Gl, may be obtained by a dam of the height proposed in this appraisal study, as described below.

Some reservoir space may be obtained at the Bjallar development, the size, of course, depending on the dam height. Two variants of this development will be put forward here. One of them will provide a storage of 200 Gl, while the other will give a small pondage only. Sufficiently accurate topographical maps of the area involved in this development are not yet available. The head of the development and the storage space have been determined from the American AMS maps, with 20 m contour intervals.

The next potential reservoir site on river Tungnaá is upstream of Vatnaöldur, where a reservoir of an appreciable size may be created. The reservoir size is, of course, dependant of the height of the dam. Accurate topographical maps are not available of the site.

Two other sites for a storage dam farther upstream in the river, at Ljótipollur and at Faxafit, may be mentioned.

Common to all the above-mentioned reservoir sites is that the bottom and the sides of the reservoir basins consist of porous and pervious rocks of the Polagonite series, so that some leakage from the reservoir may be expected. The higher the water level of the reservoir the greater is the leakage to be expected. For the three uppermost sites, this leakage would be unimportant, as the leakage water would presumably reappear in the river again upstream of the power plants, at a relatively uniform rate, and might be fully utilized. The effect would then be very much the same at that of a storage, viz. even out the flow of the river. As a matter of fact, the leakage water from the Bjallar reservoir could not be utilized at that plant, but at the two plants downstream, the Tungnaárkrókur and Hrauneyjafoss plants.

As to the magnitude of the leakage to be expected from the reservoirs, nothing definite can be said here. It will only be pointed out what is generally known in this country that there are many cases of lava flows and landslides damming up streams and forming big lakes. Of course, there is some leakage from such lakes, although not always of a great magnitude, at least not in such cases where the rock underlying the lava or the landslides is reasonably tight. In the present case, of course, the bedrock is exceedingly pervious.

There are two possible reservoir sites outside the part of the Tungnaá drainage system under discussion here, the utilization of which would also increase the discharge of river Tungnaá by diversion of water from ajacent watersheds. These sites are the lakes Langisjór and Þórisvatn.

In a separate appraisal, the use of Lake Þórisvatn as a reservoir is discussed. As to Lake Langisjór, no attempt will be made here to assess its value as a storage basin, owing to lack of data, both topographical maps, depth soundings of the lake and geological data. It should however be pointed out that there is every indication that the water of Lake Langisjór should be utilized in connection with the development of river Tungnaá rather than that of river Skaftá, whereto the outlet river from the lake now discharges, as the quantity of power obtainable would be greater in the former case.

2 Summary of Alternative Development

As mentioned above, it is proposed in this appraisal study to utilize the fall in the section of river Tungnaá between the Svartikrókur and the Kaldakvísl confluence in three separate developments or stages. The intake dams would be located at Bjallar, Tungnaárkrókur and Hrauneyjafoss. For each stage, two different heights of the dam, will be discussed. Four alternatives developments of the river section will be described briefly in the following:

2.1 Alternative (2.1)

A storage dam is constructed across river Tungnaá at Ljótipollur, providing a live storage of 200 Gl, with low intake dams at all three power plants.

2.2 Alternative (2.2)

A live storage of 200 Gl is provided by the intake dam of the Bjallar development with low intake dams at Tungnaárkrókur and Hrauneyjafoss.

2.3 Alternative (2.3)

A high intake dam, providing a live storage of 205 Gl is constructed at Tungnaárkrókur, with a low intake dam at Hrauneyjafoss. The Bjallar development is omitted in this alternative.

2.4 Alternative (2.4)

Hrauneyjafoss development only. A somewhat higher intake dam than in the above alternatives, giving a live storage of 35 Gl, is constructed across river Tungnaá.

2.5 Tables

Tables summarizing the characteristic figures for the indi-vitual developments (2.5.1) and for the various alternatives (2.5.2) are reproduced below. The costs shown in the tables are taken from preliminary rough cost estimated which were based on the 1955 price level, and are shown for comparison only, but are not intended to show the power costs actually to be expected from these developments.

2.5. Survey of Individual Developments

Name of Site variant	Bjallar (611)	(612)	Tungnaár-krókur (621)	(622)	Hrauneyja-foss (631)	(632)	Unit
Max. developed disch.	83	83	98	98	107	107	m^3/s
Gross head	45-61	50	55-75	55	98-103	98	m
Installed capacity	36,5	31,4	52	42	84	81	MW
Cost of civil engineering works	169	105	112	87	127	105	Mkr
Cost of mechanical and electrical plant and equipment	43	37	55	45	94	90	Mkr
Total cost	212	142	167	132	221	195	Mkr
Total cost per kW of installed capacity	5810	4520	3210	3140	2630	2410	kr/kW

2.5.2 Summary of Various Alternatives Developments of the River Section

Alternative	(2-1)	(2-2)	(2-3)	(2-4)	Unit
Installed capacity	154,4	159,5	133	84	MW
Annual power production	927	957	798	445	GWh
Cost of civil eng. works	337	361	217	127	Mkr
Cost of mech. and el. plant	172	178	145	94	Mkr
Cost of acess roads	35	20	12	6	Mkr
Total cost	544	559	374	227	Mkr
Total cost per KW installed	3530	3510	2810	2700	kr/kW
Total cost per kWh of annual power production	58,7	58,4	46,8	51,0	aur/kWh
Storage capacity	200	200	205	35	Gl

3.1 Storage and stream-flow

As previously mentioned, no continuous stream-flow records are available of river Tungnaá at the proposed sites. The storage requirement figures given here are taken from an estimate of the probable storage requirements at different locations on river Tungnaá, made by the S.E.A's Hydrological Survey. In this appraisal the (estimated) mean discharge is selected as the developed discharge at rated plant output. According to the S.E.A.'s estimate, this discharge can be maintained uniformly for 90% of years by means of 200 Gl of storage capacity.

3.2 Stream-flow

The State Electricity Authority's Hydrological Survey has estimated monthly averages of discharge of river Tungnaá at different locations. This estimate is based on 10 year's stream flow records of river Þjórsá at Urriðafoss and some comparative discharge measurements of river Tungnaá. The results are given in the Hydrological Survey Report No. 161 Oct. 1958.

4 Conclusion

From the present appraisal study, it may be conclused that both the Hrauneyjafoss and Tungnaárkrókur sites look very promising, whereas the cost of power from the Bjallar development would presumably be appreciably higher than from the two plants mentioned first. A comparison of these three sites under discussion here with several other sites in the Þjórsá and Hvítá river basins, previously studied by us for the S.E.A., would be as shown in the table at the end of this appraisal report.

The cost of access roads to the sites and cost of transmission lines are not included in the comparison. As to design, installed capacity and total construction cost of the power plants listed above, reference is made to previous appraisal studies made by us for the S.E.A.

