Þjórsá

SPECIAL FUND PROJECT ICELAND

HVÍTÁ and THJÓRSÁ River Systems

SOUTHERN ICELAND

ANALYSIS and CONSIDERATION
of the
ICE CONDITIONS

Final Report

by

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OSLO, Oct. 1965

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Cont.

PREFACE

Our studies were carried out in accordance with our task, which was formulated by The United Nations Special Fund, Project Iceland, in several paragraphs, of which we quote this passage: "Assist the Government in getting a practical solution to the problems resulting from the formation and transport of ice in the rivers with particular reference to hydro-electric developments".

During our studies in office and in the field we had the most valuable cooperation and assistance by the Director General of The State Electricity Authority, Mr. Jakob Gislason, and his staff, among whom in particullar Mr. Jakob Bjørnsson and Mr. Sigurjón Rist have spent many busy hours and days in order to realize our proposals.

Our special collaborator, Sivil Engineer Mr. Sigmundur Freysteinsson has taken part in our work in Iceland. For all this assistance we want to express our appreciation and thanks.

Field studies.

Field reconnaissance was made of the Hvitå and Thjórså river basins during the months of April, May and August 1964. Investigation of ice conditions was divided into two periods: Studies of ice formation and ice accumulation were made during the months November and December 1964. Studies of ice production, compression and solidification of sludge ice, ice bridges, step bursts, influence of dynamic ice production on water level and discharge, and many other studies were made in March and April 1965.

Various other studies were also undertaken to acquire better knowledge of the general ice conditions, especially those of importance for power development. For the same purpose numerous photographs were taken at various places and under varying ice conditions. The collection represents and archive of lasting value.

Office studies. The office studies which form the basis for the preparation of this report were carried out i Norway. During this work we arrived at rather precise conclusions and recommendations. These are related to the practical ice problems which will encounter any Power Plant Project in the turbulent Thjo̊rså and Tungnaå rivers, and we hope that our contribution will be of use.

Oslo, October 1965.

Olaf Devik   Edvigs V. Kanavin

Chapter A. SHORT OUTLINE of the HVÍTÁ and THJÓRSÁ RIVER SYSTEMS

1. General description of the drainage systems, the bedrock formations and river types

The Thjórsá and Hvítá-Ölfusá river basins are located in the southern part of Iceland, see Fig. A-1[1]. Their drainage systems issue from a broad gathering ground encircled by the three ice caps, Langjökull, Hofsjökull and Vatnajökull in the central highlands of the country. Their flow is in nearly parallel courses with a southwesterly direction, discharging into the North Atlantic Ocean about 60 km east of the capital city, Reykjavik.

These two rivers are next to the largest one in Iceland as far as drainage area is concerned, and they comprise a drainage area of nearly 13.700 km^2 (Thjórsá 7530 and Ölfusá 6100 km^2). From the standpoint of power production, the Thjórsá and Hvitá are the most important rivers of the country.

The hydrology of the icelandic rivers is strongly influenced by the geological character of the drainage area. Our short description of the relevant features of the geology of the two river basins is based upon our excursions in the field, discussions with the State Electricity Authority and the use of specific publications. The bedrock formations will in the following be classified in accordance with the report of Gudmundur Kjartansson x).

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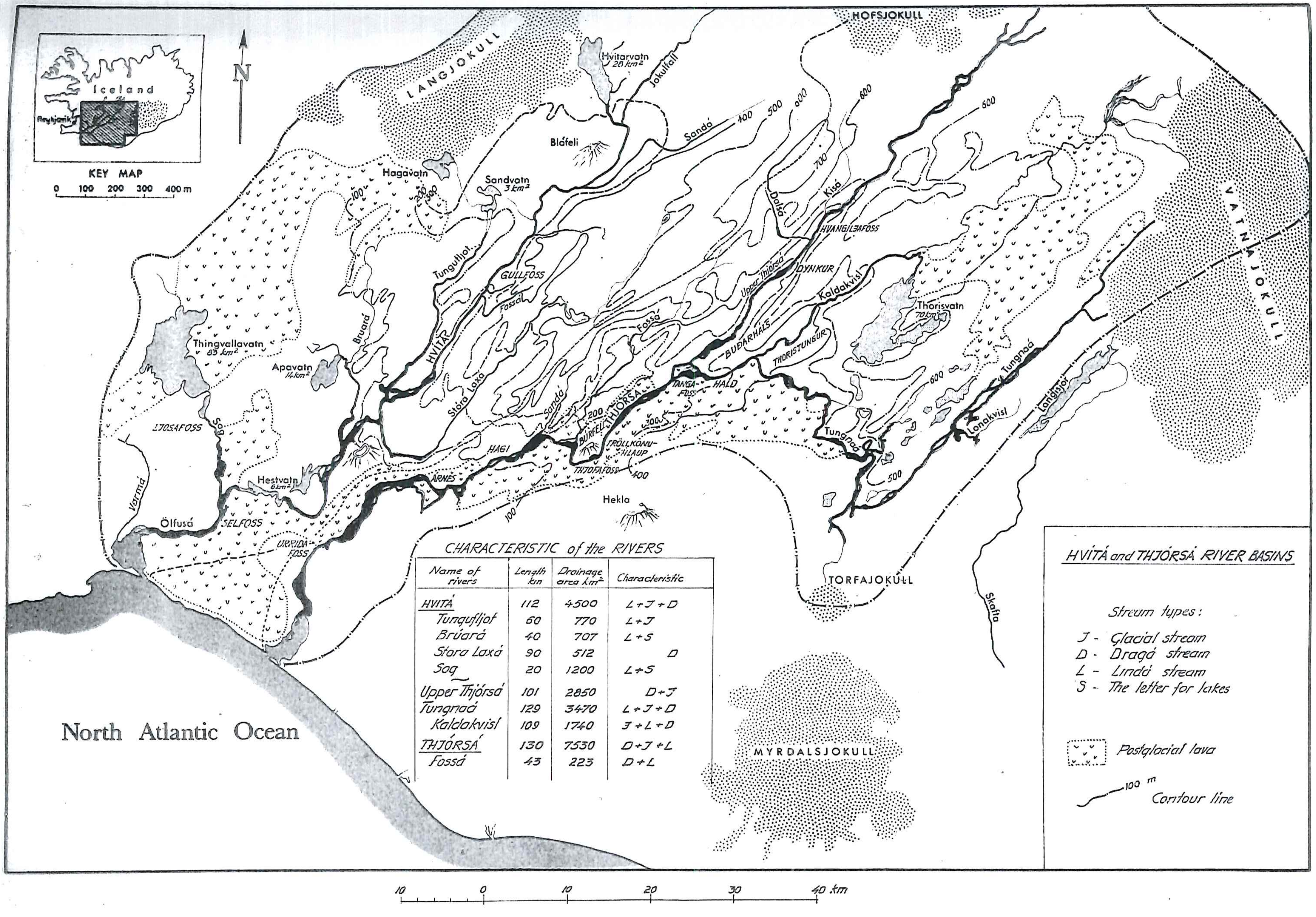
x) Gudmundur Kjartansson: Geologiske betingelser for islandske flodtyper,
Reykjavik 1964.

Fig. A-1'



CHARACTERISTIC of the RIVERS

Name of rivers	Length km	Drainage area km²	Characteristic
HVITÁ	112	4500	L+J+D
Tungufljot	60	770	L+J
Brúará	40	707	L+S
Stora Laxá	90	512	D
Sog	20	1200	L+S
Upper Thjórsá	101	2850	D+J
Tungnaá	129	3470	L+J+D
Kaldakvisl	109	1740	J+L+D
THJÓRSÁ	130	7530	D+J+L
Fossá	43	223	D+L

HVÍTÁ and THJÓRSÁ RIVER BASINS

Stream types:

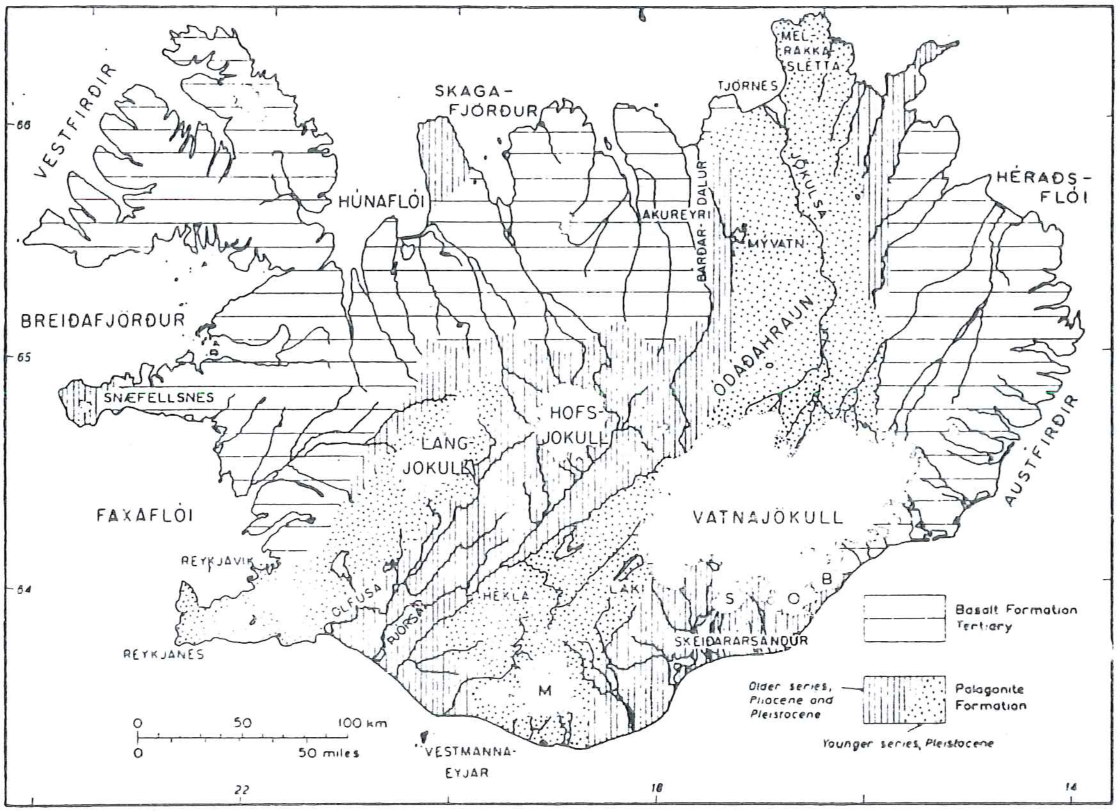
J - Glacial stream
D - Dragá stream
L - Lindá stream
S - The letter for lakes

Postglacial lava

100 m Contour line

The bedrock of Iceland may be divided into four groups: Basalt formation, Hreppar (Icel. blágrýtismyndinun), Old Grey Basalt (Icel. eldri grágrýtismyndinun), Moberg formation (Palagonite Formation) and Young Grey Basalt (Icel. yngra grágrýtid), see Fig. A-1^2.

Fig. A-1²



The bedrock formations of Iceland. Palagonite Formation = Móberg Formation. Older series = Old Grey Basalts. Younger series = Móberg Mountains and Young Grey Basalts.

The Basins of the Hvitá and the Upper Thjórsá are mainly resting upon a sequence of basalt flows and interbedded sediments, the Grey Basalt and Hreppar Formations. The topography of both valleys is streamlined in the southwesterly direction by glacial erosion and deposition.

The lower courses of the Tungnaá, the Thjórsá, and the Hvitá are in most places located along the borders of the Thjórsá lavas.

The Icelandic streams have been divided into two types, glacier streams and bergvatnsá streams (from Icelandic bergvatn, "rock water" i.e. water issuing from rock fissures, and á = river). These two types have quite different flow characteristics, depending principally on the source and nature of the water supply. The types of rivers in Iceland have been discussed by Sigurjón Rist in the SEA reports.

Glacial streams, marked by "J" in this paper (from Icelandic Jökull = Glacier), rise from the permanent ice fields of the large glaciers. These rivers carry large amount of sediments which give the water a brown colour which results from the mud becoming lighter further downstream to attain a milky colour when it is mixed with water from other streams.

The Bergvatnsá streams have been divided by Sigurjón Rist into Dragá and Lindá streams, according to the geological conditions.

Dragá rivers, marked by "D", receive the water from normal surface run-off. These rivers are found in areas of the Hreppar and Grey Basalt formation and the more watertight areas of the Palagonite rocks. Their discharge is very much dependent upon the precipitation, and the water temperature varies with the air temperature. The great floods of the dragá rivers carry great volumes of sediments, but at other times the water is clear. Formation areas are for the most part made up by accumulation of small brooks from ravines ("drag" in Icelandic).

Lindá (spring-fed) rivers, marked with "L", are found in the permeable rock formations. The water is clear, since very little sediment is carried, and has a nearly constant temperature of 3°C to 5°C. The flow is very even all the year round.

For the most part the basins of Hvitá and Thjórsá are undeveloped and uninhabited, only at the lower altitudes of the plains there are scattered farms and villages connected with a network of gravel roads. The countryside is generally barren, without trees, but with grasslands near the coastal section.

The Hvitá river is bridged at three places: Selfoss, Skalholt (Ida bridge) and Tungufell (Bruarhlöd bridge), about 15 km, respectively 60 km and 85 km, from the river mouth.

The Thjórsá has only one bridge, near Urridafoss (Thjorsár bridge), about 20 km from the ocean. Tungnaá has one bridge near Hald, about 100 km from the ocean.

The glacial rivers in the area carry large quantities of sediment load, consisting mainly of material eroded from the beds of the rivers and the glaciers. The amount transported is small during low discharges but increases rapidly with the flow. The dragá rivers may also carry a substantial volume of sediments resulting from erosion by the river itself and by the surfase run-off. The variations and the quantities of their bedload may be proportionately somewhat less than for the glacial streams, the variation of sediment with discharge, however, has a similar relationship. The spring-fed (lindá) rivers usually carry very little sediment, only small amounts of windblown sand and pumice.

2. The Hvitá - Ölfusá river system

The Hvitá river comes from the lake Hvitárvatn, located in a depression east of the Langjökull ice cap, and flows for 185 km in a southwesterly direction until it reaches the ocean at Eyrarbakki. The section downstream of the confluence with the tributary Sog, about 25 km from the ocean, is called the Ölfusá river. In the following the Hvitá - Ölfusá will be referred to as the Hvitá river only.

In Fig. A-1[1] and A-2[1] are given the size of drainage areas and longitudinal sections of Hvitá and tributaries. Table Fig. A-2[2] shows characteristies of the river system.

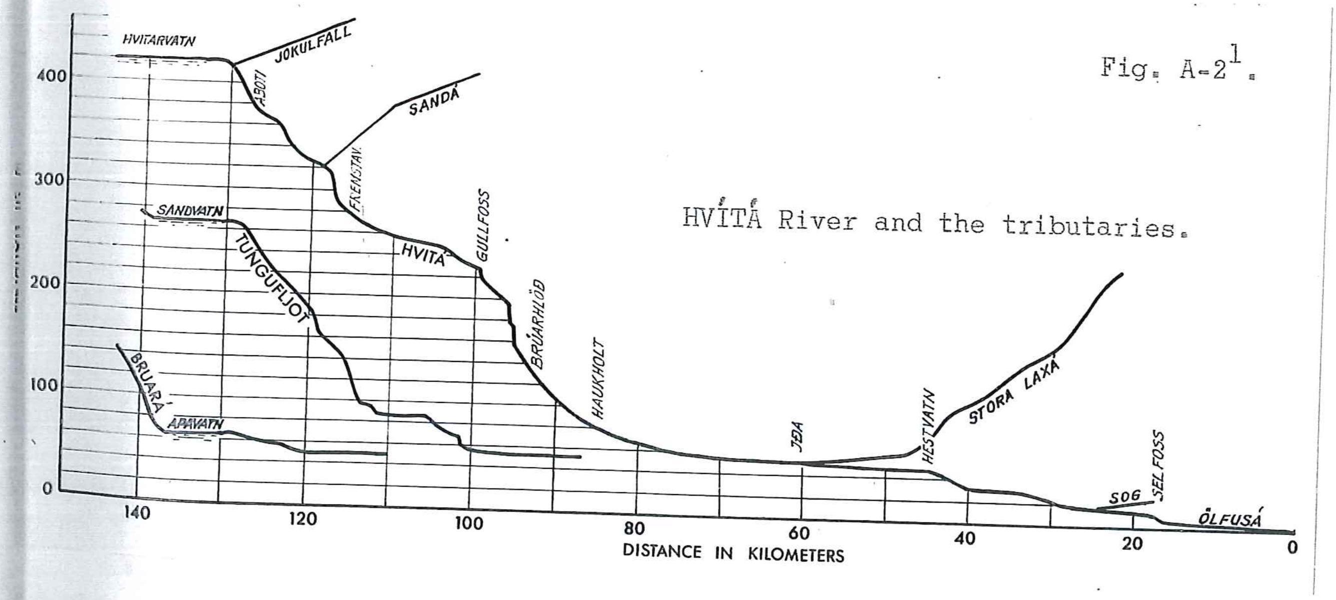


Fig. A-2[1].

HVÍTÁ River and the tributaries.

Fig. A-2^2.

CHARACTERISTICS of the HVÍTÁ RIVER SYSTEM

Name of rivers and lakes	Location	Length km	Altitude m	Drainage area km^2	Characteristic
Lake Hvitarvatn (28 km^2)			421	822	S
Svartá	Hvitarvatn	36	421	133	D
HVÍTÁ	Hvitar bridge	1	420	843	S+J
Jökulfall	Confluence	58	419	380	J+D
HVÍTÁ	Aboti	6		1230	D+J+S
Sandá	Confluence	17	249	327	D
Stangará	"	15		44	D
Búdará	"	15		65	D
HVÍTÁ	Gullfoss	40	189	2000	D+J+S+L
Dalsá	Confluence	14		31	D
Fossá	"	16		30	D
HVÍTÁ	Brúárhlöd	48	85	2075	D+J+S+L
"	Hvitardalur	53		2090	D+J+S+L
Tungufljót	Confluence	60	53	770	L+J+S
Stóra Laxá	"	90	53	512	D
Litla Laxá	"	37		105	D+L
HVÍTÁ	Ida	91	52	3540	D+L+J
Brúará	Confluence	40	50	707	L+S
Lake Apavatn (14 km^2)			59		S
Lake Hestvatn (6 km^2)		49			S
HVÍTÁ	(onfl.with Sog)	110	15	4500	L+J+D
Sog	Confluence		15	1200	L+S
Lake Thingvallavatn	(82,6 km^2)	103		ca 1000	S
ÖLFUSÁ	Selfoss	117	12	5760	L+J+S+D
"	Mouth	135	0	6100	L+J+S+D

Lake Hvitárvatn of 29,6 km^2 area is located at the SE border of the Langjökull. Max depth is appr. 84 m, average depth 27,6 m. The drainage area of the Hvitárvatn is about 820 km^2 (appr. 330 km^2 is covered by glacier). The main tributaries to the lake are Fúlakvisl and Svartá.

The main tributaries of the Hvitá river are from the right Tungufljót, Brúará and Sog, and from the left Jökulfall, Sandá and Stóra-Laxá.

Jökulfall river is a glacial river (J) coming from the Hofsjökull Ice cap and is entering Hvitá a short distance below lake Hvitarvatn. The drainage area of the Jökulfall river is about 380 km^2 (appr. 90 km^2 is covered by glacier).

Sandá with Grjótá are dragá streams (D) coming from Kerlingarfjöll. Total drainage area about 417 km^2.

Stóra-Laxá is also a direct run-off river (D) but spring-fed to some extent from Litla-Laxá. The drainage area below Geldingafell is 133 km^2 and at confluence with Hvitá 512 km^2. (Litla-Laxá 105 km^2).

Tungulfljót comes from the Sandvatn (area ca. 3 km^2). The drainage area just after Sandvatn is 566 km^2 (about 270 km^2 is covered by glacier), at Faxi 720 km^2, and the total area is about 770 km^2. The flow is to a great deal spring-fed (lindá stream (L) and the variations are to some extent evened by lakes. The river contains a tiny amount of glacial melt-water.

Brúará arising from the permeable rock formations south of Langjökull (Lambahraun and Haukadalur) is likewise a spring-fed flow (L). The drainage area is: below Bruarskord 115 km^2, below Hruta 215 km^2, at Dynjandi 670 km^2 and at confluence with Hvitá 707 km^2. The tributary Hagaos is coming from lake Apavatn, area 14 km^2, drainage area about 280 km^2.

Hestlækur river is flowing out from lake Hestvatn, area 6 km^2, drainage area about 150 km^2.

The largest tributary to the Hvitá is Sog river, a lindá flow (L) originating in lake Thingvallavatn, the largest lake in Iceland, area 84 km^2, max. depth 114 m, average depth 34,1 m.

From this upper lake, the Sog river flows southerly into a lower lake, Ulfljötsvatn, area about 3 km^2. The drainage area is: below Thingvallavatn about 1000 km^2, at Ljósafoss 1050 km^2 and at confluence with Hvitá about 1200 km^2.

Below Ulfljötsvatn the Sog river has three separate waterfalls, Ljósafoss, Irafoss and Kistufoss.

On the Sog river are built three hydroelectric power plants, the Upper Sog Plant (27 MW), the Ljósafoss Plant (6,4 MW) and the Irafoss Plant (45 MW).

The length of Hvitá from lake Hvitarvatn to the confluence with Sog is appr. 160 km. The drainage area at the confluence with Sog is about 4500 km. About 690 km^2 or 16 % of this area is covered by glaciers. The flow is to a great deal spring-fed from lindá streams (Tungufljot, Brúará and Sog), a considerable deal of glacial melt-water (from Upper Hvitá)and a little deal from direct run-off and lakes (L+J+D+S).

Below lake Hvitarvatn there are numerous small falls and rapids where the river drops 155 m over a distance of 18 km.

The highest waterfall in Hvitá river is Gullfoss, appr. 30 m. In the Gullfoss reach the river drops 100 m over a distance of 8 km.

In the lower parts of Hvitá river the greatest fall is in the reach from above lake Hestvatn to below the Selfoss, appr. 45 m over a distance of 28 km.

Of special importance for the ice production is the area of the river surface which is exposed to heat exchange with the atmosphere. Table Fig. A-2^3 shows the length, elevation, slope and area of the various river sections when the whole river is open.

Table Fig. A-2^3.

Length, elevation, slopes and areas of Hvitá river sections

	Dist. from mouth km	Elevation m a.s.l.	Length of sect. km	Diff. in elev. m	Average slope m/km	Area of section km^2	Average width of river section m
At Hvitarvatn Lake	134,0	421					
			20,8	157	7,5	1,8	87
At Fremstaver	113,2	264					
			10,0	19	1,9	1,4	140
Approx. 8 km upstream from Gullfoss	103,2	245					
			17,4	163	9,4	1,6	92
Approx. 8 km downstream from Gullfoss	85,8	82					
			9,8	22	2,2	0,9	92
Above Kopsvatnseyrar	76,0	60					
			29,5	12	0,4	14,4	488
At Hestvatn Lake	46,5	48					
			30,0	45	1,5	12,0	400
Below Selfoss	16,5	3					
			16,5	3±	0,2±	30 appr.	1820
At mouth	0	0±					

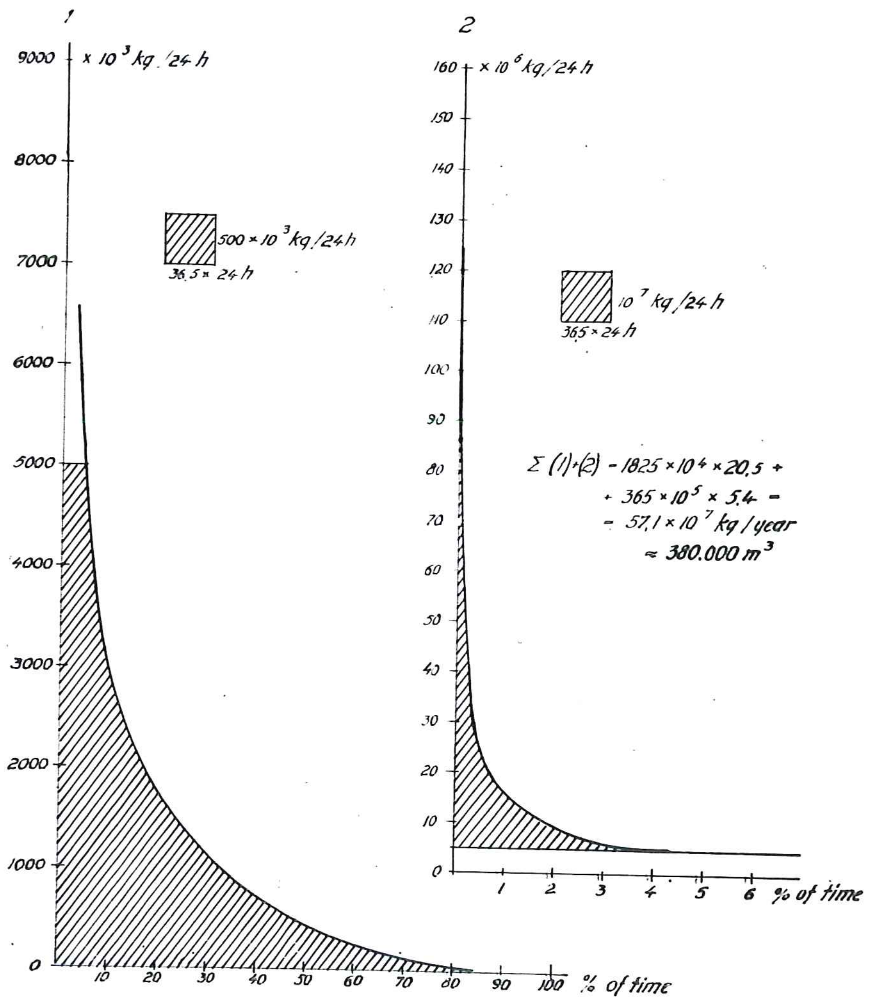
The SEA has carried out measurements of suspended sediment load in the Hvitá river. Fig. A-2^4 shows a sediment duration curve, based on the flow duration curve plus a relationship between discharge and suspended sediment, established by analysis of 43 samples from the river at different flow.

According to the figure, the average annual suspended sediment load at Gullfoss is ca 380.000 m^3.

Stóra Laxá (D) carries a great substantial volume of sediments resulting from erosion by the river itself and by the surface run-off.

Fig. A-2 4

HVÍTÁ at GULLFOSS SUSPENDED SEDIMENT



$$\Sigma\,(1)+(2) = 1825\times10^4\times20{,}5 + 365\times10^5\times5{,}4 = 57{,}1\times10^7\ \text{kg/year} \approx 380.000\ \text{m}^3$$

3. The Tungnaa and Thjorsa river system

The Thjorsa river system may suitably be divided into three main sections: Upper Thjórsá, above the confluence with the Tungnaa river, Tungnaá river with main tributary Kaldakvisl, and Lower Thjórsá, below the confluence with Tungnaá.

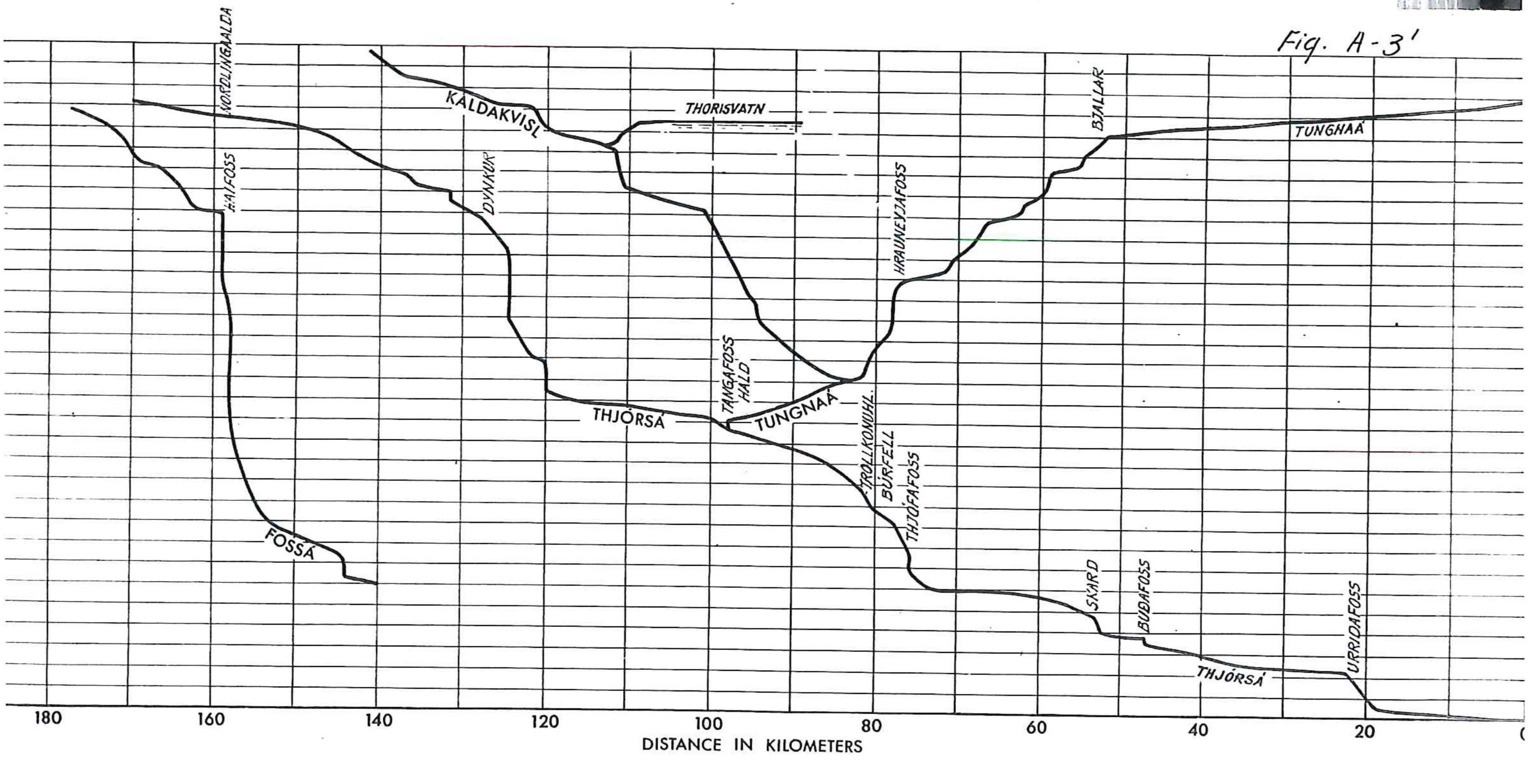


Fig. A-3'

In Fig. A-1^1 and A-3^1 are given the size of drainage areas and the longitudinal sections of Thjórsá, Tungnaá and their tributaries.

The subdivision of the drainage areas between the main tributary rivers, as well as the size of drainage areas and characteristics of the flow is shown in table Fig. A-3^2.

Fig. A-3^2.

CHARACTERISTICS of the THJÓRSÁ and TUNGNAÁ RIVER SYSTEM

Name of rivers and lakes	Location	Length km	Altitude m	Drainage area, km²	Characteristics
Upper THJÓRSÁ	Soleyjarhöfdi		580	1740	J+D
Fjordungskvisl	Confluence	28	690	260	J+D
Bjergvatnskvisl	"	32	690	227	D
Hnitá	"	11		100	J+D
Svartá	"	20		95	D
Upper THJÓRSÁ	Nordlingaalda			2060	D+J
Kisá	Confluence	17	510	147	D
Miklilækur	"	14		40	D
Dalsá	"	36	500	253	D+S
Upper THJÓRSÁ	Dynkur			2615	D+J
" "	Tungnaá		280	2850	D+J
Vatnak.+ Snjoöldukv.	Confl.w.Tungnaá			270	L+S
TUNGNAÁ	Bjallavad			1400	L+J+D
Utkvisl+Blautakv.	Confluence			93	L
TUNGNAÁ	Tungnarkrok			1555	L+J+D
"	Hrauneyjafoss		395	1625	L+J+D
Kaldakvisl	Confl.w.Tungnaá	109	318	1740	J+D+L+S
TUNGNAÁ	Hald	122		3470	L+J+D
"	Confl.w.Thjorsá	129	280	3480	L+J+D
THJÓRSÁ	Tangafoss	0	280	6320	D+J+L
"	Klofaey	9		6360	D+J+L
"	Tröllkonuhlaup			6380	D+J+L
Fossá	Confluence	72		223	D+L
Sandá	"				D+L
THJORSÁ	Stori-Nupur	42	120	6880	D+J+L
"	Budafoss	49	74	6930	D+J+L
Kalfa	Confluence	25	61	85	D
THJÓRSÁ	Krokur	72	47	7180	D+J+L
"	Urridafoss	77	21	7200	D+J+L
"	Egilsstadir	85	8	7220	D+J+L
"	Mouth	97	0	7530	D+J+L

Upper Thjórsá has a length of about 90 km. The river comes from the sources on the high plateau between Hofsjökull and Vatnajökull. The river has a total fall of about 300 m over a length of 60 km. Appr. 160 m of this fall is concentrated in the 10 km long Thjórsá Gorge, near the center of the Upper Thjórsá, by two great waterfalls, and in its associated rapids. Gentle grades prevail in the remainder of the river except for a drop of 15 m at a waterfall.

Waterfalls and rapids of considerable importance are: Hvanngiljafoss falling 14,2 m on a 600 m course, Dynkur falling 63 m on a 800 m course and Gljúfurleitarfoss - 28,5 m in concentrated fall.

A section of the river, beginning about 2 km above the confluence with Blautakvisl and stretching about 11 km upwards, is very wide and shallow.

The main tributary rivers are: Bergvatns - and Fjordungskvisl and Svartá from the left, Kisá and Dalsá from the rigth.

The flow is substantially a direct run-off (draga stream), with a considerable deal of glacial melt-water (D+J).

Tungnaá comes from Vatnajökull and is considerably larger than Upper Thjórsá. The length is about 130 km and the total drainage area about 3470 km².

The profile of the Tungnaá river may be divided into three reaches based upon position and relative gradient. The uppermost reach 80 km lang, from near Vatnajökull to the Bjallar waterfall, has a drop of about 140 m of a nearly uniform gradient. The following reach from Bjallar to near the mouth of the Kaldakvisl has a drop of about 240 m as the Tungnaá flows for 30 km along the border of the Thjórsá laves. This high degree of slope is characterized by falls and rapids concentrated at Bjallar (18 m), Tungnaarkrokur (10 m), Skeggjafoss (12 m) and Hrauneyjafoss (96 m including rapids in 5 km course), each separated from the other by short stretches where the flow has a moderate gradient. The comparatively flat lower section extends from the Kaldakvisl mouth, (321 m, m.a.s.) for 16 km to the Thjórsá (273 m, m.a.s.) having a drop of 48 m with a nearly uniform gradient.

At several places Tungnaá is divided in many shallow branches spreading into a lava field. To mention is a section about 5 km long, just above Hrauneyjafoss, and a section about 6 km long just before Tungnaá joins Thjorsá.

An important tributary river to Tungnaá is Kaldakvisl, which also originates in Vatnajökull. Lake Thorisvatn drains via the 6 km long Thorisos river to the Kaldakvisl. Upstream of the Thorisos confluence, the Kaldakvisl has a moderate and nearly uniform gradient. The flow is to a great deal a draga stream and carries glacial melt-water (D+J+S).

Lake Thorisvatn, 70 km² in area, presents a major seasonal potential storage. It is situated at an altitude of 575 m and has a considerable depth (max. depth about 110 m, average depth 40,7 m).

Total drainage area of Tungnaá is about 3470 km². The flow is to a great deal spring-fed (lindá stream), evened by lakes and to a less deal fed by a direct run-off and glacial melt-water (L+D+J+S).

The Tungnaá carries in winter very little sediment, only small amounts of wind-blown sand and pumice.

Lower Thjórsá is a broad and powerfull river. From the place of confluence with Tungnaá it is running for the most part in lava fields, respectively along the boundary of lava fields. Running on a lava field the river is generally wide and shallow such as from Tröllkonuhlaup 14 km upwards, where the width is up to 500 m, while the depth is only 0,5 - 1 m at mean discharge. The lower part of the river has long sections which are nearly 2 km wide.

The profile of the Lower Thjórsá may be divided into three reaches based on position and relative gradient. The section 20 km long between Tangafoss and Tröllkonuhlaup has a drop of about 60 m with a nearly uniform gradient. The second reach from Tröllkonuhlaup to the southerly end of Burfell has a major doncentrated drop in a series of rapids and waterfalls. The fall totals nearly 90 m over a distance of 7 km. The Thjórsá resumes a relatively gentle gradient about 1 km upstream from the mouth of the Fossá to the head of the Urridafoss. The river profile consists of long low - sloping reaches separated by short swift - current reaches with falls and rapids. The total fall of this 50 km long section is 75 m, including 15 m at the Skard rapids and 7 m at the waterfall Budafoss, both near the center of the reach. The last major concentrated drop on the Thjórsá amounts to 35 meters as the river passes through the 4 km long Urridafoss gorge. Below Urridafoss the fall amounts to only 11 m in the remaining 18 km to the ocean.

The main tributary rivers are: Fossá, Thverá and Kálfá.

The drainage area of Thjórsá at the confluence with Tungnaá is about 6320 km², at Burfell about 6400 km², at Urridafoss 7200 km², and the total area about 7530 km².

Table A-3[3] gives the area of the Thjórsá and Tungnaá river surface which is exposed to heat exchange with the atmosphere.

The flow of Thjórsá is substantially a direct run-off stream with glacial melt-water essentially from Upper Thjórsá, and springfed water to some extent from Tungnaá and Fossá.(D+J+L).

The Thjorsá is a sediment-carrying river. The lower sections are in many places covered with large gravel - and sandbanks.

Length, elevation, slopes and areas of the Thjorsa and its main tributaries.

Fig A-3^3

	Distance from mouth km	Elevation m a.s.l.	Difference in elevation m	Average slope m/km	Area of section km^2
Upper Thjorsá					
At confluence with Svartá R.	146	557			
			53	3,8	2,45
At Hvanngiljafoss Falls	132	504			
			196	16,3	2,3
Below Gljúfurleitarfoss Falls	120	308			
			20	1,1	4,9
At Confluence with Blautakv.	102	288			
			14	3,5	0,5
At confluence with Tungnaá R.	98	274			
Tungnaá					
At Hofsvað	46x)	558			
			134	7,1	2,9
Below Sigöldufoss Falls	27	424			
			8	1,3	2,0
At Hrauneyjafoss Falls	21	416			
			96	19,2	0,4
At confluence with Kaldakvísl	16	320			
			28	2,5	1,1
At Hald	5	292			
			12	2,4	2,0 (Blautakvísl) 0,2
At confluence with Thjórsá R.	0	280 274			
Lower Thjórsá					
At confluence with Tungnaá R.	98	274			
			21	2,6	4,1
Approx. 8 km downstream (Klofaey)	90	253			
			43	4,8	2,9
At Tröllkonuhlaup Falls	81	210			
			31	7,8	0,7
Approx. 4 km downstream	77	179			
			29	29,0	0,1
At Thjófafoss Falls	76	150			
			24	12,0	0,2
Below Thjófafoss Falls	74	126			
			19	1,1	6,6
Approx. 18 km downstream	56	107			
			33	3,7	3,7
At Buðafoss Falls	47	74			
			29	1,2	21,8
At Heiðartangi	22	45			(- 5,5 km of sandbanks)
			35	11,7	0,2
Below Urriðafoss Falls	19	10			
			10	1,5	28
At Skúmseyrar	0	0			

x) Distance from confluence with Thjors

The Upper Thjórsá carry large sediment quantities consisting mainly of materials eroded from the beds of the rivers and the glaciers. The amount transported is less during low discharges in wintertime but increases rapidly with the flow.

Also the Upper part of Kaldakvisl and Tungnaá carry a great volum of sediments. The variation of sediment with discharge has a similar relationship.

Within a distance of about 10 km from the ocean the tides are influencing the water level.

Chapter B. METEOROLOGICAL and HYDROLOGICAL DATA RELEVANT to the ICE CONDITIONS

Iceland is more than other european countries exposed to the passages and oscillations of the Polar Front, i.e. the borderline between cold air currents blowing from the Arctic Ocean, and warmer air currents blowing from the Atlantic Ocean. In winter time cold spells of northerly wind will sweep the country when arctic air comes, and mild southerly wind will after shorter of longer time come instead when atlantic air arrives.

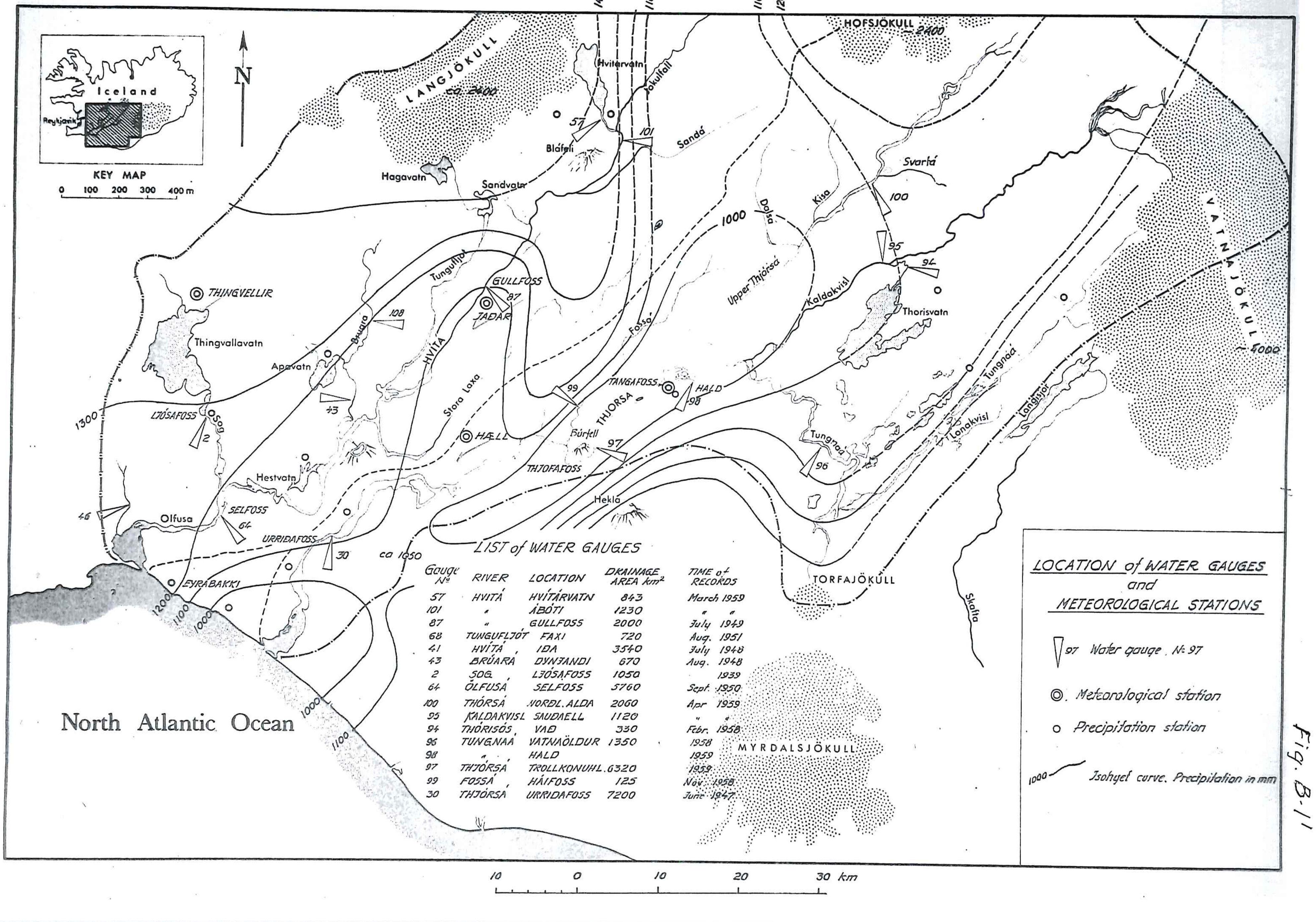
During a cold spell comes in addition the influence of the mountainous snow and ice fields of the interior districts which by clear weather become efficient producers of cold air floating down the valleys. In the Hvitá and Thjórsá river basins the direction of the valleys is about the same as the direction of the cold air current from the Arctic.

The character of the weather changes and the precipitation will determine the ice conditons in the river systems. Special importance for a detailed study of ice production will be the observations of air temperature, wind and precipitation.

1. Meteorological observations of air temperature, wind and precipitation.

Meteorological stations with continuous series of observations can practically only be placed in the inhabited regions of the country. This is the case with the three meteorological stations within the Hvitá and Thjórsá river basins, viz. Hæll, Jadar and Thingvellir, location map Fig. B-1[1].

Fig. B-11



LOCATION of WATER GAUGES and METEOROLOGICAL STATIONS

LIST of WATER GAUGES

Gauge №	RIVER	LOCATION	DRAINAGE AREA km²	TIME of RECORDS
57	HVITÁ	HVÍTÁRVATN	843	March 1959
101	"	ÁBÓTI	1230	" "
87	"	GULLFOSS	2000	July 1949
68	TUNGUFLJÓT	FAXI	720	Aug. 1951
41	HVÍTÁ,	IDA	3540	July 1948
43	BRÚARÁ	DYNJANDI	670	Aug. 1948
2	SOG,	LJÓSAFOSS	1050	1939
64	ÖLFUSÁ	SELFOSS	5760	Sept. 1950
100	THÓRSÁ	NORDL. ALDA	2060	Apr 1959
95	KALDAKVISL	SAUDAELL	1120	" "
94	THÓRISÓS,	VAD	330	Febr. 1958
96	TUNGNAÁ	VATNAÖLDUR	1350	1958
98	",	HALD		1959
97	THJÓRSÁ	TROLLKONUHL.	6320	1959
99	FOSSÁ,	HÁIFOSS	125	Nov. 1958
30	THJÓRSÁ	URRIDAFOSS	7200	June 1947

From the desolated mountaineous areas and the glaciers only occasional observations of air temperature or short series are available, and chiefly from the summer time.

Precipitation measurements will be treated separately below.

Hæll met.st. is situated in the lower part of the system, at an altitude of about 130 m. From the daily temperature observations at Hæll are calculated two types of averages, viz. monthly means, respectively pentade means for 5 - days intervals. For precipitation monthly sums or pentade sums are calculated. Monthly means or monthly sums will smooth out irregularities which will be disclosed by pentade means respectively pentade sums.

In the table Fig. B-1^2 are given the monthly means of temperature, the number of day-degrees of frost and the total precipitation at Hæll during each month, for the period 1930-60. On the top of the table are given the normal values for two periods, 1901-30 and 1931-60.

Graphic illustrations of pentade means of temperature and pentade sums of precipitation at Hæll are given in Figs. B-1^{3-5} for the period 1950-65.

More details giving daily maxima and minima of temperature at Hæll during the last 5 winters are represented by the curves, see section B-2.

The Thingvellir met.st. is situated in the lower part of the Hvitá, at the north end of the lake Thingvallavatn, at an altitude of about 105 m.

The Jadar met. st. was established in 1962 and is located near Gullfoss in the Hvita river, at an altitude of about 160 m.

A temporary meteorological station has recently been established near Tangafoss, at the Thjórsá-Tungnaá confluence, at an alititude of about 290 m.

Recordings of wind at Tangafoss and Hæll from the winter 1964-65 show that prevailing cold wind comes in most cases from direction N to E, while prevailing warmer wind mainly comes from direction S to SW.

