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Siglufjördur District Heating System, North Iceland. Decades of Direct Use of Geothermal Water for House Heating

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ABSTRACT

Rarik, Iceland State Electricity, operates a district heating system in the town of Siglufjördur, North Iceland. Hot geothermal water is pumped from wells in two geothermal systems, Skútudalur and Skarddalur. The geothermal utilization started in Skútudalur in 1975 and in Skarddalur in 2010 after a new road tunnel through the mountains adjacent to the Skútudalur system had affected pressure (water level) of the Skútudalur geothermal system and water level declined more than in previous years although production did not increase. The water chemistry in both systems is alike and well suited for direct use in house heating. In 2018 the total production of hot water from the two systems was about 720.000 m^3, with 255.000 m^3 from wells in Skútudalur and 465.000 m^3 from well SD-1 in Skarddalur.

1. INTRODUCTION

The town of Siglufjördur is situated in the Siglufjördur fjord on the north coast of Iceland (Figure 1). The town has approximately 1200 inhabitants and receives a lot of tourists, especially during the summer months. The town is heated with geothermal water from two separated low temperature geothermal fields, some 4 to 5 km away from the town centre. The temperature of the geothermal water is 70 to 75°C and the water is used directly for house-heating and other domestic use. The town is connected to the main road system through tunnels to the west, Strákagöng, and through the two Hédinsfjardargöng to Ólafsfjördur in the east.

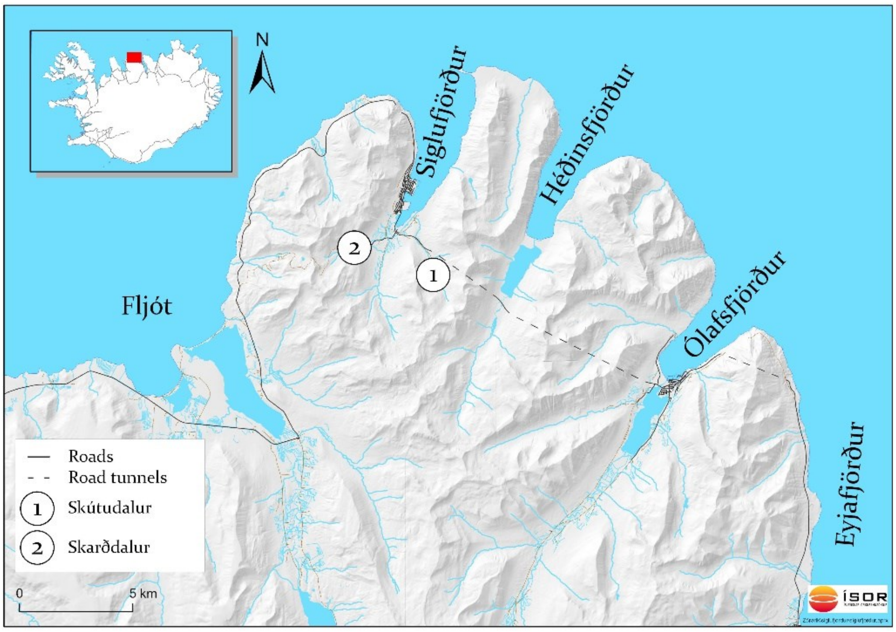

Figure 1. The location of Siglufjördur on the north coast of Iceland with present road connections through tunnels to east and west. The location of the Skútudalur and Skarddalur geothermal fields in Siglufjördur is shown.

2. THE GEOTHERMAL SYSTEMS OF SIGLUFJÖRDUR

The Siglufjördur area hosts two low temperature geothermal systems, in Skútudalur and in Skarddalur, and both are now operated for hot water production. The location of the two fields is shown on Figure 2. They are situated some 4 to 5 km away from the town centre of Siglufjördur.