The figures for the potential annual power production are based on a S.E. A. estimate of the storage requirements of the various sites and of the storage possibilities in the rivers

The comparison is in so far incomplete as the rated power of the various plants is chose somewhat arbitrarily and is therefore badly comparable.

In terms of total cost per kW installed, the Sultartangi scheme is the most advantageous, followed by the Hrauneyjafoss scheme. However, owing to the fact, that the rated power of the various plants is hardly comparable, as just mentioned, not too much importance should be attributed to this point.

A better comparison would be obtained by comparing the total construction cost per kWh of the annual production of primary power. When calculating this cost, separate storage facilities at lake Þórisvatn for the Sultartangi scheme have been assumed, as such a storage is considered a prerequisite for the practicability of that scheme. For the Hrauneyjafoss scheme storage facilities at Tungnaárhólmur have been assumed. On this basis, this scheme would be no less advantageous than the Sultartangi. Assuming pondage reservoirs only above intake dams the power cost would be lowest from the Hrauneyjafoss plant, with the Tungnaárkrókur as the second. These cheaper variants of the Hrauneyjafoss and the Tungnaárkrókur schemes are not included in the comparison, because in our opinion, the other variants, viz. those with higher intake dams, should be selected for these schemes, except in the case that further site investigations, e.g. at Tungnaárkrókur, show these variants to be impracticable. In the case that the Hrauneyjafoss is developed first with regard to the operating security of the plant, it would not in our opinion, be justifiable to select the low dam, whereas the higher one would at any rate give some storage, ab. 35 Gl. If, as the other hand, the first plant is constructed at Tungnaákrókur, the low dam might be sufficient for the Hrauneyjafoss plant, although ab. 5 m of head is lost thereby and a pondage of 4-5 Gl only is obtained both based on the selection of the dam site proposed here. However, it should be stressed once more that operating security of hydro-electric plants is greatly increased by a large and deep intake pond. With this in mind, we do not recommend the lower dam in this case either.

Concerning the danger of leakage from the reservoir, we are of the opinion that it is not as serious as might appear at first sight. This point will be further discussed in the next section, dealing with the site investigations which still have to be performed before the preparations can be said to have complied with the demands usually made for the preparatory work for hydro-power developments.

5 Further Site Investigations

As previously mentioned, the basic data available for the appraisal of the three sites under discussion here are very imcomplete. This applies both to geological and hydrological data. Accurate topographical maps are lacking for one Df the power sites and for the possible sites of storage dams and reservoirs.

5.1 Topographical Mapping

Matters are improving in this repect. Aerial photographs were taken last summer of the whole of the area of interest for the present projects. Levelling and other field work necessary for map compilation will be performed during the next summer (1959). After that time maps at the desired scales can be drawn.

5.2 Hydrological Survey

The fact that no stream-flow records are available of river Tungnaá until from the last winter cannot, of course, be altered. As mentioned previously the discharge of river Tungnaá at the proposed developments has been estimated from the stream-flow records of river Þjórsá at Urriðafoss, in the lowlands, a great distance downstream. As a matter of fact, the water level recorder of river Tungnaá at Vatnaöldur enables the discharge at that location to be compared to the discharge of river Þjórsá at Urriðafoss. Thus, a correlation may be obtained between the discharge at the two locations, which might then be extended backwards to the beginning of the Urriðafoss records, thereby "creating" records for river Tungnaá for the whole period of the Urriðafoss records. However, such a correlation can never be expected to be more than an approximation, and the deviations may be appreciable, both because the Þjórsá drainage area above Urriðafoss is so large that the weather may be different in different parts of it, and because the Tungnaá drainage area is geologically very different from the Þjórsá drainage area as a whole. Nevertheless, such "artificial" stream-flow records are much better than none at all, and may have some justification.

It should be noted that the discharge at the various dam sites has not yeat been determined by measurements at the sites themselves. As a matter of fact almost simultaneous discharge measurement have been performed at Vatnaöldur; upstream of Tungnaárkrókur and upstream of Hrauneyjafoss, but the discharge at the dam site at Tungnaárkrókur, for instance, cannot be determined from these measurements. It must be estimated, because the springs issuing into river Tungnaá, from under the lava between the two dam sites at Tungnaárkrókur are located downstream of the place where the discharge is measured. The discharge of these springs has not been measured, but has been estimated 3-5 m^3/s.

It is necessary to locate these springs, to measure their discharge frequently in order to determine its magnitude and to detect any variations in the flow. The water temperature of the springs and its variations should also be determined, as an information on this point might be valuable in assessing the water temperature at the proposed intakes. Furthermore every available method should be utilized to find out where the spring water originates, whether it comes from river Tungnaá or from somewhere else. A chemical analysis of both the spring water and the river water might be of value in this respect, and such an analysis should be made anyway in order to determine the chemical effects of the water on the proposed structures.

In a report on the ice conditions on river Þjórsá and its tributaries Mr. S. Rist, hydrologist of the S.E.A. discusses the possible effects of ice on the operation of the proposed power plants. With regard to the power schemes under discussion here, Mr. Rist comes to the conclusion that a great amount of sludge may be expected to collect at the intakes of the Tungnaárkrókur and Hrauneyjafoss plants during two periods of the year: (1) In the autumn, while an ice cover is being formed on the uppermost sections of river Tungnaá, and (2) in the winter, when sludge is formed in the river section Vatnaöldur - Hrauneyjafoss, where an ice cover is almost never lying over the river. This sludge might give rise to interruptious in the operation of the plants unless they are provided with large and deep intake ponds. This conclusion is in a full agreement with the opinion of the present writer, who, on many occosions has expressed the opinion that pure run-of-river plants are not practicable on the main rivers of Iceland, because the interruptions to be expected the operation of the plants would be beyond the tolerance limit.

In his report, Mr. S. Rist endeavours to estimate the amount of sludge in the water when an ice jam was formed in river Þjórsá at Urriðafoss last winter. He comes to the conclusion, that the part of the river flow occuring in the form of sludge may have been of the order of 6%. Not all this sludge has been collected behind the ice barrier, some of it has undoubtedly been carried downstream by the water.
Assuming the sludge conditons at the sites under discussion here to be similar to those of Urriðafoss, where the largest ice jams are formed during long frost periods, an attempt may be made to assess the necessary volume of the intake basins. Taking a discharge of 100 m^3/s and a sludge content of 6%, and assuming all the ice to be collected behind the intake, the total volume of ice collected in 4 weeks would be 14.5 Gl. As will be shown later, the storage volume of the high-dam variants of the Tungnaárkrókur and Hrauneyjafoss schemes would be 205 and 35 Gl, respectively, an indication that the higher dam at Hrauneyjafoss would provide sufficient storage capacity to avoid ice troubles at that plant.

Although this is a valuable hint in the matter, it should be noted that very little is known about the weather in the area of the proposed developments. Better knowledge on this point is very desirable.

