ORKUSTOFNUN

The Hveravellir geothermal field, NE-Iceland : conceptual model and reservoir assessment

Guðni Axelsson

Greinargerð GAx-98-08

Orkustofnun/GAx 20/01/98

THE HVERAVELLIR GEOTHERMAL FIELD, NE-ICELAND CONCEPTUAL MODEL AND RESERVOIR ASSESSMENT

1. INTRODUCTION

The Hveravellir geothermal field is one of the largest, and most powerful, low-temperature (<150 °C) fields in Iceland. It is located about 10 km west of the zone of active rifting and volcanism, which passes through the island. Surface manifestations are found in an area of 1600x400 m, elongated N-S. These are numerous hot, or boiling, springs discharging from nearly 0 to about 15 l/s. Two production wells have been drilled in the area. The reservoir temperature is of the order of 120 - 130 °C. Hot water from the field is utilized for space heating in the town of Húsavík (pop. 2,500), 18 km north of the field.

In the following the present knowledge on the nature of the geothermal system is reviewed and a simple conceptual model presented. The available data on the discharge from the field are also reviewed along with data from recent testing of the two wells. Finally a simple reservoir model, based on these data, is presented and used to estimate the potential of the geothermal reservoir.

2. THE HVERAVELLIR AREA

The Hveravellir area has for centuries been one of the two best known hot-spring areas in Iceland, the other being the Geysir area in S-Iceland. A number of explorers visited the field in earlier times, describing the area in their travel journals. Some Icelandic geologists also studied the area around the turn of the century. Most of the information available on the field today has emerged from the following studies, however:

1. Geological/geochemical exploration of the Hveravellir area in 1972/73 (Grönvold et.al., 1973).
2. A regional resistivity survey, in 1976, of an area extending about 10 km to the S and N of Hveravellir (Georgsson, 1976).
3. Magnetic mapping, as well as mapping of all surface manifestations, in the Hveravellir area in 1981/1982 (Georgsson et.al., 1982).
4. Exploration by shallow drillholes (about 50 m in depth) in 1997.
5. Drilling of two production wells in the Hveravellir area.

Figure 1 shows a map of the Hveravellir area. Most of the surface manifestations are indicated, as well as magnetic anomalies which are believed to indicate faults and fractures. The largest hot-springs are Ystihver, Strútshver, Uxahver, Syðstihver, Strokkur and Þvottahver, discharging 15, 10, 9, 5, 2 and 2 l/s, respectively, according to the latest available measurements (1974 and 1996). Until this century Uxahver used to erupt frequently, and was in fact the best known geyser in Iceland apart from old Geysir himself. This century Ystihver has been the primary erupting geyser in the area. The hot-spring activity has been influenced by tectonic activity in the past, the latest such episod occurring during earthquakes in 1872. The most pronounced effect has been on the eruptive activity (jumping from one spring to another), while the discharge from springs must also have been influenced.

In spite of being in an inhabited area, the hot water at Hveravellir was for centuries only used for bathing, washing and to some degree for cooking. The use of the hot water in agriculture started to a small degree in 1878, by heating of potato-fields. Its use for space-heating of local buildings started in 1924, and for heating green-houses in 1933. In 1970 the district heating service for Húsavík, mentioned above, started operation. At first it used hot water from a few of the major springs at Hveravellir.

Well H-1, the first geothermal production well in the area, was drilled to a depth of 450 m in 1974. It is located about 200 m north of the hot-spring Ystihver (Figure 1). It is cased with a 255 mm diameter casing to a depth of 37 m, but about 170 mm in diameter below that. The main feed-zones are located at the bottom of the well. This well has been utilized for district heating in Húsavík, since the time it was drilled, yielding between 40 and 44 l/s (38 and 42 kg/s) of 100°C water, fully open, in addition to some steam. This flow-rate equals between 145 and 160 m^3/hr, or about 1.2 - 1.3 million tons/year. Figure 2 shows a temperature-profile measured in the well during discharge. The temperature of the well is 128°C. Thus it may be estimated that the amount of steam, discharged to the atmosphere, has been about 2.0 - 2.2 kg/s, or 60,000 - 70,000 tons/year. Therefore, about 25 % of the energy discharged by the well escapes to the atmosphere. In addition to well H-1 water from two of the hot-springs is utilized for space heating in Húsavík.

