PROJECT PLANNING REPORT

VOLUME II
APPENDICES

BURFELL PROJECT

BY THE

HARZA ENGINEERING COMPANY INTERNATIONAL

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FOREWORD

This Volume II presents four appendices incorporating technical detail which formed the bases for the engineering planning of the Burfell Hydroelectric Project as presented in Volume I. The first three appendices are intended principally for technical specialists in hydrology, engineering geology, and construction materials. The fourth presents a project plan for initial storage development at Thorisvatn.

Appendix A presents a review of the fifteen years of discharge records on the Thjorsa at Urridafoss. This is followed by the development of estimated discharges through the same period for the Thjorsa at Burfell, the Tungnaa at Vatnaoldur, the Kaldakvisl at Saudafell and the Thorisos at Vad.

Appendix B presents the engineering geology important to hydroelectric development in the Thjorsa Basin. A presentation of the general geology of the entire Basin is followed by a specific discussion of the geology pertinent to the engineering of the Burfell Project.

Appendix C presents the results of the field investigations for natural construction materials in the general vicinity of the Project. This is followed by the analyses of the laboratory tests accomplished on samples selected from the more promising deposits.

Appendix D presents a Project Plan for the development of a small initial seasonal storage at Thorisvatn. This storage might prove beneficial to ice control and to flow regulation for energy production at the Burfell Project.

APPENDIX A

HYDROLOGY

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APPENDIX A

HYDROLOGY

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CHAPTER A-1

GENERAL

Description of Thjorsa Basin

The Thjorsa Basin is shown on Exhibit A-1. The Thjorsa originates in the broad gathering grounds of the two glaciers, Hofsjokull and Vatnajokull. From the high plateau of the glaciers, the Thjorsa flows southwest about 230 kilometers and enters the North Atlantic Ocean, draining an area of 7530 square kilometers and dropping about 600 meters in the course of its travel. The Tungnaa, which originates from the Vatnajokull glacier and drains an area of about half the entire Thjorsa Basin, is its only major tributary. Minor tributaries are the Fossa, Dalsa, Kisa, and Svarta.

The climate in the Thjorsa Basin is typical of the climate of Iceland, in that it is dominated by air masses of maritime polar origin during both the summer and the winter. The effect of these air masses is to keep winter temperatures relatively mild and summer temperatures relatively cool. Spring and summer seasons are of light precipitation with the greatest amount of precipitation falling during the fall and early winter months. The precipitation on the higher slopes is considerably heavier than at the lower areas near the south coast. The mean annual precipitation in the Basin is estimated to vary between 800 and 3600 millimeters, depending primarily on altitude.

At the Haell Meteorological Station, located at about 130 meters elevation in the lower reaches of the Thjorsa Basin, the normal annual precipitation is 955 millimeters. The normal annual mean temperature at the Haell Station is 3.7°C. The observed extremes of daily maximum and minimum temperatures recorded at Haell are 24°C and 17.6°C, respectively. Exhibit A-2 is a tabulation showing the normal mean monthly precipitation and temperatures at the Haell and Reykjavik Meteorological Stations.

The Thjorsa flow varies considerably from summer to winter and to a lesser degree from day to night, directly reflecting the temperature changes which take place at the glaciers. The maximum runoff usually takes place in May when the winter snows are melting, and the minimum runoff occurs in late fall or early winter. In the winter, the river is subject to flooding which may be caused by rainfall coinciding with intensive snow melting. The maximum recorded daily flow on the Thjorsa at Urridafoss, 2230 cubic meters per second, occurred in the winter of 1953. A minimum of 81 cubic meters per second occurred in December 1952.

The annual runoff is high in comparison with the drainage area. The average annual flow of the Thjorsa at Urridafoss (drainage area 7200 square kilometers) is 380 cubic meters per second. This is twice the average annual runoff of 190 cubic meters per second recorded for the Jokulsa at Dettifoss, located in the northern half of Iceland, which drains almost an equal drainage area.

Streamflow Records

The streamflow stations in the Thjorsa Basin are shown on Exhibit A-1. The most reliable index of the streamflow of the Thjorsa is the records collected at the Urridafoss gaging station. This station is located about 20 kilometers from the mouth of the river.

Prior to 1958, there were no streamflow records in the upper reaches of the Thjorsa Basin. However, since 1958, seven new stream gaging stations have been established on the Thjorsa and its key tributaries. Records at these new stations, although of short duration, are valuable in appraising the streamflow resources at potential power sites. The streamflow records at the new stations, which range from two to four years, were found to correlate fairly well with the long established records at Urridafoss. The location of several key gaging stations in the adjacent Hvits Basin, which were utilized for correlation purposes, also are shown on Exhibit A-1.

The stream gaging stations utilized either directly or indirectly in determining the water and power capabilities of the Burfell Project and the power potentialities at other key sites as they relate to the initial and ultimate development at Burfell are listed in Table A-1. The listing gives the station number, name and location of the station, the drainage area, and the number of complete water years of record. The water year, or hydrologic year, is defined as extending from September 1 through August 31 of the year following. All stations were equipped with continuous automatic water-stage recorders by 1962.

A preliminary review of the available streamflow data indicated that some of the records were subject to fairly large errors, particularly during the critical low flow periods. Accordingly, extensive review was made of all pertinent records in the Thjorsa Basin, which resulted in

TABLE A-1

Streamgaging Records - Thjorsa and Hvita Basins
Utilized in Burfell Project Studies

Station No.	Name and Location of Gaging Station	Drainage Area (square kilometers)	Years of Record Available
	THJORSA BASIN		
97	Thjorsa at Trollkonuhlaup	6380	2 years 1960-61 to 1961-62
94	Thorisos at Vad	330	4 years 1958-59 to 1961-62
95	Kaldakvisl at Saudafell	1120	2 years 1960-61 and 1961-62
96	Tungnaa at Vatnaoldur	1350	3 years 1959-60 to 1961-62
30	Thjorsa at Urridafoss	7200	15 years 1947-48 to 1961-62
98	Tungnaa at Hald	3470	1 year 1961-62
99	Fossa at Haifoss	125	4 years 1958-59 to 1961-62
	HVITA BASIN		
2	Sog at Ljosafoss	1050	22 years 1940-41 to 1961-62
64	Olfusa at Selfoss	5760	12 years 1950-51 to 1961-62
87	Hvita at Gulfoss	2000	12 years 1950-51 to 1961-62

revision of portions of many of the records. The review encompassed the records of stations needed for subsequent engineering studies, as well as those required for the Burfell Project studies. Correlation studies were also made to extend the estimates of streamflows at those locations considered pertinent.

The evaluation of existing records and the revisions that were made are discussed in Chapter A-II. The correlation studies are also described in that chapter. Flood studies for the Burfell Project are described in Chapter A-IV.

CHAPTER A-II

REVIEW OF STREAMFLOW RECORDS

Thjorsa at Urridafoss

Description of Record

The Urridafoss streamgaging station is the oldest and most reliable station in the Thjorsa Basin. The station was first established in 1947 as a staff gage by the British consulting firm, Sir William Halcrow and Partners. This gage, which is located on the left bank of the river near the farm at Krokur, was read by the observer about once every three days. In 1954 the Hydrologic Survey of the State Electricity Authority (SEA) installed a continuous water-stage recorder at Heidertangi, immediately above the Urridafoss Gorge, about 2 kilometers below the staff gage at Krokur. The collection of streamflow records in the Urridafoss area has been uninterrupted for 15 years. During this period 19 discharge measurements have been made. These records serve as the major basis for analysis of the water resources of the Thjorsa Basin.

Rating Curves

Discharges at Krokur and Heidertangi can be considered to be identical, since there is no significant drainage area between the two locations. This allowed the development of gage-height correlation curves between the two stations, as shown on Exhibit A-3. With the aid of this curve discharge measurements can be referred to either gage by converting stages from one datum to the other.

Although the gage-height correlation of Exhibit A-3 could be used directly to compute streamflows from either record, the computation of discharges was facilitated by preparing separate rating curves for Krokur and Heidertangi, to allow the direct application of the gage heights from either station to the rating table, without going through the extra step of using Exhibit A-3. The 19 discharge measurements define a good rating curve for either station. Exhibit A-4 and A-5 show the rating curve and the rating table developed for Krokur, which was used to compute streamflows at Urridafoss for the period April 1, 1947, though August 31, 1958. Exhibit A-6 and A-7 show the rating curve and the rating table developed for Heidertangi on the basis of the same 19 discharge measurements, which were used to compute discharges for the period September 1, 1958, through August 31, 1962.

The Krokur and Heidertangi ratings constitute a refinement of the several earlier ratings used by SEA in determining the daily discharges at Urridafoss. This refinement was warranted by the plotting of all 19 discharge measurements which have become available. Of necessity the earlier SEA ratings had to be based on the fewer measurements that were available at the time when the respective ratings were developed.

The stage-discharge relationships at Krokur and Heidertangi are affected by ice in the river channel during at least a portion of each winter period. Unfortunately, all of the discharge measurements that have been made have been taken during periods in which there was no ice effect. Thus the relationships shown on Exhibits A-4 to A-7 reflect open-water conditions.

Streamflow Computations

All streamflows for open water periods were computed by applying the observed gage heights at Krokur or Heidertangi to the rating tables of Exhibits A-5 to A-7. This included all summer months and those winter periods when the observer's field notes and other information, described later, indicated no ice effect.

The daily winter flows as reported by SEA were revised completely because of (a) changes in the open water rating and (b) the method that had been used in estimating the effect of backwater because of ice in the channel. In the absence of winter measurements to define the magnitude of backwater due to ice, the observer had attempted to overcome this deficiency by estimating what the river stage reading would have been if it were not affected by ice. The daily discharge was then computed by entering the open water stage-discharge rating for the adjusted gage height. While these notations by the observer were very helpful in our computations, the determination of daily discharge during periods of ice by arbitarily estimating what the gage might have read under open water conditions is subject to great error. This was borne out when it was found that the winter flows at Urridafoss as reported by the SEA were quite at variance when correlated hydrographically with flows at streamgaging stations in the adjacent Hvita Basin, which are not subject to backwater due to ice.

Generally, the practice for determining the backwater effect of ice on the stage-discharge relationship is by periodic discharge measurements. In such cases, the magnitude of the ice effect at the time of the winter discharge measurement is determined by computing the difference between the observed stage and the stage for the measured discharge which corresponds to the open water stage-discharge relationship. It is difficult without the aid of a discharge measurement to detect the time when the stage-discharge relationship begins to be affected by ice or when it ceases to be affected. Sudden rises in stage readings may be caused by an obstruction in the channel or because of sudden warm-up and increased snowmelt. On the other hand a sharp drop in the stage may be caused in part by the impounding of water in the form of ice or in part by the channel storage above the gage at places where the ice has retarded the flow.

Because of the absence of winter discharge measurements, other procedures of computing flows were adopted for estimating purposes. The best method was found to be by use of correlations with discharges of the Olfusa at Selfoss and the Sog at Ljosafoss. The flow at Selfoss is believed to be free of ice effect. The flows of the Sog also are not subject to ice effect, since the flows are determined from the sum of the discharge through the turbines of the Ljosafoss power plant and over the spillway.

Exhibits A-8 and A-9 show the monthly discharge correlations between the Thjorsa and the Olfusa and the Thjorsa and the Sog, respectively. The plotted points represent mean monthly flow values for November through April for years when Urridafoss was considered unaffected by ice. The evidence, on the basis of the observer's notes and the other related data, shows that in many winter months there were long periods of time extending to a month or more when no backwater resulted from ice. Also, with the establishment of the gage at Heidertangi, the ice effect has been eliminated except for short periods of extremely cold weather. A total of 30 open-water winter months was selected at Urridafoss to develop the correlations with the Selfoss and Ljosafoss stations.

Mean monthly flows at Urridafoss for the remaining winter months then were estimated by applying the observed Sog and Selfoss flows to the correlation curves of Exhibits A-8 and A-9. The "equal yield" line shown on Exhibit A-9 (as well as on subsequent exhibits) represents the curve that would apply if the discharge per square kilometers from each drainage area were the same.

The Sog-Urridafoss correlation was the sole basis for estimating winter Urridafoss flows prior to the year 1951, when records at Selfoss became available.

The daily discharge records of the Hvita at Gullfoss were utilized as an aid in distributing the mean monthly flows of Urridafoss on a daily basis. By this means the daily winter flows were estimated from hydrographs prepared for each year of record. The 1950-51 hydrograph is included as Exhibit A-10 to illustrate the procedure used.

Summary of Results

Exhibit A-11 gives a summary of the mean monthly discharges computed for the Thjorsa at Urridafoss for the period April 1947 through August 1962. These values represent a complete revision of the SEA records, although some of the revisions, particularly at high water, are not large. The results of the revision of the winter flows from that reported by SEA are quite significant and have an important bearing on any future power project studies. The differences between the HARZINT estimates of winter flow and those of SEA fluctuate radically from day to day and from month to month. In general, the winter flows as reported by SEA are lower. Use of our estimates tends to decrease the storage requirement in any scheme of future development where low flows at downstream sites will have to be augmented by storage releases.

The average monthly flows and median monthly flows also are shown on Exhibit A-11. The median monthly values represent the value which is equalled or exceeded 50 percent of the time during the period of record. These values are useful in predicting the most probable power production.

Thjorsa at Burfell

Description of Records

A recording gaging station was installed below the proposed diversion structure of the Burfell Project in 1961. This station is located below the waterfall Trollkonuhlaup and is officially described in SEA records by that name. However, the streamflow estimates are considered applicable to the Burfell Project and, for purposes of simplicity, are referred to in this report by the Project name. Since installation of the recording gage, five discharge measurements were made to determine the flow at that station. The measurements were made on the Thjorsa immediately below its confluence with the Fossa. The Fossa was measured on the same day, and the flow passing Burfell was computed as being the difference between the two measurements. The results of these discharge measurements are given in Table A-2.

TABLE A-2

Discharge Measurements, Thjorsa at Burfell

No. of Measurement (1)	Date (1962) (2)	Thjorsa below Fossa (M^3/sec) (3)	Fossa (M^3/sec) (4)	Discharge at Burfell (Column 3-4) (M^3/sec) (5)	Mean Stage at Burfell (centimeters) (6)
1	June 3	468	35	433	247
2	July 5	390	13	377	236
3	July 23	386	10	376	237
4	July 23	428	10	418	244
5	August 2	482	10	472	254

Computation of Flows

The measurements shown in Table A-2 do not cover a sufficient range of stage to define a dependable stage-discharge relationship for the Burfell gaging station. However, analysis of the intervening flows between Burfell and Urridafoss indicates that the flows at the two stations are about the same relation as the direct ratio between the drainage areas above the two stations.

The four years of discharge records of the Fossa indicate that the intervening 820 square kilometers of drainage area between Burfell and Urridafoss contributes, on the average, its proportionate share of runoff at Urridafoss. While these records indicate some monthly variation in this relationship, the variation is not established with sufficient accuracy to justify a variation in any month from that developed on an annual basis. The Fossa, which drains an area of 125 square kilometers, is part of the intervening drainage area between Burfell and Urridafoss. The records indicate that the Fossa tributary, which drains about 1.7 percent of the Urridafoss drainage area, contributes an average of 1.9 percent of annual discharge at Urridafoss. Conceivably, the remainder of the intervening area may contribute similarly proportioned amounts. Under these assumptions it may be reasoned that the flow originating above Burfell is proportionate to its drainage area, which is 89 percent of that at Urridafoss.

While the five discharge measurements made at Burfell did not cover a sufficient range in stage to define a stage-discharge relationship, the results of the measurements do indicate that the approach for determining the flow at Burfell on the basis of the drainage area ratios is on the conservative side. This is indicated by the comparison shown in Table A-3.

TABLE A-3

Comparison of Concurrent Flows at Urridafoss and Burfell

Date (1962)	Discharge at Urridafoss as computed from rating (M^3/sec)	Discharge Measured at Burfell (M^3/sec)	Burfell as Percent of Urridafoss
June 3	460	433	94
July 5	392	377	96
July 23	405	376	93
July 23	405	418	103
August	470	472	100

While the above percentages are higher than the direct ratio of drainage areas, it should be recognized that these apparently high percentages may be reduced if it would be possible to adjust the discharges for time of travel and simultaneous mean gage height readings at Burfell and Urridafoss. Such adjustments were not feasible with the information available. Also, the discharges measured reflect moderately high water conditions and are not necessarily representative of lower flow relationships. These factors would likely reduce these percentages and bring them to values that are closer to the 89 percent value determined on the basis of ratio of drainage areas. Accordingly, daily flows at Burfell were computed as being 89 percent of the flows at Urridafoss.

Exhibit A-12 shows graphically the computed daily flows at Burfell for the period September 1947 through August 1962 (15 water years). Exhibit A-13 shows in the tabular form the mean monthly discharges at Burfell for the same 15-year period.

The average flow of the Thjorsa at Burfell based on the 15-year period of record is 338 cubic meters per second. The most critical period of extended low flow occurred in 1950-51. Lower flows were observed in other years but were of much shorter duration.

Analysis of Flows

The flows computed for Burfell were analyzed to determine the minimum year, the median-month year, and flow durations.

The minimum year is the hydrologic year (September 1-August 31) in which the ability to sustain a specified level of flows at the Burfell Project, either by natural flow or by storage releases, is the most critical. Our analysis indicated that the period September 1950 through August 1951 is the most critical year for sustaining flows at Burfell. The median-month year is the array of median monthly values as described earlier for Urridafoss in the presentation of Exhibit A-11.

The monthly values determined for the minimum and median-month years are given in Table A-4.

TABLE A-4

Minimum and Median Flows at Burfell

Month	Minimum Year (1950-51) (cubic meters per second)	Median-Month Year (cubic meters per second)
September	320	334
October	241	297
November	209	257
December	198	237
January	202	239
February	191	258
March	180	249
April	185	271
May	472	472
June	357	436
July	363	436
August	238	387
Average	263	323

The frequency of daily flows also is important in power studies. Therefore, the flow duration curve shown on Exhibit A-14 was prepared. The duration curve was prepared on the basis of daily streamflows at Urridafoss, adjusted to Burfell by drainage area proportions. Pertinent values of the daily flow duration are given in Table A-5.

TABLE A-5

Frequency of Daily Flows at Burfell

Percent of Time When Discharge was Equal to or Greater Than That Shown	Discharge in Cubic Meters per Second
100	72
98	140
95	159
90	178
75	221
50	309

Tungnaa

Flow Computations for Vatnaoldur

Daily records for the Tungnaa at Vatnaoldur were available for the three-year period September 1959 through August 1962. The SEA rating curve was reviewed and was found to be fairly well defined by seven discharge measurements. The SEA rating was adopted and the rating table, shown on Exhibit A-15, was prepared. The rating table was applied directly to observed gage height readings except for periods of ice effect and for the period September 23-November 20, 1961, when a shift in the channel control seemed apparent. For this latter period minor adjustments were made to the gage heights, to be more consistent with the measurement made on September 20, 1961.

The Vatnaoldur station apparently is often subject to backwater caused by ice for varying periods in each winter month of record. The daily discharges on certain days,when the river stage was reported by the observer to be affected by ice, were estimated on the basis of daily temperature and precipitation at the Haell meteorological station and hydrographic comparison with the daily flows at Urridafoss.

The Vatnaoldur records were extended to the same 15-year period of record available at Urridafoss on the basis of the 3-year period of concurrent record, September 1960 through August 1962. The extension of the records was accomplished on the basis of two separate correlation curves, as shown in Exhibit A-16.

Curve A of Exhibit A-16 was drawn by plotting of concurrent monthly discharges at Vatnaoldur and Urridafoss for the summer months and for several of the winter months which experienced appreciable amounts of precipitation. This curve was used primarily for the extension of the flows of the summer months of May through October. Curve B was drawn by the plotting of three concurrent winter months of record believed to be influenced by only minor amounts of snowmelt. This curve was used for computation of flows for those winter months of November through April which, on the basis of the flows at Urridafoss and weather records at Haell, were believed to be primarily base flow runoff with insignificant amount of snowmelt.

The 15 years of monthly mean flows developed for the Tungnaa at Vatnaoldur are given on Exhibit A-17.

Flow Computations for Hrauneyjafoss

Streamgaging data have not been collected at Hrauneyjafoss, but the availability of the Vatnaoldur flow computations allowed reasonable estimates to be made of the Hrauneyjafoss flows. In addition, one year of available records on the Tungnaa at Hald, below the junction with the Kaldakvisl, proved to be of value.

The drainage areas at the three locations are as follows:

Station	Drainage Area (square kilometers)
Vatnaoldur	1350
Hrauneyjafoss	1625
Hald(includes Kaldakvisl)	3470

From this comparison it is evident that the Vatnaoldur records are the most indicative of the flows at Hrauneyjafoss, which is above the mouth of the Kaldakvisl.

The flow at Hrauneyjafoss was computed to be 114 percent of the flow at Vatnaoldur. This percentage was computed on the basis of concurrent records in 1961-62 for the two stations on the Tungnaa, Vatnaoldur and Hald. The average discharge for the seven summer months (September and October 1961 and April through August 1962) for the intervening drainage area between the two gaging stations was found to be at the rate of .050 cubic meters per square kilometer, as compared with .074 cubic meters per square kilometer above Vatnaoldur during the same seven months. On this basis, the flow at Hrauneyjafoss would be as follows:

$$Q_H = Q_V + Q_V \times \frac{(275}{(1350} \times \frac{.050)}{.074)} = 1.14\, Q_V$$

where Q_H = Flow at Hrauneyjafoss power site

Q_V = Flow at Vatnaoldur (Sta. 096) and factors 275 x 0.050 and 1350 x .074 are the relationship of the runoff between the intervening drainage area with the drainage area upstream of Vatnaoldur.

Flow Duration

Flow duration curves for Vatnaoldur and Hrauneyjafoss are shown on Exhibit A-19. The duration curve for Vatnaoldur wad developed on the basis of the three years of daily discharge record. These three years were judged to represent nearly average conditions when compared with the 12 years of additional record extended for the Tungnaa at Vatnaoldur. Exhibit A-20 shows how the runoff of each year, recorded or extended, compares with the average for the 15-year period. The individual three years of record compare with the 15-year average as follows:

Water Year	Total Discharge (M^3/sec-days)	Percent of 15-year average
1959-60	44,179	108
1960-61	39,329	96
1961-62	33,491	82
3-Year Average	39,000	95
Average 15-Year Period	40,834	100

The Hrauneyjafoss duration curve shown on Exhibit A-19 was developed by applying the factor 1.14 to the flows at Vatnaoldur. The frequency of daily discharges at Hrauneyjafoss is summarized as follows:

Percent of Time When Discharge was Equal to or Greater than Shown	Discharge in Cubic Meters per Second
100	34
98	55
95	64
90	73
75	100
50	110
25	141
5	230

Thorisos at Vad

This gaging station is located downstream from the outlet of Thorisvatn. Four years of discharge data are available at the station. Daily discharge records for the period September 1958 through August

1962 were developed on the basis of SEA rating, shown on Exhibit A-21. This rating is reasonably well defined by five discharge measurements taken during the period September 1956 to June 1959. The mean monthly flows at Vad, computed from this rating by SEA, are given in Column 3 of Exhibit A-24, introduced and described in the following section of this chapter.

The Vad gaging station is believed to measure about two-thirds of the outflow from Thorisvatn. The remainder of the discharge occurs from springs located, for the most part, some distance to the west of Thorisvatn. Upstream of the gage, a large percentage of the outflow from the lake is underground, through the frost-glacial lava formations on the east side of the Thorisos. An estimated average of about six cubic meters per second appears as surface flow at the lake outlet, compared with monthly average flows at the gaging station ranging from 10 to 27 cubic meters per second during the period of record. (The estimated average surface outflow at the outlet is only an approximation and is not the result of gaging records.) At the gaging station most, if not all, of Thorisvatn's subsurface flow along the Thorisos is believed to have appeared at the surface.

Thorisvatn Inflow Usable for Reregulation

A measure of the inflow to Thorisvatn can be obtained from the Vad discharge records. This measure of inflow was computed by adding algebraically to the Vad outflow the change in storage that has occurred, as indicated by the lake elevation at the end of each month. This procedure does not give the true inflow, because of the following:

(a) Evaporation losses are not computed.

(b) Discharge from the lake to the springs is not considered.

(c) There is no assurance that the discharge at Vad represents the true outflow from the lake in that direction, even excluding the discharge to the springs.

Although these factors will introduce appreciable discrepancies from the true inflow, the values thus derived will be very useful in studies of storage regulation by use of Thorisvatn.

The omission of evaportion for such purposes is desirable, because the evaporation loss under historic and future regulation conditions will be practically the same, since the area of the lake will not change to any significant degree under future regulation. Since this loss will be unchanged, computations under regulated conditions will be simplified if the inflow is computed without accounting for the loss.

Similarly, the omission of accounting for the discharge to the springs may not be serious. The exact head on the principal known springs has not been determined, but it is probably in the order of 75 meters. The relatively small change in head resulting from regulation of Thorisvatn probably may not change appreciably the outflow to the springs. Thus, approximately the same loss may occur under regulated as under historic conditions.

The possibility that the Vad station does not measure all of the Thorisvatn outflow (excepting the springs) could be more serious if the omission was considered significant. However, it is believed that very little subsurface outflow bypasses the gage to appear as surface flow in the Thorisos below the gaging station; on the other hand, some of the measured flow at Vad may represent groundwater from the porous lava to the east rather than Thorisvatn leakage. Thus, gain may offset loss bypassing the gaging station. Therefore, any inaccuracies in the measurements of Thorisvatn outflow at Vad may tend to equal one another in the case of a small initial storage. Any additional subsurface flow that appears below the gaging station can be trapped by the potential Kaldakvisl.diversion dam, which will increase the flow available for storage reregulation above that indicated by the method of computation presented herein.

End-of-month elevations of Thorisvatn were not available to utilize directly in the computation process. However, a sufficient number of concurrent elevations of Thorisvatn and at Vad were available to establish a relationship between the lake and the gaging station at Vad. This combination curve is shown on Exhibit A-22. By us of this curve end-of-month elevations of Thorisvatn were computed from the Vad gage heights for each month of the four-year period of record at Vad.

The change in storage during the month was computed by applying the end-of-month elevations to the area-volume curve for the lake, shown on Exhibit A-23. This amount of change, when added algebraically to the respective monthly outflow as measured at Vad, indicates the inflow to the lake that will be usable for reregulation. The computation of usable inflow is shown on Exhibit A-24.

The computations of usable inflow to Thorisvatn were extended to the same 15-year period as available for Thjorsa at Urridafoss. Annual flows for years prior to 1958-59 first were computed by correlation of the flows previously developed for Vatnaoldur with the Thorisvatn usable inflow for the period of concurrent record, 1960 through 1962. Exhibit A-25 gives the correlation between annual usable inflow to Thorisvatn and the runoff at Vatnaoldur. This correlation curve was drawn primarily on the basis of annual runoff relationship; however, some weight was also given to simultaneous monthly flows.

A "normal" monthly distribution was utilized to compute the monthly usable inflows to the lake for the period prior to the year 1958-59. Exhibit A-26 shows the "normal" monthly distribution, in which monthly flows are expressed as a percentage of the annual. These percentages were developed from the four years of computed usable inflow to Thorisvatn.

Exhibit A-27 is a summary of the monthly usable inflows to Thorisvatn for the period April 1947 through August 1962. This summary includes four years of inflow records determined on the basis of records of the outlet at Vad and 11 years of records extended by correlation with streamflow records at Urridafoss and Vatnaoldur. The records developed indicate an average usable inflow of 15.8 cubic meters per second, equivalent to about 500 million cubic meters annually. The inflow does not fluctuate radically from year to year nor from month to month. The usable inflow volume in the critical year 1950-51 was about 430 million cubic meters or about 86 percent of the average annual. The monthly usable inflow varies from a low of about eight cubic meters per second in the early winter months to a high of 26 cubic meters per second, generally occurring in the month of May. The monthly rates of inflow during the critical 1950-51 year as compared with the median-month year are given in Table A-6.

TABLE A-6

Thorisvatn Usable Inflow
Minimum and Median-Month Years

Month	Critical Year 1950-51 (M^3/sec)	Median-Month Year (M^3/sec)
September	11.1	12.9
October	12.8	14.9
November	10.4	12.1
December	8.8	10.2
January	11.2	13.0
February	14.4	16.7
March	16.3	19.0
April	18.7	21.7
May	20.6	24.0
June	14.9	17.3
July	12.6	14.7
August	11.4	13.2
Annual Average	13.6	15.8

Kaldakvisl at Saudafell

Discharge records on the Kaldakvisl are of particular significance in the event that additional water needs to be diverted and stored at Thorisvatn to increase the power development at Burfell and other potential power sites downstream on the Tungnaa and the Thjorsa. A continuous automatic gage recorder was established in April 1959 at Saudafell, about nine kilometers upstream from the mouth of the Thorisos. Gage height records were collected at this station for the open-water summer months of hydrologic years 1961 and 1962. Because of ice conditions no gage readings were recorded during the winter months of the same years.

Six measurements were obtained during the period September 1958 through December 1961, which gave a reasonably well defined rating curve. The rating developed by SEA was modified to give better agreement with the measurements, as shown on Exhibit A-28. The rating table thus developed, shown on Exhibit A-29, was used to compute discharges for the open-water summer months of 1961-62.

Monthly mean flows for the winter months of 1961 and 1962 and for the entire year prior to 1961 were computed on the basis of the correlation between flows at Vatnaoldur and at Saudafell. The correlation curve, Exhibit A-30, was developed from the concurrent monthly flows of Vatnaoldur and Saudafell during the summer months of the years 1961 and 1962. Exhibit A-31 shows the 15 years of monthly mean flows computed for Saudafell.

The minimum year and the median-month year flows at Saudafell on the basis of 15 years of record are as follows:

TABLE A-7

Kaldakvisl at Saudafell
Minimum and Median-Month Year
(Cubic Meters Per Second)

Month	Minimum Year 1950-51	Median-Month Year
September	39	39
October	31	37
November	31	38
December	29	37
January	33	36
February	32	41
March	30	37
April	31	41
May	54	54
June	43	51
July	43	50
August	40	45
Average	36	42

CHAPTER A-III

SPILLWAY DESIGN FLOOD

General

Introduction

The establishment of reliable inflow design flood values is essential to the determination of required spillway capacity. The first step frequently is the establishment of the probable maximum flood at the project site with existing upstream developments or those that will exist at the time the project is completed. The design flood might be smaller than the probable maximum flood if overtopping of the structure would not be catastrophic. In the case of a reservoir the inflow design flood is routed through the reservoir to determine required spillway capacity. If there is no appreciable storage the spillway must be able to pass the entire inflow design flood.

These values for important structures have in recent years usually been based on hydrometeorological studies of the probable maximum storm potential for the basin and consideration of hydrologic conditions which may be associated with that storm. If the probable maximum storm is combined with the most adverse hydrologic conditions that could occur in association with that storm, the resulting flood hydrograph may be considered to represent the probable maximum flood.

Parts of Iceland are subject to an unusual type of flood. These are "glacier bursts" caused either by the breaking of an ice dam where a glacier has blocked a river or lake outlet or by the breaking out of a huge pool of water formed under a glacier by the melting of ice due to volcanic action. Rist and Bjornsson[1/] found no reference to glacier burst floods in the Thjorsa Basin in 1000 years of history and sagas. Therefore, they concluded that, if any glacier burst floods occurred in that basin during that period, they did not substantially exceed the normal type floods. Glacier burst floods of the latter type are unpredictable both as to time and magnitude. This fact, along with an absence of a history of glacier burst floods, indicates that only meteorological type floods should be considered in the design of the Burfell Project spillway and other Project structures.

General Procedures

The procedure used in the studies required determination of the probable maximum storm estimation of losses such as infiltration, interception and evaporation to obtain rainfall excess, then conversion of this excess into flood runoff by use of the unit hydrograph. Possible snowmelt associated with the storm is evaluated and converted to flood flow. Base flow and recession from previous floods are then added.

Rist and Bjornsson state that the greatest floods which have occurred in the past on the Thjorsa Basin have resulted from the following sequence of events:

(a) The drainage basin is made watertight by freezing of the top layer of the soil, and all depressions are filled with ice.

1/ Rist, Sigurjon and Bjornsson, Jakob: "Thjorsa and Hvita River Systems, Southern Iceland, Some Hydrological Aspects," The State Electricity Authority, Hydrological Survey, Reykjavik, June 1959.

(b) The ground is covered with deep snow.

(c) Heavy rainfall coinciding with warm wind blowing over the drainage area causes intense melting of the snow.

It was considered, from studies of this and many other basins, that the probable maximum flood will result from a similar sequence of events,and the studies were made accordingly.

It was concluded that the most critical combination of these events is most likely to occur in March or October. In the case of March, it was assumed that the freezing of the ground surface occurred much earlier and that the snow is old and "ripe," that is, of high density and in a state of incipient melting. Four days of rapid snowmelt immediately preceeding the probable maximum flood were assumed.

Climatology

The climate of the Thjorsa Basin has been described by Rist and Bjornsson[1/]. Iceland has a rainy island climate with cool summers and warm winters. Cyclonic systems tend to follow the Gulf Stream and bring great volumes of humid warm air to the island. At times the weather is dominated by the nearby cold Polar Sea and Greenland icecap. This conflict results in marked changes in temperature and precipitation, depending on which source area happens to be dominant.

1/ *Op. cit.*

Probable Maximum Storm

The probable maximum storm is by definition the maximum storm that can occur over a basin with due consideration to season, type of storm, and precipitation variation with respect to time. The probable maximum flood will normally, but not necessarily, be associated with this storm. In some basins the maximum probable flood results from snowmelt at a season when the storm potential is low.

General Procedure

It is usual procedure to assume an antecedent storm from which the runoff has not yet been completed at the time of the probable maximum storm. Such an assumption was made for a March flood. For an October flood, it is believed that it would be unrealistic to assume that the ground could remain frozen during the antecedent rain flood, the snowmelt period, and the probable maximum storm. Therefore, the assumption was made that the freezing was immediately prior to the snowfall and the antecedent flood was omitted. An antecedent rain flood would of necessity have receded to low flow levels by the time of the probable maximum storm. An antecedent October storm was taken into consideration only to the extent of using a generous base flow value to include the residual flows from such a storm.

It is common practice to make a study of several historical storms in the problem area and to "maximize" them by assuming certain features of the storm, such as dew point and wind velocity, to be increased to the maximum possible concurrent value. This has the advantage of assuming a reasonable rainfall pattern. The most severe maximized storm is then selected as the "probable maximum storm." It was not possible to do this in the case of the Burfell Project because practically all long term rainfall data are for sections near the coast. This made it impossible to determine the areal distribution of historical storms.

Therefore, the adopted procedure was to transfer depth-area-duration data from areas where extensive studies have been made and where the transfer could be made by an adjustment of readily evaluated parameters and to assume that the areal pattern of such a storm is similar to that for the mean annual precipitation. This is called the "isopercental" method because the storm precipitation at any point bears a constant relationship with the mean annual precipitation. The study areas selected were the Sierra slopes of the Central Valley of California [1/] and the Rogue River basin in Southwestern Oregon, [2/] both basins being on the Pacific coast of the United States. Although these basins are remote from Iceland, the hydrological differences are much less than would be expected, for the following reasons:

(a) The major storms in both study basins and in southern Iceland are caused by orographic lifting of warm moist air masses as they move inland driven by on-shore winds.

1/ "Probable Maximum Precipitation on Sierra Slopes of the Central Valley of California" - Cooperative Studies Report No. 12, U. S. Department of Commerce, Weather Bureau and U. S. Department of the Interior, Bureau of Reclamation.

2/ "Design Storms for Rogue River Basin" - U. S. Department of the Interior, Bureau of Reclamation.

(b) In all three areas, the air masses have long been in contact with relatively warm ocean water and have moved over progressively cooler water as they approach shore. This makes for similar stability characteristics in the air masses and comparable moisture profiles.

(c) Both study areas are in storm track areas and their depth-area-duration data have been maximized for the maximum persisting wind velocities, as well as for maximum persisting dew point.

It was concluded that the depth-area-duration data for zones of equal mean annual precipitation for the study areas could be transferred to Iceland with a simple adjustment for maximum persisting (12-hour) dew point.

The storms that had been studied in the California area all occurred between mid-October and early April. Those in the Oregon area occurred between late September and mid-April with the most critical storms for which detailed analyses were made all occurring from November to January. It was assumed that the probable maximum storm for the Burfell Project would occur during the period of October to March. Sufficent snow to maintain an essentially complete snow cover throughout the melting period is all that is required for a maximum snowmelt contribution to the flood. March and October, with their higher temperatures, probably have the greatest snowmelt potential; therefore, these months were selected for special consideration.

Area-Elevation Data

Data on elevation of the basin are particularly important where precipitation is influenced by orographic deflection. A contour map of the basin was prepared by tracing each 100-meter interval contour from the 1959 issue of the 1:250,000 map published by the Geodetic Institute of Copenhagen. Drainage boundaries were marked off and the area above the Burfell damsite planimetered. This was determined to be 6590 square kilometers, a somewhat greater area than the area obtained by subtracting the intervening area between the damsite and the gaging station at Urridafoss, which has a drainage area of 7200 square kilometers. To assure being on the conservative side, the larger area was used in determining the probable maximum flood and the smaller area used in determining streamflow for power purposes, as explained elsewhere in this Appendix.

Mean Annual Precipitation

The mean annual precipitation of the Thjorsa Basin, and of various elevations within the Basin, plays a prominent part in the determination of probable maximum precipitation. Therefore, an essential step was the preparation of an isohyetal map of mean annual precipitation. Its determination is explained later. This map is shown on Exhibit A-32.

The first step was the tabulation of all available precipitation data for areas in or reasonably near the Basin. Some of these stations had long records and others very short records. All were reduced to a 36-year base period (1901-1930 and 1956-1961), by correlations where necessary. This split period was adopted to take advantage of data tabulated by Rist and Bjornsson and data in more recent publications. Two storage gages, Veidivatnahraun and Ljosufjall-Svartikambur, centrally located in the Basin, gave accumulated precipitation for a period of approximately two years. Precipitation at several other rain gages was determined for the same period to tie these stations into the long term average. Mean annual values were spotted on a transparent overlay over a topographic map of the Basin.

Many factors were studied to help fill in data for areas remote from precipitation stations. These included elevation, distance from the ocean, and air inflow barrier elevation. It was not possible to establish useable quantitative coefficients for all these factors, partly because of the number of variables involved and partly because of the narrow range of values for some of the terms. Elevation was believed to be a particularly important parameter, but it could not be evaluated on the basis of local data because of the near absence of stations other than at low elevations. Available data on annual precipitation versus elevation were collected for several parts of the world and an estimate made for the Thjorsa Basin. The value initially assumed was an increase of 120 millimeters annually for each 100 meters of elevation. A chart was prepared showing the long term mean precipitation for all stations plotted against elevation. A family of straight lines was drawn on the chart with a slope equal to the assumed change with elevation. In using the chart, a station reasonably close to the point in question and with generally similar values of parameters other than elevation was selected. The diagonal lines were followed from this station to the elevation at the desired point. This gave the first estimate of mean precipitation for the point.

Records of streamflow runoff were used extensively in checking and adjusting the mean annual precipitation isohyetal map. For purposes of the map it was assumed that Basin losses were 250 millimeters per year. The isohyetal lines were then adjusted until the mean annual precipitation for a sub-basin was of the general order of magnitude of the average annual runoff depth from that sub-basin plus estimated losses. Consideration was given, in adjusting the isohyetals, to distance from the ocean, shielding by higher elevations, carryover at crests of ridges, etc.

Full weight was given to all precipitation station data, in preparing the mean annual precipitation map, except for the two storage gages. It was believed that these gages under-registered the precipitation catch, especially the one at Ljosufjall-Svartikambur. It is reported that both gages are shielded against wind effects and contain an oil film to reduce evaporation. It is possible that these two precautions were not completely effective. This would be easily possible in regard to shielding. Another possibility is that wet snow may at times form an arch over the rain gage receiver preventing additional snow from entering the gage. Such difficulties are common elsewhere.

After the isohyetal map of mean annual precipitation was prepared, the various isohyets were planimetered to determine the mean annual precipitation for the Basin. This was found to be 1770 millimeters and agreed closely with the computed average runoff plus estimated losses. The planimetering of the isohyets also provided an independent check of the Basin drainage area.

Derivation of Depth-Area-Duration Data

Depth-area-duration curves for the probable maximum storm are shown on Exhibit A-33. In the duration of depth-area-duration curves, storm data were transposed from other areas. The data actually transposed were the probable maximum depth-area-duration data rather than specific storms, since local orographic features would make the latter impracticable. The depths of probable maximum rainfall for specific areas and durations were reduced on the basis of the lower persisting dew points experience in Iceland. The analysis of dew point data is shown in Table A-8.

TABLE A-8

Analysis of Dew Point Data

Item	Dew Point		Precipitable Water		
	°F	°C	inches	mm	Reduction to Iceland
California Study Area					
March	58	14.4	1.25	31.8	.54
October	63	17.2	1.61	40.9	.54
Used in Study					.54
Oregon Study Area					
March	56	13.3	1.13	28.7	.60
October	61	16.1	1.45	36.8	.61
Used in Study					.60
Southern Iceland					
March	46	7.8	.68	17.3	
October	51	10.5	.88	22.3	
Used in Study					

For each value of dew point there is a corresponding value of precipitable water. The dew point values for Iceland in Table A-6 were based on ocean surface temperatures south of Iceland between 55° and 65° north latitude. Slightly higher values obtained later from Iceland were used for making a small adjustment explained later. As indicated in the table, the data for the California study area were multiplied by a factory of 0.54 and those for the Oregon study area by 0.60.

Depth-area-duration data were available for a small 38-square-mile drainage basin in Southeastern Alaska. These data were based on daily precipitation. They substantiated the California and Oregon data for durations up to 24 hours.

The data for the California and Oregon study areas were available for areas only up to 1000 square miles (2590 square kilometers) whereas the drainage area above the Burfell damsite is substantially greater. Values were originally extrapolated on the basis of a general curve based on observed values in the United States. Curves were drawn enveloping all the points computed for the two study areas as adjusted for Iceland dew point values. These curves are shown as the solid lines on Exhibit A-33. The upper ends of these curves are based on extrapolated data. They break rather sharply to the left, especially for the longer durations, thereby indicating lower depths of precipitation than would a less sharp break. This is because of the fact that the curve on which the extrapolation was based was derived from data for the entire United States and was unduly influenced by short duration convective storms covering small areas.

To more accurately reflect the conditions in Iceland, the depth-area-duration curves were adjusted to show greater depth for larger areas and longer durations. The adjusted curves are shown as dashed lines on Exhibit A-33, and were used in determining the probable maximum flood.

Determination of Design Storm at Burfell

The design storm was computed from the depth-area-duration data. Six-hour increments of precipitation over the Basin were computed for the entire storm period. These increments were then rearranged in an order that would produce the highest peak flow, when superimposed on the snowmelt flood.

As previously mentioned, the dew point data for Iceland were originally based on ocean surface temperatures south of Iceland. These were 40°F (7.8°C) for March and 51°F (10.5°C) for October. Highest persisting March dew points were later established to be 8.0°C at Vestmannaeyjar and 8.6°C at Kirkjubaejarklaustur, both on the south coast of Iceland. Comparable values for October were 10.4°C at Vestmannaeyjar and 10.8°C at Kirkjubaejarklaustur. On the basis of these very slight changes from the values actually used, it was decided to increase the storm potential by 10 percent, and that increase was applied to all precipitation increments.

The snowmelt because of rainfall occurring below the freezing level was treated the same as rainfall since it was assumed that it would run off in the same manner (snowmelt resulting from temperature was treated separately). The formula used was:

$$M = \frac{RT}{80}$$

where:

M = Snowmelt in millimeters due to rainfall.

T = Air temperature in degrees centigrade.

R = Rainfall in millimeters.

The assumed sea level temperatures for the flood period are given in the section on "Snowmelt Contribution."

Probable Maximum Flood

The problem of determining the runoff from the probable maximum storm is essntially the determination of the amount of water that will be retained and not appear as immediate runoff and the determination of the runoff pattern for the remaining water from excess rainfall that appears as surface runoff.

Excess Rainfall

The excess rainfall is defined as rainfall minus retention losses. The retention losses include evaporation, transpiration, surface retention and infiltration. The evaporation and transpiration would be very small during a major storm, with transpiration practically non-esistent because of the sparse vegetal cover. One of the basic assumptions was that surface depressions would be full so there would be negligible retention from that source. It was also assumed that the ground would be frozen, so that infiltration would be small. The resulting retention losses were assumed to be five millimeters per six-hour period. This value is believed to be conservatively low, even with a frozen ground surface, because nearly two-thirds of the Basin is so porous that it is doubtful that freezing could effectively seal the surface.

Effective Rainfall

Because of the wide range in elevation within the Basin, the precipitation above the freezing level during the probable maximum storm will occur as snow and therefore will not contribute to the storm runoff. The freezing elevation was computed in connection with the snowmelt computations. The depth of rainfall over the Basin was multiplied by the percentage of the Basin that was below the freezing level to obtain the effective rainfall, which was the volume of precipitation falling as rain divided by the total area of the Basin.

The areas of highest elevation are also the areas of highest mean annual precipitation. Therefore, it would be expected that the heaviest storm precipitation would occur here and that the precipitation falling as rain below the freezing level would be lower than the average for the entire Basin. However, it was considered that part of the mean annual precipitation at high elevations is a carryover from storms approaching from other directions. Since it was assumed that the probable maximum storm would be accompanied by winds from the south or southwest, it was considered possible that the storm could be centered over lower elevations. Since the percentage of the Basin above the freezing level varied from only 14 percent to 22 percent during the storm period, it was considered adequate to reduce the rainfall volume on a straight area basis.

Derivation of the Unit Hydrograph

A unit hydrograph is defined as the hydrograph of runoff resulting from one unit of rainfall excess over the basin uniformly distributed over one unit of time. The units used for the Burfell Project were one centimeter of rainfall excess and six hours of time. According to the theory of the unit hydrograph, the runoff from all storms of the same duration and uniform intensity will occur in the same length of time and the ordinates of the runoff hydrograph at any time will be the ordinates of the unit hydrograph multiplied by the rainfall excess in centimeters. The theory also provides that runoff hydrographs for succeeding six-hour periods can be superimposed by staggering them--at six-hour intervals in this case. Therefore, the runoff from any storm theoretically can be reconstituted by breaking the rainfall down into sufficiently short periods so that it can be considered to be uniform during the period and then computing the runoff from each rainfall period.

The first step in determining flood runoff from known rainfalls is to determine the shape of the unit hydrograph. The best way to do this is to search streamflow and precipitation records to find an isolated storm of approximately unit time duration and then determine the resulting runoff by subtracting from the total streamflow the estimated flow from base flow or antecedent rainfall. The total flood runoff, in terms of depth over the watershed, is computed and unit hydrograph ordinates determined by dividing the actual ordinates by the multiple that the runoff depth bears to the unit depth adopted for the unit hydrograph. The unit hydrograph is then tested by using it to reconstruct runoff from several other historical storms. It was not possible to follow this procedure for the Burfell Project for the following reasons:

(a) Rainfall over the Basin for a historical storm is indeterminate because there are no rain gages actually in the Basin other than storage gages.

(b) It is very difficult to determine the runoff from an isolated storm because of the frequency of storms during the winter and the high runoff from snowmelt and glacier melt during the summer.

Where unit hydrographs cannot be determined from actual records, synthetic unit hydrographs are derived based on physical features of the drainage basin. There are several methods for deriving synthetic unit hydrographs. Probably the most widely used method for basins of comparable size to the Thjorsa is the Snyder method, which was used for the Burfell Project.

The Snyder method involves formulas and curves, based on basin dimensions and slope, for determining the time and magnitude of the peak, the time length of the base of the unit hydrograph, and the daily distribution of runoff. The volume of the unit hydrograph is established by the drainage area and the depth unit adopted. With this information and a knowledge of the drainage pattern of the basin an experienced hydrologist can determine the unit hydrograph readily. The unit hydrograph derived for Burfell is shown on Exhibit A-34.

The same factors that prevented derivation of a unit hydrograph from historical data prevented realistic testing of the synthetic unit hydrograph. A unit hydrograph was computed for the Urridafoss site in the same manner as for the Burfell unit hydrograph. Tests were attempted against three historical Urridafoss flood events using the best estimates possible of Basin precipitation. These events were those of August 8-14, 1959, August 29-September 14, 1959, and November 18-26, 1958. A reasonable reproduction was obtained only for the November 1958 event. This was considered to be as good a check as possible with the data available.

Probable Maximum Rain Flood

Determination of the probable maximum rain flood from the effective rainfall and the unit hydrograph involves a simple computation. The unit hydrograph has a seven-day base composed of 28 six-hour periods as shown on Exhibit A-34. The effective rainfall involved 12 consecutive six-hour periods. For each of the rainfall periods the flood discharge was computed for each of the 28 runoff periods by multiplying the effective rainfall in that period, in centimeters, by the successive ordinates of the unit hydrograph.

Snowmelt Contribution

As mentioned earlier, the assumption was made that the probable maximum flood would result from the runoff from the probable maximum storm being superimposed on a flood caused by rapid melting of snow. Therefore, it was assumed that four days of rapid snowmelt took place before the start of the storm and that snowmelt continued at a lesser rate during the storm. The four-day period is sufficient to allow the snowmelt runoff to approach its maximum rate by the time the rain peak arrives, thereby producing the maximum total peak.

Sea level temperature sequences were assumed to be as shown in Table A-9.

TABLE A-9

Temperature Sequences in Probable
Maximum Flood Runout

	March Flood	October Flood
1st day	9.0°C	12.0°C
2nd day	10.0	13.0
3rd day	11.0	14.0
4th day	12.0	15.0
5th day (start of rain)	7.2	10.0
6th day	7.8	10.6
7th day	6.7	9.5
8th day	6.1	8.9

The elevation of the freezing level was determined for each day of snowmelt by using the dry adiabatic lapse rate for the first four days of no rain and the pseudoadiabatic lapse rate for the last four days during which the rainstorm occurred. The depth of snowmelt each day was computed at each of several elevations up to the freezing elevation. Snowmelt for the area below the freezing level was taken to be 5.4 millimeters per degree day of mean temperature (centigrade) above 0^oC for March and 3.6 millimeters per degree day for October. The higher value for March was due to the assumption that the snow was old and "ripe." The mean temperature was the average of sea level temperature and 0^oC at the freezing level. These depths of snowmelt were combined with appropriate areas to determine the volume of snowmelt for each day.

The runoff from the snowmelt was assumed to follow the same general pattern as the storm runoff but to extend over twice as long a period, or for fourteen instead of seven days. The general procedure for determining snowmelt runoff was therefore similar to that for storm runoff.

Runoff from Antecedent Storm and Base Flow

To determine the total flow during the flood period, it is necessary to add to the storm runoff and the snowmelt runoff the flow from possible antecedent conditions.

In the case of the March flood, the runoff from an antecedent storm and from base flow was combined. The recession from the peak of March 5, 1958, at Urridafoss was used as the basis for this combined flow. The daily flow at Urridafoss was plotted on semi-logarithmic paper for the period March 6-20, 1948. This plot indicated that the flow followed a true recession through March 8, 1948, but was more than the true recession thereafter because of additional rainfall or snowmelt. The true curve was extended on the basis of judgment through March 20, 1948. It is usual practice to assume a flood comparable to the largest flood of record as representing the runoff from antecedent conditions. Because of the short records on the Thjorsa River, it was considered appropriate to multiply these Urridafoss values by 1.5 to give a reasonable approximation of a major flood at Burfell. This flow was considered to include any runoff from snowmelt prior to the snowmelt computations.

In the case of the October flood, it was considered unrealistic to assume a major storm prior to the beginning of the snowmelt period and still assume frozen ground throughout the entire flood period. Since frozen ground would add more to the flood peak than would an antecedent flood, the antecedent storm was omitted. However, a high base flow was used. The historical flow records for the Urridafoss gage were examined and a base flow of 400 cubic meters per second adopted for Burfell, which appeared to be well in excess of any historical October base flow.

