ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

ÚTLÁN
Bókasafn Orkustofnunar

VIRKIR
CONSULTING GROUP LTD

SIGALDA

HYDROELECTRIC PROJECT

PROGRESS REPORT ON 3RD AND 4th IMPOUNDING

GROUNDWATER AND LEAKAGE STUDIES ON BASIS OF CHEMICAL ANALYSES

BJÖRN JÓNASSON
SIGURÐUR R. GUÐMUNDSSON

PREPARED FOR
LANDSVIRKJUN
THE NATIONAL POWER COMPANY
JUNE 1978

OS-ROD-7821

C O N T E N T S

T A B L E S

E X H I B I T S

0 ABSTRACT

This progress report deals with groundwater and leakage studies by chemical analyses of water samples collected on June 8 to October 2 1977 during the last part of the 3rd and beginning of the 4th impounding of the Sigalda reservoir and headrace canal. The following main results and interpretations are: Third impounding. The reservoir water (leakage water) in the groundwater is 65-100% before maximum lake (reservoir) level on the Damsite Area. The "contact zone" of the lavas THf-THh, i.e. the scoriaceous top layer of THf, the interbed, but inbetween is rhyolitic tephra layer (H_4) from Mountain Hekla, and last but not least the scoriaceous bottom layer of the lava THh, is the main leakage path. The draining ditches nearest the dam and a spring which discharges from the "contact zone" of the lavas THf-THh in about 700 m distance directly west of the southern abutment of the dam have the highest percentage of reservoir water or 90-100%. The share of the reservoir water decreases in general farther from the dam and is least about 65% in the draining ditch most far off and in the springs that discharge from the contact of the lava THf and the Sigalda moberg. A previous diversion canal (MW-1) is peculiar in this respect as it mainly drains water below the dam. "Contamination" appeares after the maximum lake level in the way that calculations show different mixing and everywhere much lower share of reservoir water than there actually is and are therfore insignificant. This "contamination" surely occurs when the groundwater covers new places in the strata and when the groundwater level is lowered the "contamination" appeares, but that happens immediately with lowering of lake level. The share of reservoir water in the spring water is 65-100% just before maximum lake level on the Headrace Canal Area. The main leakage paths are related to the tectonic lineations and probably to the contact of the moberg facies and its roughest facies too (cube jointed basalt, pillow lava, pillow lava breccia). New springs that appeared because of the impounding in the younger moberg but there in the headrace canal is excavated show the share of the reservoir water to be 95-100%. A spring that discharges from the older moberg but tillit layer seperates it from the younger shows the share of the reservoir water just to be 65%. There appeared many springs on the bottom of the reservoir after the end of the 3rd impounding. In the beginning the share of the reservoir water was about 40% but approximately 1 month later the share had decreased to 0-25%. Just before the 4th impounding the same kind of "contamination" was detected that characterized the spring water in the Damsite Area.

Fourth impounding. In the beginning the above "contamination" is still active except that the mixing calculations show now a fairly good internal regularity that was not the case in the beforementioned "contamination". Mixing calculations show now the share of the reservoir water to extend to 50%, that is probably insignificant. It seems to be sure that this "contamination" can be traced to 3rd impounding but it lasted for 5 months and in the 2 months that lasted inbetween 3rd and 4th impoundings the groundwater had not reached its previous (natural) chemical composition. Percentage somewhat like before with respect to the reservoir water appeares at the end (Okt.2) and can most likely be derived to the same matter, i.e. to the 3rd impounding.

Results of measurements of discharge and mixing calculations of the spring water in the course of Tungnaá, springs and draining ditches show that all or almost all additional flow on the Damsite Area about 11 m^3/sec. with that circumstances that dominated June 8-10 1977 can be traced to leakage from the reservoir and not to natural groundwater flow under the reservoir bottom induced by the impounding.

1. INTRODUCTION

This progress report is a direct continuation of "Sigölduvirkjun, Áfangaskýrsla um 2. og 3. áfyllingu. Jarðvatns- og lekarannsóknir í ljósi efnagreininga, hita-, tvívetnis- og þrívetnismælinga", published in July 1977.

The primary purpose of the chemical analysis is to detect and trace the spatial degree of mixing of the reservoir water (leakage water) with the groundwater from time to time during the above period. In this way a general idea of the leakage and leakage paths in the ground can be obtained and a clearer picture of the behaviour of the reservoir water and/or groundwater in the Sigalda area established. The study was centered on the areas in the vicinity of the engineering structures, i.e. the lava area to the west and downstream of the dam, the so-called damsite area and the moberg area at the headrace canal site, the so-called headrace area.

All analizations, totalling 56 samples, were performed by the Industrial Research Institute. The following components were analyzed: Cl^-, SiO_2, Ca^{++}, Mg^{++}, Na^+, K^+ and $CaCO_3$. The conductivity of all the samples and the alcalinity of half their number were also observed. The water samples are designated by location numbers, S01-S43, see Exhs. 1 and 2, but as in most cases more than one sample is taken at each station the dates of sampling are used to distinguish individual samples from the same location.

Calculations of the chemical analyses are done in the following manner. First, the values obtained by the chemical analization expressing the content of the above mentioned components in ppm (ppm = mg/l) are converted into mille-Moles, then so-called Mole-

ratios are calculated with reference to chlorine,i.e. [X]/[Cl^-].
On the values thus obtained the calculations of mixing are based in such a way that the basic values or Mole-ratios for each component in the reservoir water on one hand and natural or uncontaminated groundwater on the other are used to find the percentage of reservoir water in the groundwater or mixed water at various places and times.

2. CHEMICAL ANALYSIS

2.1 Tables

The chemical analysis used as basis for mixing calculations are listed in table 1. So-called basic values are obtained signifying the chemical composition of the ground-water and reservoir water respectively under circumstances of undisturbed, natural conditions of the groundwater. The reference samples were taken in 1976. In 1977 two additional samples, S 25 and S 26, were taken for camparison in mixing calculations. Sample S 05 from Tngnaá is not included in the averages for the reservoir water, as the reservoir at that time almost exclusively consisted of spring water and diverted water from lake Thórisvatn. At this time the glacial component in Tungnaá river was negligible.

Tables 2-4 contain chemical analysis of water samples from the final stage of the 3rd impounding and later, primarily spring water, i.e. a varying mixture of groundwater and reservoir water, except for samples S 30 and S 33 taken from the reservoir water represented in its basic values.

Table 5 shows the chemical composition of the spring water at the beginning of the fourth impounding. In tables 6 - 10 on the other hand, are listed the obtained results, so-called Mole-ratios, of the chemical analysis with regard to chlorine, i.e. [X]/[Cl^-].
These ratios are obtained by first converting the values of the

analizations into mille-Moles, as already stated.

Finally, tables 11 and 12 show the general, spatial and temporal share of the reservoir water in the spring water on the damsite and headrace areas as well as the reservoir bottom.

2.2 Basic values

The mixing calculations are based on the results of chemical analysis of the following water samples which yield the initial or basic chemical values for groundwater and reservoir water respectively:

Groundwater: S 04, 76.11.08, S 06, 76.11.08, and S 07, 76.11.09, see table 6.

Reservoir water: S 22, 77.03.15, S 30, 77.06.08 and S 33, 77.06.08, see tables 6 and 8.

