ÍSLENSKAR ORKURANNSÓKNIR
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Drilling Success in Geothermal Fields Utilized by Major District Heating Services in Iceland

Björn Már Sveinbjörnsson

Prepared for Orkustofnun
(National Energy Authority of Iceland, NEA)

ÍSOR-2018/043

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Abstract

The report describes success of 446 production wells drilled in the years 1928-2017 in 63 low- and medium enthalpy geothermal fields which are exploited by the 64 major district heating services in Iceland. The dataset on which the report is based has been collected from the National Well Registry of boreholes and available reports. To the extent verifiable data are available, the assembled dataset is presented in an Excel document accompanying the report on CD. About 93% of the drilled wells were productive, i.e. encountered feeders that could yield a flow from the well. Of the productive wells 164 are still in use, with an average production capacity of 31.7 l/s at 90.3°C. The main reasons for productive wells not in use are: a) drawdown of reservoir pressure, b) replaced by better wells or c) idle but could produce. About 49% of the main feeders are shallower than 500 m, 76% are shallower than 1,000 m and 95% are shallower than 1,600 m. About 88% of the 446 drilled production wells fulfilled the minimum criterion set for space heating of a discharge temperature of 60°C and 65% fulfilled the criterion of 80°C discharge temperature. The far largest low enthalpy geothermal field, Reykir in Mosfellsbær, has a present production capacity equivalent to 1.800 l/s of 85.4°C hot water or a thermal power potential of 367 MW_{th} above 35°C. The largest well fields, Æsustaðir and Suður-Reykir, in the Reykir field have a thermal power potential above 35°C of 139.7 and 96.7 MW_{th} respectively. The total thermal power potential of all the geothermal fields exploited by the 64 major district heating services is equivalent to 1,770 MW_{th} above 35°C.

Key words	ISBN-number
Low enthalpy geothermal fields, medium enthalpy geothermal fields, productivity of wells, drilling success, thermal power potential, Iceland	
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1 Introduction

Geothermal resources in Iceland have been classified as high temperature fields when temperatures above about 200°C are found in the uppermost 1,000 m, but as low temperature fields where temperatures are less than about 150°C in the uppermost 1,000 m (Böðvarsson, 1961; Friðleifsson, 1979; Arnórsson, 1995a, b). Geothermal fields with reservoir temperatures between 100 and 200°C have been referred to as boiling low temperature areas (Arnórsson and Þórhallsson, 2001). In a report on boiling low temperature fields (Sveinbjörnsson, 2016) we preferred a classification based on fluid enthalpy which distinguishes between high-, medium- and low enthalpy geothermal resources. There 200°C were used as the lower limit of high enthalpy resources and 100°C as the upper limit of low enthalpy resources, see Table 1.

Table 1. *Classification of geothermal resources by enthalpy and temperature used in this report (Sveinbjörnsson, 2016).*

Enthalpy	Classification of Geothermal Resources	Temperature
(kJ/kg)		(°C)
852 ≤ 2,107	High Enthalpy Resource	200 ≤ 374.15
419 < 852	Medium Enthalpy Resource	100 < 200
0 < 419	Low Enthalpy Resource	< 100

High enthalpy hydrothermal resources have been developed in seven geothermal fields in Iceland for generation of electricity and in three of those cogeneration of hot water for space heating and industrial uses takes place. A report on the success of high temperature geothermal wells in Iceland was published in 2014 (Sveinbjörnsson, 2014).

Medium enthalpy resources have been developed in over 80 fields in Iceland for space heating, greenhouses, balneology and industrial uses. A report about the thermal and electric potential of medium enthalpy geothermal resources in Iceland was published in 2016 (Sveinbjörnsson, 2016).

Low enthalpy resources have been utilized for space heating in Iceland for more than 90 years, but also for several other direct uses i.e. cultivation of plants and vegetables in greenhouses, balneology, industrial processing, aquaculture and snow melting (Björnsson, 2009, Ragnarsson, 2015).

Orkustofnun, the National Energy Authority of Iceland (NEA) maintains a Well Registry covering all drilled wells in Iceland. In order to evaluate the potential of low enthalpy resources in Iceland for cascade utilization, data have been collected from the National Well Registry of boreholes grouped after geothermal fields. The evaluation in this report is, however, limited to the low- and medium enthalpy fields used by the 64 major district heating services. In addition to the standard documentation in the Well Registry, data on success and capacity of wells were collected from available reports. This report presents data on 446 production wells (nearly 50% of all drilled production wells in

Iceland for hot water) in 39 low and 24 medium enthalpy fields in Iceland. These fields have formation temperatures up to 200°C, and the thermal production capacity of the resources for space heating above 35°C ranges from a few MW_{th} up to 367 MW_{th}. Some of the district heating services do also exploit high enthalpy systems which have already been evaluated in the reports of (Sveinbjörnsson, 2014 and 2016).

The largest low enthalpy well fields have a thermal power potential of 140 MW_{th} from fluid above 35°C, and up to 213 MW_{th} above 5°C. During the first decades of geothermal use, various small rigs were used for the drilling, and the deepest wells were only about 500 m. Since 1958, large rotary drill rigs from the oil industry drilled wider and deeper wells. The wells drilled since 1958 were therefore analyzed separately and compared with the total group of 1928-2018.

A dataset and a report of this nature is not one man's work. The author enjoyed cooperation and assistance of numerous colleagues at Orkustofnun, Iceland GeoSurvey (ÍSOR) and the geothermal district services. A few of them are named here in Icelandic alphabetic order: Árni Ragnarsson, Benedikt Steingrímsson, Guðni Axelsson, Grétar Ívarsson, Hrefna Kristmannsdóttir, Kristján Sæmundsson, Rósa Jónsdóttir, Sigrún Gunnarsdóttir, Sigvaldi Thordarson, Steinunn Hauksdóttir, Sveinbjörn Björnsson, Sverrir Þórhallsson, Þorgils Jónasson and Þórólfur H. Hafstað.

One of the objectives of this report was to strengthen the database of the National Energy Authority. It is a partial contribution from Iceland to the International Energy Agency - Geothermal Implementing Agreement (IEA-GIA), Annexes VII and XI, and the Lower Cost Drilling Annex of the International Partnership for Geothermal Technology (IPGT).

1.1 Potential for exploitation

1.1.1 Thermal power potential

A mass flow of Q (kg/s) from a geothermal well at a temperature T with an enthalpy h_T (kJ/kg) carries a thermal power of $P = Q * h_T$. Direct use of this thermal power depends on the possibilities for cascade utilization down to environmental temperatures. For the mean annual temperature in Iceland of 5°C the ultimate usable power would be $P_5 = Q * (h_T - h_5)$. For district heating services a final rejection temperature of 35°C is common. In Chapter 4 the thermal power potential of wells and fields is calculated, both for the discard temperature of 35°C and the ultimate minimum 5°C using the formulas $P_{35} = Q * (h_T - h_{35})$ and $P_5 = Q * (h_T - h_5)$. Generally, the flow from a well or a spring is given as volumetric flow in l/s. The flow value is converted into mass flow, Q (kg/s), according to the water density at the respective discharge temperature. Enthalpy values are based on the steam table "Properties of water and steam in SI units" edited by Grigull (1979).

1.1.2 Geothermal utilization

The Líndal Diagram gives an overall view of geothermal utilization depending on the resource temperature, see Fig. 1.

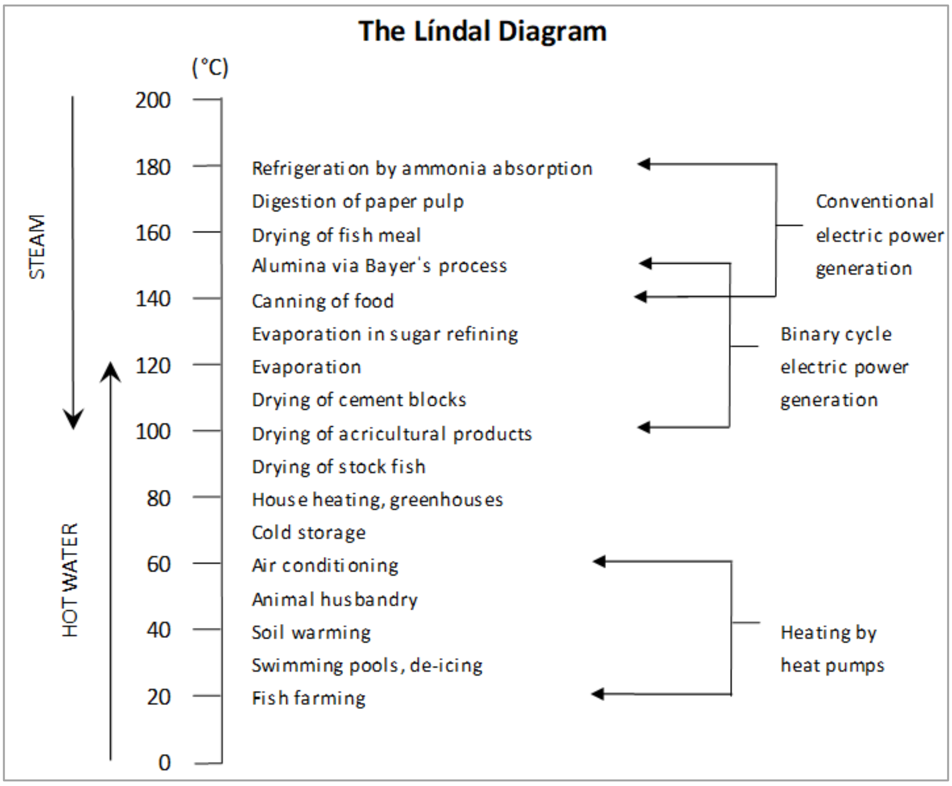

Figure 1. *Líndal Diagram over different utilization of geothermal resources (redrawn from Guðmundsson et al., 1985).*

In Iceland, low enthalpy resources are used for most of the purposes listed in the Líndal Diagram but the dominating utilization by the licensed heating services has been direct use of hot water for space heating down to about 35°C.

2 Definitions and Overview of the Dataset

The dataset on which this report is based covers 446 production wells in low- and medium enthalpy geothermal fields exploited by the 64 major district heating services, which utilize over 100 well fields of 63 geothermal fields in 33 districts in Iceland. A reservoir temperature in these fields is anticipated from recorded temperatures in wells or indications from silica geothermometers. For the estimates of the thermal power potential of the low enthalpy fields, major thermal springs in 6 geothermal fields are also included. The dataset describes 63 low- and medium enthalpy geothermal fields and 115 drilling fields within these fields. To the extent verifiable data are available, the assembled dataset is presented in an Excel document accompanying the report on CD. Description of the columns is as follows:

2.1 Location of well

Column A: Mark for District
Mark in Latin/Roman alphabet letter for the district in Iceland where the well is located in.

Column B: District
Defined name of the district where a district heating service is located.

Column C: Mark for a District Heating Service
Mark in Arabic number for the district heating service which owns/operates the well.

Column D: District Heating Service
Defined name of the district heating service that utilizes low- and /or medium enthalpy geothermal fields.

Column E: Mark for Fields
Mark in Latin/Roman numbers for the geothermal field where the well is located.

Column F: Geothermal Field

Defined name of the geothermal field where wells are located. A geothermal field may consist of several well fields.

Column G: Type of Geothermal Field

Classification of geothermal field according to Table 1 for enthalpy of the discharge.

(L): Low enthalpy of 0 < 419 kJ/kg or below 100°C;

(M): Medium enthalpy of 419 < 852 kJ/kg or between 100 < 200°C.

Column H: Mark for well field or field
Mark in Latin/Roman numbers for the well field where the well is located or a field with no wells, only hot springs.

Column I: Well field or field (with no wells, only hot springs)
Defined name of the well field where wells are located.

Column J: Well
Recorded name of the well.

Column K: Code-number
Code-number of the well.

Column M: Current municipality
Current name of the municipality in which the well is located.

Column N: Older municipality
Former name of the municipality in which the well is located.

2.2 Well status

Column O: Purpose of drilling
Purpose with which the well was drilled.

Column P: Productive
Whether the well was productive or not after drilling.

Column Q: In use

Whether the well is in use or not

Column R: Reason for not in use or not productive
Reason for that the well is not in use.

Column S: Successful - For direct heating (T ≥ 80°C)
Whether the well was successful yielding water at T ≥ 80°C or not.

Column T: Successful - For direct heating (T ≥ 60°C)
Whether the well was successful yielding water at T ≥ 60°C or not.

2.3 Description of well

Column U: When drilled
Date when the drilling or deepening of the well was finished.

Column V: Length of well
Drilled length of the well in meters, not the true vertical depth.

Column W: WH elevation
Height of the wellhead in meters above sea level.

Column X: Inclination
Whether the well was drilled directionally or vertical (d/v).

Column Y: Bit
Diameter of the drilling bit in the production section of the well, in inches.

Column Z: Production casing diameter
Outer diameter of the production casing in the well, in inches.

Column AA: Production casing depth
Length of the production casing in the well, in meters.

2.4 Reservoir characteristics

Column AB: Maximum measured temperature
Recorded maximum measured temperature (or discharge temperature) in the well in Celsius degrees.

Column AC: Depth of maximum temperature
Depth (along the well length) of the maximum measured temperature in the well, in meters.

Column AD: Date of maximum temperature
Date of the maximum measured temperature in the well.

Column AE: Depth of feeder 1
Drilled depth of the main feeder in the well, in meters.

Column AF: Temperature of feeder 1
Temperature of the main feeder in the well, in Celsius degrees.

Column AG: Depth of feeder 2
Drilled depth of the second largest feeder in the well, in meters.

Column AH: Temperature of feeder 2
Temperature of the second largest feeder in the well, in Celsius degrees.

Column AI: Depth of feeder 3
Drilled depth of the third largest feeder in the well, in meters.

Column AJ: Temperature of feeder 3
Temperature of the third largest feeder in the well, in Celsius degrees.

2.5 Production characteristics

Column AL: Date of recorded water-table depth
Date when the water-table in the well was measured.

Column AM: Depth of water-table
Measured depth of the water-table in the well, in meters.

Column AN: WHP flowing
Wellhead pressure of the total flow from the well, in bar-g.

Column AO: Free-flow
Amount of free-flow from the well, in liters per second.

Column AP: Pumped
Amount of pumped flow from the well, in liters per second

Column AQ: Discharge temperature
Temperature of the discharged flow, in Celsius degrees.

Column AR: Date of discharge flow
Date when the discharge temperature was measured.

2.6 Thermal power potential of well field and geothermal field

Column AS: Well field - Thermal power potential above 35°C (MW_{th})
Thermal power potential above 35°C of the well field, in megawatts.

Column AT: Well field - Thermal power potential above 5°C (MW_{th})

Thermal power potential above 5°C of the well field, in megawatts.

Column AU: Geothermal field- Thermal power potential above 35°C (MW_{th})

Thermal power potential above 35°C of the geothermal field, in megawatts.

Column AV: Geothermal field - Thermal power potential above 5°C (MW_{th})

Thermal power potential above 5°C of the geothermal field, in megawatts.

3 Overview of the Major Geothermal District Heating Services in Iceland

3.1 Largest operators of district heating services

In recent years energy companies have been established and they have taken over the operation of many of the former district heating services of the communities. The district heating services operated by these energy companies are marked in the following text with their corresponding abbreviations.

The company Veitur Utilities PLC (Veitur), a subsidiary of Orkuveita Reykjavíkur (OR, Reykjavík Energy), operates licensed geothermal district heating services in Reykjavík, Mosfellsbær, Kjalarnes, Kópavogur, Hafnarfjörður, Garðabær, Akranes, Borgarbyggð, Stykkishólmur, Hveragerði, Þorlákshöfn, Hvolsvöllur and Hella. It also operates seven district heating services without concession in South- and West Iceland (Austur in Ölfus, Grímsnes in Grímsnes and Grafningur District, Hlíða in Bláskógabyggð District, Rangá in Rangárþing ytra District, Skorradalur, Munaðarnes and Norðurárdalur in Borgarbyggð District.

The energy company Rafmagnsveitur Ríkisins (RARIK, Iceland State Electricity) operates geothermal district heating services in the Dalabyggð District, Blönduós/Skagaströnd in the Húnavatnshreppur District, Siglufjörður in the Fjallabyggð District and in preparation is Höfn in the Hornafjörður District.

The company Orkubú Vestfjarða (OV) operates geothermal heating services at Reykhólar in Reykhólahreppur District and Suðureyri in the Ísafjarðarbær District.

The Húnaþing vestra District Heating (HÚV) operates three district heating services at Borðeyri, Reykir in Hrútafjörður, Hvammstangi/Laugarbakki, all in the Húnaþing vestra District.

The company Skagafjarðarveitur (SKV) operates six geothermal heating services (Steinsstaðir, Sauðárkrókur, Varmahlíð, Hólar, Hofsós and Sólgarðar/Langhús, all in the Skagafjörður District).

The company Norðurorka (NO) operates the geothermal district heating services in Ólafsfjörður in the Fjallabyggð District, Ytrivík in Dalvíkurbyggð District, Akureyri and Hrísey in Akureyrarkaupstaður, and Reykir (with Þingeyjarsveit commune) in Þingeyjarsveit District.

The energy company Orkuveita Húsavíkur (OH) operates the geothermal heating services Hafralækur and Aðaldalur/Kinn in Þingeyjarsveit District, Húsavík in Norðurþing District and Öxarfjörður in Norðurþing District.

The Bláskógar District Heating service (BV) operates three district heating services at Laugarvatn, Reykholt and Laugarás, all in Bláskógar District.

3.2 Location of the major geothermal district heating services

Table 2 lists the major 64 geothermal district heating services in Iceland utilizing low and medium enthalpy geothermal fields and their 33 districts. The district heating services are numbered clockwise around Iceland from the capital area and Fig. 2 shows the locations of the district heating services. The red dots denote the places of utilization but not the fields where the hot geothermal water is produced. The fields and the distribution areas are described in detail in Chapter 4. It should be noted that the district heating service of Suðurnes operated by HS Veitur is not included in this overview. This is due to the fact that the production of hot water is only by heating of cold ground water using high enthalpy fluid from the field of Svartsengi and no low or medium enthalpy utilization is involved.

Table 2. *Districts and the 64 major district heating services in Iceland.*

Districts		District Heating Services (Owner)	
A	Seltjarnarnes	1	Seltjarnarnes District Heating
B	Reykjavík	2	Reykjavík District Heating (Veitur)
C	Mosfellsbær	3	Mosfellsbær District Heating (Veitur)
D	Kjósarhreppur	4	Kjós District Heating
-	-	5	Hvammsvík District Heating (Veitur)
E	Skorradalshreppur	6	Skorradalur District Heating (Veitur)
F	Borgarbyggð	7	Akranes/Borgarfjörður District Heating (Veitur)
-	-	8	Húsafell District Heating
-	-	9	Reykholt District Heating
-	-	10	Kleppjárnsreykir District Heating
-	-	11	Brúarreykir District Heating
-	-	12	Varmaland District Heating
-	-	13	Stafholtstungur District Heating
-	-	14	Munaðarnes District Heating (Veitur)
-	-	15	Norðurárdalur District Heating (Veitur)
G	Helgafellssveit	16	Stykkishólmur District Heating (Veitur)
H	Dalabyggð	17	Dalabyggð District Heating (RARIK)
I	Reykhólahreppur	18	Reykhólar District Heating (OV)
-	Reykhólahreppur	19	Thorverk District Heating
J	Ísafjörður	20	Suðureyri District Heating (OV)
K	Kaldrananeshreppur	21	Drangsnes District Heating
L	Húnaþing vestra	22	Borðeyri District Heating (HÚV)
		23	Reykir District Heating (HÚV)
		24	Hvammstangi/Laugarbakki District Heating (HÚV)
M	Húnavatnshreppur	25	Blönduós District Heating (RARIK)
-	-	26	Skagaströnd District Heating (RARIK)
N	Skagafjörður	27	Steinsstaðir District Heating (SKV)
-	-	28	Sauðárkrókur District Heating (SKV)
-	-	29	Varmahlíð District Heating (SKV)
-	-	30	Hólar District Heating (SKV)
-	-	31	Hofsós District Heating (SKV)
-	-	32	Sólgarðar/Langhús District Heating (SKV)
O	Fjallabyggð	33	Siglufjörður District Heating (RARIK)
-	-	34	Ólafsfjörður District Heating (NO)
P	Dalvík	35	Dalvík District Heating
-	-	36	Árskógsströnd District Heating
-	-	37	Ytrivík District Heating (NO)
Q	Hörgársveit	38	Akureyri District Heating (NO)
R	Akureyrarkaupstaður	38	Akureyri District Heating (NO)
-	-	39	Hrísey District Heating (NO)
S	Eyjafjarðarsveit	38	Akureyri District Heating (NO)
T	Þingeyjarsveit	40	Reykir District Heating (NO)
-	-	41	Reykjadalur District Heating
		42	Aðaldalur/Kinn District Heating (OH)
-	-	43	Hafralækur District Heating (OH)
U	Norðurþing	44	Húsavík District Heating (OH)
-	-	45	Öxarfjörður District Heating (OH)
V	Fljótsdalshérað	46	Egilsstaðir/Fell District Heating
W	Fjarðabyggð	47	Fjarðabyggð District Heating
X	Hornafjörður	48	Höfn District Heating (RARIK)
Y	Rangárþing ytra	49	Rangá District Heating (Veitur)
Z	Hrunamannahreppur	50	Flúðir District Heating
AA	Skeiða- og Gnúpverjahreppur	51	Gnúpverjar District Heating
-	-	52	Brautarholt District Heating
AB	Bláskógabyggð	53	Laugarvatn District Heating
-	-	54	Reykholt District Heating
-	-	55	Laugarás District Heating
-	-	56	Hlíða District Heating (Veitur)
AC	Grímsnes- og Grafningshreppur	57	Grímsnes/Grafningur District Heating
-	-	58	Vaðnes District Heating
-	-	59	Grímsnes District Heating (Veitur)
AD	Flóahreppur	60	Selfoss District Heating
AE	Árborg	60	Selfoss District Heating
AF	Hveragerði	61	Hveragerði District Heating (Veitur)
AG	Ölfus	62	Austur District Heating (Veitur)
-	-	63	Ölfus District Heating (Veitur)
-	-	64	Þorlákshöfn District Heating (Veitur)

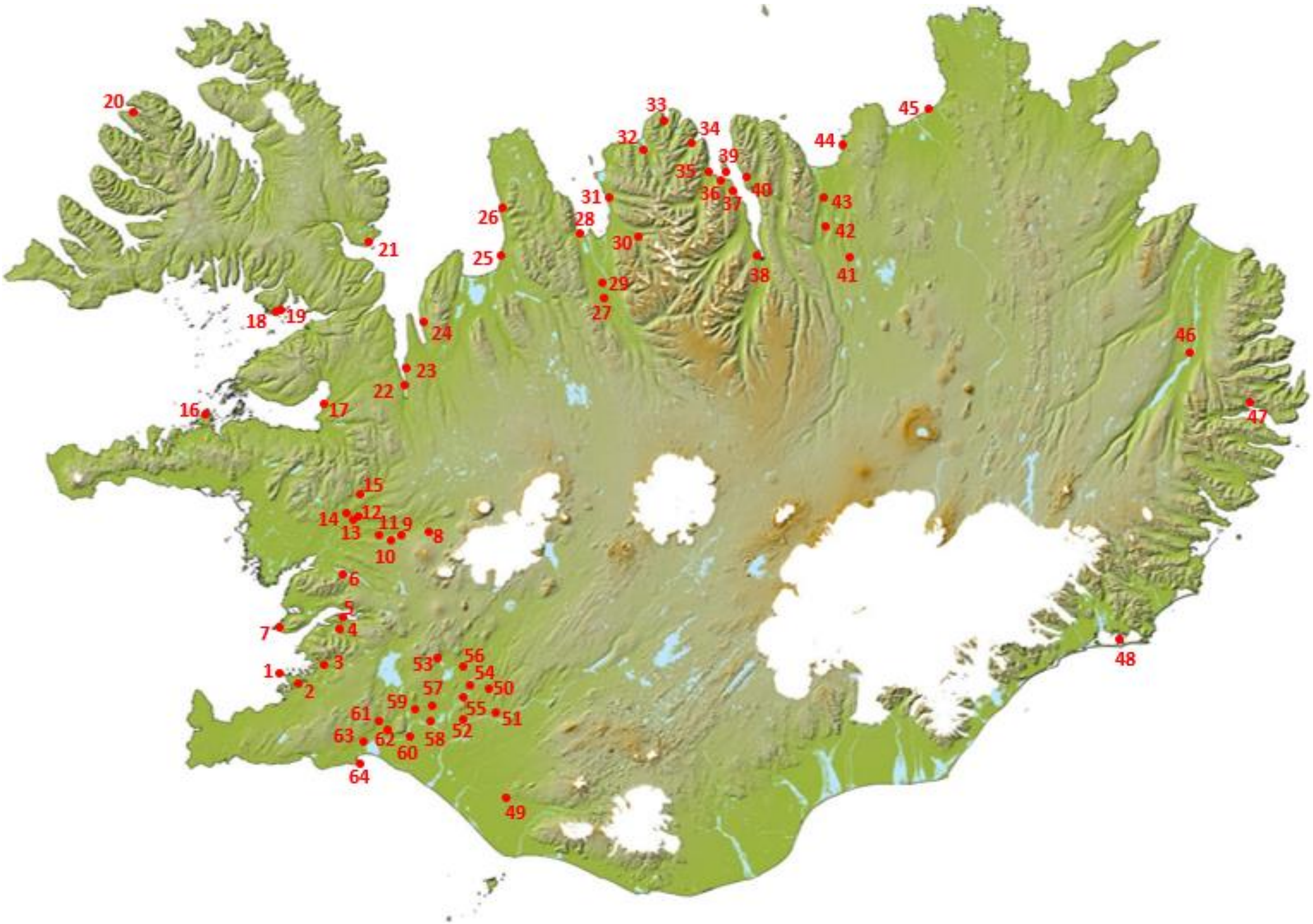

Figure 2. *Location of the 64 major district heating services in Iceland (modified from NEA's Geoportal).*

4 Results of Drilling

This chapter gives a brief account of the results of drilling in low- and medium enthalpy geothermal fields exploited by 64 major district heating services in Iceland. For a list of the licensed services we refer to Table 1 in the report by Oddsdóttir and Ketilsson (2012).

The geothermal district heating services are listed geographically from Seltjarnarnes and the capital Reykjavik, clockwise around the country as in Fig. 2. The location of well fields and drilled wells is shown in figures within each subchapter. Some wells lack, however, coordinates and can therefore not be marked on the maps.

4.1 Seltjarnarnes

4.1.1 Seltjarnarnes District Heating

The Seltjarnarnes District Heating is operated under Regulation 237/2011. It uses a medium enthalpy resource described by Sveinbjörnsson (2016).

Seltjarnarnes Geothermal Field

Production wells have been drilled in five well fields within the Seltjarnarnes geothermal field; Bakki, Nes, Nýibær, Bygggarður and Ráðagerði.

Bakki well field

Two exploration wells and one production well, SN-1, have been drilled, see Fig. 3.

Figure 3. *Overview of the production wells and well fields in the Seltjarnarnes geothermal field (modified from NEA's Geoportal).*

Well SN-1, was drilled to 1,283 m depth and has a maximum measured temperature of 117°C but is currently not in use (Kristmannsdóttir et al., 2001). At the end of drilling 3 l/s were pumped from the well for several days resulting in 1 l/s of artesian flow (Haraldsdóttir, 1984a).

Nes well field

Two exploration wells and one production well, SN-3, have been drilled, see Fig. 3. Temperatures in SN-3 reached 133°C at 1,700 m depth, and it produced 15 l/s of 102°C water, but is currently not in production (Kristmannsdóttir and Björnsson, 2014). No well is in use from the Nes field (Kristmannsdóttir et al., 2001).

Nýibær well field

One production well, SN-6, which was drilled in 1986 to 2,701 m depth, has maximum measured temperature of 144°C at 2,650 m depth and is in use, see Fig. 3. The yield is up to 25 l/s of 118-121°C water (Kristmannsdóttir et al., 2001; Kristmannsdóttir and Björnsson, 2014).

Assuming 25 l/s of 120°C one obtains a thermal power potential of P_{35} = 8.4 MW_{th} and P_5 = 11.4 MW_{th} for the Nýibær well field.

Bygggarður well field

Two exploration wells and two production wells SN-4 and SN-5, have been drilled, see Fig. 3. The exploration well SN-2 was productive, yielding about 3 l/s pumped at 80°C (Tómasson et al., 1977).

Well SN-4 which was drilled in 1986 to 2,025 m depth, found highest temperature of 127°C at 2,000 m, yields up to 35 l/s of 85-114°C water and is in use (Kristmannsdóttir and Björnsson, 2014).

Well SN-5, also drilled in 1986 to 2,207 m depth, found 119°C at 2,180 m depth, yields up to 25 l/s of 98-109°C water and is in use (Kristmannsdóttir et al., 2001; Kristmannsdóttir and Björnsson, 2014).

Assuming 35 l/s of 100°C and 25 l/s of 103°C one obtains a thermal power potential of P_{35} = 16.0 MW_{th} and P_5 = 23.2 MW_{th} for the Bygggarður well field.

Ráðagerði well field

Two exploration wells and one production well, SN-12, have been drilled, see Fig. 3. SN-12 was drilled in 1986 to 2,714 m depth, has maximum measured temperature of 145°C at 2,538 m depth, yields up to 35 l/s at 106-113°C and is currently in use (Harðardóttir and Kristmannsdóttir, 1999; Kristmannsdóttir et al., 2001; Kristmannsdóttir and Björnsson, 2014).

Assuming 35 l/s of 109°C one obtains a thermal power potential of P_{35} = 10.3 MW_{th} and P_5 = 14.5 MW_{th} for the Ráðagerði well field.

Five of the production wells in the Seltjarnarnes geothermal field are productive. The four production wells in use, SN-4, SN-5, SN-6B and SN-12, are interconnected and the average production temperature depends on which wells are being pumped. With aid of downhole pumps, the production capacity of the field could be increased considerably. The geothermal field would also benefit from increased reinjection.

Adding the thermal power potential of the well fields one obtains P_{35} = 34.7 MW_{th} and P_5 = 49.1 MW_{th} for the Seltjarnarnes geothermal field.

4.2 Reykjavík

4.2.1 Reykjavík District Heating (Veitur)

Veitur Utilities (Veitur) is a subsidiary of Reykjavík Energy (OR). It operates under Regulation 297/2006 and produces hot water for Reykjavík District Heating from the medium enthalpy geothermal field Laugarnes in Reykjavík, described by Sveinbjörnsson (2016), the low enthalpy field Elliðaár in Reykjavík, and the low enthalpy field Reykir in Mosfellsbær. It also buys hot water from the energy company Orka náttúrunnar (ON), which is also a subsidiary of Reykjavík Energy (OR). ON produces the hot water by heating fresh groundwater in cogeneration of electricity in the high enthalpy fields Nesjavellir and Hellisheiði of the Hengill geothermal field, see Fig. 4.

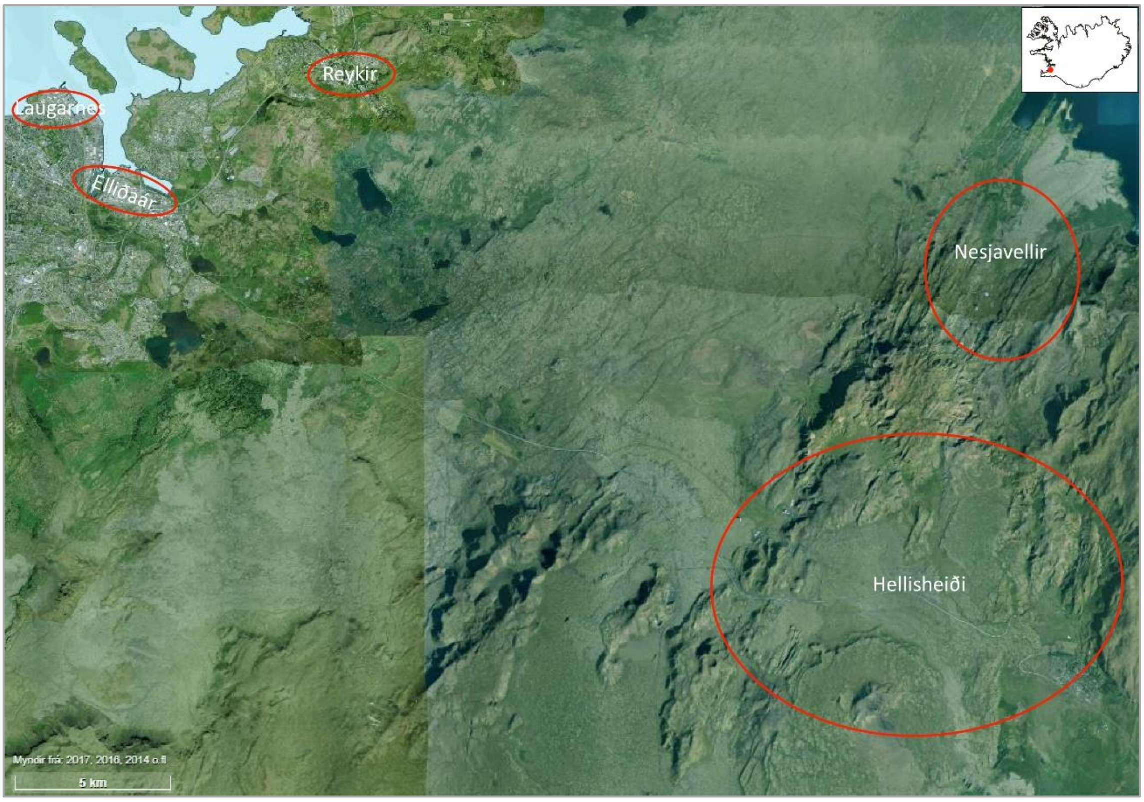

Figure 4. *Location of the geothermal fields utilized by Reykjavík District Heating, Laugarnes, Elliðaár, Reykir, Hellisheiði and Nesjavellir (modified from NEA's Geoportal).*

Geothermal water from the high enthalpy fields cannot be used directly for space heating. Instead it is used to heat fresh water up to ~80°C with heat exchangers. Due to different chemistry and problems of scaling the heated fresh water it cannot be mixed with geothermal water from medium or low enthalpy fields. Therefore, the distribution systems in Reykjavik District Heating are kept separate as shown in Fig. 5.

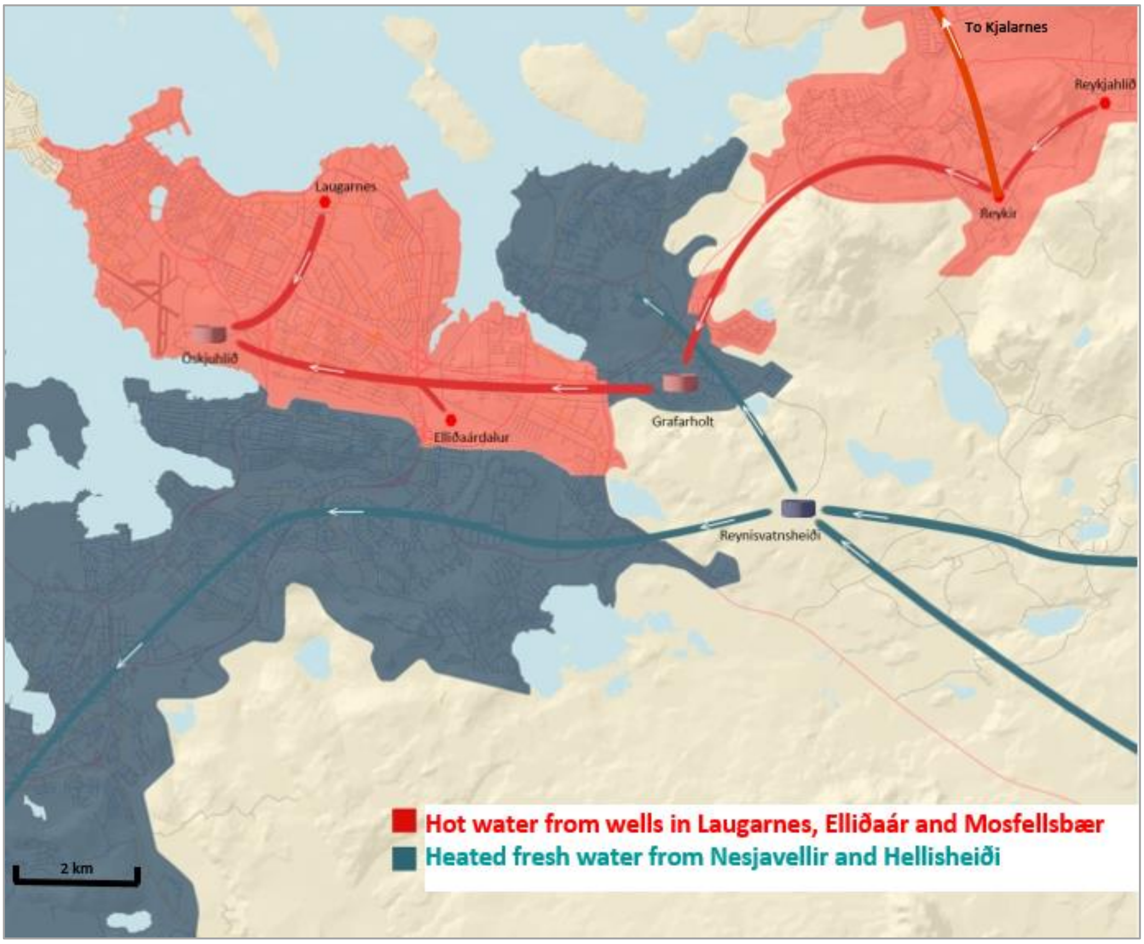

Figure 5. *Distribution within the capital area in 2017 of heated fresh water from the high enthalpy fields at Nesjavellir and Hellisheiði (dark areas) and geothermal water from the medium and low enthalpy fields (red areas). (Modified from Reykjavík Energy Webpage).*

The water production used by Veitur for the Reykjavík District Heating in the year 2015 was 73.63 million m^3 or on average 2,333 l/s with a weighted temperature average of 86.3°C. The total thermal power production above 35°C was P_{35} = 484 MW_{th}. The production from each geothermal field for 2015 is shown in Table 3 (Ívarsson, 2016).

Table 3. *Water production of the Reykjavík District Heating in 2015 (Ívarsson, 2015).*

Geothermal Fields	Average flow		Percentage	Average temperature	Thermal production P_{35}	Thermal production P_5
	(m^3*10^6)	(l/s)	(%)	(°C)	(MW_{th})	(MW_{th})
Laugarnes	5.12	162.2	6.9	127.2	59.0	78.1
Elliðaár	2.04	64.6	2.8	87.1	13.7	21.5
Reykir	28.43	900.9	38.6	87.3	190.6	300
Nesjavellir	26.79	848.9	36.4	80.0	155.5	259.1
Hellisheiði	11.25	356.5	15.3	80.0	65.3	108.8
Total / *weighted average*	**73.63**	**2,333**	**100**	***86.3***	**484.0**	**767.5**

Laugarnes Geothermal Field

The Laugarnes geothermal field is a medium enthalpy resource described by Sveinbjörnsson (2016).

First attempts to drill geothermal wells in Iceland took place in Laugarnes in August 1755 (Stefánsson et al., 1993). Hot water from thermal springs was used for washing and bathing but it was not until 1928 that drilling for hot water for space heating began.

In the period 1928-1965 a total of 41 slim wells, ranging from 20 to 770 m in depth, were drilled in the town Reykjavik. A new rig capable of drilling wider wells down to 2,000 m was acquired in 1957. It was then decided to drill deeper and wider wells in the area and use downhole pumps to increase the yield. Another large rig with drilling capacity down to 3,600 m depth was bought in 1975. This led to drilling of 43 additional wells in Reykjavík from 1958 to 2001, ranging from 633 to 3,085 m depth Fig. 6. Of the new wells, 26 were drilled in the Laugarnes geothermal field. The wells found a deep reservoir with temperature from 130 to 165°C at 700 m to 3,085 m depth. Of the wells ranging from 600 to 2,850 m in depth, 12 are presently used as production wells to serve the Reykjavík District Heating.

Figure 6. *Overview of production wells in the well fields of the Laugarnes geothermal field (modified from NEA's Geoportal).*

Laugarnes well field

Nine exploration wells and 23 production wells, thereof seven wide production wells, R-5, R-10, R-12, R-13, R-17, R-35 and R-40, have been drilled.

Fig. 7 shows depth of wells, casings and the downhole pumps of wells in use in the Laugarnes geothermal field. Yield and discharge temperature are also indicated for each well in 2015. The reported yield is the maximum for each well but interaction between wells may reduce the total yield that can be obtained (Ívarsson, 2016).

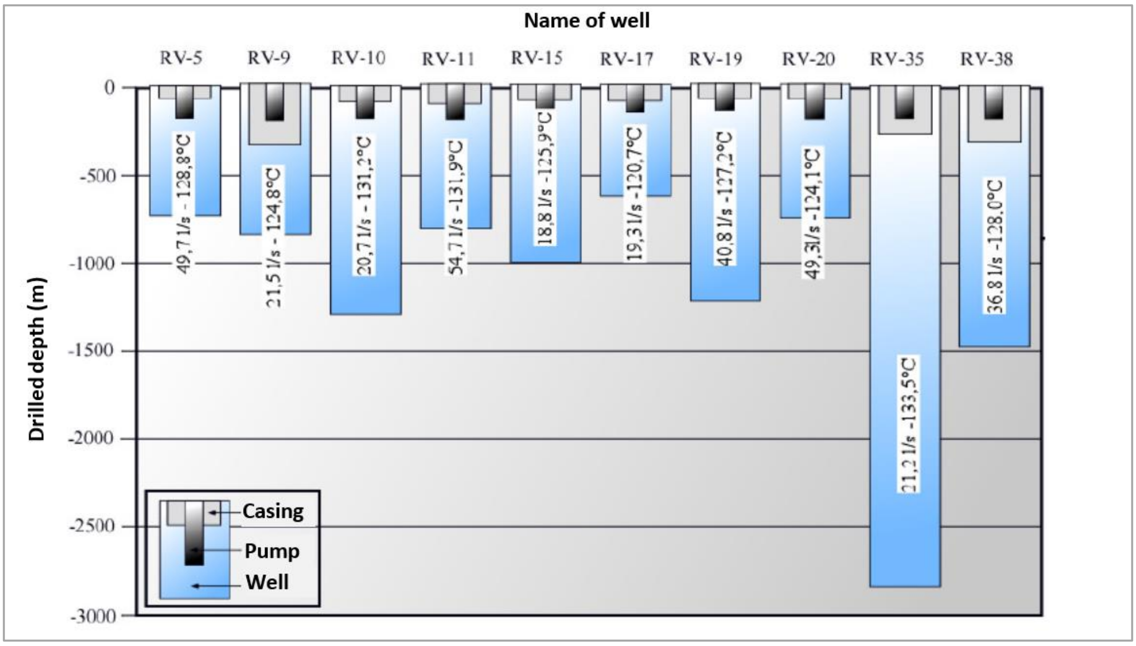

Figure 7. *Depth of wells, downhole pumps and production casings, average yield and discharge temperature of production wells in the Laugarnes geothermal field in the year 2015 (modified from Ívarsson, 2016).*

The first 14 wells, H-1 to H-14, drilled from 1928 to 1930, were shallow (20–246 m depth) and slim, and yielded together in free-flow 15-20 l/s of 95°C hot water (Thorsteinsson and Elíasson, 1970).

The exploration well H-24 was used for district heating. (Björnsson, 2007).

Four of the production wells are in use, R-5, R-10, R-17 and R-35. The drilled depths range from 633 to 2,857 m. Maximum measured temperature is from 131-164°C (Friðleifsson et al., 1985). The wells yield 110.9 l/s of 121-134°C hot water (Ívarsson, 2016).

Using the production data of wells in Fig. 7 a thermal power potential of P_{35} = 40.9 MW_{th} and P_5 = 54 MW_{th} is obtained for the Laugarnes well field.

Lækjarhvammur well field

Five deep production wells have been drilled. Four of them are currently in use, R-11, R-15, R-19 and R-20. Well R-22 was productive but is not in use. The drilled depths range from 765-1,239 m. Maximum measured temperatures range from 135-139°C. The wells yield 163.6 l/s of 124-132°C hot water (Ívarsson, 2016).

Using flow data from the wells in Fig. 7 we obtain a thermal power potential of P_{35} = 59.7 MW_{th} and P_5 = 79.0 MW_{th} for the Lækjarhvammur well field.

Rauðarárholt well field

One exploration well and 4 production wells, R-3, R-9, R-21 and R-34, have been drilled, see Fig. 6. One well, R-9, is in use. It was drilled to 862 m depth, has a maximum measured temperature of 124°C and yields 21.5 l/s of 125°C hot water (Ívarsson, 2016).

Using flow data from well R-9 in Fig. 7 we obtain a thermal power potential of P_{35} = 7.6 MW_{th} and P_5 = 10.2 MW_{th} for the Rauðarárholt well field.

Rauðará well field

Two exploration wells and 2 production wells, H-16 and H-19, were drilled in 1942 and 1956, see Fig. 6. The exploration well, H-28 and the production wells were used for district heating until about 1960 (Björnsson, 2007).

Hátún well field

One exploration well and 4 production wells, R-4, R-7, R-16 and R-38, have been drilled, see Fig. 6. Well R-7 was productive and used for the first tests of downhole pumps but it is no longer in use (Zoëga, 2004). At present, only well R-38 is in use. It was drilled to 1,488 m depth. Maximum temperature of 141°C was found at 1,130 m depth (Thorsteinsson, 1985b). The well yields 36.8 l/s at 128°C (Ívarsson, 2016).

Using data from well R-38 a thermal power potential of P_{35} = 13.5 MW_{th} and P_5 = 17.8 MW_{th} is obtained for the Hátún well field.

Sigtún well field

One exploration well, H-25, and 3 production wells, R-1, R-8 and R-18, were drilled in 1957 and 1963, to depths of 1,067, 1,397 and 1,442 m, respectively, see Fig. 6. The exploration well H-25 was used for district heating and also well R-1 into the 1960s (Björnsson, 2007). None of them are currently in use.

Thermal power of the Laugarnes geothermal field in 2015

Fig. 8 shows the percentage of the thermal power potential that was produced on average from each of the wells during 2015.

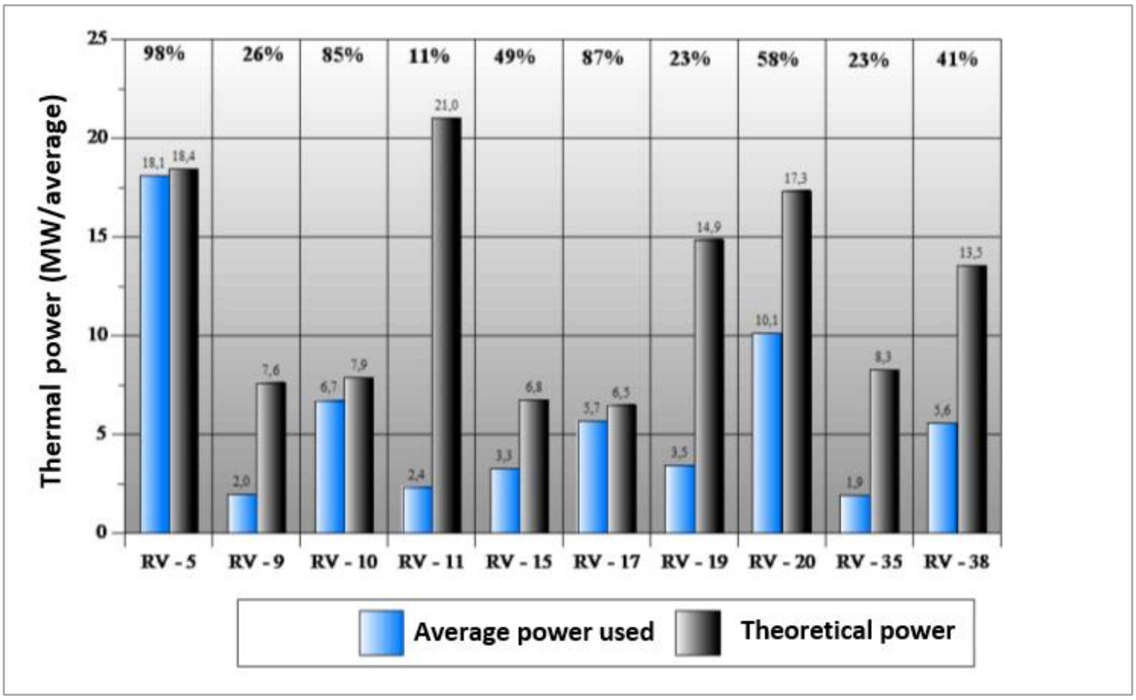

Figure 8. *Thermal power of wells in Laugarnes geothermal field. Dark columns show the thermal power potential above 40°C or P_{40}. Blue columns indicate the thermal power used in the year 2015. Numbers at the top indicate the percentage of the thermal power potential that was used in each well in 2015 (modified from Ívarsson, 2016).*

Adding the thermal power potential of the Laugarnes, Lækjarhvammur, Rauðarárholt and Hátún well fields we obtain a total thermal power potential of P_{35} = 121.8 MW_{th} and P_5 = 160.9 MW_{th} for the Laugarnes geothermal field.

Elliðaár Geothermal Field

The Elliðaár geothermal field is a low enthalpy field within Reykjavík situated in Quaternary strata west of the volcanic zone. The area is affected by The Krýsuvík volcanic fissure swarm, which extends into the area and has created secondary permeability of faults and fissures, see Fig. 9.

The Elliðaár geothermal field lies in the drainage area of the Elliðaár rivers in the capital Reykjavík. It includes the well fields Árbær, Ártún and Breiðholt. The Elliðaár field has been in operation since 1968.

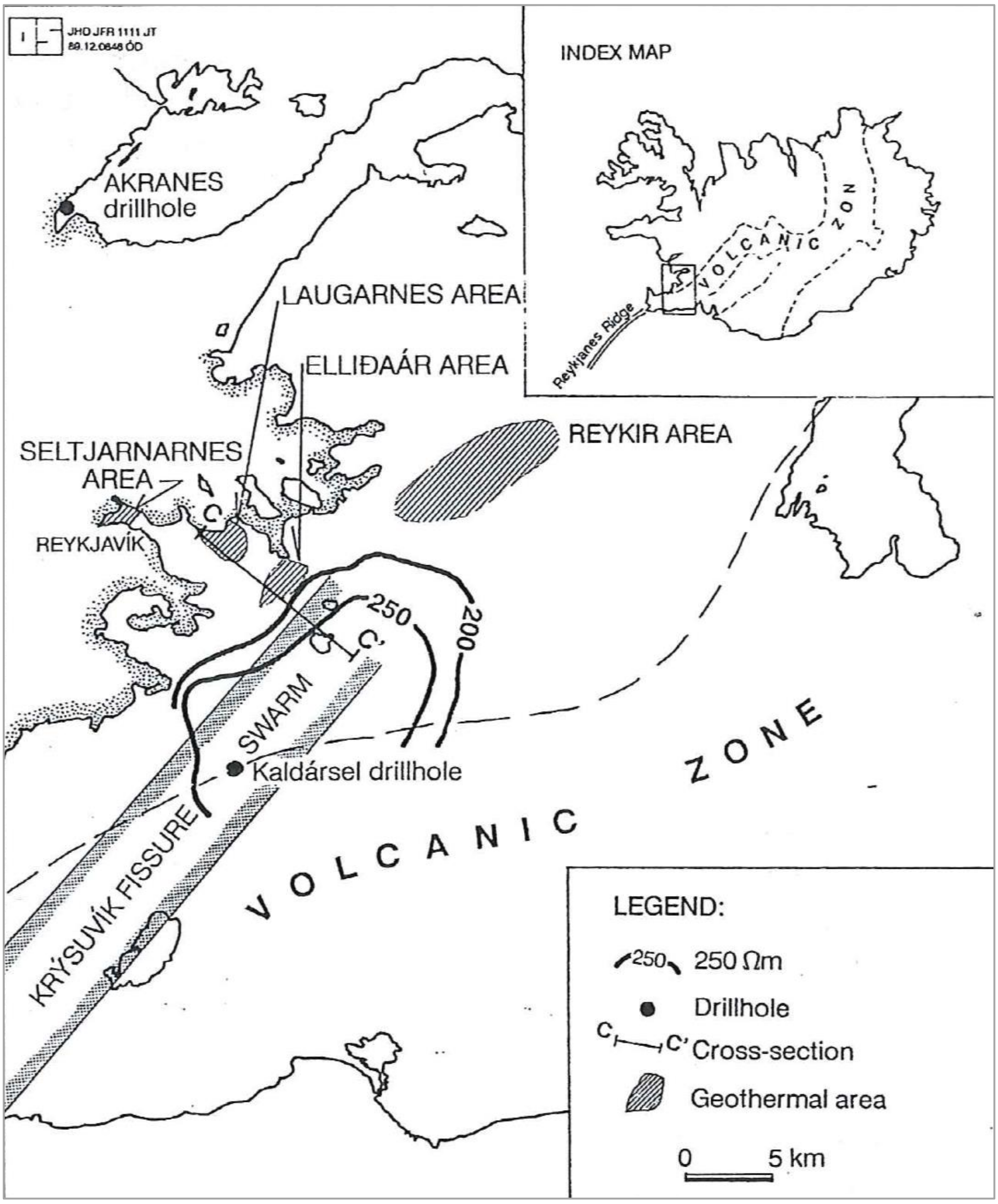

Figure 9. *Geothermal fields and the Krýsuvík fissure swarm extending from the volcanic zone into the Reykjavík Area (Sigurðsson, 1986; Tómasson, 1990).*

Árbær well field

Two exploration wells and one production well, R-41, have been drilled in Árbær, see Fig. 10. Well R-41 was drilled to 1,605 m depth and reached temperature of 110°C at 1,062 m depth. None of the wells are currently in use.

Figure 10. *Overview of the production wells in the well fields Árbær, Ártún and Breiðholt of the Elliðaár geothermal field (modified from NEA's Geoportal).*

Ártún well field

Two exploration wells and one production well, R-24, have been drilled in the area, see Fig. 10. Well R-24 reached temperature of 96°C at 850 m but intersected no feeders (Tómasson, 1992). None of the wells are in use today.

Breiðholt well field

Three exploration wells and eleven production wells, R-23, R-25 to R-31, R-36, R-37 and R-39, were drilled from 1932-1984, see Fig. 10.

The well field is the only production zone in the Elliðaár geothermal field. Prior to drilling there were some hot springs in the Breiðholt area which disappeared when production with downhole pumps began.

The depths range from 861-2,312 m. Maximum measured temperatures range from 89-112°C. There are 8 wells currently in use, R-23, R-26, R-29, R-30, R-31, R-36, R-37 and R-39. Downhole pumps are in all the wells except well R-36. Well R-27 found no feeders, the wells R-25 and R-28 were productive but had a cold inflow and well R-29 is idle (Tómasson, 1992; Ívarsson, 2016).