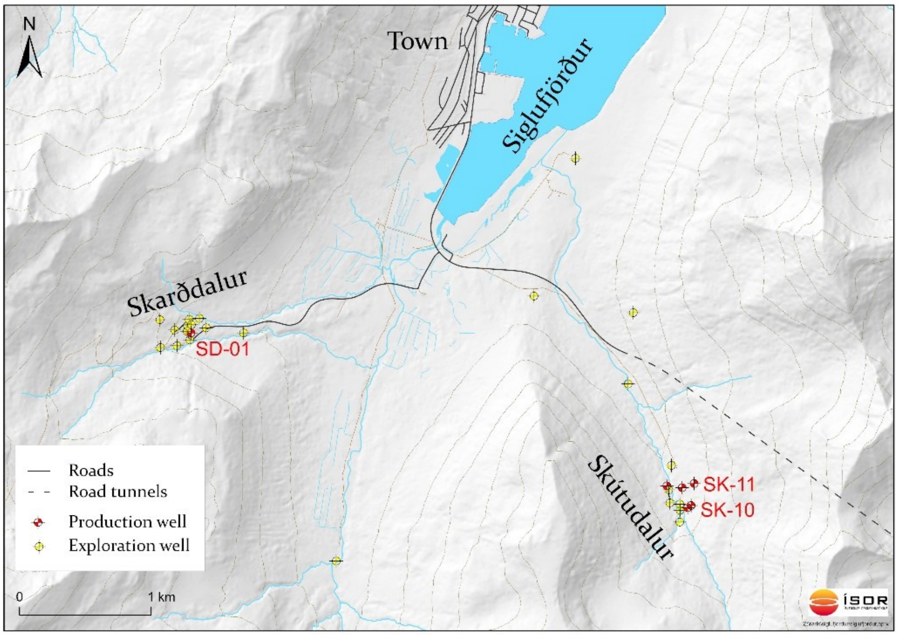

Figure 2. The location of Skútudalur and Skarddalur geothermal fields and some of the wells in each field.

2.1 The geothermal system of Skútudalur

Warm springs were known in Skútudalur with a temperature up to 45°C and as early as 1934 plans were made to utilise the hot water for a swimming pool, but the plan was not realised. In 1960 the town of Siglufjördur bought the land and exploration drilling began in 1964 with one shallow well drilled to the depth of 100 m. In 1969 to 1971 five more wells were drilled with the depth range 300 to 500 m. In 1975 a deep well was drilled, and the first houses were connected to the district heating system in December 1975. New wells were drilled for more water during 1976 to 1983. The well head temperature from the first wells was about 65°C but increased to over 70°C with later wells (Thórdarson, S., 1998; Tómasson, J., et al., 1979). Table 1 shows an overview of the main production wells in Skútudalur.

Table 1. Overview of the main production wells in Skútudalur, past and present.

Well	Year of drilling	Depth (m)	Status
SK-7	1975	1152	Not in use
SK-8	1976	1672	Not in use
SK-9	1976	1360	Not in use
SK-10	1977	1098	In use
SK-11	1983	870	In use

2.2 Influence of the road tunnel on the Skútudalur reservoir

In 2006 to 2008 Vegagerdin (Icelandic Road Administration) build a road tunnel through the mountains adjacent to the geothermal system in Skútudalur. The tunnel is in two parts, one from Ólafsfjördur to Hédinsfjördur, 7.1 km long and the other from Hédinsfjördur to Siglufjördur, 3.9 km long. The geothermal systems of Ólafsfjördur and Skútudalur reside within these mountains. During the tunnelling several fractures were encountered with water temperature up to 25°C in the tunnel leg from Hédinsfjördur to Siglufjördur and the total flowrate was as high as 45-50 L/s. It became soon clear that the tunnel, or the water flow from the tunnel, affected the geothermal system. The water level of the reservoir decreased, although production did not increase correspondingly, and it became more difficult to simulate the water-level with a reservoir model of the system, which had been regularly updated. The chemical composition of the water changed to some extent as well (Axelsson, G., 2009; Axelsson, G. and Ólafsson, M., 2010).

Figure 3 shows measured and calculated waterlevel data from the Skútudalur reservoir (based on data from well SK-7) from 1975 to 2010. The measured data is shown with boxes whereas calculated waterlevel based on a lumped parameter pressure model is shown with a black line. The model is based on the waterlevel measurements showed with filled black boxes. The waterlevel measurements not used in the model are shown as open boxes. The difference between the measured values and the calculated ones since autumn 2006 indicates changes within the reservoir. These changes can partly be attributed to increased production peaks in 2007 and 2008, but the results show deviations which can only be associated with the road tunnel, or more precisely with water leakage from them which may have affected the pressure regime within the reservoir (Sigurdsson, Ó. et al., 1987; Axelsson, G. and Ólafsson, M., 2010).

