ORKUSTOFNUN
Jarðhitadeild

STAÐUR
HYDROLOGICAL INVESTIGATIONS
PREFEASIBILITY REPORT
Final results

Orkustofnun
Vatnaskil Consulting Engineers
Prepared for Iceland Salmon Ltd.

OS-85010/JHD-02 Mars 1985

ORKUSTOFNUN
Grensásvegi 9, 108 Reykjavík

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ORKUSTOFNUN
NATIONAL ENERGY AUTHORITY

Our date
1985-03-04
Your date

Our ref.
VOD/340/8933/8-1985/FS
Your ref.

ICELAND SALMON, Ltd.
Suðurlandsbraut 32
108 REYKJAVÍK

Re.: HYDROLOGICAL INVESTIGATIONS AT STADUR.

The second phase of the investigation on the freshwater and seawater supply for a proposed aquaculture complex at Stadur is now completed. It was carried out by the National Energy Authority and Vatnaskil Consulting Engineers Ltd.

The results of the first phase have already been presented to you in a preliminary report. As it contains much of the data compiled for the purpose of the investigations, we shall not repeat these data in the present final report, but concentrate on a short review and summation of the most important results. The report is divided into two parts:

1. Summary of results.
2. Results of the second phase with a review of the first phase.

It is our opinion, that it is convenient to bring the investigations to a close at this stage by this prefeasibility report on the water supply, although it is obvious that in the case of exploitation some further research will inevitably become necessary.

Sincerely yours,

Freysteinn Sigurðsson
group leader in commission

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SUMMARY OF RESULTS

1. FRESHWATER INVESTIGATIONS

1.1 The Stadur area is a part of a groundwater basin stretching south to the coast from the central parts of Reykjanes peninsula. It is bordered on both sides by rows of hyaloclastite mountains, some rising above the lava field, some buried beneath it. The groundwater flows predominantly along scoriaceous contacts between or in the lava-flows, so the bedrock is very permeable. This permeability is enchanced by numerous tectonic fissures, running SW-NE. The proposed location for extraction of freshwater is at the fissure Lambagja, 1.4 km from the coast.

1.2 Because of anisotropy in the Lambagja area the transmissivity is greatest in SW-NE direction being of the value 6.3 m^2/s (permeability 0.32 m/s) whereas in SE-NW direction the value is 2.1 m^2/s (permeability 0.11 m/s). Due to the high permeability strong tidal response is observed reaching 40% at the Graenabergsgja and 30% at Lambagja, which means 0.7-1.0 m variation in groundwater level in Lambagja. High and low tide appear about 2 hours and 20 minutes later than at the coast. Further inland, as in the fissure Hrafnagja some 1800 m NE from Lambagja, the amplitude ratio is down to 8%.

1.3 The equivalent thickness of the freshwater lens in the Lambagja area is 20 m. In the center of the peninsula the thickness is 50 m. Maximum permissible drawdown in Lambagja is 6 cm. The results of the investigation indicate that at least 350 l/s can be pumped from Lambagja without danger of seawater intrusion (upconing).

1.4 A step drawdown test was conducted in Lambagja from November 24 to December 7 1984. A drawdown of maximum 1 cm was observed when the pumping rate was 150 l/s. The temperature of the pumped water was 7°C and the salinity fluctuated around 2 o/oo. The water was saturated with oxygen. The chloride content in the pumped water was 800-1400 ppm Cl^- fluctuating due to tidal effects. Pumping af 350 l/s might increase the salinity slightly. In order to decrease this entrainment process the fissure has been filled partly with gravel. Freshwater with less than 1 o/oo salinity is available 1 km further inland in NE-direction.

2. SEAWATER INVESTIGATIONS

2.1 From January 24 to 28, 1985 a pumping test was conducted in an excavation in Stadargja at both high and low tide. The excavation was approximately 5.4 m in diameter and reached 0.5 m below low tide.

The pumping test of the excavation produced the following results:

1. Pumping rate 200 l/s.
2. Temperature of pumped water 6.5°C.
3. Salinity of pumped water 6-8 o/oo.
4. Oxygen concentration of pumped water 9.5 ppm.
5. Drawdown in excavation 29 cm.
6. Drawdown in an observation well 55 meters away 3 cm.
7. Transmissivity 1.5-2.5 m^2/s (permeability 0.09-0.15 m/s).

Transmissivity estimated from tidal response analysis is in good agreement with the results of the pumping test.

2.2 The equivalent thickness of the "freshwater" lens in the Stadargja area is 17 m. Calculations show that this site can be expected to yield 250 l/s of water with salinity greater than 7 o/oo. It is recommended that the initial total pumping rate of freshwater from Lambagja and pumping from Stadargja does not exceed 600 l/s

2.3 Due to the high permeability strong tidal response is observed in Stadargja. The amplitude ratio is 60% corresponding to 1-2 m variation in groundwater level. High and low tide appear about one hour later than at the coast.

2.4 Another pumping test was conducted in Stadargja from February 1 to February 6 1985, this time closer to the sea than the first one. The test was conducted at both high and low tide. The test produced the following results:

1. Pumping rate 215 l/s.
2. Temperature of pumped water 0.1-5°C depending on the amount of surface runoff from a pond in direct contact to the sea at high tide.
3. Salinity 7-26 o/oo also depending on the amount of surface runoff from the pond created behind the "seawall" at each high tide. For higher pumping rates the surface runoff would not be sufficient to maintain the high salinity.

4. Oxygen concentration 7 ppm.
5. Drawdown in an observation well 30 m away 2.5 cm.
6. Transmissivity 1.5-2.0 m^2/s (permeability 0.09-0.12 m/s)

Transmissivity values estimated from tidal response analysis in observation wells close to the pumping site are in good agreement with the results of the pumping test.

2.5 The results to date indicate that it will be impossible to supply seawater from surface fissures or from shallow wells in the vicinity of Stadargja. The reason for this is the presence of a freshwater lens that is approximately 17 m thick.

2.6 Three observation wells were drilled just behind the "seawall". Tidal response analysis shows that the amplitude ratio is 70% and high and low tides appear half an hour later than at the coast. The estimated transmissivity is 0.6-0.9 m^2/s (permeability 0.04-0.06 m/s). This permeability is high and corresponds to the permeability of fine gravel.

2.7 The main conclusions to be drawn from well logs and downhole samples from the wells close to the "seawall" are the following:

1. The maximum salinity found so far is 20-30 o/oo.
2. The uppermost 15 m in the wells have water with lower salinity, or roughly 10-15 o/oo.
3. The temperature of the saline water in the wells is approximately 5°C , at this time of the year, and the more dilute part has slightly higher temperature (6.5°C).
4. The oxygen content is 6-7 ppm in the uppermost part of the wells. Samples collected close to the well bottom confirms 2-5 ppm oxygen. This concentration is less than half as compared to that in water saturated with oxygen at this temperature.
5. The iron content in samples from wells SH-9, 11, 12, 13 have been measured up to 200 ppb.
6. The tidal response measurement shows favorable permeability in the area close to the shore as a whole. In spite of this the water is surprisingly low in salinity and oxygen.

2.8 We recommend that a large diameter well be drilled close to the sea to test the yield of such a well and to monitor any change in the chemical composition. The well should be drilled to 35-40 m depth and the top 15 m cased off. It would be wise to consider the position of the floodlevel when siting the well.

The high value of the observed transmissivity (permeability) indicates that the drawdown in the well will not be the determining factor for the future useability of the well, as up to 300 l/s can probably be withdrawn. The exact yield must however be determined by a pumping test, which is also necessary to find out if the salinity and oxygen content of the pumped water increases from the values already observed.

1 INTRODUCTION

This report is a summary of the groundwater research done so far at Stadur in Grindavik, as requested by Iceland Salmon Ltd. It was carried out by the National Energy Authority of Iceland (NEA) and Vatnaskil Consulting Engineers Ltd. Preliminary results were presented in a report in December 1984, "Stadur Hydrological Investigations. Prefeasibility Report OS-84096/JHD-43 B".

The Stadur area is a part of a groundwater basin stretching south to the coast from the central parts of the Reykjanes peninsula. It is bordered on both sides by rows of hyaloclastite mountains, some rising above the lava field, some buried beneath it. The groundwater flows predominantly along scoriaceous contacts between or in the lava-flows, so the bedrock is very permeable. This permeability is enhanced by numerous tectonic fissures, running SW-NE. The extent of the basin is approximately 10-12 km in SW-NE direction and approximately 6 km NW-SE. The proposed location for extraction of seawater is in the Stadargja area, and the proposed freshwater site is at the fissure Lambagja 1.4 km from the coast.

Figure 1 is a location map of the Stadur area showing the main fissures and all observation wells. Figure 2 is a location map of the Stadargja area.

2 TIDAL RESPONSE

Tidal response has been recorded in all the wells and fissures in the area, see location map. The response at Lambagja and observation well SH-11 are shown as examples on figs. 3 and 4. Amplitude ratio and timelag is given in table 1. As can be seen from the table and figure 5 the amplitude ratio decreases with increasing distance from the shore and timelag increases as expected. The diffusivity, T/S, is shown in the table estimated both from the amplitude ratio and the timelag. The diffusivity is small at the coast indicating smaller transmissivity (permeability) than in the Lambagja area.

TABLE 1 Results from tidal response analysis

Observation well	Amplitude ratio %	Timelag hours	T/S from amplitude ratio m^2/s	T/S from timelag m^2/s
SH-13	67.4	0.53	5	10
SH-12	71.6	0.52	9	14
SH-11	70.1	0.75	13	11
SH-10	68.2	0.80	11	10
SH-9	62.7		13	
Stadargja, A	70.0		22	
Stadargja, B	55.9	0.83	19	35
SH-1	63.1	1.32	21	10
SH-2	58.9	0.95	33	39
SH-3	50.6	1.43	20	17
SH-5	24.7	2.67	2	2
SH-6	37.5	1.65	19	25
Stadarbergsgja	49.7	1.23	36	45
Graenabergsgja	40.8	1.90	107	91
SH-4	37.5	2.08	98	83
SH-7	29.2	2.03	85	120
Lambagja	30.8	2.28	94	95

3 WELL-LOGS, TEMPERATURE AND RESISTIVITY

In the Stadur-area water is accessible in open fissures, as well as in a number of boreholes, which have been drilled in connection with the present investigation (observation wells SH-1 - SH-13). These wells have been logged for temperature and electrical resistivity in the groundwater. The resistivity is measured as conductivity and converted to resistivity. The absolute values of the temperature may have an error as great as +/- 0.2^{o}C, or even more in extreme cases. The conductivity of the water depends on its chemical contents. It has in most cases a composition comparable to diluted seawater.