Production in the Breiðholt well field began in 1968. The maximal pumping rate has been about 220 l/s and the maximal drawdown about 140 m. The amount of water pumped from the area until end of 1987 was 74 Gl. In the beginning the average temperature of the water pumped from the area was 104°C. Due to the drawdown and influx of colder groundwater the temperature of the discharge dropped about 0.5°C/year the first 12 years of production. Cooling in wells amounts to 6-21°C. The inflow of cold water also contaminated the geothermal water with dissolved oxygen. Due to these disadvantages, several wells were worked over and deeper production casings installed and cemented. Production from the field has also been reduced and intermittent in the last decades. Most hot water production has been from well R-39, which has the lowest amount of dissolved oxygen in the liquid. Other wells have more oxygen but that has not been a problem because the water is immediately mixed with water from the Reykir field, which is rich of hydrogen sulfide that reacts with the oxygen (Ívarsson, 2016).

Fig. 11 shows depth of wells, casings and the downhole pumps of the production wells in the Breiðholt well field of the Elliðaár geothermal field. Yield and discharge temperature in 2015 are also indicated for each well. Some of the values are estimated. The reported yield is the maximum for each well but interference between wells may reduce the total yield that can be obtained (Ívarsson, 2016).

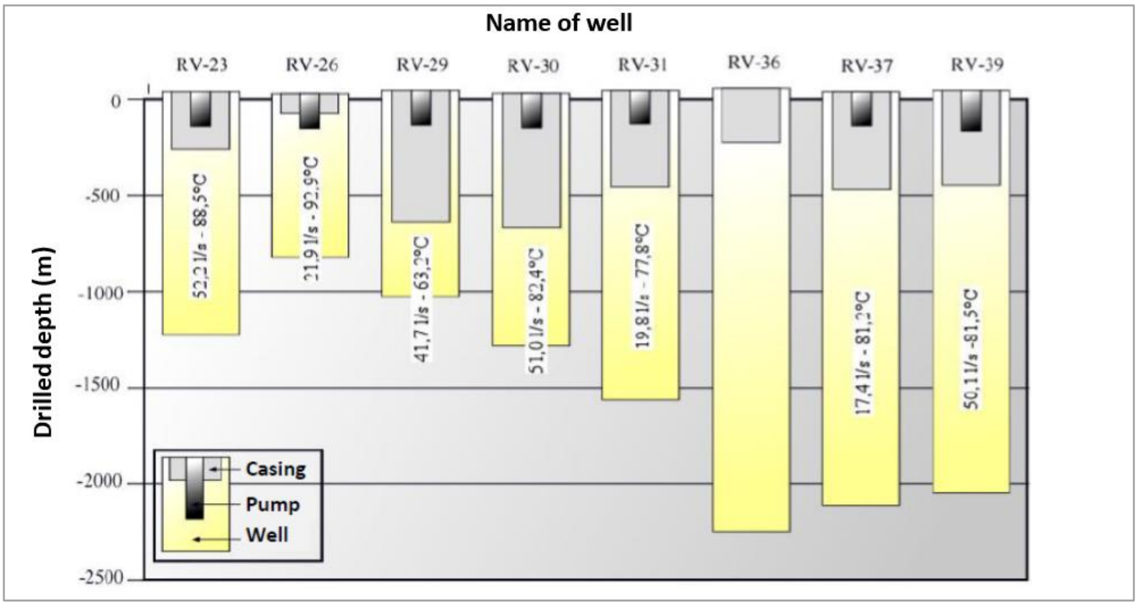

Figure 11. *Depth of wells, production casings and pumps, average yield and temperature of production wells in the Breiðholt well field of the Elliðaár geothermal field in 2015 (modified from Ívarsson, 2016).*

Fig. 12 shows the percentage of the thermal power potential that was used on average in each of the wells in 2015.

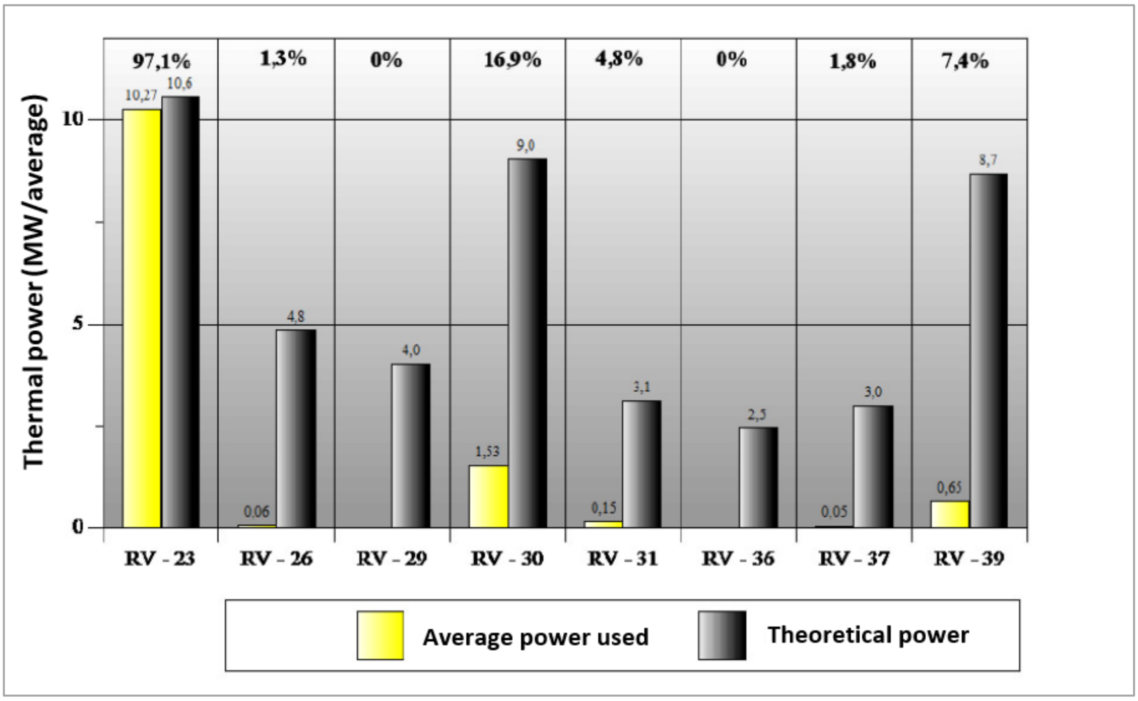

Figure 12. *Thermal power of wells in the Breiðholt well field of the Elliðaár geothermal field. Dark columns show the thermal power potential above 40°C or P_{40}. Blue columns indicate the thermal power used in the year 2015. Numbers above the columns indicate the percentage of the thermal power potential that was used from each well in 2015 (modified from Ívarsson, 2016).*

The total yield of the wells in the Breiðholt well field of the Elliðaár geothermal field is 254.1 l/s of 87.1°C water (Ívarsson, 2016). According to that flow and temperature the total thermal power potential of the production wells of the Elliðaár field is P_{35} = 53.6 MW_{th} for rejection temperature 35°C and P_5 = 84.5 MW_{th} above 5°C.

4.3 Mosfellsbær

4.3.1 Mosfellsbær District Heating (Veitur)

The district heating is operated under Regulations 202/2005 (Mosfellsbær District Heating) and 297/2006 (Reykjavík Energy). Reykjavík Energy/Veitur is the owner since 1943.

The Reykir geothermal field in the Mosfellsbær is a part of an ancient high temperature system formed by volcanic activity in the Stardalur volcanic centre about 2 million years ago (Friðleifsson, 1985) (Fig. 13).

Figure 13. *Location of the Reykir geothermal field consisting of the subfields Suður-Reykir and Reykjahlíð in Mosfellsbær (modified from NEA's Geoportal).*

This volcanic system spanned tens of square kilometer and is at least 150-200 thousand years old. It could have produced the magma which erupted in Mosfell and Sandfell in Kjós about 200-300 thousand years ago (Sæmundsson and Friðleifsson, 1980). Ocean floor spreading pushed the system west, out of the belt of volcanic activity and therefore the tectonic activity slowed down. Much later, the volcanic system in Krýsuvík and Trölladyngja developed a fissure swarm that propagated north to Mosfellsbær and all the way up to Kjós, see Fig. 14 (Sæmundsson, 2014).

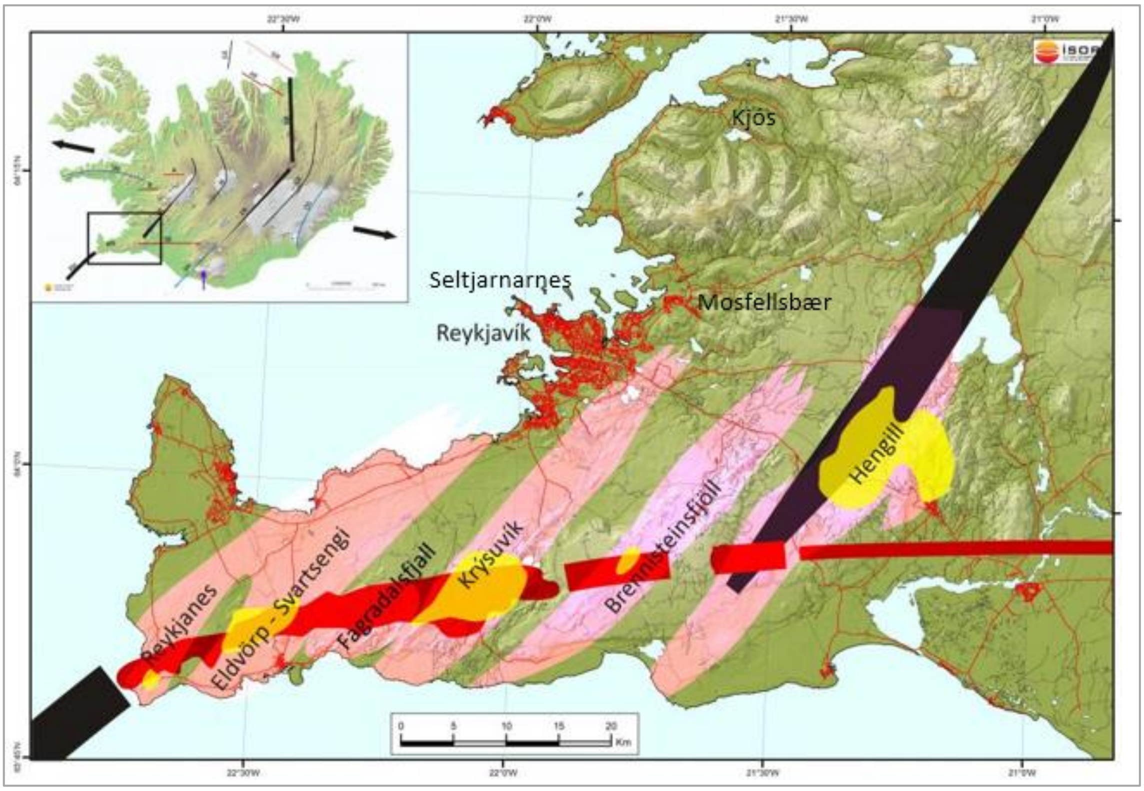

Figure 14. *Fissure swarms from the volcanic zone on Reykjanesskagi that extend to the capital area and affect permeability and heat mining in the geothermal fields in Seltjarnarnes, Reykjavík, Mosfellsbær and Kjós (modified from Sæmundsson, 2010a).*

It is very likely that the faults from the fissure swarm of Krýsuvík and Trölladyngja, which now stretch at least north to Úlfarsfell and Reynisvatnsheiði, have opened a way for cold water from the south to the geothermal areas at Mosfellsbær. It is also likely that the faults reach into, and have much impact on water flow in the geothermal field (Björnsson and Steingrímsson, 1995a).

The thermal aquifers are essentially horizontal but irregularly distributed, both laterally and vertically, through volcanics of Quaternary age, hyaloclastites and basalt flows in various stages of hydrothermal alteration. Values of transmissivity and coefficient of storage are high. Three impermeable vertical boundaries, created by northeast-striking step faults intersect the production area. Two of them are shown in Fig. 15 (Thorsteinsson, 1975).

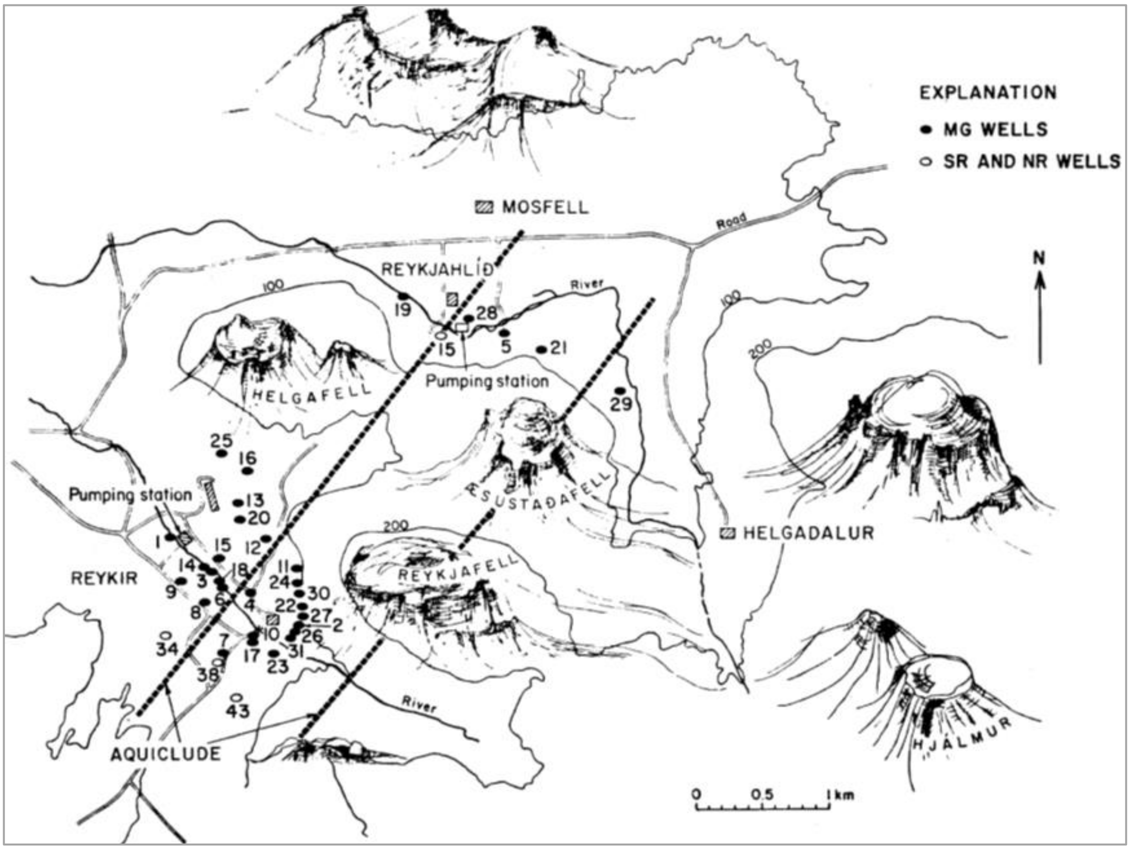

Figure 15. *Map of the Suður-Reykir and Reykjahlíð subfields within Reykir geothermal field showing the location of deep production wells (solid circles), some earlier shallow wells (open circles) and aquicludes (bold lines) (Thorsteinsson, 1975).*

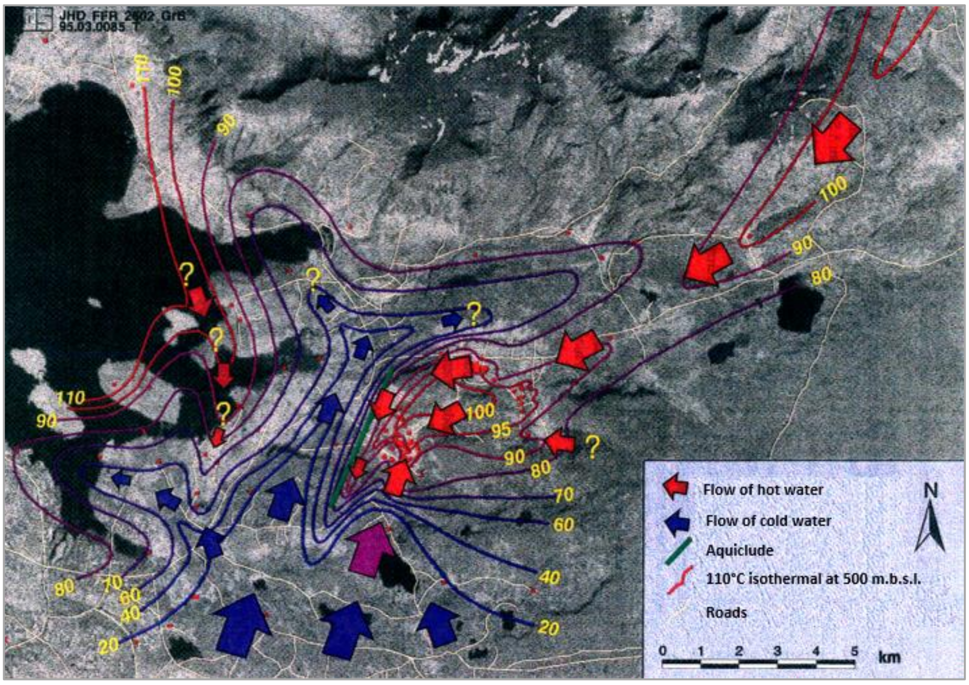

Figure 16. *Conceptual model of flow of hot and cold water in the Reykir geothermal field in Mosfellsbær (Björnsson and Steingrímsson, 1995a).*

The Reykir geothermal field consists of two subfields, Suður-Reykir in the valley Reykjadalur and Reykjahlíð in the valley Mosfellsdalur, which respectively include several well fields.

Prior to drilling for hot water in the Suður-Reykir field the natural discharge of the hot springs was in total about 110 l/s with varying temperature up to 83°C, mostly in the farmland of Suður-Reykir in Reykjadalur. Springs in the Reykjahlíð field had a flow of about 10 l/s of 83°C, in the farmland of Norður-Reykir in Mosfellsdalur (Pálmason et al., 1985).

Drilling began in 1933 at the well field Suður-Reykir (SR-wells in the Suður-Reykir subfield) and 14 years later at Norður-Reykir (NR-wells in the Reykjahlíð subfield). Very little information is available about productivity of these wells. In 1944 the combined flow from 21 wells and the two hot springs at Suður-Reykir was 200 l/s of about 87°C hot water (Sigurðsson, 1947). Fig. 17 shows what the area looked like before the free-flow wells were harnessed.

Figure 17. *The steaming Suður-Reykir subfield due to runoff from the free-flow wells before they were harnessed. (Photo archive: Orkuveita Reykjavíkur, 2018).*

By the end of the initial development phase, in 1955, free-flow from the Reykir geothermal field had increased and was reported 360 l/s of 86°C hot water, from 43 shallow wells in the Suður-Reykir subfield and 26 wells at Reykjahlíð subfield. Up to 1960, there were drilled 77 rather shallow and narrow production wells with Calyx-type rigs. All wells, except one, were successful with free-flowing water. By 1970 the flow had decreased to about 300 l/s, thereof 220 l/s from the wells in the Reykjahlíð subfield and 80 l/s from the wells at the Suður-Reykir subfield, which was less than the initial discharge at Suður-Reykir before the drilling began (Thorsteinsson, 1975).

A new rotary oil rig purchased in 1958 made it possible to drill 2000 m deep large-gauge wells intended for production by submergible turbine pumps. The Reykir geothermal field was redeveloped from 1970-1977 with 37 wider and deeper wells (MG-wells). Production of geothermal water at the end of January 1975 amounted to 851 l/s with an average temperature of 83.5°C from 20 pumped wells (Thorsteinsson, 1975). This increased production from the new wells had by then caused a drawdown of 20-35 m of the relatively steady state 1970 piezometric surface of the area, thereby eliminating free-flow from the older wells.

The Suður-Reykir subfield

The Suður-Reykir subfield has been developed in the well fields at Reykjahvoll, Helgafell and Suður-Reykir. Seven exploration wells and 77 production wells have been drilled in the fields. During the initial development phase 51 production wells were drilled (SR-wells) and 26 production wells (MG-wells) were drilled in the redevelopment phase.

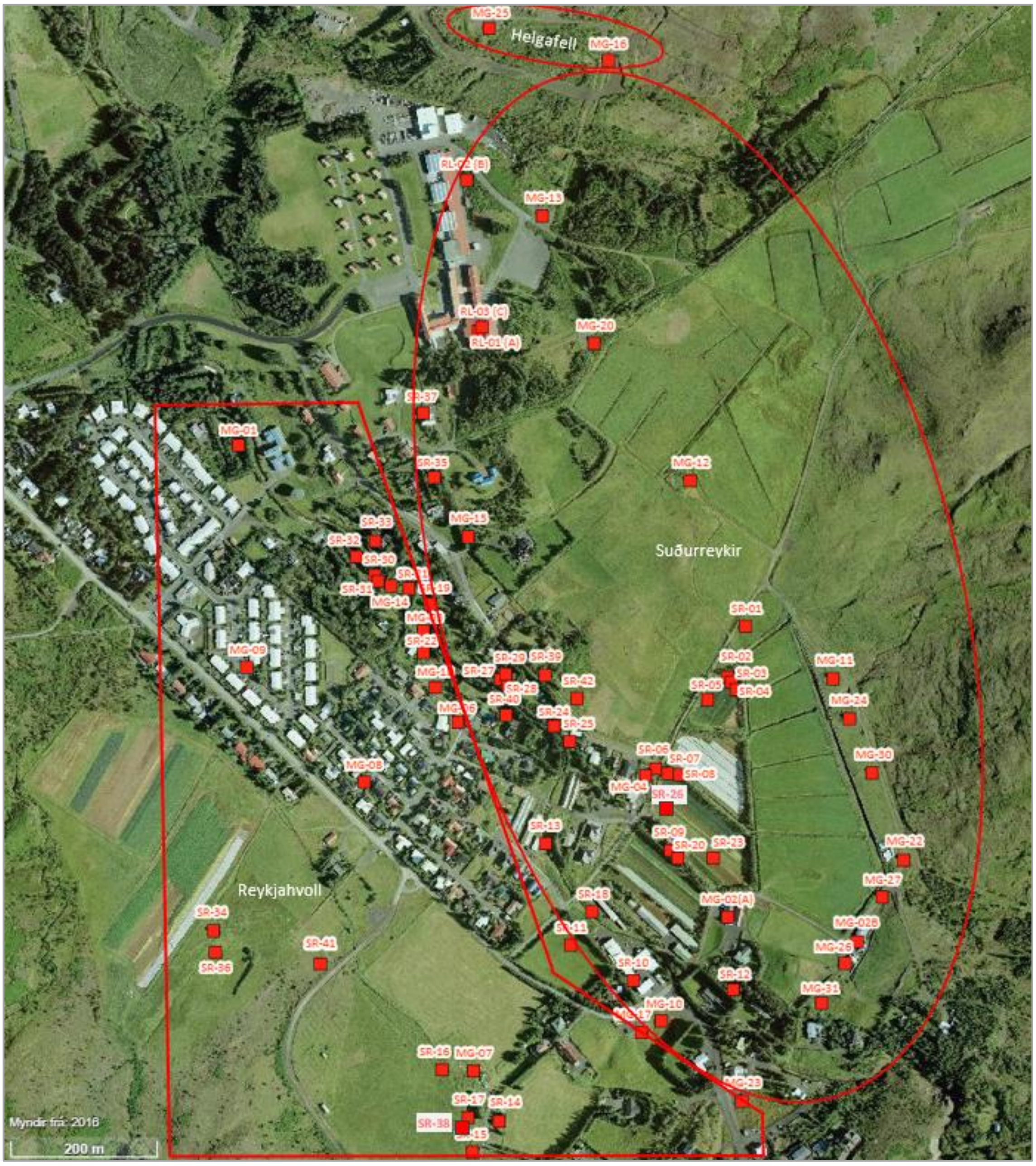

Figure 18. *Overview of production wells in the well fields Reykjahvoll, Helgafell and Suður-Reykir of the Suður-Reykir subfield (modified from NEA's Geoportal).*

Fig. 19 gives an overview of the deep redevelopment wells, which are still in use in the Suður-Reykir subfield. The figure shows depth of wells, casings and the downhole pumps. Yield and discharge temperature are also indicated for each well in 2015. The reported yield is the maximum for each well but interference between wells may reduce the total yield that can be obtained (Ívarsson, 2016).

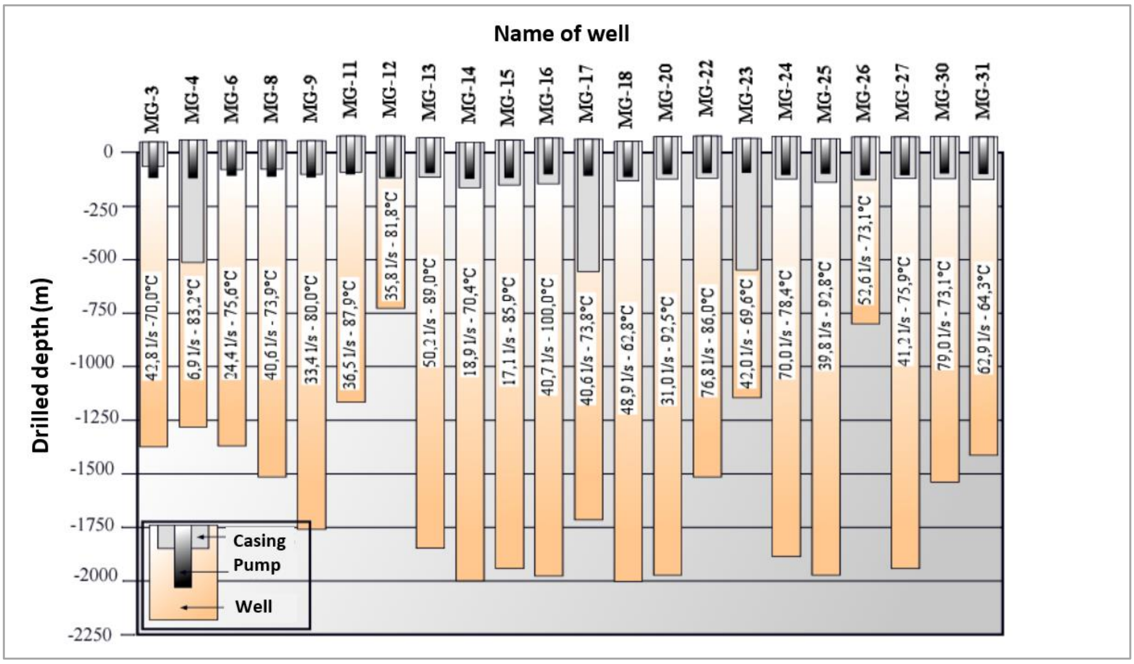

Figure 19. *Overview of the redevelopment wells which are still in use (2015) in the Suður-Reykir subfield. The figure shows depth of wells, production casings and downhole pumps. Maximum yield and discharge temperature are also indicated for each well in 2015 (modified from Ívarsson, 2016).*

Reykjahvoll well field

Five exploration wells, HS-34, HS-39, HS-41, HS-42 and HS-49 were drilled in 1993-1997, and 26 production wells from 1936 to 1974. Thereof 15 older and shallow production wells drilled from 1936 to 1947, SR-14 to SR-17, SR-19, SR-21, SR-22, SR-30, SR-31, SR-32, SR-34, SR-36, SR-38, SR-40, SR-41 and SR-43 and eleven wider wells drilled from 1960 to 1974, MG-1, MG-3, MG-6 to MG-10, MG-14, MG-17, MG-18 and MG-23, see Fig.18. Well MG-1 was nonproductive but the other wells were production wells after drilling. Wells MG-7 and MG-10 were plugged in 1989 and 1991, respectively to stop down flow of shallow water.

Four wells, MG-8, MG-9, MG-17 and MG-23 were in use in 2015. Wells MG-3, MG-6, MG-14 and MG-18 were idle in the year 2015 (Ívarsson, 2016).

Using the 2015 flow data for the wells in Fig. 19 we obtain a thermal power potential of P_{35} = 41.4 MW_{th} and P_5 = 76.0 MW_{th} for the Reykjahvoll well field.

Helgafell well field - South

One exploration well, HS-37, was drilled in 1993 and two deep wide diameter production wells, MG-16 and MG-25, were drilled at Helgafell in 1973 and 1974 respectively. The production well MG-37 recorded at Helgafell is located north of the mountain in the area of the Reykjahlíð subfield, see Fig. 18. Both of the production wells, MG-16 and MG-25, were in use in 2015 (Ívarsson, 2016).

Using the data on wells in Fig. 19 we obtain a thermal power potential of $P_{35} = 19.3$ MW_{th} and $P_5 = 28.8$ MW_{th} for the Helgafell well field South.

Suður-Reykir well field

One exploration well and 42 production wells have been drilled from 1933 to 1975, see Fig. 18. The exploration well, SR-26, and 26 production wells, SR-1 to SR-13, SR-18, SR-20, SR-23 to SR-29, SR-33, SR-35, SR-37, SR-39 and SR-42, were shallow small diameter wells, drilled from 1933-1947. Thirteen deep wide diameter production wells, MG-2B, MG-4, MG-11 to MG-13, MG-15, MG-20, MG-22, MG-24, MG-26, MG-27, MG-30 and MG-31, were drilled from 1963-1975 and also three production wells, RL-1 to RL-3 for the US-Army at Reykjalundur during the second world war, see Fig. 18.

Eleven wells (MG-11 to MG-13, MG-15, MG-20, MG-22, MG-24, MG-26, MG-27, MG-30 and MG-31) were in use in 2015 and have combined potential up to 535.6 l/s of 78.8°C (Ívarsson, 2016). MG-2B is not productive. MG-4 was idle in the year 2015 but has a potential of 6.9 l/s of 83.2°C.

Using the 2015 flow data on the production wells in Fig. 19 one obtains a thermal power potential of $P_{35} = 96.7$ MW_{th} and $P_5 = 162.9$ MW_{th} for the Suður-Reykir well field.

Thermal power of wells in the Suður-Reykir subfield

Fig. 20 shows the percentage of the thermal power potential above 40°C that was used on average in each of the wells in the Suður-Reykir subfield in 2015 (Ívarsson, 2016**)**.

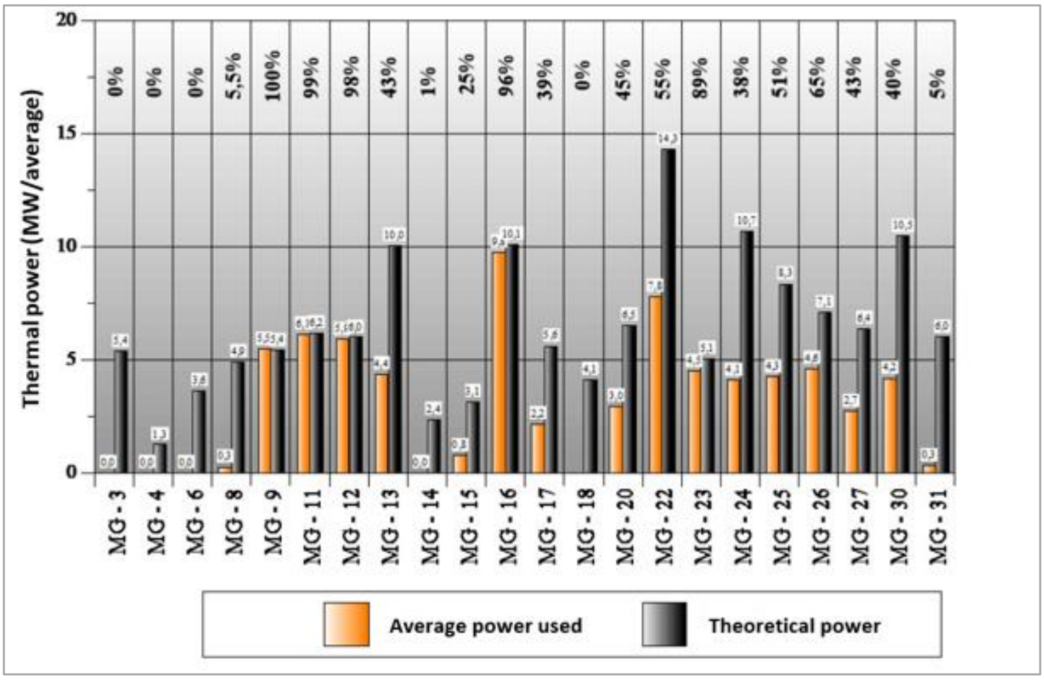

Figure 20. *Thermal power of wells in the Suður-Reykir subfield. Dark columns show the thermal power potential above 40°C or P_{40}. Orange columns indicate the thermal power used in the year 2015. Numbers above the columns indicate the percentage of the thermal power potential that was used from each well in 2015 (modified from Ívarsson, 2016).*

Table 4 shows the thermal power potential of the 22 production wells still in use in the Suður-Reykir subfield, calculated for rejection temperatures of 35°C and 5°C.

Table 4. *Thermal power potential above 35°C and 5°C of the wells still in use in the Suður-Reykir subfield in 2015.*

Suður-Reykir subfield	Discharge			Potential P_{35}	Potential P_5
	Flow	Temperature	Enthalpy		
Well	(l/s)	(°C)	(kJ/kg)	(MW_{th})	(MW_{th})
MG-3	42.8	70.0	293.0	6.1	11.4
MG-4	6.9	83.2	348.4	1.4	2.2
MG-6	24.4	75.6	316.5	4.0	7.0
MG-8	36.0	72.6	303.9	5.5	9.9
MG-9	32.6	79.8	334.1	5.9	9.9
MG-11	36.4	80.7	337.9	6.8	11.2
MG-12	34.6	81.5	341.2	6.5	10.8
MG-13	49.1	88.9	372.3	10.7	16.7
MG-14	18.7	70.1	293.4	2.7	5.0
MG-15	16.5	85.7	358.9	3.4	5.4
MG-16	40.3	100.0	419.1	10.5	15,4
MG-17	39.8	73.7	308.5	6.3	11.2
MG-18	45.9	61.5	257.4	5.0	10.7
MG-20	30.0	91.9	384.9	6.9	10.5
MG-22	73.9	86.3	361.4	15.4	24.3
MG-23	41.6	69.1	289.2	5.8	10.9
MG-24	66.5	78.5	328.6	11.8	19.9
MG-25	38.1	92.4	387.0	8.8	13.4
MG-26	51.5	73.0	305.6	8.0	14.3
MG-27	41.8	76.5	320.2	7.1	12.2
MG-30	76.8	72.6	303.9	11.8	21.2
MG-31	58.5	64.6	270.4	7.1	14.3
Total/*weighted*	**902.7**	***77.9***		**157.5**	**267.7**

The water production from the Suður-Reykir subfield in 2015 was 12.80 million m^3 or 406 l/s at a temperature of 81.4°C on average. That corresponds to an average power capacity above 35°C of P_{35} = 76.5 MW_{th}. The average power above 5°C was P_5 = 126.0 MW_{th}. Highest monthly fluid production was in December 2015, about 600 l/s (Ívarsson, 2016).

The Reykjahlíð subfield

In the Reykjahlíð subfield, the well fields are Helgafell North, Hrísbrú, Reykjahlíð, Norður-Reykir, Reykjadalur, Varmaland, Æsustaðir, Hraðastaðir and Helgadalur.

Fifteen exploration wells and 45 production wells have been drilled in these well fields from 1945 to 1993, see Fig. 21.

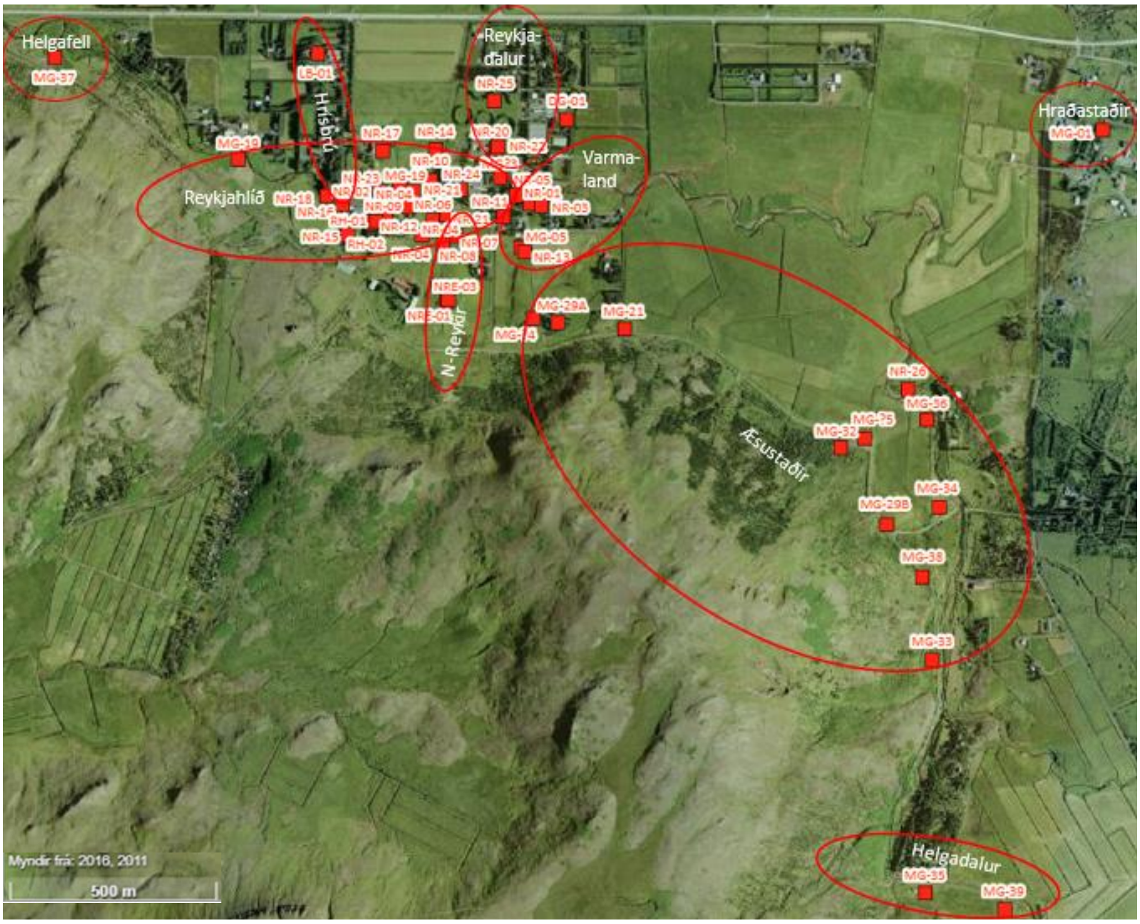

Figure 21. *Overview of the production wells in the well fields Helgafell, Hrísbrú, Reykjahlíð, Norður-Reykir, Reykjadalur, Varmaland, Æsustaðir, Hraðastaðir and Helgadalur in the Reykjahlíð subfield (modified from NEA's Geoportal).*

Fig. 22 gives an overview of the deep wide redevelopment wells in the Reykjahlíð subfield. The figure shows depth of wells, production casings and downhole pumps. Yield and discharge temperature are also indicated for each well. The reported yield is the maximum for each well but interference between wells may reduce the total yield that can be obtained (Ívarsson, 2016).

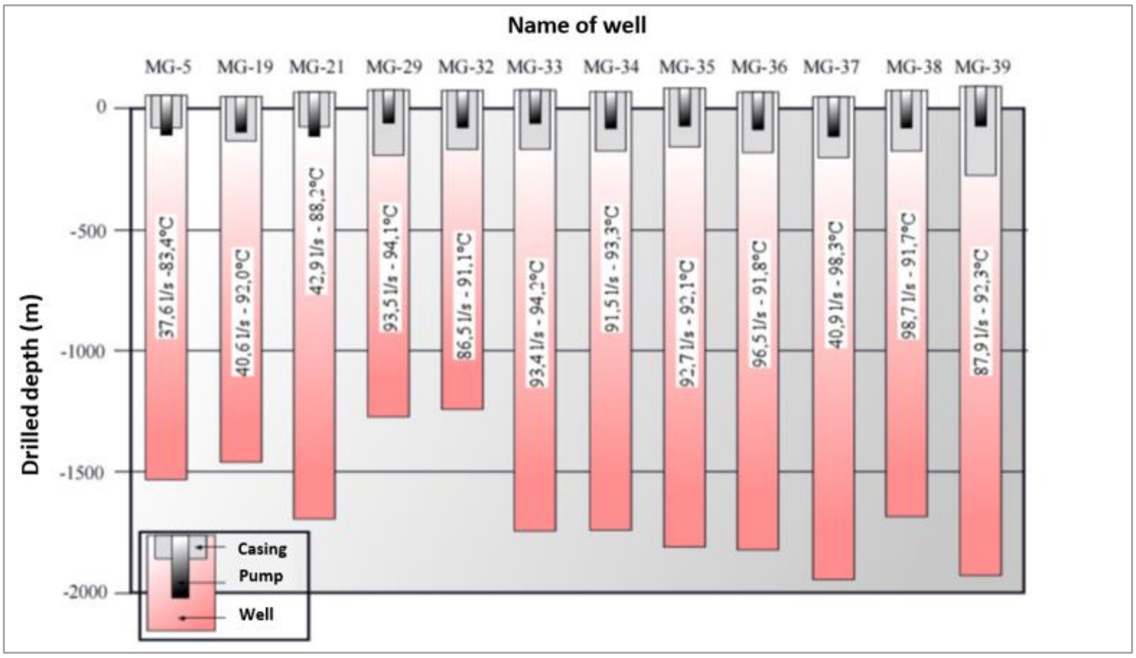

Figure 22. *Overview of the redevelopment wells which are still in use (2015) in the Reykjahlíð subfield. The figure shows depth of wells, production casings and downhole pumps. Maximum yield and discharge temperature are also indicated for each well (modified from Ívarsson, 2016).*

Helgafell well field - North

One production well, MG-37 has been drilled on the north side of Mt. Helgafell and is therefore a part of the Reykjahlíð area whereas two wells on the south side belong to the Suður-Reykir field, see Fig. 21. The well was drilled to 1,999 m depth in 1977 and was in production in 2015 (Ívarsson, 2016).

Using the 2015 flow data for the wells in Fig. 22 a thermal power potential of P_{35} = 10.4 MW_{th} and P_5 = 15.3 MW_{th} for the Helgafell well field North is obtained.

Hrísbrú well field

One exploration well, HS-38, was drilled in 1993 and 3 production wells, LB-1, drilled in 1945, NR-16 and NR-18 drilled in 1952, see Fig. 21. None of the wells are in use today (Ívarsson, 2016).

Reykjahlíð well field

Thirteen production wells, RH-1, RH-2, NR-2, NR-4, NR-6, NR-9, NR-10, NR-12, NR-14, NR-15, NR-17, NR-19 and NR-23, were drilled in the initial development phase from 1945-1955. Two deeper production wells, MG-19 and MG-28, were drilled in the redevelopment phase from 1973-1974. MG-19 was in use in 2015, but MG-28 is a monitoring well for pressure draw down, see Fig. 21 (Ívarsson, 2016).

Using the data on wells in Fig. 22 a thermal power potential of P_{35} = 9.3 MW_{th} and P_5 = 14.3 MW_{th} for the Reykjahlíð well field is obtained.

Norður-Reykir well field

One exploration well (NRE-2) and five production wells (NR-7, NR-8, NR-21, NRE-1, and NRE-3), were drilled from 1945-1954, see Fig. 21. None of them are in use today (Ívarsson, 2016).

Reykjadalur well field

Four production wells (NR-20, NR-22, NR-24 and NR-25) were drilled 1953-1955, see Fig. 21. None of them are in use today (Ívarsson, 2016).

Varmaland well field

Five production wells (NR-1, NR-3, NR-5, NR-11 and NR-13) were drilled in the initial development phase from 1948-1951. One deeper production well, MG-5 was drilled in the redevelopment phase in 1970 and was in use in 2015 and had a maximum yield of 37.6 l/s of 83.4°C hot water, see Fig. 21 and Fig. 22 (Ívarsson, 2016).

Using the 2015 flow data for the wells in Fig. 22 a thermal power potential of P_{35} = 7.4 MW_{th} and P_5 = 12.0 MW_{th} for the Varmaland well field is obtained.

Æsustaðir well field

Seven deeper production wells (MG-21, MG-29B, MG-32, MG-33, MG-34, MG-36 and MG-38) were drilled from 1973-1975, see Fig. 21. All of them were in use in 2015 (Ívarsson, 2016). The wells could give up to 603 l/s of about 92°C hot water.

Using the 2015 flow data of the wells in Fig. 22 a thermal power potential of P_{35} = 139.7 MW_{th} and P_5 = 212.6 MW_{th} for the Æsustaðir well field is obtained.

Hraðastaðir well field

One production well, NR-26, was drilled in the initial development phase 1960 to 475 m depth and reached highest temperature of 110°C at 470 m depth. The well is currently not in use.

Helgadalur well field

Two production wells, MG-35 and MG-39, were drilled from 1976-1977 and both were in use in 2015, see Fig. 21 (Ívarsson, 2016).

Using the 2015 flow data on wells in Fig. 22 a thermal power potential of P_{35} = 42.5 MW_{th} and P_5 = 64.3 MW_{th} for the Æsustaðir well field is obtained.

Thermal power of wells in the Reykjahlíð subfield

Fig. 23 shows the percentage of the thermal power potential above 40°C that was used on average in each of the wells in the Reykjahlíð subfield in 2015 (Ívarsson, 2016**)**.

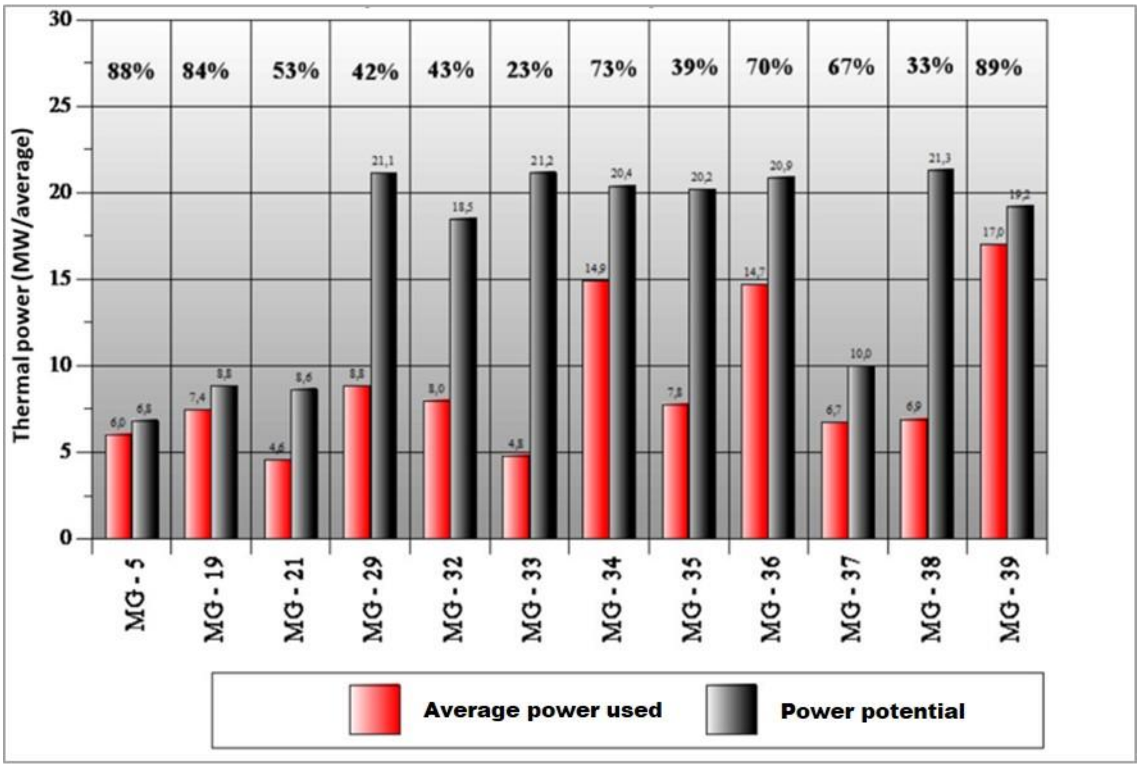

Figure 23. *Thermal power of wells in the Reykjahlíð area. Dark columns show the thermal power potential above 40°C or* P_{40}*. Red columns indicate the thermal power used in the year 2015. Numbers above the columns indicate the percentage of the thermal power potential that was used from each well in 2015 (modified from Ívarsson, 2016).*

Table 5 shows the thermal power potential of the 12 redevelopment wells still in use in the Reykjahlíð subfield, calculated for rejection temperatures of 35°C and 5°C.

Table 5. *Thermal power potential above 35°C and 5°C of the wells still in use in the Reykjahlíð subfield in 2015.*

Reykjahlíð subfield	Discharge			Potential P_{35}	Potential P_5
	Flow	Temperature	Enthalpy		
(Well)	(l/s)	(°C)	(kJ/kg)	(MW_{th})	(MW_{th})
MG-5	37.6	83.4	349.2	7.4	12.0
MG-19	40.6	92.0	385.4	9.3	14.3
MG-21	42.9	88.2	369.4	9.2	14.4
MG-29	93.5	94.1	394.2	22.3	33.6
MG-32	86.5	91.1	381.6	19.6	30.1
MG-33	93.4	94.2	394.6	22.3	33.6
MG-34	91.5	93.3	390.8	21.5	32.6
MG-35	92.7	92.1	394.6	22.2	33.4
MG-36	96.5	91.8	384.5	22.1	33.8
MG-37	40.9	98.3	411.9	10.4	15.3
MG-38	98.7	91.7	384.1	22.6	34.5
MG-39	87.9	92.3	386.6	20.3	31.0
Total / *weighted average*	**902.7**	***92.2***		**209.3**	**318.6**

The water production from the Reykjahlíð subfield in the year 2015 was 15.63 million m^3 or 495.3 l/s at a temperature of 92°C on average.

That corresponds to an average thermal power of the well fields in the Reykjahlíð subfield above 35°C of $P_{35} = 114.0$ MW_{th}. The average power above 5°C is $P_5 = 173.9$ MW_{th}. Highest monthly productivity recorded was in December 2015, about 700 l/s (Ívarsson, 2016).

Adding up the numbers of thermal power potential for the subfields Suður-Reykir and Reykjahlíð gives a total thermal power potential for the Reykir Geothermal Field as $P_{35} = 366.8$ MW_{th} and $P_5 = 586.2$ MW_{th}.

4.4 Kjósarhreppur

There are two medium enthalpy geothermal fields used by the district heating services in the Kjósarhreppur, Möðruvellir and Hvammsvík described by Sveinbjörnsson (2016). Fig. 24 shows the location of the two fields and the production wells.

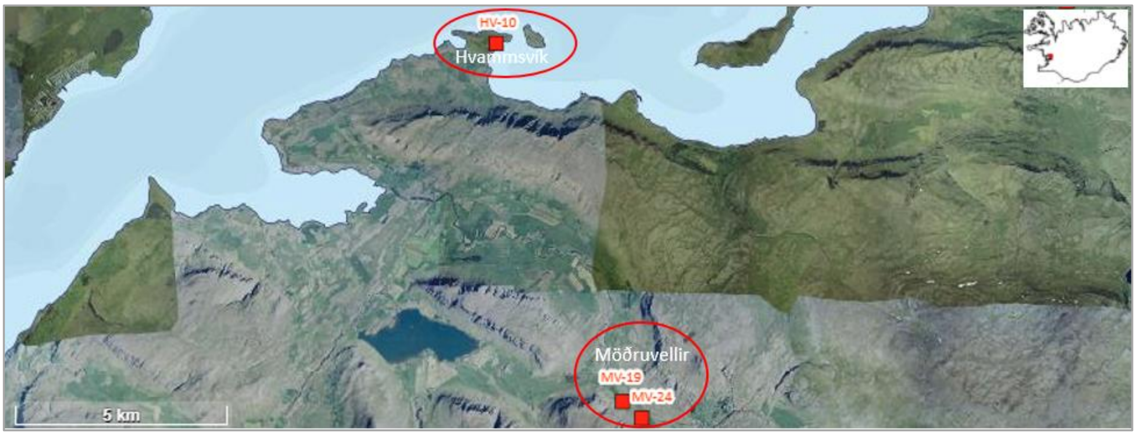

Figure 24. *Overview of the production wells in the geothermal fields Möðruvellir and Hvammsvík in the Kjósarhreppur (modified from NEA's Geoportal).*

4.4.1 Kjós District Heating (Kjósarveita)

A district heating named Kjós District Heating, is under construction in Kjós that will utilize the Möðruvellir medium enthalpy field.

Möðruvellir Geothermal Field

A total of 19 shallow exploration wells and two deep production wells, MV-19 and MV-24, have been drilled, see Fig. 24. Both production wells were successful.

Well MV-19 is 822 m deep and found 80°C water at 650 m depth. Pumping tests indicated a yield of 20 l/s with 100 m drawdown.

Well MV-24 is 1,704 m deep and discovered a deeper reservoir with a temperature of 144°C at 1,630 m. The formation temperature at 1,000 m depth is 140°C. The well yields 19 l/s of 135°C free-flowing and 40 l/s with 120 m drawdown (Hafstað, 2015b; Hjartarson and Sæmundsson, 2003b; Hafstað and Sæmundsson, 2013). Due to the success of MV-24, well MV-19 is idle today.

It is estimated that the Möðruvellir field can give a flow of 40 kg/s of 135°C water. That corresponds to a thermal power potential of P_{35} = 16.8 MW_{th} and P_5 = 21.9 MW_{th}.

4.4.2 Hvammsvík District Heating (Veitur)

The Hvammsvík district heating operates under Regulation 297/2006. Reykjavík Energy/Veitur is the owner since 1996. It uses the medium enthalpy Hvammsvík field described by Sveinbjörnsson (2016).

Hvammsvík Geothermal Field

Nine exploration wells and one production well, HV-10, well have been drilled, see Fig. 24. The well HV-10 was drilled in 1991 to 1,466 m depth and delivers 25 l/s of 89°C water with 85 m drawdown (Björnsson, 1992a; Sigurðsson, 1995a).

Assuming a flow of 25 l/s at 89°C for the Hvammsvík field, we obtain a thermal power potential of P_{35} = 5.5 MW_{th} and P_5 = 8.5 MW_{th}.

4.5 Skorradalshreppur

4.5.1 Skorradalur District Heating (Veitur)

Reykjavík Energy/Veitur is the owner since 2006-2007. The district heating operates under the Regulation 297/2006. It uses the Stóra-Drageyri well field in the Brautar-tunga/England geothermal field and serves farms and summerhouses in the valley Skorradalur, see Fig. 25.

Figure 25. *The service area of the Skorradalur District Heating (Olsen, 2016a).*

Brautartunga/England Geothermal Field

Stóra-Drageyri well field

Five exploration wells and one production well, SD-6, have been drilled, see Fig. 26. The field is in a medium enthalpy field described by Sveinbjörnsson (2016).