The second production well in the area, well H-10, was drilled in May 1997 to a depth of 652 m. It is located about 60 m west of well H-1. It is cased with a 275 mm diameter casing to a depth of 154 m, but about 220 mm in diameter below that. The main feed-zone is located at a depth of 638 m, while a minor feed-zone was encountered at a depth of 330 m. Soon after the end of drilling this well yielded about 80 l/s (76 kg/s) of boiling water, fully open, which equals 290 m^3/hr. Figure 2 shows two temperature-profiles for the well, one measured during discharge but the other in the closed well. The well temperature appears to be about 125°C, while it should be pointed out that the well may still have been cooled down since drilling. In this case the amount of steam, discharged to the atmosphere, is about 3.6 kg/s. Well H-10 appears to yield about 80% more than well H-1. This is mostly because the production part of well H-10 is 220 mm in diameter, while the production part of well H-1 is only 170 mm wide.

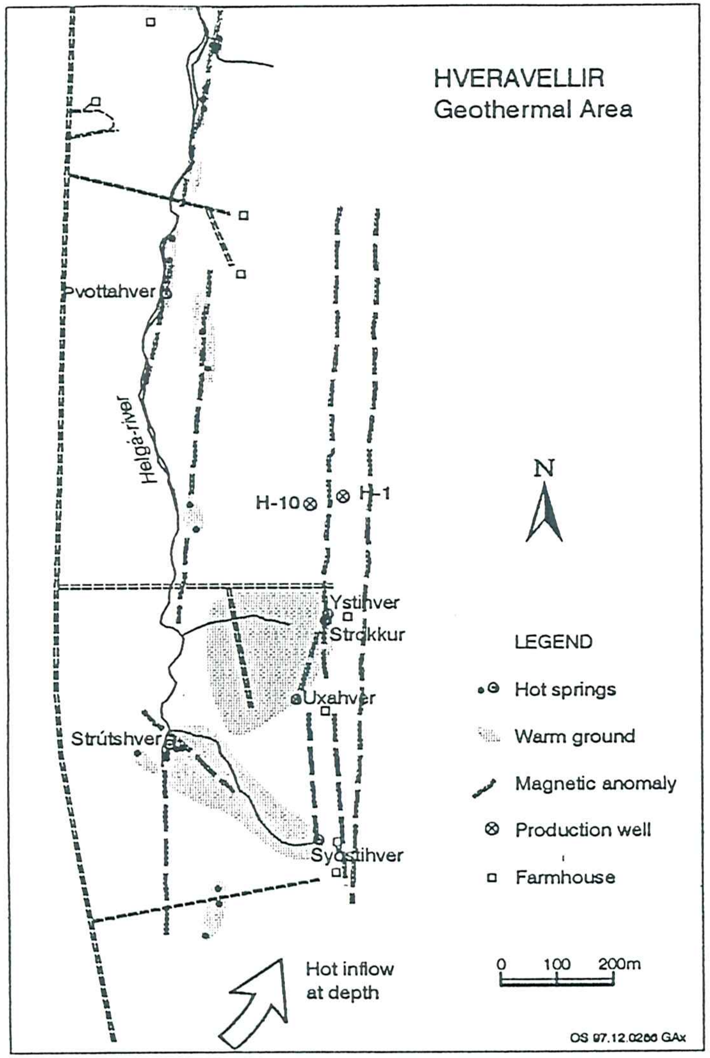

Figure 1. *Map of the Hveravellir geothermal area showing the surface manifestations and production wells.*