5.3. Geological Investigations

A broad outline of the geology of the Tungnaá area has been given previously in this report, based on a description by Mr. Guðmundur Kjartansson, geologist. At the same time it was stated that no assessment had been made of the enginneering aspects of the local geology at the sites.

In the following, the geological conditions at the various sites will be described as they appeared to the present writer. At the same time, the investigations necessary for the preparation of a preliminary project for a development at each of the three sites will be discussed.

5.3. 1 Dam Site at Hrauneyjafoss

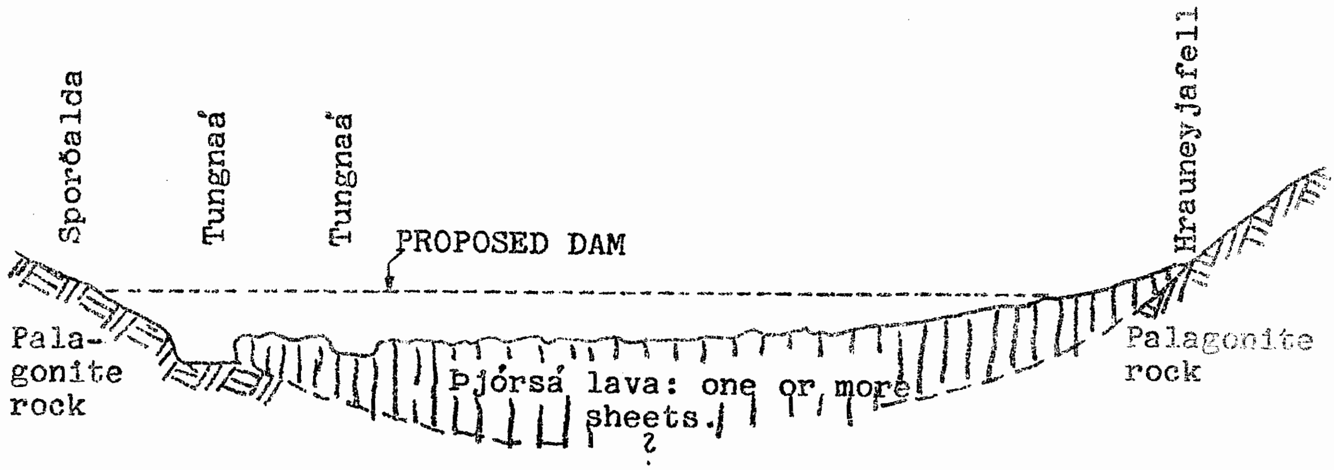

Fig. 1: Dam site at Hrauneyjafoss.

A profile of the dam site is shown on fig 1.
At the dam site, river Tungnaá is flowing in two branches, one of which has cut its bed into the palagonite rock at the edge of the lava, theother is flowing on the lava sheet.

In the higher-dam variant proposed here, the lenght of the dam is somewhat above 1800 m. The water depth at the dam in the eastern river branch where it is greatest, is within some 10-11 m, and within 7-8 m eslewhere so that this is a relatively low dam.

With exceeption of the eastern river branch, which as mentioned above, has cut its channel into a palagonite rock, the whole dam has to be founded on a pastglacial lava flow, a so-called Þjórsá lava, which has flowed through the pass between two hills, the Hrauneyjafell and the Sporðalda. Three Þjórsá lava flows are known to exist one on top of the other. The lava forming the ground surface at the site is the youngest of those three. Whether one or more lava flows are present at the site can only be ascertained by drilling.

A short description of the physical structure of postglacial lavas is held to be in place here. However, this description will by no means be exhaustive, and it must be pointed out, that the physical structure of lavas is in genera., so variable that deviations may always be expected and that no general description applies to all lava flows.

Broadly speaking, a lava sheet may be divided horizontally into three parts or zones. At the surface the lava is very uneven and broken-up with large openings and cavities and, in case of a "helluhraun" or "Pahoehoe" lava with slabs lying upset, like heap of floes. The rock is vesicular, heavily jointed and extremely pervious. Core recovery is very poor from such a surface layer.

Below this layer, but without any sharp boundary is a central zone, with a columnar rock, which is sound in itself and far less vesicular than the surface layer, although vesicles may be found in it. The individual columns consist of an impervious rock. The only leakage paths in this zone are the joints between the columns. The diameter of the columns is very variable from one location to another. Their direction is perpendicular to the cooling surface of the lava flow, i.e. in most cases vertical. Core recovery is generally very high from this zone.

The lowest zone is again heavily jointed and irregular, like the surface zone and very pervious. The boundary is not sharp in this case either.

Below the lava sheet, or between two lava sheets, soil beds may be expected. Although compressed by the weight of the overlying lava, such soil beds are, in general, of a loose consistency and poorly indurated.

Judging from the edge in the Hrauneyjafoss canyon wall, the columns in the central zone of the lava at the Hrauneyjarfoss dam site are rather large in diameter.

In the Laxá river development, northern Iceland (completed in 1953), a concrete gravity dam, 10 m in height, was constructed on two lava sheets lying one on top of the other in the gorge of river Laxá. The surface layer of the upper sheet was removed and the dam founded on the central zone of that sheet. After the filling of the pond, insignicficant leakage was observed in a few places. The total amount of leakage water was within 10 litres per second. This leakage diminished gradually and is now invisible.

At the Laxá the lava has flowed through a narrow gorge. At the gorge sides, at the boundary between the lava and the surrounding rock, the lava was very scoriaceous. At neither end was the dam carried down through this scoriaceous layer, although the dam was 15-16 m high at the western abutment. The risk involved in this method was accepted, a few grouting pipes being left in the dam to enable the foundations to be grouted if required, which, however, did not prove to be necessary.

It should be noted that the Laxá case is not directly comparable to the present one. At the Laxá, the lava has flowed through a narrow river gorge, resulting in a considerably less sound lava than at the sites under discussoin here. If there is any difference at all, the latter lava should, in general, be better suited for the foundations of a dam.

However, nothing definite can be said on this point. Exceptional formations and even large caverns may always be expected in a lava flow. Generally speaking, lava sheets are so inhomogeneous that the exploration of a dam site on lava by drilling is of little use, except if the borings are spaced very closely e.g. 1 or 2 metres apart, which however would obviously lead to quite prohibitive exploration costs. As it is doubtful that anything is to be gained by drilling many holes, it is here suggested that, initially, only two holes be drilled at the dam site at Hrauneyjafoss. The holes should be sunk through the lava and well into the underlying bedrock, in order to assess the thickness of the lava sheet(s) and the character of the bedrock. The aggregate depth of these two holes may be assumed to lie between 40 and 80 metres. The drilling should be supplemented by resistivity measurements, as they might give additional information.