Figure 26. *Overview of the production well, SD-6 in the Stóra-Drageyri well field of the Brautartunga/England geothermal field (modified from NEA's Geoportal).*

The well SD-6 was drilled in 1994 to 836 m depth and yields 10-15 l/s of 98°C water by pump (Björnsson and Sæmundsson, 1994; Georgsson et al., 2010).

Assuming a flow of 12.5 l/s of 98°C water one obtains for the Stóra-Drageyri well field of the Brautartunga/England geothermal field a thermal power potential of P_{35} = 3.2 MW_{th} and P_5 = 4.7 MW_{th}. Average production in 2015 was 9.8 l/s of 97°C (Olsen, 2016a).

4.6 Borgarbyggð

The Borgarbyggð is rich in medium- and low enthalpy resources. The natural discharge of the hot springs is estimated to be equivalent to more than 450 l/s of boiling water. The geothermal activity is divided into three separate geothermal fields, Bær/Varmaland, Reykholt and Húsafell (Georgsson et al., 2010), see Fig. 27.

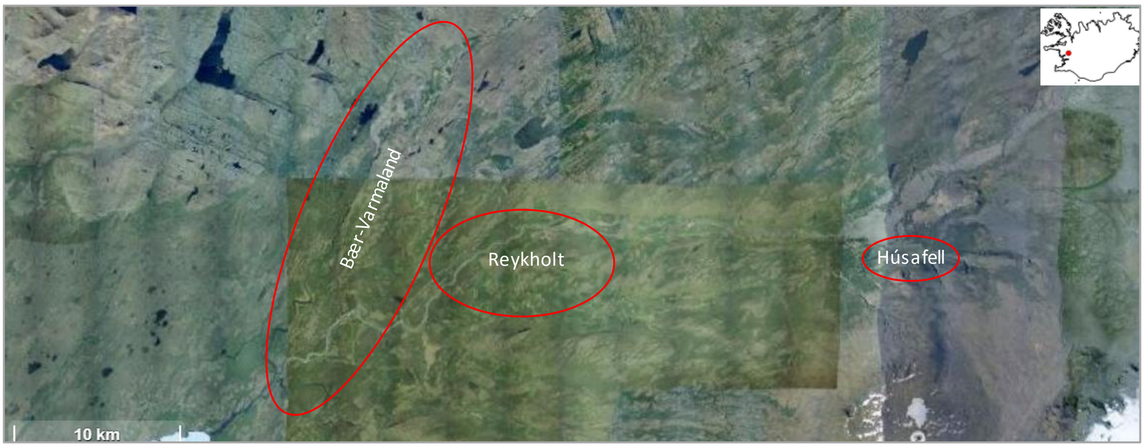

Figure 27. *Location of the geothermal fields Bær/Varmaland, Reykholt and Húsafell (modified from NEA's Geoportal).*

Fig. 28 shows the main hot springs and production wells in Borgarbyggð located within the three geothermal fields and the locations of the main production wells.

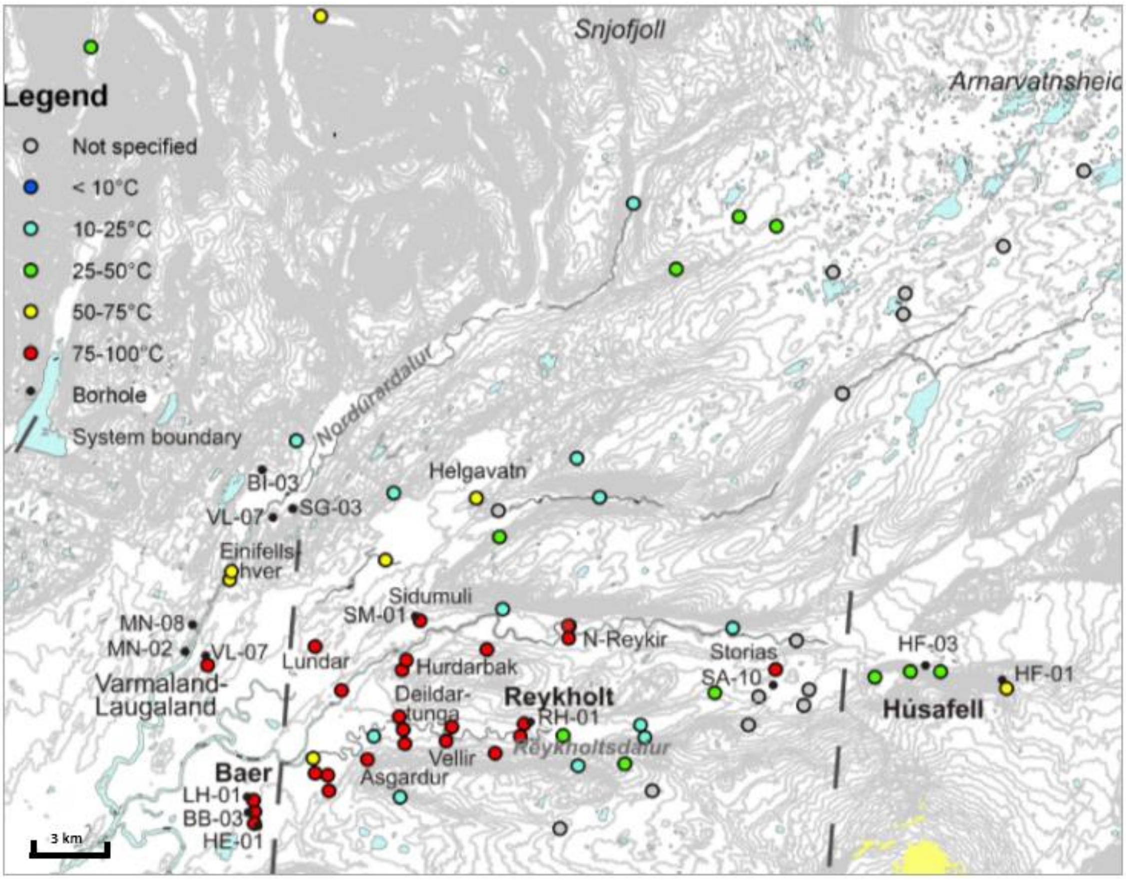

Figure 28. *The main hot springs and production wells in the Borgarbyggð district and the three geothermal fields, Bær/Varmaland, Reykholt and Húsafell (Georgsson et al., 2010).*

Bær/Varmaland Geothermal Field

The Bær/Varmaland field includes the well fields at Bær, Laugarholt, Hellur, Varmaland/Laugaland, Munaðarnes, Hreðavatn and Svartagil (see Figs. 28 and 29).

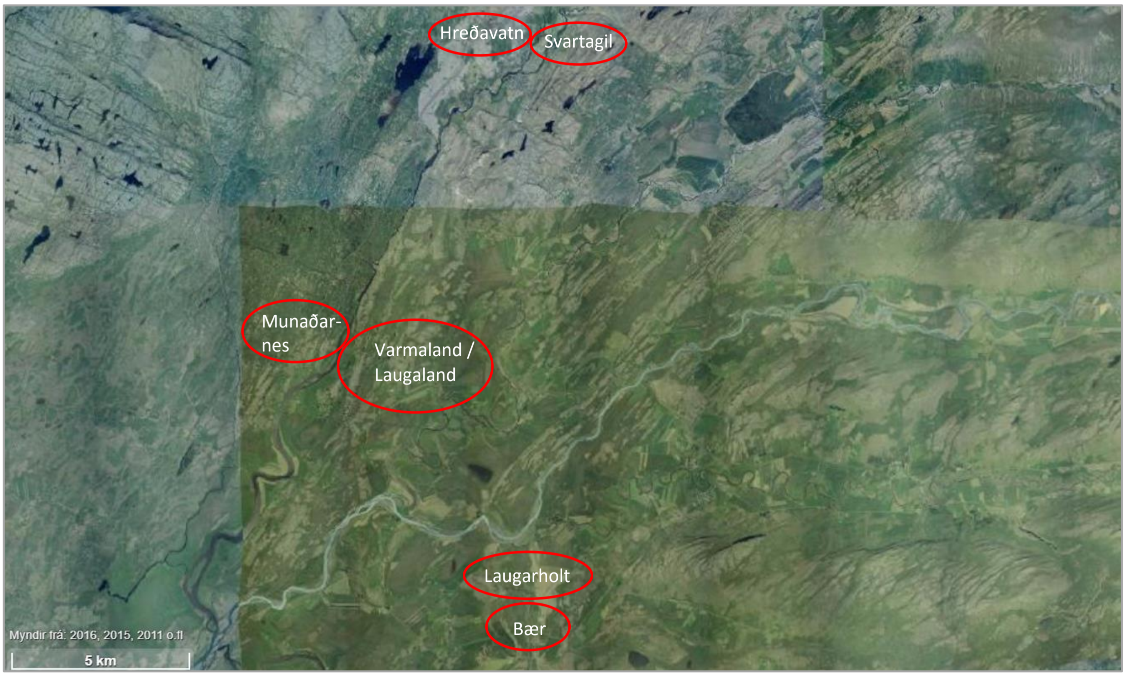

Figure 29. *Location of the well fields, Bær, Laugarholt, Varmaland/Laugaland, Munaðarnes, Hreðavatn and Svartagil (modified from NEA's Geoportal).*

Reykholt Geothermal Field

Reykholt is by far the largest geothermal field in Borgarfjörður (Georgsson et al., 2010). It is a medium enthalpy resource described by Sveinbjörnsson (2016). It includes the well fields Reykholt, Deildartunga, Kleppjárnsreykir, Brúarreykir, Hurðarbak-Síðumúli, Vellir, Hægindi-Kópareykir and Norður-Reykir, see Figs. 27, 28 and 30. Only few wells have been drilled in these fields as there is abundant free flow from the hot springs. The Deildartunga and Kleppjárnsreykir fields contain the Deildartunga hot spring discharging 180 l/s of boiling water and the Kleppjárnsreykir hot spring with 70 l/s.

Figure 30. *Location of the well fields Reykholt, Deildartunga, Kleppjárnsreykir and Brúarreykir (modified from NEA's Geoportal).*

Húsafell Geothermal Field

The Húsafell geothermal field is the eastern-most main field in Borgarbyggð, see Figs. 27 and 28.

The geothermal activity is classified as a remaining heat in a former central volcano. Natural flow from springs in Húsafell is about 19 l/s, mostly below 40°C. The hottest springs are in Teitsgil and give 4.8 l/s of 61.5°C (Sæmundsson, 1986 and 1993).

District heating services in the Borgarbyggð

There are nine district heating services in the Borgarbyggð District (Table 6). They use hot water from eleven well fields in the three main geothermal fields previously mentioned (Jóhannesson et al., 1980; Gunnlaugsson, 1980; Georgsson et al., 1984a).

Table 5. *District heating services in the Borgarbyggð, the geothermal fields and well fields utilized by these services.*

District Heating Service	Geothermal field	Well field
Akranes- and Borgarfjörður District Heating	Bær/Varmaland	Bær in Bæjarsveit
Akranes- and Borgarfjörður District Heating	Bær/Varmaland	Laugarholt
Akranes- and Borgarfjörður District Heating	Reykholt	Deildartunga
Húsafell District Heating	Húsafell	Húsafell
Reykholt District Heating	Reykholt	Reykholt
Kleppjárnsreykir District Heating	Reykholt	Kleppjárnsreykir
Brúarreykir District Heating	Reykholt	Brúarreykir
Varmaland District Heating	Bær/Varmaland	Varmaland/Laugaland
Stafholtstungur District Heating	Bær/Varmaland	Varmaland/Laugaland
Munaðarnes District Heating	Bær/Varmaland	Munaðarnes
Norðurárdalur District Heating	Bær/Varmaland	Hreðavatn
Norðurárdalur District Heating	Bær/Varmaland	Svartagil

4.6.1 Akranes/Borgarfjörður District Heating (Veitur)

Reykjavík Energy/Veitur is the owner since 2001-2002. The district heating is operated under Regulation 754/2002 (OR Regulation 297/2006). The service uses water from the spring Deildartunga in the Reykholt geothermal field. It also uses two wells at the well fields Bær and Laugarholt in the Bær/Varmaland geothermal field. The district heating serves the southern part of the Borgarfjörður district all the way to the town Akranes, see Fig. 31 (Olsen, 2016b). The water is transported in longest geothermal pipeline in Iceland, 63 km long.

Figure 31. *The service area of the Akranes/Borgarfjörður District Heating (Olsen, 2016b).*

Reykholt Geothermal Field

Deildartunga well field

The well field is in the Reykholt geothermal field, see Figs. 28 and 30. Three exploration wells, VG-1, VG-2 and VG-3, have been drilled at Deildartunga. The hot spring Deildartunga is the highest yielding in Iceland and delivers 180 l/s of 99°C hot water, see location on Fig. 32.

Figure 32. *Overview of the hot spring at Deildartunga (modified from NEA's Geoportal).*

The production from the spring Deildartunga in 2015 was 4.4 million m³ or about 140 l/s on an average (Olsen, 2016b).

The thermal power potential of the spring Deildartunga (180 l/s of 99°C) above 35°C is P_{35} = 46.3 MW_{th} and that above 5°C is P_5 = 68.0 MW_{th}.

Bær/Varmaland Geothermal Field

Hellur well field

One exploration well and 3 production wells, HE-1, HE-2 and HE-3, have been drilled at Hellur, see Figs. 28 and 33. The wells produce an insignificant free-flow (Georgsson et al., 1981b; Georgsson, 2010).

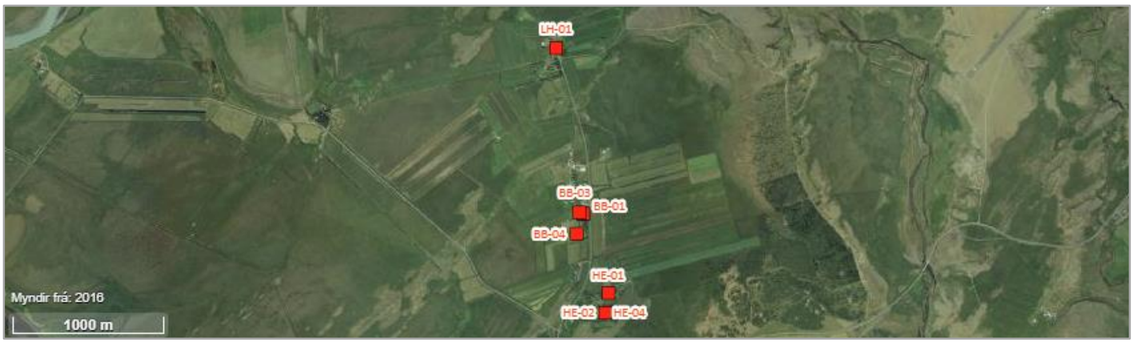

Figure 33. *Overview of the production wells in the well fields Hellur (HE-1, HE-2 and HE-4), Bær (BB-1, BB-3 and BB-4) and Laugarholt (LH-1) of the Bær/Varmaland geothermal field (NEA's Geoportal).*

Bær well field

Four production wells, BB1 to BB-4, have been drilled, see Figs. 28 and 33. The field is a medium enthalpy resource described by Sveinbjörnsson (2016). None of them yielded significant free-flow but one of them, BB-3, drilled to 1,151 m depth, yields with pump about 17 l/s of 110-115°C hot water from rather shallow aquifers (Axelsson, 2010; Georgsson et al., 1981; Georgsson et al., 2010; Olsen, 2014a)

Assuming a flow of 17 l/s at 112°C we obtain a thermal power potential for the Bær well field above 35°C of P_{35} = 5.1 MW_{th} and above 5°C of P_5 = 7.2 MW_{th}.

Laugarholt well field

One production well, LH-1, has been drilled, see Figs. 28 and 33. The field is a medium enthalpy resource described by Sveinbjörnsson (2016). The production well, LH-1 that was drilled to 1,013 m depth, yields with downhole pump 45 l/s of 93°C water (Axelsson, 2010).

The thermal power potential of that well above 35°C is P_{35} = 10.5 MW_{th} and above 5°C of P_5 = 16.0 MW_{th}. Average production in 2015 was 33.9 l/s of 93°C hot water (Olsen, 2016b).

The production from Bær and Laugarholt in 2015 was 540 thousand m^3 or 17.1 l/s on an average (Olsen, 2016b).

The combined thermal power potential of the well fields Deildartunga, Bær and Laugarholt used by the Akranes/Borgarfjörður District Heating is P_{35} = 61.9 MW_{th} and P_5 = 91.2 MW_{th}.

4.6.2 Húsafell District Heating

The service uses water from the production wells in the Húsafell geothermal field.

Húsafell Geothermal Field

Two production wells, HF-1 and HF-3, have been drilled, see Figs. 28 and 34.

Figure 34. *Overview of the production wells in the Húsafell geothermal field (NEA's Geoportal).*

The wells, HF-1 in Teitsgil and HF-3 were drilled to 397 and 606 m depths with highest measured temperature of 81°C at 380 m and 62°C at 450 m respectively. Both were successful, free-flowing, and are in use today. Well HF-1 gives 20 l/s of 77°C hot water and well HF-3 produces 24 l/s of 62°C hot water (Oddsdóttir and Ketilsson, 2012; Sæmundsson, 1993).

The thermal power potential of the Húsafell geothermal field is P_{35} = 6.1 MW_{th} above 35°C and P_5 = 11.5 MW_{th} above 5°C

4.6.3 Reykholt District Heating

Reykholt Geothermal Field

The Reykholt field is a medium enthalpy resource described by Sveinbjörnsson (2016).

Reykholt well field

Two production wells, RH-1 and RH-2, have been drilled, see Figs. 28 and 35.

Figure 35. *Overview of the production wells in the Reykholt well field (NEA's Geoportal).*

Well RH-1, was drilled at Reykholt in 1974. At 25 m depth the well intersected feeders and reduced the flow of the hot springs Skrifla and Dynkur which supplied water to houses and a swimming pool at Reykholt. The feeder was sealed off by a casing and the well deepened. It is 251 m deep and produces about 20 l/s in free-flow with a temperature of 116°C, but has a maximum temperature of 127°C at 225 m depth. To avoid rock fragments in the flow the discharge is limited to 8 l/s. It is still the hottest producing well in the region (Georgsson et al., 2010; Sæmundsson, 2010b; Þorbjörnsson and Guðmundsson, 2010). As the casing of well RH-1 is not sufficiently deep a leakage into the formation at shallow levels has occurred.

Well RH-2 was drilled in 2017 to replace RH-1. It found 125°C water and will replace well RH-1 in the near future (Skessuhorn Webpage; Sæmundsson, pers. comm.).

Assuming that the well field can produce 20 l/s of 116°c water, the thermal power potential above 35°C equals P_{35} = 6.4 MW_{th} and that above 5°C P_5 = 8.8 MW_{th}.

4.6.4 Kleppjárnsreykir District Heating

The service uses a hot spring in the Kleppjárnsreykir well field in the Reykholt geothermal field, described by Sveinbjörnsson (2016), see Fig. 28.

Kleppjárnsreykir well field

Three exploration wells have been drilled but no production well. The district heating utilizes the flow from the hot spring at Kleppjárnsreykir, see Fig. 36.

Figure 36. *Overview of the hot spring at Kleppjárnsreykir (modified from NEA's Geoportal).*

The hot spring at Kleppjárnsreykir produces about 70 l/s of 97°C hot water (Georgsson et al., 2010; Olsen, 2016b).

The thermal power potential of the hot spring above 35°C is P_{35} = 17.5 MW_{th} and that above 5°C is P_5 = 25.9 MW_{th}.

4.6.5 Brúarreykir District Heating

Brúarreykir well field

The district heating uses geothermal water from the hot spring at Brúarreykir but no wells have been drilled yet, see Figs. 28 and 37.

Figure 37. *Overview of the hot spring at Brúarreykir (modified from NEA's Geoportal).*

The spring delivers 15 l/s of 84°C hot water (Georgsson et al., 1989; Oddsdóttir and Ketilsson, 2012).

The thermal power potential of the hot spring at Brúarreykir above 35°C is P_{35} = 3.0 MW_{th} and that above 5°C is P_5 = 4.8 MW_{th}.

4.6.6 Varmaland District Heating

Bær/Varmaland Geothermal Field

The Bær/Varmaland field is furthest to the west of the geothermal fields of the Borgarbyggð region, see Figs. 28 and 29. The field is a medium enthalpy resource described by Sveinbjörnsson (2016).

Varmaland/Laugaland well field

Six shallow exploration wells and one production well, VL-7, have been drilled, see Fig. 38.

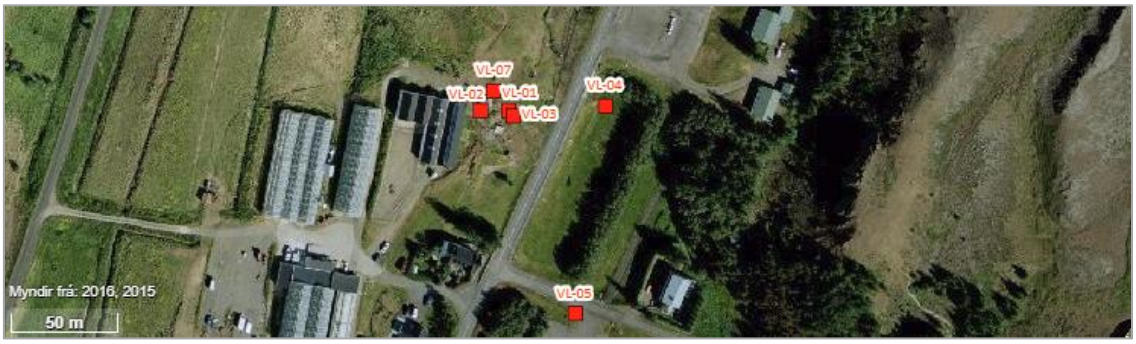

Figure 38. *Overview of the exploration wells and the production well, VL-7, in the Varmaland/ Laugaland well field (modified from NEA's Geoportal).*

The natural manifestations consisted of several small hot springs at 80-97°C yielding 5-10 l/s in total. Through the 1950's and 1960's, the flow seemed to decline. This was counteracted, in the late fifties, by drilling of 6 shallow wells 60 to 105 m depth. Three of them were productive and gave 97 to 100°C hot water. The wells and the springs were, however, connected and the flow of the springs continued to diminish. In the sixties and early seventies, the total flow from wells and hot springs was measured to be 5 to 7 l/s (Georgsson et al., 2010). The Borgarfjörður earthquakes in 1974 seemed to have a reviving effect on the hot springs and the wells as the total flow increased to 9 l/s of 90 to 100°C water (Jóhannesson et al., 1979; Georgsson et al., 1984b).

Well VL-7, drilled in late 1983 to 671 m depth, was a major success. At 661 m depth a large feed zone was intersected. In free-flow the well gave 41.5 l/s of 105°C water, but temperature logs in the well showed 113°C at 650 m depth. Production tests showed that the well could be expected to sustain at least a production of 15 l/s in free-flow, and more with pumping if necessary (Georgsson et al., 1984b). With the well producing under slight wellhead pressure, it has so far not had much effect on flow from the hot springs and the old wells.

Assuming a yield from well VL-7 of 15 l/s of 105°C one obtains a thermal power potential for the well of P_{35} = 4.2 MW_{th} and P_5 = 6.0 MW_{th}.

For the hot springs of 9 l/s of 97°C water the thermal power potential is P_{35} = 2.2 MW_{th} and P_5 = 3.3 MW_{th}. The total thermal power potential of the Varmaland/Laugaland well field then corresponds to P_{35} = 6.4 MW_{th} and P_5 = 9.3 MW_{th}.

4.6.7 Stafholtstungur District Heating

The service buys hot water from well VL-7 in the Varmaland/Laugaland well field in the Bær/Varmaland geothermal field, see Figs. 23, 24, 25 and 34.

4.6.8 Munaðarnes District Heating (Veitur)

Reykjavík Energy/Veitur is the owner since 2004. The district heating operates under Regulation 297/2006. It uses hot water from production wells in Munaðarnes well field which is located in the Bær/Varmaland geothermal field, see Figs. 28, 29 and 38. The service area of Munaðarnes District Heating is shown in Fig. 39.

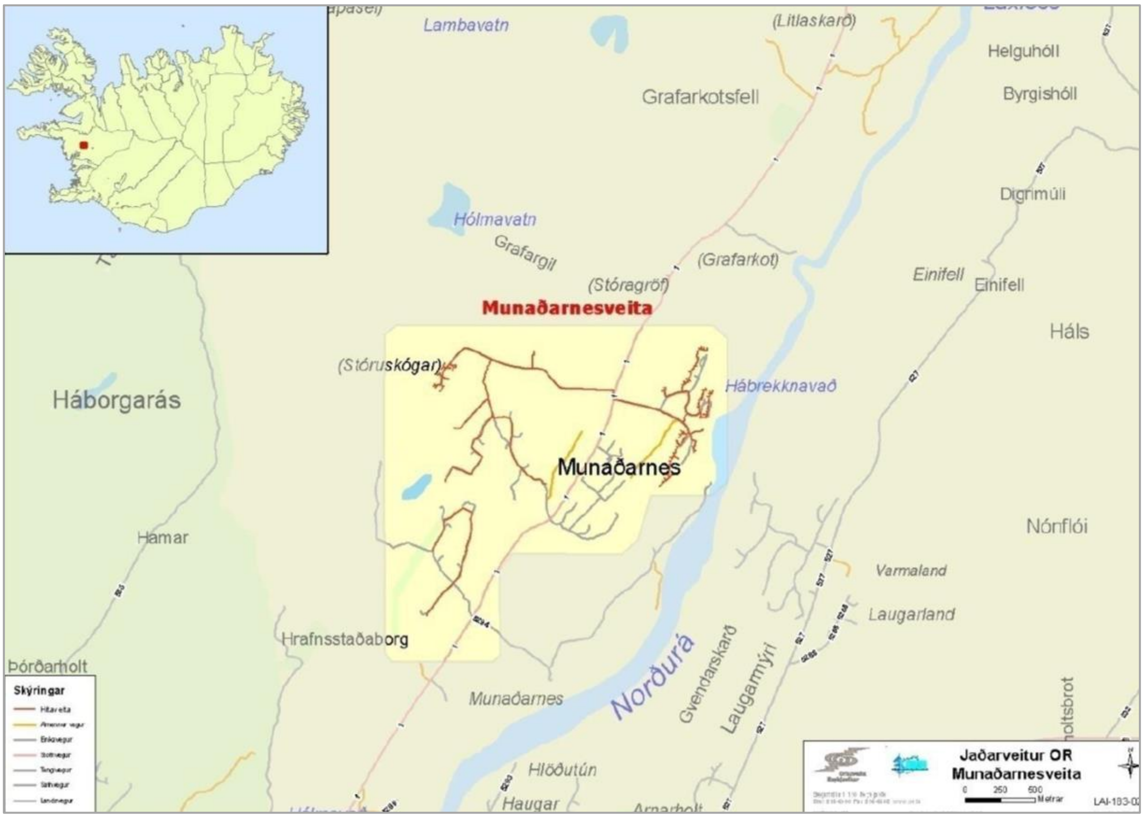

Figure 39. *The service area of the Munaðarnes District Heating (Olsen, 2016c).*

Munaðarnes well field

Six exploration wells and two production wells, MN-2 and MN-8, have been drilled, see Figs. 28 and 40.

Figure 40. *Overview of the production wells in the Munaðarnes well field (NEA's Geoportal).*

The production wells, MN-2 and MN-8 were drilled to 969 and 900 m depths. Highest temperatures measured in those wells are 86°C at 630 m depth and 93°C at 506 m respectively.

Well MN-2 was successful, but it had a collapse at 260 m depth but with a free-flow of 3 l/s of 80°C hot water (Björnsson and Sæmundsson, 1992). The well was measured again in 2002 and then the free-flow was 2 l/s of 86°C hot water (Hafstað, 2002). Well MN-2 is in local use (Georgsson et al., 2010).

Well MN-8 did not intersect the main upflow zone in the system. It is has been estimated that possible minimum production from the geothermal field is 20-30 l/s (Hjartarson, 2004). The average production by pump from well MN-8 was 6.7 l/s of 88°C hot water in 2015 and maximum 7.1 l/s in December (Olsen, 2016c). The well has a capacity of 10 l/s of 88°C hot water (Hjartarson et al., 2003).

The thermal power potential of the well MN-8 (10 l/s of 88°C water) at Munaðarnes well field above 35°C is P_{35} = 2.1 MW_{th} and that above 5°C is P_5 = 3.4 MW_{th}.

4.6.9 Norðurárdalur District Heating (Veitur)

Reykjavík Energy/Veitur bought the district heating in 2002. It operates under Regulation 297/2006. The service uses water from production wells in the well fields Hreðavatn and Svartagil of the Bær/Varmaland geothermal field, see Figs. 28 and 29. The service area of the Norðurárdalur District Heating is shown in Fig. 41.

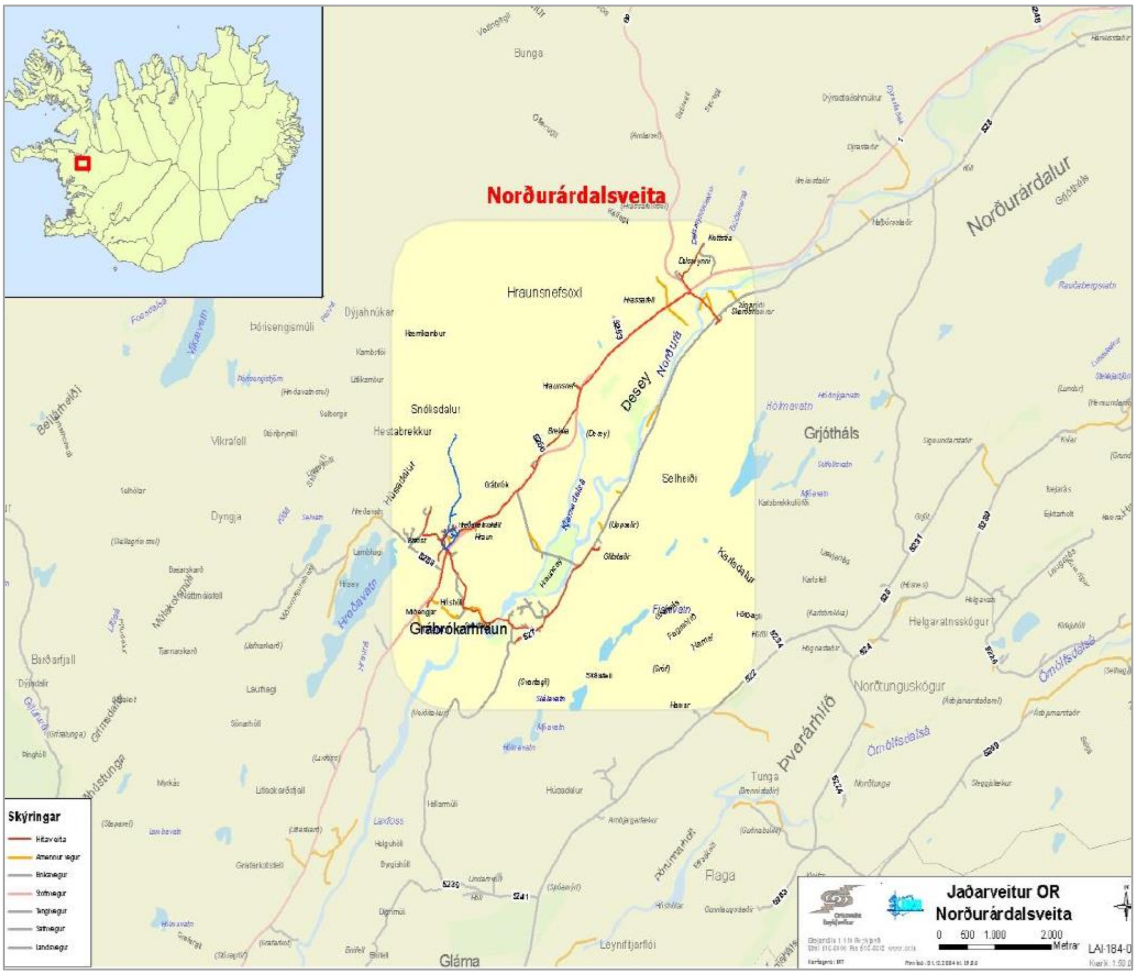

Figure 41. *The service area of the Norðurárdalur District Heating (Olsen, 2016d).*

The Norðurárdalur field

Hreðavatn well field

Twelve exploration wells and one production well, BI-3, have been drilled, see Figs. 28 and 42.

Figure 42. *Overview of the production wells in the well fields Hreðavatn and Svartagil in the Norðurárdalur field of the main Bær/Varmaland geothermal field (NEA's Geoportal).*

Well BI-3 was drilled to 409 m depth and has a production, by pump, from 11.0-14.4 l/s of 68.4°C hot water and is in use (Olsen, 2016d; Sigurðsson, 1991a).

Assuming 14.4 l/s of 68.4°C one obtains a thermal power potential for well BI-3 at Hreðavatn of P_{35} = 2.0 MW_{th} and P_5 = 3.7 MW_{th}.

Average production from well BI-3 in 2015 was roughly 154 thousand m^3 or about 4.9 l/s of 68.4°C hot water (Olsen, 2016d).

Svartagil well field

One exploration well, SG-1, and one production well, SG-3 have been drilled, see Figs. 28 and 42. Well SG-3 has a production potential up to 30 l/s of 68°C hot water, limited by shallow casing and is currently in use (Olsen, 2016d; Sæmundsson and Hafstað, 2000).

Average production, by pump, from well SG-3 in 2015 was roughly 154 thousand m^3 or about 4.9 l/s of 66.3°C hot water (Olsen, 2016d).

Taking the flow of well SG-3 at Svartagil as 30 l/s at 68°C, we obtain a thermal power potential of P_{35} = 4.1 MW_{th} and P_5 = 7.7 MW_{th} at Svartagil and a total for the Hreðavatn and Svartagil well fields of P_{35} = 6.1 MW_{th} and P_5 = 11.4 MW_{th}

4.7 Helgafellssveit

4.7.1 Stykkishólmur District Heating (Veitur)

The Stykkishólmur District Heating service operates under Regulation 869/1999. Reykjavík Energy/Veitur operates the district heating service since 2005 under Regulation 297/2006. Fig. 43 shows the distribution area of the Stykkishólmur District Heating service. The service uses water from the Hofsstaðir geothermal field.

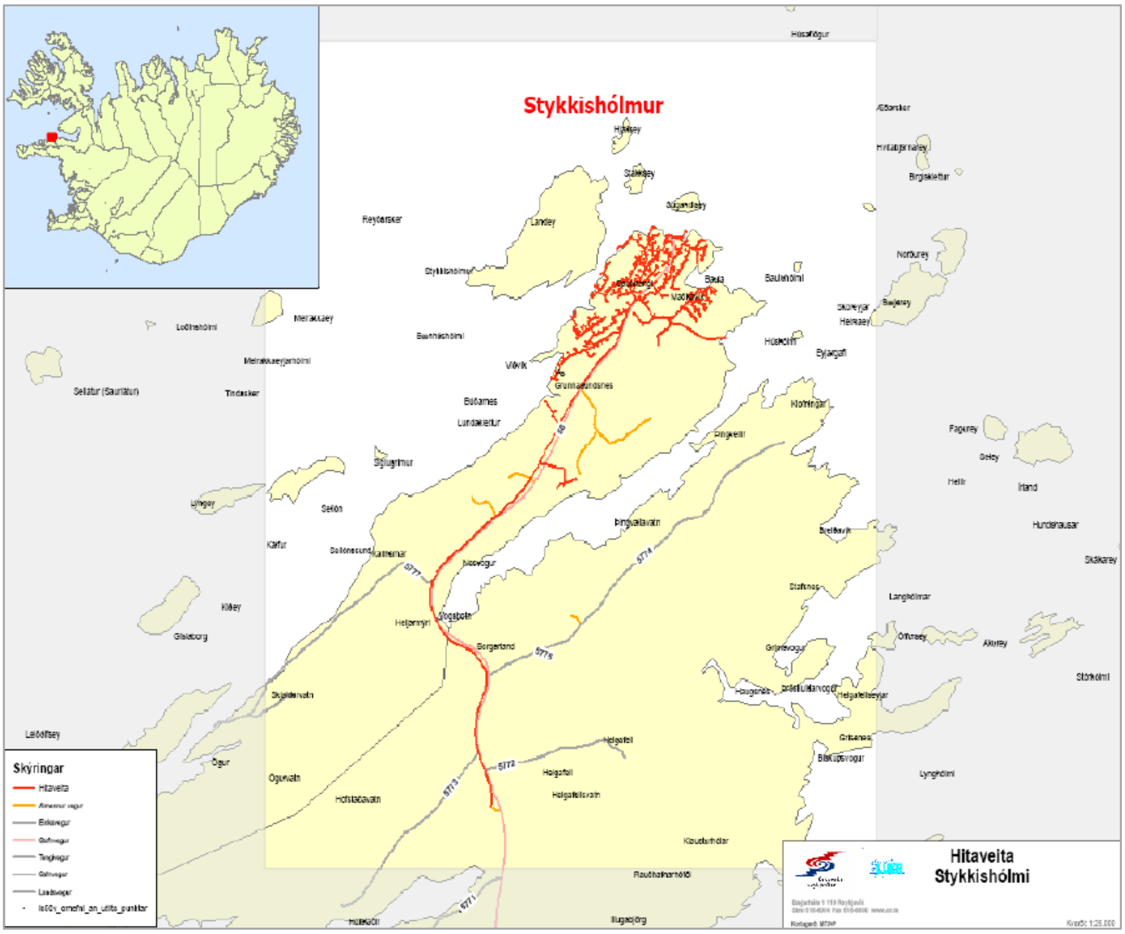

Figure 43. *The service area of the Stykkishólmur District Heating (Olsen, 2016e).*

Hofsstaðir Geothermal Field

The service uses water from the production well HO-1 in the Hofsstaðir well field of the Hofsstaðir geothermal field, which includes three well fields, Arnarstaðir, Hofsstaðir and Ögur.

Arnarstaðir well field

Ten shallow temperature wells and one production well, AS-1, have been drilled, see Fig. 44.

Figure 44. *Overview of the production wells in the well fields Arnarstaðir (AS-1), Hofsstaðir (HO-1) and Ögur (HO-2-injection well) (NEA's Geoportal).*

AS-1 was drilled to 403 m depth and reached temperature of 87°C at 396 m depth. The well was tested in the end of drilling and gave by air pumping 32.5 l/s of 87°C hot water (Björnsson et al., 1998).

That flow corresponds to a thermal power potential of P_{35} = 6.8 MW_{th} and P_5 = 10.8 MW_{th}

Hofsstaðir well field

Fifteen shallow temperature gradient wells were drilled before location of the production well, HO-1, was decided, see Fig. 44. The well was drilled to 855 m depth and reached 89°C temperature at 810 m depth.

Utilization of well HO-1 in the first years indicates that the reservoir has very limited recharge and behaves nearly as confined. The water table has steadily declined, and some injection is needed to counteract with the drawdown of the water table (Björnsson and Friðleifsson, 1996; Axelsson et al., 2005; Kristmannsdóttir et al., 2002a; Ólafsson et al., 2005; Axelsson and Ólafsson, 2007. The water is saline and cannot be used directly (Kristmannsdóttir et al., 2002a). It is piped to the town and used there to heat water in the closed loop of distribution system in a central heat exchanger.

The well HO-1 produced, by pump, about 30 l/s of 86°C hot water in 2015 (Olsen, 2016e).

Assuming that 2015 flow data a thermal power potential for the Hofsstaðir well field of P_{35} = 6.2 MW_{th} and P_5 = 9.8 MW_{th} is obtained.

Ögur well field

Eleven shallow temperature wells were drilled to select the site of the production/-injection well, HO-2, see Fig. 44. The well HO-2 was drilled to 413 m depth and was tested by pumping air through the drill string in the end of drilling in July 2006 and gave about 39 l/s of about 80°C (Hafstað and Axelsson, 2006). The well is used as an injection well today and as a substitute well for well HO-1 at Hofsstaðir. The average injection into the well was 21 l/s in 2015 or 70% of the production from well HO-1. (Oddsdóttir and Ketilsson, 2012). Well HO-2 is not taken into the evaluation of thermal power.

The thermal power potential of the Hofsstaðir geothermal field (Hofsstaðir and Arnarstaðir well fields) adds thus up to P_{35} = 13.0 MW_{th} and P_5 = 20.6 MW_{th}.

4.8 Dalabyggð

4.8.1 Dalabyggð District Heating (RARIK)

The Dalabyggð District Heating is licensed under Regulation 897/2000. It is operated by RARIK under the Regulation 122/1992. The service uses water from wells in the Gröf well field of the Miðdalir geothermal field. The water is used for the swimming pool Grafarlaug and transported some 20 km to the village Búðardalur and farms on the way (Björnsson et al., 2005). The temperature drops about 15°C on the way from the well field to the road intersection at the Kambsnes airport and further 7°C from there and throughout the village (Níelsson and Helgadóttir, 2012).

Miðdalir Geothermal Field

The upflow of the geothermal field is assumed to be in the mountain south of Grafarlaug, in Reykjadalur, close to the caldera rim of the extinct volcano Reykjadalur (Jóhannesson, 1975; Níelsson and Helgadóttir, 2012; Sverrisdóttir, 1991a). The geothermal field is artesian and the wells free-flowing (Sæmundsson and Björnsson, 2000).

Gröf well field

Eleven exploration wells and four production wells, GR-8, GR-9, GR-11 and GR-15, have been drilled, see Fig. 45.

Figure 45. *Location of the production wells in the Gröf well field (modified from NEA's Geoportal).*

The production wells, were drilled to 1,019-1,493 m depth and have highest measured temperature of 96°C. All the wells were successful.

Well GR-08 hit an 85°C hot feeder and gave 10-20 l/s of free-flow after drilling which declined as high pressurized geothermal systems do often (Björnsson et al., 2005). The well gave only up to 1 l/s of 75°C hot water in the year 2000 (Sæmundsson and Björnsson, 2000).

Tests at the end of drilling well GR-9 resulted in an artesian flow of 21 l/s. By pump, the flow was 26 l/s with the water table at 60 m and 31 l/s with the water table at 100 m but the flow declined below 9 l/s of 80°C hot water (Björnsson et al., 2005; Níelsson and Helgadóttir, 2012; Sæmundsson and Björnsson, 2000).

Well GR-11 was drilled in 2000 and was the first directionally drilled well in a low enthalpy field in Iceland. After drilling the well, the free-flow of GR-9 declined to 6.7 l/s of roughly 80°C hot water and combined flow from the wells, GR-9 and GR-11 was about 20 l/s of nearly 85°C hot water (Sæmundsson and Björnsson, 2000).

Well GR-15 was directionally drilled in 2007 when more water was needed. Production test in the end of drilling by air pumping gave 52-65 l/s (Ólafsson et al., 2007). There is a possibility that the well has capacity of free-flowing 25 l/s of 87°C hot water if wells GR-9 and GR-11 are closed. If a pump is installed into GR-15 and operated at 100-250 m depth the flow capacity would rise up to 50 l/s (Níelsson and Helgadóttir, 2012).

Average production from wells GR-11 and GR-15 in the year 2014 was about 11 l/s of 87°C hot water. (Harðardóttir and Óskarsson, 2015).

Assuming flow of 25 l/s with temperature of 87°C, the thermal power potential of the well field Gröf in Miðdalir geothermal field is P_{35} = 5.3 MW_{th} and P_5 = 8.3 MW_{th}.

4.9 Reykhólahreppur

4.9.1 Reykhólar District Heating (OV)

The Reykhólar District Heating is operated by Orkubú Vestfjarða (OV) and licensed under OV Regulation 514/1996. It uses three production wells, RH-1, RH-2 and RH-7 in the medium enthalpy Reykhólar geothermal field described by Sveinbjörnsson (2016).

Reykhólar Geothermal Field

Reykhólar well field

Eight production wells, RH-1 to RH-8, have been drilled, see Fig. 46.

Figure 46. *Overview of the production wells in the Reykhólar well field (modified from NEA's Geoportal).*

Total natural discharge from hot springs prior to drilling was about 30 l/s of 60-100°C water (Torfason, 2003). Six of the wells, ranging from 187 to 1,070 m in drilled depth, with highest measured temperature in well RH-4 of 117°C at 690 m depth, yield about 55 l/s of 90-111°C hot water, with weighted average of 108°C (Björnsson and Sigvaldason, 1989; Hafstað, 2012; Hafstað and Björnsson, 2000a; Harðardóttir, 2012a; Harðardóttir, 2012b). Well RH-3 gave 2 l/s of about 95°C hot water, only if well RH-2 was closed (Hafstað and Björnsson, 2000a). RH-8 is privately owned.

4.9.2 Thorverk Seaweed Plant

The Thorverk seaweed plant utilizes geothermal water and steam from wells RH-3, RH-4, RH-5 and RH-6 in the Reykhólar well field, see Fig. 46.

The thermal power of the wells in the Reykhólar geothermal field is 55 l/s of 108°C water, which corresponds to a thermal power potential of P_{35} = 16.0 MW_{th} (Sveinbjörnsson, 2016) and P_5 = 22.6 MW_{th}.

4.10 Ísafjarðarbær

4.10.1 Suðureyri District Heating (OV)

The Suðureyri District Heating operates under the OV Regulation 514/1996. Orkubú Vestfjarða (OV) owns the district heating service and uses water from wells in the Laugar well field of the Suðureyri geothermal field. The geothermal water is 60-65°C hot and is led into a heating plant which raises the temperature up to 80°C (Þórðarson, 1998).

Suðureyri Geothermal Field

Laugar well field

Three exploration wells and two production wells, LA-2 and LA-5, have been drilled, see Fig. 47.

Figure 47. *Overview of the production wells in the Laugar well field at Suðureyri (modified from NEA's Geoportal).*

Drilling of wells LA-2 and LA-5 proved that the upflow of the geothermal field is in a fracture (at least 430 m long), parallel to the coast of Súgandafjörður (Sæmundsson, 2015). Prior to drilling a hot spring of 40°C water was utilized for a swimming pool, but after the drilling the hot spring disappeared (Sæmundsson, 2015).

The wells LA-2 and LA-5 were drilled to 684 and 1,142 m depth respectively and have highest measured temperature of 66 and 67°C near bottom.

Well LA-2 gave 18 l/s in a production test by air lifting, with a drill string at 60 m depth, after the well had been deepened.

Well LA-5 gave up to 23 l/s of in a production test by air pump at the end of drilling (Sæmundsson, 2015). The wells are interconnected and have been used by pump for the district heating (Ólafsson, 2010a). In the year 2015, only well LA-2 was in use by pump and the production was on an average 9.6 l/s of 68°C hot water and has been 10 to 12 l/s last years (Óskarsson, 2016; Sæmundsson 2015).

Assuming flow of 12 l/s with temperature of 68°C, the thermal power potential of the Suðureyri geothermal field is P_{35} = 1.6 MW_{th} and P_5 = 3.1 MW_{th}.

4.11 Kaldrananeshreppur

4.11.1 Drangsnes District Heating

The Drangsnes District Heating operates under Regulation 301/2001. It uses the Drangsnes geothermal field at the mouth of the fjord Steingrímsfjörður, near the village Hólmavík in Northwest Iceland.

A hot spring with a flow of 80°C hot water is near the coast at Hveravík but it was considered too far away from the village at Drangsnes to pipe the water to the village. Later it was decided drill exploration wells inside the village (Jóhannesson, 2010).

Drangsnes Geothermal Field

Drangsnes well field

A total of 17 shallow exploration wells and one production well, DN-16, have been drilled in the village, see Fig. 48.

Figure 48. *Overview of the production well in the Drangsnes well field (modified from NEA's Geoportal).*

A temperature gradient well, DN-7 was drilled to 134 m and gave about 10 l/s of 60°C hot water. It was in use until 2002. Well DN-16 was drilled to 276 m depth and has the highest measured temperature of 62°C at 210 m depth. It gives about 20 l/s of 61°C hot water and is in use (Jóhannesson, 2010).

Assuming flow of 20 l/s with temperature of 61°C, the thermal power potential of the Drangsnes geothermal field is P_{35} = 2.1 MW_{th} and P_5 = 4.6 MW_{th}.

4.12 Húnaþing Vestra

4.12.1 Húnaþing Vestra District Heating

The Húnaþing Vestra District Heating operates under Regulations 63/2001, 645/2002 and 1192/2012. It consists of Borðeyri District Heating and Reykir District Heating in Hrútafjörður, and Hvammstangi/Laugarbakki District Heating in Miðfjörður. The geothermal fields utilized are Borðeyri, Reykir in Hrútafjörður and Laugarbakki, see Fig. 49.

Figure 49. *Location of the geothermal fields at Borðeyri, Reykir in Hrútafjörður and Laugarbakki in the Húnaþing Vestra District (modified from NEA's Geoportal).*

Borðeyri Geothermal Field

Laugarmýri well field

Seven exploration wells, up to 123 m deep, and one production well BE-8, 456 m deep, have been drilled, see Fig. 50.

Figure 50. *Overview of the production well in the Laugarmýri well field of the Borðeyri field (NEA's Geoportal).*

The production well, BE-8, has highest measured temperature of 62°C at 280 m depth. Silica content of the water indicates a reservoir temperature of about 100°C. The well gave free-flowing 45 l/s of 61°C hot water while it was being drilled, but the flow declined rapidly (Sæmundsson, 2001). In 2016 the well was still in use and produced on average about 1 l/s of 57°C hot water (Harðardóttir, 2017a).

Assuming a flow of 1 l/s of 57°C hot water one obtains a thermal power of P_{35} = 0.1 MW_{th} and P_5 = 0.2 MW_{th} for the Borðeyri geothermal field.

Reykir in Hrútafjörður Geothermal Field

Reykir well field

Nine exploration wells and 3 production wells, RS-3, RS-7 and RS-14, have been drilled, see Fig. 51.

Figure 51. *Overview of the production wells in the Reykir well field (NEA's Geoportal).*

Prior to drilling there were about five boiling springs near the school Reykjaskóli, giving 0.5-8.0 l/s of 92-100°C hot water but they cannot be seen today (Böðvarsson, 1947; Jónsson and Ingimarsson, 2015; Torfason, 2003).

The production wells were drilled to 284 m, 41 m and 186 m depths respectively.

Well RS-3 found water at 3 m above the bedrock but was not productive (Einarsson et al., 1981).

Well RS-7 was productive and used until RS-14 became available (Ólafsson, 2014).

Well RS-14 has the highest measured temperature of 104°C at 130 m depth and is now the main producer. It gives about 5 l/s of free-flowing 97°C hot water (Jónsson and Ingimarsson, 2015).

Assuming a flow of 5 l/s of 97°C hot water one obtains a thermal power potential of P_{35} = 1.2 MW_{th} and P_5 = 1.9 MW_{th} for the Reykir in Hrútafjörður geothermal field.

4.12.1 Hvammstangi/Laugarbakki District Heating

The Hvammstangi and Laugarbakki District Heating in Miðfjörður uses water from two wells in the well field Ytri-Reykir within the Laugarbakki geothermal field. The water serves the villages Hvammstangi and Laugarbakki, as well as a number of farms in Miðfjörður and Línakradalur (Harðardóttir, 2017b).

Laugarbakki Geothermal Field

The geothermal field is a medium enthalpy resource described by Sveinbjörnsson (2016)

Ytri-Reykir well field

Three production wells, LB-1, LB-2 and LB-3 have been drilled, see Fig. 52.

Figure 52. *Overview of the production wells in Ytri-Reykir well field (NEA's Geoportal).*

Well LB-1 was drilled in 1964 to 284 m depth. Below 220 m it found a feeder which gave 3 l/s. In 1971 the well was deepened to 290 m depth and found at that depth a feeder which gave initially free-flow of 16 l/s but was measured 13 l/s of 97°C water in 1972 (Ragnars, 1972).

Well LB-2 was drilled to 337 m depth in 1971 and deepened in 1972 to 887 m. It has highest measured temperature of 107°C found near bottom, just a day after drilling. It found feeders at 390-410 m depth and gave 25 l/s of 100°C hot water in a pumping test in 1976 (Jónsson, 1976).

The wells are interconnected but yielded together free flow of 19.7 l/s of 97°C water.

Well LB-3, 350 m deep, drilled in 1977, is in use and yielded 14.5 l/s of 95.8°C hot water on average in the year 2014 (Ólafsson, 2015).

Estimated pumped potential for a long period is 40-50 l/s with 90 m drawdown and it is estimated that the field could deliver a long-term flow of some 50-100 l/s of 95°C water if more wells were drilled (Björnsdóttir and Axelsson, 2007).

Assuming a flow of 50 l/s of 95°C hot water one obtains a thermal power potential of P_{35} = 12.1 MW_{th} and P_5 = 18.1 MW_{th} for the Laugarbakki geothermal field.

4.13 Húnavatnshreppur

4.13.1 Blönduós District Heating (RARIK)

The Blönduós District Heating operates under Regulation 582/1989 and since 1.7.2005 under RARIK Regulation 122/1992. It serves the village Blönduós, using water from the Reykir at Reykjabraut geothermal field, west of the lake Svínavatn about 14 km from the village. The water cools down 4°C on the way, see Fig. 53.

Figure 53. *The well field Reykir at Reykjabraut, west of the Lake Svínavatn and the villages Blönduós and Skagaströnd (modified from NEA's Geoportal).*

Reykir at Reykjabraut Geothermal Field

Reykir well field

Prior to drilling of the first well in 1964 there was natural flow of about 2 l/s of 68°C hot water and the first exploration well gave 4 l/s of free-flowing 70°C hot water (Sigurðsson et al., 1968; Tulinius et al., 1991; Níelsson et al., 2012).

Fourteen exploration wells, thereof one drilled to 608 m depth and 6 production wells, RR-4, RR-5, RR-6, RR-12, RR-21 and RR-22, have been drilled, see Fig. 54.

Figure 54. *Overview of the production wells in the Reykir at Reykjabraut well field (modified from NEA's Geoportal).*

The production wells have a drilled depth range from 438 to 1,676 m and have highest measured temperature ranging from 62 to 101°C in RR-6, which is the deepest one. In the beginning from 1964-1979 the first wells had an artesian flow, highest up to 50-60 l/s in 1976. But right from the beginning it was clear that the pressure in the system was declining. From 1979-1980 pumps were installed in the wells (Björnsson, 1992b).

The three newest production wells, RR-12, RR-21 and RR-22 have replaced the older wells and were in use in 2016 (Björnsson, 1996a; Harðardóttir, 2017b). The average production from the wells in 2016 was by pumps 33 l/s of about 73°C hot water. Average water-table in the wells is at the depth of 90 m +/- 20 m (Axelsson and Þorgilsson, 2015)

Assuming a 2016 flow data of 33 l/s of 73°C, for the Reykir at Reykjabraut geothermal field, one obtains a thermal power potential of P_{35} = 5.1 MW_{th} and P_5 = 9.2 MW_{th}.

4.13.2 Skagaströnd District Heating (RARIK)

The Skagaströnd District Heating is operated as part of the Blönduós District Heating. It uses water from the Reykir at Reykjabraut geothermal field. A pipeline was constructed in 2013 connecting Skagaströnd to the Blönduós distribution system, a distance of 30 km. The water cools 16°C on the way (Harðardóttir, 2017b), see Fig. 53.