Total Flood Runoff

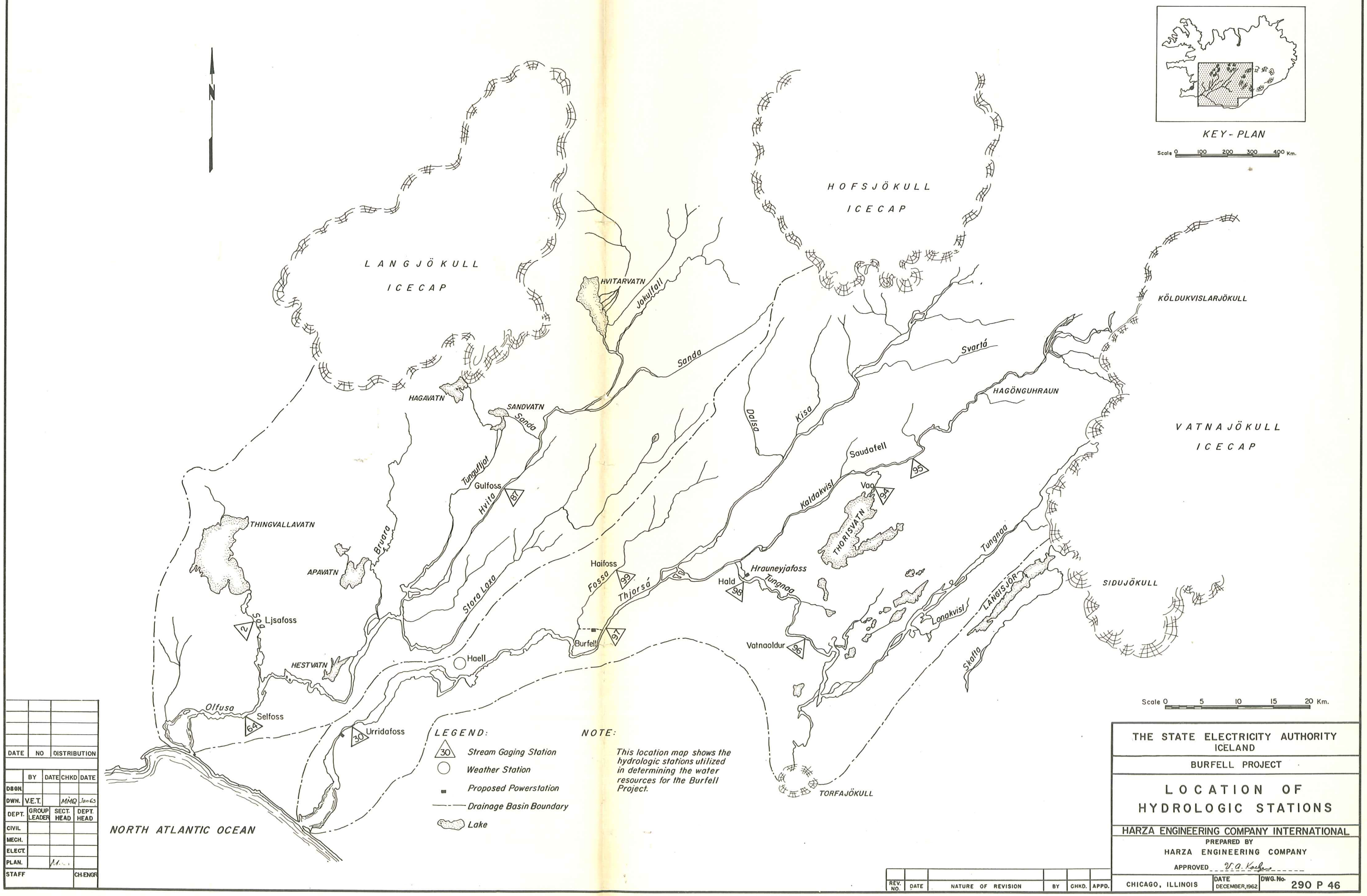
The total flood flow was determined by adding the three components of flow: the storm runoff, the snowmelt runoff, and the base flow (combined with flow from an antecedent storm in the case of the March flood). In combining the flow, the start of the snowmelt period was assumed to coincide with the first day of recession from the antecedent flood. The probable maximum storm was assumed to start four days later. The hydrographs for the March and October floods are shown on Exhibits A-35 (a) and A-35 (b), respectively.

It was found that the October flood had a peak of 7750 cubic meters per second as compared with a peak of 7550 cubic meters per second for the March flood. Therefore, the October flood was used as the inflow design flood peak for the Burfell Project. This corresponds to a value of C in the Creager formula of 48, which appears reasonable for the area. The estimated maximum flood is almost four times the maximum flood of record at Burfell, which was about 2000 cubic meters per second,occurring in March 1953.

THE EXHIBITS

A-1 Location of Hydrologic Stations
A-2 Normal Monthly Mean Precipitation and Temperatures at Haell and Reykjavik Climatological Stations
A-3 Gage Height Correlation Curve, Heidertangi vs. Krokur
A-4 Rating Curve, Thjorsa at Urridafoss (Krokur Location)
A-5 Rating Table for Thjorsa at Urridafoss (Krokur)
A-6 Rating Curve, Thjorsa at Urridafoss (Heidertangi Location)
A-7 Rating Table for Thjorsa at Urridafoss (Heidertangi)
A-8 Correlation of Monthly Discharge, Olfusa and Thjorsa
A-9 Correlation of Monthly Discharge, Thjorsa and Sog
A-10 Thjorsa at Urridafoss - Determination of Winter Daily Discharge 1950-51
A-11 Thjorsa at Urridafoss - Monthly Mean Discharges 1947-62
A-12 Daily Discharge Hydrograph, Thjorsa at Burfell 1947-62
A-13 Thjorsa at Burfell - Monthly Mean Discharges 1947-62
A-14 Flow Duration Curve, Thjorsa at Burfell
A-15 Rating Table for Tungnaa at Vatnaoldur
A-16 Correlation of Monthly Discharge, Thjorsa and Tungnaa
A-17 Tungnaa at Vatnaoldur - Monthly Mean Discharge 1947-62
A-18 Tungnaa at Hrauneyjafoss - Monthly Mean Discharges 1947-62
A-19 Flow Duration Curve Tungnaa at Vatnaoldur and Hrauneyjafoss
A-20 Tungnaa at Vatnaoldur - Annual Runoff in Percent of Average 1947-62
A-21 Rating Table for Thorisos at Vad dated February 26, 1958
A-22 Stage Relationship - Thorisvatn and Thorisos at Vad
A-23 Thorisvatn Area and Volume Curves
A-24 Usable Thorisvatn Inflow 1959-62
A-25 Correlation of Annual Inflow, Tungnaa and Thorisvatn
A-26 Usable Thorisvatn Inflow, Normal Monthly Distribution
A-27 Thorisvatn Monthly Usable Inflow 1947-62
A-28 Rating Curve, Kaldakvisl at Saudafell
A-29 Rating Table for Kaldakvisl at Saudafell
A-30 Correlation of Monthly Discharge, Tungnaa and Kaldakvisl
A-31 Kaldakvisl at Saudafell Monthly Mean Discharge 1947-62
A-32 Thjorsa River Basin, Mean Annual Precipitation
A-33 Thjorsa Basin, Depth-Area-Duration of Probable Maximum Storm
A-34 Thjorsa at Burfell - Unit Hydrograph
A-35 Probable Maximum Flood, Thjorsa at Burfell

EXHIBIT A-1



DATE	NO	DISTRIBUTION

	BY	DATE	CHKD	DATE
DSGN.				
DWN.	V.E.T.		MMQ	Jan 63

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			
MECH.			
ELECT.			
PLAN.		M.	
STAFF			CH.ENGR

REV. NO	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

LOCATION OF HYDROLOGIC STATIONS

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED V. a. Kolz

CHICAGO, ILLINOIS | DATE DECEMBER, 1962 | DWG. No. 290 P 46

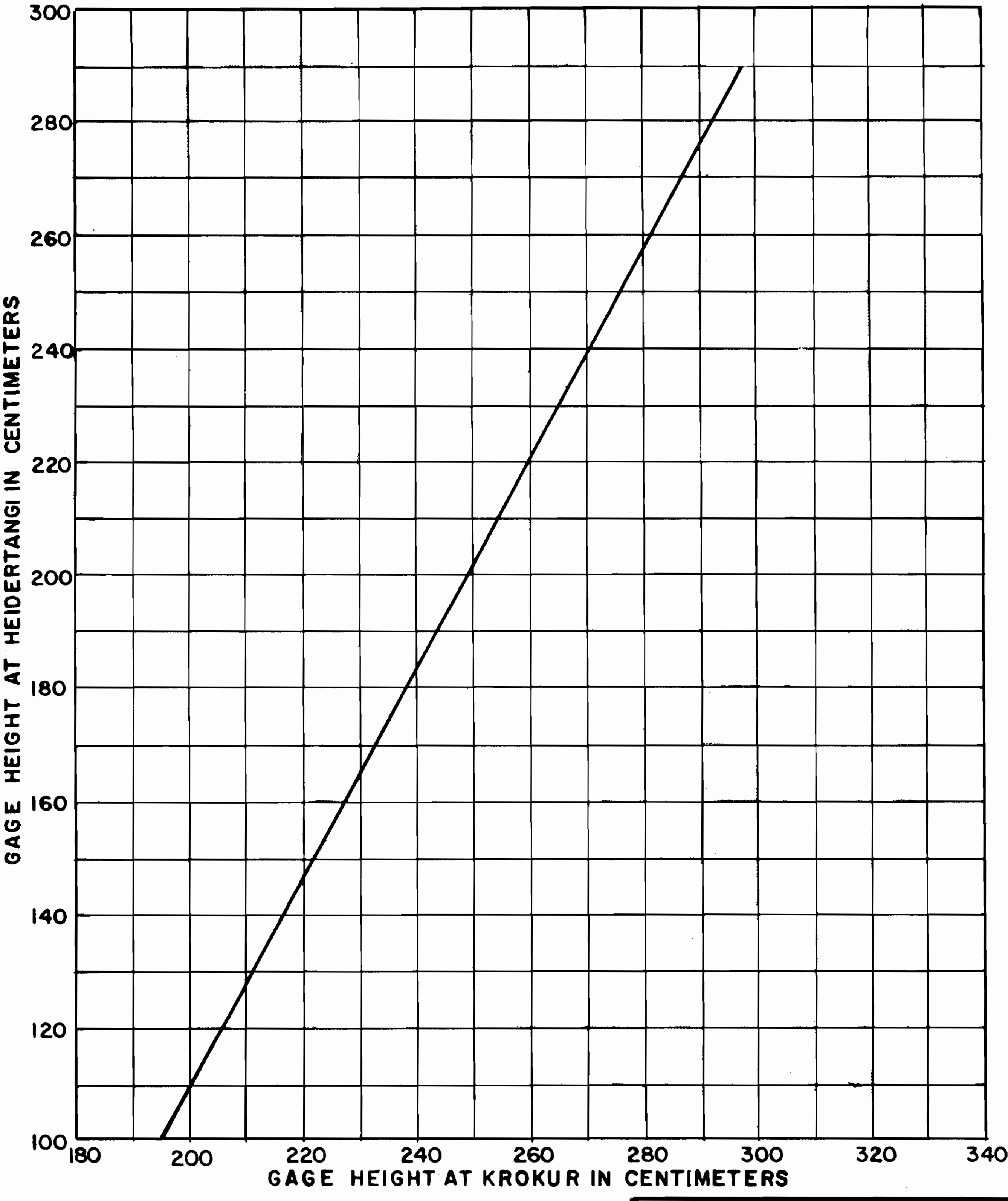
NORMAL MEAN MONTHLY PRECIPITATION AND TEMPERATURE

AT HAELL AND REYKJAVIK CLIMATOLOGICAL STATIONS

Month	Reykjavik Station Normal Mean Temperature °C	Reykjavik Station Precipitation in Millimeters	Haell Station Normal Mean Temperature °C	Haell Station Precipitation in Millimeters
January	-0.6	103	-1.8	75
February	-0.2	87	-1.2	75
March	-0.5	75	-0.8	75
April	2.6	61	1.4	65
May	6.3	51	5.5	60
June	9.6	49	9.5	65
July	11.3	51	11.4	70
August	10.6	52	9.9	60
September	7.8	91	7.1	115
October	4.3	90	3.4	110
November	1.4	96	0.3	90
December	0.0	98	-0.9	95
ANNUAL	4.5	904	3.7	955

Source: Meteorological Reports of State Electricity Authority

EXHIBIT A-3



Source: From data submitted by SEA.

THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT

GAGE HEIGHT CORRELATION CURVE HEIDERTANGI vs. KROKUR

HARZA ENGINEERING CO. CHICAGO
APPROVED V. A. Koelzer

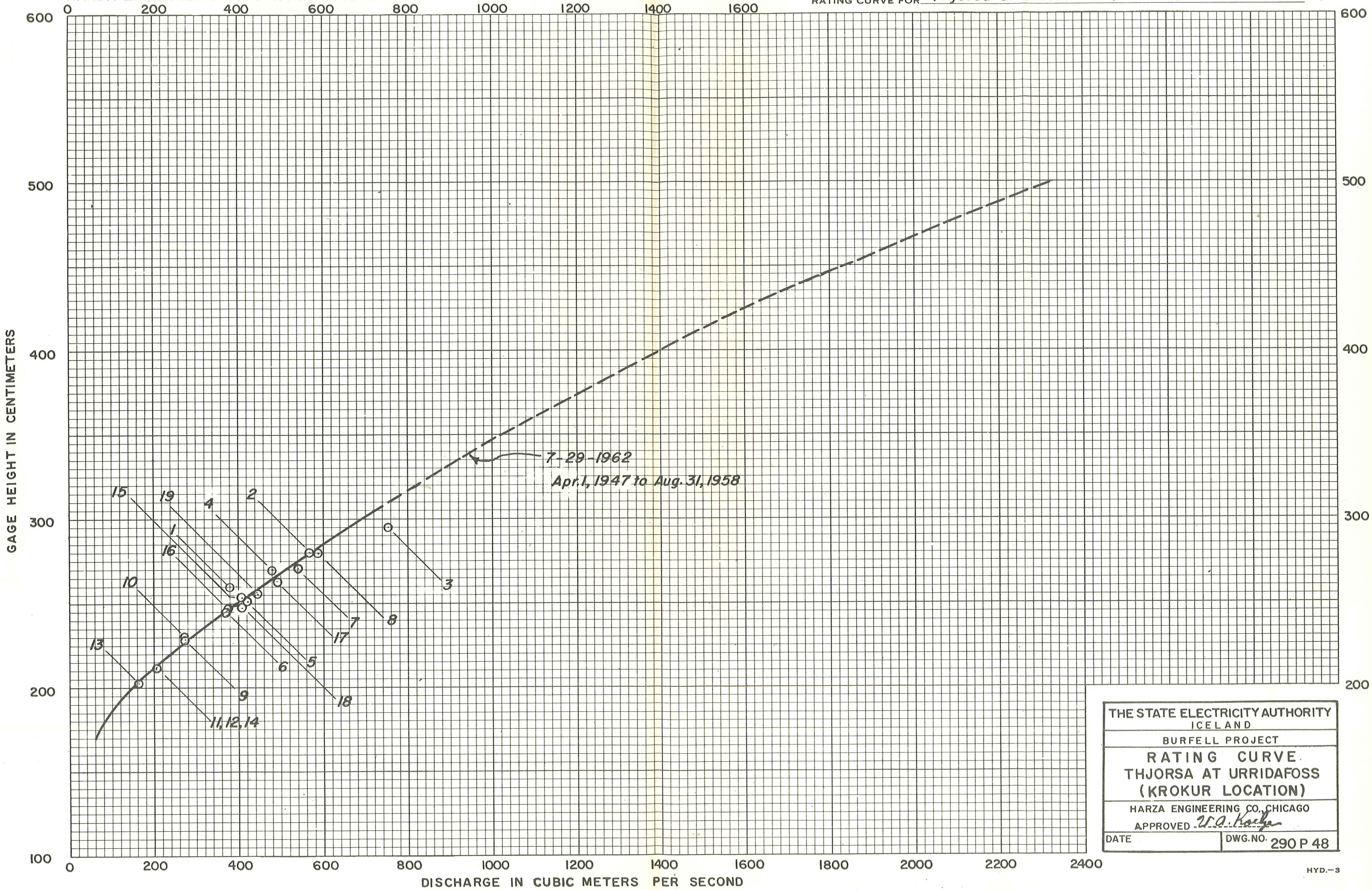
Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

DATE

DWG. NO. 290 P 47

HARZA ENGINEERNG COMPANY INTERNATIONAL

RATING CURVE FOR *Thjorsá at Urridafoss (Krokur).* EXHIBIT A-4



HARZA ENGINEERING COMPANY

Rating table for THJORSA AT URRIDAFOSS (Krokur) Dated July 29, 1962

fr. April 1, 1947 to August 31, 1958 ; from .... to ....

from .... to .... ; from .... to ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
	(cubic meters per second)										
1.0											
.1											
.2											
.3											
.4											
.5											
.6					50	51	53	55	57	59	
.7	61	63	65	67	69	71	73	75	77	79	
.8	81	84	88	92	95	98	101	104	107	110	
.9	114	117	120	123	127	130	134	137	141	145	
2.0	148	152	156	160	164	170	176	180	184	188	
.1	192	196	201	207	214	218	222	227	231	236	
.2	241	245	250	254	259	264	269	273	277	282	
.3	287	292	297	304	311	316	321	326	331	336	
.4	341	346	351	356	363	371	376	381	386	391	
.5	396	402	407	412	417	422	428	434	439	445	
.6	450	458	467	473	479	484	490	495	501	506	
.7	512	518	524	530	536	542	548	554	560	566	
.8	572	578	584	590	596	602	608	614	620	627	
.9	633	639	645	651	657	664	670	676	683	690	
3.0	696	702	708	715	721	727	733	740	746	753	
.1	760	766	773	780	786	793	800	806	713	820	
.2	827	834	841	848	855	862	867	872	877	883	
.3	890	897	904	912	919	926	933	940	948	953	
.4	958	964	970	976	983	990	996	1003	1010	1018	
.5	1026	1035	1043	1051	1060	1067	1073	1080	1087	1093	
.6	1100	1108	1116	1125	1131	1137	1143	1150	1158	1166	
.7	1175	1183	1191	1200	1208	1216	1225	1233	1241	1250	
.8	1256	1262	1268	1275	1281	1287	1300	1308	1316	1325	
.9	1332	1338	1344	1350	1358	1366	1375	1383	1391	1400	

Computed by S.I.A. 9/17/1962; Checked by M.S.S. 12/15/1962 Remarks ....

10—10377

HARZA ENGINEERING COMPANY

Rating table for THJORSA AT URRIDAFOSS (Krokur) **Dated** July 29, 1962

from April 1, 1947 to August 31, 1958 ; from ______ to ______

from ______ to ______ ; from ______ to ______

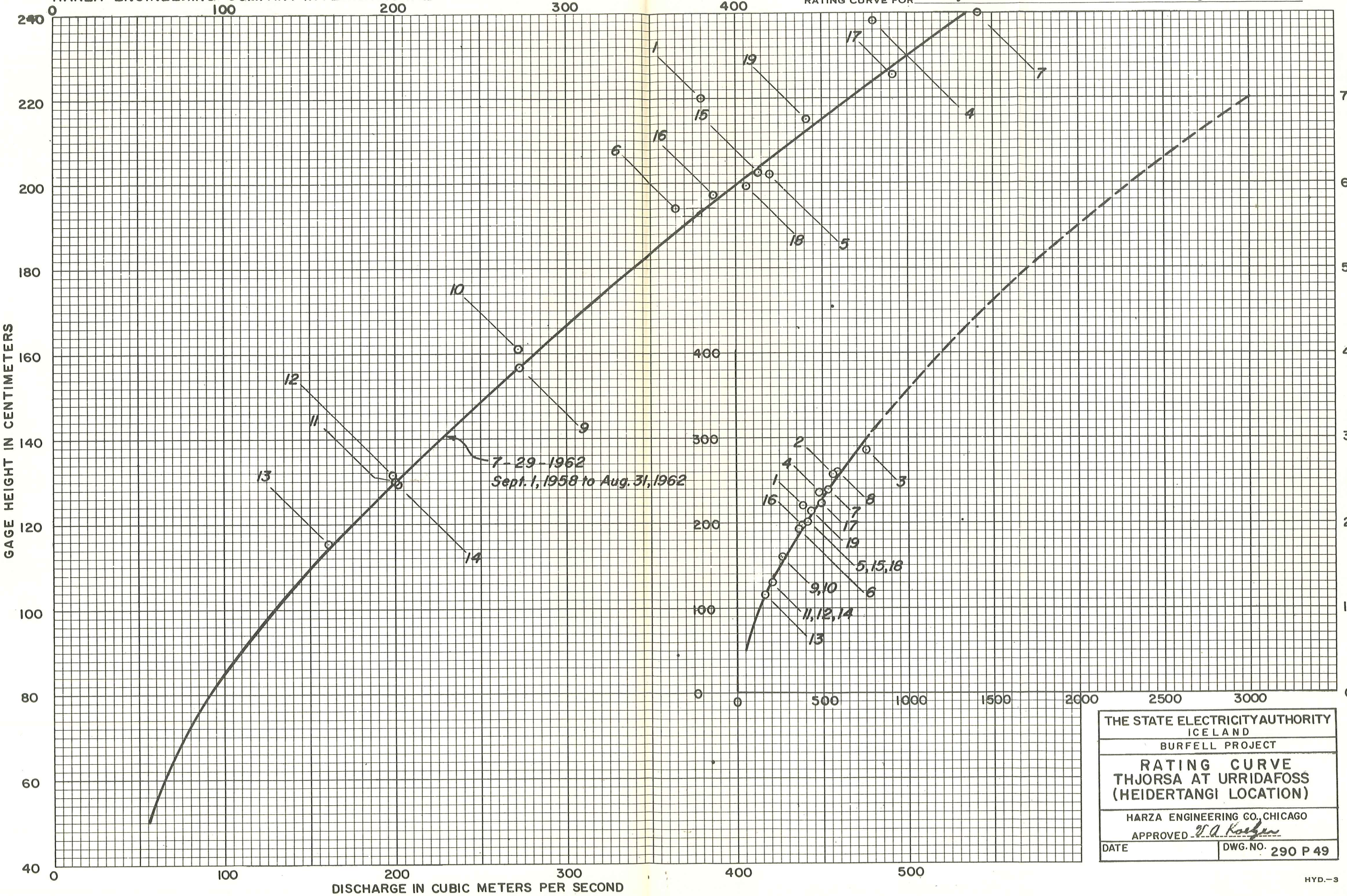
Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
				(cubic meters per second)							
4.0	1406	1412	1418	1425	1433	1441	1450	1458	1467	1475	
.1	1483	1492	1500	1508	1516	1524	1532	1540	1548	1557	
.2	1566	1575	1584	1593	1602	1611	1620	1627	1635	1643	
.3	1650	1660	1670	1680	1690	1700	1710	1720	1730	1740	
.4	1750	1760	1772	1784	1796	1808	1820	1827	1835	1842	
.5	1850	1858	1867	1875	1883	1891	1900	1910	1920	1930	
.6	1940	1947	1955	1962	1970	1980	1990	2000	2010	2020	
.7	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	
.8	2130	2140	2150	2160	2170	2180	2190	2200	2210	2220	
.9	2230	2240	2250	2260	2270	2280	2290	2300	2310	2320	
5.0	2330	2340	2350	2360	2370	2380	2390	2400	2410	2420	
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

Computed by S.I.A. 9/17/1962; Checked by M.S.S. 12/15/1962 Remarks ______

16—10377

HARZA ENGINEERING COMPANY INTERNATIONAL

RATING CURVE FOR *Thjorsá at Urridafoss (Heidertangi).* EXHIBIT



HARZA ENGINEERING COMPANY

Rating table for THJORSA AT URRIDAFOSS (Heidertangi) *Dated* July 29, 1962

fro. September 1, 1958 *to* August 31, 1962 *; from* .... *to* ....

from .... *to* .... *; from* .... *to* ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
	(cubic meters per second)										
0.0											
.1											
.2											
.3											
.4											
.5	56	56	57	58	59	60	61	62	63	64	
.6	65	66	67	68	70	71	72	74	75	76	
.7	77	78	79	81	82	84	85	87	89	90	
.8	92	93	95	97	99	101	103	105	107	109	
.9	110	112	114	116	118	120	122	124	126	128	
1.0	130	132	134	136	138	141	143	145	147	150	
.1	152	154	156	159	161	164	166	168	170	173	
.2	176	178	181	183	186	188	191	193	196	198	
.3	201	203	206	208	211	214	217	220	222	225	
.4	227	229	232	235	238	241	244	246	249	252	
.5	254	257	260	263	266	269	272	274	277	280	
.6	282	285	288	291	294	297	300	303	306	308	
.7	311	314	317	320	323	326	329	332	335	338	
.8	341	344	347	350	353	356	359	362	365	368	
.9	371	374	377	380	383	386	389	392	395	398	
2.0	402	405	408	411	414	417	420	424	427	430	
.1	434	437	440	443	447	450	454	457	460	464	
.2	467	470	473	477	481	484	488	491	494	498	
.3	501	504	507	511	514	518	522	525	529	532	
.	536	540	543	547	550	554	557	561	565	569	
.5	572	576	579	583	586	590	593	597	600	604	
.6	608	612	616	620	623	627	630	634	638	641	
.7	645	649	653	657	660	664	667	671	675	679	
.8	683	687	691	695	698	702	706	710	714	718	
.9	721	724	728	732	736	740	744	748	752	756	

Computed by SIA 9/14/1962; *Checked by* MSS 12/15/1962 *Remarks* ....

HARZA ENGINEERING COMPANY

Rating table for THJORSA AT URRIDAFOSS (Heidertangi) **Dated** July 29, **19**62

fr. September 1, 1958 *to* August 31, 1962 *; from* .... *to* ....

from .... *to* .... *; from* .... *to* ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
	(cubic meters per second)										
3.0	760	764	768	772	776	780	784	788	792	796	
.1	800	804	808	812	816	820	824	828	832	836	
.2	841	845	849	854	858	862	866	870	874	878	
.3	883	888	892	896	900	904	909	913	917	922	
.4	926	930	934	939	944	948	953	957	962	966	
.5	970	974	978	982	986	990	994	998	1002	1006	
.6	1010	1015	1020	1025	1030	1035	1040	1045	1050	1055	
.7	1060	1064	1068	1072	1076	1080	1084	1088	1092	1096	
.8	1100	1105	1110	1115	1120	1125	1130	1135	1140	1145	
.9	1150	1155	1160	1165	1170	1175	1180	1185	1190	1195	
4.0	1200	1205	1210	1215	1220	1225	1230	1235	1240	1245	
.1	1250	1255	1260	1265	1270	1275	1280	1285	1290	1295	
.2	1300	1305	1310	1315	1320	1325	1330	1335	1340	1345	
.3	1350	1355	1360	1365	1370	1375	1380	1385	1390	1395	
.4	1400	1405	1410	1415	1420	1425	1430	1435	1440	1445	
.5	1450	1455	1460	1465	1470	1475	1480	1485	1490	1495	
.6	1500	1505	1510	1515	1520	1525	1530	1535	1540	1545	
.7	1550	1555	1560	1565	1570	1575	1580	1585	1590	1595	
.8	1600	1606	1612	1618	1624	1630	1636	1642	1648	1654	
.9	1660	1666	1672	1678	1684	1690	1696	1702	1708	1714	
5.0	1720	1726	1732	1738	1744	1750	1756	1762	1768	1774	
.1	1780	1786	1792	1798	1804	1810	1816	1822	1828	1834	
.2	1840	1845	1850	1855	1860	1865	1870	1875	1880	1885	
.3	1890	1896	1902	1908	1914	1920	1926	1932	1938	1944	
.4	1950	1956	1962	1968	1974	1980	1986	1992	1998	2004	
.5	2010	2016	2022	2028	2034	2040	2046	2052	2058	2064	
.6	2070	2076	2082	2088	2094	2100	2106	2112	2118	2124	
.7	2130	2137	2144	2151	2158	2165	2172	2179	2186	2193	
.8	2200	2206	2212	2218	2224	2230	2236	2242	2248	2254	
.9	2260	2266	2272	2278	2284	2290	2296	2302	2308	2314	

Computed by SIA 9/14/1962; Checked by MSS 12/15/1962 Remarks ....

HARZA ENGINEERING COMPANY

Rating table for THJORSA AT URRIDAFOSS (Heidertangi) *Dated* July 29, *19*62

fro September 1, 1958 *to* August 31, 1962 *; from* .... *to* ....

from .... *to* .... *; from* .... *to* ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
				(cubic meters per second)							
6.0	2320	2326	2332	2338	2344	2350	2356	2362	2368	2374	
.1	2380	2386	2392	2398	2404	2410	2416	2422	2428	2434	
.2	2440	2447	2454	2461	2468	2475	2482	2489	2496	2503	
.3	2510	2517	2524	2531	2538	2545	2552	2559	2566	2573	
.4	2580	2587	2594	2601	2608	2615	2622	2629	2636	2643	
.5	2650	2657	2664	2671	2678	2685	2692	2699	2706	2713	
.6	2720	2727	2734	2741	2748	2755	2762	2769	2776	2783	
.7	2790	2797	2804	2811	2818	2825	2832	2839	2846	2853	
.8	2860	2867	2874	2881	2888	2895	2902	2909	2916	2923	
.9	2930	2937	2944	2951	2958	2965	2972	2979	2986	2993	
7.0	3000										
.1											
.2											
.											
.4											
.5											
.6											
.7											
.8											
.9											
.0											
.1											
.2											
.3											
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.6											
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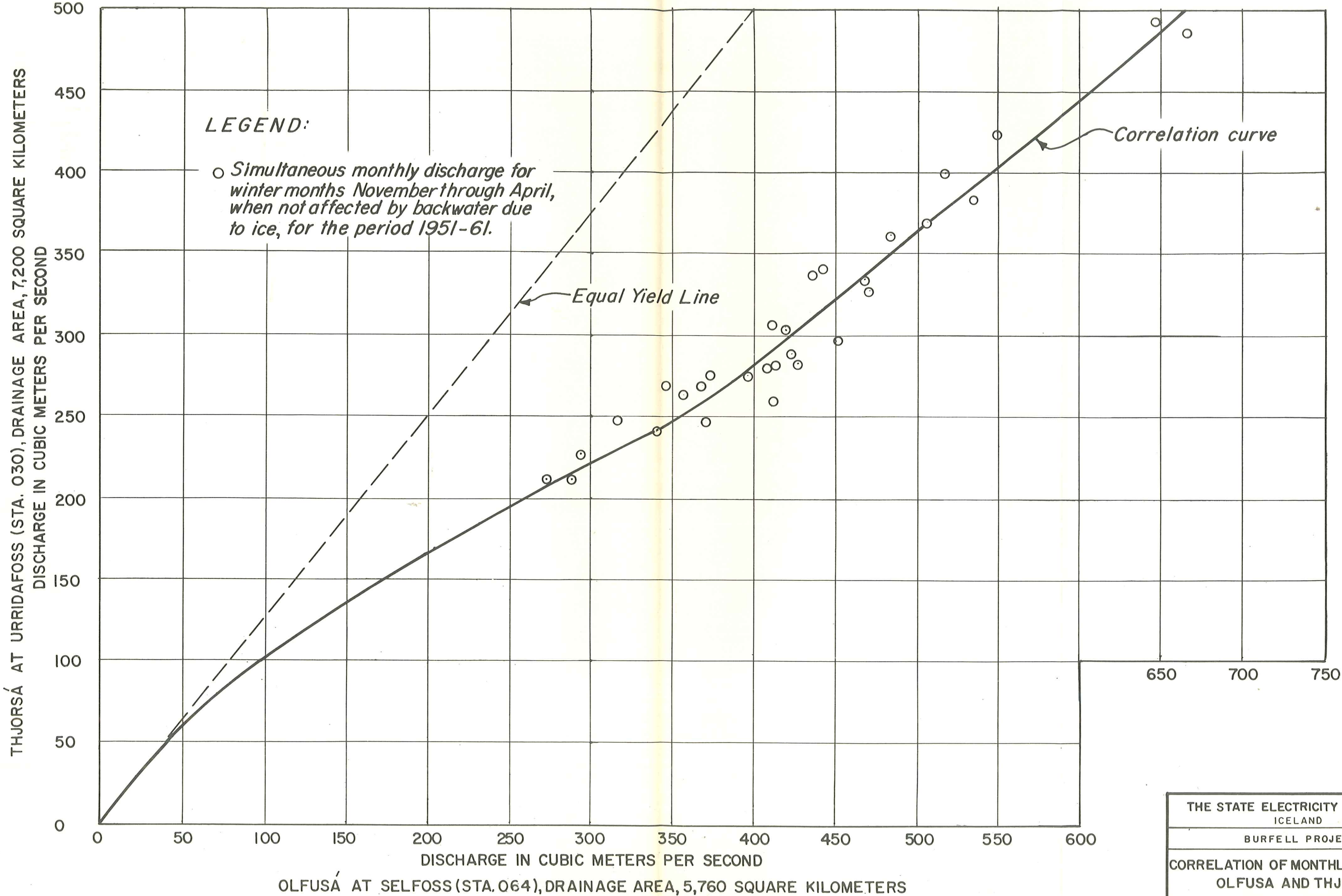
.9											

Computed by SIA 9/14/1962 *; Checked by* MSS 12/15/1962 *Remarks* ....

EXHIBIT A-8



THE STATE ELECTRICITY AUTHORITY
ICELAND

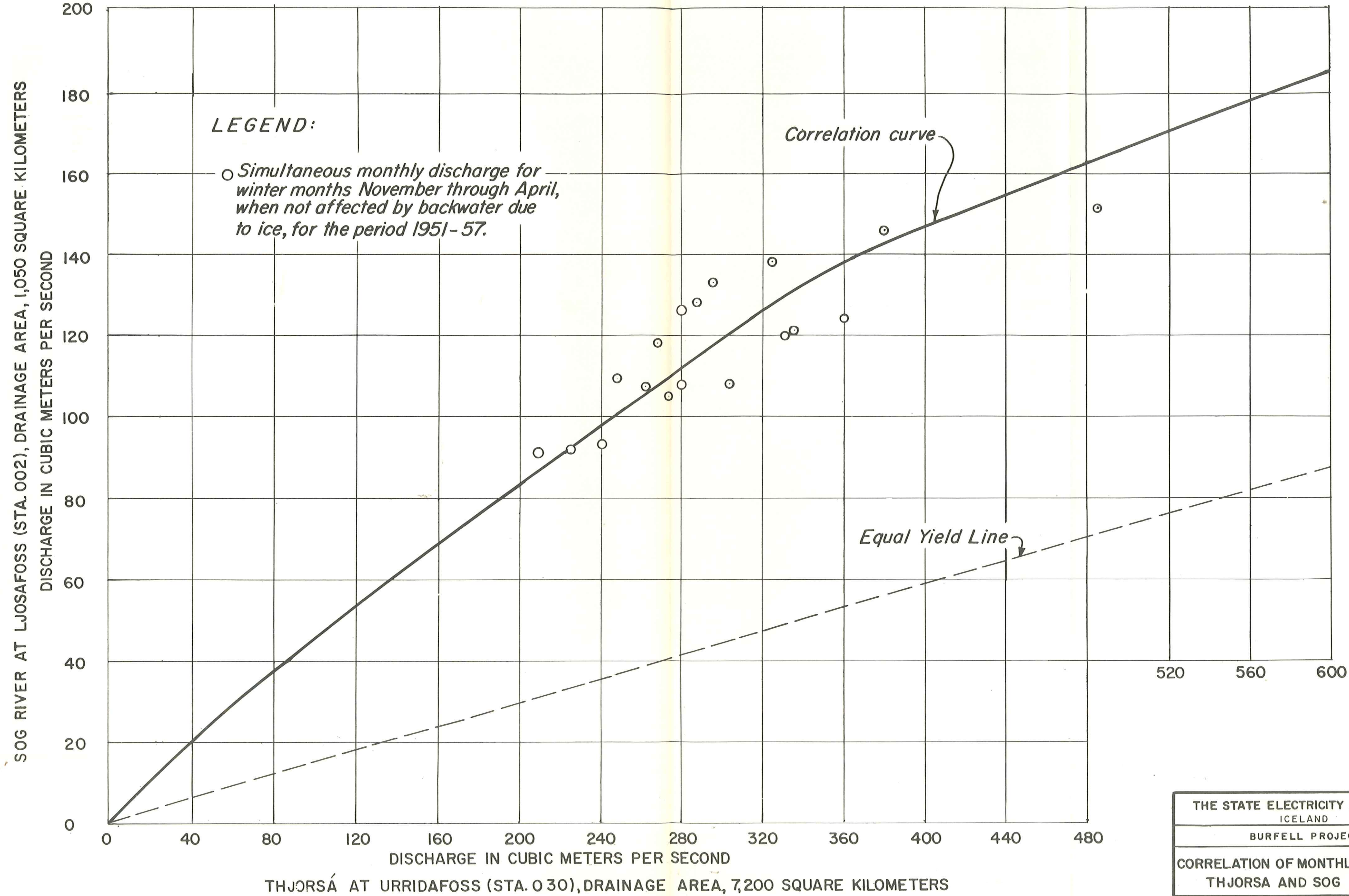
BURFELL PROJECT

CORRELATION OF MONTHLY DISCHARGE
OLFUSA AND THJORSA

HARZA ENGINEERING COMPANY
APPROVED V. A. Koelzer
CHICAGO, ILLINOIS | DATE | DWG. NO. 290 P 50

Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

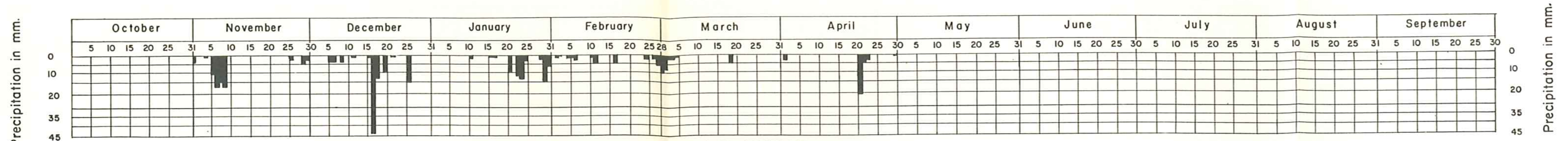
EXHIBIT A-9



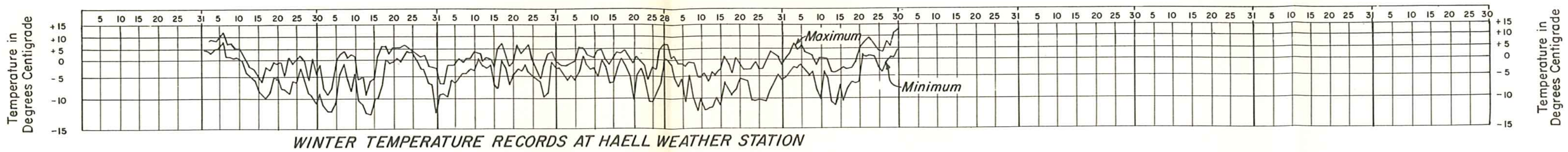
Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT
CORRELATION OF MONTHLY DISCHARGE
THJORSA AND SOG
HARZA ENGINEERING COMPANY
APPROVED V. A. Koelzer
CHICAGO, ILLINOIS | DATE | DWG. NO. 290 P 51

EXHIBIT A-10

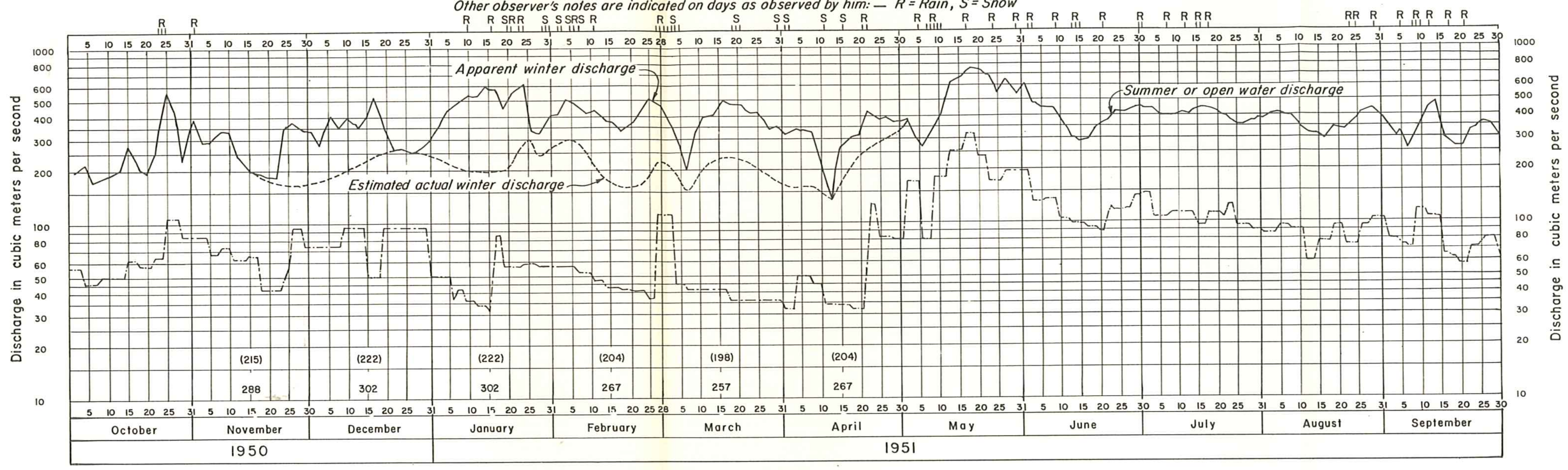


WINTER PRECIPITATION RECORDS AT HAELL WEATHER STATION



WINTER TEMPERATURE RECORDS AT HAELL WEATHER STATION

OBSERVERS NOTES: *Observer's daily notes indicate that stage-discharge relationship was subject to backwater due to ice during period November 19, 1950 through April 29, 1951. Other observer's notes are indicated on days as observed by him:— R = Rain, S = Snow*



DAILY DISCHARGE HYDROGRAPHS

LEGEND:

Daily discharge for Thjorsa at Urridafoss (Sta. 030).

Estimated actual winter daily discharge for Thjorsa at Urridafoss (Sta. 030).

Daily discharge Havita at Gulfoss (Sta. 087).

Estimated average montly discharge in cubic meters per second:

(215) *Thjorsa at Urridafoss*

288 *Olfusa at Selfoss*

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.	V.E.T.			

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			
MECH.			
ELECT.			
PLAN.		M.	
STAFF			CH.ENGR.

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

THJORSA AT URRIDAFOSS
DETERMINATION OF WINTER
DAILY DISCHARGE 1950-1951

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED [signature]

CHICAGO, ILLINOIS | DATE JANUARY, 1963 | DWG. No. 290 P 52

EXHIBIT A-11

THJORSA AT URRIDAFOSS (Sta. 030)

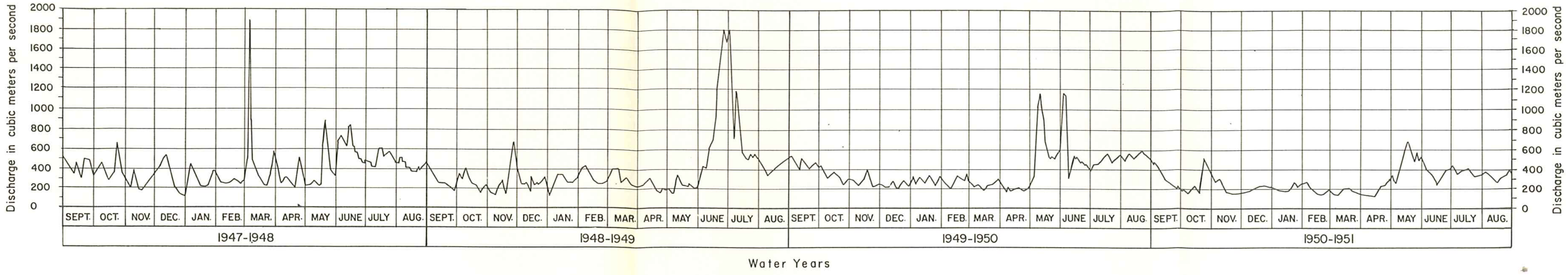
MONTHLY MEAN DISCHARGES - 1947-62

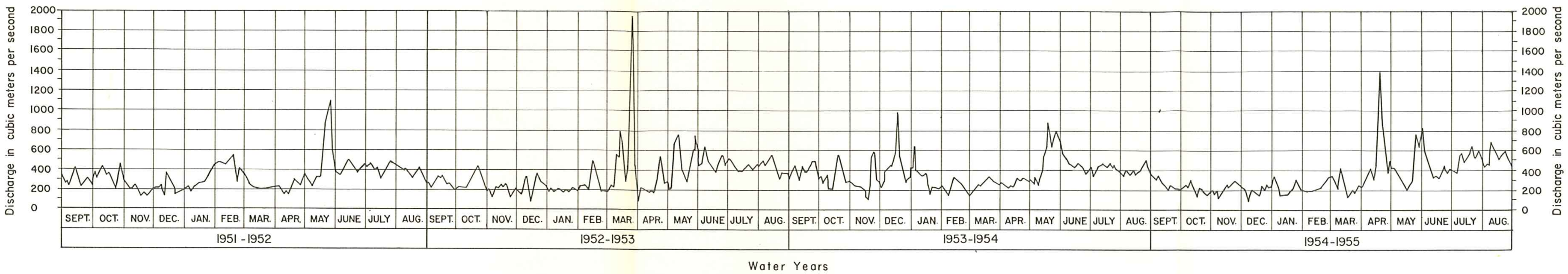
(cubic meters per second)

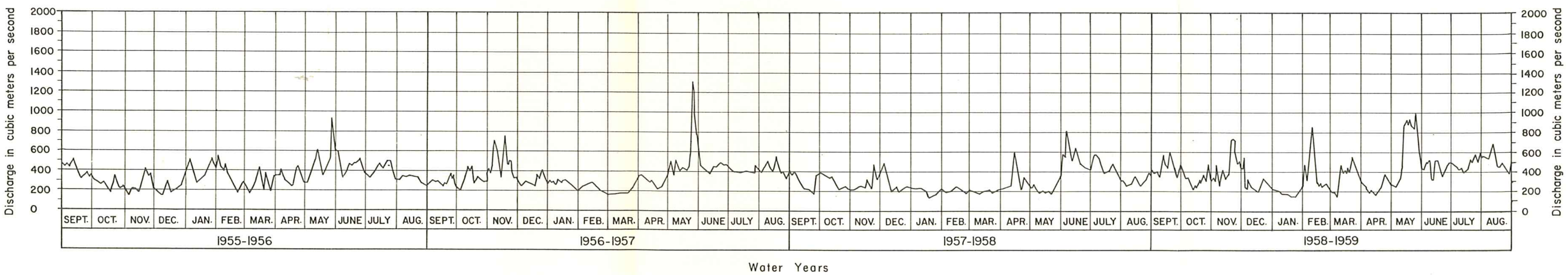
Water Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Annual Mean Discharge
1946-47								(277)	(633)	(381)	(566)	(657)	-
1947-48	447	401	295	327	304	290	497	304	440	(596)	(501)	(428)	(403)
1948-49	304	288	306	288	305	351	323	254	247	1037	859	479	420
1949-50	505	361	306	266	325	314	253	219	657	628	543	596	415
1950-51	359	271	235	223	227	215	202	208	530	401	408	369	305
1951-52	334	377	210	233	316	494	249	274	604	459	452	428	369
1952-53	289	285	222	260	221	277	700	269	529	534	485	496	382
1953-54	453	388	328	486	380	267	277	325	636	524	481	441	417
1954-55	300	234	248	248	264	249	291	545	457	505	600	623	381
1955-56	424	267	264	229	389	347	280	336	511	483	435	331	358
1956-57	307	334	515	329	296	252	224	330	631	479	458	476	387
1957-58	317	342	304	307	218	221	210	338	240	584	494	345	327
1958-59	482	362	492	302	202	424	399	272	661	498	541	571	434
1959-60	561	500	282	270	259	365	314	382	522	461	526	427	406
1960-61	391	238	210	222	268	393	339	300	726	390	406	396	357
1961-62	375	319	289	226	216	256	229	459	515	411	429	380	342
Median Month Year	375	334	289	266	268	290	280	304	530	490	490	435	363
Average	390	331	300	281	279	314	319	318	534	523	512	465	380

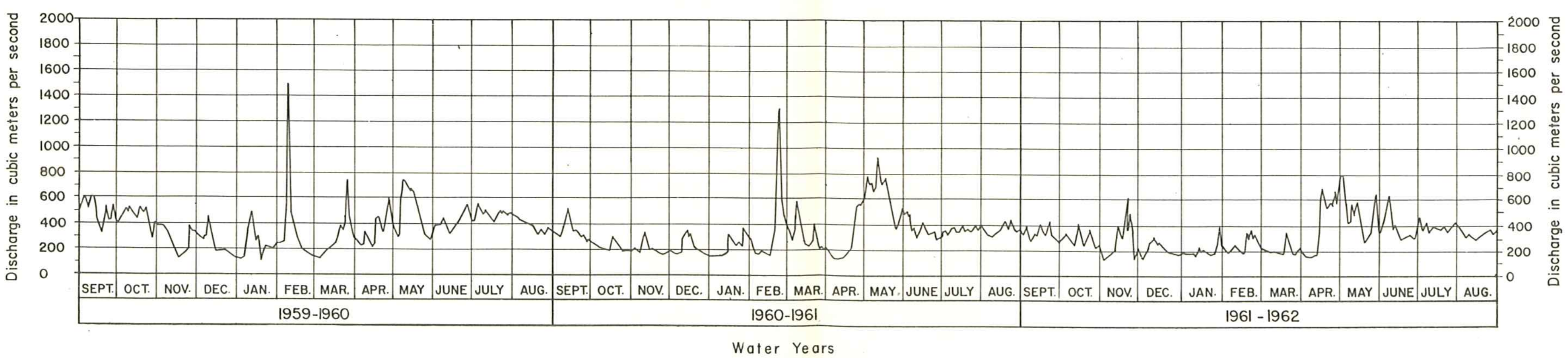
Note: The monthly mean discharges shown in the paranthesis are not based on daily discharge computations, but are the monthly means shown in the SEA annual streamflow report and modified slightly by application of rating dated July 29, 1962 (Krokur).

EXHIBIT A-12









NOTE:

Daily discharge at Burfell computed on the basis of daily discharge records for Thjorsa at Urridafoss by applying a factor of 0.89, which is the ratio of drainage areas at Burfell (6,380 km²) and at Urridafoss (7,200 km²).

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.	V.E.T.		M.N.D.	

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			
MECH.			
ELECT.			
PLAN.		MSS	VAK
STAFF			CH.ENGR.

