THE HYDROLOGICAL SURVEY OF ICELAND

ADVISORY REPORT TO

STATE ELECTRICITY AUTHORITY

By

DAVID E. DONLEY
American Specialist

August 9, 1961

Reykjavík

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Mr. Jakob Gíslason
Director General
State Electricity Authority
Reykjavík, Iceland.

Dear Mr. Gíslason:

The organization, responsibilities, and activities of the Hydrological Survey of Iceland have been reviewed during the past two months. Many of the hydrological data collecting stations, located throughout Iceland, have been visited. Procedures used in the collection, processing, and publication of hydrologic data have been observed and analyzed. Equipment used by the Survey has been inspected and its operation noted. Solutions to various streamflow measurement problems have been devised and discussed with the Hydrologist. Most of these are now being carried out. This review and report were made possible by a grant issued by the United States Department of State, as a part of the International Education Exchange Program.

I am very happy to have had, even a small part, in collecting the hydrologic data required for planning and developing Iceland's great hydroelectric power potential. I take pleasure in presenting the attached report, containing my obervations on the activities of the Hydrological Survey and some suggestions for improvement in its operations and equipment.

The suggestions offered in this report are based upon my personnal experience and upon procedures developed by similar data-collecting agencies in the United States. These suggestions have been formulated with the sincere hope that they may prove helpful to the Hydrological Survey. None of these suggestions are intended as a criticism of the operations or equipment of the Survey.

Assistance from members of your Staff has been most helpful in making this survey and preparing this report. Mr. Sigurjón Rist, Hydrologist, provided transportation and accompanied me to many parts of Iceland where we visited streamflow stations, power plants, and other data collecting stations. He explained the many activities, for which he is responsible, and the procedures and equipment he has developed for carrying them out. He also explained the methods he has devised for compiling, analyzing, and publishing hydrologic data for Iceland. Mr. Jakob Björnsson, Civil Engineer, discussed many phases of the hydrologic data collection program and the problems that have been encountered. He was most helpful in the formulation of the scope of this report. He arranged for it to be typed so that it might be completed prior to my leaving Iceland. My sincere thanks are tendered to these gentlemen and to the other members of your staff who have assisted me. Without their help and suggestions, this review and report would not have been possible.

Mrs. Donley and I have both enjoyed our stay in Iceland and appreciate very much your providing this wonderful opportunity for us to see and enjoy so much of your beautiful country. Thank you and your staff for your hospitality and for making it possible for us to learn so much about your interesting country. We hope we may be able to visit Iceland again sometime in the future.

Sincerely yours

David E. Donley
American Specialist

S U M M A R Y

The State Electricity Authority established the Hydrological Survey, under direction of a Hydrologist in 1947. He undertook the making of a hydrological survey of the Country to determine the quantity, quality, and characteristics of its water resources and the potential for their development and use. He is responsible for the measurements of streamflow, gage heights, sediment load, depths of lakes, temperature, ice and snow, the determination of water quality, and for the compiling, analyzing and publishing of these data.

The Hydrological Survey continued the operation of 23 previously established streamflow stations and has expanded this network to over 100 statinns, covering the entire country. It has made over 1500 streamflow measurements at these stations and at miscellaneous points on the many rivers and lakes. Hydrographic surveys have been completed on a number of lakes and are continuing. A limited number of sediment, temperature and water quality measurements have been made. Cooperation between the Hydrological Survey and the Meteorological Survey has resulted in collection and publication of data from a number of snow survey courses and storage-type precipitation gages.

Streamflow data covering their record prior to 1958 have been collected, analyzed and published for about 15 streamflow stations. Two general reports on "Icelandic Fresh Waters" has been completed and published, as well as a special report on the hydrology of the Thjorsa and the Hvíta River Systems. The Hydrologist has prepared a number of technical reports on special problems relating to water supply at various points in Iceland.

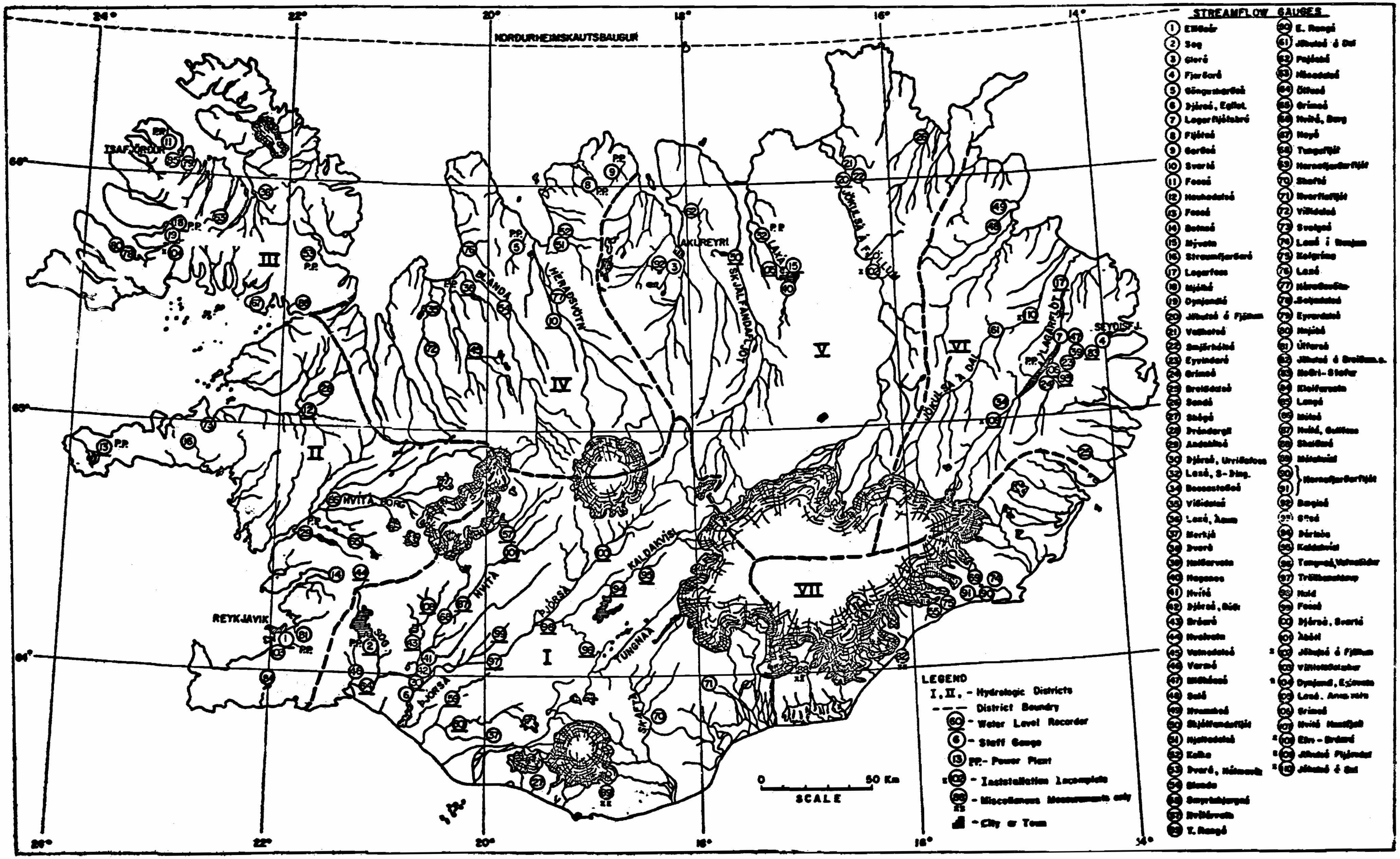
This study of the organization, operations, and methods developed by the Hydrological Survey, was made at the request of the Director General, State Electricity Authority.

It also included a field survey of about 20 streamflow stations in various parts of Iceland where special hydrologic problems have been encountered. Solutions have been suggested for these problems. Sites for additional streamflow stations were also selected during the fidd survey.

The various procedures developed, the equipment used, and the results obtained by the Hydrological Survey have been carefully observed and are described. Suggestions for improvements in the organization, equipment, operation, and methods used by the Survey, are included and discussed. Recommendations are made on the order in which these improvements should be undertaken and for the additional personnel that will be required. The establishment of a hydraulic laboratory as a cooperative undertaking by the State Electricity Authority and the University of Iceland, is proposed.

EXHIBIT A

HYDROLOGIC DISTRICTS — AUGUST 1961



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A. INTRODUCTION

Iceland is drained by many rivers and lakes. There are 85 main streams, draining about 71 percent of the entire country, and over 100 lakes with surface areas exceeding one square kilometer. Twentyseven of the rivers drain at least 1000 square kilometers and the largest one, the Jökulsá á Fjöllum, has a draining area of 7950 square kilometers. Thingvallavatn is the largest lake and has a surface area of 82 square kilometers. There are a total of 27 lakes, with areas of at least 5 square kilometers. Tables 1 and 2 list the largest of these rivers and lakes.

The pure, fresh, water in its rivers and lakes is Iceland's greatest natural resource. The development of this resource will provide many opportunities of expansion of the national economy. It will greatly increase the wealth of the country and the well-being of its citizens. Limited development of this resource has already been accomplished, and reliable estimates of potential hydroelectric power in the Hvita and the Thjorsa River Systems have been made. These show that about 2,500,000 kilowatts of power and 13,000 million kilowatt-hours of average annual energy can be developed in these two river systems alone. This is equivalent to that developed on the Tennessee River System in the United States by the Tennessee Valley Authority. Development of potential hydroelectric power resources on the other major rivers in Iceland may be expected to more than double the power and energy estimated as available from the Hvita and the Thjorsa River Systems.

TABLE 1

LARGEST RIVERS IN ICELAND

(Drainage Areas 1000 km^2 or more)

Name	Length	Drainage Area	Drainage Area under Glacier: Area	Drainage Area under Glacier: Percent	Remarks
	km	km^2	km^2	%	
Jökulsá á Fjöllum	206	7950	1700	21.4	
Kreppa	71	1330	730	55.0	Tributary of Jökulsá á Fjöllum
Thjórsá	230	7530	1200	15.9	
Tungnaá	129	3470	688	19.8	Tributary of Thjórsá
Ölfusá	185	6100	690	11.3	
Hvítá í Árnessýslu	160	4500	690	15.3	Tributary of Ölfusá
Sogið	53	1200	-	-	Tributary of Ölfusá
Skjálfandafljót	178	3860	140	3.6	
Héradsvötn	130	3650	225	6.2	
Eystri-Jökulsá	81	1200	145	21.1	Tributary of Héraðsvötn
Hvítá í Borgarfirði	117	3550	365	70.3	
Jökulsá á Brú	150	3500	660	18.9	
Lagarfljót	140	2900	190	6.6	
Jökulsá í Fljótsdal	61	1050	190	18.1	Tributary of Lagarfljót
Blanda	125	2370	200	8.4	
Laxá, S-Thing.	93	2150	-	-	
Kúdafljót	115	1970	420	21.3	
Skaftá	70	1375	350	25.2	Tributary of Kúdafljót
Hólsá, Rang.	71	1860	10	0.5	
Ytri-Rangá	58	1000	-	-	Tributary of Hólsá
Fnjóská	117	1310	-	-	
Eyjafjardará	60	1300	-	-	
Markarfljót	100	1200	250	20.8	
Hnausakvísl, A-Hún.	74	1170	-	-	
Bjargaós, V-Hún.	69	1130	-	-	
Hofsá í Vopnafirði	85	1100	-	-	
Skeidará 1)	30	100	975 2)	97.5 2)	
Totals	2275	55,600	7025	12.6	

1) Vid Jökuljadar
2) Variable

Source: Iceland Fresh Waters - State Electricity Authority Reykjavik, Iceland, 1956

TABLE 2
LARGEST LAKES IN ICELAND

Names	Surface Area km^2	Formation
Thingvallavatn	82	Subsidence. Lava dam.
Thorisvatn	70	Glacier eroded. Lava dam.
Lögurinn	52	Glacier eroded valley lake.
Myvatn	38	Subsidence. Lava dam.
Hopid	29	Lagoon Lake.
Hvitarvatn	28	Glacier eroded basin.
Langisjor	27	Subsidence?
Graenalon	18[1)]	Ice-dammed Lake.
Skorradalsvatn	14	Glacier eroded valley lake.
Apavatn	14	Glacier eroded.
Svinavatn	12	Glacier eroded valley lake.
Öskjuvatn	11	Subsidence.
Vesturhopsvatn	10	Glacier eroded valley lake.