For those places where there are direct leakage paths from the reservoir the mean value for S 30, 77.06.08 and S 33, 77.06.08 = I_1 is used, but otherwise S 22, 77.03.15. is included in the mean in such a way that the mean for S 30 and S 33 have equal validity to S 22 = I_2. These two basic values for the reservoir water are quite different with regard to Mole-ratios, thus the Magnesium and Natrium ratios differ as much as half their value whereas the Kalium ratios are quite similar, which makes them highly relible as basic values for the reservoir water. This can be seen very clearly in the following table which show the basic values (Mole-ratios) for reservoir water and groundwater in the damsite lavas and in the moberg on the headrace canal site:

M O L E - R A T I O S

Watertypes	Notes for basic values	$\frac{[SiO_2]}{[Cl^-]}$	$\frac{[Ca^{++}]}{[Cl^-]}$	$\frac{[Mg^{++}]}{[Cl^-]}$	$\frac{[Na^+]}{[Cl^-]}$	$\frac{[K^+]}{[Cl^-]}$
Reservoir Water	I_1	1,5303	0,7883	0,4821	2,3307	0,1062
	I_2	1,7383	1,0194	0,7352	3,2990	0,1065
Groundwater in the lavas at the damsite area	II	2,7668	1,9659	1,7103	5,5716	0,2192
	III	2,5650	2,1387	1,3896	5,7975	0,2214
Groundwater in the moberg at the headrace area	IV	2,5405	1,7936	1,3879	5,5951	0,1816

The basic values (Mole-ratios) for the groundwater in the reservoir bottom are the same as those for the damsite area but the values for a spring on the bottom, S 37, 77.07.21, see table 9, are taken into account, being the only place on the bottom of the reservoir where two samples were taken on the same place at different times.

3. THIRD IMPOUNDING, the final stage and later (June 8 to July 23, 1977).

All the samples taken before the peak lake level was reached indicate fully normal interrelationship, see Tables 11 and 12.
The calculations of mixing ratios after the maximum level of the third impounding was reached on the other hand show rising Mole-ratios. This variation in the chemical composition of the spring water applies to the entire damsite area, where numerous samples were taken after emptying of the lake was begun, see Dam control diagram, Exh. 3. Therefore, far lower percentages of reservoir water are found in the spring water than there actually are, e.g. at a similar lake level before and after the peake level (490,16 m). This chemical deviation is highest in the silicon-ratios but least in the Kalium-ratios while other ratios are more variable. Where

there is great irregularity between individual Mole-ratios of a single sample the percentage of the reservoir water is indicated by a~symbol in Table 11, but where there are normal ratios it is omitted.

3.1. Damsite Area

As shown in Table 11 the share of the reservoir water in the groundwater on the damsite area had become remarkably high just before the maximum lake level of the third impounding especially at sampling stations MW-1 and 2 (S04, S14 and S36) as well as at the contact between THf and THh at about 700 m distance directly west of the southern abutment of the dam, or as high as 90-100%, see S31 on Exh.2. With distance from the dam, the leakage water share in the draining ditches decreases, being 75% at MW-3 (S15) and 65% at MW-4 (S16) respectively. In the springs (S06, S25 and S32) at the contact between Sigalda moberg and lava THf the share has decreased to 65-75%.

As already stated the mixing calculations show a considerably lower leakage water share after the lake level peak was reached than there actually was. The results of the calculations are presented in Table 11. In accordance with the above said and previous ground-water temperature measurements the contact zone between lavas THf-h, i.e. the scoriaceous upper zone of THf, the interbed which a.o. contains the acidic tephra layer H_4 originating from Hekla, and not least the scoriaceous bottom zone of lave THh, constitute the main leakage path for reservoir water.

The draining ditch MW-1, previous diversion canal, is pequliar in this respect as it drains water from both below the dam and water conveyed along the length of the dam from south to north.

The reservoir water appearing at MW-2 (S14 and S36, Exh.2) probably to a large extent comes from the contact zone THf-h.

The high percentage of reservoir water at the contact zone THf-h (S31, Exh. 2) at about 700 m distance to the west of the southern end of the dam is noticeable, but temperature measurements performed during the 2nd impounding had already indicated the presence of a leakage path there. The springs designated S06, S25 and S32 show a lower leakage water share, still further supporting the supposition of a THf-h leakage path.

3.2 Headrace Area

In the headrace area, where three samples were taken on June 10, the share of the leakage water is very high at sampling locations. S34 and S35, 95 and 100% respectively, but 65% in a spring (S07) below Sigalda waterfall, see Table 12.

Two of the samples were taken from the uppermost part of the "groundwater" from pure leakage paths, see Exh. 2, but the last one (S07) from the deeper part of the groundwater, i.e. from a spring seeping out of the older moberg into which the powerhouse and headrace canal are excavated. This spring was already present before the impounding of the headrace canal at the beginning of the 3rd impounding and at the time of sampling its discharge had not seemingly increased. The other sampling stations were created by the rising groundwater level due to leakage from the headrace canal.

3.3 Reservoir Area

Shortly after the emptying of the lake one sample was taken (S37, 77.06.30) from one of the numerous springs on the lake bottom. These springs had not existed before as far as known. The reservoir water share in this sample proved to be 35-40%, see Table 12.

Three weeks later sampling from springs at various locations on the reservoir bottom, see Table 12 and Exh. 1, was accomplished. The mixing caculations showed a markedly lower percentage of reservoir water in the springs (S37-41) this time, ranging from 0 to 25%. The last two samples were taken on August 10 and 20 (S42 and S43) shortly before the 4th impounding was started. Now the calculations show marked irregularities and that the contamination characterizing the samples taken after the maximum lake level of the third impounding is also present here.

4. FOURTH IMPOUNDING (August 20 to OCTOBER 2, 1977).

4.1 Damsite Area

On the damsite samples were only taken at four locations, i.e. at MW-1 (S04) and in the springs (S06, S25 and S32). The results of the chemical analyses and Mole-ratios are listed in Tables 5 and 10. The rising (behavior) of the reservoir and ground-water levels and the observed discharge of spring water is shown on Exhs. 4 and 5.

The calculations of mixing indicate a fairly good internal regularity, but the samples taken on the first day of the 4th impounding show quite different Mole-ratios from the basic ones. Calculations on basis of the above-mentioned basic values of August 20 yield 40-50% reservoir water in the groundwater but S25 is peguliar by 10-20% leakage water share.

It cannot be stated with certainty wether the share of the reservoir water in the groundwater is actully of the above percentage or wether the groundwater is contaminated due to the high lake level during the 3rd impounding. In any case this contamination is derived from the high water of the 3rd impounding, which lasted for about 5 months. Presumably, the groundwater did not regain its natural chemical composition during the 2 months interval between the 3rd and 4rd impoundings.

Samples taken from springs S06 and S32 show unchanged or rising Mole-ratios during the period August 20 to October 2, which shows that the contaminated water is still prevailing. As mentioned above spring S25 is pequliar and the Mole-ratios of samples S25, 77.09.05 are almost identical to those of natural water. A sample from that spring at a later date, October 2, shows 50% reservoir water. The most probable explanation of this is that the contaminated groundwater is reemerging and/or the reservoir water from the 4th impounding may also be the case. Sampling station MW-1 (S04) is out of this picture due to its direct linkage to the reservoir. Mixing calculations on basic of the contaminated groundwater values S04, 77.08.20, give 50-60% reservoir water share on September 5 and October 2 1977 at this location.