4.14 Skagafjörður

The energy company Skagafjarðarveitur (SKV) operates six district heating services in the Skagafjörður District. They are: Steinsstaðir, Sauðárkrókur, Varmahlíð, Hólar, Hofsós, and Sólgarðar/Langhús. Fig. 55 shows the locations and service regions of these distribution systems, average flow in l/s and total m^3 usage in 2016 (SKV, Webpage).

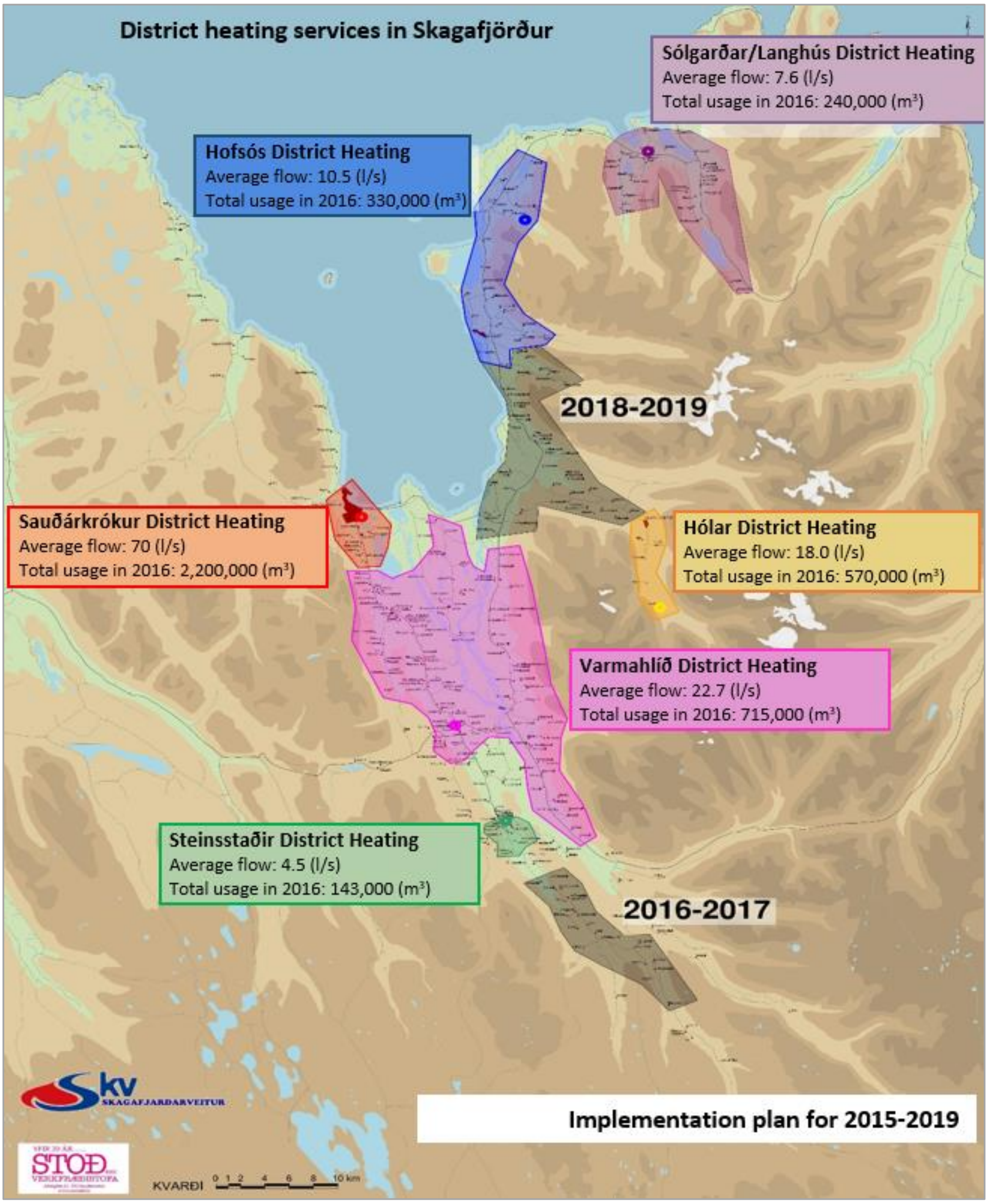

Figure 55. *Average flow and total usage in 2016 and areas of the district heating services Steinsstaðir, Sauðárkrókur, Varmahlíð, Hólar, Hofsós and Sólgarðar/Langhús, located in the Skagafjörður District (modified from SKV, Webpage)*.

Fig. 56 shows the location of the geothermal fields in the Skagafjörður District.

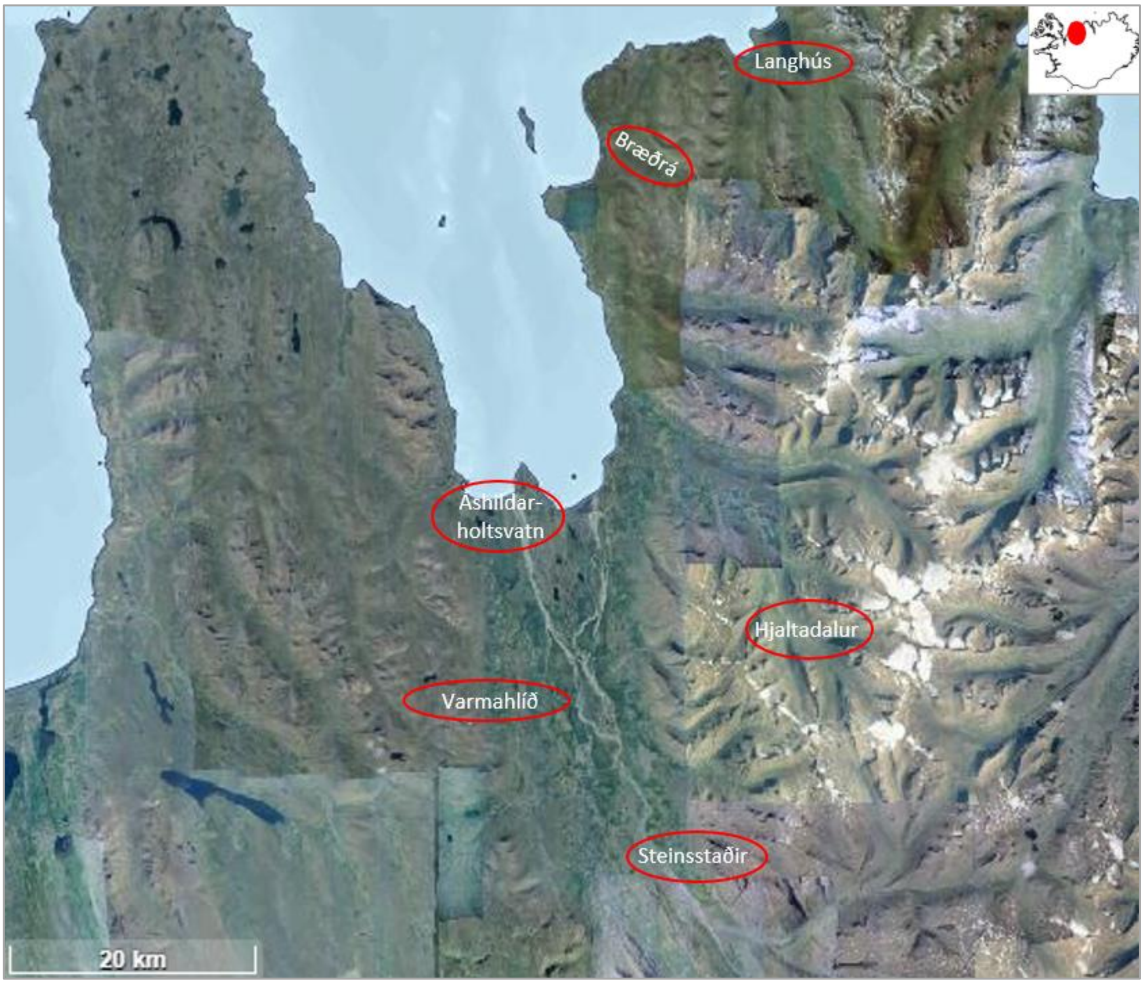

Figure 56. *Location of the geothermal fields at Steinsstaðir, Varmahlíð, Áshildarholtsvatn, Hjaltadalur, Bræðrá and Langhús in Fljót in the Skagafjörður District (modified from NEA's Geoportal).*

4.14.1 Steinsstaðir District Heating (SKV)

The Steinsstaðir District Heating operates under Regulation 87/2013. It serves the houses at Steinsstaðir, swimming pool, nearby farms and greenhouses (see Fig. 55) and uses water from wells and the hot spring in the Steinsstaðir geothermal field (see Fig. 56).

Steinsstaðir Geothermal Field

Steinsstaðir well field

Three exploration wells, drilled shallower than 100 m and three production wells, LB-1, LH-1 and LE-2, were drilled to 206, 136 and 120 m depths, respectively, see Fig. 57.

Figure 57. *Overview of the production wells and the hot spring in the Steinsstaðir well field (modified from NEA's Geoportal).*

Well LB-1 gave 10 l/s of free-flowing 60°C hot water after drilling in 1965 but the flow had declined to 4.5 l/s in 1980. The water was used for greenhouses.

Well LH-1 gave 4 l/s of free-flowing 58°C hot water (Sæmundsson, 2000). The flow from the hot spring has not declined after drilling of the wells and is still estimated 21 l/s of 61°C hot water (Sæmundsson, 2000).

Well LE-2 was drilled in 2000. It found only 50°C water at 90 m.

In 2016 the total flow of Steinsstaðir District Heating was 143,000 m^3 or on average 4.5 l/s (SKV, Webpage).

The hot spring at Steinsstaðir (21 l/s of 60°C) has a thermal power potential of P_{35} = 2.2 MW_{th} and P_5 = 4.8 MW_{th} and the wells (9 l/s of 61°C) P_{35} = 0.9 MW_{th} and P_5 = 2.0 MW_{th}.

Adding the potentials of the hot spring and the wells in the Steinsstaðir geothermal field, one obtains a total thermal power potential of P_{35} = 3.1 MW_{th} and P_5 = 6.8 MW_{th}.

4.14.2 Sauðárkrókur District Heating (SKV)

The Sauðárkrókur District Heating operates under Regulation 87/2013. It serves the village Sauðárkrókur and its neighbourhood, see Fig. 55. The hot water comes from the Áshildarholtsvatn geothermal field under the lake Áshildarholtsvatn, see Fig. 56.

Áshildarholtsvatn Geothermal Field

Borgarmýrar well field

One exploration well, BM-0 and 13 production wells, BM-1 to BM-13, have been drilled see Fig. 58.

Figure 58. *Overview of the production wells in Borgarmýrar well field of the Áshildarholtsvatn geothermal field (NEA's Geoportal).*

The first well BM-0 in the Borgarmýrar well field was drilled in 1948, 17.5 m deep (Böðvarsson, 1953; Smárason and Karlsdóttir, 1987; SKV, Webpage).

Well BM-1 was drilled on a manmade platform in the lake, first to 29.5 m depth in 1948 and deepened to 250 m in 1953. It yielded 23 l/s of 70°C hot water. This success led to construction of a distribution system in the Sauðárkrókur village.

Wells BM-2 to BM-8 were drilled in the years 1948-1964, ranging between 120 and 158 m in depth. They yielded much less, some 1-4 l/s each (Smárason and Karlsdóttir, 1987).

In June 1965 well BM-9, drilled to 384 m depth, gave 20 l/s of 71°C water (SKV, Webpage).

Next wells were drilled in Borgarmýrar on the banks of the lake but the wells in Áshildarholtsvatn were abandoned and filled with cement, except for well BM-9 which was kept for monitoring.

The new wells at Borgarmýrar, BM-10, BM-11, BM-12 and BM-13, were drilled to depths of 577.5, 554.3, 524.4 and 666.8 m respectively. The new wells yield a free-flow of 140 l/s of 70°C water.

In 2016 the total flow of Sauðárkrókur District Heating was 2.2 million m^3 or on average 70 l/s (SKV, Webpage).

Taking the free-flow of the Borgarmýrar wells one obtains a total flow of 140 l/s of 70°C hot water or the thermal power potential of P_{35} = 20.0 MW_{th} and P_5 = 37.2 MW_{th}.

4.14.3 Varmahlíð District Heating (SKV)

The Varmahlíð District heating operates under Regulation 87/2013. The service area is shown on Fig. 55. It uses the Varmahlíð geothermal field, see Fig. 56.

Varmahlíð Geothermal Field

Reykjarhóll well field

Nine exploration wells and 3 production wells, VH-2, VH-3 and VH-12 have been drilled, see Fig. 59.

Figure 59. *Overview of the production wells in the Reykjarhóll well field of the Varmahlíð geothermal field (NEA's Geoportal).*

Well VH-2 was drilled in 1972 to 200 m depth. It gave a good yield of 90°C water, more than the school needed and led to the decision to establish a heating service for Varmahlíð and nearest farms (SKV, Webpage).

Well VH-3 was drilled in 1986 to 414 m depth and delivered 20 l/s of 90°C water in free-flow.

Well VH-12 was drilled in 1997 to 427 m depth, with highest measured temperature of 95°C at 200 m depth. It yielded on a year average, 2013, about 20 l/s of pumped 95 °C hot water. There is an estimate that the well has a potential of over 40 l/s (SKV, Webpage; Tryggvason et al., 2014).

In 2016 the total flow of Varmahlíð District Heating was 0.72 million m^3, or on average 22.7 l/s.

The combined potential of the production wells, 40 l/s at 95°C, corresponds to a thermal power potential of P_{35} = 9.7 MW_{th} and P_5 = 14.5 MW_{th} for the Varmahlíð geothermal field (Sveinbjörnsson, 2016).

4.14.4 Hólar District Heating (SKV)

The Hólar District Heating operates under Regulation 87/2013. It uses hot water from the Reykir in Hjaltadalur geothermal field, located 8 km from Hólar. The district heating serves the Hólar University College, the salmon production company Hólalax and the community in Hjaltadalur, see Figs. 55 and 56.

Reykir in Hjaltadalur Geothermal Field

Reykir well field

Two production wells, RH-1 and RH-2, have been drilled, see Fig. 60.

Figure 60. *Overview of the production wells in the Reykir well field of the valley Hjaltadalur (NEA's Geoportal).*

Well RH-1 was drilled in 1978 to 603 m depth. At first the well had a shut-in wellhead pressure of 25 bar-g which is unusually high for a low enthalpy well. Long term flow tests indicate a yield of 20 l/s of 56°C water (Ólafsson and Elíasson, 1997).

Well RH-2 was drilled in 2005 to 1,080 m depth and gives 28 l/s of 60.8°C water (Odds-dóttir and Ketilsson, 2012).

In 2016 the total flow of Hólar District Heating was 0.57 million m^3 or on an average 18 l/s (SKV, Webpage).

Assuming a total flow of 47 l/s of 60°C hot water one obtains thermal power potential of P_{35} = 4.8 MW_{th} and P_5 = 10.6 MW_{th}.

4.14.5 Hofsós District Heating (SKV)

The Hofsós District Heating operates under Regulation 87/2013. The service area is shown in Fig. 55. The water comes from the Bræðrá well field in the Bræðrá geothermal field in the valley Hrollleifsdalur, 13 km from Hofsós, see Fig. 56.

Bræðrá Geothermal Field

Bræðrá well field

Fourteen exploration wells and 2 production wells, SK-28 and SK-32, have been drilled, see Fig. 61.

Figure 61. *Overview of the production wells in the Bræðrá well field (NEA's Geoportal).*

Well SK-28 was drilled in 2005 to 973 m depth and yields about 15 l/s at 83°C with 97 m drawdown. (Axelsson, 2006).

Well SK-32 was drilled in 2012 to 1,100 m depth. It is estimated to yield 12.5-15.0 l/s with a 200-230 m drawdown. The main feeder delivers 100°C water (Egilson et al., 2012).

In 2016 the total flow of Hofsós District Heating was 0.33 million m^3 or an average of 10.5 l/s (SKV, Webpage).

Assuming 30 l/s of 90°C water the thermal power potential is P_{35} = 6.7 MW_{th} and P_5 = 10.3 MW_{th}.

4.14.6 Sólgarðar/Langhús District Heating (SKV)

The Sólgarðar/Langhús District Heating operates under Regulation 87/2013. The service area is shown in Fig. 55. It uses the well fields, Langhús and Barð of the Langhús geothermal field, see Figs. 56.

Langhús Geothermal Field

Barð well field

On production well, BL-1, has been drilled by the hot spring Barðslaug in 1974. The well intersected 67°C water above 40 m depth (Sæmundsson, 1990). It is 163 m deep, and has heated the school and a swimming pool at Sólgarðar, see the service area in Fig. 55 and location of the well in Fig. 62.

Langhús well field

Four production wells, LH-1 to LH-4, have been drilled, see Fig. 62.

Figure 62. *Overview of the production wells in the well fields Barð (BL-1) and Langhús (LH-1-LH-4) of the Langhús geothermal field (NEA's Geoportal).*

The Sólgarðar/Langhús District Heating uses well LH-1 at Langhús which was drilled in 1997 to 79 m depth and yields 1.3 l/s of 101°C water and is used to heat houses in its neighborhood.

Well LH-2, drilled next to the hot spring Dælislaug at Langhús, to 204 m depth, yields 5.4 l/s of 102°C water (Hafstað, 2014a, 2014b and 2015a; Hafstað and Óskarsson, 2015; Tryggvason et al., 2014; Jóhannesson, 2008; Óskarsson, 2013). Both wells at Langhús have free-flowing water.

Well LH-3 was drilled to 381 m depth and has a bottom temperature of 101.4 °C but insignificant flow.

Well LH-4 hit on a good feeder of boiling water at 170 m depth. The well yields up to 30 l/s of 106-111°C water and has a shut-in wellhead pressure of 5 bar-g (Hafstað, 2017).

Assuming 30 l/s of 106°C hot water one obtains a thermal power potential for the Langhús geothermal field of $P_{35} = 8.5$ MW_{th} and $P_5 = 12.1$ MW_{th}.

In 2016 the total flow of Sólgarðar/Langhús District Heating was 0.24 million m^3 or on average 7.6 l/s (SKV, Webpage).

4.15 Fjallabyggð

There are two district heating services operating in the Fjallabyggð District, Siglufjörður District Heating and Ólafsfjörður District Heating. There are three geothermal fields used by the services, Skarðdalur, Skútudalur and Ólafsfjörður, see Fig. 63.

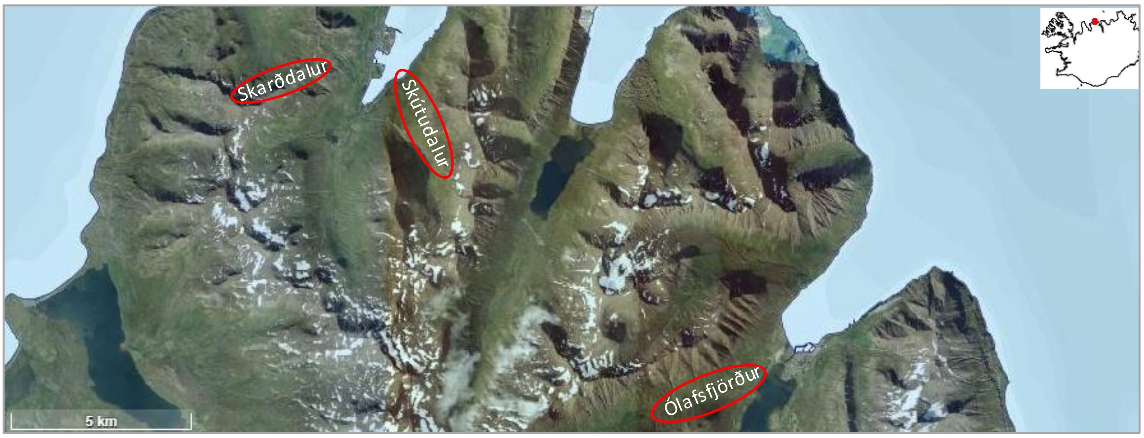

Figure 63. *Location of the geothermal fields, Skarðdalur, Skútudalur and Ólafsfjörður in the Fjallabyggð District (modified from NEA's Geoportal).*

4.15.1 Siglufjörður District Heating (RARIK)

The Siglufjörður District Heating is owned by the RARIK energy company and operates by Regulation 122/1992. It exploits the two geothermal fields, Skarðdalur and Skútudalur, see Fig. 63.

Skarðdalur Geothermal Field

Skarðdalur well field

Thirteen exploration wells and one production well, SD-1, have been drilled at Skarðdalur, see Fig. 64.

Figure 64. *Overview of the production well, SD-1, in the Skarðdalur well field (NEA's Geoportal).*

Well SD-1 was drilled to 702 m depth and delivers 25 l/s of 75.6°C hot water (RARIK, Webpage). In 2016 the well produced 398.521 m^3 or an average of 12.6 l/s (Harðardóttir, 2017c).

Taking 25 l/s of 75.6°C water one obtains a thermal power potential of P_{35} = 4.1 MW_{th} and P_5 = 7.2 MW_{th} for the Skarðdalur geothermal field.

Skútudalur Geothermal Field

Skútudalur well field

Seven exploration wells and 6 production wells, SK-6 to SK-11, have been drilled, see Fig. 65.

Figure 65. *Overview of the production wells in the Skútudalur well field (NEA's Geoportal).*

The depths of the production wells, drilled in the years 1971 to 1982, range from 491 to 1,672 m in depth. The feeding zones in the wells are interconnected.

It was estimated that well SK-6 would yield 15-20 l/s of 67°C water with a drawdown of 120 m (Arnórsson, 1971).

Well SK-7 was estimated to yield 23 l/s of 67°C hot water with 126 m drawdown (Björnsson et al., 1976).

Well SK-8 intersected few feeders and yielded 3 l/s by pumping (Tómasson et al., 1979).

Well SK-9 produced 5 l/s by pumping of about 77°C hot water but has some bottom fall and is therefore not usable (Haraldsson and Thorsteinsson, 1983).

Well SK-10 produced 9 l/s by air-pumping and is used when needed (Halldórsson, 1980a; Axelsson, 2009). Testing after drilling of well SK-11 indicated that the field could give 22-30 l/s with tolerable drawdown (Björnsson et al., 1983).

Well SK-11 produced 462.240 m^3 or an average of 14.6 l/s in 2016 (Harðardóttir, 2017c).

Taking 30 l/s of 67°C from Skútudalur geothermal field, one obtains a thermal power potential P_{35} = 3.9 MW_{th} and P_5 = 7.6 MW_{th}.

4.15.2 Ólafsfjörður District Heating (NO)

The Ólafsfjörður District Heating is owned by the energy company Norðurorka and operates under Regulation 58/1989 and the Laws 159/2002. The water comes from the well fields Skeggjabrekka and Ósbrekka of the Ólafsfjörður geothermal field.

Ólafsfjörður Geothermal Field

There are two well fields in the Ólafsfjörður geothermal field, Skeggjabrekka (Garðsárdalur) and Ósbrekka (Laugarengi), see Fig. 66.

Figure 66. *Location of the well fields Skeggjabrekka and Ósbrekka in the Ólafsfjörður geothermal field (modified from NEA's Geoportal).*

Skeggjabrekka well field

Fourteen exploration wells and 3 production wells, SK-12, SK-13 and SK-16, have been drilled, see Fig. 67.

Figure 67. *Overview of the production wells in the Skeggjabrekka well field* (*NEA's Geoportal).*

In the autumn of 1939 geothermal exploration was carried out at Garðsá in Skeggjabrekkudalur. The hot springs and the spring Garðslaug had a total flow of 9.5 l/s in the temperature range 50-53°C. A district heating system was constructed and taken into use near the end of year 1944. It served 700 people in 150 apartments.

Exploration wells SK-1 to SK-11 were drilled in the valley of Skeggjabrekka in the years 1947 to 1958 but their locations are not known. The drilled depths ranged from 15 to 75 m.

Well SK-12, was drilled in 1962 to 277 m depth and has been the main production well since. It delivered originally 28 l/s of 56°C water but with time the flow declined to 14 l/s of 54°C (Karlsdóttir and Helgason, 1978).

Well SK-13, was drilled in 1962 to 593 m depth (Karlsdóttir and Helgason, 1978). The well was unsuccessful and was filled up in 1996.

Well SK-16 was drilled in 2015 to 274 m depth to replace SK-12. It was successful and produces free-flowing 16 l/s water (Norðurorka, Webpage a).

Norðurorka indicates maximum production from Skeggjabrekka (Garðsárdalur) of 16 l/s of 56°C water) (Norðurorka, Webpage a). That corresponds to a thermal power potential of P_{35} = 1.4 MW_{th} and P_5 = 3.4 MW_{th}.

Ósbrekka well field

Five exploration wells and 4 production wells, ÓS-1 to ÓS-4, have been drilled, see Fig 68.

Figure 68. *Overview of the production wells in Laugarengi of the Ósbrekka well field* (*NEA's Geoportal).*

Since 1975 hot water has been produced at Laugarengi in Ósbrekka.

Well ÓB-1, drilled in 1972 to 466 m depth gave 1 l/s of free-flowing 66°C hot water but was replaced by ÓB-3 and ÓB-4 (Tómasson et al., 1992).

Well ÓB-2, drilled in 1973 to 298 m depth gave 1.5 l/s of free-flowing 66°C hot water but was replaced by ÓB-3 and ÓB-4 (Tómasson et al., 1992).

Well ÓB-3 was drilled in 1974 to 1,168 m depth and gave 13.5 l/s of 66°C water in free-flow and 24 l/s when pumped (Hjartarson and Harðardóttir, 2002).

Well ÓB-4 was drilled in 1981 to 1,484 m depth and gave considerably more than well ÓB-3 and has been the main production well at Ósbrekka but well ÓB-3 is used in reserve (Hjartarson and Harðardóttir, 2002).

In 1994 five exploration wells, ÓB-5 to ÓB-9, were drilled but not followed by a product-ion well.

Norðurorka indicates maximum production from Ósbrekka (Laugarengi) of 50 l/s of 67°C water (Norðurorka, Webpage b). That corresponds to a thermal power potential of P_{35} = 6.6 MW_{th} and P_5 = 12.7 MW_{th}.

The thermal power potential of the two well fields in Ólafsfjörður adds up to P_{35} = 8.0 MW_{th} and P_5 = 16.1 MW_{th}.

4.16 Dalvíkurbyggð

Three geothermal fields are located within Dalvíkurbyggð; Hamar, Árskógsströnd and Ytrivík.

4.16.1 Dalvík District Heating

The Dalvík District Heating operates under Regulation 893/1999. It uses the well field Hamar of the Hamar geothermal field in the valley Svarfaðardalur, see Fig. 69.

Figure 69. *Location of the geothermal fields Hamar, Árskógsströnd and Ytrivík in the Dalvíkurbyggð District (modified from NEA's Geoportal).*

Hamar Geothermal Field

Hamar well field

Eight exploration wells and 3 production wells, HA-9 to HA-11, have been drilled, see Fig. 70.

Figure 70. *Overview of the production wells in the Hamar well field (NEA's Geoportal).*

Utilization began in 1969, serving the village Dalvík. Well HA-9 was drilled in 1975 to 253 m depth, HA-10 in 1977 to 838 m and HA-11 in 1987 to 860 m. Well HA-9 gave estimated flow of 30 l/s by pump in 1979 (Axelsson, 1995).

The two latest wells are presently in use, delivering 64°C hot water (Dalvíkurbyggð, Webpage).

Well HA-10 yielded on average 42 l/s in 1982 and 26.4 l/s in 1987 (Axelsson, 1995).

Well HA-11 yielded 26.4 l/s in 1989 and 27.6 l/s in 1994. A combined average annual production of 37 l/s is predicted to cause a drawdown to 45 m depth in 2015 (Axelsson, 1995).

The thermal power potential of 37 l/s of 64°C water for the Hamar geothermal field would be P_{35} = 4.4 MW_{th} and P_5 = 9.0 MW_{th}.

4.16.2 Árskógsströnd District Heating

At Brimnes/Birnunes on Árskógsströnd utilization by the Dalvík District Heating began in 1998, serving the communities Árskógssandur, Litli-Árskógur, Hauganes and the service and industry area at Árskógur.

Árskógsströnd Geothermal Field

Brimnes/Birnunes well field

Twenty exploration and 2 production wells, ÁRS-29 and ÁRS-32, have been drilled, see Fig. 71.

Figure 71. *Overview of the production wells in the Brimnes/Birnunes well field* (*NEA's Geoportal)*

Since December 2007 the well field also provides hot water for the rural area at Svarfaðardalur. The main production wells are ÁRS-29 and ÁRS-32 drilled in 1997 and 2006 to 440 and 901 m depths respectively (Dalvíkurbyggð, Webpage).

Well ÁRS-29 delivers 16 l/s of 73°C water with 35 m drawdown (Flóvenz et al., 2004a).

Well ÁRS-32 delivers 65 l/s of 75°C water (Blischke et al., 2006).

The combined thermal power potential of 16 l/s of 73°C and 65 l/s of 75°C water would be P_{35} = 13.1 MW_{th} and P_5 = 23.0 MW_{th} for the Árskógsströnd geothermal field.

4.16.3 Ytrivík District Heating (NO)

The Ytrivík District Heating is now operated by Norðurorka (NO) and utilizes the well fields Ytrivík at Sólbakki and Syðrihagi, in the Ytrivík geothermal field, see Fig. 69.

Ytrivík Geothermal Field

Ytrivík at Sólbakki well field

Six exploration wells and one production well, YV-20, have been drilled, see Fig. 72.

Figure 72. *Overview of the production wells in the well fields Ytrivík at Sólbakki and Syðrihagi of the Ytrivík geothermal field (NEA's Geoportal).*

Well YV-20 was drilled at Ytrivík in the land of Sólbakki in 2017 to 254 m depth and yields 12-14 l/s of 85°C water in free-flow (Norðurorka, Webpage b).

A flow of 14 l/s at 85°C yields a thermal power potential of P_{35} = 2.8 MW_{th} and P_5 = 4.5 MW_{th} for the well field Ytrivík at Sólbakki.

Syðrihagi well field

Seven exploration wells and 2 production wells, YV-14 and YV-19 have been drilled, see Fig. 72.

Well YV-14 (HV-7) was drilled in 1996 to 182 m depth and delivers 10 l/s of 77°C in free-flow (Flóvenz and Smárason, 1997).

Well YV-19 was successful and used until well YV-20 at Ytrivík well field was drilled in 2017 (Hafstað, pers. comm.).

The flow of 10 l/s of 77°C from YV-14 yields a thermal power potential of P_{35} = 1.7 MW_{th} and P_5 = 2.9 MW_{th} for the Syðrihagi well field.

The total thermal power potential for the Ytrivík geothermal field adds up to P_{35} = 4.5 MW_{th} and P_5 = 7.4 MW_{th}.

4.17 Hörgársveit

Hörgársveit has two geothermal fields, Þelamörk and Hjalteyri, which are utilized by Akureyri District Heating, owned by the energy company Norðurorka and operated under Regulation 186/1989 and Laws 159/2002. Fig. 73 shows the location of the geothermal fields.

Figure 73. *Location of the geothermal fields, Hjalteyri and Þelamörk, in the Hörgársveit District (modified from NEA's Geoportal).*

4.17.1 Akureyri District Heating (NO)

Þelamörk Geothermal Field

The Þelamörk geothermal field has one well field at Laugaland.

Laugaland at Þelamörk well field

Eleven exploration wells and six production wells, LL-1, LL-2, LL-3, LL-4, LL-10 and LL-11, have been drilled, see Fig. 74.

Figure 74. *Overview of the production wells in the Laugaland well field (NEA's Geoportal).*

The first 4 production wells, drilled between 1941 and 1970 to depths from 375.0 to 1,088.5 m, gave limited flow, total about 5 l/s of 90°C water (Flóvenz et al., 1984b).

Well LL-10, was first drilled in 1992 to 925 m, but later deepened to 1,707 m and gave 15-20 l/s of 103°C water with drawdown to 200 m (Norðurorka, Webpage b).

Well LL-11 was drilled in 1992 to 454 m depth and total loss of circulation at 430 m. It yielded 16 l/s of 91°C water with drawdown less than 240 m (Flóvenz et al., 1994).

Norðurorka estimates the maximum capacity of the field with acceptable drawdown to be 25 l/s of 103°C (Norðurorka, Webpage b).

That gives a thermal power potential for the Þelamörk geothermal field of P_{35} = 6.8 MW_{th} and P_5 = 9.8 MW_{th}.

Hjalteyri Geothermal Field

Arnarnes well field

Eighteen exploration wells and two production wells, HJ-19 and HJ-20, have been drilled, see Fig. 75.

Figure 75. *Overview of the production wells in the Arnarnes well field of the Hjalteyri geothermal field (NEA's Geoportal).*

Well HJ-19 was drilled in 2002 to 1,448 m depth and yielded a free-flow of 20 l/s of 87-88°C hot water (Egilson et al., 2017).

Well HJ-20 was drilled in 2005 to 1,515 m depth and yields 120 l/s by pump (Egilson, 2017.

Estimates indicate that the maximum yield may be at least 250-280 l/s without risking that the pumping draws in contamination of sea water (Axelsson and Egilson, 2017).

Well HJ-21 was drilled in 2018, to 1,286 m depth. Well testing results indicate a productivity index (PI) of 625 (l/s)/bar of 87.4°C (Egilson and Þorsteinsdóttir, 2018). This result is preliminary and has not been included in estimates in this report of thermal power potential for the Hjalteyri geothermal field.

Before the drilling of HJ-21, Norðurorka estimated that the Arnarnes well field can produce a maximum of 145 l/s of 87°C water (Norðurorka, Webpage c) corresponding to a thermal power potential of P_{35} = 30.5 MW_{th} and P_5 = 48.1 MW_{th}.

4.18 Akureyrarkaupstaður

The energy company Norðurorka operates district heating services producing hot water at Ólafsfjörður in Fjallabyggð, Ytrivík in Dalvíkurbyggð, Hjalteyri and Þelamörk in Hörgársveit, Glerárdalur and Hrísey in Akureyri, Laugaland, Ytri-Tjarnir/Björk, Botn/ Hrafnagil in Eyjafjarðarsveit and Reykir in Fnjóskadalur.

Table 7 lists the production fields of Norðurorka and their capacity (Norðurorka Webpage b; Egilson et al., 2017; Gautason et al., 2017a).

Table 6. *Production fields of Norðurorka and their capacity (Norðurorka, Webpage b).*

District – Geothermal Fields – Well fields	Initial year	Discharge		Maximum pumping
		Temperature	Annual average	
		(°C)	(l/s)	(l/s)
Fjallabyggð - Ólafsfjörður - Garðsárdalur	1944	56	15	16
Fjallabyggð - Ólafsfjörður - Laugarengi	1975	67	19	50
Dalvíkurbyggð - Ytrivík - Syðrihagi	2016	82	10	24
Hörgársveit - Hjalteyri - Arnarnes	2003	87	109	145
Hörgársveit - Laugaland - Þelamörk	1994	103	14	25
Akureyri - Glerárdalur	1982	60	11	20
Akureyri - Hrísey	1987	79	5	16
Eyjafjarðarsveit - Laugaland	1977	94	49	144
Eyjafjarðarsveit – Ytri-Tjarnir/Björk	1979	81	32	40
Eyjafjarðarsveit - Botn/Hrafnagil	1981	83	26	30
Reykir in Fnjóskadalur	2005	91	13	16
SUM/*weighted annual average*		***84***	**303**	**526**

Fig. 76 shows a map of the district heating services and their pipelines in Eyjafjörður.

Figure 76. *The district heating services of Norðurorka in Eyjafjörður. The red lines show extent of pipelines for hot water (Norðurorka, Webpage b).*

4.18.1 Akureyri District Heating (NO)

There are two geothermal fields within the Akureyri District, at Glerárdalur and in the island Hrísey, see Fig. 77.

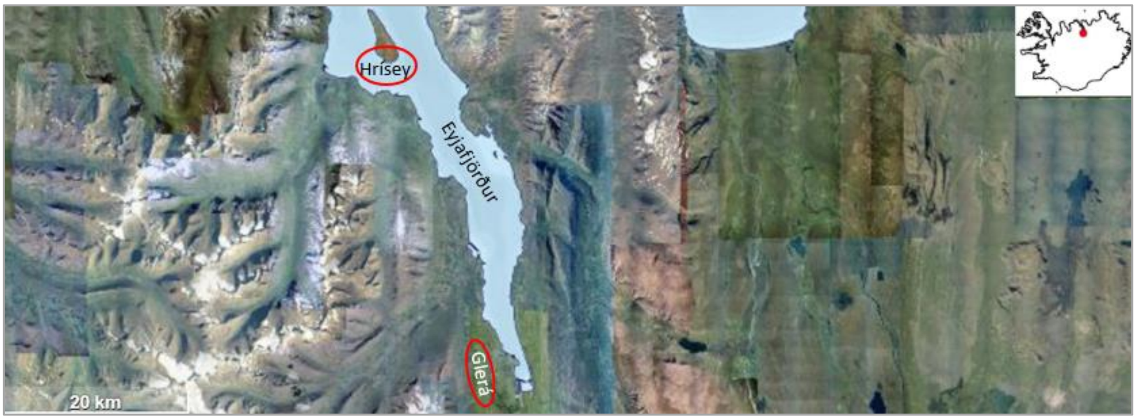

Figure 77. *Location of the geothermal fields Glerárdalur and Hrísey in the Akureyri District (modified from NEA's Geoportal).*

Glerárdalur Geothermal Field

The Akureyri District Heating using the Glerárdalur geothermal field is operated by Norðurorka under Regulation 186/1989 and the Laws 159/2002, see Fig. 77.

Glerárdalur well field

Twelve production wells have been drilled, GL-1 to GL-12, see Fig. 78.

Figure 78. *Overview of the production wells in the Glerárdalur well field (NEA's Geoportal).*

Well GL-1 was drilled in 1930 to 100 m depth. Wells GL-2 and GL-3, drilled in 1940, were 26 and 66 m deep. They were not successful (Flóvenz et al., 1984).

Well GL-4 was in 1965 drilled to 647 m depth, and gave only 1 l/s by pump (Flóvenz et al., 1984).

Wells GL-5 to GL-12 were drilled in the years from 1980 to 1982 to less than 300 m, except GL-7 which was drilled to 798.1 m. Well GL-7 intersected the feeding fractures of the Glerárdalur hot springs and delivered 30 l/s of 61°C water (Flóvenz et al., 1984).

Norðurorka estimates a maximum capacity of 20 l/s of 60°C water (Norðurorka, Webpage b) or thermal power potential of P_{35} = 2.1 MW_{th} and P_5 = 4.5 MW_{th} for the Glerárdalur geothermal field.

4.18.2 Hrísey District Heating (NO)

The Hrísey District Heating is operated under Regulation 323/1973 and the Laws 159/2002 and uses water from the Hrísey geothermal field, see Fig. 77.

Hrísey Geothermal Field

Hrísey well field

Ten production wells have been drilled, HR-1 to HR-10, see Fig. 79.

Figure 79. *Overview of the production wells in the Hrísey well field* (*NEA's Geoportal).*

Well HR-1, drilled in 1966 to 99 m depth, found feeders and 66°C hot water (Sæmundsson and Kristmannsdóttir, 1983).

The heating service pumped water from HR-2, which was drilled in 1972 to 132 m depth, in the years 1973 to 1979, but the water temperature sank from 64°C to 52°C due to influx of colder water (Norðurorka, Webpage d).

Wells HR-3, HR-4 and HR-5 were drilled in 1979 to 637.2, 322.7 and 320 m depths, respectively. Wells HR-3 and HR-4 were not successful but gave hints where to drill HR-5. It found a good feeder at 96 m depth. From the beginning of 1980 until 1982, the well HR-5 was used but the operation was halted due to cooling of the water, contamination of oxygen and problems with pumps. The well was deepened to 1,056 m in 1985 but did not find new feeders. It was estimated that the well could give by pump about 10 l/s of 59°C hot water (Björnsson and Flóvenz, 1985).

Well HR-6 found good feeder (Sæmundsson and Kristmannsdóttir, 1983. A new field was selected for drilling.

Wells HR-7, HR-8 and HR-9, drilled in 1987, to 156, 176 and 224 m depths, respectively. The wells were productive but had cold inflow and were replaced by HR-10 (Björnsson, 1991).

Well HR-10, drilled in 1987 to 330 m depth, became the main production well. It delivers free-flow of 10 l/s at 79.2°C (Björnsson et al., 1988).

Norðurorka estimates a maximum capacity of 16 l/s of 78.5°C water (Norðurorka, Webpage d) or thermal power potential of P_{35} = 2.8 MW_{th} and P_5 = 4.8 MW_{th} for the Hrísey geothermal field.

4.19 Eyjafjarðarsveit

There are four geothermal fields, Reykhús, Botn/Hrafnagil, Laugaland and Ytri-Tjarnir, in the district used by Norðurorka for the Akureyri District Heating in addition to the geothermal fields to the north, Þelamörk and Hjalteyri. The operation is under Regulation 186/1989 and the Laws 159/2002. Fig. 80 shows the location of these geothermal fields.

Figure 80. *Location of the geothermal fields, Reykhús, Botn/Hrafnagil, Laugaland and Ytri-Tjarnir in the Eyjafjörður District (NEA's Geoportal).*

Reykhús Geothermal Field

Reykhús well field

Nine exploration wells and one production well, RH-7, have been drilled, see Fig. 78.

Figure 81. *Overview of the production well, RH-7, in the Reykhús well field (NEA's Geoportal).*

Well RH-7 is 1,819 m deep and was used to heat the rural area at Kristnes and Reykhús. In 2008 the houses were connected to the pipeline from Syðra-Laugaland and utilization of well RH-7 was discontinued (Egilson et al., 2017).

Botn/Hrafnagil Geothermal Field

Hrafnagil well field

Eleven exploration wells, one production well, HG-10 and one injection well, HN-13, have been drilled, see Fig. 82.

Figure 82. *Overview of the production wells and the injection well, HN-13, in the well fields Hrafnagil (HG-10 and HN-13) and Botn (BO-1) (modified from NEA's Geoportal).*

Well HG-10 at Hrafnagil was drilled in 1988 to 1,050.2 m depth and yields 25 l/s of 78°C hot water with a drawdown of 230 m (Axelsson and Björnsson, 1992; Egilson, 2017).

That flow corresponds to a thermal power potential of P_{35} = 4.4 MW_{th} and P_5 = 7.4 MW_{th}.

Botn well field

Six exploration wells and one production well, BO-1, have been drilled, see Fig. 82. The well is in use today and delivers about 6 l/s of 92°C hot water (Axelsson et al., 2009; Egilsson, 2017).

That flow corresponds to a thermal power potential of P_{35} = 1.4 MW_{th} and P_5 = 2.1 MW_{th}.

Norðurorka estimates the maximum capacity of Botn/Hrafnagil geothermal field to be 30 l/s of 83°C water (Norðurorka, Webpage b) or a thermal power potential of P_{35} = 5.8 MW_{th} and P_5 = 9.5 MW_{th}.

Laugaland Geothermal Field

Syðra Laugaland well field

Four exploration wells and 8 production wells, LA-5 to LA-12, have been drilled, see Fig. 83.

Figure 83. *Overview of the production wells and the injection well, LA-8 in the Syðra Laugaland well field (NEA's Geoportal).*

Wells LA-1 to LA-4 were drilled in 1947 and 1948. They were shallower than 80 m and are here regarded as exploration wells.

Well LA-5 was drilled in 1975 to 1,305 m depth and yielded free-flow of 95-100 l/s of 94°C water (Axelsson et al., 2009).

Wells LA-6 to LA-12 were drilled in the years 1976-1978 to 1,606 to 2,820 m depths. The success was limited and only wells LA-7 and LA-12 are in use and the wells LA-5 and LA-11 are idle. The production capacity of the well field turned out to be rather limited and the drawdown excessive. LA-6 and LA-9 were not productive. LA-10 gave by pumping 7.5 l/s of 91°C hot water but has been used. Well LA-8 which was drilled to 2,820 m depth has been used as an injection well to counteract the drawdown (Axelsson et al., 2009, 2000a and 2000b; Gautason et al., 2017b).

Norðurorka estimates the production capacity of the Laugaland geothermal field to be 144 l/s of 94°C water (Norðurorka, Webpage b) or thermal power of P_{35} = 34.3 MW_{th} and P_{5} = 51.7 MW_{th}.

Ytri-Tjarnir/Björk Geothermal Field

Ytri-Tjarnir Well field

Three production wells have been drilled, see Fig. 84.

Figure 84. *Overview of the production wells in the well fields Ytri-Tjarnir and Björk (NEA's Geoportal).*

In the years 1978-1980 three production wells, YT-1, YT-2 and YT-4 were drilled to 1,109, 1,482 and 1,554 m depths respectively. All the wells were productive but with excessive drawdown. Currently only well YT-4 is used (Axelsson et al., 1988; Egilsson, et al., 2017).

Björk well field

One production well, YT-3, was drilled in 1980 to 1,554 m depth, see Fig. 84. The well intersected 78°C hot water at 970 m depth but has not been used for production (Flóvenz and Thorsteinsson, 1984).

Norðurorka estimates the maximum capacity of the Ytri-Tjarnir/Björk geothermal field to be 40 l/s of 81°C water (Norðurorka, Webpage b) or thermal power potential of P_{35} = 7.5 MW_{th} and P_5 = 12.4 MW_{th}.

4.20 Þingeyjarsveit

There are four district heating services in the Þingeyjarsveit District. They are the Reykir in Fnjóskadalur District Heating, operated by Norðurorka and Þingeyjar District, using water from wells at Reykir in Fnjóskadalur; the Reykjadalur District Heating, operated by the Þingeyjar District Heating, using water from the geothermal fields in Reykjadalur and at Stórutjarnir; the Aðaldalur/Kinn District Heating, using water from the Hvera-vellir geothermal field; and Hafralækur District Heating operated by Orkuveita Húsa-víkur, using water from the Hafralækur geothermal field. Fig. 85 shows the location of the geothermal fields.

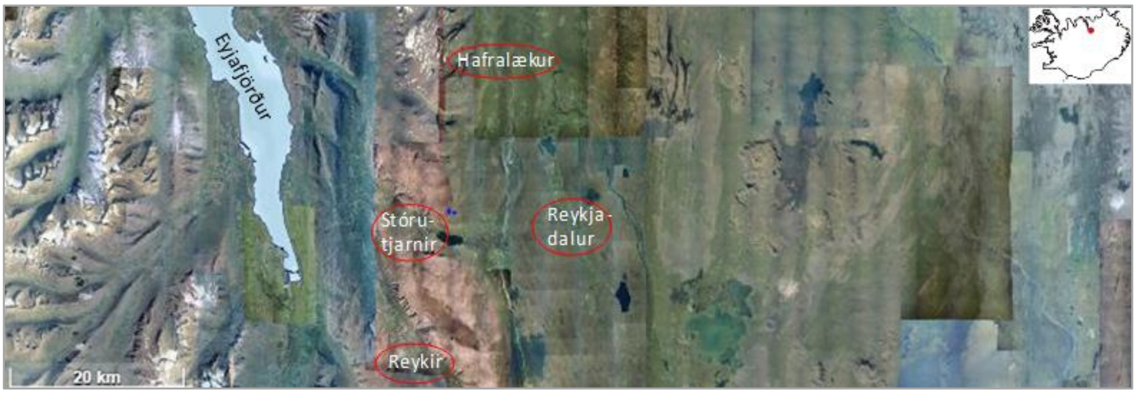

Figure 85. *Location of the geothermal fields Reykir in Fnjóskadalur, Stórutjarnir, Reykjadalur and Hafralækur in the Þingeyjarsveit District (modified from NEA's Geoportal).*

4.20.1 Reykir District Heating (NO)

The Reykir District Heating is operated by Norðurorka and uses the well field at Reykir in Fnjóskadalur, see Fig. 85. The geothermal water is piped north through the Fnjóskadalur valley, across the pass Dalsmynni and north to the village Grenivík, see Fig. 76.

Reykir in Fnjóskadalur Geothermal Field

Reykir in Fnjóskadalur well field

Eleven exploration wells and 2 production wells, RF-7 and RF-9, have been drilled, see Fig. 86.

Figure 86. *Overview of the production wells in the Reykir in Fnjóskadalur well field (NEA's Geoportal).*

Well RF-7 was drilled in 1982 to 650 m depth and yielded 15-20 l/s of 90°C water and is in use (Norðurorka, Webpage e).

Well RF-9 was drilled in 2008 to 120 m depth and gave similar results and is idle (Axelsson et al., 2009; Norðurorka, Webpage e; Oddsdóttir and Ketilsson, 2012).

Norðurorka estimates the maximum capacity of the Reykir in Fnjóskadalur geothermal field to be 16 l/s at 91°C (Norðurorka, Webpage e) which corresponds to a thermal power potential of P_{35} = 3.6 MW_{th} and P_5 = 5.6 MW_{th}.

4.20.2 Reykjadalur District Heating

The Reykjadalur District Heating uses water from the geothermal fields Stórutjarnir and Reykjadalur, see Fig. 85.

Stórutjarnir Geothermal Field

Stórutjarnir well field

Six exploration wells and one production well, ST-7, have been drilled, see Fig. 87.

Figure 87. *Overview of the production well, ST-7 in the Stórutjarnir well field (NEA's Geoportal).*

The exploration well ST-4, drilled in 1966 to 61.6 m depth, yielded 2 l/s of 64°C water (Sverrisdóttir, 1991b; Ólafsson, 1987).

Well ST-6, drilled in 1975 to 595 m depth, yields very little (Björnsson, 1995).

Well ST-7, drilled in 1977 to 457.7 m, yielded 5 l/s of 69°C. ST-7 could give 10 l/s of 70°C water with 50-70 m drawdown (Björnsson, 1995; Björnsson and Steingrímsson, 1995b).

Assuming a production of 10 l/s of 70°C water one obtains a thermal power potential of P_{35} = 1.4 MW_{th} and P_5 = 2.7 MW_{th} for the Stórutjarnir geothermal field.

Reykjadalur Geothermal Field

Litlulaugar well field

Two production wells, LS-1 and LS-2, have been drilled, see Fig. 88.

Figure 88. *Overview of the production wells in the Litlulaugar well field of the Reykjadalur geothermal field (NEA's Geoportal).*

Well LS-1 was drilled in 1971. It found only 50°C at 25 m depth.

Well LS-2 which was drilled in 1974-1975 to 687 m depth, delivered free-flow 76 l/s of 68°C water and is in use (Sæmundsson, 1975).

Taking 76 l/s of 68°C water one obtains a thermal power potential of P_{35} = 10.3 MW_{th} and P_5 = 19.6 MW_{th} for the Reykjadalur geothermal field.

4.20.3 Aðaldalur/Kinn District Heating (OH)

The Aðaldalur/Kinn District Heating is operated by Orkuveita Húsavíkur (OH). It uses water from the Hveravellir geothermal field in the Norðurþing District, see Figs. 90 and 91 below.

4.20.4 Hafralækur District Heating (OH)

The Hafralækur District Heating is operated by Orkuveita Húsavíkur (OH) and uses water from the Hafralækur geothermal field, see Fig. 85.

Hafralækur Geothermal Field

Hafralækur well field

One exploration well and two production wells, HA-1 and HA-4, have been drilled, see Fig. 89.

Figure 89. *Overview of the production wells in the Hafralækur well field. (NEA's Geoportal).*

Well HA-1 at Hafralækur was drilled in 1964 to 101 m depth and yields 7 l/s of 74°C hot water (Georgsson and Sæmundsson, 1988).

Well HA-4, drilled in 1996 to 123 m did not have success in finding feeders.

Assuming 7 l/s of 74°C water in the Hafralækur geothermal field, corresponding to a thermal power potential of P_{35} = 1.1 MW_{th} and P_5 = 2.0 MW_{th}.

4.21 Norðurþing

There are two district heating companies in the Norðurþing District, Orkuveita Húsavíkur (OH) using the geothermal field at Hveravellir and the Öxarfjörður District Heating using the Ærlækur well field in the Öxarfjörður medium enthalpy geothermal field. A third geothermal field at Húsavík is not used for heating because of saline water and low productivity. Fig. 90 shows the locations of these fields.

Figure 90. *Location of the geothermal fields, Hveravellir, Húsavík and Öxarfjörður in the Norðurþing District (modified from NEA's Geoportal).*

Orkuveita Húsavíkur (OH) operates under Regulations 647/1995 and the Laws 1227/2012. It runs the heating services in the village of Húsavík in the Norðurþing District; the Aðaldalur/Kinn District heating and the Hafralækur District Heating in the Þingeyjarsveit District.

4.21.1 Húsavík District Heating (OH)

Hveravellir Geothermal Field

The Hveravellir geothermal field is a medium enthalpy resource described by Sveinbjörnsson (2016), see Fig. 90. Water is piped from the field to the village of Húsavík and also to the Aðaldalur/Kinn District Heating in Þingeyjarsveit District.

Hveravellir well field

Thirteen exploration wells and 5 production wells, HV-1, HV-2, HV-10, HV-16 and HV-18, have been drilled, see Fig. 91.

Figure 91. *Overview of the production wells in the Hveravellir well field (NEA's Geoportal).*

Three of the production wells, HV-1, HV-10 and HV-16, yield 95 l/s of 124°C water at 1.5 bar-g wellhead pressure. Hot springs issue 55-60 l/s of boiling water. It is estimated that the wells can give a sustainable yield of 190 l/s free-flowing from the wells without drastic reduction in the hot springs (Hjartarson et al., 2002; Ólafsson, 2011).

Adding the flow of springs, 55 l/s of 100°C water (P_{35} = 14.4 MW_{th} and P_5 = 21.0 MW_{th}) to the 190 l/s at 124°C from the wells (P_{35} = 66.8 MW_{th} and P_5 = 89.2 MW_{th}) corresponding to a thermal power potential of P_{35} = 81.2 MW_{th} and P_5 = 110.2 MW_{th} for the Hveravellir geothermal field.

Húsavík Geothermal Field

Húsavík well field

Eight exploration wells were drilled in the years 1943 to 1964 and one production well, HU-6 in 2001 (Tómasson et al., 1969). (Fig. 92).

Figure 92. *Location of the only shallow production well, HU-6, in the Húsavík well field (modified from NEA's Geoportal).*

The exploration well, HU-1, drilled in 1961 to 1,505 m depth found 110°C at 1,145 m depth. The well was productive but could not yield free flow. The water in the well was salty and the diameter of the well did not allow suitable downhole pumps. It is estimated, however, that the well may yield 8 l/s of about 100°C water with 70 m drawdown (Hafstað, 2014b). The well has not been used for space heating. In 2001 there was an unsuccessful attempt to drill well HU-6 to 156 m depth to provide warm water for fish hatcheries.

The thermal power potential above 35°C of the exploration well HU-1 corresponds to P_{35} =2.1 MW_{th} and P_5 = 3.1 MW_{th} for the Húsavík geothermal field, but is not taken into calculations for the whole database.