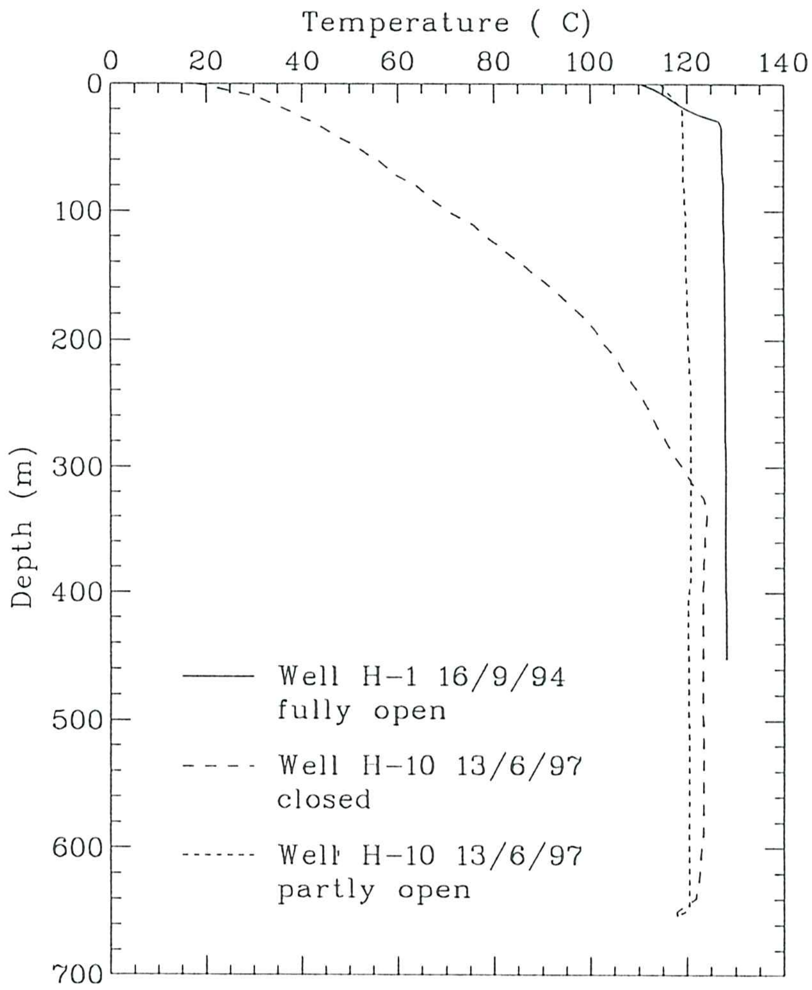

Figure 2. *Temperature logs from wells H-1 and H-10.*

3. CONCEPTUAL MODEL

The current conceptual model of the Hveravellir geothermal system, which is descriptive rather than quantitative, incorporates the essential features of the system revealed by analysis of all available information. It should be kept in mind, however, that this model is mostly based on indirect data, since only two relatively shallow wells, 60 m apart, have been drilled in the area. The conceptual model may be described as follows:

The Hveravellir geothermal system is embedded in approximately 2 Myrs. old crust, composed of basaltic layers and hyaloclastic units. These are intersected by faults and dikes, striking N-S. The existence of the system is the result of the interaction of an abnormally hot crust and tectonic activity, which maintains open fractures for the circulating water. Figure 3 shows a sketch of the conceptual model. According to the model the hot inflow to the system is at depth from the south. This is somewhat speculative, but based on the results of regional resistivity measurements. This is water which has percolated through the crust, to a depth of 1 - 2 km. Consequently the water is heated by extracting heat from the hot rocks, and rises because of reduced density, through open vertical fractures. Once inside the geothermal area some of the water reaches the surface in the hot springs, while most of it flows horizontally, along fractures and inter-beds. This water exits the geothermal system as horizontal runoff into the local ground-water system. The two production wells are believed to intersect the same sub-vertical fracture, which tilts to the east.