1) Variable area. For last few years area has been less than 18 km^2.

Source

Iceland Fresh Waters, State Electricity Authority Reykjavík, Iceland, 1956.

Full economic development of this great natural resource requires that a survey be made to determine accurately its extent, characteristics, and development potential. The Althing realized this in 1946, when it passed the Electricity Act and established the State Electricity Authority. This Act assigned the responsibility for making a hydrological survey and a detailed investigation of Iceland's water resources to the Director General of the Authority. The Director General established the Hydrological Survey in 1947 and assigned it, as its main tasks, the measurements of streamflow, gage heights, sediment load, the depths of lakes, temperature, ice and snow, as well as investigation of the quality of water. He directed that the results of these many measurements be compiled and analyzed, and be made available upon request to anyone interested in the water resources of the country.

The State Electricity Authority early in 1961, requested the Department of State, of the United States, to send an American expert in hydrology to Iceland. The services of this expert were desired to assist the Hydrological Survey in the solution of a number of hydrologic problems that had been encountered by the Survey in its water resource investigations. It was also desired that this specialist review the general operations of the Hydrological Survey, and offer suggestions for further improvement in the work carried on by that agency.

The request was transmitted by the American Ambassador in Reykjavik, to the American Specialists Branch, Office of Cultural Exchange, Department of State, Washington, D.C. The American Specialists Branch undertook the recruitment of a hydrologist, and I was selected as the American Specialist to assist the State Electricity Authority of Iceland. I arrived in Reykjavik Iceland, June 1, 1961 and spent the ensuing 10 weeks considering the work of the Hydrological Survey and the solution of the problems it had encountered. This is my report on these problems and my suggestions for improvements in the operation of the Hydrological Survey.

B. ORGANIZATION

The Hydrological Survey was established in 1947 and Sigurjon Rist was appointed as the first hydrological surveyor, or Hydrologist, of the State Electricity Authority. Later Eberg Elefsen was appointed as his assistant, and one additional assistant was added last year. These three men have been responsible for all the hydrological data collected, analyzed, and published by the Authority. They have had some assistance from a number of local farmers living near stream gaging stations. These men have been employed by the Authority as gage readers for the many staff gages and to change the charts on some of the water level recorders. Operators at Authority power plants have assisted by reporting the water available at their plants, and in one case making a limited number of streamflow measurements. Authority to employ local labor for construction of gaging stations, snow courses and precipitation gages was granted the Hydrologist only last year.

The execution of the hydrologic survey in Iceland is rendered more difficult than that in other countries by the rigorous climate, lack of communication, difficult and hazardous travel in winter, and the fact that the country is thinly populated. Large areas of the interior of Iceland are uninhabited and lack all transportation facilities. Most of the major streams rise in such areas and streamflow stations are required for their measurement. The small organization has spent much time and effort in constructing, maintaining, and servicing these gages and in making streamflow measurements in these difficult-access areas. The other streamflow stations are widely scattered adjacent to the coastal areas around Iceland and require extensive travelling to operate them. The limited number of available vehicles and the severe winter conditions has taxed the energies of the personnel in the Hydrological Survey to the limit, in many years.

C. RIVER MEASUREMENTS

Streamflow Stations.

About 30 staff gages were in operation when the Hydrological Survey was established in 1947. The operation and maintenance of these stations was transferred to the new organization which has operated them since that time. The Survey has located and constructed over 70 additional stations since 1947 and has replaced a number of staff gages with water level recorder stations. It now operates over 100 stations, about 27 of which are equipped with water level recorders. Locations have been selected and construction is underway to increase the number of recorders to about 40. Some of these will replace staff gages but a number of them will become new streamflow stations. The location and names of these stations are shown on Exhibit A. A tabulation listing 91 of these stations, that were established prior to 1956, is shown in ÍSLENZK VÖTN [1]).

A number of additional sites have been selected for streamflow stations. Local labor is being used to construct stilling wells at these sites, but installation of water level recorders is being seriously delayed by lack of personnel and time to install them. No records can be obtained until these installations are completed and in operation.

Streamflow Measurements.

Systematic, country-wide streamflow measurements were begun by the Hydrological Survey in 1947. Very few such measurements had been made prior to that time. The wide

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1) RIST, S. - Íslenzk vötn, Icelandic Fresh Waters, Hydrological Survey, State Electricity Authority, Reykjavík, Iceland, 1956.

dispersion of streamflow stations requires the Survey personnel to travel long distances each year to carry out this phase of the work. Very severe weather conditions and poor road conditions in winter, make it impossible to secure many measurements in this season. Heavy ice on many of the rivers and lakes further add to measurement problems. The 3-man personnel of the Hydrological Survey is only sufficient to permit one measuring party to secure streamflow data. A few additional measurements are now being made by one of the power plant operators in the northern section. This operator has been furnished a current meter and instructed in its operation, however his other duties require most of his time and few measurements are made.

Despite these many handicaps and lack of personnel the Hydrological Survey made over 700 individual current meter measurements between 1947 and 1956. The results of these are listed in Íslenzk vötn.[1)] This listing shows that, in addition to measurements at about 87 streamflow stations, one or more miscellaneous measurements were made at each of over 200 locations. It appears, that measurements at established stations, averaged only about 5 per station during the entire 10-year period. **About 800 additional** streamflow measurements have been made by the Hydrological Survey since 1956.

a. Method of Measurement. All streamflow measurements are made by wading or from a small boat. Propeller-type current meters, of Swiss or German design and rod-mounted, are used by the Hydrological Survey. Measurement sections are selected in the vicinity of streamflow stations, or at locations where miscellaneous measurements are required. A steel cable, with markers at 5-meter intervals, is stretched across the stream at the measuring section. This acts as a reference line to determine points for vertical measurements and as an anchor line, when a boat is used for measuring.

The current meter is mounted on a 4-meter graduated steel rod and electrically connected to a battery-operated bell. The meter is so constructed that this bell will ring each time the meter's propeller has made 50 revolutions. A stop-watch is used by the meter operator to determine the time in seconds required for each 50 revolutions of the propeller on the meter. Each time a current meter is rated an equation is derived for the meter. This equation permits the time required, for any given number of propeller revolutions, to be converted into the velocity of the current in centimeters per second.

The meter operator lowers the meter and rod to the bottom of the stream at each point selected across the measuring section. He notes the total depth of the stream on the meter rod and calls it out to the notekeeper. The notekeeper is the other member of a measuring party, and either remains on the bank during wading measurements, or operates the boat when one is used. The notekeeper enters the location of the measuring point and the total depth of the stream at that point in his Field Book.

The meter operator measures the time with a stopwatch, that is required for the current meter to record a selected number of 50-revolution intervals. He repeats these data to the notekeeper who records them in his Field Book. The meter is raised vertically about one-half meter and the measuring process repeated. This same process is repeated at a number of points in the vertical section, the last one measured is located just below the water surface.

The meter operator repeats the vertical measurements at 5- or 10-meter intervals across the entire measuring section. All of these data are entered in the Field Book and are later converted, by means of the meter equation, to velocities in centimeters per second of time.

b. Determination of Discharge. The depth and velocity recorded at each of the points in the vertical measurement are platted to a suitable scale on graph paper. Depths are plotted as ordinates and the corresponding velocities as abscissa. A smooth curve is drawn to connect these points and is known as a vertical velocity curve. The area inclosed by each of these curves is determined graphically with a pair of dividers and entered on the curves.

A line representing the width of the stream at the measuring section, is platted to a suitable scale on graph paper. Each of the points, where vertical measurements were made, is located on this line. Vertical lines are projected downward from this line at each of these points. The areas determined for each of the velocity curves are platted to a suitable scale on their respective vertical lines. A smooth curve is drawn connecting these vertical points. The area enclosed by this curve is determined graphically with a pair of dividers and a scale conversion factor applied to reduce it to cubic meters per second. This result is the flow in the stream in cubic meters, or kiloliters per second, at the time the measurement was made. This value and its corresponding stage, as measured on the nearby gage, provide one point for determination of the stage-discharge relationship curve for the streamflow station.

c. Stage-Discharge Relationships. Weather conditions, changes in temperature, and variations in precipitation, produce wide variations in stages in Iceland's rivers and lakes. These in turn represent wide variations in streamflow. It is necessary therefore to measure each stream, at as many different stages as practicable, to establish the stage-discharge relationship for its entire range in flow.

Only very preliminary determinations have been made of the stage-discharge relationship at many streamflow stations. Lack of personnel, time, and suitable measuring equipment for high stages, has been responsible for this situation. Lack of time and the difficult access to many stations has resulted in few measurements of flow being made at many stations. Lack of suitable measuring equipment has prevented measuring most streams during high-water stages. Therefore almost all measurements have been made at low-water, or medium stages. It has been impossible to determine the upper portion of stage-discharge curves from the streamflow data secured. Almost all of these curves have been extended to high stages by extrapolation of the lower portions of the curves. Some computations have been made, using survey data and open channel formulas, in attempts to check these curve extensions. These computations are necessarily approximate, due to the nature of the basic data, and result in very poor checks on the extrapolated curves. None of these methods can take the place of streamflow measurements, made during highwater stages, for the upward extension of stage-discharge curves.

Determination of Daily Discharges

Daily discharges are determined for each streamflow station from daily stages and the stage-discharge curve determined in the above manner. River stages and staff gages are generally read by observers only once, or twice, each week. Stages for all intermediate days must be interpolated, or estimated by comparison with the nearest station. Current practice assumes that each observed stage remains constant until the next stage observation is made. Water level recorders produce a graph showing the variation of the river level with time. Many of the rivers in Iceland are glacial rivers and these have rather wide daily fluctuations. Average daily stages must be determined so as to accurately represent the average daily flow. Ice conditions, and inaccuracies in recorder operation must be adjusted in each case before daily discharges can be computed. Estimates of daily stages must be made for all periods where recorders may have failed to operate for various reasons. The checking of stage records and this determination of daily stages at over 100 streamflow stations now in operation, constitutes a major undertaking in the Hydrological Survey.

The wide dispersion of the streamflow stations and the large amount of time necessary for their operation and rating, leaves very little time for the processing of their records. The limited personnel of the Hydrological Survey can use only the short intervals between field trips and those brief periods when extremely severe weather prevents field operations, to work on this processing. Consequently a large amount of streamflow data have accumulated and are awaiting checking and daily stage determinations. These data are unavailable for use in water resources investigations until their processing is completed, and they are essentially useless until this is done.