It has been proposed in this appraisal to construct the 360 m long spillway section of the dam across both river branches and extending to both sides of it, as a gravity dam, with the end sections as rock-fill embankments with a concrete cut-off. Spoil from the tunnel would be used for these embankments. The construction of an impervious blanket on top of the lava, upstream of the cut-off wall might be useful for increasing the lenght of the leakage path, as some leakage under the dam must, of course, be expected. As a matter of fact, a great part of the bottom of the proposed reservoir and the edge of the lava sheet is covered with sediment from the water and may thus be expected to be relatively watertight, but the reservoir would extend beyond these parts, where water may be expected to percalate down into the lava.

While stating that it is hardly possible to estimate the magnitude of the leakage we are nevertheless of the opinion, that it will not be excessive, as the dam is relatively low, especially if it proves to be only one lava sheet on the site. We do not think that there is any danger of piping, on the contrary, the leakage will with certainty decrease with time, owing to the silt in the river water. Any objectionable leakage appearing after the construction of the dam might, in our opinion, be restrained by available methods, such as by grouting. However, at this stage of the matter, nothing can be said with certainty about the cost of such measures.

It is, of course, unnecessary to state that the lava has sufficient bearing strength to support a dam of the height in question here.

A possible path for leakage water from the reservoir is under the lava to the south of the Hrauneyjafell hill. In this connection, the exploration of the thickness of the lava there would be of interest. However, at that location the lava surface dips towards the river, and its base may be expected to dip in the same direction, which makes leakage rather improbable.

After the lava on the dam site itself has been explored, there might be a reason to investigate the lava to the south of the hill, especially if there are more than one lava sheet on the dam site. In any case, this leakage path would be so long that one should hardly expect any serious leakage along it.

As to the palagonite rock cropping out at both ends of the dam, and presumably forming the base of the lava on the dam site, it is certainly strong enough to support the dam. There would presumably be no objectionable leakage through this rock under the dam or around its ends, although the palagonite is by no means a watertight rock. There is no danger of piping. Should any leakage appear, it might be restrained by relatively small amount of grouting operations.

5.3.2 Tunnel Route of the Hrauneyjafoss Development

The total length of the proposed tunnel is 3150 m, where of the headrace tunnel is 600 m. At this stage, we do not find ourselves in a position to make any comments on the tunnel route. River Tungnaá has cut a deep canyon into the slope extending from the Hrauneyjafoss waterfall down to river Kaldakvísl. An experienced geologist is undoubtedly able to assess with a good approximation the geological structure on the tunnel route by studying this canyon. Nevertheless, the route should also be explored by drilling.. Initially, two holes would be sufficient e.g. one hole at the proposed power house and one on the tailrace tunnel. The total depth of both holes would presumably be about 160 m.

The headrace tunnel would presumably lie above the ground-water table, except in the immediate vicinity of the river, but the tailrace tunnel would undoubtedly lie below the ground-water table, so that some leakage might be expected in it. However, further dicussion of this point is of no use at this stage of the matter.

It is to be pointed out that the boreholes may be used to test the permeability of the surrounding rock.

5.3.3 Dam Sites of the Tungnaárkrókur Development

Two alternative dam sites have been proposed in this place, cf. drwg A 1817 and fig. 2.

It can be said right at the start that we recommend the lower one of these two dam sites.

River Tungnaá has not always flowed in its present channel. No attempt will be made here to guess its ancient bed, but it must have been to the west of the present one.

Three lava sheets are clearly apparent at the dam site, each from a separate flow. The first of them has filled the old river bed and presumably pushed the river to the east, to the palagonite hills near the site. The same has been repeated when the second lava flow occurred, it has dammed the river at the hills, forming a rather deep lake upstream of the lava dam, as is evidenced by terraces of alluvial deposits found on the slopes of the basin once containing the lake. Subsequently, river Tungnaá has cut its bed into the palagonite hill at the margin of the two lava sheets, forming a canyon with a maximun depth of ab. 50 m. The river bed has been cut down farther than to the base of the lava, and the river is now flowing on a palagonite breccia.

The palagonite contains great amount ot basalt. In the canyon walls, pillow lava is present to a great extent, an indication that the rock is strong enough to support a dam. In some places, the breccia forms almost vertical walls, 40-50 m in height.

The third lava flow has not reached the river.

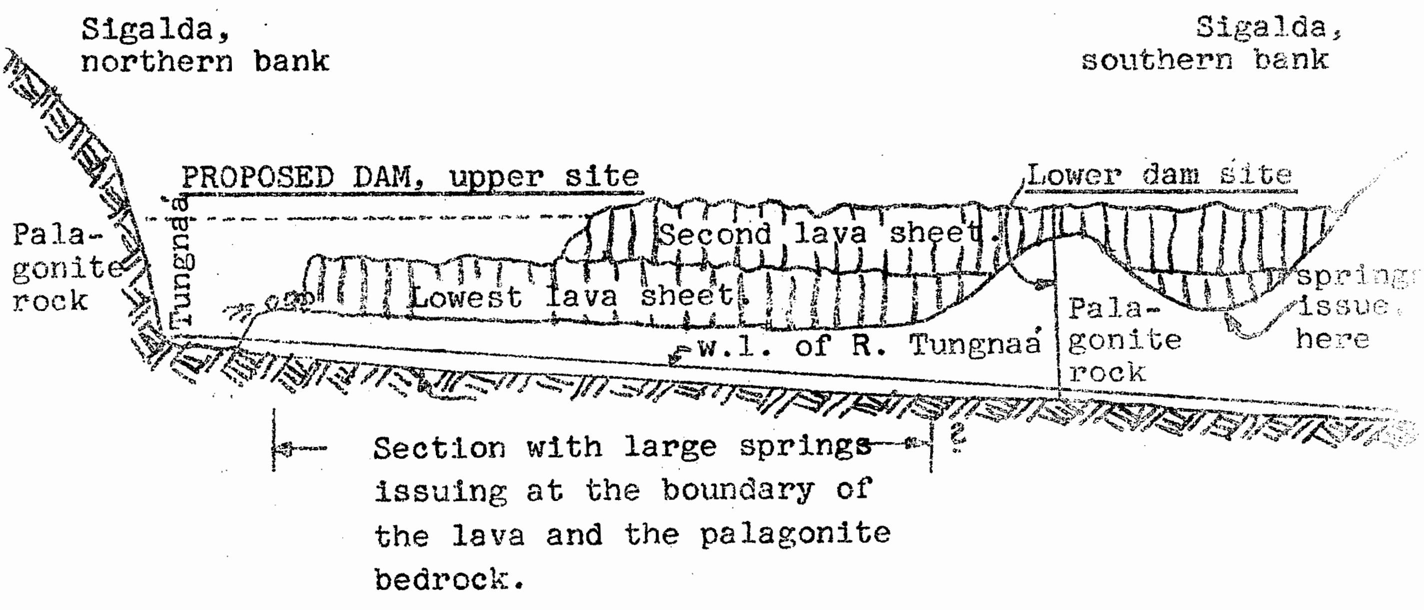

Fig. 2: Upper dam site at Tungnaárkrókur and section through the canyon of R. Tungnaá, until downstream of the lower dam site, looking west.