Fig. B-12

METEOROGICAL OBSERVATIONS, MONTHLY SUMMARIES

HÆLL met. st., 1930-60

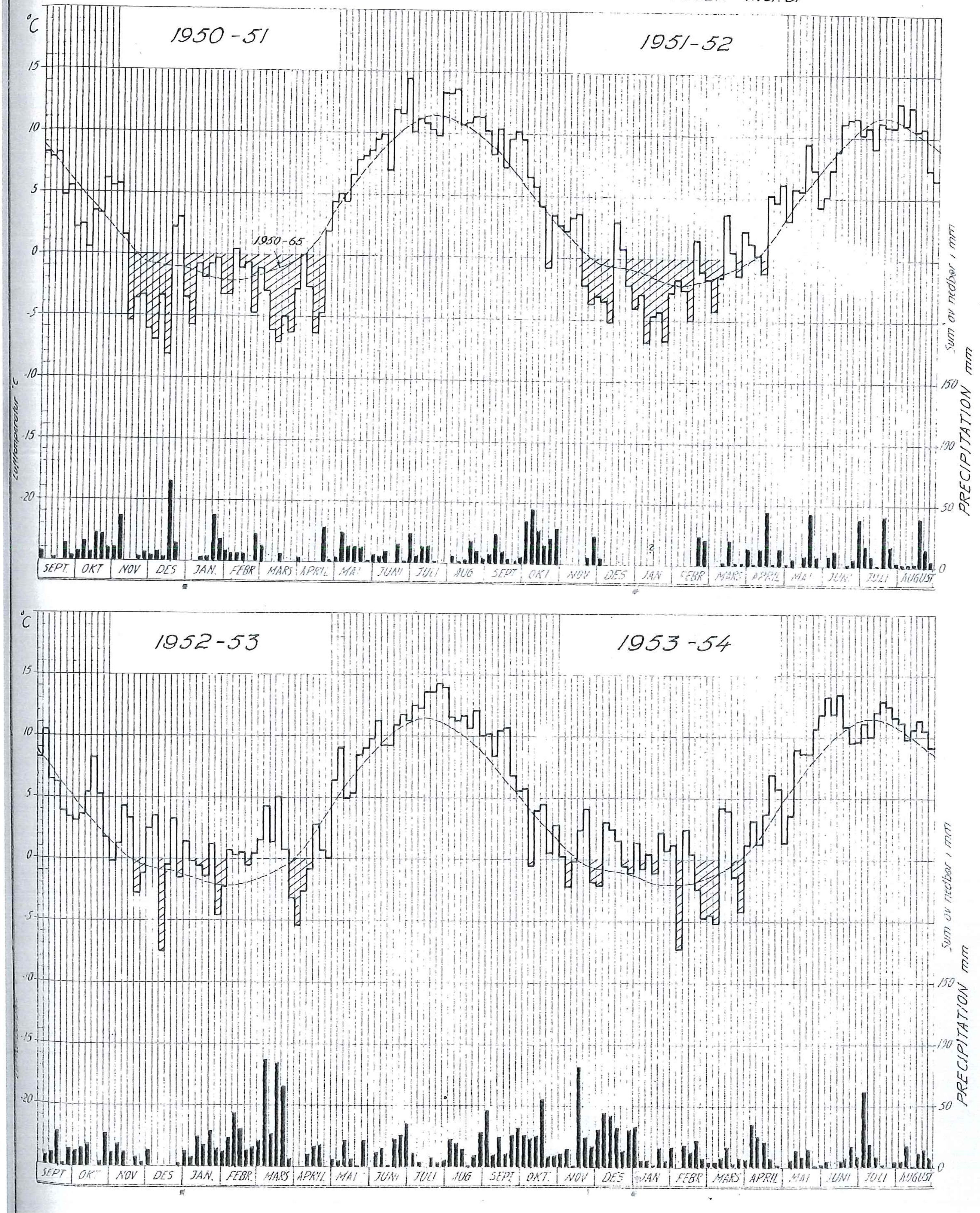
Vinter	NOVEMBER AIR TEMP. °C	NOVEMBER PRECIPIT. mm	DECEMBER AIR TEMP. °C	DECEMBER PRECIPIT. mm	JANUARY AIR TEMP. °C	JANUARY PRECIP. mm	FEBRUARY AIR TEMP. °C	FEBRUARY PRECIP. mm	MARCH AIR TEMP. °C	MARCH PRECIP. mm	APRIL AIR TEMP. °C	APRIL PRECIP. mm	Frost-sum ([illegible])	PRECIPITATION in mm
Normal/ 1901-30	0,3	90	-0,9	95	-1,8	75	-1,2	75	-0,8	75	1,4	65	4,9	475
1931-60	1,2	103	-0,4	95	-1,7	92	-1,6	84	0,3	82	2,2	74	3,7	530
1930 - 31														
31 - 32														
32 - 33					0,0	240	-5,0	48	0,8	70	1,8	30		
33 - 34	3,0	148	3,3	205	-0,7	143	0,0	330	-2,3	31	2,0	51	3,0	908
34 - 35	-0,1	164	1,9	40	1,1	163	-5,5	71	1,9	160	1,1	17	5,6	615
35 - 36	1,5	66	-1,2	(41)	-5,8	1	-2,3	43	0,3	71	3,5	36	9,3	258
36 - 37	0,1	158	-4,5	86	-0,3	51	-2,9	62	-4,1	1	4,5	92	11,8	450
37 - 38	1,5	95	0,9	90	-2,1	89	0,0	138	0,6	171	3,2	169	2,1	752
38 - 39	-0,1	37	1,0	89	-3,8	26	0,4	110	2,5	78	3,8	76	3,9	416
39 - 40	-0,1	43	-0,2	145	0,3	103	0,4	70	-1,2	58	2,4	72	1,5	491
1940 - 41	-0,2	93	1,0	151	-2,3	57	-3,3	43	0,5	56	4,2	35	5,8	435
41 - 42	3,1	88	0,7	150	-0,1	117	-0,1	75	1,8	38	2,5	92	0,2	560
42 - 43	2,0	129	0,6	65	-1,0	15	-2,6	131	-0,1	108	1,6	95	3,7	543
43 - 44	-0,1	104	0,4	160	-3,7	75	-1,4	70	-0,8	96	2,3	73	6,0	578
44 - 45	-1,0	52	-1,3	85	-5,2	32	-1,2	42	2,9	167	3,0	100	8,7	478
45 - 46	4,7	178	0,6	76	1,4	79	-1,5	61	1,7	69	2,2	113	1,5	576
46 - 47	-0,2	46	1,8	(95)	2,5	128	-3,1	9	-3,8	2	1,2	39	7,1	319
47 - 48	-0,7	28	-0,4	135	-0,3	43	0,8	92	2,4	253	0,8	43	1,4	594
48 - 49	1,8	104	0,1	108	-4,1	100	-1,3	88	-1,2	96	-0,9	50	7,5	546
49 - 50	1,6	56	-2,7	78	1,7	131	-2,2	19	-0,1	81	1,2	16	5,0	381
1950 - 51	-0,9	65	-2,8	98	-2,2	66	-1,6	32	-4,7	34	-1,0	34	12,2	329
51 - 52	0,5	36	-2,0	(45)	-4,7	74	-1,2	152	0,1	26	2,9	92	7,9	425
52 - 53	0,7	78	-0,2	28	-1,0	107	0,1	135	1,4	301	-1,0	45	1,2	692
53 - 54	0,4	147	0,7	191	0,3	65	-1,7	77	0,1	41	3,8	95	1,7	616
54 - 55	1,5	148	-2,4	72	-3,4	125	-4,2	40	-0,3	65	5,1	123	10,3	573
55 - 56	3,3	76	-3,8	18	-4,7	73	1,1	69	2,9	59	2,6	80	8,5	375
56 - 57	3,5	220	0,6	96	-0,2	161	-3,2	11	-0,6	18	3,6	94	4,0	600
57 - 58	1,7	125	-1,8	122	-4,2	80	-3,8	68	-1,0	29	3,2	168	10,8	592
58 - 59	3,6	228	-1,0	41							0,8	43		
59 - 60	0,3	63	-0,5	86	0,8	91	-2,8	98	2,8	69	4,0	125	3,3	532
Max	4,7	228	3,3	205	2,5	240	1,1	330	2,9	301	5,1	169	12,2	908
1st quart	2,0	148	0,7	135	0,3	125	0,0	98	1,8	96	3,6	95	8,5	594
Med	0,7	93	-0,2	89	-1,0	80	-1,6	70	0,1	69	2,4	74	5,3	544
2st quart	-0,1	56	-1,8	65	-3,8	57	-3,1	43	-1,0	34	1,2	41	2,1	425
Min.	-1,0	28	-4,5	18	-5,8	1	-5,5	9	-4,7	1	-1,0	16	0,2	258

Fig. B-1³

FIVE - DAY MEANS of AIR TEMPERATURE ·

PENTADEMIDLER av LUFTTEMPERATUR og NEDBØR

HÆLL met.st



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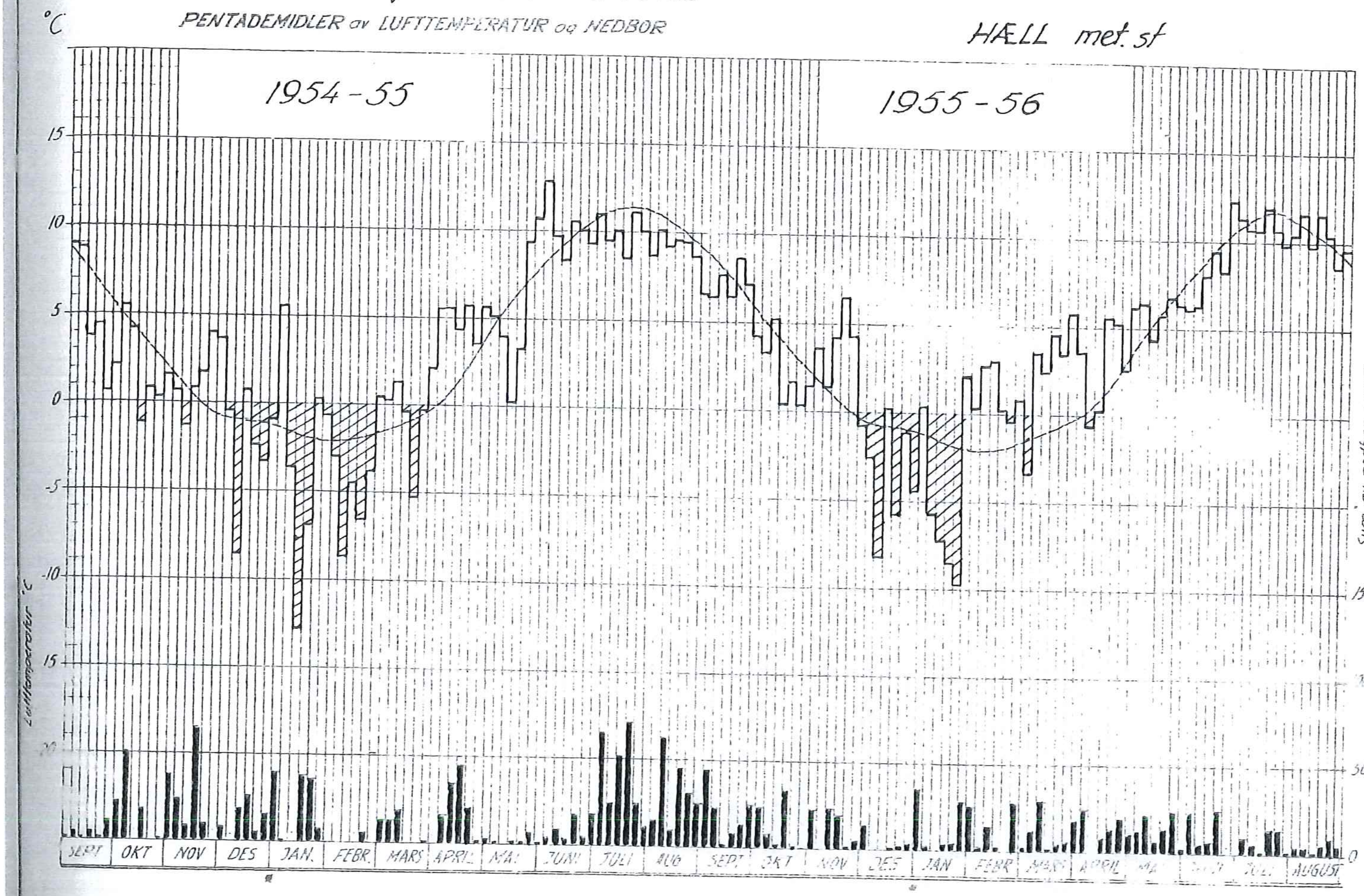
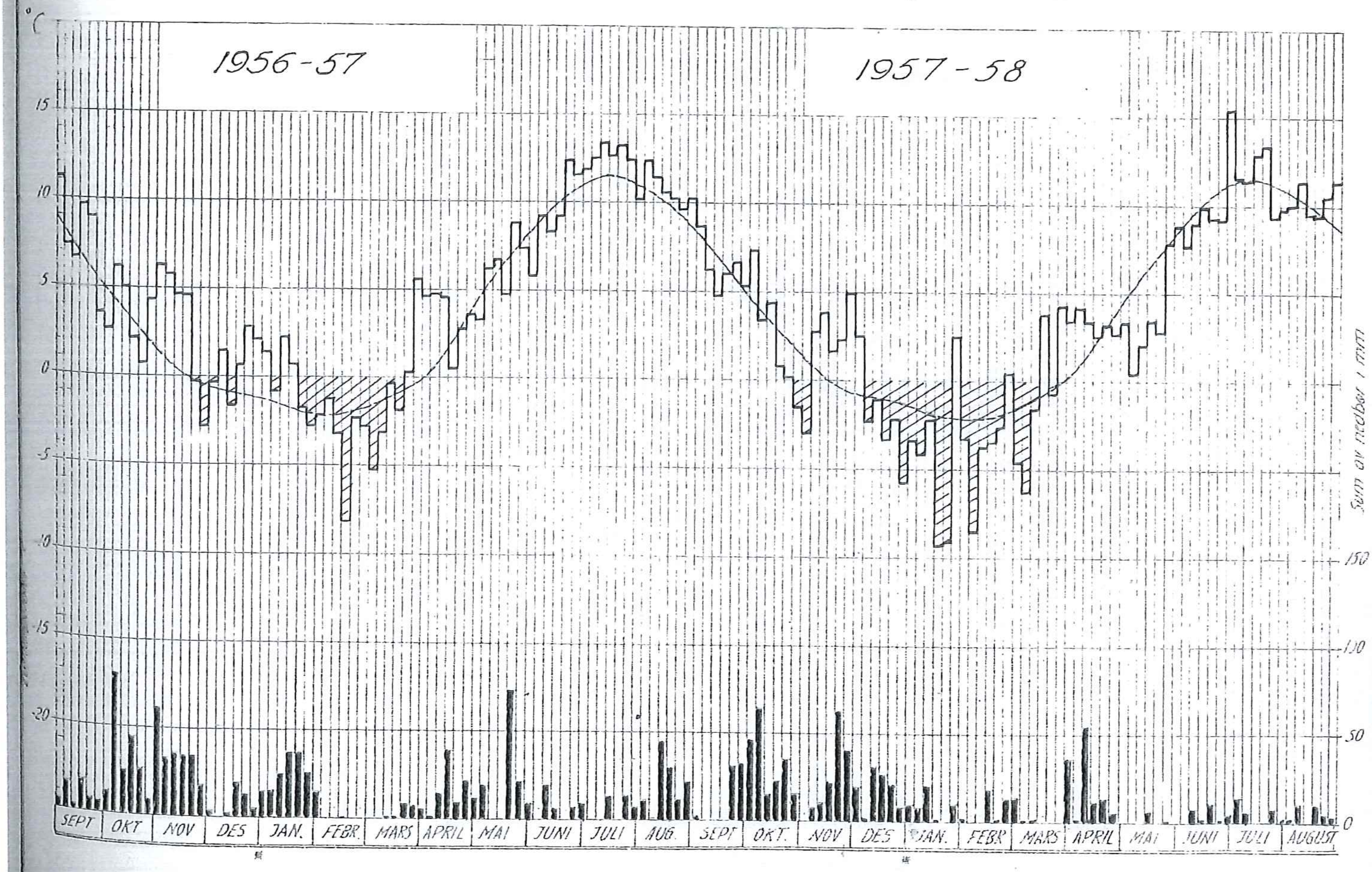
FIVE - DAY MEANS of AIR TEMPERATURE

PENTADEMIDLER av LUFTTEMPERATUR og NEDBØR

HÆLL met. st





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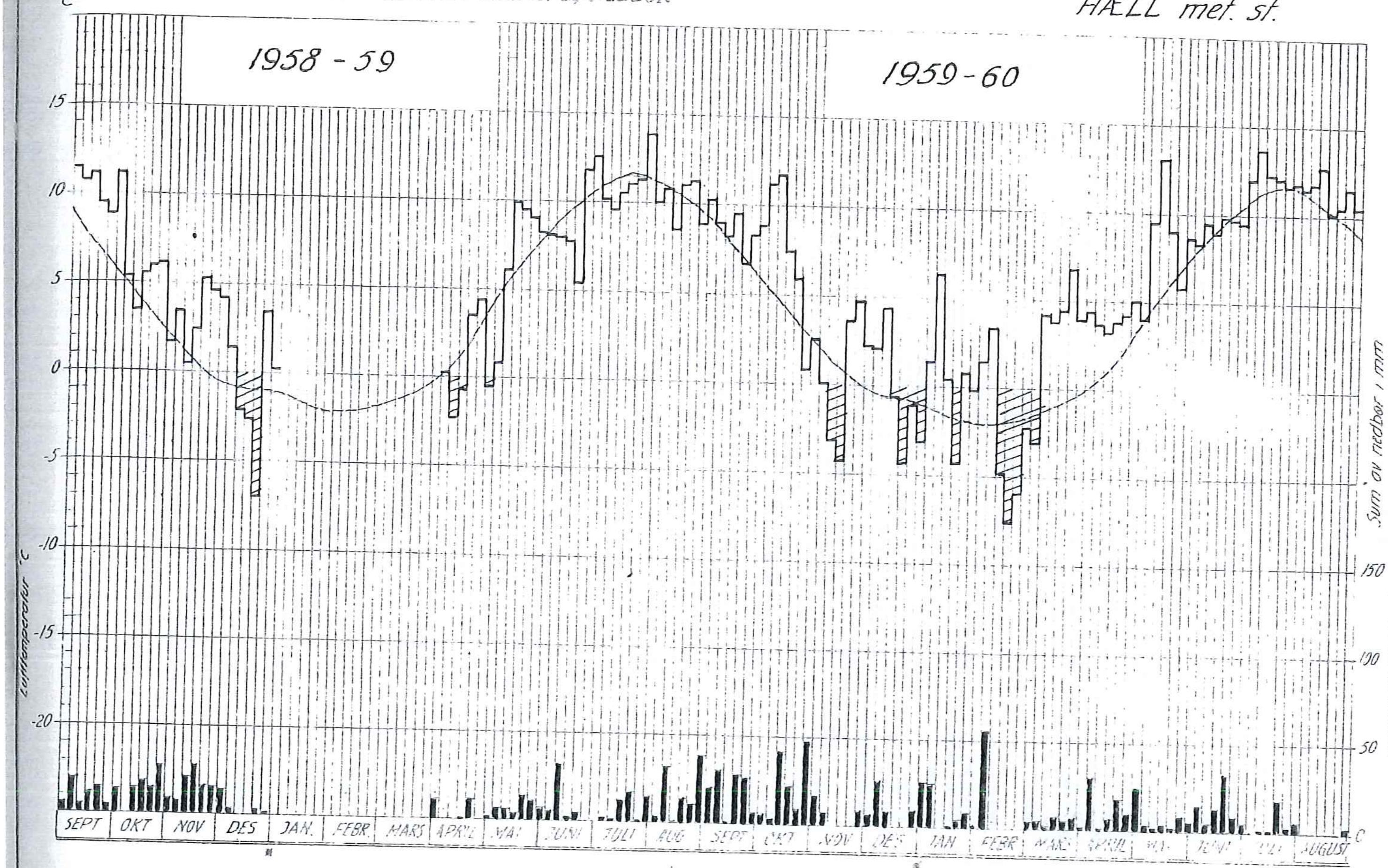
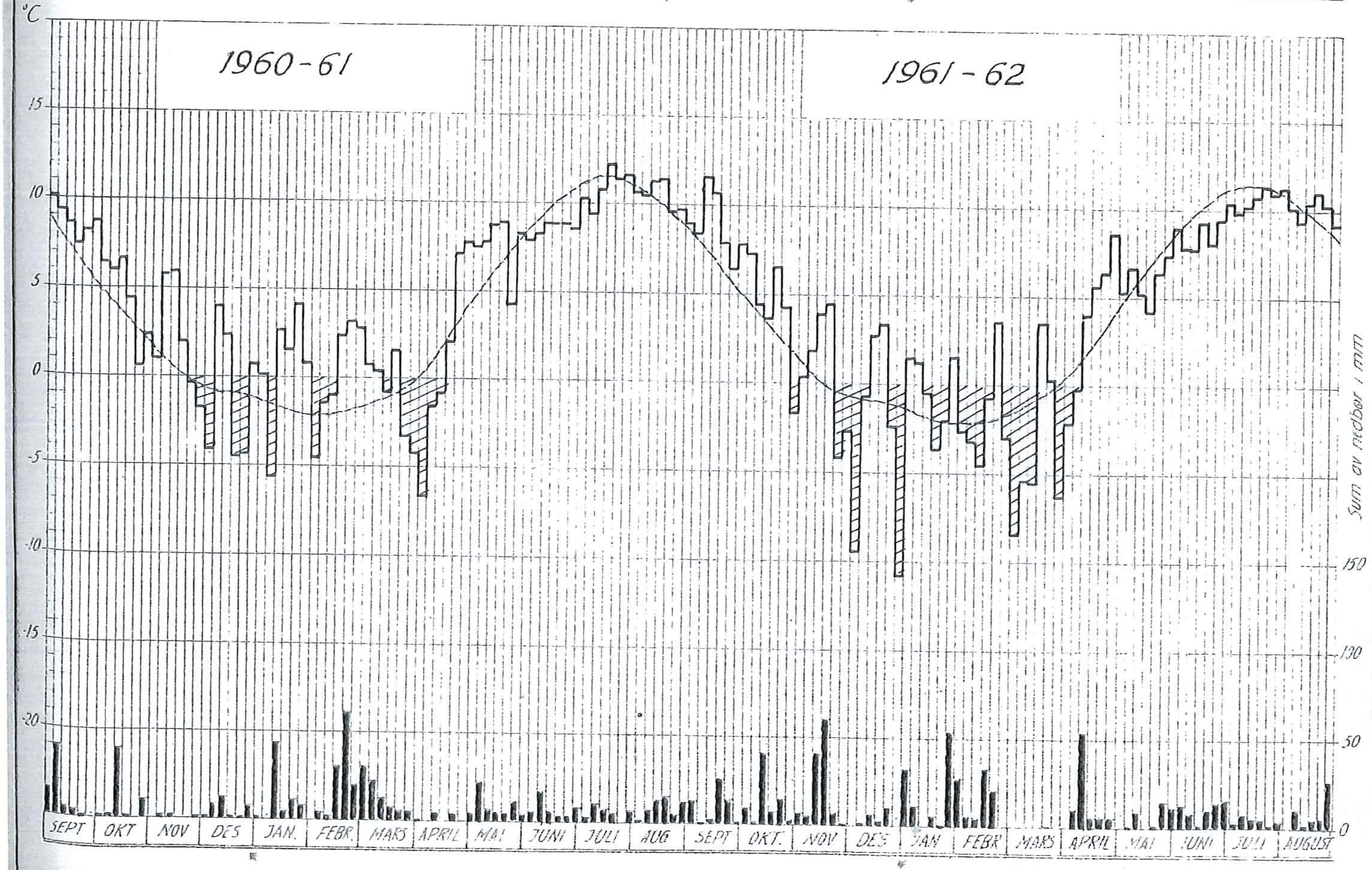
FIVE-DAY MEANS of AIR TEMPERATURE

PENTADEMIDLER av LUFTTEMPERATUR og NEDBØR

HÆLL met. st.





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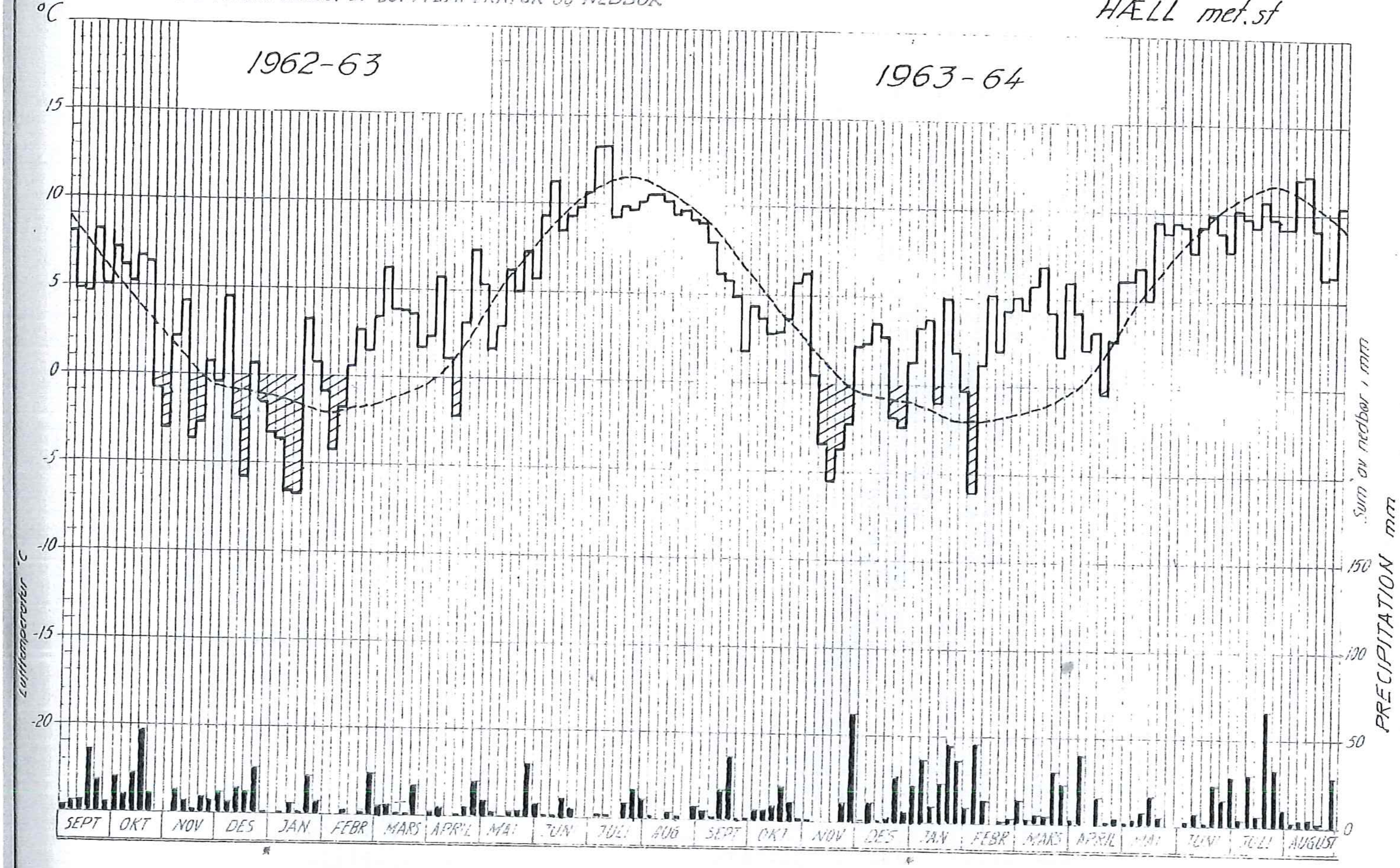
FIVE-DAY MEANS of AIR TEMPERATURE

PENTADEMIDLER av LUFTTEMPERATUR og NEDBØR

HÆLL met.st



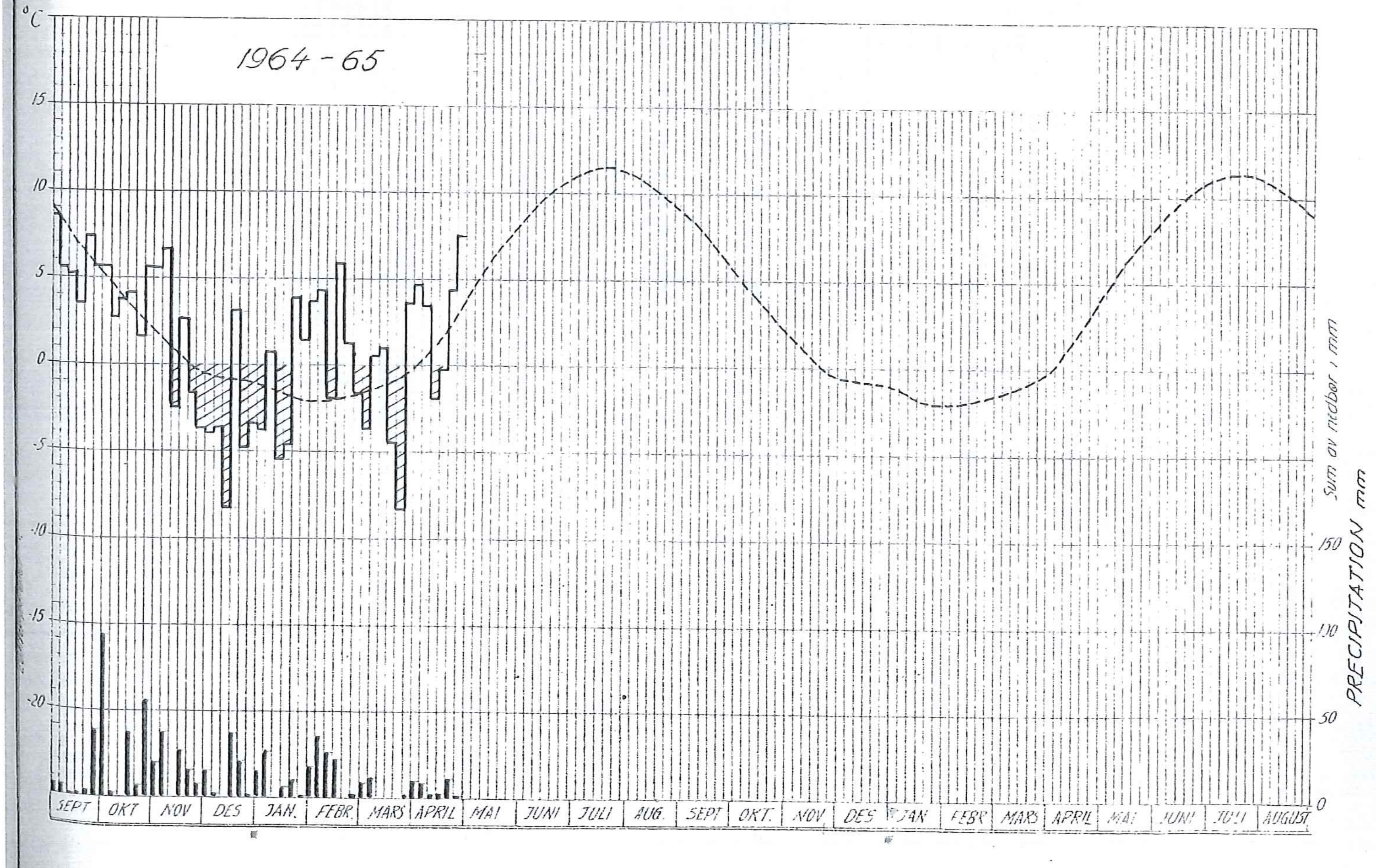
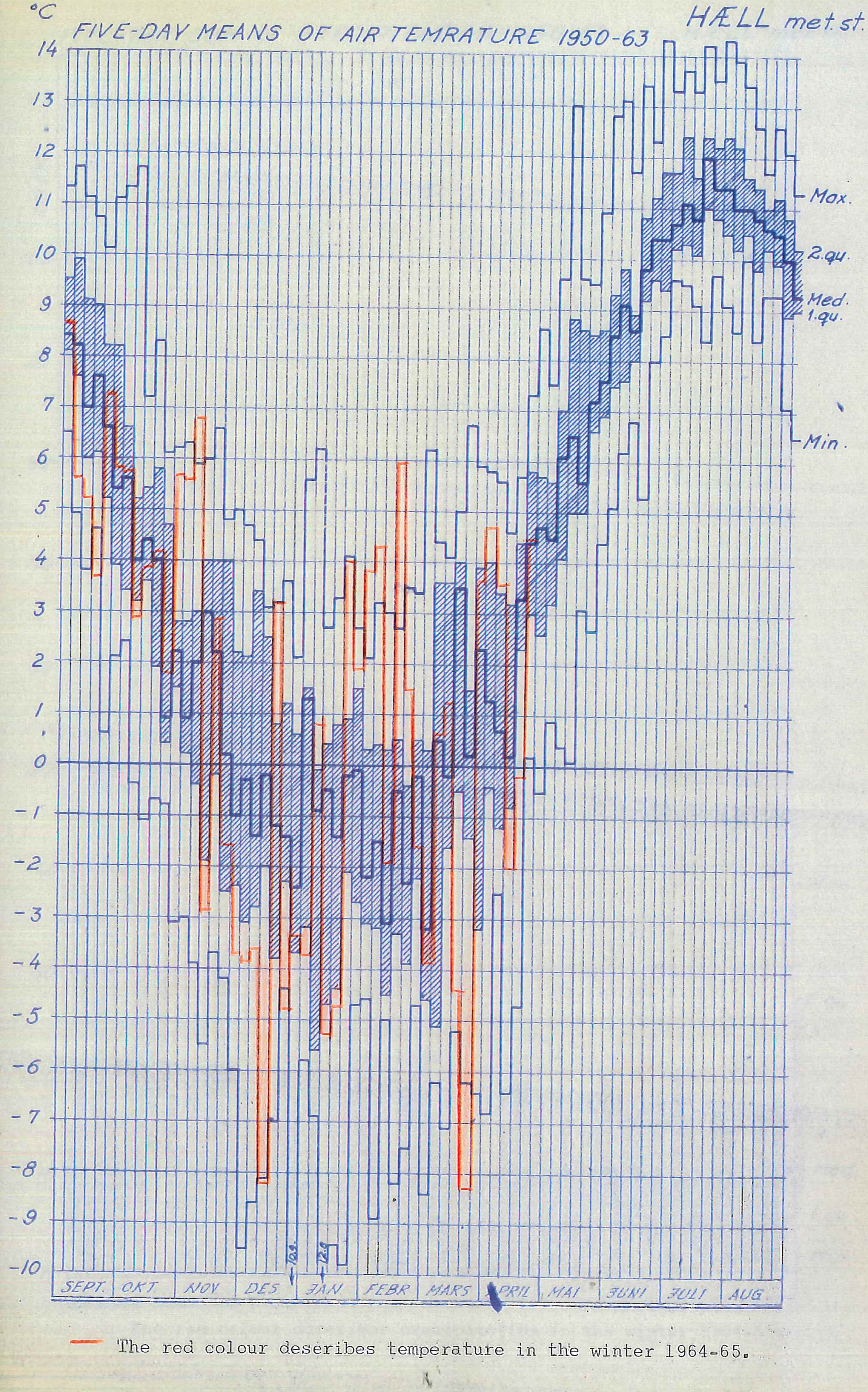


Fig. B-14



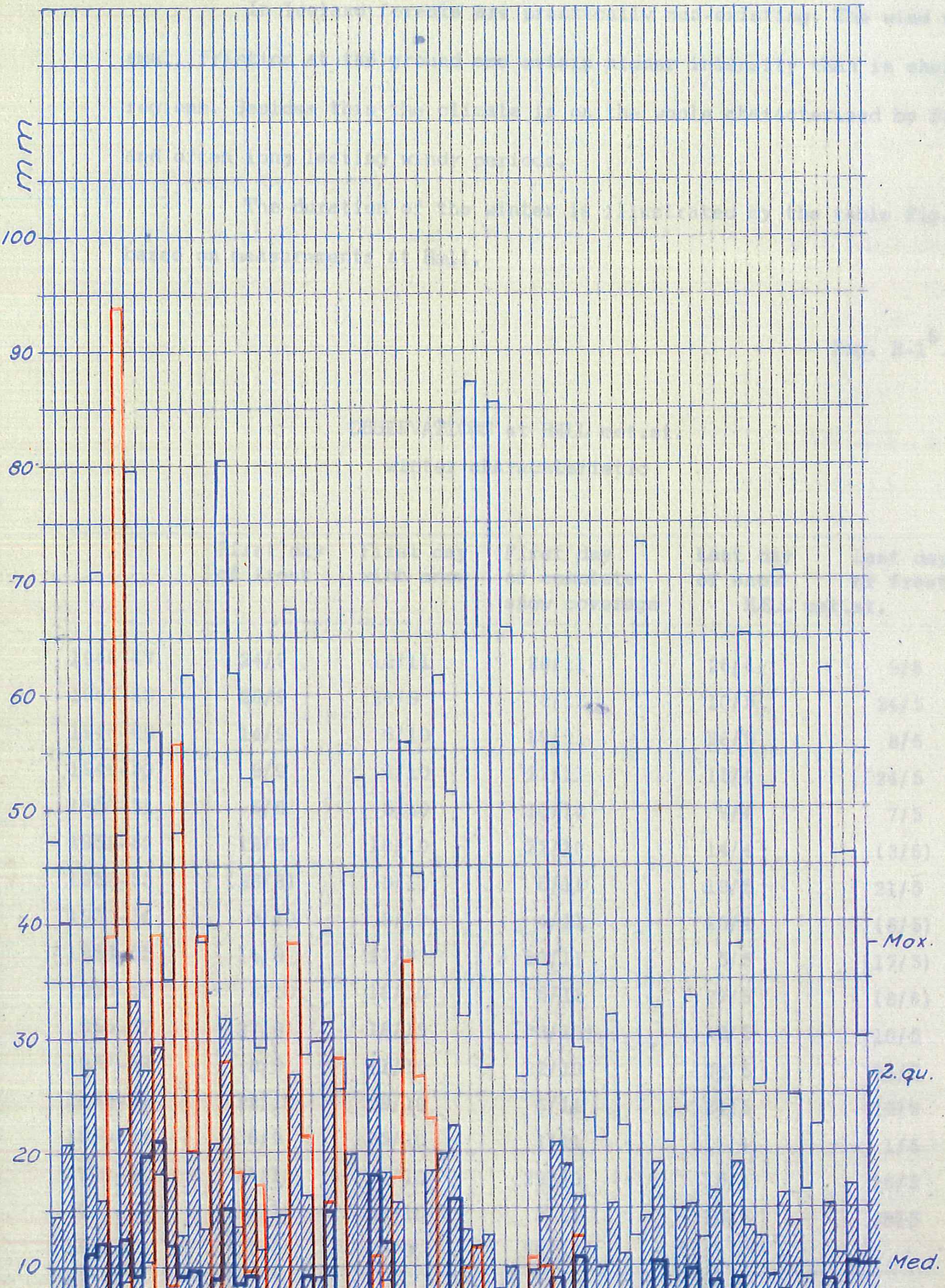
FIVE-DAY MEANS OF AIR TEMRATURE 1950-63

HÆLL met. st.

The red colour deseribes temperature in the winter 1964-65.

Fig. B-15

FIVE-DAY SUM OF PRECIPITATION 1950-63. HÆLL met. st.



The red colour deseribes precipitation in the winter 1964-65.

In Iceland forests are practically non-existing. The wind will meet small friction at the ground and attain higher intensity than in sheltered regions. Besides this the climate is on the whole characterised by frequent and often long lasting windy periods.

The duration of the winter is illustrated by the table Fig. B-1^{6} based on measurements at Hæll.

Fig. B-1^{6}.

OBSERVATIONS at HÆLL met.st.
winter charachteristic

	First day of frost	First day with snow	First day of complete snow coverage	Last day of snow HÆLL met.st.	Last day of frost
1946-47	24/9	12/11	28/11	26/4	9/6
1947-48	28/9	28/9	8/12	10/5	24/5
1948-49	14/9	6/10	29/11	28/5	8/6
1949-50	9/9	4/10	27/11	15/4	24/5
1950-51	6/9	5/10	10/12	9/4	7/5
1951-52	18/9	18/10	22/10	14/4	(3/6)
1952-53	(28/8)	3/11	6/11	19/5	21/5
1953-54	3/10	8/10	4/11	15/4	(8/5)
1954-55	14/9	27/9	10/11	5/5	(17/5)
1955-56	3/10	18/10	5/12	27/5	(8/6)
1956-57	(27/8)	18/10	(23/10)	5/5	10/5
1957-58	8/9	11/10	22/10	20/5	24/5
1958-59	12/10	29/10	6/11	24/5	19/6
1959-60	6/9	25/10	1/11	11/4	1/5
1960-61	11/10	29/10	29/10	15/4	26/5
1961-62	12/10	28/10	5/11	15/5	30/5
1962-63	11/9	25/9	26/10		
Earliest	(27/8)	25/9	22/10	9/4	1/5
1. quartile	7/9	4/10	28/10	15/4	14/5
Median	14/9	18/10	6/11	1/5	24/5
2. Quartile	3/10	28/10	28/11	17/5	6/6
Latest	12/10	12/11	12/12	28/5	19/6

1946-63

The observation material from these meteorological stations give a useful description of the character of the weather and the precipitation in the Hvitá - Thjórsá district. The tables and curves for Hæll given above demonstrate how very changeable the weather may be. At any time of the winter may come shorter or longer periods of frost, with ice production and declining discharge, which may be followed by shorter or longer periods of mild weather with rainfall and melting of snow and ice. This will cause increase of the river discharge.

Even in the monthly means of temperature are the fluctuations over a long period of years impressive, as will be seen from the table Fig. B-1^7 giving the monthly maxima and minima of temperature at Hæll, Thingvellir and Reykjavík.

Fig. B-1^7.

MONTHLY MAXIMA and MINIMA of AIR TEMPERATURE

1930-60

Meteorological st.		S.	O.	N.	D.	J.	F.	M.	A.	M.	J.	J.	A.
Hæll	max.			4,7	3,3	2,5	1,1	2,9	5,1				
	min.			-1,0	-4,5	-5,8	-5,5	-4,7	-1,0				
Thingvellir	max.			4,9	1,8	2,2	1,1	2,3	5,0				
	min.			-2,7	-4,4	-6,6	-5,9	-7,9	-2,1				
Reykjavik	max.	11,5	7,7	6,3	4,4	3,6	5,2	3,9	5,6	8,9	10,9	12,5	12,1
	min.	6,1	2,2	-0,1	-2,6	-3,8	-3,5	-3,0	-0,0	3,9	8,3	10,0	9,3

An illustration of the frequency of cold spells is seen from the curves giving the five-days means of air temperature at Hæll met.st., when we count the number of pentades with means of temperature equal to or lower than e.g. -4°C. This would correspond to about 6,5°C at an altitude of 300 m, i.e. to the place ~~Hald~~ Tengafoss at Tungnaá, see location map. Fig. B-1^1. We then get this table:

Number of pentades with mean temperature equal to or colder than -4°C at Hæll, respectively -6,5°C at Tangafoss.

1950-51	12 pentades	1957-58	7 pentades
51-52	8	58-59	- (missing)
52-53	3	59-60	6
53-54	5	60-61	7
54-55	7	61-62	8
55-56	7	62-63	4
56-57	2	63-64	2
		64-65	6

1 pentade = 5 days

Precipitation. In the south-western districts of Iceland has been established a number of precipitation stations which for the last 5 years give a comprehensive report of the precipitation. In the fig. B-1[1] is shown the distribution of precipitation in the lower districts of Hvitá and Thjorsá. It will be seen that two minima exist, (nearly 1000 mm) one near the coast and one between Thjorsá and Rangá. Maxima between 1500 and 1600 mm lie on the west side of Hvitá and the east side of Thjórsá. Very high precipitation has the region south of Vatnajökull, where the mean precipitation exceeds 3500 mm (according to measurements at Kvisker precipitation station).

From many years observations at Reykjavik are given an analysis of the yearly variations of precipitations, see Fig. B-1[8]. The estimation methods, see supplement table.

As can be seen from the graphic the precipitation shows great variations in the period.

Snow measurements on the glaciers and 7 integrating collectors of precipitation, placed in the southern parts of the highland, give supplementary data of the precipitation.

Estimation of the yearly variations of precipitation

Reykjavik, 1924-62.

	Total,mm	$k=\frac{x}{\bar{x}}$	k - 1	$\sum_1^n (k-1)$	$\sum_1^n (k-1)-a$
					-0,58
1924	937	1,14	0,14	0,14	-0,44
25	1110	1,35	0,35	0,49	-0,09
26	1019	1,24	0,24	0,73	0,15
27	928	1,13	0,13	0,86	0,28
28	764	0,93	-0,07	0,79	0,21
29	855	1,04	0,04	0,83	0,25
30	838	1,02	0,02	0,85	0,27
1931	998	1,21	0,21	1,06	0,48
32	735	0,90	-0,10	0,96	0,38
33	912	1,11	0,11	1,07	0,49
34	808	0,98	-0,02	1,05	0,47
35	655	0,80	-0,20	0,85	0,27
36	824	1,00	0,00	0,85	0,27
37	819	1,00	0,00	0,85	0,27
38	839	1,02	0,02	0,87	0,29
39	784	0,95	-0,05	0,82	0,24
40	755	0,92	-0,08	0,74	0,16
1941	739	0,90	-0,10	0,64	0,06
42	825	1,00	0,00	0,64	0,06
43	765	0,93	-0,07	0,57	-0,01
44	769	0,94	-0,06	0,51	-0,07
45	840	1,02	0,02	0,53	-0,05
46	908	1,10	0,10	0,63	0,05
47	895	1,09	0,09	0,72	0,14
48	964	1,17	0,17	0,89	0,31
49	742	0,90	-0,10	0,79	0,21
50	671	0,82	-0,18	0,61	0,03
1951	560	0,68	-0,32	0,29	-0,29
52	628	0,76	-0,24	0,05	-0,53
53	1080	1,31	0,31	0,36	-0,22
54	769	0,94	-0,06	0,30	-0,28
55	640	0,78	-0,22	0,08	-0,50
56	930	1,13	0,13	0,21	-0,37
57	813	0,99	-0,01	0,22	-0,36
58	783	0,95	-0,05	0,15	-0,43
59	1080	1,31	0,31	0,46	-0,12
60	597	0,73	-0,27	0,19	-0,39
1961	720	0,88	-0,12	0,07	-0,51
62	764	0,93	-0,07	0,00	-0,58
			0	+2270 7	
				a= 0,58	

Σ= 32062

$\bar{x}$= 822,1 mm

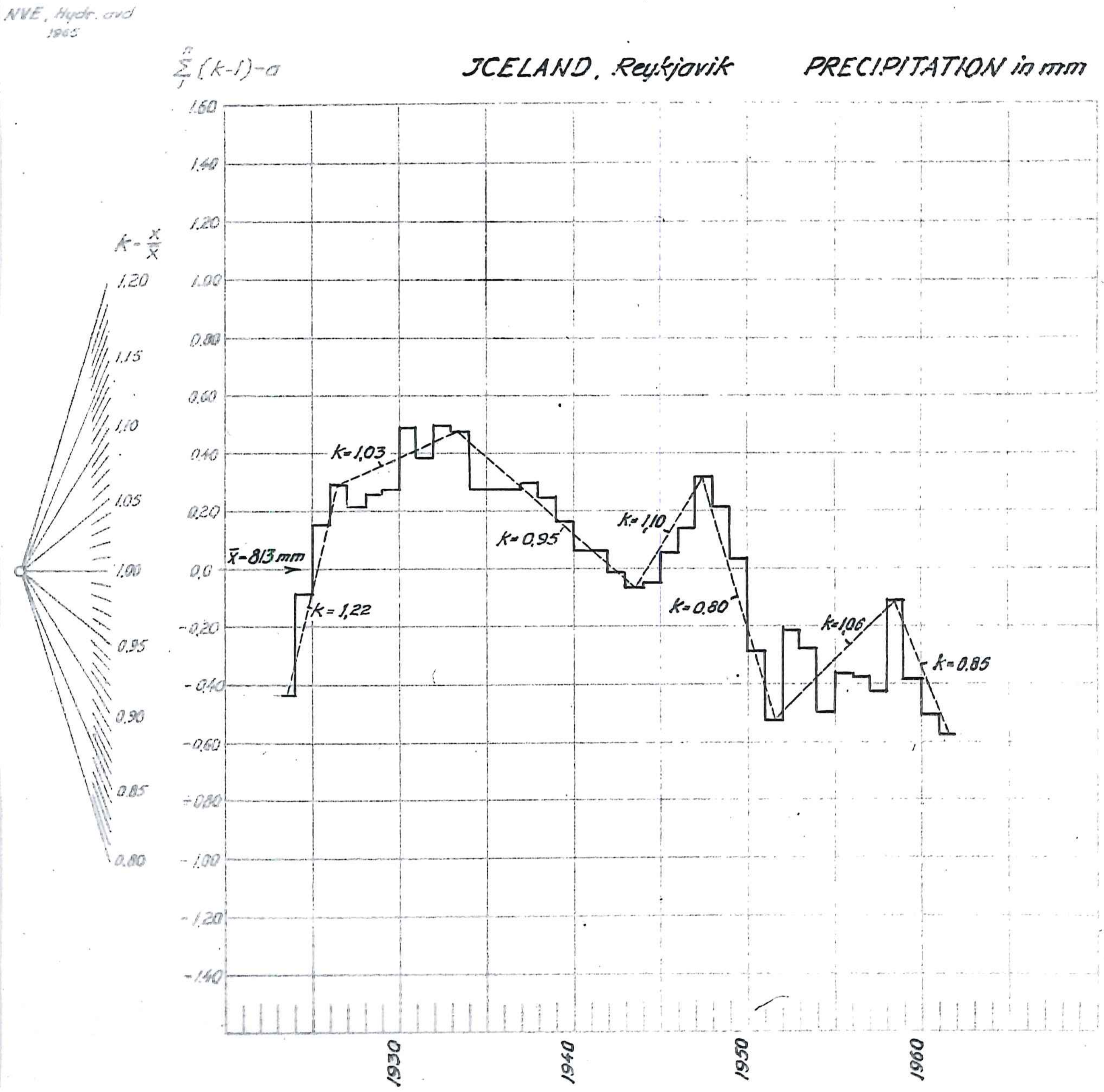


Fig. B-1⁸

A fraction of the precipitation fall as snow in the months September-May, the percentage is, however, much influenced by the local topography and the climate, and it is certainly very changing during the winter. It may safely be expected that a rainfall may occur at any month and at any place in the country during winter time.

