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Possible Seasonal Injection Of Surplus Hot Water From The Hengill Area Into A Low Temperature System Within Iceland´s Capital Region

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ABSTRACT

The district heating system in Reykjavík and its neighbouring communities is operated by Veitur Utilities, a subsidiary of Reykjavík Energy. The system receives water from two different sources; on one hand it receives geothermal water from low temperature fields in the city´s vicinity and on the other hand it receives heated groundwater from two co-generation high temperature geothermal power plants in the Hengill Area. These two water types have a different chemical composition and cannot be mixed within the system due to precipitation of magnesium silicates. To avoid this, the two waters are kept separated within the distribution system. The space heating demand in the capital region is growing fast, especially within areas that mainly use water from the low temperature systems. The production capacity of the low temperature systems is, however, limited. The heat production of the power plants in the Hengill Area, on the other hand, can and will be increased. They operate on base load in electricity generation and consequently they produce excess hot water during the summer months when the space heating demand is lower.

This discrepancy between demand and supply requires new solutions. One solution could be to inject the surplus hot water produced in the Hengill Area during the summer into one of the low temperature systems. The two water types would then be mixed within the reactive basaltic bedrock instead of within the distribution system, which presumably would solve chemical issues related to the mixing. This solution would reduce energy waste, provide pressure support for the low temperature systems and possibly allow heat storage until the following winter when demand rises again.

Numerical simulations need to be carried out to test the effect of such an injection. A simplified flow model of the Reykir/Reykjahlíð low temperature system has been developed as part of the HEATSTORE project. The model was calibrated against formation temperature profiles and production history – i.e. pressure draw-down and temperature of produced fluid. This paper describes the model development and presents preliminary results from different injection scenarios. The model will estimate the feasibility of storing the surplus water from the high temperature systems in low temperature areas. The simulations will analyze the system's response to seasonal injection of water and the effect of injecting water with a different chemical composition than the formation water. The aim is to see whether this method could be one of the solutions to the capital region's future heating demand.

1. INTRODUCTION

Veitur Utilities utilize three low temperature fields; Laugarnes, Elliðaárdalur and Reykir/Reykjahlíð, and two high temperature fields in the Hengill area; Hellisheiði and Nesjavellir, to supply hot water for the capital region. The water from the low temperature systems has a relatively low mineral content and can be used directly in the district heating system. Geothermal water from the high-temperature fields, however, has a higher mineral content and cannot be used directly. Because of this, the geothermal fluid from the high-temperature systems is used to heat up cold groundwater which is then supplied to the district heating system. Mixing of these two water types can cause precipitation of magnesium silicates in the distribution system (Hauksson et al., 1992) and because of that risk, the two types of water are kept separate within the system (Fig.1).

There is a fast-growing demand for hot water in the capital region, especially within areas that rely on water from the low temperature fields. The low temperature fields, however, have a finite production capacity. The thermal plants in the high-temperature fields in the Hengill Area, on the other hand, can and are being expanded. The water from Hellisheiði and Nesjavellir comes from two combined heat and power plants that operate on base-load all year round. Because of lower heating demand in the summertime, 250 – 300 l/s of hot water from Nesjavellir are normally disposed of during the summer months. The water is injected into shallow wells located between Nesjavellir and Reykjavík. Considering the production pressure on the low temperature systems, wasting hot water is not considered an acceptable long-term option.

In search of better ways to use the resource, the idea of rather injecting the excess water into one of the currently utilized low temperature systems was proposed. This would reduce energy waste and thus improve the efficiency of the hot water production at Nesjavellir and provide pressure support in the low temperature system. A simple schematic is shown in Fig.2.