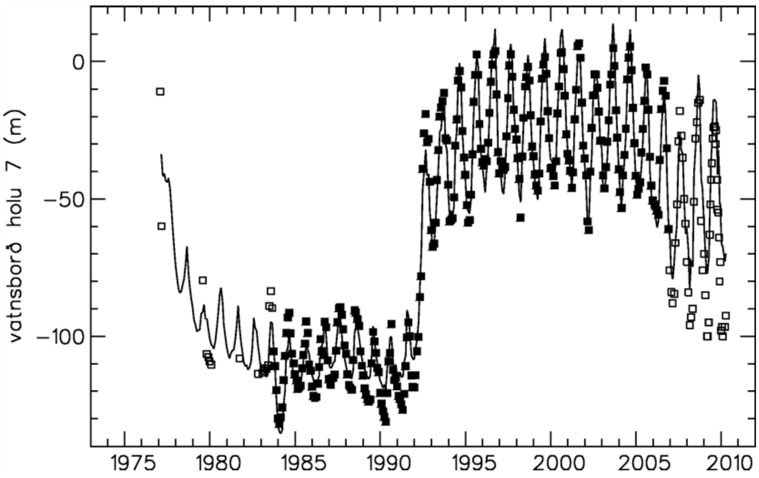

Figure 3. Measured and calculated water-level in the Skútudalur reservoir (well SK-7) from 1975 to 2010.

2.3 The geothermal field of Skarddalur

When it came obvious that the road tunnel between Siglufjördur and Hédinsfjördur, or more precisely the water leakage from them, affected the water-level within the Skútudalur geothermal reservoir, RARIK decided to look for another thermal field in the Siglufjördur area. As early as 1988 to 1990 several shallow temperature gradients wells had been drilled in the area and a thermal anomaly observed in Skarddalur (Torfason, H., 1989; Torfason, H., et al., 1991). No surface manifestation of geothermal water had been observed in the Skarddalur area prior to drilling. In 2010 a few more temperature gradient wells were added to locate the anomaly more precisely and, in the autumn of 2010, a new production well, SD-1, was drilled (Jóhannesson, H., 2010; Jóhannesson, H. et al., 2010). The well was tested with a downhole pump for two and half months prior to being put into production in 2011 (Junrong, L., 2011). Monitoring data during the test showed that a downhole pump should be placed at a depth of 150 m to sustain constant pumping of 10 L/s and at 200 m depth to cope with short term peak production of 35-40 L/s. Since production started the well head temperature has been rather constant at about 74°C (Table 2).

Table 2. The production well SD-1 in Skarddalur

Well name	Year of drilling	Depth (m)	Status
SD-1	2010	702	In use

3. WATER PRODUCTION AND WATER CHEMISTRY

The production of hot water for the Siglufjördur district heating system started in 1975 and for the first ten years the monitoring of e.g. production, temperature and water table was rather poor but from about 1985 the monitoring has been on a regular basis as well as chemical monitoring of the geothermal water. Figure 4 shows the average annual production of hot water from 1975 to date. From 1975, the hot water was produced from wells in Skútudalur and since 2010 from one well in Skarddalur as well as the Skútudalur wells. It should be noted that the drop in the production in 1992 is due to a change in how the water was metered to individual customers. Until 1992 each customer bought a fixed amount of water, often a few litres per minute per household, whereas since 1992 the water was sold by the amount used. This caused a rather large drop in the total production of water from the geothermal system. It should be noted here that production data for 2012 and 2016 have been omitted on the figure, due to unrealistic numbers, which need to be checked (data from RARIK database).