Some of the resistivity and temperature logs are shown on figs. 6 and 7. On the figures both resistivity and salinity are given. On figure 6 we see clearly how the salinity increases towards the coast. In the fissure in Toftarkrokar some 3 km from the shore salinity is less than 1 o/oo corresponding to chloride content near to or just above 200 ppm Cl^-. The resistivity log in Lambagja shows that the top 17 m are freshwater, salinity around 2 o/oo, then there is a 5-6 m zone of brackish water and below that seawater. According to the resistivity profile there is a salinity gradient in Lambagja, the salinity increasing perhaps 100-200 ppm Cl^- from surface down to depth of 9 m.

Observation wells SH-2 and SH-3 are only 300 m from the coast at Stadur, but there is no clear freshwater layer in the wells as in Lambagja. The chloride content is most likely higher than 3000 ppm Cl^- in the top 10 m of the wells.

While salinity increases towards the coast, temperature decreases, as can be seen on figure 6.

The results of the resistivity and temperature logs in wells close to the shore (figure 7), show that the temperature and salinity profiles in all the wells are virtually the same. The difference in temperature in the top 10 m of SH-11 and SH-12 is most likely because SH-12 is close to the pond at the "seawall" (figure 2), and may therefore be receiving sewater from the surface.

Figure 8 shows a schematic profile of the groundwater layer at Stadur. The figure is based on temperature and resistivity logs.

4 WELL TESTING

4.1 Well testing of Stadargja

Two pumping tests were conducted in Stadargja with a submergible pump. The first one was from January 24 to 28 1985, at an excavation made in the Stadargja fissure marked P1 in figure 2. With the help of a datalogger waterlevel at three places, air and water temperature and flowrate were measured and stored for future use. The pumping test was conducted at both high and low tide. During pumping groundwater level was measured at pumping site, in SH-3 and at observation site B (see fig. 2). Figure 9 shows an example of the measured drawdown and pumping rate. Measured drawdown was 28-30 cm at pumping site and 2.5-3.0 cm at observation site B for 200 l/s pumping rate. None or very little drawdown was measured in SH-3. Turbulent drawdown which is about 90% of the drawdown at the pumping site can be avoided by deeper wells.

Results from calculations are that porosity, S, lies in the interval 6-9% and transmissivity, T, in the interval 1.5-2.5 m^2/s and permeability 0.09-0.15 m/s. In table 2 transmissivity from tidal response is shown for observation sites A and B and wells close to Stadargja, using porosity, S=7.5%. By using the mean groundwater level to estimate the thickness of the "freshwater" lens the permeability is calculated, and also given in the table.

TABLE 2 Transmissivity and permeability from tidal response and well testing

Observation well	Transmissivity m^2/s	Permeability m/s
Stadargja, A	1.7	0.10
Stadargja, B	2.0	0.11
SH-3	1.4	0.08
SH-9	1.0	0.06
SH-10	0.8	0.05
SH-2	2.7	0.15
SH-1	1.2	0.08
SH-13	0.6	0.04
SH-12	0.9	0.06
SH-11	0.9	0.06

As can be seen in table 2 transmissivity calculated from tidal response in Stadargja is in good agreement with the transmissivity calculated from pumping test. Table 2 shows clearly that the transmissivity at the "seawall" is a little lower than in the Stadargja area, but on the whole very high. The salinity and cloride content of the pumped water are listed in table 3. The temperature remained fairly constant, about 6.5°C.

TABLE 3 Salinity and chloride content of pumped water at pumping site P1

Date	Time	Cloride content ppm	Salinity o/oo
85.01.24	11.15		6.0
"	13.14		6.2
"	14.00		6.3
"	14.30		6.2
"	16.00		6.2
"	17.05	3725	6.9
"	17.50	3798	6.9
85.01.25	10.14	4392	7.7
"	11.30	4205	7.4
"	14.55		6.9
"	16.40		6.8
85.01.26	9.45		8.1
"	11.00		7.6
"	12.25		7.5
"	14.45		
"	16.00		7.3
85.01.27	14.00	4009	7.2
"	16.30		7.0
85.01.28	13.30	4303	7.3

The small variations in salinity are due to tidal effects.

The second pumping test that was conducted in Stadargja from February 1 to February 6 1985 was at observation site marked A on figure 2. Very little drawdown was observed. Measured salinity and temperature of pumped water is listed in table 4.

TABLE 4 Salinity and temperature of pumped water at pumping site A

Date	Time	Salinity o/oo	Temperature °C
85.02.01	14.00	7.0	
"	14.35	9.0	
"	15.00	9.6	4.9
"	15.40	10.0	2.9
"	16.10	25.0	0.1
"	16.15	26.2	
85.02.05	15.10	15.4	5.0
"	15.35	14.3	5.0
"	16.45	14.9	
"	22.00	25.5	
"	22.30	24.2	3.9
"	23.30	20.3	4.2
"	24.00	18.9	4.4
85.02.06	00.30	17.5	4.5
"	01.00	15.9	4.6
"	01.30	15.6	4.7
"	10.30	31.3	3.6
"	11.00	27.5	3.6
"	11.55	23.9	4.3
"	12.40	22.0	4.5
"	13.00	21.2	4.2
"	13.30	19.0	4.6
"	14.00	18.0	4.7
"	14.15	16.0	4.7
"	14.30	17.1	4.7
"	14.45	16.0	4.9
"	15.00	16.2	4.9
"	15.15	16.0	4.9
"	15.30	17.0	4.9
"	16.00	16.4	4.9

Table 4 shows that there is a great variation in the salinity. From figure 10 we can see that the variation is due to tidal effect. Fig. 2 shows that surface runoff from a pond in direct contact to the sea at high tide, flows into Stadargja at the pumping site. This causes more salinity of the pumped water at high tide. For higher pumping rates than in the pump test the surface runoff would not be sufficient to maintain the high salinity.

4.2 Well testing of Lambagja

The testing of Lambagja was conducted in the period November 24 to December 7 1984 with the same equipment as in Stadargja. Due to great variation of the watertable from tides and infiltration it was very difficult to analyse the results although the pumping test was conducted at either high or low tide. Results of the pumping test show about 1 cm drawdown in the fissure for 150 l/s pumping rate. Estimated porosity, S, is between 8-10%, transmissivity, T, between 7-10 m^2/s and permeability 0.36-0.51 m/s. Using S=9% we see from the tidal response analysis (table 1) that transmissivity, T, for Lambagja is 8.6 m^2/s, which is in a good agreement with the above value.

The available chloride analyses are given in table 5. The temperature of the pumped water was fairly constant about 7 ^oC. The tidal fluctuations in Lambagja during the testing period are given on fig. 11. The chloride content is also shown on the figure. Figure 12 shows the groundwater elevation in Lambagja versus chloride content in ppm. For higher tides and pumping rates the chloride content will exceed 1400 ppm. In order to decrease this entrainment process the fissure has been filled partly with gravel. The undisturbed chloride content decreases linearly with the tidal amplitude ratio. Tidal amplitude ratio of 15% corresponds to 200 ppm undisturbed chloride content. According to fig. 5 this ratio is reached at a distance of 2300 m from the coast.

TABLE 5 Chloride content and salinity of pumped water in Lambagja

Date	Time	Chloride content ppm	Salinity o/oo
84.11.24	15.05	965	1.8
84.11.26	10.30	1166	2.0
84.11.26	11.30	1234	2.3
84.11.26	14.08	1113	2.1
84.11.26	14.35	1068	2.0
84.11.26	17.35	1040	1.9
84.11.26	22.09	1247	2.3
84.11.27	10.55	1325	2.4
84.11.27	17.00	1041	2.1
84.11.28	13.45	1142	2.2
84.11.28	22.35	1032	2.1
84.11.29	12.00	1131	2.1
84.11.29	23.00	918	1.9
84.11.30	13.15	1007	1.8
84.11.30	15.00	985	1.8
84.11.30	17.00	874	1.7
84.12.01	00.50	874	1.8
84.12.01	12.00	830	1.7
84.12.02	00.05	791	1.7
84.12.02	12.30	793	1.7
84.12.03	13.06	813	1.7

5 GROUNDWATER MODELLING

The basis for the groundwater modelling is the hydrogeological map in the report prepared for the Sudurnes Regional Heating "SVARTSENGI I. Grunnvatnsrannsoknir vegna ferskvatnsoflunar fyrir varmaorkuver", Orkustofnun 1980. In cooperation with Mr. Freysteinn Sigurdsson, geologist, the original hydrogeological map has been revised at the Stadur area, see "Stadur Hydrological Investigations. Prefeasibility Report OS-84096/JHD-43B". The main difference from the original map is the tighter formations at the coast. This was confirmed by the results of the tidal response calculations and permeability estimates.

The result of these calculations is shown on figure 13. The following four cases have been calculated:

1) Pumping of 100 l/s from Lambagja
2) Pumping of 350 l/s from Lambagja
3) Pumping of 700 l/s from Lambagja
4) Pumping of 350 l/s from Lambagja and 150 l/s from Husatoftir area.

On figure 14 results from case 2 are shown. More detailed figure of groundwater level for all five cases are in the prefeasibility report see "Stadur, Hydrological Investigations. Prefeasibility Report OS-84096/JHD-43B".

The transmissivity in the model is estimated by matching the model calculations with the measured mean groundwater level. The results are listed in table 6 along with transmissivity from well testing and tidal response, where well numbers and fissures are used for references.

TABLE 6 Transmissivity in the Stadur area

Observation site	Transmissivity from tidal response m^2/s	Transmissivity from well testing m^2/s	Transmissivity in model m^2/s
Stadargja, A	1.7	1.5-2.5	0.73
Stadargja, B	2.0	1.5-2.5	0.73
SH-1	1.2		0.50
SH-2	2.7		0.81
SH-3	1.4		0.81
SH-9	1.0		0.73
SH-10	0.8		0.73
SH-11	0.9		0.32
SH-12	0.9		0.32
SH-13	0.6		0.32
Lambagja	8.6	7.0-10.0	6.3
SH-7	9.2	7.0-10.0	6.3

As can be seen in the table transmissivity in the model is lower than transmissivity calculated from tidal response and well testing. Our estimation of the freshwater yield of Lambagja is based on the transmissivities in the model, and should therefore be on the safe side. Drawdown calculations with the model show that 350 l/s can be pumped from Lambagja without danger of seawater intrusion. Calculations with the model also indicate that pumping of 150 l/s at

Husatoftir has very small effect on the groundwater level in the Stadur area.

6 CHEMICAL ANALYSES OF FRESH AND SALINE WATER

The analysis of "freshwater" samples from fissures and wells at Stadur are compiled in table 7 and analysis of "seawater" in table 8. In table 9 are shown measurements of conductivity, oxygen and iron concentration of deepwater from the seawater wells SH-9, 11, 12 and 13. The analytical methods used for analyse are described in appendix.

A minimum of ten major chemical components were analysed in all samples listed in tables 7 and 8 except in the two samples from Stadargja by the lagoon where further analyse was considered useless.