The application of average daily stages to the stage-discharge curves, at the many stations, is processed on IBM machines and the resulting daily discharges tabulated by these machines. Before this can be accomplished each of the daily stages for each year must be punched into an IBM card. For determining discharges at 100 stations this requires the punching of 36,500 cards for each year. This can only be done after the checking and determination of each daily stage record has been completed. Additional cards must be punched for many intervals on the stage-discharge curve for each station. The average number of cards required for each station is 300. This amounts to an additional 30,000 cards required for 100 stations. However, these cards can be used for more than one year, if no change occurs in the stream control of the station, or additional measurements do not require changing the stage-discharge curve. Each time this curve is changed a new set of punch cards must be prepared for the station stage-discharge curve.

The tabulations prepared by the IBM machines constitute the annual record of daily discharges and are suitable to use for their publication in many copies, by the offset printing process.

D. OTHER HYDROLOGIC DATA

Hydrographic Surveys of Lakes

The Hydrological Survey is responsible for making hydrographic surveys of the lakes in Iceland. This includes the soundings of these lakes, the preparation of hydrographic maps, and systematic observations of the lake level fluctuations. Echo sounding methods are used to secure data for the hydrographic maps. Water level gages have been installed in many of them, and frequent levels are taken on lakes where no gages have been installed. Many of these lakes are crater lakes and a number of them are located in uninhabited areas of Iceland. Access to these lakes with sounding equipment is often difficult and time consuming. Climatic conditions are such that hydrographic surveys can only be carried out during the months of May to August inclusive.

Hydrographic surveys and maps have been completed at a number of the larger lakes and at some of the smaller ones. A considerable number of the larger ones and most of the smaller ones remain to be done. This work requires the use of all the personnel currently in the Hydrological Survey and streamflow measurements, compilation, analysis, and publication of data must be suspended while lake surveys are being made. Determination of the characteristics, fluctuations and capacities of Iceland's lakes are necessary as a part of its water resource investigations and it is essential that this program be completed at an early date.

Collection of Sediment Data

Glacial rivers in Iceland carry a large amount of suspended material. This is largely finely ground glacial flour produced from the rocks by movement of the ice over them. This material deposits as sand bars in the lower reaches of the glacial rivers. Most of the rivers in the north and east sections of Iceland flow in valleys deeply carved during and immediately following the last Ice Age. Many of these valleys have been refilled as the ice retreated, and the present streams flow on top of these major deposits of boulders and other sediments. These rivers produce high velocities due to their rather steep slopes and much of this material is transported as bed load. The glaciated hills in some of these areas have rather deep deposits of finer materials, which are subject to a moderate amount of erosion due to rainfall and snowmelt. This further adds to the sediment load transported by the rivers of northern and eastern Iceland.

Most of the rivers in southern and southwestern Iceland drain areas where extensive volcanism has occurred since the last ice age. Much of their drainage areas are covered with lavas and by very extensive cinder and ash deposits. These deposits are generally very porous and practically no surface runoff occurs. Valleys have been blocked by lava flows in many places and the streams can move only very limited amounts of bed loads. Exceptions to this occur at the lower ends of deep river gorges where high velocities are able to transport the eroded materials as bedload for short distances. A good example is the Hvíta River at Gullfoss. The spring-fed rivers originating in the lava fields transport essentially no suspended or bedload material. The porous material covering most of the mountainsides in this area shows little signs of surface erosion and contributes little to the sediment transported in the rivers of this area. Therefore almost all of the sediment carried is the material released by the glaciers to the streams of glacial origin.

The collection of sediment data has only recently been undertaken and a very limited number of samples of suspended sediment have been secured and analyzed. These samples have been secured by attaching plastic one-liter bottles to a long rod and filling the bottles in turbulent sections of the streams. It is very difficult to secure any idea of depth distribution of sediment with this method of sampling. Therefore the data available are sufficient only to give a very approximate indication of the material in suspension. They are inadequate to permit any reasonable determination of the quantity of material being transported by any of the streams. An intergrator type sediment sampler, P-43, is available but cable suspension equipment and a cable reel for operating it are not available and the sampler cannot be used until they are obtained.

It is understood that no samples of bedload material have been taken and analyzed. These are necessary to obtain data on particle size and distribution. No facilities are available, or contemplated, whereby this important portion of the sediment transported can be estimated.

Water Quality

Some of the water samples, secured as a part of sediment data collection, have been analyzed to determine chemical composition. These analyses were made by the University of Iceland, but this work will soon be transferred to the new laboratory established by SEA. Chemical analyses of samples taken in the Hvita and Thjorsa River Basins, prior to June 1959, are shown in "Thjorsa and Hvita River Systems, Southern Iceland. Some Hydrological Aspects." [2] These analyses

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[2] Rist, S., and Jakob Bjornsson - Thjorsa and Hvita River Systems, Southern Iceland, Some Hydrological Aspects, Hydrological Survey, State Electricity Authority, Reykjavik, Iceland, June 1959.

are indicative of water quality in these two streams but are insufficient to show any seasonal variations in quality. No similar data are known to have been determined for the other rivers of Iceland.

Water Temperature Data

A submersion type thermometer is used by the Hydrological Survey to determine water temperatures. Readings are taken at various intervals at a considerable number of points. These are usually taken at streamflow stations each time they are visited by the Hydrologist, or when discharge measurements are made. No systematic program for water temperature measurements has been adopted.

The Hydrologist has made many personal observations of ice conditions in the various rivers and lakes. He has prepared a series of charts showing general ice occurrences in the rivers of southern and southwestern Iceland. These are most useful in the selection of sites for streamflow stations and for other structures that would be subject to ice interference. These are contained in "Thjorsa and Hvita River Systems, Southern Iceland, Some Hydrological Aspects." 2)

Cooperation with Meteorological Survey

a. Snow Surveys. The Hydrological Survey cooperates with the Meteorological Survey in the collection of data on snow depths and snow water content. About 16 snow survey courses have been constructed in the Hvita, Botnsa and Thjorsa River Basins. These courses consist of metal stakes, generally installed in the form of a cross. Each arm of the cross contains five stakes, located at 20 meter intervals. These stakes are installed so that they project two meters above the normal ground surface. This enables the observer to determine the depth of the snow by measuring down from the top of each stake at the time of each winter visit. The depths measured at the 20 stakes are averaged to give the mean depth of snow at the course. Snow samples are promptly melted and the water measure, to obtain the water content of the snow. Measurements are made at various times during the winter by the Hydrological Survey, during trips by Snowmobile to gaging stations. The data collected are furnished the Meteorological Survey for publication with their records.

b. Precipitation Measurements. A storage-type precipitation gage, or totalizer, has been installed at each snow course and is known locally as a "Totalizer Gage". It consists of a heavy metal, can-type, gage, mounted on metal supports about 4 meters above the ground so as to be well above the ground snow-level in winter. It is equipped with a wind shield and a strong solution of calcium chloride and water is added to prevent it freezing and bursting in winter. A small amount of SAE-10 motor oil is also added to present evaporation in summer. Measurements are made each time the gage is visited by the Hydrological Survey during the year. The results are reported to the Meteorologica Survey for publication with their data. This type of gage only measures approximately the total precipitation that occurs between each two observations. There are about 16 of these gages in operation at the present time.

E. PUBLICATION OF DATA

Streamflow Records

Streamflow records are compiled for publication by water years. The water year begins on September 1st each year and ends on August 31st the following year. Each of the staff gage readers record the gage readings in a record book when they are taken. At the end of each month he makes a copy of the month's readings and mails it to the Hydrological Survey in Reykjavik. After September 1st each year he mails his original record book for the year to Reykjavik. The monthly reports are filed when they are received and compared with the record book at the end of the water year. The Gage Record Books are filed in the Hydrological Survey and become the permanent stage records for the staff gages. The charts from all water level recorders are sent to the Hydrological Survey in Reykjavik when they are removed from the gages. These are filed by stations and become the permanent record for the recorder stations.

All gage readings and recorder charts are carefully checked and missing daily values are estimated. Missing periods on the recorder charts are estimated by comparison with other similar stations. Where recorder charts show diurnal fluctuations, these are averaged to give an average stage for each day. All of these daily stages are placed on IBM punch cards and sent to the IBM processing center for conversion to discharge by the machines.

Programs have been devised for the IBM operations so that tabulations of daily discharges are made for the entire water year for each streamflow station. These tabulations show the number of the station, each day in the water year, the mean discharge for the day in kiloliters per second, the total flow during the day in gigoliters, the mean discharge for each seven-day period throughout the year, and the total flow during each seven-day period. They also show two summations of the daily flows in gigoliters, one starting on September 1st of the respective water year and the other starting at the beginning of flow records at the streamflow station. Monthly and yearly summary sheets are also prepared by the IBM machines. These show the monthly and yearly total flows and the highest, lowest, and mean flows during each month and during the year.

An additional IBM machine operation lists all of the daily flows in descending order in both kiloliters per second and in gigoliters per day. This tabulation shows for each day, the percent of time its flow is equalled or exceeded. The total volume in gigoliters under the duration curve has been computed for each percentage interval of time, represented by each daily flow and tabulated opposite that flow. The volume of flow under the duration curve and above each flow interval, has been determined and is shown as a percentage of the entire volume under the duration curve for the year.

All of the above tabulation sheets are bound together for each streamflow station for each water year. This is entitled "Rennslisskýrsla, or Stream-flow Data" and is available for use in water resources investigations. Table 3 shows the stations when records have been compiled in this manner. A check on the number of station-years of continuous records in the Hydrological Survey files, indicates there are about 950 station-years. Table 3 shows that only about 150 of these station-years of record have been processed and published. This leaves approximately 800 station-years of records to process.

TABLE 3

PUBLISHED STREAMFLOW DATA

ICELAND

No.	Stream	Station	Years 32-33	33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	42-43	43-44	44-45	45-46	46-47	47-48	48-49	49-50	50-51	51-52	52-53	53-54	54-55	55-56	56-57	57-58
10	Svartá	Reykjafoss	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
12	Haukadalsa	Haukadalsvatn									-	-	-	-	-	-	-	-	-	-	x	x	x	x	x	x	x	
16	Straumfjardaá	Baularvallavatn													x	x	x	x	x	x	x	x	x	x	x	x	x	x
17	Lagarfljót	Lagarfoss													-	-	-	-	-	x	x	x	x	x	x	x		
20	Jökulsá á Fj.	Dettifoss								x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
24	Grímsa	Grímsarfoss													x	x	x	x	x	x	x	x						
25	Breiddalsa	Beljandi													-	-	-	-	-	-	x	x	x	x	x	x	x	
27	Skaga	Skagafoss																x	x	x	x	x	x	x	x	x	x	
32	Laxa, S-Thing	Bruarfossar																x	x	x	x	x	x	x	x	x		
36	Efri-Laxa	Svinavatn																x	x	x	x	x	x	x	x	x		
44	Botnsa	Hvalvatn												-	-	-	-	-		x	x	x	x	x	x	x	x	
50	Skjalfanda-fljót	Godafoss																		x	x	x	x	x	x	x		
55	Smyrlabjargaá	Borgarhafnar-heidi																				x	x	x	x	x	x	
74	Laxa í Nesjum	Medalfells-gljufur										-	-	-	-								x	x	x	x	x	
45	Vatnsdalsa	Forsaeludal																										

The Hydrologist is frequently called upon to prepare reports showing the water available and the flow characteristics at potential dam sites. He makes a study of applicable streamflow data and transfers it to the dam site being investigated. He is also called upon to prepare or assist in preparing general reports covering river basins and covering all of Iceland. "Íslenzk Vötn" [1] and "Thjorsá and Hvitá River Systems" [2] are good examples of such reports. Another recent report is "Vatnafraedi, virkjun Hvitár vid Hestvatn", prepared by Mr. Rist in January 1961.