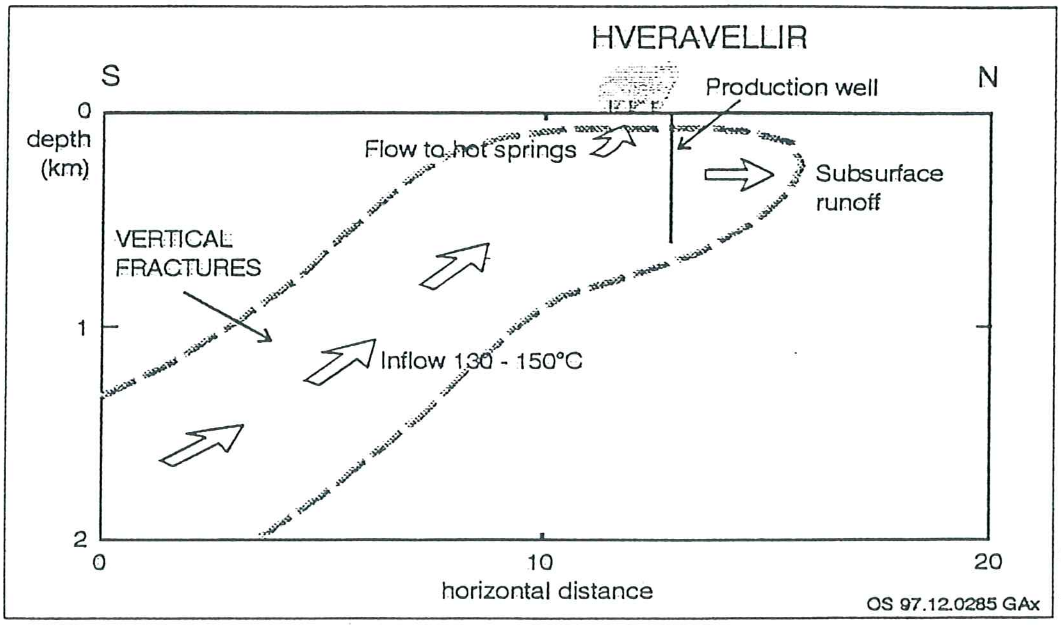

Figure 3. *The current conceptual model of the Hveravellir geothermal system.*

4. *DISCHARGE HISTORY*

The discharge from the hot-springs in the Hveravellir area, as well as the flow-rate from well H-1, has been measured occasionally during the last half a century. These data are listed, and reviewed, by Fjarhitun (1997). They are shown in Figure 4. It should be pointed out that due to several reasons these measurements are not quite comparable:

1. Long-term (years/decades) changes in hot-spring and ground-water flow.
2. Seasonal variations in hot-spring flow, such that measurements done at different times of the year may cause apparent differences.
3. Inherent inaccuracy in flow-rate measurements.
4. Different measurement methods at different times, different personnel involved.
5. Water from one hot-spring may issue at several locations, all of which are perhaps not included in each measurement.