Four of the "freshwater" samples were analysed for several heavy metals and six for iron, ammonium, nitrate and nitrite. Oxygen was measured wherever possible due to sampling method.

The concentration of all major components, sulphate and the cations, is found to be balanced by the salinity. This is to be expected in cold groundwater infiltrated by seawater.

The concentration of iron in the freshwater is well below 50 ppb in all but the sample from the fissure by well SH-4. There the concentration is 90 ppb. The concentration of other metals in the "freshwater" samples is also quite low although it is somewhat variable.

In the seawater samples iron concentration is also low, but in Stadargja there appears to be an increase in iron concentration by time of pumping. In Stadargja by the lagoon and in the seawater wells SH-9, 11, 12 and 13 the concentration of iron is higher than in the other seawater samples. There it exceeds 100 ppb but as the measurements were done with a poorer accuracy than the others the exact concentration is not known. The concentration of iron in seawater just outside the coast of Stadur is less than 1/10 of the concentration in those samples. The samples of deep water are undersaturated with respect to oxygen, whereas the pumped water is not far from saturation. The decrease in oxygen content by depth is clearly displayed in table 9.

TABLE 7 Freshwater analyses

Sampling Site	Lambagjá fissure 1 m depth	Lambagjá fissure 7 m depth	Grænabergsgjá fissure	Fissure near SH-4	Lambagjá fissure Pump test	Lambagjá fissure Pump test	Lambagjá fissure Pump test	Staðarbergsgjá 5 m depth	Staðarbergsgjá 9 m depth
Sample no	840096	840097	840098	840099	840103	840107	840109	850015	850014
Sampling date	84-11-06	84-11-06	84-11-06	84-11-12	84-11-27	84-11-30	84-12-07	85-01-16	85-01-16
pH/°C	7.30/22.1	7.33/22.1	7.53/22.1	7.48/21.5	7.62/21.5	7.59/20.2	7.60/20.8	7.68/22	7.72/28.6
Conductivity (micro-S at 21.0°C	2200	2300	4810	4410	3450	3190	2490	6210	6620
SiO_2 (mg/l)	15.1	14.8	14.2	13.9	15.8	15.8	16.0	14.4	14.5
Na^+ (mg/l)	354	372	809	737	556	518	398	1117	1215
K^+ (mg/l)	14.1	14.8	34.0	30.7	21.1	19.7	15.7	46.0	50.5
Ca^{++} (mg/l)	35.1	36.4	55.8	51.5	48.2	44.9	37.8	63.2	68.4
Mg^{++} (mg/l)	44.2	46.2	96.1	89.5	67.0	63.8	47.9	133.6	145.9
Total carbonate (as mg CO_2/l)	21.0	21.9	28.9	26.3	25.4	23.4	21.9	30.5	33.3
Br^- (mg/l)	2.4	2.5	5.3	5.1	3.9	3.4			
SO_4^{--} (mg/l)	80.6	87.0	194.0	180.0	134.0	121.0	90.0	266.4	289.0
Cl^- (mg/l)	674	718	1557	1416	1034	957	750	2065	2220
O_2 (mg/l)	n.m.	n.m.	4.5	7.0	9.0	9.0	9.0		
NH_3 (as micro-mol N/l)	0.3	0.4	0.4	0.5	0.3	0.1			
NO_2 (as micro-mol N/l)	0.1	0.1	0.1	0.1	0.1	0.1			
NO_2^- + NO_3^- as micromol N/l)	5.0	4.9	3.9	4.3	5.4	4.6			
Fe (total)(micro-g/l)	15	31	25	90	38	38			
Al (total)(micro-g/l)	40	10			10	15	35	0	0
Cu (total)(micro-g/l)	2.8	3.0			1.7	1.5			
Zn (total)(micro-g/l)	13.3	22.8			4.7	3.1			
Pb (total)(micro-g/l)	<1	<1			<1	<1			
Cd (total)(micro-g/l)	<1	<1			<1	<1			
Hg (total)(nano-g/l)	<10	<10			<10	<10			

Table 8 Seawater analyses

Sampling Site	Seawater well SH-2 10m depth	Seawater well SH-2 40m depth	Staðargjá ** pumping of seawater	Staðargjá ** pumping of seawater	Staðargjá *** at lagoon	Staðargjá *** at lagoon	Seawater offshore	Seawater at 35‰ salinity (Turekian,1969)
Sample no.	840100	840101	850022	850023	850026	850027	840102	
Sampling date	84-11-12	84-11-12	85-01-25	85-01-28	85-02-06	85-02-06	84-12-25	
pH/°C	6.92/21.5	7.83/21.5	7.82/21.0	7.80/21.1	7.90/21.8	7.96/21.8	7.96/21.5	8.0/25
Conductivity (micro-S at 21.0°C)	10900	38500	10500	11110	25000	41670	45500	
SiO_2 (mg/l)	11.6	4.3	13.2	13.0			1.5	2.9
Na^+ (mg/l)	1996	8247	2107	2263			9717	10800
K^+ (mg/l)	89.2	361.0	88.2	92.7			415.0	390
Ca^{++} (mg/l)	95.6	323	98.5	105			381	410
Mg^{++} (mg/l)	235	1021	261	277	605	1062	1223	1290
Total carbonate (as mg CO_2/l)	53.1	87.5	40.8	40.4			103.0	102.0
Br^- (mg/l)	13.2	54.8	-	-			67.9	67.0
SO_4^{--} (mg/l)	508	2122	514	552.6	1278	2282	2531	2710
Cl^- (mg/l)	3784	15985	3865	4173	9370	16776	18037	19400
O_2 (mg/l)	4.5	2	9			7		
NH_3 (as micromol N/l)	4.7	1.4					1.5	
NO_2 (as micromol N/l)	3.1	0.4					0.6	
NO_2^- 0 NO_3^- (as micromol N/l)	9.1	10.1					11.8	
Fe (total)(micro-g/l)	75	35	0	<100*	ca 100*	ca 150*	10	3.4

* not by graphite furnace

** pumping site P1 (fig 2)

*** pumping site A (fig 2)

Table 9 Oxygen, iron and conductivity of deepwater from SH-9, 11, 12 and 13 at Staður

Sampling site	SH-9	SH-11	SH-11	SH-11	SH-11	SH-12	SH-12	SH-12	SH-12	SH-13
Sample no.	850097	850096	850095	850094	850093	850092	850091	850090	850089	850088
Depth (m)	29	30	25	15	5	38	25	14	6	38
Date of sampling	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01	85-03-01
Conductivity (in micro S)	36000	36000	35000	29000	14500	38000	35000	29000	24000	40000
Fe (mg/l)	ca 0.1	<0.1	<0.1	ca 0.1	<0.1	ca 0.2	ca 0.15	ca 0.15	<0.1	0.2
O_2 (mg/l)	4.5	4.5	7	6	8	5	7	7	7	5

7 YIELD OF THE STADUR AREA

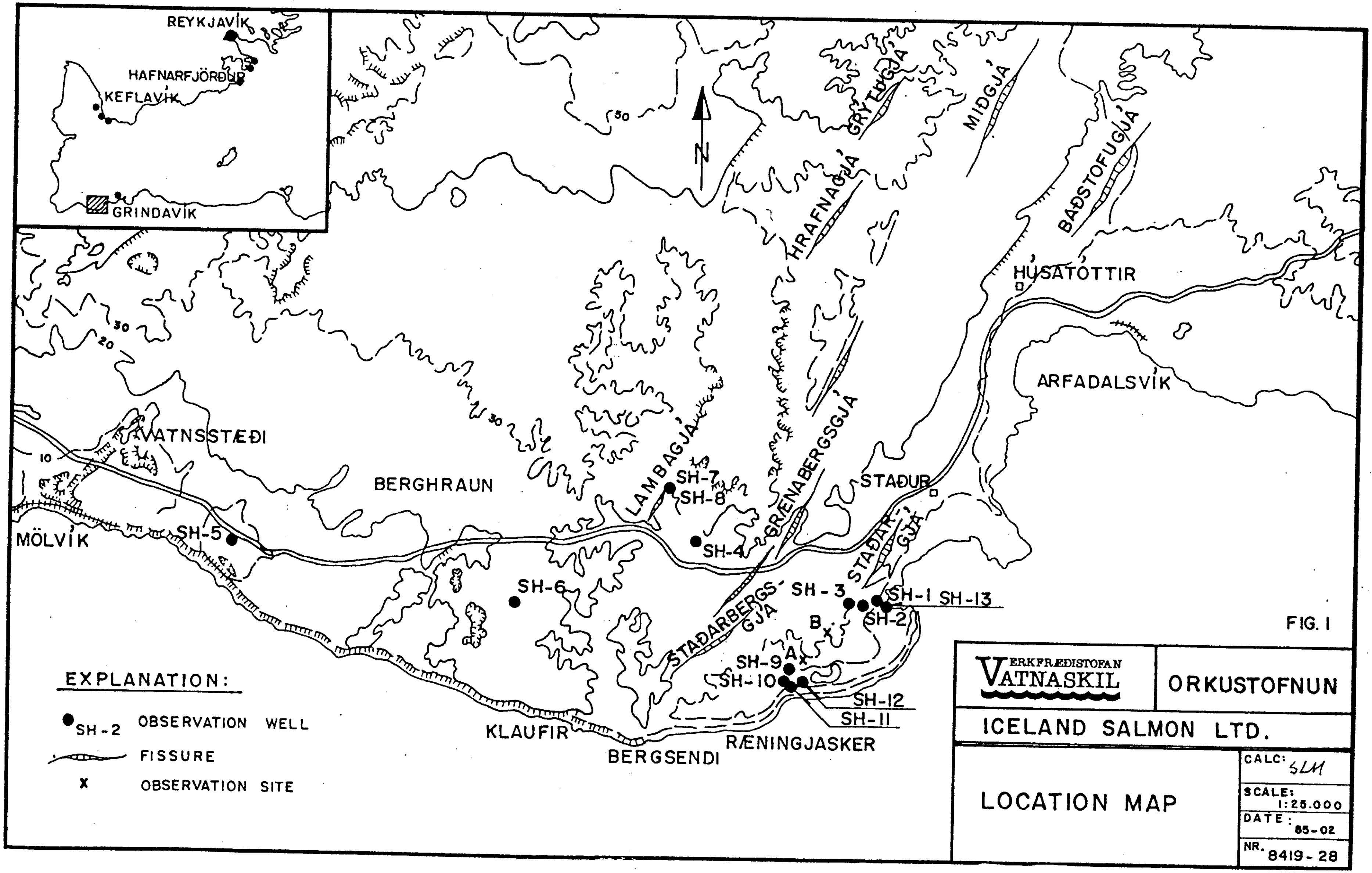
From well-logs in Lambagja (figure 6) it is clear that there is seawater below 20 m depth. There is therefore danger of seawater intrusion (upconing) when freshwater is withdrawn from Lambagja. Calculations show, that to avoid upconing maximum permissible drawdown in Lambagja is 6 cm. The results of the investigation indicate that at least 350 l/s can be pumped from Lambagja without danger of seawater intrusion. It is to be noted that pumping of 350 l/s from Lambagja might increase the salinity of the freshwater slightly. Freshwater with less than 1 o/oo salinity is available 1 km further inland, in NE-direction.