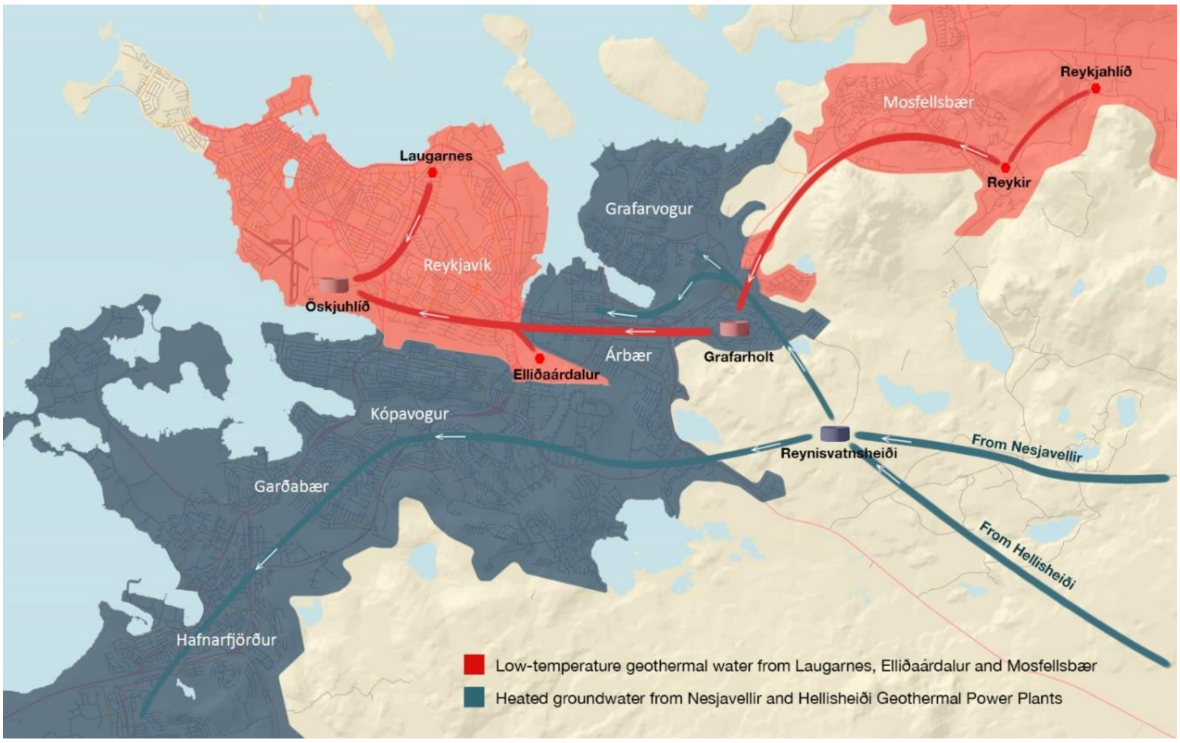

Figure 1: A map showing how the hot water is distributed throughout the capital. The low temperature fields are marked with red circles. The red shaded areas receive water from the low temperature areas and the blue shaded areas receive water from Hellisheiði and Nesjavellir. Transition of the Árbær neighbourhood over to heated groundwater is in process.