5. DISCHARGE

5.1. The share of Leakage water (Reservoir Water) in Spring Water on the Damsite Area.

Due to the relatively great number of sampling stations and water samples collected on the damsite area the fairly good results of the chemical analyses and last but not least the fact that the discharge of Tungnaá river was measured just above Sigalda waterfall at this time, an attempt is made to estimate to what degree the water emerging in springs and ditches downstream of the dam (on the damsite area) owes its origin to the reservoir and otherwise how this water can be traced to natural groundwater on one hand and reservoir water (leakage water) on the other. At this time the bottom outlets were closed so there was only spring water in channel.

On June 10 1977 the spring water discharge was measured as 15,7 m^3/s in the Tungnaá channel above Sigalda waterfall. The lake level was at 488,95 m elevation. The water samples used as a basis for the estimations and calculations of the share of the reservoir water in the groundwater on the damsite area were taken on June 8 - 9, 1977. At that time the elevation of the reservoir water level was 488,7-488,8 m a.s.l. Under these conditaions the groundwater is out of pahse with the reservoir water, which rises more quickly than the groundwater. In spite of this a certain equilibrium has been gained as the lake level has been stable for a fairly long time or just over 5 months.

The mixing calculations for the damsite area, see Table 11, on one hand show the share of the reservoir water in draining ditches (MW-1-MW-4) and in the spring (S1-S3) in the Sigalda canyon on the other. The following results were obtained.

MW-1 and 2	95%	Reservoir water
MW-3 and 4	~70%	" "
Springs S1-S3	~70%	" "

5.2. Results

Total, measured discharge of Tungnaá	15,7 m^3/s
Estimated drainage from headrace canal area	1 "
Spring water from damsite area	14,7 m^3/s

On June 8 the total discharge from draining ditches (MW-1 to 4) was 5,6 m^3/s. The total discharge from springs is thus 14,7 minus 5,6 = 9,1 m^3/s.

The following table is a summing up of the main quantitative results:

Station	Total discharge m^3/s	Share of reservoir water m^3/s	%
MW-1 and 2	2.6	2.5	95
MW-3 and 4	3.0	2.1	70
Springs in Sigalda Canyon, left bank	9.1	6.4	70
Total	14.7	11.0	75.0

The share of the natural groundwater is therfore roughly 3,7 m^3/s, which is about 25% of the total drainage from the damsite area according to our calculations. Direct measurements of the natural spring water flow in the Sigalda canyon at the beginning of 4th impounding showed it to be 4.4 m^3/s.

According to the above estimate and calculations it seems clear that all or almost all additional flow on the damsite area about 11 m^3/s under the stated circumstances can be traced to leakage from the reservoir and not to natural groundwater flow under the reservoir bottom induced by the impounding.

TABLE 1

CHEMICAL ANALYSES OF WATER SAMPLES

Location number see location map	Date	Sampling station	Cl^- ppm	SiO_2 ppm	Ca^{++} ppm	Mg^{++} ppm	Na^+ ppm	K^+ ppm	Hardness $CaCO_3$ ppm	Conductivity micromhos/cm at 25°C	pH
S04	76.11.08.	MW-1	4,1	17,8	9.9	3.9	15.4	1,0	40,8	170	8,05
S05	76.11.08.	Tungnaá river at Bottom outlet	4,2	15,2	5.1	2,5	10,8	0,67	23,0	114	7,85
S06	76.11.08.	Spring S1	4,1	19,2	9,1	4,8	14,8	0,99	42,5	175	7,80
S07	76.11.09.	Spring in Sigalda, below Sigalda fall	4,0	17,2	8,1	3,8	14,5	0,80	35,9	158	8,00
S22	77.03.15.	Reservoir in front of Bottom outlet	3,4	11,2	4,8	2,3	9,4	0,40	21,5	103	7,90
S25	77.04.21.	Spring S2	3,4	18,4	7,2	4,1	15,2	0,89	34,9	158	7,50
S26	77.04.23.	Spring S3	4,0	18,2	5,9	3,5	13,5	0,87	29,1	138	7,40

TABLE 2

CHEMICAL ANALYSES OF WATER SAMPLES

Location number see location map	Date	Sampling station	Cl^- ppm	SiO_2 ppm	Ca^{++} ppm	Mg^{++} ppm	Na^+ ppm	K^+ ppm	Hardness $CaCO_3$ ppm	Conductivity micromhos/cm at 25°C	pH
S04	77.06.08.	MW-1	5,0	15,2	5,1	2,1	8,0	0,62	21,3	94	
S04	77.06.15.	MW-1	4,1	15,0	5,7	2,4	9,2	0,61	24,1	107	7,65
S04	77.06.25.	MW-1	4,1	16,1	5,6	2,5	8,9	0,78	24,3	106,6	7,10
S06	77.06.09.	Spring S1	4,8	17,7	6,1	3,2	11,2	0,79	28,5	121	
S06	77.06.15.	Spring S1	4,2	18,4	6,4	3,4	11,9	0,74	30,0	127	7,60
S07	77.06.10.	Spring in Sigalda, below Sigalda fall	5,0	16,5	6,6	3,3	13,3	0,73	29,9	132	
S14	77.06.08.	MW-2	4,8	17,6	5,0	2,2	8,8	0,54	21,4	97	
S14	77.06.17.	MW-2	4,2	17,0	5,9	2,6	9,9	0,82	25,4	110	7,90
S14	77.06.26.	MW-2	4,0	17,1	6,8	3,1	9,1	0,79	29,7	118,6	7,12
S15	77.06.08.	MW-3	5,6	17,9	6,3	3,3	12,9	0,83	29,3	133	
S15	77.06.17.	MW-3	4,2	18,4	5,7	3,0	11,3	0,73	26,6	117	8,0
S15	77.06.25.	MW-3	4,1	17,7	6,1	3,3	10,3	0,86	28,8	122,7	7,16
S16	77.06.08.	MW-4	5,6	17,7	6,6	3,6	14,1	0,92	31,2	144	
S16	77.06.17.	MW-4	4,1	18,4	5,9	3,3	12,5	0,78	28,3	128	8,20
S16	77.06.25.	MW-4	4,4	17,4	6,4	3,6	12,2	0,89	30,8	134,1	7,23