The equivalent thickness of "freshwater" lens in Stadargja is 17 m. From pump test and model calculation Stadargja can be expected to yield at least 250 l/s of water with salinity greater than 7 o/oo.

It is recommended that the initial total pumping rate of freshwater from Lambagja and pumping from Stadargja does not exceed 600 l/s.

Result from investigations done so far in Stadargja and at the coast at Stadur is, that it is impossible to withdraw water which is 70% seawater or more (salinity > 25 o/oo) from Stadargja. The high value of the observed transmissivity (permeability) and results from pumping test indicate that the drawdown in a large diameter well drilled close to the coast at Stadur should not be the determining factor for the future useability of such well. Calculations indicate that up to 300 l/s could probably be withdrawn from a large diameter well close to the coast. The exact yield must however be determined by pumping test, which is also necessary to find out if the salinity and oxygen content of the pumped water increases from the values already observed. We therefore recommend a drilling of a large diameter well close to the coast at Stadur. The well should be cased of for the top 15 m to avoid "freshwater".

FIGURES


REYKJAVÍK
HAFNARFJÖRÐUR
KEFLAVÍK
GRINDAVÍK
N
50
30
20
10
MÖLVÍK
VATNSSTÆÐI
BERGHRAUN
SH-5
SH-6
KLAUFIR
BERGSENDI
RÆNINGJASKER
LAMBAGJÁ
SH-7
SH-8
SH-4
HRAFNAGJÁ
GRÝTUGJÁ
MIÐGJÁ
BAÐSTOFUGJÁ
HÚSATÓTTIR
ARFADALSVÍK
GRÆNABERGSGJÁ
STAÐUR
STAÐAR-GJÁ
STAÐARBERGS-GJÁ
SH-3
SH-1 SH-13
SH-2
B
A
SH-9
SH-10
SH-12
SH-11
FIG. I
EXPLANATION:
SH-2 OBSERVATION WELL
FISSURE
X OBSERVATION SITE
VERKFRÆÐISTOFAN VATNASKIL
ORKUSTOFNUN
ICELAND SALMON LTD.
LOCATION MAP
CALC: SLH
SCALE: 1:25.000
DATE: 85-02
NR. 8419-28

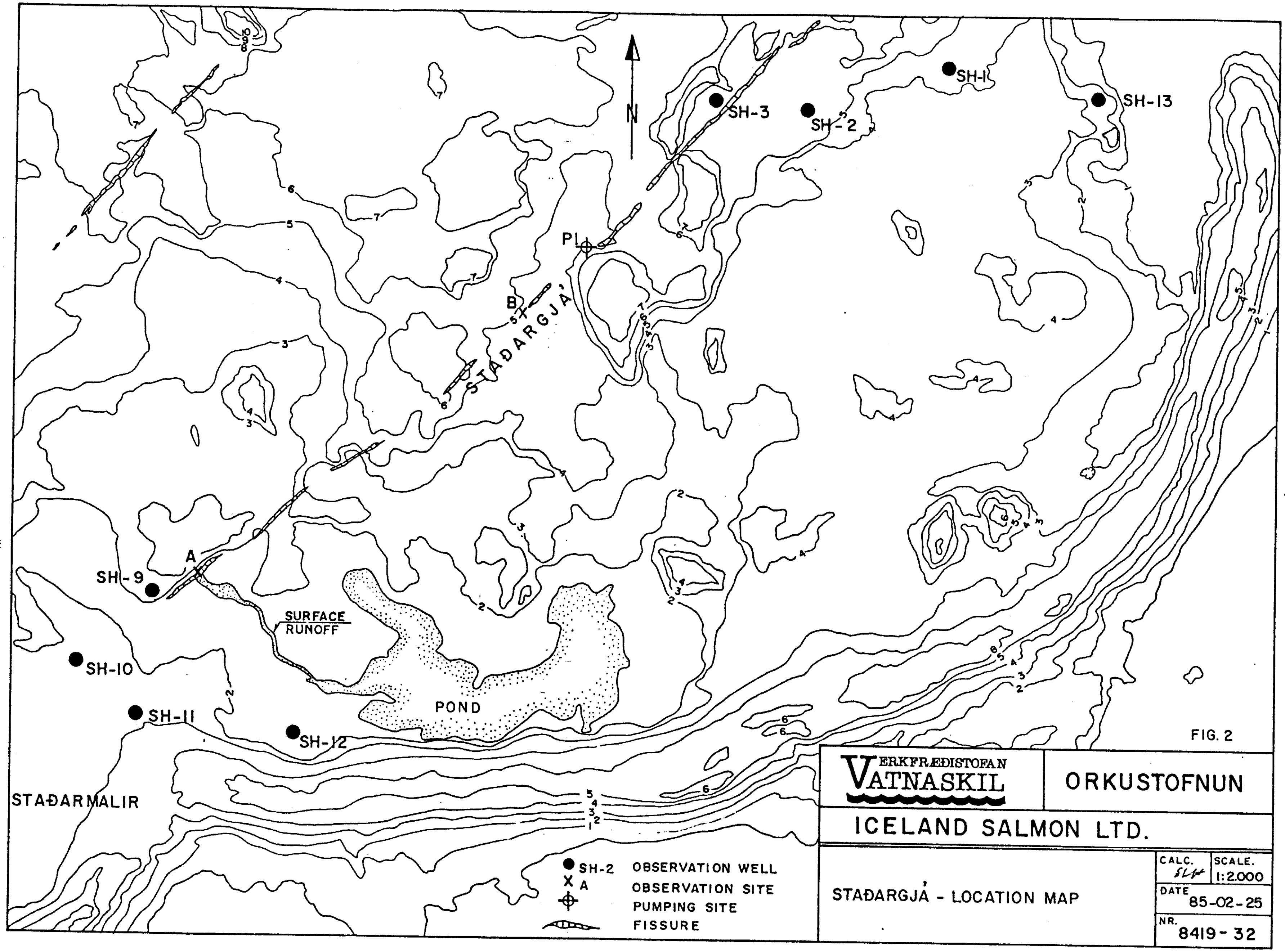

N
SH-13
SH-1
SH-2
SH-3
PI
B
STAÐARGJÁ
A
SH-9
SH-10
SH-11
SH-12
SURFACE RUNOFF
POND
STAÐARMALIR
SH-2 OBSERVATION WELL
X A OBSERVATION SITE
PUMPING SITE
FISSURE
VERKFRÆÐISTOFAN VATNASKIL
ORKUSTOFNUN
ICELAND SALMON LTD.
STAÐARGJÁ - LOCATION MAP
CALC.
SCALE. 1:2.000
DATE 85-02-25
NR. 8419-32

FIG. 2

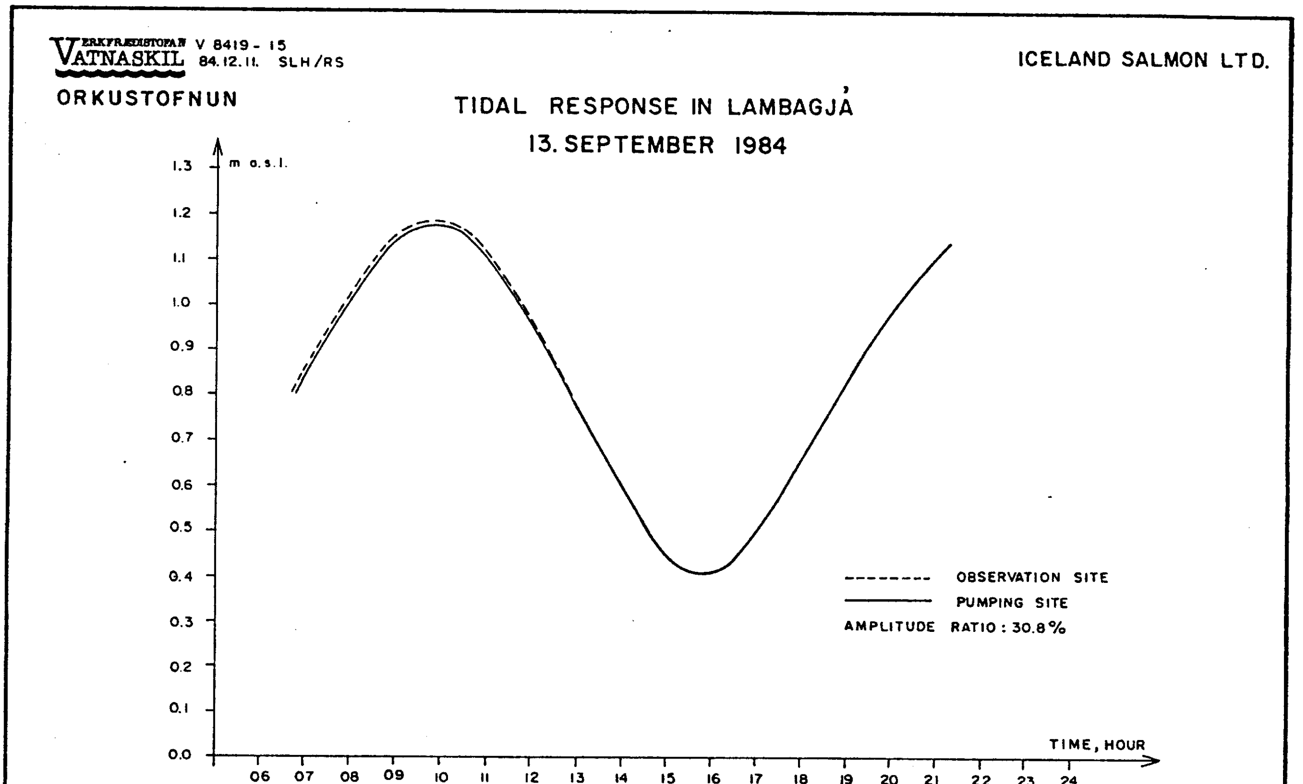

VERKFRÆDISTOFAN VATNASKIL
V 8419 - 15
84.12.11. SLH/RS
ORKUSTOFNUN
ICELAND SALMON LTD.
TIDAL RESPONSE IN LAMBAGJÁ
13. SEPTEMBER 1984
m a.s.l.
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
OBSERVATION SITE
PUMPING SITE
AMPLITUDE RATIO : 30.8%
TIME, HOUR
06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 3