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

DAILY DISCHARGE HYDROGRAPH THJORSA AT BURFELL 1947 - 1962

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED A.P. Geuss

CHICAGO, ILLINOIS | DATE JANUARY, 1963 | DWG. No. 290 P 31

THJORSA AT BURFELL (Sta. 097)

EXHIBIT A-13

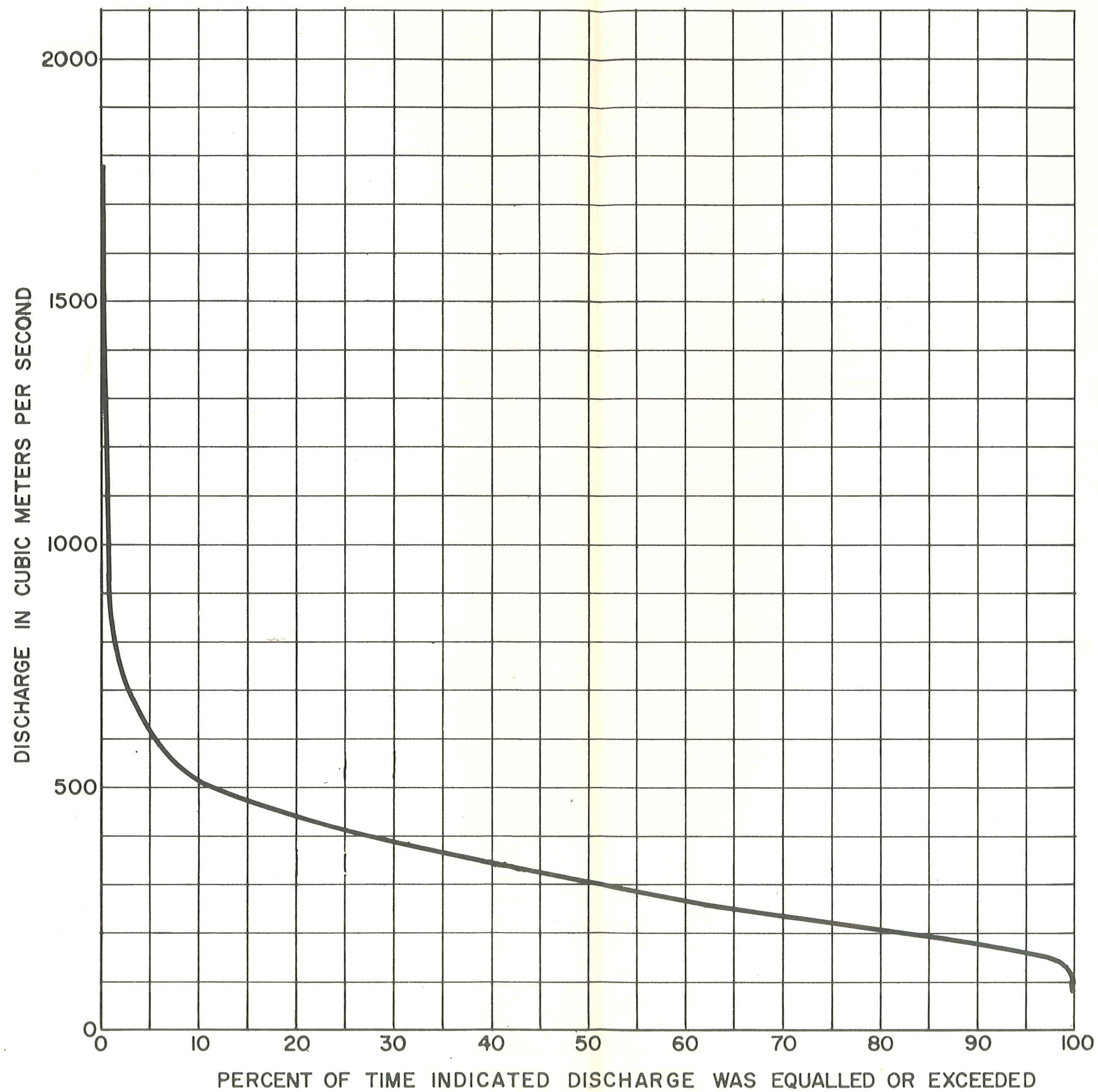
MONTHLY MEAN DISCHARGES - 1947-62

(cubic meters per second)

Water Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Annual Mean Discharge
1946-47								(247)	(563)	(339)	(504)	(585)	
1947-48	398	357	263	291	271	258	442	271	392	(530)	(446)	(381)	359
1948-49	271	256	272	256	271	312	287	226	220	923	765	426	374
1949-50	449	321	272	237	289	279	225	195	585	559	483	530	369
1950-51	320	241	209	198	202	191	180	185	472	357	363	328	271
1951-52	297	336	187	207	281	440	222	244	538	409	402	381	328
1952-53	257	254	198	231	197	247	623	239	471	475	432	441	340
1953-54	403	345	292	433	338	238	247	289	566	466	428	392	371
1954-55	267	208	221	221	235	222	259	485	407	449	534	554	339
1955-56	377	238	235	204	346	309	249	299	455	430	387	295	319
1956-57	273	297	458	293	263	224	199	294	562	426	408	424	344
1957-58	282	304	271	273	194	197	187	301	214	520	440	307	291
1958-59	429	322	438	269	180	377	355	242	588	443	481	508	386
1959-60	499	445	251	240	231	325	279	340	465	410	468	380	361
1960-61	348	212	187	198	239	350	302	267	646	347	361	352	318
1961-62	334	284	257	201	192	228	204	409	458	366	382	338	304
Median Month Year	334	297	257	237	239	258	249	271	472	436	436	387	323
Average	337	295	267	250	242	280	284	283	475	466	455	414	338

Note: Monthly mean discharge at Burfell computed on basis of ratio of drainage areas as measured at Burfell (6,380 km^2) and Urridafoss (7,200 km^2) or 0.89 of Urridafoss discharge.

EXHIBIT A-14



NOTE:

The duration curve at Burfell has been developed by applying the ratio of 89 percent to the frequency of flows determined on the basis of the daily flow records for the Thjorsá at Urridafoss. The 89 percent is the direct ratio of the drainage areas of the Thjorsá at Burfell and Urridafoss.

DATE	NO.	DISTRIBUTION
PRINTS		
	BY	CHKD.
DSGN.	MMQ	MMQ
DWN.	RFL	MMQ
DEPT.	ENG.	HEAD
CIVIL		
MECH.		
ELECT.		
PLAN.	MSS	
STAFF		CH.ENG.

Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

THE STATE ELECTRICITY AUTHORITY
ICELAND

FLOW DURATION CURVE
THJORSA AT BURFELL

HARZA ENGINEERING CO., CHICAGO
APPROVED V. A. Koelzer

DATE JANUARY 1963 DWG.NO. 290 P 54

HARZA ENGINEERING COMPANY

Rating table for TUNGNAA AT VATNAOLDUR *Dated* November 20, 1958

fro. September 1959 *to* August 1962 *; from* .... *to* ....

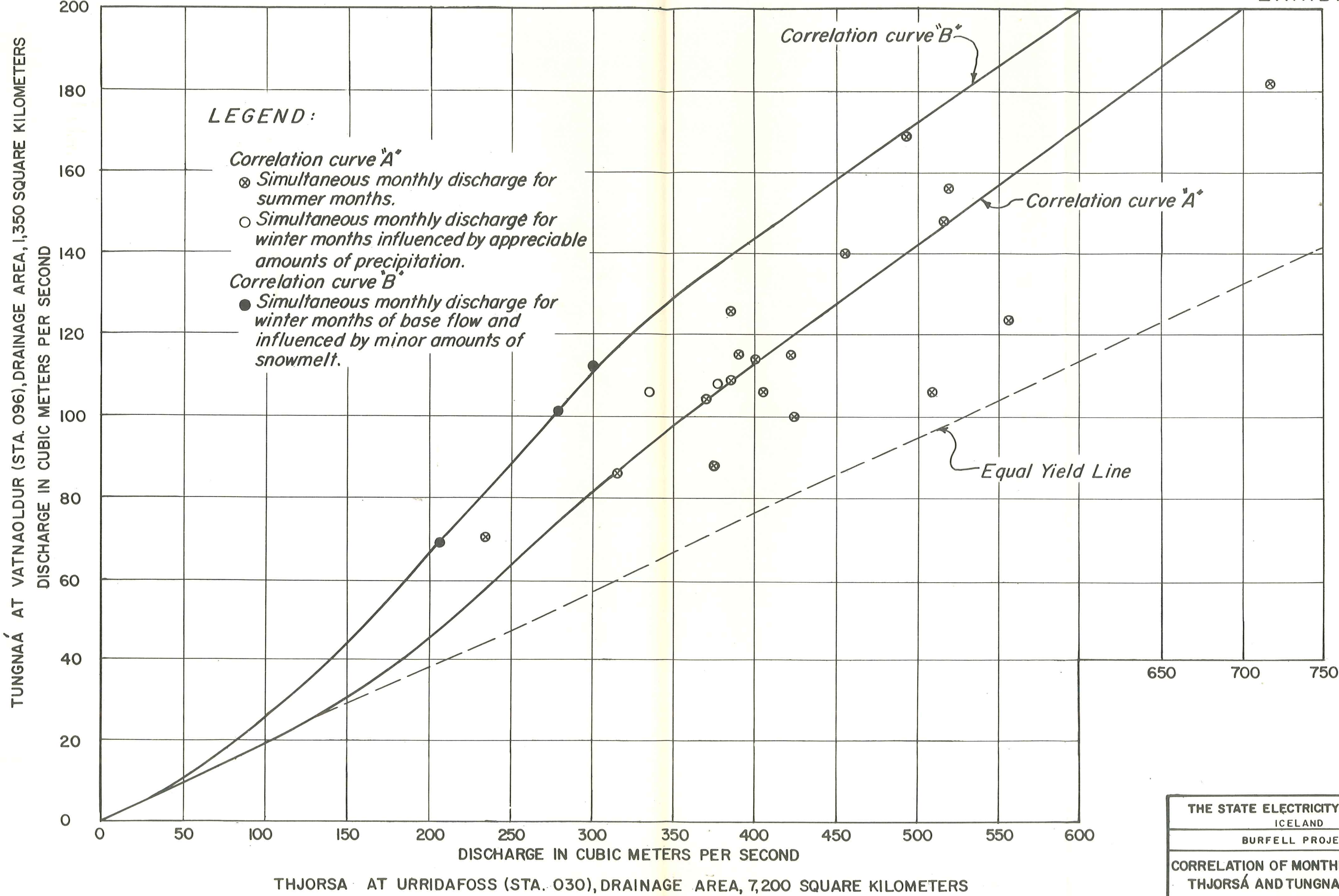
from .... *to* .... *; from* .... *to* ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
				(cubic meters per second)							
0.0											
.1											
.2											
.3											
.4			0.3	0.6	0.9	1.3	1.7	2.1	2.5	2.9	
.5	3.3	3.7	4.1	4.5	4.9	5.4	5.9	6.4	6.9	7.4	
.6	8.0	8.5	9.0	9.6	10.1	10.7	11.3	11.9	12.5	13.1	
.7	13.7	14.3	14.9	15.5	16.1	16.7	17.4	18.1	18.7	19.3	
.8	20.0	20.6	21.2	21.9	22.5	23.2	23.8	24.5	25.2	25.8	
.9	26.5	27.2	27.9	28.6	29.3	30.0	30.7	31.4	32.1	32.8	
1.0	33.5	34.3	34.9	35.6	36.4	37.0	37.8	38.6	39.4	40.2	
.1	41.0	41.8	42.7	43.6	44.5	45.4	46.3	47.2	48.1	49.0	
.2	50	51	52	53	54	55	56	57	58	59	
.3	60	61	62	63	64	66	67	68	69	70	
.4	71	72	73	75	76	77	78	80	81	82	
.5	83	84	86	87	88	90	91	92	94	95	
.6	96	98	99	101	102	104	105	106	108	109	
.7	111	113	114	116	117	119	120	122	123	125	
.8	127	128	130	132	133	135	137	139	141	143	
.9	145	147	149	150	152	154	156	158	160	162	
2.0	164	166	168	171	173	175	177	180	182	184	
.1	186	189	191	193	196	198	200	203	205	207	
.2	209	212	214	217	219	222	225	227	230	233	
.3	235	237	240	243	246	248	251	254	257	260	
.4	263	266	269	272	276	279	282	286	289	292	
.5	295	299	302	305	309	312	316	319	322	326	
.6	329	332	336	340	343	347	351	355	359	363	
.7	367	371	375	380	384	388	392	397	401	405	
.8	409	413	418	422	427	431	436	441	445	450	
.9	455	460	465	470	475	480	485	490	495	500	

Computed by S. Rist 2/23/1961; *Checked by* EE/PBS ..../..../19.... *Remarks* The rating table is the same as submitted by S.E.A.

10—19077

EXHIBIT A-16



THE STATE ELECTRICITY AUTHORITY ICELAND
BURFELL PROJECT
CORRELATION OF MONTHLY DISCHARGE THJORSÁ AND TUNGNAÁ, 1959-62
HARZA ENGINEERING COMPANY APPROVED
CHICAGO, ILLINOIS · DATE · DWG. NO. 290 P 55

Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

EXHIBIT A-17

TUNGNAA AT VATNAOLDUR (Sta. 096)

Monthly Mean Discharges 1947-1962

(Cubic Meters Per Second)

YEAR	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	Annual Mean Discharge
1946-1947								99	179	106	160	186	
1947-1948	125	111	[a]93	120	111	105	[a]155	[a]96	123	168	141	119	122.4
1948-1949	82	76	[a]97	104	[a]96	128	[a]103	[a]76	61	297	245	134	124.7
1949-1950	142	100	112	94	[a]104	115	88	73	186	178	153	168	126.1
1950-1951	99	70	[a]68	[a]64	76	71	65	68	149	111	113	102	88.2
1951-1952	91	105	69	[a]68	[a]101	[a]154	[a]86	[a]84	171	129	126	119	108.5
1952-1953	77	75	[a]63	91	[a]62	[a]86	[a]199	95	149	150	136	139	110.5
1953-1954	127	108	[a]105	[a]152	[a]121	[a]81	86	[a]104	180	147	135	123	122.8
1954-1955	81	56	[a]74	86	[a]80	[a]74	91	154	128	142	169	176	109.5
1955-1956	118	69	[a]80	78	[a]124	[a]111	100	[a]108	143	135	121	91	106.4
1956-1957	83	91	145	[a]106	[a]93	88	75	[a]106	179	134	128	133	113.6
1957-1958	86	94	[a]96	[a]98	73	74	69	[a]108	58	165	139	95	96.2
1958-1959	135	100	138	110	65	[a]134	[a]126	[a]84	187	140	152	161	127.6
1959-1960	124	169	101	85	85	106	109	108	148	140	156	115	121.0
1960-1961	109	70	69	76	77	141	106	111	182	126	114	115	108.0
1961-1962	104	86	77	77	75	91	80	113	106	106	100	88	91.8
Median Month-Year	104	91	93	91	85	105	91	104	149	140	136	119	110.4
Average	106	92	92	94	90	104	103	106	155	158	153	138	105.3

NOTE: Mean monthly discharges for the months September through November 1959, April through November 1960, March through November 1961, and for April through August 1962 are recorded flows based on the stage discharge relationship as defined by S.E.A. rated dated 20-11-1958.

Mean monthly discharges for the winter months of available record affected by ice, December 1959, January through March and December 1960, January, February, December 1961 and January through March 1962 determined on basis of the observed daily gage heights and as modified for the backwater due to ice on the days when considered applicable.

Correlation curves were developed to extend the records prior to September 1959. Mean monthly flows for the period April 1947 through August 1959 were determined from the correlation curves based on the simultaneous records of Tungnaa River at Vatnaoldur and Thjorsa River at Urridafoss. The two correlation curves (1) based on summer months and (2) based on winter months of base flow plus snow melt, shown in Exhibit A-16 were used as follows:

Discharge for the months May through October determined from correlation based on summer months. Discharge for winter months November through April, with little precipitation determined from base flow plus snow melt correlation; the discharge for the months with appreciable precipitation marked by the letter "a" was determined from the mean of the amount indicated by the two correlation curves.

TUNGNAA AT HRAUNEYJAFOSS

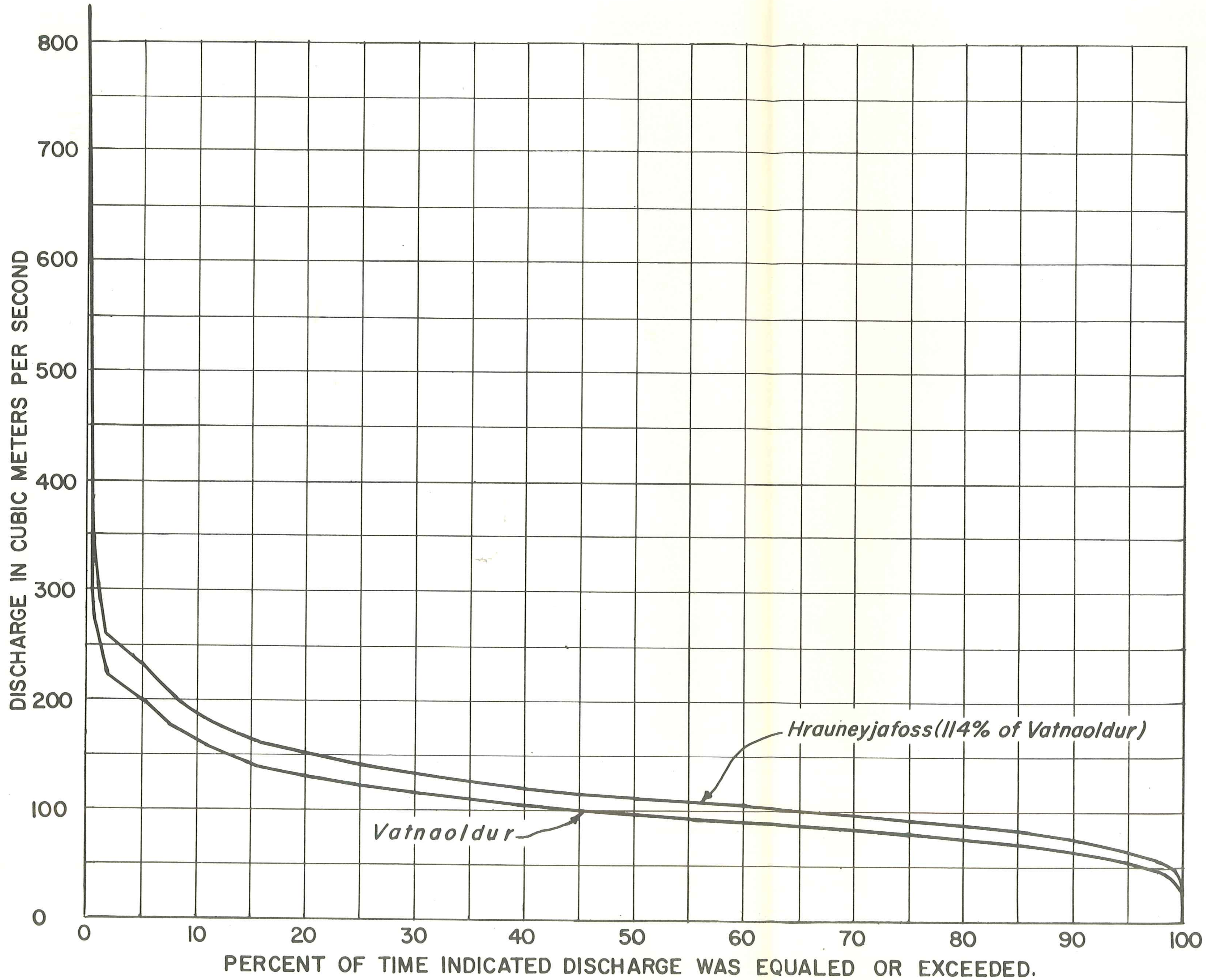
MONTHLY MEAN DISCHARGES 1947-1962

(Cubic Meters Per Second)

YEAR	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	Annual Mean Discharge
1946-1947													
1947-1948	143	127	106	138	127	120	177	109	140	192	161	136	139.8
1948-1949	93	87	111	119	109	146	117	87	70	339	279	153	142.3
1949-1950	162	114	128	107	119	131	100	83	212	203	174	192	143.9
1950-1951	113	80	78	73	87	81	74	78	170	127	129	116	100.7
1951-1952	104	120	79	78	115	176	98	96	195	147	144	136	123.9
1952-1953	88	86	72	104	71	98	227	108	170	171	155	158	126.1
1953-1954	145	123	120	173	138	92	98	119	205	168	154	140	140.0
1954-1955	92	64	84	98	91	84	104	176	146	162	193	201	124.9
1955-1956	135	79	91	89	141	127	114	123	163	154	138	104	121.4
1956-1957	95	104	165	121	106	100	86	121	204	153	146	152	129.6
1957-1958	98	107	109	112	83	84	79	123	66	188	158	108	109.6
1958-1959	154	114	157	125	74	153	144	96	213	160	173	184	145.6
1959-1960	141	193	115	97	97	121	124	123	169	160	178	131	137.6
1960-1961	124	80	79	87	88	161	121	127	207	144	130	131	110.6
1961-1962	119	98	88	88	86	104	91	129	121	121	114	100	104.8
Median Month-Year	119	104	106	104	97	120	104	119	170	160	155	136	124.5
Average	120	105	105	107	102	119	117	113	163	173	162	143	126.7

NOTE: Mean monthly discharges at Hrauneyjafoss are calculated from Vatnaoldur (Sta. 096) on Tungnaa River, using the established relationship $Q_{Hrauneyjafoss} = 1.14\ Q_{Vatnaoldur}$.

EXHIBIT A-19



Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

THE STATE ELECTRICITY AUTHORITY ICELAND
FLOW DURATION CURVE TUNGNAA AT VATNAOLDUR & HRAUNEYJAFOSS
HARZA ENGINEERING CO., CHICAGO APPROVED V. A. Koelzer
DATE / DWG.NO. 290 P 56

K+E PHOENIX N106 TRACING CLOTH

TUNGNAA AT VATNAOLDUR

ANNUAL RUNOFF IN PERCENT OF AVERAGE 1947-62

Year	Runoff (M^3/sec-days)	Percent of 15 Year Average
1947-48	44,785	110
1948-49	45,533	112
1949-50	46,053	113
1950-51	32,177	79
1951-52	39,712	97
1952-53	40,339	99
1953-54	44,813	110
1954-55	39,968	98
1955-56	38,955	95
1956-57	41,459	102
1957-58	35,128	86
1958-59	46,593	114
1959-60	44,179	108
1960-61	39,329	96
1961-62	33,491	82
Average 15 Year Period	40,834	100

Note: Percent of average shown above could be applied to Hrauneyjafoss flow since the latter was taken as 114 percent of Vatnaoldur (Sta. 096) flow.

EXHIBIT A-21

HARZA ENGINEERING COMPANY

Rating table for THORISOS AT VAD *Dated* February 26, 1958

from September 1958 *to* August 1962 *; from* .... *to* ....

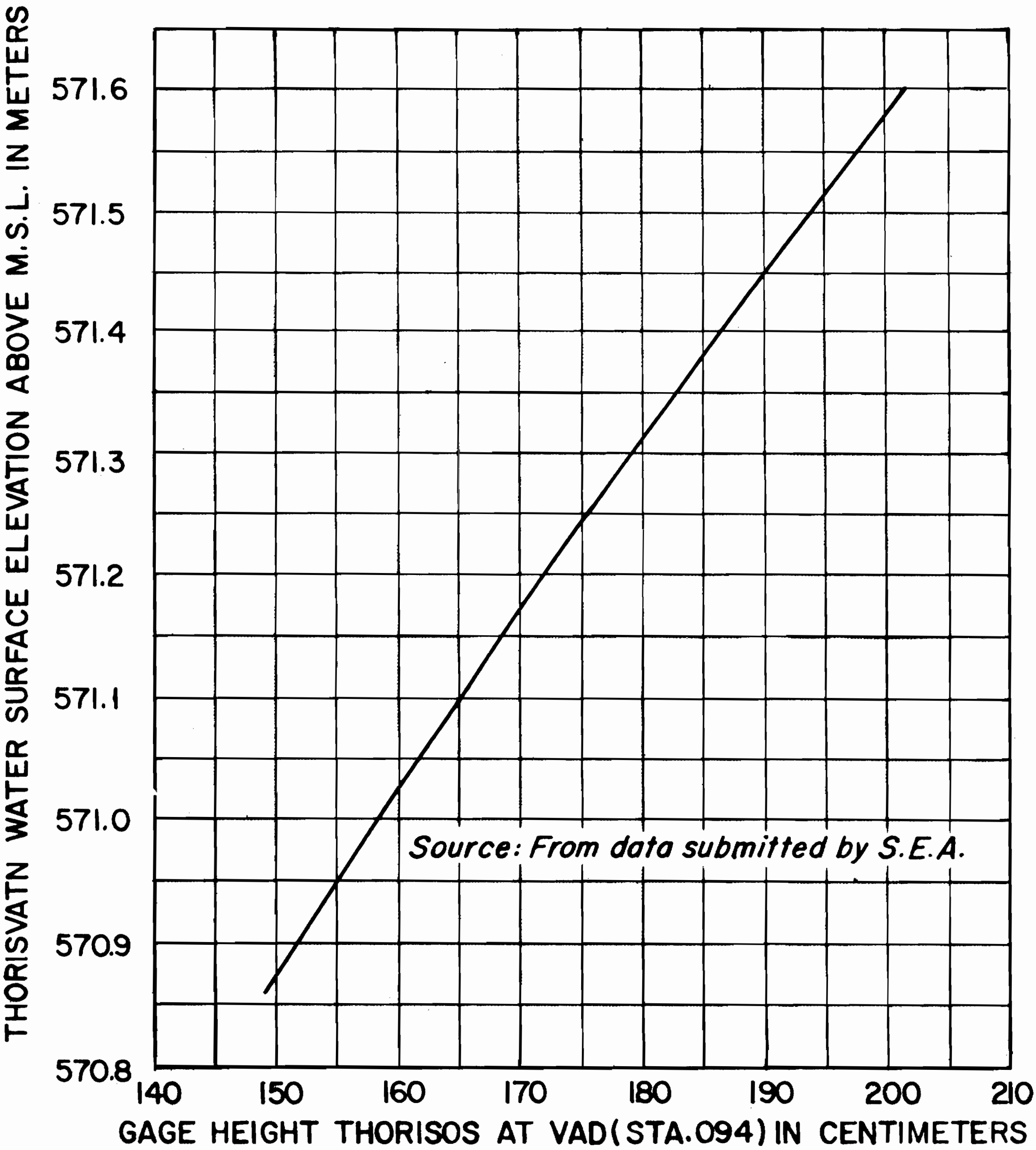
from .... *to* .... *; from* .... *to* ....

Gage height (Meters)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
				(cubic meters per second)							
1.0											
.1											
.2											
.3	4.05	4.25	4.45	4.64	4.84	5.04	5.24	5.44	5.63	5.83	
.4	6.03	6.28	6.52	6.77	7.02	7.27	7.51	7.76	8.01	8.25	
.5	8.50	8.80	9.10	9.40	9.70	10.0	10.3	10.6	10.9	11.2	
.6	11.5	11.9	12.2	12.6	13.0	13.3	13.7	14.1	14.4	14.8	
.7	15.2	15.6	16.0	16.4	16.9	17.3	17.7	18.1	18.6	19.0	
.8	19.4	19.9	20.4	20.8	21.3	21.8	22.3	22.8	23.3	23.7	
.9	24.2	24.8	25.3	25.8	26.4	26.9	27.5	28.0	28.6	29.1	
2.0	29.6	30.2	30.8	31.4	32.0	32.5	33.1	33.7	34.3	34.9	
.1	35.4										
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

Computed by S. Rist/PBS /......./19.......; *Checked by* .... /......./19....... *Remarks* The rating table is the same as submitted by S.E.A.

16—16377

EXHIBIT A-22



THE STATE ELECTRICITY AUTHORITY ICELAND
BURFELL PROJECT
STAGE RELATIONSHIP THORISVATN AND THORISOS AT VAD
HARZA ENGINEERING CO., CHICAGO APPROVED *V.A. Kolg...*

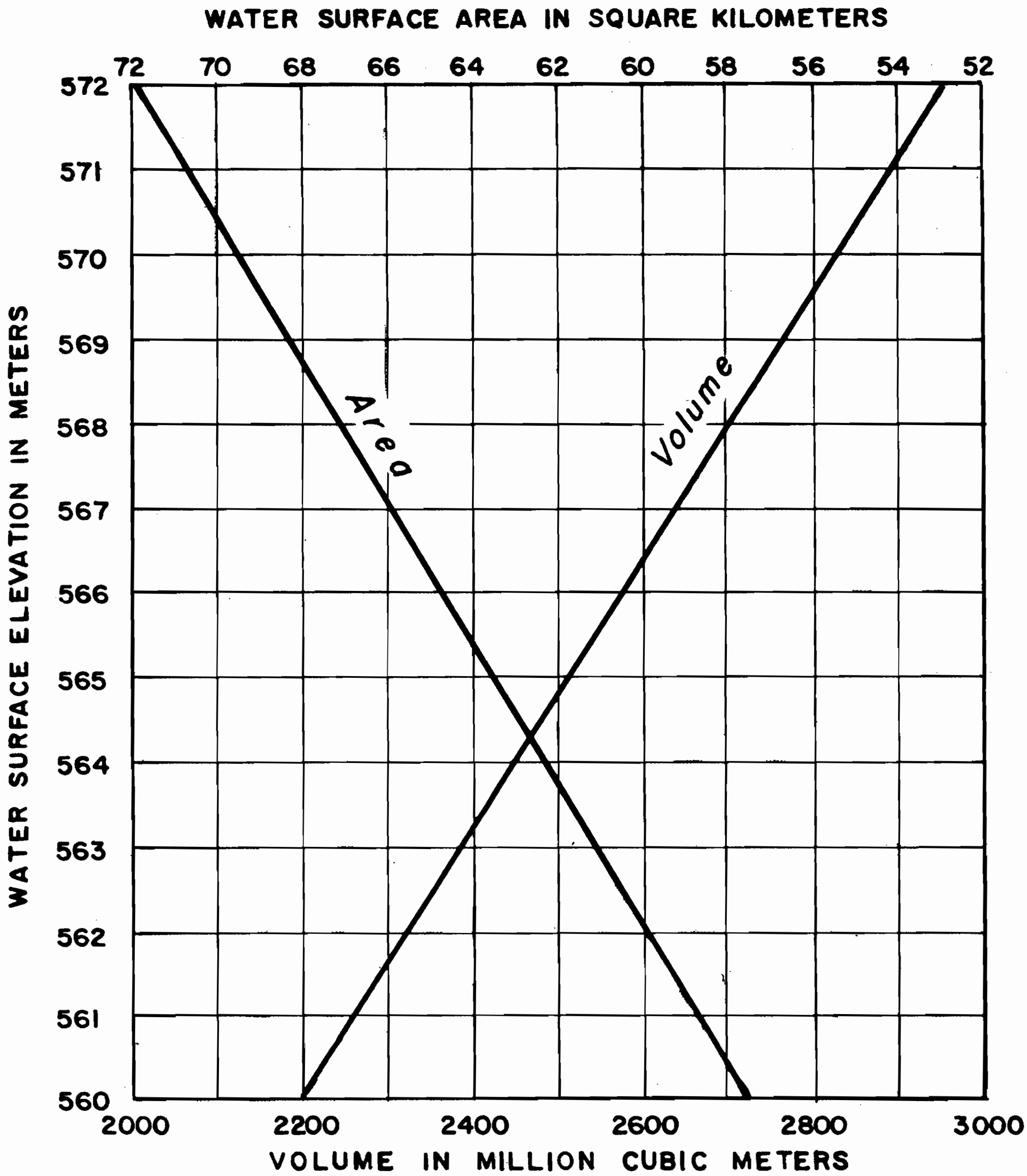
Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

DATE

DWG. NO. 290 P 58

K+E PHOENIX N186 TRACING CLOTH

EXHIBIT A-23



Source: From data submitted by S.E.A.

THE STATE ELECTRICITY AUTHORITY ICELAND	
BURFELL PROJECT	
THORISVATN AREA AND VOLUME CURVE	
HARZA ENGINEERING CO., CHICAGO APPROVED V. A. Koelzer	
DATE	DWG. NO. 290 P 59

Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

K•E PHOENIX N166 ® TRACING CLOTH

USABLE THORISVATN INFLOW 1959-62*

EXHIBIT A-24

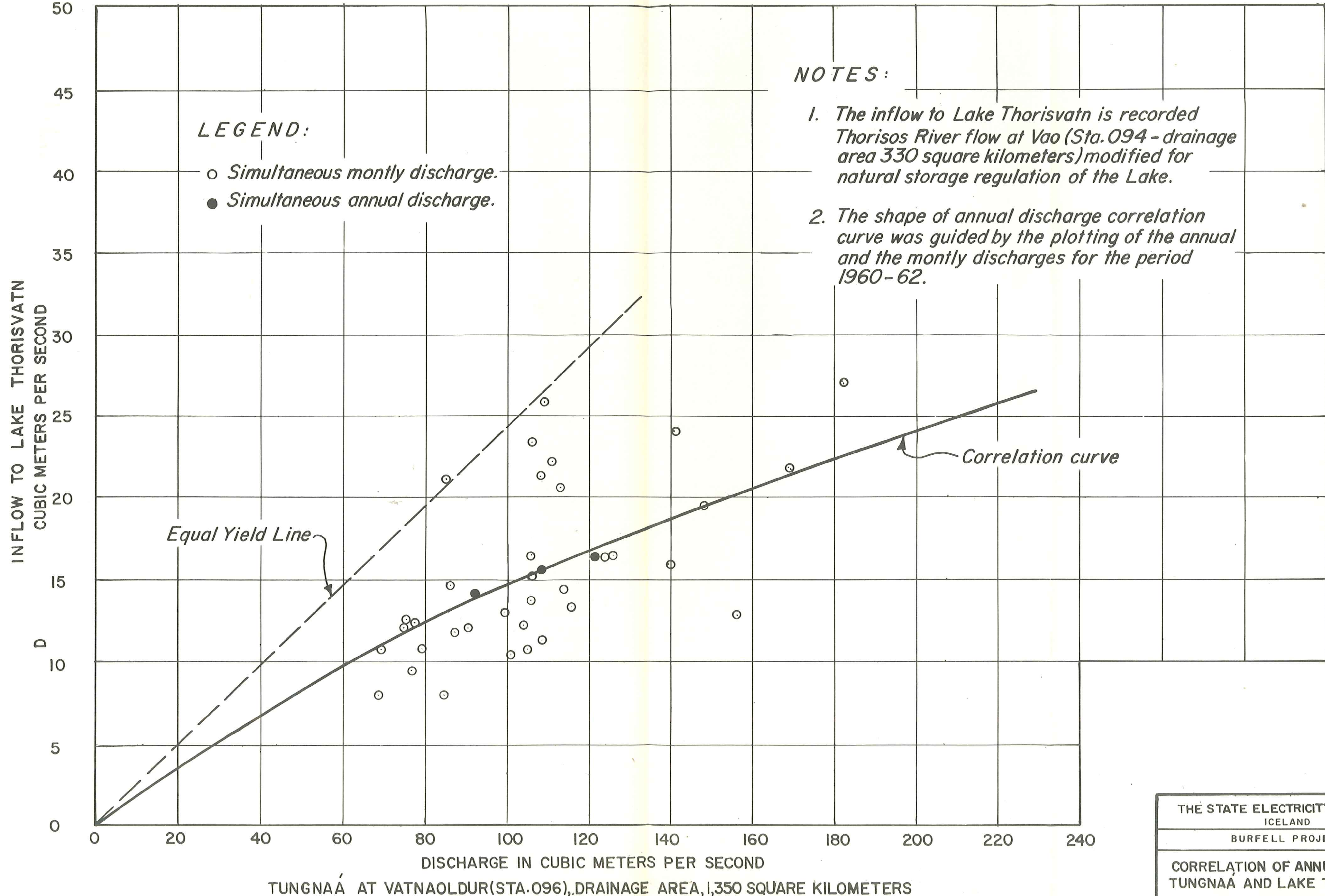
Year and Month	End of Mo. Gage Height at Vad (Meters)	End of Mo. Thorisvatn Elevation (Meters)	Outflow from the Lake (MCM)	Change in storage (+) or (-) (MCM)**	Inflow to the Lake (MCM)
1958-59	(1)	(2)	(3)	(4)	(5)
September	1.59	571.01	30.2	-1.4	28.8
October	1.60	571.03	30.6	+1.4	32.0
November	1.68	571.15	34.9	+8.4	43.3
December	1.59	571.01	31.0	-9.8	21.2
January	1.55	570.95	27.6	-4.2	23.4
February	1.60	571.03	31.8	+5.6	37.4
March	1.76	571.26	43.5	+16.1	59.6
April	1.86	571.40	46.5	+9.8	56.3
May	1.88	571.43	66.0	+2.1	68.1
June	1.81	571.33	58.8	-7.0	51.8
July	1.77	571.28	50.7	-3.5	47.2
August	1.74	571.23	45.3	-3.5	41.8
Total			496.9	+14.0	510.9
1959-60					
September	1.73	571.22	43.7	-0.7	43.0
October	1.84	571.37	47.8	+10.5	58.3
November	1.73	571.22	37.9	-10.5	27.4
December	1.55	570.95	40.1	-18.9	21.2
January	1.71	570.19	39.9	+16.8	56.7
February	1.64	571.09	41.8	-7.0	34.8
March	1.87	571.42	46.0	+23.1	69.1
April	1.86	571.40	56.7	-1.4	55.3
May	1.80	571.32	56.4	-5.6	50.8
June	1.75	571.25	47.7	-4.9	42.8
July	1.68	571.15	41.5	-7.0	34.5
August	1.62	571.06	35.1	-6.3	28.8
Total			534.6	-11.9	522.7

Year and Month	End of Mo. Gage Height at Vad (Meters)	End of Mo. Thorisvatn Elevation (Meters)	Outflow from the Lake (MCM)	Change in storage (+) or (-) (MCM)	Inflow to the Lake (MCM)
1960-61	(1)	(2)	(3)	(4)	(5)
September	1.60	571.03	31.7	-2.1	29.6
October	1.58	571.00	30.0	-2.1	27.9
November	1.53	570.92	26.3	-5.6	20.7
December	1.58	571.00	27.9	+5.6	33.5
January	1.54	570.93	30.4	-4.9	25.5
February	1.79	571.30	32.1	+25.9	58.0
March	1.75	571.25	48.1	-3.5	44.6
April	1.88	571.43	45.1	+12.6	57.7
May	1.89	571.44	71.8	+0.7	72.5
June	1.78	571.29	53.6	-10.5	43.1
July	1.71	571.19	46.2	-7.0	39.2
August	1.69	571.16	39.3	-2.1	37.2
Total			482.5	+7.0	489.5
1961-62					
September	1.65	571.10	36.2	-4.2	32.0
October	1.66	571.12	38.0	+1.4	39.4
November	1.64	571.09	34.3	-2.1	32.2
December	1.63	571.07	34.5	-1.4	33.1
January	1.62	571.06	33.2	-0.7	32.5
February	1.62	571.06	29.1	0.0	29.1
March	1.60	571.03	30.9	-2.1	28.8
April	1.78	571.29	35.1	+18.2	53.3
May	1.81	571.33	60.0	+2.8	62.8
June	1.74	571.23	46.6	-7.0	39.6
July	1.67	571.13	42.0	-7.0	35.0
August	1.63	571.07	34.5	-2.8	31.7
Total			454.4	-4.9	449.5

Explanation of columns: Column 1 and 3 from SEA streamflow reports
Column 2 from stage relationship between water levels at Thorisvatn and Thorisos at Vad, Exhibit A-22
Column 4 from Thorisvatn area and volume curves, Exhibit A-23.
Column 5 = algebraic sum of columns 3 and 4.

* The inflow presented herein is that considered to be usable for storage regulation. It does not represent true inflow because evaporation losses, discharges to springs, and other possible small losses are not accounted for.

** MCM = millions of cubic meters.



Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

CORRELATION OF ANNUAL INFLOW TUNGNAÁ AND LAKE THORISVATN

HARZA ENGINEERING COMPANY
APPROVED V.A. Koelzer

CHICAGO, ILLINOIS | DATE | DWG. NO. 290 P 60

THORISVATN INFLOW

NORMAL MONTHLY DISTRIBUTION

Month	Usable monthly inflow in million cubic meters					Normal Monthly Distribution	
	1958-59	1959-60	1960-61	1961-62	4-year Average	Expressed in percent of Average Annual	Rate of usable inflow (M^3/sec)
September	28.8	43.0	29.6	32.0	33.4	6.7	12.9
October	32.0	58.3	27.9	39.4	39.4	8.0	14.7
November	43.3	27.4	20.7	32.2	30.9	6.3	11.9
December	21.2	21.2	33.5	33.1	27.2	5.5	10.2
January	23.4	56.7	25.5	32.5	34.5	7.0	12.9
February	37.4	34.8	58.0	29.1	39.8	8.1	16.3
March	59.6	69.1	44.6	28.8	50.5	10.2	18.9
April	56.3	55.3	57.7	53.3	55.7	11.3	21.5
May	68.1	50.8	72.5	62.8	63.6	12.9	23.7
June	51.8	42.8	43.1	39.6	44.3	9.0	17.1
July	47.2	34.5	39.2	35.0	39.0	7.9	14.6
August	41.8	28.8	37.2	31.7	34.9	7.1	13.0
ANNUAL	510.9	522.7	489.5	449.5	493.2	100.0	15.6

THORISVATN MONTHLY USABLE INFLOW 1947-1962

(Cubic Meters Per Second)

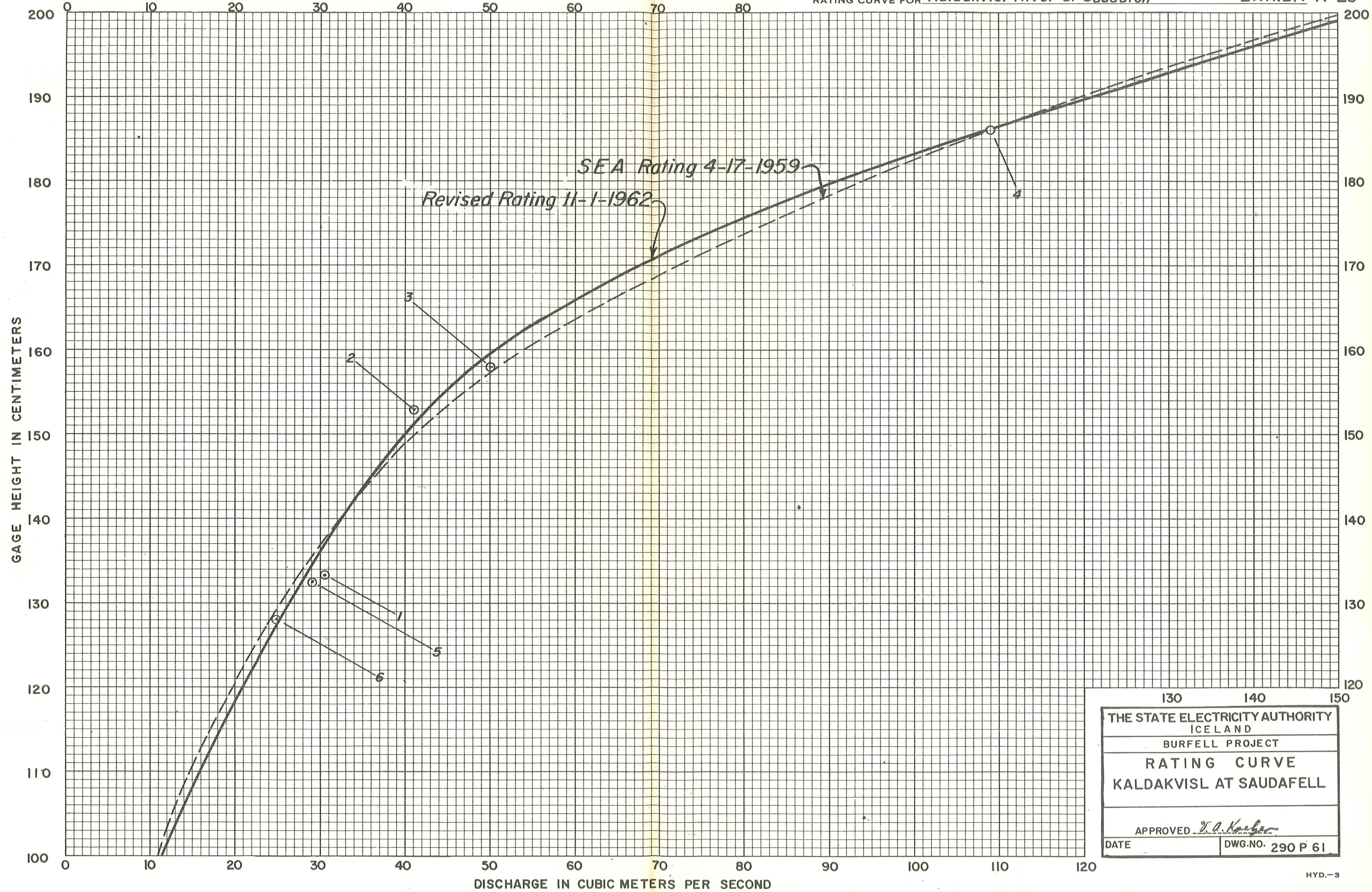
YEAR	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	Annual Mean Discharge
1947-1948	14.0	16.2	13.1	11.1	14.1	17.5	20.6	23.6	26.0	18.8	15.9	14.3	17.1
1948-1949	14.1	16.3	13.3	11.2	14.3	18.2	20.8	23.8	26.3	18.9	16.1	14.5	17.3
1949-1950	14.2	16.4	13.3	11.3	14.4	18.4	20.9	23.9	26.4	19.1	16.2	14.5	17.4
1950-1951	11.1	12.8	10.4	8.8	11.2	14.4	16.3	18.7	20.6	14.9	12.6	11.4	13.6
1951-1952	12.8	14.8	12.1	10.2	13.0	16.0	18.9	21.6	23.9	17.2	14.6	13.2	15.7
1952-1953	12.9	14.9	12.1	10.2	13.0	16.7	19.0	21.7	24.0	17.3	14.7	13.2	15.8
1953-1954	13.9	16.1	13.1	11.1	14.1	18.1	20.5	23.5	26.0	18.7	15.9	14.3	17.1
1954-1955	12.9	14.9	12.1	10.2	13.0	16.7	19.0	21.7	24.0	17.3	14.7	13.2	15.8
1955-1956	12.7	14.6	11.9	10.1	12.8	15.9	18.7	21.4	23.6	17.0	14.5	13.0	15.5
1956-1957	13.2	15.3	12.4	10.5	13.4	17.1	19.5	22.3	24.6	17.7	15.1	13.5	16.2
1957-1958	11.7	13.5	11.0	9.3	11.9	15.2	17.3	19.8	21.9	15.8	13.4	12.0	14.4
1958-1959	11.1	11.9	16.7	7.9	8.8	15.4	22.2	21.7	25.5	20.0	17.6	15.6	16.2
1959-1960	16.6	21.8	10.5	8.0	21.2	13.9	25.8	21.3	19.4	16.1	12.9	10.8	16.5
1960-1961	11.5	10.8	8.0	12.5	9.5	24.0	16.7	22.2	27.2	16.7	14.6	13.9	15.6
1961-1962	12.3	14.7	12.4	12.3	12.2	12.1	10.8	20.6	23.4	15.3	13.1	11.8	14.2
Median Month-Year	12.9	14.9	12.1	10.2	13.0	16.7	19.0	21.7	24.0	17.3	14.7	13.2	15.8
Average	13.0	15.0	12.2	10.3	13.1	16.6	19.1	21.9	24.2	17.4	14.8	13.3	15.9

NOTE: The monthly mean inflows to Lake Thorisvatn for the four year period September 1958 through August 1962 based on recorded monthly discharge of Thorisos River at Vad (Sta. 094) and adjusted for change in natural storage at the lake.

The monthly mean inflows for the years prior to September 1958 are based on correlation of annual inflow Tungnaa and Thorisvatn, Exhibit A-25, and the distribution of the monthly inflows on basis of the established normal for the four year period of record 1959-62.

HARZA ENGINEERING COMPANY INTERNATIONAL

RATING CURVE FOR *Kaldakvisl River at Saudafell* EXHIBIT A-28



Rating table for

HARZA ENGINEERING COMPANY

EXHIBIT A-29

KALDAKVISL AT SAUDAFELL — *Dated* November 1, 1962

fra September 1961 *to* August 1962 *; from* .... *to* ....

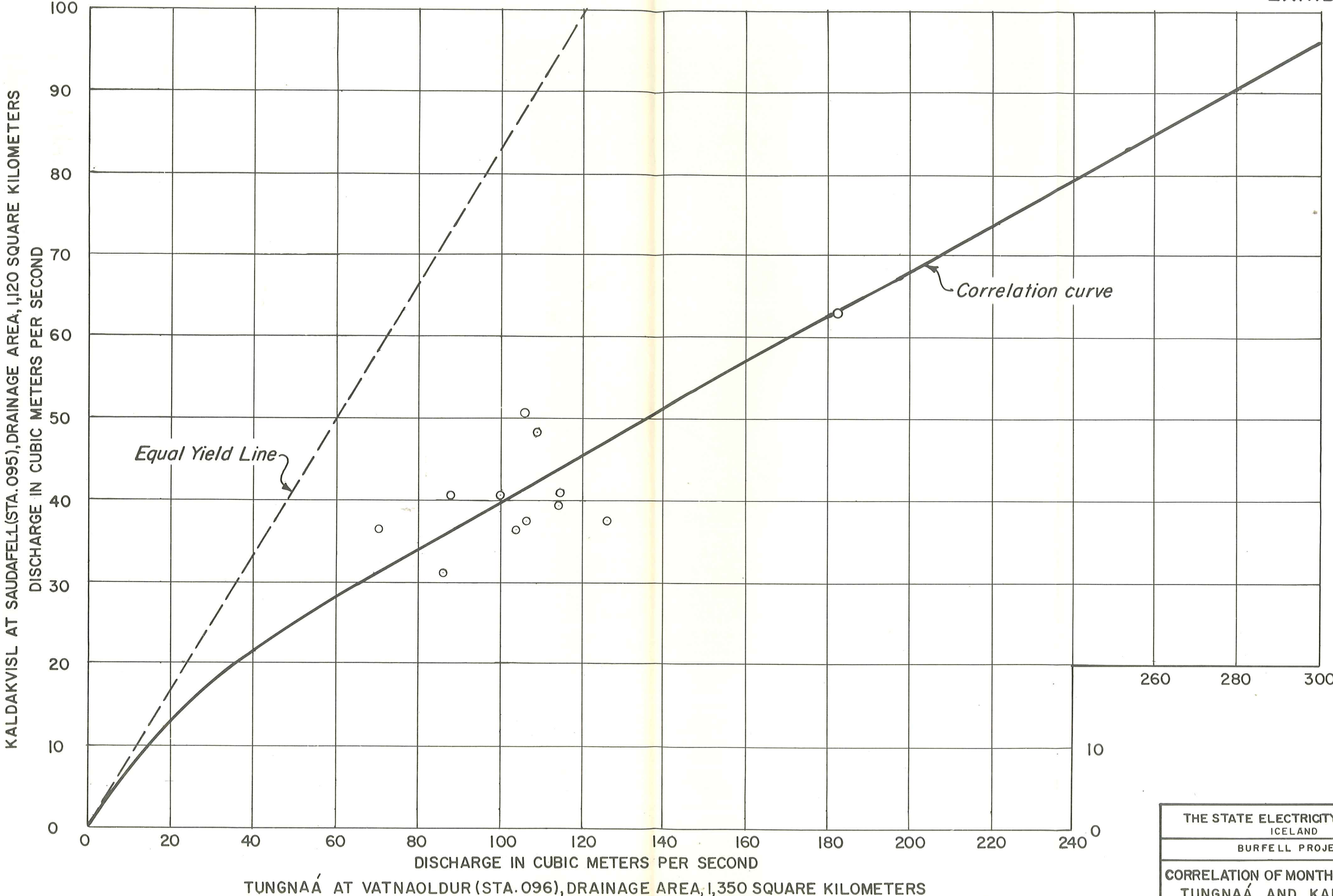
from .... *to* .... *; from* .... *to* ....

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
0.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
1.0	11.5	12.0	12.4	12.9	13.3	13.7	14.1	14.6	15.0	15.5	
.1	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	
.2	21.0	21.5	22.1	22.6	23.2	23.7	24.3	24.8	25.4	26.0	
.3	26.5	27.1	27.7	28.3	28.9	29.5	30.1	30.7	31.3	31.9	
.4	32.5	33.2	34.0	34.7	35.5	36.2	37.0	37.7	38.5	39.2	
.5	40.0	41.1	42.2	43.3	44.4	45.5	46.6	47.7	48.8	49.9	
.6	51.0	52.7	54.4	56.1	57.8	59.5	61.2	62.9	64.6	66.3	
.7	68.0	70.4	72.6	75.0	77.4	79.8	82.2	84.6	87.0	89.4	
.8	92.0	95.0	98.0	100	103	106	109	112	115	118	
.9	121	124	127	130	133	137	140	143	146	149	
2 .0	153	156	159	163	166	169	173	176	179	183	
.1	186	189	192	196	199	202	206	209	212	216	
.2	219	222	225	229	232	235	239	242	245	249	
.3	252										
.4											
.5											
.6											
.7											
.8											
.9											

Computed by W.L. 11/2/1962; *Checked by* M.S.S. 12/15/1962. *Remarks* Rating the same as SEA rating dated 4-17-1959 except that it is slightly modified to more nearly represent the six measurements made during the period September 1958 through December 1961.