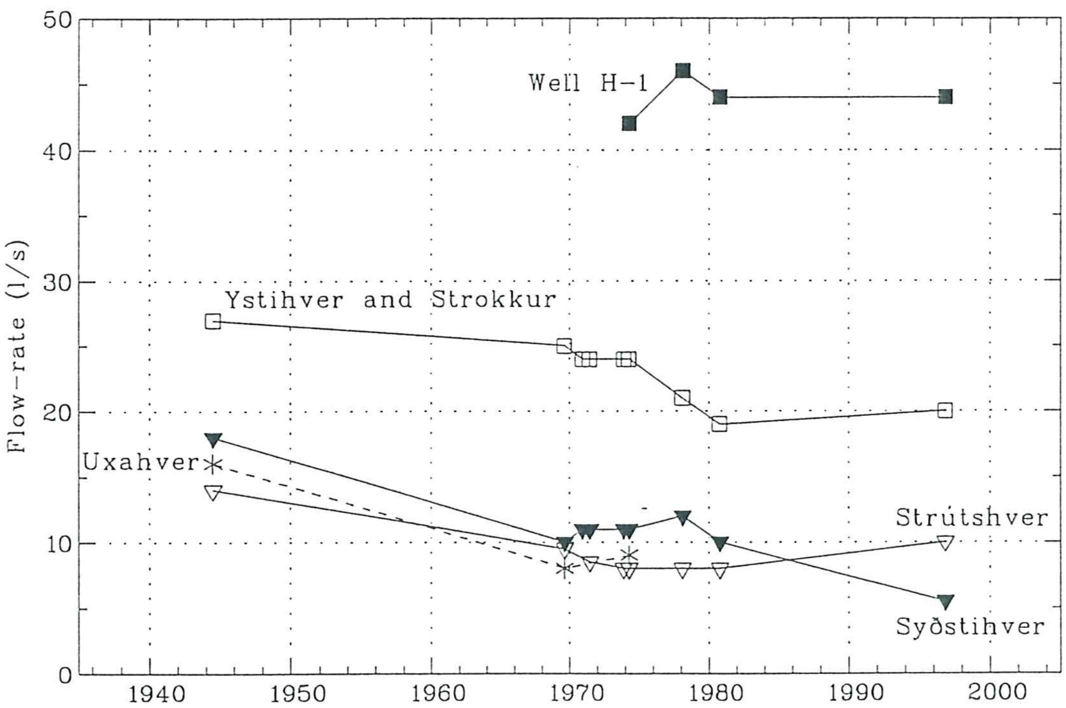

Figure 4. *Available measurements of the discharge of springs and wells in the Hveravellir field from 1944 to 1996.*

In spite of the possible discrepancies, the data clearly indicate the following. Firstly, spring flow-rates appear to have declined during the 50 yr period, most likely due to natural variations. Secondly, the flow-rates from Ystihver and Strokkur, the springs closest to well H-1, appear to have decreased after the well was drilled in 1974. This, however, is believed to have been only about 1 - 2 l/s, not 5 l/s as appears from the figure.

This discrepancy is mainly due to item 5 above. Thirdly, the flow-rate from well H-1, as well as Ystihver and Strokkur seem to have been stable since the late seventies. Thus the reservoir pressure appears not to have declined with time, as is often the case, indicating that an equilibrium is reached between inflow into the geothermal system and discharge from hot-springs and wells.

It should be mentioned that the temperature and pressure conditions of well H-1 were logged in 1994 (Björnsson and Steingrímsson, 1994). The results indicated that very limited pressure drawdown had occurred in the reservoir since the well was drilled, and that during discharge the pressure draw-down was also limited. This agrees with the conclusion, which was reached on the basis of the discharge history of the field. In addition the chemical content of the water produced from well H-1 has been monitored on a yearly basis since 1986 (Ólafsson, 1997). No significant changes have been noted in the chemical content, which indicates that not a large portion of the increased inflow into the geothermal system, induced by production from well H-1, is cold surface water.

5. *RECENT TESTING*

Wells H-1 and H-10 were step-rate tested in May and June of 1997. A step-rate test involves increasing (decreasing) the flow from a well in steps and measuring the well-head pressure during each step. This yields information on the characteristics of the wells. The results are presented in Figure 5. The figure shows that well H-10 is twice as productive as well H-1, as already discussed. The figure also shows by the concave nature of the curves that, when the wells are fully open (well-head pressure 0 bars), a large part of the pressure drop occurs because of turbulence pressure losses in the wells themselves, and in the feed-zones next to the wells. Only a small part actually represents a reservoir pressure drop. When well H-1 discharges 35 - 40 l/s the turbulence pressure drop is of the order of 4 bars, while the corresponding pressure drop in well H-10 is 5 bars when it discharges 80 l/s.

Since early December 1997 the two wells are also being long-term flow-tested. The wells are discharging at a well-head pressure of 2 bars-g. The flow-rates of the two wells are measured carefully once a week by the staff of the Húsavík District Heating Service, as well as the discharge from the nearest hot-spring, Ystihver. The data collected until the middle of January 1998 are presented in Figure 6. During this test well H-10 has yielded between 62.9 and 67.3 l/s of water, as well as an estimated 3 kg/s of steam. Well H-1 has yielded between 24.4 and 26.1 l/s of water, as well as 1.3 kg/s of steam. The combined discharge of the two wells is, thus, about 90 l/s, or twice the production from well H-1 before the test. The hot-spring Ystihver has yielded between 14.1 and 15.2 l/s of boiling water. It should be pointed out that the measurement inaccuracy may be of the order of 2-4%.

Figure 6 shows that very little changes in the flow-rates have occurred during the test, except a slight decline in January. On the 14th of January well H-1 yielded 25 l/s, about 3 l/s less than expected on the basis of the data presented in Figure 5. At the same time well H-10 yielded 63 l/s, only 2 l/s less than expected from the figure. Ystihver yielded 14.1 l/s, which is about 1.3 l/s less than before the test. These changes are, of course, the result of a drop in reservoir pressure due to increased production. They amount to a roughly 10% decline for both well H-1 and Ystihver. By inverting the output curves in Figure 5 one can estimate that this decline corresponds to a decline in reservoir pressure of 0.2 bars for well H-10 and 0.6 bars for well H-1.