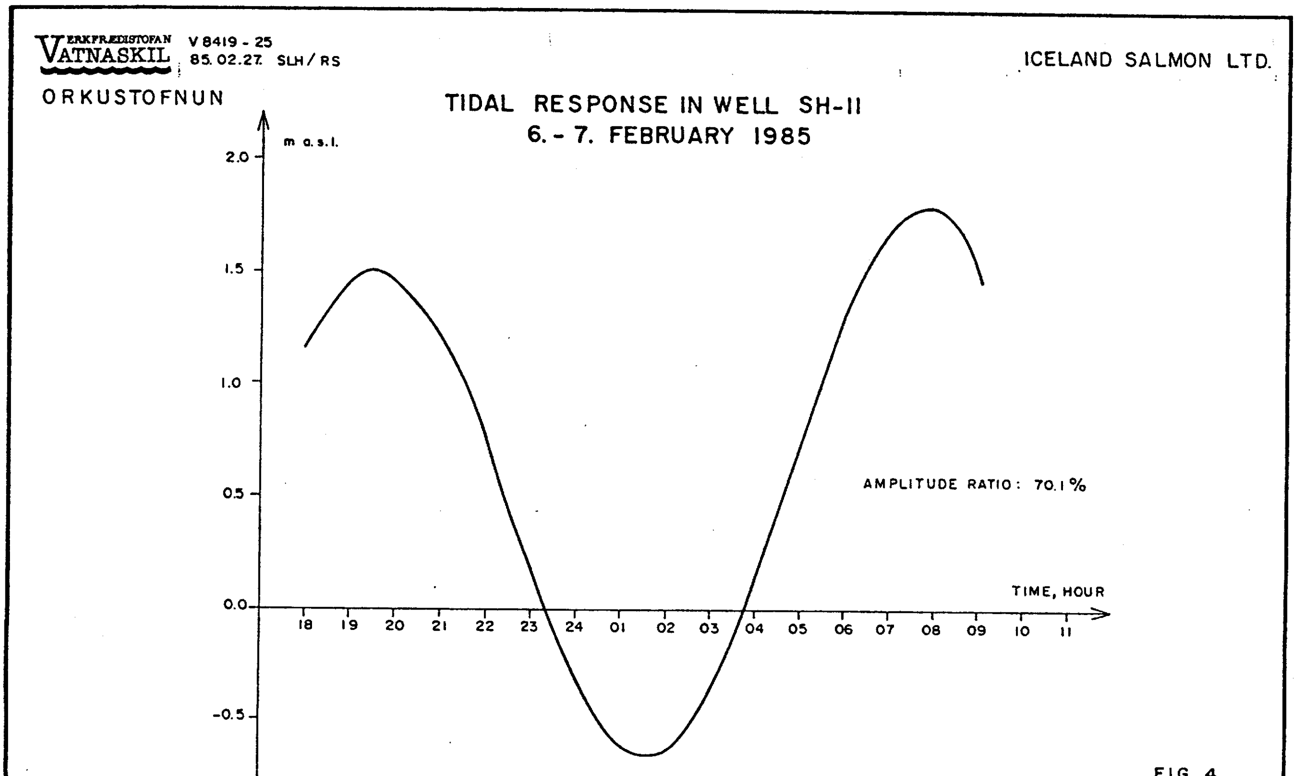

VERKFRÆDISTOFAN VATNASKIL
V 8419 - 25
85.02.27. SLH/RS
ORKUSTOFNUN
ICELAND SALMON LTD.
TIDAL RESPONSE IN WELL SH-11
6. - 7. FEBRUARY 1985
m a.s.l.
2.0
1.5
1.0
0.5
0.0
-0.5
AMPLITUDE RATIO: 70.1%
TIME, HOUR
18 19 20 21 22 23 24 01 02 03 04 05 06 07 08 09 10 11

FIG. 4

VERKFRÆDISTOFAN VATNASKIL V 8419-31 85.02.22. SLH/RS

ORKUSTOFNUN

ICELAND SALMON LTD.

DECREASING TIDAL AMPLITUDE FROM THE COAST

FIG. 5

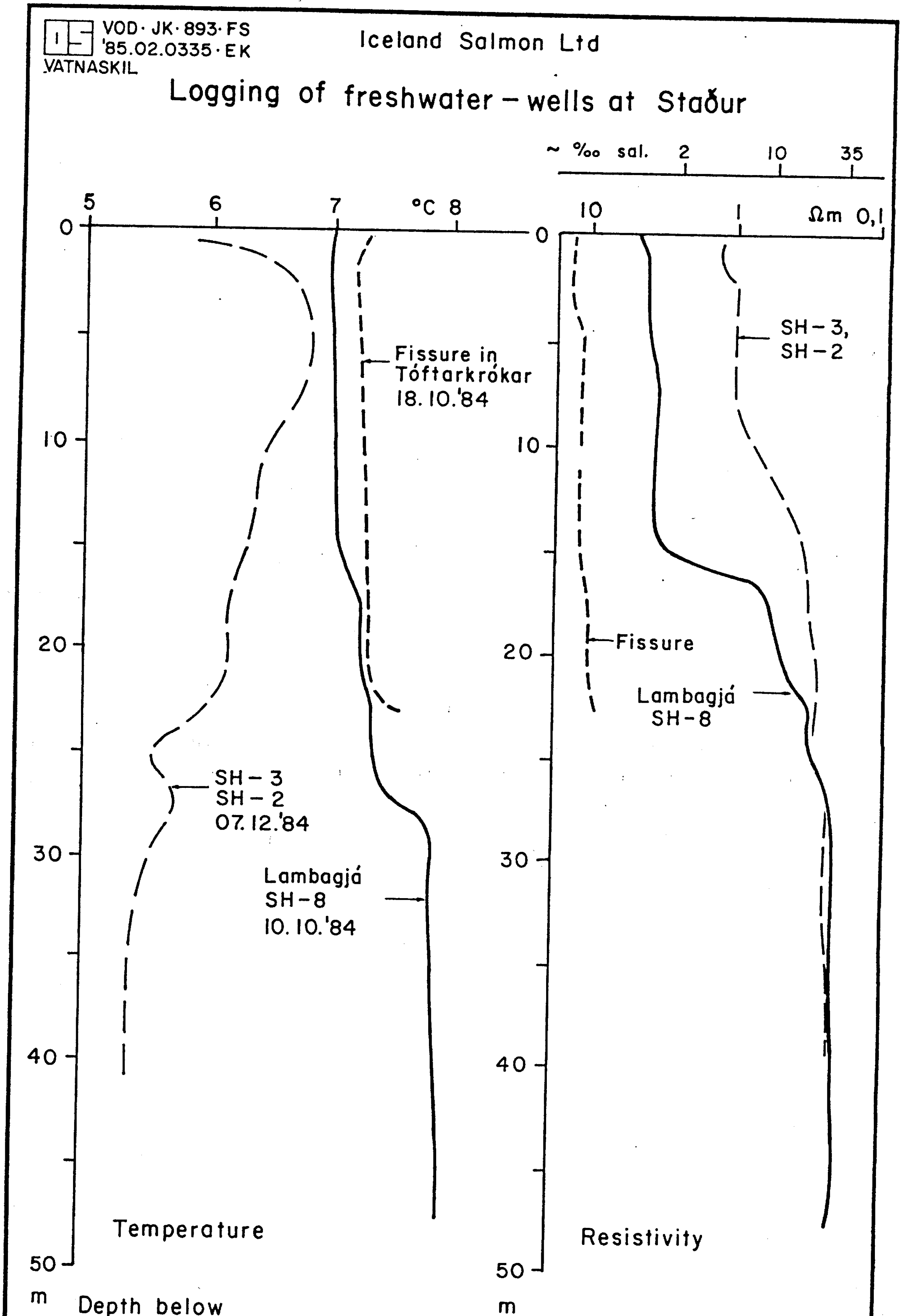

VOD·JK·893·FS
'85.02.0335·EK
VATNASKIL
Iceland Salmon Ltd
Logging of freshwater – wells at Staður
~ ‰ sal. 2 10 35
5 6 7 °C 8
10 1 Ωm 0,1
0
10
20
30
40
50
m
Fissure in
Tóftarkrókar
18.10.'84
SH – 3
SH – 2
07.12.'84
Lambagjá
SH – 8
10.10.'84
SH – 3,
SH – 2
Fissure
Lambagjá
SH – 8
Temperature
Resistivity
Depth below
watertable