TABLE 3

CHEMICAL ANALYSES OF WATER SAMPLES

Location number see location map	Date	Sampling station	Cl^- ppm	SiO_2 ppm	Ca^{++} ppm	Mg^{++} ppm	Na^+ ppm	K^+ ppm	Hardness $CaCO_3$ ppm	Conductivity micromhos/cm at 25°C	pH
S25	77.06.09.	Spring S2	5,3	17,6	6,8	3,9	14,3	0,89	33,0	151	
"	77.06.15.	"	4,2	18,4	6,5	3,9	14,1	0,98	32,3	143	7,80
"	77.06.26.	"	4,2	17,4	6,4	3,6	12,8	0,94	30,8	134,5	7,17
S30	77.06.08.	Reservoir, inlet of headrace canal	5,0	13,3	4,5	1,7	7,6	0,59	18,2	87	
"	77.06.25.	"	3,9	15,8	4,4	2,6	9,3	0,84	21,7	105,7	6,93
S31	77.06.09.	Springs from contact TH_{f-h}	5,3	18,2	6,2	3,1	10,7	0,56	28,2	123	
"	77.06.15.	"	4,1	19,2	6,7	3,2	10,6	0,58	29,9	124	7,45
S32	77.06.09.	Spring S3 close to drillh. VIII	5,6	17,8	5,9	3,6	12,2	0,84	29,4	134	
"	77.06.15.	"	4,2	17,9	5,8	3,4	11,8	0,83	28,5	126	7,60
"	77.06.26.	"	4,6	17,7	6,2	4,1	14,4	0,97	32,4	135,9	7,67
S33	77.06.08.	Headrace canal	5,0	12,6	4,4	1,6	7,5	0,58	17,6	86	
S34	77.06.10.	Spring close to eastern wall of power house	5,5	16,3	6,8	3,4	12,7	0,65	31	138	

TABLE 4

CHEMICAL ANALYSES OF WATER SAMPLES

Location number see location map	Date	Sampling station	Cl^- ppm	SiO_2 ppm	Ca^{++} ppm	Mg^{++} ppm	Na^+ ppm	K^+ ppm	Hardness $CaCO_3$ ppm	Conductivity micromhos/cm at 25°C	pH
S35	77.06.10.	Spring in Sigalda, above Sigalda fall	5,0	11,7	3,8	2,0	6,5	0,43	17,6	83	
S36	77.06.09.	Drainage from dam close to PZ-3	5,3	18,3	6,3	2,8	9,7	0,67	27,3	118	
S37	77.06.30.	Springs in bottom of reservoir	4,2	17,0	6,9	3,7	12,9	0,82	32,5	139	8,20
"	77.07.21.	"	4,1	16,8	8,2	4,5	14,4	0,97	39,0	158,2	7,75
S38	77.07.21.	"	4,0	17,1	7,6	4,7	16,1	0,96	38,3	160,7	7,65
S39	77.07.21.	"	4,2	17,4	7,8	4,7	14,6	0,98	38,8	154,8	7,64
S40	77.07.22.	"	4,3	17,7	7,0	4,8	14,3	0,95	37,2	151,4	7,80
S41	77.07.23.	"	4,3	16,8	7,1	4,6	14,3	0,89	36,7	151,6	8,24
S42	77.08.10.	"	4,3	15,8	7,8	5,3	12,7	0,89	41,3	139,4	7,58

TABLE 5

CHEMICAL ANALYSES OF WATER SAMPLES

Location number see location map	Date	Sampling station	Cl^- ppm	SiO_2 ppm	Ca^{++} ppm	Mg^{++} ppm	Na^+ ppm	K^+ ppm	Hardness $CaCO_3$ ppm	Conductivity micromhos/cm at 25°C	pH
S04	77.08.20.	MW-1	4,2	16.0	7,5	3,5	12,3	0,81	33,1	142	7,30
"	77.09.05.	"	4,2	16,4	6,0	2,5	9,4	0,65	25,3	108	7,35
"	77.10.02.	"	4,0	16,6	6,2	2,6	9,9	0,59	26,2	113	7,60
S06	77.08.20.	Spring S1	4,2	18,2	7,2	3,5	12,5	0,74	32,4	137	7,30
"	77.09.05.	"	3,7	18,2	6,4	3,2	11,4	0,65	29,2	126	7,60
"	77.10.02.	"	4,2	18,4	7,0	3,6	12,6	0,74	32,3	130	7,80
S25	77.08.20.	Spring S2	3,7	17,6	7,5	3,9	14,7	0,86	34,8	150	7,30
"	77.09.05.	"	3,2	18,2	7,5	3,9	14,5	0,87	34,8	154	7,80
"	77.10.02.	"	4,4	18,4	7,2	3,9	14,1	0,82	34,0	148	8,10
S32	77.08.20.	Spring S3 close to drill-hole VIII	4,7	18,2	7,0	4,2	14,6	0,88	34,8	149	7,40
"	77.09.05.	"	4,3	18,0	6,3	3,9	13,6	0,84	31,8	139	7,65
"	77.10.02.	"	4,2	18,4	6,0	3,8	12,0	0,83	30,6	132	7,75
S43	77.08.20.	Spring in bottom of reservoir	4,7	19,2	6,1	4,8	20,0	0,80	35,0	143	7,50

TABLE 6

CHEMICAL ANALYSES OF WATER SAMPLES

Mole-ratio [X]/[Cl^-]

Location number see location map	Date	Sampling station	Cl^-	SiO_2	Ca^{++}	Mg^{++}	Na^+	K^+
S04	76.11.08.	MW-1	X	2,5650	2,1387	1,3896	5,7975	0,2214
S05	76.11.08.	Tungnaá river at Bottom outlet	X	2,1382	1,0755	0,8696	3,9689	0,1448
S06	76.11.08.	Spring S1	X	2,7668	1,9659	1,7103	5,5716	0,2192
S07	76.11.09.	Spring in Sigalda below Sigalda fall	X	2,5405	1,7936	1,3879	5,5951	0,1816
S22	77.03.15.	Reservoir in front of Bottom outlet	X	1,9462	1,2504	0,9883	4,2673	0,1068
S25	77.04.21.	Spring S2	X	3,1974	1,8757	1,7617	6,9003	0,2377
S26	77.04.23.	Spring S3	X	2,6882	1,3064	1,2783	5,2092	0,1975

TABLE 7

CHEMICAL ANALYSES OF WATER SAMPLES

Mole-ratio $[X]/[Cl^-]$

Location number see location map	Date	Sampling station	Cl^-	SiO_2	Ca^{++}	Mg^{++}	Na^+	K^+
S04,	77.06.08.	MW-1	X	1,7961	0,9034	0,6136	2,4696	0,1126
"	77.06.15.	"	X	2,1615	1,2314	0,8552	3,4634	0,1351
"	77.06.25.	"	X	2,3200	1,2098	0,8908	3,3505	0,1727
S06	77.06.09.	Spring S1	X	2,1786	1,1256	0,9739	3,6014	0,1494
"	77.06.15.	"	X	2,5884	1,3497	1,1826	4,3732	0,1600
S07	77.06.10.	Spring in Sigalda below Sigalda fall	X	1,9497	1,1692	0,9642	4,1057	0,1326
S14	77.06.08.	MW-2	X	2,1663	0,9226	0,6696	2,8297	0,1021
"	77.06.17.	"	X	2,3914	1,2442	0,9044	3,6382	0,1773
"	77.06.26.	"	X	2,5258	1,5057	1,1322	3,5114	0,1793
S15	77.06.08.	MW-3	X	1,8885	0,9964	0,8609	3,5555	0,1346
"	77.06.17.	"	X	2,5884	1,2021	1,0435	4,1527	0,1578
"	77.06.25.	"	X	2,5506	1,3178	1,1759	3,8775	0,1904
S16	77.06.08.	MW-4	X	1,8674	1,0439	0,9392	3,8863	0,1492
"	77.06.17.	"	X	2,6515	1,2746	1,1759	4,7057	0,1727
"	77.06.25.	"	X	2,3364	1,2883	1,1953	4,2796	0,1836