From the following table Fig. B-1^{9} giving monthly means of precipitation for the period 1931-60 is seen that May and June are the drier months at these stations. The highest precipitation is measured in the months October-January.

Fig. B-1^{9}.

Monthly means of precipitation in mm in the period 1931-60

Station	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	June	July	Aug.
Hæll	113	131	103	95	92	84	82	74	59	63	76	92
Eyrarbakki	127	160	137	139	138	108	109	98	72	72	79	103
Thingvellir	120	157	139	134	134	103	110	90	70	68	72	95
Ljösafoss	162	204	171	144	155	115	140	109	91	92	96	127
Reykjavik	72	97	85	81	90	65	65	53	42	41	48	66

The local variations in the monthly sums of precipitation are also great. At the station Hveradalir at Hvitá has been measured 595 mm in January and 584 mm in September 1933.

The amount of precipitation during 24 hours may occasionally be great. At Fagurhólsmýri st. was for instance measured 121,5 mm on the 4. July 1960. In the following table Fig. B-1^{10} are given the highest measured precipitation during 24 hours during the period 1931-60, at the stations Vík, Hæll and Reykjavik.

Fig. B-1^{10}.

Maximum of precipitation through 24 hours in the period 1931-60.

Station	Sep.	Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	June	July	Aug.
Vik	150	77	139	76	64	78	49	68	78	92	75	93
Hæll	44	54	55	46	36	67	68	38	32	32	59	42
Reykjavik	49	37	44	55	36	40	57	22	19	30	31	35

The fluctuations of precipitation cause variations of the river discharge. Floods may occur at any time during the winter and the intensity may be increased by melting of a snow cover through rainfall and air temperature above zero.

Snow deposits in the central highland.

Winter precipitation above an elevation of 500 m mostly will fall as snow. During the last few years the Hydrological Survey has collected some descriptive informations of snow deposits in these areas. Two snow survey stations were established last autumn in the upper Thjorsá drainage area. The mean snow dept at one of them was 440 cm on the 18. April 1959, average spec. gravity was 0,572 g/cm^3, giving a water content of 252 cm. The precipitation as measured by a totalizer for the period 13. Oct. - 18. April was 500 cm.

Max. snow depth (cm) at Jadar met. st.

Winter	Nov.	Dec.	Jan.	Febr.	March	April
1957-58			19	-	20	4
1958-59	-	17	5	18	24	13
1959-60	16	6	23	1	12	11
1960-61	0	18	6	25	17	17
1961-62	6	-	18	32	-	9
1962-63	7	15				

2. Hydrological data

There are at present 22 gauging stations in the Hvitá and Thjórsá basin; see location map. B-1[1]. Several of these are equipped with Stevens recorder A-35 or Ott recorder, type X. Direct measurements of discharge have been performed at all these stations to check the readings and the recordings.

In Nov. 1964 a number of benchmarks have been established along the Tungnaá and Thjórsá rivers as refererences for measurement of water level variations caused by ice.

Differences in precipitation and run-off conditions in the Hvitá and Thjórsá and its tributaries result in great variations in the streamflow pattern and characteristics. Especially the discharge of the glacial and draga streams may fluctuate between wide limits and therefore floods are mostly confined to these two river types. Lindá flow may occur only under special circumstances.

A distinction between 5 types of floods have been discussed by Rist and Björnsson in the SEA report[x]:

1. Spring floods, caused by melting of snow in the highlands.
2. Winter floods, caused by mild weather and heavy rainfall coinciding with intense snow melting. These floods break up the ice on rivers.
3. Floods caused by heavy rainfall alone. Floods of this type may occur at any time of the year, but they have not reached the same magnitude as the other two flood-types.
4. Floods caused by the bursting of an ice barrier in the river. Such floods are usually low in the Hvitá and Thjórsá rivers.
5. Jökulhlaups, violent outbursts of water from water basins locked up under a glacier.

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[x] Thjórsá and Hvitá river systems in Southern Iceland. Some hydrological aspects by Sigurjon Rist and Jakob Björnsson, Reykjavik, June 1959.

The hydrological year in Iceland is counted from 1. September through 31. August the following year. In September the melting of snow in the mountain areas is as a rule very little and snow accumulation starts again. On the main glaciers there are no sharp time boundaries between melting and accumulation. There is always some melting in the middle of summer and usually some snowing in every month of the year.

In the following the results of stream gauging in the Hvitá and Thjórsá basins are summarized. Table Fig. B-2$^{1-5}$ show the monthly averages of discharge at various stream gauging stations for the whole period of record.

Streamflow of the Hvitá river and tributaries

In the uppermost reach at Bláfell, the Hvitá river is primarily a glacial river with a pronounced fluctuation in flow from summer to winter. The estimated monthly average flow at Aboti fall off from 97 m^3/s. in July to ca. 58 m^3/s. in January. The average discharge of Hvitarvatn is estimated to be 53 m^3/s.

This characteristic has to some degree been modified on the way to Gullfoss by considerable inflow of surface run-off water. The estimated monthly average discharge at Gullfoss is 131 m^3/s. in June and 99 m^3/s. in January. The estimated average annual discharge is 110 m^3/s. The max. observed floods have occurred in March 1953. Its max. discharge was of the order of 2000 m^3/s.

The lindá rivers (Tungufljöt, Bruará and Sog) entering the Hvitá downstream of Gullfoss tend to reduce the variations in flow even further.

The following table gives the drainage area and estimated average flow of the main tributaries listed in sequence proceeding downstream.

Fig B-2'

Monthly Averages of Discharge Q m³/s HVÍTÁ at ÁBÓTI , A = 1223 km²

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	51	42	44	53	33	34	30	35	127	77	71	56	55
51-52	53	71	47	81	26	72	51	64	153	93	101	90	75
52-53	62	59	46	42	52	63	250	74	124	118	104	94	91
53-54	88	92	99	157	118	59	71	92	121	125	107	82	101
54-55	64	55	54	42	47	25	43	146	73	96	131	147	77
55-56	102	62	68	49	71	81	66	79	86	87	82	58	74
56-57	54	72	127	59	71	55	42	77	98	90	90	84	77
57-58	57	73	60	73	48	38	34	77	45	97	88	61	63
58-59													
59-60													
60-61													
61-62													
62-63													
63-64													
64-65													
Max.	102	92	127	157	118	81	250	146	153	125	131	147	101
Min.	51	42	44	42	26	25	30	35	45	77	71	56	55
Av.	66	66	68	70	58	53	73	81	103	98	97	84	77

ICE CONDITIONS

Monthly Averages of Discharge Q m³/s HVÍTÁ at GULLFOSS , A = 2000 km

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	79	64	67	82	51	52	46	54	195	119	109	86	84
51-52	81	109	73	124	40	111	78	99	236	143	155	138	116
52-53	95	91	71	64	80	97	384	114	191	181	160	145	140
53-54	136	141	153	242	181	91	110	142	186	192	165	126	156
54-55	98	85	83	64	73	38	66	224	113	147	202	226	119
55-56	157	95	104	76	109	124	102	122	133	134	126	90	114
56-57	83	111	195	91	110	84	65	118	151	139	138	130	118
57-58	87	113	93	113	74	59	53	118	70	149	136	94	97
58-59	125	112	206	118	112	155	157	95	225	153	151	151	146
59-60	192	185	128	94	101	154	99	101	126	124	139	119	130
60-61	114	83	71	70	89	129	105	107	223	106	109	108	109
61-62	109	91	87	70	70	76	61	214	138	132	120	105	106
62-63	105	127	96	127	98	81	105	111	106	161	118	108	112
63-64	89	91	102	84	150	137	125	83	107	106	138	115	111
64-65	71	109	109	76	66	168	62	75	94				
Max	192	185	206	242	181	168	384	224	236	192	202	226	156
Min	71	64	67	64	40	38	46	54	70	106	109	86	84
Av.	108	107	109	99	99	103	107	118	152	132	131	116	110

ICE CONDITIONS

Fig. B-2^2

Monthly Averages of Discharge $Q\ m^3/s$ TUNGUFLJÓT at FAXI, $A = 720\ km^2$

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51													
51-52	48	48	38	42	36	44	40	41	38	38	44	51	43
52-53	43	38	37	36	43	45	71	38	41	44	50	53	45
53-54	52	52	49	64	54	46	45	49	46	50	53	56	51
54-55	50	45	49	40	42	36	45	50	41	49	63	67	48
55-56	67	56	50	41	46	45	48	45	48	47	49	48	49
56-57	45	56	63	49	48	41	39	43	44	47	49	51	48
57-58	50	50	46	45	39	38	38	44	37	36	46	46	43
58-59	48	50	60	44	45	52	48	43	47	47	47	53	49
59-60	60	60	44	42	44	52	45	45	46	49	52	57	49
60-61	52	45	41	40	45	53	47	40	49	43	43	47	45
61-62	46	44	42	37	43	39	34	57	40	41	43	42	42
62-63	44	46	44	46	40	36	39	36	38	40	43	43	41
63-64	41	38	39	37	52	44	38	36	33	36	42	42	40
64-65	39	43	44	38	37	48	35						
Max.	67	60	63	64	54	53	71	57	49	50	63	67	51
Min.	39	38	37	36	36	36	34	36	33	36	42	42	40
Av.	48	47	46	42	43	44	43	43	43	43	48	50	45

ICE CONDITIONS

Monthly Averages of Discharge $Q\ m^3/s$ BRÚARÁ at DYNJANDI, $A = 670\ km^2$

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	55	55	58	65	65	56	61	58	70	54	53	50	58
51-52	50	64	57	67	66	74	70	76	63	57	59	53	63
52-53	52	54	56	53	57	73	134	68	66	57	58	54	65
53-54	62	77	88	118	92	79	75	77	64	59	58	55	75
54-55	55	60	69	59	68	66	61	76	54	54	79	79	65
55-56	81	74	70	63	80	80	73	67	67	62	55	52	69
56-57	52	69	92	78	81	68	57	68	67	58	54	54	66
57-58	52	67	75	72	58	57	58	71	54	51	49	48	59
58-59	53	65	93	76	77	91	80	63	64	62	54	59	70
59-60	77	83	76	70	72	81	70	72	61	60	59	54	70
60-61	58	56	57	55	66	89	85	62	81	56	54	53	64
61-62													
62-63													
63-64													
64-65													
Max	81	83	93	118	92	91	134	77	81	62	79	79	75
Min	50	54	56	53	57	56	57	58	54	51	49	48	58
Av	58	65	71	70	71	74	74	68	64	57	57	55	65

ICE CONDITIONS

Fig. B-2 3

Monthly Averages of Discharge Q m^3/s SOG at LJÓSAFOSS, $A = 1050\ km^2$

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	93	94	104	93	90	91	88	84	105	94	89	82	92
51-52	82	98	91	93	93	94	99	105	109	102	99	91	96
52-53	86	89	91	85	90	108	127	118	110	107	105	100	101
53-54	105	114	120	152	146	135	128	138	126	115	111	105	124
54-55	97	101	109	109	104	96	101	111	100	102	111	118	105
55-56	118	110	107	103	105	124	126	121	119	114	106	99	113
56-57	96	108	136	138	133	120	108	122	120	118	104	100	117
57-58	96	107	108	116	109	102	96	109	103	96	93	85	102
58-59	89	97	124	120	105	126	131	120	116	165	76	104	115
59-60	126	139	125	119	122	119	120	125	108	105	104	88	117
60-61													
61-62													
62-63													
63-64													
64-65													
Max.	126	139	136	152	146	135	131	138	126	165	111	118	124
Min.	82	89	91	85	90	91	88	84	100	94	76	82	92
Av.	98	105	111	112	109	111	112	115	111	111	99	97	108

ICE CONDITIONS

Monthly Averages of Discharge Q m^3/s ÖLFUSÁ at SELFOSS, $A = 5760\ km^2$

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	283	292	288	302	302	267	257	267	456	313	315	283	302
51-52	279	379	286	339	463	645	359	396	462	341	358	330	386
52-53	283	291	292	278	288	413	854	368	424	390	386	369	386
53-54	403	479	468	667	530	414	423	471	439	396	382	351	452
54-55	312	312	370	312	357	341	368	535	344	381	538	581	396
55-56	496	400	356	322	514	484	409	437	420	408	352	307	409
56-57	304	437	628	461	451	362	303	449	467	409	360	351	415
57-58	312	396	419	418	288	302	282	424	299	355	346	293	344
58-59	339	382	648	411	411	550	518	372	489	466	346	395	443
59-60	541	506	426	352	412	507	393	412	394	372	382	322	418
60-61	355	300	270	266	347	481	443	352	532	328	323	314	358
61-62	336	351	398	301	317	364	291	575	398	365	344	306	362
62-63	334	415	358	467	355	301	376	339	334	394	309	302	357
63-64	305	342	341	322	507	457	387	334	326	302	376	325	360
64-65	283	400	425	368	322	505	298	303	287				
Max	541	506	648	667	530	645	854	575	532	466	538	581	452
Min	279	291	270	266	288	267	257	267	287	302	309	283	302
Av	344	378	398	372	390	426	397	402	404	372	365	344	384

ICE CONDITIONS:

Fig B-2^4

Monthly Averages of Discharge Q m^3/s TUNGNAÁ at VATNAÖLDUR (96)

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
59-60	124	169	101	93	92	89	115	108	148	140	156	115	121
60-61	109	70	69	75	72	146	106	111	182	126	114	115	108
61-62	105	92	78	57	48	54	41	101	106	106	99	87	81
62-63	70	62	61	78	53	51	106	93	100	115	120	117	86
63-64	75	83	69	62	112	83	132	79	96	88	96	85	88
64-65	63	78	63	61	65	77	58						
Max	124	169	101	93	112	146	132	108	182	140	156	117	121
Min	63	62	61	57	48	51	41	79	96	88	96	86	81
Av.	91	92	73	71	73	83	93	98	126	114	116	103	96

Monthly Averages of Discharge Q m^3/s KALDAKVISL at SAUDAFELL (95)

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
60-61	50	37	31	26	32	37	35	35	66	38	40	42	39
61-62	37	31	24	22	20	18	16	45	53	38	42	42	32
62 63	32	31	30	33	23	20	47	46	52	47	53	39	38
63-64	24	20	22	20	25	21	31	22	25	24	29	28	24
64-65													
Max	56	37	31	33	32	37	47	46	66	47	53	42	39
Min	24	20	22	20	20	18	16	22	25	24	29	28	24
Av	35	29	26	25	25	24	32	37	49	36	41	37	33

Monthly Averages of Discharge Q m^3/s TUNGNAA at HALD

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
61-62	217	183	153	141	124	145	126	232	230	209	198	178	178
62-63	162	150	124	161	104	105	222	186	186	215	215	210	171
63-64	144	154	124	123	195	160	224	148	197	178	197	178	168
64-65	131	154	130	113	130	153	103	135	178				
Max	217	183	153	161	195	160	224	232	230	215	215	210	178
Min	131	150	124	113	104	105	103	135	178	178	197	178	168
Av.	164	160	133	135	138	141	169	175	198	201	203	189	172

ICE CONDITIONS

Fig. B-25

A = 6320 km

Monthly Averages of Discharge Q m^3/s THJÓRSÁ at TRÖLLKONUHLAUP

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51													
51-52													
52-53													
53-54													
54-55													
55-56													
56-57													
57-58													
58-59													
59-60													
60-61	326	202	182	200	240	420	303	305	737	357	365	348	332
61-62	340	284	273	210	199	224	207	405	453	368	398	353	310
62-63	228	295	205	238	154	160	310	308	358	472	405	387	299
63-64	244	229	172	164	276	243	345	237	392	349	406	355	285
64-65	240	297	235	180	165	283	161	220	367				
Max.	340	297	273	238	276	420	345	405	737	472	406	387	332
Min.	228	202	172	164	154	160	161	220	358	349	365	348	285
Av.	276	261	213	198	207	266	265	295	461	387	394	360	307

ICE CONDITIONS

Monthly Averages of Discharge Q m^3/s THJORSÁ at URRIDAAFOSS, $A = 7200\ km^2$

Water year	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	The year
1950-51	338	268	280	260	207	176	127	106	555	407	410	368	293
51-52	332	367	211	215	163	290	211	274	679	461	455	433	342
52-53	288	283	214	183	180	260	848	230	557	555	498	507	385
53-54	456	388	339	509	382	230	287	318	691	548	484	441	424
54-55	307	232	241	197	257	213	195	533	454	531	630	667	372
55-56	432	272	270	178	274	340	290	343	539	497	440	327	351
56-57	305	338	540	342	245	144	169	334	688	485	461	482	378
57-58	317	341	294	310	197	250	206	347	242	612	552	391	338
58-59	490	361	509	306	210	443	405	272	746	508	557	595	450
59-60	582	508	286	280	265	399	354	383	551	464	537	427	421
60-61	390	240	216	234	273	450	340	324	802	388	403	392	371
61-62	371	317	294	241	223	258	235	493	543	419	429	376	350
62-63	325	373	250	289	200	204	336	350	403	528	416	404	340
63-64	288	272	230	224	381	349	417	276	440	378	439	368	339
64-65	252	343	293	223	211	371	187	252	408				
Max	582	508	540	509	382	450	848	533	802	612	630	667	450
Min	252	232	211	178	163	144	127	106	242	378	403	327	293
Av	365	327	298	266	245	292	307	322	553	484	479	441	368

ICE CONDITIONS

Streamflow data for Hvitá river tributaries.

River	Drainage area km^2	Average annual flow m^3/s
Jökulfall	380	23
Sandá	327	18
Tungufljot	770	45
Stóra - Laxá	512	30
Bruará	707	65
Sog	1200	108

The Hvitá - Ölfusa river is the largest in Iceland on the basis of average flow. The following table Fig. B-2[6] gives the estimated monthly discharge at Selfoss.

Fig. B-2[6].

Estimated montly discharge m^3/s at Selfoss 1950 - 65.

	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	Apr.	May	June	July	Aug.	The year
Max.	541	506	648	667	530	645	753	575	532	466	538	581	452
Min.	279	291	270	266	288	267	257	267	287	302	309	283	302
Av.	344	378	398	372	390	426	397	402	404	372	365	344	384

At Ölfusá, Selfoss, the max. observed flood occured in March 1948 (winter flood). Its max. discharge was of the order of 3000 m^3/s.

Streamflow of the Thjorsá river.

The Upper Thjorsá begins as a glacier river, but its streamflow becomes modified progressively downstream from Nordlingaalda to the confluence with the Tungnaá, by inflow from the tributaries which are all of the draga type. These two contributions produce a pronounced variation from high summer to low winter flows. The estimated monthly average flow at Nordlingaalda fall off from 200 m^3/s in July to ca 40 m^3/s in January. Proceeding downstream the relative proportion in only slightly less.

The Tungnaá river upstream from its confluence with the Kaldakvisl drains an area composed almost entirely of the four permeable rock types refered to above in chapter A. It receives some meltwater from Vatnajökull and from Torfajökull. The streamflow of this section of the Tungnaá is, accordingly, rather uniform. The estimated monthly average discharge at Vatnaöldur is 115 m^3/s in June and 73 m^3/s in January. The estimated average annual discharge is 96 m^3/s.

The course of the Kaldakvisl river, and that of the Tungnaá downstream, tends to follow the boundary between the impermeable rocks to the northwest and the permeable rocks to the southeast, each with their different run-off characteristics. It receives some meltwater from Vatnajökull.

The following table Fig. B-2[7] gives the drainage area and estimated average flow of the Upper Thjorsá and of the main tributaries of Tungnaá and Thjorsá.

Fig. B-2[7].

Estimated monthly averages of discharge m^3/s for Thjorsá river tributaries, according to observations within the period 1958 - 64.

River and location	Drain. area km^2	Sept.	Okt.	Nov.	Des.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Year
Upper Thjorsa														
Nordlingaalda	2060	110	60	60	50	45	60	60	40	130	190	200	170	99
Thjorsargljufur		140	75	75	73	73	90	90	59	210	245	250	213	132
Tungnaá														
Vatnaöldur	1350	91	92	73	71	73	83	93	98	126	114	115	103	96
Hrauneyjafoss		110	110	90	85	80	90	105	115	140	170	140	130	110
Hald	3470	164	160	133	135	138	141	169	175	198	201	203	189	172
Kaldakvisl														
Saudafell	1120	35	29	26	25	25	24	32	37	49	36	41	37	33
Thorisos,Vad	330	13	14	14	13	13	12	12	13	16	17	17	14	14
Kaldakvisl + Thorisos	1450	48	43	40	38	38	36	44	50	65	53	58	51	47
Fossa														
Haifoss	125	5	9	7	5	4	4	8	12	15	9	7	5	7,5
Thjorsá														
Skard		360	310	280	260	240	253	290	300	530	450	430	400	350

Monthly mean values of discharge may smooth out important changes of short duration. Better representation is given by mean values for intervals of seven-days, a week, or for five-days, a pentade.

In order to obtain a survey of the hydrological conditions over a number of years, 5-day means (pentade means) of the discharge in m^3/s have been computed for Hvitá at Gullfoss (gauge No 100), for Ölfusa at Selfoss (gauge No 64) and for Thjórsá at Urridafoss (gauge No 30) for the years 1950-64, see tables and curves Fig. B-2^{8} to B-2^{16}. Seven-day means of discharge for Thjórsá at Tröllkonuhlaup (gauge No 97) see curves Fig. B-2^{17}.

The relevant representation covering the changes is not given as average values, but as usual in statistics. The characteristic data are given as minimum, 1st quarter, median, 2nd quarter and maximum. The curves Fig. B-2$^{9,\ 11 \text{ and } 14}$ give a graphic representation of such data for the discharge delivered in each pentade.

The curves Fig. B-2$^{12 \text{ and } 16}$ give a graphic representation of discharge for the Hvitá at Gullfoss and Selfoss and for the Thjórsá at Tröllkonuhlaup and Urridafoss for the hydrological years 1950-51, 1952-53 and 1953-45. The winter 1950-51 was extremely cold, the winter 1952-53 had a considerable winterflood and the winter 1953-54 had extreme precipitation.

At the present time the streamflow records are of too short duration for planning purposes, especially for the Thjórsá river system. In order to transfer these records were used a direct proportion from the reduced drainage area.

Fig. B-2^{18} gives an analysis of the proportional values between discharge for Hvitá recorded at Selfoss and Gullfoss and for Thjórsá recorded at Urridafoss and Tröllkonuhlaup.

According to the graphics, one has to be very cautious in direct transferring of such records.

NVE Hydr. avd. Iskontoret
13a

Fig. 13 - 2⁸

PENTADEMIDLER av VASSFÖRINGEN i m³/s

FIVE-DAY MEANS OF DISCHARGE

Vassdrag: HVÍTÁ

Vm Gullfoss

Nr 87

1. halvår

1950 - 65

Nedbörfelt 2000 km²

Pentade / År	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Karakteristiske data				
																	Min.	1. kv.	Med.	2. kv.	Max.
1/1 - 5/1		49	37	56	345	102	270	117	77	87	98	63	82	99	67	58	37	58	82	102	345
6/1 - 10/1		40	39	64	181	87	80	99	69	87	174	56	75	80	157	92	39	64	80	99	181
11/1 - 15/1		34	39	80	181	69	75	98	74	74	107	151	72	74	189	67	34	69	74	107	181
16/1 - 20/1		67	38	100	160	69	75	143	65	43	78	102	55	83	144	62	38	62	75	102	160
21/1 - 25/1		58	32	84	129	61	72	113	72	124	83	80	60	91	226	58	32	60	80	113	226
26/1 - 30/1		58	32	92	111	53	86	93	85	207	73	86	76	161	124	62	32	62	86	111	207
31/1 - 4/2		57	144	81	104	47	166	91	57	220	75	68	58	102	83	127	47	58	83	127	220
5/2 - 9/2		54	130	72	90	43	136	89	57	253	463	77	69	78	154	257	43	69	89	154	463
10/2 - 14/2		47	36	77	74	36	172	85	67	133	131	60	69	75	256	122	36	60	75	131	256
15/2 - 19/2		43	71	184	102	31	98	80	60	105	80	87	80	75	144	231	31	71	80	105	231
20/2 - 24/2		41	95	74	92	36	76	83	55	107	75	311	94	71	91	150	36	71	83	95	311
25/2 - 1/3		82	186	51	82	41	88	76	60	97	86	178	82	103	85	76	41	76	82	97	186
2/3 - 6/3		72	87	90	60	41	67	69	54	86	92	105	68	213	80	54	41	60	72	90	213
7/3 - 11/3		42	77	467	50	88	114	65	52	101	89	163	61	110	113	92	42	61	89	113	467
12/3 - 16/3		42	67	616	80	92	143	61	52	128	76	90	58	75	160	80	42	61	80	128	616
17/3 - 21/3		37	94	424	190	61	104	59	54	233	99	87	61	73	140	44	37	59	87	140	424
22/3 - 26/3		36	68	598	158	55	91	58	52	247	153	98	59	81	94	44	36	55	81	153	598
27/3 - 31/3		35	61	173	130	65	100	78	55	163	89	70	55	71	136	59	35	59	71	130	173
1/4 - 5/4		39	55	107	97	108	172	126	66	102	76	69	55	75	137	121	39	66	97	121	172
6/4 - 10/4		47	49	80	79	179	91	113	57	83	84	66	57	127	102	71	47	57	80	102	179
11/4 - 15/4		34	52	65	94	212	75	118	214	71	81	67	362	80	87	51	34	65	80	118	362
16/4 - 20/4		33	125	105	270	490	134	115	128	67	148	71	358	80	75	51	33	71	115	148	490
21/4 - 25/4		89	122	249	137	185	172	95	143	146	107	156	232	103	59	77	59	95	137	172	249
26/4 - 30/4		82	174	81	176	170	88	141	103	106	114	212	222	202	71	78	71	82	114	176	222
1/5 - 5/5		152	166	186	105	155	83	166	86	98	96	256	195	108	95	86	83	95	108	166	256
6/5 - 10/5		119	71	279	87	92	130	136	61	127	162	242	138	78	90	69	61	78	119	138	279
11/5 - 15/5		226	114	222	151	77	141	130	58	326	171	285	143	99	93	103	58	99	141	222	326
16/5 - 20/5		288	345	140	278	67	104	106	61	321	131	251	104	90	80	85	61	85	106	278	345
21/5 - 25/5		197	429	134	249	81	130	153	60	265	97	167	99	100	140	95	60	97	134	197	429
26/5 - 30/5		189	287	179	236	187	199	215	83	226	101	148	153	150	133	118	83	133	179	215	287
31/5 - 4/6		168	141	193	243	220	134	140	138	157	114	144	137	186	109	134	109	134	141	186	243
5/6 - 9/6		132	114	261	218	162	101	132	164	148	120	110	195	209	97	105	97	110	132	195	261
10/6 - 14/6		103	166	151	191	130	145	122	136	153	116	97	140	168	92	91	78	103	136	153	191
15/6 - 19/6		95	140	156	170	117	129	146	153	149	111	109	113	157	96	78	78	109	129	153	170
20/6 - 24/6		105	151	155	168	141	166	149	142	148	134	99	104	128	99	68	68	104	141	151	168

13 b

Cont.

PENTADEMIDLER av VASSFÖRINGEN i m³/s
Five-Day means of Discharge m³/s

Vassdrag: HVÍTÁ

Vm. Gullfoss

Nr. 87

2. halvår

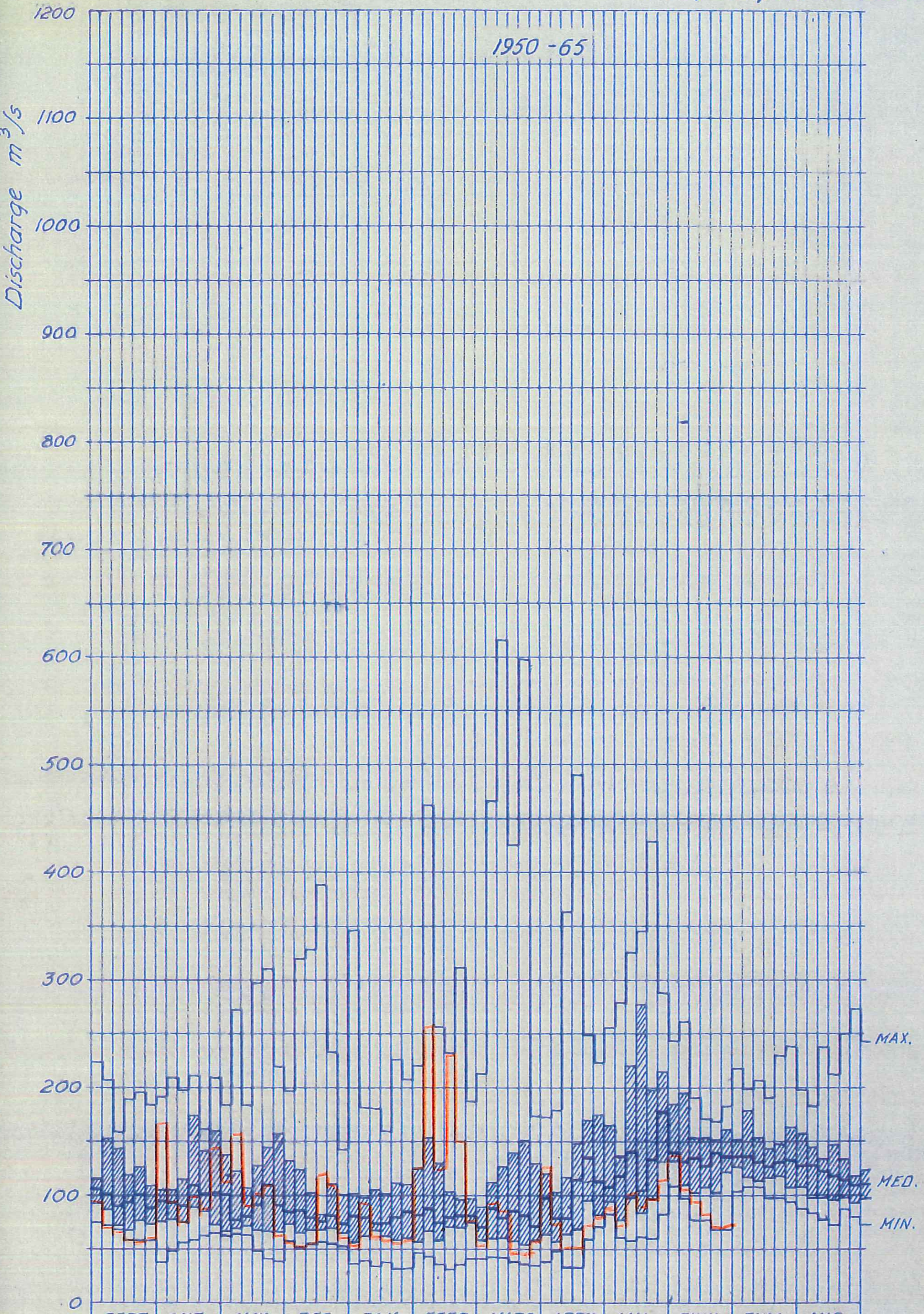
1950 - 65

Nedbørfelt 2000 km²

År / Pentade	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	-1964	1965					Karakteristiske data				
																					Min.	1.kv.	Med.	2.kv.	Max.
25/6 - 29/6		122	161	183	165	129	138	145	153	164	143	86	101	126	136	69					69	122	138	161	183
30/6 - 4/7		137	173	218	151	130	121	151	176	148	128	105	133	137	118						105	128	137	151	218
5/7 - 9/7		108	185	200	152	194	119	133	179	137	137	108	118	147	128						108	119	137	179	200
10/7 - 14/7		111	161	155	180	207	124	135	135	129	136	108	115	115	117						108	115	132	155	207
15/7 - 19/7		101	120	143	186	191	132	141	125	164	127	111	117	99	130						99	117	128	143	191
20/7 - 24/7		119	124	132	174	230	138	133	120	168	147	112	114	99	135						99	119	132	147	230
25/7 - 29/7		94	172	124	151	238	129	141	100	163	153	109	122	105	166						94	109	135	163	238
30/7 - 3/8		88	162	127	127	199	96	130	97	166	138	109	124	134	157						88	109	128	[illegible]	199
4/8 - 8/8		92	151	135	126	184	96	144	84	148	130	98	109	125	132						84	98	128	144	184
9/8 - 13/8		78	122	203	127	238	104	127	96	194	125	95	98	116	134						78	98	124	134	238
14/8 - 18/8		73	118	174	131	212	95	147	90	153	118	116	96	97	137						73	96	118	147	212
19/8 - 23/8		87	144	134	132	250	88	124	91	136	107	117	100	99	116						87	99	116	134	250
24/8 - 28/8		87	147	113	120	273	80	113	98	118	106	112	107	94	94						80	94	110	118	273
29/8 - 2/9		99	113	105	132	243	72	124	113	160	111	107	115	(93)	82						72	99	112	124	243
3/9 - 7/9	106	75	93	146	115	183	82	114	113	223	102	112	106	94	91						75	93	106	115	223
8/9 - 12/9	95	106	96	157	101	203	83	87	122	206	152	104	89	86	73						73	87	101	152	206
13/9 - 17/9	72	90	89	155	102	158	73	73	142	148	135	109	82 -	88	68						68	73	90	142	158
18/9 - 22/9	63	59	94	119	88	129	87	68	144	189	107	102	101	90	60						59	68	94	119	189
23/9 - 27/9	60	74	108	104	83	130	95	77	107	196	91	126	133	101	59						59	77	101	126	196
28/9 - 2/10	58	71	86	95	80	109	76	93	127	183	89	99	111	73	63						58	73	89	109	183
3/10 - 7/10	39	89	75	124	91	96	59	104	94	190	82	95	105	68	167						38	75	94	105	190
8/10 - 12/10	49	93	66	176	105	90	102	134	82	209	77	81	100	68	96						49	77	93	105	209
13/10 - 17/10	56	109	66	75	104	91	114	119	76	198	91	105	117	68	75						56	75	91	114	198
18/10 - 22/10	58	116	179	211	75	93	114	110	113	174	92	89	205	79	100						58	89	110	174	211
23/10 - 27/10	91	82	93	161	63	104	136	104	151	153	77	97	141	101	85						63	85	101	141	161
28/10 - 1/11	89	208	69	114	69	93	173	103	159	184	73	65	97	153	144						65	73	103	159	208
2/11 - 6/11	77	137	66	101	67	96	182	62	156	162	73	68	102	115	116						62	68	101	137	182
7/11 - 11/11	70	66	68	95	65	78	271	72	141	122	76	73	120	81	158						65	70	78	122	271
12/11 - 16/11	68	62	73	95	72	81	184	73	141	115	73	107	99	74	89						62	73	81	107	184
17/11 - 21/11	47	56	88	124	89	133	235	78	298	127	67	122	92	68	101						47	68	92	127	298
22/11 - 26/11	57	40	67	309	114	144	171	137	292	117	62	91	86	68	111						40	67	111	144	309
27/11 - 1/12	82	37	65	209	94	91	105	157	219	116	74	66	84	194	63						37	66	91	157	219
2/12 - 6/12	74	93	69	97	86	80	83	168	171	108	75	65	196	133	59						59	74	86	133	196
7/12 - 11/12	87	179	68	319	65	66	85	112	135	124	71	65	109	88	52						52	66	87	124	319
12/12 - 16/12	77	270	65	328	56	82	81	114	103	97	69	72	71	90	59						56	69	81	103	328
17/12 - 21/12	77	69	57	388	58	74	77	101	82	79	62	79	80	73	119						57	69	77	82	388
22/12 - 26/12	95	80	65	221	56	76	114	97	103	72	71	71	233	82	110						56	71	82	110	233
27/12 - 31/12	86	72	61	142	54	78	107	72	100	82	74	67	115	72	60						54	67	74	100	142

Fig. B-29

FIVE-DAY MEANS of DISCHARGE m^3/s HVÍTÁ, Gullfoss $A = 2000\ km^2$



— The red colour describes discharge in the winter 1964-65.

NVE Hydr. avd. Iskontoret
13a

Fig. B-2¹⁰

PENTADEMIDLER av VASSFÖRINGEN i m³/s
Five-Day means of Discharge m³/s

Vassdrag: ÖLFUSÁ

Vm Selfoss

Nr 64

1. halvår

1951-65

Nedbörfelt 5760 km²

År / Pentade	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965						Karakteristiske data				
																					Min.	1. kv.	Med.	2. kv.	Max.
1/1 - 5/1	257	315	282	822	553	473	404	314	319	377	253	264	332	296	295						253	282	315	404	822
6/1 - 10/1	257	384	262	521	375	512	383	286	329	665	252	270	326	525	424						252	270	375	512	665
11/1 - 15/1	257	387	294	563	275	436	476	270	329	432	376	316	306	685	325						257	294	329	436	685
16/1 - 20/1	308	458	294	412	257	487	582	264	329	329	565	319	335	434	272						257	294	329	458	582
21/1 - 25/1	414	604	306	475	322	615	465	265	366	365	323	243	367	575	283						243	306	366	475	615
26/1 - 30/1	315	588	294	412	363	554	409	325	787	321	329	299	412	495	338						294	321	363	495	787
31/1 - 4/2	285	651	313	444	296	587	376	314	666	321	287	521	399	401	425						285	313	399	521	666
5/2 - 9/2	289	607	382	391	264	614	371	302	674	1007	337	318	303	389	673						264	303	382	614	1007
10/2 - 14/2	294	549	354	440	338	577	368	282	519	589	273	348	292	852	432						273	294	368	549	852
15/2 - 19/2	252	620	655	456	389	405	365	283	472	338	425	316	294	470	617						252	316	405	472	655
20/2 - 24/2	211	736	366	382	384	336	361	327	488	380	924	443	275	335	465						211	335	380	465	924
25/2 - 1/3	340	673	387	357	403	395	325	306	428	339	603	397	316	326	339						306	326	357	403	673
2/3 - 6/3	329	414	412	417	403	326	301	289	341	333	453	286	561	305	258						258	301	333	414	561
7/3 - 11/3	236	343	822	433	449	415	294	272	475	397	671	300	498	325	340						236	300	397	475	822
12/3 - 16/3	232	317	1220	419	458	506	286	278	511	352	401	292	300	427	372						232	292	372	458	1220
17/3 - 21/3	238	433	688	465	308	421	281	284	676	355	363	347	303	389	292						238	292	355	433	688
22/3 - 26/3	225	319	1482	414	280	397	288	274	633	526	424	307	296	342	249						225	280	319	424	1482
27/3 - 31/3	218	301	579	407	285	367	368	293	502	396	336	244	337	431	276						218	285	337	407	579
1/4 - 5/4	232	329	384	424	373	504	530	305	393	328	287	240	272	463	365						232	287	365	424	530
6/4 - 10/4	245	292	347	424	458	442	420	349	380	371	303	238	358	353	305						238	303	353	420	458
11/4 - 15/4	190	282	322	440	523	329	362	627	321	373	274	246	334	363	282						190	282	329	373	627
16/4 - 20/4	199	549	345	611	903	397	506	436	325	484	274	1401	268	317	263						199	274	397	549	1401
21/4 - 25/4	384	426	488	486	535	540	398	456	432	413	426	664	297	303	312						297	384	426	488	664
26/4 - 30/4	347	500	326	449	405	409	449	371	384	446	547	532	385	295	294						294	347	405	449	547
1/5 - 5/5	442	414	412	410	370	375	490	346	347	341	580	554	451	352	299						299	347	410	451	580
6/5 - 10/5	387	322	634	354	317	409	435	322	356	487	543	404	305	309	274						274	317	356	435	634
11/5 - 15/5	560	373	421	421	294	441	415	285	640	484	676	381	306	317	288						285	306	415	484	676
16/5 - 20/5	528	530	333	500	285	385	370	284	598	405	543	374	308	302	289						284	302	374	528	598
21/5 - 25/5	447	604	319	479	319	399	421	274	502	331	468	383	284	376	273						273	319	383	468	604
26/5 - 30/5	391	549	424	458	442	492	652	280	509	327	401	424	373	343	300						280	343	424	492	652
31/5 - 4/6	380	359	382	442	475	420	491	332	397	324	390	386	435	302	324						302	332	386	435	491
5/6 - 9/6	329	327	389	451	407	348	406	380	424	356	336	448	427	291							291	336	384	424	451
10/6 - 14/6	310	363	403	391	357	437	379	343	470	339	313	426	439	286							286	339	371	426	470
15/6 - 19/6	273	343	361	363	333	401	429	371	542	337	323	374	392	295							273	333	362	392	542
20/6 - 24/6	289	329	361	373	382	435	399	352	494	402	315	302	381	276							276	315	367	399	494

PENTADEMIDLER av VASSFÖRINGEN i m³/s   Cont.

Five - Day means of Discharge m^3/s

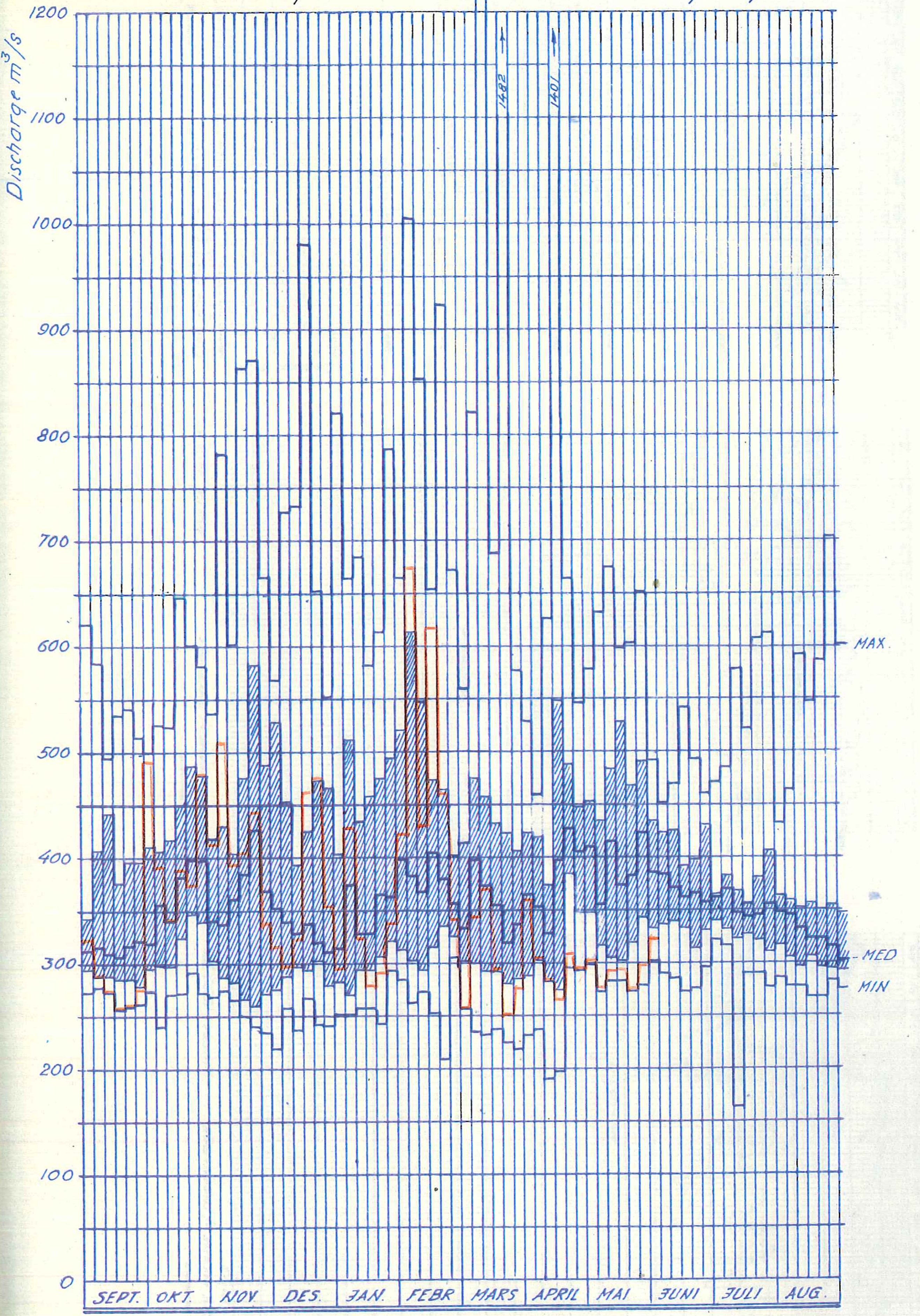
Vassdrag: ÖLFUSÁ   Vm. Selfoss   Nr. 64

2. halvår   1951 - 65   Nedbörfelt 5760 km²

År / Pentade	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964						Karakteristiske data				
																					Min.	1.kv.	Med.	2.kv.	Max.
25/6 - 29/6		303	331	438	359	359	432	379	345	460	461	314	296	357	347						296	331	358	432	461
30/6 - 4/7		340	343	472	363	366	355	393	363	364	397	335	366	323	328						323	340	363	366	472
5/7 - 9/7		317	384	433	398	486	332	367	381	317	373	326	378	335	359						317	332	370	384	486
10/7 - 14/7		317	345	373	394	579	349	360	368	303	367	328	331	164	324						164	324	348	368	579
15/7 - 19/7		331	306	357	403	532	367	354	337	351	352	326	327	291	331						291	327	344	357	532
20/7 - 24/7		315	345	352	389	609	442	346	330	381	377	319	323	292	335						292	323	346	381	609
25/7 - 29/7		278	407	354	363	613	357	350	310	368	433	310	320	288	484						278	310	356	407	613
30/7 - 3/8		287	366	350	354	542	312	350	298	390	365	317	345	328	432						287	317	348	365	432
4/8 - 8/8		289	345	359	347	465	306	355	279	373	348	286	330	316	376						279	306	346	359	465
9/8 - 13/8		282	322	421	345	593	326	352	289	490	342	278	296	310	344						278	296	334	352	593
14/8 - 18/8		269	306	426	331	549	329	357	294	392	317	319	298	310	347						269	306	324	357	549
19/8 - 23/8		269	329	350	350	588	303	352	294	364	295	330	298	288	319						269	295	324	350	588
24/8 - 28/8		292	354	322	363	704	291	346	294	363	295	339	309	285	295						285	294	316	354	704
29/8 - 2/9	(289)	296	303	324	359	602	282	347	315	431	303		297	292	277						277	292	303	347	602
3/9 - 7/9	289	275	273	384	326	558	297	343	312	623	296	342	313	294	326						273	294	313	343	623
8/9 - 12/9	289	280	278	428	324	586	311	317	315	572	407	316	300	283	290						278	289	315	407	586
13/9 - 17/9	287	294	303	454	315	496	312	289	366	442	444	309	272	288	274						272	288	309	442	496
18/9 - 22/9	278	262	285	391	306	426	365	286	376	536	359	321	295	307	258						258	285	307	376	536
23/9 - 27/9	278	273	285	396	285	431	299	292	326	541	317	358	412	335	260						260	285	317	396	541
28/9 - 2/10	278	280	262	396	278	437	306	339	351	515	306	369	425	321	273						262	278	321	396	515
3/10 - 7/10	275	294	287	417	299	411	284	359	318	500	298	343	360	305	493						275	294	318	411	500
8/10 - 12/10	241	384	271	458	347	386	406	466	299	526	289	320	356	301	388						241	299	356	406	526
13/10 - 17/10	271	458	289	417	315	389	482	410	298	524	313	374	333	296	341						271	298	341	417	524
18/10 - 22/10	273	377	324	648	329	378	484	383	383	520	322	381	450	309	389						273	324	381	450	648
23/10 - 27/10	361	347	301	521	292	450	469	399	487	513	294	363	602	402	369						292	347	399	487	602
28/10 - 1/11	345	461	273	438	282	364	582	375	532	498	289	339	398	427	478						273	339	398	478	582
2/11 - 6/11	315	340	275	387	303	317	518	329	515	537	274	270	361	365	419						270	303	340	419	537
7/11 - 11/11	366	282	287	336	275	324	782	348	476	430	296	322	351	276	518						275	287	336	430	782
12/11 - 16/11	280	278	322	361	303	321	603	404	525	375	282	384	429	267	392						267	282	361	404	603
17/11 - 21/11	259	250	329	426	507	384	726	422	865	358	261	476	360	267	404						250	267	384	476	865
22/11 - 26/11	241	255	282	806	454	427	639	557	871	400	260	583	329	256	444						241	260	427	583	871
27/11 - 1/12	252	271	262	488	389	367	477	501	666	395	235	344	326	498	340						235	271	367	488	666
2/12 - 6/12	273	257	275	451	350	353	437	568	529	377	220	300	529	554	314						220	275	353	529	568
7/12 - 11/12	259	292	340	727	340	265	538	382	410	451	284	287	498	326	299						259	287	340	451	727
12/12 - 16/12	280	493	238	734	329	355	434	393	386	374	318	298	303	298	325						238	298	329	393	734
17/12 - 21/12	417	387	301	982	294	295	426	436	363	293	267	342	348	273	467						267	294	348	426	982
22/12 - 26/12	310	319	273	602	266	317	472	360	370	302	242	320	652	336	473						242	302	320	472	652
27/12 - 31/12	278	301	241	551	278	336	451	328	366	311	266	277	492	290	352						241	278	311	366	551

Fig. B-2''

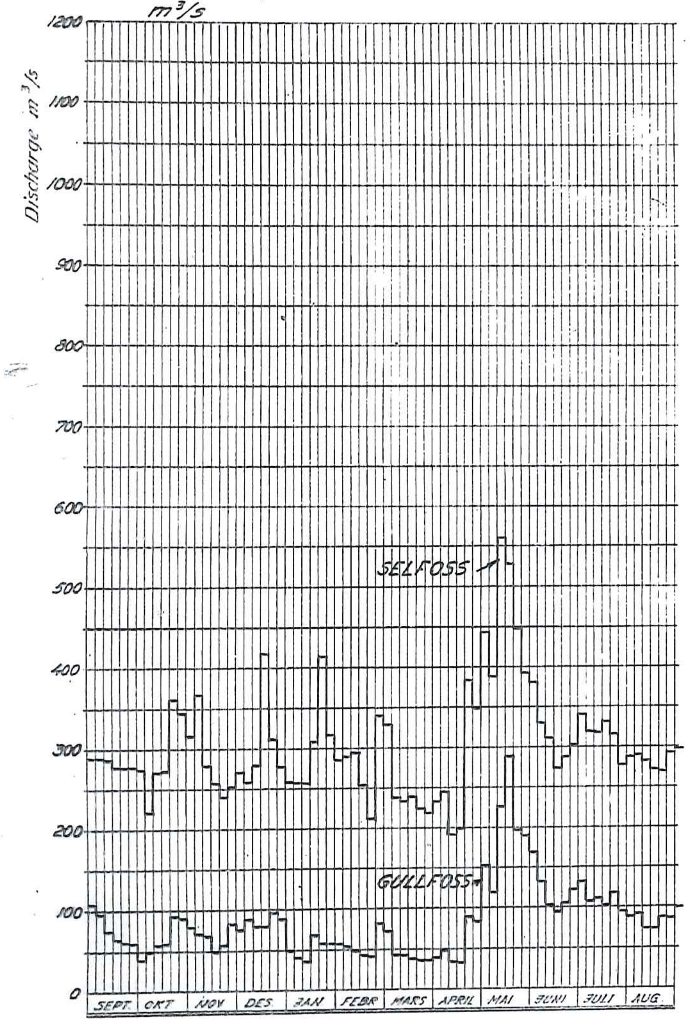
FIVE-DAY MEANS of DISCHARGE ÖLFUSÁ, Selfoss $A = 5760\ km^2$



The red colour describer discharge in the winter 1964-65.