FIG. 6

VOD·JK·893·FS
'85.02.0336·EK
VATNASKIL

Iceland Salmon Ltd

Logging of sea-wells at Staður

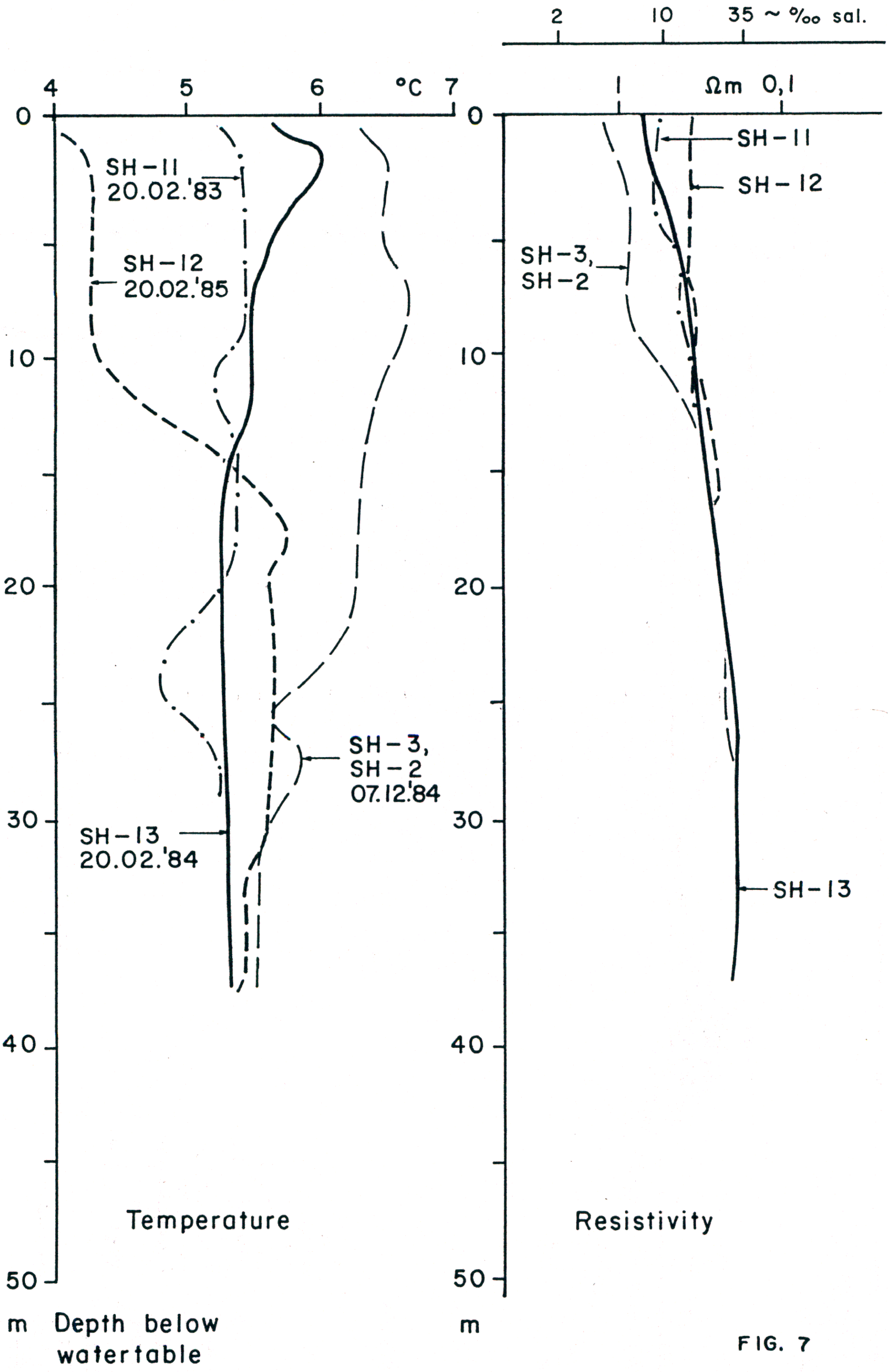
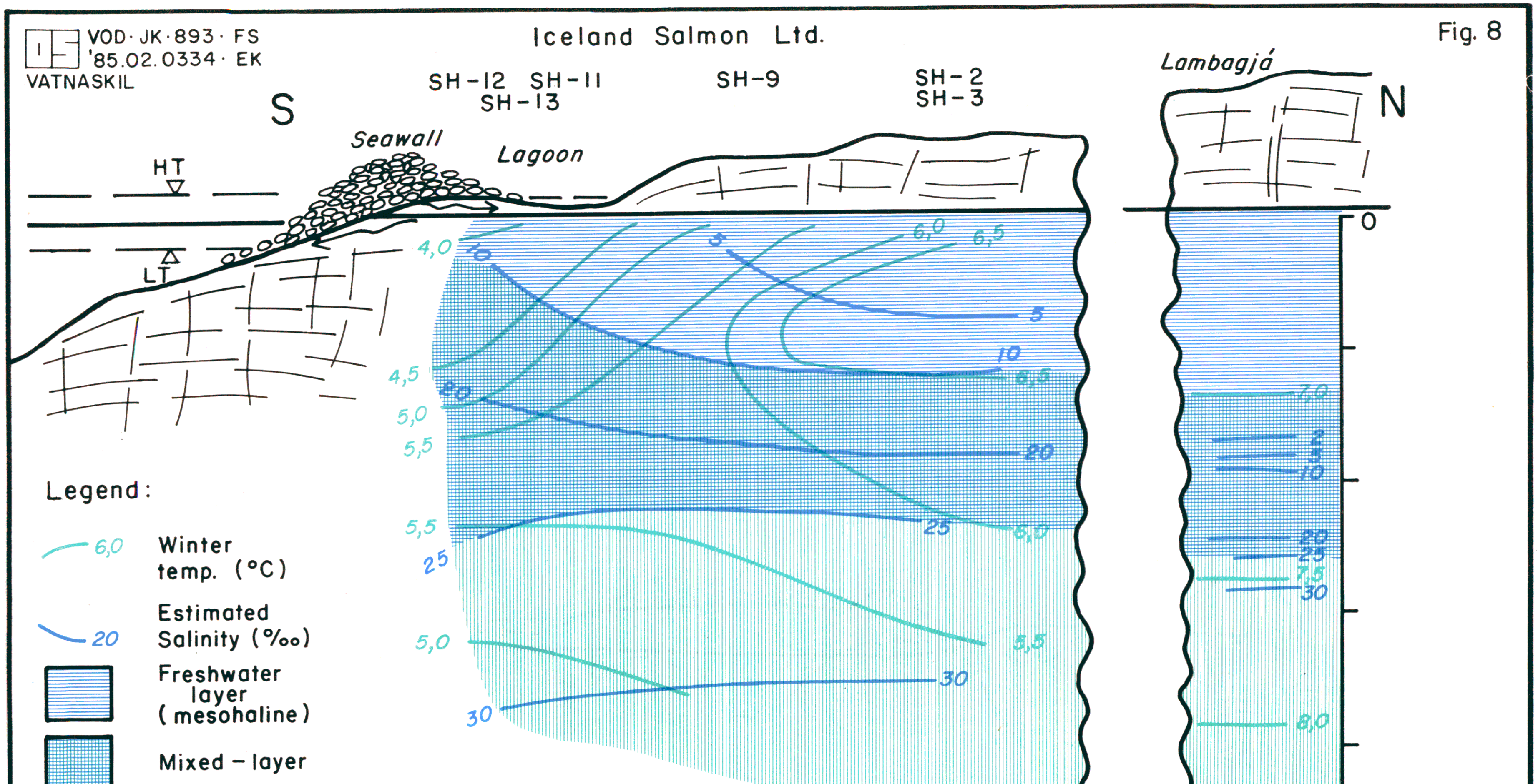


FIG. 7

Fig. 8



Schematic profile
of
Coastal groundwater
at Staður

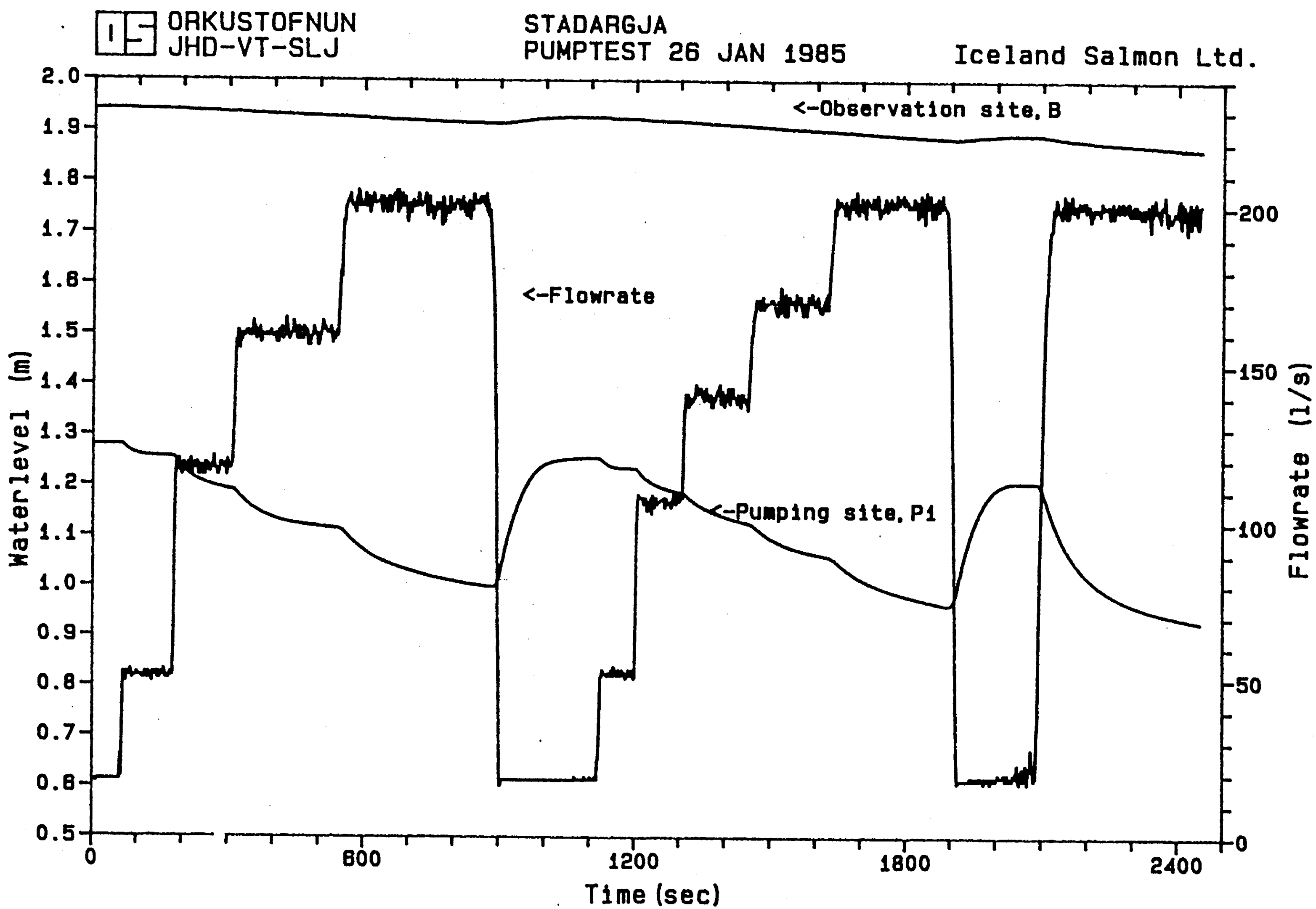

ORKUSTOFNUN
JHD-VT-SLJ
STADARGJA
PUMPTEST 26 JAN 1985
Iceland Salmon Ltd.
<-Observation site, B
<-Flowrate
<-Pumping site, P1
Waterlevel (m)
Flowrate (l/s)
Time (sec)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0
600
1200
1800
2400
200
150
100
50
0

FIG. 9

VERKFRÆDISTOFAN VATNASKIL V 8419 - 33
85.03.04. SLH /RS

ORKUSTOFNUN

ICELAND SALMON LTD.