4.21.2 Öxarfjörður District Heating

The Öxarfjörður District Heating is operated under Regulations 1227/2012, 261/2003 and 647/1995. The District Heating serves the village Kópasker and rural area in Öxarfjarðarhreppur. The total pipeline is 20 km long. The service uses the well field Ærlækjarsel in the Öxarfjörður geothermal field where two production wells have been drilled, see Fig. 90.

Öxarfjörður Geothermal Field

Ærlækjarsel well field

Two exploration wells and 2 production wells, ÆR-3 and ÆR-4, have been drilled, see Fig. 93.

Figure 93. *Overview of the production wells in the Ærlækjarsel well field (NEA's Geoportal).*

Well ÆR-3 was drilled to 322 m depth and has highest measured temperature of 121°C at 203 m depth. It yields 47 l/s of 106°C free-flowing hot water (Ólafsson, 1995a).

Well ÆR-4 was drilled to 455 m depth and has highest measured temperature of 150°C at 340 m depth. It yields over 10 l/s of 132°C hot water with a wellhead pressure of 2.6 bar-g, but is idle (Ólafsson et al., 1992; Þórhallsson and Sigurðsson, 1994).

The thermal power potential above 35°C of the wells in the well field Ærlækjarsel is P_{35} = 17.2 MW_{th} and P_5 = 24.0 MW_{th}.

4.22 Fljótsdalshérað

4.22.1 Egilsstaðir/Fell District Heating (HEF)

The district heating operates under Regulation 564/2008 and serves the villages Egilsstaðir and Fell. The geothermal water comes from the Ekkjufellssel and Urriðavatn well fields in the Urriðavatn geothermal field.

Urriðavatn Geothermal Field

Urriðavatn well field

Eight exploration wells and 2 production wells, UV-4 and UV-6, have been drilled, see Fig. 94.

Figure 94. *Overview of the production wells in the well fields Urriðavatn and Ekkjufellssel of the Urriðavatn geothermal field (modified from NEA's Geoportal).*

Well UV-4, drilled in 1977 to 1,600 m depth gave 15 l/s of 64°C water from a shallow feeder. The well had a cold inflow, but was used as the main producer until 1983 when it was replaced by well UV-8 in the Ekkjufellssel well field (Axelsson, 2012).

Well UV-6, drilled in 1981 to 877 m depth. The well gave 8 l/s by air-pumping and 0.3 l/s free-flowing, but was replaced by newer wells drilled within the adjacent Ekkjufellssel well field (Benjamínsson, 1981; Steingrímsson et al., 1976).

Assuming 22 l/s of 75°C hot water, gives the thermal power potential of the Urriðavatn well field above 35°C of 3.6 MW_{th} and above 5°C of 6.3 MW_{th}.

Ekkjufellssel well field

Eleven exploration wells and six production wells, UV-3, UV-5, UV-8, UV-9, UV-10A and UV-10B, were drilled in the years 1975-2005 to 851 to 1,840 m depths, see Fig. 94.

Well UV-3, drilled in 1980 to 1,600 m depth gave only 0.2-0.3 l/s of 43°C hot water (Benjamínsson, 1981).

Well UV-5 was productive but UV-8 has been the main producer up to 2005 (Axelsson and Hauksdóttir, 2005).

Well UV-8 intersected a good feeder of 75°C at 940 m depth. It gave 20-24 l/s and is in use (Tryggvason and Harðardóttir, 2017).

Well UV-9 could produce 20 l/s with 200-220 m drawdown and interference with UV-8 (Guðmundsson et al., 2004).

Well UV-10A was drilled directionally in 2005 but gave insignificant flow and therefore it was decided to drill a breakout well, UV-10B (Axelsson, 2018).

UV-10B was drilled in 2005 and gave 60 l/s of 76°C and is now the main producer of the geothermal field (Axelsson, 2012).

Adding the potentials of UV-8 (22 l/s of 75°C; P_{35} = 3.6 MW_{th} and P_5 = 6.3 MW_{th}) and UV-10B (60 l/s of 76°C; P_{35} = 10.0 MW_{th} and P_5 = 17.4 MW_{th}) corresponding to a thermal power potential for the Urriðavatn geothermal field of P_{35} = 13.6 MW_{th} and P_5 = 23.7 MW_{th}.

4.23 Fjarðabyggð

4.23.1 Fjarðabyggð District Heating

The Fjarðabyggð District Heating operates under Regulation 908/2005 and serves the village Eskifjörður. The water comes from the well fields Eskifjörður and Eskifjarðarsel of the Eskifjörður geothermal field.

Eskifjörður Geothermal Field

Eskifjörður well field

Twenty-three exploration wells and 2 production wells, ES-2 and ES-2A have been drilled, see Fig. 95.

Figure 95. *Overview of the production wells in the well fields Eskifjörður (ES-2 and ES-2A) and Eskifjarðarsel (ES-1) (modified from NEA's Geoportal).*

Well ES-2 was drilled to 1,300 m without any success.

Well ES-2A was directionally drilled and intersected a feeder at 630 m depth. The well yields 35-40 l/s of 81°C geothermal water (Halldórsdóttir and Gautason, 2013).

The temperature gradient wells, FB-32 and FB-37 are used as injection wells (Oddsdóttir and Ketilsson, 2012).

A flow of 35 l/s at 81°C yields a thermal power potential of P_{35} = 6.5 MW_{th} and P_5 = 10.8 MW_{th} for the Eskifjörður well field.

The Eskifjarðarsel well field

One exploration well, FB-35, which is used as an injection well (Oddsdóttir and Ketilsson, 2012) and one production well, ES-1, have been drilled, see Fig. 92.

Well ES-1 was drilled to 1,200 m depth and yields 15 l/s of 81°C water (Halldórsdóttir and Gautason, 2013).

A flow of 15 l/s at 81°C yields a thermal power potential of P_{35} = 2.8 MW_{th} and P_5 = 4.6 MW_{th} for the Eskifjarðarsel well field.

Adding the potential of the two well fields one obtains a thermal power potential P_{35} = 9.3 MW_{th} and P_5 = 15.4 MW_{th} for the Eskifjörður geothermal field.

4.24 Hornafjörður

4.24.1 Höfn District Heating (RARIK)

The Höfn District Heating is owned by the energy company RARIK and operates under Regulation 122/1992. The hot water is currently heated by electricity at a central heating plant but a direct use geothermal water district heating system is being prepared. RARIK has carried out geothermal exploration at the well field Hoffell in Nesjar in the Hoffell geothermal field. Recent drilling has been successful where hot geothermal water has been found that will be used for the district heating of the village Höfn and the nearby rural area.

Hoffell Geothermal Field

Hoffell well field

Eighteen exploration wells and 4 production wells, HF-1 to HF-4, have been drilled, see Fig. 96.

Figure 96. *Overview of the production wells in the Hoffell well field (modified from NEA's Geoportal).*

Well HF-1 was drilled in 2012-2013 to 1,608 m depth and yields 28 l/s of 73°C water with 150 m drawdown (Kristinsson et al., 2016).

Well HF-2, was drilled in 2014, to 1,684 m depth. It found a feeder at 380 m depth which gave 5 l/s of 51°C hot water, but it was sealed off by casing down to 398 m. A few, small feeders were found below the casing and the well gave only 0.5 l/s by pump (Kristinsson, 2015).

Well HF-3 was drilled in 2016 to 1,084 m depth and yields 35 l/s of 75°C with 90 m drawdown (Kristinsson et al., 2016).

Well HF-4 was drilled in 2017 to 1,750 m depth and yields 35 l/s of 82-83°C water with less drawdown than HF-3 (Kristinsson et al., 2017).

Assuming a production of 35 l/s of 83°C water one obtains a thermal power potential $P_{35} = 6.8$ MW_{th} and $P_5 = 11.1$ MW_{th} for the Hoffell geothermal field.

4.25 Rangárþing ytra

4.25.1 Rangá District Heating (Veitur)

The Rangá District Heating is owned by Reykjavík Energy/Veitur. It operates under Regulations 632/1982 and the Laws 297/2006. It serves the villages Hella, Hvolsvöllur, Rauðalækur, Laugaland and neighboring area, see Fig. 97.

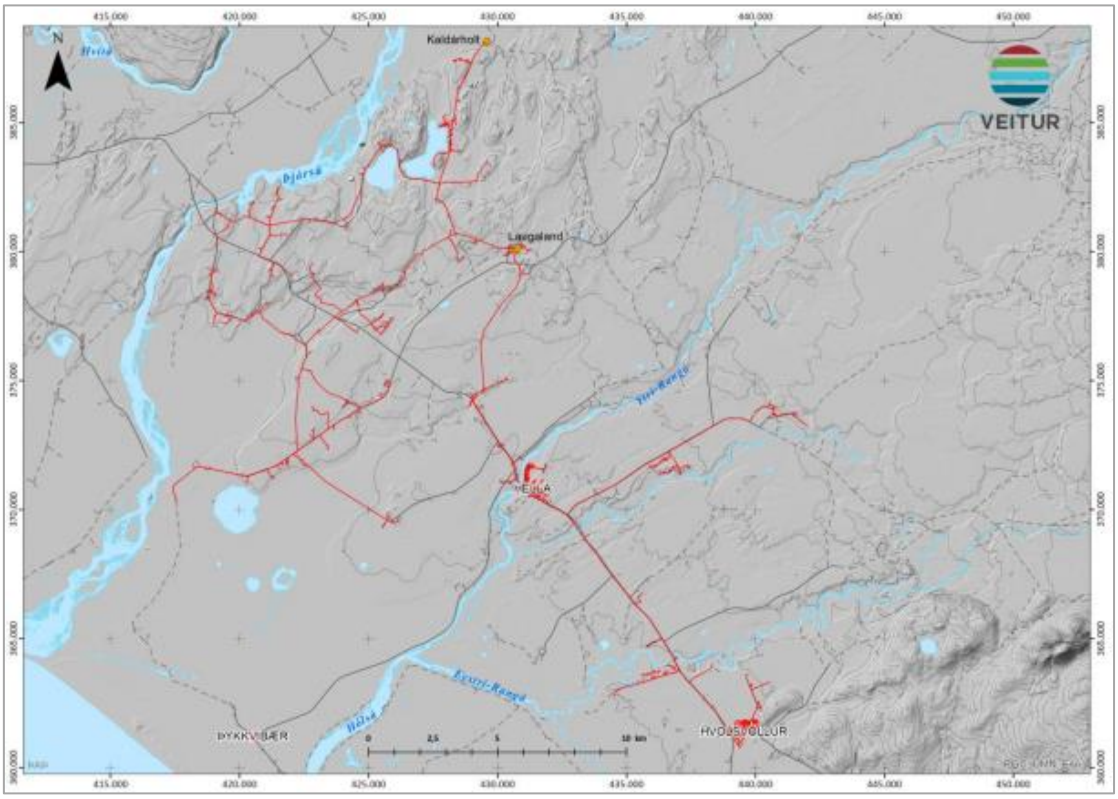

Figure 97. *Service area of Rangá District Heating (Gunnlaugsson, 2017).*

The hot water comes from the geothermal fields at Laugaland in Holt and Kaldárholt, see Fig. 98.

Figure 98. *Location of the geothermal fields, Laugaland in Holt and Kaldárholt in the Rangárþing ytra District (modified from NEA's Geoportal).*

Laugaland in Holt Geothermal Field

The Laugaland geothermal field is a medium enthalpy resource described by Sveinbjörnsson (2016), which includes the well fields Gata and Nefsholt.

Gata well field

One production well, GA-1, was drilled in 1984 to 1,027 m depth and is presently used as an injection well of geothermal water from Kaldárholt, see Fig. 99.

Figure 99. *Overview of the injection well, GA-1, in the Gata well field, the production wells and the exploration well, LL-3, in the Nefsholt well field (NEA's Geoportal).*

Nefsholt well field

Four exploration wells and 4 production wells LL-1, LL-2, LL-4 and LL-5, have been drilled, see Fig. 99. The production wells are LL-1, drilled to 91.0 m depth; LL-2, drilled in 1963 to 205.8 m depth; and LL-4, drilled in 1978 to 1,014 m depth, LL-5, drilled in 2017 to 1,885 m depth.

Well LL-1 gave 3 l/s of 42°C hot water and was used for the swimming pool and the meeting (Georgsson et al., 1978).

Well LL-2 gave 4 l/s of about 40°C hot water and was used for the school at Laugaland (Georgsson et al., 1978).

The exploration well LL-3, drilled in 1977 to 1,308 m depth gave 1 l/s of free-flowing 33°C hot water (Jónsson, 1987) and gave about 10 l/s with little drawdown. Feeder at 20 m depth cools the discharge. If the well would be cased down to 20 to 100 m it could give at least a few l/s of 50°C hot water (Björnsson, 1998).

Well LL-4 is presently used for the district heating. In the year 2016 it delivered an average of 11.4 l/s of 96.5°C water (Gunnlaugsson, 2017).

Well LL-6 was drilled in the end of the year 2017 and does not appear to be successful (Hafstað, 2018).

Assuming that the production of LL-4 is 11.4 l/s of 96.5°C water, a thermal power potential of P_{35} = 2.8 MW_{th} and P_5 = 4.2 MW_{th} is obtained for the Nefsholt well field.

Kaldárholt Geothermal Field

Kaldárholt well field

Thirty-five exploration wells and 3 production wells KH-36, KH-37 and KH-38, have been drilled, see Fig. 100.

Figure 100. *Overview of the production wells in the Kaldárholt well field (NEA's Geoportal).*

Well KH-1 was drilled in 1968 to 96 m depth but was not successful (Kristmannsdóttir et al., 2002). Well KH-2 was drilled in 1974. It was 37.5 m deep and found 43°C water (Sæmundsson, 1985b).

A new phase of exploration was attempted in 1989 – 1990 drilling wells KH-3 to KH-10, with a depth ranging from 77 to 130 m (Kristmannsdóttir et al., 2002). A third phase of exploration was undertaken in 1998, drilling wells KH-11 to KH-33, to a depth of 120 m or less (Kristmannsdóttir et al., 2002). After drilling KH-33, exploration wells KH-34 and KH-35 were drilled in 1998 to 456 m and 540 m depths respectively. These two wells yielded some 30 l/s of 68-69°C water.

The drilling was continued with production well KH-36 in 1999 to 445 m depth and well KH-37 in 2005 to 522 m depth. Well KH-36 yields 20 l/s of 66°C water and well KH-37 yields 43 l/s of 66°C water.

Well KH-38 was drilled in 2007 to 1,910 m depth but it is not productive due to drilling problems (Kristmannsdóttir et al., 1998 and 2002; Ingimarsdóttir, 2009; Gunnlaugsson, 2017).

The wells KH-36 and KH-37 in the Kaldárholt field have a thermal power potential of P_{35} = 8.0 MW_{th} and P_5 = 15.8 MW_{th}.

4.26 Hrunamannahreppur

4.26.1 Flúðir District Heating

The Flúðir District Heating operates under Regulation 729/2003. It serves the village Flúðir, farms in Hrunamannahreppur and three farms in Skeiða- and Gnúpverja-hreppur. The water comes from the geothermal field at Flúðir.

Flúðir Geothermal Field

The Flúðir field has a reservoir temperature of up to 108°C and is therefore classified as a medium enthalpy resource (Sveinbjörnsson, 2016). Fig. 101 shows the location of the well fields Grafarbakki and Hellisholt.

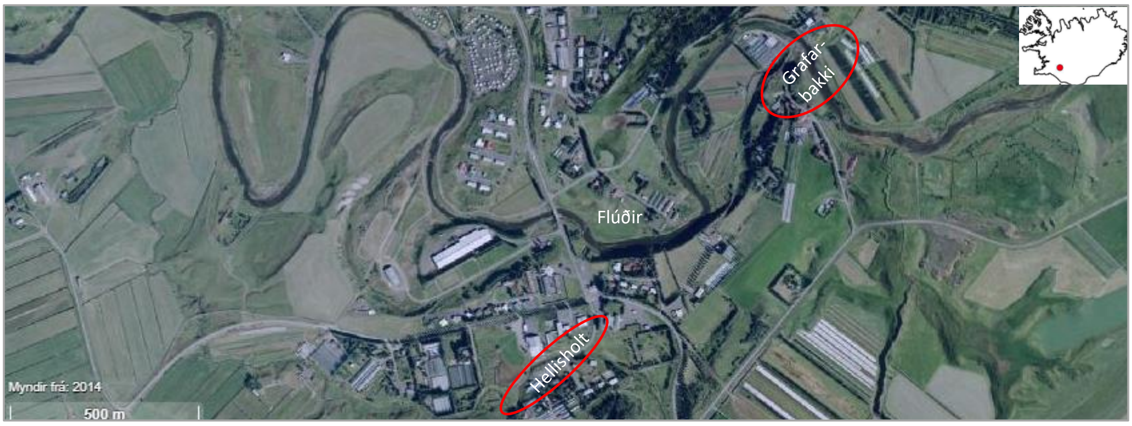

Figure 101. *Location of the well fields Grafarbakki and Hellisholt of the Flúðir geothermal field (modified from NEA's Geoportal).*

The first utilisation can be traced back to 1929. Drilling began in 1945 and up to year 2000 14 wells, ranging from 22 to 365 m in depth, had been drilled (Ólafsson et al., 2000).

Grafarbakki well field

Two production wells have been drilled at Grafarbakki, GB-1 in 1945 to 58 m depth, and GB-2 in 1997 to 187 m depth, see Fig. 102.

Figure 102. *Overview of the production wells in the Grafarbakki well field. (NEA's Geoportal).*

Well GB-1 gave 1.3 l/s of 86°C hot water but it had dried up in 1996 (Björnsson, 1966, Chaturvedi, 1969; Sigurðsson, 1996; Ólafsson, 1999).

Well GB-2 yields about 110 l/s of 108°C water (Björnsson, 1999).

That corresponds to a thermal power potential of P_{35} = 32.1 MW_{th} and P_5 = 45.2 MW_{th}.

Hellisholt well field

Nine, rather shallow, production wells, HH-1 and FL-1 to FL-8, have been drilled, see Fig. 103.

Figure 103. *Overview of the production wells in the Hellisholt well field (NEA's Geoportal).*

Well HH-1 was drilled in 1949 to 28 m depth. It was productive but has been replaced.

Well FL-1 gave 5 l/s of 96°C and is still in use for the swimming pool (Flúðir, Webpage a).

Well FL-2 gave 6 l/s and FL-3 gave 2 l/s, but neither of them is in use today (Flúðir, Webpage b).

Well FL-7 gave 1 l/s of free-flowing 101°C hot water and is idle (Sæmundsson, 1994a).

The production wells, delivering 100-115 l/s of 104°C water, now in use are: FL-4, drilled in 1966 to 205.5 m; FL-5, drilled in 1973 to 321 m; FL-6, drilled in 1985 to 365 m and FL-8, drilled in 1994 to 275.7 m (Flúðir, Webpage a).

The thermal power potential for the Hellisholt well field with 107 l/s at 104°C is P_{35} = 29.6 MW_{th} and P_5 = 42.4 MW_{th}.

The thermal power potential of the Hellisholt and Grafarbakki corresponds to a thermal power potential of P_{35} = 61.7 MW_{th} and P_5 = 87.6 MW_{th} for the Flúðir geothermal field.

4.27 Skeiða- and Gnúpverjahreppur

There are two geothermal district heating services in the Skeiða- and Gnúpverjahreppur District operating under licence issued by Orkustofnun. They are the Gnúpverjar District Heating, using the Þjórsárholt geothermal field and the Brautarholt District Heating, using the Brautarholt geothermal field. Fig. 104 shows the location of the fields.

Figure 104. *Location of the geothermal fields, Þjórsárholt and Brautarholt in the Skeiða- and Gnúpverjahreppur District (modified from NEA's Geoportal).*

4.27.1 Gnúpverjar District Heating

Þjórsárholt Geothermal Field

Þjórsárholt well field

Three exploration wells and one production well, ÞH-4, have been drilled, see Fig. 105.

Figure 105. *Overview of the production well in the Þjórsárholt well field (NEA's Geoportal).*

Well ÞH-4 was drilled in 1980 to 126.9 m depth and yielded with a pump 20-30 l/s of 65°C water (Þórðarson, 1998).

Assuming 25 l/s of 65°C water, a thermal power potential of P_{35} = 3.1 MW_{th} and P_5 = 6.2 MW_{th} is obtained for the Þjórsárholt geothermal field.

4.27.2 Brautarholt District Heating

The Brautarholt District Heating operates under the Regulation 76/1979. It is one of the first district heating services in Iceland, initiated in 1950.

Brautarholt Geothermal Field

Brautarholt well field

Two production wells, BH-1 and BH-2, have been drilled, see Fig. 106.

Figure 106. *Overview of the production wells in the Brautarholt well field (NEA's Geoportal).*

Well BH-1 drilled in 1941 was only 40 m deep. It gave 1 l/s of 57°C water but the temperature soon decreased to 43°C (Gunnarsdóttir, 1983).

Well BH-2 drilled in 1950 to 120 m depth and yielded originally 15 l/s of 73°C water but flow and temperature decreased with time. The well is currently in use and delivers about 3 l/s of 71°C water (Stefánsson and Sigurmundsson, 1975; Sæmundsson, 1987a).

Assuming 3 l/s of 71°C at Brautarholt, a thermal power potential of P_{35} = 0.5 MW_{th} and P_5 = 0.8 MW_{th} is obtained for the Brautarholt geothermal field.

4.28 Bláskógabyggð

There are two district heating services in the Bláskógar District, Bláskógar District Heating and Hlíðaveita District Heating. The services use the geothermal fields at Reykholt, Efri-Reykir and Laugarvatn, see Fig. 107.

Figure 107. *Location of the geothermal fields Reykholt, Efri-Reykir and Laugarvatn (modified from NEA's Geoportal).*

4.28.1 Bláskógar District Heating

Bláskógar District Heating operates under Regulation 505/2008 with the district heating services of Laugarvatn, Reykholt and Laugarás.

4.28.2 Laugarvatn District Heating

The Laugarvatn District Heating uses water from the Laugarvatn hot spring.

Laugarvatn Geothermal Field

Laugarvatn well field

Only one exploration well was drilled in 1939 to 32 m depth. Fig. 108 shows an overview of the hot springs at Laugarvatn and the farm Útey.

Figure 108. *Overview of the hot springs (red dots) at the village Laugarvatn and the farm Útey (modified from NEA's Geoportal).*

The spring Laugarvatn delivers 30 l/s of boiling water. It is estimated from silica geothermometers that the field is a medium enthalpy resource with reservoir temperatures up to 200°C. Hot springs in the land of Útey, within the Laugarvatn geothermal field, deliver 17 l/s of 76-98°C water (Georgsson et al., 1988).

Assuming a flow of 40 l/s at 100°C water, a thermal power potential of P_{35} = 10.4 MW_{th} and P_5 = 15.3 MW_{th} is obtained for the Laugarvatn geothermal field.

4.28.3 Reykholt District Heating

The Reykholt District Heating uses the hot spring Reykholtshver in Biskupstungur and two production wells in the well field Stórafljót of the Reykholt medium enthalpy geothermal field, described by Sveinbjörnsson (2016).

Reykholt Geothermal Field

Stórafljót well field

Two exploration wells and 2 production wells, RH-1 and RH-4, have been drilled, see Fig. 109.

Figure 109. *Overview of the production wells and the spring Reykholt in the Stórafljót well field (modified from NEA's Geoportal).*

The hot spring delivers 14 l/s of 98°C and two production wells, RH-1, drilled in 1970 to 756 m depth; and RH-4, drilled in 1991 to 1,146 m depth, yield 13 and 15 l/s of 128°C of water respectively (Ólafsson, 2010b; Þorbjörnsson and Guðmundsson, 2010).

The combined flow the springs (14 l/s of 98°C; P_{35} = 3.5 MW_{th} and P_5 = 5.2 MW_{th}) and the wells (13 and 15 l/s of 128°C; P_{35} = 10.3 MW_{th} and P_5 = 13.5 MW_{th}.), adds up to a total thermal power potential of P_{35} = 13.8 MW_{th} and P_5 = 18.7 MW_{th} for the Stórafljót well field.

4.28.4 Laugarás District Heating

The Laugarás District Heating operates under Regulation 207/1985. The service uses water from hot springs in the Laugarás field. It has been suggested that the Laugarás geothermal field is connected to the Reykholt geothermal field by a major NNE tectonic fault (Khodayar et al. 2010).

Laugarás Geothermal Field

No wells have been drilled but there are the large hot springs, Bær, Þvottur and Hildur, see Fig. 110.

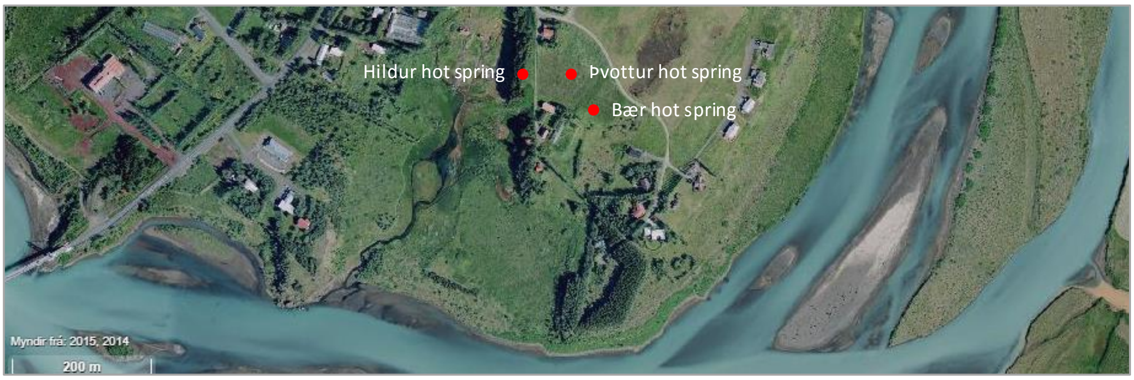

Figure 110. *Overview of the hot springs Bær, Þvottur and Hildur in the Laugarás geothermal field (modified from NEA's Geoportal).*

The hot spring Hildur delivers 55 l/s of 96°C water and Þvottur 14.5 l/s of 90°C. Total flow from hot springs is 90 l/s of 90-99°C water (Pálmason et al., 1985).

Assuming a total flow of 90 l/s at 95°C water, a thermal power potential of P_{35} = 21.8 MW_{th} and P_5 = 32.6 MW_{th} is obtained for the hot springs at Laugarás.

4.28.5 Hlíðaveita District Heating (Veitur)

Reykjavík Energy/Veitur operates Hlíðaveita District Heating under Regulation 297/2006. It distributes hot water from one well, ER-23, in the medium enthalpy Efri-Reykir geothermal field to several quarters of summerhouses and farms in the district, see Figs. 107 and 111.

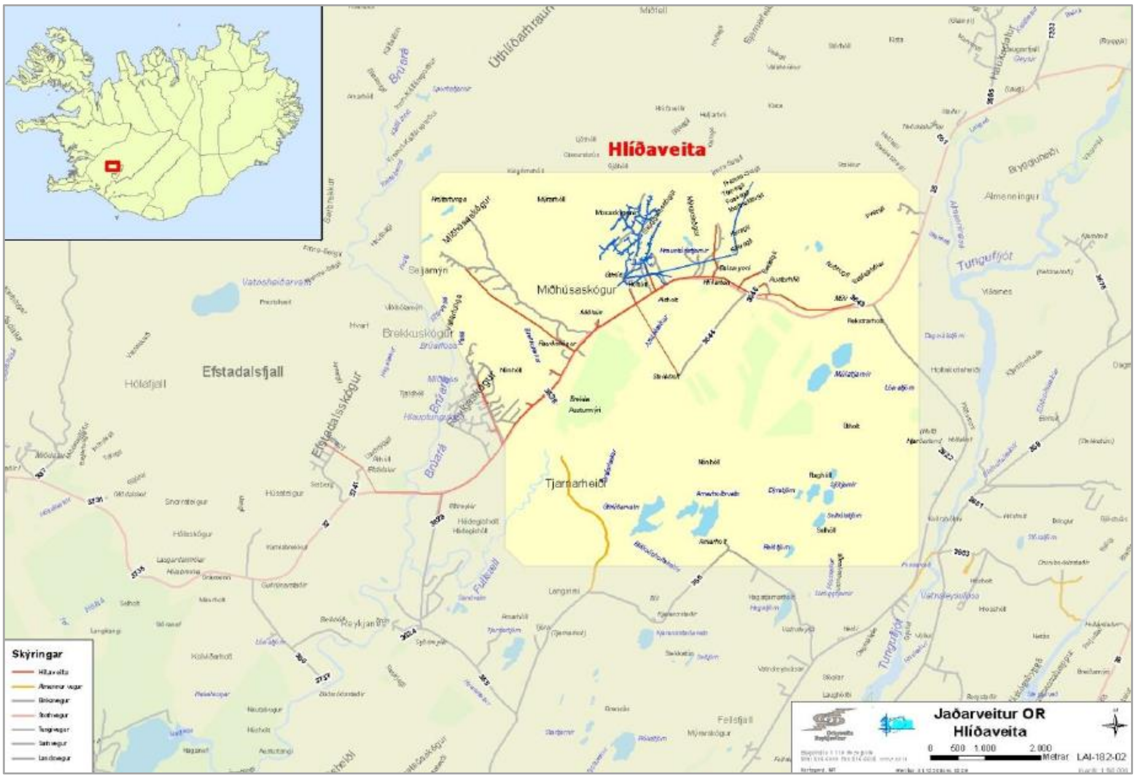

Figure 111. *Service area of the Hlíðaveita District Heating (Olsen, 2016f).*

Efri-Reykir Geothermal Field

Efri-Reykir well field

Twenty exploration wells and 3 production wells, ER-21, ER-22 and ER-23, have been drilled, see Fig. 112.

Figure 112. *Overview of the production wells in the Efri-Reykir well field (NEA's Geoportal).*

Well ER-21 was drilled in 1986 to 152 m depth gave 2 l/s of 115 °C hot water (Sæmundsson, 1987b).

Well ER-22 was not productive and cold.

Well ER-23 was drilled in 1988 to a depth of 722 m, yields 50 kg/s of 145°C at 2.4 bar and 64 kg/s at 1 bar-g (Björnsson and Steingrímsson, 1996; Olsen, 2014a).

The thermal power potential of the Efri-Reykir geothermal field for a flow of 64 kg/s at an enthalpy that corresponds to an inflow of 145°C is P_{35} = 29.7 MW_{th} and P_5 = 37.7 MW_{th}.

4.29 Grímsnes- and Grafningshreppur

There are three district heating services in the Grímsnes- and Grafningshreppur District. They are the Grímsnes/Grafningur District Heating, the Vaðnes District Heating and the Grímsnes District Heating. The first one produces water from the geothermal field Kringla and buys water from the Vaðnes District Heating, which operates the Vaðnes geothermal field. The Grímsnes District Heating uses water from the Öndverðarnes geothermal field. Fig. 113 shows the location of the geothermal fields.

Figure 113. *Location of the geothermal fields, Kringla, Vaðnes and Öndverðarnes, in the Grímsnes- and Grafningshreppur District (modified from NEA's Geoportal).*

4.29.1 Grímsnes/Grafningur District Heating

The Grímsnes/Grafningur District Heating operates under Regulation 252/2001.

Kringla Geothermal Field

Kringla well field

Two production wells have been drilled, KR-1 in 1983 to 504 m depth and KR-2 in 2001 to 616 m depth, see Fig. 114.

Figure 114. *Overview of the production wells in the Kringla well field (NEA's Geoportal).*

Well KR-1 gave over 5 l/s of 62-80°C hot water. The main feeder is at 427 m depth and yields water at about 80°C. Cold inflow from feeders at 60 and 140 m reduces the temperature to 62.5°C. The well is not in use. (Ólafsson, 1985; Sæmundsson, 1995).

Well KR-2 yields 7.5 l/s of 85°C water which is distributed to houses in the neighbourhood of Kringla (Ólafsson, 2003). The water from Vaðnes is used in the community at the village Borg and summerhouses nearby.

The thermal power potential of the Kringla geothermal field is P_{35} = 1.5 MW_{th} and P_5 = 2.4 MW_{th}.

4.29.2 Vaðnes District Heating

Vaðnes Geothermal Field

Vaðnes well field

Seven exploration wells and two production wells, VN-5 and VN-13B, have been drilled, see Fig. 115.

Figure 115. *Overview of the production wells in the Vaðnes well field (NEA's Geoportal).*

Well VN-5 drilled in 1985 to 56.2 m depth delivered 72°C hot water. The main feeders are at 30-37 m depth. The well is no longer in use due to cold inflow (Jónsson et al., 1988a; Ólafsson, 1986).

Well VN-13B drilled in 1988 to 404 m depth yields 36 l/s of 78°C water and is in use (Jónsson et al., 1988a). The water is distributed to summerhouses at Vaðnes and Hraunkot and also sold to the Grímsnes/ Grafningur District Heating.

Assuming the flow of VN-13B (36 l/s at 78°C) a thermal power potential of P_{35} = 6.3 MW_{th} and P_5 = 10.7 MW_{th} is obtained for the Vaðnes geothermal field.

4.29.3 Grímsnes District Heating (Veitur)

The Grímsnes District Heating is operated by Reykjavík Energy/Veitur under Regulation 297/2006. The water comes from the Öndverðarnes geothermal field, see Fig 113. It serves Öndverðarnes, Norðurkot, Miðengi, Ásgarður, part of the Búrfell Region, Ljósafoss, Írafoss and Úlfljótsvatn, see Fig. 116.

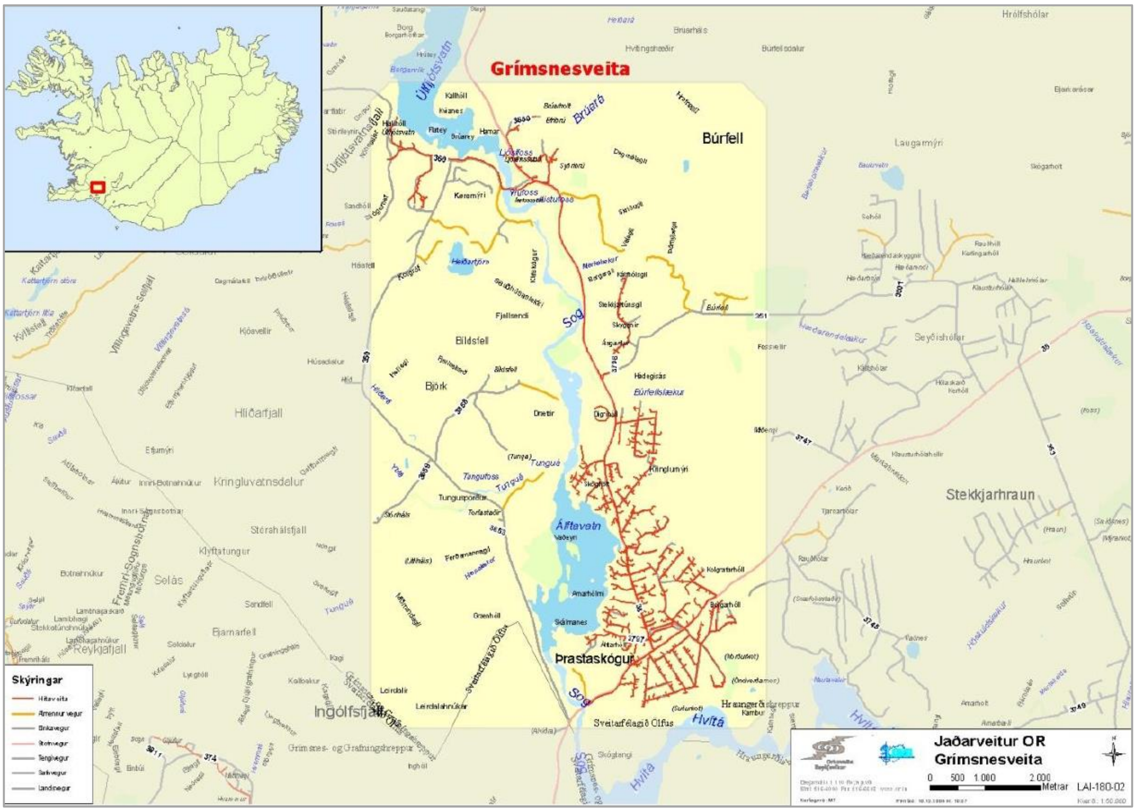

Figure 116. *Service area of the Grímsnes District Heating (Olsen, 2014b).*

Öndverðarnes Geothermal Field

Öndverðarnes well field

Twenty-two exploration wells and 6 production wells, ÖN-1, ÖN-12, ÖN-18, ÖN-28, ÖN-29 and ÖN-30, have been drilled, see Fig. 117.

Figure 117. *Overview of the production wells in the Öndverðarnes well field (NEA's Geoportal).*

Well ÖN-1 was drilled in 1991 to 110 m depth. It gave 68.3°C water and was the only well used until August 2003 when well ÖN-29, drilled in 2002 to 342 m depth, yielded about 35 l/s of 81°C water and came into use (Axelsson et al., 2007).

Well ÖN-12 gave 30 l/s of 64°C hot water but has a cold inflow and is used for the swimming pool (Sæmundsson, 1995).

Wells ÖN-18 (74°C) and ÖN-28 were productive but the yield was limited due to inflow of colder water and the wells are not in use.

Well ÖN-29 was drilled in 2002 to 342 m depth. Highest measured temperature is 122°C. The well delivers about 35 l/s of 81°C hot water (Axelsson et al., 2007; Olsen, 2016h).

Well ÖN-30 was drilled in 2007 to 960 m depth and discovered a medium enthalpy resource with feeders which yield 30 l/s of 111°C water (Axelsson et al., 2007).

Assuming the flow of well ÖN-30, a thermal power potential of P_{35} = 9.1 MW_{th} and P_5 = 12.7 MW_{th} is obtained for the Öndverðarnes geothermal field.

4.30 Flóahreppur

4.30.1 Selfoss District Heating (Selfossveitur)

The Selfoss District Heating in the Flói District operates under Regulation 504/1990. It also includes the former Eyrar District Heating (Regulation 559/1981) and serves the villages Selfoss, Eyrarbakki and Stokkseyri. The service was commissioned in the summer 1948 and used water from wells drilled in the well field Laugardælir (Thorsteinsson, 1966). The Selfoss District Heating uses the well fields Ósabotnar, Þorleifskot and Laugardælir and Jórutún in the Selfoss geothermal field, see Fig. 118.

Figure 118. *Location of the well fields of the Selfoss geothermal field, Ósabotnar, Þorleifskot and Laugardælir, in the Flóahreppur District and Jórutún well field in the Árborg District (modified from NEA's Geoportal).*

Selfoss Geothermal Field

Ósabotnar well field

Three production wells, ÓS-1, ÓS-2 and ÓS-3, have been drilled, see Fig. 119.

Figure 119. *Overview of the production wells in the Ósabotnar well field of the Selfoss geothermal field (NEA's Geoportal).*

Well ÓS-1 was drilled to 804 m depth and yields 10-40 l/s of 80°C water (Axelsson and Ólafsson, 2006).

Well ÓS-2 was drilled to 1,723 m depth, attains a temperature of 104°C at 1,720 m depth, and yields 50-60 l/s of 92°C water with 80-110 m drawdown (Snæbjörnsdóttir, 2009).

Well ÓS-3 is drilled to 1,500 m depth and yields 100 l/s of 83°C with 65 m drawdown (Hafstað and Gunnarsdóttir, 2014). An assessment of the performance of the area after four years of production history indicated that the well field in Ósabotnar could give up to 100 l/s average production (Axelsson and Ólafsson, 2006). All the wells are in use (Harðardóttir, 2016).

Assuming a flow of 100 l/s of 92°C water indicates a thermal power potential of P_{35} = 23.0 MW_{th} and P_5 = 35.1 MW_{th} for the Ósabotnar well field.

Þorleifskot and Laugardælir well fields

The well fields at Þorleifskot and Laugardælir are closely connected (Sæmundsson, 1998). The geothermal resource is divided into an upper reservoir between 100 to 1,000 m depth with an original temperature of 80-90°C and a lower reservoir with water at 125-140°C. The main up-flow from a deeper reservoir appears to come through the Þorleifskot-fracture. Permeability is high in the eastern half of the upper reservoir but low in the lower reservoir.

Þorleifskot well field

Twenty-seven exploration wells (thereof 3 pressure gradient wells) and 11 production wells, ÞK-7 to ÞK-11 and ÞK-13 to ÞK-18 have been drilled in the Þorleifskot well field, see Fig. 120.

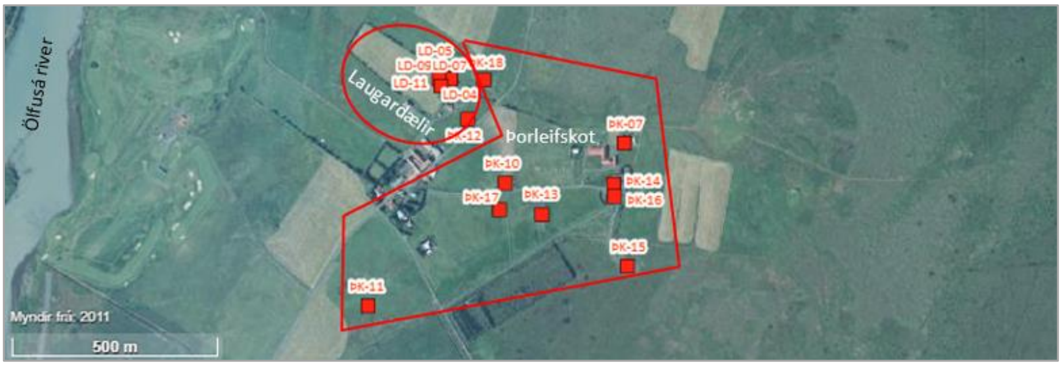

Figure 120. *Overview of the production wells in the well fields Þorleifskot and Laugardælir of the Selfoss geothermal field (NEA's Geoportal).*

Well ÞK-7, drilled in 1963 to 430 m depth, was productive and in use and gave 84°C hot water by pump (Tómasson, 1965 and 1966).

Well ÞK-8, drilled in 1977 to 781 m depth, was productive and in use from 1966 to 1985 and gave 40 l/s of 86°C hot water, by pump, but got a cold inflow and is not in use today (Halldórsson, 1980b; Tómasson, 1988).

Well ÞK-9, drilled in 1977 to 1,335 m depth, found temperature of 137°C at 1,320 m, was productive and in use for several years, giving 45 l/s of 70°C hot water by pump, but got a cold inflow and is not in use today (Halldórsson, 1980b; Tómasson, 1988).

Well ÞK-10, drilled in 1979 to 1,859 m depth, delivers 60 l/s. The best feeders are above 650 m. The discharge temperature has fallen from 88°C to 46°C in well in 15 years of operation (Harðardóttir, 2014; Harðardóttir and Ólafsson, 2013). The drawdown is 120-145 m in winters and about 40 m in summers (Sæmundsson, 1998).

Well ÞK-11 was drilled in 1980 to 2,007 m depth. It found 147°C at 1,651 m but the yield was disappointing (Tómasson et al., 1984; Sæmundsson, 1998; Haraldsdóttir 2013).

Well ÞK-13 delivers 41 l/s. The best feeders are, like in well ÞK-10, above 650 m. The discharge temperature has fallen from 78°C to 70°C in well in 15 years of operation (Harðardóttir, 2014; Harðardóttir and Ólafsson, 2013). The drawdown is 120-145 m in winters and about 40 m in summers (Sæmundsson, 1998).

Well ÞK-14, drilled in 1989 to 1,430 m depth, yielded about 38 l/s of nearly 70°C water from feeders above 850 m depth but the water has cooled down to 59°C (Ólafsson and Axelsson, 2007).

Well ÞK-15, drilled in 1999 to 2,381 m depth and is cased down to 645 m. It yields 14 l/s of 83°C water with about 100 m draw-down (Harðardóttir, 2014; Harðardóttir and Ólafsson, 2013). The main feeders are at 700 and 850 m depth (Sæmundsson, 1998).

Well ÞK-16 was drilled in 1999 to a depth of 2,012 m. It found a temperature of 142°C at 1,598 m but the yield was disappointing (Haraldsdóttir, 2013).

Well ÞK-17 was drilled in 2012 to a depth of 1,110 m. The casing was 550 m deep to prevent inflow of colder feeders. Maximum temperature of 106°C was found at 1,017 m depth. The well yields about 8.5 l/s of 95°C water with a drawdown of 150 m (Hafstað, and Gunnarsdóttir, 2013).

The last well, ÞK-18 which was drilled in 2017 to 1,564 m depth and cased down to 1,489 m to prevent cold influx. It yields 10-15 l/s of 120°C water (Hafstað et al., 2018, Morgunblaðið, 2017; Árborg, Webpage).

Wells ÞK-10, ÞK-13, ÞK-14, ÞK-15, ÞK-17 and ÞK-18 are in use today (Harðardóttir, 2016).

Assuming a flow of 100 l/s of 120°C water, a thermal power potential of P_{35} = 33.7 MW_{th} and P_5 = 45.5 MW_{th} is obtained for the Þorleifskot well field.

Laugardælir well field

Fourteen exploration wells and two production wells, LD-11 and ÞK-12, have been drilled, see Fig. 120. The wells LD-4 to LD-7 and LD-9, drilled in 1946-1948, were shallow, 20 to 97 m deep and are here regarded as exploration wells.

Well LD-11 is cased down to 360 m. It has a feeder at 1,113 m depth with 95°C water and a shallow feeder at 380 m with only 40°C. The discharge mixture is only 60°C hot and the mixing of water of different origin leads to problems of scaling in pumps.

Well ÞK-12 was drilled to 1,936 m depth and reached a temperature of 144°C at 1,810 m depth. It produces 5 l/s of 116°C hot water from feeders at 1,400-1,500 m depth (Sæmundsson, 1998; Harðardóttir and Ólafsson, 2013)

Assuming a flow of 5 l/s of 116°C water, a thermal power potential of P_{35} = 1.6 MW_{th} and P_5 = 2.2 MW_{th} is obtained for the Laugardælir well field.

The total thermal power potential of the Selfoss geothermal field for Ósabotnar, Þorleifskot and Laugardælir is P_{35} = 58.3 MW_{th} and P_5 = 82.8 MW_{th}.

4.31 Árborg

4.31.1 Selfoss District Heating (Selfossveitur)

Jórutún well field

The Jórutún well field is on the Western bank of the river Ölfusá near the bridge in the town Selfoss. Two exploration wells and one production well, SE-34, have been drilled, see Fig. 121.

Figure 121. *Overview of the production well SE-34 in the Jórutún well field of the Selfoss geothermal field (NEA's Geoportal).*

Well SE-34 was drilled in 2017 to 864 m depth and cased down to 300 m to prevent influx of colder water. It delivers 13.5 l/s of 70°C water with 50 m drawdown (Ingimarsson et al., 2017a). The well will be used by Selfoss District Heating.

Assuming a flow of 13.5 l/s of 70°C water indicates a thermal power potential of P_{35} = 1.9 MW_{th} and P_5 = 3.6 MW_{th} for the well SE-34 at Jórutún.

4.32 Hveragerði

4.32.1 Hveragerði District Heating (Veitur)

The Hveragerði District Heating has a Regulation 320/2000 but it is now operated by Reykjavík Energy/Veitur under Regulation 297/2006. It uses the well fields Hverasvæðið and Hveragerði village of the medium enthalpy Hveragerði geothermal field (Sveinbjörnsson, 2016). The Hveragerði District Heating also uses water from the wells HV-2 and HV-4 in the outflow zone of the high enthalpy geothermal field Ölfusdalur in the Ölfus District (Sveinbjörnsson, 2016). Fig. 122 shows the location of these geothermal fields.

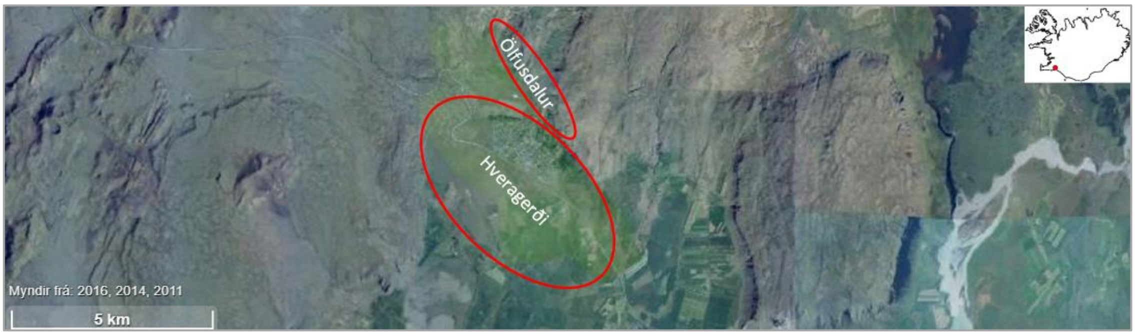

Figure 122. *Location of the Hveragerði geothermal field in the Hveragerði District and the Ölfusdalur geothermal field in the Ölfus District (modified from NEA's Geoportal).*

Hveragerði Geothermal Field

Hverasvæðið well field

The main well field of the Hveragerði geothermal field is the Hverasvæðið in the middle of the village Hveragerði. Eleven production wells have been drilled and they were all productive. Two wells are now in use, HS-8, drilled in 1989 to 254 m; and HS-9, drilled in 1999 to 373 m, see Fig. 123. Well HS-8 yields 32.5 kg/s at 155°C and well HS-9 35 kg/s at 158°C.

Figure 123. *Overview of the production wells in the well fields Hverasvæðið (HS-8 and HS-9) and Hveragerði village (HS-3, 5, 6, and 7). The figure also shows the location of the wells HV-2 and HV-4 in the well field Reykjakot of the Ölfusdalur geothermal field (Oddsdóttir and Ketilsson, 2012).*

Together these wells in Hverasvæðið well field have a thermal power potential of P_{35} = 34.7 MW_{th} and P_5 = 43.2 MW_{th}.

Hveragerði village well field.

Twelve exploration wells and 28 production wells have been drilled in the Hveragerði village well field. All the production wells, except one, were productive but most of these wells, drilled in 1941 to 1958, were shallower than 100 m and did not last long. The wells that are in use are HS-3, drilled in 1963 to 245 m depth and used as an injection well (Sæmundsson and Þórhallsson, 2007); HS-5, drilled in 1968 to 350 m, used for production; HS-6, drilled in 1979 to 1,003 m, idle (Jónasson 2008) and HS-7, drilled in 1999 to 602 m, used for injection.

Well HS-3 yields 8.5 kg/s at 149°C water and well HS-5 yields 4 kg/s at 143°C. Together these wells have a thermal power potential of P_{35} = 5.9 MW_{th} and P_5 = 7.5 MW_{th}.

Wells in the fields of Hverasvæðið and Hveragerði village have found temperatures of 160-180°C and are prone to calcite scaling problems and have to be cleaned regularly. The pressure in the system has declined in recent years of unknown reasons. (Björnsson et al., 2000; Þórhallsson, 2008; Þórhallsson et al., 1999). The heating service operates in two divisions. Half of the houses in the village receive freshwater heated up to about 80°C with steam from the wells. The other half is heated directly with steam (Margeirsson, 2006).

4.33 Ölfus

There are three district heating services in the Ölfus District. These include the Austur District Heating, using water from the Gljúfurárholt well field in the Hveragerði geothermal field and the district heating services, Ölfus and Þorlákshöfn, using water from the Bakki geothermal field, see Figs. 122 and 124.

Figure 124. *Location of the geothermal fields Ölfusdalur and Bakki in the Ölfus District (modified from NEA's Geoportal).*

4.33.1 Austur District Heating (Veitur)

The Austur District Heating is operated by Reykjavík Energy/Veitur under Regulation 297/2006. The service area reaches to farms from the mountain Ingólfsfjall south to the farm Ferjunes, see Fig. 125.

Figure 125. *Service area of the Austur District Heating (Olsen, 2016a).*

Hveragerði Geothermal Field, Gljúfurárholt

Gljúfurárholt well field

Six exploration wells and 3 production wells, GH-2, GH-3 and GH-4, have been drilled, see Fig. 126.

Figure 126. *Overview of the production wells in the Gljúfurárholt well field of the Hveragerði geothermal field (NEA's Geoportal).*

Well GH-2, drilled in 1985 to 170 m found 60°C (Jónsson et al. 1985).

Well GH-3, drilled in 1987 to 328 m, gave 15 l/s of 107°C, prior to the drilling of GH-04 (Hafstað and Danielsen, 2006).

Well GH-4, drilled in 2006 to 1,014 m, found 120°C yields 40 l/s of 115°C water (Olsen, 2014c).

Water from the hotter wells is mixed with water from GH-2 to obtain 80°C water for distribution

Assuming 40 l/s of 115°C water, a thermal power potential of P_{35} = 12.7 MW_{th} and P_5 = 17.5 MW_{th} is obtained for the Gljúfurárholt well field.

4.33.2 Ölfus District Heating (Veitur)

The Ölfus District Heating is owned by Reykjavík Energy/Veitur and operates under Regulation 297/2006. It uses wells in the well fields Þóroddsstaðir and Eystribakki in the medium enthalpy Bakki geothermal field in Ölfus, see Fig. 124. Fig. 127 shows the service area.

Figure 127. *Service area of the Ölfus District Heating (Olsen, 2016g)***.**

Bakki Geothermal Field

The Bakki field includes the four well fields, Þóroddsstaðir, Eystribakki, Bakki and Hjallakrókur.

Þóroddsstaðir well field

One exploration well and one production well, ÞS-1, have been drilled, see Fig. 128.

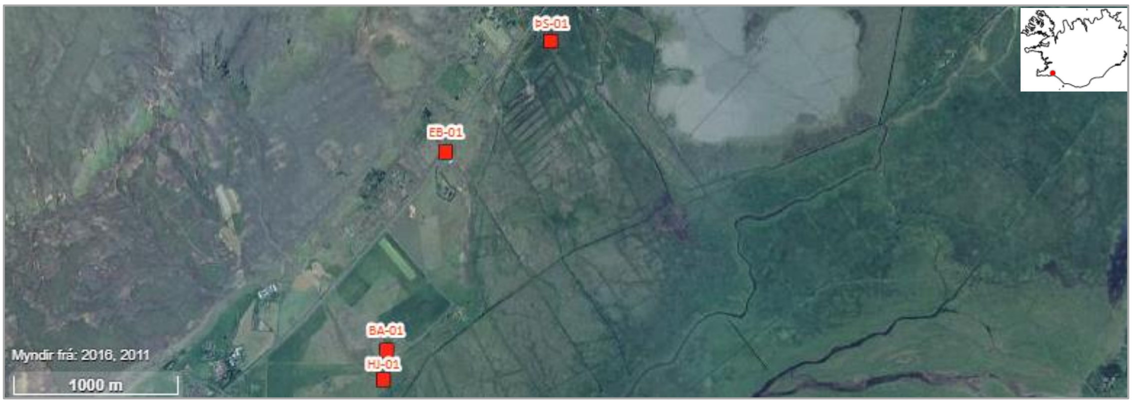

Figure 128. *Overview of the production wells in the well fields Þóroddsstaðir (ÞS-1), Eystribakki (EB-1), Bakki (BA-1) and Hjallakrókur (HJ-1) (modified from NEA's Geoportal).*

Well ÞS-1 was drilled in 1977 to 1,734 m depth and gave 13 l/s of 117°C but has not been in use since 2010 (Olsen, 2014d).