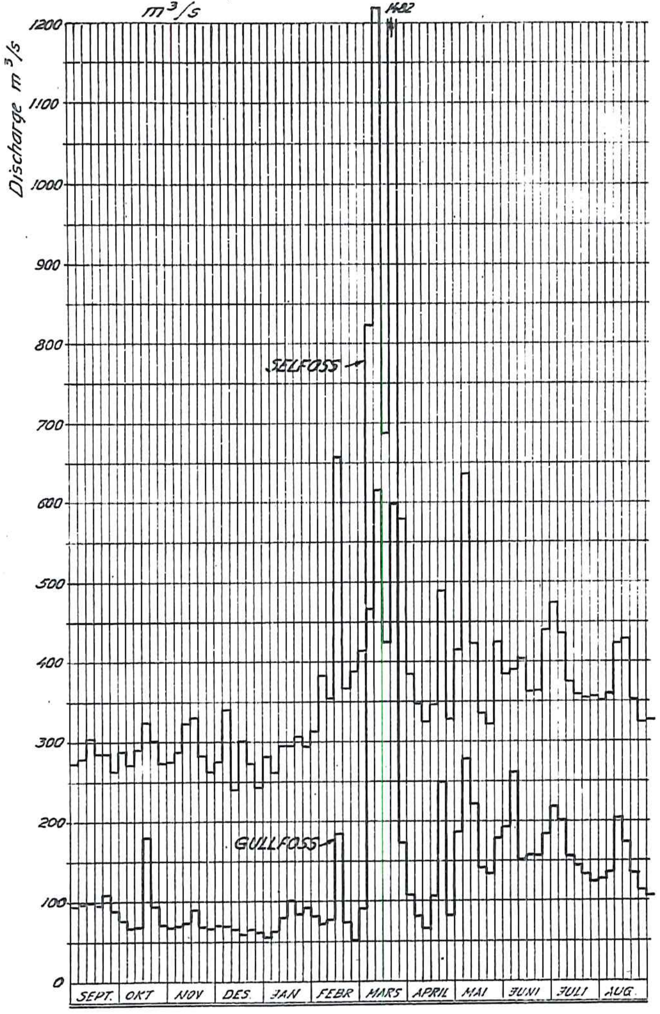
NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE HVÍTÁ 1950-51
m³/s



NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE HVÍTÁ 1952 53
m³/s



NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE HVÍTÁ 1953-54
m³/s

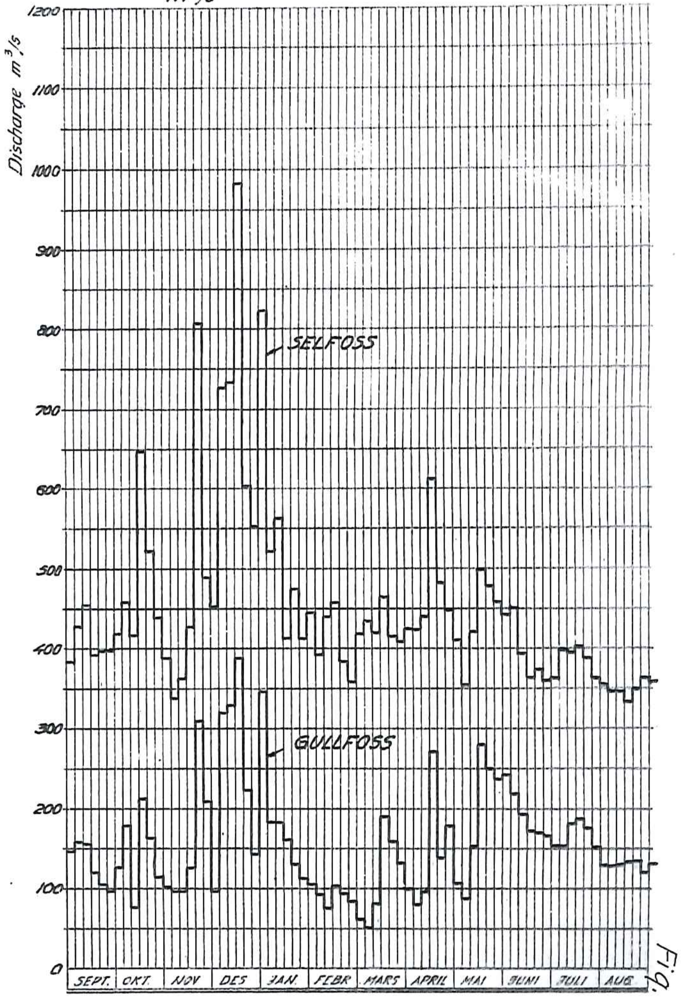


Fig. B-2¹²

13a

Fig. B-2^{13}

PENTADEMIDLER av VASSFÖRINGEN i m^3/s
Five - Day means of Discharge m^3/s

Vassdrag: THJORSÁ

Vm URRIDAFOSS Nr 30

1949 - 61

Nedbörfelt 7200 km^2

1. halvår

År Pentade		1949	1950	1951	1952	1953	1954	1954	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965			Karakteristiske data				
																					Min.	1. kv.	Med.	2. kv.	Max.
1/1 - 5/1		165	270	241	148	178	604	324	364	243	215	238	159	185	214	172	227	168			148	171	215	257	604
6/1 - 10/1		214	264	225	166	186	399	252	309	233	210	216	372	184	202	165	391	216			165	194	216	287	399
11/1 - 15/1		286	166	210	166	199	384	226	263	335	187	202	370	253	215	160	359	219			160	193	219	311	384
16/1 - 20/1		241	390	191	166	169	316	241	198	328	182	192	215	341	223	219	600	194			166	192	219	322	600
21/1 - 25/1		179	458	209	166	155	329	248	177	236	175	184	240	277	204	232	456	229			155	163	229	263	458
26/1 - 30/1		166	455	171	166	184	284	250	314	118	202	214	235	389	270	252	318	228			118	178	235	299	455
31/1 - 4/2		422	525	183	166	204	270	236	400	135	280	357	273	252	214	194	211	215			135	199	236	319	525
5/2 - 9/2		591	382	194	241	233	163	227	419	135	274	636	990	247	217	177	475	550			135	206	247	513	990
10/2 - 14/2		468	287	181	241	206	194	221	467	204	266	751	442	222	232	220	478	432			181	213	241	455	751
15/2 - 19/2		326	204	169	304	379	323	212	304	158	256	292	276	257	279	210	367	304			158	211	279	312	367
20/2 - 24/2		199	187	163	364	214	249	193	215	122	203	289	206	995	343	185	246	418			122	190	214	316	995
25/2 - 1/3		173	337	167	402	203	176	188	238	100	219	257	180	698	264	302	292	242			100	181	238	315	698
2/3 - 6/3		523	300	158	236	245	253	187	195	135	198	211	225	354	230	751	135	167			135	177	225	277	751
7/3 - 11/3		307	240	130	166	616	325	197	231	153	148	349	256	520	209	285	431	182			130	182	240	325	616
12/3 - 16/3		226	191	124	166	760	304	213	367	180	138	459	284	301	219	231	442	266			124	171	231	337	700
17/3 - 21/3		166	193	121	214	689	335	204	329	170	232	482	337	286	302	238	493	172			121	182	238	336	689
22/3 - 26/3		166	214	113	243	(2541)	261	189	327	182	256	571	506	327	221	257	286	155			113	187	256	327	254
27/3 - 31/3		250	302	108	233	366	265	184	282	205	264	392	522	233	230	216	607	162			108	211	250	334	607
1/4 - 5/4		166	335	110	251	138	291	292	358	442	304	270	283	187	204	217	395	316			110	196	283	326	442
6/4 - 10/4		230	166	113	213	150	271	385	392	370	273	241	335	190	187	380	305	312			113	189	271	353	392
11/4 - 15/4		241	156	88	194	137	279	445	274	328	511	216	302	204	338	165	267	226			88	180	24[illegible]	315	511
16/4 - 20/4		166	188	84	266	218	322	789	255	271	344	245	380	214	720	214	229	187			84	201	245	333	789
21/4 - 25/4		166	156	97	321	468	348	765	463	262	356	352	380	487	720	385	223	213			97	218	352	467	76
26/4 - 30/4		235	163	142	368	268	395	532	324	332	297	312	595	665	785	744	320	273			142	271	324	586	78
1/5 - 5/5		212	273	304	374	252	357	490	282	465	277	273	356	900	829	320	288	393			212	273	320	429	90
6/5 - 10/5		188	741	296	293	937	273	367	361	526	227	287	750	866	540	248	354	264			188	269	357	641	93
11/5 - 15/5		325	1374	564	339	634	594	267	615	463	218	814	827	1057	582	423	321	375			218	330	564	724	137
16/5 - 20/5		254	770	775	581	342	1009	259	417	470	221	1205	708	940	396	364	596	491			221	353	491	773	120
21/5 - 25/5		272	581	696	1326	418	859	458	453	808	212	1070	407	589	357	345	638	325			212	351	458	699	132
26/5 - 30/5		237	574	666	1196	721	1007	822	576	1369	269	873	320	508	589	651	516	485			237	497	584	848	136
31/5 - 4/6		265	979	581	424	603	782	895	643	595	484	509	395	552	418	691	394	556			265	421	556	667	97
5/6 - 9/6		474	1196	458	402	699	666	628	401	439	820	528	452	385	668	798	344	435			344	419	474	684	119
10/6 - 14/6		674	578	356	535	566	504	402	442	413	592	480	427	334	217	544	351	329			217	354	442	555	67
15/6 - 19/6		1055	587	292	505	449	468	391	505	494	683	519	372	422	328	452	353	.			290	382	460	512	105
20/6 - 24/6		1956	548	370	439	473	537	484	535	516	559	446	482	355	335	382	442				335	411	478	536	195

PENTADEMIDLER av VASSFÖRINGEN m^3/s

Five-Day means of Discharge m^3/s

Cont.

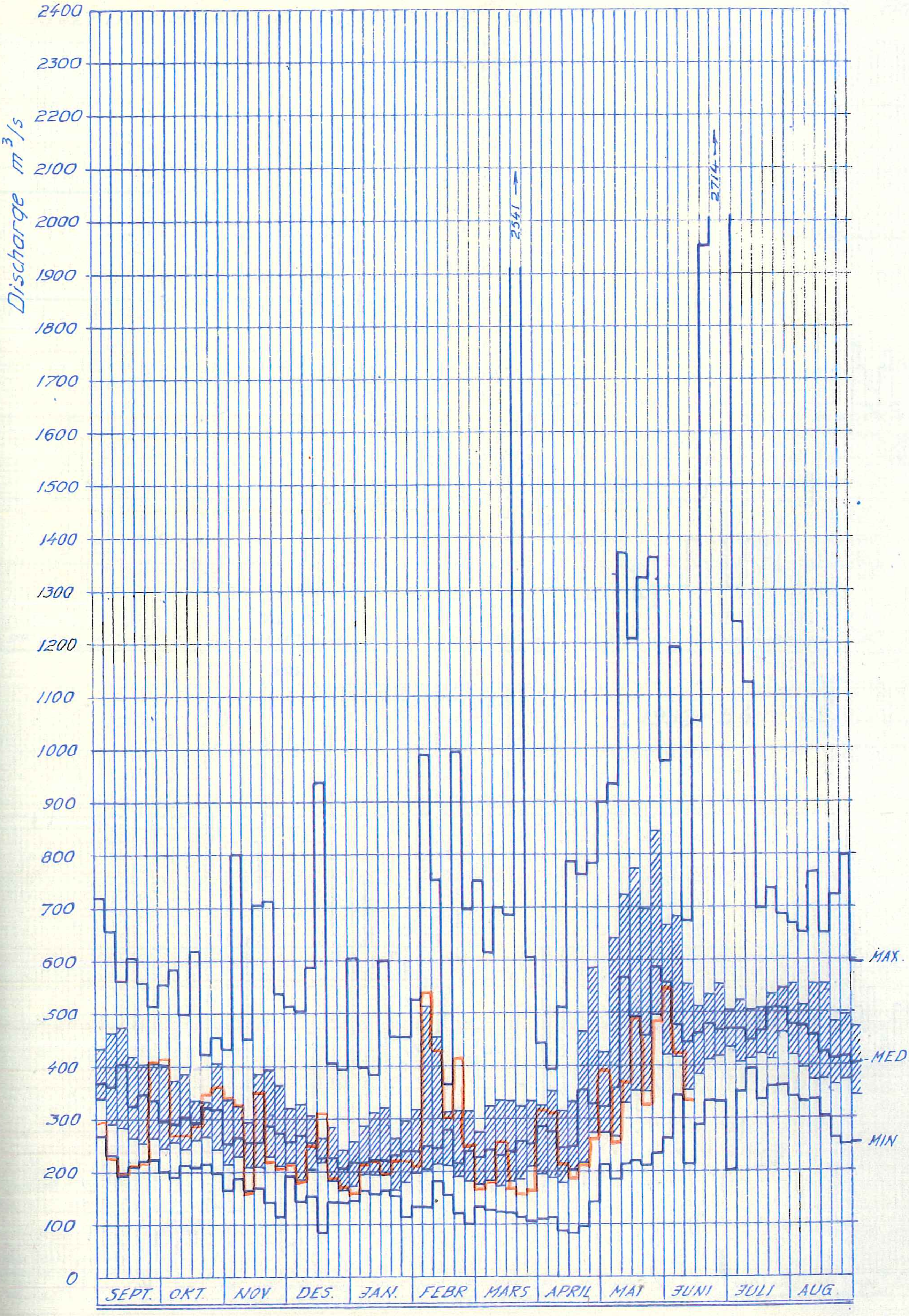
Vassdrag: THJORSÁ　Vm. URRIÐAFOSS　Nr 30

2. halvår　1949-64　Nedbörfelt 7200 km

Pentade \ År	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	Karakteristiske data				
																	Min.	1.kv.	Med.	2.kv.	Max.
25/6 - 29/6	2714	490	432	435	589	420	440	568	513	507	555	602	333	335	376	357	333	420	465	555	2714
30/6 - 4/7	2514	363	475	502	580	459	438	400	498	622	532	486	361	457	449	201	201	438	467	502	2514
5/7 - 9/7	1242	447	399	527	563	441	526	351	439	712	487	598	376	408	518	379	351	408	467	527	1242
10/7 - 14/7	1125	493	406	445	451	508	634	413	443	570	443	555	407	421	396	405	396	413	444	508	1125
15/7 - 19/7	656	542	444	354	444	510	699	491	454	504	581	473	413	413	340	423	340	423	464	510	699
20/7 - 24/7	599	513	404	396	484	502	738	522	435	513	633	513	407	419	362	551	362	413	508	536	738
25/7 - 29/7	640	516	355	510	472	486	687	507	507	421	629	565	424	435	365	495	365	463	507	549	687
30/7 - 3/8	574	562	380	500	482	440	671	342	446	429	657	547	401	472	545	410	342	420	477	555	671
4/8 - 8/8	475	519	406	470	528	423	533	335	517	336	652	500	351	389	485	451	335	398	473	518	652
9/8 - 13/8	393	586	344	457	582	430	708	342	526	420	769	469	356	339	442	481	339	375	455	557	769
14/8 - 18/8	439	554	304	415	652	415	634	354	563	386	516	430	401	326	348	371	304	379	423	559	652
19/8 - 23/8	490	616	334	390	429	455	723	354	478	384	540	360	439	374	373	265	265	367	410	484	723
24/8 - 28/8	534	540	407	482	423	495	799	322	408	395	495	353	417	391	343	252	252	372	413	495	799
29/8 - 2/9	581	515	403	333	400	424	544	256	425	434	598	402	287	401	332	354	256	344	403	475	598
3/9 - 7/9	591	462	308	270	437	364	487	296	413	435	720	355	374	362	340	294	270	340	369	437	720
8/9 - 12/9	475	403	327	282	444	386	535	301	309	456	658	491	334	267	276	233	233	292	360	466	658
13/9 - 17/9	526	298	399	341	438	310	431	271	259	563	455	509	406	263	301	199	199	285	403	478	563
18/9 - 22/9	462	260	270	316	459	247	330	291	231	608	568	362	381	330	315	211	211	265	323	420	608
23/9 - 27/9	487	245	336	275	560	240	406	372	264	401	520	306	404	360	231	221	221	255	348	405	560
28/9 - 2/10	491	234	344	223	393	223	349	299	407	518	488	298	309	320	224	411	223	266	332	409	518
3/10 - 7/10	445	201	377	241	345	251	301	228	433	383	555	256	359	339	229	417	201	246	296	406	555
8/10 - 12/10	348	192	432	245	321	278	274	348	422	290	585	239	290	398	237	278	192	260	290	373	585
13/10 - 17/10	389	243	402	262	356	214	243	453	363	265	500	230	381	339	217	277	214	243	303	385	500
18/10 - 22/10	368	214	261	336	599	219	211	307	261	320	572	286	305	620	261	288	211	261	296	336	620
23/10 - 27/10	260	422	267	381	379	226	324	291	270	403	424	218	334	389	272	357	218	269	321	334	424
28/10 - 1/11	311	397	458	246	323	199	249	416	241	430	401	205	204	247	453	376	199	244	317	409	458
2/11 - 6/11	309	322	248	216	294	208	162	407	200	423	435	217	224	253	249	336	169	217	251	339	435
7/11 - 11/11	267	321	241	230	263	196	219	800	251	342	322	262	231	354	185	328	188	231	263	325	800
12/11 - 16/11	302	231	236	258	260	164	210	453	267	366	167	228	351	247	226	165	164	210	253	295	453
17/11 - 21/11	390	196	179	268	240	207	386	708	294	696	171	212	415	213	223	356	171	210	254	388	708
22/11 - 26/11	287	283	144	194	640	322	377	491	415	712	259	182	310	247	238	221	144	230	286	396	712
27/11 - 1/12	248	303	201	119	326	281	260	384	392	539	348	198	232	209	450	212	119	211	271	366	539
2/12 - 6/12	233	306	198	220	307	243	231	333	516	366	302	196	200	432	273	218	196	219	258	320	516
7/12 - 11/12	174	277	167	277	506	148	190	351	353	308	407	196	261	289	241	179	148	185	269	330	506
12/12 - 16/12	158	241	336	205	589	209	195	306	240	263	309	349	300	194	286	246	158	208	254	308	589
17/12 - 21/12	188	241	249	85	939	215	153	301	230	247	236	259	279	225	228	314	85	220	224	264	939
22/12 - 26/12	172	241	192	147	403	173	145	379	243	325	228	199	222	391	234	190	145	182	225	284	403
27/12 - 31/12	166	241	146	166	352	180	143	393	242	299	190	216	204	205	209	168	143	167	205	241	393

Fig. B-2 14

FIVE-DAY MEANS of DISCHARGE m³/s 1950-65 THJÓRSÁ, Urriðafoss, A=7200 km²

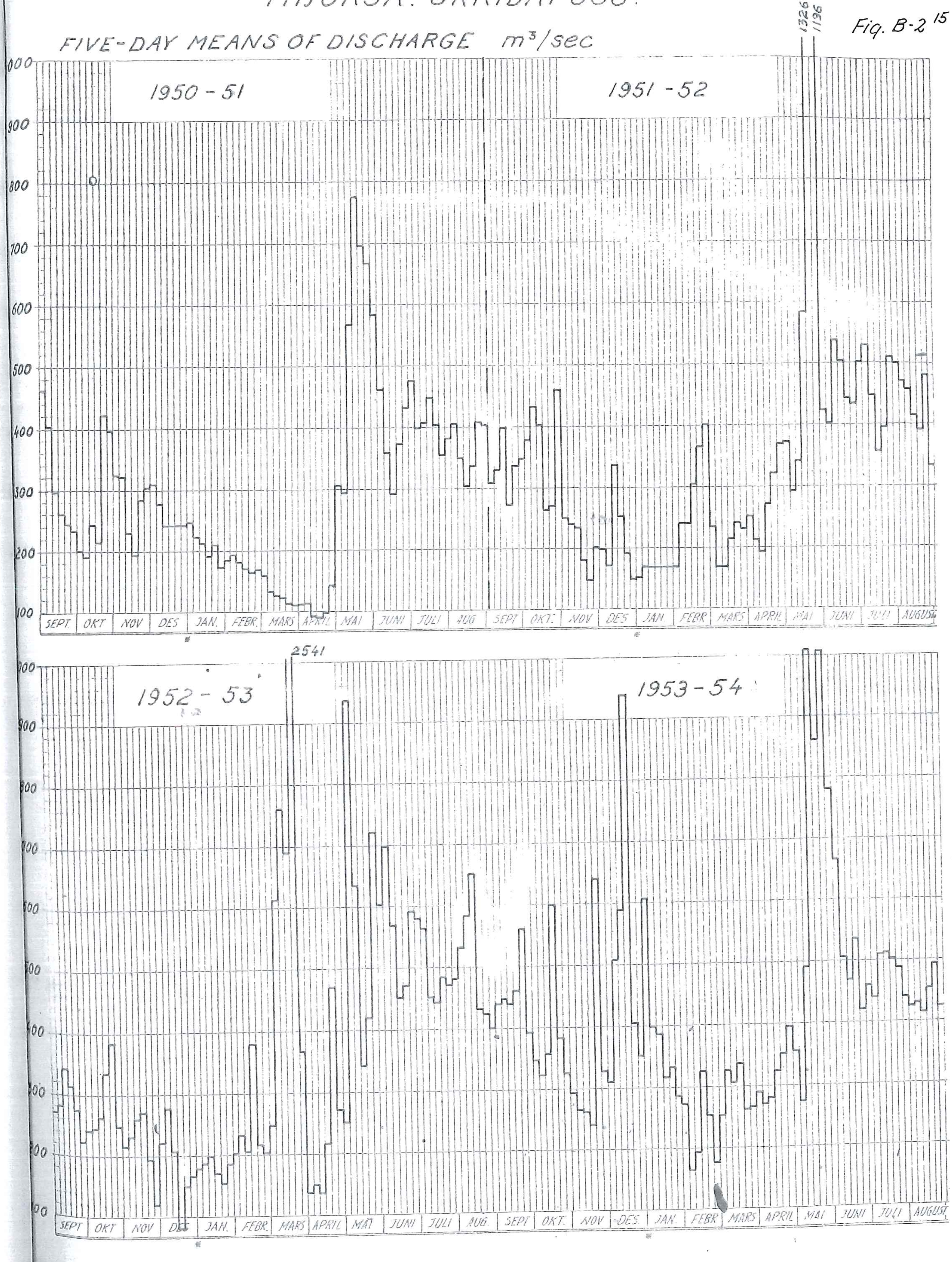


— The red colour describes discharge in the winter 1964-65.

THJÓRSÁ. URRIÐAFOSS.

FIVE-DAY MEANS OF DISCHARGE m³/sec

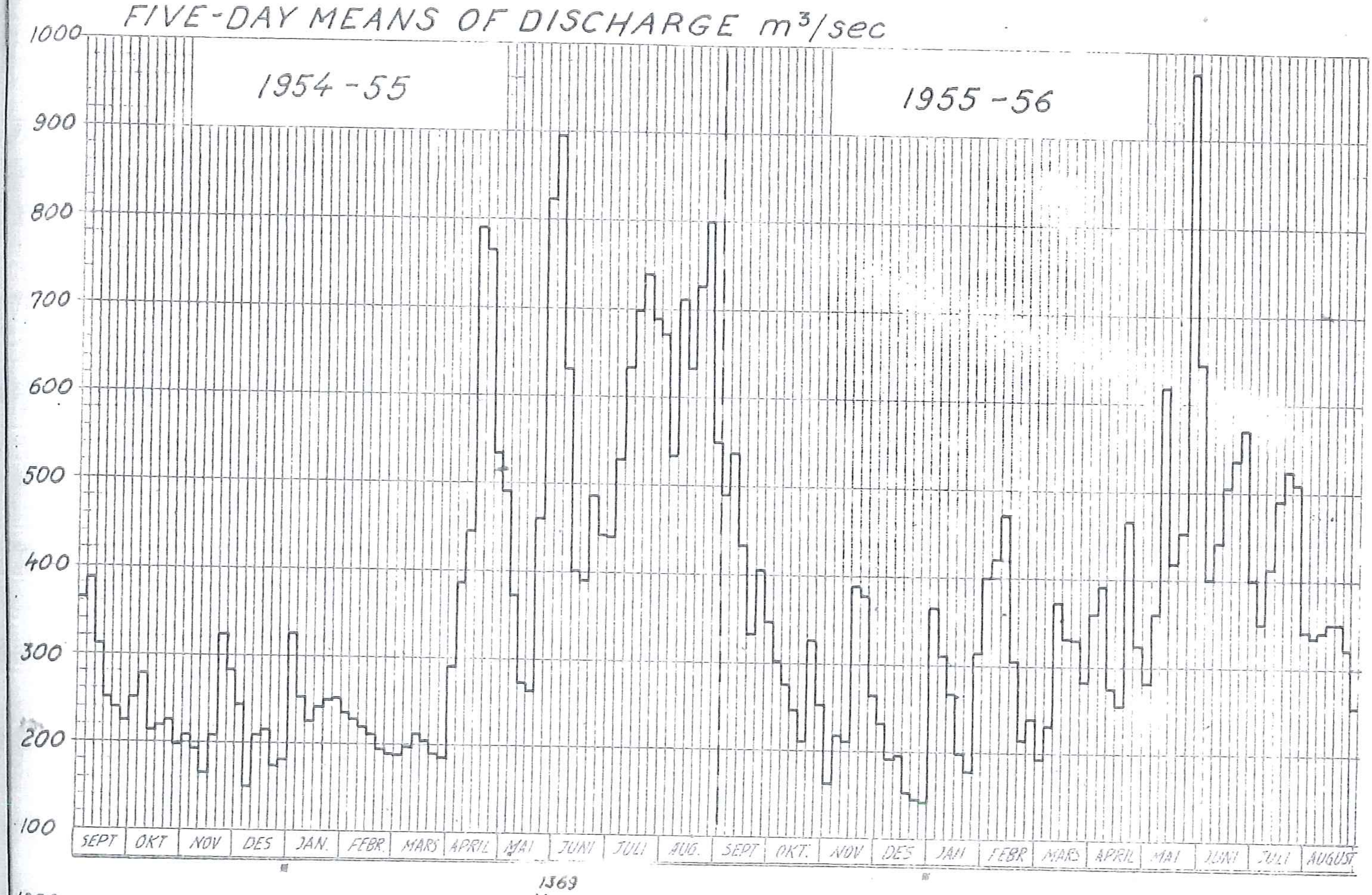
Fig. B-2 15

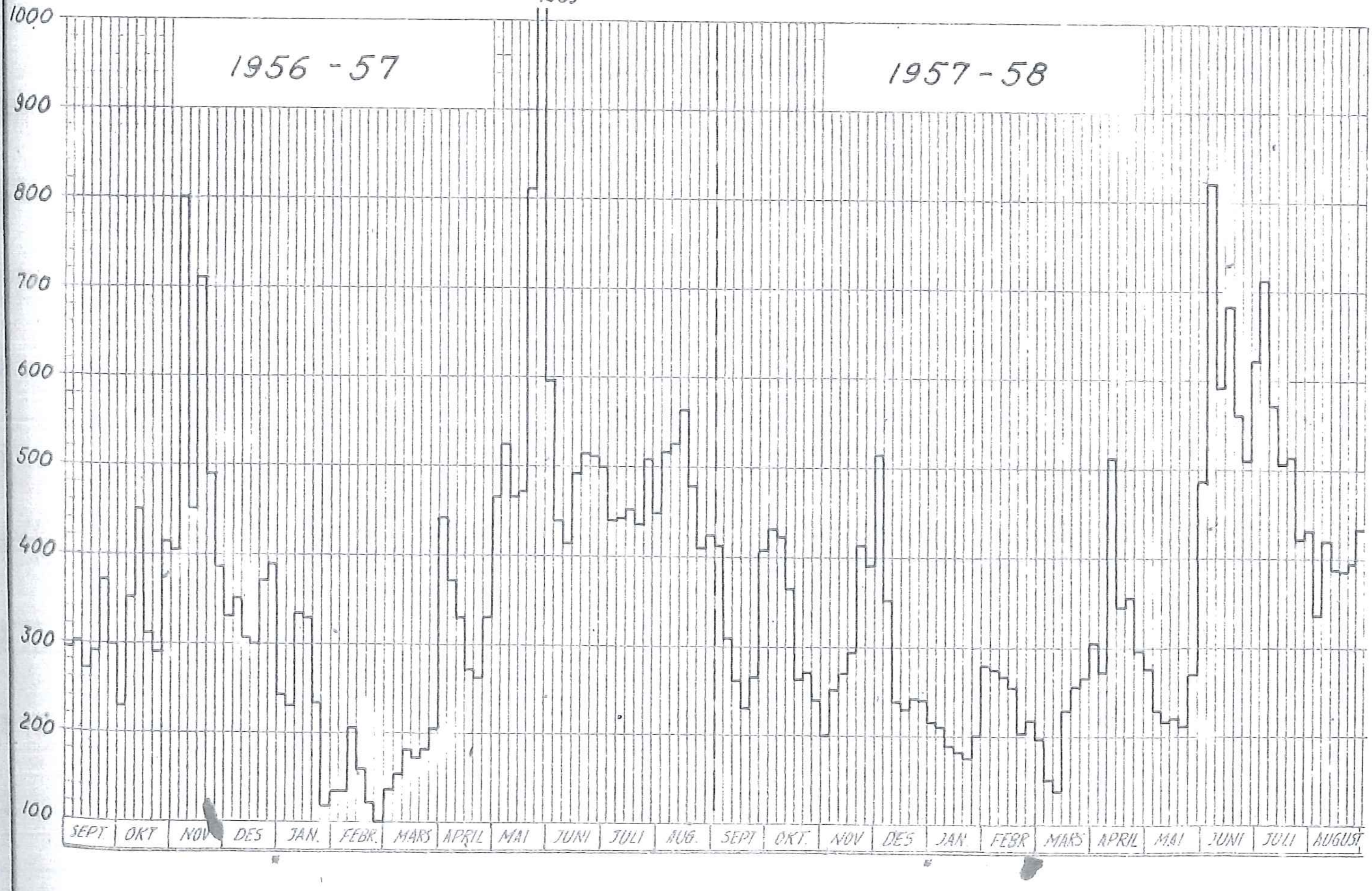


THJÓRSÁ. URRIÐAFOSS.

Cont.

FIVE-DAY MEANS OF DISCHARGE m³/sec

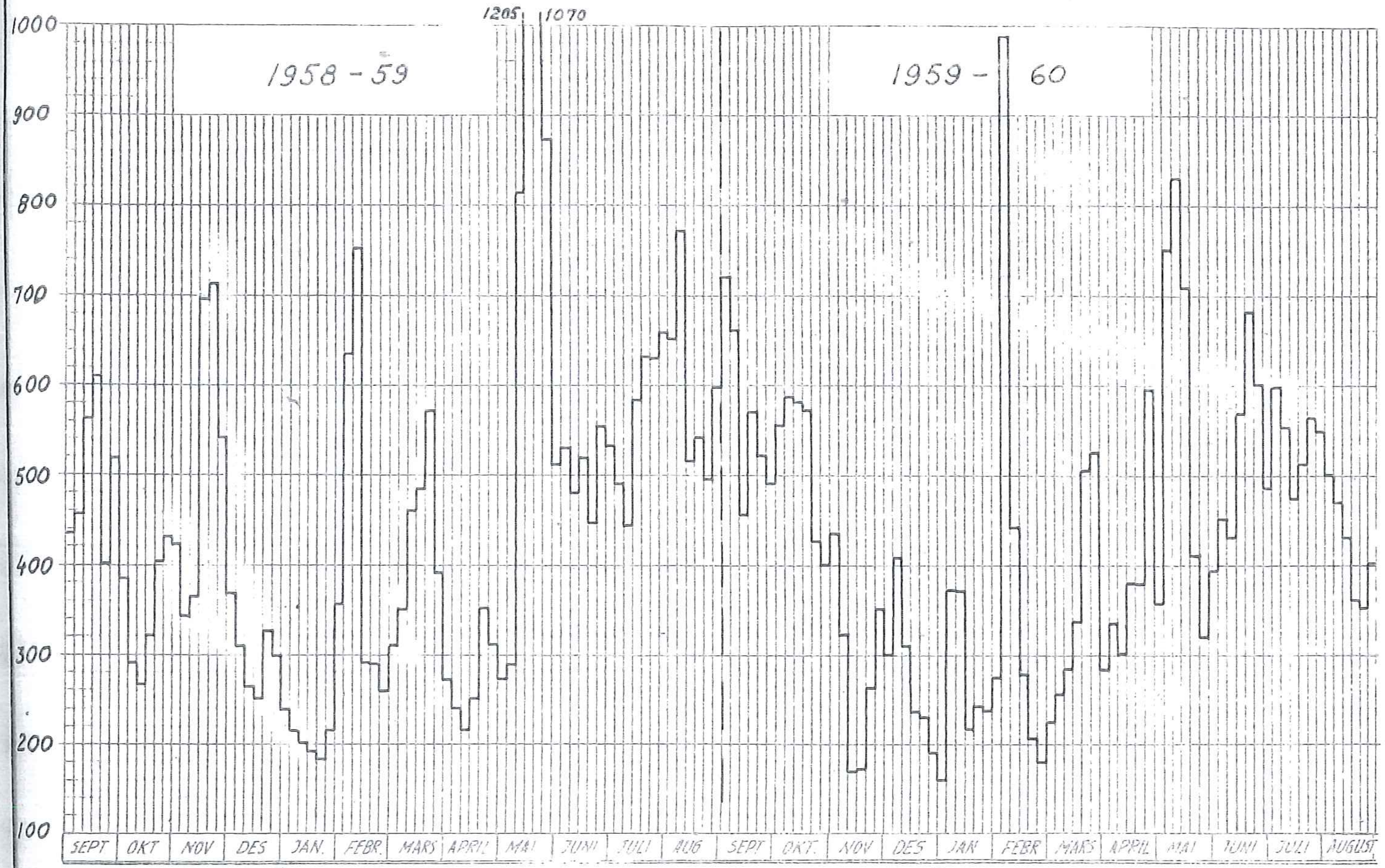


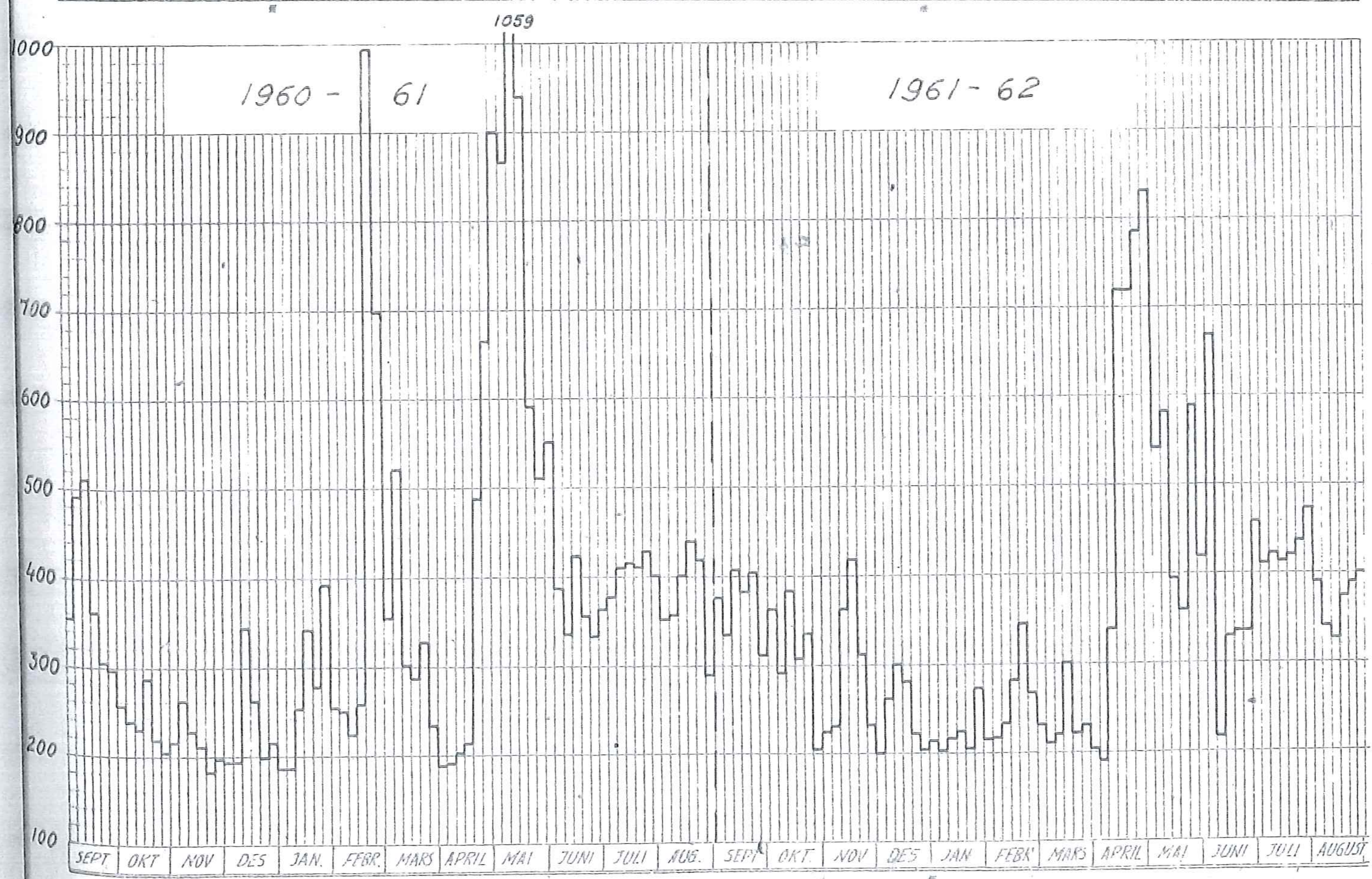


THJÓRSÁ. URRIÐAFOSS.

FIVE-DAY MEANS OF DISCHARGE m^3/sec

Cont.

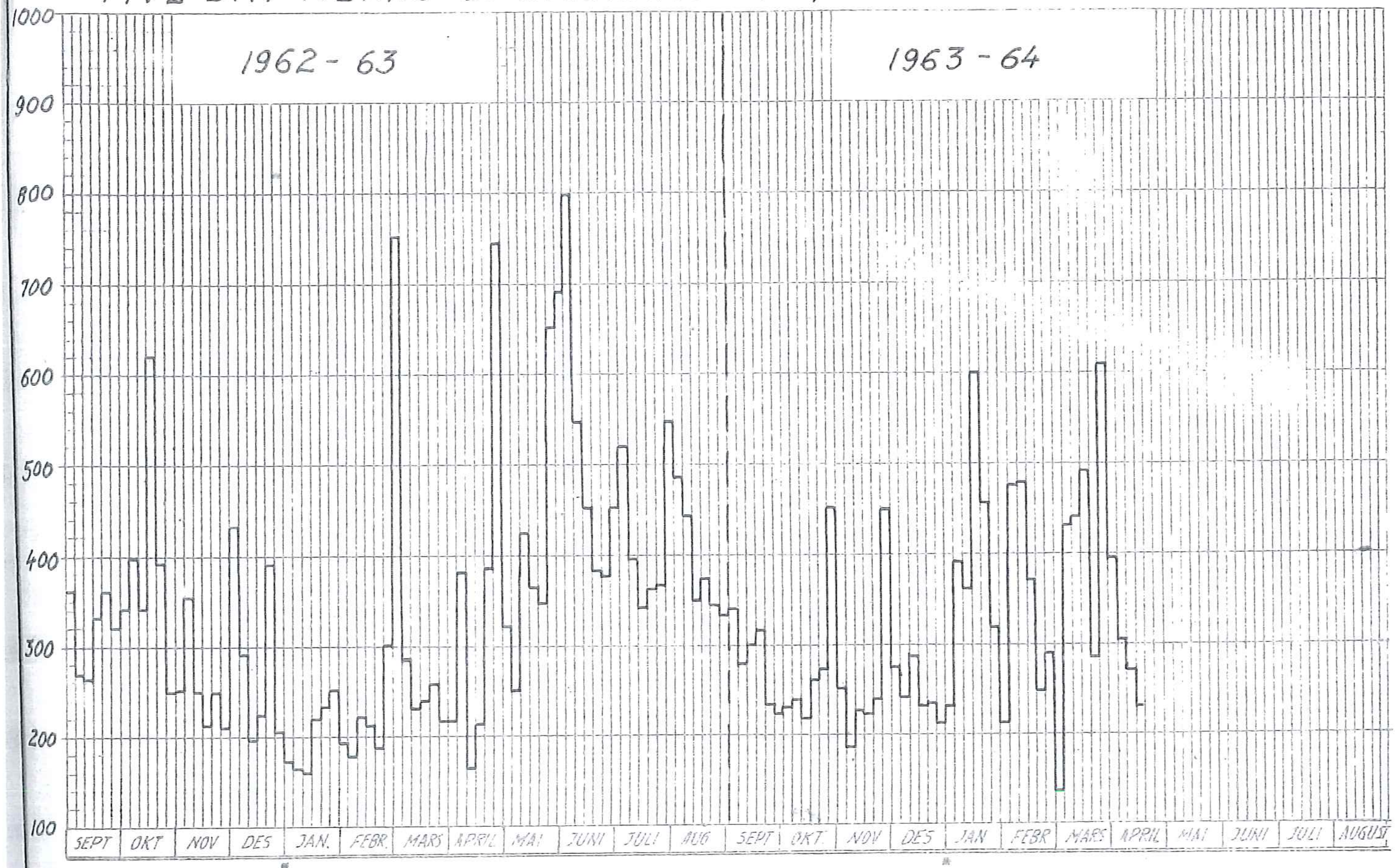


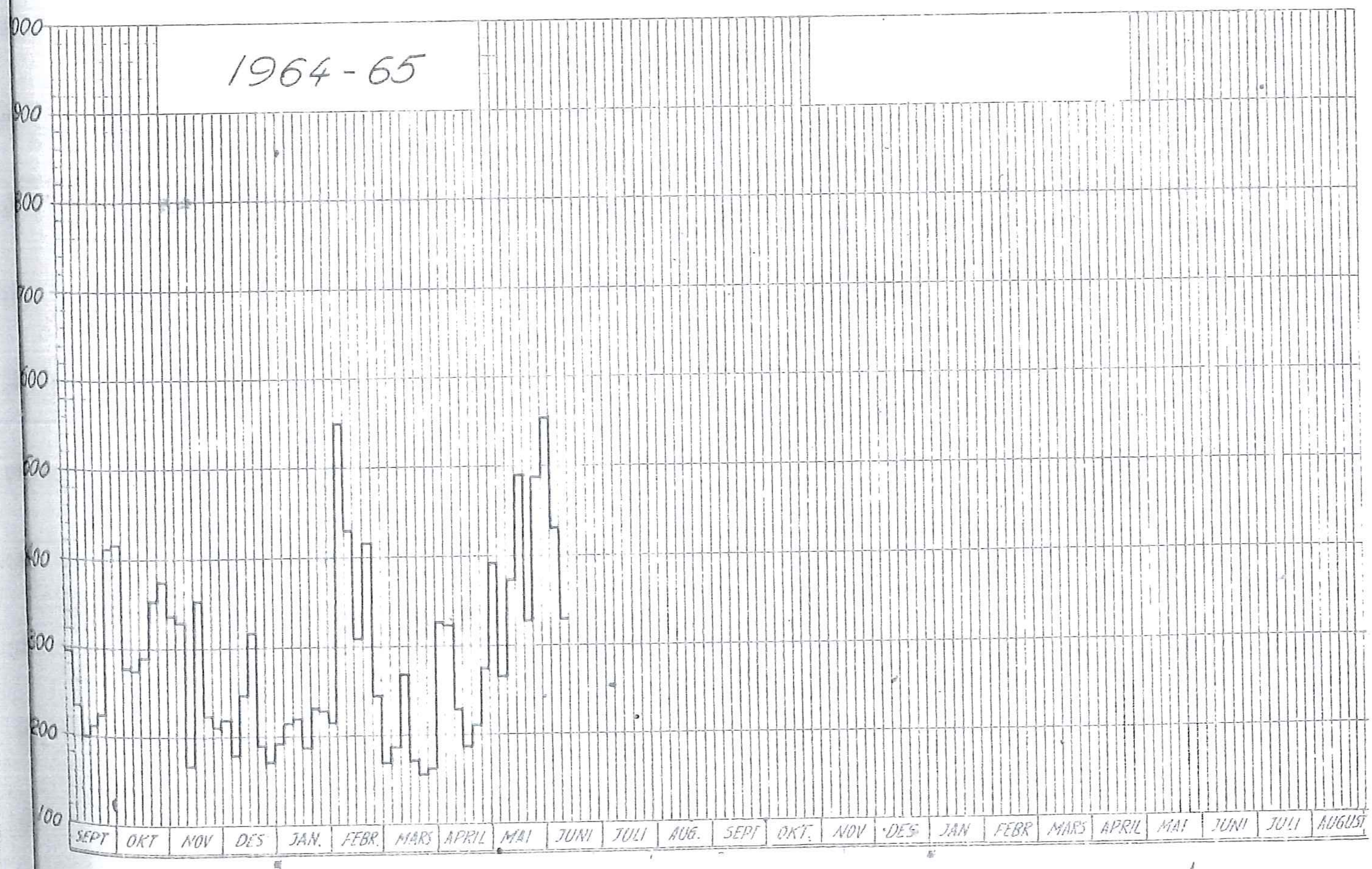


THJÓRSÁ. URRIÐAFOSS.