10—19377

EXHIBIT A-30



THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

CORRELATION OF MONTHLY DISCHARGE
TUNGNAÁ AND KALDAKVISL

HARZA ENGINEERING COMPANY
APPROVED V.A. Koelzer

CHICAGO, ILLINOIS | DATE | DWG. NO. 290 P 62

Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL

KALDKVISL AT SAUDAFELL (Sta. 095)

MONTHLY MEAN DISCHARGE 1947-1962

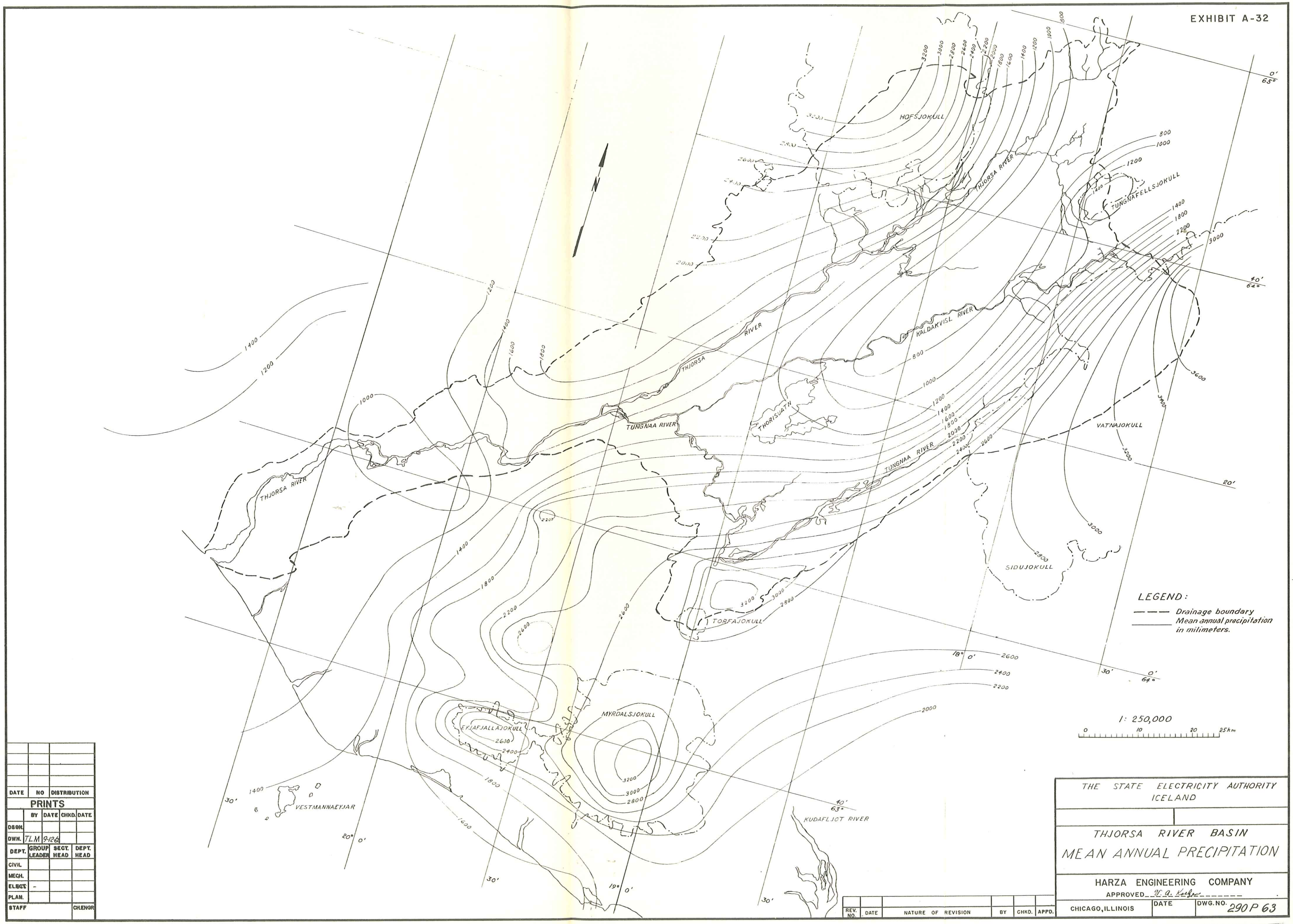
(Cubic Meters Per Second)

YEAR	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	Annual Mean Discharge
1946-1947								39	62	41	57	64	-
1947-1948	47	43	38	45	43	41	55	39	46	59	51	45	46.0
1948-1949	35	33	39	41	39	48	41	33	29	95	81	50	47.0
1949-1950	52	40	43	38	41	44	36	32	64	62	55	59	47.2
1950-1951	39	31	31	29	33	32	30	31	54	43	43	40	36.4
1951-1952	37	41	31	31	40	55	36	35	60	48	47	45	42.1
1952-1953	33	33	29	37	29	36	68	38	54	54	50	51	42.8
1953-1954	47	42	41	54	46	34	36	41	63	53	50	46	46.2
1954-1955	34	27	32	36	34	32	37	55	48	52	59	61	42.3
1955-1956	45	31	34	34	47	43	40	42	52	50	46	37	41.7
1956-1957	35	37	54	41	38	36	33	41	62	49	48	49	43.6
1957-1958	36	38	39	39	32	32	31	42	28	58	51	38	38.7
1958-1959	50	40	51	43	30	49	47	35	64	51	55	57	47.7
1959-1960	47	59	40	36	36	41	42	42	53	51	56	44	45.6
1960-1961	48.3	36.4	31	33	33	51	41	43	63.1	37.5	39.3	41.0	41.4
1961-1962	36.4	31.0	33	33	33	37	34	43	50.7	37.4	40.6	40.6	37.5
Median Month-Year	39	37	38	37	36	41	37	41	54	51	50	45	42.2
Average	41	37	38	38	37	41	40	39	53	53	52	48	43.1

NOTES: Monthly mean discharges for the months September and October of 1960 and 1961 and for the months May through August of 1961 and 1962 are recorded flows based on the stage-discharge relationship as defined by SEA rating dated 17-4-1959 and revised by Harza on 1-11-1962.

Monthly mean discharges for the winter months November through April in 1961 and 1962 and the extension of records back to 1947 based on the correlation curve "Correlation of Monthly Discharge Tungnaa and Kaldkvisl." (Exhibit A-30)

EXHIBIT A-32


HOFSJOKULL
THJORSA RIVER
TUNGNAFELLSJOKULL
KALDAKVISL RIVER
THJORSA RIVER
TUNGNAA RIVER
THORISVATN
TUNGNAA RIVER
VATNAJOKULL
THJORSA RIVER
SIDUJOKULL
TORFAJOKULL
MYRDALSJOKULL
EYJAFJALLAJOKULL
VESTMANNAEYJAR
KUDAFLJOT RIVER
LEGEND:
Drainage boundary
Mean annual precipitation in milimeters.
1: 250,000
0 10 20 25km
65°
64°
63°
18° 0'
19° 0'
20° 0'
30'
40'
20'
DATE | NO | DISTRIBUTION
PRINTS
BY | DATE | CHKD. | DATE
DSGN.
DWN. TLM 9-12-62
DEPT. | GROUP LEADER | SECT. HEAD | DEPT. HEAD
CIVIL
MECH.
ELECT.
PLAN.
STAFF | CH.ENGR
REV. NO. | DATE | NATURE OF REVISION | BY | CHKD. | APPD.
THE STATE ELECTRICITY AUTHORITY
ICELAND
THJORSA RIVER BASIN
MEAN ANNUAL PRECIPITATION
HARZA ENGINEERING COMPANY
APPROVED
CHICAGO, ILLINOIS
DATE
DWG. NO. 290 P 63

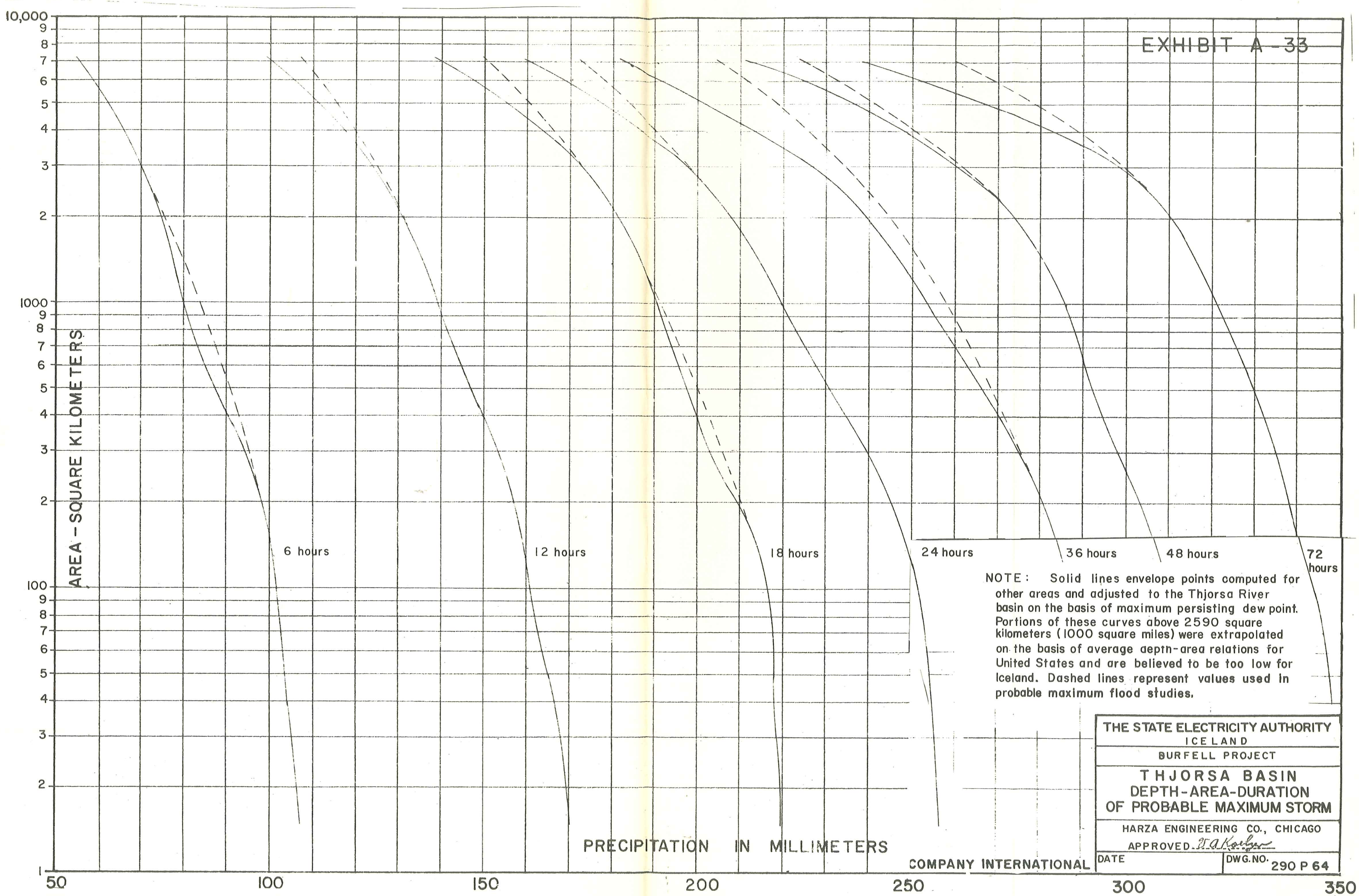
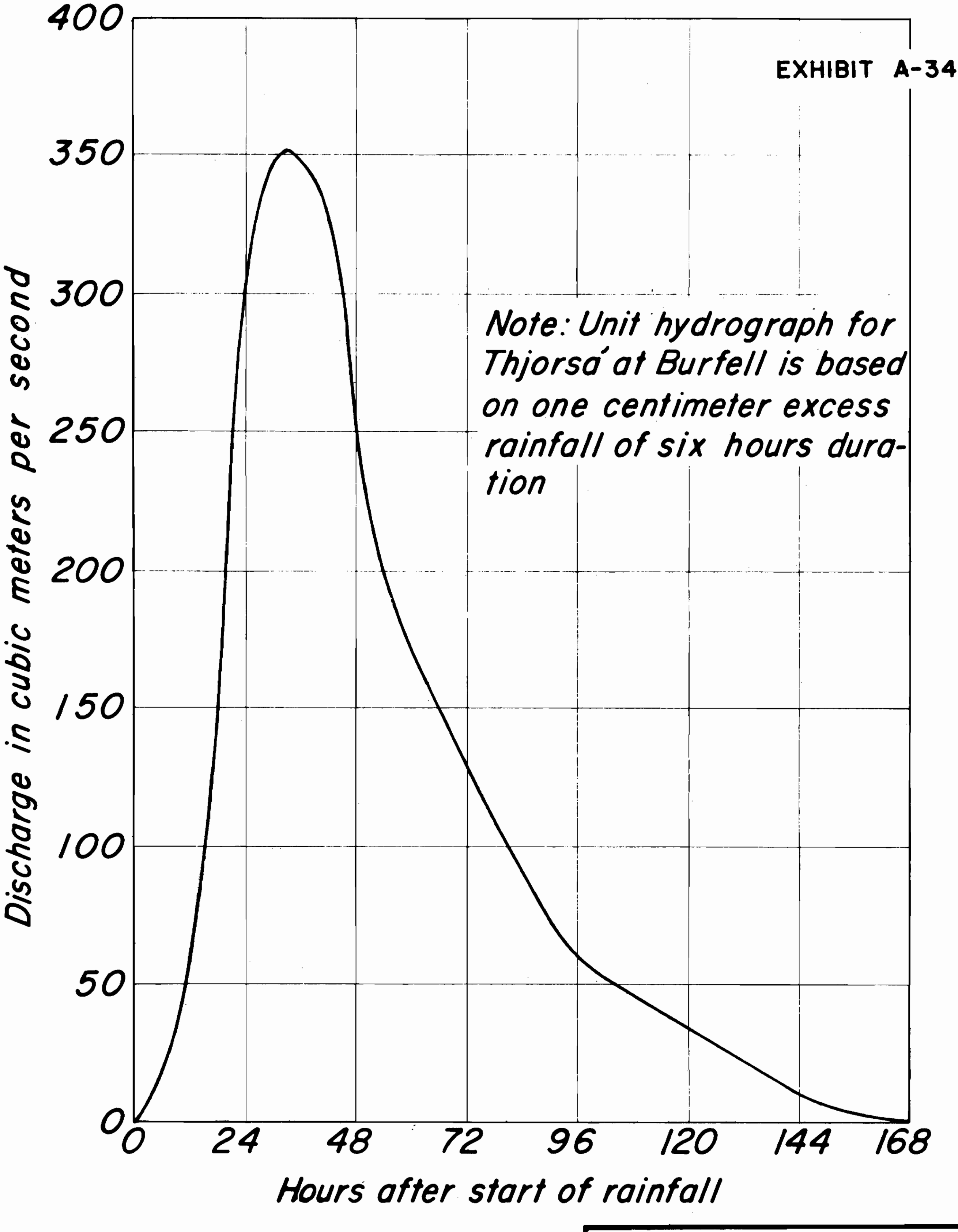


EXHIBIT A-33
AREA - SQUARE KILOMETERS
10,000
1000
100
1
PRECIPITATION IN MILLIMETERS
50
100
150
200
250
300
350
6 hours
12 hours
18 hours
24 hours
36 hours
48 hours
72 hours
NOTE: Solid lines envelope points computed for other areas and adjusted to the Thjorsa River basin on the basis of maximum persisting dew point. Portions of these curves above 2590 square kilometers (1000 square miles) were extrapolated on the basis of average depth-area relations for United States and are believed to be too low for Iceland. Dashed lines represent values used in probable maximum flood studies.
THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT
THJORSA BASIN
DEPTH-AREA-DURATION
OF PROBABLE MAXIMUM STORM
HARZA ENGINEERING CO., CHICAGO
APPROVED
COMPANY INTERNATIONAL
DATE
DWG.NO. 290 P 64



THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT

THJORSA AT BURFELL
UNIT HYDROGRAPH

HARZA ENGINEERING CO., CHICAGO
APPROVED V. a. Koelzer

DATE JAN. 1963 | DWG. NO. 290 P 65

Prepared for:
HARZA ENGINEERING COMPANY INTERNATIONAL

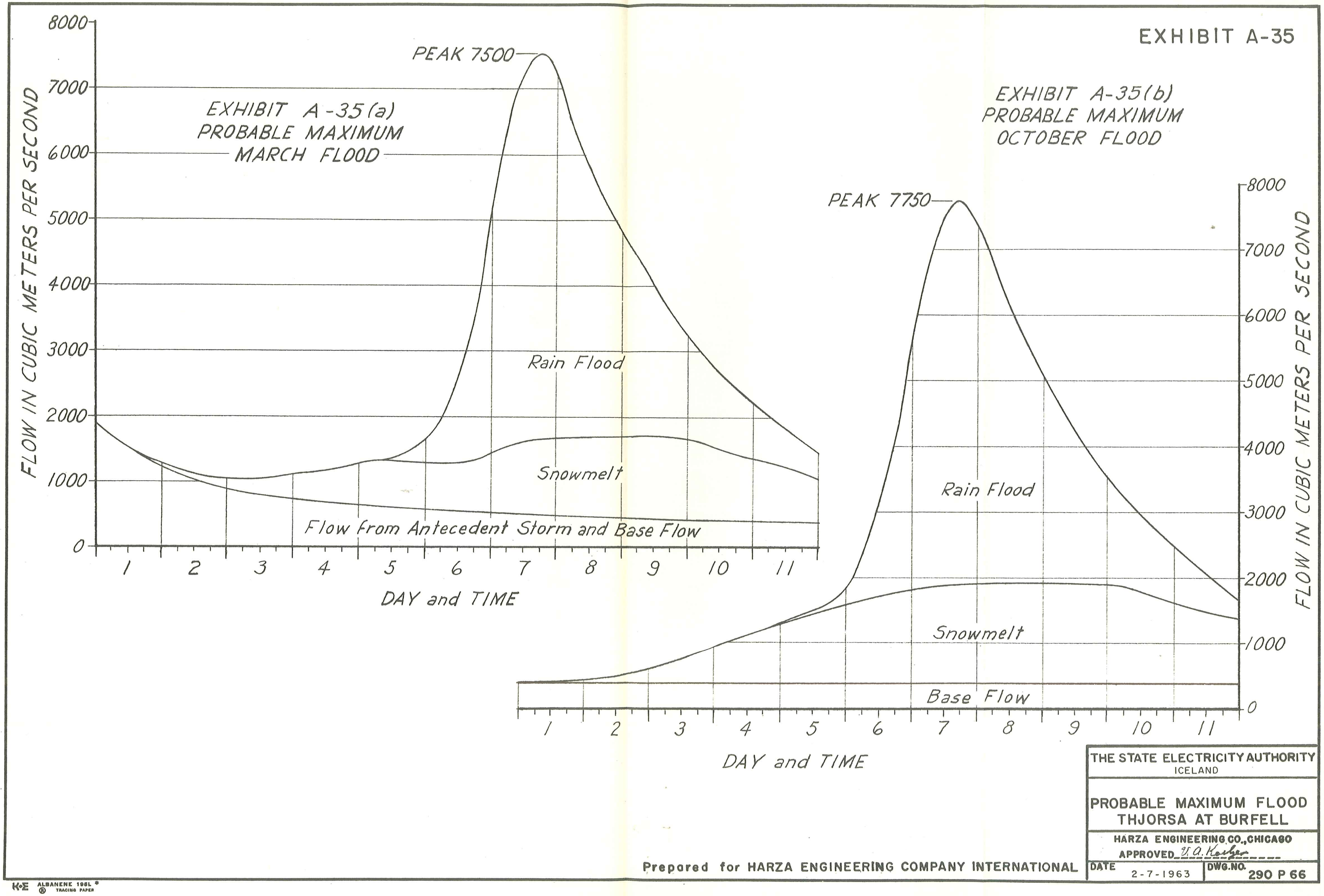


EXHIBIT A-35
EXHIBIT A-35(a)
PROBABLE MAXIMUM
MARCH FLOOD
PEAK 7500
FLOW IN CUBIC METERS PER SECOND
8000
7000
6000
5000
4000
3000
2000
1000
0
Rain Flood
Snowmelt
Flow from Antecedent Storm and Base Flow
1 2 3 4 5 6 7 8 9 10 11
DAY and TIME
EXHIBIT A-35(b)
PROBABLE MAXIMUM
OCTOBER FLOOD
PEAK 7750
FLOW IN CUBIC METERS PER SECOND
Rain Flood
Snowmelt
Base Flow
DAY and TIME
THE STATE ELECTRICITY AUTHORITY
ICELAND
PROBABLE MAXIMUM FLOOD
THJORSA AT BURFELL
HARZA ENGINEERING CO., CHICAGO
APPROVED V.O. Kaiser
DATE 2-7-1963
DWG. NO. 290 P 66
Prepared for HARZA ENGINEERING COMPANY INTERNATIONAL
K+E ALBANENE 196L TRACING PAPER

APPENDIX B

ENGINEERING GEOLOGY

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APPENDIX B

ENGINEERING GEOLOGY

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APPENDIX B

ENGINEERING GEOLOGY

Introduction

Geologic studies and investigations represent one of the most important aspects of hydroelectric development. They are important to the location of (1) storage reservoir sites, (2) head concentrations favorable for power development, (3) deposits of natural construction materials, and (4) the most favorable foundations for engineering structures. They are also important to the understanding of the hydrology of the river as well as the subsurface permeability relationships. This information requires a general knowledge of the regional geology and a specific knowledge of the detailed geology at the site of planned engineering structures.

The geology as it relates to the engineering of each of the above aspects of the Burfell Project is presented and discussed in this Appendix. Information with respect to the regional geology was obtained from reconnaissance by geologists and engineers of the Harza Engineering Company International (HARZINT) and, especially, from work accomplished by Icelandic geologists. Much of the latter work is presented in published and unpublished documents. The detailed site geology was interpreted from geologic mapping, diamond core borings, "Borro" soundings, an exploration tunnel, bulldozer trenches, groundwater table and groundwater movement measurements, permeability tests, auger holes, test pits, test blasts, and laboratory tests and examinations. This extensive field and office work was adequate for planning of the Project and provided much detailed information required for final design and construction. More information, however, is desirable in preparation for the future phases of detailed design engineering. The observations and results of these regional and site geologic studies are presented briefly below.

Geologic Setting

General

Iceland is a large volcanic island built on top of the Mid-Atlantic Ridge which, in the North Atlantic region, has a generally NE-SW trend. Volcanic activity seems to have been more or less continuous since the Eocene epoch, many millions of years ago, to the present, and there are still at least 30 active volcanoes in Iceland, plus a much larger number of extinct craters.

The older lavas, which date from before the Glacial (Pleistocene) epoch, are several kilometers thick. They are generally referred to as the Plateau Basalts. The Plateau Basalts have been faulted and tilted to form a series of blocks which were then deeply eroded. Up to a five-kilometer thickness of basalt was removed from the edges of some of the rising blocks resulting in a landsurface of relatively low relief. Deep, relatively broad valleys were formed, separated by ridges of the Plateau Basalts.

A broad depression in the Plateau Basalts, averaging over 100 kilometers wide, extends in a NE-SW direction completely across

Iceland, and is known as the Central Icelandic Graben. In Southwest Iceland the Hvita and Thjorsa valleys occupy roughly the central part of this depression, which is both bordered and underlain by the Plateau Basalts. The Plateau Basalts outcrop mainly in eastern and western Iceland and thus are too far removed or too deeply buried to be of direct interest to the Burfell Project study.

Grey Basalts

A formation of Grey Basalts with intercalated tillites, sediments and fanglomerates, of late Tertiary or early Pleistocene age, lies discordantly on the Plateau Basalts in the Central Icelandic Graben. These Grey Basalts are commonly referred to as the Hreppar Series. Their outcrops dominate the area above about elevation 100 meters northwesterly of the Thjorsa-Tungnaa-Kaldakvisl line as far as and slightly beyond the Hvita. They are exposed in another broad belt lying generally between Myrdalsjokull and Vatnajokull and paralleling the southeast coast of Iceland.

The Grey Basalts, in general, comprise layers of breccia, tuff and basalt. They contain many small basaltic intrusions. Joints are generally tight. They contain, locally, rhyolitic intrusions, which, where hydrothermally altered as is frequently the case, should be avoided completely as the foundations for engineering structures. The basalts and breccias are, for the most part, sound rocks well suited as foundations for surface structures and underground excavations. The intercalated materials are weaker and should be avoided so far as feasible.

Where exposed, the surfaces of the Grey Basalts have been subjected to intense glaciation which has tended to leave only sound rock, though covered by moraine over wide areas. This combination presents a moderately impermeable surface permitting rapid runoff of rainfall and snowmelt, and also providing relatively little in the way of groundwater storage to sustain stream flows.

Palagonite-Tuff Series

The bedrock sequence next younger than the Grey Basalts is referred to in Iceland as the Palagonite-Tuff Series. The Series is made up of two types of rock (1) the palagonite rock (or moberg) proper, and (2) irregular basalt intercalations. The palagonite rock is the more voluminous of the two types, at least on the surface. It is a clastic rock of basaltic volcanic materials. Its most fine-grained variety is tuff. Other varieties of the palagonite rock contain angular fragments of cuptalline basalt of various size with the interstitial spaces usually filled with tuff-like materials. Frequently the basalt fragments constitute the main part of the rock.

The irregular basalt intercalations within the Palagonite-Tuff Series have an irregular shape and jointed structure. Many of them are typical pillow lavas, often of considerable thickness. The intermediate spaces between pillows are usually filled with a tuff-like material or with a breccia of pillow fragments. In general the amount of basalt in the Series appears to increase with depth, outcropping in the lower part of slopes or gorges. On the other hand, most mountain tops are of the palagonite rock only.

The Central Icelandic Graben contains the Palagonite-Tuff Series of Pleistocene age which was built up beneath glaciers (subglacial). Rocks of this type may still be forming under the icecaps which form about thirteen percent of Iceland's surface area of 100,000 square kilometers. Outcrops of the Palagonite-Tuff Series are found in the middle portion of the Central Icelandic Graben, between the two principal exposures of the Grey Basalts referred to above.

A principal feature of engineering importance with respect to the Palagonite-Tuff Series is the generally high permeability of the mass of the material. The more impervious beds within the mass tend to produce perched watertables. The high degree of permeability provides an important groundwater storage to sustain stream flows.

Glacial Deposits

Pleistocene moraine and finiglacial deposits sporadically overlie the Grey Basalts and the rocks of the Palagonite-Tuff Series. They may also underlie even younger rocks. The moraine tends to be heterogeneous, coarse-grained and gravelly, but locally may be fine-grained and cohesive. In general, it is the least pervious of all the surface formations. Thus, it may result in the formation of perched water tables. The suitability of moraine for impervious core material is an important engineering feature.

The finiglacial deposits consist of sand or sand and gravel. These deposits were probably built up as moraine beaches or deltas when the crust was depressed by the load of the great ice sheets to a level as much as about 130 meters lower than present. Some parts of these deposits may represent aggradation by braided streams. The finiglacial deposits include the extensive strandlines found in southern Iceland. From the engineering standpoint, these deposits represent important sources of natural construction materials.

Holocene Deposits

The Holocene deposits include post-glacial lavas, pyroclastic materials including pumiceous lapilli and volcanic ash, loess, sediments in lava-dammed lakes, river alluvium, and glacial outwash.

The post-glacial lavas include basalt flows from fissures, such as the Thjorsa flows, and flows from volcanoes, such as the Hekla lava flows, both discussed later. The pyroclastic materials originated from the same two basic types of sources. Both the fissures and volcanoes are, to a large degree, associated tectonically with the Central Icelandic Graben. The lava flows are generally porphyritic basalts and are frequently separated from each other in any sequence by interbeds of soil, ash, and lapilli. The lava flows from the volcanoes tend to be non-porphyritic basalts.

The post-glacial pyroclastic materials from the fissures consist predominantly of loose pumiceous lapilli with large lumps of other ejectamenta. Their thickness near the fissure of origin may amount to hundreds of meters, but decreases away from the centers. Locally they tend to fill pre-existing valleys. These materials are exceedingly pervious and, as a consequence, the watertable is deep and flat. Thus, they represent an important source of groundwater to equalize stream flows.

The pyroclastic material from the volcanoes, such as Hekla, consists mostly of pumiceous lapilli. It was carried by the wind, generally in a northward direction, and deposited over wide areas, locally up to several tens of meters in depth. After initial deposition, it has, to some extent, been carried by water and the wind and redeposited. It is everywhere highly permeable. Where found in interbeds in the post-glacial lavas, its presence permits rapid movement of groundwater, which must be considered whenever these interbeds are associated with hydraulic structures.

The fine-grained wind-deposited superficial materials in Iceland include volcanic ash and loess. The volcanic ash is the product of the volcanoes and is widely dispersed within the soils of Iceland. Loess covers wide areas of Iceland's coastal lowlands. Fine-grained sediments are to be found in a very few lakes, mostly now completely filled, which were formed behind dams created by post-glacial lava flows. These fine-grained materials, when low in ash, are generally suitable for impervious fill dam construction.

Coarser materials are found in alluvial and glacial outwash deposits. River alluvium is found within and along the low gradient reaches of all the present rivers and sometimes as interbeds between post-glacial lava flows. Generally, it consists of clays, silts, and fine sands, with locally coarse sands and gravels. The glacial outwash consists of the same materials and represents, in large measure, the basic source of the river alluvium. These glacial deposits are found close to the present glaciers. Both of these types of deposits represent sources of natural construction materials when conveniently located.

Rock weathering is confined to superficial breaking of the rock by frost action mainly. Chemical weathering is practically non-existent. Residual soils are not to be found.

Volcanism

In Iceland where volcanic eruptions occur next to and even beneath glaciers, some rather spectacular floods may be expected. Such floods, called Jokulhaup, are not uncommon and have been known to reach a flow of more than 100,000 cubic meters per second. Grimsvatn volcano, near the western edge of Vatnajokull, has been known to cause floods of up to 150,000 cubic meters per second with a periodicity ranging from once about every 5 to 12 years. . The total volume of big floods may be as much as 49,000,000 cubic meters. The water released is stored under the glacier, and floods occur when the water level rises to a height sufficient to force its way under the ice. During a flood the level of the stored water sinks about 200 meters. It may be that the rise of the trapped water floods the volcanic crater and causes the eruptions. At least a part of these floodwaters may drain into the Upper Tungnaa and Kaldakvisl, both of which flow into the Thjorsa. Floods may also be caused by the tapping of ice-dammed lakes.

Like most volcanic regions, Iceland is visited by fairly frequent earthquakes, most of them of very moderate intensity. A moderately heavy earthquake has been recorded on the Mid-Atlantic Ridge a considerable distance to the north of the island. The Burfell region was visited by moderate earthquakes in 1896 and 1912. The epicenter of the first was about 15 kilometers west and the second 15 kilometers south of Burfell. The intensity was 7 to 7.5. Earthquakes of this comparatively moderate intensity should not seriously damage well designed and carefully constructed engineering structures.

Summary

Iceland, in short, has been built up mainly by volcanic action; its surface has been sculptured primarily by glaciation, and to a lesser extent by wind, wave, and stream erosion, and by slump and other agencies activated directly by gravity. Volcanism and glaciation are still active, but on a much reduced scale as compared with Iceland's eventful geologic past. Erosion by streams along with slump and other agencies activated directly by gravity are now the principal forces slowly modifying the landscape. In the vicinity of steep slopes, slump is particularly active. The rivers and lakes of Iceland are now destined to be harnessed for the production of hydroelectric power.

Thjorsa Basin

General

The Thjorsa Basin lies towards the east side and south end of the Central Icelandic Graben. Its surface contains all of the identified rock types and superficial materials referred to above with the exception of the Plateau Basalts.

Impermeable Areas

The Grey Basalts form nearly all of that part of the Basin lying northwesterly of a line formed by the main Thjorsa, the Tungnaa, and the Kaldakvisl. Large parts of this area, however, are covered by moraine above about elevation 100 meters, and by loess, alluvium, and pumiceous mantles at lower elevations. Along the Lower Thjorsa downstream of its junction with the Tungnaa, Thjorsa lavas have invaded this area in places.

Because of the watertightness of the Grey Basalt bedrock and of the overlying moraine, where present, most of the rainfall thereon and snowmelt thereform runs off in brooks and small rivers, of the "draga" type, such as the Fossa. These streams are characterized by relatively great fluctuations in discharge because of seasonal and meteorological circumstances. Groundwater contributions are relatively small. The Thjorsa upstream from its junction with the Tungnaa is primarily a draga river, but with its flow augmented seasonally by meltwater from the Hofsjokull Glacier at its source. The presence of Grey Basalts modifies in some degree the runoff of the Kaldakvisl. Grey Basalts occupy about one-third of the Thjorsa Basin.

Permeable Areas

The bedrock underlying nearly all the remainder of the Thjorsa Basin consists of the Palagonite-Tuff Series and post-glacial lavas and pyroclastics. Generally, upstream of the mouth of the Fossa, the post-glacial extrusives overlie the Palagonite-Tuff. Pyroclastics extruded from fissures or small volcanoes dominate in a belt about ten kilometers wide and thirty-five kilometers long trending in a southwest-northeast direction with Vatnaoldur, which probably represents their main source. Sporadic irregular deposits of these pyroclastics occur elsewhere, usually within the boundaries of the Palagonite-Tuff Series.

Post-glacial lava flows from fissures occupy two large areas of the Thjorsa Basin, as well as a few smaller areas towards the headwaters. One of these major areas covers many square kilometers to the northeast and east of the lake, Thorisvatn. The present level of Thorisvatn resulted from damming by this flow. This lava appears to be even more permeable than the rocks of the Palagonite-Tuff Series which surround and underlie it.

Thjorsa Lavas

The Thjorsa lavas are the most important and wide-spread of the post-glacial fissure lava flows. They erupted from fissures in the Vatnaoldur district, then flowed down the present general course of the Thjorsa as far as the ocean between the mouths of the Thjorsa and the Olfusa. The Thjorsa lava flows have served to create head concentrations favorable for hydroelectric development in the Tungnaa and the Thjorsa downstream from the junction. This importance justifies some discussion with respect to these flows.

There appear to be seven lava sheets making up the Thjorsa flows. This was established by the 1961 drilling east of the mountain Burfell. One of these may, however, be an overflow. These seven flows have been designated in order from "a" to "g" beginning with the oldest. Their total thickness is 95 to 100 meters. Individual flows in the maximum are somewhat thicker than twenty meters.

Distinctions between the lava sheets were found to be possible through: (1) color differences, (2) presence of interbeds, (3) high permeabilities at contacts, and (4) differing numbers and sizes of feldspar phenocrysts. The groundmass of the different flows becomes darker with age. The uppermost sheet is grey, deeper ones become darker, and the deepest is bluish-grey. Interbeds, variously of loose silts, sands, gravels, loess and lapilli occur between all flows except "b" and "c." Thick layers of rhyolithic Hekla pumice occur between flows "f" and "g." The contacts were also established by core examination and permeability tests. Differences in the phenocrysts are also evident. Flows "f" and "g," which are the more important ones from an engineering standpoint, can be distinguished readily on this basis.

While, apparently, no less than seven flows reached as far as the east side of Burfell, most of them extended very little farther. Lava edges south and southwest of that mountain indicate that only the second oldest, "b," extended beyond that general vicinity. It was the one which extended on to the sea.

The Thjorsa lavas, taken collectively, are thus over 130 kilometers long and cover an area of 770 square kilometers. It is one of the largest lava flows in the world exposed at the surface.

Carbon 14 datings have given some indication of the relative ages of the flows as well as some information relating to Hekla activity. The second oldest was dated at 8000 BP (Before Present) by dating of a peat layer under the flow near Urridafoss. The youngest is between 2700 BP and 4000 BP based on dating of overlying and underlying Hekla Tephra layers.

The Thjorsa lavas flowed down ancient courses of the Tungnaa and Thjorsa. Until the outpouring of flow "b," it is possible that the Thjorsa extended south from Burfell to the sea, following approximately the present course of the Ytri-Ranga. This second flow diverted the Thjorsa to its present course westward from Burfell; on the right (north) edge of the flow for the first one-quarter of the way; then crossing over to follow, generally, the left edge on to the sea. Other streams to the west, probably including the Stora-Laxa, Hvita, and Olfusa were also diverted to their present positions in the lower reaches. The Thjorsa at this time picked up the Fossa and other smaller rivers to the west which previously probably drained either directly to the sea or to the Hvita. The Ytri-Ranga also developed at this time, following first the left edge of the lava east of Burfell, then leaving it to flow on southward to the sea.

The youngest Thjorsa lava, "g," because of filling of the valley east of Burfell to about the height of the Rauda Gap by older flows, succeeding in flowing through that Gap and overspreading the Thjorsardalur as far southward as the present Thjorsa, and possibly coming in contact with the remainder of the flow which passed around Burfell to the south. This diversion altered somewhat the course of the lower Fossa to its present position.

The effect of the first six flows on the course of the Tungnaa is uncertain. The youngest flow diverted it to flow along the right (north) edge of the lava to near its present junction with the Thjorsa. Subsequent downcutting produced head concentrations favorable for power development at the Tungnaarkrokur and Hrauneyjafoss sites. Damming by the lava produced marginal lakes at each of these sites. The former was filled with sediments, then drained by the subsequent downcutting. The latter is now virtually sediment filled. The lava damming may also have produced a now-filled lake in the lower reaches of the Upper Thjorsa.

The Thjorsa lava flows have provided the head concentration available for power development at Burfell. Previous to the oldest flow the valley floor east of Burfell was at a similar elevation to that of the ancient Thjorsardalur. The lifting of the valley floor east of Burfell has provided about 120 meters of avilable head.

Similarly, the diversion and subsequent downcutting has provided the head concentration, and even the river itself, at Urridafoss. Smaller concentrations of head elsewhere along the Tungnaa and Thjorsa owe their existance to these same Thjorsa lava flows.

The exposed surface of the Thjorsa lavas is generally level and moderately permeable. It has virtually no surface runoff. The rainfall and snowmelt, for the most part, percolate downward through the jointing and are intercepted by the highly permeable interbeds. The upper interbed carries the water to exits in springs where the interbed is intercepted by the local watercourses. In places, these may be the main rivers, the Tungnaa and Thjorsa. The lava-marginal streams, Bjarnalaekur and Ytri-Ranga, which flow at lower level than the Thjorsa, receive substantial contributions of groundwater from interbeds, particularly the uppermost. Percolating water not intercepted by an overlying interbed proceeds downward to progressively lower ones. Each interbed thus provides a perched groundwater table. The permeability relationships of these interbeds, particularly the upper one or two, are an important consideration with respect to the design of hydraulic structures erected in their proximity.

On the other hand, the joints of the rock have been largely filled by sediments in and near the riverbeds. Thus little downward percolation of river water is possible, and the rivers flow on perched beds. Likewise reservoirs of low head located on the surface of the Thjorsa lavas should seal these beds rather quickly.

Young Lavas and Pyroclastics

There are lavas at scattered places on the surface of the Thjorsa Basin which are even younger than the Thjorsa lavas. Many of these may be traced to a definite vent or fissure. They include a fairly large expanse of rhyolites and acid lavas in the southeast portion of the Basin, south of Vatnaoldur. A portion of the north side of the famed active volcano ridge, Hekla, lies within the Thjorsa Basin and, in part, is covered with recent lavas from that source. Hekla lies about twelve kilometers southeast of Burfell. All of these more recent lavas tend to be highly permeable.

The recent volcanism of Hekla started about 6600 BP. It has been a great producer of pyroclastics, volcanic ashes, and lavas. The light materials have overspread much of the Basin around Burfell and on to the northeast. Hekla seems to have had four periodic cycles with each cycle starting with a violent rhyolitic eruption followed by less powerful andesite and basalt eruptions. These successive cycles have been dated at about 6600, 4000, 2700 and 860, all BP. Since the beginning of the last cycle, 1104 AD, there have been 15 eruptions of Hekla, with the latest in 1947-48.

Glaciation

The whole of the Thjorsa Basin was overrun by the late Pleistocene glaciers as evidenced by numerous roches moutonnees, boulder erratics, and striae. The striae indicate a movement generally to the west and southwest. On that portion of the Basin east and south of the Grey Basalts, the only significant surface deposits of moraine overlie the Palagonite-Tuff Series in the vicinity of Thorisvatn. Other exposures are scattered and small. Moraine may underlie locally the post-glacial lavas and pyroclastics, which cover more than one-half that portion of the Basin outside the Grey Basalt areas.

The finiglacial deposits in the Basin are represented by several strand lines at low elevations in the area west of Burfell not covered by Thjorsa lavas, and by a few, relatively small, delta-like deposits. One of the latter is found on the west side of Burfell along the lower reaches of the Fossa. The significant deposits of recent alluvium occur in the lake deposits referred to above, along low gradient reaches of the rivers, and a few other scattered places. The larger river deposits are found along the Tungnaa upstream of Vatnaoldur, in Thjorsardalur, and generally along the Thjorsa downstream of Burfell. Alluvium underlies the loess cover outside the Thjorsa lava areas and between the present and ancient sea shores. There are no significant loess deposits in the Basin upstream of Burfell. A few small deposits, however, are useful for impervious fill dam materials when their ash content is low.

Structural Geology

The most prominent structural features in the Thjorsa Basin are two sets of faults, one of which strikes N 60° E, the other N 10° E, or roughly parallel to the trend of the Mid-Atlantic Ridge. The N 60° E set is more prominent. Displacement appears to have been mainly in a horizontal direction, but vertical displacements are also known. Faulting presumably began far back in the geologic past and has continued with decreasing intensity along the same trends. Although several large fissures can be traced in a northeast direction for long distances, the amount of displacement along these fissures seems to be slight, at least in the Thjorsa lavas as well as where observed in the Grey Basalts. In the older underlying Plateau Basalts, displacement along these fissures may be considerable. From an engineering point of view, the faults and fissures are of only minor importance.

Hydrology and Climatology Related to Geology

The nature of the bedrock of the Thjorsa Basin is of hydrological significance. It may be said generally that one-third of the Basin is represented by the impermeable Grey Basalts and their partial moraine cover, while the remaining two-thirds of the Basin is covered by highly permeable rocks almost equally divided between rocks of the Palagonite-Tuff Series and post-glacial lavas and pyroclastics. The Grey Basalt one-third permits rapid surface drainage; the remainder permits practically no surface drainage, but provides a large reservoir of groundwater. The large lake, Thorisvatn, with 70 square kilometers of surface area, plus a number of smaller lakes probably aggregating a roughly similar area provide a significant amount of surface storage.

The annual climate of the Basin has no pronounced wet and dry season. Precipitation is well distributed throughout the year, though somewhat heavier in the fall and winter than the other seasons. There are normally no long sustained cold periods in the winter which continuously lock the precipitation throughout the Basin into a snowpack. Winter snowpacks are, of course, found each winter at the higher elevations but not the lower. Severe cold periods which prevent recharge of the groundwater supply and eliminate most of the surface runoff are few and short. The glaciers at the headwaters of the Basin provide meltwater in the spring and summer but remain frozen during the colder months. This meltwater tends to offset the reduced flows resulting from lesser rainfall during the warmer months.

This combination of climatic, geologic and glacial conditions results in an unusually uniform flow throughout each year, not marked by either extreme low flows or high flood discharges. Minimum, average, and maximum discharges estimated from the gaging station at Urridafoss, near the mouth, for fifteen years of record are 81, 390, and 2250 cubic meters per second, respectively. The geology of the Basin permits the development of storage, notably at Thorisvatn and at basins which may be developed on the Foss at Fossolduver, on the Upper Thjorsa at Novrdlingaalda, and on the Tungnaa at Tungnaarkrokur and at Bjallar. Development of storage would equalize the flow further.

The maximum recorded flow is relatively not great in relation to the average. This can be accounted for readily by the relatively small percentage of the Basin subject to any appreciable surface runoff. Larger flows are, of course, possible and probable. They would result from unusual storm rainfall accompanied by snowmelt, and abetted by frozen ground conditions inhibiting movement to groundwater storage in at least portions of the Basin. They could also result from glacial bursts as discussed above. A combination of the two is in the highest degree unlikely.

The physical evidence does not indicate a flood during the past several centuries much larger than the one recorded. A flood in the order of magnitude of twice the flood of record would almost certainly have permanently diverted all or a portion of the Thjorsa into the Ytri-Ranga to follow its ancient course to the sea. Even a slight diversion of this nature has apparently not happened since the great deposits of lapilli in this area were laid down from Hekla nearly 900 years ago. There is definite evidence, however, that Thjorsa floods exceeding about 2000 cubic meters per second are relieved by partial diversion into the Fossa through the Rauda Gap. These diversions are, however, believed to have been small and have been of little help in preventing the above-mentioned diversion to the Ytri-Ranga. There is some slight evidence of a brief and temporary similar small diversion of the Thjorsa into the Bjarnalaekur near its head.

Accordingly, there is no definite evidence of any glacial burst floods ever having occurred on the Thjorsa within the past nearly 900 years. Such floods, if they did occur, could not have been appreciably larger than rainfall-produced floods.

It is considered hydrometeorologically possible for a flood to occur on the Thjorsa approximating somewhat more than three times the flood of record. A flood of even this magnitude is not considered really large in relation to the size of the drainage Basin. Thus, colossal spillway structures are not needed for dams on the Thjorsa; relatively low cost structures will be adequate.

The Thjorsa then receives substantial contributions of ground-water, especially from the Tungnaa and Kaldakvisl and from springs along its own course. In the winter this is not entirely to the good. The springwater is a few degrees in temperature above the freezing point. This tends to keep the central portion of the channel in the higher gradient reaches free of a surface ice cover. Frazil ice is formed during severe frost periods, particularly when winds are high, and these ice crystals are carried along in the stream. Further, the winds blow snow from the vast barren surfaces into the open water. This snow is carried along as sludge ice within the stream. These conditions present ice problems to the operation of hydroelectric projects.

In the lower gradient reaches of the Thjorsa and at the sea, the velocity is slowed sufficiently to permit the formation of an ice cover.

The ice sheet blocks the flow of the frazil and sludge ice, and produces extensive ice jams downstream. These jams occur on the Thjorsa every winter downstream of Urridafoss and also downstream from the mouth of the Fossa. These ice jams could tend to increase tailwater at hydroelectric projects located at Urridafoss, at Burfell, and possibly elsewhere. A diversion structure crossing the Thjorsa might also create similar ice jams.

Summary

The general uniformity of the flow, head concentrations produced by the Thjorsa lavas and by erosion in the Grey Basalts, and storage potentials are factors favoring economical hydroelectric power development within the Thjorsa Basin. Each of these factors has been controlled strongly by the geology of the Basin. With this background of Basin geology, the site geology as it pertains to the specific development of the hydroelectric power potential at Burfell is discussed hereinafter.

Site Geology

Location of Area

The Burfell Hydroelectric Project will be located on the Thjorsa with the structures near the north end of the mountain, Burfell. The location is about midway between the south coast of Iceland and the glaciers and mountains of the central part of the country. The site will develop the fall in the reach from 86 to 73 kilometers upstream from the mouth.

The physical structures of the Project extend from the Thjorsa, about six kilometers upstream from the waterfall, Trollkonuhlaup, then westward on the surface through the Bjarnalaekjarbotnar before passing underground to extend through Samsstadamuli to the Fossa, about two kilometers above its mouth. Their location is outlined on Exhibits B-3 and B-4. The river continues on beyond the diversion dam to circle the south end of the mountain, Burfell. West of the mountain it turns westward as it receives its diverted waters from the mouth of the Fossa.

Relief of Area

The general Burfell Project area consists of relatively flat plains with rather steep mountains rising from the plains. The highest mountain is Burfell, 669 meters high. Northward from Burfell and more or less in line are the lower mountains, Skalarfell, Samsstadamuli, Skeljafell, Skeljafellsspordur, and Stangarfjall, ranging in elevation from about 300 to 425 meters. The plains south and west of Burfell lie at a general elevation between 120 and 130 meters. The plain in the valley east of Burfell slopes gently southward on a grade of 10 to 15 meters per kilometer, beginning at elevation 250 meters at the north end of the Project area. Rising to the southeastward from this plain are the slopes of Hekla.

The Fossa drains the area west of these mountains plus a small portion to the east contributed by the Rauda before that tributary passes through the Rauda Gap located between Skeljafell and Stangarfjall. A small brook, the Trjavidarlaekur, drains from the fault valley, Samsstadaklif, located between Burfell and Samsstadamuli, to the Fossa. The lava marginal stream, Bjarnalaekur, drains the south slopes of Skeljafell, the Bjarnalaekjarbotnar, and the east slopes of Burfell. Principally, though, it drains the groundwater from the upper interbeds within the Thjorsa lavas which form the plain to the east. The other lava marginal stream, Ytri-Ranga, on the east side of the plain also drains these interbeds as well as the northwest slopes of Hekla. The Thjora receives the waters of all these streams, with the exception of the Ytri-Ranga, plus a few smaller brooks. This unusual drainage pattern in the general Project area and shown on Exhibit B-2 owes its origin to the Thjorsa lavas.

General Stratigraphy

The Burfell Project area is situated on the limits between the Grey Basalts and the Palagonite-Tuff Series, with the former to the west. The actual contact is buried east of Burfell under the Thjorsa lavas which form nearly all of the plains area. The only exposures of the Palagonite-Tuff Series within the general area are located on the Ballar slope of Hekla and on Valafell, to the southeast and east. The Grey Basalts form the beckrock of Burfell and the low mountains to the north.

The bedrock encountered in the general area of the Burfell Project consists mainly of several groups of thick accumulations of volcanic rocks (flows and intercalated sediments) separated by major erosional unconformities with appreciable relief. The lava flows exhibit considerable variations in their physical characteristics. They are often separated by clastic interbeds and overlap with accumulations of clastic deposits at their margins. Their stratigraphic sequence and notation are shown in the columnar section on Exhibit B-1, and their distribution and occurrence are shown in plan and section on Exhibit B-2.

The detailed geology in the vicinity of the structures of the Burfell Project is shown in plan on Exhibits B-3 and B-4. Selected sections along the proposed engineering structures are shown on Exhibits B-5 and B-6.

The Hekla pyroclastics, mostly lapilli, cover the bedrock over much of the Project area with the exception of some of the steeper slopes and some of the more level areas which were subjected to severe wind erosion. They are also to be found within the interbeds of the Thjorsa lavas.

Soil cover and vegetation are both rare in the Project area. The loess may have at one time covered much of the plains area. However, volcanic activity and extensive wind erosion during the centuries since Iceland was inhabited resulted in its burial or removal. The high dunes south of Burfell may, in part, represent the redeposited soil cover from the Thjorsa plain east of Burfell and from the Thjorsardalur. The few scattered remanents of loess in and near the Project area represent one possible source of impervious core materials for the planned rock-fill dikes.

There are only a few widely scattered deposits of moraine known to overlie the bedrock in the Project area. There is one thick deposit in a small depression in the bedrock east of Samsstadaklif. The exploration tunnel was driven in this moraine for the first 130 meters. The indicated depth is over 60 meters. The material in the moraine consists of silty clay with inclusions of scattered gravel and small boulders. The base is more sandy and contains a higher proportion of gravel and boulders. The material is not cemented but is well packed and hard, requiring light blasting for removal. It tends to slake after exposure to the air. This moraine is a potential source of impervious core material, as is discussed in Appendix C.

Another deposit of moraine was located on the slopes southeast of Rangarbotnar.

The flat plain south of Samsstadamuli between Burfell and the Fossa consists of finiglacial materials, probably of deltaic origin. The materials consist of medium to coarse sands with some lenses of fine gravel. The sand is usually unconsolidated, but the upper portion tends to be slightly cemented with bog iron. The thickness is not known, but the bottom is below any important interest to the Project.

Deposits of river alluvium are located along the Thjorsa a few kilometers upstream from the diversion structures and below the mouth of the Fossa. Another deposit is located in the bed of the Fossa west of Samsstadamuli.

The Grey Basalts within the Project area have been divided into the following groups or formations which are, from oldest to youngest, as follows:

(a) Older Burfell Group (OB)

(b) Samsstadamuli Group (SM)

(c) Burfell Pillow Lava (BP)

(d) Samsstadaklif Basalt (SB), and the

(e) Skeljafells Dolerite (SD)

Each of these groups and formations, shown in the columnar section of Exhibit B-1, is discussed in more detail below.

Older Burfell Group

Rocks of the Older Burfell Group are the oldest encountered in the Burfell Project area. They represent a thick series of basaltic, andesitic and rhyolitic lava flows with clastic interbeds. Outcrops occur at Samsstadaklif and in the lower part of Skeljafell.

The Group has been divided into four members. OBa, the lowest, is at least 30 meters thick and consists of two andesitic lava flows separated by a thick, hydrothermally altered scoriaceous zone representing the top of the lower bed. The andesites are very dark in color and are glassy. The exploration tunnel was driven into these beds beyond the moraine referred to above.

OBb consists of several basalt beds and such clastic rocks as tuffaceous sandstone and breccia. It ranges in thickness from 25 meters to over 100 meters. The basalts are rather fine grained and without phenocrysts, except for one bed which can be recognized easily because of the presence of large olivine phenocrysts. The contacts are usually altered, but there is only moderate alteration in the clastic beds.

OBc consists of three andesite flows totaling 30 meters in thickness. All flows are very glassy, and two have distinct flow lamination. The contacts are scoriaceous and highly altered.