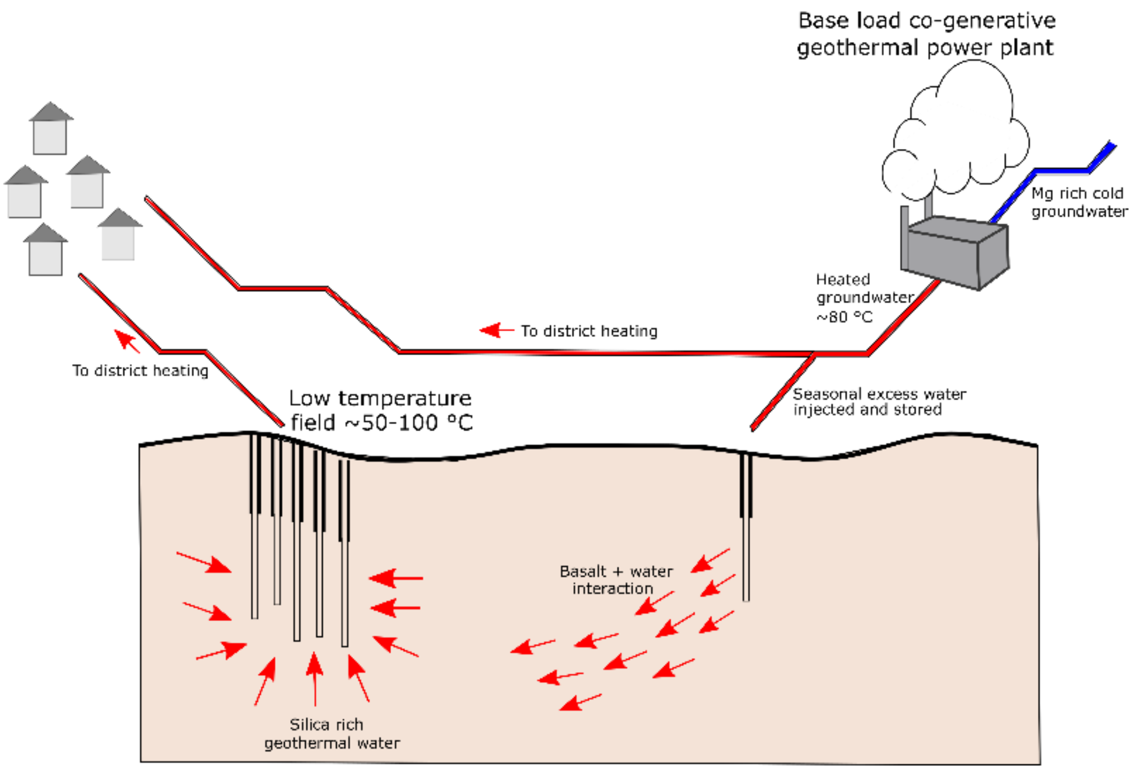

Figure 2: Schematic for seasonal injection of excess heat from Nesjavellir.

Before trying this, simulations need to be carried out to explore the effects such an injection would have. Two low temperature systems could be considered for injection; the Reykir/Reykjahlíð system and the Elliðaárdalur system. The Reykir/Reykjahlíð system was chosen as the first case study since much more geothermal fluid is produced from that system than the Elliðaárdalur system. A flow model has been developed to test the effect of injecting 80°C warm water from Nesjavellir into the system. This article reviews the model development and calibration as well as preliminary results from different injection scenarios.

2. SYSTEM GEOMETRY AND PRODUCTION HISTORY

2.1 System geometry and local geothermal conditions

The Reykir/Reykjahlíð low temperature system is located on the western edge of the active rift zone that runs through Iceland. The geothermal system covers about 10 km^2 and is separated into two subareas, Reykir and Reykjahlíð. They are both at an elevation of about 20-80 m above sea level (m a.s.l.) but they lie 2-3 km apart from each other and are separated by hills which rise to 220-250 m a.s.l. The stratigraphy in the area is characterized by alternating sequences of subaerial basaltic lava flows and hyaloclastite formed during glacial periods (Tómasson, 1997). The field is a part of an ancient high-temperature system formed through volcanic activity 2 million years ago in the extinct Stardalur volcano (Friðleifsson, 1985). Active fissure swarms from the Krísuvík and Trölladyngja volcanic system in the Reykjanes Peninsula reach into the field and have caused recent fracturing in the older bedrock. The current geothermal system is thought to have developed through convection in such fractures (Arnórsson, 1995). Permeability in the system is largely affected by the presence of these fractures which extend in a SW-NE direction. Water level changes in nearby wells accompanying pumping during pressure tests conducted between 1972-1977 showed greater hydrological connection between wells in the main fracture direction than perpendicular to it. The overall results from the tests showed that the field can be roughly split up into different sections that are aligned in the main fracture direction. They are called Helgafellssvæði, Vestursvæði and Austursvæði (Thorsteinsson and Einarsson, 1990). Hydrological connection towards the SW/NE is also confirmed by seasonal water level fluctuations in wells as far as 20 km northeast of the production zone (Vatnaskil, 1994; Björnsson and Steingrímsson, 1995). Sporadic water level measurements in research wells outside the production area show that the hydrological connection is much poorer towards the west.

Wells in the area show a levelled temperature over a long depth range due to convection. The highest temperature is however found at 500-600 m depth and then the temperature decreases slightly reversing the temperature profiles. This could be due to horizontal spreading of warm water in a permeable layer (Björnsson and Steingrímsson, 1995) or due to recharge of colder water at depth (Arnórsson, 1995). Recharge into the system is considered to come mainly from two directions; the northeast and the southwest (Björnsson and Steingrímsson, 1995).