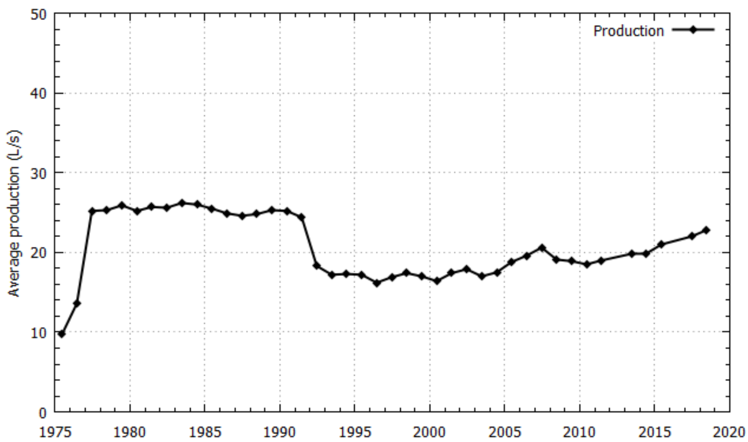

Figure 4. The average annual production of water in L/s from the geothermal fields in Siglufjördur from 1975 to 2018. From 1975 to 2010 the water comes from wells in Skútudalur and since 2010 also from a well in Skarddalur.

In 2018 the total production of hot water from the two systems was about 720.000 m^3, with 255.000 m^3 from wells in Skútudalur and 465.000 m^3 from well SD-1 in Skarddalur. In 2017 the total production was about 691.300m^3 and about 238.600 m^3 came from Skútudalur and 452.700 m^3 from Skarddalur. As can been seen in Figure 4 the average annual production of hot water has been increasing during the last several years. This is better shown in Figure 5 where the total annual production for the Skútudalur and Skarddalur fields from 2012 to 2018 is shown in m^3. The increase in water production during this time has been about 16%.

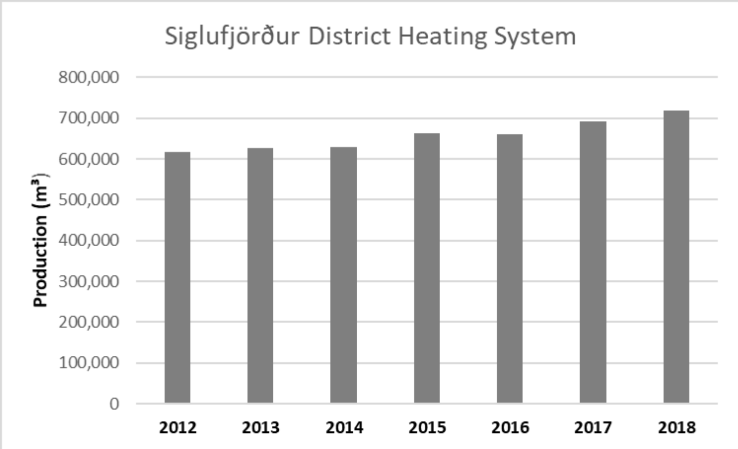

Figure 5. The annual production of hot water for the Siglufjördur district heating system in 2012 to 2018. The increase in production from 2012 to 2018 is about 16%.

As is the case of all district heating systems in Iceland a large variation is in the use of hot water during winter times compared to summer times. This variation is shown in Figure 6 for Siglufjördur for the year 2018. During that year the peak production was in January and December, about 75.000 m^3 per month and the lowest production in June and July about 42.000 m^3. This is a difference of about 45%, from maximum production to the minimum production (Ólafsson, M. and Óskarsson, F., 2019).

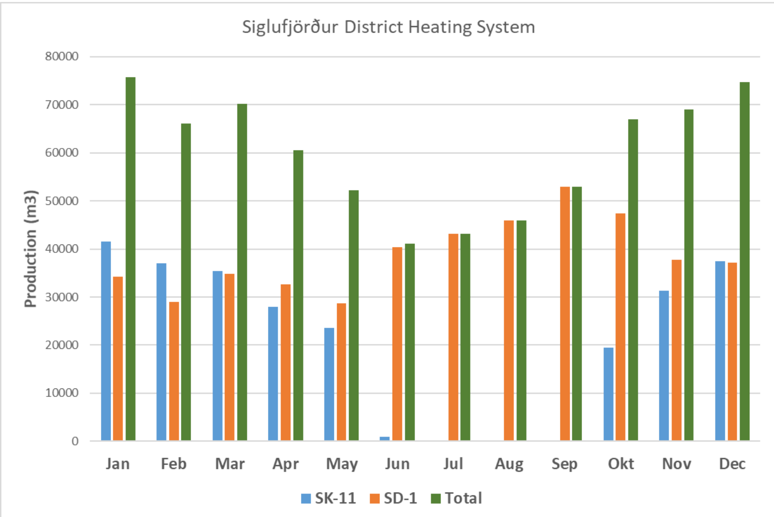

Figure 6. The monthly production of water from wells in Skútudalur (SK-11) and Skarddalur (SD-1) in 2018 as well as the total production of hot water. The production in June is about 45% less than in January, reflecting the weather conditions in the area.