Other Data

Sediment, water quality, and temperature data are filed in the Hydrological Survey and extracts included in general reports like those listed above. Snow survey and precipitation data are collected and tabulated. They are furnished the Meteorological Survey, where they are compiled and published by that agency.

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1) Rist, S. - Íslenzk vötn, Icelandic Fresh Waters Hydrological Survey SEA, Reykjavik, Iceland, 1956.

2) Rist, S. and Jakob Björnsson - Thjorsá and Hvitá River Systems, Southern Iceland, Some Hydrologic Aspects - Hydrological Survey, SEA, Reykjavik, Iceland, June 1959.

F. FIELD SURVEY OF STREAMFLOW STATIONS

A number of field trips were made between June 1 and July 27 to visit streamflow stations and to consider the problems that have been encountered at a number of these stations. The Hydrologist provided transportation and explained the difficulties in each case. These were discussed in detail in the field with the Hydrologist and solutions were suggested in most cases. A total of 30 streamflow stations were visited in the different sections of Iceland. At a number of these no particular problems were encountered and only a routine inspection was made of the installation. Table 4 lists the various stations visited on these various trips. The stations where problems existed and their suggested solutions follow.

a. No. 7 - Lagarfljotsbru on the Lagarfljot. This gage was visited on July 27. It is a staff gage attached to the base of one of the bridge piers near the middle of the Lagarfljot. Water was above the top of the gage and the observer was measuring down to water from bridge each time he observed gage. It was suggested that an extension of this gage be painted on a diagonal concrete brace that extends down from bridge to top of pier near top of existing gage. This suggestion was adopted and the Hydrologist arranged to have the work done.

b. No. 10 - Reykjafoss on Svartá. This is currently a staff gage, and has been operated since 1929. Examination of site on July 20 1961 indicated that the control is somewhat questionable. A decision had already been made to replace the staff gage with a water level recorder. A new site was selected near the falls, where the ledge at top of the falls will act as a permanent control. The new site was adopted and construction started on the new gage the same day.

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TABLE 4

STREAMFLOW STATIONS VISITED

No.	Stream	Station	Date Visited
2	Sog	Ljósafossstöð	June 6, 1961
6	Thjórsá	Egilsstaðir, Flóa	June 5, 1961
7	Lagarfljót	Lagarfljótsbrú	July 27, 1961
10	Svartá, Skagafirði	Reykjafoss	July 20, 1961
15	Mývatn	Grímsstaðir	July 22, 1961
17	Lagarfljót	Lagarfoss	July 26, 1961
20	Jökulsá á Fjöllum	Ferjubakki	July 25, 1961
29	Andakílsá, Borgarf.	Fossar	July 18, 1961
30	Thjórsá	Krokur	June 3, 1961
32	Laxá, S-Thing.	Laxárvirkjun	July 23, 1961
36	Efri Laxá, Ásum	Tindabrú	July 19, 1961
43	Brúará, Biskupst.	Dynjandi	June 8, 1961
45	Vatnsdalsá, A-Hún.	Forsæludal	July 19, 1961
54	Blanda, A-Hún.	Guðlaugsstadir	July 20, 1961
57	Hvítá	Hvítavatn	June 22, 1961
59	Ytri-Rangá	Hella	June 6, 1961
60	Eystri-Rangá	Djúpidalur	June 6, 1961
64	Ölfusá	Selfoss	June 6,1961
68	Tungufljót	Faxi	June 8, 1961
87	Hvítá	Gullfoss	June 8, 1961
93	Gilsá	Grímsá P.P.	July 26, 1961
94	Thorisós	Thorisós	July 7, 1961
95	Kaldakvísl	Kaldakvísl	July 7, 1961
96	Tungnaá	Vatnaöldur	July 6, 1961
97	Thjórsá	Búrfell	June 13, 1961
98	Tungnaá	Hald	June 13, 1961
100	Thjórsá	Norðlingaalda	July 8, 1961
101	Hvítá	Abóti	June 22, 1961
102	Jökulsá á Fjöllum	Grímsstaðir *	July 25, 1961
105	Mývatn	Arnarvatn	July 22, 1961
106	Grímsá	Grímsá P.P.	July 26, 1961
108	Efri - Brúará	Böðmóðsstaðir *	June 8, 1961
109	Jökulsá Fljótsdal	Fljótsdal *	July 24, 1961
110	Jökulsá á Dal	Jökulsá á Dal *	July 25, 1961

* New Water Level Recorder Stations

c. No. 15 - Myvatn at Grimsstadir. This is currently a staff gage located on the west side of Myvatn. It is operated to measure the lake level for comparison with the lake level on south side, as recorded at Gage No. 40, located at Haganes. A decision had previously been made to convert this station to a water level recorder station. A new site was selected on July 22 and an automatic recorder left with the gage reader. It will be installed at an early date.

d. No. 17 - Lagarfoss on Lagarfljot. This station was visited on July 26 and a discharge measurement made. The measuring section is only a short distance above the falls and measurements cannot be made safely from a boat above medium low-water stage. It is understood that an important dam site is located a short distance downstream. Extension of the stage-discharge curve is very essential to the design of this project. It was suggested that a cableway be constructed near the present measuring site, so that high flows can be measured and the complete stage-discharge curve developed.

e. No. 20 - Ferjubakki on Jökulsá á Fjöllum. This station is located just below the new suspension bridge near the mouth of Jökulsá á Fjöllum. It was inspected on July 25 and found to have a very unstable control. The river is flowing in a refilled glacial valley and its bed is composed of boulders and gravel. No rock ledge was apparent in this vicinity. A proper stage-discharge curve will require many measurements and will probably have to be determined each year after ice conditions are over. It was suggested that the proposed cable suspension equipment for the current meters be used and measurements made from the deck of the new suspension bridge at this station.

f. No. 30 - Krokur on Thjorsá. This recorder is located near the head of the Thjorsá rapids, upstream from Urridafoss.

A site for one of the major potential power plants is located below this station. The site was visited on July 18 and inspected. It is important that the stage-discharge curve be extended by highwater measurements at this site so that it can be used in hydroelectric power investigations. It is suggested that a cableway be constructed a short distance below the gage to provide a means of making highwater measurements.

g. No. 32 - Laxá Power Plant on Laxá River. Two power plants have been constructed at this site. The new one was constructed just downstream from the old one. Discharge from the upper one has a rapid drop into the pool of the lower one. A distance recorder-type gage was installed between the plants and located so as to be read in the power house of the upper plant. It was supposed to record the stages of the flow by-passing the upper plant. The dynamiting of ice jams in the vicinity of the gage is understood to have changed the control and the gage now is said to read inaccurately. The site was inspected on July 23 and possible calibration of the spillway and outlets of the upper dam was discussed. Measurements of flow by-passing the power plant were also discussed. Neither of these solutions appears feasible without the expenditure of much time and money to secure the measurements needed. Besides the turbines in the plant have been in use about 14 years and their estimated efficiencies, as used to compute the flow through this plant, appear very questionable.

A new site was selected for a water level recorder about 2 kilometers upstream from the upper end of the upstream power pool. The site is near a dam site where a third plant is being considered on the Laxá River. It was suggested that a monthly water level recorder be installed above a rock area forming a channel control. It was also suggested that a cableway be installed near the gage to permit measurements to be made at high stages. The plant operator agreed to service the new recorder, when it was installed.

h. No. 36. Tindabru on Efri-Laxá, Ásum. This station was visited on July 19 and the control dam at the lake above the plant inspected. This dam and its small spillway are in rather poor condition. A high wind over the lake may very well raise the water to heights that will overtop the dam and breach it. This would result in very considerable damage to the power plant below and would probably put it out of operation for several days. It is suggested that immediate steps be taken to increase the safety at this dam.

i. No. 45 - Forsaeludal on Vatnsdalsá. The water level recorder at this station was visited on July 19. The control is very poor below this gage and the stage-discharge relation very unstable. No facilities are available for even medium flow measurements. It was suggested that a low concrete weir be constructed across the channel about 50 meters below the gage and a cableway be constructed at about the same location. The narrow channel would not require a very expensive weir and cableway. These would remedy the poor conditions at this station and permit reasonably accurate discharges to be determined. This station is practically useless in its present condition.

j. No. 54 - Gudlaugsstadir on Blanda. The staff gage on this site was inspected on July 20. It is located in a gorge section and the control looks quite unstable. The river generally is flowing in a refilled glacial valley and the boulders and gravel in the channel shift each year. A new location was selected near the new suspension bridge where channel conditions are more stable. High stage measurements in the Blanda could be made from the nearby bridge. It is suggested that a water level recorder be constructed at the new site.

k. No. 87 - Gullfoss on Hvítá. This gage is located at the lower end of the Gullfoss gorge and is subject to high water and ice. The riverbed is composed of boulders and gravel and looks quite unstable. No rock ledges are to be seen in this vicinity. There does not appear to be any other suitable location for this gage in this general reach of the river. This station was visited on June 8 before glacier melt had increased the flow in the Hvítá but velocities were too great at this low stage to permit measuring in this vicinity.

A method for estimating high flow at Gullfoss was discussed with the Hydrologist. It would consist of determining a cross section of the river to the highest stages expected, a short distance below the gage and a measurement of water slopes through the adjacent reach. The Manning Formula would be used to compute a stage discharge curve from these data. The result would be very approximate due to the inability to estimate slopes and roughness accurately. It would however give an approximate point for the upper end of the stage-discharge curve.

It is suggested that cable suspension equipment be secured for the current meter and temporarily discharge measurements be made from the highway bridge a few kilometers below the Gullfoss gage. A cableway should be constructed as early as practicable below the gage, to permit high stages to be measured. The unstable channel in this area will require many measurements, at various stages each year, to accurately determine daily discharges at Gullfoss. This is an important key gaging station and will justify the additional expenditure of funds to properly determine its stage-discharge relationships.

l. No. 93 - Gilsá near Grimsá Power Plant. This gage was visited on July 26 and the recorder was found not to be operating satisfactorily. It is a very steep stream and its flows are subject to excessive pulsations. These were being recorded on the chart as a wide band and satisfactory stages could not be determined from the chart. The Hydrologist suggested the installation of a vertical steel pipe in the stilling well. The float for the gage would operate in this 18 cm pipe and the pulsations would be damped by this confined column of water. The pipe would also permit the float to operate in an oil cover on the water in winter and prevent the gage becoming frozen. The suggestion was a good one and steps were taken to secure and install this pipe immediately.

m. No. 95 - Saudafell on Kaldakvisl. This gage was inspected on July 6. It is located at the junction of a smaller stream with the Kaldakvisl and its stages may be affected by backwater from the smaller stream at some flows. The control looks unstable but there did not appear to be any better site for the gage in this vicinity. It is suggested that as many measurements as practicable be made at this station to establish a stage-discharge curve and determine annual changes in this station's rating.

n. No. 96 - Vatnaöldur on Tungnaá. This station was inspected on July 6 and appeared to have a satisfactory channel control. This station is difficult to measure except at low or moderate stages. There are no bridges across the Tungnaá and a cableway across the river near the station should be constructed and all measurements made with a meter suspended on a cable.

o. No. 98 - Hald on Tungnaá. This station was inspected on June 13 and a measurement observed here on the following day. This station measures almost all of the flow in the Tungnaá and its records will play an important part in future power investigations. Only low, or medium, flows can be measured at this station under present conditions. It is strongly suggested that a cableway be constructed at this station so that the stage-discharge curve can be determined for the full range in Tungnaá stages. It is anticipated that a bridge may be constructed across the Tungnaá at this point some time in the future. Records at this station have so much importance that the cableway should be constructed now and used until the anticipated bridge is constructed, perhaps as much as 10 to 15 years in the future.

p. No. 97 - Burfell on Thjorsá. This station is located a short distance below the Tröllkonuhlaup Falls on the Thjorsá River. It is near the head of the long series of rapids and falls in the reach of the Thjorsá around the southern end of Burfell. This is a reach that possesses major possibilities for a large power development. The flows determined at this station will be most important for use in the studies for this series of developments. The rapids and high velocity flow at this station make it difficult to measure even at low stages. It is strongly suggested that a cableway be constructed just below the gage, so that the stage-discharge relationship can be determined accurately for the full range in stage at Burfell.