FIVE-DAY MEANS OF DISCHARGE m³/sec

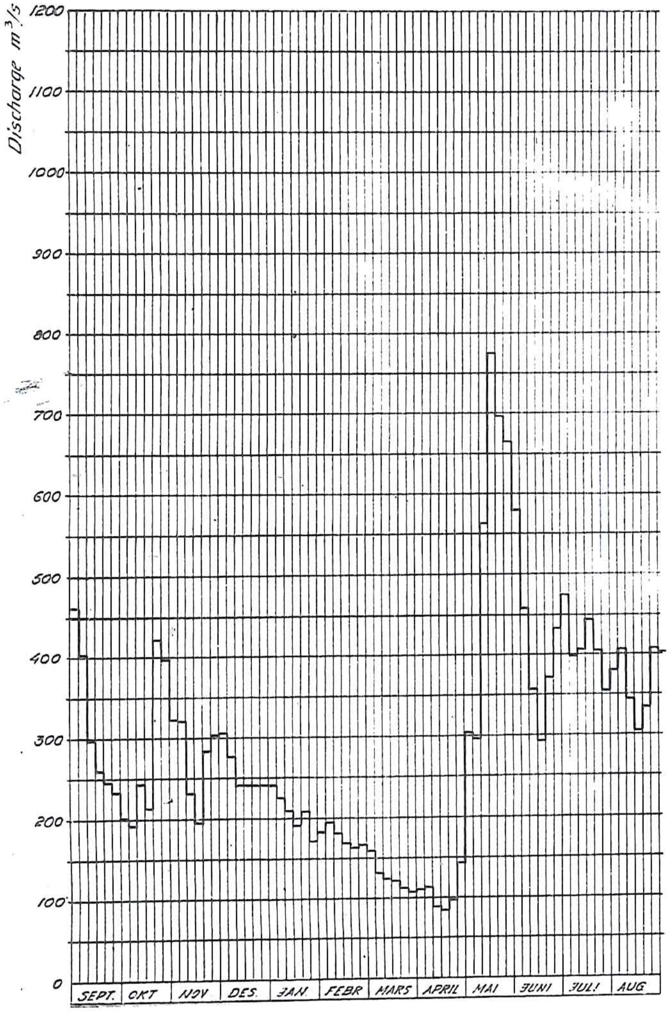
Cont.





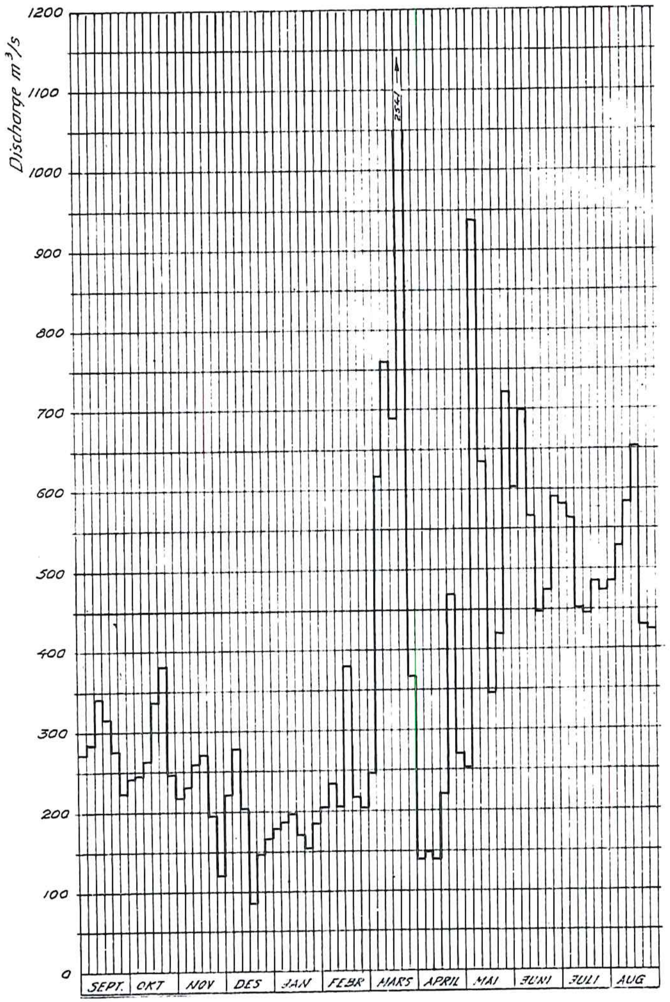
NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE m³/s THJORSÁ, Urridafoss 1950-51



NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE m³/s THJÓRSÁ. Urridafoss 1952-53



NVE Hydr. avd. Iskontoret
9

FIVE-DAY MEANS of DISCHARGE m³/s THJÓRSÁ. Urridafoss 1953-54

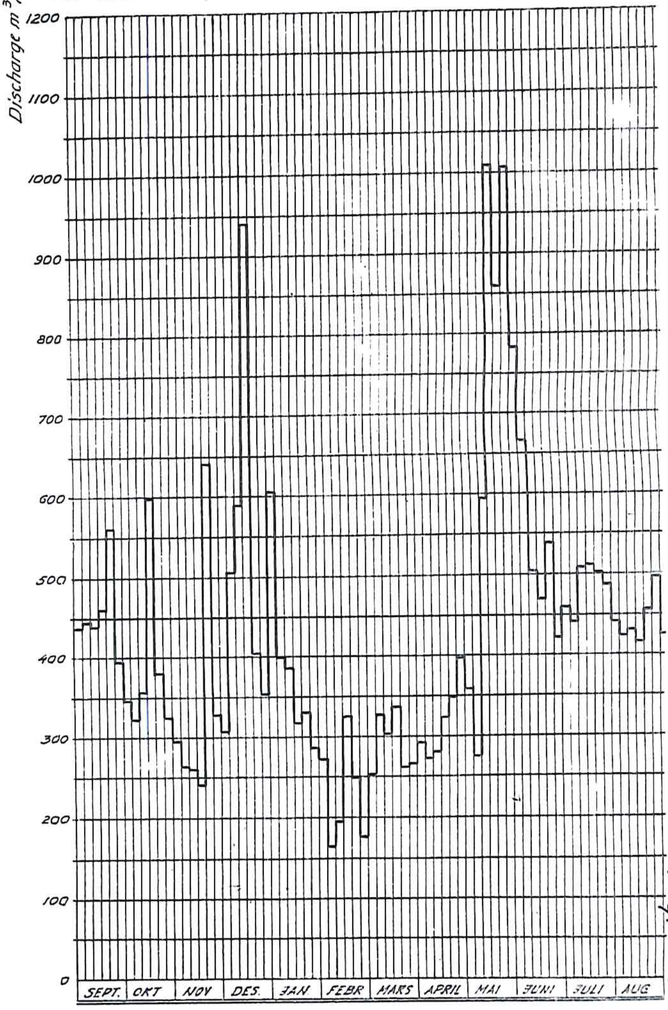


Fig. B-2/16

Fig. B-2^{17}

SEVEN-DAY MEANS of DISCHARGE m^3/s

THJORSÁ at TRÖLLKONUHLAUP, A = 6320 km^2

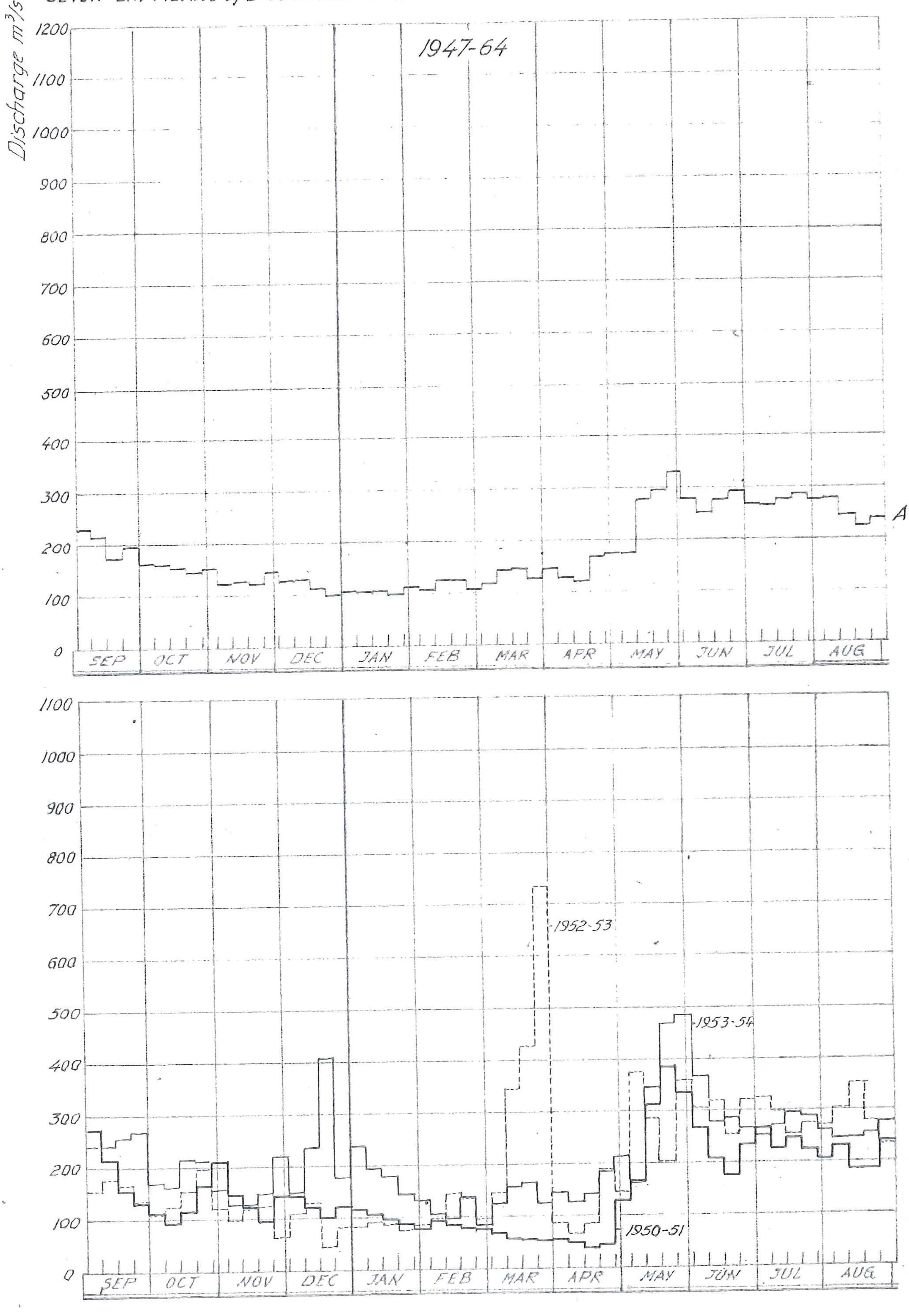
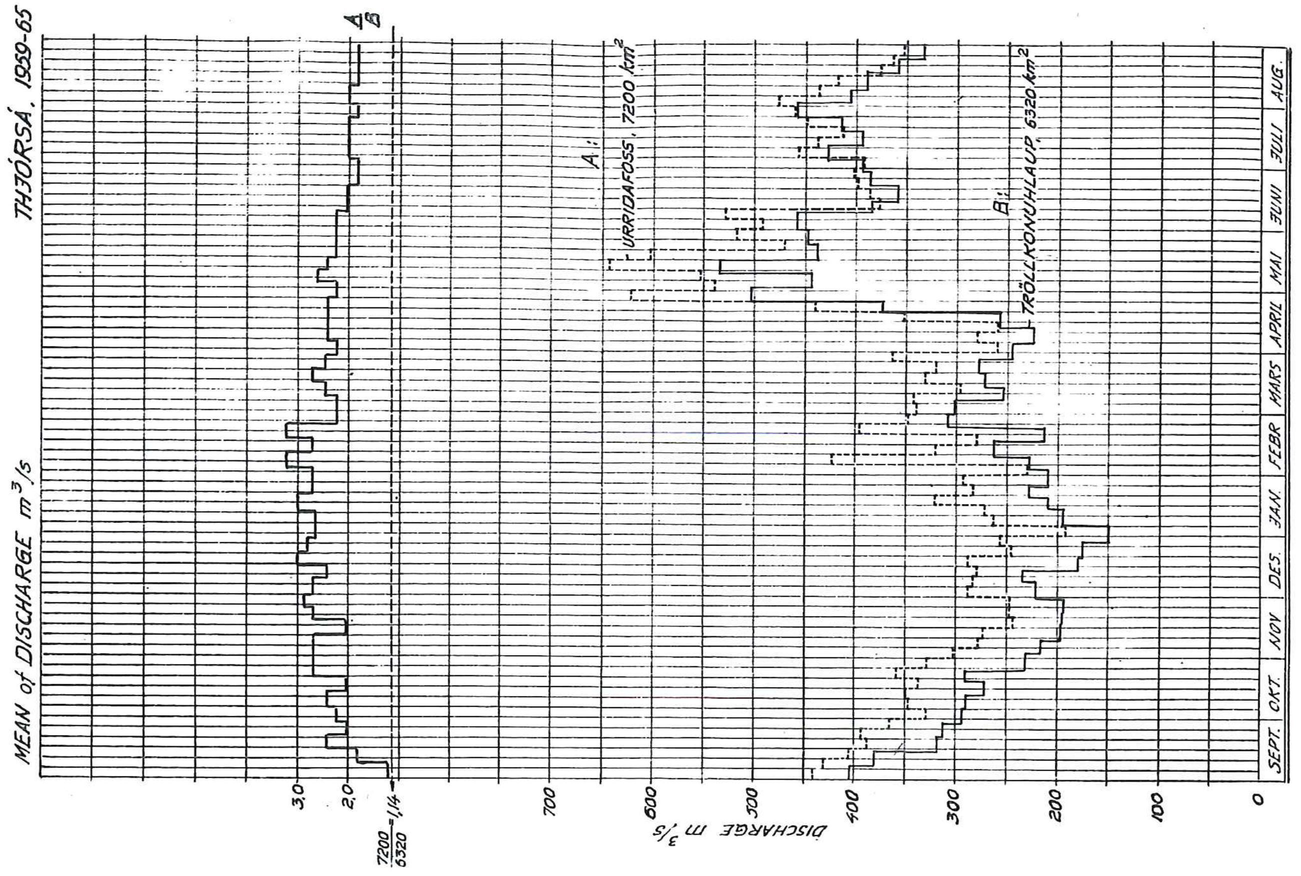
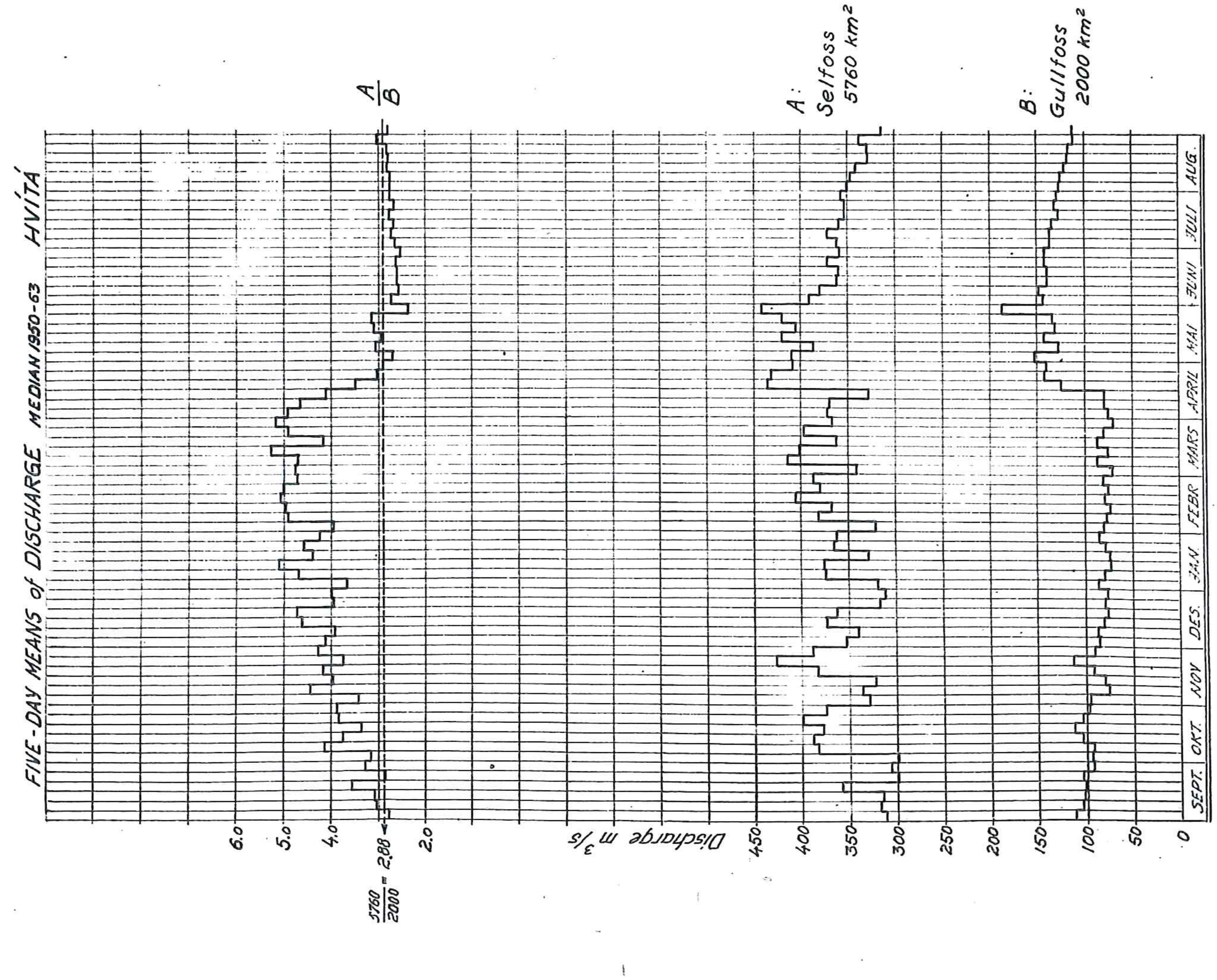


Fig. B-2 18 61

NVE Hydr. avd. Iskontoret
9



NVE Hydr. avd. Iskontoret
9



The curves of fig. B-2$^{19 \text{ and } 20}$ give a survey of the daily discharge in the Hvitá at Gullfoss and Selfoss, in the Tungnaá at Hald and in the Thjórsá at Tröllkonuhlaup and Urridafoss, respectively, for the period 1959-65.

The observations demonstrate that floods may occur at any time of the winter, sometimes causing serious influence on the discharge, through ice production and ice transport e.g. reported by Rist:

"The discharge in Thjórsá river near Urridafoss on 11 April 1963 dropped from 340 to 20 m^3/s in 24 hours. The river was open almost to the glacier when a cold, dry storm from the NE suddenly sat in, causing an extremely high rate of ice formation over nearly the whole river length".

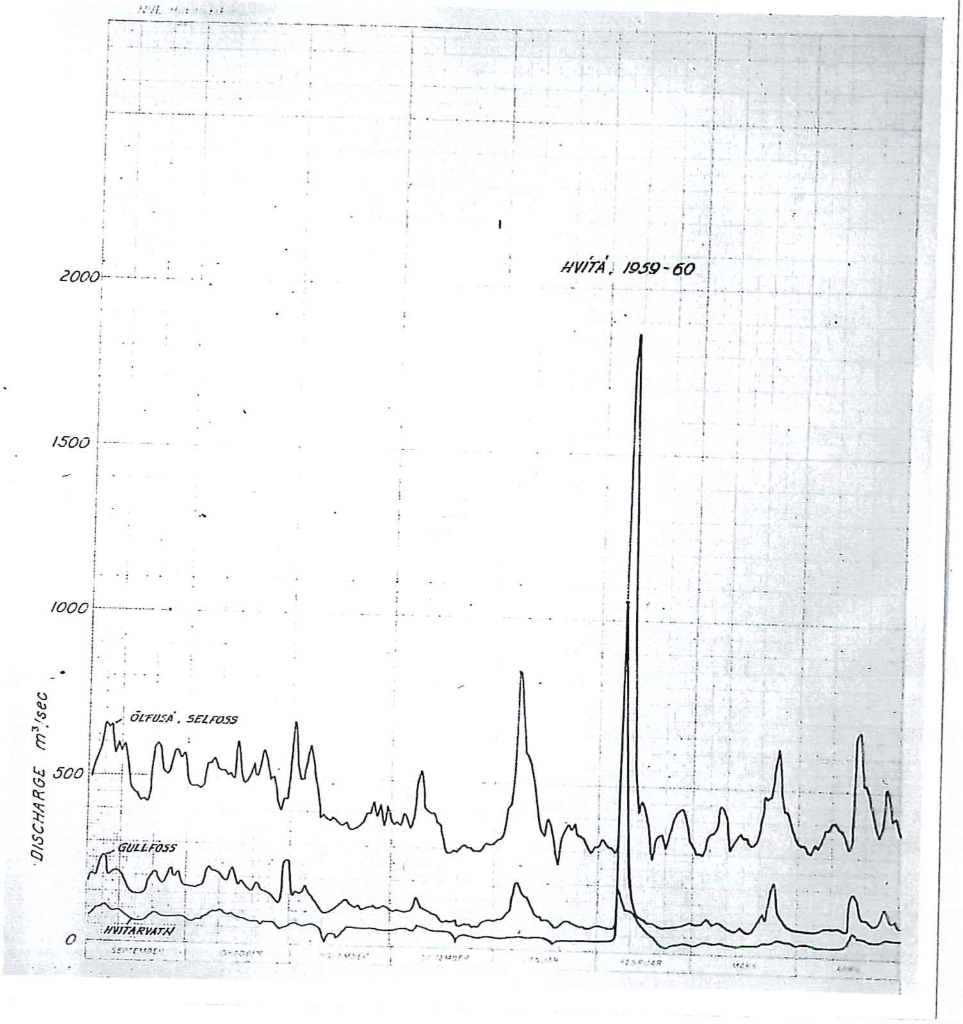
The ice disturbances at the gauges are based solely on a study of the recorder charts and on notes which the observers have made on the charts.

The gauges under consideration are all located in places where the rivers are ice-free most of the winter in practically all years.

It appears that there may be distinguished between three types of ice disturbances at the gauges, namely 1. rise in stage caused by ice obstructions in the river channel (border ice and bottom ice), ice dams, ice jams or ice floes, 2. step bursts (caused by a surge wave due to successive breakening up of individual dams in a series of ice dams or "steps" and 3. freezing in the stilling wells. The characteristics 1 and 2 are treated in chapter C.

The nomogram Fig. B-2^{21} give ratings for 3 gauges in Tungnaá and Thjórsá rivers.

Fig. B-2 19


HVÍTÁ, 1959-60
DISCHARGE m³/sec
2000
1500
1000
500
0
ÖLFUSÁ, SELFOSS
GULLFOSS
HVITÁRVATN
SEPTEMBER
OKTOBER
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL

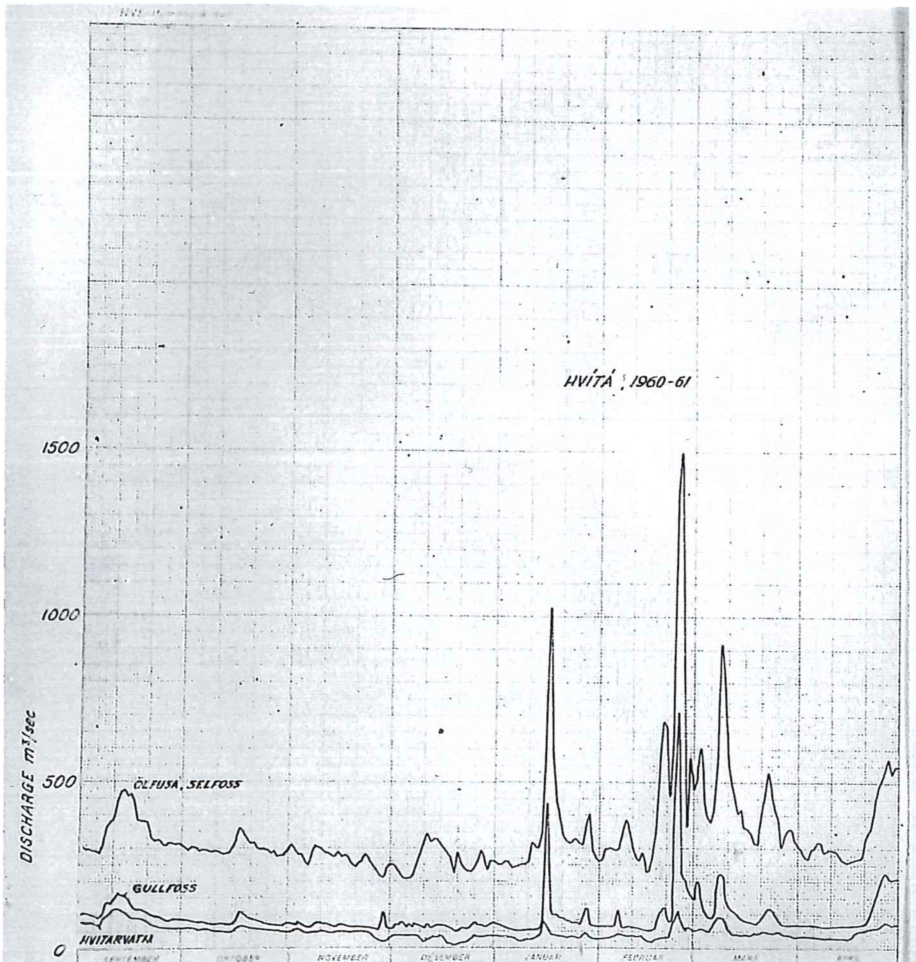
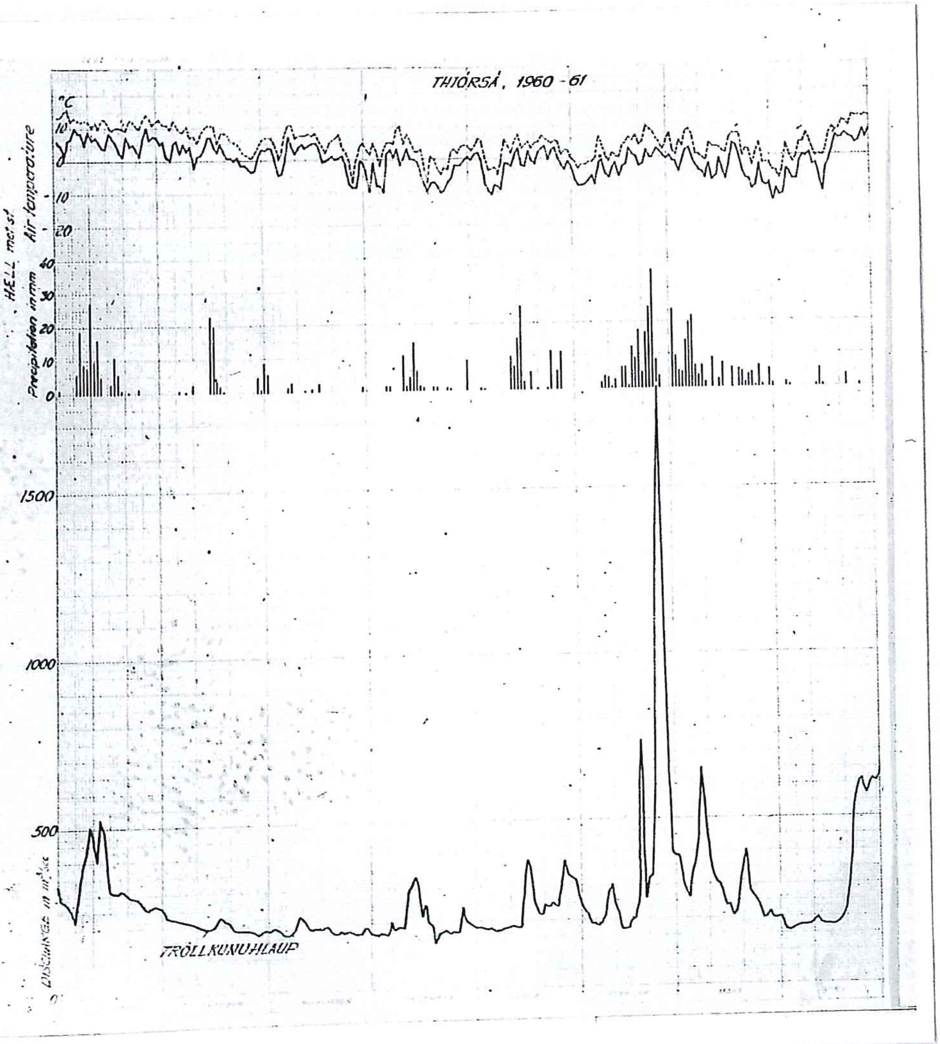
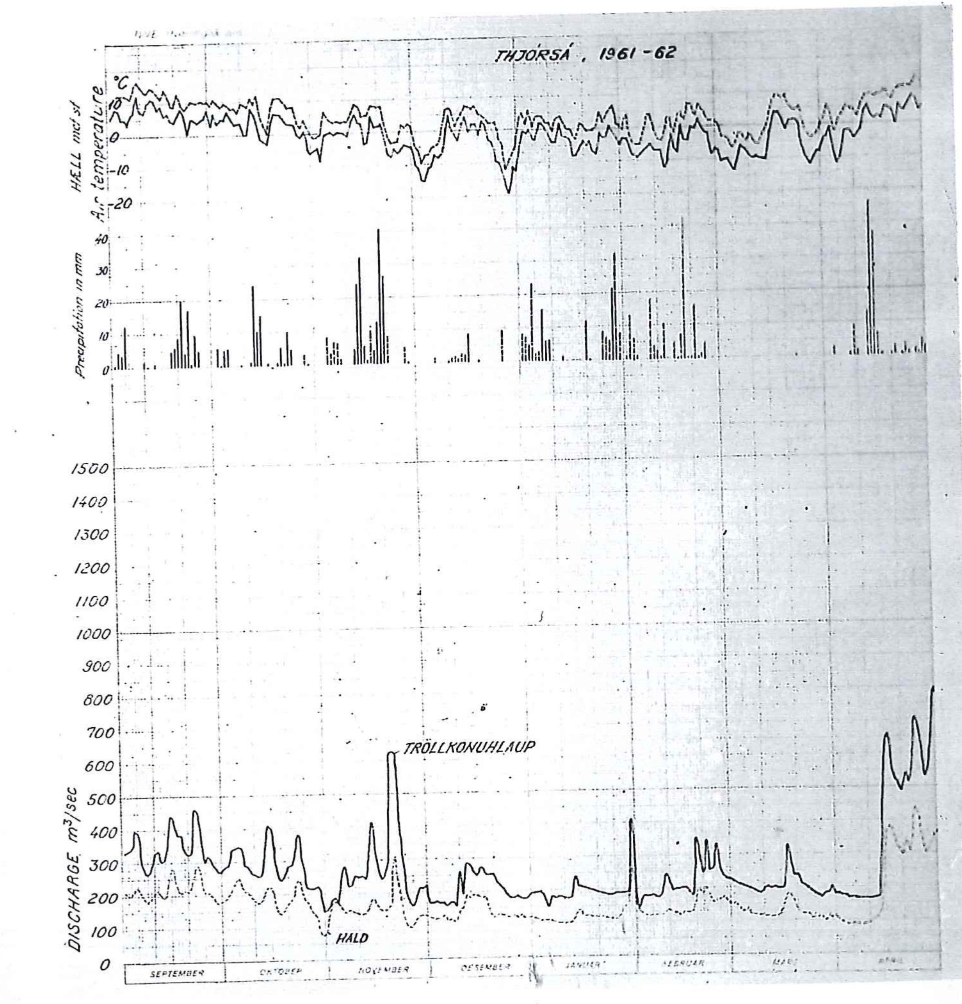
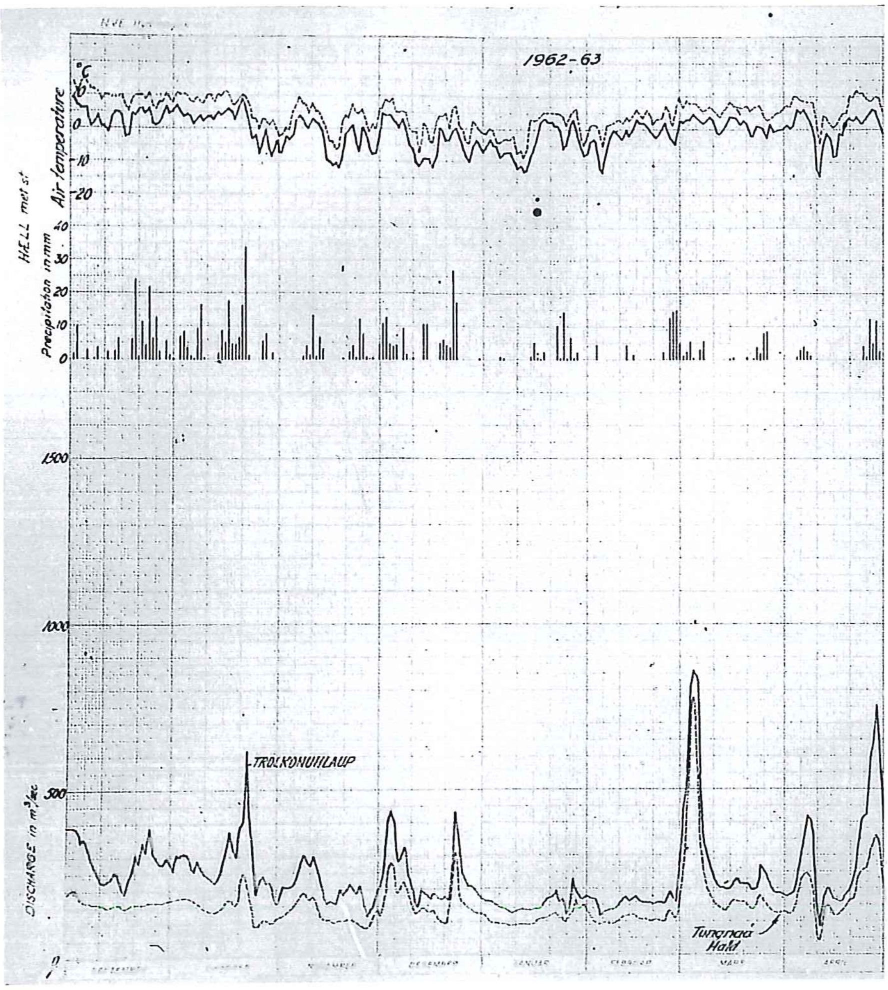

HVÍTÁ, 1960-61
DISCHARGE m³/sec
1500
1000
500
0
ÖLFUSÁ, SELFOSS
GULLFOSS
HVITÁRVATN
SEPTEMBER
OKTOBER
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL

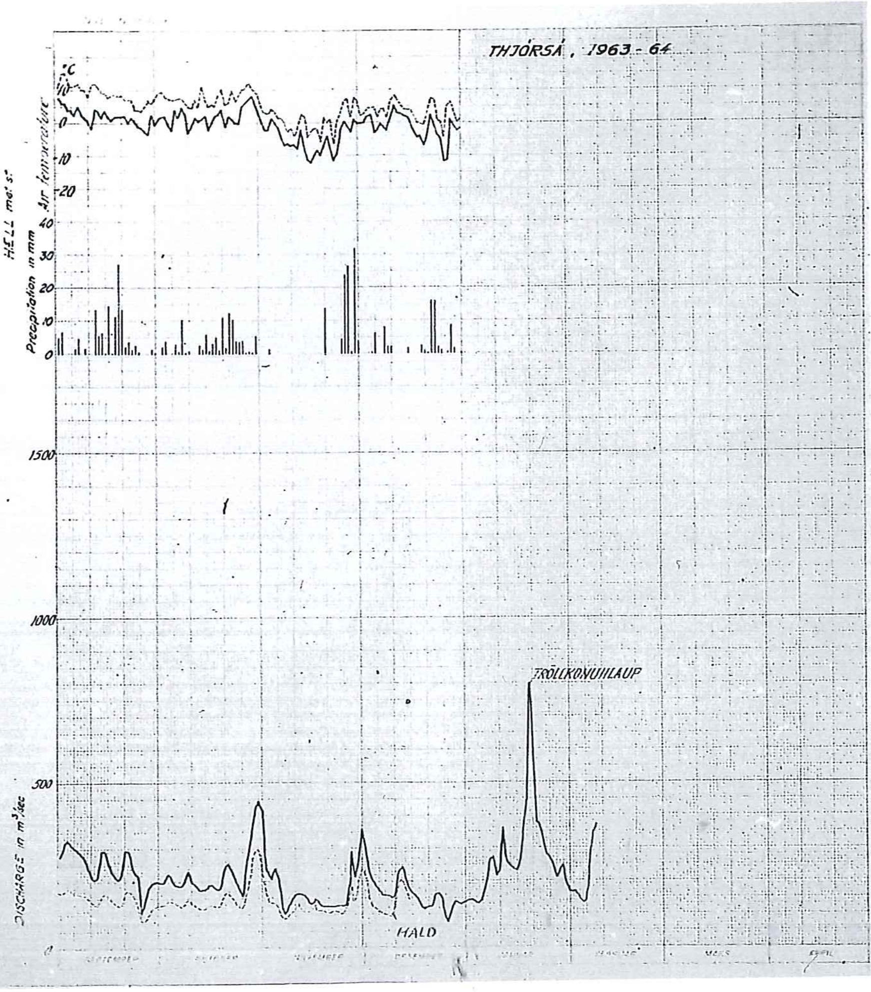
Fig. B-2^{20}


THJÓRSÁ, 1960-61
°C
10
0
-10
-20
HÆLL met st.
Air temperature
Precipitation in mm
40
30
20
10
0
1500
1000
500
0
Discharge in m³/sec
TRÖLLKONUHLAUP

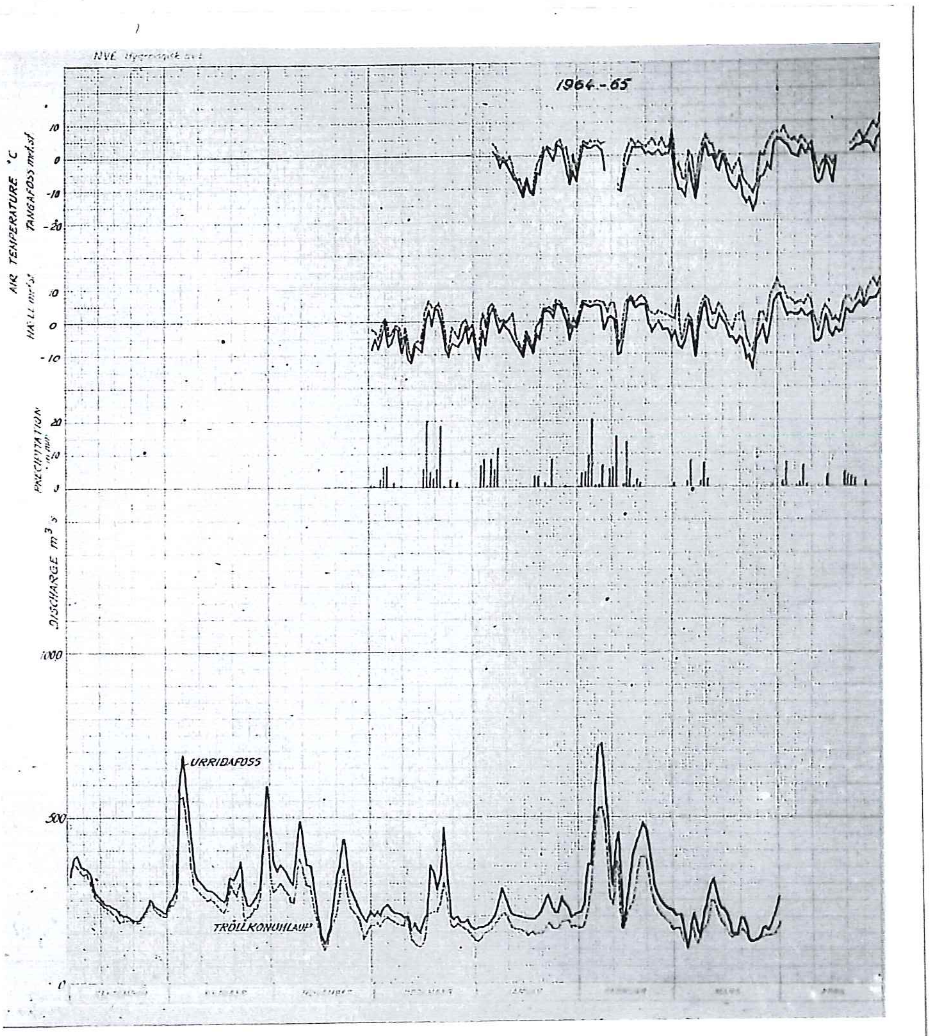

THJÓRSÁ, 1961-62
°C
10
0
-10
-20
HÆLL met st.
Air temperature
Precipitation in mm
40
30
20
10
0
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
DISCHARGE m³/sec
TRÖLLKONUHLAUP
HALD
SEPTEMBER
OKTOBER
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL

Cont.


1962-63
°C
10
0
-10
-20
Air temperature
HELL met st
Precipitation in mm
40
30
20
10
0
1500
1000
500
0
DISCHARGE in m³/sec
TRÖLLKONUHLAUP
Tungnaá
Hald
DESEMBER
JANUAR
MARS

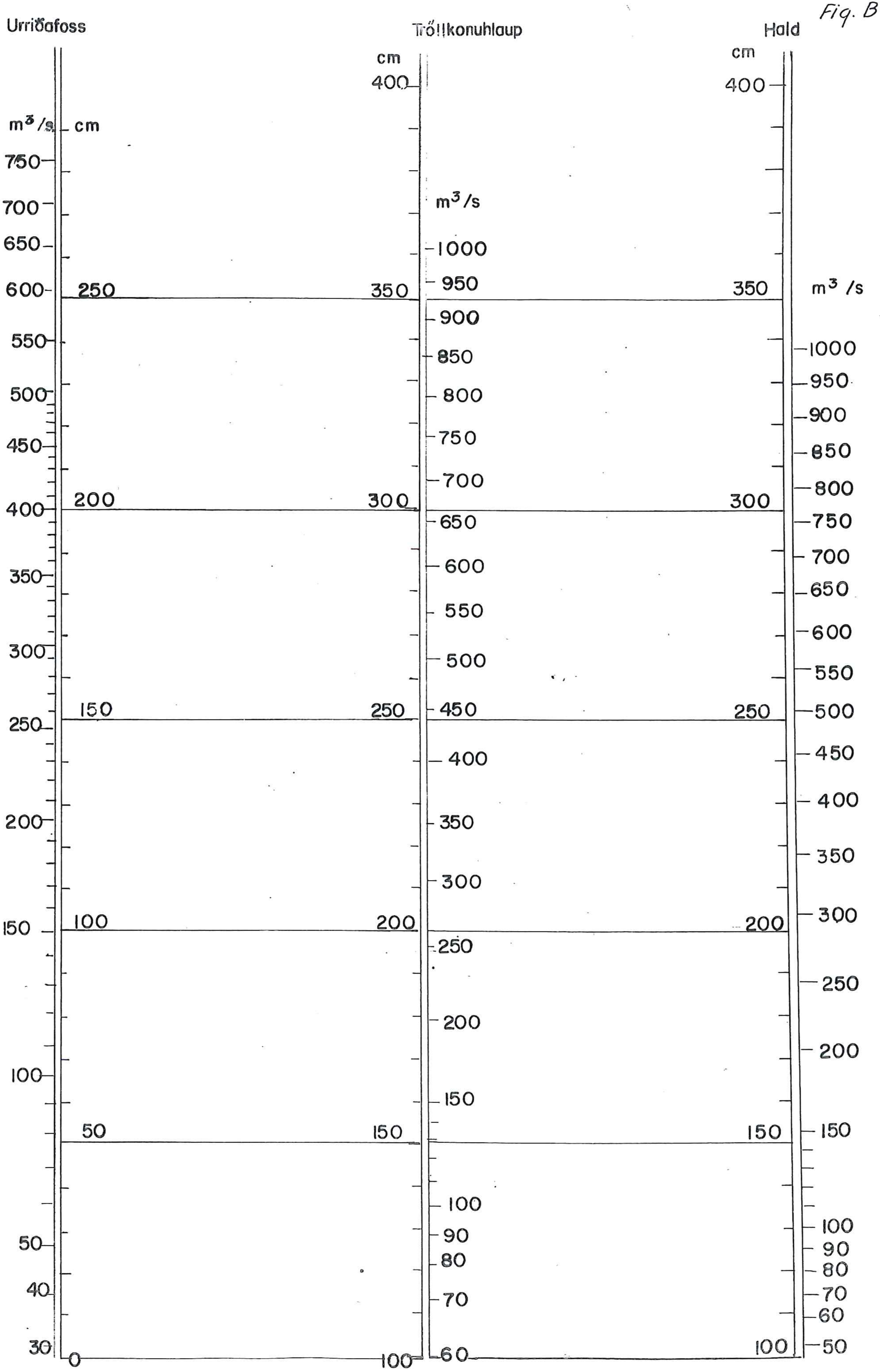

THJÓRSÁ, 1963-64
°C
10
0
-10
-20
Air temperature
HELL met st
Precipitation in mm
40
30
20
10
0
1500
1000
500
0
DISCHARGE in m³/sec
TRÖLLKONUHLAUP
HALD
DESEMBER
MARS

Cont.


NVE Hydrologisk avd.
1964-65
AIR TEMPERATURE °C
TANGAFOSS m.o.h.
HALLI m.o.h.
10
0
-10
-20
PRECIPITATION mm
20
10
0
DISCHARGE m³/s
1000
500
0
URRIDAFOSS
TRÖLLKONUHLAUP

The STATION RATING

Fig. B-2 21



Chapter C: ICE CONDITIONS

It is a great difference between the three stream types, viz. the glacial (J), dragå (D) and lindá (L) streams. To appreciate this difference is of importance for the understanding of the ice conditions in Icelandic rivers.

The temperature of the glacial melt-water is close to 0°C at the edge of the glacier all the year round. The glacial streams are generally distributed over a large area in wide and shallow branches and consequently the water temperature is easily affected by the changes of air temperature. Porous ice formation will be seen along the banks after one night of freezing. The water level rises on account of the formation of floating frazil ice and underwater-ice at the bottom, and the rivers will freeze in a short time when the winter is setting in.

The discharge of the dragá-streams is very much dependent on the weather. As the river beds are generally broad the water temperature responds quickly to variations in air temperature. Ice is rapidly formed in the water as the air temperature goes below 0°C, and usually some underwater-ice will locally swell up at the bottom before the rivers freezes at the surface. This process will raise the water level but will generally not cause any real flood, partly because the river bed is so large that the ice is seldom lifted above the highest flood level, and partly because the discharge will be decreasing during a frost period.