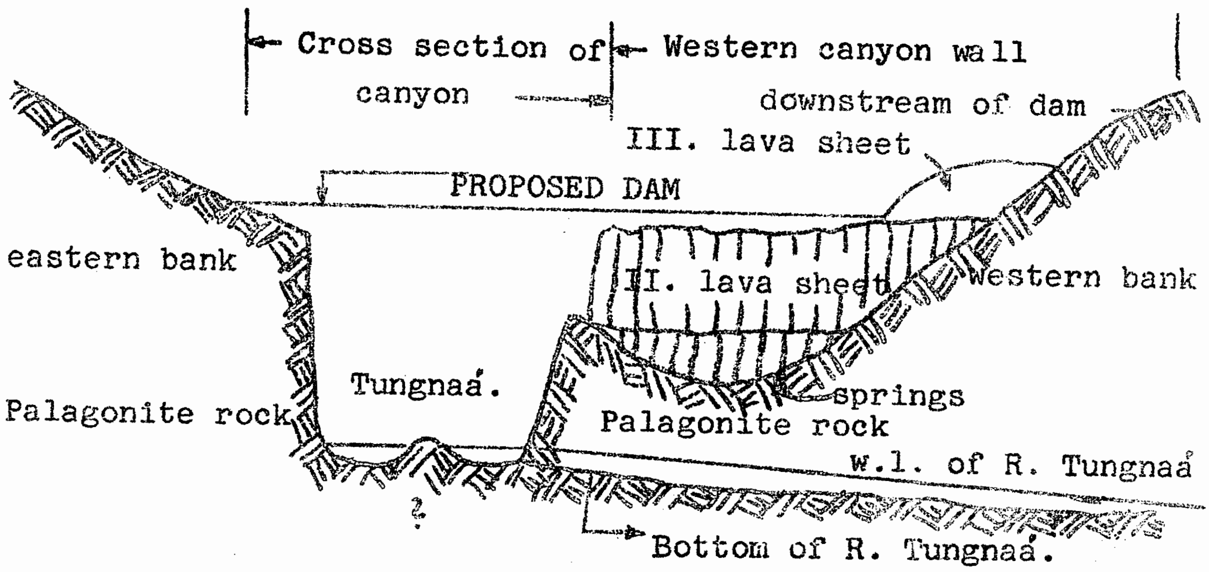

Fig. 3: Lower dam site at Tungnaárkrókur and section through canyon, downstream of the site, looking west.

As is evident from figs 2 and 3, the Tungnaárkrókur dam sites are in so far similar to the Hrauneyjafoss dam site that the eastern abutment consists of palagonite, the western one of lava. In this case, however, the thickness and number of the lava sheets at the dam site is known.

At the upper Tungnaárkrókur dam site, river Tungnaá has cut its channel a few metres into the palagonite bedrock. At the boundary between the bedrock and the lava in a 1000 m section along the river some large springs issue

The total discharge of these springs has been estimated to be of the order of 3-5 m^3/s as previously mentioned. There is thus no choice but to restrain this leakage if this dam site is selected. It is here assumed that this restraining will be accomplished by injection grouting into the lava, although the great flow of water may make this method difficult to apply. Almost certainly, other grouting materials than the usual cement mixture must be resorted to.

The upper dam site is out of the question, except for a low intake dam, giving a gross head of 50 m only for the development. If a greater head and some storage capacity is desired, the dam must be constructed at the lower site.

In this appraisal, a dam of nearly 50 metres height has been assumed for the lower dam site. As usual in the case of dams of such a height, grouting of the palagonite in the bottom and sides of the canyon has been assumed necessary.

A grout curtain must also be constructed on the bank of the canyon, between the dam and the palagonite hill on the western river bank (Sigalda fremri), in order to tighten the boundary between the lava and the underlying palagonite bedrock.

As far as the dam sites are concerned, borholes are not considered necessary, except for the purpose of exploring the thickness of the palagonite rock and testing its permeability. One or two boreholes should be sufficient for that purpose, and they need not be sunk until the development has been finally decided upon. At the present stage, these holes may be postponed, as some conclusions might be drawn from boreholes which must be sunk on the tunnel route before a final design of the development can be made.

5.3.4 Tunnel Route of the Tungnaárkrókur Development

The total length of the tunnel will be ab. 1650 m, that of the headrace tunnel ab. 1050 m and the tailrace tunnel ab. 600 m.

The headrace tunnel will be in the palagonite rock. The excavation for a tunnel of this size may be assumed to be reasonably easy and there should be no danger of leakage, as the tunnel will presumably lie above the ground water table until close to the intake. However, sand and gravel lenses are present in the palagonite and they are, of course loose.

The power house will presumably have to be excavated in a similar rock. It and the tailrace tunnel will most likely be below the ground-water table so that some leakage may be expected there. The tailrace tunnel will possibly lie through a different rock type for a part of its length, as a tillite bed is apparent both overlying the pillow lava and interbedded with it in the river bed. This question will presumably be further clarified when a geological survey has been made of the site, and undoubtedly when the drilling has been performed.

In order that a preliminary project of the scheme can be drawn up, at least two boreholes must be sunk on the tunnel route, one at the power house and one on the tailrace tunnel. The aggregate depth of both holes may be assumed to be ab. 110 m. Pumping in tests of the rock permability should be performed in the boreholes.

Two springs issue in the ravine to the east of the Skeggjafoss waterfall. One of them, the one lying next to the river, may be a leakage water from river Tungnaá, which, at a distance of some 15-20 is flowing at a considerably higher elevation. The other the easternmost one is presumably coming from a greater distance, although it cannot here be stated with certainty. The discharge of the springs is not very great.

5.3.5 Reservoir Site at Tungnaárkrókur

The reservoir site is rather extraordinary in that the bottom and the western bank of the proposed reservoir consist of the three lava sheets mentioned above.

The high dam on the lower site, (spillway elevation 500 m) butts against the edge of the uppermost lava sheet. The water can, therefore, easily flow under all three lava sheets, as a very pervious setcion is almost certainly present at the boundary between the sheets and between the lava and the bedrock. At the first look therefore the reservoir site is not very promising and a considerable leakage might be expected from it. However, in our opinion there will hardly be any objectionable leakage from the reservoir. The reasons will be given below.