This station was first inspected on June 13 and again on July 10. The stilling well was found clogged with silt on June 13 and was opened with a small dynamite charge. It was operating in good order on July 10.

An inspection was made of the reach of river around Burfell on June 13 and attempts made to locate a site for a recording gage at the lower end of the rapids section. No suitable site was found where a gage could be installed and operated. Three fixed points were established by cementing steel pipes at suitable locations on the rock ledges overlooking the river. These were placed on the left bank at various intervals down the gorge section. Their elevations and definite locations will be determined by the Geodetic Survey. Measurements to determine river levels at each point will be made at intervals in the future. These levels can be plotted against corresponding discharges as measured at Burfell to determine reasonably accurate stage-discharge relationships at each fixed point. These can be used as approximate tailwater curves for power planning investigations for this section of the Thjorsá. Later it may be necessary to station an observer at these points, so as to determine sufficient levels for a wide range in stages.

q. No. 100 - Thjorsá at Nordlingaalda. This is the most inaccessible streamflow station operated by the Hydrological Survey. It is located in an uninhabited region near the center of Iceland. To reach this station the wide Tungnaá must be forded above Vatnaöldur, the Thorisos at the northern end of Thorisvatn, the Kaldakvisl near Saudafell, and the Svarta near the station. In addition to fording these streams, over 50 kilometers of desert, filled with old craters, cinders, ash and lava, has to be traversed after crossing the Tungnaá at Vatnaöldur. Only the tracks from the last trip are available to indicate the trail over much of this route. This station was visited on July 8 and a streamflow measurement made about 3 kilometers above the station. The control for this station appears quite unstable but no stable control could be found in this general reach of the Thjorsa. This station is near the site of a future major storage project and it will require a lot of effort to determine the stage-discharge relationship here. This relationship may be expected to change each year, due to ice and flood conditions. It appears that an access road will have to be constructed and maintained, in order to successfully operate this gage and secure reliable discharges at Nordlingaalda. It may be possible to use a helicopter to make the many flow measurements that will be required for this station. Access roads and the use of helicopters are discussed later in this report.

r. No. 101 - Hvitá at Aboti. This station is located on the Hvitá below the mouth of the Jökulfall. It was inspected on June 22 and measurements made on the Jökulfall just above its mouth and on the Hvitá about a kilometer above the gage. The Hydrologist reports that severe ice conditions exist in the Hvitá at this station and winter records are very poor. He has located a better place for this gage some distance downstream. It is suggested that this station be moved to the new location as early as practicable. This station was constructed to provide an estimate of the flow available for potential projects in the rapids and gorge section of the Hvitá, where it flows around Blafell. However, the Grjótá, Sandá and other smaller streams enter this reach and additional ones enter below Blafell and above the gage at Gullfoss. None of these streams have gages, or are being measured now, principally due to the difficulty of reaching them and the Blafell section of the river. It is strongly suggested that a new access road be constructed along the east, or left, bank of the Hvitá from Gullfoss to Hvitárvatn. This would permit these smaller streams to be measured and a much more accurate determination made of the flows in the Blafell reach. Under present conditions only very approximate estimates are possible for the Blafell reach of the Hvitá. Access roads to this area are discussed later in this report.

s. No. 105 - Myvatn. This station is located on the principal outlet from Myvatn to the Laxá River. It was inspected and the water level recorder installed on July 22. Release from the lake through this outlet is controlled by two lift gates and one depressible tainter gate at headworks about 2 kilometers upstream from the gage. These headworks were operated so that three different stages and flows could be measured a short distance downstream from the gage. The headgates are operated by motors driven by electric power supplied by a Diesel motor-generator located at the headworks.

It was found that the gate keeper did not have any calibration on the gate stems so he could not tell how much he had the gates open, or closed. He does not have any way to estimate the quantity of water he is releasing, or how much is being released through a side sluice for a local power unit a short distance downstream. He does not maintain any record of his releases or of the lake level at the headworks. It is suggested that the gate keeper maintain a record of his gate operations and of lake levels at this outlet. It is also suggested that the gates be calibrated to show depth of opening and the quantity of water being released at all times. Future operation of this lake makes such records very necessary.

t. No. 106 - Power Plant at Grimsá. This installation is located on the Grimsá a short distance below the Grimsá Power Plant. It is serviced by the operator of that plant who uses it and his plant records to determine daily discharges for the Grimsá. It was inspected on July 26 and the determination of these discharges discussed with the Assistant Plant Operator.

This is a new plant and the Hydrologist has calibrated the spillway and gates and provided curves and tables from which discharges are determined from headwater readings. He has also provided similar tables, based on head and plant efficiency, for determining water flowing through the turbines. The operator observes a headwater gage located in the intake tower above the dam and makes these computations. He sends daily discharges once a month to the Hydrologist in Reykjavik.

Inspection of the headwater gage in the intake tower, however, showed it to be out of order. The float was jammed and incorrect readings were being recorded on the operating board in the power house. The Assistant Operator indicated that this condition had existed for considerable time. He explained that headwater levels were measured at frequent intervals and that the measurements were used instead of those indicated on the power board. He also said the Chief SEA Mechanic, from Reykjavik, was expected to visit the plant in the near future. He would be asked to repair this gage.

It is very important that this gage be repaired. It is part of the control system for the plant and is intended to sound an alarm in the power house when there is any sudden increase in headwater levels. The Operator must then operate the controls for the intake gates in the intake tower, to protect the plant. The jammed condition of this gage endangers the safety of the plant and could result in much damage to the turbines. It was suggested that immediate action be taken to have this gage repaired. Its condition was reported to the Authority in Reykjavik on July 28.

u. Locaction of New Streamflow Stations. Seven additional locations were selected during the survey for the installation of water level recorders on the following rivers:

no. 43 Bruara at Dynjandi
no. 49 Ytri Ranga at Hella
no. 60 Eystri Ranga near Keldur
no.102 Jökulsa á Fjöllum at Grimsstadir
no.108 Efri Bruara near Efstidalur
no.109 Jökulsa Fljótsdal
no.110 Jökulsá á Dal at Hjardarhagi

The first three of these, replace existing staff gages and the last four are at somewhat isolated locations where it would be difficult to secure gage readers and operate staff gages.

G. SUGGESTED IMPROVEMENTS

Organization Changes

Observation of the operations of the Hydrological Survey show that at present it has insufficient personnel to effectively and efficiently carry out its assigned tasks. The wide range of technical responsibilities assigned, the extensive area over which the Survey must operate, and the difficult terrane and severe weather conditions encountered, make it impossible for the Hydrologist to effectively carry out his responsibilities. Both he and his assistants are now working and travelling from 10 to 14 hours on many days. This impairs their efficiency and is still insufficient time to perform all the work required. This heavy work load requires the personnel, and particularly the Hydrologist, to spend most of the time in the field. This leaves very little time for office activities and there is a large accumulation of unprocessed station records. The large amount of field work, now being done by the Hydrologist, makes it impossible for him to be available in Reykjavik much of the time for consultation and for interpretation of the hydrological data collected. Much of these data will be needed in the near future for water resources studies and project planning and should be available when required. The following changes in organization are suggested to improve this situation:

a. Subdivision of Area. It is suggested that all of Iceland be subdivided along major drainage lines into seven Hydrologic Districts. The approximate limits of these districts are shown on Exhibit A. Each district would constitute a separate unit for operation under the general supervision of the Hydrologist. Existing and future streamflow stations in each district would be operated by the district instead of by the main office in Reykjavik.

b. Personnel. An Assistant Hydrologist would be selected and trained and then assigned to each Hydrologic District. He would be authorized to employ a local assistant at such times as necessary to assist in streamflow measurements, construction and repair of gaging stations, cableways, or other hydrologic activities. Each Assistant Hydrologist would be responsible for the work of the Hydrological Survey in his District but would be under the general supervision of the Chief Hydrologist in Reykjavik. He would be assigned the necessary equipment and transportation to carry out the work in his District. Hydrologic data collected in each District would be checked by the District Hydrologist and forwarded to Reykjavik for final check, interpretation, processing and publication.

An Assistant Hydrologist would also be secured and placed in charge of the final checking, processing, and publication of hydrologic records. He would be located in the Chief Hydrologist's office in Reykjavik and would assist the Chief Hydrologist in operating this office. He would be responsible for checking and filing all the original records received from the seven Districts and from other field activities. He would also assist the Chief Hydrologist in interpretation of data and in improvement of methods for data collection and processing. He would act for the Chief Hydrologist, during the latters absence from the office in Reykjavik.

The Chief Hydrologist would be responsible for the supervision of operations in the seven Districts. He would visit each of them as often as necessary and advise the Assistant Hydrologists in the solution of the problems in each District. He would supervise the final checking, compiling, interpreting, and publishing of all the data secured by the Hydrological Survey. He would interpret these data and be responsible for the preparation of technical memoranda and reports on various hydrologic problems. He would also be responsible for the selection, operation and maintenance of all equipment required by the Survey. When a Hydraulic Laboratory is established, the Chief Hydrologist would be responsible for its programs and operation.

This subdivision of work and the additional assistants are intended to greatly increase the data collecting and processing capacity of the Survey. They will permit much earlier development of stage-discharge relations and permit a decided increase in accuracy of daily discharge data. They will permit current publication of records and make them much more readily available for early use in water resources studies and planning. They will give the Chief Hydrologist more time for checking and interpretation of records and will make him available for consultation on the complex hydrologic problems of Iceland, when needed by planning and operating personnel.

Equipment Changes

A number of equipment changes are suggested to increase the efficiency and capacity of the Hydrological Survey. Generally the types of equipment now in use are satisfactory and have been selected to meet the particular problems of data collection in Iceland. Equipment suggested, is intended to supplement, or provide replacements, for that currently in use.

a. Transportation Equipment. The heavy truck and converted bus, now used by the Hydrological Survey, both date from near the end of World War II. They have had many repairs and replacement of parts. It appears that they may both become inoperative at any time. It is understood that local commercial trucks are suitable to transport most of the equipment moved by the 2 1/2 -ton truck. It is suggested that such equipment, either be supplied by other departments of the Authority when needed, or that the Hydrologist be given authority to rent such equipment when needed.