OBd consists of basalt and rhyolite flows interbedded within conglomerate. The thickness is about 30 meters. The rhyolitic bed is to the top. Alteration is present. The OBd represents the top beds at the head of Samsstadaklif.

From the engineering standpoint, the beds of the older Burfell Group are usually thin with thick, highly altered scoriaceous zones at their tops. The clastic beds are relatively soft but well cemented and only slightly altered. The rocks are not highly permeable; Lugeon Unit values where determined are seldom over 10. The contacts are usually waterbearing and represent perched groundwater tables. Rocks of the lower portion of the Group will be encountered by the access tunnel. Rocks of the upper portion will represent the foundations for a portion of the dike at the west end of the Bjarnalaekur Pond. Their relation to the structures of the Burfell Project is shown in section on Exhibit B-5. Their present extent to the north in this area has been limited by subsequent erosion.

Samsstadamuli Group

Near the end of the Pliocene epoch, a broad northeast-southwest trending valley was eroded into the rocks of the Older Burfell Group in the area between the present location of Burfell and of Stangarfjall, six kilometers to the north. This valley was then partially filled with a complex sequence of materials consisting of tuffaceous sandstones interfingering at the margins with coarse talus breccias which were derived probably from higher topography to the south. A complex sequence of basalt flows and intercalated sediments then accumulated progressively on top of these materials. This sequence is known as the Samsstadamuli Group (SM). It lies unconformably on the rocks of the Older Burfell Group.

Rocks of the Samsstadamuli Group are exposed on the west and east end of Samsstadamuli, the north end of Skalarfell, and around the sides of Burfell. They were penetrated by most of the deep core borings in Samsstadamuli, and also by the shallow borings at the west end of the Bjarnalaekur Dike, both from the surface and under the Thjorsa lavas.

The tuffaceous sandstone (TS) occurs in the lower part of the valley, and the talus breccia and fanglomerate (TF) occur along the unconformity and interfingering with the basalt flows. The upper part of the valley fill is mainly the basalt flows.

The basalts of the Samsstadamuli Group consist essentially of eight flows, designated SMa through SMh from the oldest to the youngest (assuming none are intrusive). Most flows are separated by the clastic interbeds referred to above. The basalt flows are dark colored, dense, and not notably porphyritic. Most of them show columnar jointing and an irregular bottom breccia. In general they are well suited for underground excavations.

The tuffaceous sandstone has an unknown thickness but may be at least 70 meters. It contains lenses of coarse material, but generally becomes finer grained in the lower part, and is mostly sandstone. In general the sandstone is well cemented and tight. The sandstone will be encountered along a substantial portion of the proposed tailtunnel for the Project, and will require concrete lining. Some support will be necessary. It is by no means to be preferred for the larger excavations.

A bed of pillow lava and volcanic breccia (PL) interfingers with the tuffaceous sandstone. The PL was found in drill holes located on the west side of Samsstadamuli. It was penetrated to a depth of 35 meters, but its extent is unknown. It probably represents a lava flow which entered the same lake or sea in which the TF was deposited. The pillow lava is well welded and tight. It should be satisfactory where encountered by the concrete-lined tailtunnel, and require little temporary support.

At least one tongue of intrusive basalt (IT) is located between the sandstone and the talus-fanglomerate on the west end of Samsstadamuli. There may be others.

The talus-fanglomerate (TF) is highly variable in thickness, but locally the depth is as much as 100 meters. It tends to consist of small rock fragments and some larger angular blocks in a matrix of sand and silt. The rock fragments in the lower part are more rounded and the matrix more glassy. The lower portions are well cemented, while the upper part is well packed but only lightly cemented, except locally.

Accordingly, the TF exhibits highly variable permeabilities with the better cemented parts having a permeability of 10 LU or less, and permeabilities of the upper part ranging as high as 100 LU.

The TF will be encountered by underground excavations for the Burfell Project. Drilling, blasting, and removal should be relatively easy. The tailtunnel where it encounters this rock in its upstream portion can be expected to be in the better cemented portion, probably requiring little support but needing concrete lining. The same is true for an intermediate portion of the access tunnel. The pressure shafts will pass through zones of the TF overlying the SMa basalt flow. Support will be required through these high-level, weakly cemented zones of the TF. However, because of the high variability of the TF, excavation may pass rather suddenly from very weak to relatively strong zones, and vice versa. It may be that the powerstation and surge chamber roofs will penetrate close or into an interbed of the TF, and this will present excavation problems requiring supports. However, a location at this level is much to be preferred to any lower level.

The SMa bed is the lowest and thickest of the basalt flows in the Samsstadamuli Group. It is also the most important from the engineering standpoint. It varies in thickness up to more than 75 meters, and consists of sound, dense, nearly impermeable rock. Its nature, position, and thickness make it by far the most suitable rock found in the entire Project area within which to carve the huge excavations required for the underground powerstation. The lateral limits of the SMa dictated the selection of a tailrace type of development for the power features.

The specific location of the powerstation within the SMa basalt was controlled by two factors. The first factor was a location far enough from the edge of the flow to assure an adequate thickness of sound basalt. This controlled the location in a northerly direction. The second factor involved keeping the penstocks as short as feasible. This, together with surface topographic and geologic relationships associated with the power intake, controlled the powerstation location in the easterly direction. The selected location of the powerstation and associated features is shown in geologic section on Exhibit B-5.

There has been some speculation that the SMa flow may, in fact, be intrusive. The absence of vesicles tends to indicate this manner of origin. On the other hand, there appears no structural deformation to indicate the intrusion of such a large body. The important engineering fact is that the SMa basalt presents a near-ideal formation for the Burfell powerstation, regardless of mode of origin.

The basalt flows in the sequence higher than SMa are relatively thinner, ranging from about 10 to 50 meters each as a maximum. Some may actually be fingers of one basic flow. The thickness of each may be much greater (or less) at some distance. For example, SMf was found to be less than 10 meters thick in Samsstadamuli, but its exposures in Burfell approach 50 meters.

The sections of Exhibit B-5 show that all eight of the basalt flows are not everywhere present in the area of specific engineering interest to the power features. In fact, SMh is not shown in this geologic section. However, it does represent the surface rock in patches towards the west end of Samsstadamuli and on the north end of Skalarafell.

These exposures show a rock suitable for quarry production of natural construction materials, as discussed in Appendix C.

The basalts of the Samsstadamuli Group are usually medium to coarse grained and represent excellent rock for the foundations of engineering structures. On the whole they are almost impermeable, seldom having a permeability in excess of 10 LU. Perched groundwater tables occur mainly where the talus-fanglomerate interfingers with the basalt beds. Some water flows will be encountered during construction, but they are nowhere expected to be high in the rocks of the Samsstadamuli Group.

Burfell Pillow Lavas

The Burfell Pillow lavas (BP), although nearly 300 meters thick, are restricted to Burfell Mountain and were probably extruded from fissures cutting through the mountain, possibly when the region was covered by a glacier. Sporadic deposits of glacial till at the base of the Burfell Pillow lavas, and overlying the rocks of the Samsstadamuli Group, mark the onset of Pleistocene glaciation. It may be that this formation represents one of the older beds of the Palagonite-Tuff Series.

The nearest exposures of the BP rocks occur on the north end of Skalarfell, a few hundred meters south of the Burfell Project structures. They are of no real engineering interest to the Project.

Samsstadaklif Basalt

In early to mid-Pleistocene time a deep canyon was eroded into the strata of the Older Burfell and the Samsstadamuli Groups. The development of the canyon probably followed the margins of the Samsstadamuli basalt flows where they interfingered with the talus. This canyon was filled with basalt flows and basaltic breccias which are known as the Samsstadaklif basalt (SB). This basalt thus lies unconformably on the older rocks.

The SB basalt formation outcrops in Samsstadaklif and the top of the east and central portions of Samsstadamuli. These flows extend down to an elevation of at least 185 meters on the south slopes of Samsstadamuli. There are two small outcrops rising above the lapilli cover of Bjarnalaekjarbotnar and in the bed of Bjarnalaekur. The SB probably underlies the pyroclastics in the east one-half of that basin.

The SB consists of several dark, fine-grained basalt flows with volcanic breccia at the base of each. There are practically no intercalated sediments between flows; although boulders and brown clay are found occasionally. The breccia is well cemented. The individual flows are thin, usually less than 10 meters, but vary greatly in thickness. The permeability sometimes exceeds 100 LU in the uppermost part of the formation, but is low in the lower part, being less than 10 LU.

As a whole the Samsstadaklif basalt consists of sound, strong rocks well suited as foundations for engineering structures. They will form the foundation for the intake and sluice structures and a portion of the associated dike in the divide between Samsstadaklif and Bjarnalaekjarbotnar. The sluiceway channel will be excavated in the SB. This excavation will make excellent rock shell material for the dike.

The upper portion of the pressure shafts will pass through the SB. Support, other than rock bolts, should not be required.

Erosion may have occurred subsequent to the deposition of the Samsstadaklif basalt, but this is not definitely established.

Skeljafells Dolerite

The Skeljafells dolerite (SD) was deposited over the Samsstadaklif basalt without any noticeable signs of an unconformity. It forms the surface rock on Skeljafell and overlies the SB to form the crest of Skjafellsspordur. Some small outcrops of the underlying SB within the general outcrop pattern of SD on the latter mountain are the result of more recent erosion.

The Skeljafells dolerite passes under the Thjorsa lavas to the east in the Project area, and there loses any important engineering significance to the Project. It forms the surface rock under the lapilli towards the east end of the Bjarnalaekur Pond, as shown on Exhibit B-4. A portion of the diversion canal will be dug in the SD, and the excavation will make good shell material for the nearby dikes. The same will be true of quarries located in the SD. A portion of the Bjarnalaekur dike contiguous to that portion of the canal will be founded on the SD. Since it is highly impermeable, little, if any, foundation grouting will be required under that portion of the impervious core. As a whole the SD is without engineering problems.

The Skeljafells dolerite consists of lava flows without intercalated sediments. These lava flows are coarse grained basalts with small phenocrysts. The SD represents the uppermost formation of the Grey Basalts within the Project area.

The tuffs, breccias, and pillow lavas of the Palagonite-Tuff Series, which generally overlie the Grey Basalts with an unconformable relationship,are too far removed from the area of the Project to be of any specific engineering interest. Their general engineering interest to the Project has been discussed above.

Thjorsa Lavas

The post-glacial Thjorsa lavas in their general geologic-engineering relation to hydroelectric power development on the Thjorsa River have been discussed above. As shown by the plan of Exhibit B-4 and the geologic section of Exhibit B-6, they have an important relationship to the river diversion and pondage structures of the Burfell Project. Their stratigraphic relationships are shown in the columnar section of Exhibit B-1. Flow THg, and, to a lesser extent, flow THf are of primary importance to the Project.

The youngest of the Thjorsa flows, THg, forms the bedrock surface in the vicinity of the Project structures. It will be the foundation rock for all of the structures associated with river diversion, and for a major portion of the Bjarnalaekur dike, which will retain the regulating pond. Its surface is covered by Hekla lapilli over nearly the entire area outside the river channel itself. The highly permeable first interbed and, to a lesser extent, the second interbed (below flow THf) are of crucial importance to the underseepage problem.

Unlike most of the other flows, which are pahoehoe lavas (helluhraun), the THg flow is an aa lava (apalhraun). Therefore, its surface is irregular, blocky and rubbly, a condition which extends downward for several meters. Below this crusty surface, the lava is adequately sound and strong to carry the loads of the concrete structures proposed and the core section of the dikes. Since the lava tends to be rather permeable, provision of slush grout in the core trench and, perhaps, locally, of consolidation grouting will be required to protect the core against erosion from the underside. Extensive curtain grouting to reduce underseepage under the structures would not be justified. The silts and the sands of the bedload in the Thjorsa will seal readily the fissures and fractures in the rock as they have now done in the riverbed itself. The crusty surface in most places should be of adequate strength to support the shells of the low dikes. The above statements do not necessarily hold with respect to consideration of a high dam as would be required for storage purposes.

In general, the basalt from THg, where found below the crusty surface, would be very suitable for shell material in rock-fill dam or dike construction.

The geologic section under the proposed structures of Exhibit B-6 shows the THg basalt to be fairly uniform in thickness except where it thins near the western edge. The maximum thickness is about 18 meters.

The interbed below THg represents the principal engineering problem associated with the diversion and pondage structures of the Burfell Project. The permeability is very high, almost always in excess of 200 LU. Groundwater movement measurements, discussed later, showed average flow velocities as large as 12 meters per minute. Flow through THg is the source of large springs in the Bjarnalaekur a short distance downstream from the Bjarnalaekur dike. This interbed lies beneath almost the entire area of the diversion structures and, therefore, could represent a source of leakage unless treated.

Seepage by downward percolation through the Thjorsa lava to an intercept by the groundwater table within the interbed is possible. However, contributions from this source, even initially, are not expected to be great enough to be of any concern. The silting of the lava surface will reduce even this nominal leakage rather rapidly.

The interbed daylights in the Bjarnalaekur at the site of the springs and also under the lapilli cover at the contact of the THg with the SM, SB, and SD basalts and dolerites in the Bjarnalaekjarbotnar. Thus, it will be open to water in the Bjarnalaekur pond under the lapilli overburden and where cut by the excavation for the diversion canal. There is thus the strong possibility of short-path leakage between these sources and the Bjarnalaekur downstream of the proposed dikes. Leakage could occur with velocities adequate to result in serious piping of the interbed materials. It will be necessary to seal this leakage by grouting and protective clay blanketing.

The interbed is up to ten meters thick between THg and the basalts older than the Thjorsa lavas. It is particularly thick at the face of the THf flow where it blends with the interbed under that flow. On the basis of groundwater flow measurements, the strongest flows appear to be channeled in this deep section. Apparently, groundwater moves from the east and north in the interbed to the filled channels at the face of the THf flow, which acts as a collecting channel to conduct the natural seepage to the Bjarnalaekur Springs. The thickness between THg and THf is only about two meters; it is the same between THf and THe. Both interbeds consist largely of pumice mixed with some sand, all completely unconsolidated.

The second interbed between THf and THe presents little reason for concern from the engineering standpoint.

Hekla Lavas

The nearest Hekla lavas are about two kilometers east of the nearest Project structure, the diversion dam. Their only point of engineering importance is that they may represent a suitable source of shell material for the left bank dike. The Hekla lavas are non-porphyritic basalts, and are the youngest rocks in the Project area. Their age is probably about 2000 years.

Geologic-Engineering Features

The most prominent joints in the igneous rocks are invariably the contraction joints formed by cooling of the molten lava. These joints are of special engineering importance and have a strong bearing on rock breakage in excavations, particularly tunnels. Columnar jointing is frequently present, especially towards the middle of an individual flow. The spacing may vary from a few centimeters to several meters, with the spacing frequently consistent over large areas in any one flow. Frequently, with columnar jointing, there are also joints more or less parallel to the flow. Their spacing may vary widely from a very few to tens of centimeters. Breakage may result in flakes when the spacing is small to large blocks when the spacing is large. The major portion, and sometimes nearly all, of an individual flow, however, has irregular, closely-spaced joints which separate the rock into pieces a few tens of centimeters across. A usual size is 20-30 centimeters. It is, then, a cube-jointed rock (kubbaberg).

These two main types of jointing can only be recognized clearly on the evidence available at exposures or within tunnels. The core from diamond core dilling provides very little reliable information. Thus, the jointing pattern in the basalts of the Samsstadamuli Group, which are of major importance to the underground excavations of the Burfell Project, is not known definitely. However, the SMf, SMg, and SMh flows show columnar jointing in their surface exposures with joints up to one-half a meter apart.

The Skeljafells dolerite and basalts have similar columnar jointing, while the Samstadaklif basalts are cube-jointed. The andesites of of the Older Burfell Group all have columnar jointing with large columns. They are thin-jointed in the other direction. The Thjorsa lavas appear generally to be columnar jointed. The uppermost flow, THg, however, is cube-jointed in places.

The jointing of the important SMa basalt is not now known. Considering its great thickness, it is possible that much of it has a column-like jointing of relatively wide spacing. If it is, in fact, an intrusive the spacing of these vertical joints may be even greater than if it is an extrusive as is now suspected. In any event, large column-like blocks may be expected in the walls and the center of the excavation for the machine hall and the surge chamber. There will always be some tendency in columnar-jointed basalt for alternate columns to break loose from the walls. Grouting is usually ineffective in controlling this tendency. Rock bolting represents the most feasible means of control. Extensive rock bolting will be required in the walls of these two great excavations. Further, rather long rock bolts will be required. In general, they should be placed nearly normal to the jointing to develop maximum friction between columns and to permit minimum lengths of rock bolts. In general, the above comments apply almost equally to the tailtunnel and the access tunnel excavations where they pass through the SMa basalt.

It will be important to control overbreak and accomplish good breakage with respect to all excavations and particularly to those associated with the powerstation. It is probable that the drilling pattern should be rather close, at about one-half the average diameter of the columns. This does not mean a heavy use of blasting powder. On the other hand, powder requirements in the SMa basalts should be rather reasonable.

The roof of the surge chamber and machine hall will probably be in a breccia zone averaging about two meters thick at the tip of the SMa basalt and may even break through into or through the overlying tuffaceous fanglomerate (TF), which is about five meters thick. This probable situation dictates initial excavation, possibly by a multiple drift method, followed by immediate concreting before proceeding with excavation.at the lower levels. Heavy supports plus some rock bolting will almost certainly be required. The situation in the tailtunnel and access tunnel roofs, where in the SMa basalt, will be different and should not cause serious problems. If the columns are wide, there may be a tendency for the roof to break out flat and be supported by beam rather than arch action.

In general, tunneling in the cube-jointed basalt results in less overbreak than in columnar-jointed rock, particularly when the columns are large. The irregularity of the cube jointing tends to develop interlock between blocks, reducing the danger of fall-outs. This generally more favorable situation may not exist to any extent at Burfell.

Jointing in the sedimentary rocks and talus-fanglomerate (TF) at Burfell is much less prominent than in the basalts. There are some bedding planes with inherent weakness in the sandstone (TS). There is also some jointing in the finer sediments trending in the same direction as the regional faults and fissures. The tunnels and shafts in the TS and TF formations should not prove difficult. Overbreak will be erratic, and there may be locally some rather large fall-outs in weakly cemented blocky zones unless controlled. Both formations, however, should stand up reasonably well with only light steel supports--locally none at all. There may be some heavy water flows, particularly at basalt contacts and in porous zones, but these should not prove seriously troublesome. These formations will not be resistant to water erosion,and concrete lining will be required in all water passages. Lining will also be required throughout vertical shafts, both for stability and permanent water control.

The morainal materials in the access tunnel, while tough and compact, will require light steel supports and lagging for an excavation of the size contemplated. Heavier supports may be necessary near the gravelly bed of the moraine. Overbreak should not be serious if very light blasting procedures are adhered to.

Some local steel support may be necessary where the tunnel passes through rocks of the Older Burfell Group (OB), particularly at flow contacts and in hydrothermally altered zones, which are generally the same. Considerable roof bolting will be required. Strong, but not serious, water flows may occur at the contact between OB and TF, and from the flow contacts. Concrete lining of the access tunnel will be required in the talus-fanglomerate and in steel supported areas. Only a light lining will be required in the moraine to protect the steel and prevent slaking..

Channel, open structural, and quarry excavation in the basalts will represent no problems. Some of the general statements made above for the SMa basalt will apply. Much of the slabby surface of the Thjorsa lava (THg) can be removed easily by bulldozers, draglines and power shovels without any blasting. Excavation of the pyroclastics can be accomplished with exceptional ease. The same is true generally for the alluvium and loess. Excavation of the moraine will require light blasting.

Structural Geology

There are few structural geology features of important concern to the engineering of the Burfell Project. There are few vertical to near-vertical faults or fissures shown in plan on Exhibits B-3 and B-4, and in section on Exhibit B-5. Their vertical and horizontal displacement is small within the rocks to be encountered. Further, their planes do not appear to contain any breccia zones, except perhaps locally. From the engineering standpoint, they can be considered of little more significance than a vertical joint.

Virtually all of the beds within the zone of engineering interest are flat lying or nearly so. The rocks of OB dip northeast about 4^{o} to 5^{o}. The other basalts dip usually eastward less than two degrees. The Thjorsa lavas dip in their direction of flow, paralleling the surface of the plains they have formed. In general, local irregularities of contacts are somewhat more pronounced than the regional dip.

The unconformities and flow contacts are, from the engineering viewpoint, more important structural features than are the others referred to above. Nearly all tend to contain pervious interbeds, scoriaceous and breccia zones. Frequently, they represent perched watertables. A prime example of engineering importance is the interbed below THg, discussed above. Unconformities and flow contacts almost invariably represent zones of weakness requiring special engineering and construction considerations. Further, strong water flows can usually be expected during construction wherever they occur.

The Project area has a history of rather frequent moderate earthquakes, but no history of really severe ones. They thus present no unusual problem with respect to the design or operation of the Burfell Project.

Further volcanic activity which might affect the Project during its useful life is not to be expected to any serious degree.

Geologic Field Investigations

General

Much of the geologic information and interpretations presented above for the Project area was obtained by extensive field investigations conducted during 1961 and 1962. This scope has been previously referred to. Some of the important details are presented below.

Large scale topographic mapping served as the basis for adding the detailed areal and bedrock surface geology presented for the Project site on the geologic maps on Exhibits B-3 and B-4. Smaller scale mapping served similarly for the regional geology shown on Exhibit B-2, and for the location of natural construction materials as discussed in Appendix C. The geologic mapping included the systematic examination and identification of outcrops. It also involved petrographic examination of some typical rock samples. The details of these examinations are not of significant engineering importance and are not presented herein.

It was necessary to coordinate the geologic mapping of the surface exposures with the topographic mapping and with the results of extensive subsurface investigation to provide useful geologic information for engineering purposes related to the layout of the Project, the preliminary design of its component structures, and the proper estimation of costs of the civil engineering features of the Project. A summary of the foundation explorations follows.

Foundation Explorations

The foundation explorations included Borro soundings, bulldozer trenching, diamond core borings, and driving an exploratory tunnel.

The Borro soundings were aimed to determine the thickness and, to some extent, the character of the overburden. The thickness was determined by direct measurement, while relative densities were determined approximately by analyses of the driving forces. A few samples were obtained. The soundings represented a principal source of information with respect to superficially covered bedrock surfaces and permitted contour mapping of those surfaces. This facilitated the selection of the optimum locations for the dikes and diversion canals.

The Borro soundings were concentrated in the area of the diversion structures, Bjarnalaekur Pond, and in the general reach along the Fossa between the proposed tailtunnel outlet and the Thjorsa. 232 soundings, averaging nearly six meters in depth, were made in the first two areas, which are contiguous. Forty soundings were made in the Fossa area to assist in the location of the tailrace channel and to appraise the possible lowering of the Fossa grade to attain more head.

Numerous bulldozer trenches were used to supplement the Borro soundings, and for the same purpose. Inspection of the sides of the trenches gave detailed information on the nature of the overburden. The trenches were especially useful where a continuous rock profile was desired and could be obtained easily, such as at the west abutment of the Bjarnalaekur dike where the overburden was thin.. Many of the trenches were located on the east side of the river to assist in locating the best alignment for the left-bank dike.

Bedrock subsurface information was obtained by diamond core borings, taking NX-size core primarily. The core was preserved carefully and studied for engineering-geologic purposes. Seventy-two borings were made for a total length of 3626 meters. Their location is shown on Exhibits B-3 and B-4. The drilling was supervised carefully, which resulted in the remarkably high core recovery of approximately 93 percent in the area of the power features and somewhat less in the area of the diversion structures. The drilling was accomplished in two general areas--the location of the diversion structures and the vicinity of the power features. The general program differed between the two areas.

The geologic reconnaissance showed that the diversion structures would be founded primarily on the uppermost of the Thjorsa lava flows (THg). The relationship of the Thjorsa lavas and their interbeds together with the general characteristics of the uppermost flow was well known from the 1961 drilling at the Lower Site. With this knowledge and the consideration that only low structures were involved, it was feasible to lay out a program of near-maximum economy and efficiency. Forty-seven borings were made for a total length of 792 meters in the area of the diversion structures, and were situated to explore the foundation of each structure. Most of the holes were relatively shallow and were carried into the rock only far enough to determine suitable foundation levels for each structure.

Fifteen holes, distributed to give the widest coverage, penetrated through the first interbed and into the second Thjorsa lava flow (THf). Of these, three were carried through the second flow. This deeper drilling permitted gathering important stratigraphic information. All holes in the Thjorsa lava near the western end were carried through the first interbed because of the known critical relationship of that bed with respect to short-path leakage. Five shallow holes were drilled from the surface of the older rocks (SM, SB, and SD) beyond the western limits of the Thjorsa lavas.

The initial geologic mapping indicated that the geology in the vicinity of the power features would be complex. The subsequent drilling and geologic mapping revealed that it was indeed very complex, as discussed above. A principal aim was to discover the most favorable rock formation for the cavern of the underground powerstation. The progress of the drilling led to the selection of a tailrace type of development; hence, the deep holes tend to be concentrated towards the east end of Samsstadamuli near where the initial hole (BH-14) was drilled in late 1961. The other two 1961 holes near Trjavidarlaekur never penetrated through the overburden. The selection of the tailrace type of development meant also that drilling to tailtunnel level would be deep.

Altogether, 25 holes, totaling 2834 meters, were drilled for the foundations of the power features. In addition BH-14 was deepened 30 meters. Two of the 25 borings were relatively shallow holes located on the west slope of Samsstadamuli to investigate the foundations of the tailrace tunnel portal. Five shallow holes were drilled at the head of Samsstadaklif to explore the foundations for the western retaining dike of the Bjarnalaekur Pond and for the sluiceway channel. Sixteen holes were each more than 100 meters deep, and the remaining two were almost that deep. All of the drill holes obtained important information to assist in interpreting the complex geology.

The core obtained from each hole was preserved, then logged descriptively. These descriptions were converted to graphic core legs, which are included as Exhibits B-7 to B-16, inclusive. These logs also indicate the type of overburden, where present. The rock encountered is indicated according to the formation codes of the columnar section shown on Exhibit B-1. The basic rock type and pertinent physical characteristics where appropriate are also shown on the graphic logs.

Where core was not recovered, either because of drilling procedures used or because of a basic rock weakness, drilling information obtained at the time was used to permit the preparation of a complete log. Thus, core losses are not shown. The logs are related both to depth and to elevation.

Exploration tunnels, drifts, and shafts are considered to be by far the best exploratory procedure to follow for underground powerstations after the preliminary location has been established by geologic studies and coreborings. They permit visual examination of the rock in place and permit enlarging this information by relatively short coreborings from within the tunnels. Detailed information thus obtained assists greatly in final design by the engineer and bid preparations by the contractor.

An exploration tunnel was started at the Burfell Project in mid-1962 on the assumption that a tailrace type of development would be most favorable. It was positioned to serve as a pilot bore for the access tunnel. Driving was suspended 259 meters from the portal when it became evident that the probable location of the powerstation would not be reached in time to provide information for the planning studies. Budget considerations also had a bearing on the temporary suspension.

The completed portion of the exploratory tunnel penetrated 148 meters of moraine before entering somewhat altered andesite of the Older Burfell Group for the remainder of the distance, as shown in profile on Exhibit B-5. The tunnel revealed the moraine as an adequate and suitable source of impervious core material for the dikes. Important data were also supplied with respect to tunneling characteristics and groundwater conditions in that portion of the future access tunnel.

Groundwater and Subsurface Permeability Measurements

Groundwater levels and movement and the permeability of the bedrock represent important geologic-engineering data to be obtained from boreholes. These data permit evaluation of leakage from reservoirs and waterways as well as into excavations. This evaluation serves as a guide to remedial treatment. Groundwater levels were measured in all the Project boreholes during and immediately after drilling. Many of the holes were preserved for continued long-term measurement of the groundwater level. These measurements are continuing on a periodic basis. The measured elevation taken on October 10, 1962, in some of the holes pertinent to the geologic sections is plotted on the sections of Exhibit B-6.

The watertable measurements in the boreholes which penetrated the interbed under THg but not as far as the interbed under THf reflect the levels of the perched watertable in that interbed. The geologic-engineering importance of that particular interbed is discussed above. The elevation differences between holes provided important information with respect to the general slopes of that watertable. This permitted an evaluation of the general direction of groundwater movement.

Data with respect to the slope of the groundwater table permitted the organization of further tests associated with both the general direction and the apparent average velocity of groundwater movement.

Flourescein sodium dye was injected into selected holes, then followed by observations in appropriate nearby holes and at the Bjarnalaekur Springs in order to determine the time of movement. Detection at the observation point was accomplished with the aid of ultra-violet light on water samples obtained at each point. The time requirement for obtaining water samples from the drill holes could affect the accuracy of the measurements somewhat. This was not true for samples obtained at the selected four Bjarnalaekur Springs.

Three tests were accomplished. Dye was injected into holes PC-5, BD-9 and PC-3, in that order. The holes and springs for observation were selected for each test based on expected movement as inferred from the groundwater table measurements. The results of these tests are shown on Table B-1. The table shows the recorded elapsed time between injection and first observation, together with the distance between each observation point and the injection hole. The relation of time and distance gives the approximate apparent average velocity of movement within the groundwater table. These measured velocities are only apparent because the actual flow may not be on a straight line in each instance. In a few cases noted on the table, there was some question, because of low concentrations, that dye was actually present.

The noted velocities would, therefore, be the observed maximum average. The test made from borehole PC-5 showed the highest velocity, based on definite dye detection, to be towards BD-5 where the average slope of the groundwater table approaches three percent. This velocity was 4.9 meters per minute. On the basis of questionable detection of dye, it may be nearly three times greater.

TABLE B-1

Burfell Project
Groundwater Movement Measurements

Dye Placed in Borehole	Boreholes and Springs Observed	Elapsed Time	Distance (Meters)	Apparent Average Velocity (Meters per Minute)
TEST I				
PC-5	PC-4	(20 hrs. 44 min.)	175	
	BD-5	25 min. ?	305	12.2?
	BD-5	1 hr. 5 min.	305	4.7
	BD-10	(20 hrs. 47 min.)	410	
	BD-4	(21 hrs. 3 min.)	485	
	BD-6	(20 hrs. 50 min.)	500	
	Spring 1	(24 hrs. 30 min.)	945	
	Spring 2	(24 hrs. 30 min.)	975	
	DT-1	(24 hrs. 22 min.)	980	
	Spring 3	(24 hrs. 30 min.)	1005	
TEST II				
BD-9	BD-5	4 hrs. 50 min.	315	1.1
	BD-4	(16 hrs. 40 min.)	340	
	PC-4	(17 hrs. 15 min.)	365	
	BD-10	(16 hrs. 30 min.)	570	
	BD-6	(16 hrs. 35 min.)	620	
	Spring 4	6 hrs. 25 min.	550	1.4
	Spring 2	(16 hrs. 50 min.)	845	
	Spring 3	(16 hrs. 50 min.)	875	
	DT-1	(16 hrs. 45 min.)	940	
TEST III				
PC-3	PC-8	(20 hrs. 15 min.)	190	
	PC-9	1 hr. 10 min. ?	205	2.9?
	PC-9	2 hrs. 14 min.	205	1.5
	DI-4	1 hr. 15 min. ?	235	3.1?
	DI-4	2 hrs. 18 min.	235	1.7
	DI-3	2 hrs. 15 min. ?	425	2.9?
	DI-2	(19 hrs. 45 min.)	575	
	BD-11	(19 hrs. 40 min.)	695	
	BD-10	(19 hrs. 35 min.)	840	
	BD-6	2 hrs. 50 min. ?	925	5.4?
	BD-5	50 min. ?	1220	24.4?
	BD-5	1 hr. 40 min.	1220	12.2
	Spring 2	(19 hrs. 20 min.)	1905	
	Spring 3	(19 hrs. 25 min.)	1910	

Notes: ? - Detection of dye not definite.
(20 hrs. 44 min.) - Refers to total elapsed time of observations without detecting dye.

The test with dye injected into BD-9 showed a higher average velocity towards the springs than directly toward the face of the THf lava front even though the average groundwater slope was much higher in the latter direction and comparable to that from PC-5 to BD-5. The average velocity over this longer distance was 1. 5 meters per minute.

Dye injected into PC-3 was measured in the general direction of the lava front of the THf flow. The average velocity in the direction paralleling that front was quite high, exceeding 12 meters per minute between PC-3 and BD-5, even though the average slope of the groundwater table in the distance of 1210 meters was only about one-third of one percent. Velocities, where determined in other directions, was relatively much less.

These measurements, while somewhat approximate and limited in scope, when considered along with the groundwater table measurements, indicate strongly that the thick and pervious interbed along the face of the second Thjorsa lava flow (THf) provides an intercept channel (pipe) for the groundwater within the first interbed, except perhaps locally towards the western end. The high velocity in this intercept channel indicates extreme permeability. The fines originally in the channel area may have been nearly all piped out. The measurements and location factors also show that the water concentrated in this channel discharges as the Bjarnalaekur Springs and makes a relatively large, although unmeasured, contribution to the flow of the Bjarnalaekur.

The measurements made of dye movement from boreholes PC-5 and BD-9 also show the need for treatment to prevent loss of water from the Bjarnalaekur Pond through this same interbed.

All boreholes were water pressure tested in sections ranging from 1.5 to 3.0 meters using single and double rubber packers. Where boreholes penetrated unconsolidated interbeds between lava flows, percolation tests were performed. The results of the permeability tests were converted to Lugeon Units (LU) and are shown along the graphic core logs on Exhibits B-7 to B-16, inclusive. These tests formed the basis for determining the permeabilities in each of the various formations, as discussed above.

Conclusion

As is usually the case, the detailed geology of the Burfell site, shown on the attached exhibits and discussed above, was found to exercise a controlling influence on the planning, design, and construction of this hydroelectric project. The geologic reconnaissance, mapping, structural relationships as revealed, in part, by subsurface explorations and interpretations are believed to be adequate for the engineering planning of the Burfell Project. In addition, important information useful in the subsequent, more detailed, design phase and in the construction stage of the Project has been provided. The broad relationships with respect to deposits of natural construction materials have been discussed above. Their geology is discussed in more detail in Appendix C.

However, more field information and study is required in advance of and coincident with the ultimate preparation of contract and design drawings. The desired subsurface investigations include the completion of the exploratory tunnel into the zone of the powerstation. Exploration drifts should be made in that location away from the main tunnel. Some diamond core drilling should also be accomplished from the tunnel in this zone. More deep core borings are also desired in order to explore in greater detail the geology along the route of the proposed tailtunnel to include, possibly, some shifting of that feature as may be required to assure that it encounters the best rock available. Possible savings may greatly exceed costs. Additional core boring at the site of other planned structures is always desirable to finalize their location and design with maximum economy.

Further geologic investigations and studies should extend in detail throughout the construction phase of the Project. This is particularly important when consideration is given to the fact that a substantial portion of the Project investment is represented by structures located underground. The geologic work will greatly assist in adapting the designs to the actual foundation conditions as revealed by the constructions to assure a safe and economical Project. They will also greatly assist in establishing suitable and economical construction procedures such as blasting and tunneling excavation techniques, roof and wall support, foundation treatment, etc.

Acknowledgements

Special thanks are due the following Icelanders whose previous or current work provided important assistance in the preparation of this engineering geology appendix:

Jacob Gislasson, Director General, State Electricity Authority

Erikur Briem, Director, State Electricity Works

Gudmundur Kjartansson, Geologist, Department of Geology and Geography, Museum of Natural History

Dr. Thorleifur Einarsson, Geologist, The University Research Institute

Haukur Tomasson, Geologist, State Electricity Authority

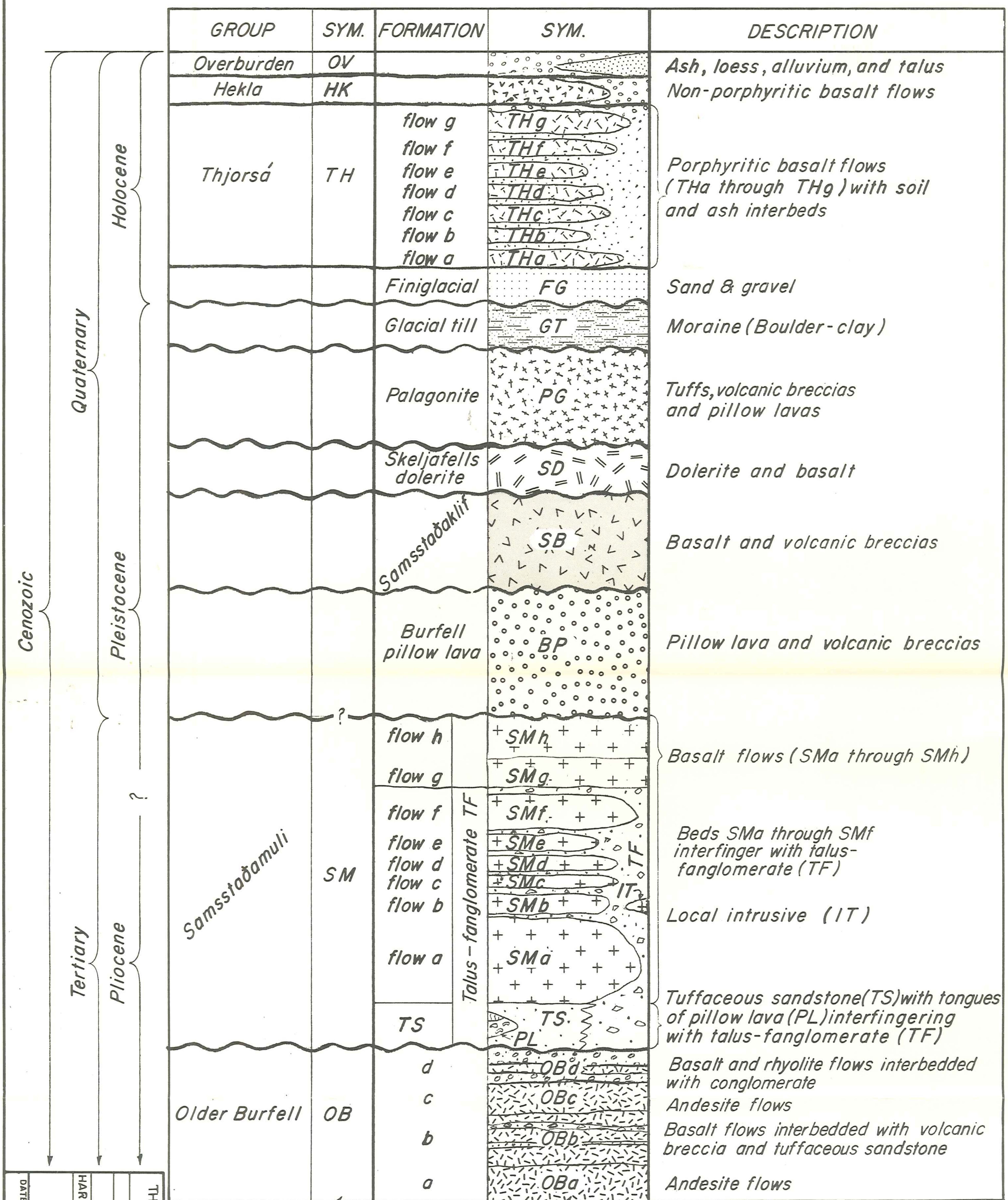
Elsa G. Vilmundardotter, Student Geologist

THE EXHIBITS

B-1	Columnar Section
B-2	Geologic Map, Burfell Area
B-3	Geologic Map, Project Area, Sheet 1 of 2
B-4	Geologic Map, Project Area, Sheet 2 of 2
B-5	Geologic Sections, Sheet 1 of 2
B-6	Geologic Sections, Sheet 2 of 2
B-7	Graphic Core Logs, Sheet 1 of 10
B-8	Graphic Core Logs, Sheet 2 of 10
B-9	Graphic Core Logs, Sheet 3 of 10
B-10	Graphic Core Logs, Sheet 4 of 10
B-11	Graphic Core Logs, Sheet 5 of 10
B-12	Graphic Core Logs, Sheet 6 of 10
B-13	Graphic Core Logs, Sheet 7 of 10
B-14	Graphic Core Logs, Sheet 8 of 10
B-15	Graphic Core Logs, Sheet 9 of 10
B-16	Graphic Core Logs, Sheet 10 of 10

EXHIBIT B-1

COLUMNAR SECTION



LEGEND

〜 Unconformity
SYM Symbol

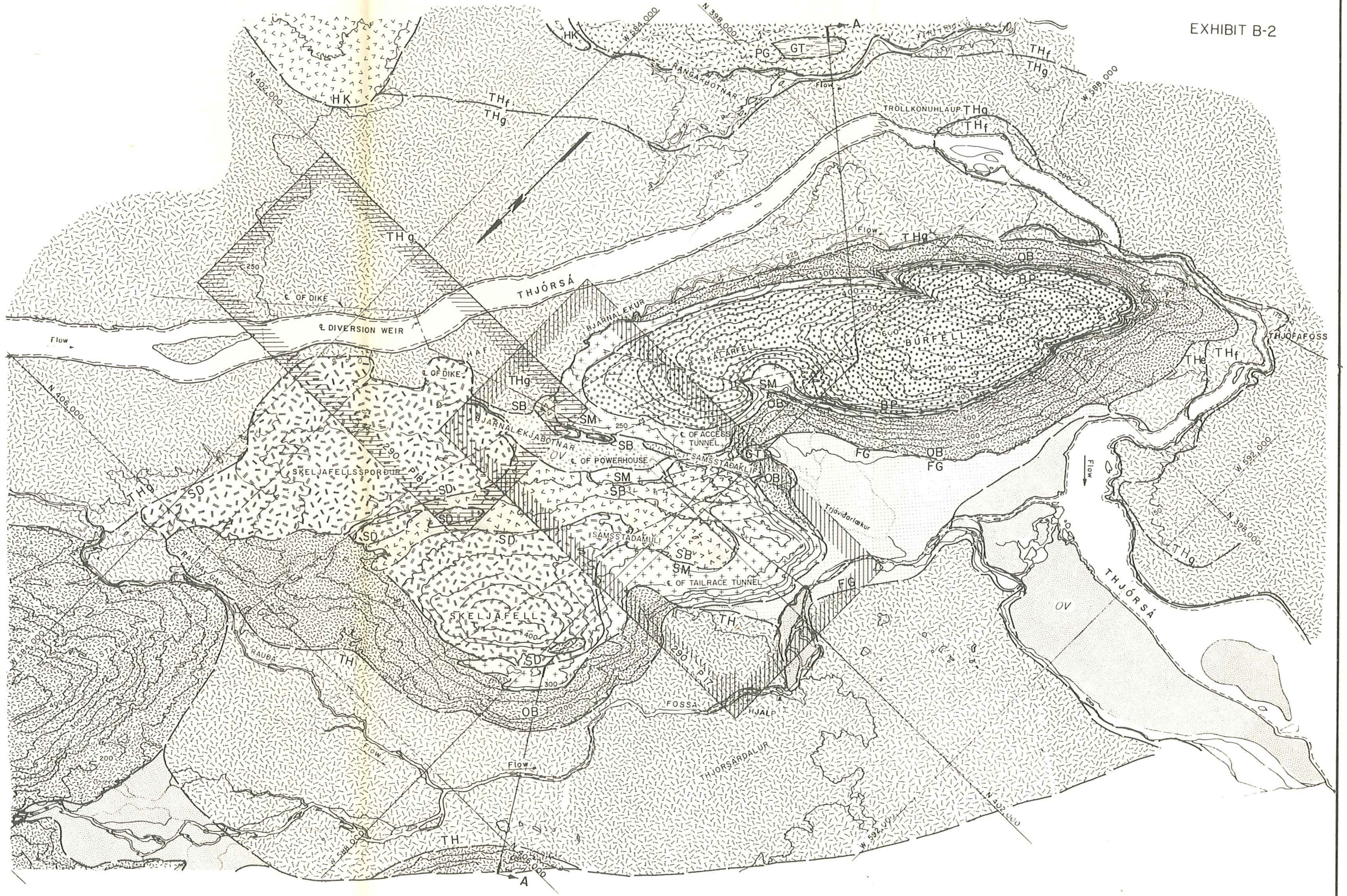
THE STATE ELECTRICITY AUTHORITY ICELAND	
BURFELL PROJECT	
COLUMNAR SECTION	
HARZA ENGINEERING COMPANY INTERNATIONAL	
PREPARED BY HARZA ENGINEERING CO. CHICAGO APPROVED BY [signature]	
DATE JAN. 1963	DWG. NO. 290 P 24

CJF Jan. 1963

EXHIBIT B-2

LEGEND

- Overburden (OV) — River alluvium; Ash and lapilli
- Hekla (HK) — Non-porphyritic basalt flows
- Thjorsá group (TH) — Porphyritic basalt flows, THa through THg with soil and ash interbeds
- Finiglacial (FG) — Sand and gravel, unconsolidated
- Glacial till (GT) — Moraine (boulder, clay)
- Palagonite (PG) — Tuffs, volcanic breccia and pillow lava
- Skeljafell dolerite (SD) — Dolerite and basalt
- Samsstaðaklif basalt (SB) — Basalt and volcanic breccia
- Burfell pillow lava (BP) — Pillow lava and volcanic breccia
- Samsstaðamuli group (SM) — Basalt flows (SM) interfingering with talus-fanglomerate (TF). Tuffaceous sandstone (TS) with tongues of pillow lava (PL)
- Older Burfell (OB) — Basalt, andesite and rhyolite flows with clastic interbeds
- Approximate geologic contact
- Fault

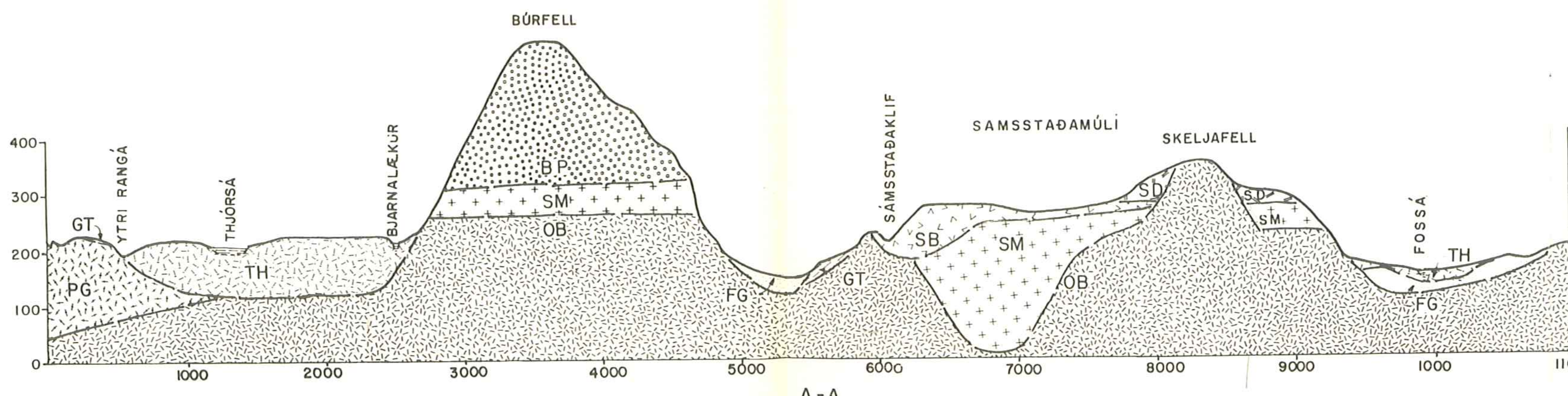


NOTES:

Topography based on topographic mapping performed under the direction of Harza Engineering Co. International and on aerial surveying performed by Wideroe Aerial Survey Co, Norway

Geologic sections shown on drawings 290 P19 and 290 P20

Scale 0 500 1000 Meters



A-A
GENERALIZED SECTION

DATE	NO.	DISTRIBUTION

PRINTS

	BY	DATE	CHKD	DATE
DSGN				
DWN.				
DEPT.	GROUP LEADER	SECT HEAD	DEPT. HEAD	
CIVIL				
MECH.				
ELECT				
PLAN				
STAFF			CH ENGR	

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD	APPD

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ICELAND

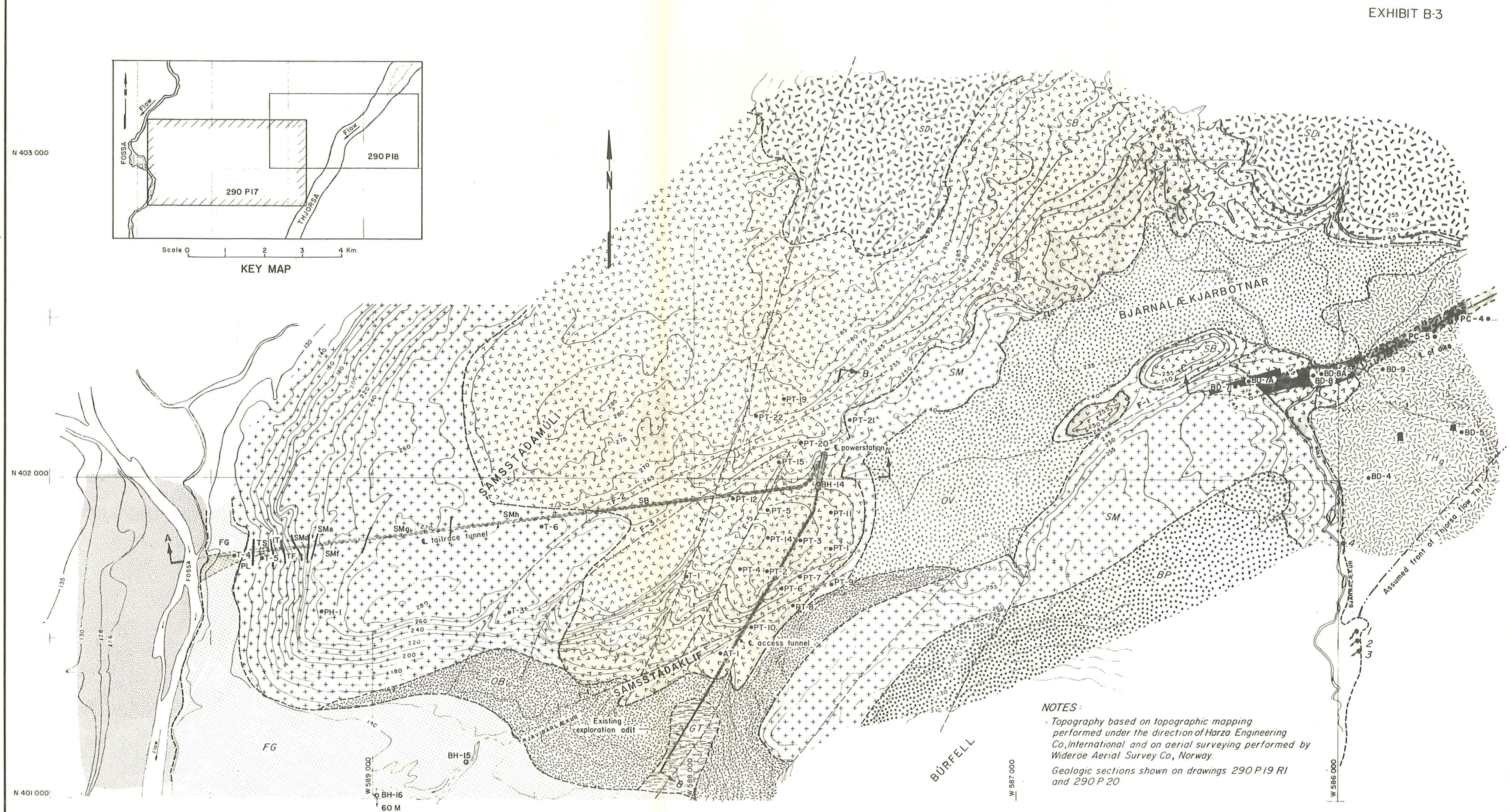
BURFELL PROJECT

GEOLOGIC MAP BURFELL AREA

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED

CHICAGO, ILLINOIS	DATE JAN. 1963	DWG. No. 290 P16

EXHIBIT B-3



LEGEND:

- **Overburden (OV)** — River alluvium; Ash and lapilli
- **Thjorsá flow (THg)** — Upper flow of Thjorsá group, consisting of porphyritic basalt flows with soil and ash interbeds
- **Finiglacial (FG)** — Sand and gravel, unconsolidated
- **Glacial till (GT)** — Moraine (boulder, clay)
- **Skeljafell dolerite (SD)** — Dolerite and basalt
- **Samsstaðaklif basalt (SB)** — Basalt and volcanic breccia
- **Burfell pillow lava (BP)** — Pillow lava and volcanic breccia
- **Samsstaðamuli group (SM)** — Basalt flows (SM) interfingering with talus-fanglomerate (TF). Tuffaceous sandstone (TS) with tongues of pillow lava (PL)
- **Older Burfell (OB)** — Basalt, andesite and rhyolite flows with clastic interbeds
- Outline of structures
- Approximate geologic contact between groups
- Approximate geologic contact between formations
- Fault
- Exploration hole drilled under supervision of Harza Engineering Co, International 1961 during exploration for the "Lower Site"
- Exploration hole drilled under supervision of Harza Engineering Co, International 1962 during exploration for the "Upper Site"
- 2 Springs
- Trench

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD	DATE
DSGN				
DWN				

DEPT.	GROUP LEADER	SECT HEAD	DEPT HEAD
CIVIL			
MECH			
ELECT			
PLAN			
STAFF			CH ENGR

NO	DATE	NATURE OF REVISION	BY	CHKD	APPD
1	2-7-63	[illegible]	T.L.M	WGD	ARE

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BURFELL PROJECT

GEOLOGIC MAP-PROJECT AREA
SHEET 1 OF 2

HARZA ENGINEERING COMPANY INTERNATIONAL
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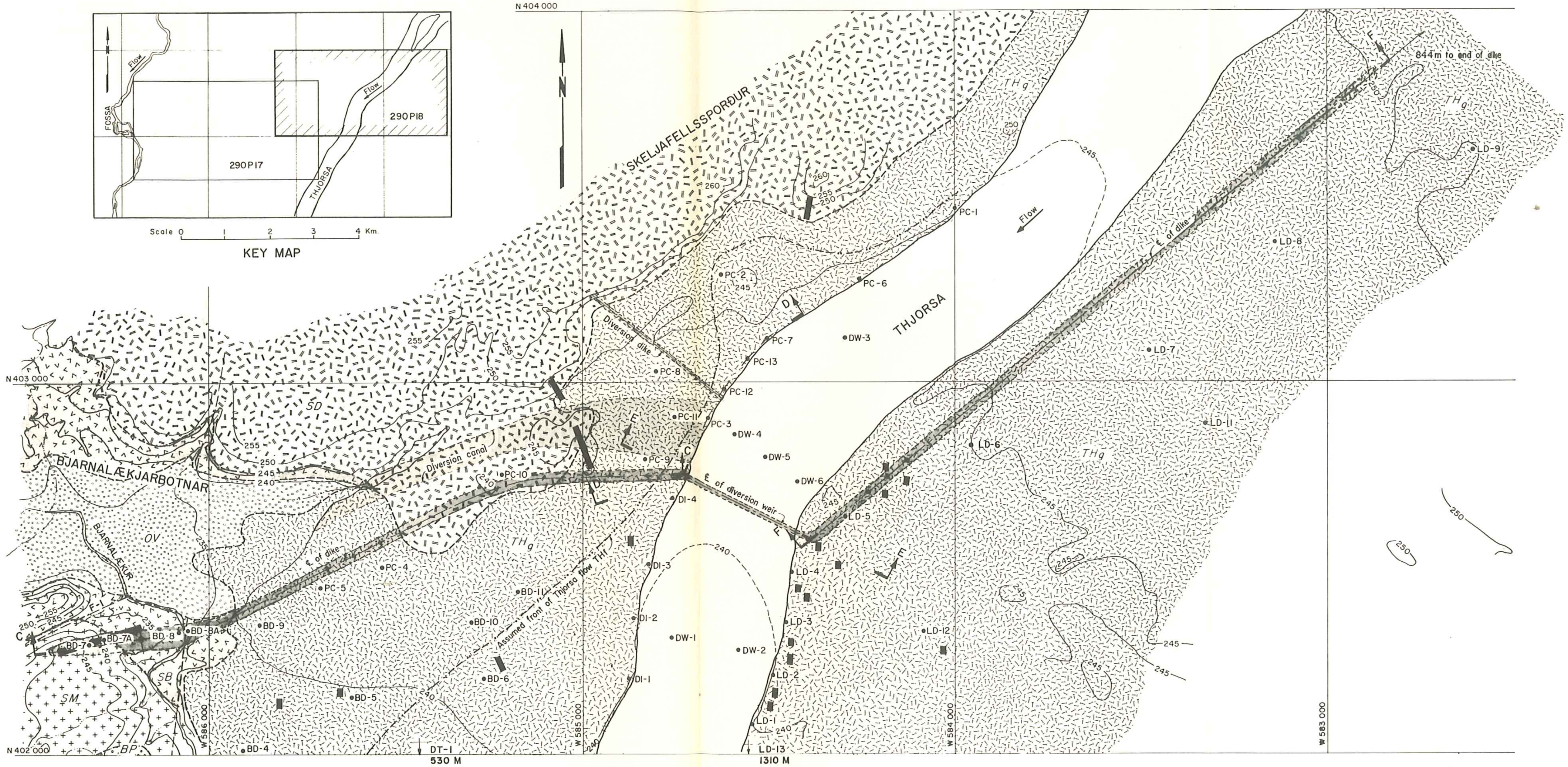
CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG. No. 290 P 17 R1

EXHIBIT B-4



LEGEND:

Overburden (OV)
Ash and lapilli

Thjorsa flow (THg)
Upper flow of Thjorsa group, consisting of porphyritic basalt flows with soil and ash interbeds

Skeljafell dolerite (SD)
Dolerite and basalt

Samsstaðaklif basalt (SB)
Basalt and volcanic breccia

Samsstaðamuli group (SM)
Basalt flows

Approximate geologic contact between groups

Fault

Exploration hole drilled under the supervision of Harza Engineering Co. International 1961 – 1962

Trench

Outline of structure

NOTES:

Topography based on topographic mapping performed under the direction of Harza Engineering Co, International and on aerial surveying performed by Wideroe Aerial Survey Co, Norway.