In general, the geothermal water from both systems is very well suited for direct use in house heating and other household appliances (Ólafsson, M., and Óskarsson, F., 2019). A representative analysis of geothermal water from production wells SK-10, SK-11 and SD-1 is shown in Table 3. Figures 7 and 8 show some of the monitoring data for well head temperature and silica. As can be seen from Table 3 and Figure 8 the mineral content of the water is low. The earliest data on Figure 8 shows clear indication of the influence of groundwater of lower mineral content used during the drilling of the well. Scaling has not been a problem as indicated on Figure 9 which shows the saturation index for calcite, calculated at well head temperature. The water from the two systems differ slightly based on their isotopic composition as shown in Figure 10, where the water from the SD-1 well in Skarddalur show a slightly lighter isotopic composition. Water in both systems is of meteoric origin as indicated by the global meteoric water line on Figure 10. For a long time, the water from Skútudalur contained dissolved oxygen, which caused corrosion problems for steel pipes. In order to remove the oxygen, the geothermal water was dosed with small quantities of sodium sulphite, which reacts with oxygen to form sulphate according to the following formula:

$$Na_2SO_3 + \frac{1}{2}O_2 \Rightarrow 2Na^+ + SO4^{2-} \quad (1)$$

At the time when the Icelandic Road Company was constructing the road tunnel between Hédinsfjördur and Siglufjördur in 2007 a change in the chemical composition of the geothermal water in well SL-11 was noted. The change was best displayed in an increase in the magnesium concentration of the water as indicated on Figure 11. This increase in the magnesium content disappeared soon and has not been seen since. It is believed that the reason for the increased content was due to a disturbance to the geothermal reservoir when the tunnel was being dug through some fractures linked to the reservoir. It is worth mentioning here that soon after the change in the chemistry of the water in well SK-11 the concentration of dissolved oxygen decreased to a level comparable to other low temperature waters in Iceland with similar reservoir temperature, down to less than 0.005 mg/L and the dosing of sodium sulphite could be lowered.

Table 3. Representative analyses of geothermal water from wells SK-10, SK-11 and SD-1. Concentrations in mg/L, except where noted otherwise (ÍSOR data base).

Well	SK-10	SK-11	SD-01
Well id	B-42310	B-42311	B-42151
Date	2010-02-23	2017-04-26	2018-03-15
Sample number	20100047	20170085	20180059
Well head temperature (°C)	66.4	70.7	74.5
pH and pH-temperature	9.89 / 20.6	9.90 / 20.5	9.75 / 21.6
Conductivity at 25°C (µS/cm)	209	203	252
Carbonate (total as CO_2)	16.3	15	16
Hydrogen sulphide (H_2S)	-	<0.02	0.15
Dissolved oxygen (O_2)	0.1	0.002	<0.001
Boron (B)	0.027	0.05	0.08
Silica (SiO_2)	90	95.7	120
Sodium (Na)	38.4	44.9	54.5
Potassium (K)	0.64	0.69	1.2
Magnesium (Mg)	0.004	0.002	0.004
Calcium (Ca)	1.54	1.54	2.23
Fluoride (F)	0.33	0.329	0.47
Chloride (Cl)	8.57	8.44	15
Bromide (Br)	-	0.019	0.027
Sulphate (SO_4)	9.13	9.18	22.6
Aluminium (Al)	0.0599	0.0688	0.0303
Arsenic (As)	0.00187	0.00237	0.00263
Barium (Ba)	0.000045	0.000033	0.000055
Cadmium (Cd)	<0.000002	0.000004	0.000003
Cobalt (Co)	0.00002	<0.000005	<0.000005
Chromium (Cr)	0.0011	0.000018	<0.000001
Copper (Cu)	0.000304	0.000309	<0.0001
Iron (Fe)	0.0083	0.00212	0.00192
Mercury (Hg)	0.000006	<0.000002	<0.000002
Lithium (Li)	-	-	0.00996
Manganese (Mn)	0.000219	0.000091	0.000055
Molybdenum (Mo)	0.00276	0.00287	0.00653
Nickel (Ni)	0.000695	<0.000005	<0.000005
Lead (Pb)	0.000266	0.000815	0.000019
Strontium (Sr)	0.00155	0.00242	0.00838
Vanadium (V)	-	0.00528	0.00106
Zinc (Zn)	0.00575	0.00139	0.00059
Total dissolved solids (TDS)	204	202	268
Ionic balance (%)	2.73	16.41	10.19
δD (‰ SMOW)	-76.89	-78.1	-84.5
$\delta^{18}O$ (‰ SMOW)	-11.33	-11.38	-12.02