SALINITY OF PUMPED WATER AND TIDAL RESPONSE IN WELL SH-9

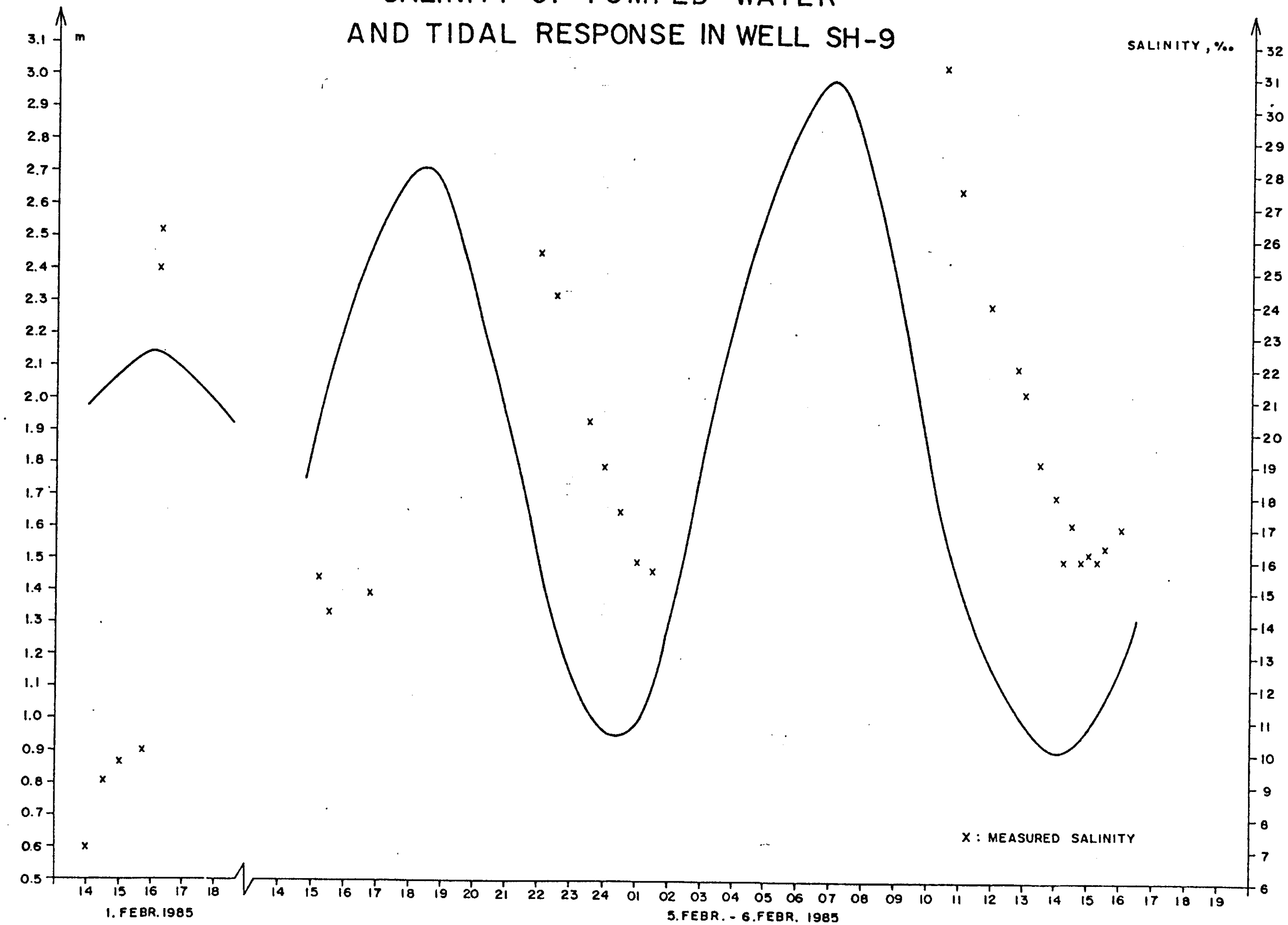


FIG. 10

VERKFRÆDISTOFAN VATNASKIL V 8419 - 21
84.12.14. SLH/SPK/RS

ICELAND SALMON LTD

ORKUSTOFNUN

CHLORIDE CONTENT OF PUMPED WATER AND TIDAL RESPONSE IN LAMBAGJA'