TABLE 8

CHEMICAL ANALYSES OF WATER SAMPLES

Mole-ratio [X]/[Cl^-]

Location number see location map	Date	Sampling station	Cl^-	SiO_2	Ca^{++}	Mg^{++}	Na^+	K^+
S25	77.06.09.	Spring S2	X	1,9620	1,1364	1,0750	4,1645	0,1525
"	77.06.15.	"	X	2,5884	1,3708	1,3566	5,1817	0,2118
"	77.06.26.	"	X	2,4477	1,3497	1,2522	4,7039	0,2032
S30	77.06.08.	Reservoir, inlet of headrace canal	X	1,5716	0,7972	0,4967	2,3461	0,1071
"	77.06.25.	"	X	2,3936	0,9993	0,9739	3,6806	0,1956
S31	77.06.09.	Springs from contact TH_{f-h}, to west from end of the dam	X	2,0289	1,0361	0,8545	3,1161	0,0959
"	77.06.15.	"	X	2,7668	1,4474	1,1402	3,9905	0,1284
S32	77.06.09.	Spring S3 close to drillhole VIII	X	1,8780	0,9332	0,9392	3,3626	0,1362
"	77.06.15.	"	X	2,5180	1,2231	1,1826	4,3364	0,1794
"	77.06.26.	"	X	2,2734	1,1938	1,3021	4,8318	0,1915
S33	77.06.08.	Headrace canal	X	1,4889	0,7794	0,4675	2,3152	0,1053
S34	77.06.10.	Close to eastern wall of power house	X	1,7510	1,0951	0,9031	3,5640	0,1073

TABLE 9

CHEMICAL ANALYSES OF WATER SAMPLES

Mole-ratio $[X]/[Cl^-]$

Location number see location map	Date	Sampling station	Cl^-	SiO_2	Ca^{++}	Mg^{++}	Na^+	K^+
S35	77.06.10.	Springs in Sigalda above Sigalda fall	X	1,3825	0,6732	0,5844	2,0065	0,0781
S36	77.06.09.	Drainage from dam close to PZ-3	X	2,0400	1,0528	0,7718	2,8249	0,1148
S37	77.06.30.	Spring in Bottom of reservoir	X	2,3914	1,4551	1,2870	4,7407	0,1773
"	77.07.21.	"	X	2,4209	1,7715	1,6034	5,4210	0,2148
S38	77.07.21.	Spring in Bottom of reservoir	X	2,5258	1,6829	1,7166	6,2125	0,2179
S39	77.07.21.	"	X	2,4477	1,6449	1,6348	5,3654	0,2118
S40	77.07.22.	"	X	2,4320	1,4419	1,6308	5,1330	0,2006
S41	77.07.23.	"	X	2,3083	1,4625	1,5628	5,1330	0,1879
S42	77.08.10.	"	X	2,1709	1,6067	1,8007	4,5586	0,1879

TABLE 10

CHEMICAL ANALYSES OF WATER SAMPLES

Mole-ratio [X] / [Cl^-]

Location number see location map	Date	Sampling station	Cl^-	SiO_2	Ca^{++}	Mg^{++}	Na^+	K^+
S04'	77.08.20.	MW-1	X	2,2507	1,5817	1,2174	4,5202	0,1751
"	77.09.05.	"	X	2,3070	1,2653	0,8696	3,4545	0,1405
"	77.10.02.	"	X	2,4519	1,3729	0,9496	3,8201	0,1339
S06	77.08.20.	Spring S1	X	2,5602	1,5184	1,2174	4,5937	0,1600
"	77.09.05.	"	X	2,9062	1,5321	1,2635	4,7556	0,1595
"	77.10.02.	"	X	2,5884	1,4762	1,2522	4,6304	0,1600
S25	77.08.20.	Spring S2	X	2,8104	1,7954	1,5399	6,1322	0,2110
"	77.09.05.	"	X	3,3603	2,0759	1,7805	6,9939	0,2468
"	77.10.02.	"	X	2,4707	1,4494	1,2949	4,9461	0,1692
S32	77.08.20.	Spring S3 close to drillhole VIII	X	2,2879	1,3192	1,3055	4,7946	0,1700
"	77.09.05.	"	X	2,4732	1,2977	1,3250	4,8817	0,1774
"	77.10.02.	"	X	2,5884	1,2653	1,3218	4,4099	0,1794
S43	77.08.20.	Spring in Bottom of reservoir	X	2,4136	1,1496	1,4920	6,5680	0,1545

TABLE 11

DAMSITE AREA

PERCENTAGE OF RESERVOIR WATER

Max. reservoir level 13th June 490,16 m

			Rising reservoir level		Falling reservoir level			
	Reservoir level		∿488,7	∿488,8	∿489,5	∿487,3	∿477,3	empty
			Date 77.06.08.	Date 77.06.09.	Date 77.06.15.	Date 77.06.17.	Date 77.06.25.	Date 77.06.26.
	Location number see location map	Sampling station	Reservoir water %	Reservoir water %	Reservoir water %	Reservoir water %	Reservoir water %	Reservoir water %
Measuring weirs	S04	MW-1	95		∿ 80		∿ 60	
	S14	MW-2	90-100			∿ 65		∿ 55
	S36	Drainage from dam close to PZ-3		95				
	S15	MW-3	75			55	∿ 40-50	
	S16	MW-4	65			40	∿ 40	
Springs	S06	Spring S1		65	50			
	S25	Spring S2		65	∿ 30			∿ 40
	S32	Spring S3		75	∿ 45			∿ 35
	S31	Springs from contact TH_{f-h}.		90	∿ 75			