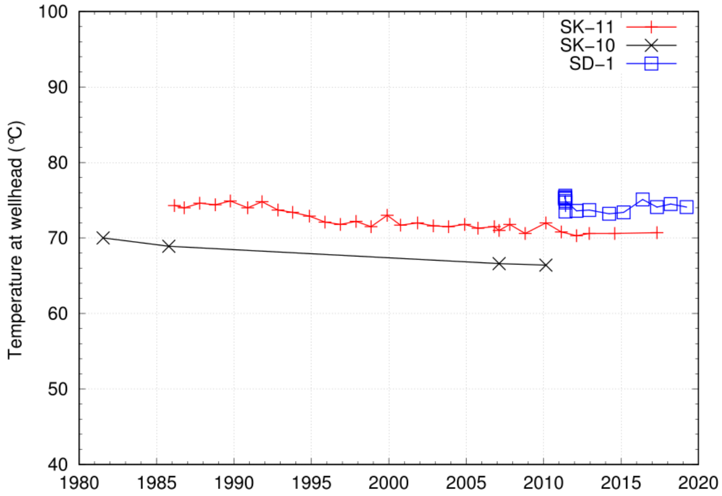

Figure 7. Well head temperature at the time of water sampling for wells SK-10, SK-11 and SD-1.

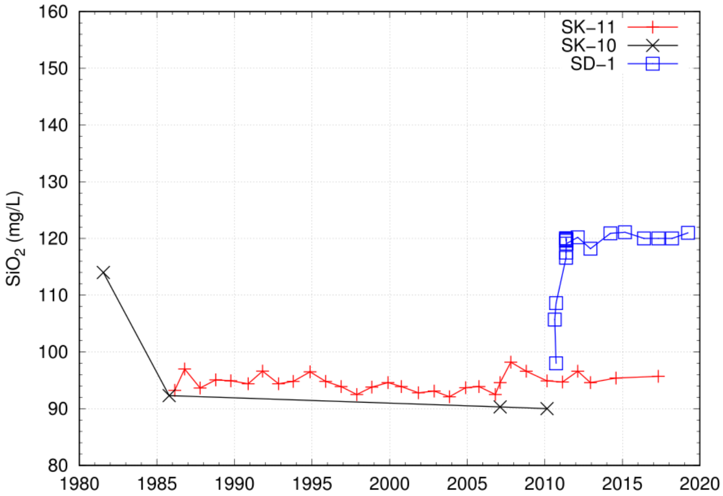

Figure 8. The silica concentration of water samples from wells SK-10, SK-11 and SD-1. The first samples from well SD-1 show a clear indication of influence from groundwater used during the drilling of the well.