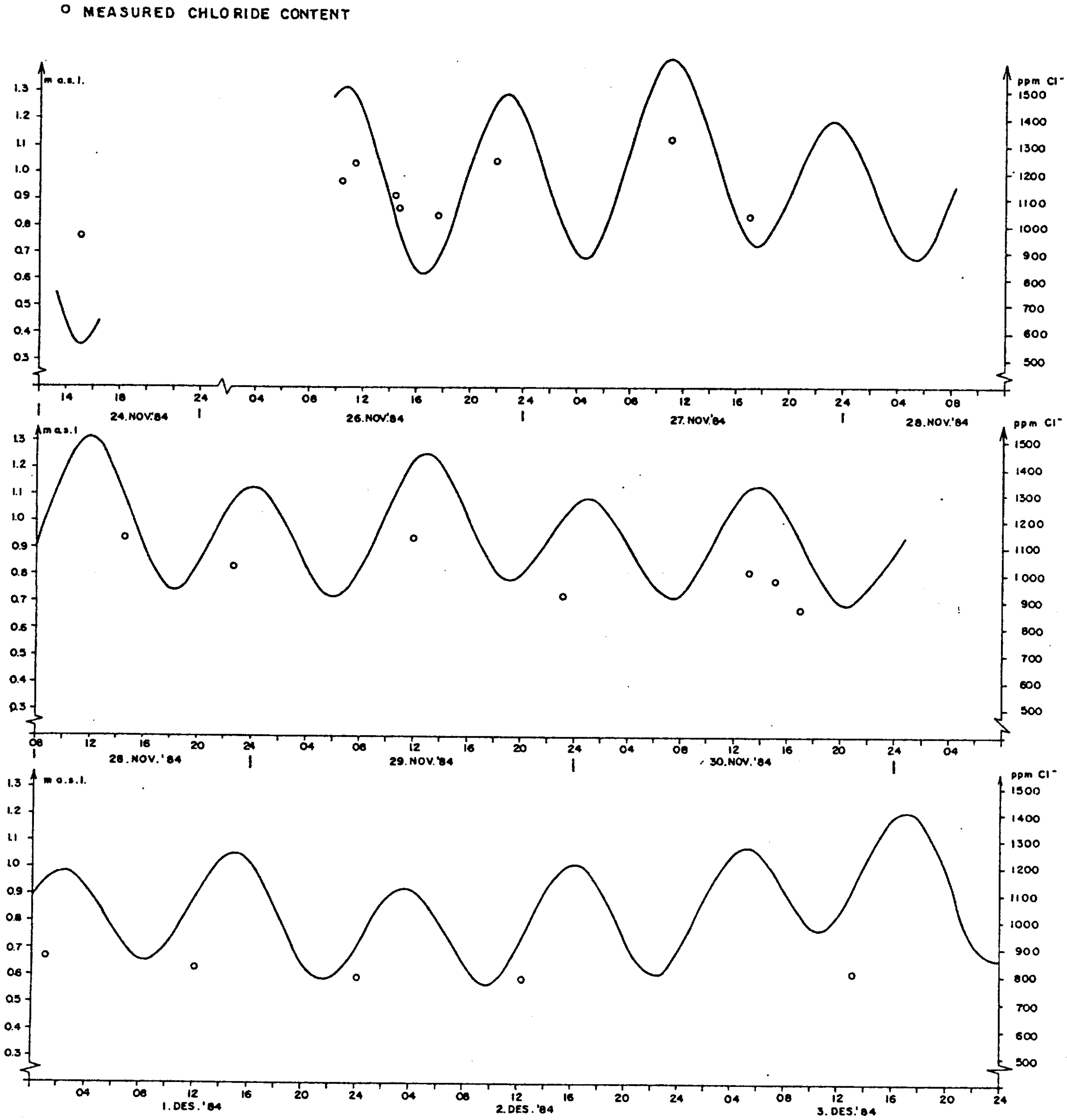


FIG.11

VERKFRÆDISTOFAN VATNASKIL V 8419 - 20
84.12.13. SLH/RS

ICELAND SALMON LTD

ORKUSTOFNUN

GROUNDWATER ELEVATION IN LAMBAGJÁ AND CHLORIDE CONTENT OF PUMPED WATER

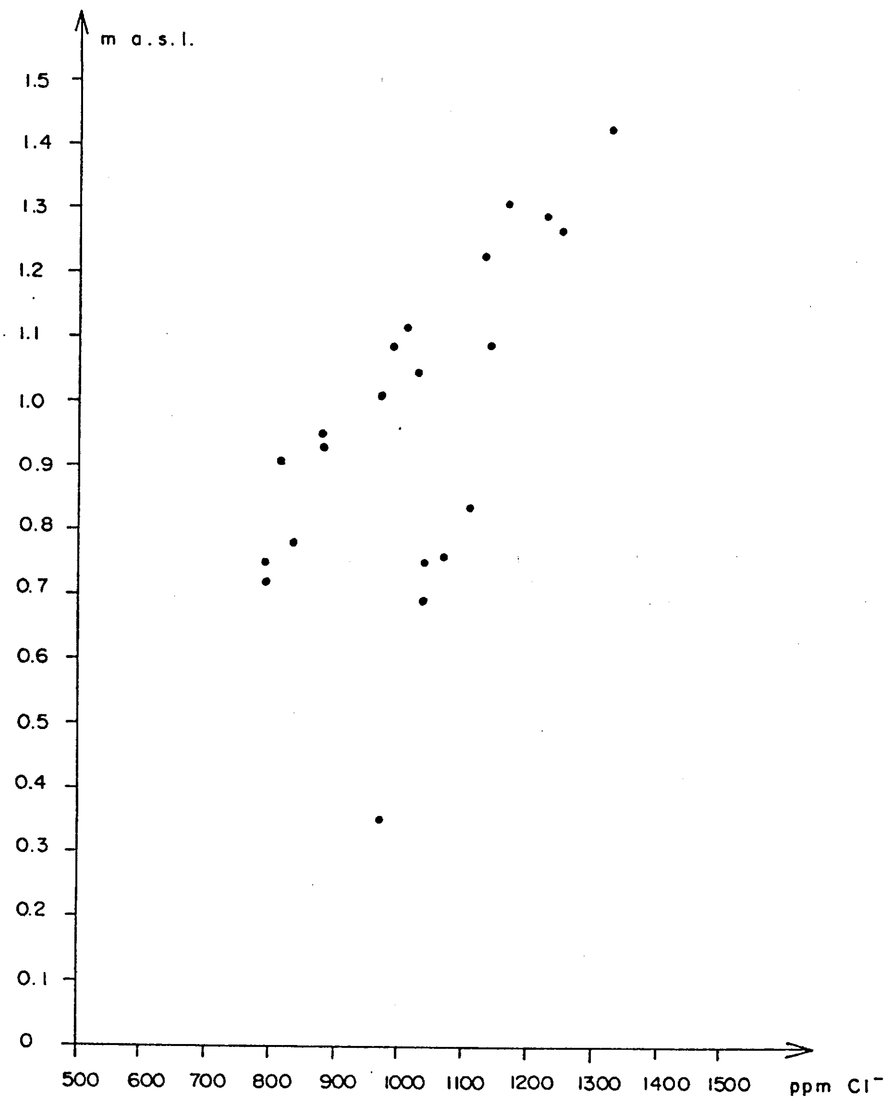


FIG. 12

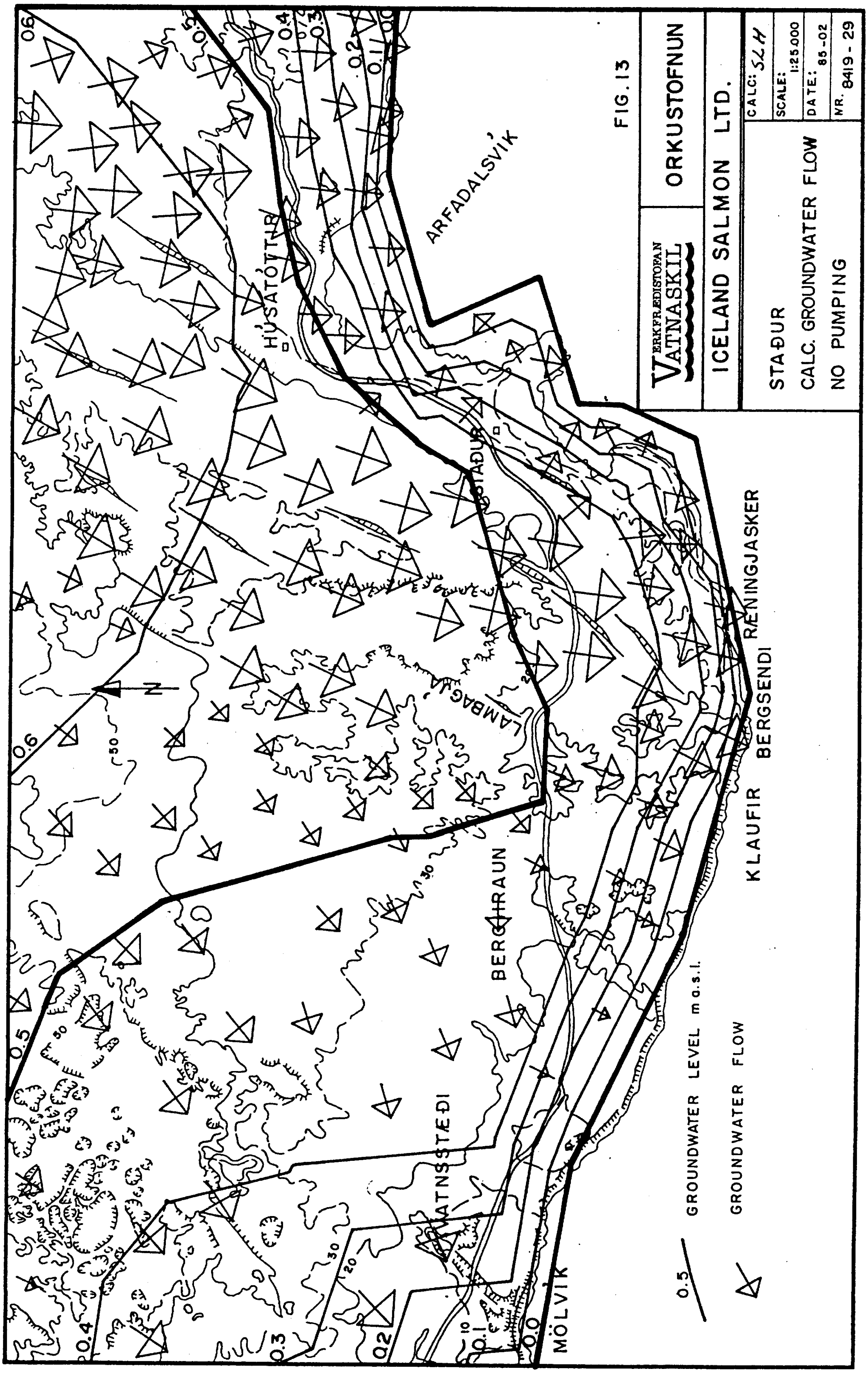


FIG. 13
VERKFRÆÐISTOFAN VATNASKIL
ORKUSTOFNUN
ICELAND SALMON LTD.
STAÐUR
CALC. GROUNDWATER FLOW
NO PUMPING
CALC: SLH
SCALE: 1:25.000
DATE: 85-02
NR. 8419-29
ARFADALSVÍK
HÚSATÓTTIR
STAÐUR
RÆNINGJASKER
BERGSENDI
KLAUFIR
BERGHRAUN
LAMBAGJÁ
VATNSSTÆÐI
MÖLVIK
N
0.5 GROUNDWATER LEVEL m a.s.l.
GROUNDWATER FLOW

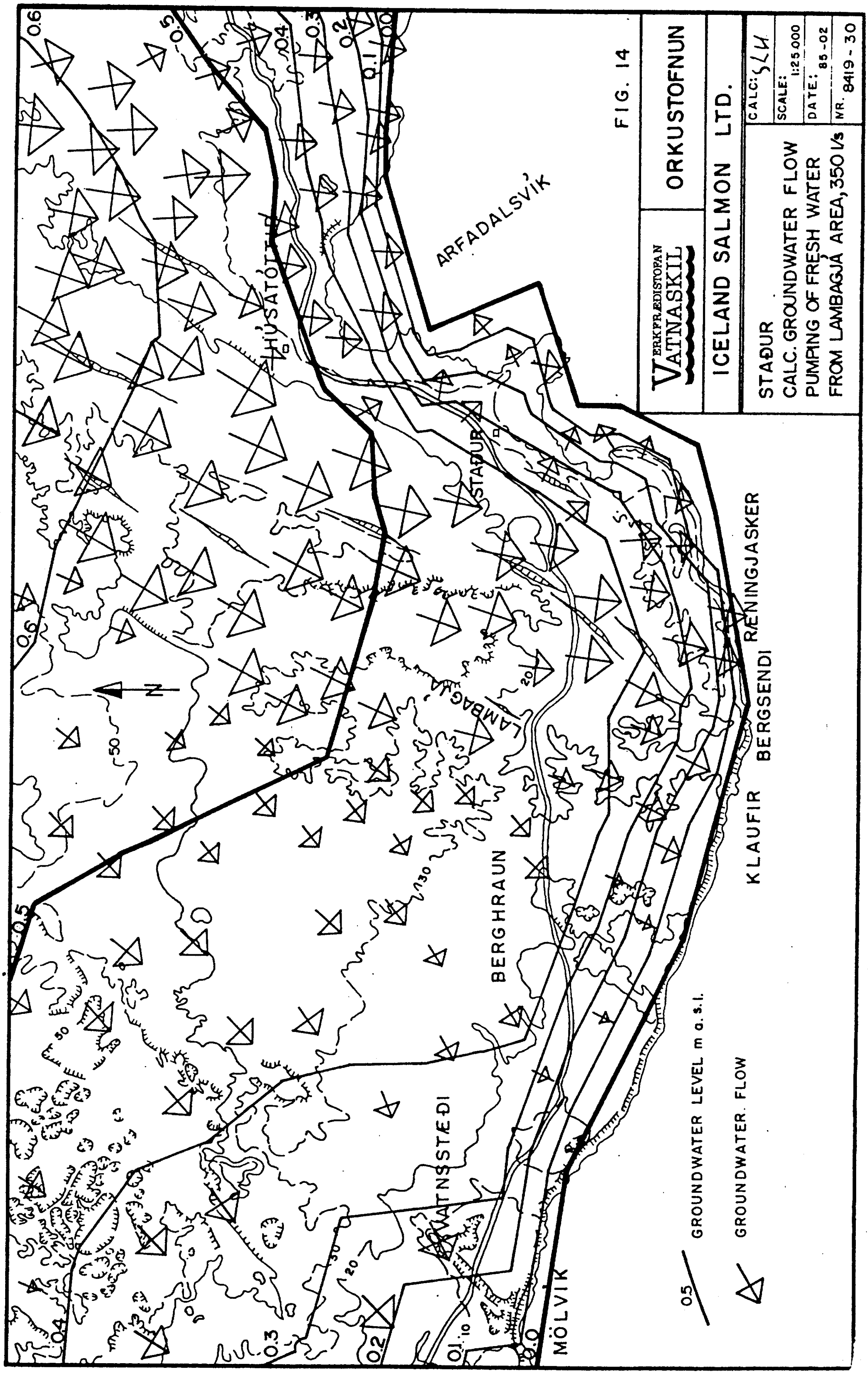

VERKFRÆÐISTOFAN VATNASKIL
ORKUSTOFNUN
ICELAND SALMON LTD.
STAÐUR
CALC. GROUNDWATER FLOW
PUMPING OF FRESH WATER
FROM LAMBAGJÁ AREA, 350 l/s
CALC: SLU
SCALE: 1:25 000
DATE: 85-02
NR. 8419-30
GROUNDWATER LEVEL m a.s.l.
GROUNDWATER FLOW
ARFADALSVÍK
HÚSATÓTTIR
STAÐUR
LAMBAGJÁ
RÆNINGJASKER
BERGSENDI
KLAUFIR
BERGHRAUN
VATNSSTÆÐI
MÖLVÍK
N

FIG. 14

APPENDIX

ANALYTICAL METHODS USED FOR
ANALYSES OF SAMPLES OF THE
FRESH AND SALINE WATERS AT STADUR:

pH is measured by a pH-meter with a glass electrode.

Dissolved O is measured with a Chemét test kit based on reaction with rhodazine D.

Total carbonate as CO is measured by titration with 0.1N HCl using a pH-meter (from pH 8.2 to pH 3.8).

Conductivity is measured by a conductivity meter.

Salinity is measured by a conductivity meter.

Na is measured by atomic absorption spectrophotometric methods.

K is measured by atomic absorption spectrophotometric methods.

Ca is measured by atomic absorption spectrophotometric methods.

Mg is measured by atomic absorption spectrophotometric methods.

Cl is measured by ion chromatography.

SO_4 is measured by ion chromatography.

F is measured by an ion sensitive electrode.

SiO_2 is measured spectrophotometrically as yellow silicomolybdate complex or reduced to molybdenum blue complex (1).

Fe is measured by atomic absorption spectrophotometry (graphite furnace).

Al is measured by fluorimetric spectrophotometry with lumogallion (2).

Cu is extracted by dithizone in chloroform (3) and measured by atomic absorption spectrophotometry.

Zn is extracted by dithizone in chloroform (3) and measured by atomic absorption spectrophotometry.

Cd is extracted by dithizone in chloroform (3) and measured by atomic absorption spectrophotometry.

Pb is extracted by dithizone in chloroform (3) and measured by atomic absorption spectrophotometry.

Hg is collected into KMnO solution and measured by flameless atomic absorption spectrophotometry (4).

NH_3* is measured with indophenolblue in autoanalyser (5).

NO_2* is measured by azodyecolorometric method in autoanalyser (5).

NO_3* is transformed to nitrite by Cu - Cd reduction and analysed by azodyecolorometric method in autoanalyser (5).

Note: * Performed at the Icelandic Marine Research Institute.

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