The shut-in pressure of the two wells was measured before the current test, as well as on January 14th. Before the test the well-head pressure of both wells was registered at 5.6 bars-g, after they had been shut for 5 min. On January 14th the well-head pressure of well H-10 was 5.3 bars-g while the well-head pressure of well H-1 was 5.0 bars-g, also after 5 min. in both cases. These values are in a good agreement with the estimates presented in the previous paragraph, and indicate an average reservoir pressure decline of the order of 0.5 bars.

6. RESERVOIR POTENTIAL

Even though the data available on the response of the Hveravellir reservoir is very limited, it is clear that the potential of the reservoir is considerably more than the current production of about 45 l/s. The criteria to be used to determine the potential is not clear, however. On one hand, the production may certainly be increased greatly by further drilling as well as pumping from wells. On the other hand, greatly increased production will seriously influence the hot springs in the area, which have an intrinsic environmental value, in particular the erupting Ystihver.

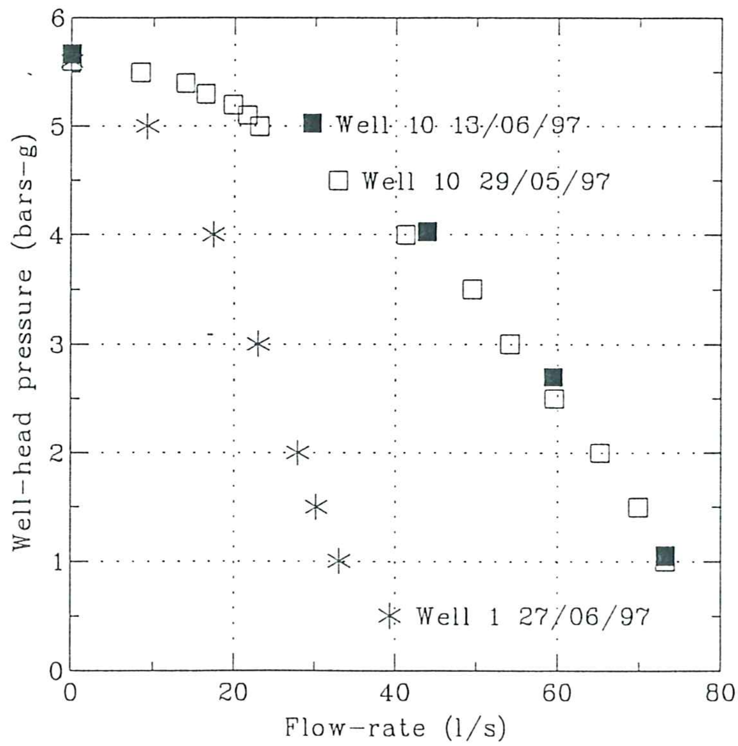

Figure 5. *Output curves, i.e. results of short-term step rate testing of wells H-1 and H-10 at Hveravellir in 1997.*