Assuming 13 l/s of 117°C water, a thermal power potential of P_{35} = 4.2 MW_{th} and P_5 = 5.8 MW_{th} is obtained for the Þóroddsstaðir well field.

Eystribakki well field

One production well, EB-1, was drilled in 1986 to 1,045 m depth, see Fig. 128. It delivers 2.9 kg/s of 119°C water (Olsen, 2014d).

Assuming 2.9 kg/s of 119°C water, a thermal power potential of P_{35} = 1.0 MW_{th} and P_5 = 1.4 MW_{th} is obtained for the Eystribakki well field.

4.33.3 Þorlákshöfn District Heating (Veitur)

The Þorlákshöfn District Heating operates under Regulation 245/2001 and is owned by Reykjavík Energy/Veitur. It serves the village Þorlákshöfn and neighbouring farms, see Fig. 129. The District Heating uses two wells from the well fields Bakki and Hjallakrókur.

Figure 129. *Service area of the Þorlákshöfn District Heating (Olsen, 2013).*

Bakki well field

One production well, BA-1, was drilled in 1977 to 886 m depth (Kristmannsdóttir et al., 1990), see Fig. 128. It delivered a free-flow of 11.6 kg/s of 113°C in 2012 (Olsen, 2013).

The well has thermal power potential of P_{35} = 3.8 MW_{th} and P_5 = 5.3 MW_{th}

Hjallakrókur well field

One production well, HJ-1, was drilled in 1983 to 605 m depth and delivered 18.8 kg/s of 104°C water in 2012 (Olsen, 2013), see Fig. 128.

The well has thermal power potential of P_{35} = 5.4 MW_{th} and P_5 = 7.8 MW_{th}

5 Drilled Wells and Thermal Power Potential

5.1 Productivity and success of wells

Defining success of drilling and capacity of wells in low enthalpy geothermal fields is not as straightforward as in high enthalpy systems.

High enthalpy wells are considered successful for generation of electricity if they can deliver steam at a wellhead pressure higher than the inlet pressure of the turbines in the generating plant (Sveinbjörnsson, 2017). Productive wells in high enthalpy systems are generally considered successful for space heating with the aid of heat exchangers, but the geothermal water cannot be used directly in the distribution systems because of dissolved minerals and high scaling potential.

Medium enthalpy wells deliver water and steam at 100 - 200°C which can be utilized both for generation of electricity with a Rankine thermodynamic cycle and space heating. Due to dissolved gases the boiling discharge does though often not have a temperature higher than 95°C. In a report on the success of drilled wells in medium enthalpy fields in Iceland (Sveinbjörnsson, 2016) wells discharging water hotter than 95°C were considered successful for generation of electricity. Productive wells in medium enthalpy fields with discharge temperatures above 60°C are generally considered successful for space heating but direct use of the water may not be feasible due to dissolved solids and risk of scaling.

In low enthalpy fields productive wells are similarly considered successful for space heating if they discharge water at temperatures above 60°C although in some cases water at a temperature as low as 45°C may be used directly without the aid of a heat pump. In low enthalpy fields dissolved solids in the geothermal water seldom cause a problem for direct use of the water, except for saline waters.

High enthalpy wells do seldom have hydrostatic pressure to issue free-flow but become active through boiling that maintains high wellhead steam pressure during discharge. Medium and low enthalpy wells are often artesian and have considerable hydrostatic wellhead pressure. They then yield free-flow in the first years of utilization but the flow decreases as pressure declines in the reservoir due to production. Downhole pumps are widely used in these systems to maintain and increase the yield and there are cases of up to tenfold increase in yield compared to the former free-flow of wells and hot springs. Long term downhole pumping does however lower the reservoir pressure and generally leads to drying out of hot springs and wells that have issued free-flow.

In this report on low and medium enthalpy wells we define a well productive if it encounters feeders that can yield a flow into the well, either a free-flow or discharge with the aid of airlifting or downhole pumps. Wells that can discharge water with a temperature above 60°C are considered successful for direct space heating. In general, the distribution heating services select the best producers for long term uses and some production wells may even be used as injection wells if the downhole pumping is causing excessive drawdown. Good producers with free-flow may also become dry if the field is re-drilled and subjected to downhole pumping in the new production wells.

The thermal power potential calculated for fields and systems is an indicator of the proven potential. One must, however, consider that in cases of the power potential of hot springs or free-flowing wells the estimate is likely to be less than the actual thermal power potential of the field.

5.2 Status of wells and thermal power potential

5.2.1 Table of wells

Table 8 lists the number of drilled exploration and production wells in 63 low- and medium enthalpy geothermal fields that are utilized by the major district heating services. The table also shows the status of the production wells and the proven thermal power potential of the respective geothermal fields and their well fields. The 64 major district heating services are marked in Fig. 2, numbered clockwise after districts, starting from the capital area, Seltjarnarnes and Reykjavík. Some of the services also utilize high enthalpy resources but this report only describes the low- and medium enthalpy resources exploited.

The data is arranged by 33 districts, in capital letters, 64 district heating services in Arabic numbers, 63 geothermal fields, marked with Roman capital numbers, thereof 39 low enthalpy fields, 24 medium enthalpy fields and well fields in Roman lowercase numbers. The names of districts are reported as they were in May 2014 according to National Land Survey of Iceland. The table reports all 446 production wells listed in the National Well Registry in 63 low- and medium enthalpy geothermal fields and 115 well fields. Of the 446 production wells, 420 are known to have been productive after drilling, 26 wells were, however, not productive.

Table 7. *Number of drilled exploration and production wells and status of production wells in the low- and medium enthalpy geothermal fields used by the 64 major district heating services in Iceland.*

DISTRICTS (Capital letters) District heating services (Owners), (Arabic numbers) *Geothermal Fields, (Roman capital numbers)* Well fields, (Roman lowercase numbers)		Geothermal fields enthalpy type	Wells						Thermal Power Potential			
			Drilled		Status				Well field		Geothermal field	
Marks	Names		Exploration	Production	Unknown	Unproductive	Productive	In use	> 35°C (MW_{th})	> 5°C (MW_{th})	> 35°C (MW_{th})	> 5°C (MW_{th})
A	**SELTJARNARNES**											
1	Seltjarnarnes District Heating											
I	*Seltjarnarnes Geothermal Field*	*M*	*8*	*6*			*6*	*5*			*34.7*	*49.1*
i	Bakki well field		2	1			1	0				
ii	Nes well field		2	1			1	1				
iii	Nýibær well field		0	1			1	1	8.4	11.4		
iv	Bygggarður well field		2	2			2	2	16.0	23.2		
v	Ráðagerði well field		2	1			1	1	10.3	14.5		
B	**REYKJAVÍK**											
2	Reykjavík District Heating (Veitur)											
II	*Laugarnes Geothermal Field*	*M*	*14*	*41*		*1*	*40*	*10*			*121.7*	*161.0*
vi	Laugarnes well field		9	23		1	22	4	40.9	54.0		
vii	Lækjarhvammur well field		0	5			5	4	59.7	79.0		
viii	Rauðarárholt well field		1	4			4	1	7.6	10.2		
ix	Rauðará well field		2	2			2	0				
x	Hátún well field		1	4			4	1	13.5	17.8		
xi	Sigtún well field		1	3			3	0				
III	*Elliðaár Geothermal Field*	*L*	*7*	*13*			*13*	*5*			*53.6*	*84.5*
xii	Árbær well field		2	1			1	0				
xiii	Ártún well field		2	1			1	0				
xiv	Breiðholt well field		3	11			11	5	53.6	84.5		
C	**MOSFELLSBÆR**											
3	Mosfellsbær District Heating (Veitur)											
IV	*Reykir Geothermal Field*	*L*	*9*	*114*		*1*	*113*	*29*			*366.7*	*586.2*
	Suður-Reykir Subfield	X	7	70		1	69	17	157.4	267.7		
xv	Reykjahvoll well field		5	26		0	26	4	41.4	76.0		
xvi	Suður-Reykir well field		1	42		1	41	11	96.7	162.9		
xvii	Helgafell well field - South		1	2		0	2	2	19.3	28.8		
	Reykjahlíð Subfield	X	2	44		0	44	12	209.3	318.5		
xviii	Helgafell well field - North		0	1		0	1	1	10.4	15.3		
xix	Hrísbrú well field		1	3		0	3	0				
xx	Reykjahlíð well field		0	15		0	15	1	9.3	14.3		
xxi	Norður-Reykir well field		1	5		0	5	0				
xxii	Reykjadalur well field		0	4		0	4	0				
xxiii	Varmaland well field		0	6		0	6	1	7.4	12.0		
xxiv	Æsustaðir well field		0	7		0	7	7	139.7	212.6		
xxv	Hraðastaðir well field		0	1		0	1	0				
xxvi	Helgadalur well field		0	2		0	2	2	42.5	64.3		
D	**KJÓSARHREPPUR**											
4	Kjós District Heating (Kjósarveita)											
V	*Möðruvellir Geothermal Field*	*M*	*19*	*2*	*0*		*2*	*1*			*16.8*	*21.9*
xxvii	Möðruvellir well field		19	2	0		2	1	16.8	21.9		
5	Hvammsvík District Heating (Veitur)											
VI	*Hvammsvík Geothermal Field*	*M*	*9*	*1*	*0*		*1*	1			*5.5*	*8.5*
xxviii	Hvammsvík well field		9	1	0		1	1	5.5	8.5		
E	**SKORRADALSHREPPUR**											
6	Skorradalur District Heating (Veitur)											
VII	*Brautartunga/England Geothermal Field*	*M*	*5*	*1*			*1*	1			*3.2*	*4.7*
xxix	Stóra-Drageyri well field		5	1			1	*1*	3.2	4.7		
F	**BORGARBYGGÐ**											
7	Akranes/Borgarfjörður District Heating (Veitur)											
VIII	*Reykholt Geothermal Field, Deildartunga*	*M*	*3*	*0*			*0*	*0*			*46.3*	*68.0*
xxx	Deildartunga well field, spring		3	0			0	*0*	46.3	68.0		
IX	*Bær/Varmaland Field, Hellur, Bær, Laugarholt*	*M*	*1*	*8*			*8*	2			*15.6*	*23.2*
xxxi	Hellur well field		1	3			3	0				
xxxii	Bær well field		0	4			4	1	5.1	7.2		
xxxiii	Laugarholt well field		0	1			1	1	10.5	16.0		
8	Húsafell District Heating											
X	*Húsafell Geothermal Field*	*L*	*0*	*2*			*2*	*2*			*6.1*	*11.5*

Table 8. *(Cont.)*

xxxiv	Húsafell well field		0	2			2	2	6.1	11.5		
9	Reykholt District Heating											
VIII	*Reykholt Geothermal Field, Reykholt*	*X*	*0*	*2*			*2*	*1*			*6.4*	*8.8*
xxxv	Reykholt well field		0	2			2	1	6.4	8.8		
10	Kleppjárnsreykir District Heating											
VIII	*Reykholt Geothermal Field, Kleppjárnsreykir*	*X*	*3*	*0*			*0*	*0*			*17.5*	*25.9*
xxxvi	Kleppjárnsreykir well field,		3	0			0	0				
xxxvi	Kleppjárnsreykir well field, spring								17.5	25.9		
11	Brúarreykir District Heating											
VIII	*Reykholt Geothermal Field, Brúarreykir*	*X*									*3.0*	*4.8*
xxxvii	Brúarreykir field, spring								3.0	4.8		
12	Varmaland District Heating											
IX	*Bær/Varmaland Geothermal Field, Varmaland*	*X*	*6*	*1*			*1*	*1*			*6.4*	*9.3*
xxxviii	Varmaland/Laugaland well field		*6*	*1*			*1*	*1*	6.4	9.3		
xxxviii	Varmaland/Laugaland well field, well								4.2	6.0		
xxxviii	Varmaland/Laugaland well field, springs								2.2	3.3		
13	Stafholtstungur District Heating											
IX	*Bær/Varmaland Geothermal Field, Varmaland*	*X*	*X*	*X*	*X*	*X*	*X*	*X*			*X*	*X*
14	Munaðarnes District Heating (Veitur)											
IX	*Bær/Varmaland Geothermal Field, Munaðarnes*	*X*	*6*	*2*			*2*	*1*			*2.1*	*3.4*
xxxix	Munaðarnes well field		6	2			2	1	2.1	3.4		
15	Norðurárdalur District Heating (Veitur)											
IX	*Bær/Varmaland Geothermal Field, Norðurárdalur*	*X*	*13*	*2*			*2*	*2*			*6.1*	*11.4*
xl	Hreðavatn well field		12	1			1	1	2.0	3.7		
xli	Svartagil well field		1	1			1	1	4.1	7.7		
G	**HELGAFELLSSVEIT**											
16	Stykkishólmur District Heating (Veitur)											
XI	*Hofsstaðir Geothermal Field*	*L*	*36*	*3*			*3*	*1*			*13.0*	*20.6*
xlii	Arnarstaðir well field		10	1			1	0	6.8	10.8		
xliii	Hofsstaðir well field		15	1			1	1	6.2	9.8		
xliv	Ögur well field		11	1			1	0				
H	**DALABYGGÐ**											
17	Dalabyggð District Heating (RARIK)											
XII	*Miðdalir Geothermal Field*	*L*	*11*	*4*			*4*	*2*			*5.3*	*8.3*
xlv	Gröf well field		11	4			4	2	5.3	8.3		
I	**REYKHÓLAHREPPUR**											
18	Reykhólar District Heating (OV)											
XIII	*Reykhólar Geothermal Field*	*M*	*0*	*7*	*1*		*7*	*6*			*16.0*	*22.6*
xlvi	Reykhólar well field		0	7	1		7	6	16.0	22.6		
19	Thorverk seaweed plant											
XIII	*Reykhólar Geothermal Field*	X	X	X	X	X	X	X			X	X
xlvi	Reykhólar well field	X	X	X	X	X	X	X	X	X		
J	**ÍSAFJÖRÐUR**											
20	Suðureyri District Heating (OV)											
XIV	*Suðureyri Geothermal Field*	*L*	*3*	*2*			*2*	*1*			*1.6*	*3.1*
xlvii	Laugar well field		3	2			2	1	1.6	3.1		
K	**KALDRANANESHREPPUR**											
21	Drangsnes District Heating											
XV	*Drangsnes Geothermal Field*	*L*	*17*	*1*			*1*	*1*			*2.1*	*4.6*
xlviii	Drangsnes well field		17	1			1	1	2.1	4.6		
L	**HÚNAÞING VESTRA**											
22	Borðeyri District Heating (HÚV)											
XVI	*Borðeyri Geothermal Field*	*L*	*7*	*1*			*1*	*1*			*0.1*	*0.2*
xlix	Laugarmýri well field		7	1			1	1	0.1	0.2		
23	Reykir District Heating (HÚV)											
XVII	*Reykir in Hrútafjörður Geothermal Field*	*L*	*9*	*3*		*1*	*2*	*1*			*1.2*	*1.9*
l	Reykir well field		9	3		1	2	1	1.2	1.9		
24	Hvammstangi/Laugarbakki District Heating (HÚV)											
XVIII	*Laugarbakki Geothermal Field*	*M*	*0*	*3*			*3*	*1*			*12.1*	*18.1*
li	Ytri-Reykir well field		0	3			3	1	12.1	18.1		
M	**HÚNAVATNSHREPPUR**											
25	Blönduós District Heating (RARIK)											
XIX	*Reykir at Reykjabraut Geothermal Field*	*L*	*14*	*6*			*6*	*3*			*5.1*	*9.2*
lii	Reykir at Reykjabraut well field		14	6			6	3	5.1	9.2		
26	Skagaströnd District Heating (RARIK)											
XIX	*Reykir at Reykjabraut Geothermal Field*	*X*	*X*	*X*	*X*	*X*	*X*	*X*			*X*	*X*
N	**SKAGAFJÖRÐUR**											
27	Steinsstaðir District Heating (SKV)	*L*										
XX	*Steinsstaðir Geothermal Field*		*3*	*3*		*1*	*2*	*1*			*3.1*	*6.8*
liii	Steinsstaðir well field		3	3		1	2	1	0.9	2.0		
liii	Steinsstaðir, spring								2.2	4.8		

Table 8. *(Cont.)*

28	Sauðárkrókur District Heating (SKV)											
XXI	*Áshildarholtsvatn Geothermal Field*	*L*	*1*	*13*			*13*	*4*			*20.0*	*37.2*
liv	Borgarmýrar in Sjávarborg well field		1	13			13	4	20.0	37.2		
29	Varmahlíð District Heating (SKV)											
XXII	*Varmahlíð Geothermal Field*	*M*	*9*	*3*			*3*	*3*			*9.7*	*14.5*
lv	Reykjarhóll well field		9	3			3	3	9.7	14.5		
30	Hólar District Heating (SKV)											
XXIII	*Reykir in Hjaltadalur Geothermal Field*	*L*	*0*	*2*			*2*	*2*			*4.8*	*10.6*
lvi	Reykir in Hjaltadalur well field		0	2			2	2	4.8	10.6		
31	Hofsós District Heating (SKV)											
XXIV	*Bræðrá Geothermal Field*	*L*	*14*	*2*			*2*	*2*			*6.7*	*10.3*
lvii	Bræðrá well field		14	2			2	2	6.7	10.3		
32	Sólgarðar/Langhús District Heating (SKV)											
XXV	*Langhús Geothermal Field*	*M*	*0*	*5*		*1*	*4*	*3*			*8.5*	*12.1*
lviii	Langhús well field		0	4		1	3	2	8.5	12.1		
lix	Barð well field		0	1			1	1				
O	**FJALLABYGGÐ**											
33	Siglufjörður District Heating (RARIK)											
XXVI	*Skarðdalur Geothermal Field*	*L*	*13*	*1*			*1*	*1*			*4.1*	*7.2*
lx	Skarðdalur well field		13	1			1	1	4.1	7.2		
XXVII	*Skútudalur Geothermal Field*	*L*	*7*	*6*			*6*	*1*			*3.9*	*7.6*
lxi	Skútudalur well field		7	6			6	1	3.9	7.6		
34	Ólafsfjörður District Heating (NO)											
XXVIII	*Ólafsfjörður Geothermal Field*	*L*	*19*	*7*			*7*	*2*			*8.0*	*16.1*
lxii	Skeggjabrekka well field		14	3			3	1	1.4	3.4		
lxiii	Ósbrekka well field		5	4			4	1	6.6	12.7		
P	**DALVÍK**											
35	Dalvík District Heating (HD)											
XXIX	*Hamar Geothermal Field*	*L*	*8*	*3*			*3*	*2*			*4.4*	*9.0*
lxiv	Hamar well field		8	3			3	2	4.4	9.0		
36	Árskógsströnd District Heating (HD)											
XXX	*Árskógsströnd Geothermal Field*	*L*	*20*	*2*			*2*	*2*			*13.1*	*23.0*
lxv	Brimnes/Birnunes well field		20	2			2	2	13.1	23.0		
37	Ytrivík District Heating (NO)											
XXXI	*Ytrivík Geothermal Field*	*L*	*13*	*3*			*3*	*1*			*4.5*	*7.4*
lxvi	Ytrivík well field at Sólbakki		6	1			1	1	2.8	4.5		
lxvii	Syðrihagi well field		7	2			2	0	1.7	2.9		
Q	**HÖRGÁRSVEIT**											
38	Akureyri District Heating (NO)											
XXXII	*Þelamörk Geothermal Field*	*M*	*11*	*6*		*1*	*5*	*1*			*6.8*	*9.8*
lxviii	Laugaland at Þelamörk well field		11	6		1	5	1	6.8	9.8		
XXXIII	*Hjalteyri Geothermal Field*	*L*	*18*	*2*			*2*	*2*			*30.5*	*48.1*
lxix	Arnarnes well field		18	2			2	2	30.5	48.1		
R	**AKUREYRARKAUPSTAÐUR**											
38	Akureyri District Heating (NO)											
XXXIV	*Glerárdalur Geothermal Field*	*L*	*0*	*12*		*9*	*3*	*1*			*2.1*	*4.5*
lxx	Glerárdalur well field		0	12		9	3	1	2.1	4.5		
39	Hrísey District Heating (NO)											
XXXV	*Hrísey Geothermal Field*	*L*	*0*	*10*			*10*	*1*			*2.8*	*4.8*
lxxi	Hrísey well field		0	10			10	1	2.8	4.8		
S	**EYJAFJARÐARSVEIT**											
38	Akureyri District Heating (NO)											
XXXVI	*Reykhús Geothermal Field*	*L*	*9*	*1*			*1*	*0*				
lxxii	Reykhús well field		9	1			1	0				
XXXVII	*Botn/Hrafnagil Geothermal Field*	*L*	*18*	*2*			*2*	2			*5.8*	*9.5*
lxxiii	Hrafnagil well field		12	1			1	1	4.4	7.4		
lxxiv	Botn well field		6	1			1	1	1.4	2.1		
XXXVIII	*Laugaland Geothermal Field*	*L*	*4*	*8*		2	*6*	*2*			*34.3*	*51.7*
lxxv	Syðra Laugaland well field		4	8		2	6	2	34.3	51.7		
XXXIX	*Ytri-Tjarnir/Björk Geothermal Field*	*L*	0	*4*			*4*	*1*			*7.5*	*12.4*
lxxvi	Ytri-Tjarnir well field		*0*	3			3	1	7.5	12.4		
lxxvii	Björk well field		0	1			1	0				
T	**ÞINGEYJARSVEIT**											
40	Reykir District Heating (NO+ÞS)											
XL	*Reykir in Fnjóskadalur Geothermal Field*	*L*	*11*	*2*			*2*	1			*3.6*	*5.6*
lxxviii	Reykir in Fnjóskadalur well field		11	2			2	1	3.6	5.6		
41	Reykjadalur District Heating											
XLI	*Stórutjarnir Geothermal Field*	*L*	*6*	*1*			*1*	*1*			*1.4*	*2.7*
lxxix	Stórutjarnir well field		6	1			1	1	1.4	2.7		
XLII	*Reykjadalur Geothermal Field*	*L*	*0*	*2*		1	*1*	*1*			*10.3*	*19.6*
lxxx	Litlulaugar well field		0	2		1	1	1	10.3	19.6		
42	Aðaldalur/Kinn District Heating (OH)											

Table 8. *(Cont.)*

XLIII	*Hveravellir Geothermal Field*	M	X	X		X	X	X			X	X
43	Hafralækur District Heating (OH)											
XLIV	*Hafralækur Geothermal Field*	L	1	2		1	1	1			1.1	2.0
lxxxi	Hafralækur well field		1	2		1	1	1	1.1	2.0		
U	**NORÐURÞING**											
44	Húsavík District Heating (OH)											
XLIII	*Hveravellir Geothermal Field*	X	13	5		1	4	3			81.2	110.2
lxxxii	Hveravellir well field		13	5		1	4	3	66.8	89.2		
lxxxii	Hveravellir, springs								14.4	21.0		
XLV	*Húsavík Geothermal Field*	M	7	1		1	0	0				
lxxxiii	Húsavík well field		7	1		1	0	0				
45	Öxarfjörður District Heating											
XLVI	*Öxarfjörður Geothermal Field, Ærlækjarsel*	M	2	2			2	1			17.2	24.0
lxxxiv	Ærlækjarsel well field		2	2			2	1	17.2	24.0		
V	**FLJÓTSDALSHÉRAÐ**											
46	Egilsstaðir/Fell District Heating (HEF)											
XLVII	*Urriðavatn Geothermal Field*	L	19	8		1	7	2			13.6	23.7
lxxxv	Urriðavatn well field		8	2		0	2	0				
lxxxvi	Ekkjufellssel well field		11	6		1	5	2	13.6	23.7		
W	**FJARÐABYGGÐ**											
47	Fjarðabyggð District Heating											
XLVIII	*Eskifjörður Geothermal Field*	L	24	3		1	2	2			9.3	15.4
lxxxvii	Eskifjörður well field		23	2		1	1	1	6.5	10.8		
lxxxviii	Eskifjarðarsel well field		1	1		0	1	1	2.8	4.6		
X	**HORNAFJÖRÐUR**											
48	Höfn District Heating (RARIK)											
XLIX	*Hoffell Geothermal Field*	L	18	4			4	3			6.8	11.1
lxxxix	Hoffell well field		18	4			4	3	6.8	11.1		
Y	**RANGÁRÞING YTRA**											
49	Rangá District Heating (Veitur)											
L	*Laugaland in Holt Geothermal Field*	M	5	5		1	4	3			2.8	4.2
xc	Gata well field		0	1		0	1	0				
xci	Nefsholt well field		4	4		1	3	3	2.8	4.2		
LI	*Kaldárholt Geothermal Field*	L	35	4		0	4	2			8.0	15.8
xciii	Kaldárholt well field		35	4		0	4	2	8.0	15.8		
Z	**HRUNAMANNAHREPPUR**											
50	Flúðir District Heating											
LII	*Flúðir Geothermal Field*	M	0	11			11	6			61.7	87.6
xciii	Grafarbakki well field		0	2			2	1	32.1	45.2		
xciv	Hellisholt well field		0	9			9	5	29.6	42.4		
AA	**SKEIÐA- OG GNÚPVERJAHREPPUR**											
51	Gnúpverjar District Heating											
LIII	*Þjórsárholt Geothermal Field*	L	3	1			1	1			3.1	6.2
xcv	Þjórsárholt well field		3	1			1	1	3.1	6.2		
52	Brautarholt District Heating											
LIV	*Brautarholt Geothermal Field*	L	0	2			2	1			0.5	0.8
xcvi	Brautarholt well field		0	2			2	1	0.5	0.8		
AB	**BLÁSKÓGABYGGÐ**											
53	Laugarvatn District Heating (BV)											
LV	*Laugarvatn Geothermal Field*	M	1	0			0	0			10.4	15.3
xcvii	Laugarvatn well field, spring		1	0			0	0	10.4	15.3		
54	Reykholt District Heating (BV)											
LVI	*Reykholt Geothermal Field, Stórafljót*	M	2	2			2	2			13.8	18.7
xcviii	Stórafljót well field		2	2			2	2	10.3	13.5		
	Stórafljót, spring								3.5	5.2		
55	Laugarás District Heating (BV)											
LVI	*Reykholt Geothermal Field, Laugarás*	X	0	0	0	0	0	0			21.8	32.6
xcix	Laugarás field, springs								21.8	32.6		
56	Hlíðaveita District Heating (Veitur)											
LVII	*Efri-Reykir Geothermal Field*	M	20	3		1	2	1			29.7	37.7
c	Efri-Reykir well field		20	3		1	2	1	29.7	37.7		
AC	**GRÍMSNES- OG GRAFNINGSHREPPUR**											
57	Grímsnes/Grafningur District Heating											
LVIII	*Kringla Geothermal Field*	L	0	2			2	1			1.5	2.4
ci	Kringla well field		0	2			2	1	1.5	2.4		
LIX	*Vaðnes Geothermal Field*	X	X	X	X	X	X	X			X	X
cii	Vaðnes well field		X	X	X	X	X	X	X	X		
58	Vaðnes District Heating											
LIX	*Vaðnes Geothermal Field*	L	7	2			2	1			6.3	10.7
cii	Vaðnes well field		7	2			2	1	6.3	10.7		
59	Grímsnes District Heating (Veitur)											
LX	*Öndverðarnes Geothermal Field*	M	22	6			6	1			9.1	12.7

Table 8. *(Cont.)*

ciii	Öndverðarnes well field		22	6			6	1	9.1	12.7		
AD	**FLÓAHREPPUR**											
60	Selfoss District Heating (Selfossveitur)											
LXI	*Selfoss Field, Ósabotnar, Þorleifskot, Laugardælir*	*M*	*41*	*16*			*16*	*10*			*58.3*	*82.8*
civ	Ósabotnar well field		0	3			3	3	23.0	35.1		
cv	Þorleifskot well field		27	11			11	6	33.7	45.5		
cvi	Laugardælir well field		14	2			2	1	1.6	2.2		
AE	**ÁRBORG**											
60	Selfoss District Heating (Selfossveitur)											
LXI	*Selfoss Geothermal Field, Jórutún*	*X*	*2*	*1*			*1*	*1*			*1.9*	*3.6*
cvii	Jórutún well field		2	1			1	1	1.9	3.6		
AF	**HVERAGERÐISBÆR**											
61	Hveragerði District Heating (Veitur)											
LXII	*Hveragerði Geothermal Field, Hverasvæðið*	*M*	*12*	*34*		*1*	*33*	*3*			*40.6*	*50.7*
cviii	Hverasvæðið well field		0	11			11	2	34.7	43.2		
cix	Hveragerði village well field		12	23		1	22	1	5.9	7.5		
AG	**ÖLFUS**											
61	Hveragerði District Heating (Veitur)											
62	Austur District Heating (Veitur)											
LXII	*Hveragerði Geothermal Field, Gljúfurárholt*	*X*	*6*	*3*		*1*	*2*	*2*			*12.7*	*17.5*
cxi	Gljúfurárholt well field		6	3		1	2	2	12.7	17.5		
63	Ölfus District Heating (Veitur)											
LXIII	*Bakki Geothermal Field*	*M*	*1*	*4*			*4*	*4*			*14.4*	*20.3*
cxii	Þóroddsstaðir well field		1	1			1	1	4.2	5.8		
cxiii	Eystribakki well field		0	1			1	1	1.0	1.4		
64	Þorlákshöfn District Heating (Veitur)											
cxiv	Bakki well field		0	1			1	1	3.8	5.3		
cxv	Hjallakrókur well field		0	1			1	1	5.4	7.8		
	SUM FOR WELLS		**590**	**446**		**27**	**419**	**164**	**1,269**	**1,926**	**1,269**	**1,926**
	SUM FOR HOT SPRINGS (MW$_{th}$)								**121.3**	**180.9**	**121.3**	**180.9**
	TOTAL SUM FOR WELLS AND HOT SPRINGS (MW$_{th}$)								**1,390**	**2,107**	**1,390**	**2,107**

6 Analysis of the Results

6.1 Analysis of all 446 drilled production wells since 1928

6.1.1 Description of wells

The report analyses 446 production wells drilled in the years 1928 to 2017. The purpose of drilling was to find hot water (431 wells) or steam (15 wells). The average age of these wells is 46.6 years. The oldest well was drilled in 1928 in the wellfield Laugarnes in Reykjavík. The elevation of wellhead is known for 297 wells and averages 54 m a.s.l. Most of the wells (434) were drilled vertically, only 12 were drilled directionally. Drilled depths range from 15.7 to 3,085 m and average 752.3 m (data for 442 wells). Fig. 130 shows the drilled depth of wells through the period 1928-2017.

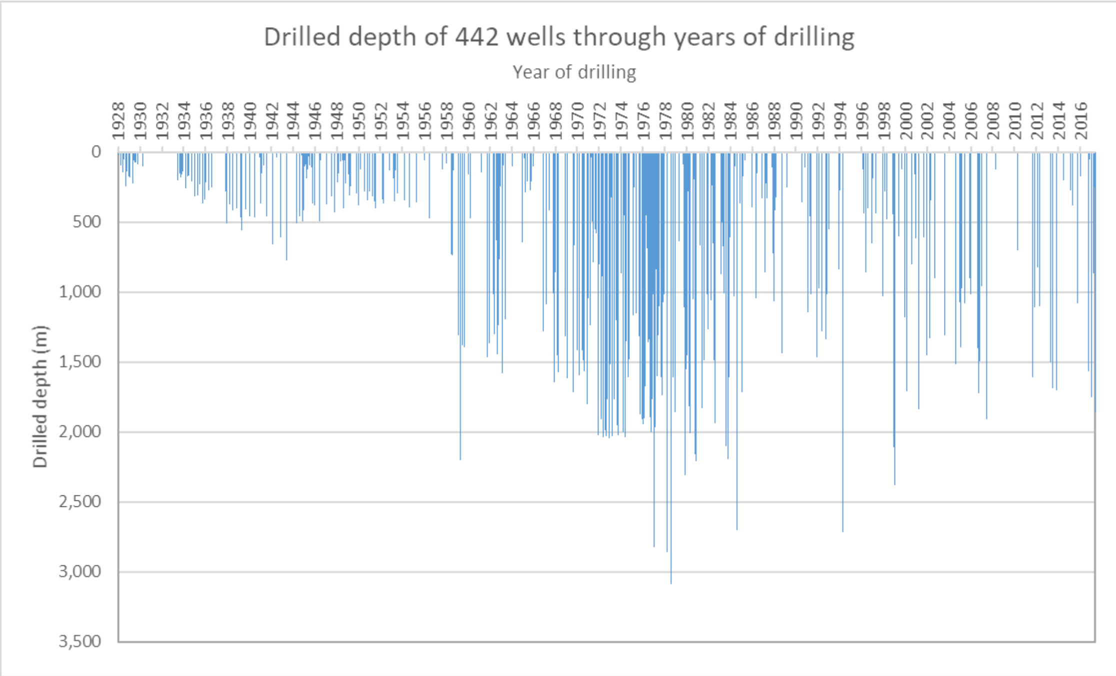

Figure 130. *Drilled depths of 442 wells from 1928-2017.*

Fig. 131 shows the number of wells and frequency distribution of drilled depths of 442 wells in 300 m depth intervals.

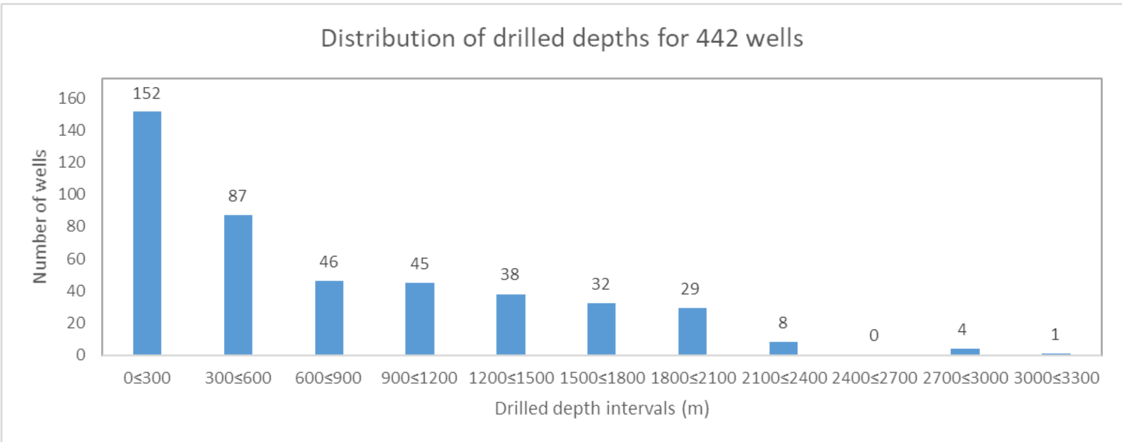

Figure 131. *Number and frequency of drilled depth for 442 production wells in 300 m drilled depth intervals.*

From 1928 to 1958 most of the wells were drilled with small rigs and the wells were generally shallower than 500 m. In the late fifties large oil well drilling rigs took over which could drill much faster and were capable of drilling wider wells that could accommodate downhole pumps and reach 2,000-3,000 m depth.

The average depth of the production casing is 200 m (291 wells). The outside diameter of the casing is known in 284 wells. The most common diameters are 10¾ inches (83 wells), 9⅝ (44 wells), 8⅝ (40 wells) and 13⅜ (33 wells). In the production section below the production casing the most common drill bit diameters are 8½ inches (63 wells) and 8¾ inches (52 wells).

6.1.2 Productive wells

Of the 446 drilled production wells 419 or 93.9% were productive, i.e. encountered feeders that could yield a flow from the well, either free-flow or discharge with the aid of air-lifting or downhole pumps, see Fig. 132.

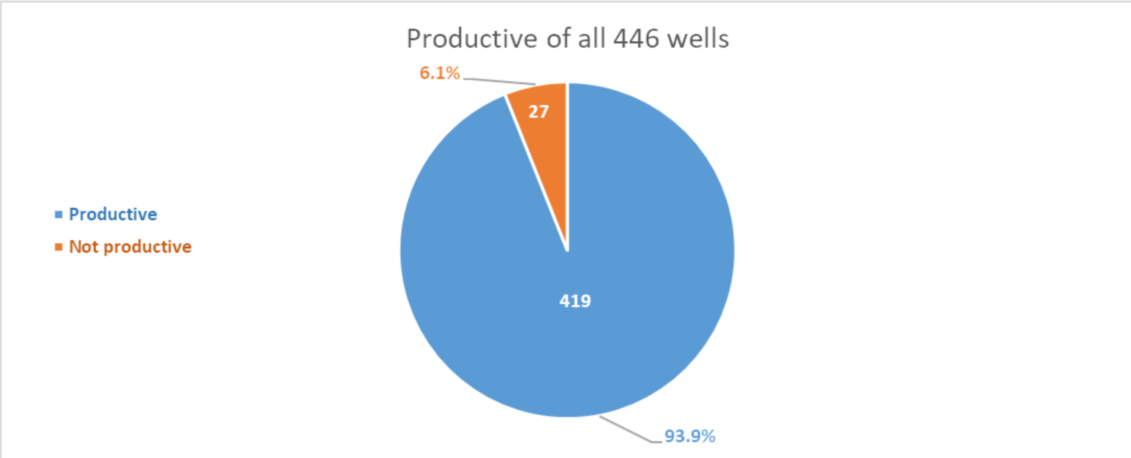

Figure 132. *Productive wells of all 446 drilled low and medium enthalpy wells from 1928 to 2017.*

Fig. 133 shows the number of drilled wells and productive wells by decades.

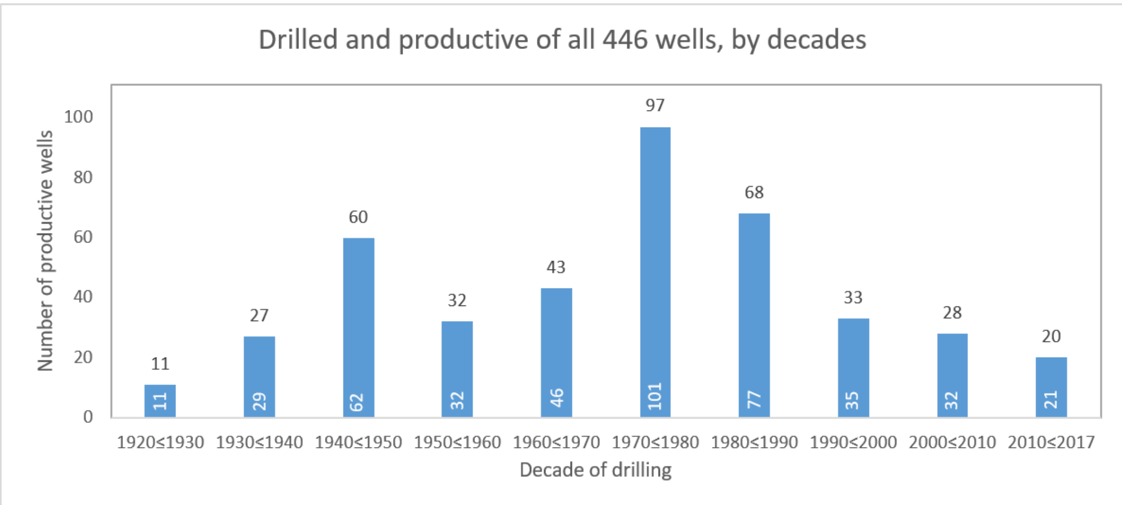

Figure 133. *Drilled wells in decades (white data) and number of productive wells of all drilled wells from 1928 to 2017.*

Data on yield are available for 252 of the 419 productive wells. About 206 of these wells had a yield above 5 l/s, 20 wells a yield between 3 and 5 l/s, and 26 wells between 1 and 3 l/s.

Of the twenty-seven wells that were not productive, eighteen found no feeders, six were reported cold and not yielding, two failed due to drilling problems and one of unknown reason, see Fig. 134.

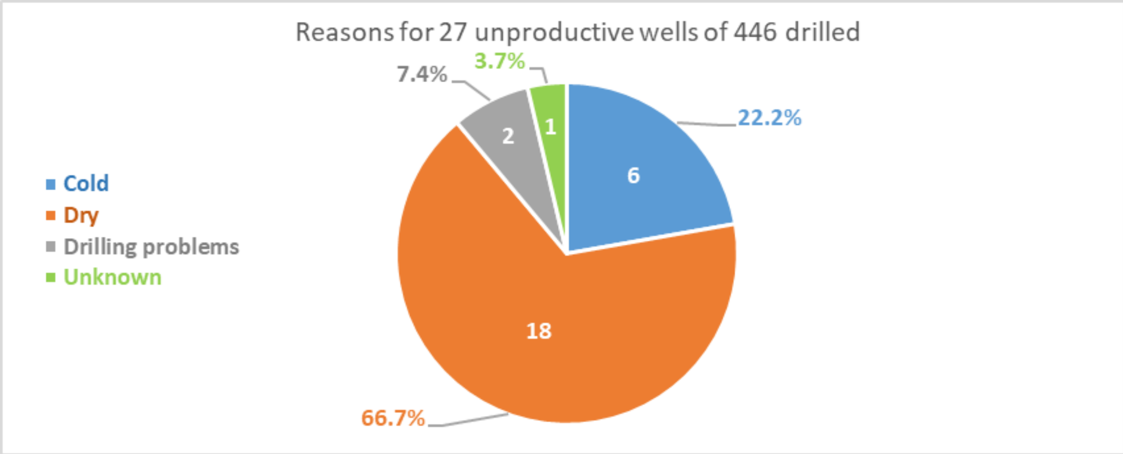

Figure 134. *Reasons for the 27 unproductive wells. White data for number of wells.*

It is generally expected that the success rate percentage of drilling improves as more wells are drilled in the same geothermal field. If the sequence number of wells drilled in the same field is defined as n, the cumulated success rate percentage for all productive drilled wells up to and including sequence number n in the data set is calculated as $C_n = 100 * (P_1 + P_2 + ...P_n) / (D_1 + D_2 + ...D_n)$ where P_n denotes the number of productive wells and D_n the number of drilled wells for the sequence number n. The number of wells drilled in geothermal fields varies greatly. Only 3 of the 63 fields have more than 17 drilled wells. While sequence number n=1 has $D_1 = 63$ wells drilled, n=17 has only $D_{17} = 4$ wells.

Fig. 135 shows the development in the cumulative average success rate percentage of productive wells, across all geothermal fields in the dataset. As the success rate is already high in the first wells drilled the average stays high throughout the sequence.

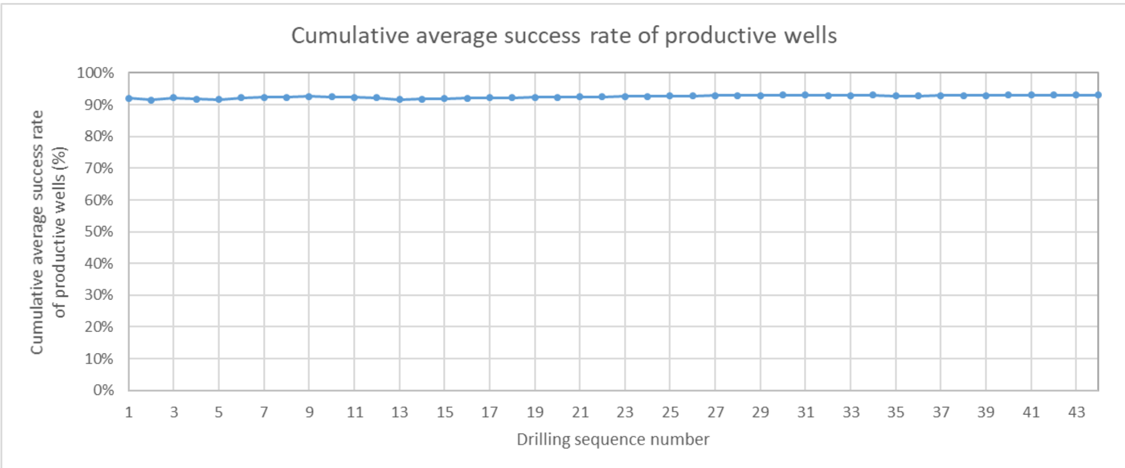

Figure 135. *Learning curve for productive wells by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1928.*

6.1.3 Status of wells

Status of all drilled wells

Of the 446 drilled wells 419 were productive and 164 are still in use, see Figs. 136 and 137. The average age of the wells in use is 32.9 years.

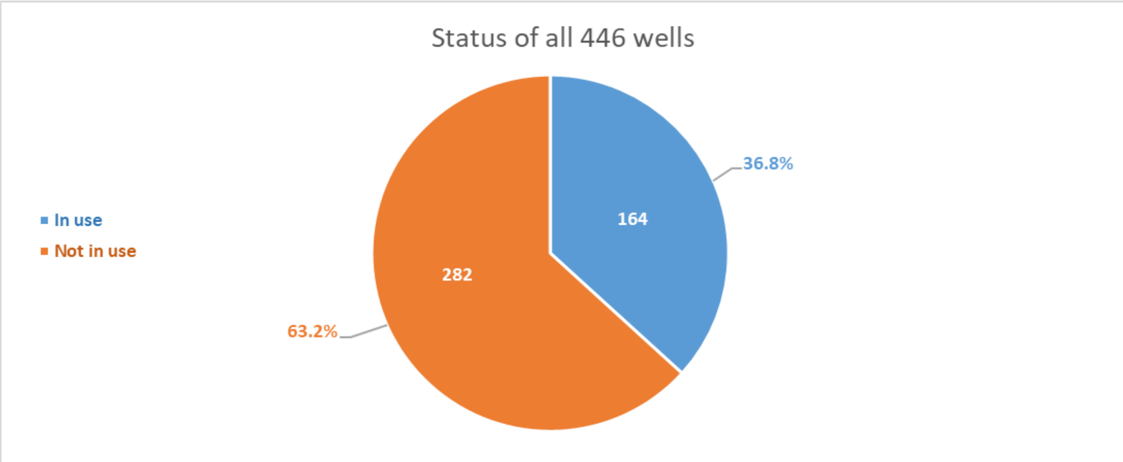

Figure 136. *Status of all drilled wells.*

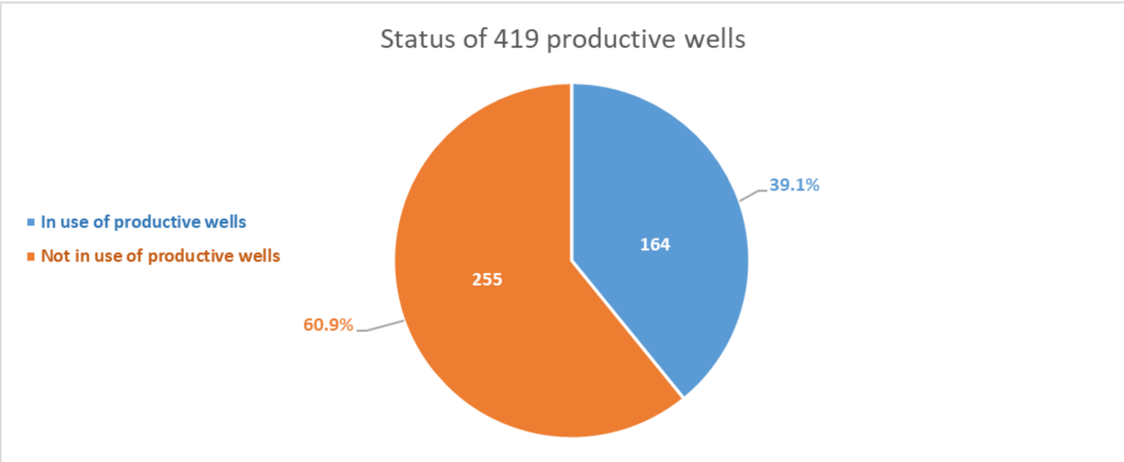

Figure 137. *Status of 419 productive wells.*

Fig. 138 shows the decades of drilling of the 164 wells that are still in use.

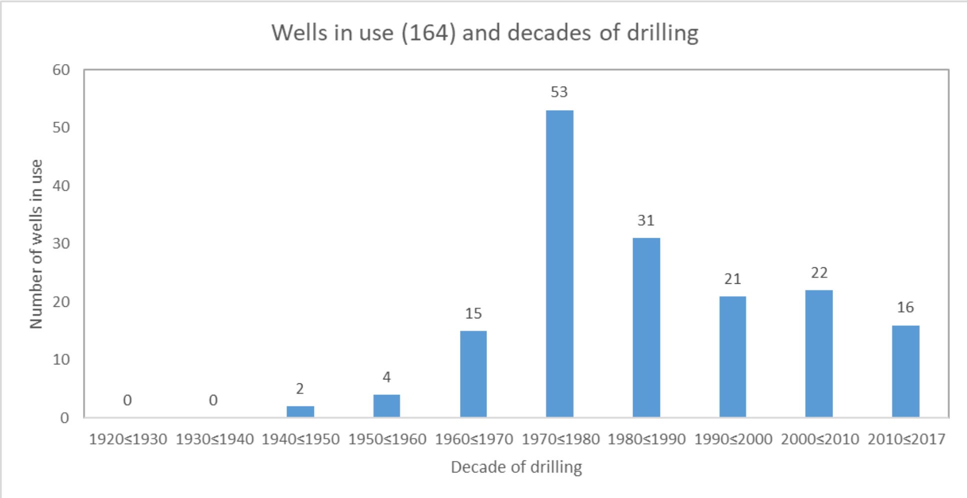

Figure 138. *Overview of 164 wells still in use and decades of drilling.*

The rise of oil prices after 1970 led to increased economic interest in finding geothermal water for space heating in Iceland. The six oldest wells which are still in use are drilled in the fourties and fifties:

Laugaland - Nefsholt, well LL-1, drilled in 1946 to 91 m depth and has served the swimming pool.

Flúðir, well FL-1, drilled in 1949 to 65 m depth and has been used for the swimming pool.

Brautarholt, well BH-2, drilled in 1950 to 120 m depth and serves the Brautarholt District Heating.

Reykhólar, well RH-1, drilled in 1953 to 187 m depth and serves the Reykhólar District Heating.

Laugarnes, wells R-5 and R-10, drilled in 1959 to 740 and 1,306 m depths, respectively and serve Reykjavík District Heating.

Fig. 139 explains why 255 of the 419 productive wells are not in use.

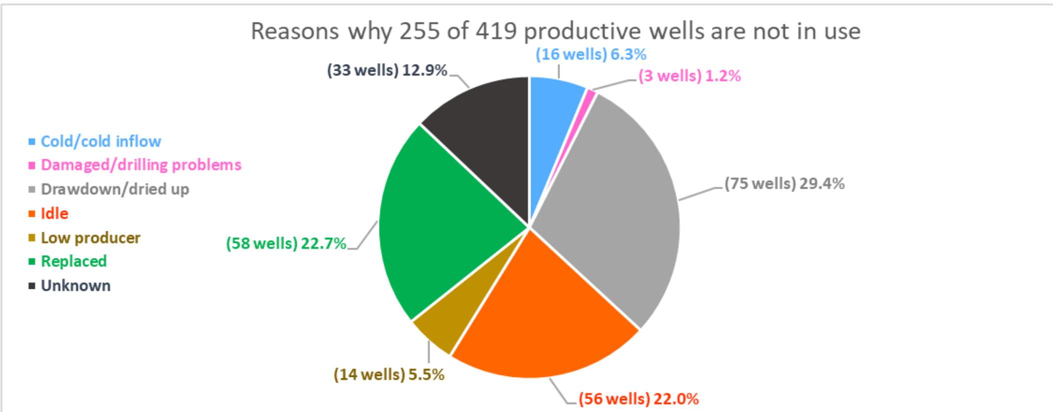

Figure 139. *Reasons why 255 wells of initially 419 productive wells are not in use.*

About 6.3% of the wells not in use are cold or have a cold inflow, 1.2% are damaged, 29.3% have dried up due to drawdown of reservoir pressure due to pumping, 21.9% are idle but could produce, 5.5% are low producers, 22.7% have been replaced by better wells and 12.9% are not in use but for unknown reasons.

6.1.4 Downhole temperature

Maximum downhole temperature

Fig. 140 shows the frequency distribution of maximum downhole temperatures in 400 wells.

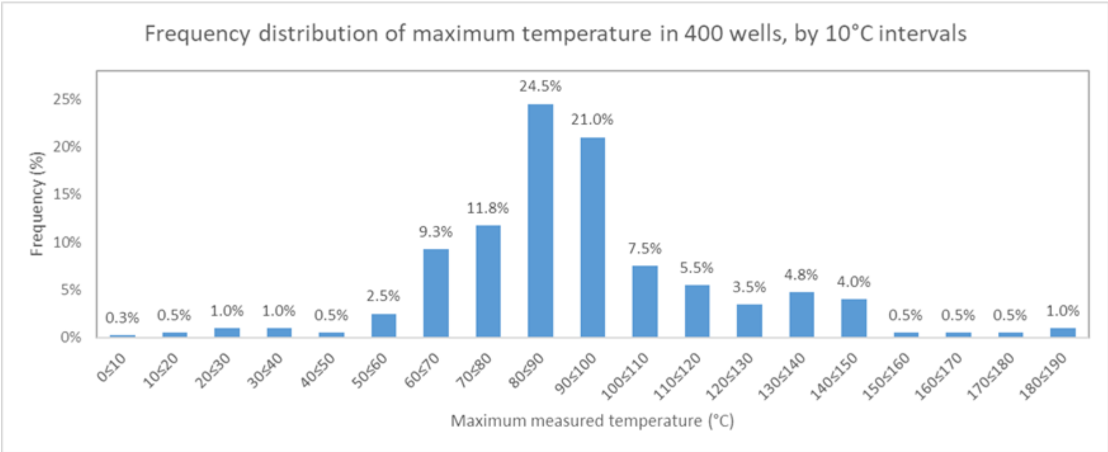

Figure 140. *Distribution of maximum measured temperature in 400 wells, by 10°C intervals.*

The maximum temperature ranges from 9°C to 184°C. The average is 93°C and 74.1% of the wells have maximum downhole temperatures in the range of 60 to 110°C. The highest measured temperature of 184°C is in well HS-06 in Hveragerði. The drilled depth down to the maximum temperature averages 612 m (385 wells).

6.1.5 Main feeder

Fig. 141 shows the frequency distribution of the drilled depth down to the main feeder in 279 wells.