Geologic sections shown on dwg. 290 P 20

Scale 0 100 200 300 Meters

DATE	NO	DISTRIBUTION		
PRINTS				
	BY	DATE	CHKD.	DATE
DSGN.				
DWN.	W.H.			
DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD	
CIVIL				
MECH.				
ELECT.				
PLAN.				
STAFF			CH. ENGR.	

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

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BURFELL PROJECT

GEOLOGIC MAP-PROJECT AREA
SHEET 2 OF 2

HARZA ENGINEERING COMPANY INTERNATIONAL
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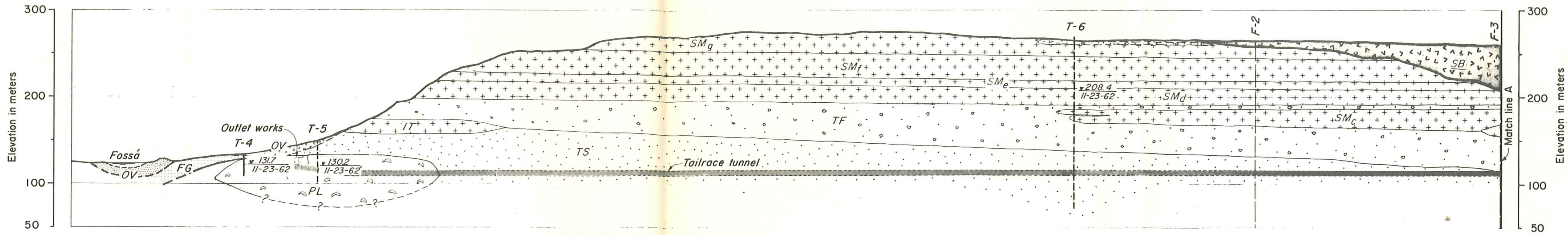
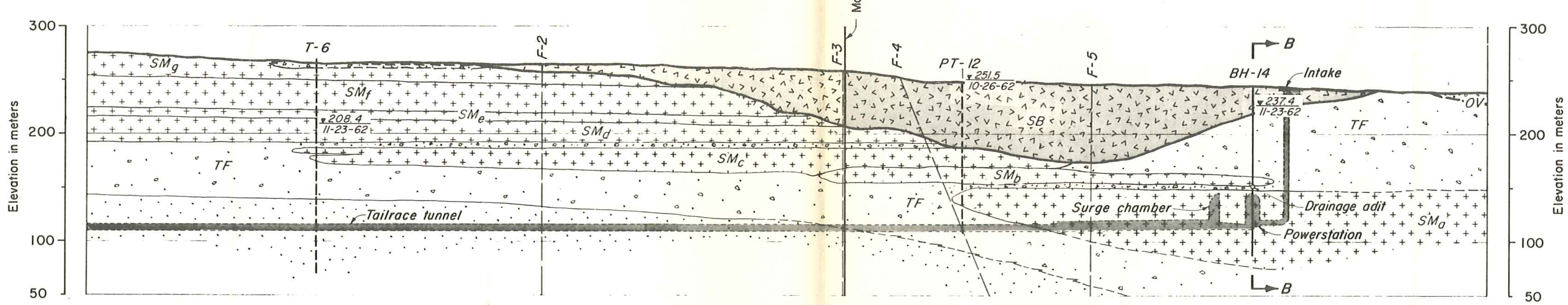
EXHIBIT B-5



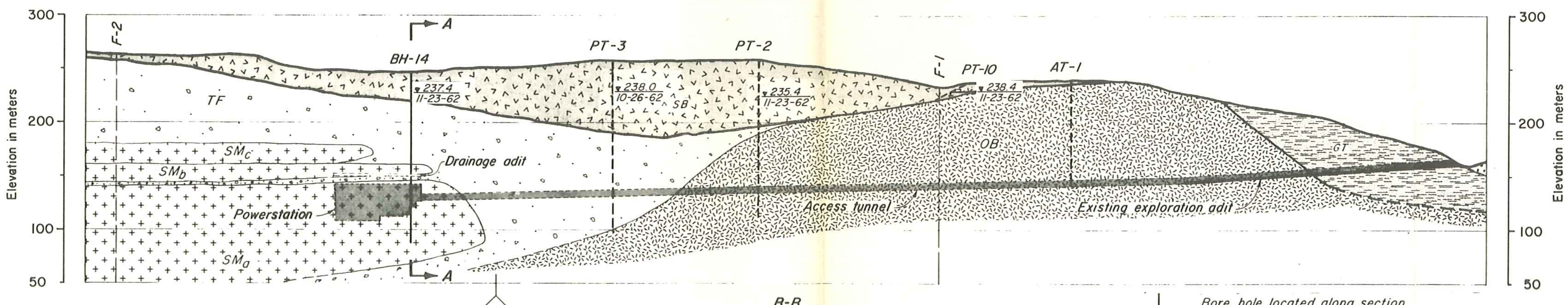
A-A

SECTION ALONG ℄ OF TAILRACE TUNNEL



A-A (continued)

SECTION ALONG ℄ OF TAILRACE TUNNEL



B-B

SECTION ALONG ℄ OF ACCESS TUNNEL

NOTES:

For location of geologic sections see dwg. 290 P 17 R1

Scale 0 50 100 Meters

1cm = 20m

LEGEND

Overburden (OV)
- River alluvium
- Ash, lapilli and talus

Finiglacial (FG) — Sand and gravel, unconsolidated

Glacial till (GT) — Moraine (boulder, clay)

Samsstaðaklif basalt (SB) — Basalt and volcanic breccia

Samsstaðamuli group (SM)
- Basalt flows (SMa through SMh) and intrusive (IT)
- Tuffaceous sandstone (TS)
- Talus-fanglomerate (TF)
- Pillow lava (PL)

Older Burfell (OB) — Basalt, andesite and rhyolite flows with clastic interbeds

227.1 Ground water elevation
10-10-62 Date of recording

- Bore hole located along section
- Bore hole projected to section. See dwg. 290 P 17 R1 for exact distance.
- Geologic contact between groups
- Geologic contact between formations
- Inferred geologic contact between groups
- Inferred geologic contact between formations
- Section turns
- Outline of structures
- Fault

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.	N.H.			1-9-63

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL		RJF	WHB
MECH.			
ELECT.			
PLAN.			
STAFF			CH.ENGR.

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.
1	2-7-63	Water levels added	TLM	WGD	APF

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BURFELL PROJECT

GEOLOGIC SECTIONS
SHEET 1 OF 2

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
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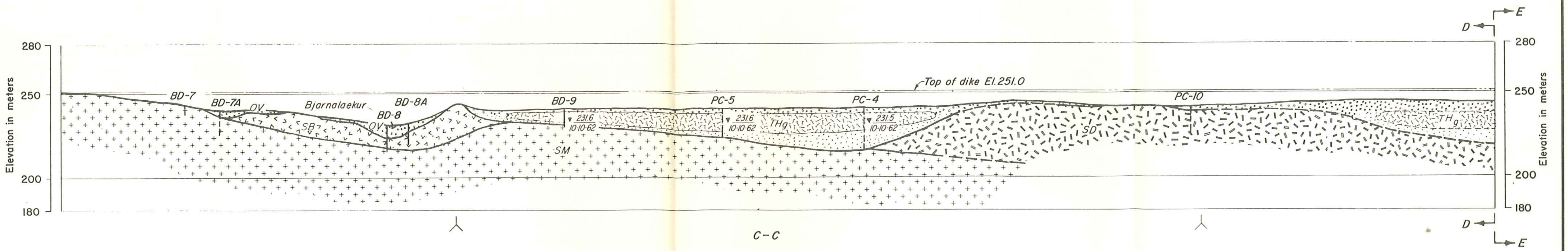
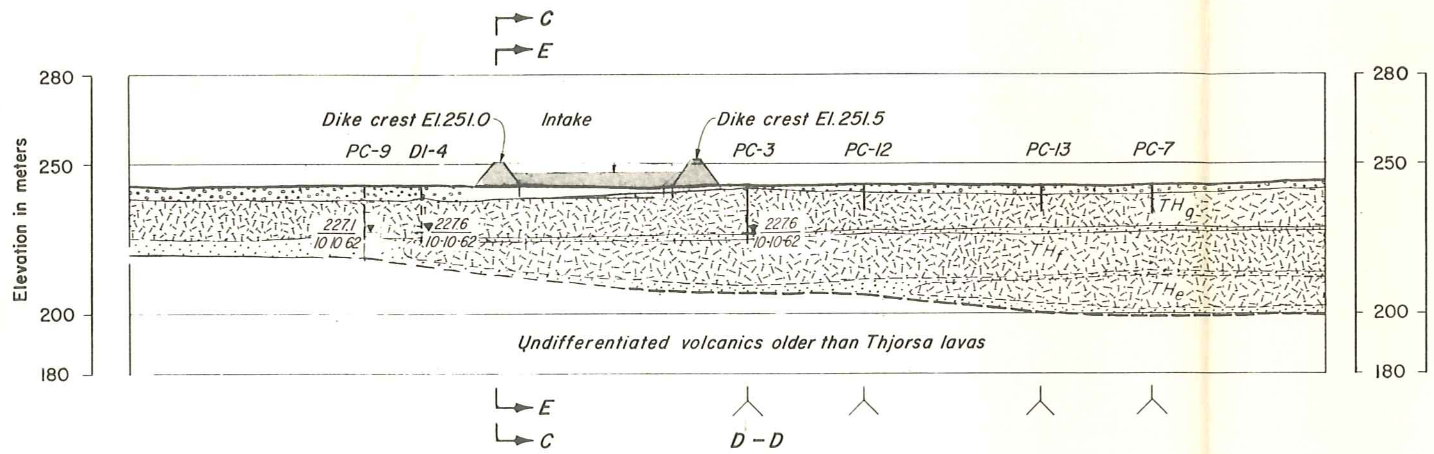
CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG. No. 290 P 19 R1

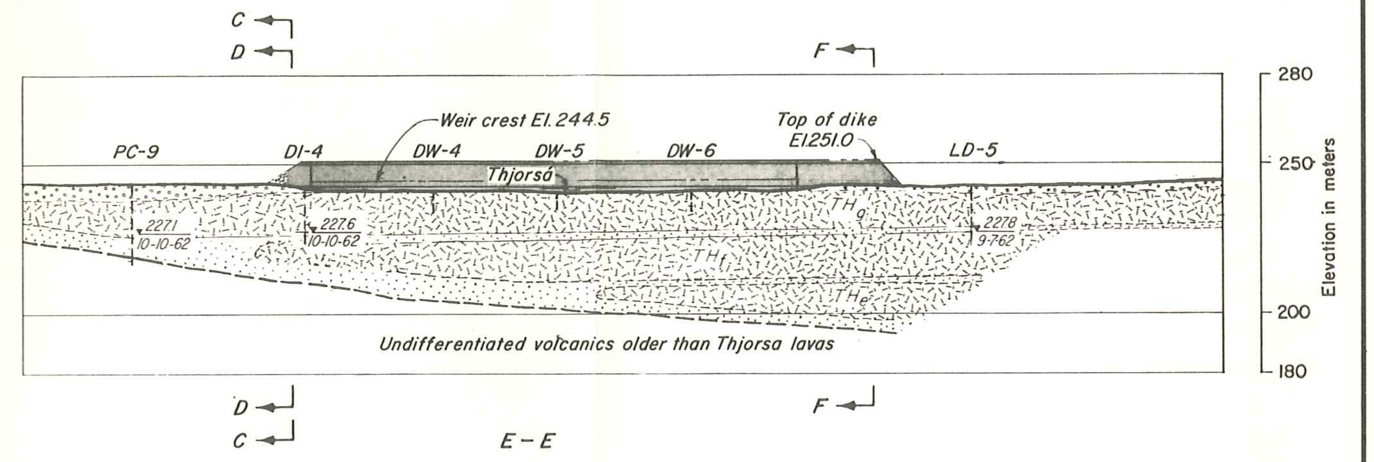
EXHIBIT B-6



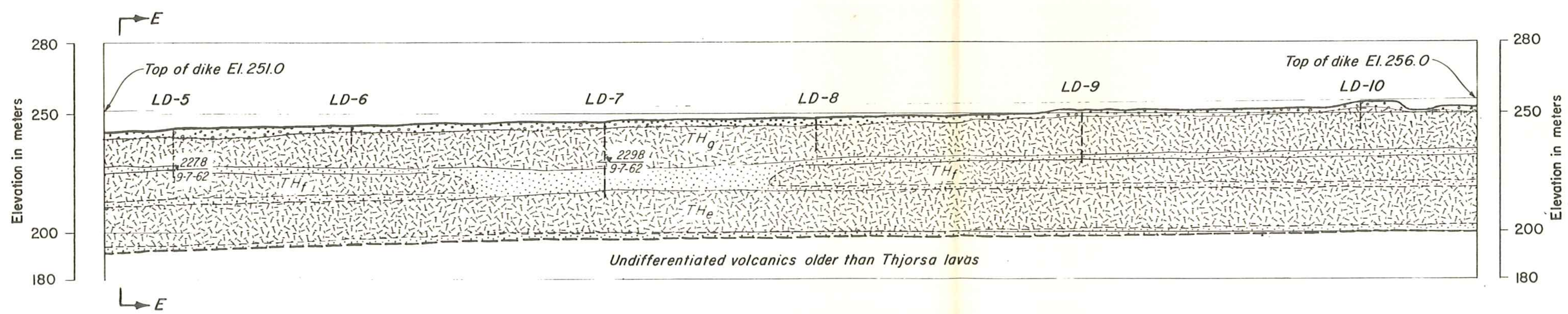
C-C



D-D



E-E



F-F

Scale 0 100 Meters

NOTES:
For location of geologic sections see dwg. 290 P 18

Horiz. scale 0 50 100 Meters
Vert. scale 0 50 Meters
Except as noted

LEGEND

Overburden (OV)	Ash, lapilli and talus	Skeljafell dolerite (SD)	Dolerite and basalt
Thjorsá group (TH)	Basalt flows (THa through THg)	Samsstaðaklif basalt (SB)	Basalt and volcanic breccia
	Soil and ash interbed	Samsstaðamuli group (SM)	Basalt flows
			Outline of structures
		▼ 227.1 10-10-62	Ground water elevation Date of recording

- Bore hole located along section
- Bore hole projected to section. See dwg. 290 P 18 for exact distance.
- Geologic contact between groups
- Geologic contact between formations
- Inferred geologic contact between groups
- Inferred geologic contact between formations
- Section turns

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.	W.G.D.	12-20-62		
DWN.	HLS	1/4/63	R.D.	1/12/63

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL		LJF	WHB
MECH.			
ELECT.			
PLAN.			
STAFF			CH. ENGR.

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

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ICELAND

BURFELL PROJECT

GEOLOGIC SECTIONS
SHEET 2 OF 2

HARZA ENGINEERING COMPANY INTERNATIONAL
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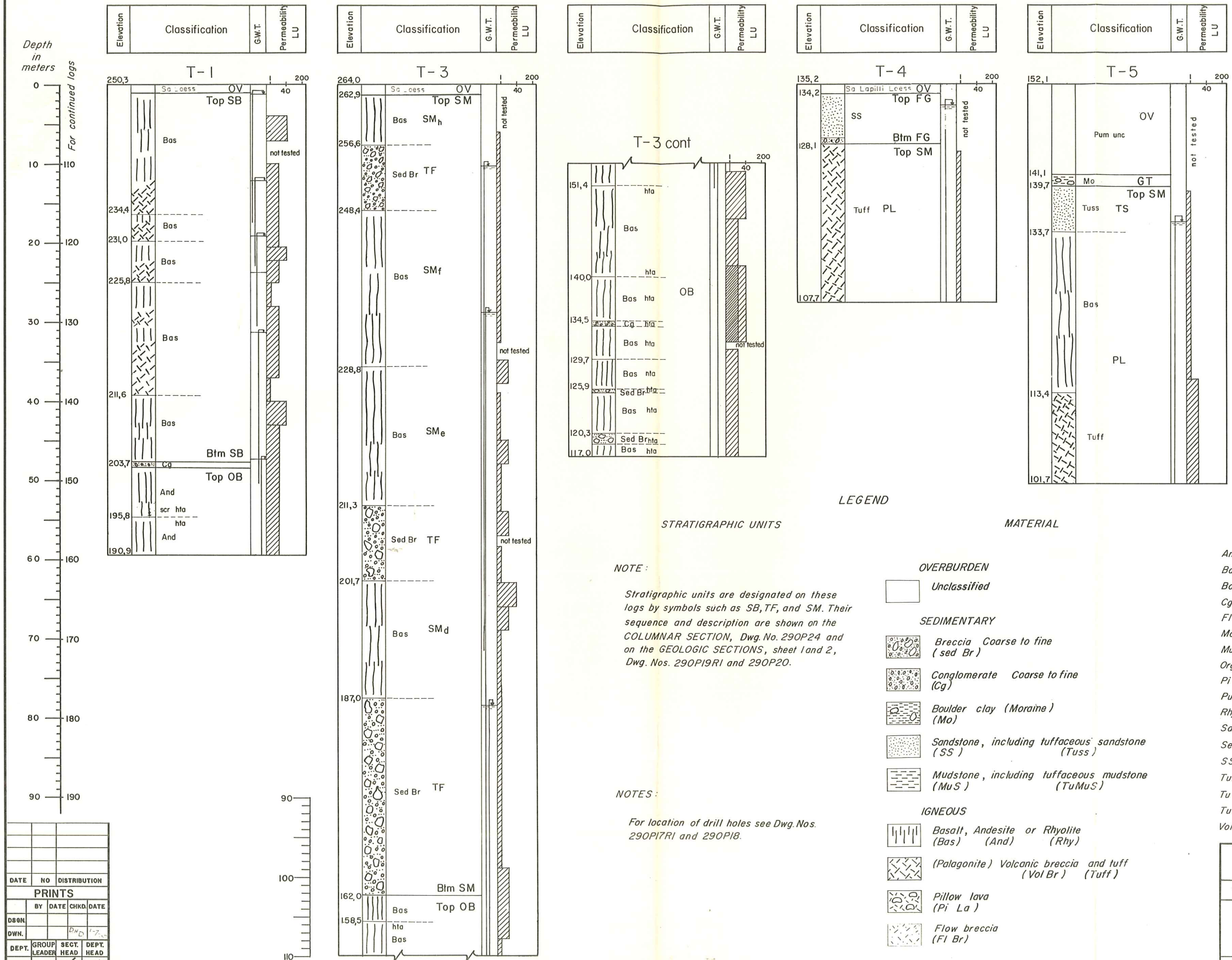
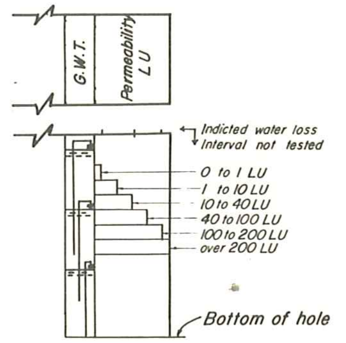
EXHIBIT B-7





PERMEABILITY AND GWT EXPLANATION

NOTE: Ground water levels are shown by the arrows. Base of the arrows indicate the hole depth when water level changed. Successive levels are shown from left to right in the same sequence as observed during drilling. If no change in level was observed the arrow reaches to hole bottom.

LEGEND

STRATIGRAPHIC UNITS

NOTE:

Stratigraphic units are designated on these logs by symbols such as SB, TF, and SM. Their sequence and description are shown on the COLUMNAR SECTION, Dwg. No. 290P24 and on the GEOLOGIC SECTIONS, sheet 1 and 2, Dwg. Nos. 290P19R1 and 290P20.

NOTES:

For location of drill holes see Dwg. Nos. 290P17R1 and 290P18.

MATERIAL

OVERBURDEN

- *Unclassified*

SEDIMENTARY

- *Breccia Coarse to fine (sed Br)*
- *Conglomerate Coarse to fine (Cg)*
- *Boulder clay (Moraine) (Mo)*
- *Sandstone, including tuffaceous sandstone (SS) (Tuss)*
- *Mudstone, including tuffaceous mudstone (MuS) (TuMuS)*

IGNEOUS

- *Basalt, Andesite or Rhyolite (Bas) (And) (Rhy)*
- *(Palagonite) Volcanic breccia and tuff (Vol Br) (Tuff)*
- *Pillow lava (Pi La)*
- *Flow breccia (Fl Br)*

ABBREVIATIONS

MATERIAL

And	andesite
Bas	basalt
Bo	basalt blocks
Cg	conglomerate
Fl Br	flow breccia
Mo	moraine
MuS	mudstone
Org Silt	organic silt
Pi La	pillow lava
Pum	pumice
Rhy	rhyolite
Sa	sand
Sed Br	sedimentary breccia
SS	sandstone
Tuff	tuff
Tu MuS	tuffaceous mudstone
Tuss	tuffaceous sandstone
Vol Br	volcanic breccia

DESCRIPTIVE

brr	brecciated
hta	hydrothermal alteration
scr	scoriaceous
unc	unconsolidated

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.				

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			
MECH.			
ELECT.			
PLAN.			
STAFF			CH.ENGR

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APD.

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BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 1 of 10

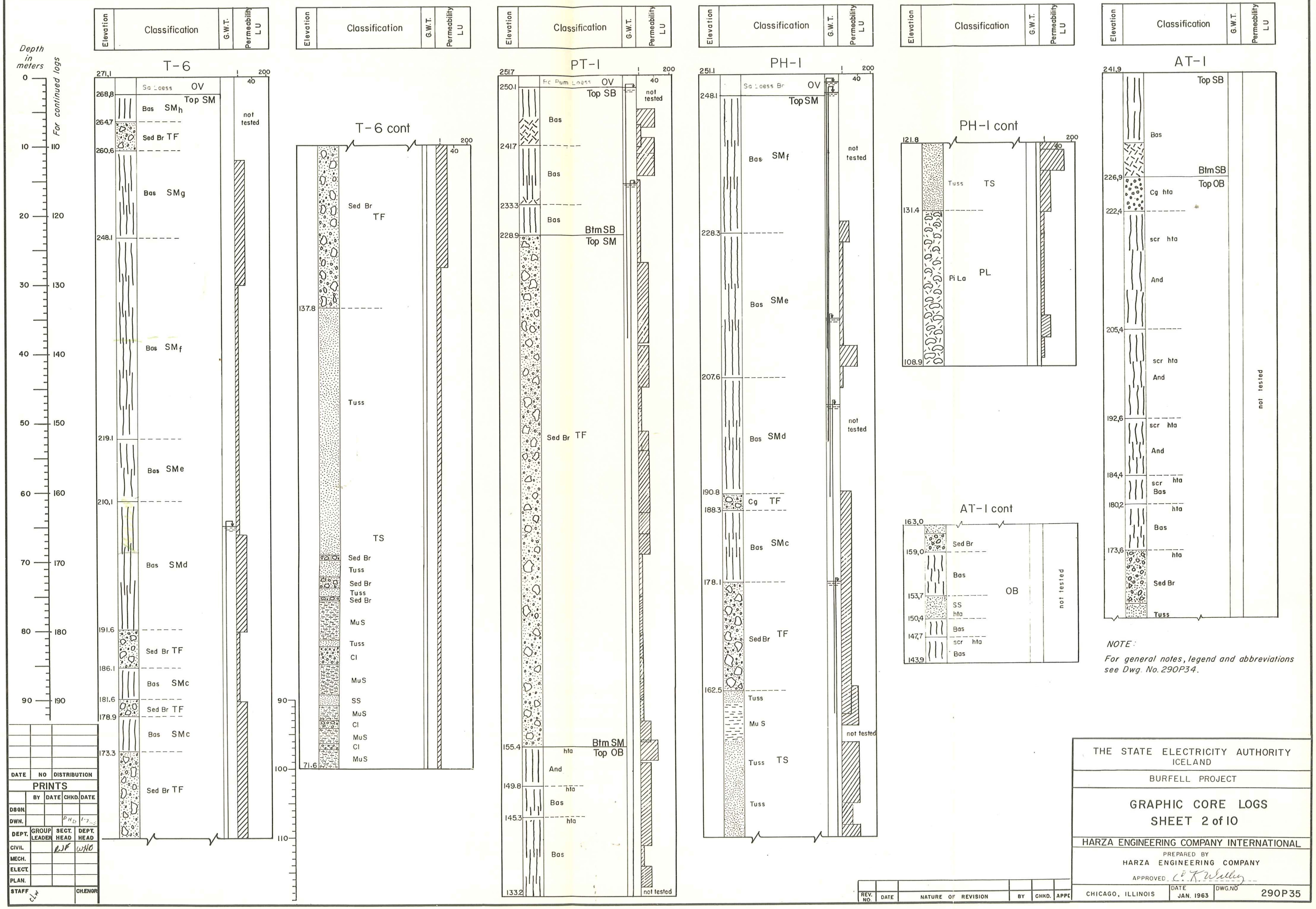
HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED: C. K. Willey

CHICAGO, ILLINOIS | DATE JAN, 1963 | DWG. NO. 290P34

EXHIBIT B-8



NOTE:
For general notes, legend and abbreviations see Dwg. No. 290P34.

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BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 2 of 10

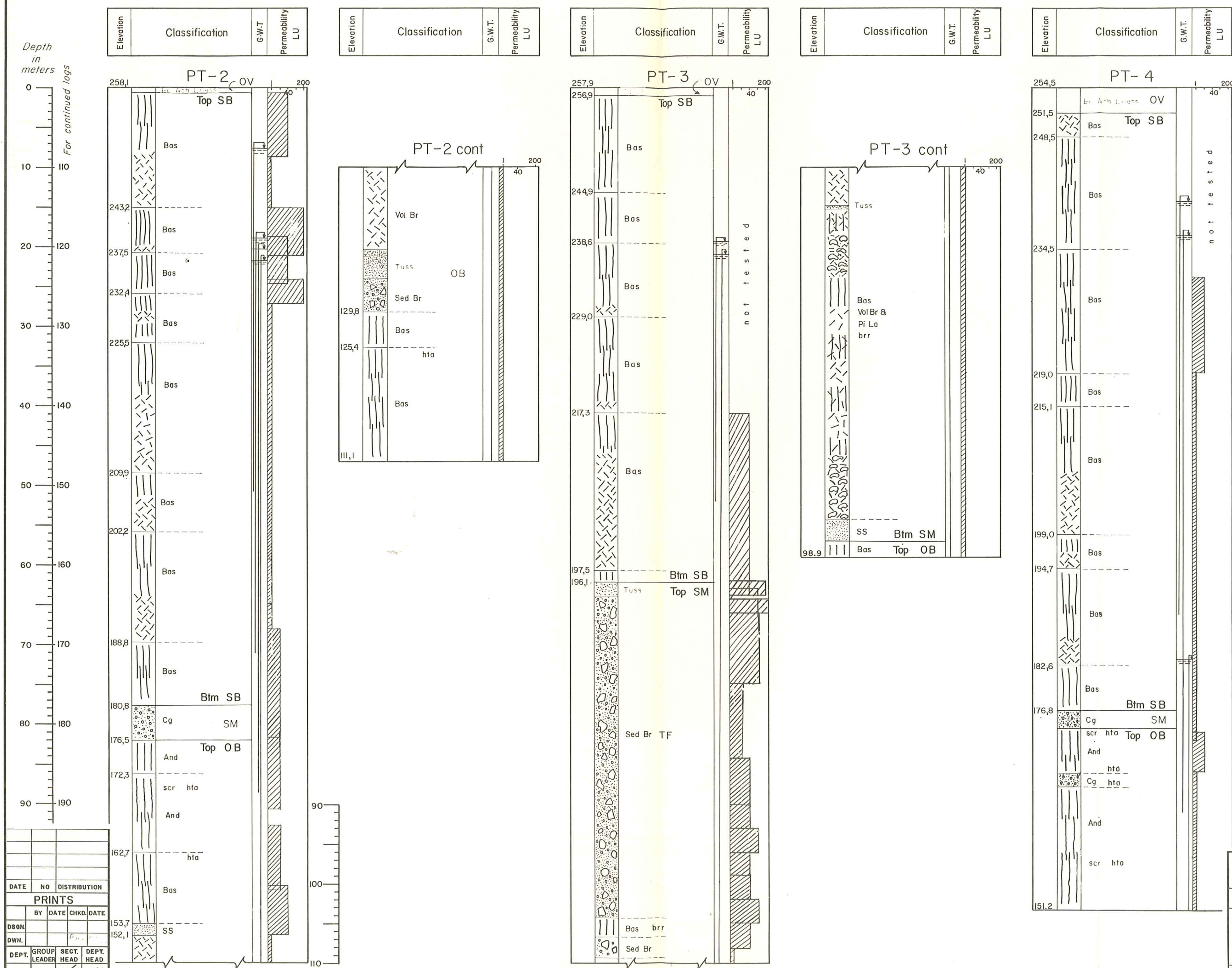
HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED

CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG. NO. 290P35

EXHIBIT B-9



NOTE:
For general notes, legend and abbreviations see Dwg No. 290P34.

DATE	NO	DISTRIBUTION
PRINTS		

	BY	DATE	CHKD.	DATE
DSGN.				
DWN.				

DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL			WHB
MECH.			
ELECT.			
PLAN.			
STAFF		CH.ENGR.	

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

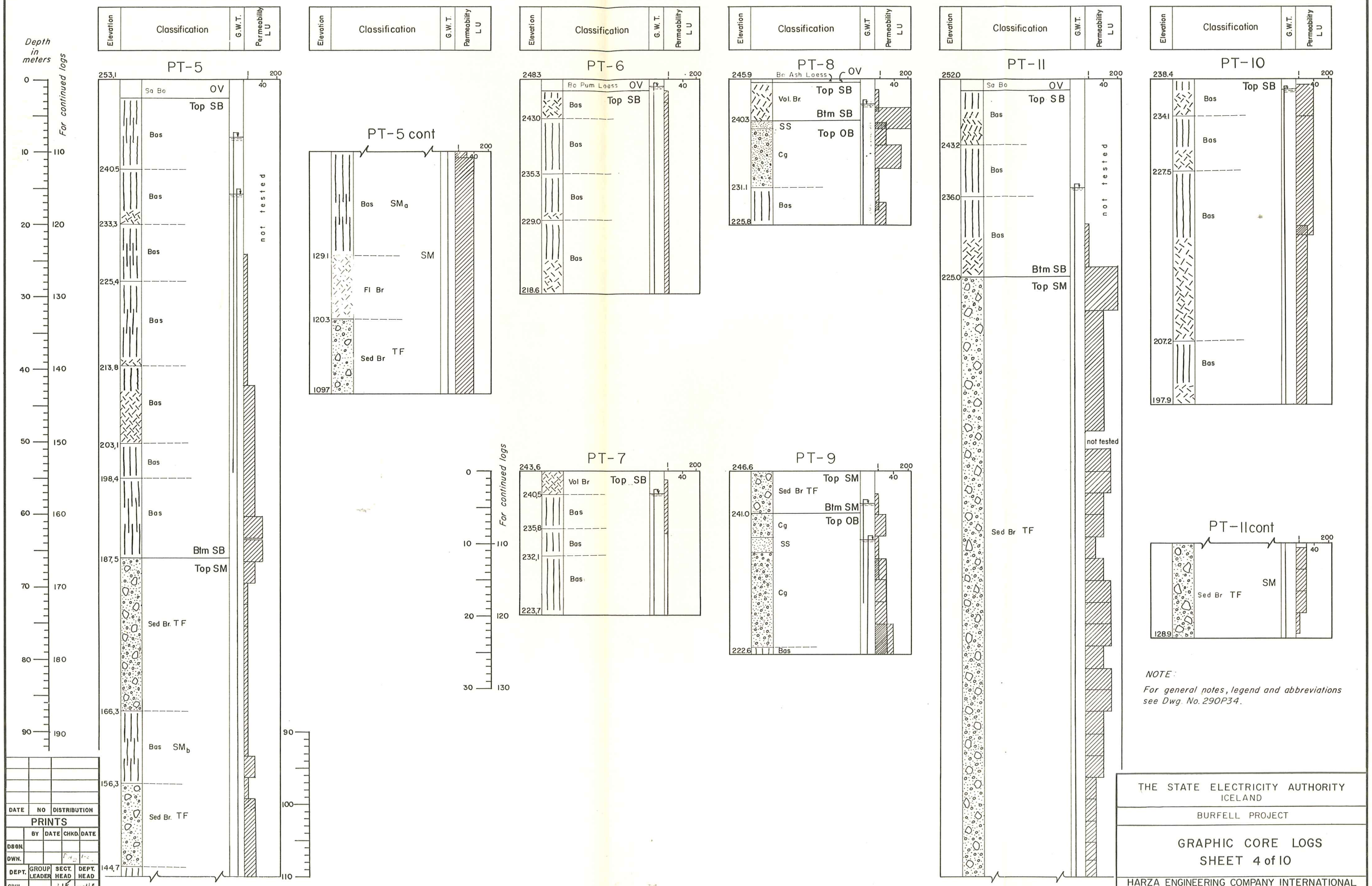
BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 3 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG.NO. 290P36

EXHIBIT B-10



NOTE:

For general notes, legend and abbreviations see Dwg. No. 290P34.

DATE	NO	DISTRIBUTION

PRINTS	BY	DATE	CHKD.	DATE
DSGN.				
DWN.				
DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD	
CIVIL		RJF	WHE	
MECH.				
ELECT.				
PLAN.				
STAFF		CH.ENGR.		

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APP'D

THE STATE ELECTRICITY AUTHORITY
ICELAND

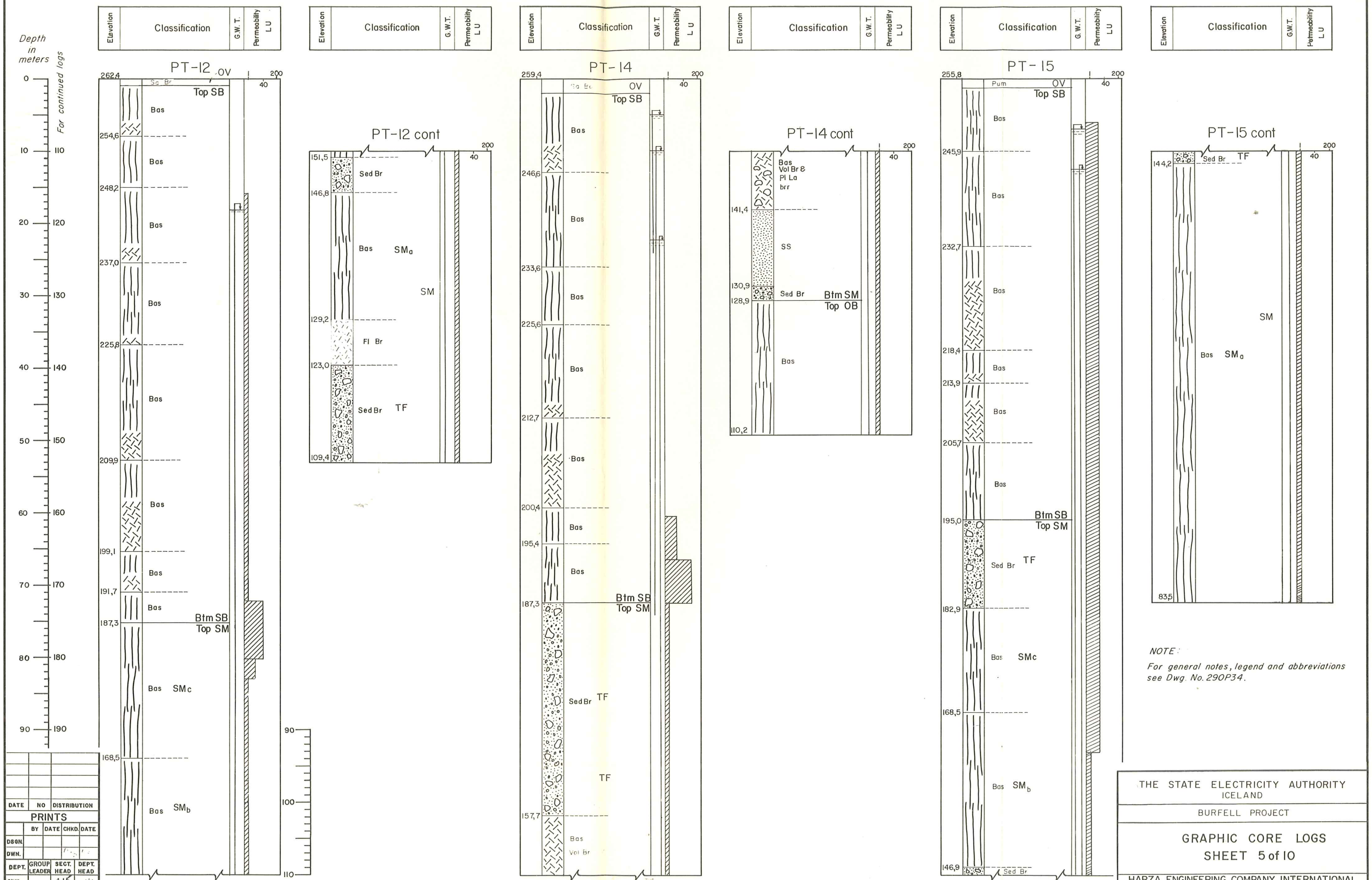
BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 4 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE JAN., 1963 | DWG. NO. 290P37

EXHIBIT B-11



NOTE:
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DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
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THE STATE ELECTRICITY AUTHORITY
ICELAND

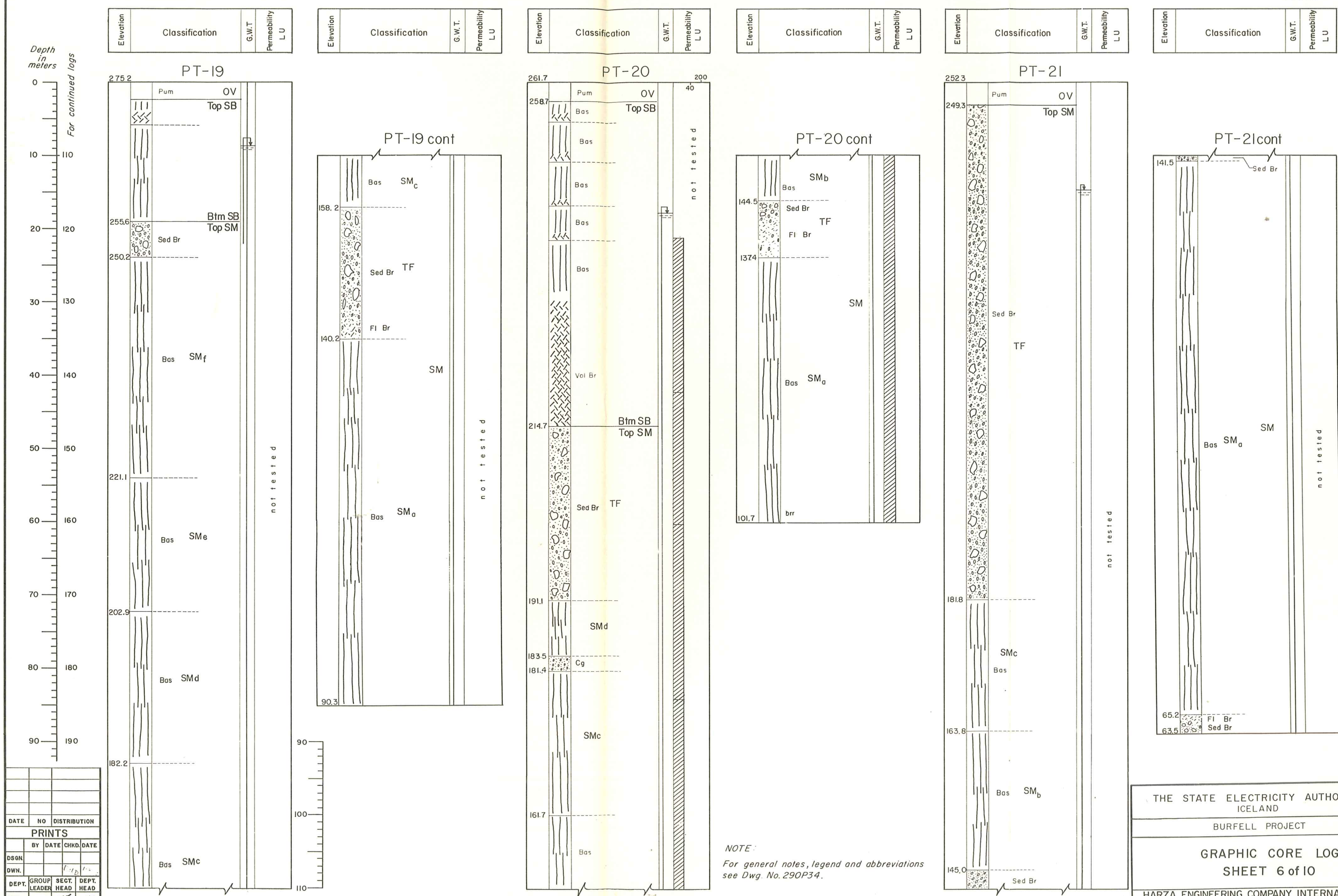
BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 5 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE JAN., 1963 | DWG. NO 290P38

EXHIBIT B-12



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ICELAND

BURFELL PROJECT

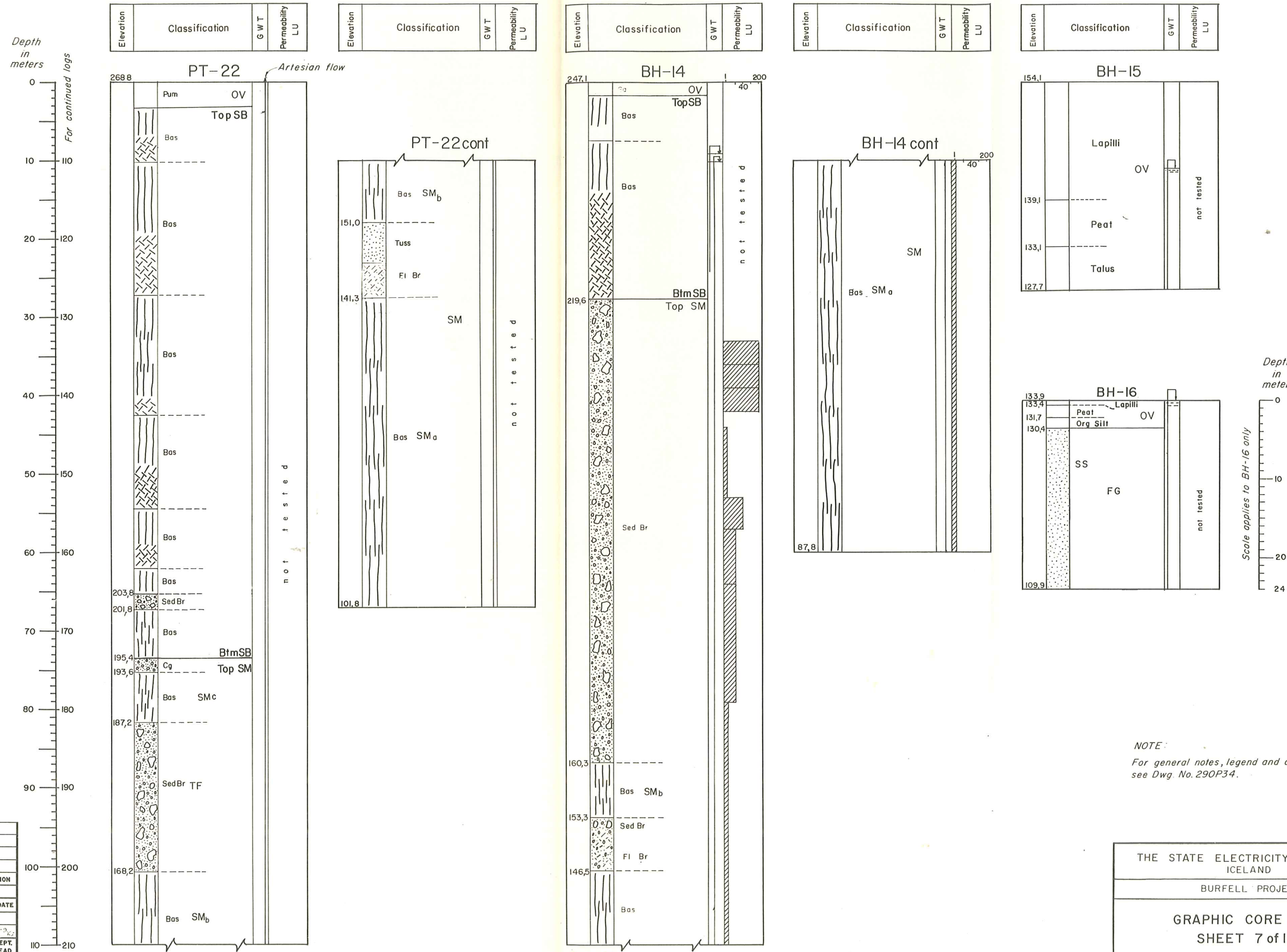
GRAPHIC CORE LOGS
SHEET 6 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED C.K. Willey

CHICAGO, ILLINOIS | DATE JAN, 1963 | DWG. NO. 290P39



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ICELAND

BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 7 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Wiley

CHICAGO, ILLINOIS | DATE JAN, 1963 | DWG. NO. 290P40

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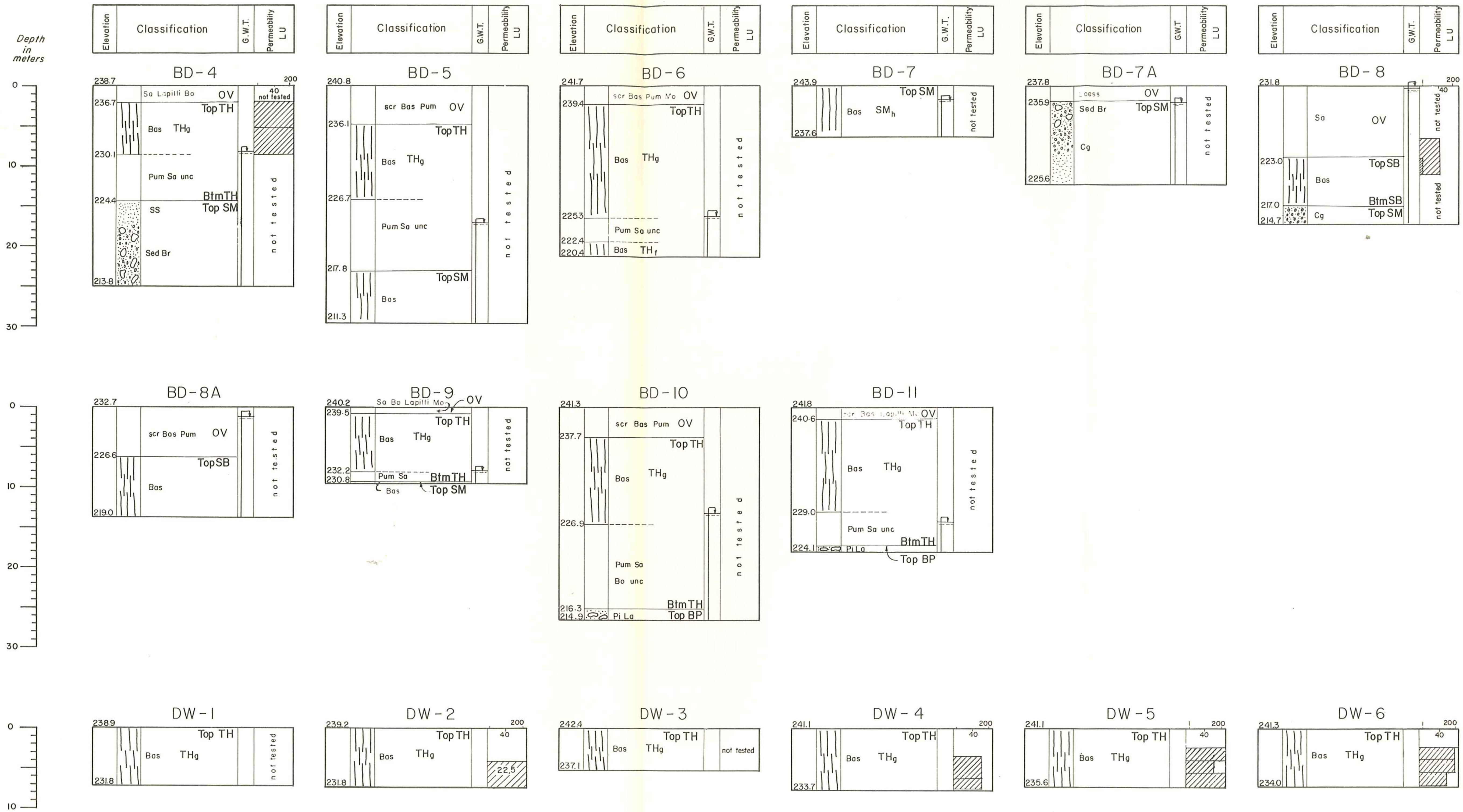

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For general notes, legend and abbreviations see Dwg. No. 290P34.