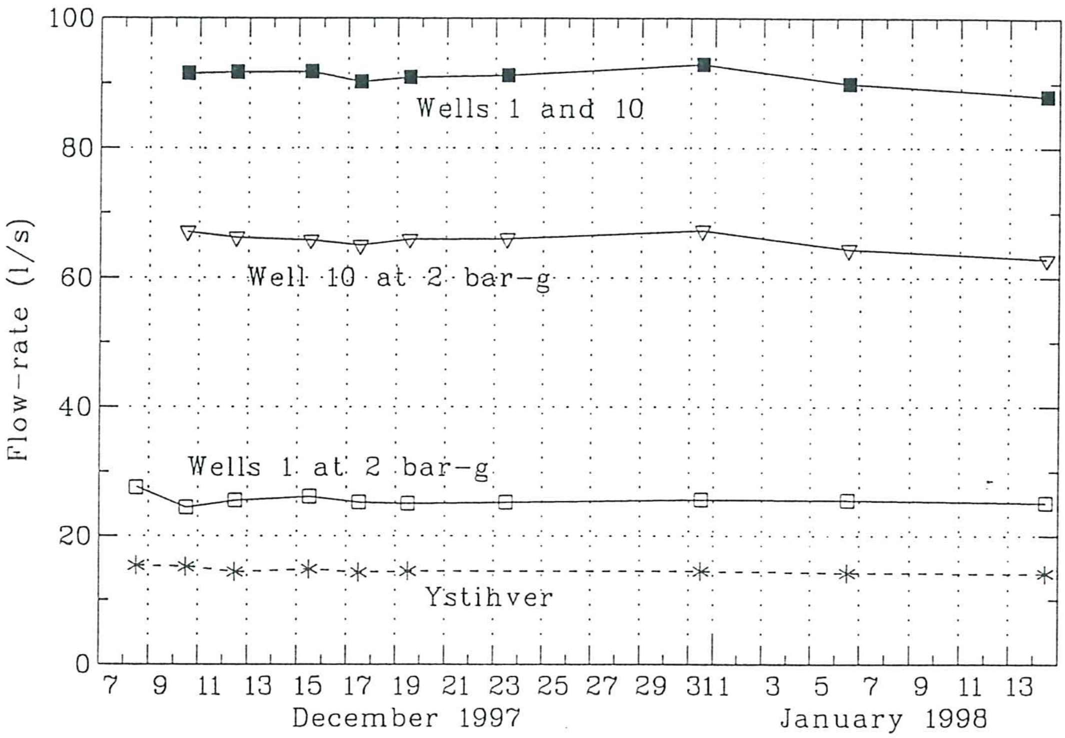

Figure 6. *Flow-rate data collected during the current discharge test.*

The available data, reviewed above, can be used to estimate the effects of increased production. For this purpose a very simple analytical reservoir model was developed. It involves a extensive horizontal reservoir, of constant thickness and reservoir properties. The reservoir is bounded to the south by a constant pressure boundary such that inflow into the model equilibrates with production from the field, during long-term production. The properties of the model are:

thickness, $h = 500$ m
permeability, $k = 1.2\times10^{-13}\,m^2 = 0.12$ Darcy
porosity, $\phi = 8\%$

and the constant pressure boundary is located 400 m south of Ystihver. This model simulates the limited data on the response of the reservoir reasonably well. The permeability of the model is high, supporting the contention that production from the field may be increased considerably. It should be emphasised, however, that the model is very simple, and its results rather inexact. A more complex model is not warranted because of the limited data available. The model should be revised and refined as more data becomes available, i.e. at the end of the ongoing flow-test.

Finally this model, as well as the data on flow-rate and pressure changes in the field, were used to estimate flow-rates for a few production scenarios. The results are presented in Table 1. In addition to two scenarios, involving the present production and the ongoing test, three scenarios were considered. One using wells H-1 and H-10 fully open (at 0.5 bar-g actually) and two involving one or two new wells yielding a total of 50 and 100 l/s, respectively. These wells have not been located yet, but it is assumed that they will be drilled at least 200 m south of Ystihver (see Figure 1). Before more wells are drilled, further exploration of the area is needed, such as by drilling of shallow exploration wells.

Table 1. *Estimated flow-rates, including steam, and reservoir pressure change (Δp), for different production scenarios.*

Scenario	H-1 (l/s)	H-10 (l/s)	New well(s) (l/s)	Wells total (l/s)	Ystihver (l/s)	Springs[1] (l/s)	Δp (bars)
Current prod.	42-46	0	0	42-46	15.5	29	0
97/98 test.	26	64	0	90	14.0	26	0.5
H-1 and 10 fully open	33	77	0	110	13.5	25	0.7
New well(s)[2]							
50 l/s	30	70	50	150	12.5	23	1.1
100 l/s	27	63	100	190	11.0	20	1.5

1) Ystihver, Strútshver and Syðstihver 2) Located appr. 200 m south of Ystihver

The table shows that as the production from the field increases, the flow from the older wells and springs, such as Ystihver, decreases. According to our calculations the discharge from well H-1 will decrease from about 44 to 27 l/s when the total production from well is increased from 44 to 190 l/s. For the same production increase the flow from Ystihver is estimated to decrease from 15.5 to 11 l/s, and the reservoir pressure is estimated to decrease by about 1.5 bars, corresponding to a 15 m water-level draw-down. The flow-rate decrease is only about 30-40%. These changes are small considering that the increase in total production is more than 300%. This again supports the contention that the potential of the Hveravellir field is considerably more than the present production. How much a 30% decrease in flow-rate will affect the hot springs in the area remains to be seen, however.