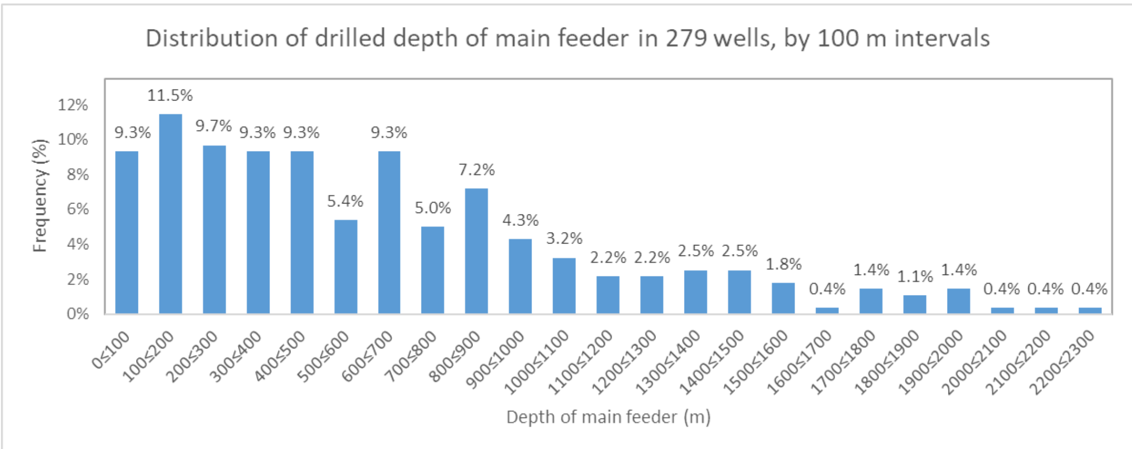

Figure 141. *Distribution of drilled depth of main feeder in 279 wells, by 100 m intervals.*

About 49.1% of the main feeders are shallower than 500 m, 76% are shallower than 1,000 m and 95% are shallower than 1,600 m. Only three of the wells have a main feeder deeper than 2,000 m. The average temperature of the main feeder was found to be 88°C (278 wells).

Fig. 142 compares the depth down to the main feeder against the final drilled depth of the well.

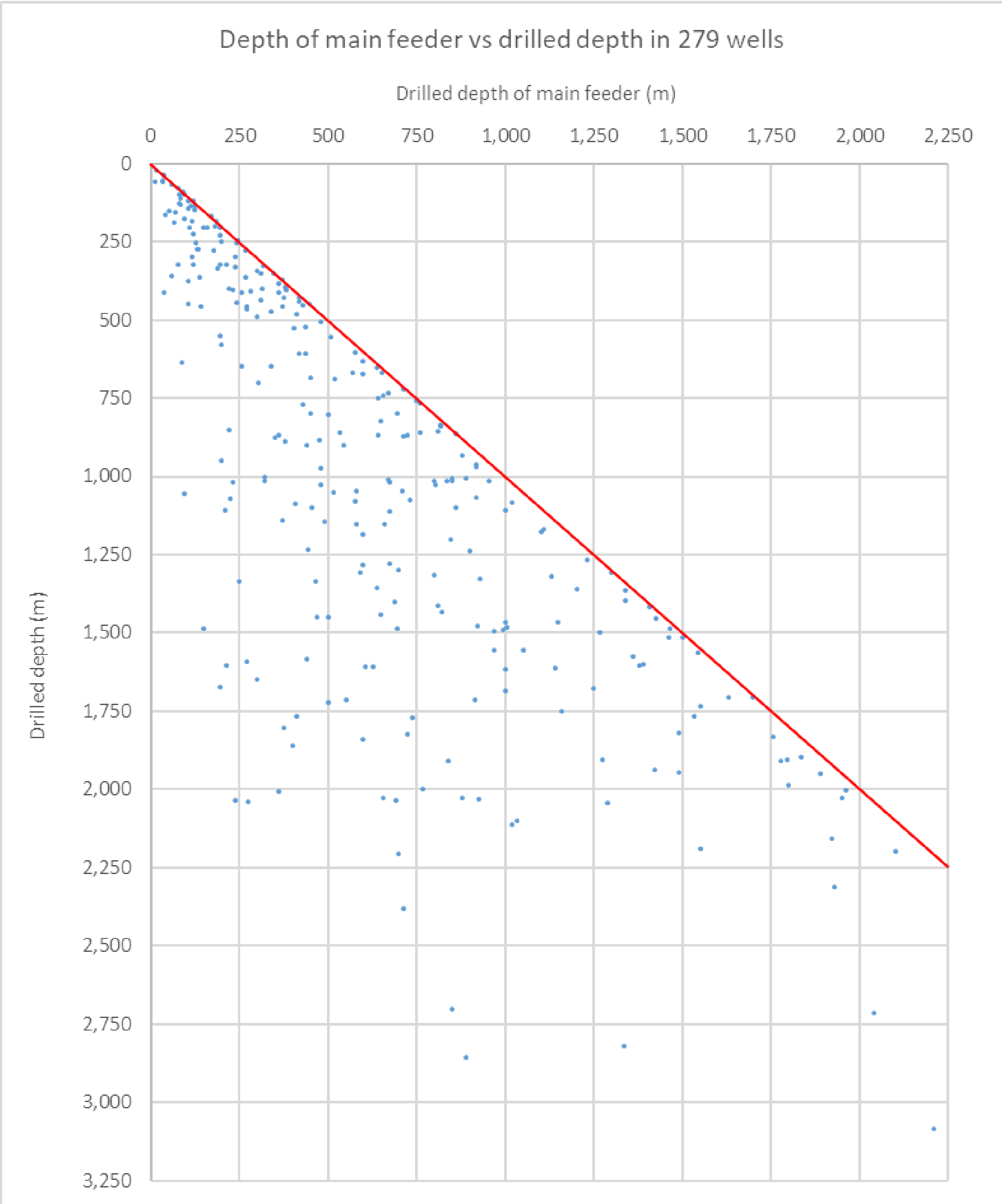

Figure 142. *Depth of main feeder vs drilled depth in 279 wells.*

In many wells drilling was stopped soon after the well had intersected the main feeder.

6.1.6 Discharge

Data on discharge are available for 252 production wells. The discharge is sometimes free flow but is usually obtained by downhole pumping of the wells. The average yield of the 252 wells is 25.6 l/s and the weighted average temperature for 237 wells is 88.3°C.

Fig. 143 shows the frequency distribution of the yield of wells.

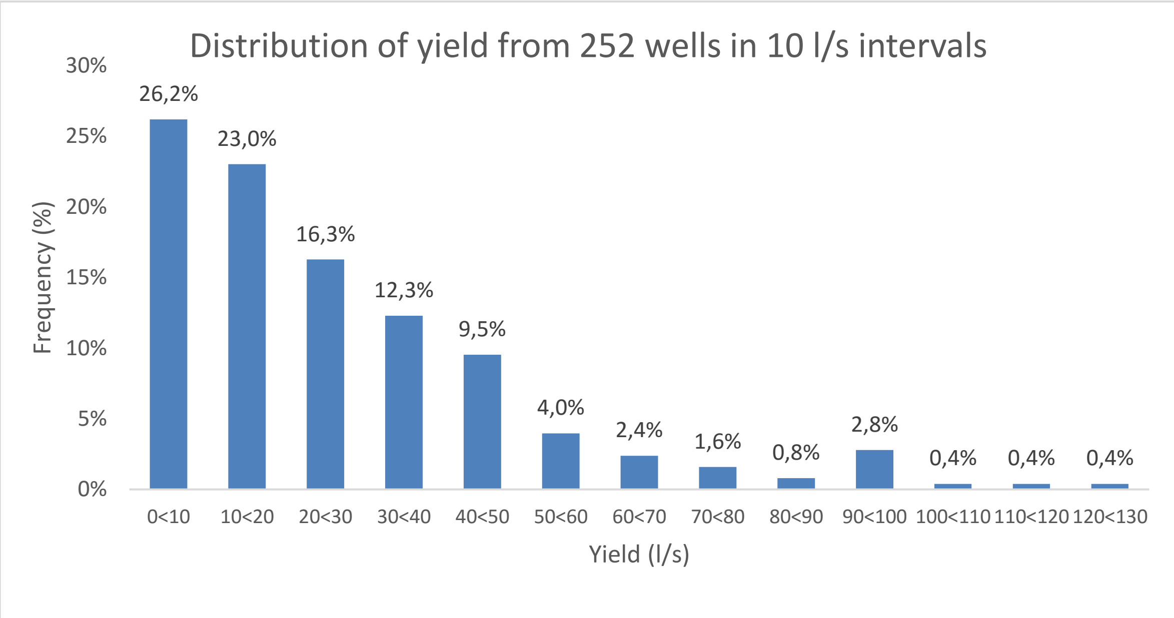

Figure 143. *Frequency distribution of discharge from 252 wells.*

About 49.2% of the wells yield a flow less than 20 l/s, 77.8% yield less than 40 l/s and 91.2% less than 60 l/s. The remaining 8.8% have a yield in the range 60-120 l/s.

Fig. 144 compares the yield of wells to the depth of the main feeder in 234 wells.

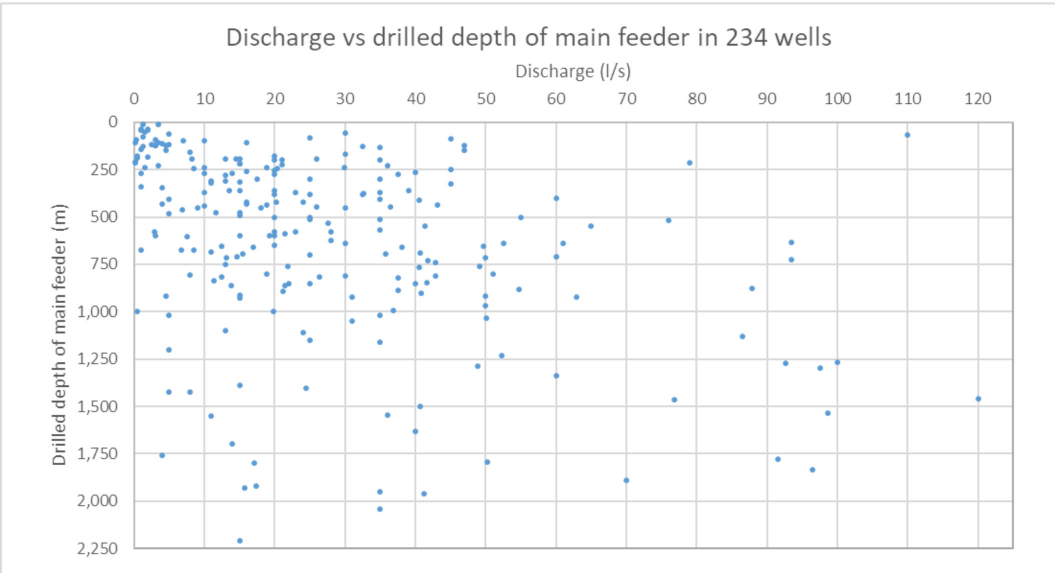

Figure 144. *Discharge and depth of the main feeder in 234 wells.*

Feeders shallower than 500 m rarely yield more than 50 l/s. Wells with feeders in the depth range 500-1,000 m often give a yield up to 65 l/s and wells with feeders between 1,000 and 2,000 m may have a yield up to 100 l/s.

Fig. 145 compares yield of wells to the discharge temperature in 237 wells.

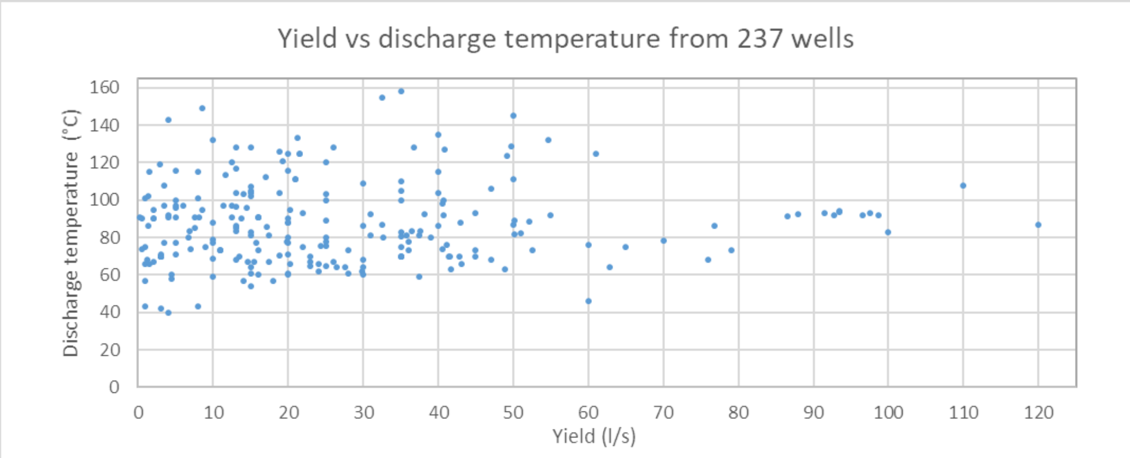

Figure 145. *Yield and discharge temperature from 237 wells.*

Wells with highest yield have discharge temperatures between 80 and 100°C but there is no other tendency to be seen.

Of the 164 wells now in use 148 wells have a potential discharge in the range of 5 to 120 l/s, 8 wells between 3 and 5 l/s, 6 wells between 1 and 3 l/s, and 2 wells have unknown yield.

The average discharge potential of 162 wells now in use is 31.7 l/s and the weighted average discharge temperature 90.3°C.

6.1.7 Success of wells

The minimum criterion used here for success of wells for space heating is set at discharge temperature of 60°C. Fig. 146 shows that 87.9% of the 446 drilled production wells fulfilled this criterion.

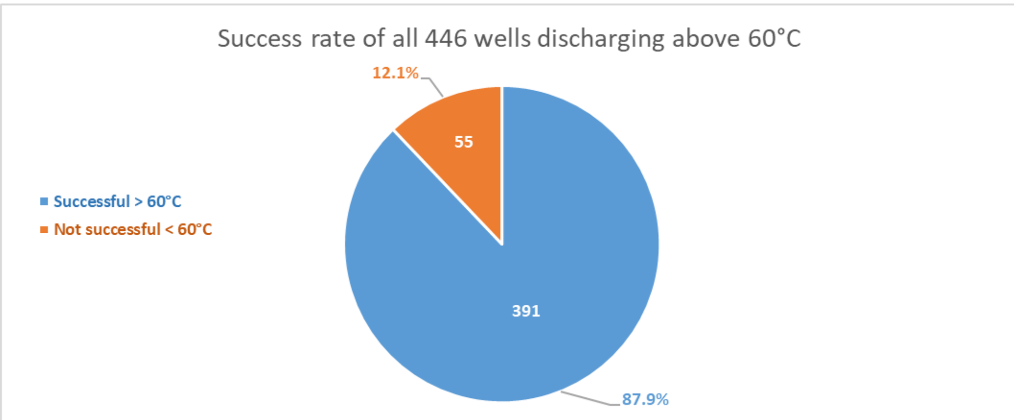

Figure 146. *Success rate of wells with discharge temperature above 60°C.*

Fig. 147 shows the cumulative average success percentage rate for drilled wells that met the criterion of discharge temperature above 60°C. The cumulative average begins at a rate of 78% but climbs steadily up to a value of 86%.

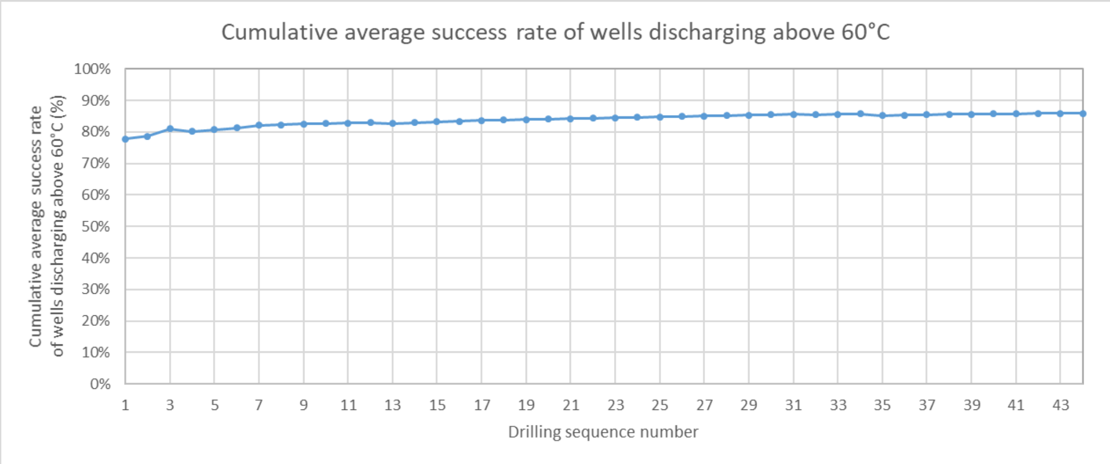

Figure 147. *Learning Curve for successful wells discharging above 60°C by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1928.*

Fig. 148 shows the proportion of the 164 wells now in use that reach the criterion of 60°C. Only 8 wells now in use do not reach this criterion.

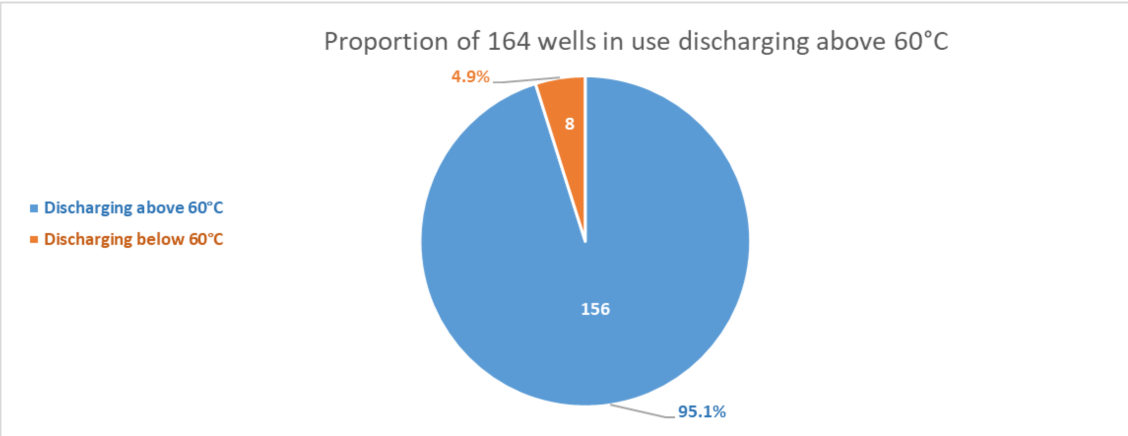

Figure 148. *Proportion of 164 wells drilled since 1928 and still in use that yield a discharge above 60°C.*

Although a discharge temperature of 60°C is useable for direct space heating a temperature of 80°C is preferred if available. Fig. 149 shows the success rate with that criterion.

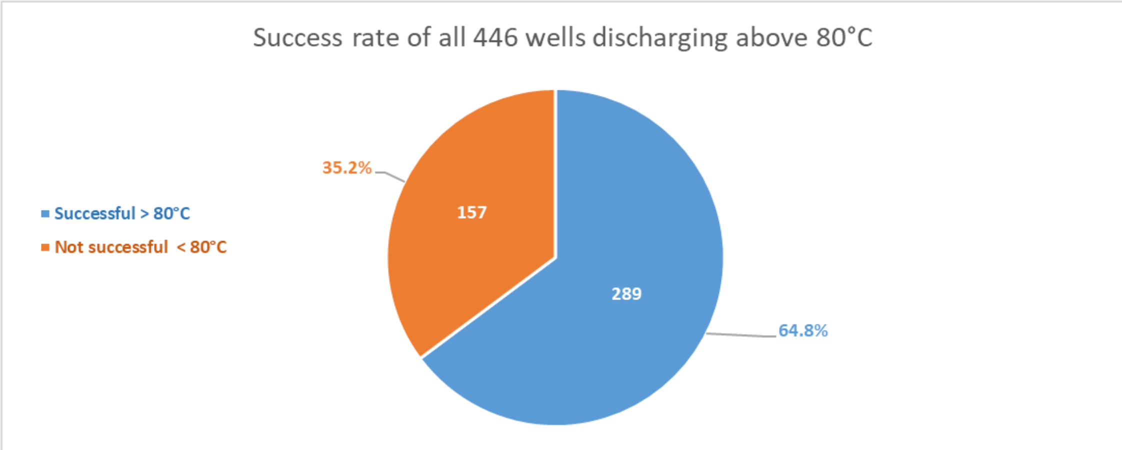

Figure 149. *Success rate of wells with discharge temperature above 80°C.*

About 64.8% of the 446 drilled production wells were successful in achieving discharge temperatures of 80°C.

Fig. 150 shows cumulative average success rate percentage of all drilled wells that met the criterion of a discharge temperature above 80°C. The average starts at about 41%, reaches 49% in the third well and then rises steadily to a final value of 62%.

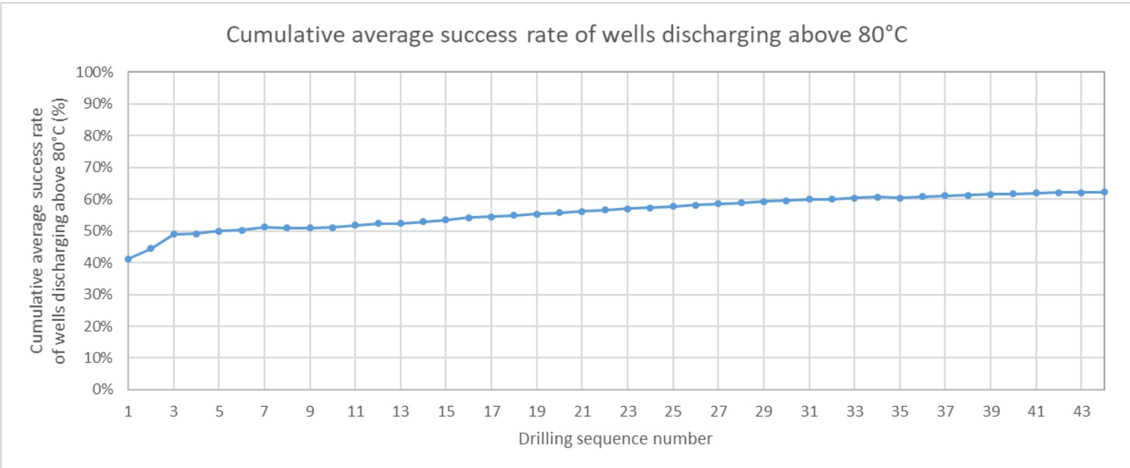

Figure 150. *Learning curve for successful wells discharging above 80°C by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1928.*

Fig. 151 shows the proportion of the 164 wells now in use that reach the criterion of 80°C. About 58 wells now in use do not reach this criterion.

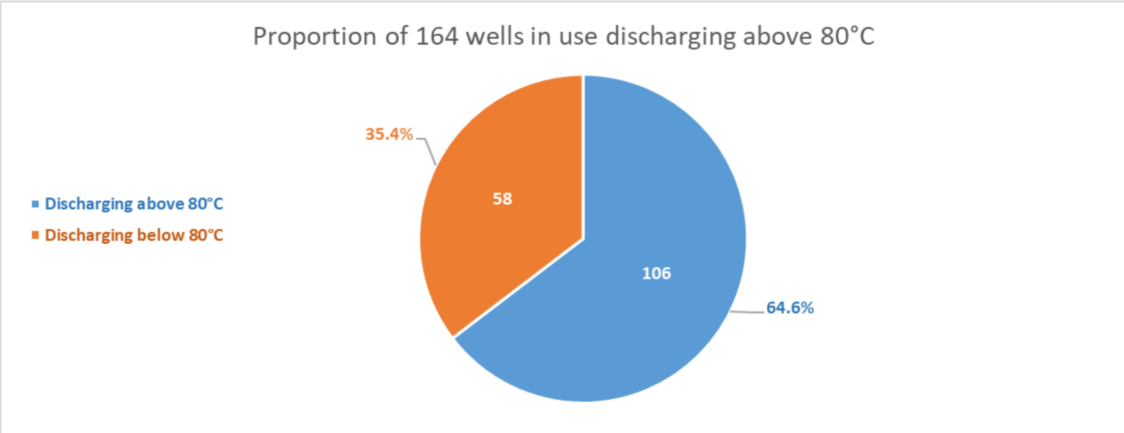

Figure 151. *Proportion of 164 wells drilled since 1928 and still in use that yield a discharge above 80°C.*

Fig. 152 shows the number of successful wells, discharging above 60°C and 80°C, drilled in each decade from 1928 to 2017.

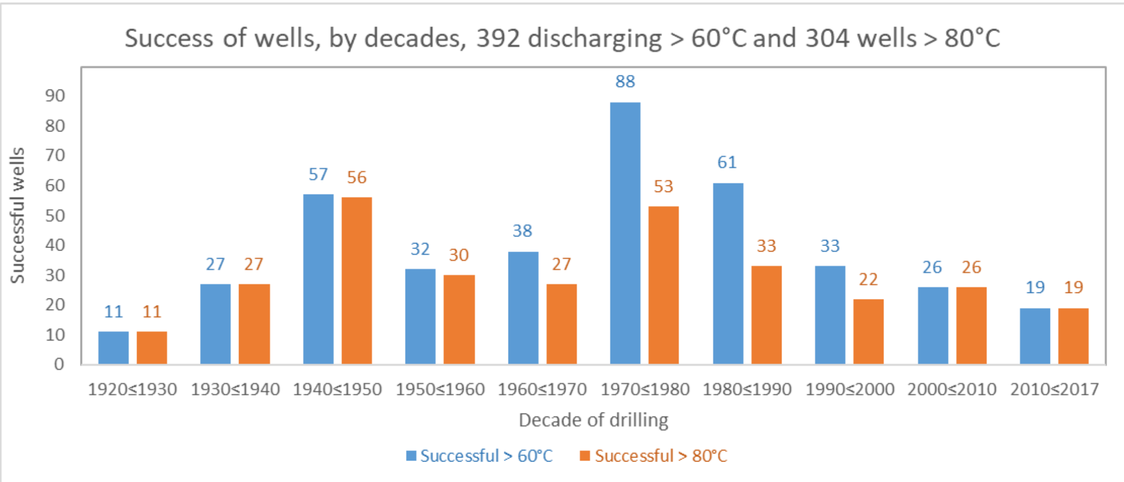

Figure 152. *Successful wells with discharge temperature above 60°C and 80°C, by decade of drilling.*

In the decades 1920-1960 and 2000-2017 all successful wells reached both the 60°C and the 80°C limit but in the decades 1960-2000 more wells were drilled that only reached the 60°C limit. That reflects the increased demand for geothermal heating which led to drilling in well fields of lower temperature in the decades from year 1960 to 2000. After 2000 the drilling has again focused on hotter fields.

6.2 Analysis of 320 production wells drilled since 1958

As already stated all wells drilled in the first decades from 1928 to 1958 were drilled by small rigs. The wells were narrow and shallower than 500 m. Since 1958 large oil well drilling rigs took over and deeper wide wells that could accommodate downhole pumps were drilled. These periods are therefore not directly comparable and an analysis of wells drilled after 1957 is more likely to deliver results that are valid for present technology.

6.2.1 Description of wells

The report analyses 320 production low and medium enthalpy wells drilled in the years 1958-2017. The purpose of drilling was to find hot water (310 wells) or steam (10 wells). The average age of these wells is 35.4 years. The elevation of wellhead is known for 215 wells and averages 56.1 m a.s.l. Most of the wells, or 308, were drilled vertically, only 12 are drilled directionally. Data for drilled depths are available for 318 wells and range from 20 to 3,085 m with an average of 955.5 m. Fig. 153 shows the drilled depth of 318 wells through the period 1958-2017.

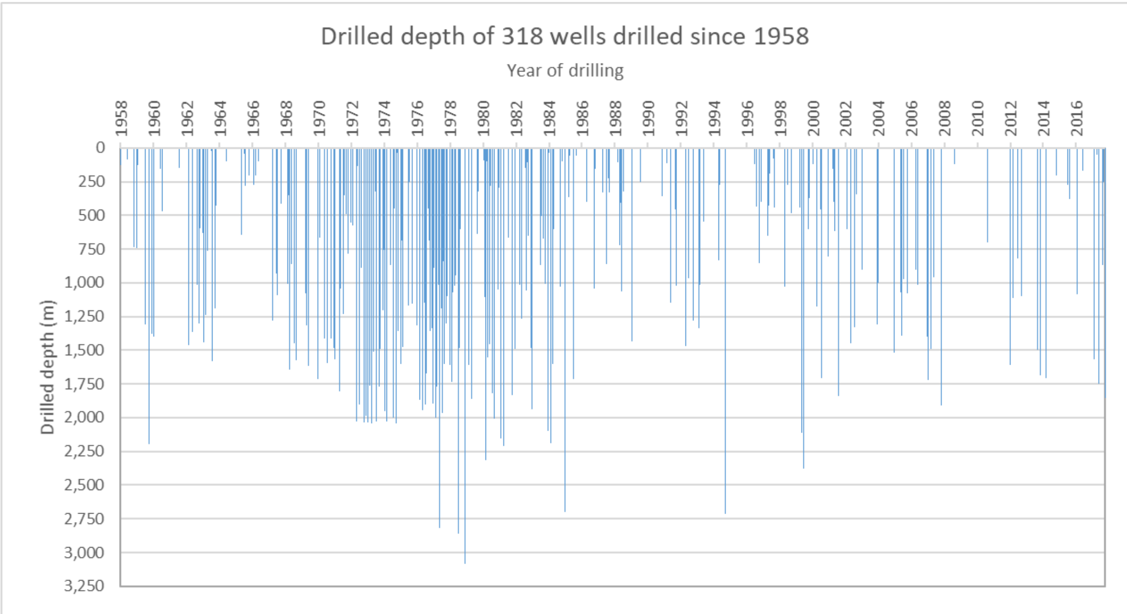

Figure 153. *Drilled depths of 318 wells drilled since 1958, through years of drilling.*

The first well deeper than 2,000 m was drilled in 1959. Drilling became intensive in 1968 and continued so through the seventies up to 1985. This was a period of re-drilling some of the fields with many wells reaching 2,000 m and the deepest well beyond 3,000 m.

Fig. 154 shows the number of wells and frequency distribution of drilled depths of these wells in 300 m depth intervals.

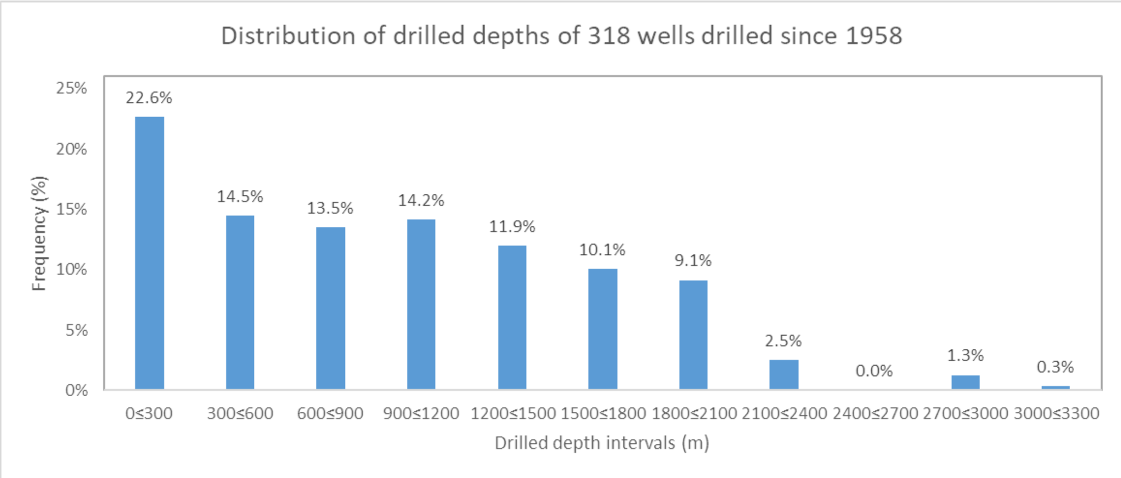

Figure 154. *Distribution of drilled depths of 318 wells drilled since 1958.*

About 37.1% of the wells are shallower than 600 m, 27.7% in the range of 600-1,200 m, 31.1% in the range of 1,200-2,100 m, and 4.1% deeper than 2,100 m.

The average depth of the production casing is 201 m (288 wells). The outside diameter of the casing is known in 282 wells. The most common diameters are $10^{3/4}$ inches (83 wells), $9^{5/8}$ (44 wells), $8^{5/8}$ (41 wells) and $13^{3/8}$ (33 wells). In the production section below the production casing the most common drill bit diameters are $8^{1/2}$ inches (63 wells) and $8^{3/4}$ inches (52 wells).

6.2.2 Productive wells

Of the 320 drilled production wells, 297 or 92.8% were productive, i.e. encountered feeders that could yield a flow from the well, either free-flow or discharge with the aid of air-lifting or downhole pumps, see Fig. 155.

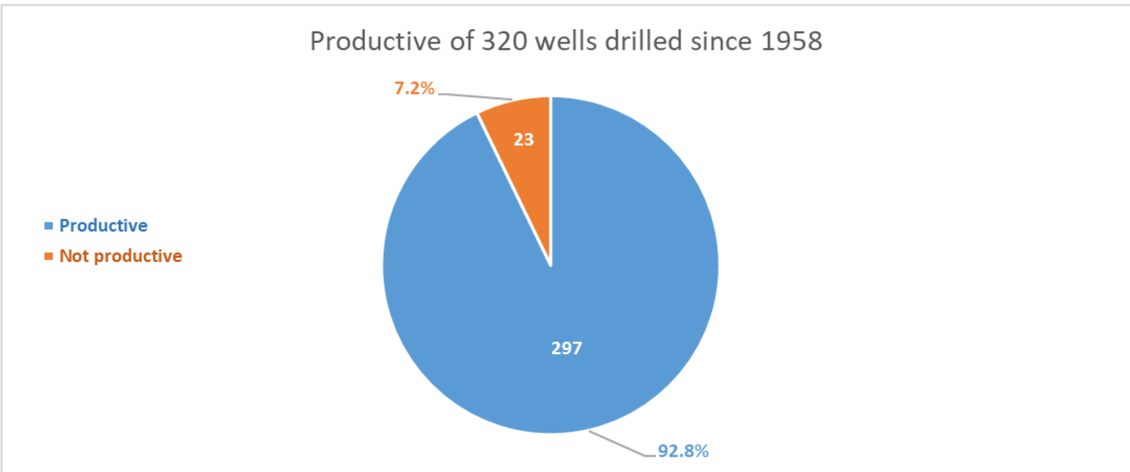

Figure 155. *Productivity of 320 wells drilled since 1958.*

Fig. 156 shows the number of drilled wells and productive wells by decades.

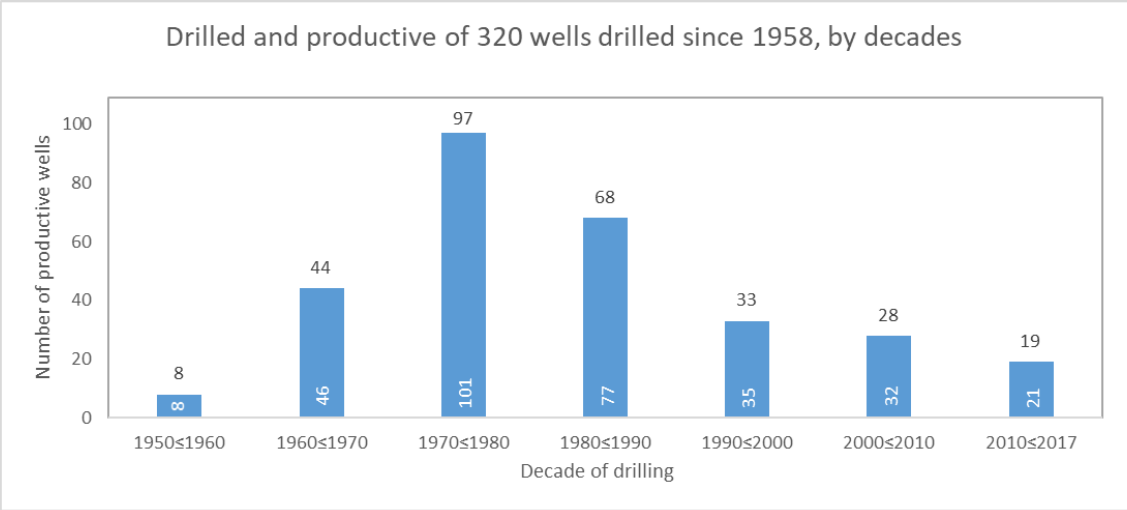

Figure 156. *Drilled (white data) and productive wells of 320 wells drilled since 1958, by decades of drilling.*

Data on yield are available for 242 of the 297 productive wells. About 204 of these wells had a yield above 5 l/s, 16 wells a yield between 3 and 5 l/s, and 22 wells between 1 and 3 l/s.

Of the twenty-three wells that were not productive, fifteen found no feeders, six were reported cold and not yielding, one failed due to drilling problems and one of unknown reason, see Fig. 157.

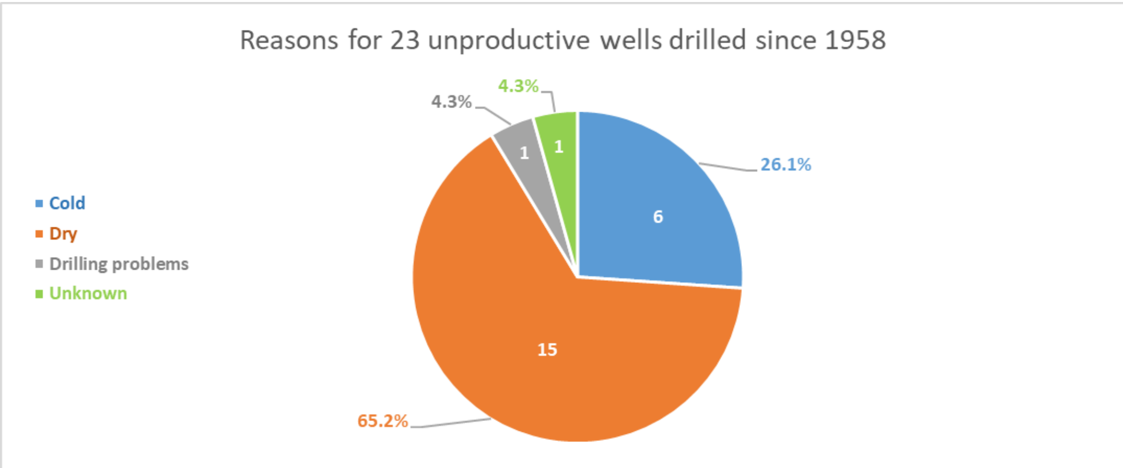

Figure 157. *Reasons for 23 not productive wells drilled since 1958.*

It is to be expected that the first wells drilled in a field are less likely to be successful than subsequent wells, as the developer gains a better understanding of the size, location, and dynamics of the targeted reservoir. Fig. 158 shows the development in the cumulative average success rate percentage of all drilled wells since 1958 that were productive.

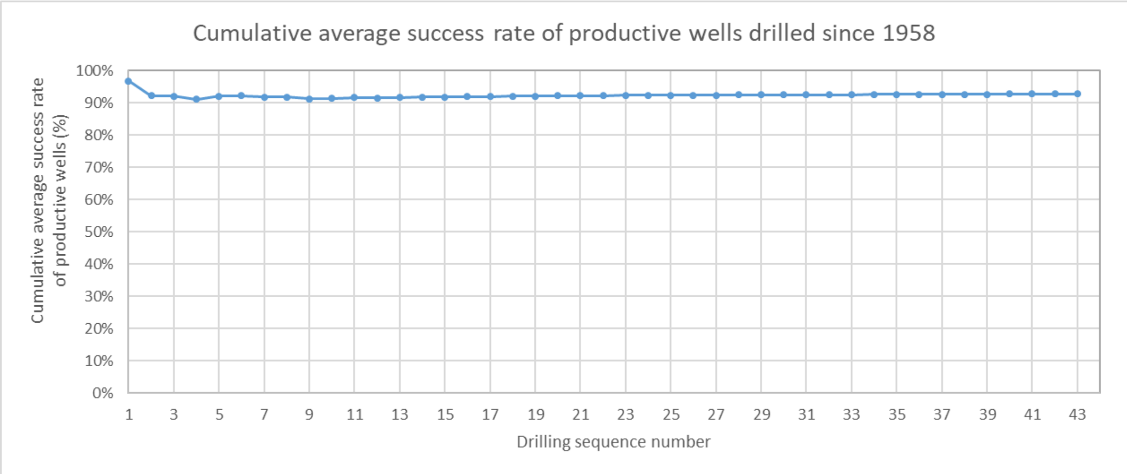

Figure 158. *Learning curve for productive wells by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1958.*

The cumulative average starts at 97% bit drops down to 92% by well 2 and stays at that level.

6.2.3 Status of wells

Of the 320 wells drilled 297 were productive and 160, or half of the wells, are still in use, see Figs. 159 and 160. The average age of the wells in use is 32.0 years.

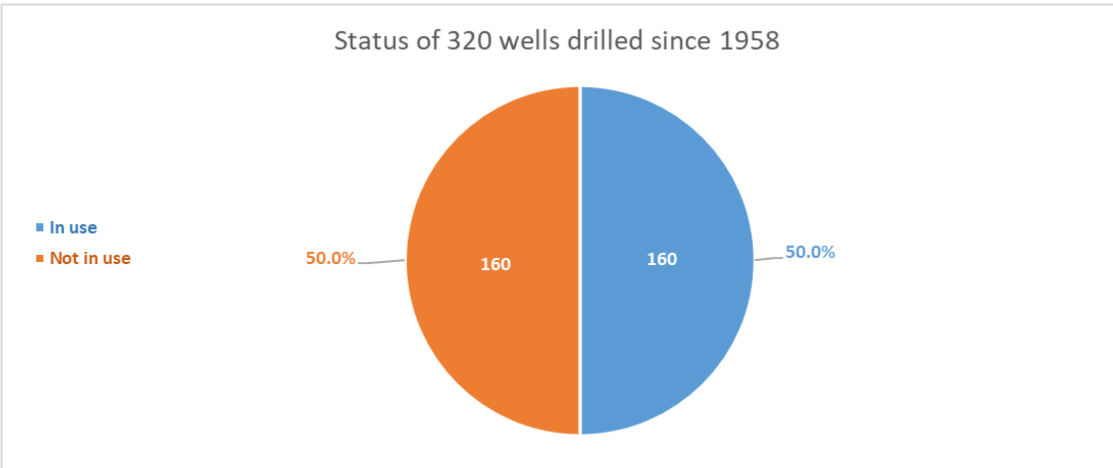

Figure 159. *Status of 320 wells drilled since 1958.*

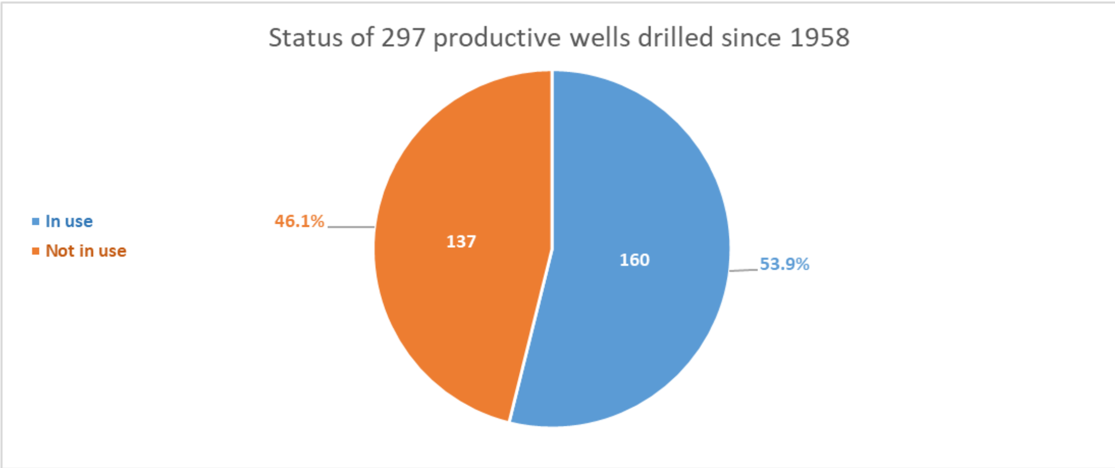

Figure 160. *Status of 297 productive wells drilled since 1958.*

Of 297 initially productive wells, 160 or 53.9% are still in use.

Fig. 161 shows wells in use and decade of drilling.

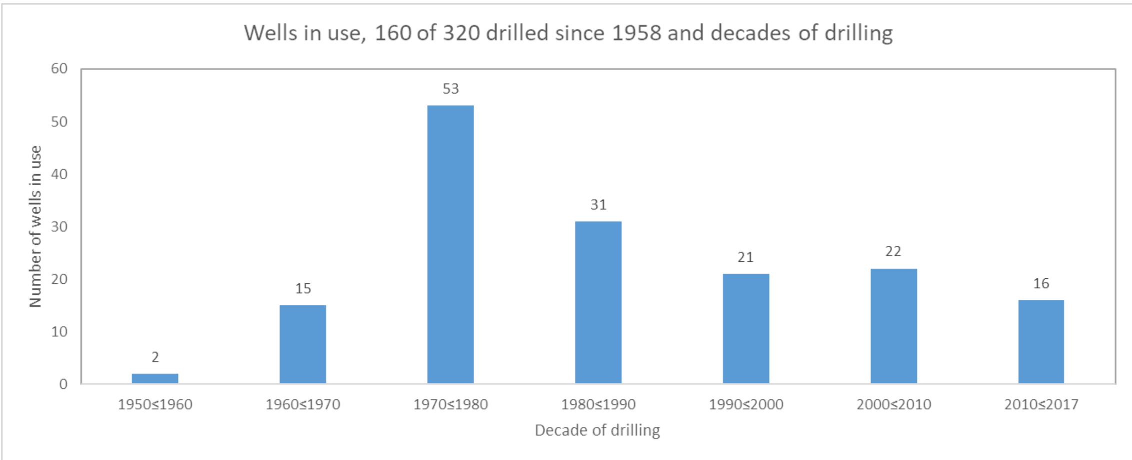

Figure 161. *Wells drilled since 1958 in use and decades of drilling.*

Two wells drilled in 1959 are still in use. Of the 160 wells in use 15 were drilled in 1960-1970, 53 were drilled in 1970-1980 and 31 well in 1980-1990.

Fig. 162 explains why 137 of the 297 productive wells drilled since 1958 are not in use.

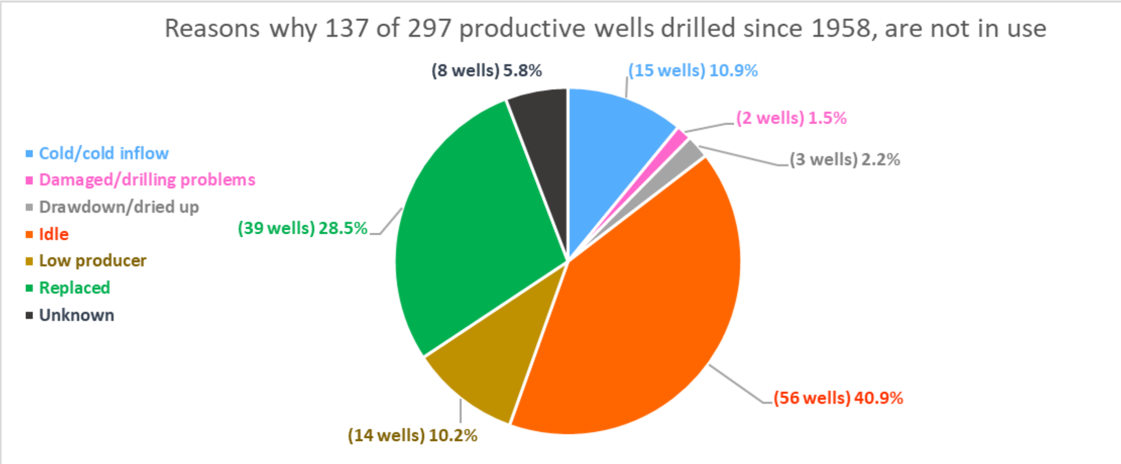

Figure 162. *Reasons why 137 of 297 productive wells drilled since 1958, are not in use today.*

About 10.9% of these wells are cold or have a cold inflow, 1.5% are damaged, 2.2% have dried up due to drawdown of reservoir pressure, 40.9% are idle but could produce, 10.2% are low producers, 28.5% have been replaced by better wells and 5.8% are not in use but for unknown reasons.

6.2.4 Downhole temperature

Maximum downhole temperature

Fig. 163 shows the frequency distribution of maximum downhole temperatures in 314 wells.

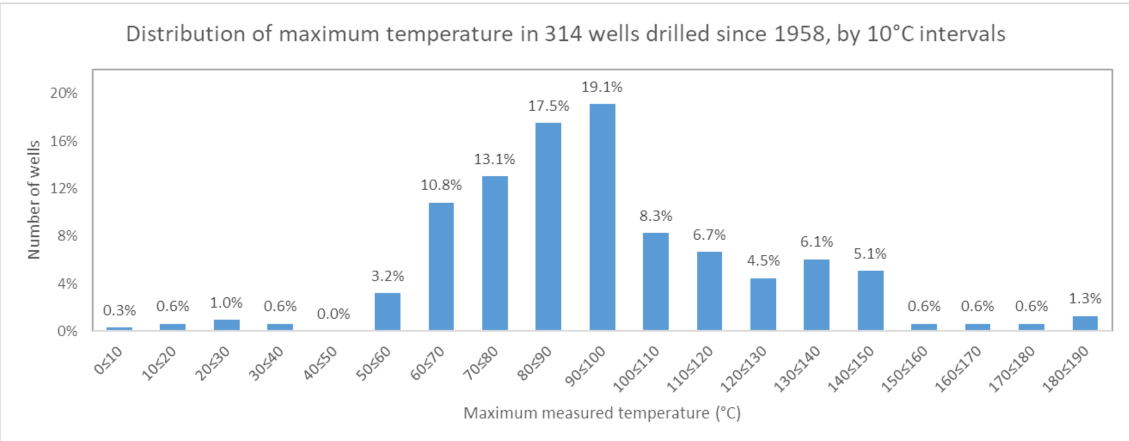

Figure 163. *Distribution of maximum measured temperature in 314 wells drilled since 1958, by 10°C intervals.*

The maximum temperature ranges from 9°C to 184°C. The average is 95°C and 68.8% of the wells have maximum downhole temperatures in the range of 60 to 110°C. The highest measured temperature of 184°C is in well HS-6 in Hveragerði. The drilled depth down to the maximum temperature averages 710 m (303 wells).

6.2.5 Main feeder

Fig. 164 shows the frequency distribution of the drilled depth down to the main feeder in 267 wells.

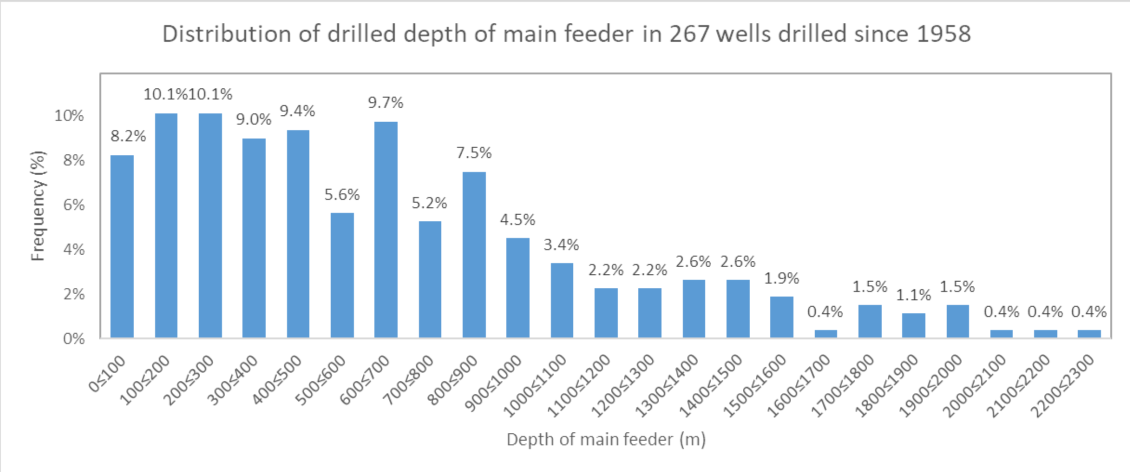

Figure 164. *Distribution of drilled depth of main feeder in 267 wells drilled since 1958.*

About 46.8% of the main feeders are shallower than 500 m, 79.3% are shallower than 1,000 m and 94.2% are shallower than 1,600 m. The average temperature of the main feeder was found to be 88.7°C (266 wells).

Fig. 165 compares the depth down to the main feeder against the final drilled depth of the well.

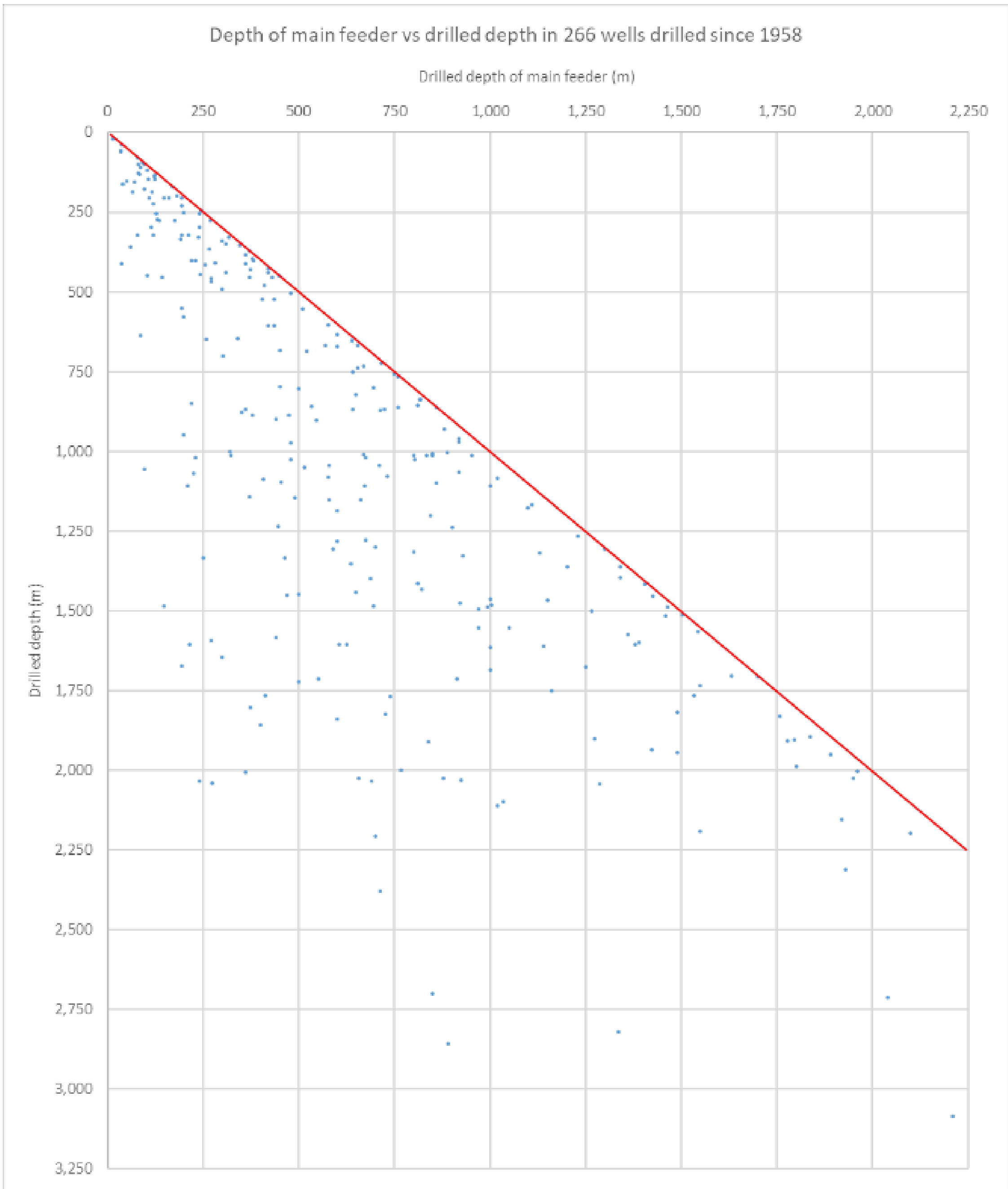

Figure 165. *Depth of main feeder versus drilled depth in 266 wells drilled since 1958.*

In many wells drilling was stopped soon after the well had intersected the main feeder. As shown in Fig. 165, about 94% of the main feeders are found above 1,600 m depth and only three of the wells have a main feeder deeper than 2,000 m.