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ICELAND

BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 8 of 10

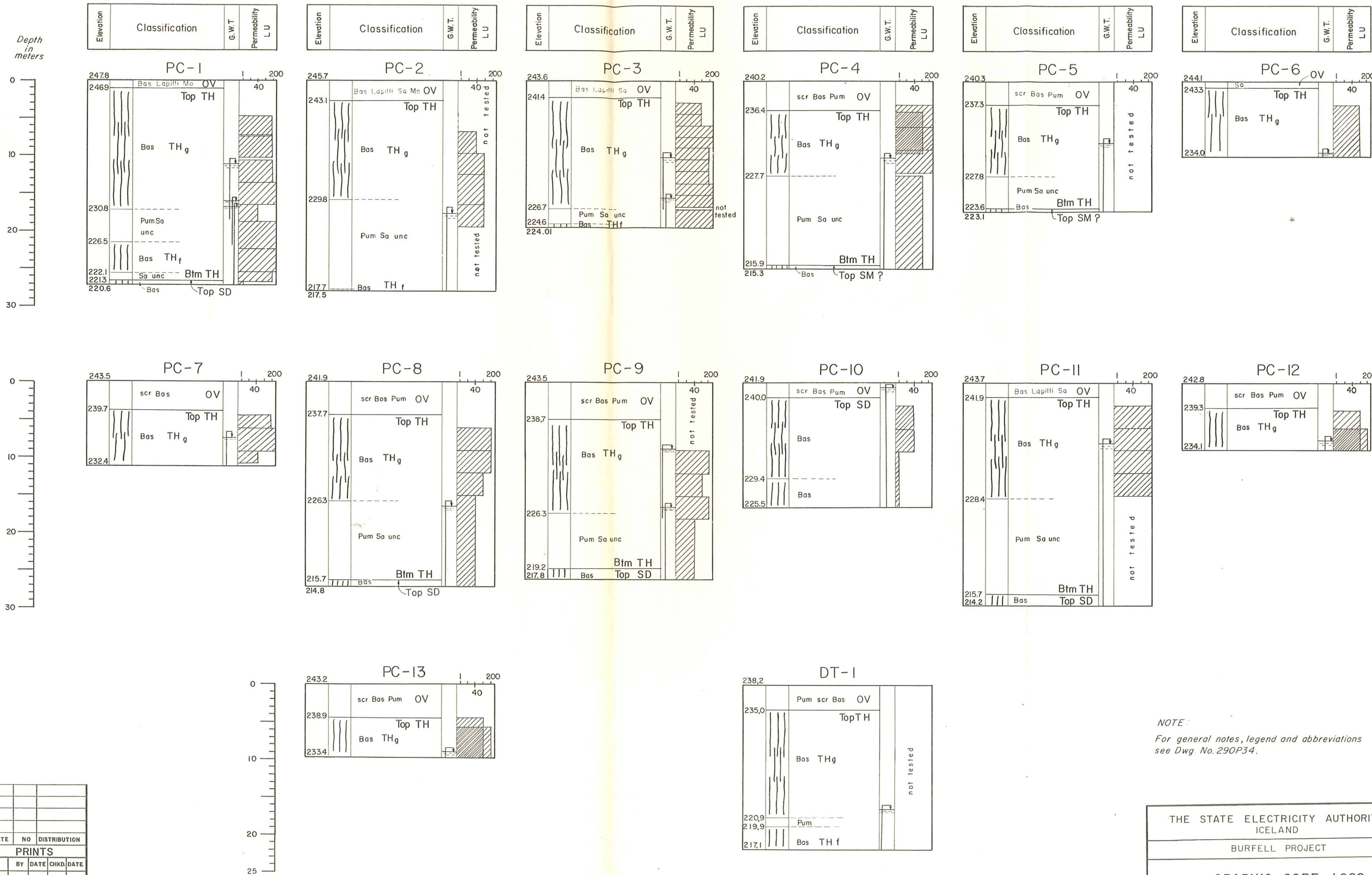
HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE JAN., 1963 | DWG. NO. 290P41

EXHIBIT B-15



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For general notes, legend and abbreviations see Dwg. No. 290P34.

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ICELAND

BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 9 of 10

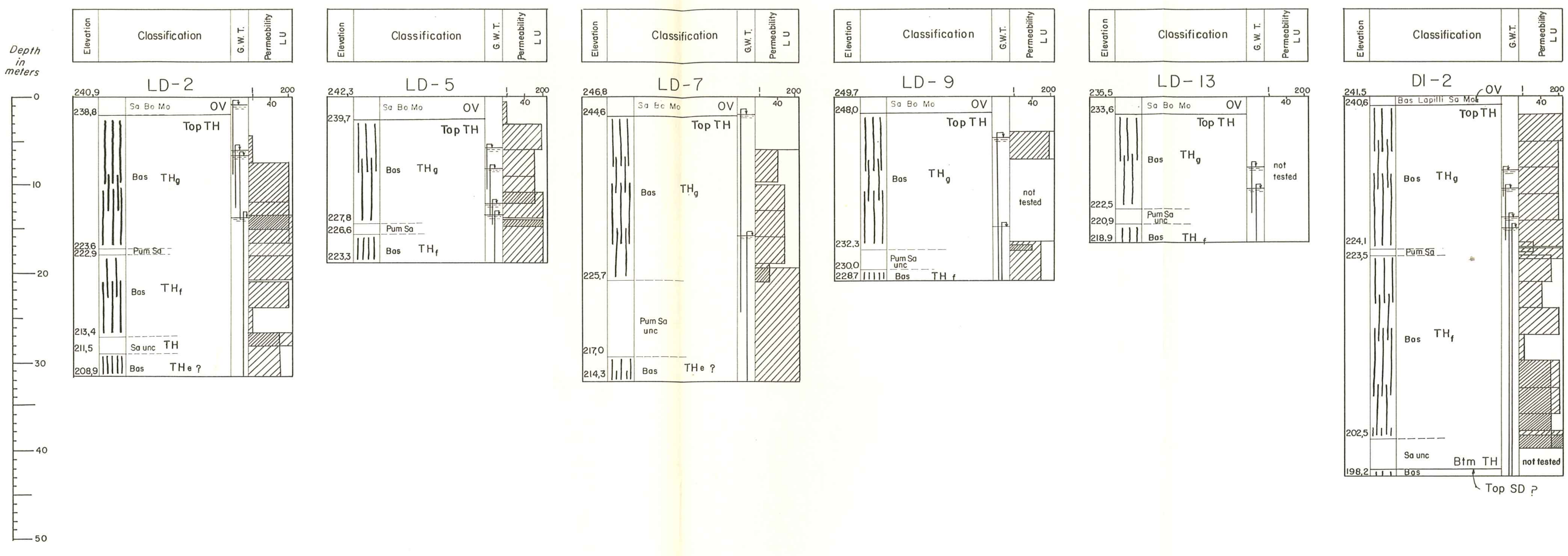
HARZA ENGINEERING COMPANY INTERNATIONAL

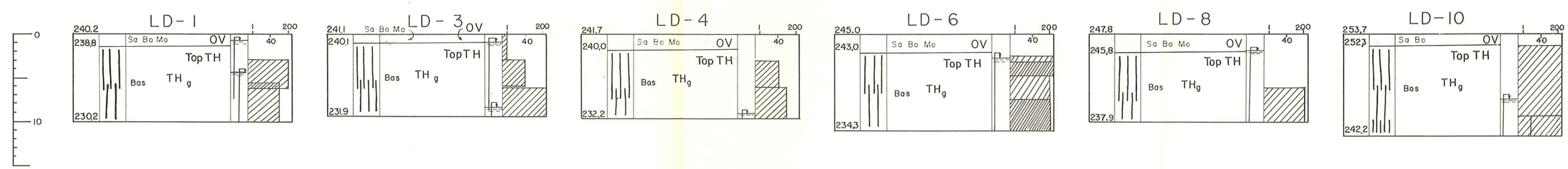
PREPARED BY
HARZA ENGINEERING COMPANY

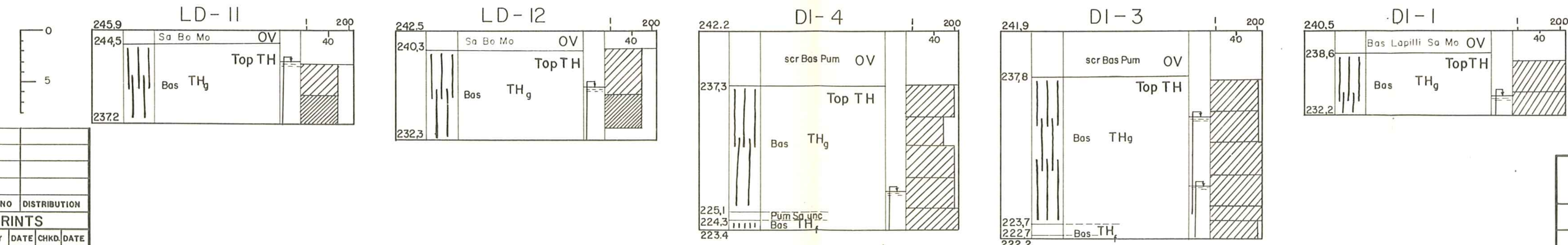
APPROVED: C. K. [signature]

CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG. NO. 290P42

EXHIBIT B-16







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For general notes, legend and abbreviations see Dwg. No. 290P34.

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STAFF CLW			CH.ENGR

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

GRAPHIC CORE LOGS
SHEET 10 of 10

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE JAN. 1963 | DWG.NO 290P43

APPENDIX C

NATURAL CONSTRUCTION MATERIALS

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APPENDIX C

NATURAL CONSTRUCTION MATERIALS

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APPENDIX C

NATURAL CONSTRUCTION MATERIALS

General

The construction of the Burfell Project requires such natural construction materials as coarse and fine aggregates for concrete, sand and gravel for filters, rock shell material, riprap, fine grained impervious core material, and road metal. The availability and quality of these construction materials have an important bearing on Project costs. An extensive reconnaissance was conducted to locate potential sources of each of these materials. This included the location of bedrock exposures suitable for quarry sites, alluvial and glacial sand and gravel deposits, and deposits of soil and glacial moraine. The topographic mapping and regional geologic mapping assisted this reconnaissance greatly. Further, the geologic studies discussed in detail in Appendix B provided much important information as to location, type, nature and general characteristics of potential deposits. Nearness to the site of estimated use was an important consideration.

The first field investigations were accomplished in the summer of 1960 by the Icelandic Engineering firm, ALMENNA, and were concentrated principally on investigations of alluvial deposits as sources of concrete aggregates. Some sampling and a limited amount of testing were accomplished. A development location at the Lower Site, east of Burfell, was under contemplation at that time.

In the summer of 1961, the Harza Engineering Company International (HARZINT) made a reconnaissance with respect to sources of impervious core material for a fill dam at the Lower Site. An excellent deposit of loessy soil was located in the dunes area on the farm, Galtalaekur, a few kilometers south of the mountain, Burfell. Samples were obtained therefrom for testing. With the moving of the proposed dam to a location farther north, this deposit was considered too far removed to be economical, except as a last resort.

Extensive investigations were resumed under the technical direction of HARZINT in the spring and summer of 1962 with specific reference to the selected site of the Burfell Project. These field investigations of natural construction materials were initiated in the immediate vicinity of the Project. The area of investigation was gradually widened until all promising sources of the various types of materials required, lying within a reasonable distance of the construction site, had been examined.

Deposits located by the reconnaissance were then appraised as to type, quantity and quality. Numerous auger holes and test pits were made in promising deposits of unconsolidated materials to permit sampling and determination of depth. When appropriate, each deposit was mapped or cross-sectioned. Selected samples were subjected to standard laboratory tests. Three potential quarry sites out of four investigated were drilled and test blasted. Samples were selected for laboratory tests. The drill core was studied to evaluate the use of required excavation for other appropriate constructions. A few cores were tested. Most of the laboratory testing was accomplished in Iceland. A few tests, hereinafter discussed, were accomplished in the United States.

The various areas investigated are shown in plan on Exhibit C-1. The locations of auger borings, test pits and test blasts are also shown on this Exhibit. The results of laboratory tests made on selected samples are shown on Exhibit C-2. Sufficient quantities of suitable materials to meet all construction needs were found to be available within haul distance of the Project.

Sampling of alluvium and of some deposits of loessy soil was done by means of a rotary auger 45 centimeters in diameter and by hand-dug test pits. Depth of the auger borings averaged about three meters. Auger samples of the cohesionless materials could not be taken from below the watertable. In most of the borings, however, the watertable was not encountered and was often below the adjacent river level. Precautions were taken to prevent contamination of the auger samples by caving of the side walls, and the samples are believed to be reasonably representative of the materials in place. In estimating the volume of alluvial materials available, their depth was considered the same as the average depth of the borings and test pits. It is practically certain that these deposits extend below the assumed depth, and the quantities estimated are therefore conservative.

Four prospective quarry sites were examined. Test blasts were made at Quarry Sites 1, 2, and 4 in order to obtain samples of the fresh rock for testing and to determine the breakage characteristics of the rock. Approximately 50 cubic meters of rock were blasted in each test.

Concrete Aggregates

General

Concrete aggregates may be obtained by processing sand and gravel from alluvial deposits or by crushing excavated bedrock, either from quarries or required excavations. Four alluvial deposits were investigated. Three, F, T, and TH, were west of Burfell and near the Fossa, while the fourth, R, was along the west side of the Thjorsa approximately six kilometers upstream of the diversion structures. The latter deposit appears to be the most desirable. The three deposits near the Fossa and in the Thjorsa downstream therefrom contain more undesirable volcanic ash and scoriaceous constituents than deposit R. Chemical tests indicate the possible presence of alkali reactive minerals. Mortar bar tests will, therefore, be made. It is understood that the Iceland cement plant (Sementsverksmidjan) can produce low alkali pozzolanic cement which may possibly permit the use of aggregate containing alkali reactive minerals.

The four quarry sites, designated Quarries Nos. 1 to 4 inclusive, represent flat-lying exposures not covered by a significant amount of overburden or weak rock. They were laid out to permit easy working by conventional quarry excavation methods. Nearness to the area of probable use was also an important consideration. All four quarries contain dense, hard rock. All except Quarry No. 1 were investigated with respect to their possible use as concrete aggregates by crushing. That quarry was considered too far removed from the concrete structures for most favorable use.

Alluvial Deposits

Materials from Area F appear to be generally suitable for concrete aggregates. Twelve auger borings were made in that Area and a composite sample was taken from each boring. According to the results of the laboratory tests shown on Exhibit C-2, the grain size is generally below 50 millimeters, and approximately three percent passes the No. 200 sieve. A discontinuous cobble layer occurs on the surface, but these materials were not included in the sample. This deposit contains a fairly high percentage of volcanic ejecta including considerable lapilli. The remaining material is almost entirely dark porphyritic basalt. The estimated quantity of material available is 220,000 cubic meters. Borro probings in the area on either side of the Fossa downstream of Area F indicate the channel fill exceeds 25 meters in depth, and the actual quantities available are thus expected to exceed by many times the estimated quantity.

In Area TH, near the confluence of the Fossa and Thjorsa, composite samples were taken from ten borings. Grain-size curves of these materials are almost identical with those of Area F. The TH deposit contains less lapilli, which accounts for the higher unit weight. The chief constituent is fresh, unaltered porphyritic basalt. The quantity available in Area TH, within the limits sampled, exceeds 360,000 cubic meters. Only a small part of this extensive deposit was sampled because melting ice hampered moving the truck-mounted auger.

An extensive sand plain is found along the left bank of the Fossa in the reach below Hjalp. The plain is considered a finiglacial deposit of deltaic origin. Area T includes a part of this plain where high banks of sand are exposed on the left bank of the Fossa. Borehole BH-16 at Trjavidarlaekur encountered 20 meters of sand without penetrating through it, and the entire region west of Burfell and east of the Fossa is probably underlain by this material. The deposit is mainly fine and medium sand with thin gravel horizons. The sand is generally unconsolidated, but a surface layer two to three meters deep may be cemented by bog iron. A composite sample was taken from several localities along the five-to-six-meter-high exposure in the left bank of the Fossa. The coarser fraction and about 25 percent of the material passing the No. 16 sieve are composed of basalt grains, vesicular to pumiceous. The remainder is basaltic glass. This sand was tested for acceptability for blending with crushed aggregates. The volume available exceeds greatly the requirements of the Project.

Area R appears to contain materials somewhat more suitable for concrete aggregate than do the other alluvial deposits. Sixteen auger borings were made initially and fifteen composite samples collected. Three additional surface samples of selected rock fragments suspected of being altered rhyolite and volcanic glass were collected. Later, an additional 25 auger borings were made, extending to the south and west of the deposit. An additional five samples were collected. The rock types represented are mainly grey dense basalt and black vesicular basalt which is derived mainly from the Thjorsa lavas. The materials become increasingly coarse in a downstream direction because of the increasing abundance of cobbles and boulders of vesicular basalt. Loess material is also abundant in a downstream direction. The total of materials in Area R is estimated at 250,000 cubic meters.

All the alluvial materials in the Burfell region must be suspected of containing contaminating materials. Varying amounts of volcanic ash, tuff, and lapilli influence durability of the materials, particularly the finer portions. Altered andesites and rhyolites, volcanic glass, and minerals such as opal and zeolites are also found. These materials often prove to be deleterious. Consequently, extensive laboratory testing was indicated.

Quarry Deposits

The four quarry sites were selected as additional potential sources of aggregate and of rockfill and riprap. Quarry sites 2, 3, and 4 are favorably located as potential sources of crushed aggregates. The location of each prospective quarry in relation to the geologic formations discussed in Appendix B is as follows:

Quarry No.	Formation	Symbol
1	Skeljafells Dolerite	SD
2	Samsstadamuli Group - Flow h	SMh
3	Samsstadamuli Group - Flow h	SMh
4	Samsstadamuli Group - Flow g	SMg

The geology of each formation is discussed in detail in Appendix B. In general, the rocks of the Samsstadamuli Group appear most favorable as crushed concrete aggregates.

Rock from the SMg basalt located on portions of the top of the west end of Samsstadamuli appears, as a result of tests on samples from the test blast, to be acceptable. It is well positioned for production purposes. Similar physical tests on the blasted material from the SMh basalt outcropping on the extreme north end of Skalarfell showed comparable results, but this basalt contains minerals showing potential alkali reactivity. The rock in Quarry No. 3 is identical to that found in Quarry No. 2 and therefore was not tested.

The rock where exposed in all four quarries is characterized by a distinct columnar and horizontal jointing, which separates the rock into hexagonal prisms about 80 centimeters across and 1.5 meters long. Surface exposures are characteristically light grey in color. These rocks form prominent exposures, which afford evidence of their resistance to weathering and frost action. Test blasts were conducted at Quarry Nos. 2 and 4 in order to determine the breakage characteristics of the rock and to obtain samples for testing. Quarry No. 2 contains over 1,000,000 cubic meters solid volume of easily accessible rock, while Quarry No. 4 contains over 2,000,000 cubic meters. The basalt from SMg in Quarry No. 4 is much finer grained and denser than that from any of the other proposed quarries. It is the only rock exposed at the surface among the four quarry sites which does not appear to contain any potentially alkali-reactive minerals.

The SMa basalt in which the underground powerstation is to be located is being tested for possible use as crushed aggregate. This rock is dense and hard, and petrographic analysis indicates that there may be no deleterious reaction with cement alkalis. It is expected to prove suitable.

The rock from Quarry No. 3 is a medium to fine grained doleritic basalt (SMh). This quarry contains in excess of 1,000,000 cubic meters solid measure.

Materials from the above-described potential sources were subjected to laboratory tests, discussed below, to determine their actual and relative suitability in the production of concrete aggregates.

Laboratory Tests

The acceptance of either natural sand and gravel or quarry rock for use as concrete aggregate must be based on the results of standard acceptance tests (American Society of Testing Materials, American Association of State Highway Officials, British Standards, or others). The acceptance or rejection of an aggregate source requires experience and judgment in interpreting the results of the tests. Moreover, the tests do not in themselves always tell how a given material will act as an aggregate in concrete. The actual concrete-making properties of a material are best determined by preparing trial concrete specimens using various aggregate and cement combinations. The laboratory tests do aid, however, in the selection of the more favorable aggregate sources.

The University Research Institute in Reykjavik made all tests on the aggregates with the exception of the Los Angeles abrasion tests, which were made in the United States. The University Research Institute has been requested to make acceptance tests on material from the powerstation excavation area. Lengths of core from drill holes which penetrated the area were submitted for the tests. These samples were given the designation Q-5. To date only the petrographic analysis has been received. The Los Angeles abrasion tests on this material were made in the United States.

The results of the laboratory tests made to date are presented on Exhibit C-2 and are discussed below:

1. Specific Gravity. The chief significance of specific gravity of an aggregate is that high specific gravity tends to indicate a sound and strong aggregate. A low specific gravity does not necessarily call for rejection of an aggregate, but it does serve to warn that additional tests are required before it can be accepted. A bulk specific gravity (surfaces of aggregate particles wetted but intergranular voids not water-saturated) for sand and gravel of 2.60 is often considered the lower limit. As shown by Exhibit C-2, the materials from Area T fell below this figure, materials from Area R were slightly above, and crushed rock from Quarry Nos. 2 and 4 exceed 2.90.

2. Absorption. The absorption test determines the amount of water the aggregate particles will absorb in order to become saturated. Materials with high absorption often lack durability under freezing and thawing conditions. An absorption significantly more than one percent may indicate poor quality, but does not necessarily mean that an aggregate must be rejected. The aggregates of the Burfell region all contain more or less vesicular material and may show high absorption with

inclusions of only relatively minor amounts of such materials. Materials from Area T show an absorption of 4.4 percent, and materials from Area R show an average absorption of 3.1 percent for fine aggregate and 2.3 percent for the coarse aggregate. These results must be related to those of other tests before being considered as an indication of lack of durability. Crushed fine aggregate from Quarry No. 2 has an absorption of 1.07 percent, while that from Quarry No. 4 is 2.38 percent. The absorption of the crushed coarse aggregate from these sites was 2.56 and 2.38 percent, respectively.

3. Organic Impurities. Organic impurities in aggregates from alluvial sources are determined by standard colorimetric tests. Results of these tests on materials from Areas R and T, plotted on Exhibit C-2, indicate that no significant amounts of deleterious organic compounds are present.

4. Magnesium Sulphate Soundness Test. This test provides an index of structural weaknesses that may be present within aggregate particles. Experience shows that there is a relationship between the percentage loss during the magnesium sulphate test and the freezing and thawing resistance of a concrete made with the aggregate. Aggregates are generally considered acceptable if the weighted loss for sand is less than 15 percent and for gravel less than 18 percent, each after five cycles of immersion and drying. The coarse aggregate from Area R and Quarry Nos. 2 and 4 had a maximum loss of less than 4 percent, and both are, therefore, well within the specified limits. Sand from Area R lost only 10 percent. On the other hand, sand from Quarry No. 2 lost 16.5 percent, and sand from Quarry No. 4 lost 13.3 percent. The

former exceeds the specified limit. It is believed that incipient fracturing of the particles was caused by the laboratory jaw crusher and may have contributed to these relatively high losses for both samples.

5. Petrographic Analysis. Petrographic analysis aids in the interpretation of physical and chemical tests of aggregates and may discover characteristics not disclosed by the standard tests. Of particular importance is the detection of minerals having potential deleterious reactivity with the alkalis in cement. The results of chemical methods of detecting potential reactivity are sometimes influenced by extraneous materials, and the more reliable mortar bar test requires considerable time to complete. Consequently, petrographic analysis may be very helpful during the earlier stages of aggregate testing. Alkali-aggregate reactivity results in the formation of silica gels, which in the presence of water increase in volume with resulting cracking and deterioration of the concrete. Known reactive materials include opal, chalcedony, zeolites, glassy to cryptocrystalline rhyolites, and andesites and their tuffs. All of these materials are found in the Burfell region and may therefore be expected to be found in the aggregates.

6. Quick Chemical Test. A preliminary indication of potential alkali-aggregate reactivity can be obtained from this test. Tests were made on materials from Quarry Nos 2 and 4 and Areas R and T. As shown by Exhibit C-2, doleritic rock from Quarry No. 2 and gravel from Area R were found to be potentially reactive. On the other hand, basalt from Quarry No. 4 and sand from Areas R and T were found not potentially reactive.

7. Mortar Bar Test. The quick chemical test indicates only potential reactivity and does not furnish data relative to the amount of expansion to be expected. Consequently, this information must be supplied from the results of the mortar bar test. The University Research Institute has been requested to obtain the equipment required for this test (Potential Alkali Reactivity Mortar Bar Method) on the suspected aggregates. The mortar bar tests are being made with both high and low alkali cements. The low alkali cement will be used to determine if expansions other than those caused by alkali-aggregate reactions occur.

However, even should alkali reactivity be found to occur, it will not necessarily cause rejection of an aggregate source. Experiments by Sementsverksmidjan show that they can produce a cement which effectively prevents reactivity with the Icelandic aggregates which they have tested. It is believed that this cement can be produced at a cost comparable to the cement now being manufactured by them. The mortar bar tests presently being made at the University Research Institute are on materials from alluvial Area R, Quarry No. 4 and rock from the powerstation area.

8. Red Devil Shaker Test. A method of determining the approximate percentage of soft constituents in sands has been developed by the Corps of Engineers, United States Army. This method, designated NPD tentative method of test for soft constituents in fine aggregate (Red Devil Shaker Test Method), is a mechanized version of the manually performed tentative Rub-out Test Method employed by the Corps of Engineers from 1954 to 1960. The Red Devil Shaker Test measures the breakdown of the sand and has the following general significance: (a) 6 percent or more

passing the No. 200 sieve is indicative of soft constituents; (b) 12 percent or more passing the No. 100 sieve is indicative of a tendency to mixer grinding. The sand used by the Corps of Engineers to establish these criteria was not available for check runs with the Burfell sands. Since the results of the test may be influenced significantly by slight variations in the operation of the machine, the results of the Burfell tests can only be used to compare the various Burfell fine aggregate sources one to the other. An attempt was made to use Ottawa sand as a reference, but none of this sand passed the No. 200 sieve after 20 minutes of operation of the shaker machine.

After 12 minutes in the Red Devil Shaker Machine, sands from Areas R and T and crushed sand from Quarry Nos. 2 and 4 were found to have 3, 4, 6, and 10 percent, respectively, passing the No. 200 sieve and 9, 7, 12, and 16 percent, respectively, passing the No. 100 sieve. The high loss in sand from Quarry No. 4 is attributable to the flaky shape produced by the laboratory jaw crusher. Although not usable as a basis for acceptance or rejection of a fine aggregate source, this test indicates that manufactured sand from quarry sites may be less durable than the more rounded natural sands from Areas R and T. On the other hand, the indicated high loss may represent mostly rounding of the sand grains, and the finished product may well be stronger and more durable than the natural sand. This relationship will be developed in the subsequent trial mix tests.

9. Los Angeles Abrasion Test. This test supplies information concerning the hardness and toughness of an aggregate, and gives indications of the breakdown to be expected during production, stockpiling,

handling, and transportation. There is also a definite relationship between the strength of the concrete and the quality of the aggregate as measured by this test. ASTM specifications limit the loss to not over 10 percent after 100 revolutions of the testing machine, or more than 40 percent after 500 revolutions of the machine. As shown by Exhibit C-2, after 500 revolutions of the testing machine, the four samples tested from alluvial Area R, Quarry Nos. 2 and 4 and rock from the powerstation area had a loss which did not exceed 20 percent. These results indicate all the materials tested are adequately durable.

Impervious Fill Materials

General

A surface reconnaissance of the Burfell region found that there are only two types of impervious materials available in the amounts required. They are morainal materials deposited by glaciers and loess soils occurring both in place and in scattered dunes where they have been redeposited by winds. Locations of these deposits are shown on Exhibit C-1.

Morainal Deposits

Only two deposits of morainal material were located in the general area of the Burfell Project. The most favorable deposit, designated IMP-I, fills a valley on the west side of Skalarfell. The exploration adit for the powerstation area was driven through this material. As shown by Exhibit C-2, the material consists of well-compacted till grading from approximately ten centimeters down to one micron in grain size, with about 55 percent falling within the silt and clay range as determined by the U. S. Standard sieves. A few scattered cobbles and boulders were encountered in the exploration adit, but they are not numerous enough to require special handling when placing the material in a fill. Judging from experience gained during driving the exploration adit, light blasting may be required to excavate this material. This deposit has a volume in excess of 1,000,000 cubic meters.

A second morainal deposit, designated IMP-III on Exhibit C-1, is situated on the east bank of the Ytri-Ranga on the slopes above the Rangarbotnar. About 40 percent of the material sampled falls within the silt and clay range,and the remaining material ranged to two centimeters maximum size. The quantities are in excess of those required by the Project. Material from this morainal deposit will supplement the loess from IMP-II for impervious fill in the left bank dike.

Samples from both morainal deposits were tested for specific gravity, grain size, standard and modified compaction, and permeability characteristics. Sample I-2 from deposit IMP-I was tested for triaxial shear. The results of laboratory tests are tabulated on Table C-1.

Loess Deposits

A number of deposits of loess were discovered by the reconnaissance. Many were rejected because of too limited an available volume to permit economic working, or because of too high a volcanic ash content. The latter would result in too light a unit weight and poor workability in the fill. Six deposits which appeared attractive were investigated in some degree of detail. All were located close to the Thjorsa and from one to six kilometers upstream from the proposed river diversion structure. One deposit, IMP-II, is located on the left bank, while the other five, IMP-V to IMP-IX, inclusive, are located on the right bank. These locations generally limit their use as impervious core material to the dikes on their respective sides of the Thjorsa. Their locations are shown on Exhibit C-2.

Each of these six deposits was investigated with either auger borings, test pits, or both. Samples were selected for testing, and the results of the tests are shown on Exhibit C-2.

The tests were liminted to samples from deposits II and VI, each on opposite sides of the Thjorsa. Samples of the loess were each tested for specific gravity, grain size, standard and modified compaction, and permeability characteristics. Tests were conducted on Samples II-1 and II-2 from deposit IMP-II and Sample VI Composite from deposit IMP-VI. The latter composite sample was composed of equal amounts of material from Samples VI-1 through VI-6. Sample II-1 was representative of the loess deposit, IMP-II, without including material from the fifteen-centimeter lapilli and ash cover found on the deposit. Sample II-2 included the lapilli and ash cover, and this fact is reflected in the test results by the lower specific gravity, coarser particle size and lower dry density. Sample II-3 was tested for triaxial shear.

Deposit IMP-II was estimated by measurement to have an approximate volume of 60,000 cubic meters of avilable material. A smaller deposit, located a few hundred meters farther downstream, may have a volume of 10,000 cubic meters. This smaller deposit was not sampled. The IMP-II deposit will provide about one-half of the requirements for the left bank dike.

Deposit IMP-VI was estimated to contain 25,000 cubic meters of usable material which is well located for use in the right bank dikes. Additional impervious fill required for structures located on that bank will probably need to be obtained from the morainal deposit, IMP-I.

The remaining deposits sampled, IMP-V, VII, VIII, and IX, are dunes lying on the right bank adjacent to the Thjorsa and downstream from IMP-VI. They are small deposits, unusually rich in volcanic ash and pumice derived mainly from Hekla. These soils exhibit low unit weights and low plasticity, which along with the beds of volcanic ash and lapilli make them generally unsuitable for use as impervious fill materials.

Laboratory Test Results

The results of the laboratory tests of the impervious fill materials as shown on Exhibit C-2 are summarized on Table C-1.

The tests show the much higher maximum density of the morainal material as compared to the loess. However, the latter is indicated to be workable in the fill over a wider moisture range without appreciable effect on unit weight. The grain size distribution of these same samples is shown graphically on Exhibit C-2.

TABLE C-1

Burfell Project - Impervious Materials Tests

Item	Sample No.				
	IMP I-1	IMP II-1	IMP II-2	IMP III-1	IMP VI Comp.
Type of Material	Moraine	Loess	Loess	Moraine	Loess
Gradation in Percent					
Gravel	15	1	3	18	--
Sand	28	43	31	44	47
Silt	52	52	61	34	49
Clay	5	4	5	4	4
Sp. Gravity:					
1	3.01 (a)	2.64 (a)	2.79 (c)	3.01 (c)	2.84 (c)
2	--	--	1.89 (d)	2.98 (e)	2.52 (d)
3	2.86 (b)	1.01 (b)	--	--	--
Composite	2.98	2.60	2.71	2.96	2.82
Permeability at 20°C Centimeters/second	2.2×10^{-6}	3.0×10^{-5}	3.9×10^{-5}	2.5×10^{-6}	2.2×10^{-5}
Compaction					
Optimum Moisture - Percent	10	23	20	17	22
Max. Dry Density					
Lbs/cu. ft.	136	93	88	115.5	96
Kg/m^3	2180	1490	1410	1850	1540

(a) Material passing No. 80 sieve
(b) Material retained on No. 4 sieve
(c) Material passing No. 40 sieve
(d) Material retained on No. 40 sieve
(e) Material retained on No. 40 sieve but passing No. 4 sieve

The results of the triaxial tests for the morainal material in deposit IMP-I and for the loess in deposit IMP-II are shown graphically in Mohr circle form and in tabular form on Exhibit C-2.

Filter Materials

All alluvial deposits investigated for concrete aggregate contain materials suitable for use as filters. Mechanical processing will be required in order to obtain the proper size gradation. Area R probably contains enough suitable filter material to satisfy all requirements for structures on the right bank. Supplementary fine-grained filter materials, if required, can be obtained in practically unlimited quantities from Area T. Additional coarser filter materials are available from either Areas F or TH.

There appear to be no workable deposits of gravel on the left bank of the Thjorsa for use as filters in the left bank dike. The materials required might possibly be obtained by screening finer portions of the Thjorsa lava surface rubble. It would probably be more economical, however, to transport the required materials from alluvial deposits on the opposite bank, or to crush them from either the Thjorsa or Hekla lavas. All requirements for filter material for both sides of the river could be manufactured from quarry deposits.

Rockfill and Riprap

The shells for the dikes located west of the Thjorsa are planned to be constructed of suitable rock from the excavation required for the concrete diversion structures, outlet canal, intake canal, and sluiceway. The quantity is believed sufficient. Any deficiencies would be offset by a northward enlargement of the diversion canal or from quarries in the older basalt to the west.

Quarry Nos. 1, 2, and 3 are located favorably to supplement the material obtained from the above excavations. Quarry No. 1 is on the right bank of the proposed diversion canal. The rock is gray dolerite. It is jointed into columns averaging about a meter across and jointed transversely at about 1.5 meters. A test blast showed breakage to be excellent, except when blast holes were placed directly between columns. The quantity available far exceeds the requirements needed for the dikes.

Quarry No. 2 is situated on the north side of Burfell just above the termination of the proposed Bjarnalaekur dike. Quarry No. 3 is directly across Bjarnalaekjabotnar from Quarry No. 1. The rock at both of these sites is texturally similar to that found at Quarry No. 1. A test blast at Quarry No. 2 site showed breakage to be excellent. Quarry Nos. 2 and 3 each have an excess of 1,000,000 cubic meters of readily available rock. Aggregate-acceptability tests on rock from Quarry No. 2 indicate that the basalts are tough and durable.

Rock shell material and riprap required for the left bank dike can be quarried from either the Thjorsa or Hekla.lavas. Either source will be entirely satisfactory. However, some portion of the slabby surface may be unsuitable and will need to be spoiled.

In general, any required riprap, such as for the river cofferdams would be select rock from the excavations.

Road Metal

Road metal of suitable quality is abundant almost everywhere in the Burfell area. The alluvial deposits referred to above can be used by proper blending. The scoriaceous surface of lava flows, almost everywhere abundant, can be easily worked into a suitable road surface.

Summary

Extensive field investigations and laboratory tests indicate that sufficient quantities of natural construction materials suitable for all construction needs are available within the immediate vicinity of the Burfell Project. Concrete aggregates may be manufactured from rock excavated from the powerstation and supplemented by quarried basalt or alluvial deposits, if required. Filter and pervious fill materials are available from alluvial deposits and may also be quarried from selected basalt flows. Impervious fill may be obtained from loess and morainal deposits. Rockfill will be obtained from required excavations or quarries.

THE EXHIBITS

C-1 Location of Construction Materials
C-2 Construction Materials Test Results

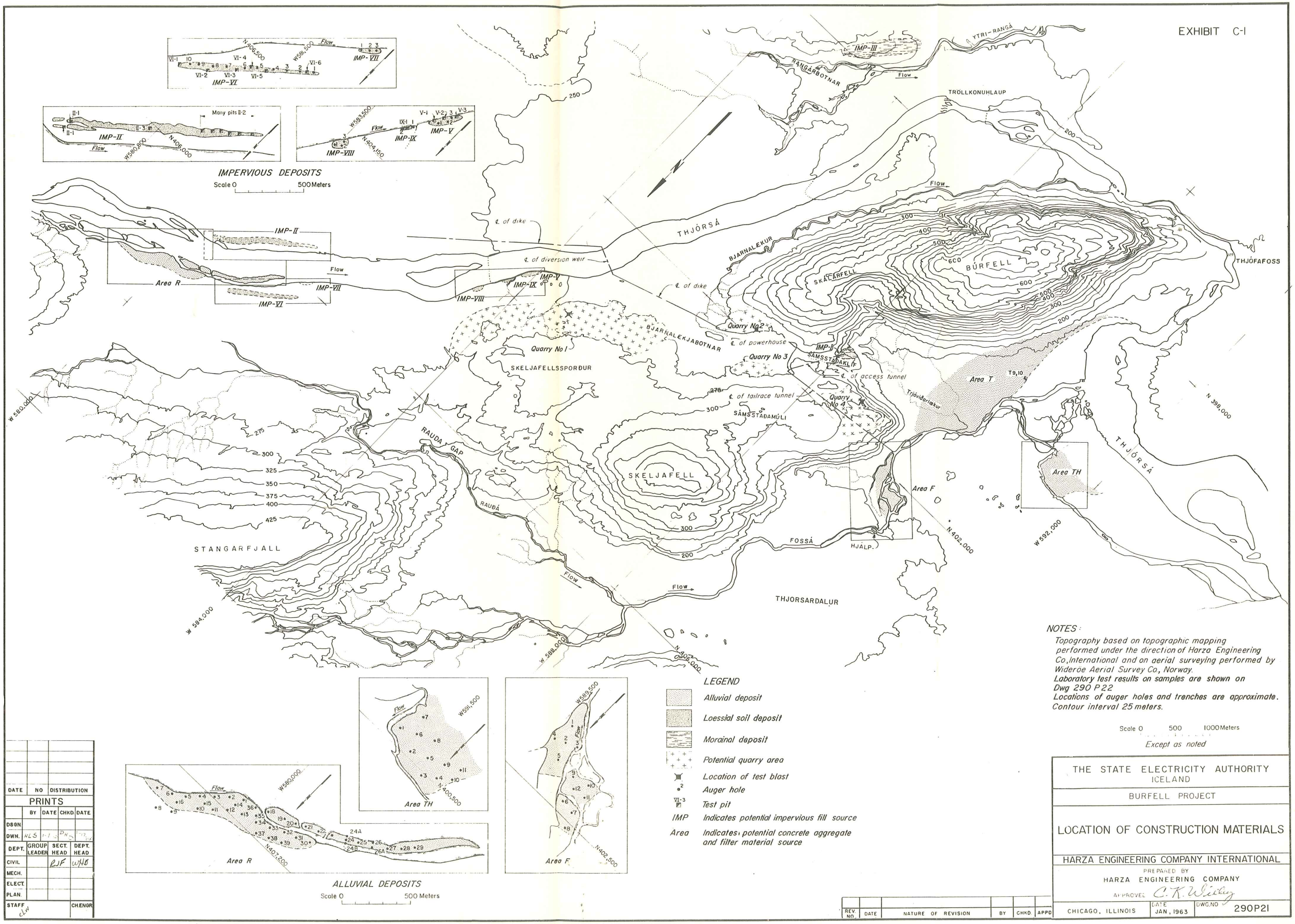
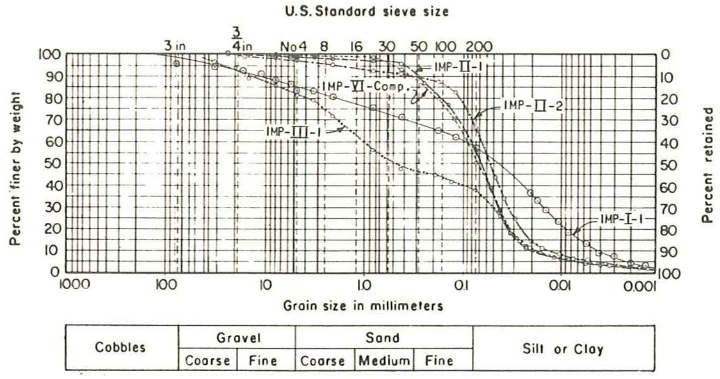
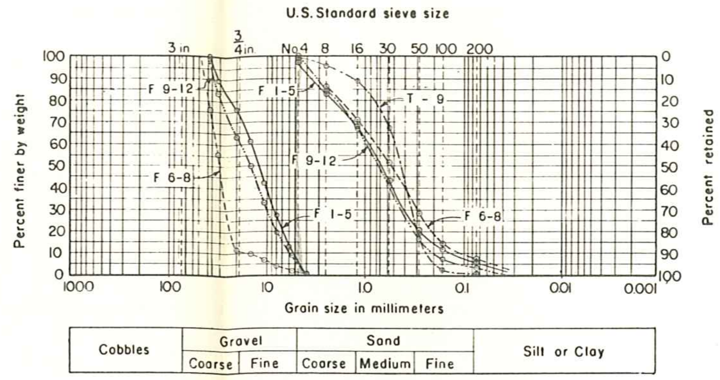
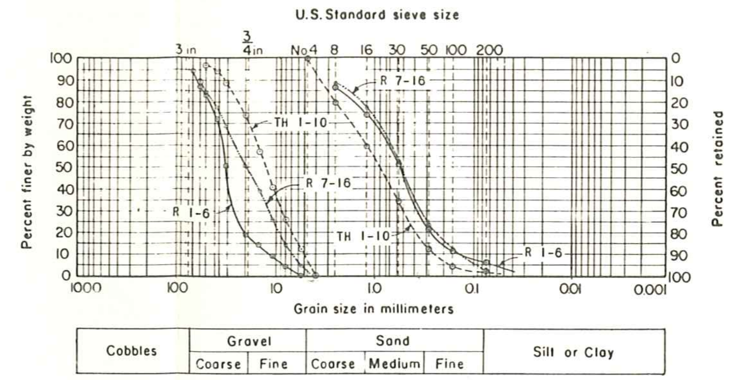


EXHIBIT C-I
IMPERVIOUS DEPOSITS
Scale 0 500 Meters
IMP-VI
IMP-VII
IMP-II
Many pits II-2
IMP-VIII
IMP-IX
IMP-V
IMP-III
Flow
YTRI-RANGÁ
RANGÁRBOTNAR
TROLLKONUHLAUP
THJÓRSÁ
BJARNALÆKUR
BÚRFELL
SKÁLARFELL
THJÓFAFOSS
℄ of dike
℄ of diversion weir
Area R
Quarry No 1
Quarry No 2
Quarry No 3
Quarry No 4
BJARNALÆKJABOTNAR
℄ of powerhouse
SÁMSSTAÐAKLIF
℄ of access tunnel
℄ of tailrace tunnel
SKELJAFELLSSPORÐUR
SÁMSSTAÐAMÚLI
Area T
Area TH
Area F
RAUÐÁ GAP
RAUÐÁ
SKELJAFELL
STANGARFJALL
FOSSÁ
HJÁLP
THJORSARDALUR
NOTES:
Topography based on topographic mapping performed under the direction of Harza Engineering Co, International and on aerial surveying performed by Wideröe Aerial Survey Co, Norway.
Laboratory test results on samples are shown on Dwg 290 P 22
Locations of auger holes and trenches are approximate.
Contour interval 25 meters.
Scale 0 500 1000 Meters
Except as noted
LEGEND
Alluvial deposit
Loessial soil deposit
Morainal deposit
Potential quarry area
Location of test blast
Auger hole
Test pit
IMP Indicates potential impervious fill source
Area Indicates potential concrete aggregate and filter material source
ALLUVIAL DEPOSITS
Scale 0 500 Meters
THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT
LOCATION OF CONSTRUCTION MATERIALS
HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey
CHICAGO, ILLINOIS
DATE JAN, 1963
DWG. NO 290P21
PRINTS
DATE NO DISTRIBUTION
REV NO DATE NATURE OF REVISION BY CHKD APPD

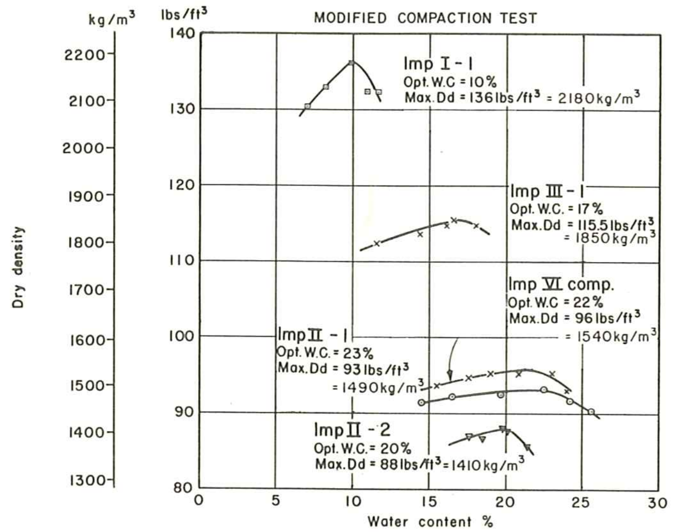
EXHIBIT C-2



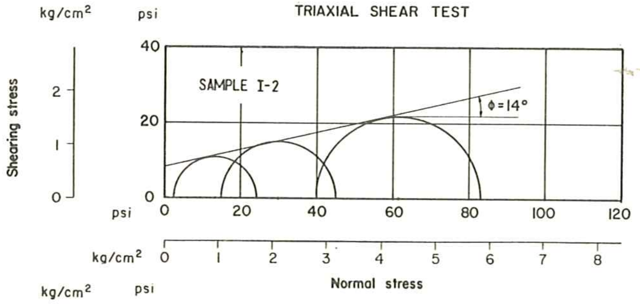


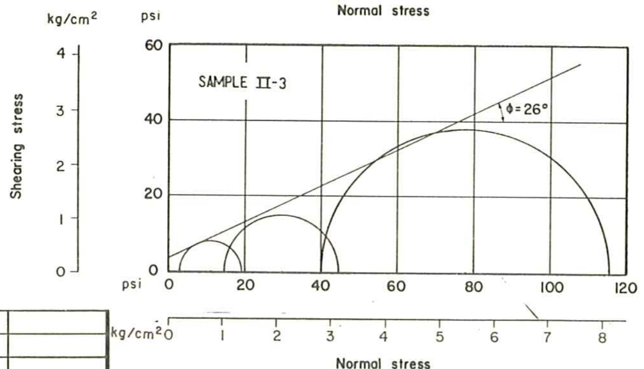


MODIFIED COMPACTION TEST



TRIAXIAL SHEAR TEST



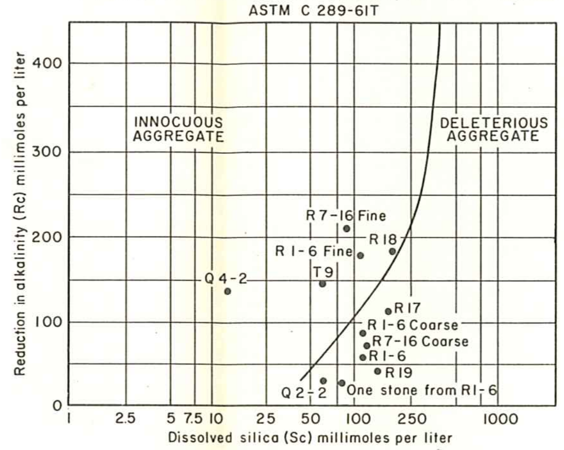


TRIAXIAL SHEAR DATA

	Major principal stress		Minor principal stress		Dry density		% Water content
	psi	kg/cm²	psi	kg/cm²	pcf	kg/m³	
Sample I-2							
Circle 1	24.5	1.72	3.0	0.21	136.0	2180	11.0
Circle 2	45.0	3.16	15.0	1.06	138.0	2210	11.0
Circle 3	83.0	5.83	40.0	2.81	134.4	2160	11.0
Sample II-3							
Circle 1	19.5	1.37	3.0	0.21	89.2	1430	24.0
Circle 2	44.6	3.14	15.0	1.05	94.2	1510	24.0
Circle 3	115.5	8.19	40.0	2.81	92.1	1480	24.0

IMPERVIOUS MATERIALS TESTS

POTENTIAL REACTIVITY OF AGGREGATES, CHEMICAL METHOD
ASTM C 289-61T



MAGNESIUM SULFATE SOUNDNESS TEST (ASTM 88-61T) % LOSS IN WEIGHT			BULK SPECIFIC GRAVITY SATURATED SURFACE DRY BASIS	% ABSORPTION
SAMPLE	TEST RESULTS	ASTM LIMIT		
T-9 (Fine)	21.9	15.0 max.		
R-1-6 (Fine)	10.2	15.0 max.		
R-1-6 (Coarse)	3.4	18.0 max.		
Q-2-2 (Fine)	16.5 *	15.0 max.	2.98	1.07
Q-2-2 (Coarse)	9.7	18.0 max.	2.89	2.56
Q-4-2 (Fine)	13.3	15.0 max.	2.90	2.38
Q-4-2 (Coarse)	1.3	18.0 max.	2.92	2.39

* High loss believed attributble to flaky particle shape produced in the laboratory jaw crusher

SAMPLE	FINENESS MODULUS	COLORIMETRIC	BULK SPECIFIC GRAVITY SATURATED SURFACE DRY BASIS	% ABSORPTION
R 1 - 6 (Fine)	2.58/2.50	Plate 0.5	2.68	3.28
R 7-16 (Fine)	2.48	Plate 1.0	2.66	3.00
T 9 (Fine)	2.29	Plate 0	2.34	4.40
R 1 - 6 (Coarse)			2.63	2.14
R 7-16 (Coarse)			2.61	2.31

LOS ANGELES ABRASION TEST
ASTM C-131

SAMPLE	% LOSS IN WEIGHT - 500 CYCLES TEST RESULTS	ASTM LIMIT
R 1 - 16 Comp	19.9	50.0
Q 2 - 3	16.3	50.0
Q 4 - 4	13.4	50.0
Q 5 - 1	9.9	50.0

COLORIMETRIC CHART
ASTM DESIGNATION C 40-45

PLATE 1	Sands suitable for use in high grade concrete
PLATE 2	Sands which may be used in unimportant concrete work
PLATE 3	Sands which should never be used in concrete
PLATE 4	An unusually bad sand, soil or loam
PLATE 5	

Chart shows suggested ranges of application of sands for concrete which contain organic impurities

CONCRETE AGGREGATES TESTS

ABBREVIATIONS

Opt. W.C.	*Optimum water content*
Max. Dd.	*Maximum dry density*
W.C.	*Water content*
IMP I-2	*Refers to impervious fill source (I) and the sample tested (2)*
F 9-12, RI-6, T-9, TH I-10	*Refer to alluvial deposits and the sample or samples tested*
Q2-3	*Refers to quarry site (2) and sample tested (3)*
Comp	*Composite sample*

NOTES:

For location of samples see Dwg. No. 290 P 21

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

CONSTRUCTION MATERIALS
TEST RESULTS

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C.K. Willey

CHICAGO, ILLINOIS	DATE JAN., 1963	DWG. NO	290P22

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD

DATE	NO	DISTRIBUTION	
PRINTS			
	BY	DATE	CHKD. DATE
DSGN.	WGD	1-3-63	
DWN.	W.H.	1-7-63	DHD 1-19-63
DEPT.	GROUP LEADER	SECT. HEAD	DEPT. HEAD
CIVIL		RJF	WHB
MECH.			
ELECT.			
PLAN.			
STAFF			CH. ENGR.