Finally, it should be pointed out that the results presented in Table 1 are based on the assumption of a constant flow-rate. During future utilization of the Hveravellir field considerable seasonal variations in production may be expected. The yearly average production may be expected to be about 30% less than the maximum production. Thus, the resulting average reservoir changes (pressure and flow-rates) will be considerably less than those calculated for the maximum production.

7. SUMMARY AND CONCLUSIONS

The Hveravellir geothermal field is one of the most powerful, and best known, low-temperature fields in Iceland. Surface manifestations are found in a large area, and the six largest hot-springs discharge a total of more than 40 l/s of boiling water. The reservoir temperature is of the order of 120 - 130 °C. Hot water from the field is utilized directly for space heating in the town of Húsavík, 18 km north of the field. The Hveravellir system is embedded in 2 Myrs. old basaltic crust, intersected by faults and dikes. The existence of the system is the result of the interaction of an abnormally hot crust and tectonic activity, which maintains open fractures for the circulating water. Hot inflow to the system is believed to be at depth from the south. The first geothermal production well in the area (H-1) was drilled in 1974, and has yielded between 40 and 44 l/s of 100°C water since then. The second production well (H-10) was drilled in 1997, and appears to yield about 80% more than the older well, mainly because of the larger diameter of its production part. Limited data are available on the flow-rate from springs and well H-1 through the years, except for data being collected during an on-going long-term flow-test (winter of 1997/98). These data, as well as a simple analytical model of the geothermal reservoir, were used to estimate the effects of increased production on the flow rate of wells and hot-springs. It is clear that the potential of the reservoir is considerably more than the current production of about 45 l/s, and that increased production will not influence the reservoir pressure significantly. Yet greatly increased discharge will influence the hot springs in the area, which have an intrinsic environmental value, in particular the erupting Ystihver. It is estimated that the two production wells will yield about 90 l/s (water and steam) a 2 bars-g, but that this will cause the discharge from Ystihver to decrease from about 15.5 to 14.0 l/s. By the drilling of one or two new production wells, 400 - 500 m south of wells H-1 and H-10, the production from wells may be increased to at least 190 l/s. It is estimated that this will, however, cause the discharge from Ystihver and well H-1 to decline by about 30%. Before more wells are drilled, further exploration of the area is needed.

REFERENCES

Björnsson, G. and B.S. Steingrímsson, 1994: Logging of well H-1 at Hveravellir in Reykjahverfi during the fall of 1994 (in Icelandic). Report GrB/BS-94/04, National Energy Authority, Reykjavík, 4 pp.

Fjarhitun hf., 1997: Hot water flow-rate measurements (in Icelandic). Report 009/KÓJ, Fjarhitun Consulting Engineers, Reykjavík, 18 pp.

Georgsson, L.S., 1976: Resistivity measurements in Reykjahverfi during the summer of 1976 (in Icelandic). Report OS-JHD-7644, National Energy Authority, Reykjavík, 14 pp.

Georgsson, L.S., I.Þ. Magnússon and M. Kjartansdóttir, 1982: Hveravellir in Reykjahverfi - Geothermal investigation (in Icelandic). Report OS-82088/JHD-12, National Energy Authority, Reykjavík, 45 pp.

Grönvold, K., V. Stefánsson and S. Sigurmundsson, 1973: Geothermal research at Hveravellir in Reykjahverfi (in Icelandic). Report OS-JHD-7324, National Energy Authority, Reykjavík, 18 pp.

Ólafsson, M., 1997: Chemical monitoring for the Húsavík District Heating Service for 1996 (in Icelandic). Report MÓ-97/12, National Energy Authority, Reykjavík, 6 pp.