Mr. Guðmundur Kjartansson, geologist has been kind enough to lend the present writer his diary from a trip to this area in July 1949. The following comments are quoted from that diary:

".......... At Tungnaárkrókur and near river Blautakvísl 3 or 4 sheets of Þjórsá lava of different age may be distinguished. The lowest one was nowhere visible on the southern side of the river, except at the nameless water-falls which I have studied before. This lava has dammed up river Tungnaá diverted the river to the north-west a short distance east of Sigalda and has created the big lake extending over the Tungnaárkrókur peninsula and the Blautakvísl valley. The whole of the lowest lava sheet and the northern edge of the overlying one is to a very great extent covered with alluvial gravel and silt deposits. The edge of the third lava sheet is still farther south and the alluvial deposits does not cover that edge, but it is not apparent whether or not they extend under it. The fourth lava sheet is the Blautakvísl lava, which is overlying the alluvium. The lake has been drained as river Tungnaá cut its canyon 20 m into a palagonite ridge to the north-east of the Fremri-Sigalda. In the canyon, cross sections of the two older lava sheets are apparent, in some places a sill, covered with vegetation at the boundary of the sheets. Downstream of the canyon mouth a huge heap of large boulders from the canyon is present. Some of the boulders are of Þjórsá lava, others of pala-gonite rock. They are somewhat rounded-off. The largest boulders are 8-10 m^3 andthey have been carried some hundreds of metres from the mouth of the canyon.

No distinct edge can be traced across the youngest Þjórsá lava sheet anywhere from the Tjörfafellspollur down to Galtalækur. However it is not certain that the lava surface is everywhere in this area from the same flow .... "

A study of a topographical map of the area reveals that the upper surface of the middle lava sheet, the one that, according to Mr. Kjartansson, is covered with alluvial deposits, is at el. 500 m. The deposits do not extend upwards on the edge of the uppermost sheet. The level of the old lake has thus been the same as that of the proposed reservoir.

In a recent trip to the site the present writer studied the alluvial deposits overlying the lava. It appeared that the uppermost lava sheet is overlying the alluvium, although it could not be ascertained beyond doubt.

On the southern side of the river, the alluvium consists of a glacial clay whereas a terrace of a coarser material could be observed on the slopes of the Sigalda on the northern side of the river.

The impounded water of river Tungnaá has overlain this area for centuries before the river had cut its canyon through the Sigalda. The length of that time might possible be estimated from a study of the alluvium.

There is no doubt that an apprceiable leakage has found its way through and under the lowest lava sheets for some time after they were formed. The direction of the leakage was that of the hydraulic gradient. Later on, this leakage path became silted up, the water level of river Tungnaá rose and its surface outflow increased. As the leakage from the lake decreased, its surface level rose, making it easier for the river to cut a canyon along the edge of the lava through the depression in the Sigalda. Probably, the third lava flow played the final part in this process, although it is not certain that it did so.

Taking the fact into account that river Tungnaá has all this time carried a great amount of sediment, there can be no doubt that all leakage paths under and between the two lowest lava sheets have been well tighted up. A case in point here is the river Helliskvísl, which, although carrying much less sediment than river Tungnaá, has tighted up its bed and extended its course a long way over a lava flow in the course of somewhat within 50 years.

The lava sheets dip towards the river. Now it may be assumed that the dip of a lava sheet is, in main determined by that of its base, so this is another point in favour of the hypothesis that the leakage from the proposed reservoir will not be great.

Now, it may be argued that the big springs issuing from under the lowest lava sheet do by no means indicate a small leakage between and under the lava sheets. But the conditions are, in our opinion, different in this case. When the lava flows moved the course of river Tungnaá close to the slope of the Sigalda, there was no leakage path through ridge. Therefore, no flow of water could take place in direction toward the ridge, and accordingly, the lava next to it has not been tighted up. Besides, the part of the lava lying immidiately at the foot of the ridge, has been broken off from the rest by the river. This was the part of the lava most likely to have been silted up if some leakage has, in fact, taken place in direction towards the ridge, as the base of the lava was in this place dipping in an opposite direction to the rest of it i.e. up to the ridge.

Although we are of the opinion that the site of the proposed reservoir may be relied upon, we would like to point out that this hypotheses should be confirmed by tests as far as is possible at a tolerable cost.

A ridge of palagonite mountains extends from the Sigalda to the southwest, as indicated by hills extending above the lava flow. The lava has flowed through three depressions in this ridge, between the hills. Although there is a long way from the proposed reservoir to these lavafilled depressions, viz. 2, 5 and 7 km, respectively, we are of the opinion that the thickness of the lava (total thickness and the thickness of the individual sheets) in all three depressions should be explored by drilling and the elevation of the underlying bedrock determined. At the beginning, two boreholes in each of the depressions should be sufficient, but they should be supplemented by resistivity measurements. Apart from showing the thickness of the lava sheet(s), the boreholes would also yild information on the ground-water conditions in the depressions. Resistivity measurements and explorations of the ground-water table should also be performed in the lava field to the east of the ridge.

From the results of these investigations, conclusions may be drawn as to whether or not measures should be taken to restrain leakage through the depressions. Further, the positon of the ground-water table may be registered at the boreholes after the development has been carried out and a possible subterraneous flow of water may be observed.

It is not possible to state beforehand the aggregate depth of the boreholes but the six holes required may be assumed to total some 90-150 m in depth, or more.

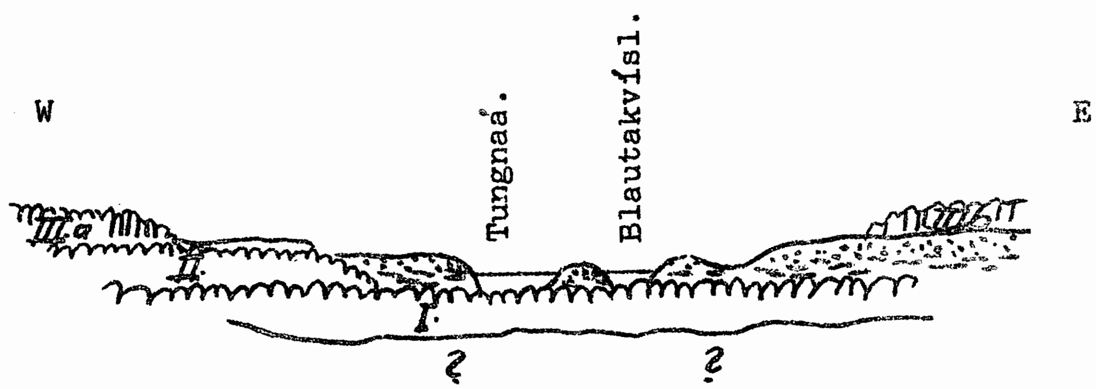

Fig. 4; from Mr. Kjartansson's diary.

The lava sheets are numbered in order of decreasing age

Clay.

Gravel and Sand.