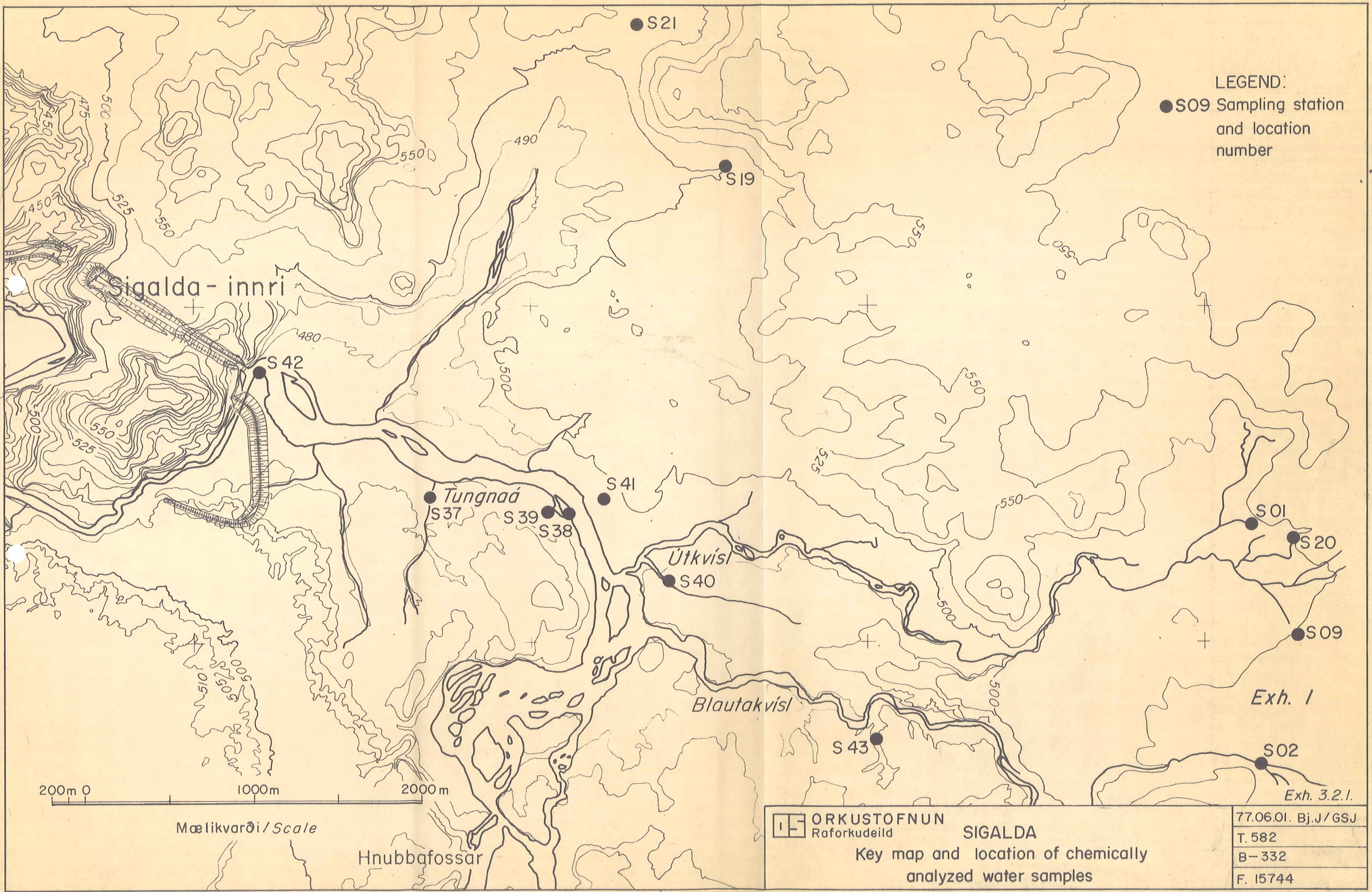
TABLE 12

HEADRACE AND RESERVOIR AREAS
PERCENTAGE OF RESERVOIR WATER

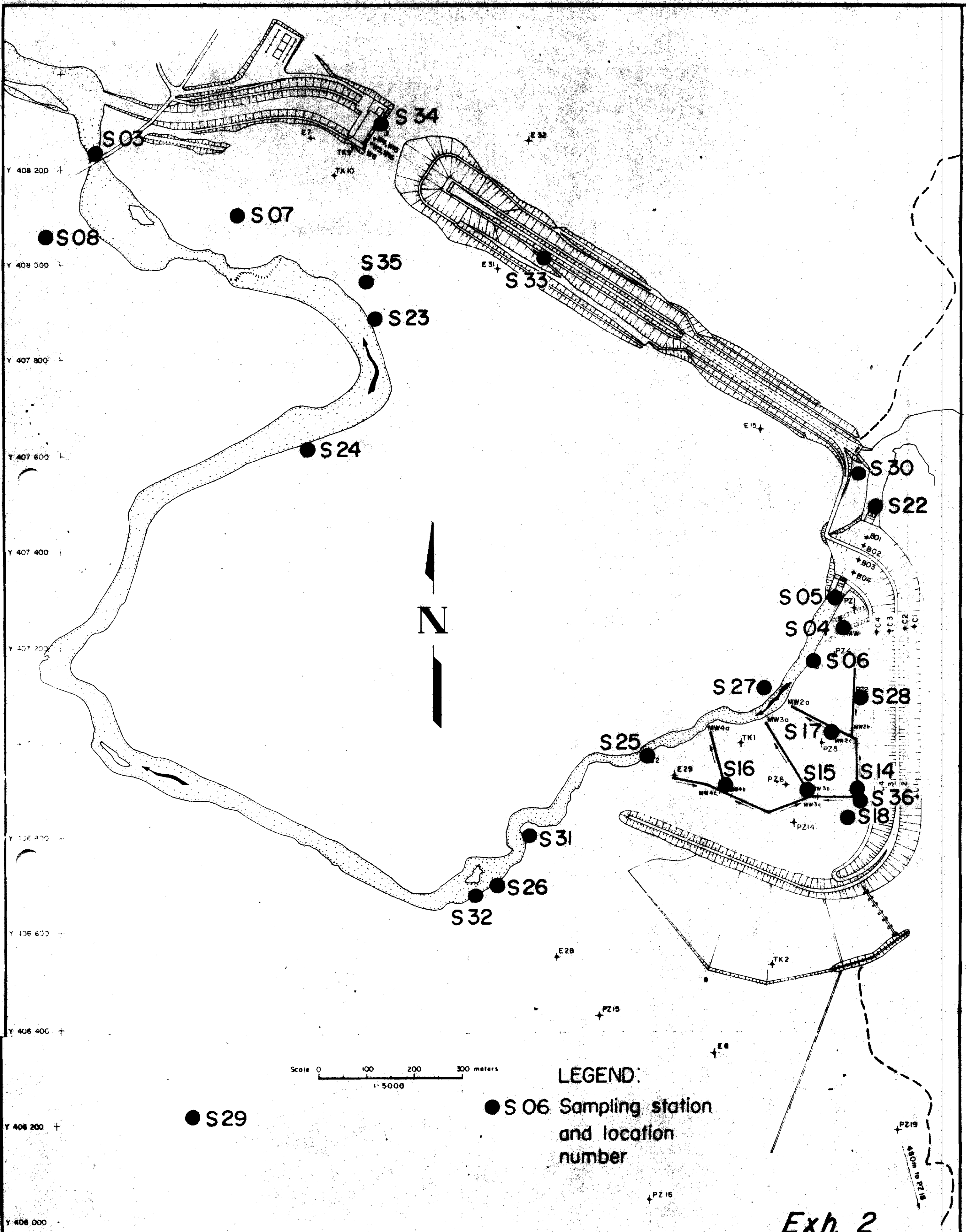
HEADRACE AREA

Max. reservoir level 13th June 490,16 m

Reservoir level		∿488,9	Empty	Empty
		Date 77.06.10.	Date 77.06.30.	Date 77.07.21.-23.
Location number see location map	Sampling station	Reservoir water %	Reservoir water %	Reservoir Water %
S07	Spring in Sigalda below Sigalda fall	65		
S34	Spring close to eastern wall of power house	95		
S35	Spring in Sigalda above Sigalda fall	100		
RESERVOIR AREA				
S37	Spring in bottom of reservoir		35-40	
"	"			5-10
S38	"			0
S39	"			5-10
S40	"			10-15
S41	"			15-25