APPENDIX D

THORISVATN INITIAL STORAGE

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APPENDIX D

THORISVATN INITIAL STORAGE

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EXHIBITS

D-1 Topography and Exploration for Thorisvatn Initial Storage Development

D-2 Thorisvatn Initial Storage, Section A-A, Profile Along Outlet Canal

D-3 Thorisvatn Outlet Works

D-4 Cost Estimates, Thorisvatn Outlet Works

APPENDIX D

THORISVATN INITIAL STORAGE

Introduction

The large natural lake, Thorisvatn, represents what is almost certainly the most attractive possibility for seasonal storage development in the Thjorsa Basin. Adequate natural volume is available to permit seasonal or holdover storage of its own controllable inflow and the flow of the Kaldakvisl by diversion of that stream into the lake. Stored waters may then be released to aid in control of the amount of flow available for power production at downstream power plants. Normally, when associated with power development, releases are accomplished to increase low flows at the powerstations and firm up their energy production. Releases may also be made for other beneficial purposes associated with powerstations such as ice or silt sluicing.

Thorisvatn has been under engineering study as a storage development for several years. Studies by the State Electricity Authority (SEA) began in about 1958, and have extended to the present. The Harza Engineering Company International (HARZINT) has provided consulting engineering services thereon since 1959.

These studies have revealed that Thorisvatn may be developed in either of two principal ways. One would be a relatively small development accomplished by withdrawing the naturally stored waters on a seasonal basis, with refill accomplished in subsequent periods of little or no demand. The refill would be accomplished by the difference between natural inflow and losses via natural surface and underground outlets. The second plan of development would involve the diversion of the Kaldakvisl into Thorisvatn. This plan would permit almost complete control of the sum of Kaldakvisl and Thorisos flows. The latter river represents the present outlet for most of the natural inflow into the lake. The remainder of the inflow discharges through underground routes through the ridge to the west. This last outflow is probably not feasible to control, but it does contribute to Kaldakvisl flows downstream.

Either plan of development would utilize primarily only the natural lake volume below its present level of about 571 meters. In addition, there may be some ground storage available, especially within the porous formations to the east. This possible supplemental volume is not very feasible to estimate. Operation of a completed project could give some determination of the quantity thereof. An increase of a few meters in the normal maximum controlled lake level, with the large development only, appears technically but not economically feasible. The larger plan has been under study through the period of investigations. These studies are continuing,and an appraisal study is currently in preparation. The smaller development was first considered in connection with the appraisal studies on the Burfell Project. The results of these brief studies were presented in the Report, dated March 1962, by HARZINT.

The early 1962 studies of Thorisvatn were aimed to present a possible economic means of providing a relatively small amount of storage to firm the energy production of the Burfell Project appraised in the March Report. After the Burfell Project moved into the project planning stage, as presented in Volume I of this Report, a detailed hydrology study was made of the Thjorsa.

These hydrologic analyses, discussed in Appendix A, revealed that the low flows of the Thjorsa occurring in the 15-year historic period at Burfell were by no means as severe as considered in the earlier study. The 180,000-kilowatt initial development at Burfell, as proposed in Volume I, required a plant best gate flow of 174 cubic meters per second. This flow was determined to be available for 91 percent of the time. The deficiencies during the remaining nine percent of the time would represent a much smaller deficiency in energy production than thought from the earlier 1962 studies. This deficiency could be offset by load curtailment or, in part, by energy from other System sources. It was concluded that an initial small development at Thorisvatn (or elsewhere) could not be justified economically to firm the flow at Burfell and assure a fully continuous primary energy supply from that power-station. However, some stored water might be required for other purposes.

The planning of the Project revealed that some flows might be required at the river diversion works to aid in the sluicing of ice and possibly, to a minor extent, silt also. The requirement for these supplemental flows, if any, has not been established. The low nine percent of the flows occur entirely in the winter and are normally associated with severe frost periods which contribute also to ice production in the Thjorsa. In general then, the most severe ice problems may possibly occur at the time of lowest flows.

An initial storage development at Thorisvatn represents the most economical means of providing any required supplemental water for aiding in the control of ice problems at the Burfell Project. This appendix represents a plan of such an initial storage development at Thorisvatn, together with an estimate of the capital thereof.

Site Description

Location and Access

The location of Thorisvatn in relation to the Burfell Project is shown on Exhibit D-1. It is conveniently located between the Tungnaa and its principal tributary, the Kaldakvisl. The Tungnaa is a left bank tributary to the Thjorsa, flowing in a westerly direction and joining the Thjorsa about 15 kilometers upstream of the Burfell Diversion Site. The Kaldakvisl, flowing in a southwesterly direction parallel to the Upper Thjorsa, joins the Tungnaa about 15 kilometers upstream of its confluence with the Thjorsa. Thorisvatn is about five kilometers north of the Tungnaa and about three kilometers south of the Kaldakvisl. The south end of the lake is about thirty kilometers east-northeast of the Burfell Project.

The general area is undeveloped and uninhabited. The lake is accessible over a trail in the favorable summer season. None of the rivers are bridged,but each can be forded at several locations when not in flood. An extisting airstrip west of the lake could be improved or relocated to be suitable for light planes.

Topographic Setting

Thorisvatn is the second largest natural lake in Iceland, with a surface area of about 70 square kilometers at its normal level of 571 meters. The lake is over 100 meters deep over large areas and has a total volume of water estimated at 3000 million cubic meters. Its principal surface outlet is via the Thorisos, a seven-kilometer-long, low gradient river, extending from the lake westerly to the Kaldakvisl. Most of the drainage area is represented by the permeable, gently sloping lava plain to the east. A small portion is represented by the slopes of ridges to the west and south.

A ridge to the west of the lake separates it from the lower reaches of the Kaldakvisl. A second ridge to the south, dominated by the mountain, Vatnsfell, separates the lake from the middle reach of the Tungnaa. There are several low saddles within these ridges which tend to limit any feasible increases in lake levels for storage purposes. Such increases are also limited for an initial small storage development by geologic considerations, hereinafter discussed, particularly at the present natural outlet. Accordingly, utilization of storage in Thorisvatn, either in the initial or ultimate stages presented above, must be accomplished principally by drawdown below present levels.

Low saddles in the ridges to the south and east present potential release routes for a small initial storage utilization. Release would be accomplished by canals, tunnels, or a combination of the two, each incorporating a control works. The saddle east of Vatnsfell is at elevation 600 and separates Thorisvatn from a relatively large undrained depression to the south. A route via this saddle was not considered feasible economically because of its height and the length of water conductors required. Either of the two lowest saddles in the ridge to the west appears more attractive as a releast route.

The most northerly of these two saddles is at elevation 585 and is located about six kilometers southwest of the existing outlet to the Thorisos. The discharge route would be via the Rjupnadalur to the Kaldakvisl. Development along this route is not favored because it has the disadvantage of preventing use of the storage waters in the planned Tungnaarkrokur and Hrauneyjafoss Projects on the Tungnaa. A route through the other low saddle would permit this utilization.

The favored low saddle is located at the northwestern foot of Vatnsfell, and at the extreme southwest corner of Thorisvatn. The height of the saddle is at 580 meters. Detailed field investigations were conducted in the summer and fall of 1962 along the route. The results of the studies for development along this route are presented in this Appendix.

Geology

The geology of the Thorisvatn area bears importantly on the engineering of the development of that lake for regulated storage use. The general geology of the Thjorsa Basin is discussed in Appendix B. The detailed engineering geology of the Thorisvatn area is discussed in detail in a report by Gudmundur Kjartansson to the SEA, dated August 1959. Important geologic observations and interpretations presented in the Kjartansson report are summarized below. The general geologic relationships have been verified by HARZINT reconnaissance.

The depression occupied by Thorisvatn can be explained by: (1) glacial erosion, (2) tectonic subsidence, (3) building up of the surrounding hills by subglacial volcanism, or (4) any combination of the first three. The latter is most probable. Post-glacial lava-flows developed the original depression into its present form.

The surface drainage outlet in post-glacial times has always been in the same place or northward to the Kaldakvisl via the Thorisos. One, and possibly two, post-glacial lava flows, of the Thjorsa lava type, partially dammed the outlet and raised the lake level to approximately its present level. The lava flow forced the Thorisos to the western edge of the lava sheet. It may be that more recent downcutting by the outlet river has lowered the normal level of the lake by about a meter or so. The post-glacial lavas cover large areas of the drainage basin to the east. It is everywhere highly permeable, and most of both the inflow and outflow of the lake is by underground routes within these lavas.

Thorisvatn and its drainage basin lie within rocks of the Palagonite-Tuff Series predominately. The contact with the Grey Basalts lies generally along the Kaldakvisl a short distance to the northwest of Thorisvatn. The bedrock from Thorisos for about six kilometers to the southwest is a moderately impermeable basalt, possibly belonging to the Grey Basalts. Glacial moraine overlies large areas of the bedrock west of Thorisvatn and may, in places, underlie the post-glacial lavas and pyroclastics which cover most of the drainage basin. The permeable Palagonite rocks which form the retaining ridges to the south and west permit substantial subsurface water losses from the lake, particularly to the west.

The development of a natural lake for storage utilization requires, in part, considerations of controlling the natural outflow. The general overall permeability of the Palagonite rocks in the ridge to the west precludes any serious consideration of reducing leakage in that direction by subsurface treatment. Most of the Thorisos outflow is also by subsurface routes. The extent and permeability of the lava dam at the head of the Thorisos would require extensive and expensive engineering works to control a reasonable percentage of the outflow of that river for a relatively small initial controlled storage. This fact has been well established at other developments with similar problems, such as at Guijá in El Salvador. Accordingly, any control of natural outflow at Thorisvatn for a small initial storage development was abandoned.

The detailed geology of the outlet area proposed herein for the Thorisvatn outlet works was not dicussed in detail by Kjartansson in his report. The bedrock of the vicinity consists of rocks of the Palagonite-Tuff Series overlain, in part, by moraine and alluvium. Detailed field investigations were accomplished to determine the interrelation between these materials.

Field Investigations

The field investigations for the outlet works proposed for the development of initial storage at Thorisvatn consisted of topographic mapping, Borro soundings, a diamond core boring, and a single hand-excavated test pit. The proposed plan consists of a canal with a concrete control works near the downstream end. An undrained depression occurs farther downstream at about elevation 510 meters. Preliminary reconnaissance indicated that water released from Thorisvatn by this general route might drain from this depression to either the Kaldakvisl or the Tungnaa, with the latter route desired.

The topographic mapping, shown on Exhibit D-1, covered the general area of the proposed canal and diversion works as well as that of the depression referred to above. The topography was obtained by terrestrial methods on a scale of 1:2000, with one-meter contours. All of this area, as well as the entire area around Thorisvatn, had been covered by topography at a scale of 1:20,000 with a five-meter contour interval accomplished by aerial survey methods. In addition, a hydrographic survey based on five-meter contours had been accomplished for Thorisvatn and was used for determining reservoir area-volume relationships.

The reconnaissance and the large-scale topography showed that the area encompassing the proposed outlet works was relatively low and flat, with few bedrock exposures except in the vicinity of the proposed control structure. The bedrock is covered by alluvial and glacial materials. Accordingly, the depth to bedrock or to hard moraine was determined by a number of Borro soundings. The location of these soundings is shown in plan on Exhibit D-1. The results of these soundings were used to establish the bedrock profile along the center-line of the proposed structures as shown on Exhibit D-2. Sound rock (or hard moraine) is shown to be overlain by a considerable thickness of relatively loose alluvial ancient and recent shoreline materials, possibly including some wind-deposited pyroclastics. These materials represent easily removable "common" excavation not requiring systematic drilling and blasting.

These soundings together with bedrock surface exposures developed the most favorable location for the control structure. One diamond core boring was drilled at this site. The boring showed the bedrock to be somewhat broken pillow lava, suitable in bearing strength to carry the load of the proposed control structure. Some cut-off grouting would be required under and beyond the structure. Several Borro soundings, shown in plan on Exhibit D-1, were also made in the low saddles separating the depression at about elevation 510 from the Kaldakvisl drainage. These soundings showed high bedrock levels in the two low saddles.

The alluvial deposits within the present and older lake shore will provide suitable sand for concrete fine aggregate. They may also contain suitable gravel for coarse aggregate. However, the estimates are based on crushed coarse aggregates.

Hydrology

The controllable inflows to a storage reservoir taken in consideration with the available storage volume determine largely the effectiveness of that reservoir for the regulation of flows downstream. The studies showed that, with a small initial storage reservoir, it was not feasible economically to either reduce known leakage through the ridge to the west or to control the outflow via the Thorisos. Withdrawals from storage can be controlled accurately at the proposed control works. However, these controlled releases will lower the lake level and thus reduce both surface and underground natural outflow by effective head reduction. Flows downstream will suffer a corresponding reduction, which must be offset by an equating additional release at the control works. Conversely, the refill of vacant storage can be accomplished only by the net differential between inflow and total outflow. This net will decrease to zero as the reservoir returns to the full stage. Reservoir refill may involve a period of months.

The natural inflow-outflow relationships of Thorisvatn are not known exactly. The flows which appear in Tjaldkvisl, Utkvisl, Blaritakvisl, and a few other brooks almost certainly represent principally leakage from Thorisvatn through the ridge to the west. This leakage, which is fairly constant, was estimated by Kjartansson to be between seven and ten cubic meters per second. It all reaches the Kaldakvisl. There may be other unknown leakage from Thorisvatn, including some southward to the Tungnaa. The lowering of Thorisvatn seasonally by only a few meters may reduce this leakage only slightly.

A lowering by twenty meters or so with ultimate storage development may result in substantial leakage reduction, but is not under consideration herein.

Inasmuch as the contributing drainage area to Thorisvatn is known to be highly permeable, nearly all of the inflow is from underground sources which cannot be measured. The highly permeable post-glacial lavas and pyroclastics which cover a large area to the east of Thorisvatn tend to mask the underlying Palagonite bedrock. Thus, the actual drainage area for hydrologic purposes may not be the same as the topographic drainage area.

The natural outflow of Thorisvatn which will have the most effect on utilization of Thorisvatn as an initial storage reservoir is that of Thorisos. The hydrology of this river has been discussed in Appendix A. The estimated average annual flow of the recent four-year period of record was 15.6 cubic meters per second. The corresponding average flows for the past fifteen years and for the critical water year of 1950-1951 were 15.8 and 13.6 cubic meters per second, respectively. The latter two represent estimates based, in part, on correlation procedures which may not be very reliable.

The measurements for the recent four-year period of record, however, were made at the Vad gage. It is known that most of the recorded flow reaches the Thorisos by underground routes. The surface outflow of Thorisvatn at the lake outlet has been estimated roughly at about six cubic meters per second. Some of this may enter the groundwater before reappearing in the Thorisos. The total groundwater which enters the Thorisos upstream of the gage may include some contribution from the lava plain to the east in addition to contributions from Thorisvatn. Conversely, there may be some groundwater from Thorisvatn which bypasses the gage through the narrow belt of permeable, post-glacial lavas to the east. It is considered that these relative gains and losses may be offsetting. Therefore, measurements at Vad should represent fairly accurately the outflow of Thorisvatn via Thorisos.

Thorisvatn tends to reregulate its inflow somewhat by small changes in stage. This effect was considered in establishing Thorisvatn usable inflow from the dicharge records at Vad as presented in Appendix A. The effect of lake stage on Vad discharge is shown on Exhibit A-22 of Appendix A for a very small range in stage in the vicinity of the normal level of about elevation 571 meters. This record shows a change in discharge amounting to about 1.9 cubic meters per second per each one-tenth meter change in stage. It also shows that the Thorisos outflow is about 11 cubic meters per second for a lake stage of 571.0. The flow records also show that the stage would most likely be within one or two tenths of a meter of elevation 571 whenever winter releases were desired downstream.

Subsequent lowering of the lake by storage releases would decrease the outflow via Thorisos. Inasmuch as the permeable lava dam at the head of Thorisos may extend down as far as about elevation 550 meters, some outflow would occur within all probable lake stages of reservoir operation for initial storage operation. The rate of decrease would almost certainly become less as the lake is lowered. The surface outflow would probably cease before elevation 570 was reached.

Extrapolation of the effect in the vicinity of elevation 571 would indicate that outflow would cease at about elevation 570.4, which is not considered possible. Most likely, the outflow would reduce to about five cubic meters at lake elevation 570, then decrease slowly as the lake elevation is lowered even farther. Thus, there would be no problem with respect to storage releases. Stage information from Vad, and possibly also from a gage on Tjaldkvisl, received by Telemark at the Burfell powerstation would provide the required data with respect to increases in the controlled discharge rate to offset losses in natural flow available at Burfell because of lower Thorisvatn levels.

The principal effect of the uncontrolled outflow will be with respect to reservoir refill. The uncontrolled flow of the Thorisos will not be available for refill purposes. This will probably not represent any serious problem except for the refill of the last meter of storage up to about elevation 571 as the outflow rate approaches the usable inflow rate. On the other hand, the usable inflow rate during the usual spring refill months subsequent to March almost always exceeds 20 cubic meters per second, and is always in excess of 11 cubic meters per second through about October. Any refill problems should be minor with a relatively small initial storage.

It is considered herein that the development of any relatively small initial storage at Thorisvatn, if constructed, would be primarily for ice control at the Burfell diversion works. However, any controlled storage would almost certainly be useful for firming energy production at Burfell whenever flows are below the best gate hydraulic capacity of 174 cubic meters per second. Such energy production use would be secondary to ice control, however.

The discharge records for Burfell, presented in Appendix A, show that a gross volume of about 140 million cubic meters is required in the critical 1950-1951 winter low flow period to firm the flows to 174 cubic meters per second. Deficiencies occurred in four periods separated by natural flows in excess of this rate. This total volume could be provided by a drawdown of about two meters below elevation 571 as shown by the reservoir area-volume curve on Exhibit D-1. However, a small amount of refill could be accomplished during the interim higher Thjorsa flow periods of that winter. For reasons discussed above, this refill cannot be evaluated reliably.

The maximum average daily deficiency in natural flows at Burfell is about 60 cubic meters per second. This deficiency in rate occurred in mid-April 1951, towards the end of the low flow period. Thus, the maximum rate could almost coincide with maximum required drawdown at Thorisvatn.

Neither the rate nor the seasonal quantity of water required for ice control at Burfell is determinable at this time. In general, the greatest ice problems can be expected to occur coincidently with lowest natural flows since both relate normally to extreme frost periods. However, requirements for water to control ice might also occur before, after, or between the periods of low flow less than best gate station capacity. On the other hand, it is possible that ice control water may be required at some more or less constant rate throughout all winter seasons, but augmented further for relatively brief periods during the more severe periods within each winter, including those of the critical year. Thus, it appears evident that ice control water could represent a substantial volume of storage, perhaps exceeding firming energy requirements for the critical year. Further, the required rate of release may also be equally as great. However, provision of storage by a few meters of drawdown in Thorisvatn appears feasible to provide substantial benefits with respect to both ice control and firming energy at the Burfell Project.

From the above, it is evident that specific design criteria do not now exist for planning the outlet works to develop a relatively small initial storage at Thorisvatn. The design adopted for presentation is discussed hereinafter.

Project Description

General

The low saddle beyond the southeast corner of Thorisvatn was selected as the site for the outlet and control works with an initial storage development. The reasons for the selection of this site were discussed above. The outlet works will consist of an open channel about three kilometers long. Control will be provided by a concrete structure positioned in the downstream portion of the canal and equipped with a gate. The grade of the canal will be dropped a few meters ahead of the control structure, then continued somewhat more steeply through the discharge channel to connect with natural watercourses extending to the Tungnaa upstream of Tungnaarkrokur. The location of the structures is shown on the Key Plan of Exhibit D-3. Plans, sections, and a profile of the proposed structures are also shown thereon.

Releases will cause considerable erosion between the location of the control structure and the Tungnaa, especially during the early months of operation, Ultimately, a reasonably stable channel should develop. The eroded material will add somewhat to the bedload and suspended load in the river downstream, but no serious detrimental effects are expected.

No direct consideration has been given to incorporating the initial construction into the ultimate development of Thorisvatn. However, since such a development will involve the diversion of Kaldakvisl into Thorisvatn, the initial structures may be adapted for high lake level releases, including periods when storage releases are not required. The structures may also be adapted, in whole or in part, into a spillway.

Design Criteria

The selected designs shown are illustrative primarily. The difficulty of establishing exact design criteria has been discussed above. The basic design has been used for evaluating the capital cost of several levels of storage. However, the detailed design shown is based on a reasonable development which is capable of firming nearly all of the primary energy deficiencies at the initial Burfell Project as presented in

Volume I of this Report. It is also capable of providing a substantial volume of storage and a relatively high release rate for ice control at the site of the Burfell diversion structures.

The designs shown on Exhibit D-3 permit utilization of four meters of storage down to elevation 567, and a release rate at that elevation of about 75 cubic meters per second. Since at this lake level the reduction in natural outflow may be in the order of 5 to 15 cubic meters per second, depending on inflow, the net rate of storage release might be between 60 and 70 cubic meters per second. An additional nearly four meters of storage could be released, but at a progressively lesser rate, as shown by the outlet capacity versus lake elevation graph on Exhibid D-3. The maximum outlet capability with the reservoir at elevation 571 is shown by this same graph to be about 125 cubic meters per second.

The storage volume in the top four meters of the lake, as shown by the volume curve of Exhibit D-3, is about 275 million cubic meters. This amount is nearly twice the volume required to firm the Burfell Project flows to 174 cubic meters per second in the critical low flow period of the 1950-51 winter. The additional available volume in the reservoir between elevation 567 and the maximum elevation of 563 in the canal grade amounts to about the same quantity as in the upper four meters. These volumes represent only surface storage. Underground storage, which may be substantial, would be in addition thereto.

The amount of storage which might be refilled during the months between the end of the 1950-51 low flow season in April 1951 and mid-October 1951, when a successive low flow period might begin, has not been evaluated because of the unknowns discussed above under "hydrology." The Vad flow records indicate, however, that refill during this six-month refill period might be less than 200 million cubic meters. Thus full utilization of the volume in the upper four meters of Thorisvatn might exceed inflow capability on the severe assumption of critical low flow periods in two successive winters.

Canal

The canal was designed to be constructed at minimum cost. The plan, profile, and a typical section are shown on Exhibit D-3. The location was selected to follow without excessive curvature both the lowest topography and the lowest bedrock profile in the saddle to the northwest of Vatnsfell and towards the hills designated Sigalda. These data were supplied as a result of the field investigations discussed above. The total length of the canal will be about 3200 meters, of which about 200 meters will be in Thorisvatn and about 700 meters will be downstream of the control structure.

The grades and the cross section of the canal were based on hydraulic and economic considerations. The approach canal upstream of the diversion structure will be excavated at a uniform grade of 1.3 meters per kilometer from the entrance at elevation 563 to elevation 560 immediately upstream of the control structure. This slope corresponds to the average hydraulic gradient for maximum discharge at minimum normal reservoir level. The depth of water will thus be approximately four meters throughout the canal under these conditions. The canal will have a bottom width of six meters and side slopes of two horizontal to one vertical in overburden and one-half horizontal to one vertical in rock. The maximum velocities will be about 1.5 meters per second in the overburden sections and about 2.5 meters per second in the rock sections. Velocities in the transition sections will be between these two values.

The discharge canal beyond the control structure will be of a design similar to the approach canal, but will have a slightly steeper grade at approximately two meters per kilometers. The maximum velocities are estimated at 2.5 meters per second, and some erosion of the overburden materials is expected.

The base width of the canal was set at six meters in order to accommodate large construction equipment and achieve ecnomy. The use of power shovels, draglines, and trucks was assumed as the basis for the cost estimates. However, for construction of that portion of the canal extending into Thorisvatn, the estimates are based on dragline casting. The dragline would work from a dike on the right side of the canal constructed of rock spoil. Casting would be to behind the dike. The dike would represent a permanent feature to prevent refilling of the canal by wave and water current actions.

The designs show that most of the canal would be constructed in easily removable overburden. However, the rock is not expected to be difficult to blast and excavate. Almost 80 percent of the required excavation of about 640,000 cubic meters is expected to be overburden. Much of the overburden excavation can be cast by dragline without truck haul.

The detailed topography in the area of the undrained depression downstream of the canal at about elevation 510 meters indicates that there is no immediate danger of flow diversion to the Kaldakvisl instead of to the Tungnaa. However, eroded material from the discharged waters accumulating in the depression may alter this situation unfavorably. The cost estimates assume that a portion of the discharge channel excavation will be spoiled to build up a dike in the low saddles on the right side of the depression and assure diversion to the Tungnaa only.

Control Structure

The control structure will be a mass concrete dam across the canal about 2300 meters downstream of the lake. It will be provided with an opening at the bottom for release of water as required. The structure will be approximately 15 meters high from the foundations at elevation 557.5 to the crest at elevation 572.5. A plan and a section of the structure are shown on Exhibit D-3.

A stilling basin will be provided immediately downstream of the gravity section to protect the foundations against erosion from the outlet discharge. The stilling basin will be of concrete construction and designed so that a hydraulic jump will form within the basin for some flows.

The outlet will be submerged about two meters below normal minimum operating headwater levels. It will be provided with a 3.5-meter by 3.5-meter wheeled gate operated by a hydraulic cylinder. An electric motor driven hydraulic pump will operate the cylinder. This small power supply will be by storage batteries. A small gasoline engine driven battery charger will be supplied. All normal operation will be by remote control from the Burfell powerstation. Charging of the batteries during winter may be accomplished by periodic visits of operating personnel at about monthly intervals.

Bulkheads may be inserted in slots provided at the upstream end of the outlet to permit inspection of the wheeled gate.

The hydraulic cylinder and operating equipment will be housed within a blockout below the deck level. This space and the gate guides will be heated by an oil fired burner with adequate fuel storage to last the entire winter season.

Construction

All of the required civil engineering construction is relatively simple and needs no elaboration. The radio controls for operation may, however, be somewhat complex relatively, but are not unusual for remote control operations of this type.

It is entirely feasible with adequate construction equipment to build the Project in one summer season. Inasmuch as this may not be economical, two summer seasons were assumed in the cost estimates, which are discussed below.

Capital Costs

Basic Design Project

The costs of the initial Thorisvatn Storage as described above were determined on the basis of estimated quantities and unit prices. Lump sums were included for items which could not be conveniently estimated by the unit cost procedure. The detailed estimate is presented on Exhibit D-4.

The total investment was estimated at $1,500,000. This amount includes allowances for contingencies, engineering and overhead, and construction interest on the estimated direct cost. Import duties and taxes on imported equipment and materials were not included. There is also no allowance for working capital and interest reserves, neither of which is believed necessary.

Alternative Projects

Preliminary cost estimates were made for storage developments of 200, 350, and 500 million cubic meters. These volumes correspond to a normal drawdown of 3.0, 5.0, and 7.3 meters below elevation 571. Each development is designed for a discharge capacity of 90 cubic meters per second at these respective drawdowns. Each layout was similar to the basic plan described above, except that the bottom elevations of the canal and of the outlet structure were each varied to correspond with the normal drawdown indicated.

The results of these preliminary estimates are presented below for general information since they agree very well with the more detailed estimate for the selected plan.

Estimated Costs of
Alternative Storage Projects

Amount of Storage in Million Cubic Meters	Estimated Total Investment in U. S. Dollars
200	1,200,000
350	1,700,000
500	2,250,000

The above costs compare closely with the estimate presented in the March 1962 Appraisal Report by HARZINT. The estimates in the Appraisal Report are for construction cost only, exclusive of interest during construction, whereas the above costs are for total investment including construction interest.

Any small initial development of storage at Thorisvatn will provide some firming energy at Burfell. The average annual deficiencies for the 180,000 kilowatt Burfell plant presented in Volume I amounted to about 17 million kilowatthours. On the assumption of a three U.S. mill energy value, the total annual value to Burfell would be about $50,000. An assumed seven percent capitalization would justify a capital expenditure of $700,000. This approach would provide about one-half of the investment cost for the storage development presented on Exhibits D-3 and D-4. The remainder would represent a cost for ice control.

THE EXHIBITS

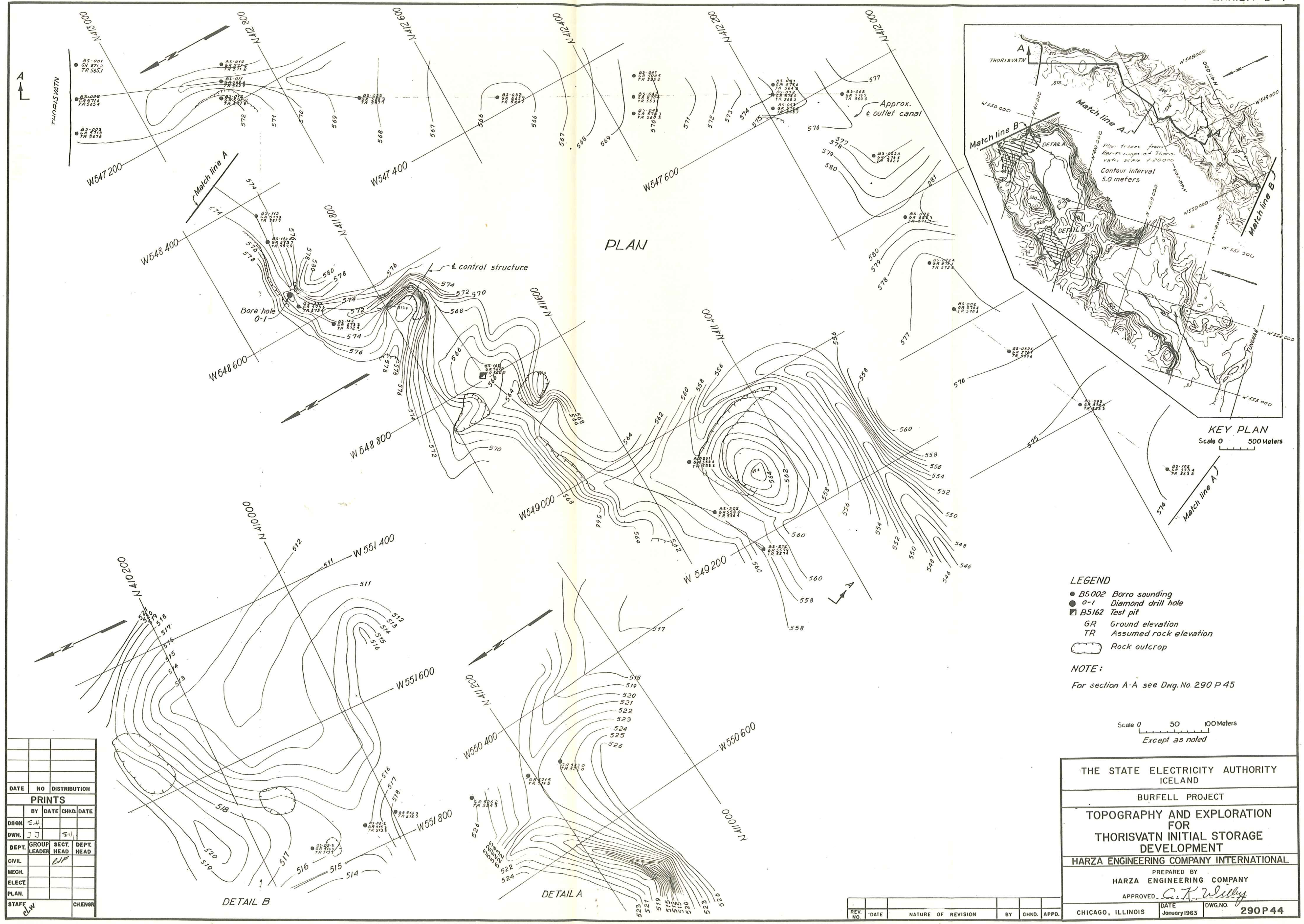
D-1 Topography and Exploration for Thorisvatn Initial Storage Development

D-2 Thorisvatn Initial Storage, Section A-A, Profile Along Outlet Canal

D-3 Thorisvatn Outlet Works

D-4 Cost Estimates, Thorisvatn Outlet Works

EXHIBIT D-1


PLAN
THORISVATN
Match line A
Match line B
Bore hole O-1
℄ control structure
Approx. ℄ outlet canal
DETAIL A
DETAIL B
KEY PLAN
THORISVATN
DETAIL A
DETAIL B
Plan traced from Rarik maps of Thorisvatn scale 1:20000
Contour interval 5.0 meters
Scale 0 500 Meters
LEGEND
● BS002 Borro sounding
● O-1 Diamond drill hole
BS162 Test pit
GR Ground elevation
TR Assumed rock elevation
Rock outcrop
NOTE:
For section A-A see Dwg. No. 290 P 45
Scale 0 50 100 Meters
Except as noted
THE STATE ELECTRICITY AUTHORITY
ICELAND
BURFELL PROJECT
TOPOGRAPHY AND EXPLORATION FOR THORISVATN INITIAL STORAGE DEVELOPMENT
HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY HARZA ENGINEERING COMPANY
APPROVED C. K. Willy
CHICAGO, ILLINOIS
DATE January 1963
DWG. NO. 290 P 44
REV. NO.
DATE
NATURE OF REVISION
BY
CHKD.
APPD.
DATE
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PRINTS
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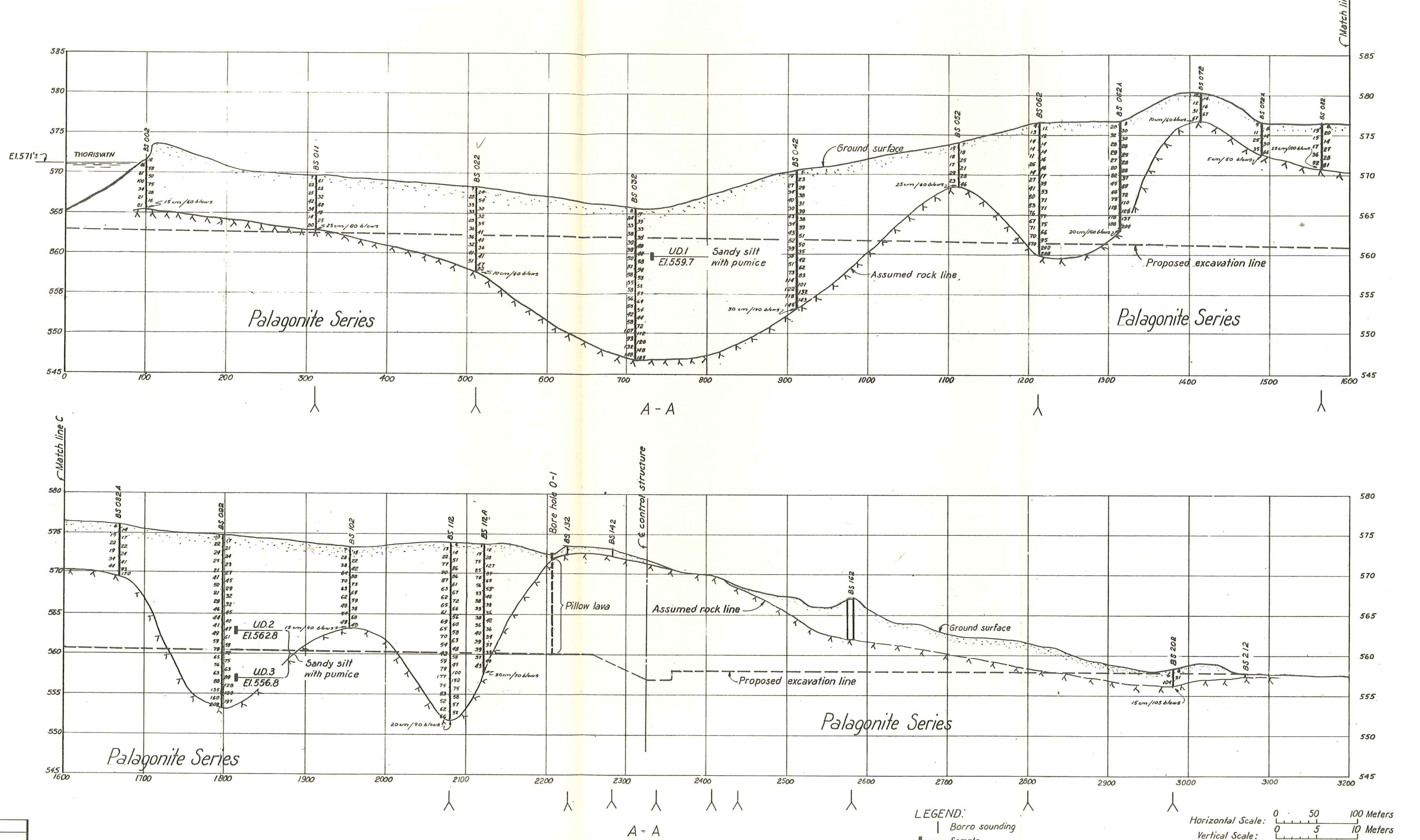

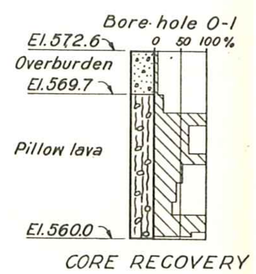

NOTES:

1. For location of section see drawing 290 P 44

LEGEND:

- Borro sounding
- Sample
- Diamond drill hole
- Test pit (hand dug)
- Ground surface
- Assumed rock line
- Section turns

BORRO SOUNDING EXPLANATION

Numbers indicate blows per 50 cm. penetration
Rod size 32 mm.
Hammer weight 65 kg.
Hammer drop 50 cm.

Horizontal Scale: 0 50 100 Meters
Vertical Scale: 0 5 10 Meters

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.
R1	9-27-63	Blow counts added to bottoms of holes and late bottom of holes corrected	S.H.		

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

THORISVATN INITIAL STORAGE
SECTION A-A
PROFILE ALONG OUTLET CANAL

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY

APPROVED C. K. Willey

CHICAGO, ILLINOIS | DATE January 1963 | DWG. NO. 290 P 45

DATE	NO	DISTRIBUTION

PRINTS

	BY	DATE	CHKD.	DATE
DSGN.	S.H.			
DWN.				

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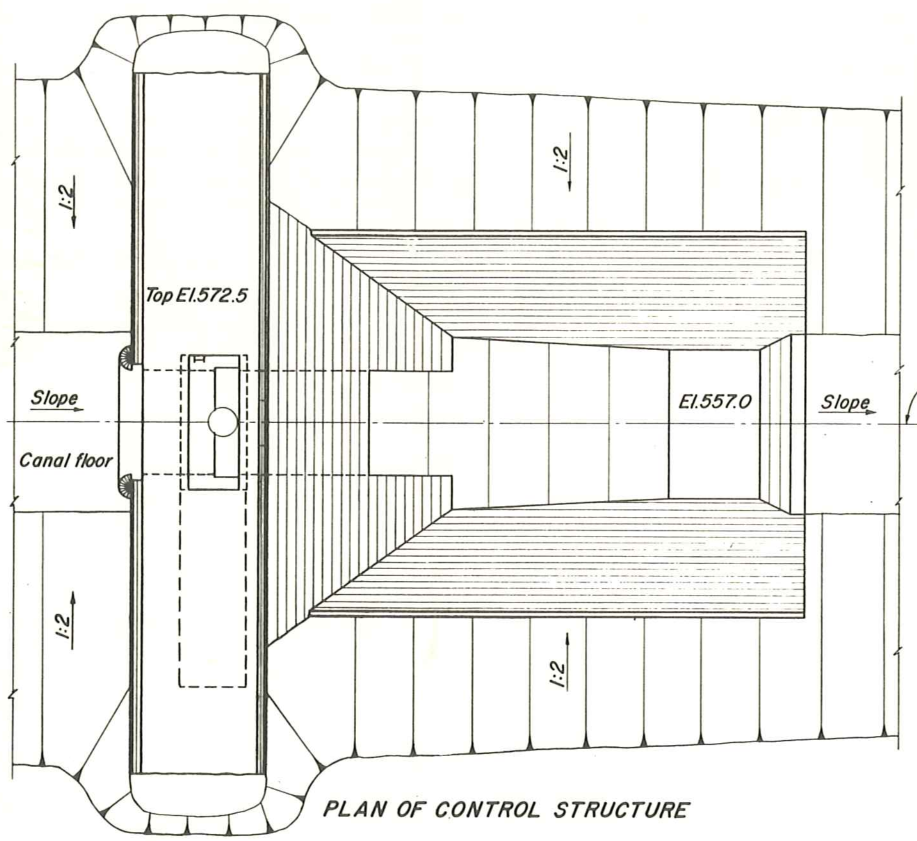
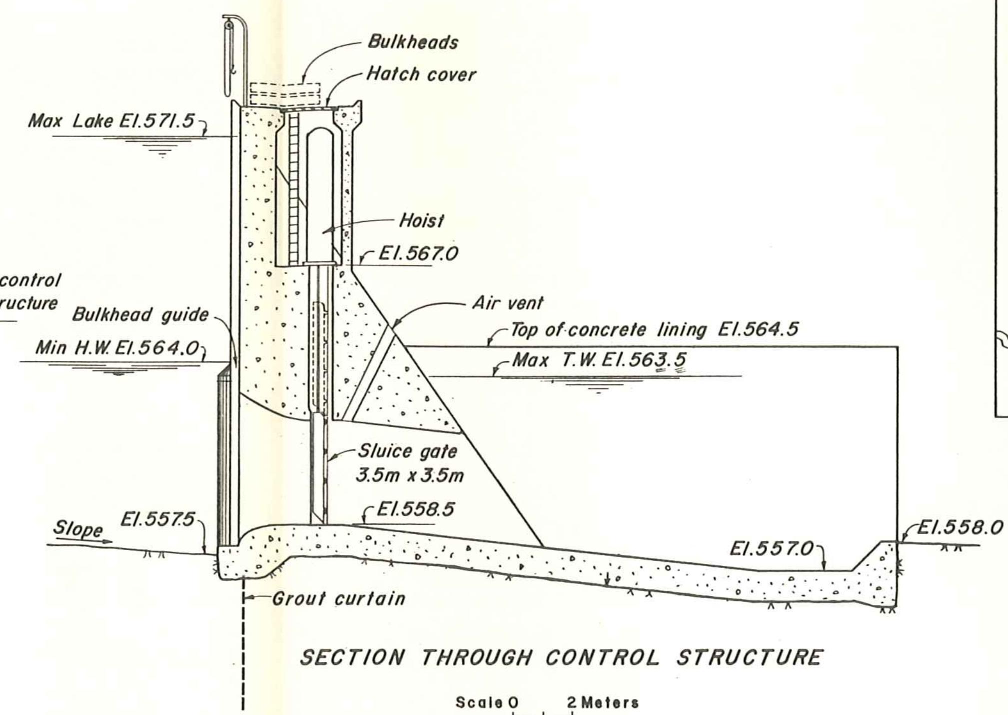


PLAN OF CONTROL STRUCTURE

Scale 0 2 Meters



SECTION THROUGH CONTROL STRUCTURE

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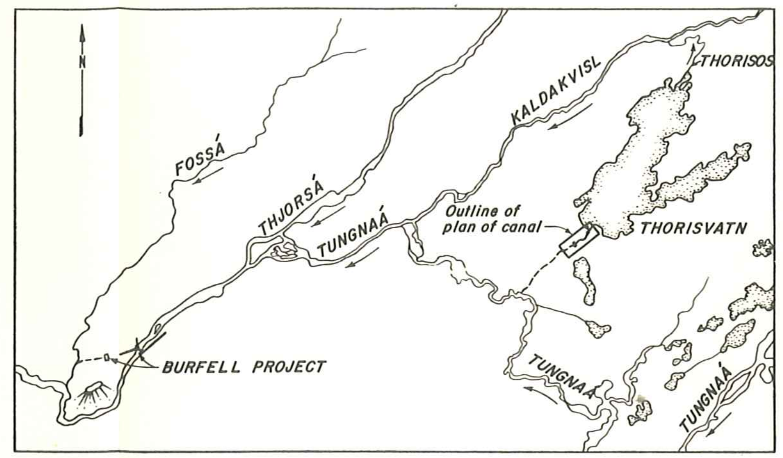
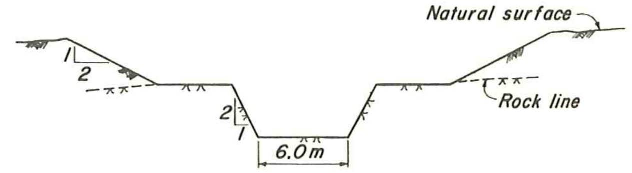


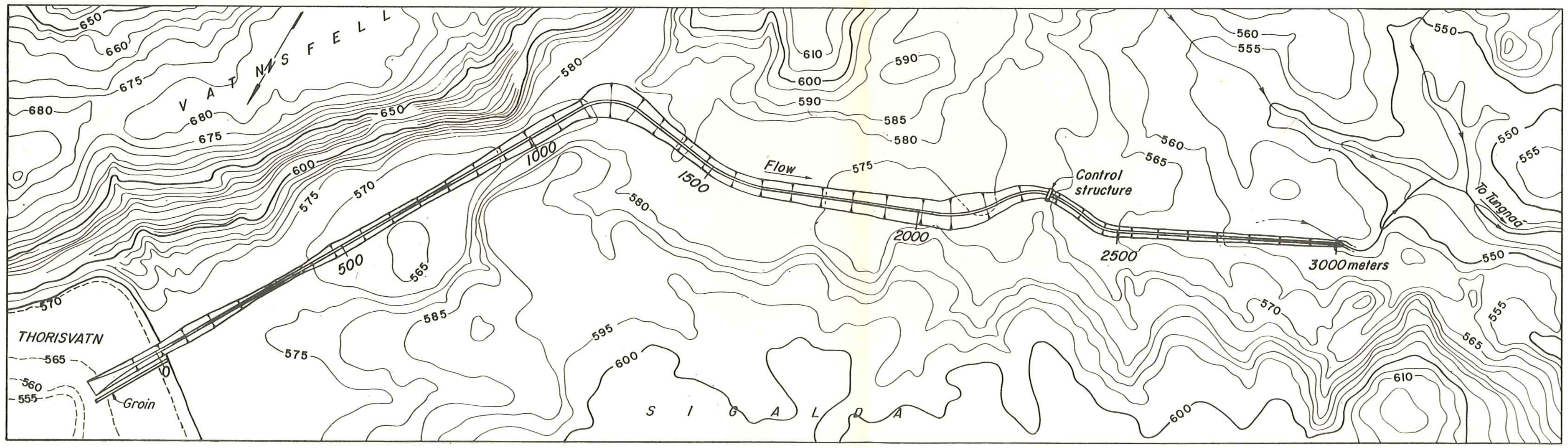
KEY PLAN

Scale 0 5 Kilometers



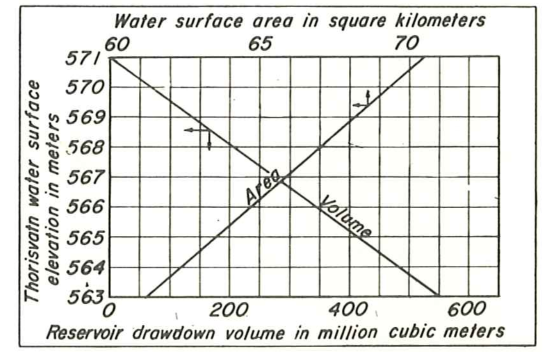
TYPICAL CANAL SECTION

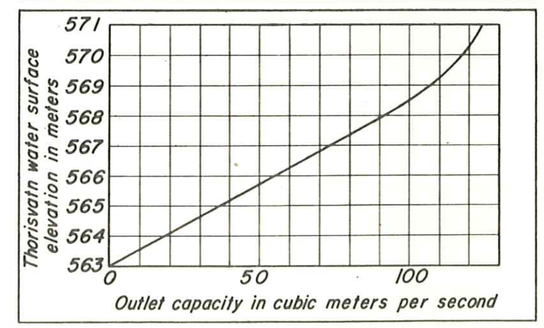
Scale 0 5 Meters

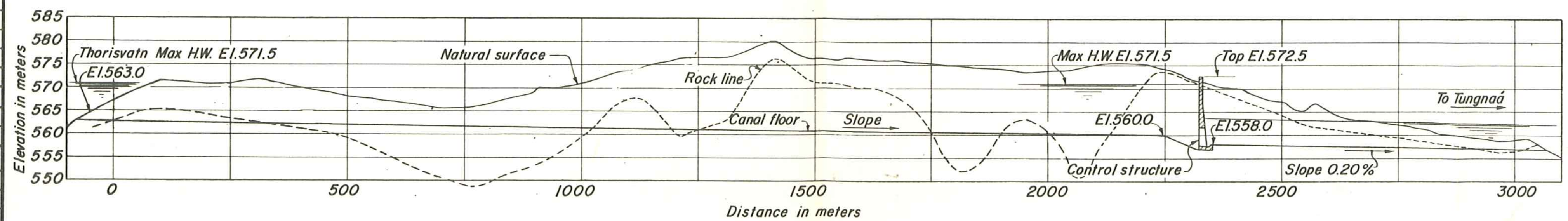


PLAN OF CANAL

Scale 0 100 Meters







PROFILE OF CANAL

DATE	NO	DISTRIBUTION

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DSGN.	JNF	12/22/62		
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MECH.			
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PLAN.	J.N.F.	ARE	VAK
STAFF			CH.ENGR.

REV. NO.	DATE	NATURE OF REVISION	BY	CHKD.	APPD.

THE STATE ELECTRICITY AUTHORITY
ICELAND

BURFELL PROJECT

THORISVATN OUTLET WORKS

HARZA ENGINEERING COMPANY INTERNATIONAL
PREPARED BY
HARZA ENGINEERING COMPANY
APPROVED C. K. Willey

CHICAGO, ILLINOIS	DATE JAN. 1963	DWG. NO. 290 P 27

Burfell Project

Cost Estimates
Thorisvatn Outlet Works

Item	Quantity	Unit Price $ U.S.	Amount $ U.S.
Excavation, common	500,000 m^3	1.00	500,000
Excavation, rock	140,000 m^3	3.25	455,000
Breaching to Thorisvatn		L.S.	25,000
Foundation preparation and grouting		L.S.	5,000
Concrete, mass	720 m^3	25.00	18,000
Concrete, structural	290 m^3	35.00	10,150
Formwork	1,050 m^2	11.00	11,550
Reinforcing steel	15,000 kg	0.28	4,200
Sluice gate, frame, and guides	4,400 kg	1.20	5,280
Gate operating cylinder		L.S.	5,000
Housing and heating		L.S.	5,000
Control equipment		L.S.	10,000
Miscellaneous		L.S.	1,000
SUBTOTAL DIRECT COST			1,055,180
Contingencies, 20%			204,820
TOTAL DIRECT COST			1,260,000
Engineering and Supervision, 8% ±			120,000
Preliminary Investigation Costs			20,000
CONSTRUCTION COST			1,400,000
Interest During Construction			100,000
PROJECT INVESTMENT			1,500,000