5.3. 6 Dam and Reservoir Sites at Bjallar

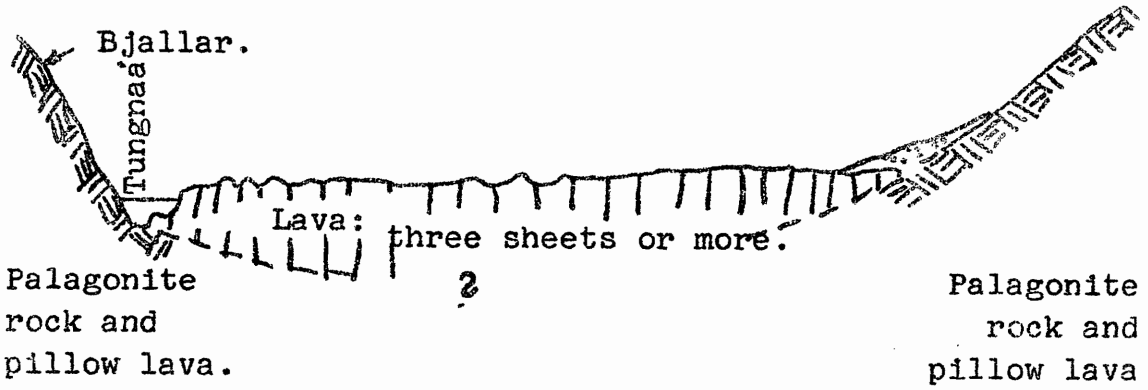

Fig. 5: Dam site at Bjallar.

The lava flow(s) have moved the course of river Tungnaá close to the slopes of the Bjallar mountains. At least three lava sheets are present at the sites. Except for its northern abutment, which consists of palagonite rock or pillow lava, the dam must be founded wholly on lava. There will thus surely be some leakage under the dam. The leakage water will presumably reappear in river Tungnaá and could be utilized by power plants farther downstream on the river. It is, however, possible that the lava might be tighted up, by injection grouting for instance.

As a profile only, but no adequate topographical maps are available of the sites, a further discussion of them is not considered timely.

The same is true of the site for a storage dam on river Tungnaá at Vatnaöldur or farther upstream. It should only be pointed out that a possible leakage from the reservoir would not affect the usefulness for downstream power plants of storage dams at these sites, as the leakage water would reappear as a regulated flow above these plants.

5.3.7 Construction Materials

Last summer, an extensive survey of construction materials near lake Þórisvatn and in other places was carried out. The results of this survey will be the subject of a seperate report. As a matter of fact this survey was not performed with the Tungnaá developments in mind, so that the question of construction materials for them needs further consideration.

At a first look it may be expected that concrete aggregates (gravel and sand) will have to be transported a long way for the Hrauneyjafoss and Tungnaárkrókur developments. Borrow pits for rock for crushing and production of gravel on the other hand are available near the sites, as the lava may be used for that purpose. Rock-fill dams have been proposed at both sites with the view at utilizing the tunnel spoil, as that material is, beyond any doubt, quite suitable for a dam of this type. Material from lava borrow pits may be used for the riprap on the upstream face of the dam.

Mr. Kjartansson thinks that appreciable quantities of clay are present in the terraces above Tungnaárkrókur. A similar clay may be assumed to be present at river Tungnaá upstream of Hrauneyjafoss. This should be studied further, and samples taken of this material.

Although the properties of the lava basalt are fairly well known, samples should be taken from the lava at the two sites and subjected to chemical analysis.

5.3.8 Roads

As is known, there are no roads to the sites but,c course, good access roads are a prerequisite for the development of the sites.

No study had been made of the best road routes or what bridges have to be constructed, and so on, nor has any estimate been made of the cost of such works.

As the power plants to be constructed at the sites are large, the roads must be able to sustain the transport of heavy loads and large quantities of materials.

6 Description of Individual Developments and their Variants

6.1 Bjallar Development

The drainage area above the interception dam is 1380 km^2. Estimated mean discharge 83 m^3/s. No sufficiently accurate topographical maps exist of the site, the following comments are based on the American AMS maps, a longitudinal profile of the river and a profile of the dam site. Two variants are put forward. In one of them, the dam would be of sufficient height to create a reservoir with a live storage of ab. 200 Gl. As previously mentioned, such a storage could ensure for 90% of years a uniform discharge equivalent to ab. 70% of the mean discharge, interconnection of the power plants being assumed. The other variants provides for as low a dam as may be assumed to ensure a reasonable security of operation for the power plants.

Seperate storage dams are assumed in this variant.

6.1.1 Variant (611)

Max developed discharge	83 m^3/s
Gross head	45-61 m
Average net head	53 m
Installed capacity	36500 kW

The site of the proposed dam is located ab. 3 km upstream of the Bjallar ford. Total length of the dam will be somewhat in exess of 1000 m, its max. height ab. 23 m. Section with bottom outlets is proposed in the river bed, an overflow spillway section, 200 m long on the southern river bank. South of the spillway section, a rock-fill embankment with a concrete cut-off, 760 m in length, is contemplated. Elevation of the spillway crest is 566 m, top elevation of other sections is 568 m.

The intake is located a short distance upstream of the dam.

From the intake, a headrace tunnel, ab. 2900 m in length, leads to a surge basin excavated into the northern slope of the Vesturbjallar. It is concrete-lined, with a cross section area of 28 m^2. From the surge basin, a vertical penstock shaft, circular, with an inside diameter of 5 m leads to the underground power house. The penstock is lined with concrete and steel.

A short tailrace tunnel connects the draft tube with river Tungnaá at el. 505 m.

The underground power house contains one generating unit rated 36500 kw. The transformers are located above ground. An access tunnel connects the power house with the ground surface.

6.1.2 Variant (612)

Max developed discharge	83 m^3/s
Gross head	50 m
Net head	45,5 m
Installed capacity	31400 kW

The dam site is the same as in var. (611). Total length og the dam ab. 900 m, its max. height ab. 12 m.

Two outlets each 10 m wide are provided for in the dam section across the river bed, closed by gates of the Hakenschützen type. A 200 m long spillway section is on the southern river bank, followed by a 650 m long rock-fill section, with a concrete cut-off.

Spillway crest elevation is 555 m, that of other dam sections 557 m. The intake, which is circular in shape, will be located just upstream of the dam. It will be sperated from the dam structurally, but connected with it by a bridge.

The conduits and power house will be similar to var. (611). One generating unit rated 31400 kW is contemplated.

6.2 Tungnaárkrókur Development

The drainage area above the dam is 1555 km^2, estimated mean discharge at the site is 98 m^3/s.

The appraisal is based on S.E.A. topographical maps of the site at scales 1:20 000 and 1:5000. The AMS maps have also been consulted.

Two variants differing in the site and the height of the dam are forwarded. In var. (621), a dam across river Tungnaá in the middle of the canyon downstream of Tungnaárkrókur is proposed. Crest el. of the spillway section is 500 m. A drawdown of the reservoir to el. 480 is contemplated, giving a live storage of 205 Gl.