A four-wheel drive vehicle, with extra high clearance, is needed to transport men and materials to the more inaccessible parts of Iceland. Many trips are required to service and maintain the streamflow gages in these areas. Complete lack of eating and sleeping accommodations in such areas requires that camping facilities be carried on these trips. Stream gaging and other hydrological equipment must be transported in these areas. The converted bus, now in use, should be replaced. It is suggested that equipment using a Diesel motor be secured. A number of streams must be forded and Diesel equipment is much better suited for this purpose. Four-wheel drive is absolutely essential to movement through many of the lava, sand, ash, and cinder areas encountered. Extra high clearance is also essential to movement through these same areas. Space for two men to sleep in the vehicle is desirable but not absolutely essential. A carrying capacity of one to one and a half tons is necessary. It is suggested that the "Thames Trader", manufactured in England, be considered. Also that consideration be given to specially-built American vehicles designed for hunting and fishing. In any event provisions should be made for replacing the converted bus as early as practicable in order to prevent serious delays in the Hydrological Survey activities.

The Hydrologist should be furnished a Jeep station wagon, or a "Gypsy Austin" for use in inspecting and servicing the many activities of the Hydrological Service. At present he is using his own personal station wagon on many of these trips. A Jeep station wagon should be provided the Assistant Hydrologist in each District when it is organized. This transport will be necessary for him to inspect and service his stations and to make the many streamflow measurements that are so urgently needed. No additional transport will be needed by the Assistant Hydrologist who will become the assistant in Reykjavik.

b. Stream Gaging Equipment. The current meters, now being used, are admirably suited to use in Iceland streams. They are sturdy and suitable for the grass and sediment carried by these streams. It is suggested that cable suspension equipment, including hangers, cable, cable reels, meter cranes, and additional heavy weights, be secured for each of these meters. This will permit highwater measurements to be made from existing bridges and from future cableways. These highwater measurements are urgently needed to permit more accurate daily discharges to be determined. Use of these bridges and cableways will enable many meter measurements to be made in less than half the time now required by use of boats. They will also increase the safety and accuracy with which these measurements are made.

High velocities during floods and medium stages prevent streamflow measurements being made under these conditions with available equipment, at almost all stations. The above suggested changes in metering equipment will enable these to be made at the small number of existing bridges. Bridges are not available near many stations. It is suggested that single-cable cableways be designed and constructed at a considerable number of stations where they are badly needed. A satisfactory design for cableways has been developed by the United States Geological Survey. The theory and methods used in design of cableways are contained in U.S. Geological Survey Circular 17,[1)] dated September 1947 and available from that agency in Washington, D.C. Two copies of this Circular have been ordered for the SEA. Photostat copies of cableway installations in Lebanon and the United States have been supplied the Hydrologist.

[1)] Pierce, Charles H., - Structures for Cableways, Circular No. 17, United States Geological Survey, Washington D.C. September 1947.

c. Sediment Sampling Equipment. The collection of sediment samples, by the use of plastic bottles attached to a long rod, that is now being used, gives results that are often very misleading. It is very difficult to secure representative samples by this method and determinations of sediment concentrations are usually much too small.

One intergration-type Sediment Sampler, P-43, is now available. However, no equipment for suspending it in the water is available and it cannot be used until these necessary accessories are obtained. These consist of suspension cable, suspension bar, and a reel to handle the cable and raise and lower the heavy sampler. It is understood that glass bottles for use in the sampler are also lacking.

It is suggested that the required accessories for equipping the available sampler be secured at the earliest practicable date and this sampler placed in active use. It is also suggested that at least one additional sediment sampler, P-43 type, be secured and placed in operation at an early date.

d. Snow Measuring Equipment. The water equivalent in snow on the ground is understood to be determined in Iceland by collecting a snow sample, melting it, and measuring the water released. Snow sampling equipment have been developed in the United States and are used extensively in snow surveys in Western States by the Soil Conservation Service, Department of Agriculture. This consists of a light-weight, sectional, metal sampling tube, about 3 centimeters in diameter, and a pair of spring scales for weighing the tube and its snow sample. The metal tube is in about 1-meter sections, for ease in carrying. It is quickly assembled and is pushed down through the snow cover to obtain representative samples. The scales are small and easily carried in parka pockets. The sections of the tube are weighed when empty and when filled with the snow sample. The difference in weight is that of the sample and this can easily be converted to water content by applying a specific gravity factor. Use of this sampler decreases the time required to make snow surveys as well as increasing their accuracy. It is suggested that at least one set of snow sampling equipment be procured before the next snow survey season.

Sediment Sampling Program

The accurate estimating of potential sediment deposition in storage reservoirs and power pools is a most important factor in the planning and design of these power facilities. This can only be accomplished if an organized sediment program be undertaken and adequate equipment provided. Sediment samples, to be representative of the load transported, must be taken at a wide range of stages. They must also be taken at various depths in the vertical section to determine vertical, as well as horizontal, sediment concentrations. Sufficient samples must be secured at each sampling station to permit sediment-discharge relationships to be established over the full range of stages and discharges.

No satisfactory method has yet been developed for accurately determining bedload movement. Various types of weirs and catch basins have been developed to try to secure representative samples of this form of sediment transport. These have only been partially successful when used on relatively small streams with low to moderate slopes. None of these appear applicable to stream conditions in Iceland. Here the streams are steep, velocities are high, and many of the rivers in the northern and eastern sections, move in channels carved in valleys that have been refilled by glacial material. Bed load material is also moved extensively by ice in many of the rivers, and its movement is often affected by the forming and breaking of many ice barriers each spring. It will constitute a rather large proportion of material that will be moved and deposited each year in storage reservoirs. Methods for estimating movements in this type of material must be devised for use in Iceland.

An organized sediment measuring program is badly needed in Iceland, to provide data at an early date for designing storage reservoirs. It is suggested that such a program be initiated as early as practicable. It is suggested that suspended sediment samples be taken at as many stage intervals as possible at each of the following locations:

Thjorsa at Urridafoss Bridge
Thjorsa at Trollkonuhlaup Bridge
Tungnaa at Hald (cableway recommended)
Kaldakvisl at Saudafell (cableway recommended)
Hvita at Bruarhlod Bridge
Hvita at Aboti (cableway recommended)
Hvita at Hvitarvatn Bridge
Tungufljot at Faxi Bridge
Jökulsa á Fjollum at Grimsstadir Bridge.

It is suggested that a reach of each river, several kilometers long, be selected near the upper end of each proposed reservoir, for a survey of bed load movement under natural conditions. Cross sections of the channel and both banks of the river would be selected, surveyed, and their ends carefully marked on the ground. These sections would be resurveyed at least twice each year, once in the spring before glacier melt water starts to flow, and again later in the fall when most of the melt water flow has ceased. The changes in the cross-sectional areas of these sections will represent the approximate movement of bed load material. These areas, multiplied by the lengths of river they represent, will give an approximation of the quantity of material moving. These qualities should be reduced somewhat, to compensate for the suspended material that may have deposited in the reach. Judgment will have to be employed in estimating the reductions to be made. The following reaches are suggested for bedload study:

Thjorsa - Upper End of Nordlingaalda Reservoir
Tungnaa - Upper End of Lower Tungnaa Reservoir
Hvita - Above Aboti Streamflow Station
Hvita - Upper End of Hestvatn Reservoir.

Bedload samples should be taken, during low water, from the channel and from along both banks in the reaches being studied. These samples should be representative of the materials found in the reaches and should be about 20 to 30 kilograms in size. These should be carefully analyzed by sieving methods in the laboratory and all their particle sizes and size distribution determined. The larger rocks, retained on the largest opening sieve, should have their smallest diameters measured and recorded. Samples should be taken and analyzed each time the cross sections are re-measured in each reach. The results of these analyses should be correlated with flows in the rivers and with the results obtained from suspended material samples.

Access Roads

Gaging stations, located in the upper portion of the Hvita and Thjorsa Rivers, are very difficult to reach under present conditions. These include the following gaging stations:

No. 57 - Hvitarvatn - Hvita River
101 - Aboti - Hvita River
100 - Nordlingaalda - Thjorsa River
94 - Thorisos - Thorisos
95 - Saudafell - Kaldakvisl
96 - Vatnaoldur - Tungnaa
98 - Hald - Tungnaa

Two alternative methods are suggested to permit better access to these gages and thereby improve the records obtained at these important locations. The first and preferable method would be use a heliocopter to visit these stations. A single trip, requiring from 1 to 2 days, would be sufficient to permit visiting all 7 of these stations for changing their records and winding the clocks on the gages. To insure continuous operation and good records, one trip a month should be made for this purpose. Additional trips should be made to each of them at various times during the year to permit measuring their streamflow variations and developing reliable stage-discharge curves. Measuring equipment including a small boat, could be transported by the heliocopter at the same time as the measuring party was transported. This method would save a great deal of time for the hydrologist and for the measuring party. These trips would each require not more than two days. At present it requires a minimum of six days to visit these seven stations just to wind the clocks and change the records. Additional time is required to do this in the period from November to April. Under present conditions these stations are inaccessible by truck during part of this period each year.

The second alternative is the construction of additional roads and bridges to improve access to these stations. This sonstruction would improve access during summer but would have little benefit during winter and spring. This road construction would consist of a new road from Burfell to the Tungnaa at Hald; a bridge across the Tungnaa at Hald; a new road from Hald to a bridge across the Kaldakvisl gorge, about 4 km below the mouth of Thorisos; a bridge across the Kaldakvisl gorge and a new road from the bridge to the Thorisos gage and to the Saudafell gage on the Kaldakvisl; and a new road from near the Kaldakvisl bridge to the Nordlingaalda gage on the Thjorsa.

The new road from Hald to the Kaldakvisl bridge would extend north between the Thjorsa and the Kaldakvisl and would generally follow the Kaldakvisl. This road from Burfell, via Hǫld, would have a length of about 60 km to the Thorisos gage; about 65 km to the Saudafell gage; and about 70 km to the Nordlingaalda gage on the Thjorsa. The present route from Burfell via the ford over Tungnaa at Vatnaoldur is about 90 km to Thorisos; about 95 km to the Saudafell gage on Kaldakvisl; and about 120 km to Nordlinga-alda.

The proposed new road would reduce the distance to the Thorisos and to the Saudafell gages by about 30 km; that to Nordlingaalda by about 50 km. The distance of about 40 km to the Vatnaoldur gage would remain the same. One of the main advantages of the new road is, that it would eliminate the dangerous ford over the Tungnaa near Vatnaoldur. This ford is not only dangerous to cross but is difficult as well. It is impassable at stages very much above low water. Ice conditions at this ford are very bad and much of the time in winter it is impassable by snowmobile.

The new road with a bridge over the Tungnaa at Hald would be most useful to the farmers. There are vast grass areas between the Thjorsa and the Kaldakvisl and north of the Tungnaa. In order to use these, sheep have to be taken across the Tungnaa in boats. This is a very slow and expensive process, especially since it must be done at least twice a year. A bridge at Hald would eliminate this expense and would make this vast grass area readily available for grazing.

This new road would be quite scenic and would offer additional tourist attractions, such as the gorge and falls on the Kaldakvisl. There are distant views of both Vatnajokull and Hofjokull. It appears likely that this road may later become part of an alternate central road to connect Reykjavik and Akureyri.

The bridge across the Tungnaa at Hald is the only expensive item on this proposed road. It is believed that a number of the above interests, that would benefit by it, might very well cooperate and share in the cost of the construction of this bridge. The bridge across the gorge of the Kaldakvisl, below the Thorisos, would be only 12 to 13 meters long and would be only moderately expensive.