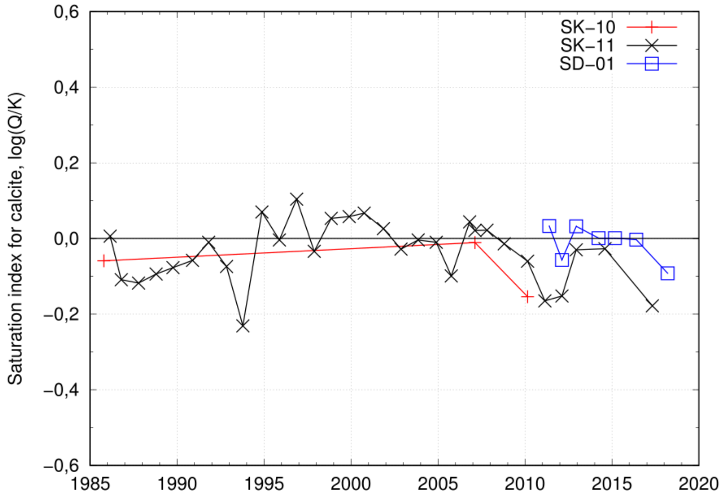

Figure 9. The saturation index for calcite for water sample from wells SK-10, SK-11 and SD-1. Most of the samples fall on or below the equilibrium line at log(Q/K) = 0. Calcite scaling has not been observed within the distribution system.

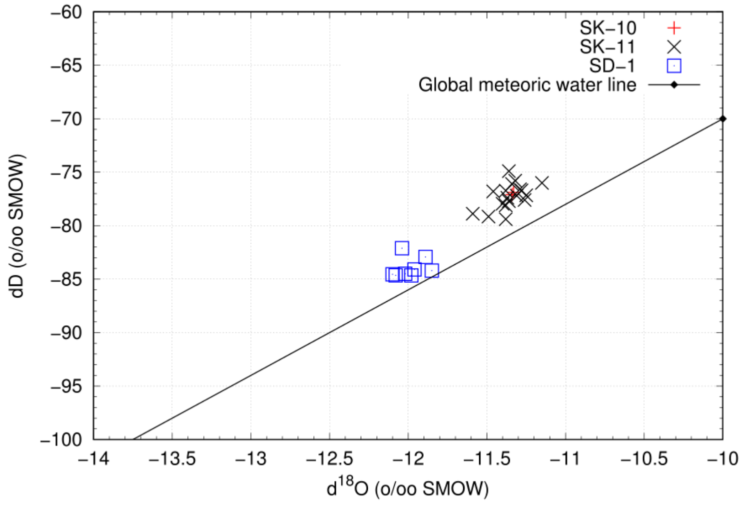

Figure 10. The isotopic composition of water from production wells in Skútudalur and Skarddalur. The global meteoric water line is shown for comparison.

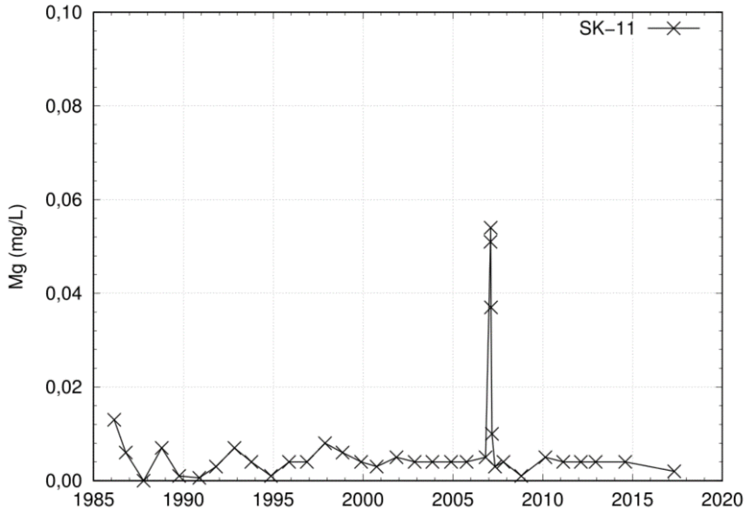

Figure 11. The magnesium content of water from well SK-11 in Skútudalur. The increased Mg content in 2007 is most likely caused be disturbances within the geothermal reservoir caused by the construction of the road tunnel between Hédinsfjördur and Siglufjördur.

CONCLUSIONS

The district heating system for the town of Siglufjördur, North Iceland, has been operated since 1975. Until 2010 the hot geothermal water was produced from wells in the Skútudalur geothermal field and since 2010 also from the Skarddalur field. In 2006 to 2008 a road tunnel was constructed through the mountains adjacent to the geothermal system in Skútudalur affecting the pressure regime within the system. The hot water production was consequently partly moved to the Skarddalur field. Since 1985 the production from the fields has been monitored thoroughly with respect to production, temperature, chemistry etc. The water is well suited for direct use in house heating and the average annual production rate for the two fields combined was about 23 L/s in 2018.

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