In the other variant (622), the dam would be located in the upper part of the canyon. It would be a low dam, spillway crest el. 480 m., providing a live storage of a few Gl only which would give an adequate daily pondage but insignificant storage.

6.2.1 High-dam variant (var. 621)

Max. developed discharge	98 m^3/s
Gross head	75-55 m
Average net head	64 m
Installed capacity	52000 kW

As mentioned above, the dam is located in the middle of the canyon section of river Tungnaá just downstream of the Tungnaárkrókur peninsula.

The dam section across the canyon is of the rock-fill type, with a concrete slab on the upstream face. Max height above the canyon bed is ab. 50 m, crest elevation of this section is 502,5 m, its length 230 m.

On the lava on the eastern river bank (el.ab. 498 m), a 200 m long gravity section is contemplated, with a 160 m long spillway. Spillway el. 500 m. A concrete wall 230 m long paralled to the conyon a short distance from the edge prevents the spillway discharge from falling into the canyon too close to the downstream toe of the dam.
Further, a grout curtain is proposed in the dam foundations and in the lava on the eastern bank all the way from the dam to the palagonite hill farther downstream. The length of this grout curtain in the lava will be ab. 1000 m.

A tunnel 300 m in length, will be excavated in the western river bank at the dam site in order to divert the river from the site during the construction of the dam. After completion of the plant, this tunnel will be used for emptying the reservoir and for discharging the biggest floods. The tunnel is lined with concrete, the cross section area of 26 m^2.
From the surge basin, two circular penstocks, with an internal diameter of 4 m lead to the two generating units of the power house. The penstock, which is 90 m long, is lined with concrete and steel.

The power house is of the underground type. It will accommodate two Francis units, each rated 26000 kW.

A 580 m long tailrace tunnel, concrete lined, with a cross section area of 32 m^2 connects the powerhouse with river Tungnaá at el. 425 m.

Total length of conduit is ab. 1670 m.

A road access tunnel, 160 m in length, connects the power house with the ground surface.

6.2.2 Low-dam variant (Alt. 622)

In this alternative, the crest of the proposed dam is at el. 480 m only. The dam is to be constructed in the upper part of the canyon downstream of the Tungnaárkrókur peninsula. The dam is composed at two sections: (1) A gravity section, 95 m long, across the canyon. Two outlets each 10 m wide, are built into this section. (2) A low overflow spillway section, 580 m long, constructed on the lava sheet on the eastern river bank. As an appreciable amount of spring water issues from under the lava, a grout curtain must be constructed from the dam all the way to the lower dam site described above (621). The length of this grout curtain would be 1250 m approximately.

The arrangement of the power house and tunnel is identical with var. (621) except that the rating of each of the two generating units installed is here 21000 kW.

6.3 Hrauneyjafoss Development

The drainage area above the dam is ab. 1625 km^2, estimated mean discharge at the site is 107 m^3/s.

The appraisal is based on S.E.A. topographical maps of the site at scale 1: 20 000 and 1: 5000.

Two variants are put forward, differing mainly in the height of the interception dam. In one of these variants (631) it is proposed to utilize all the head available from the tailwater level of the Tungnaárkrókur plant (el. 425 m) down to el. 322 m, a short distance upstream of the confluence with river Kaldakvísl. This variant provides an ample pondage for a daily flow regulation, viz. ab. 35 Gl.

In the other variant, a dam with a crest level at el. 420 m situated a short distance downstream of the dam site in var. (631) is contemplated, giving a live pondage of ab. 4 to 5 Gl.

6.3.1 Variant (631)

Max dveloped discharge	107 m^3/s
Gross head	98-103 m
Average net head	94,7 m
Installed capacity	85000 kW

The proposed dam is located ab. 1200 m above the Hrauneyjafoss waterfall. Total length of the dam is ab. 1840 m, its max. height ab. 12 m. A dam section with two flood outlets, each 10 m wide, will be constructed across the Tungnaá riverbed. The outlets will be closed by gates of the hakenschützen type. A concrete overflow spillway section, 270 m in length, will be built on the southern river bank, followed by a rock-fill section 1480 m in length with a concrete cut-off. Spillway crest level is at el. 425 m, that of the other dam sections at al. 427 m.

The intake will be constructed in the Tungnaá riverbed a short distance upstream of the dam. It is circular in shape and is structurally seperated from the dam, except for a bridge connecting it with the latter.

Total lenght of the conduits is ab. 3200 m, whereof the headrace tunnel is 600 m. A surge basin is excavated into the slope of the Sporðalda. A vertical penstock shaft, circular in shape, with an internal diameter of 5.5 m connects the surge basin with the underground power house. The penstock is lined the concrete and steel. A surge chamber is located immediately downstream of the power house. From the surge chamber, a 3100 m long tailrace tunnel leads to river Tungnaá.

The tailrace tunnel, which is concrete-lined, has a cross-section area of 29 m^2.

One generating unit, rated 84000 kW is contemplated.

An elevator shaft, 90 m high, connects the power house with the surface.

6.3.2 Variant (632)

Max developed discharge	107 m^3/s
Gross head	98 m
Net head	90,7 m
Installed capacity	81000 kW

The proposed dam is located ab. 900 m upstream of the Hrauneyjafoss waterfall. Total length of the dam is ab. 1000 m, its max. height ab. 10 m. In the riverbed a section with two 10 m wide flood outlets is contemplated. The outlets will be closed by gates similar to those of var. (631). A 270 m long overflow spillway section will be constructed on the southern river bank, followed by a 530 m long rock-fill section with a concrete cut-off. Crest el. of the spillway is 420 m, of other sections 422 m. The intake is located a short distance upstream of the dam. The intake and the waterways will be similar to those of var. (631).

Two generating units, each rated 40500 kW, are contemplated.

6.4 Storage dams

As previously mentioned, no attempt will be made here to compare the various possibilities for creating a storage reservoir (seasonal storage) on river Tungnaá, as the basic data available on the alternative sites are very incomplete. However, in order to make possible a comparison of the alternative developments described above, a rough cost estimate has been made of the storage dam at Ljótipollur. A live storage of 200 Gl has been assumed, corresponding to a drawdown of 13 m. The required dam will be ab. 650 m long with a max. height of 15 m. These figures are based on a study made by the S.E.A.

Raforkumálastjóri
Vatnamælingar
Þjórsá, Urriðafoss
Tungnaá Vatnaöldur
Reiknislínur

28.4.'59 S.R./ÞA
Thr. 193
B 2/7 Vhm. 9611
Fhr. 4310

Graphs showing daily discharge in kl/s of river Tungnaá at Vatnaöldur and river Þjórsá at Urriðafoss for the period Nov. 1958 to March 1959.

————	Þjórsá river at Urriðafoss
- - - - - -	Tungnaá river at Vatnaöldur