The other access road proposed is a new road on the east side of the Hvita River from the lower end of the Gullfoss Gorge to Hvitarvatn. At the present time the road between these points is situated on the west side of Hvita and passes to the west of Blafell. It must however climb over the pass between Blafell and Geldingafell. Oftentimes in winter this pass is blocked with snow and this road cannot be used. Also a minor tributary of Hvita must be forded on the south side of Blaufell and this portion of the present road is impassable in spring and early summer.

The new road suggested along the east side of the Hvita would require relatively short bridges across the Sanda and the Grjota and a major bridge over the Jokulfall. Only this latter bridge would be particularly expensive. The grades on the new road would be low and its location would insure little interference from snow in winter. It is believed it could be used in all seasons of the year.

There are five potential power project sites in the section of the river around the foot of Blafell. At the present time all of these, except the lower and upper one, are inaccessible, except on ponies during the summer. The same is true of the sites on the Sanda and the Jokulfall. The new road would pass near all these sites and make them readily accessible for investigation and study. In addition to providing access to these sites, it would later serve as the access road during their construction and for their operation. Its early construction would permit the securing of much needed hydrologic data on profiles and flood heights in the Blafell reach of the Hvita. The inaccessibility of this section of river makes it almost impossible to secure these data at this time.

The route up the Hvita has been selected as the North-to-South route across Iceland. This new road would become a portion of this main route and would provide the best route through the Blaufell area. It would use the existing Hvita bridge below Gullfoss and a new crossing over this river would not be necessary. The distance between Gullfoss and Hvitarvatn would be approximately the same by either route, or about 40 kilometers. The new route would provide an easier tourist route to Hvitarvatn and to Langjokull. It is suggested that it be constructed at an early date.

Streamflow Measurements

It is believed that considerable time can be saved in making discharge measurements on Iceland streams by a change in the methods used in tabulating the data and in making the calculations for the discharge. Additional time can be saved by a reduction in the number of current meter, readings required for each vertical section. These changes can be made without sacrificing any appreciable accuracy in determining stream discharges.

The following proposed changes in method are based upon about 70 years of experience by the United States Geological Survey, in determining stream discharges in many of the rivers in the United States. They are essentially the methods employed by that agency and have become standardized after extensive study of the problem and of the huge mass of measurement data collected from many types of rivers.

a. Velocity Measurements. Analysis of many vertical velocity curves has shown conclusively that the average of the velocities, measured at 0.2 and 0.8 of the total depth, is very closely equivalent to the mean velocity determined from measuring a much larger number of points in a vertical. This is true for all sections where the depth is one meter or greater. For depths less than one meter, the velocity measured at 0.6 depth is equivalent to the mean velocity in the vertical. Adoption of this change in the number of points measured in the vertical, will reduce the time required to measure each vertical to about 25 percent of that required by the method being used in Iceland. It is suggested that this change in method be adopted.

b. Discharge Computations. The attached Form A has been designed to show the measurement data taken during each measurement, as well as the entire calculation for determining the discharge. It is modelled very closely after a similar form developed and used by the United States Geological Survey for this same purpose. The main difference

FORM A

DISCHARGE MEASUREMENT

No. 1

Tungnaá.........River
At .....Hald.........
Date June 15,1961 Hours...
CORRESPONDING GAGE HT........

Meter
Type............
No..............
By S.R. &......

Dist. from I.P.	AREA OF SECTION				VELOCITY IN SECTION								
	Width	Depth at Vert.	Aver. Depth	Area of Sect.	0,2 DEPTH			0,8 DEPTH			Aver. Vert. Veloc.	Mean Sect. Vel. Kl/s	Disch.
					Sec-onds	Revel olut.	Vel. Kl/s	Sec-onds	Rev.	Vel.			
m	m	cm	cm	m^2									m 3/s
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
3		0					0			0	0		
	2		37,5	0,75								23,5	0,18
5		75					56			38	47,0		
	5		122,5	6,12								61,2	3,75
10		170					94			54	74,5		
	5		240,0	12,00								69,5	8,32
15		310					76			52	64,0		
	5		362,5	18,12								110,0	19,80
20		415					173			140	156,5		
	5		420,0	21,00								172,3	36,20
25		425					200			178	189,0		
	5		411,0	20,55								164,8	33,80
30		397					176			105	140,5		
	5		366,0	18,30								165,8	30,30
35		335					222			160	191,0		
	5		325,0	16,25								188,0	30,50
40		315					212			158	185,0		
	5		315,0	15,75								174,5	27,40
45		315					194			134	164,0		
	5		291,5	14,58								152,0	22,50
50		268					156			124	140,0		
	5		261,5	13,08								131,5	17,15
55		255					146			100	123,0		
	5		242,5	12,12								119,0	14,40
60		230					144			86	115,0		
	5		237,5	11,88								121,0	14,35
65		245					144			112	128,0		
	5		222,5	11,12								127,5	14,20
70		200					140			116	128,0		
	5		187,5	9,38								123,5	11,60
75		175					150			88	119,0		
	5		155,0	7,75								119,5	9,25
80		135					154			86	120,0		
	5		121,0	6,05								107,2	6,50
85		107					112			77	94,5		
	5		76,0	3,80								70,8	2,69
90		45					56			38,5	47,2		
	3		22,5	0,68								23,6	0,16
93		0					0			0	0		

TOTAL Q 302,85

in this form and that used by the Geological Surwey is in the size of the sheet of paper used in each case. Form A is designed for a standard-size sheet of paper for ease in filing. That of the Geological Survey is about one half this size to simplify handing in the field. This larger sheet is recommended.

Blank copies of Form A should be printed on a good grade of paper to withstand rough handling in making the measurement. Copies should be fastened on a clip-board, so that meter-data can be entered on them, by the measuring party, at the time the readings are made. The following data should be entered on Form A at the time each measurement is made:

Column 1 - Distance in meters from initial point of measurement.

Column 3 - Total depth in centimeters of each vertical, where velocities are measured.

Columns 6 & 9 - The number of seconds, as measured by the stop watch, during which current meter revolutions were counted at 0.2 and 0.8 of the depth in the respective vertical.

Columns 7 & 10 - The number of revolutions of the current meter that were counted during the times in seconds shown in Columns 6 and 9, respectively.

These six columns and the heading on Form A are the only data that need to be entered on the form in the field at the time the measurement is made. The remainder of the columns show data that are derived from the above six columns and from the rating equation, or table, for the current meter used. They can be entered in the office, or at any convenient time after the measurement is completed.

Most of the headings on Form A are self-explanatory. The leaving of a blank line between each of the data entered in Columns 1, 3, 6, 7, 9 and 10 in the field greatly facilitates the computations on Form A. For instance the "Width" of each subsection between verticals is obtained by subtracting consecutive items of distance, shown in Column 1. The "Widths" are entered on the next blank line in Column 2. Likewise, the "Average Depths" for each subsection are determined by averaging the "Depth of Verticals" shown in Column 3 and are entered in Column 4 on the corresponding blank line between the items in Column 3. This results in the "Width" and "Average Depth" of each subsection being on the same line of Form A. They can be easily multiplied together to obtain the "Area of Section", which is entered on the same line in Column 5.

Velocity data for the 0.2 and 0.8 depths at each vertical are entered on the same line, as the "Distance from I P" shown in Column 1, but in Columns 6 to 11. The data determined by the Current meter and shown in Columns 6 and 7 and in 9 and 10 can be quickly converted to velocity in centimeters per second by application of a meter Rating Table like that shown in Exhibit B. This table was computed from the rating equations determined when the meter was rated. It must be revised each time the meter, to which it pertains, is rerated. Its use saves considerable time in the determination of velocities over that required to compute each item from the equations.

The velocities shown in Columns 8 and 11 can be readily averaged and entered on the same line in Column 12. This becomes the "Average Vertical Velocity". The mean of these "Average Vertical Velocities", shown in Column 12, is determined and entered in Column 13 on the blank line between them and is the "Mean Section Velocity" for each subsection.

The "Area of Section" in Column 5 and the "Mean Section Velocity" in Column 13 are on the same line for each of the subsections formed by the verticals. These values are multiplied together and the product, corresponding to the discharge through the subsection, is entered on the same line in Column 14. These values in Column 14 are summed up and entered at the bottom of Column 14 on Form A. This

EXHIBIT B

RATING TABLE
METER NO. 5
STOPPANI 45 66
Résultats du tarage 14.5.1948

D.E.D. 5/7/61

TIME IN SECONDS	50	100	150	200	250	300	350	400	450	50
				VELOCITY IN CM/SEC.						
120	16,8	27,2	37,2	48,0	58,4	68,9	79,3	89,7	100,1	110,5
119	16,9	27,4	37,9	48,4	58,9	69,4	79,9	90,4	100,9	111,4
118	17,0	27,6	38,2	48,8	59,4	70,0	80,6	91,2	101,8	112,4
117	17,1	27,8	38,4	49,1	59,8	70,5	81,2	91,8	102,5	113,2
116	17,2	27,9	38,7	49,5	60,2	71,0	81,8	92,6	103,3	114,1
115	17,3	28,1	39,0	49,9	60,7	71,6	82,5	93,4	104,2	115,1
114	17,4	28,3	39,3	50,2	61,2	72,2	83,1	94,1	105,0	116,0
113	17,5	28,5	39,6	50,6	61,7	72,8	83,8	94,9	105,9	117,0
112	17,6	28,7	39,9	51,0	62,2	73,4	84,5	95,7	106,8	118,0
111	17,7	28,9	40,2	51,4	62,7	74,0	85,2	96,5	107,7	119,0
110	17,8	29,1	40,5	51,8	63,2	74,6	85,9	97,3	108,6	120,0
109	17,9	29,3	40,8	52,2	63,7	75,2	86,6	98,1	109,5	121,0
108	18,0	29,5	41,1	52,7	64,2	75,8	87,4	99,0	110,5	122,1
107	18,1	29,8	41,4	53,1	64,8	76,5	88,2	99,8	111,5	123,2
106	18,2	30,0	41,8	53,6	65,4	77,2	89,0	100,7	112,6	124,3
105	18,3	30,2	42,1	54,0	65,9	77,8	89,7	101,6	113,5	125,4
104	18,4	30,4	42,5	54,5	66,5	78,5	90,5	102,6	114,6	126,6
103	18,5	30,7	42,8	54,9	67,0	79,2	91,3	103,4	115,6	127,7
102	18,6	30,9	43,2	55,4	67,6	79,9	92,2	104,4	116,6	128,9
101	18,8	41,1	43,5	55,9	68,3	80,6	93,0	105,4	117,7	130,1
100	18,9	31,4	43,9	56,4	68,9	81,4	93,9	106,4	118,9	131,4
99	19,0	31,7	44,3	56,9	69,6	82,2	94,8	107,4	120,1	132,7
98	19,2	31,9	44,6	57,4	70,2	82,9	95,6	108,4	121,2	133,9
97	19,3	32,2	45,0	57,9	70,8	83,7	96,6	109,4	122,3	135,2
96	19,4	32,4	45,4	58,5	71,5	84,5	97,5	110,6	123,6	136,6
95	19,6	32,7	45,8	59,0	72,2	85,3	98,5	111,6	124,8	137,9
94	19,7	33,0	46,3	59,6	72,9	86,2	99,5	112,8	126,1	139,4
93	19,8	33,3	46,7	60,2	73,6	87,0	100,5	113,9	127,4	140,8
92	20,0	33,6	47,1	60,7	74,3	87,9	101,5	115,0	128,6	142,2
91	20,2	37,9	55,7	73,5	91,2	109,0	126,8	144,6	162,3	180,1
90	20,4	38,3	56,2	74,2	92,2	110,1	128,0	146,0	164,0	181,9
89	20,6	38,7	56,8	75,0	93,2	111,4	129,5	147,7	165,8	184,0
88	20,8	39,1	57,5	75,8	94,2	112,6	130,9	149,3	167,6	186,0
87	21,0	39,5	58,1	76,7	95,2	113,8	132,4	151,0	169,5	188,1
86	21,2	40,0	58,7	77,5	96,3	115,1	133,9	152,6	171,4	190,2
85	21,4	40,4	59,4	78,4	97,4	116,5	135,5	154,5	173,5	192,5
84	21,6	40,9	60,1	79,4	98,6	117,8	137,1	156,3	175,6	194,8
83	21,9	41,3	60,8	80,3	99,8	119,2	138,7	158,2	177,6	197,1
82	22,1	41,8	61,5	81,2	101,0	120,7	140,4	160,1	179,8	199,5
81	22,4	42,3	62,2	82,2	102,2	122,1	142,0	162,0	182,0	201,9

V = 12.50 + 0.064

V = 3232 + 0.024

total is the total discharge through the entire measured section.