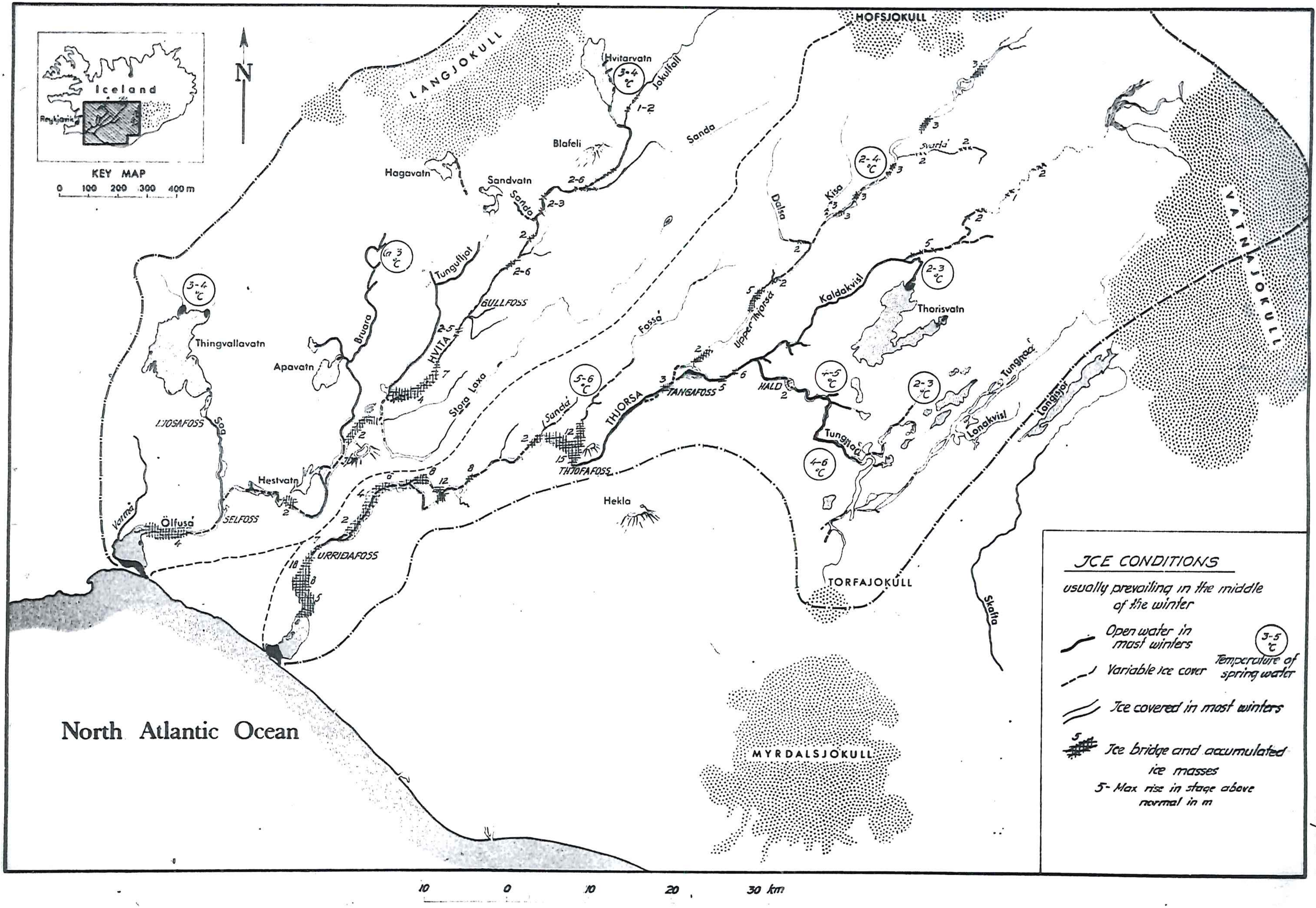
If the frost is going on, the discharge will continue to decrease, the waterflow will make its way under the ice and the water level sinks under the ice cover which also will be lowered in most places. After a long period of freezing such a draga river may become like a brook.

When the freezing process is interrupted by a thaw, the rivers grow all of a sudden and the flow may burst open the ice cover with great tumult.

The lindá-streams have a flow which is very even all the year, and the water temperature is nearly the same both winter and summer in the regions where the springs are located. The temperature of most springs in the Hvitá and Thjórsá rivers ranges from 2°C to 6°C depending on the soil temperature of the drainage area. Lindá-rivers do not freeze near the head spring even in the most severe frost. On the way from the head spring the water will gradually be cooled and ice production will start at the place where the water temperature reaches 0°C. This 0°C frontier will, however, not be stable. As soon as the frost decreases the water temperature rises and ice will be broken up even before the temperature of the air has reached above 0°C. The frontier line of 0°C water temperature thus may move downwards or upwards the river, depending upon the changes of the weather. Under a heavy frost period it happens that anchor ice and frazil ice is produced in great quantities causing reduction of the water velocity and raising of the water level. In such localities the river may flow out of its bed and this may cause damage since the water quickly may be raised above the highest flood level.

Fig. C-1 shows typical ice conditions in the river systems prevailing in the middle of the winter. The main rivers in the Hvitá and Thjórsá basins are a mixture of all three types, a fact which entails much more complicated ice conditions than in a river of a single type. The great changeability of the weather in the area has also a great effect in reducing the stability of the ice formations.

Fig. C-1


JCE CONDITIONS
usually prevailing in the middle of the winter
Open water in most winters
Variable ice cover
Ice covered in most winters
Ice bridge and accumulated ice masses
5- Max rise in stage above normal in m
3-5 °C Temperature of spring water
KEY MAP
Iceland
Reykjavik
0 100 200 300 400 m
N
North Atlantic Ocean
LANGJOKULL
HOFSJOKULL
VATNAJOKULL
TORFAJOKULL
MYRDALSJOKULL
Hvitarvatn
Jokulfall
Blafeli
Hagavatn
Sandvatn
Sanda
Tungufljot
GULLFOSS
HVITA
Bruara
Apavatn
Thingvallavatn
LJOSAFOSS
Sog
Hestvatn
SELFOSS
Ölfusa
Varma
URRIDAFOSS
Stora Laxa
Fossa
THJORSA
TANGAFOSS
THJOFAFOSS
Hekla
Dalsa
Kisa
Svarta
Upper Thjorsa
Kaldakvisl
Thorisvatn
HALD
Tungnaa
Lonakvisl
Langisjor
Skafta
10 0 10 20 30 km

1. Short survey of the ice production in the various sections of the Hvitá.

In autumn, the Hvitá tributaries in the highlands (e.g. the rivers Jökullfall, Grjótá and Sandá) freeze up just as the air temperature goes below 0°C.

The ice formation in the lake Hvitárvatn and in the first section of the Hvitá, above the confluence of river Jökullfall, starts later, soonest in November latest in December. At this time the above mentioned tributaries are covered with a solid ice cover and no drifting ice is coming from them.

The river channel of Hvitá is fairly narrow in the section downstream on the eastern and southern sides of Blåfell and the ice production is correspondingly moderate. From Fremstaver to approx. 8 km upstream of Gullfoss a section is characterized by braided flow over wide channels and shallow water depth. This gives a large cooling surface and a quick response of water temperature to changes in air temperature, and thus a possiblity of frazil ice formation. From approx. 8 km upstream from Gullfoss to approx. 9 km downstream the Hvitá has a difference of elevation of ca 163 m (average slope 9,4 m/km). This section has rather deep channels, effectively shielded against the cooling effect of winds and it has relatively large heat gains from conversion of kinetic energy. The max. rise in water level at the water gauge downstream of Gullfoss amounts to 1,5 m, lasting for about a day only.

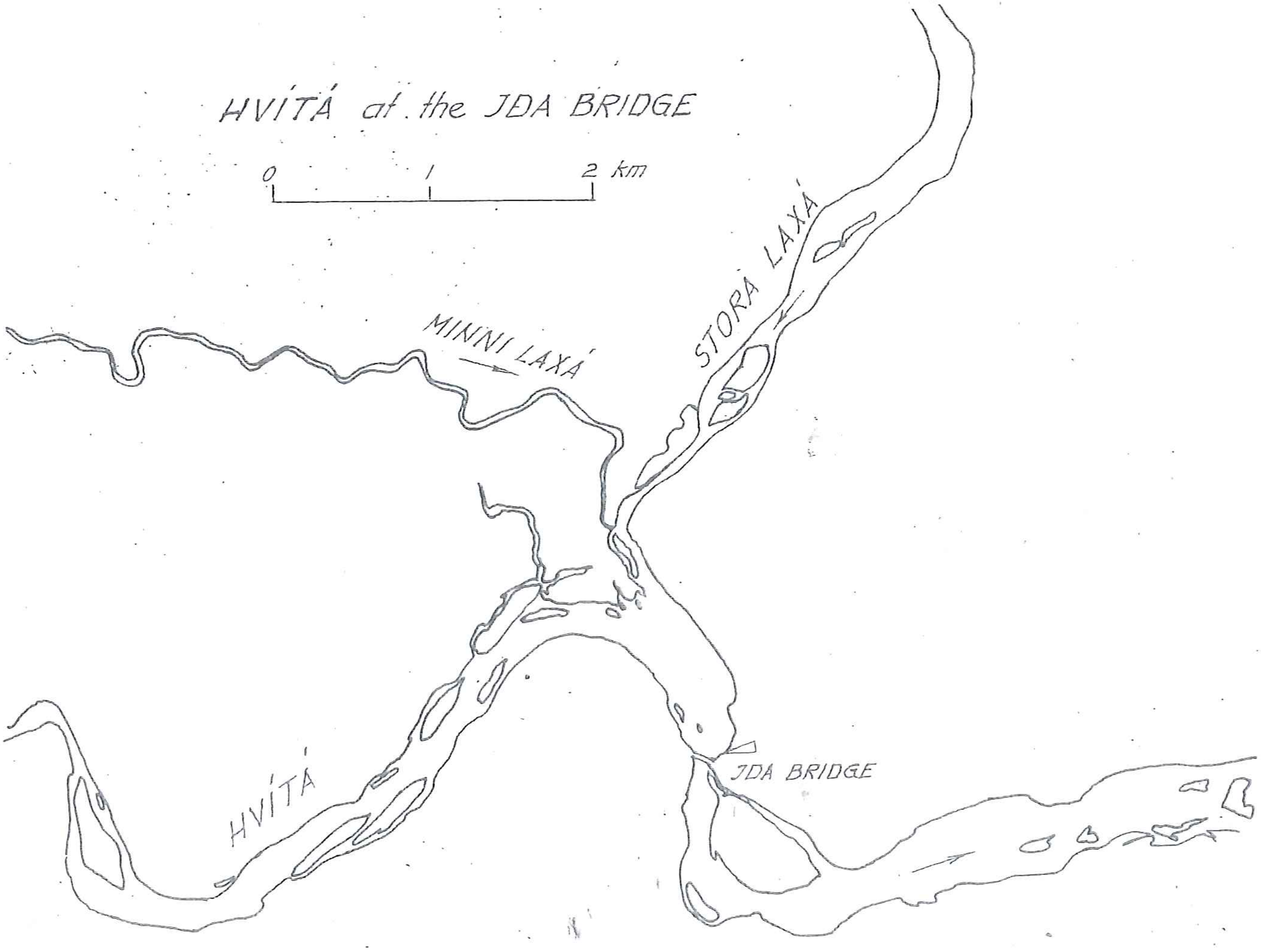
In periods of frost ice accumulation will take place in the Hvitá upstream of Kopsvatnseyrar. Further downstream very little amount of spring water enters the river until the confluence with river Bruara. Ice cover has not been observed on river Tungufljot in the section upstream of the waterfall Faxi, presumably owing to spring water. In the section between Faxi and the confluence with river Hvitá, an ice cover may be formed during periods when Hvitá is freezing up and its water level is damming up the water of river Tungufljot. When the water level of river Hvitá is lowered again, the river

Tungufljót returns to its normal channel and spring water may melt the ice. The max. water level rise of 6 m has been observed in the Hvitá on the section between Tungufljót and Brúarhlöd. In the section between Tungufljót and Hestvatn a max. rise in water level of 2 m has been observed.

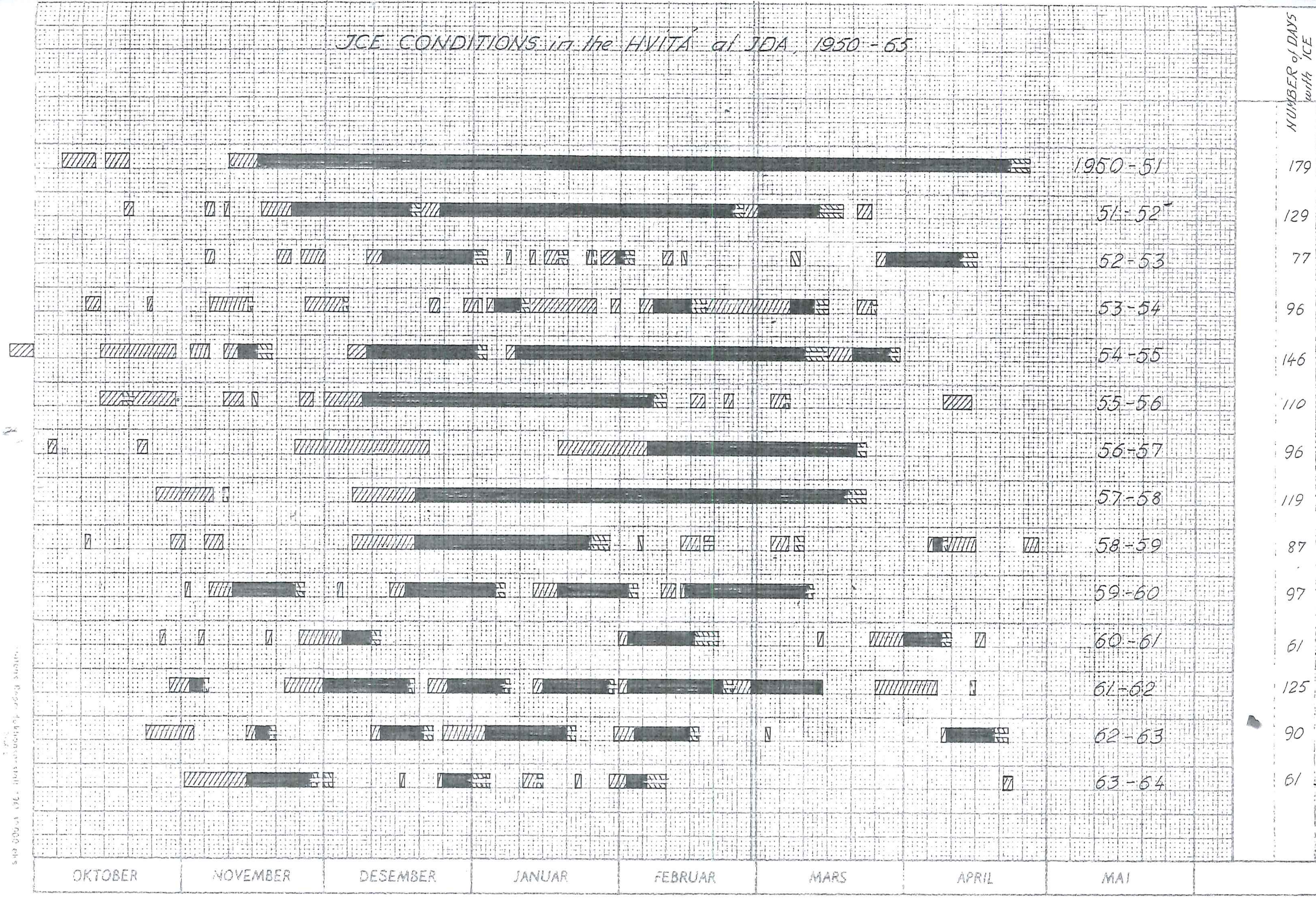
River Brúará is a typical lindá river. In extreme cases the same thing may occur in its lowest section as of river Tungufljót. Ice cover is very rare on the Brúará.

Downstream of the Brúará confluence, river Hvitá has pronounced lindá characteristics, although it happens that an ice cover is formed on the river where it is wide, as near Selfoss for instance, where a rise in water level of about 4 m has been observed.

On the Fig. C-1^1 is given the survey of the ice conditions in the Hvitá at Ida bridge.



NVE Hydrologisk avd.



ICE CONDITIONS in the HVITÁ at IDA, 1950-65

Fig. C-1'

2. Short survey of the ice conditions in the various sections of the Thjórsá river system

Ice production will first start on the Upper Thjórsá and on the upper reaches of tributaries e.g. Kaldakvisl, Tungnaá in the vicinity of the glaciers, and in the uppermost draga-rivers in the highlands, e.g. Kisa, Dalsá, the upper reaches Fossá and the streams in Sprengisandur. If the frost lasta for some time, an ice cover is formed on those rivers, but before that, a great amount of sludge ice has been carried downstream by the current, reaching sections where the river channel is wide and the loss of heat is great.

The river channel of Upper Thjórsá is fairly narrow in the section between Hvanngiljafoss and Gljufurleitarfoss falls, and the ice production is correspondingly moderate. The next section (ca 20 km long) to approx. 2 km upstream of the confluence with Blautakvisl is characterized by braided flow over wide channels and shallow water depth. This gives a large cooling surface and a solid ice cover may be formed during periods of great heat loss from the water (frost and wind). Sludge ice may be collected under the ice and the rise in water level amounts to 2-5 m.

River Tungnaá is usually uncovered below the ford at the end of the Vatnaöldur ridge, owing to the great amount of spring water flowing into the river from the great lava field on the southwestern river bank. Before an ice cover is formed on the river section lying between Vatnaöldur and the glacier a great amount of sludge ice is carried down the river. Later in the winter, when an ice cover has been formed on the upper part of Tungnaá some sludge ice may be formed in the river section from Vatnaöldur down to the Hrauneyjafoss, and carried downstream by the current. The result is that an ice cover is formed downwards the fall with an open channel in the middle.

The ice formation in the lake Thorisvatn starts later, soonest in October and latest in November. At this time the upper section of Kaldakvisl is covered with ice. During frost periods the main part of the discharge in the Kaldakvisl comes from the Thorisvatn reservoir with temperature above 2°C and an ice cover has not been observed on the river section below the efflux from Thorisvatn.

The section of Tungnaá from Kaldakvisl and downstream to the confluence with Upper Thjórsá is about 15 km long, and has a difference of elevation of ca 40 m (average slope 2,6 m/km). In most places the river channel is wide and there the ice production during frost periods is enormous. The max. rise in water level at the Hald gauging station amounts to 8 m. The amount of sludge ice in the water may decrease in places where large quantities of springwater enter the river. The result in such places is that an ice cover is formed at each shore, with an open channel in the middle, generally lasting for long periods in the winter.

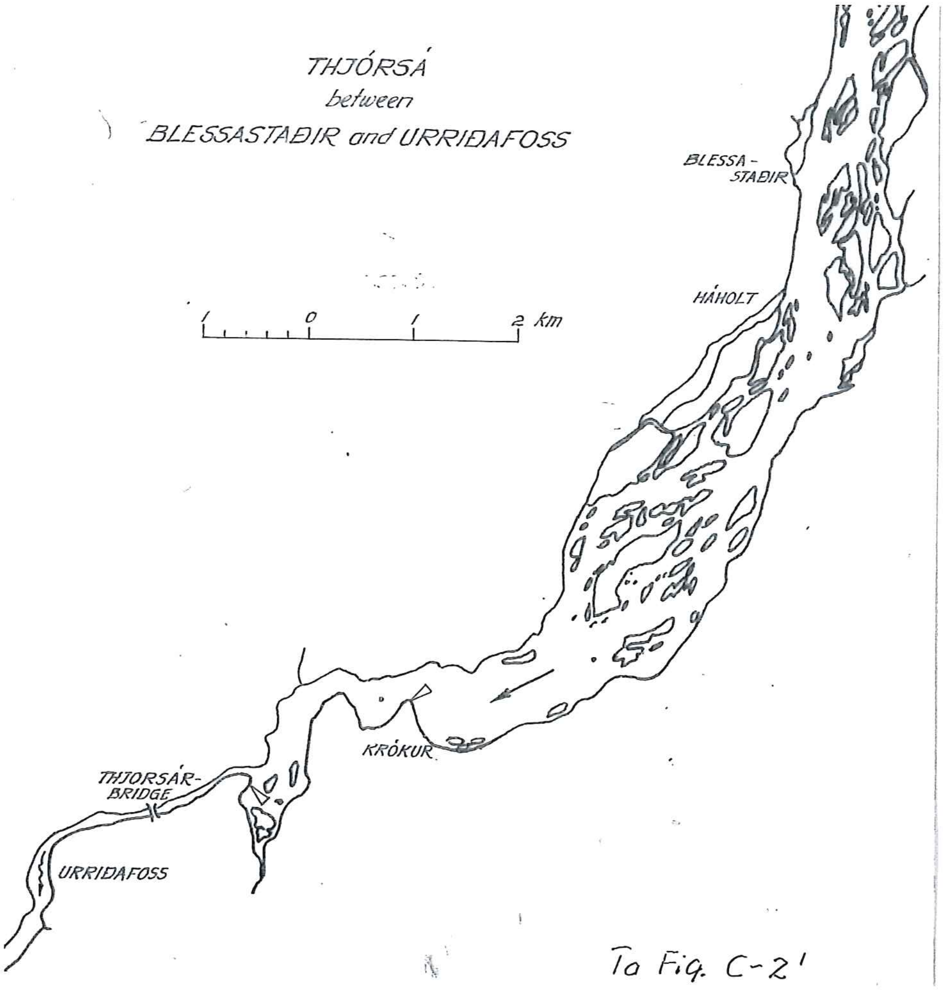
An important section of river Thjórsá, from the confluence with Tungnaá to Tröllkonuhlaup, has a length of 17 km, an area about 7-8 km² and the average slope of 3,7 m/km. The river channel is here an inclined plane with nearly the same width (400-450 m) over a distance of say 10 km and with the same shallow depth, say 0,5 m, over this distance. The river flows on top of a lava sheet. The velocity of the main waterflow in this part is during the winter within the interval 1-2,5 m/s. and the river is usually uncovered. The heat loss during cold weather and wind produce here sludge ice and bottom ice in great masses.

River parts which are getting narrow and deep will facilitate the formation of an ice carpet by compression of floating sludge ice, thus establishing an ice bridge between the river sides. The water stream will usually pass under the floating ice bridge and carry floating ice further downstream. Such places are e.g. below Tangafoss where the formation of large ice-carpet-bridges regulary occur during cold weather.

In the part of Lower Thjórsá lying below Burfell and Urridafoss the major ice production takes place where the river usually is open and consequently exposed to great heat loss from the water during periods of frost and wind. An ice cover may be formed and floating sludge ice arriving from open areas upstream may be collected under the ice, creating an ice barrier and causing a rise in the water level. This will facilitate the growth of the ice cover upstream.

Below the Thjofafoss fall the rise in water level due to ice accumulation amounts to 5-12 m. A similar rise in the water level is about 8 m at the Budafoss fall, and the rise amounts to 15-18 m at the Urridafoss rapids before the river is frozen up. This is the max. rise in water level due to ice damming and accumulation observed in any river in Iceland.

On the Fig. C-1^2 is given the survey of the ice conditions in the Lower Thjórsá at Krókur.



To Fig. C-2'

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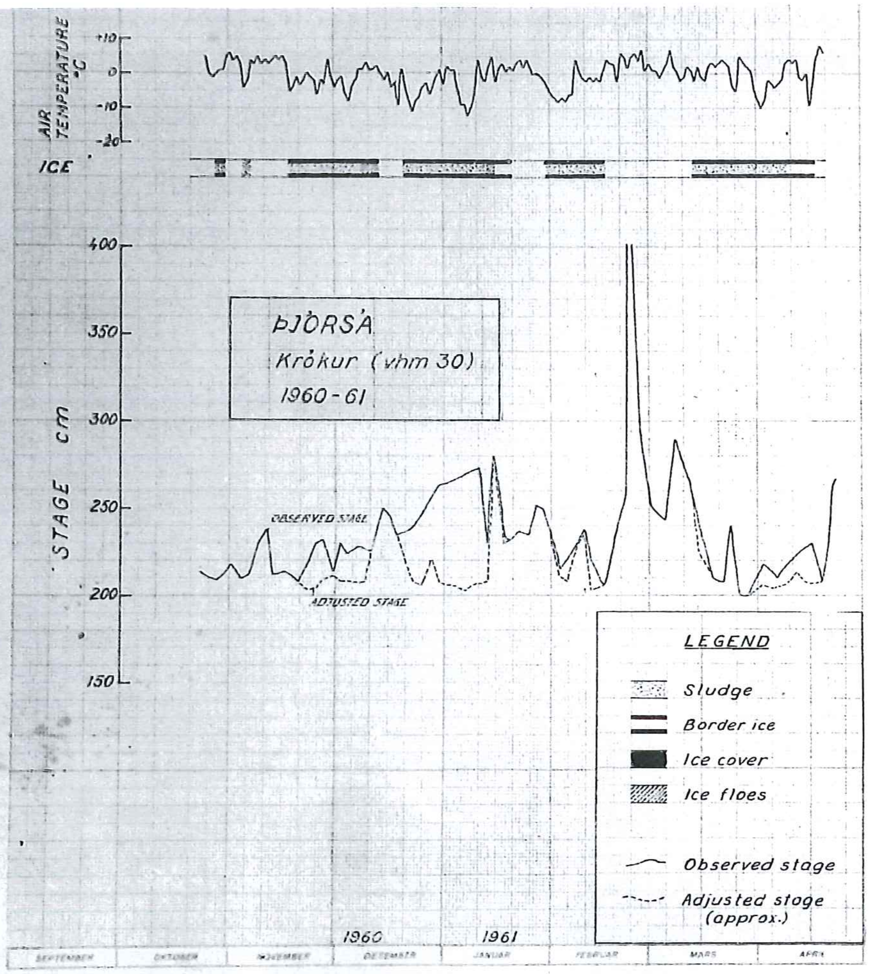
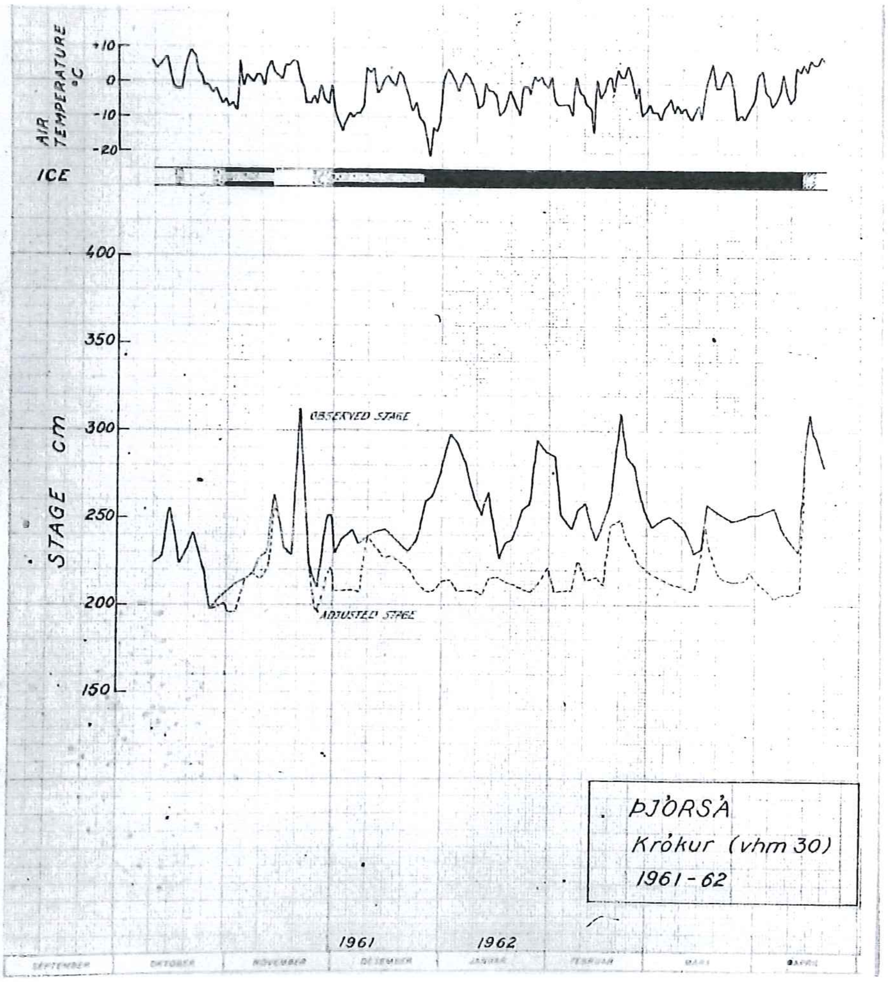

AIR TEMPERATURE °C
+10
0
-10
-20
ICE
ÞJÓRSÁ
Krókur (vhm 30)
1960-61
STAGE cm
400
350
300
250
200
150
OBSERVED STAGE
ADJUSTED STAGE
LEGEND
Sludge
Border ice
Ice cover
Ice floes
Observed stage
Adjusted stage (approx.)
1960
1961
SEPTEMBER
OKTOBER
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL


AIR TEMPERATURE °C
+10
0
-10
-20
ICE
STAGE cm
400
350
300
250
200
150
OBSERVED STAGE
ADJUSTED STAGE
ÞJÓRSÁ
Krókur (vhm 30)
1961-62
1961
1962
SEPTEMBER
OKTOBER
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL

NVE Hydrologisk avd.

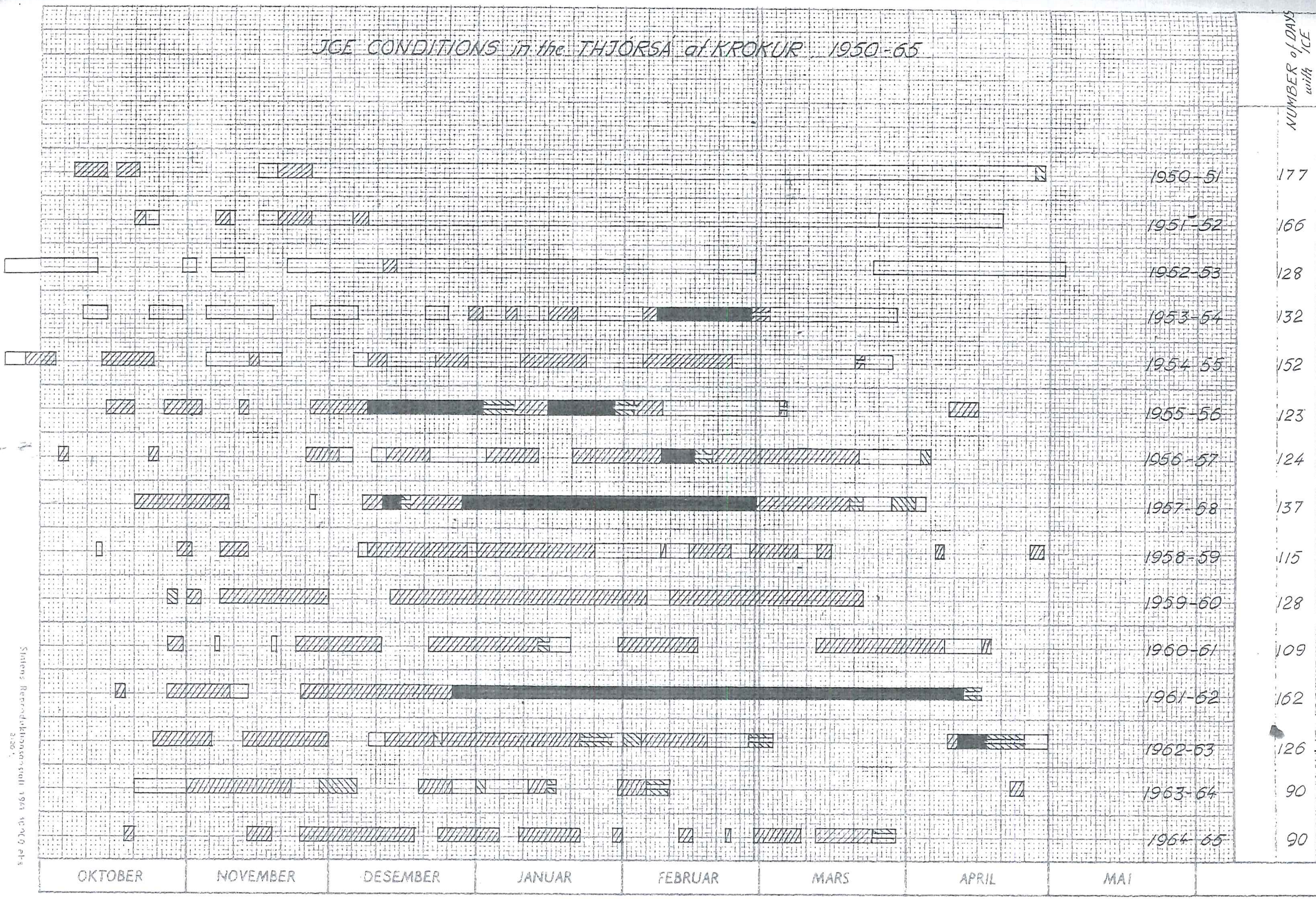
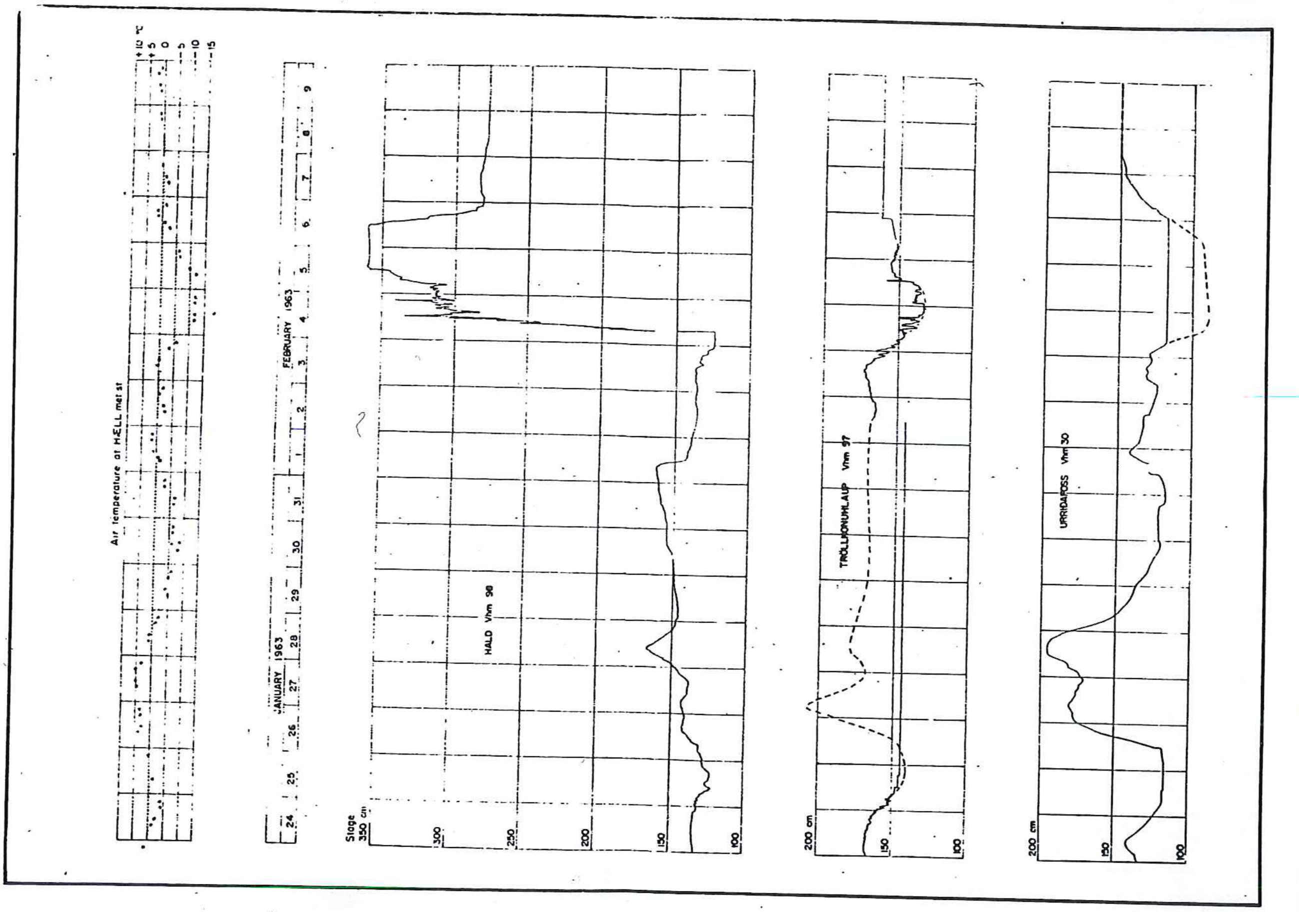
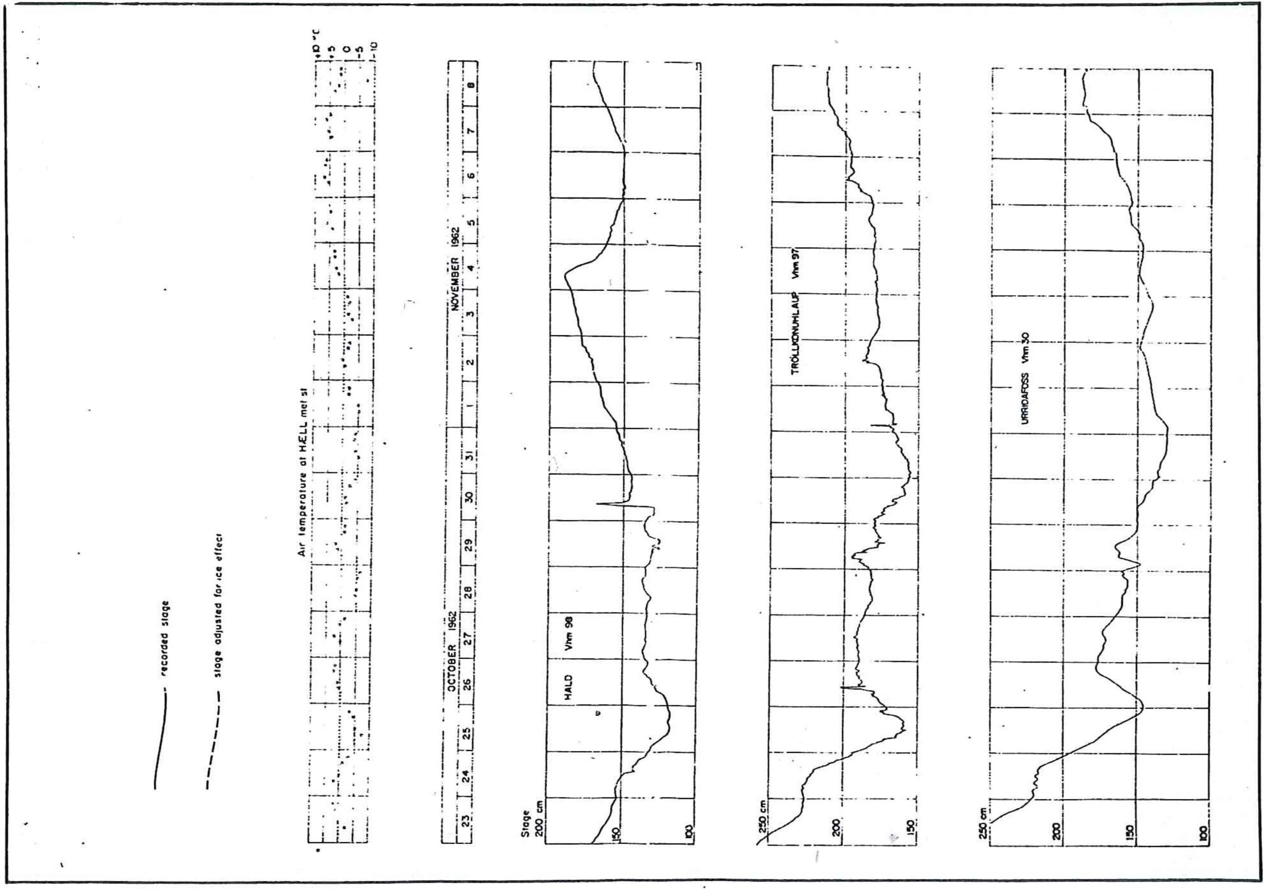


Fig. C-2'

Statens Reproduktionsanstalt 1961 10 000 eks

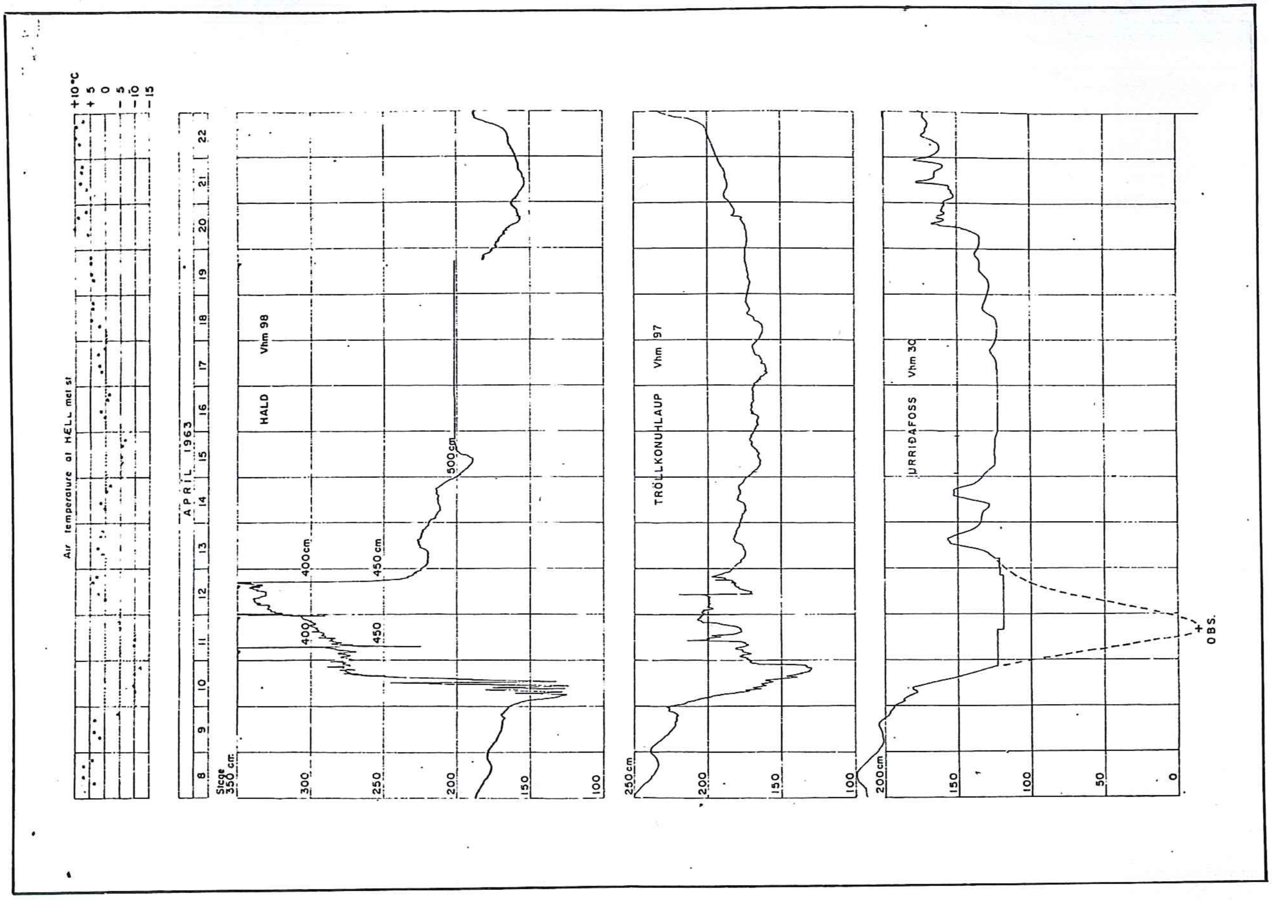
Fig. C-2^2


Air temperature at HÆLL met st
+10 °C
+5
0
-5
-10
-15
JANUARY 1963
FEBRUARY 1963
24
25
26
27
28
29
30
31
1
2
3
4
5
6
7
8
9
Stage 350 cm
300
250
200
150
100
HALD Vhm 98
TRÖLLJONUHLAUP Vhm 97
200 cm
150
100
URRIDAFOSS Vhm 30
200 cm
150
100

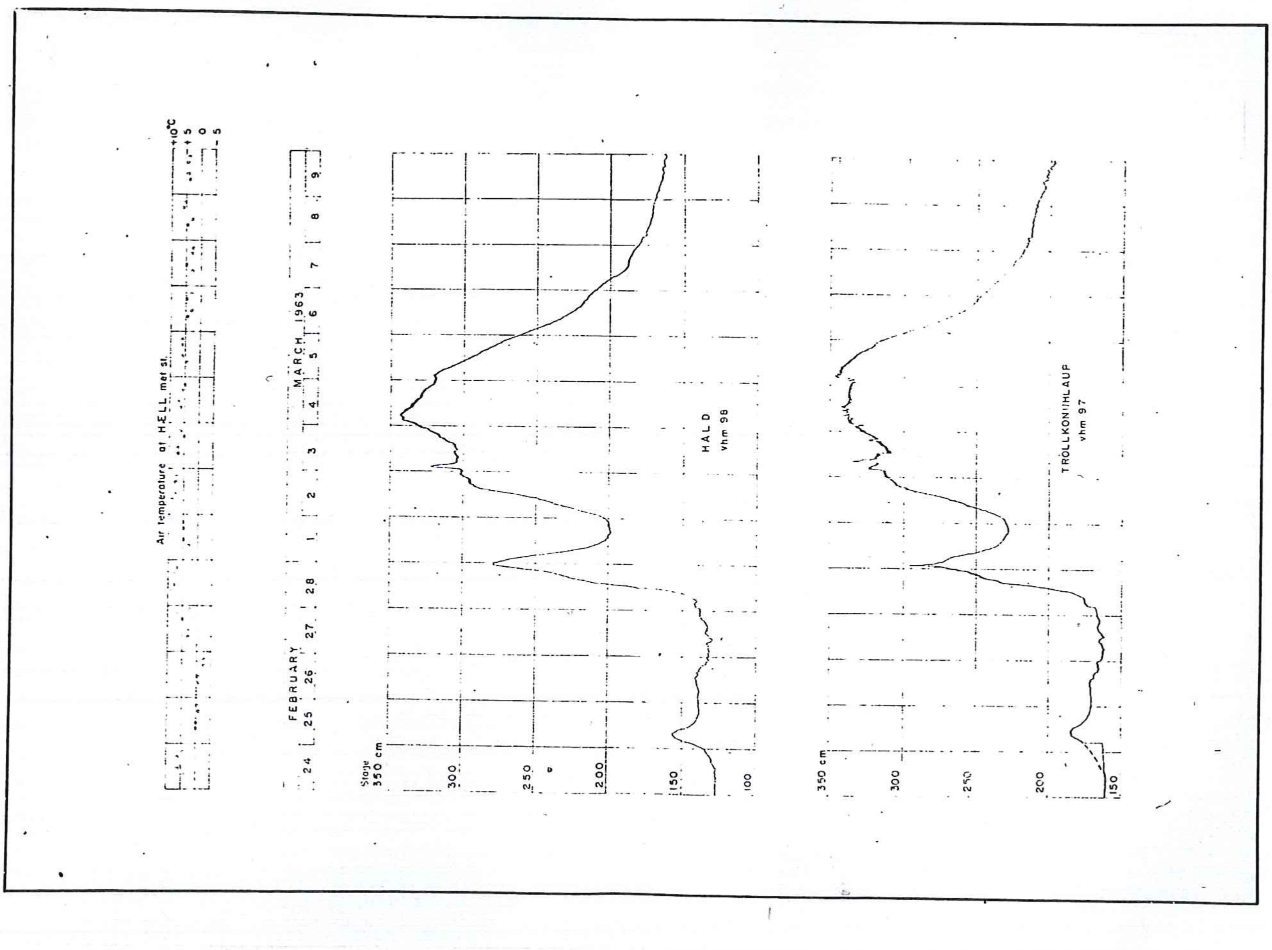

recorded stage
stage adjusted for ice effect
Air temperature at HÆLL met st
+10 °C
+5
0
-5
-10
OCTOBER 1962
NOVEMBER 1962
23
24
25
26
27
28
29
30
31
1
2
3
4
5
6
7
8
Stage 200 cm
150
100
HALD Vhm 98
TRÖLLJONUHLAUP Vhm 97
250 cm
200
150
URRIDAFOSS Vhm 30
250 cm
200
150
100

79

Cont

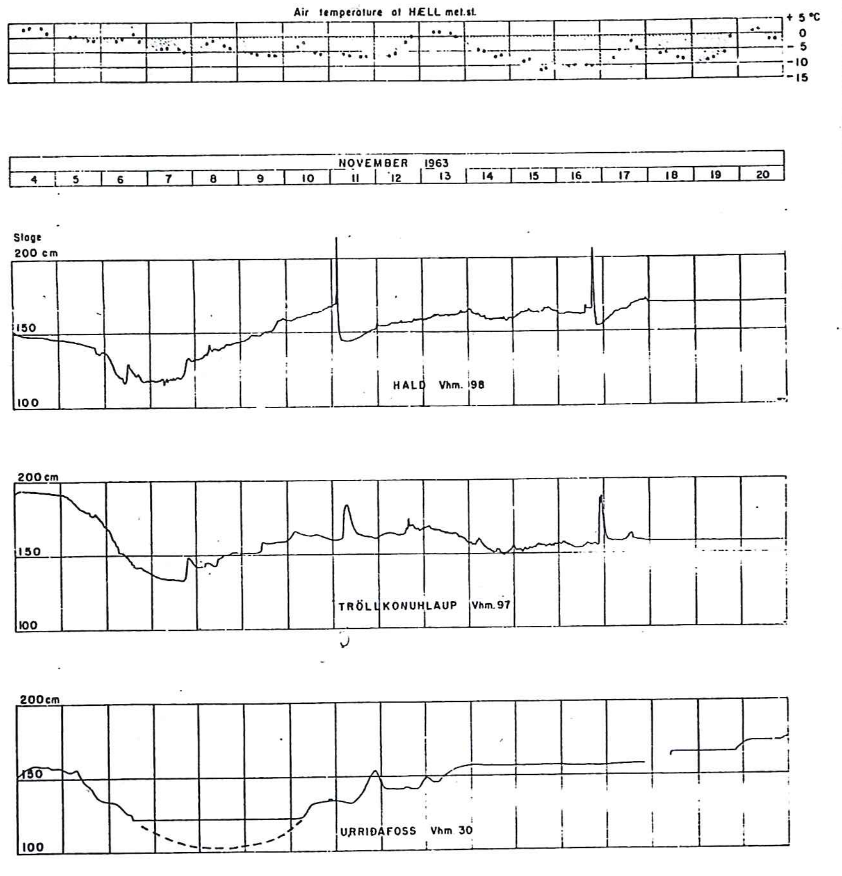


Air temperature at HÆLL met st
+10°C
+5
0
-5
-10
-15
APRIL 1963
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Stage 350 cm
300
250
200
150
100
HALD Vhm 98
400cm
450cm
500cm
400
450
250cm
200
150
100
TRÖLLKONUHLAUP Vhm 97
200cm
150
100
50
0
URRIÐAFOSS Vhm 30
OBS.