6.2.6 Discharge

Data on discharge are available for 242 production wells. The discharge is sometimes free flow but most times obtained by downhole pumping of the wells. The average yield of the 242 wells is 26.6 l/s and the weighted average temperature for 228 wells is 88.4°C. Fig. 166 shows the frequency distribution of the yield of wells.

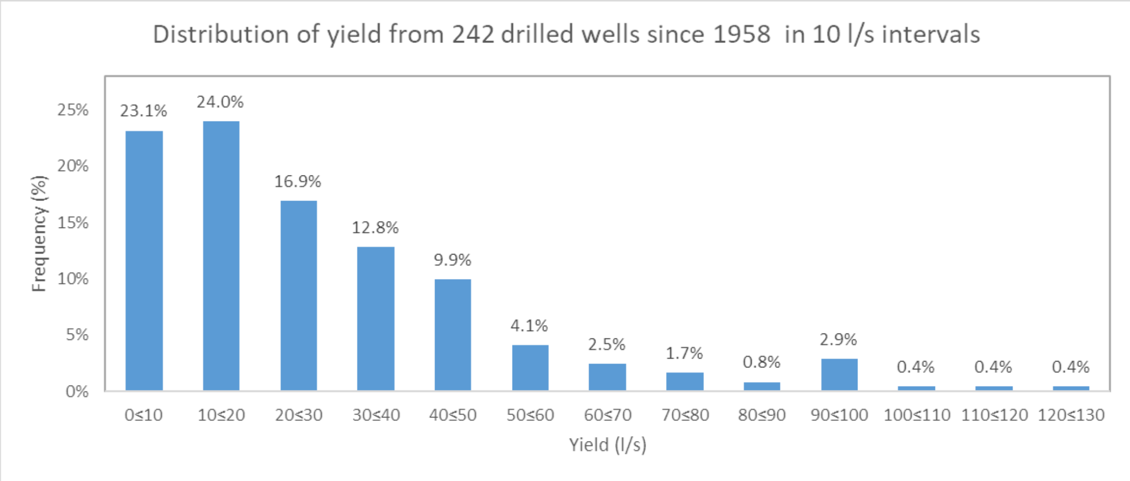

Figure 166. *Distribution of discharge from 242 wells drilled since 1958.*

About 47.1% of the wells yield a flow less than 20 l/s, 76.8% yield less than 40 l/s and 90.8% less than 60 l/s. The remaining 9.2% have a yield in the range 60-120 l/s.

Fig. 167 compares the yield of wells to the depth of the main feeder in 226 wells.

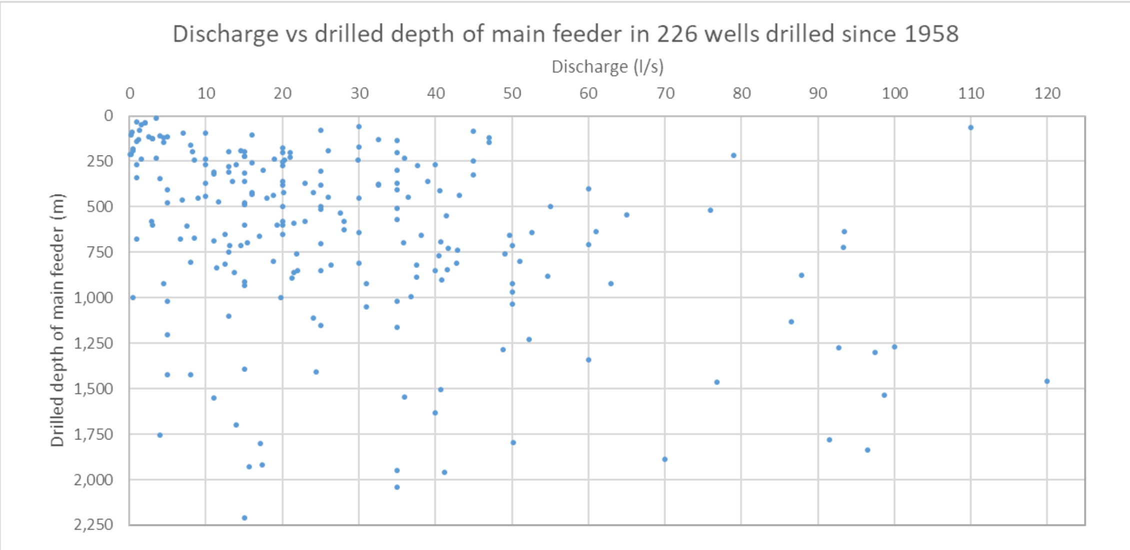

Figure 167. *Discharge versus drilled depth of main feeder in 226 wells drilled since 1958.*

Wells with feeders shallower than 500 m rarely yield more than 50 l/s. Wells with feeders in the depth range 500-1,000 m often give a yield up to 65 l/s and wells with feeders between 1,000 and 2,000 m may have a yield up to 100 l/s.

Fig. 168 compares yield of wells to the discharge temperature in 228 wells.

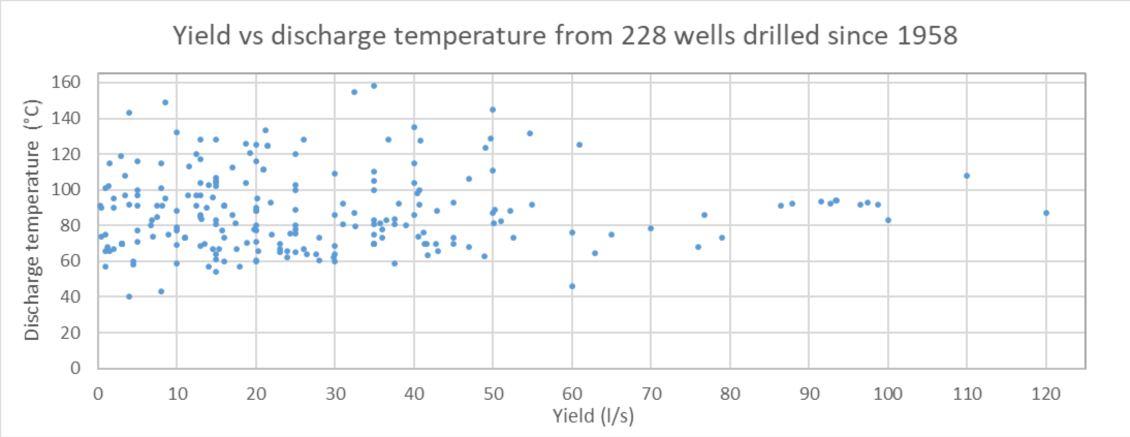

Figure 168. *Discharge versus discharge temperature in 228 wells drilled since 1958.*

Wells with highest yield have discharge temperatures between 80 and 100°C but there is no other tendency to be seen.

Of the 160 wells now in use, 147 wells have a potential discharge in the range 5 to 120 l/s, 6 wells between 3 and 5 l/s, 5 wells between 1 and 3 l/s, and 2 wells have unknown yield.

The average discharge of 158 wells currently in use is 32.4 l/s and the weighted average discharge temperature 90.3°C.

6.2.7 Success of wells

The minimum criterion used here for success of wells for space heating is set at discharge temperature of 60°C. Fig. 169 shows that 85.3% of the 320 drilled production wells drilled since 1958 fulfilled this criterion.

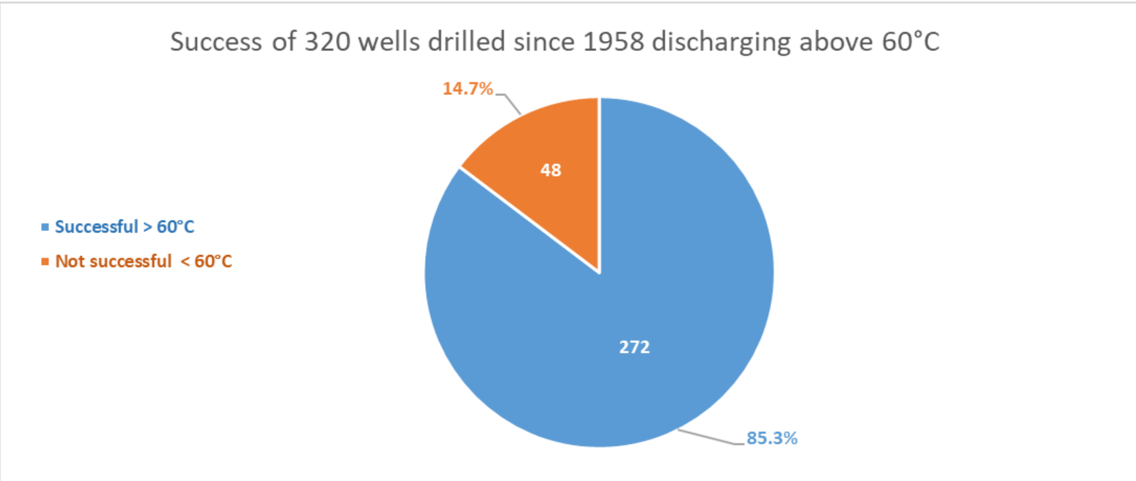

Figure 169. *Success of 320 wells drilled since 1958 with discharge above 60°C.*

Fig. 170 shows the development in the cumulative average success rate percentage for wells drilled since 1958, which reached the success limit of discharge temperature above 60°C.

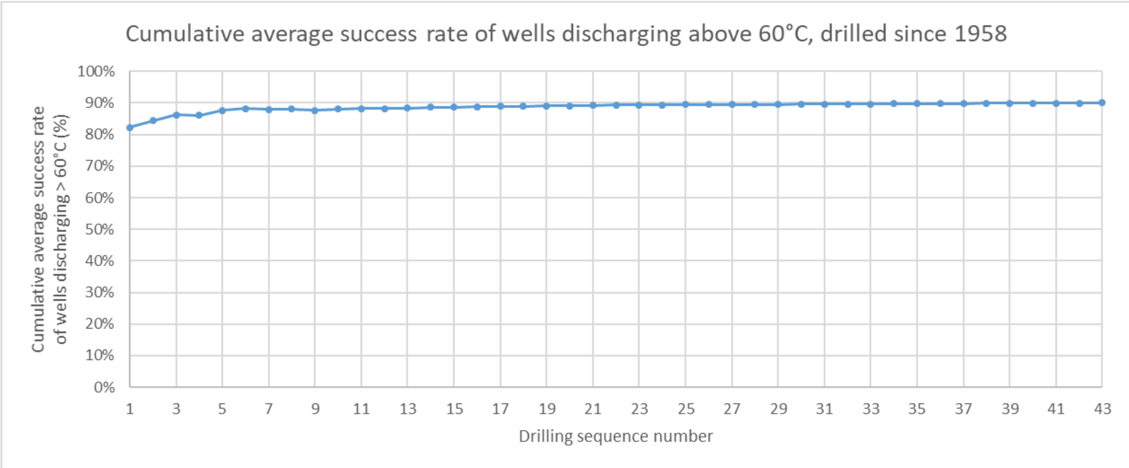

Figure 170. *Learning curve for successful wells discharging above 60°C by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1958.*

The cumulative average starts at 82%, climbs to 88% in the first 5 wells and reaches a plateau of 90% by well 21.

Fig. 171 shows the proportion of the 160 wells now in use that reach the criterion of 60°C. Only 7 wells now in use do not reach this criterion.

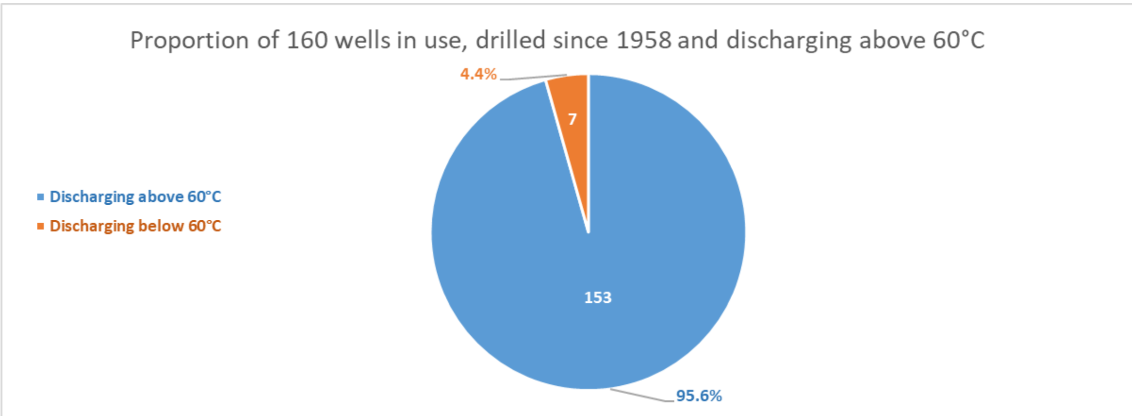

Figure 171. *Proportion of 160 wells drilled since 1958 and still in use that yield a discharge above 60°C*

Although a discharge temperature of 60°C is useable for direct space heating a temperature of 80°C is preferred if available. Fig. 172 shows the percentage of drilled wells that fulfilled that criterion.

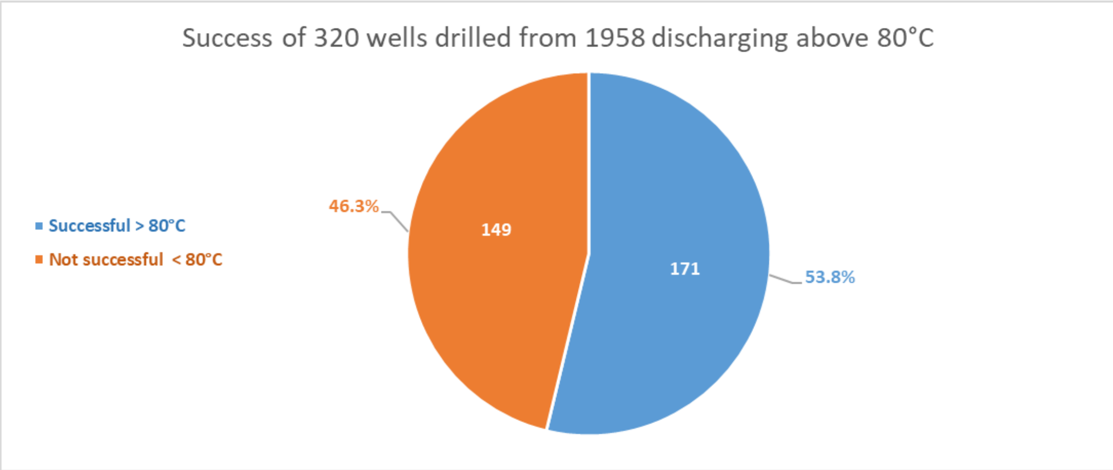

Figure 172. *Success of 320 wells drilled since 1958 with discharge above 80°C.*

About 53.8% of the 320 drilled production wells were successful in achieving discharge temperatures of 80°C.

Fig. 173 shows the development in the cumulative average success rate percentage for wells drilled since 1958 that reached the success limit of discharge temperature above 80°C.

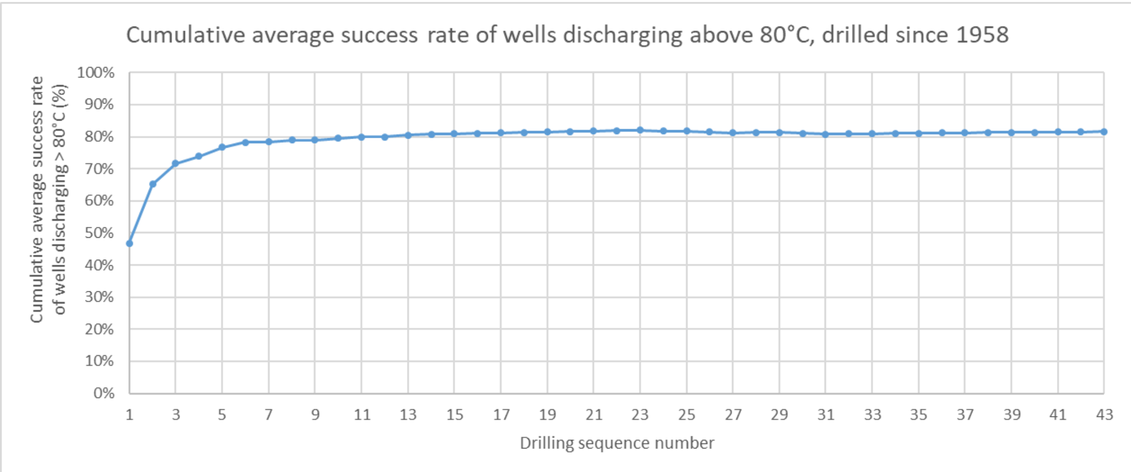

Figure 173. *Learning curve for successful wells discharging above 80°C by drilling sequence in geothermal fields - Cumulative average success rate percentage of all wells drilled since 1958.*

The cumulative average starts at some 47%, reaches 72% in well 3, 79% in well 7 and stabilizes just above 80%.

Fig. 174 shows the proportion of the 160 wells now in use that reach the criterion of 80°C. About 56 wells now in use do not reach this criterion.

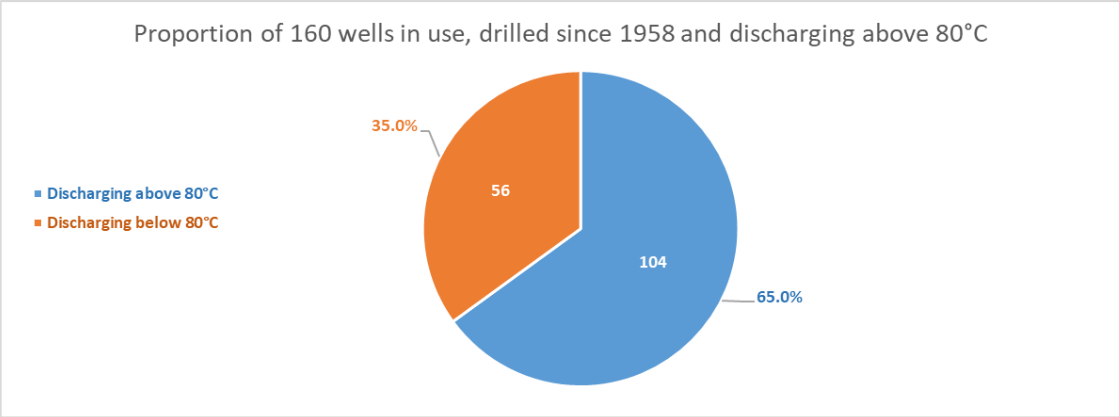

Figure 174. *Proportion of 160 wells drilled since 1958 and still in use that yield a discharge above 80°C.*

Fig. 175 shows the number of successful wells with discharge temperature above 60°C and 80°C, drilled in each decade since 1958.

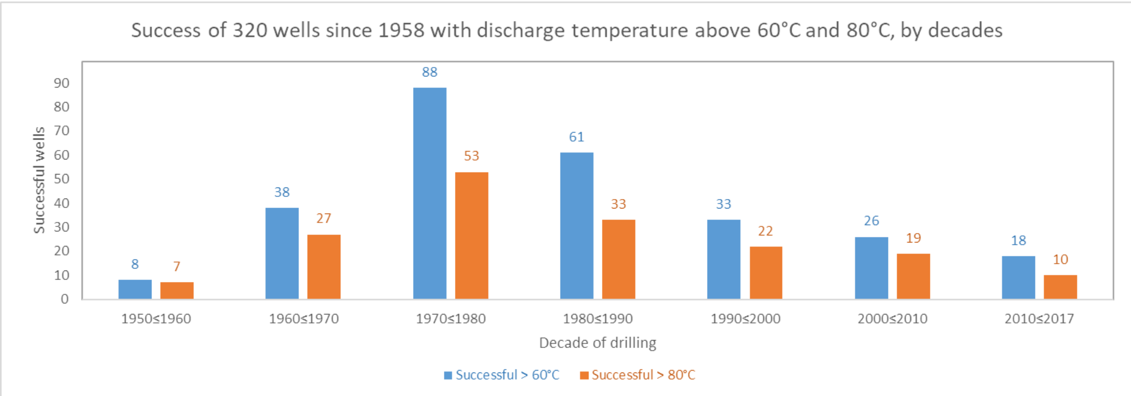

Figure 175. *Success of wells drilled since 1958, with discharge above 60°C and 80°C, by decades of drilling.*

In the decades 1920-1960 and 2000-2017 most successful wells reached both the 60°C and the 80°C limit but in the decades 1960-2000 more wells were drilled that only reached the 60°C limit. That reflects the increased demand for geothermal heating which led to drilling in well fields of lower temperature in the decades from 1960-2000. After 2000 the drilling has again focused on hotter fields.

6.3 Comparison of all 446 production wells drilled since 1928 and 320 production wells drilled since 1958

Because of the change in drilling technology that took place in 1958 it was considered necessary to compare the statistical results obtained for the group of all wells drilled since 1928 to those of the subgroup of drilled wells since 1958. Table 9 shows statistical difference between the groups.

Table 8. *Comparison of productivity, status, success and discharge of all drilled wells since 1928 and wells drilled since 1958.*

Comparison of productivity, status, success and discharge	Wells drilled since 1928		Wells drilled since 1958	
	(Data from wells)	(% & l/s)	(Data from wells)	(% & l/s)
Drilled wells	446	100%	320	100%
Productive wells	419	94%	297	93%
Wells still in use of productive	164	39%	160	54%
Wells still in use of all drilled	164	37%	160	50%
Average discharge	252	25.6 l/s	242	26.6 l/s
Successful wells discharging above 60°C	391	88%	272	85%
Successful wells discharging above 80°C	289	65%	171	53%

The difference in the percentage of productive wells is insignificant, 93% since 1958 against 94% since 1928. The same applies to average discharge of wells, 26.6 l/s against 26.5 l/s. The percentage of productive drilled wells that are still in use is significantly different, 54% since 1958 against 39% since 1928. The same is valid for the percentage of all drilled wells, 50% since 1958 against 37% since 1928. This difference can be explained by the age of wells, and poorer construction of the earliest shallow and narrow wells.

Success rate of wells discharging water above 60°C is slightly higher for the whole period since 1928 than for wells drilled since 1958, 88% against 83%. The success rate for wells discharging water above 80°C is also higher in the whole period, 65% against 53%. One explanation could be that drilling in the initial 30 years favoured hot spring areas where hot water at those temperatures was already found in thermal springs. Since 1958, drilling was also attempted in areas with weaker evidence of geothermal activity that required extensive exploration before production drilling was attempted.

6.4 Thermal power potential

6.4.1 Thermal power potential of well fields

Figs. 176-179 show the thermal power potential above 35°C and above 5°C, calculated for the low and medium enthalpy well fields utilized by the major district heating services and described in this report. Although the report does not cover all low enthalpy and medium enthalpy geothermal fields in Iceland these well fields represent the largest thermal power potential known and presently utilized. As shown in Fig. 176 seven of the eight most powerful well fields are in Mosfellssveit and Reykjavík. Hveravellir in Norðurþing is rated as the third most powerful well field. After these the next well fields are; Hverasvæðið in Hveragerði, Syðra Laugaland in Eyjafjarðarsveit, Þorleifskot in Flóahreppur, Grafarbakki at Flúðir, Arnarnes near Hjalteyri, Efri-Reykir in Bláskóga-byggð, Hellisholt at Flúðir, Ósabotnar in Flóahreppur, Borgarmýrar/Sjávarborg at Sauðárkrókur, Helgafell South in Mosfellsbær, Ærlækjarsel in Öxarfjörður, Möðruvellir in Kjós, Bygggarður on Seltjarnarnes and Reykhólar on Barðaströnd. In well fields where some of the production comes from thermal springs, the share of the springs is indicated with orange colour. Figs. 177 and 179 also show with orange colour the thermal power potential of the hot spring fields utilized where no production wells have yet been drilled. The hot spring Deildartunguhver dominates, ranking in thermal power potential between the fourth and fifth well field.

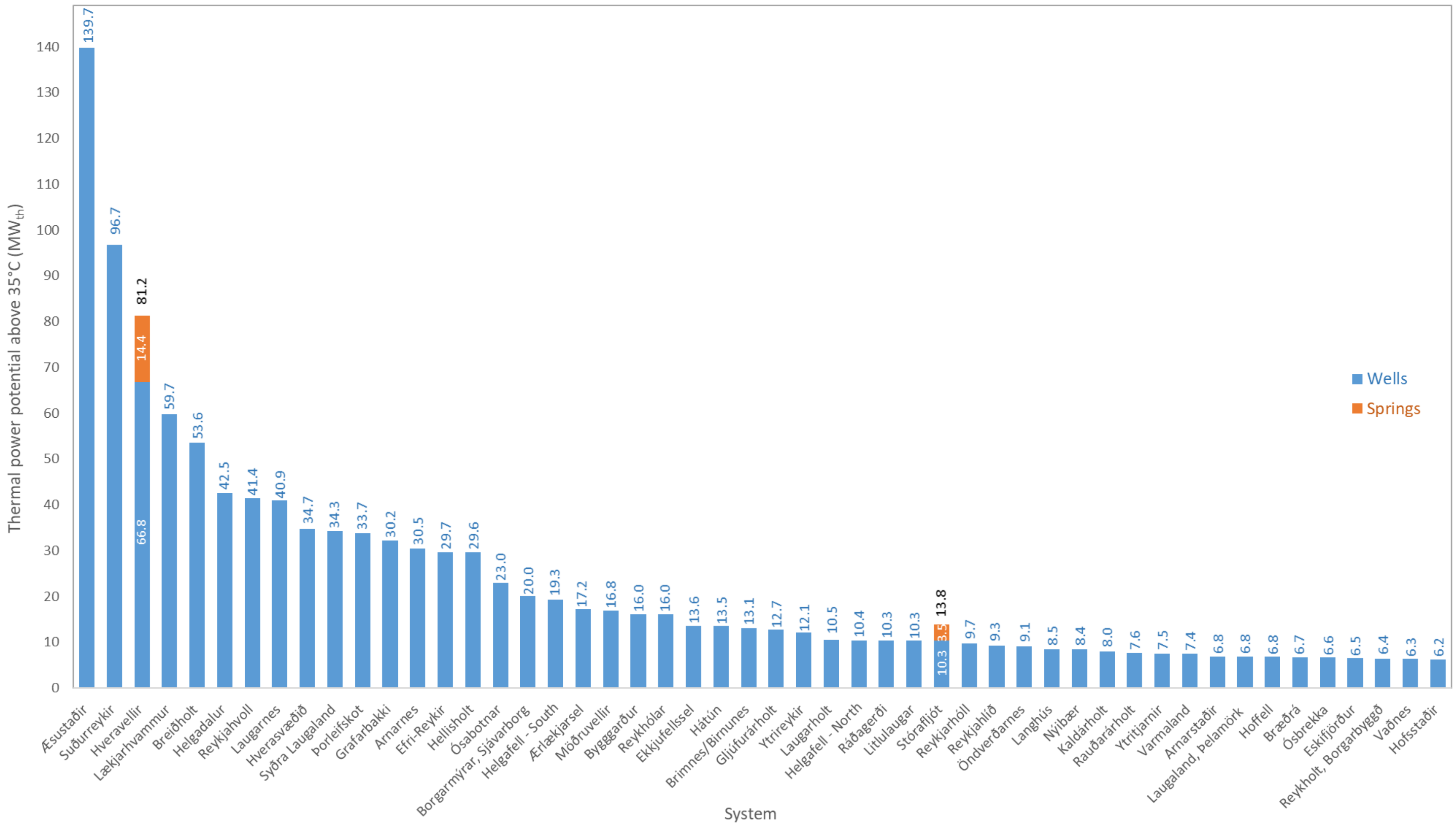

Figure 176. *Thermal power potential above 35°C for 96 well fields utilized by 64 major district heating services in Iceland (1 of 2).*

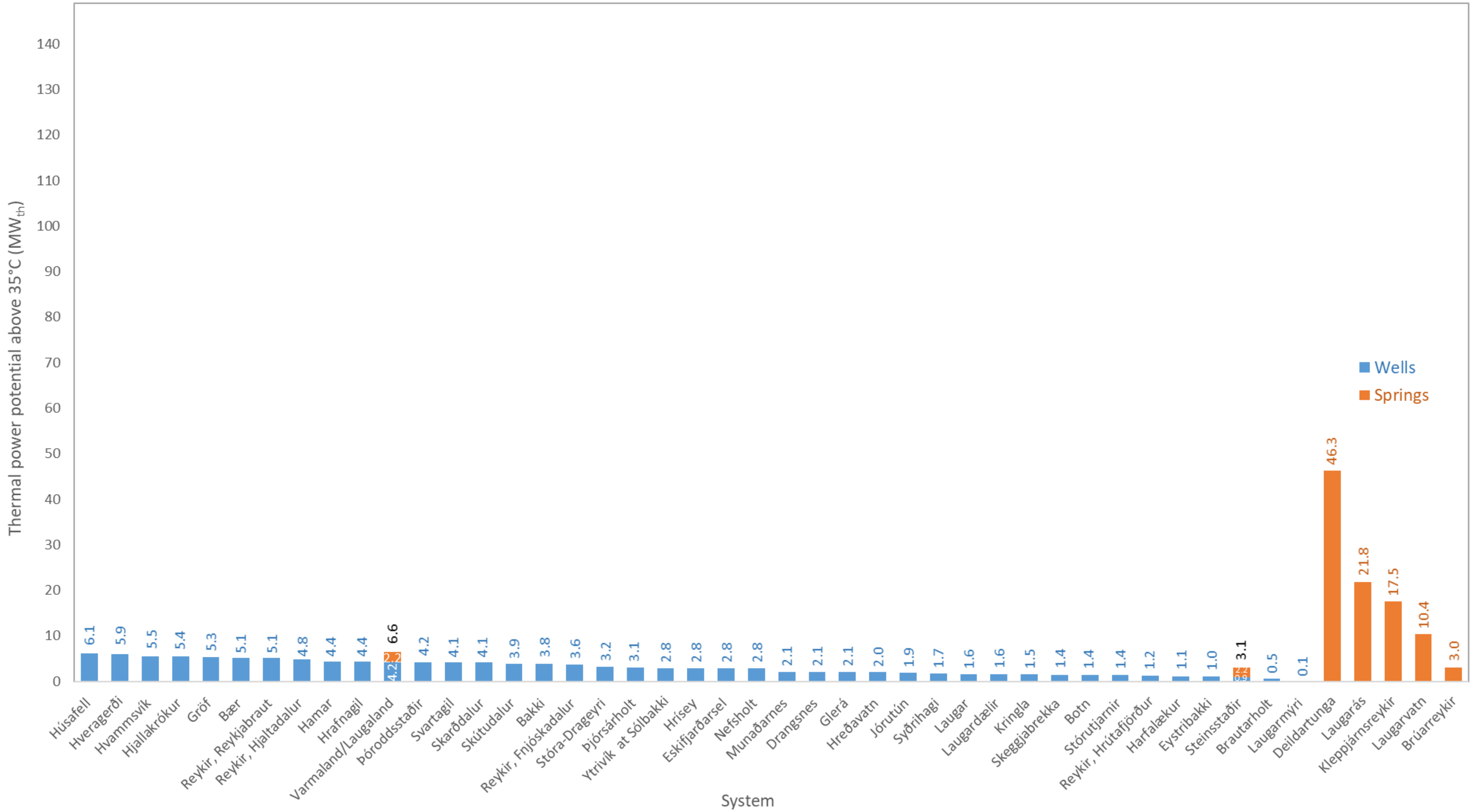

Figure 177. *Thermal power potential above 35°C for 96 well fields utilized by 64 major district heating services in Iceland (2 of 2).*

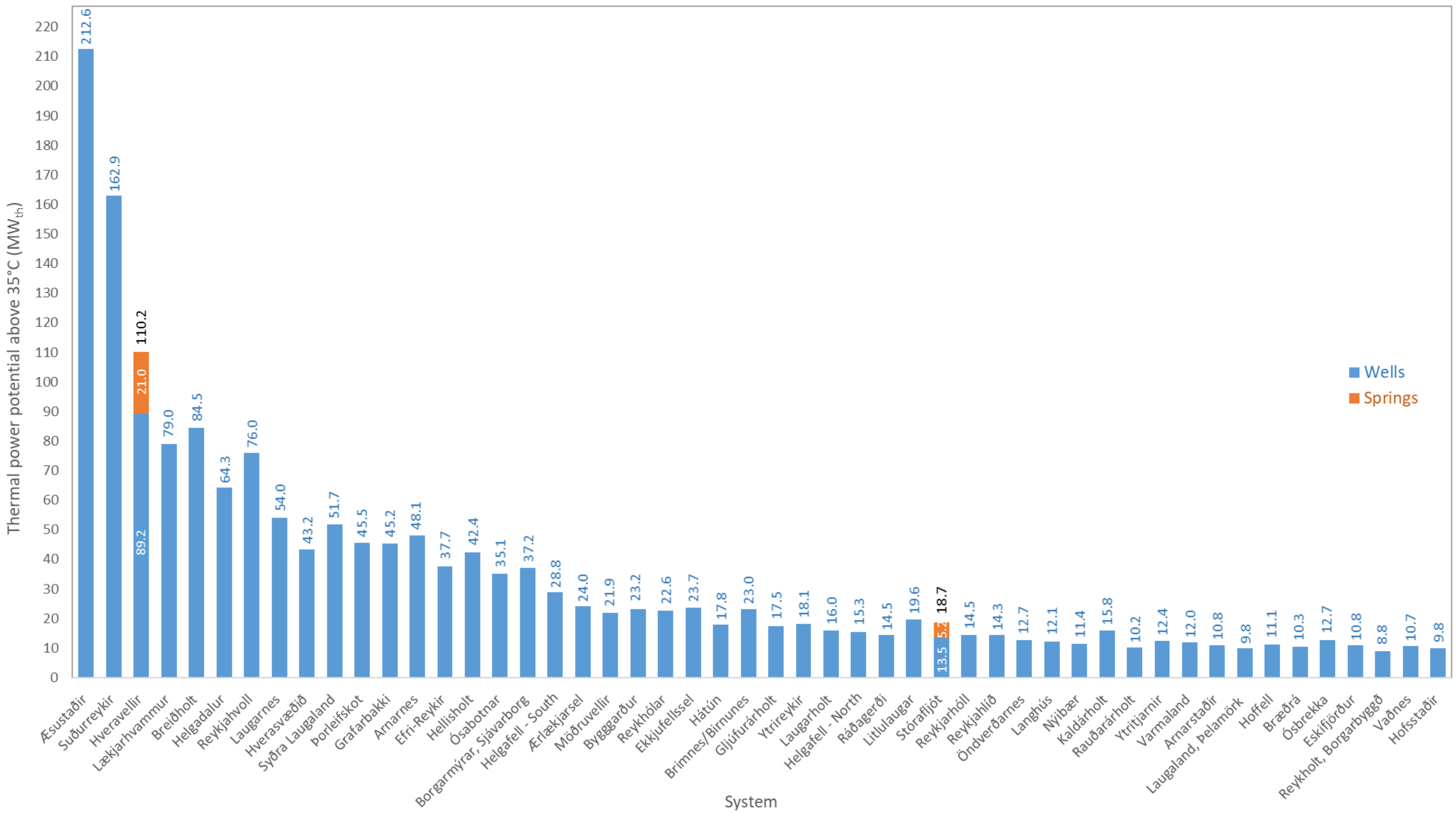

Figure 178. *Thermal power potential above 5°C for 96 well fields utilized by 64 major district heating services in Iceland (1 of 2).*

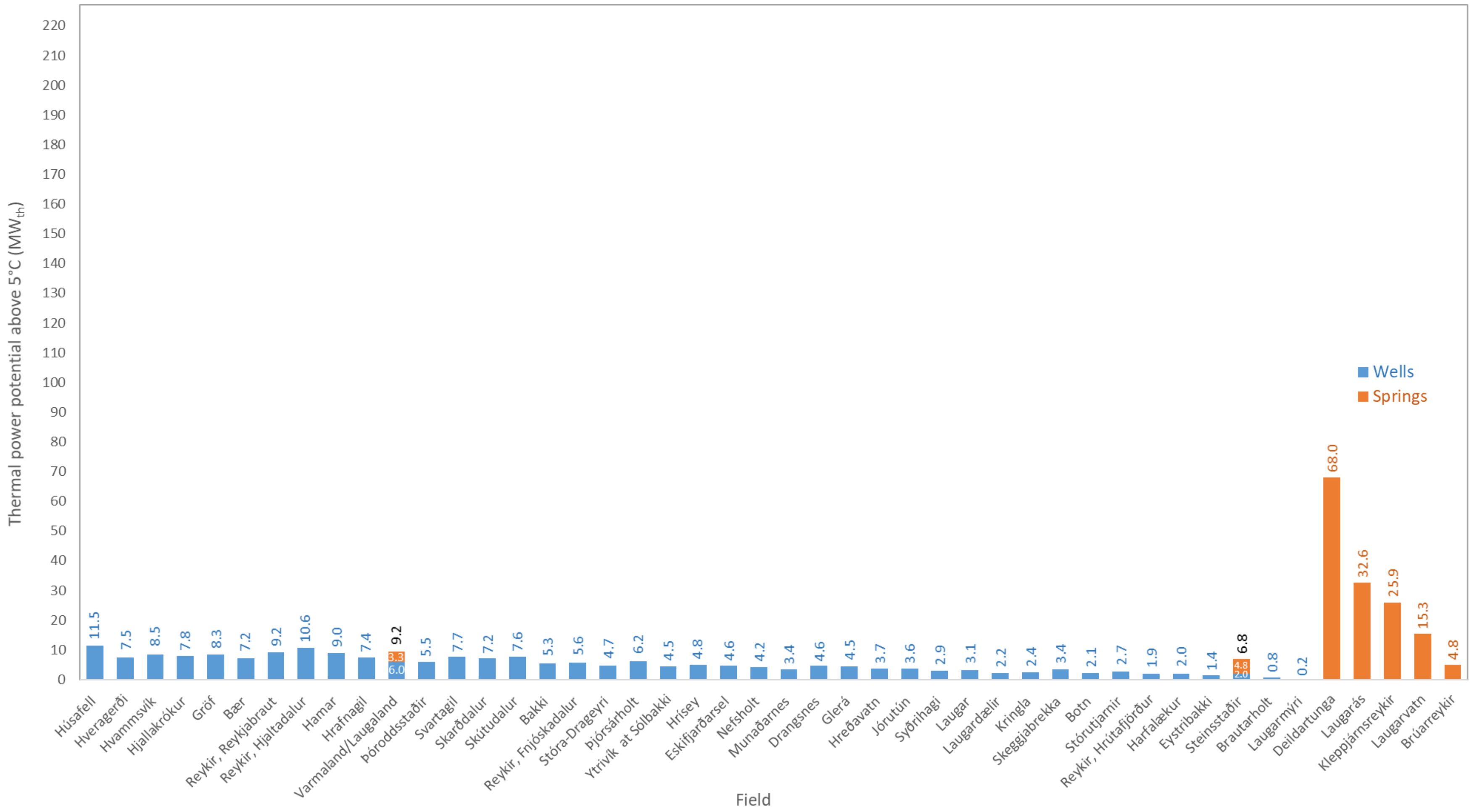

Figure 179. *Thermal power potential above 5°C for 96 well fields utilized by 64 major district heating services in Iceland (2 of 2).*

6.4.2 Thermal power potential of geothermal fields

Figs. 180 and 181 show the thermal power potential above 35°C and above 5°C, calculated for the 63 low and medium enthalpy fields utilized by the major district heating services and described in this report. Although the report does not cover all low enthalpy and medium enthalpy fields in Iceland these fields represent the largest thermal power potential known and presently utilized.

The Reykir geothermal field in Mosfellsbær is by far the largest low enthalpy field, three times larger than the next rated fields, which are the Laugarnes in Reykjavík and the Hveravellir geothermal field in Norðurþing. Next to those come the geothermal fields at Flúðir, Selfoss, Elliðaár, Hveragerði, Seltjarnarnes, Laugaland in Eyjafjarðarsveit, Hjalteyri, Efri-Reykir, Bær/Varmaland and Áshildarholtsvatn at Sauðárkrókur. The Reykholt geothermal field in Borgarbyggð stands out as fourth in total potential but most of that comes from the hot spring Deildartunguhver. The same applies to the Reykholt field in Biskupstungur which is equivalent to Seltjarnarnes but the bulk of the power potential comes from the hot springs at Laugarás.

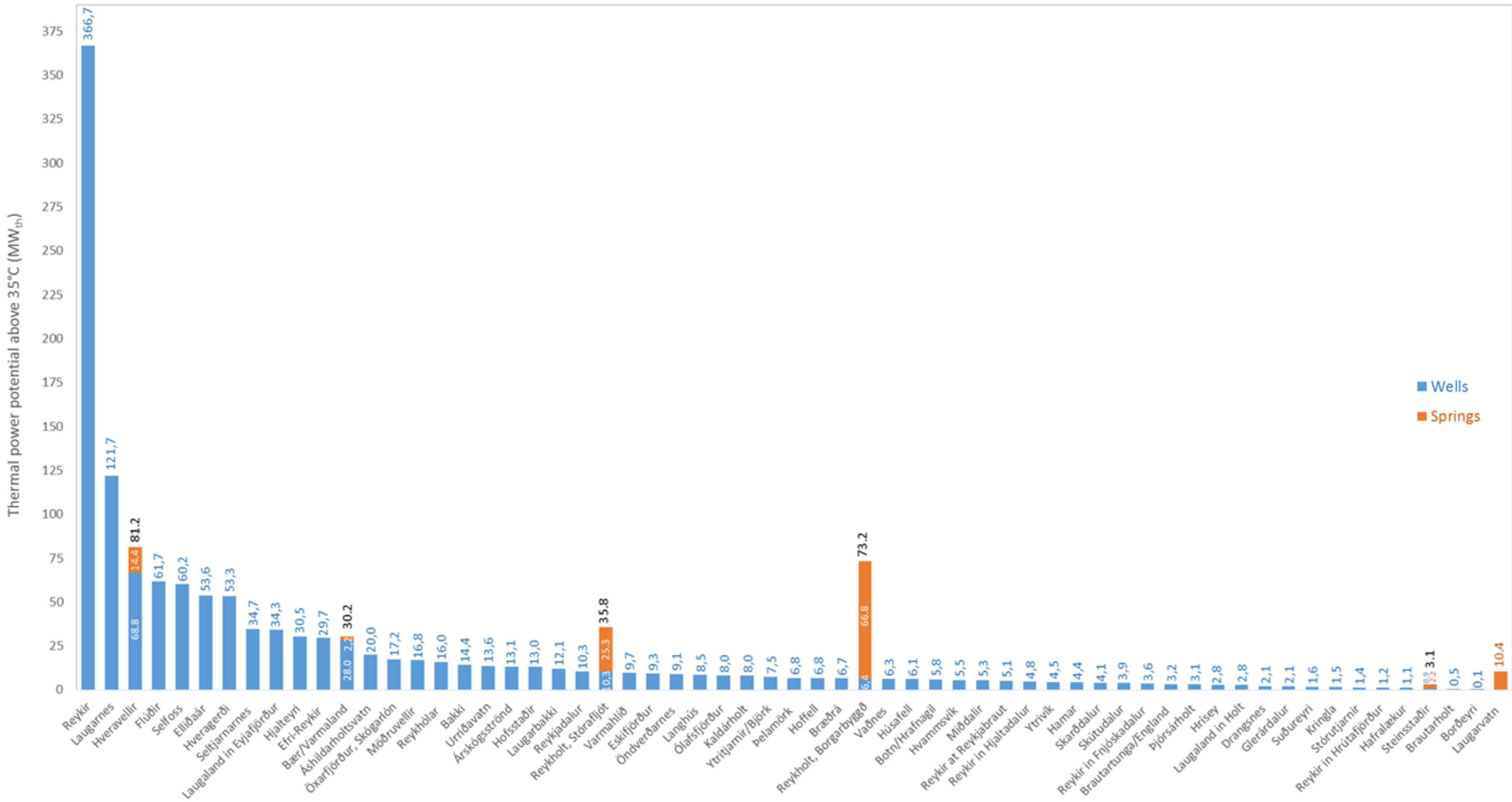

Figure 180. *Thermal power potential above 35°C for 61 geothermal fields utilized by 64 major district heating services in Iceland.*

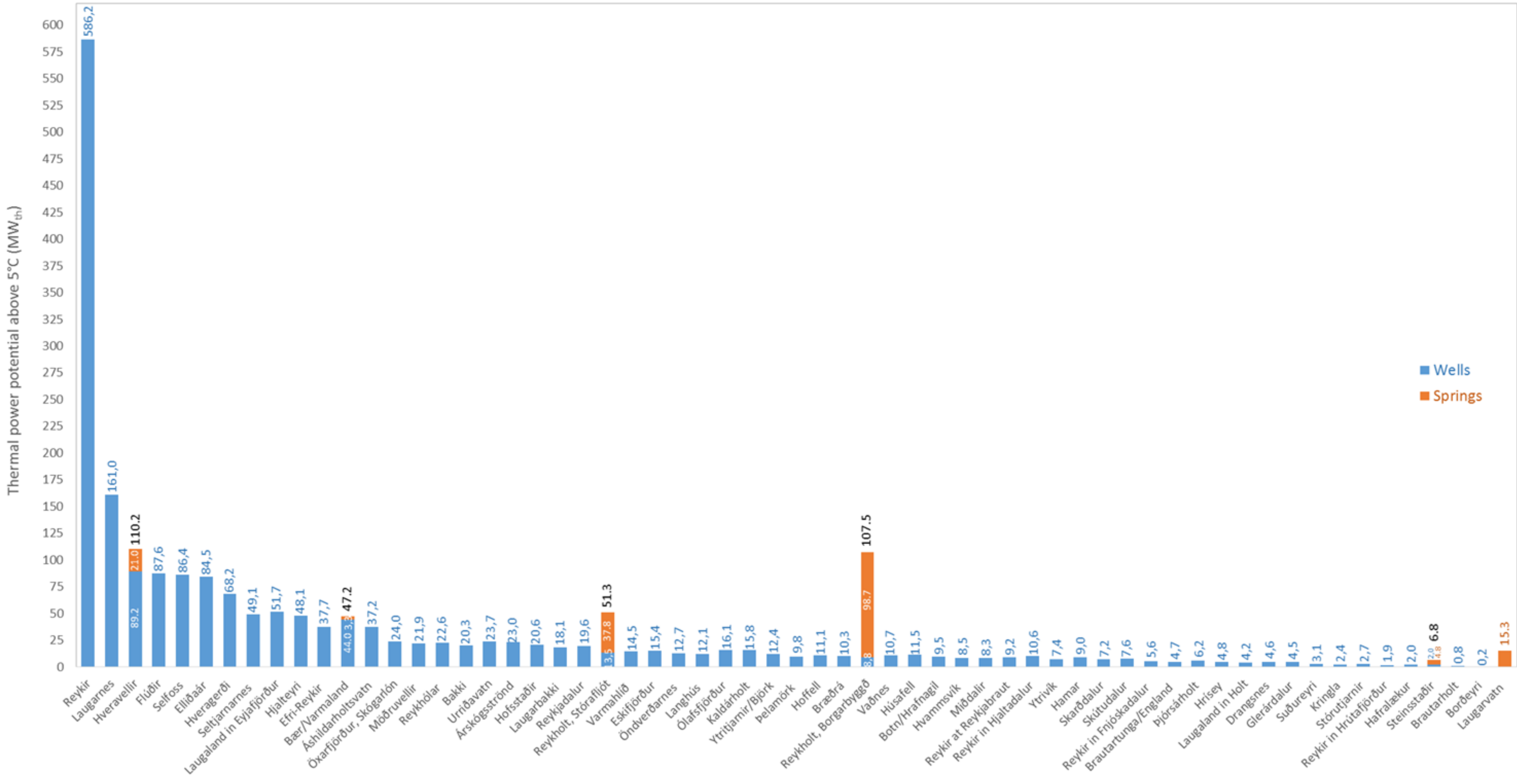

Figure 181. *Thermal power potential above 5°C for 61 geothermal fields utilized by 64 major district heating services in Iceland.*

7 Key Findings

Analysis of all 446 production wells drilled since 1928

- Of the 446 drilled production wells 419 or 93% were productive, i.e. encountered feeders that could yield a flow from the well, either free-flow or discharge with the aid of air-lifting or downhole pumps.
- Data on potential yield are available for 252 of the 419 productive wells. About 81.8% of these wells had a yield above 5 l/s, 7.9% a yield between 3 and 5 l/s, and 10.3% between 1 and 3 l/s.
- Of the twenty-seven wells that were not productive, nineteen (or 70.4%) found no feeders, six (or 22.2%) were reported cold and not yielding and two (7.4%) failed due to drilling problems.
- Of the 419 productive wells 164 are still in use. Four of them were drilled before 1958.
- Of the 164 wells in use 90.2% have a potential discharge in the range 5 to 120 l/s, 4.9% from 3 to 5 l/s, 3.7% from 1 to 3 l/s and 1.2% are with unknown yield. The average discharge potential of the 162 wells is 31.7 l/s and the weighted average discharge temperature 90.3°C.
- Of 419 initially productive wells, 255 are not in use. About 6.3% of them are cold or have a cold inflow, 1.2% are damaged, 29.3% have dried up due to drawdown of reservoir pressure, 21.9% are idle but could produce, 5.5% are low producers, 22.7% have been replaced by better wells and 12.9% are not in use but for unknown reasons.
- About 49.1% of the main feeders are shallower than 500 m, 76% are shallower than 1,000 m and 95% are shallower than 1,600 m. The average temperature of the main feeder was found to be 88°C (278 wells).
- About 49.2% of the productive wells have a potential yield less than 20 l/s, 77.8% less than 40 l/s and 91.2% less than 60 l/s. The remaining 8.8% have a potential yield of 60-120 l/s.
- About 87.9% of the 446 drilled production wells fulfilled the minimum criterion set for space heating of a discharge temperature of 60°C and 64.8% fulfilled the criterion of 80°C discharge temperature.
- The cumulative average success rate for productive wells in all geothermal fields starts at 92% for the first drilled well and climbs slowly up to 94% as more wells are drilled.
- The cumulative average success rate for wells with discharge temperature above 60°C begins at 78% for the first drilled well but climbs steadily up to a value of 86%. The same rate for discharge temperature above 80°C begins about 41% for the first well, reaches 49% in the third well and then rises steadily to a final value of 62%.

Analysis of all 320 production wells drilled since 1958

- Of the 320 drilled production wells since 1958, data for drilled depths are available for 318 wells. About 37.1% are shallower than 600 m, 27.7% in the range of 600-1,200 m, 31.1% in the range of 1,200-2,100 m, and 4.1% deeper than 2,100 m.
- 297 or 92.8% of the drilled wells were productive.
- Data on potential yield are available for 242 of the 297 productive wells. About 84.3% of these wells had a potential yield above 5 l/s, 6.6% a yield from 3 to 5 l/s, and 9.1% from 1 to 3 l/s.
- Of the twenty-three wells that were not productive, fifteen (or 65.2%) found no feeders, seven (or 30.4%) were reported cold and not yielding and one (or 4.4%) failed due to drilling problems.
- Of the 320 drilled wells 160 or 50% are still in use and 91.8% of them have a potential discharge ranging from 5 to 120 l/s, 3.8% from 3 to 5 l/s, 3.1% from 1 to 3 l/s, and 1.3% are with unknown yield. The average discharge potential of the 158 wells is 32.4 l/s and the weighted average discharge temperature 90.3°C.
- Of the 297 originally productive wells 137 are not in use. About 10.9% of these wells are cold or have a cold inflow, 1.5% are damaged, 2.2% have dried up due to draw-down of reservoir pressure, 40.9% are idle but could produce, 10.2% are low producers, 28.5% have been replaced by better wells and 5.8% are not in use but for unknown reasons.
- In the production wells drilled since 1958 about 46.8% of the main feeders are shallower than 500 m, 79.3% shallower than 1,000 m and 94.2% shallower than 1,600 m.
- Wells drilled since 1958 with feeders shallower than 500 m rarely have a production capacity above 50 l/s, when feeders at 500-1,000 m depth have often a capacity up to 65 l/s and feeders between 1,000 and 2,000 m have a production capacity up to 100 l/s.
- About 85.0% of the 320 drilled production wells since 1958 fulfilled the criterion of a discharge temperature above 60°C and 53.6% fulfilled the minimum criterion of 80°C.
- The cumulative average success rate for productive wells in all geothermal fields starts at 97% for the first well, drops to 92% for the second well and climbs slowly up to 93%.
- The cumulative average success rate for wells with discharge temperature above 60°C begins at 82% for the first drilled well in a field but climbs steadily up to a value of 90%. The same rate for discharge temperature above 80°C begins at 47% for the first drilled well, reaches 72% for the third drilled well, 79% for the seventh well and stabilizes just above 80%.

Thermal power potential

- The Reykir geothermal field in Mosfellsbær has a thermal power potential above 35°C of 366.7 MW_{th}. It is by far the largest geothermal field, three times larger than the next rated fields of Laugarnes in Reykjavík and the Hveravellir Field in Norðurþing. Next to those come the geothermal fields Flúðir, Selfoss, Elliðaár, Hveragerði, Seltjarnarnes, Laugaland in Eyjafjarðarsveit, Hjalteyri, Efri-Reykir, Bær/Varmaland and Áshildarholtsvatn.
- The well fields with the most thermal power potential are Æsustaðir and Suður-Reykir in the Reykir geothermal field in Mosfellsbær. They have a thermal power potential above 35°C of 139.7 and 96.7 MW_{th} respectively.
- In five of the utilized well fields no production wells have been drilled as the flow comes from hot springs. The largest hot spring is Deildartunguhver with a thermal power potential above 35°C of 46.3 MW_{th}.

8 References for the Report and the Excel-file with the Dataset in the Appendix

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Appendix:

Excel-file of the analysed dataset in a separate document
Confidential – for the database at National Energy Authority of Iceland, NEA