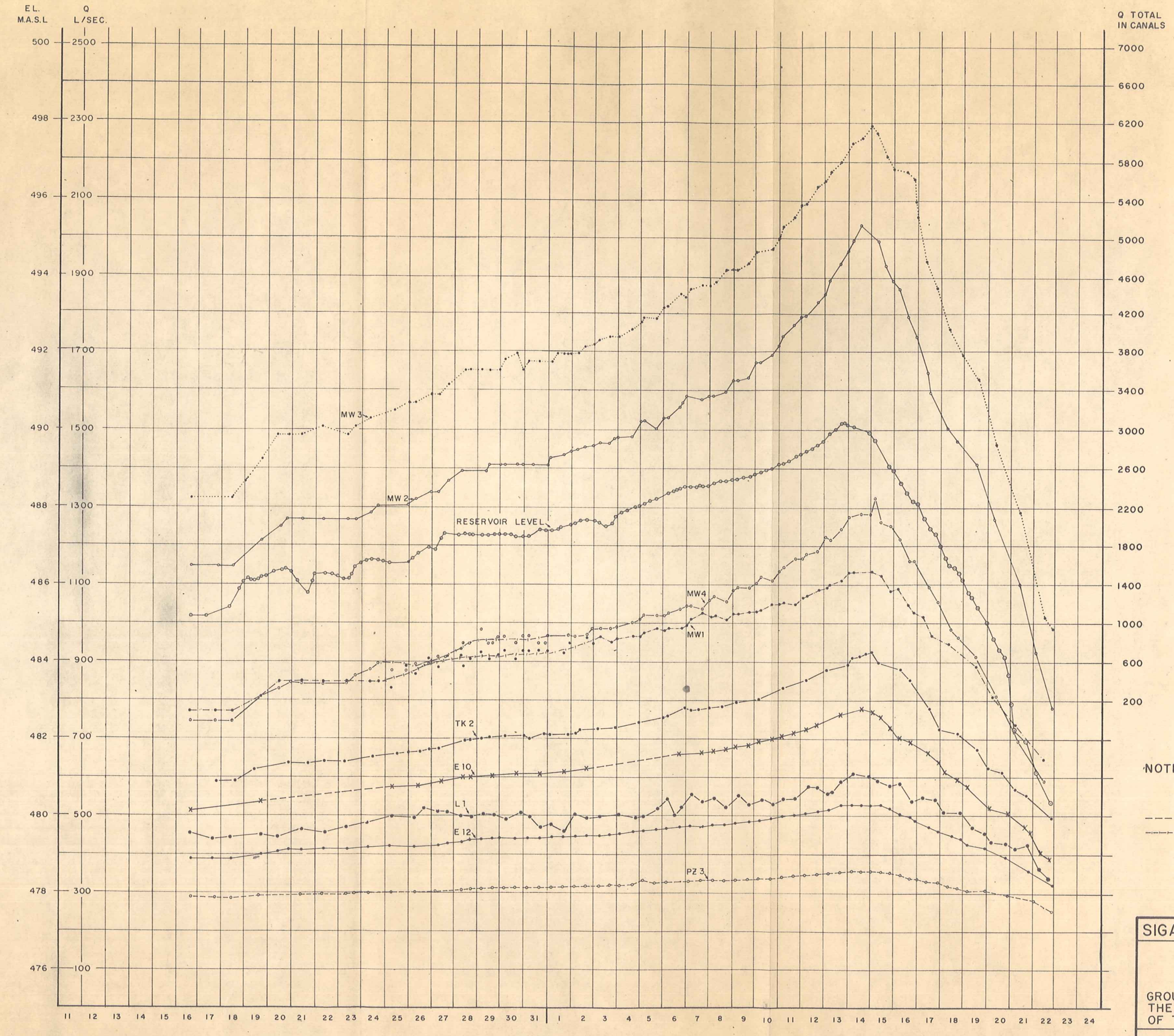


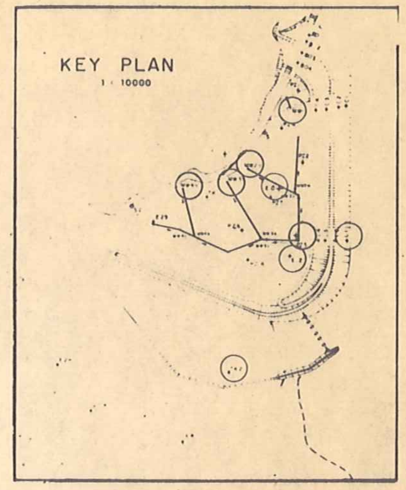
LEGEND:
S09 Sampling station and location number
Sigalda - innri
Tungnaá
Útkvísl
Blautakvísl
Hnubbafossar
S21
S19
S42
S41
S37
S39
S38
S40
S43
S01
S20
S09
S02
490
550
480
500
525
450
475
505
510
200m 0
1000m
2000m
Mælikvarði / Scale
Exh. 1
Exh. 3.2.1.
ORKUSTOFNUN
Raforkudeild
SIGALDA
Key map and location of chemically analyzed water samples
77.06.01. Bj.J/GSJ
T. 582
B-332
F. 15744



Exh. 2

ORKUSTOFNUN Raforkudeild SIGALDA Location of chemically analyzed water samples	77.06.01. Bj.J/GSJ T. 583 B-332 F. 15745





Exh. 3

NOTES:

FLUCTUATIONS FROM RESERVOIR EL. 485 SATURATED CONDITIONS TO 490 M.A.S.L. NOT SATURATED CONDITIONS.

--- PERIODS WITH NO OBTAINED INFORMATION

-·-·- FLUCTUATIONS IN LEAKAGE READINGS RELATED TO DIFFERENT JUDGMENT OF TWO SURVEYORS.