Air temperature at HÆLL met st.
+10°C
+5
0
-5
FEBRUARY
24
25
26
27
28
MARCH 1963
1
2
3
4
5
6
7
8
9
Stage 350 cm
300
250
200
150
100
HALD vhm 98
350 cm
300
250
200
150
TRÖLLKONUHLAUP vhm 97

Cont.


Air temperature at HÆLL met.st.
+ 5 °C
0
- 5
-10
-15
NOVEMBER 1963
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Stage
200 cm
150
100
HALD Vhm. 98
200 cm
150
100
TRÖLLKONUHLAUP Vhm. 97
200cm
150
100
URRIDAFOSS Vhm 30

The ice masses in Tungnaá and Thjórsá may be loosened and set into motion by a "step burst" or by a winter flood. Such weather changes with ice jams moving downstream may occur several times during a single winter. Interesting material is presented in the typed report "Studies of Ice Disturbances at water gauges No 30, 97 and 98 on the Thjórsá and Tungnaá rivers 1960-64.

On Fig. C-1^3 is given a short survey of ice disturbances at the 3 gauges in Tungnaá and Thjórsá rivers the winter 1962-63.

The daily observations of water level and discharge demonstrate how the discharges varies with the ice production, ice transport and ice accumulation.

3. Ice Conditions during the winter 1964-65.

During the winter 1964-65 the following programme has been accomplished: Daily weekly inspection trips, each lasting 3-4 days, were undertaken to the Tungnaá and Thjórsá rivers, and likewise weekly trips to the Hvitá river. During these trips water level variations and water temperature were measured to obtain better knowlege of the general ice conditions, especially those of importance for water power utilization.

Observations were made of local formation and accumulation of sludge ice and of floes carried by the water. Ice quantities were measured and the properties of frazil ice and bottom ice were studied.

Observations were made of the typical formation of ice bridges at certain places, caused by dynamic compression and accumulation of sludge ice. The course of step-bursts and similar ice surges, and likewise the melting and breaking up of the ice were studied.

On all the trips mentioned, numerous photographs were taken at various places and under varying ice conditions.

On the 14 Dec. 1964, 23 Febr. 1965 and 27 March 1965 we had the oppoutunity of participating in a photogrammetric air survey, at which a continous series of stereoscopic photographs was taken of the main rivers Hvitá, Thjórsá and Tungnaá. In April 1965, round tours were arranged by helicopter to the upper parts of these rivers in order to observe the local ice conditions. During all these tours a number of ordinary photographs were also taken.

Weather conditions and precipitation

During the winter 1964-65 several periods of quite cold weather occurred, although the winter generally was a little milder than usual. A short period of cold weather came as early as in October 1964. Enduring wintry weather sat in from the middle of November and lasted until ca 20 January, interrupted only by three short periods of thaw weather, namely 18 - 22 November, 17 - 21 December and 5 - 7 January. From 20 January to 20 February there was a strong thaw. During this time the observations at Hæll met.st. show 6 five-day means of temperature from 1,5°C to 6°C, and Tangafoss met.st. had 20 days with air temperature until 5°C. March was relatively cold and in the middle of April there were 10 days with frost.

This winter were 6 pentades with mean temperature colder than -4°C observed at Hæll met.st.

In Fig. B-1^{3} are given the five-day means of air temperature and five-days sums of precipitation observed at Hæll met.st. during the winter.

The lowland along Hvitá and Thjórsá had little of snow this winter.

Run-off conditions

A survey of the run-off conditions during the winter 1964-65 at the head gauge stations in Hvitá and Thjórsá is shown in Fig. B-2. On the diagrams are the recorded five-day means of discharge at Gullfoss, Selfoss and Urridafoss recording gauges drawn with red colour.

On Fig. $B-2^{20}$ is given a graphic of daily discharge this winter in Thjórsá at Tröllkonuhlaup and Urridafoss recording gauges.

The observations show that the winter run-off has been variable both in Hvitá and Thjórsá. Through long periods the winter run-off was considerably below the normal. During periods of thaw a number of flood waves of shorter duration occurred. Greater increase of discharge was observed in February. As can be seen from the daily observations, the discharge increased in Thjórsá at Urridafoss on the 6.th and 7.th of February until 720 m^3/s, respectively 530 m^3/s at Tröllkonuhlaup.

Sub-normal low water discharge in Thjórsá was observed during the period of cold weather in the middle of October, at Tröllkonuhlaup with ca 100 $m^3/sec.$, and at Urridafoss with ca 120 $m^3/sec.$ For several days in the middle of December and in the beginning of March, the discharge was also considerably below the normal.

A survey of the run-off conditions is given graphically for Tungnaá and for the lower part of Thjórsá in Fig. $B-3^1$ and $B-2^{2o}$.

In order to give a better view of water stage variations in Thjórsá during strong periods of cold weather extracts of recorded water stage are given for certain characteristic periods, in Tungnaa at Hald and for Thjórsá at Tröllkonuhlaup and Urridafoss, see Fig. $C-3^2$.

Fig. C-3'

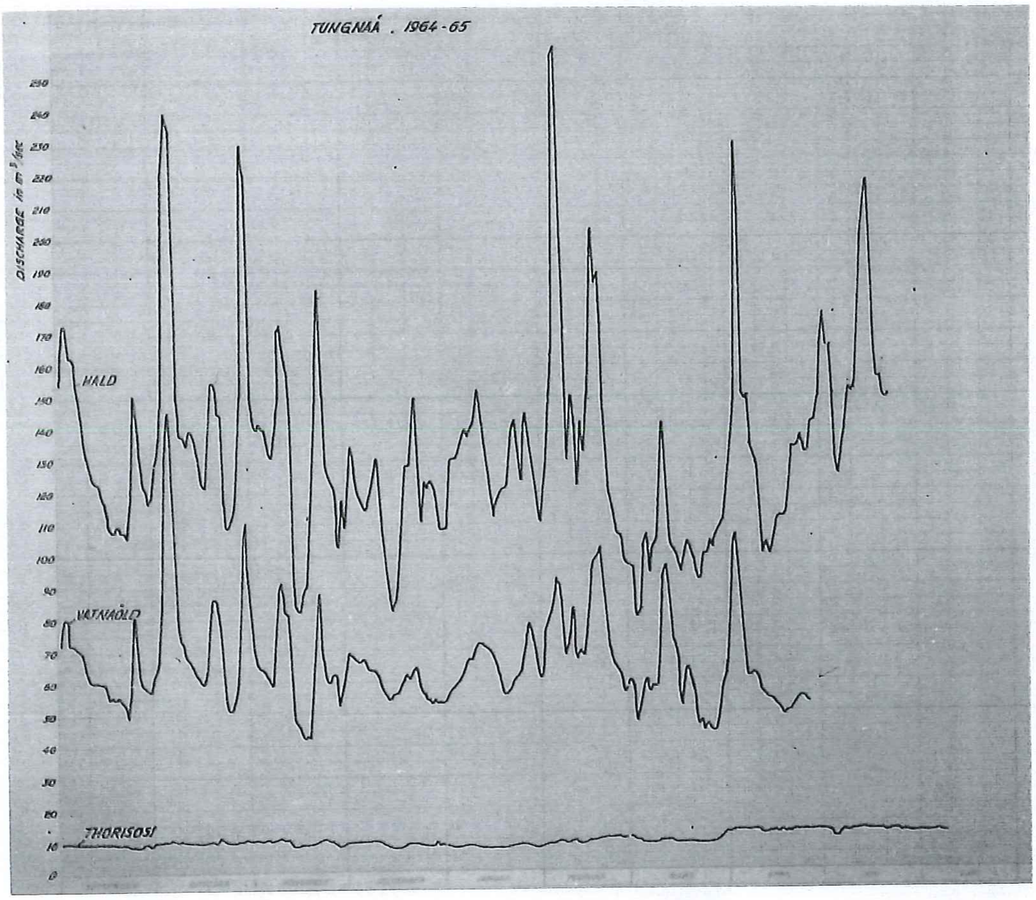
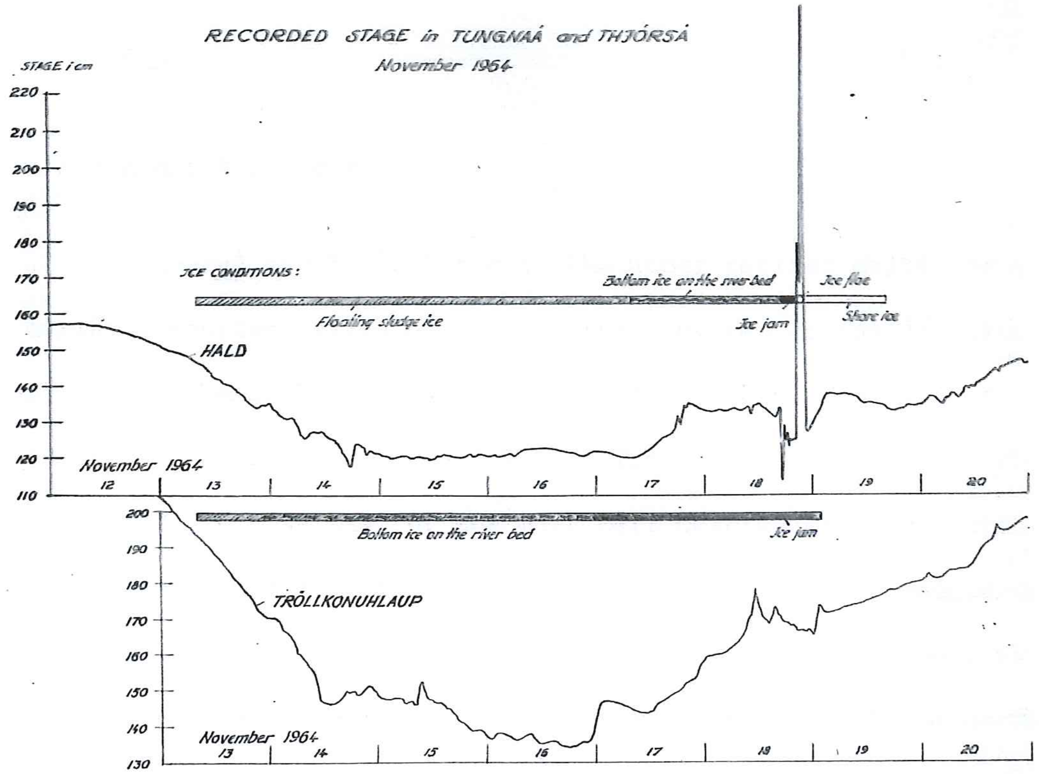
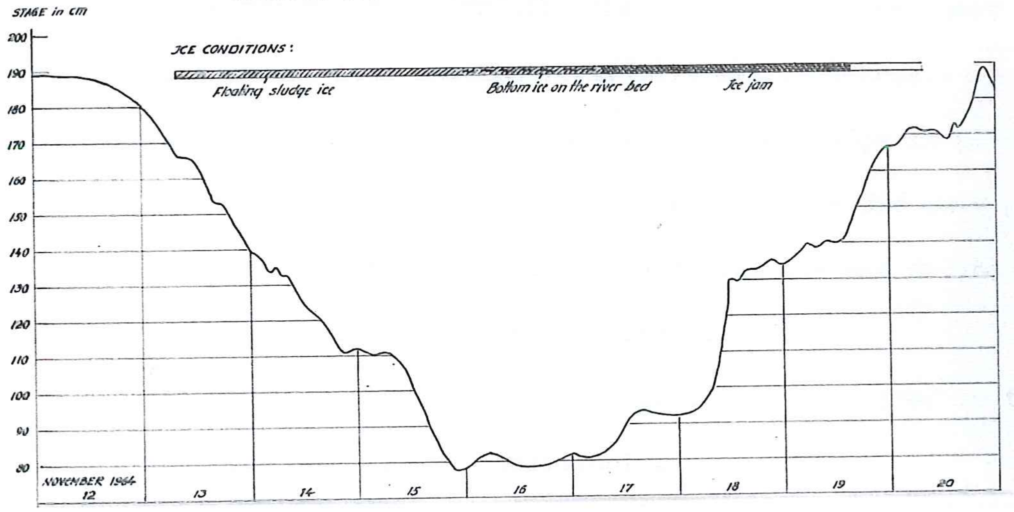
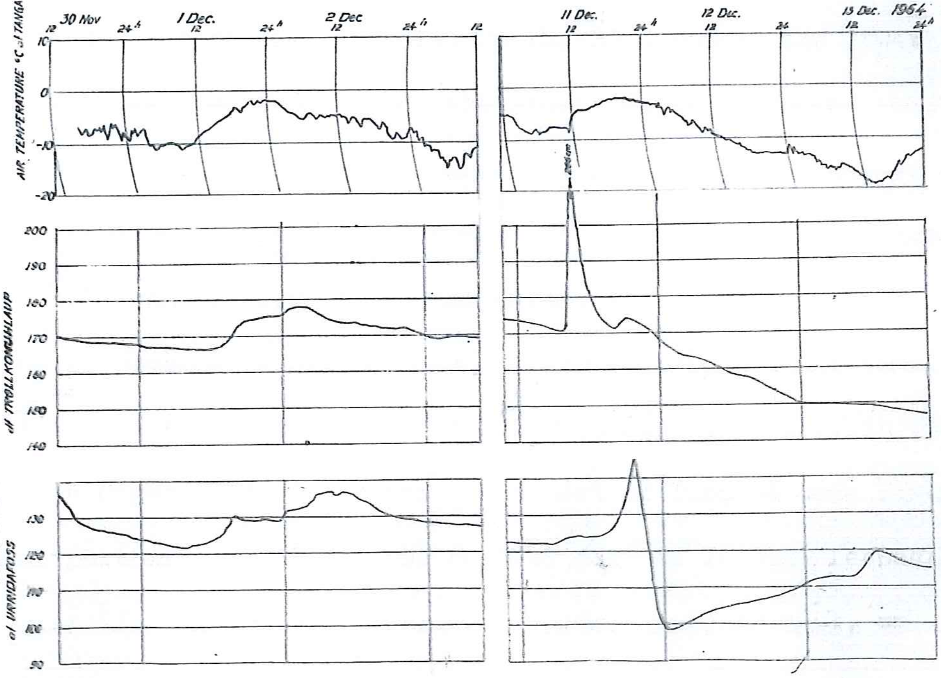

TUNGNAÁ . 1964-65
DISCHARGE in m³/sec
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
HALD
VATNAÖLD
THORISOSI

Fig. C-3^2


RECORDED STAGE in TUNGNAÁ and THJÓRSÁ November 1964


RECORDED STAGE in THJÓRSÁ at URRIÐAFOSS November 1964


RIVER STAGE at TRÖLLKONUHLAUP and URRIÐAFOSS

Ice conditions

In Tungnaá and Thjórsá and in the upper part of Hvitá the ice-formation began during a shorter period of cold weather between 21 and 25 October 1964. Lasting freezing began 12 November and in the middle of the month a very strong ice production was observed, especially in Tungnaá and Thjórsá. On the 15 November already Thjórsá was for the most part covered with ice (with local sludge ice accumulation) on the section from Hvassitangi and downwards to Thjórsárholt, at the Arnes and below Urridafoss. Tungnaá and Upper Thjórsá carried downstream great quantities of sludge ice and the sludge accumulation downwards Thjofafoss and Urridafoss increased quickly.

Sludge ice accumulation was also observed in the lower part of Upper Thjórsá, especially on the long shallow river part at Fidjaskogar. In Tungnaá ice accumulations were formed on shorter parts with ice bridge in places where the river bed is extremely narrow. The ice bridge formation did only partly stop the ice flow. The greater part of floating frazil ice was diving under the ice bridges and was carried further down the river.

In Hvitá river an accumation of sludge ice was observed on the section from the Ida bridge and upwards past Hvitarholt.

On the 17 November a change of weather (thaw) came and in a few days the ice conditions were changed quickly. On the 20 November the lower part of Hvitá and Thjórsá was open and through the mighty pack-ice masses below Thjofafoss and Urridafoss were narrow open channels formed, running between vertical ice walls. Breaking up of the ice and ice floes were observed in Tungnaá near Hald and in Hvitá from Hvitarholt and downwards.

From 22 November a strong, long period of cold weather came, and the production of ice on the open parts of the rivers started again. In the middle of December both Upper Thjórsá and the upper part of Tungnaá were covered with ice. The lower part of Tungnaá and the central part of Thjórsá (especially the ca 15 km long section from Tröllkonuhlaup upwards) were, however, open and there was an enormous ice production. Great masses of sludge were carried downwards to Thjofafoss and Urridafoss. These waterfalls were dammed down and covered with pack ice. Smaller ice floes were also observed in Tungnaá, in Thjórsá tributaries, Fosså, Sandá and Kálfa, and in the central part of Hvitá og its tributaries Fossá and Stóra Laxá.

The production of ice in Thjórsá on the lava section upstream of Tröllkonuhlaup in the period from 10 - 14 December 1964 has been calculated to be up to 25 tonns of ice per km^2, sec. In Thjórsá below Tangafoss was measured a discharge of water filled with sludge ice until 25 m^3/sek and in the central part of Thjórsá, just above Thjorsarholt was measured until 40 m^3/sec, i.e. until 3,5 mill. m^3 sludge per 24 hours. The ratio between sludge ice and water volume in the upper water flow was estimated to be 0,3 - 0,4.

Floating sludge ice taken cautiously out of the water had a density of about 0,6.

In order to achieve a better survey of the open and icecovered parts of Thjórsá and Hvitá a reconnaissance tour by plane was arranged on 14 December and a number of photographs were taken.

From 17 - 22 December there was a period of thaw, which quickly again brought changes in the ice conditions.

A third longer period of ice production began on 22 December, lasting until 20 January, interrupted only by 2 days with slight thaw. During this period Thjórsá below Burfell was for the most part ice covered, and production of sludge ice and bottom ice on this parts had decreased considerably. Upper Thjórsá was also mostly ice covered and the production of ice was restricted. The greatest quantities of floating sludge and bottom ice were produced in Tungnaá downstream Hrauneyafoss and in Thjórsá on the lava section upstream from Burfell.

The ice accumulation below Thjofafoss was measured and it was found about 12-15 mill. m^3 ice, see Fig. C-3^3: Max. ice level on the Thjórsá downwards Thjofafoss 14 January 1965.

MAX. ICE LEVEL on the THJÓRSÁ

downwards THJOFAFOSS

winter 1964-65

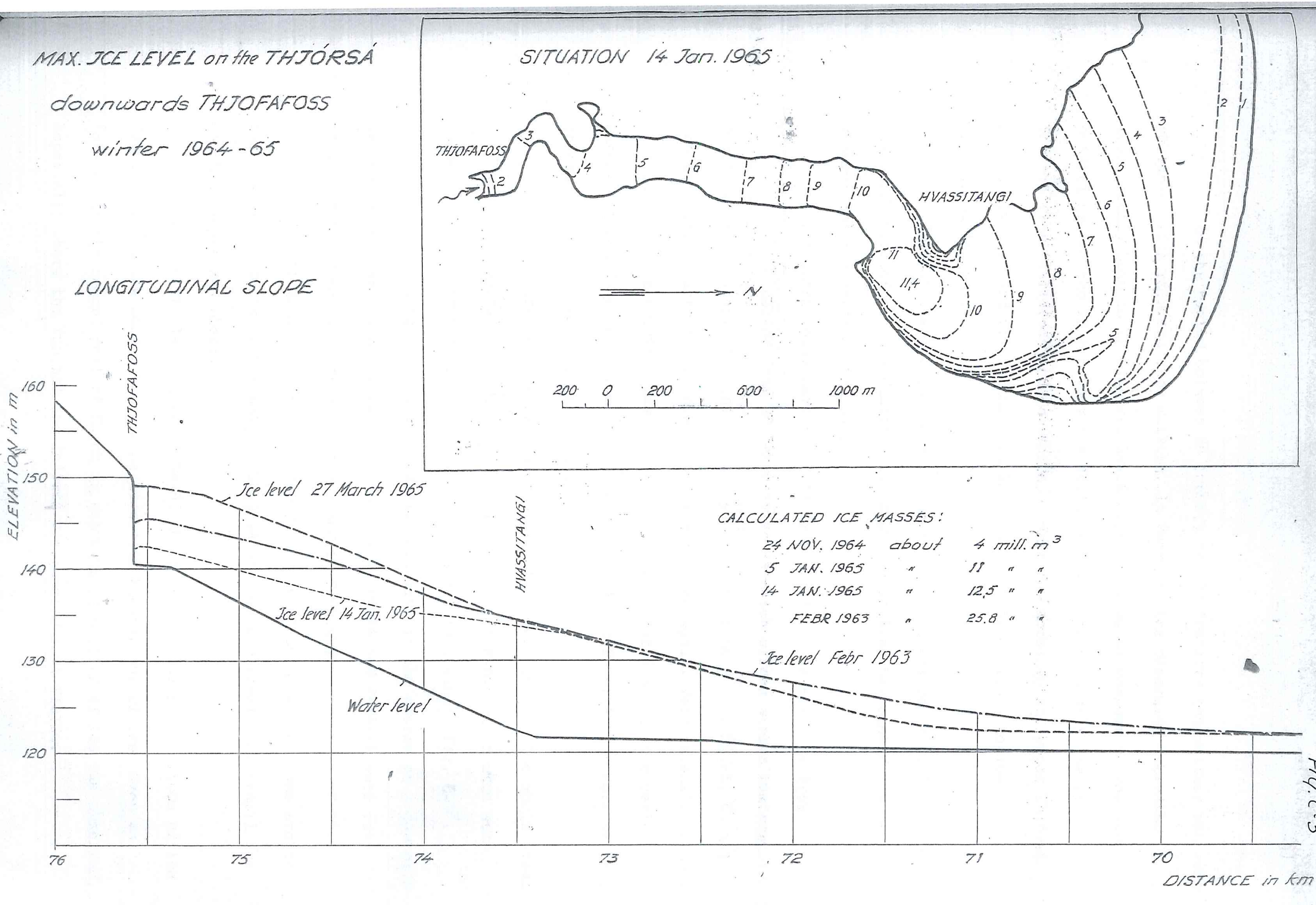


Fig. C-3³

In the period between 20 January and 20 February the weather was very variable, with rain and snow melting. In February the discharge increased considerably both in Thjórsá and Hvitá quickly bringing changes in the ice conditions. On the 20 February the following rivers were mostly ice free: Tungnaá from Fjallafoss and downwards, a distance about 40 km. Upper Thjórsá between Dynkur and Fitjaskogar (12 km), whole Thjórsá from Tangafoss to Urridafoss (80 km).

Through the ice jam below Thjofafoss on a distance of ca 5 km, and downwards Urridafoss on a distance of ca 20 km, Thjórsá had opened a wide channel between vertical ice walls.

The whole lower part of Hvitá from Gullfoss was also ice free.

In the period from 20 February to 29 March strong winter weather again occured, interrupted only by 3 days of thaw, from 8 - 11 March. On all the open river parts the production of ice started again. Very intensive sludge - or bottom ice production was observed on 3 and 6 March and in the period between 22 and 25 March. From 20 - 27 March Hvitá and Thjórsá were more or less covered as they had been in the middle of January.

On 27 March a reconnaissance of the ice-conditions on the whole areas of Thjórsá and Hvitá was undertaken by plane and continuous air photos were taken. A short survey of ice conditions of Thjórsá is given on Fig. E-3^{4}.

Ice melting took place unusually quickly. In the course of a few days in the end of March and the beginning of April, Hvitá and Thjórsá were ice free almost as they had been after the flood in February.

In the middle of April a 10 days period of cold weather came and on the open river parts in Tungnaá and Thjórsá downwards Burfell some frazil ice and bottom ice was observed.

During the last winter 1964-65 there were altogether 9 periods of ice formations and the same number of periods with breaking up of ice. Even as late as in the second part of March an enormous production of ice was observed, especially where the Tungnaá and Thjórsá are passing lava fields.

UPPER THJÓRSÁ

Surface curve and survey of
the Ice Conditions
1964-65

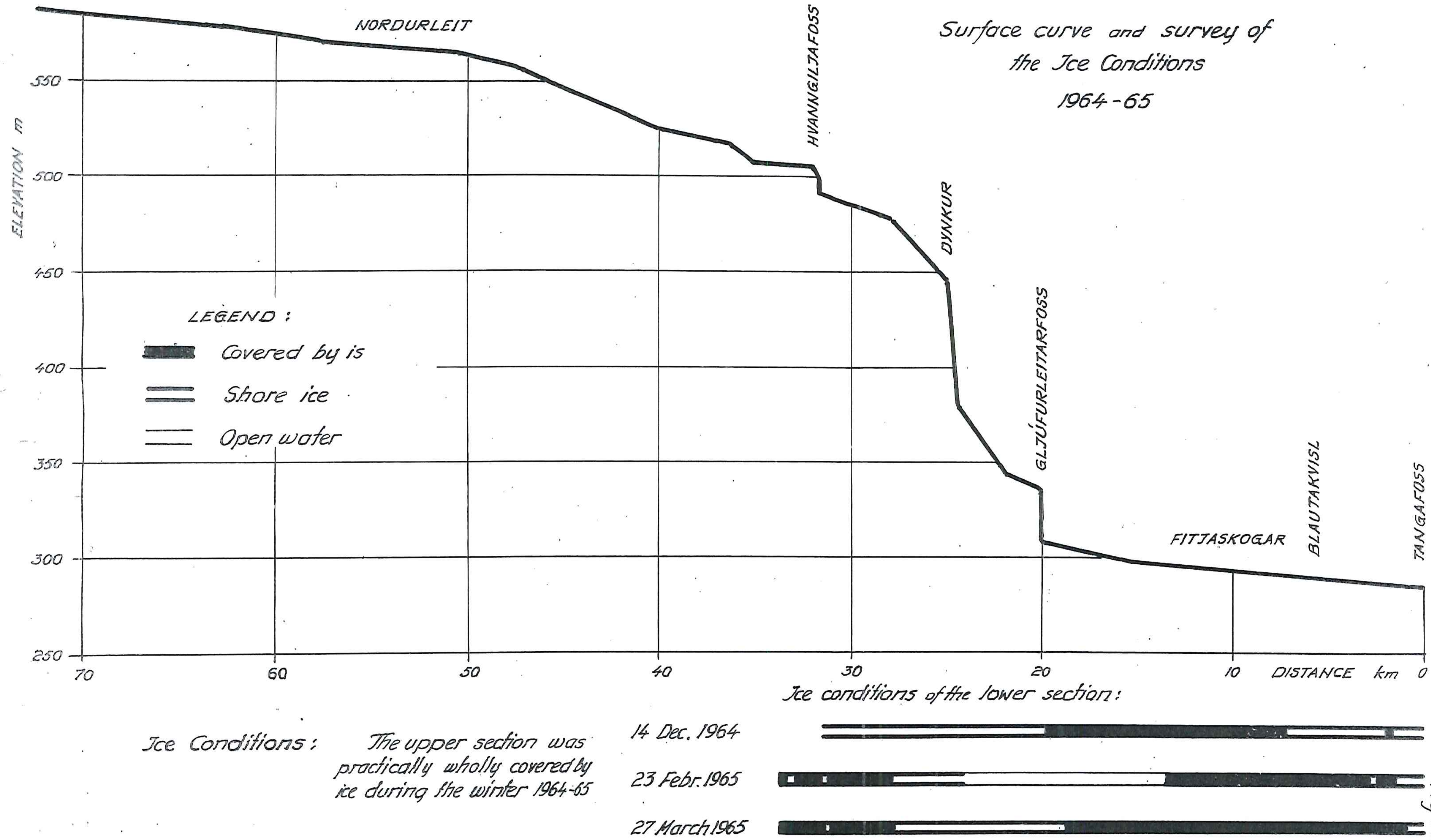
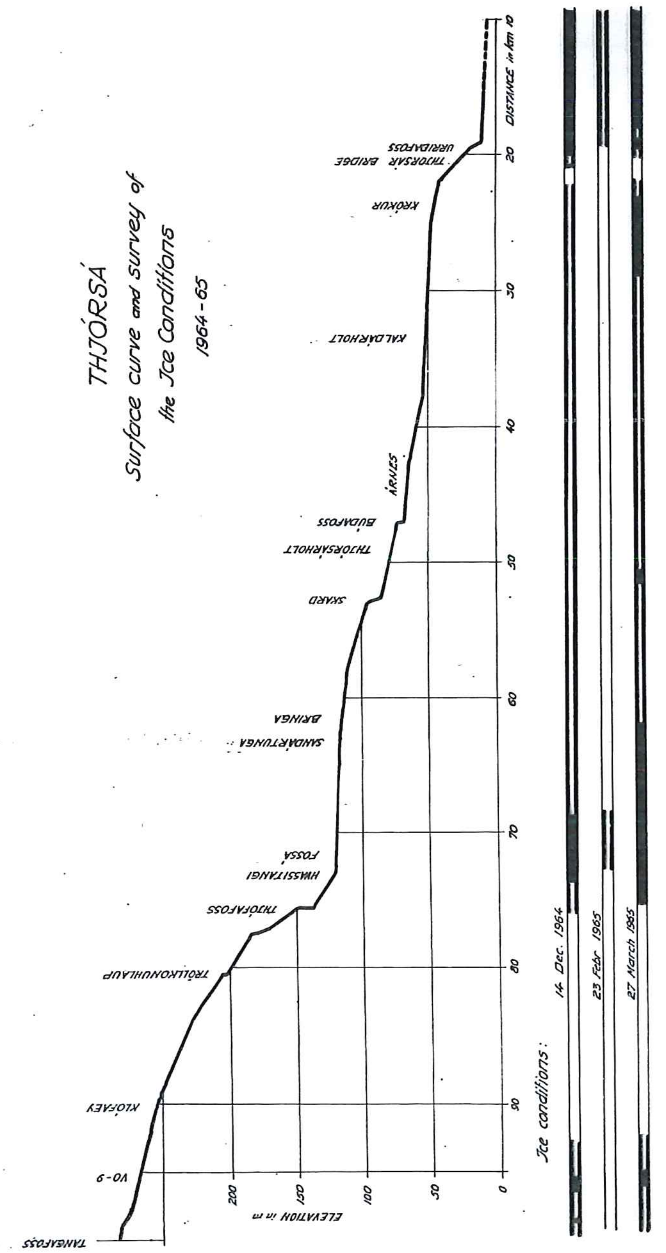


Fig. C-3⁴

9a

Cont.



THJÓRSÁ

Surface curve and survey of the Ice Conditions

1964 - 65

On Fig. C-3^5 is given a summary about quantitative studies of the production of ice in Thjórsá downwards Burfell.

A survey of ice periods in lower part of Thjórsá by regular observations is given graphically on Fig. C-3^6.

The ice conditions in Hvitá and Thjórsá may generally be characterised in the following way:

1. Both rivers have many sections which have very broad and shallow river beds, with gradients which will produce rather high water velocity and turbulent water flow. This facilitates the formation of great open water areas which will be exposed to maximum heat loss to the air and cause great ice production during cold periods.

2. During the winter both rivers have a discharge which is considerable and great enough to keep filled the major part of the river areas which did remain open during the beginning of the winter.

3. In the next sections we are going to treat how the heat budget and the ice production can be calculated from meteorological and hydrological observations. The size of calculated ice production during a cold period has been found to be in fairly good accordance with observed ice masses. The ice masses produced during cold weather are very much greater than those occurring in Scandinavian rivers, which are very different from the icelandic rivers as far as topography and winter discharge are concerned. Comparable quantities are probably rare in other northern countries as well.

4. During mild weather periods the heat transfer from the air to the great open river areas is correspondingly great, thereby increasing the water temperature, which will strongly influence the ice conditions by breaking up and melting ice masses. The great variations of the winter climate and the lack of sheltering woods make on the whole the ice regime of the icelandic rivers extremely variable.

QUANTITATIVE STUDIES of the PRODUCTION of ICE in the THJÓRSÁ at BÚRFELL, 1964-65

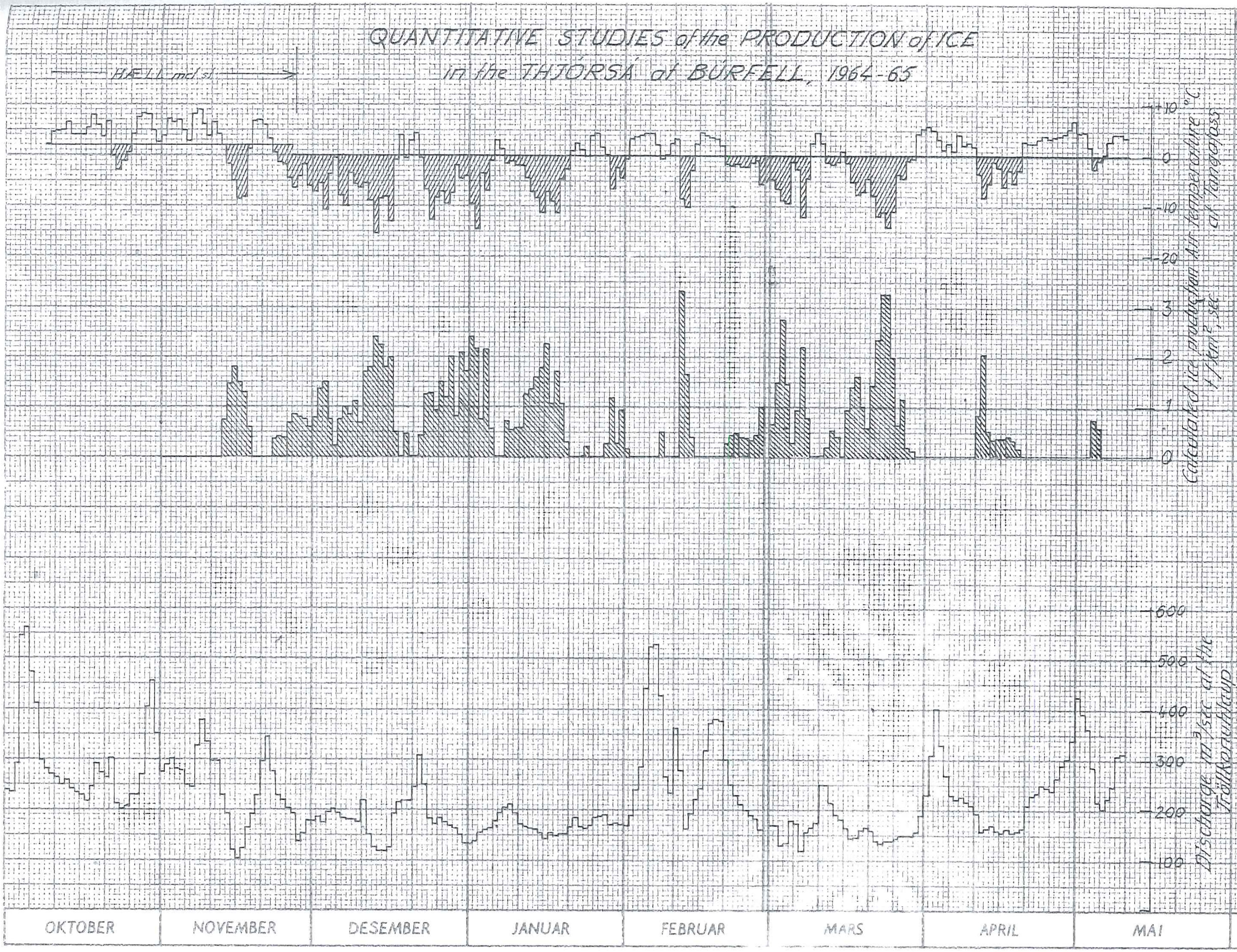
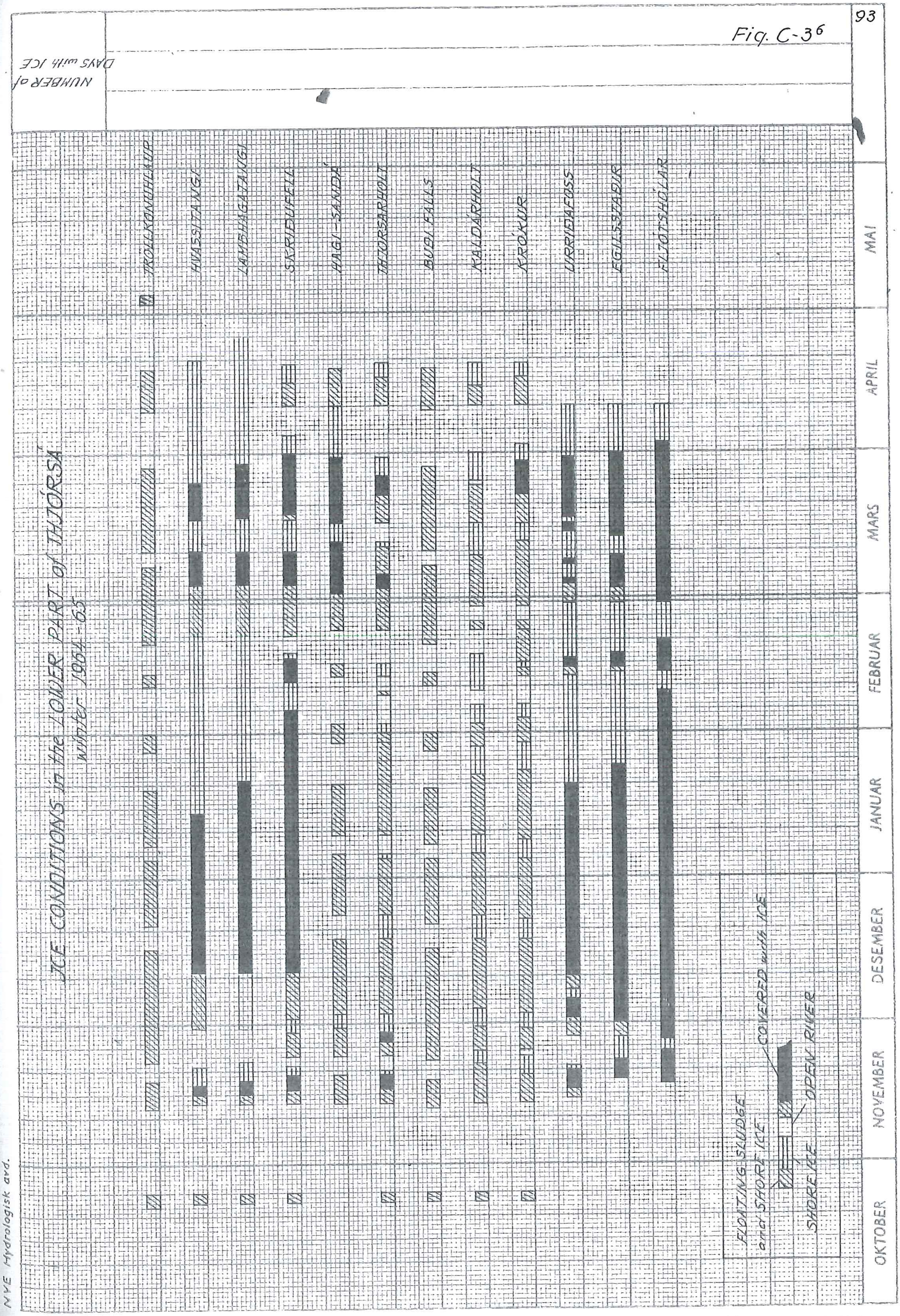


Fig. C-3⁵

Fig. C-36



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Chapter D. SHORT SURVEY of the ICE PRODUCTION in RAPID RIVERS

1. Heat loss from water surfaces. Numerical calculation

By daylight the water of a river will receive heat from direct and diffuse sun radiation (global radiation). The loss of heat is caused by outgoing long wave heat radiation from the water surface, by evaporation and by convection with the cooler air. Accordingly the greatest loss will occur during night hours. During the winter months, however, heat gain by the global radiation in the daytime will be negligible.

Additional heat may also be contributed by tributaries supplied with temperate water from thermal sources. A complete heat budjet would also contain the dynamic heating which is caused by the friction in rapids and waterfalls. When water passes a height difference of 427 m the temperature of the water would be increased by 1 °C if no other heat exchange was taking place. This contribution is, however, small in comparison with the heat losses from open water during a cold period.

Some heat will also be supplied by conduction from the material of the river bed. It is a small factor which may influence the growth and the release of bottom ice (see next section).

To calculate the heat loss from a water surface it is necessary to evaluate the different processes which contribute to the transfer of heat from the water surface to the air above the surface.

Heat loss by radiation. From a very thin film of the water surface is incessantly radiated a long wave radiation which depends upon the temperature of the water surface. From the atmosphere above is a heat radiation coming which will be absorbed in the same thin water film. This incoming heat radiation will depend upon the conditions of the atmosphere, especially upon air temperature and cloudiness. The difference between the outgoing and the incoming radiation is the heat loss by radiation, here denoted by s_1 and measured in kcal/daa, sec. = Mcal/km^2 sec.

In a paper published i 1930 [x)] Devik developed a formula giving an approximate calculation of the heat loss s_1, and similar formulae have also been published and discussed by many other authors. Taking these considerations into account, a slightly revised formula will be used here in the form

$$s_1 = 23{,}5\ (1 - 0{,}78\ n^2) + 1{,}05\ (t_w - t_a)$$

measured in kcal/daa, sec. = Mcal/km^2, sec. Here n is the cloudiness, scale 0 - 1, t_w the temperature of the water surface and t_a the air temperature.

Heat loss by evaporation. Evaporation from the surface film of the water will cause a heat loss which will a) depend upon the difference between the vapour pressure e_w at the surface itself and the vapour pressure e_a of the air, measured (as relative humidity) at normal height, and b) depend upon the wind velocity v. The influence of wind has been much discussed. Devik found that the heat loss was proportional to $(0{,}3 + v)^{0{,}5}$, partly based upon observations made by moderate wind. For evaporation by stronger wind a higher exponent than 0,5 seemed to give a better representation, according to experiments made by other scientists. To check this question special measurements were planned and performed at Tangafoss, the new observation station which is equipped with registering instruments and calorimeters of special construction for heat measurements of this type. The same question is also valid for the heat loss by convection (see p. 3 below). The measurements were analysed and the calculations performed by Mr. Sigmundur Freysteinsson.

[x)] Olaf Devik, Thermische und dynamische Bedingungen der Eisbildung in Wasserläufen, Geof. Publ. IX, No. I, 1930.

We have adoped the following revised formula for the heat loss s_2 due to evaporation:

$$s_2 = 2,25 . v_2^{0,845} (e_w - e_a)$$

measured in kcal/daa, sec. = Mcal/km², sec. Here e_w and e_a are measured in mb and v_2 gives the wind velocity in m/sec measured in 2 m height.

Heat loss by convection. The heat loss from the surface film caused by heat conduction, convection and turbulence will depend upon the temperature difference between air and water surface and the wind velocity. The influence of the wind velocity will be of the same kind as for the evaporation. The revised formula for the heat loss due to convection will be

$$s_3 = 1,4 \; v_2^{0,845} (t_w - t_a)$$

measured in kcal/daa, sec. = Mcal/km², sec.

Heat supply by global radiation. Of the direct radiation from the sun and the diffuse light from the sky a certain fraction a -- called albedo -- is reflected from the water surface, and the rest will be absorbed in the water layers. This heat supply s_4 will thus be given by

$$s_4 = G (1 - a)$$

where G denotes the global radiation from sun and sky calculated as evenly distributed over 24 hours and measured in kcal/daa, sec. = Mcal/km², sec.

If direct measurements are not available the global radiation may be calculated when date, latitude and cloudiness are given. During the winter months November - February the heat supplied by global radiation is practically negligible compared with heat loss which cause ice problems in the rivers. In the course of March the global radiation is increasing and from April onwards it becomes an important factor. The observations of global radiation at Reykjavik were used to estimate the global radiation at Tangafoss, assuming an albedo a = 0,8 for the water surface.

The total heat loss S from the water surface will thus be given by

$$S = s_1 + s_2 + s_3 - s_4$$

measured in kcal/daa, sec. = Mcal/km^2, sec.

Of special interest for the calculation of ice production in rivers is the total heat loss S_o from a water surface of 0°C. Then $t_w = 0$ and we assume for practical use that the relative humidity of the air is 75 %. In the first part A of the following table is given the heat loss by clear sky (n = 0), for different values of air temperature and wind velocity. In the second part B is given the correction for the cloudiness n (which will influence the outgoing heat radiation).

Heat loss S_o from a water surface of 0°C.

Measured in kcal/daa, sec = Mcal/km^2, sec. Relative humidity 75 %.

A. By clear sky, n = 0.

v_2 t_a =	0	-1	-5	-10	-15	-20	-25°C
1	27	30	43	57	70	82	94
5	37	46	83	124	162	197	232
10	47	64	125	195	260	321	381
15	57	79	164	261	350	434	516
20	66	95	202	324	436	543	647
25	75	110	238	383	518	645	769
30	83	125	272	431	597	745	889

t_a air temperature, °C.

v_2 wind velocity, m/sec, in 2 m height.

B

CORRECTION TABLE   N: CLOUDINESS, SCALE 0-1

N	0,1	0.2	0,3	0.4	0.5	0,6	0,7	0,8	0.9	1,0
Corr	0	-1	-2	-3	-5	-7	-9	-12	-15	-18

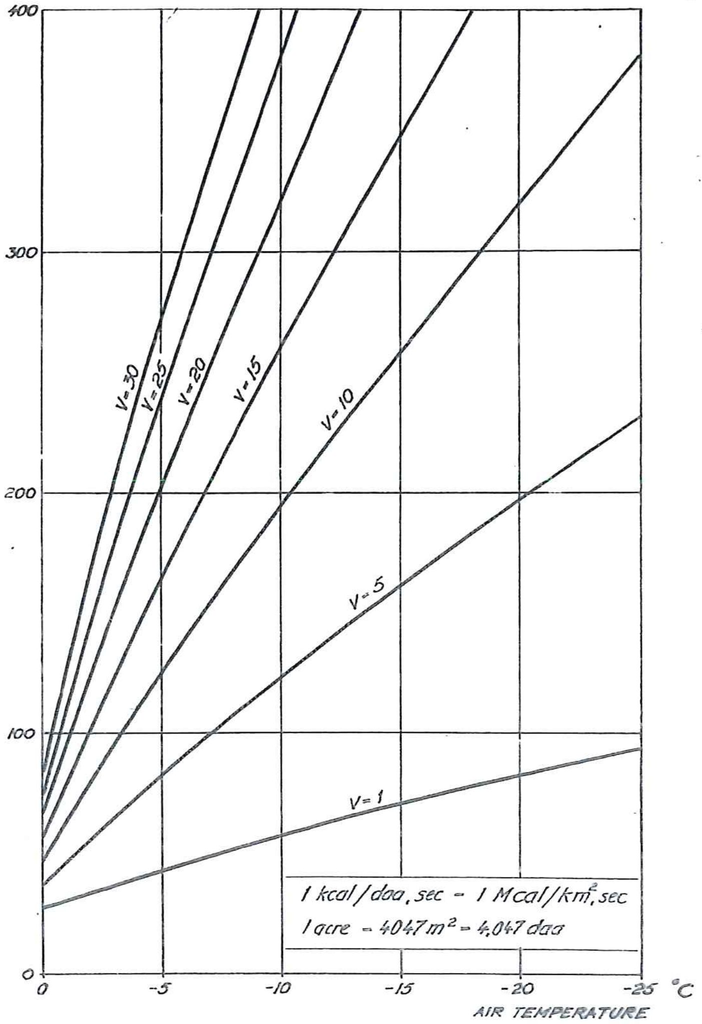
HUMIDITY -75 %   GLOBAL RADIATION -0

A convenient graphical representation of the table A. is given in Fig. D-1.