The completed Form A forms the basis for the entry to be made on the record of measurements form now in use. These completed Form A's should be filed along with the other data pertaining to the station to which they refer.

Stage-Discharge Curves

Examination of available measurement data indicates that they are barely sufficient at many stations to determine a very approximate stage-discharge relationship. Daily discharges, determined by use of these curves, should be considered as preliminary estimates only. It is strongly suggested that every effort be made to secure many additional streamflow measurements at all stations. It is also suggested that these be made at as many stages of the streams as possible. There are no available methods for stage-discharge curve extensions that can give results that compare with those secured from actual measurements.

Extension of Stage-Discharge Curves

A number of devices have been used to secure approximate extensions of stage-discharge curves. All extensions made by these mthods are approximate and should be so marked on the curves. The methods include transferring the portion of the curve from actual measurements to semi-logarithmic graph paper; the shifting of scales on this type paper; the determination of the equation of the portion developed from measurements, and assuming it to apply to all higher stages; and a simple extension by visual projection of the low-stage portion of the curve. Few streams have high-water, or flood channels, that have the same characteristics as those for low-water. Consequently the stage-discharge curve is not a simple curve for all stages but a complex, compound, one in most cases. It is this characteristic of these curves which prevents them from plotting as straight lines on semi-log, or on log paper. It is this same factor which results in entirely different equations for various sections of the stage-discharge curve, and makes it generally impossible to use the equation determined for the lower section, to determine flows for high stages.

Approximate high-flow values for discharge may be computed by use of the Manning Formula, or other open channel formulas and field survey data. These formulas result in only approximate values, due to changes in slopes and roughness values with change in stage, and the difficulty of determining these values accurately by field surveys. Computed points should only be used as approximate checks on stage-discharge curve extensions.

It is suggested that until sufficient streamflow measurements are made, that stage-discharge curves be extended by visual projections, and all flows determined from these extensions be marked as "Estimated". Later when these higher portions of the curves are determined by measurement data, all estimated discharges should be reviewed and revised by use of the new curves.

Comparison of Station Records.

Severe climatic conditions, ice interference and normal water level recorder problems, result in a number of periods when no records are obtained. These periods require discharge estimates to be made, to determine total volume for the months and years. It is suggested that estimates be made by comparison of station records from nearby streams. Care must be taken however to insure that only records from streams having essentially the same characteristics are used. For example glacial streams should be compared with other glacial streams and not with spring-fed streams.

There are a number of ways for making such comparisons. One is to develope a correlation equation from past records at the two stations. In the rivers of Iceland such equations may have to be developed for each month of the year, or on a seasonal basis. Another method is to plot a double mass, or summation curve, using flow summations for the two stations as ordinates and abscissa, corresponding to the same time at both stations. Currently such daily summations are included in "Streamflow Data" compiled for each station. The slope of the double mass curve indicates the general relation between the discharges at the two stations. Changes in this slope indicate a change in such relationship. All major changes in slope should be checked in detail. They may indicate a change in gage location, zero elevation, channel control, or an error in stage observations at either, or both, stations. It is suggested that this method be used to determine the relationship between discharges at various stations for estimating flows during missing periods of record.

It is important in water resources studies, that all periods when discharges are estimated, be known to the investigator. It is suggested that a method be devised so that all estimated flows be so indicated on the IBM tabulations of streamflow data.

Flood Routing Procedure

Flood routing is a complex computational procedure, whereby streamflow recorded at an upstream station, or water released from a reservoir, can be used to determine the shape and characteristics of a hydrograph, that may be expected to occur at a downstream point. The methods have been devised to take into account the effect of channel, or natural storage, in the reach of river between the two points. They also provide means of evaluating the effects of local inflow, and tributary stream contributions into the reach. A more complete discussion of this complicated procedure, the methods used, the field data required, and the results to be obtained are contained in Appendix I.

Hydroelectric Power System Studies

Operation of two or more hydroelectric plants in an interconnected system require a number of operation studies to determine the best order in which to use the water available. This study becomes more complex as more plants are included. The use of storage reservoirs to regulate flows further adds to the complexity of this type of investigation. These computations require the development of operation curves for storage releases, capacity curves for reservoirs, assumed power plant capacities, tailwater and headwater curves, and a number of other relationship curves. They also require detailed discharge estimates at each plant site for critical low-water, average, and highwater years. All of these computations are time-consuming and many trials must be made before the best solution is obtained.

The Corps of Engineers, U.S. Army; the U.S. Bureau of Reclamation; and the Bonnwille Power Administration, have all made such system operation studies in the United States. Recently electronic computers have come into use in the United States and can be used to advantage in the solution of this problem. Programs for its solution have been developed by one or more of the above agencies. It is suggested that when power operation studies become necessary in Iceland, that one of the above agencies be requested to furnish an electronic computer program for the solution of this problem.

Flood Frequency Studies

Statistical methods have been devised to estimate the expected recurrence of past flood events on streams.

These generally treat each past occurrence as a chance random event. The end product of these determinations is to indicate that a flood of a given magnitude has a likelihood of being equalled or exceeded a given percentage of the time. Another way of saying it is, that a flood of a given magnitude may be expected to occur once in a given number of years.

A period of at least 20 years of record is the minimum period that should be used for computation of flood frequency by any of the statistical methods. Much longer periods of record are desirable to give even reasonable results. The short periods of record on Iceland streams are much too short for results to be reliable or even significant. It is strongly suggested that determination of flood frequencies be deferred until at least 20 years of continuous record become available.

Hydraulic Laboratory

There is a need for a hydraulic laboratory in Iceland in the very near future. The development of the vast hydroelectric potential will require the continuing design and construction of a large number of dams, spillways, tunnels, outlet works and other hydraulic structures. Many of the plants will have moderate to high heads, and the topography and geology of the country will necessitate the solving of a number of difficult and somewhat unusual hydraulic problems. The successful solution of such problems will require the use of hydraulic models.

The harbors of Iceland are gradually filling with sediment from the rivers that enter them, as well as from material deposited in them by tides and littoral currents. Serious dredging problems have developed in the maintenance of these harbors and their entrance channels. The use of hydraulic models will often result in great savings in harbor and channel maintenance.

An unusual sediment problem exists in Iceland. Many of the rivers are of glacier origin and transport large quantities of glacier flour produced by the movements of the ice. A hydraulic laboratory study may be very necessary to devise means of measuring and handling of this type of material, to prevent excessive filling of storage in potential reservoirs. Data are also badly needed to determine the effect of this material on the operation of hydro turbines and the scour to be expected from it on turbine blades. Many of the rivers in Northern Iceland are flowing in glacier-cut valleys that have been refilled since the last Ice Age. These will present many foundation problems for dams and other structures. A laboratory analysis of foundation materials will help solve some of these problems.

A hydraulic laboratory would provide a most useful tool for basic research that might be undertaken at the Unicersity of Iceland. It would do much to increase the standing of the University and might be the impetus needed to encourage the University to expand their engineering work and grant degrees in engineering. It might also provide the necessary research facility, so that graduate work in basic hydraulics could be undertaken.

The nearest hydraulic laboratories available to Iceland are located in Norway, Sweden, Germany and the United States. It would be much more economical, as well as practicable, to have one here in Reykjavik. It would permit studies of hydraulic structures, maintenance of harbors, sediment problems, and basic research to be carried out in Reykjavik where basic data would be readily obtainable. It would also permit all of the current meters to be quickly re-calibrated and save the considerable expense of sending them to Sweden for this work.

It is suggested that the SEA design and construct a laboratory for the solution of hydraulic problems. It is also suggested, that the SEA, the University of Iceland, and other government agencies cooperate in this undertaking.

H. RECOMMENDATIONS

At the request of the Director General, State Electricity Authority, the suggestions made in this report have been considered and relative priorities are indicated for carrying out these suggestions. A number of these suggestions will involve only small expenditures of funds and have been included for accomplishment in 1961. Those requiring much larger expenditures are shown for 1962 and 1963. All of those listed are necessary for the successful operation of the Hydrological Survey and are recommended for adoption as early as funds can be secured.

Improvements for 1961

a. Subdivision of Iceland into Hydrologic Districts

b. Select and train an Assistant Hydrologist for Reykjavik Office

c. Purchase suspension equipment for current meter and sediment sampler.

d. Design and construct cableways for measuring streamflow at the following gages:

   Thjorsa at Krókur
   Thjorsa at Búrfell
   Tungnaa at Hald
   Tungnaa at Vatnaöldur

e. Review the need for all existing streamflow stations and discontinue those no longer needed.

f. Initiate suggested charges in methods for streamflow measurements and discharge computation.

f. Initiate studies and designs for a Hydraulic laboratory to serve various agencies in Iceland.

h. Include extra funds in 1962 Budget to make improvements scheduled for that year.

Improvements for 1962

a. Select and train three Assistant Hydrologists to take over operations of Hydrological Survey in Districts III, V, and VI. Also take over temporarily operations in District IV.

b. Provide heliocopter transportation to service and operate seven stations now nearly inaccessible in the upper portions of Hvita and Thjorsa basins.

c. Purchase a Thames Trader to replace the converted bus, to insure much needed transportation in Hvítá and Thjórsá basins in District I.

d. Provide heavy transport for short intermittent periods of station construction either by existing transportation vehicles or through local hiring of non-Government vehicles.

e. Provide a Gipsy Austin for the Chief Hydrologist to use for inspection and supervision in all the Hydrologic Districts.

f. Provide jeeps for transport in Districts III, V and VI to permit Assistant Hydrologists selected, to operate.

g. Design and construct the additional cableways suggested.

h. Initiate a systematic sediment measuring program.

i. Complete studies and designs for Hydraulic Laboratory.

j. Include extra funds in 1963 Budget to make improvements scheduled for that year.

<u>Improvements for 1963</u>

a. Select and train two Assistant Hydrologists to take over operations of Hydrological Survey in Districts II and IV,

b. Provide jeeps for transport in Districts II and IV to permit Assistant Hydrologists selected, to operate.

c. Construct Hydraulic Laboratory and secure staff for its operation.

d. Design and construct access roads to upper portions of Hvítá and Thjorsá basins to facilitate better data collection and the field investigations of potential projects.

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