SIGALDA PROJECT	RESERVOIR

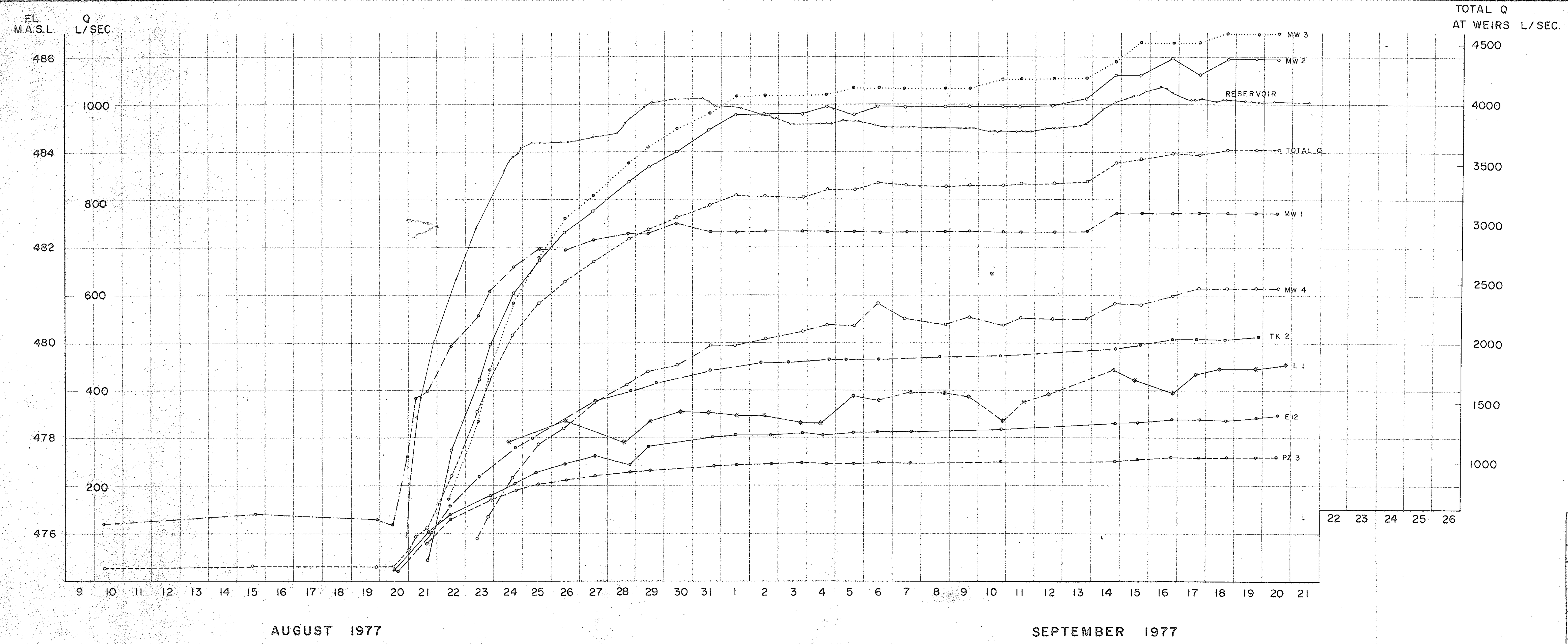
THIRD IMPOUNDING

DAM CONTROL DIAGRAM

GROUNDWATER AND LEAKAGE FLUCTUATION IN THE LAVA FLOWS TH_f AND TH_h DOWNSTREAM OF THE DAM. MAY 16th. – JUNE 22nd

LANDSVIRKJUN	Hannað. SR	Mkv.
THE NATIONAL POWER COMPANY, ICELAND	Teiknað. K.A.	Dags. 26.06.'77
Samþ. Pálmi Hannesson	Yfirfarið. P.	Nr. S-F-89e

Nr	Breyting	Dags.	Hannað	Teiknað	Samþ.



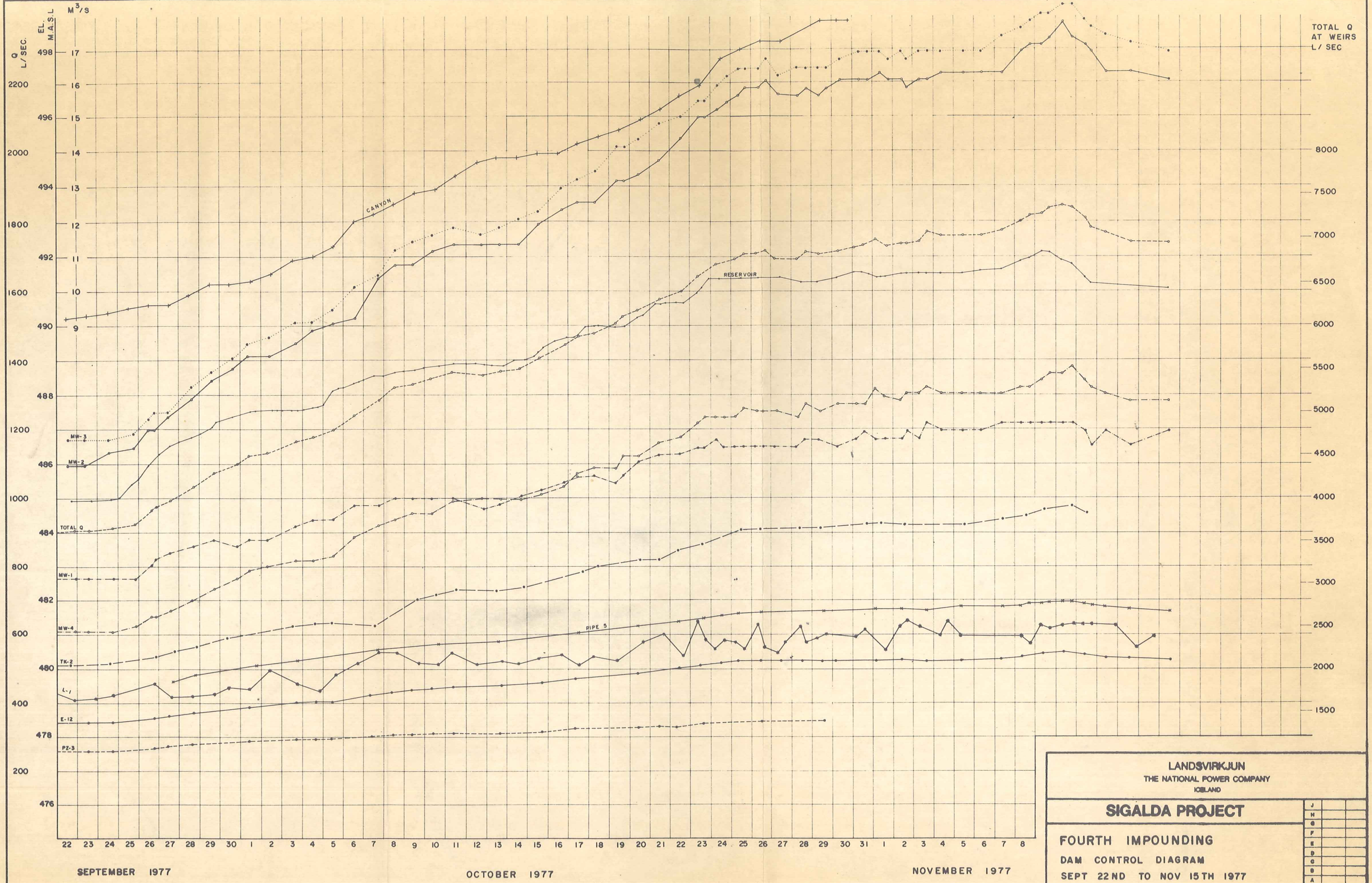
Exh. 4

LANDSVIRKJUN
THE NATIONAL POWER COMPANY
ICELAND

SIGALDA PROJECT

FOURTH IMPOUNDING
DAM CONTROL DIAGRAM
AUG 10TH TO SEPT 20TH 1977

ELECTRO-WATT CONSULTING ENGINEERS ZURICH	VIRKIR REYKJAVIK
DRA.	D. S.
CHE.	S. St. J.
DATE	26. I. 1978
DRAWING NUMBER	1 2 9 2 1 5 8 2 7 0



Exh. 5

LANDSVIRKJUN
THE NATIONAL POWER COMPANY
ICELAND

SIGALDA PROJECT

FOURTH IMPOUNDING
DAM CONTROL DIAGRAM
SEPT 22ND TO NOV 15TH 1977

ELECTRO-WATT — VIRKIR
CONSULTING ENGINEERS
ZURICH — REYKJAVIK

DRA. P.S
CHE. S. St. A.

DATE 26. 1. 1978
DRAWING NUMBER 1 2 9 2 1 5 8 2 7 1