Fig. D-1

A. HEAT LOSS in kcal/daa, sec from an OPEN WATER SURFACE at 0 °C

Cloudiness N = 0 Wind velocity V m/sec in 2m height



B CORRECTION TABLE N: CLOUDINESS, SCALE 0-1

N	0,1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Corr	0	-1	-2	-3	-5	-7	-9	-12	-15	-18

HUMIDITY = 75 % GLOBAL RADIATION = 0

In the following section will be treated the types of ice which will be produced by the heat loss S_o, mainly frazile ice, sludge ice and bottom ice. The total amount of ice Q_i produced by the heat loss S_o (measured in Mcal/km^2 sec) over an open water area A (measured in km^2) will be

$$Q_i = 0{,}0125\ S_o\ A \text{ tons ice/sec}$$

Through 24 hours it will make 1080 S_o. A tons ice/24 hours. These relations will be frequently used in the following sections. The transformation of water to ice will also represent a corresponding reduction of water volume. If the ice is floating in the water as loose masses, sludge ice, the reduction of the "useful" water volume will be even greater than the meltwater of the ice.

2. Supercooling in open waters. Formation of frazil ice, sludge ice and bottom ice in turbulent rivers

The first measurements of supercooling were performed in the river Neva by Altberg about 50 years ago. By using heat radiation and registering thermopile Devik has measured supercooling to -1,4°C in still water[x]. In calm weather the freezing of an ice cover on a lake will start with a supercooling of a thin surface film where ice crystals will grow from nuclei suspended in the water. When the first coherent ice cover has been produced, the supercooling has ended, and the growth of the ice sheet on the lake will be a slow, continuous procedure, which might be called static ice production.

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[x] Olaf Devik, Supercooling and Ice Formation in Open Waters, Geof. Publ. XIII, No. 8, 1942.

In turbulent rivers the ice production is a much more complicated dynamic ice production. When the turbulent water stream has been cooled down to 0°C the heat loss from a free water surface will cause a supercooling of a very thin water film which incessantly is being renewed through the turbulent motion of the water masses. A supercooled element of the surface film will move in an irregular way through the water and may just as often sweep the bottom as be moving along the surface. On the way down the supercooling of the element will decrease and a slight supercooling of the surrounding water will result.

An individual crystal will have to start at a solid nucleus and can only grow in surrounding water when the liberated heat of crystallization can pass from the crystal wall of 0°C to adjacent water of lower temperature i.e. supercooled water. It ought to be emphasized that as long as the heat loss continues from the water surface there will be a stationary stability in the exchange of heat between the growing individual crystals and the surrounding supercooled water stream. An open turbulent stream carrying ice crystals with it will not attain exactly 0°C through the whole water mass till the heat loss from the surface has ceased.

The growth of an ice crystal will take place at the highest rate where the motion of the supercooled water is greatest, because there the actual gradient of temperature will have extreme values. The consequence is that every peak of ice structure will have tendency to grow, so that the irregularities will not be smoothed out, but on the contrary, exaggerated. Such aggregation may just as well happen to floating ice causing floating sludge, as to the formation of bottom ice which has a loose structure. This type of ice is called frazil ice.

Through the intermixing of the supercooled surface sheet with the turbulent water masses the water may be slightly supercooled from surface to bottom. By taking the precaution to keep lukewarm the bulb of a mercury thermometer (divided in 1/100°C) before inserting it in the water, supercooling of some hundredths of a degree may be measured, before the bulb gets covered by a thin ice film raising the temperature to the freezing point. The measurement of the temperature of the surface film itself can only be performed by measuring the outgoing long vave radiation.

Frazil ice may not only be floating in the surface stream. In turbulent water frazil ice may be carried with the water stream in any depth of the river. This combination of frazil ice floating in slightly supercooled water with incessantly new formed supercooled water film elements whirling down and gradually "dying" represents a most potent factor in the ice formation in rapid rivers. It may be called "active frazil ice", in contrast to frazil ice floating in water which is not supercooled and might be classified as "passive frazil ice".

A special problem is how long path a supercooled surface element may move till it has lost its supercooling. Observations of bottom ice at depths of about 20 metres and similar facts indicate that the "life path" of a supercooled surface element probably is of the order of magnitude of 20-30 metres, depending upon the intensity of the frost and the water content of potential nuclei for the formation of ice crystals.

Evidently the chance of a crystal growth will be the greatest in the surface film, and the smallest at the bottom, where the chance will depend upon the time which the moving water film element will use on its way from surface film to bottom, i.e. upon the water velocity and the depth. The formation of bottom ice will thus be more frequent at shallow sections than at deep ones.

The number of nuclei suspended in the water may be so great (sedimentation, sand storm, snow storm) that practically all crystallization will take place in the upper layers of the water. In such cases the growth of bottom ice will become reduced or cease.

The small supply of heat from the river bed and the heat produced by turbulence in the rapids will limit the growth of bottom ice at a given locality because the bottom ice consists of crystals which are exposed to buoyancy. If the heat loss from the surface decreases, the growth of bottom ice will also decrease and finally be balanced by the heat supply mentioned. By further decrease some bottom ice will be released and float up to the surface, often with inclusions of gravel and sand from the river bed. It is a well known experience that bottom ice may float up before the air temperature has risen to 0°C.

Ice crystals have a tendency to form clusters. The buoyancy will be sufficient to keep the clusters floating if the velocity of the water current is lower than a certain critical value, which will depend upon the size of the clusters. In the uppermost strata of the water stream the floating clusters will reduce the turbulence, but the clusters will long remain as a very loose structure, sludge ice, growing gradually downwards in much the same manner as bottom ice is growing upwards. This demonstrates that there is some circulation of supercooled water through the interstices of the structure. The structure has very small cohesion when floating freely in the water. Measurement of the weight of ice per unit volume is difficult to perform with accuracy, but provisional measurements have given values between 0,3 and 0,4 kg/l for floating sludge ice in Thjórsá.

In the open surface areas between the clusters turbulent motion will still be effective, producing a supercooled waterfilm, elements of which will be moving through the water as mentioned above. At river sections, however, where the clusters cover practically the whole surface, a supercooling of the water stream under the floating cover will be very small. In that case a layer of bottom ice produced formerly would cease to grow, and when the heat balance in the bottom layer were reversed, parts of the bottom ice might float up.

When the water transport is illustrated by stream lines the following consequences will appear for the relation between surface areas covered by clusters of sludge ice and open areas between:

a. Where stream lines are diverging, open surface areas will be increased. In such places the supercooling will produce conditions for bottom ice production e.g. where the river is expanding. This is easily observed where the beach line is curved.

Another important case is the water surface just in front of an obstacle placed in the stream, e.g. a stone or a pillar, and similarly for the water surface just behind the obstacle. The shallow sections of Thjórsá abundantly show how blocks of stone are growing points for bottom ice which gradually may develop a comparatively strong structure around the original obstacle, and finally produce growing islets of ice (see next section).

b. Where streamlines are converging, for instance near an obstacle, the open areas will be reduced. As long as the velocity of the water is below the critical value mentioned above the chance for bottom ice production will also be reduced. When the convergence should increase the velocity above the critical value, however, the sludge ice would be immersed in the water, leaving the surface open to the production of a supercooled water film, the elements of which would follow the converging water stream which would be sweeping along the obstacle on its way. This case is of importance when the obstacle is a pillar placed in the stream.

3. Influence of dynamic ice production on water level and discharge

From what has been said in the preceding section it will appear that measurements of ice production in early winter will present good opportunity for studying the simultaneous production of frazile ice, bottom ice and sludge ice. Om. 1.12. 1964 comprehensive measurements were made in a section of the

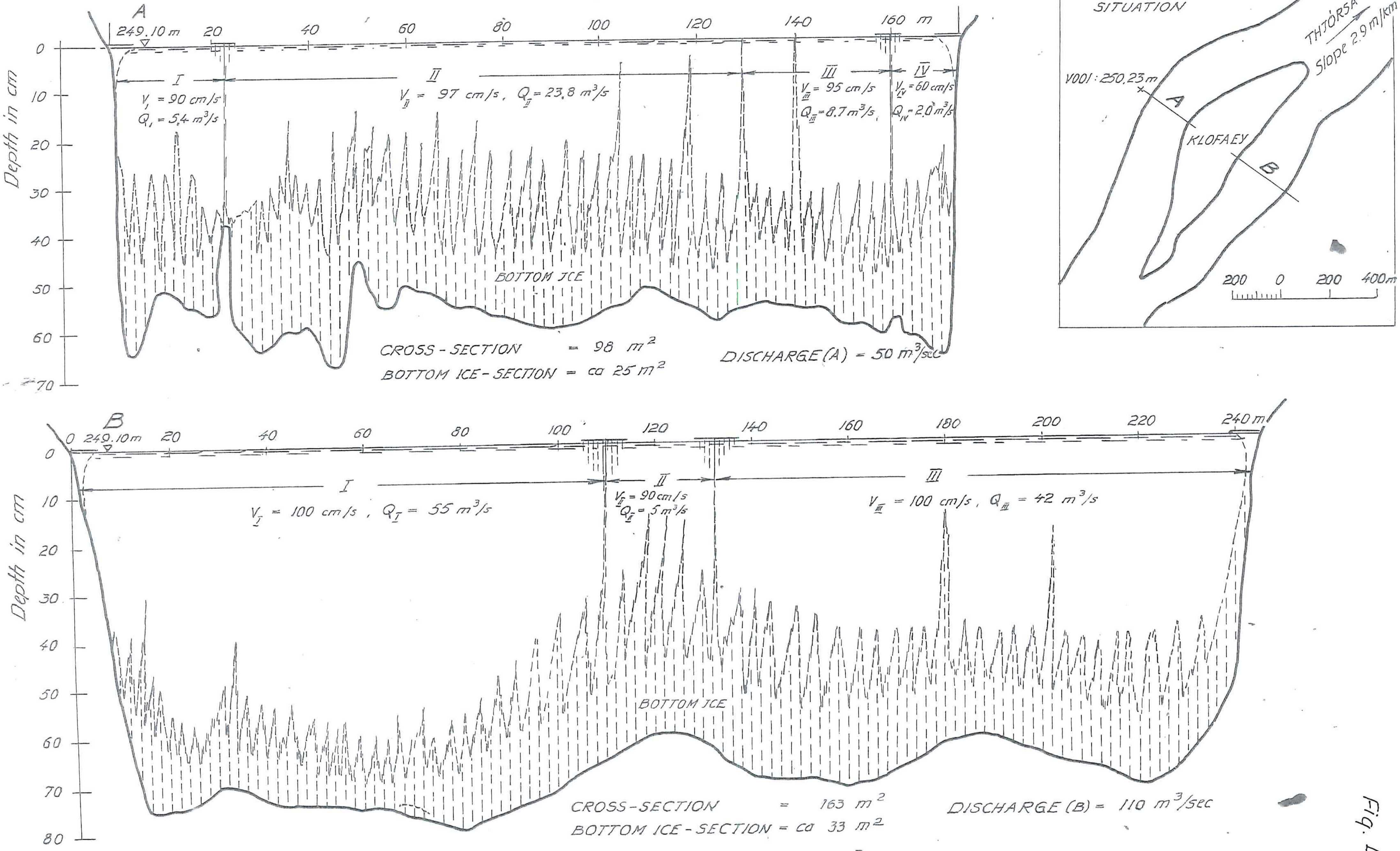
Thjórsá, crossing both branches at Klofaey, where the river bed is even and broad with the slope 2,9 m/km. The width of the eastern branch is 170 m and that of the western 240 m. At the time of the measurement the mean depth of the two branches were 0,56 m and 0,69 m, respectively. The air temperature was -10°C to -12°C and the use of current meters was handicapped by the formation of ice on the propeller after a few seconds of immersion. Sufficient current measurements were however, made in the eastern branch. In the western branch there were fewer measurements and additional observations of the surface velocity was made by using floating objects. In both branches the depth profile and the thickness of the bottom ice layer was measured.

In the Fig. D-3[1] has been reproduced the original diagram describing the ice condition within the cross section of each branch and containing data from the observations and calculation of the discharge. There are a great number of "tops" on the bottom ice layer and some of the tops even reach the surface, where isles of ice are growing. From the beach is also shore ice and bottom ice growing out in the river. (It ought to be remembered that the vertical scale unit is 100 times the horisontal scale unit.)

From the diagram of the eastern branch we find that the average depth was 0,56 m, of which the bottom ice layer occupied about 0,15 m. The water layer of thickness about 0,41 m contained immersed frazil ice and floating sludge ice which will increase the turbulent friction and cause some reduction of the water velocity ("soup is flowing slower than clean water"). It is therefore probable that the average velocity of 0,93 m/sec in the upper layer (I to IV in the diagram) is slightly lower than the velocity which ice-free water would have had by the same discharge, 55 m^3/sec. If we assume that the average velocity by ice-free water would be 0,93 m/sec or somewhat more, the average depth would be equal to or less than 0,35 m. The difference from the observed depth would be 0,21 m or somewhat more. The important conclusion will thus be :

CROSS-SECTION of BOTTOM ICE, THJÓRSÁ River at KLOFAEY

1 Dec. 1964, 12-16 o'clock
Air-temperature: -12°C



RECORDET STAGE at TRÖLLKONUHLAUP = 168 cm, DISCHARGE 166 m³/sec

Fig. D-3

1

The ice observed in the water and at the river bottom has raised the water level at least 0,21 m higher than it would have been when the river was free of ice and carried 55 m^3/sek. Of this rise of water level in the eastern branch 70-75 % is caused by the bottom ice layer, and 25-30 % by immersed frazil ice and floating sludge ice.

A rise of the water level of this order of sice will establish temporary magazines of water, and the consequences will best be demonstrated by the following example.

The Thjórsá with Tungnaá has above Thjofafoss open areas which at the beginning of the winter will be about 17 km^2 and after the first cold periods reduced to about 9 km^2. If the rise of level 0,21 m at Klofaey on the 1.12. 1964 was representative for open areas of 9 km^2 a water volume of about 1,9 mill. m^3 would temporarily be accumulated as a magazine, which would be emptied when the air temperature was rising and became positive.

During the accumulation period the discharge at Thjofafoss will be correspondingly lower than it would have been without the accumulation. In our case we do not have sufficient observations for a calculation, but the most intensive accumulation period will probably be only a part of the cold period. If we estimate 2 days, it would mean an everage accumulation of 25 m^3/sec during this time. The discharge would suffer the same reduction during the same time. It is obvious that the rise of level which has been discussed here, is of special importance for the short variations of the usable discharge.

4. Compression and solidification of sludge ice. Ice bridges and ice accumulation (pack-ice). Shear strength of accumulated pack ice. Step bursts

Sludge ice clusters floating downstream in the surface layer has a very loose structure as mentioned in the preceding section. However, when we fetch a portion of such sludge ice we can easily squeeze it to an ice ball which is quite similar to a snowball, such as we make from newly fallen and wettish snow.

Even a slight dynamic force may strengthen a loose structure of ice floating in a river. If for instance a coarse net or a series of parallel and vertical bars are placed across a shallow stream carrying frazil ice and producing supercooled water, the pressure gradient caused by the obstacle will tend to produce a more tight structure than of floating sludge ice. Immersed ice particles arriving to the structure may be caught, whereby a supercooling of the surrounding water will play an important part, and this will contribute effectively to the narrowing of the openings. The result may be that packed frazil ice may practically close the openings.

In a similar way stones on the bottom of a turbulent river will present growing points for an ice dam, the production of which is a combined effect of supercooling, crystal growth, frazil ice drift, dynamic compression and regelation. The result may be an ice dam of remarkable stability, and such a dam can in certain places raise the level considerably, for a time store great volumes of water, and thus facilitate the formation of a coherent ice cover, which will stop the supercooling as long as the ice cover is intact. This is the way in which nature itself counteracts the heat loss by reducing the open areas.

The collection of photos from Thjórsá and Tungnaá show many examples of ice dams which have been produced in the way just mentioned.

Even more impressive, however, are the photos which present the formation of ice bridges and the huge accumulation of compressed sludge ice and pack-is in certain places. The waterfalls act as giant mixmasters, producing a soup of turbulent water, a suspension of sludge and disintegrated blocks, some of them coming from shore ice and some from accumulated masses of compressed sludge ice.

The section from Thjofafoss and about 3 km further downwards to Hvassitangi presents during strong cold a dramatic illustration of how the ice content of this soup can build bridges of compressed sludge ice and accumulate huge masses of ice, the density of which will be about 0,6 -0,7 kg/l in the uppermost layer and increasing downwards to nearly 0,9 kg/l in the lowest layer.

The ice bridge which closes the water pool just at the foot of the Thjofafoss waterfall is in such a case continously rebuilt on the upper side and broken up on the lower side. Suddenly a long crack may appear between vertical ice walls which may be a couple of meters high, thus demonstrating that the solidification within the ice bridge produces a substance with a tensile strength which is by no way negligible.

> Bottom ice formation is not observed at the foot of the waterfall. The heat production through turbulence and friction will be concentrated just there, and will compensate the heat loss from the open water surface passing the waterfall. The formation of bottom ice is always due to the presence of supercooled water and is not limited by any "critical value" of water velocity. Great water velocity may on the other hand by erosion effect remove ice crystals over a certain size.

The major part of the mixture of ice and water which is leaving the Thjofafoss will pass under the ice bridge which is produced below the waterfall. The mixture will on its way downstream cause en accumulation of sludge ice and-pack ice on the broad river section between Thjofafoss and Hvassitangi. This accumulation of ice will cause the water level to rise, and the accumulation process is on the whole a variable and intensive formation and deformation of ice dams and ice bridges within the changing pattern of water streams in the broad accumulation area.

When the cold recedes and the ice production period is followed by a thaw, the water level on the accumulation site will go down and the greater part of the ice masses will be resting on the broad river bed, while the pack-ice will be broken up over the main river stream and carried away. The river will then pass through the accumulation area in a channel between vertical ice walls, which in this area may have reached a height of about 10 m during the cold period. The photos from the last winter illustrate this. The amount of ice which may be accumulated in this area has been treated in section C-3.

In the gorge of Urridafoss the accumulation of pack-ice may in many winters reach a height of 15 m and ice walls of a similar height may then occur later.

From the observations and photos mentioned above the following facts may be summarized in this way:

1) The dynamic compression of floating sludge ice which is taking place by the formation of an ice bridge gives as a result a type of ice which according to observations can exhibit vertical walls of 2-3 m height.

2) The formation of ice bridges and accumulation of pack-ice, which is taking place during a cold period of several days at such places as Thjofafoss-Hvassitangi and in the gorge of Urridafoss, may produce pack-ice layers with a thickness of 10 - 15 m. Vertical walls of a corresponding height will occur when the water level goes down after the cold period is over.

Shear strength of compressed sludge ice (pack-ice).

When an ice layer has a free vertical side (height H) this fact demonstrates that the acting forces, weight and actual stress, are in a stable equilibrium in the ice volume adjacent to the side wall.

The stability is characterised by the shear stress (s) in the plane along which a rupture will take place when the critical breaking stress (s_b) is reached. As long as the safety factor ($F = s_b/s$) is greater than 1, the ice wall will be stable. The shear stress (s) which will correspond to a given height (H) and a given density (d) of the ice layer may be calculated by applying the classical theory for earth pressure against a vertical wall[x)], with the simplification that the horisontal component in this case is zero. The stress will be

$$s = 0,5\ F\ d\ H$$

The safety factor F will be greater than 1 for a stable wall and accordingly the shear strength will be greater than 0,5 d H. In an ice layer with mean density d= 0,8 ton/m^3 the shear strength will then be greater than 0,4 H (measured in ton/m^2).

We thus find that the observed ice layers producing ice walls of a height from 2 m to 15 m will have a shear strength exceeding 0,8 ton/m^2, respectively 6 ton/m^2. Of the same order of size is the shear strength of such materials as ordinary clay (l.c. p.78).

From our observations and analysis the conclusion will be:

The formation of ice bridges and pack-ice produces a type of ice which has a shear strength comparable to that of a substance like clay.

[x)] Publication Nr. 16, Oslo 1964, from The Norwegian Geotechnical Institute, by N. Janbu, L. Bjerrum and B. Kjærnsli. Formula (5-1) p. 51.

The importance of this conclusion will be evident when we for instance consider the situation that a step burst of accumulated ice and water in the region of Hald is sweeping downstream Tungnaá and Thjórsá during a cold period. Should it happen that the floating ice masses were producing ice bridge and pack-ice filling up a shallow intake magazine, it would be extremely difficult to remove the accumulated pack-ice having a shear strength as mentioned above.

The frequency and the character of step bursts in the river sections above Tröllkonuhlaup cannot be found from daily, weekly or pentade means of descharge. It can only be found by studying the original recordings at the gauging stations Hald, Tröllkonuhlaup and, eventually, Urridafoss. Due to ice disturbances during cold periods some recordings are incomplete, but in spite of this the material demonstrates the general character of a step burst passing the river sections upside Burfell. Examples have been given in this report, see section C-3. In the observation programme for the coming winter it will be desirable to include a more detailed study of the step bursts, based upon continuous recordings at a few places and upon daily observations of water level and inspections of ice conditions at chosen river sections.

Chapter E. PRACTICAL ICE PROBLEMS at POWER PLANTS

1. Present experience on ice problems connected with the utilization of water power in Norway

The geological structure of the mountainous country of Norway is very different from that of Iceland, where the underground water represents an important storage of the precipitation. Norway has a great number of lakes which under natural conditions represent a considerable storage during the seasons when the precipitation is falling as rain. During the winter season, however, the precipitation over the mountainous country will predominantly be snow, and as a consequence the specific discharge will generally show a great decrease during the winter till the snow melting begins.

The use of natural lakes or artifical storage reservoirs will therefore be an essential part of a development scheme for water power plants in Norway, in order to secure a stable power production during the winter season.

The improved methods of tunnelling has made it possibly in many cases to assemble the discharge from great mountain areas into a single or a few storage reservoirs ("roof-gutter projects") for the power plants. In Norway the rock material is generally suitable for a wide use of tunnels.

The regulation of rivers and lakes and the building of reservoirs will in most cases not only change the natural conditions of the water courses, but also create different winter-problems for the power plants themselves. It will also have to be taken into account that the winter climate of Norway is variable. Eastern Norway generally has a rather continental winter climate with occasional advances of maritime and mild air. Western Norway, and even more Northern Norway, however, lie open to the frequent successions of warm and cold fronts bringing precipitation and changes of temperature with them.

In the appendix to this report is enclosed a reprint of a paper published in 1964[x)] dealing with Norwegian experience which is reviewed on the basis of our present knowledge of the factors which are desisive for the ice production in lakes and rivers. The text and the illustrations demonstrate an application of the same physical analysis which has been treated in this report, chapter D, on the production of ice in rivers with a turbulent flow.

The crucial point is the supercooling of a thin water film of an open water surface which is exposed to heat loss to the air during cold weather. There will always be a sufficient number of solid nuclei which become growing points for ice crystals, some of them floating in the stream as frazil ice, and others growing on the river bed as bottom ice, in certain localities producing ice dams by the combined action of supercooled water, frazil ice and bottom ice. Where the slope is steep and irregular, the river bed may be nearly full up with frazil ice and pack-ice, some times moving slowly a little way and then stopping again.

Based upon the observations of supercooling and the formation of frazil ice and bottom ice, it was assumed that the "life path" of a supercooled surface element may be of the order of 20-30 metres. If that is so, there will exist a critical area of say 30-40 metres width in front of any solid construction which is placed in a turbulent river. It may be considered as an empirical fact that ice troubles at the intake and at the trash racks of a power plant are above all caused by the mixture of supercooled water and immersed frazil ice, a combination which might be labelled "active frazil ice".

Here may be mentioned a case from early december 1959, when a great number of power plants in Norway suffered from ice troubles at the intakes, caused by strong cold and strong wind lasting for several days. The plant

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[x)] Olaf Devik, Present experience on ice problems connected with the utilization of water power in Norway, Journal of hydraulic research, vol. 2, no.1, 1964.

Rössaaga (180 Mw) had electric heating of the racks in use, nevertheless, however, the racks were completely clogged by bottom ice and frazil ice. On that occasion the broad and shallow intake reservoir was still open and exposed to low air temperature and to a persistent strong wind blowing in the direction of the intake channel, against the intake itself.

To prevent a repitition of such a situation the following precautions were established in accordance with proposals made by the authors of this report.

The inlet channel has been covered over with a big roof (900 m^2) to prevent cooling of the water surface by outgoing radiation, and in addition the water surface can be heated indirectly by long-wave radiation from a great number of electric heat elements. The heat loss by convection and evaporation might thus be compensated by directing the radiation to the surface film where the heat would be absorbed. The electric heating of the racks would be available as an additional reserve. To prevent the accumulation of floating ice a floating screen with coarse wooden bars has been installed at the entrance to the roofed-in section. Later on the shelter has been extended to protect both the racks and the rest of the open intake. During the recent winters (which have not had abnormally cold periods) the water surface under the roof has been free of ice.

For a new plant such measures may be avoided if the dimensions of the intake channel are adjusted to a water velocity not exceeding 0,6 m/sec. In this case the formation of an ice cover may be achieved within a short time, eventually by using a floating boom in front of the intake to obtain a skimming of the frazil ice. The aim will be to exclude a persistent production of supercooled water within the critical area in front of the intake, and also to prevent floating sludge ice and pack-ice from reaching the adjacent parts of the intake reservoir.

It is a common experience at many Norwegian power plants that the worst ice troubles will disappear as soon as the intake reservoir has been covered by ice.

In some cases it has been necessary to place a dam across a rapid, thus obtaining only a small intake reservoir, which soon would be filled when sludge ice and pack-ice were produced in great quantities on the river section upstream the intake dam. The dam has in such cases been constructed in a way which should make it possible to pass the floating ice masses over the weir. However, during strong cold the inevitable production of active frazil ice altered the water flow, produced bottom ice on the trash racks, the arriving ice masses blocked the movable weir constructions, and as a result the power production of the plant was reduced.

To prevent this, the remedy might be to reduce the production of ice in the river section upstream the intake dam by erecting a number of permanent threshold dams on the river section. Such dams would be able to withhold considerable quantities of floating frazil ice and ice floes, and the reduction of the water velocity would facilitate the production of an ice cover growing upstream. Experiments which are being performed in a norwegian river indicate that such threshold dams may be of a simple and permeable construction which can act as the reinforcement of an ice dam which grows up during cold weather by the production of bottom ice and frazil ice. Such a construction might be a sort of framework or a barricade of stones or concrete blocks. During cold periods the ice dams would grow up, and during thaw periods the ice content in the dam structure would melt on the spot, without being broken up and carried downstream. The experiments mentioned are promising.

The regulation of lakes and rivers in Norway will generally increase the winter flow which may be comparable with the summer flow. The discharge from a power plant will in several cases have to pass river sections which are exposed to rather intensive ice production. In such cases the ice production on the river section has been increased compared with the ice conditions under natural conditions. More important, however, is the great influence on the ice conditions which is caused by the daily and weekly variations of the discharge, due to the variations of the power production. On some river sections special ice-patrols must regularly inspect the production of ice dams and pack-ice accumulation and if necessary blow up ice dams, in order to avoid flooding of the adjacent ground.

With reference to icelandic rivers with rather great winter flow, the facts just mentioned indicate that similar natural variations (of comparatively short duration) in the water flow will make the ice conditions considerably worse.

2. Experiences from other countries.

During the preparation of this report one of us (Devik) had the opportunity of taking part in the XIth Congress of The International Association for Hydraulic Research, in Leningrad 5-11 September 1965. In one of the Seminars ice problems were discussed, which proved to be of central interest to scientists and hydraulic experts from USSR and from Canada. We know from a great number of Russian publications (which Kanavin has studied) that Siberian rivers in general present similar ice problems to the power plants as we know from Norwegian rivers, although as a rule on a bigger scale. However, some of the plants are on a moderate scale, where the technical solutions are of special interest to us. In the Seminar and during the excursions to research institutes Devik met leading Russian experts and could state that the Russian approach to the practical solution of ice problems was in full accordance with the analysis which has been demonstrated in this report.

It is a guiding claim to plants exposed to frazil ice and sludge ice coming from rivers sections upstream that supercooled water and active frazil ice must not enter the intake. Precautions are therefore taken in order to facilitate the production of an ice cover on those parts of the intake surface which can not otherwise be sheltered, e.g. by making the constructions spacious enough to keep the water velocity below the critical value, respectively by using floating beams to accelerate the ice cover formation.

In Leningrad is also a refrigeration laboratory where supercooling and the production of frazil ice and pack-ice at low air temperature has been studied experimentally during many years, and these studies have now attracted renewed interest. In the Seminar a report on similar studies in Norway was given by H. Berge (River and Harbour Research Laboratory, Trondheim).

Canadian scientists (B.Michel a.o.) presented in the Seminar studies of the forces exerted on constructions by accumulated ice. From Lasalle Hydraulic Laboratory, Quebec, was presented (by film) model studies of ice accumulation (E.Pariset and A.Gagnon).To simulate floating ice granulated plast was used. The same material is used at the model studies which are being made, relating to the Burfell project, at the River and Harbour Research Laboratory, Trondheim (H.Berge).

Such model studies with a passive material as granulated plast may give valuable information of the type of accumulation which is the combined result of buoyance and water velocity. The resemblance between accumulated carpets of granulated plast and the ice bridges which are observed in rivers is apparent. The drawback is, however, that a carpet of floating plast grains has no shear strength. Such experiments with granulated plast cannot fully simulate the effect of supercooled water combined with sludge ice,nor fully demonstrate the compression of sludge ice which produces ice bridges with a considerable shear strength (see Chapter D-4).

Another interesting contribution was made by a canadian expert (B.G. Bryce) who described a floating beam across the broad and deep river upside the weir above the Niagara falls. Logs were carried by strong steel cables which were anchored at a series of points across the river. The experiment was performed last winter and although the water velocity was too great to allow the formation of an ice cover under ordinary conditions, the beam caused the formation of a pack-ice cover, starting from the beam and growing upstream. In this way the supercooling was eliminated on the covered area, and the water flow under the ice transported passive drifting ice downstream. From our point of view the success of this experiment was due to the shear strength of the ice carpet which was produced from the beam upwards, by dynamic compression and accumulation of sludge ice and pack-ice floating in the river. The experience from this experiment may evidently have a useful application in Icelands rivers as well.

3. Practical ice problems connected with the water resources development of the Thjórsá and Hvítá rivers.

Evaluation of the actual discharge.

For the development scheme a thorough knowledge of the usable discharge at a given place will be necessary, and the relevant observation material from previous years will have to be used in order to prognosticate the discharge variations which are probable for the years to come.

We consider first the Thjórsá material, which consist of direct water level observations, water level recordings and direct measurements by current meter observations. The measurements will during the winter be influenced by the local ice conditions, and the relevant correction ("ice correction") must be applied to find the "reduced discharge" which generally is supposed to correspond to the rating curve, giving the discharge at different water level under ice-free conditions. The order of size of such ice corrections will be different at different observation places, and as an example we will here consider the recording station at Tröllkonuhlaup. The river is here about 100 m wide, and the so-called "determining profile" is a cross section downwards at a similar distance, where the river is flowing over an underwater threshold, which is near the surface in the middle of the river. Bottom ice may be formed on this part of the threshold and grow up to an isle of ice (see photos). The water level which is then recorded would correspond to a discharge too high, if the rating curve were used directly. The correction might be found by direct measurements of the discharge at a suitable place without bottom ice. A similar correction would be caused by shore ice between the station and the determining profile, and even more if some part of the river here should be covered by ice. It is, however, fortunate that the corrections mentioned above are generally rather small at this station and they may in most cases be estimated with sufficient accuracy. The basis for such estimation will be the study of the recordings under varying conditions, with due consideration of the control measurements of discharge. Ice corrections at Tröllkonuhlaup will generally be less than 5 cm. A correction of 5 cm would according to the rating curve mean a reduction which at 150 m^3/s nominal discharge would give a reduced discharge of 140 m^3/s.

It should here be noticed that when the river carries much frazil ice, this will increase the internal friction of the water flow and cause some increase of the water level. This influence will be included by using the estimation method mentioned above, in other cases, however, a "frazil ice correction" would have to be considered.

> In a paper published in 1938[x)] this effect has been studied and formulae have been deduced allowing a calculation of water level when frazil ice is present. It would be desirable to investigate this effect experimentally at a suitable place in an Icelandic river.

Occasionally the recordings at Tröllkonuhlaup show the passage of a step burst which may raise the water level to an extraordinary heigth for a short time. The water volume and the ice masses passing the station by a step burst may be estimated by means of the recorded curve.

The release of such step bursts will mainly take place in Tungnaá in the region where the Hald recording station is situated. The recording material here demonstrate great variations of water level due to the formation of ice bridges and pack-ice accumulation. During the winter 1964-65 supplementary observations are available from the Tangafoss observation station.

[x)] Olaf Devik, Über Wasserstandsänderung eines Flusses bei Eisbildung, auf Götaälv angewandt. VI Baltische Hydrologische Konferenz, Berlin 1938.

The examination of the present material from Hald and Tröllkonuhlaup has demonstrated that it undoubtedly will be rational to give the eliminitation of such step bursts a high priority within the development scheme.

It has to be mentioned that the recordings at distant stations have occasionally suffered from disruptions caused by ice formation, e.g. in the well. Improvements have been made and will be continued. The recordings now available from the stations at Urridafoss and Tröllkonuhlaup may at any rate be used primarily to study the actual variations of the discharge and secondly to study the dependence on the changes of air temperature.

Correspondence of air temperature at Hæll and Tangafoss.

From the winter 1964-65 temperature recordings exist at Hæll continuously from 8.10.64 and at Tangafoss in the period from 26.11.64 to 16.5.65. A study (by Sigmundur Freysteinsson) of the recordings for the period 26.11.64 - 30.4.65 showed that there is a good accordance between the daily mean temperature at Hæll, t_H, and that of Tangafoss, t_T, for temperatures below 3°C:

$$t_T = -2,32 + 1,035\ t_H$$

For temperatures at Hæll between zero and -10°C the corresponding temperature at Tangafoss will be found by using a correction of -2,5°C. It is a greater difference than the "normal" temperature gradient would give, and this fact is evidently caused by the production of cold air floating down the valleys from the snow-covered mountains, as mentioned in Chapter B.

The temperature recordings from the two stations show that the two curves are practically like. At strong cold and strong wind the temperature at Tangafoss may be somewhat lower than it should be expected and in this case the difference is of special interest for a detailed study. However, the comparison of the records show that it will be quite possible to use the temperature observations at Hæll in previous years to represent with good approximation the corresponding temperature at Tangafoss by applying the following table:

Observed temperature at Hæll:	+ 3	0	-5	-10	-15	-20 °C
Temperature difference :	-2,2	-2,3	-2,5	-2,7	-2,8	-3,0
Calculated temperature at Tangafoss :	+0,8	-2,3	-7,5	-12,7	-17,8	-23,0

The meteorological observations at Tangafoss may be considered as fairly representative for a great part of the Thjórsá and the Tungnaa districts upside Burfell, and likewise the observations at Hæll may be considered as fairly representative for the Thjórsá district between Burfell and Urridafoss. We know the correspondence between the air temperatures at the two stations. On the other side, however, the correspondence between the wind observations and the wind recordings at Hæll and Tangafoss from the winter 1964-65 have not yet been studied statistically. The wind recordings during the coming winter will present a good material for such a study.

Air temperature variations compared with the variations of discharge.

It is a well known fact that the discharge in Thjórsá goes down when a period of frost comes, and that the discharge goes up again when the frost period is over. To examine this correspondence we have compared the temperature curves for Tangafoss with the water level recordings at Tröllkonuhlaup. Placing the corresponding diagrams above each other, we can follow the two curves day by day and observe how very close the correspondence is between frost periods and periods of discharge reduction, and how the following increase of air temperature is related to the increase of discharge. In many cases it will be possible to estimate how much the water level has been reduced during the reduction period which corresponds to the frost period, and accordingly to find the corresponding reduction of the discharge. From this we calculate the volume of water which has been stored temporarily on the river sections in Thjórsá (and Tungnaá)above Tröllkonuhlaup, partly as ice and partly as water, which may be released during a following thaw. In such a case that the release is taking place simultaneously with a rainfall it may be difficult to separate the two components of the discharge increase.

As an illustration two examples are given here, 22 - 25 October 1964 and 14 - 18 November 1964.

From the frost period 22 - 25 October 1964 we have temperature recordings at Hæll which by a correction (-2,5°C) also represent the temperature curve at Tangafoss. From the area of the curve under the zero line is found the total of negative degree-hours, which during the frost period (78 hours) was - 350 degree-hours. The mean temperature during this period was accordingly - 350/78 = - 4,5°C.

From the Tröllkonuhlaup diagram is estimated that the discharge was reduced from ca 230 m^3/s to ca 205 m^3/s through a reduction period of ca 70 hours, whereby a water volume of about 6,2 mill. m^3 had been withheld temporarily on the river sections above Tröllkonuhlaup.

We consider next the frost period 14 - 18 November 1964 and compare the temperature curve recorded at Tangafoss with the water level recordings at Tröllkonuhlaup. During 118 hours the amount of negative degree-hours were about - 930 degree-hours, correspeonding to a mean temperature of -9,3°C. At Tröllkonuhlaup the reduction period was also about 118 hours, and the discharge went down from about 176 m^3/s to a minimum of about 100 m^3/s, whereby a water volume of ca 18 mill. m^3 was temporarily withheld in the river sections above Tröllkonuhlaup.

For simplification we here assume that the total heat loss is approximately proportional to the total of negative degree-hours and to the total size of the open areas. If we further assume that the open area of the river is the same during the two frost periods here considered, the ratio 350/930 = 0,38 will represent the relation between the total heat losses.

The relation between the amounts of withheld water is in our two cases $6,2\ 10^6 / 18.10^6 = 0,34$, i.e. practically the same relation, which means that we may use the temperature curves to estimate fairly well the amounts of withheld water in the two periods we have treated here. For later periods the total heat losses must be corrected for the reduction of the open areas.

The study of the temperature recordings at Tangafoss and the water level recordings at Tröllkonuhlaup lead to important conclusions:

1. The reduction of discharge during periods of frost is mainly due to ice production and to loss of water which is being withheld temporarily in sections above Tröllkonuhlaup. Reduction of the open areas of the river reduces this effect proportionately.

2. Knowledge of the reduced discharge during frost periods is necessary to the planning of the power production. It appears to be rational to single out the frost periods and study the connection with the corresponding recordings of water level. Such analysis might be used on the recordings at Urridafoss and Tröllkonuhlaup, compared with representative temperature data deduced from the observations at Hæll.

Conclusions.

The rivers Tungnaå and Thjórså are extremely sensible to the variations of the heat exchange between river surface and the air, especially to the influence of air temperature and wind.

The discharge is affected during periods of thaw through precipitation falling as rain in the drainage area. During frost periods the intensive ice production and the formation of local ice dams will cause temporary local increase of the water level. Thereby considerable water masses can be withheld and cause a corresponding reduction of the discharge further down in the river, lasting during the frost period. The only positive precaution to reduce this effect will be to reduce the open areas, which are the sources of ice production.

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

The analysis of the different ice problems given in our report is pointing to the possibilities which exist when we want to establish a control of the ice production. The possibilities are:

to reduce effectively the open areas,
to establish reservoirs which can store floating ice, prevent step bursts and prevent the formation of ice bridges at critical places,
to secure slow water flow and promote the formation of an ice cover at the intake of a power plant.

To illustrate the application in Tungnaå and Thjórså of such points of view will here be presented two sketches, which contain the necessary labels describing how the ice conditions will be controlled by the constructions which are indicated.

One sketch Fig. E-3^1 is illustrating the possibility of reducing the ice production and eliminating step bursts in the near region above the confluence of Tungnaå and Thjórså. The second sketch Fig. E-3^2 is illustrating the possibility of reducing the ice trouble in front of an intake which is chosen at Klofaey.

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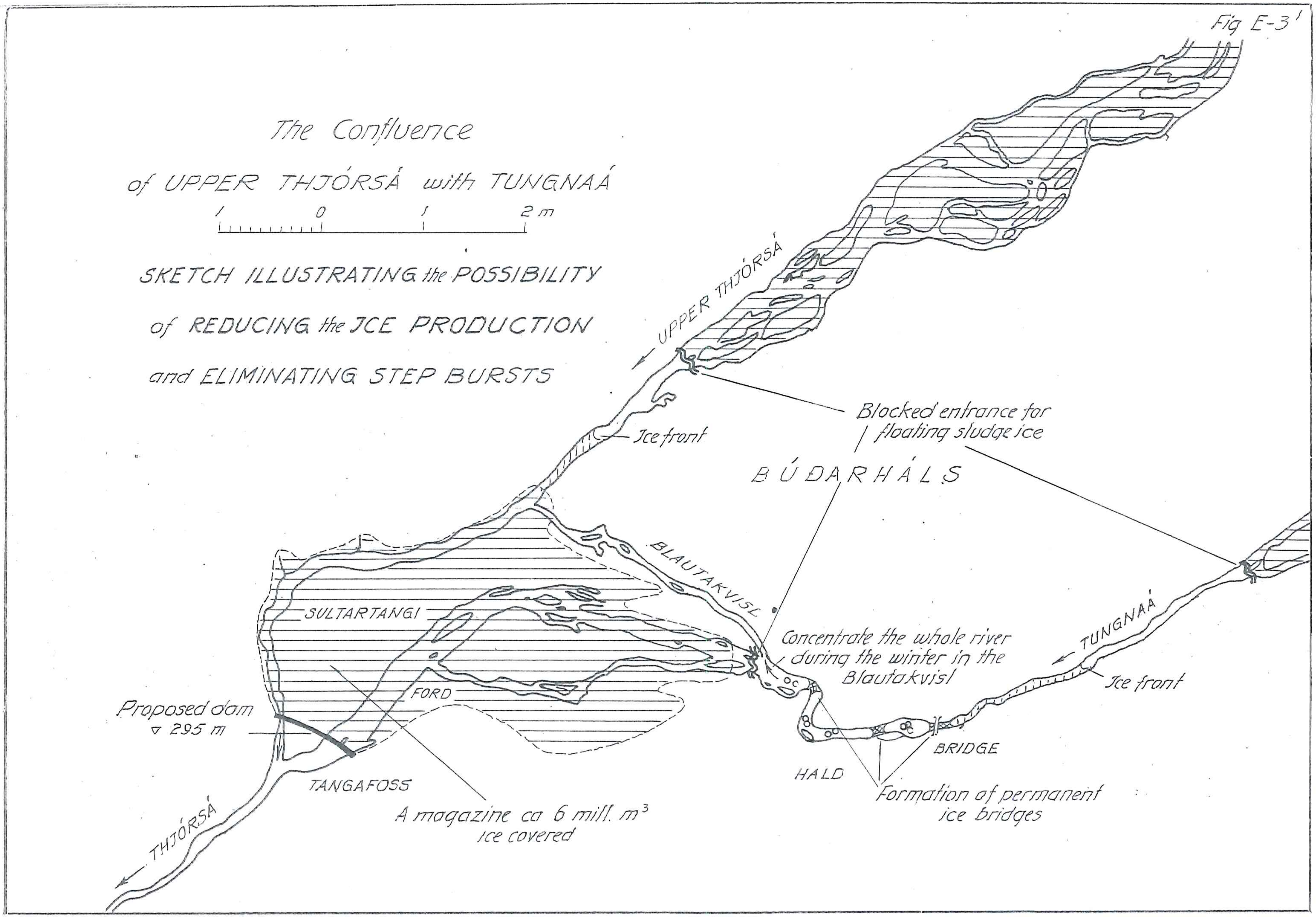
Hvitå.

In the Hvitå river the sections above Gullfoss present similar ice problems as those which have been treated for Thjórså and Tungnaå in this report, and similar precautions may be taken in order to obtain the necessary control of the ice production. The lower part of Hvitå has different hydrological conditions and a separate survey will be needed before conclusions are made, as far as ice problems are concerned.

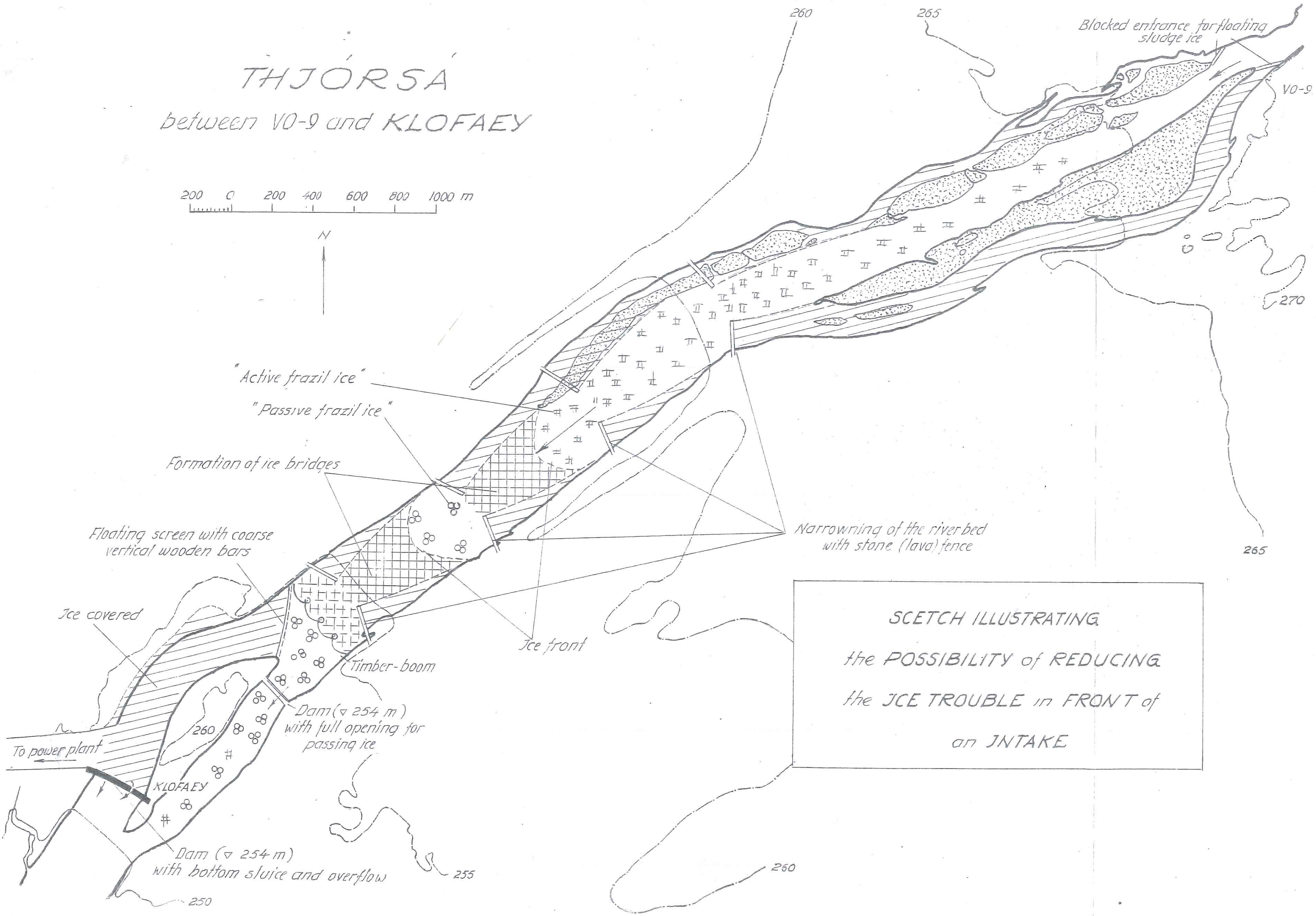
Fig E-3'



The Confluence
of UPPER THJÓRSÁ with TUNGNAÁ

SKETCH ILLUSTRATING the POSSIBILITY
of REDUCING the ICE PRODUCTION
and ELIMINATING STEP BURSTS

Fig. E-3^2



THJÓRSÁ
between V0-9 and KLOFAEY

SCETCH ILLUSTRATING
the POSSIBILITY of REDUCING
the JCE TROUBLE in FRONT of
an JNTAKE

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