2.2 Production History

Drilling in the Reykir/Reykjahlíð area started in 1933 with the drilling of numerous, shallow (<600 m deep) free flowing wells, named SR and NR wells. The production from these wells amounted to about 360 L/s but precise production data for this period does not exist. Drilling of deeper wells (> 1 km deep) started in 1959 but properly took off in 1970. These wells, named MG, are equipped with pumps and with them the average combined production from the two subareas is about 1000 L/s of 87 °C warm water (Ívarsson, 2018). Deep production caused a decline in system pressure, free flowing from shallower wells stopped and water level dropped down to a depth of 50-100 m below sea level (m b.s.l.) (Björnsson and Steingrímsson, 1995). The shallower wells (SR and NR) were cemented and closed once production from deeper wells started. Today, active production wells are 34, 22 in Reykir and 12 in Reykjahlíð (Fig. 3). The wells are generally cased off to a depth of about 150-250 m. Water level in monitoring wells (i.e. system pressure) fluctuates with seasonal production changes.

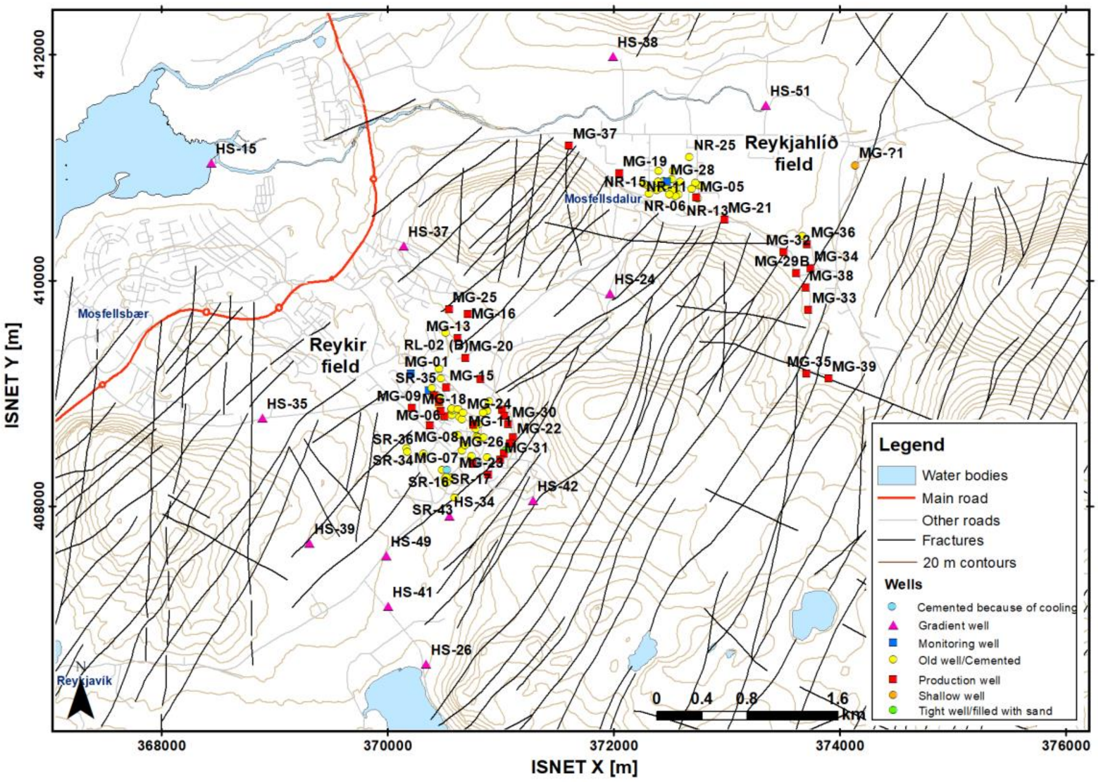

Figure 3: Map of the Reykir/Reykjahlíð fields showing wells, roads, elevation contours, and fractures that have been mapped on the surface. Active production wells are shown with red squares (Data source: National Land Survey of Iceland, Reykjavík Energy and Iceland Geosurvery, ÍSOR).

3. NUMERICAL FLOW MODEL

3.1 Model theory and software

The simulator used in this project is the TOUGH2 numerical simulator (Pruess, Oldenburg and Moridis, 2012) as implemented in forward and inverse mode within the iTOUGH2 code (Finsterle, 2007). Conceptually, the model simulates the transport of fluid and heat in a single-phase liquid geothermal system. It solves governing equations that describe the conservation of mass and energy. A numerical grid of the area was constructed using the program AMESH which uses the Voronoi tessellation method (Haukwa, 1998). The grid is refined around the production areas and has coarser blocks towards the edges. The model reaches from 320 m a.s.l. down to 2500 m b.s.l. and has 26 layers. Each layer has 2822 elements (Fig.4).

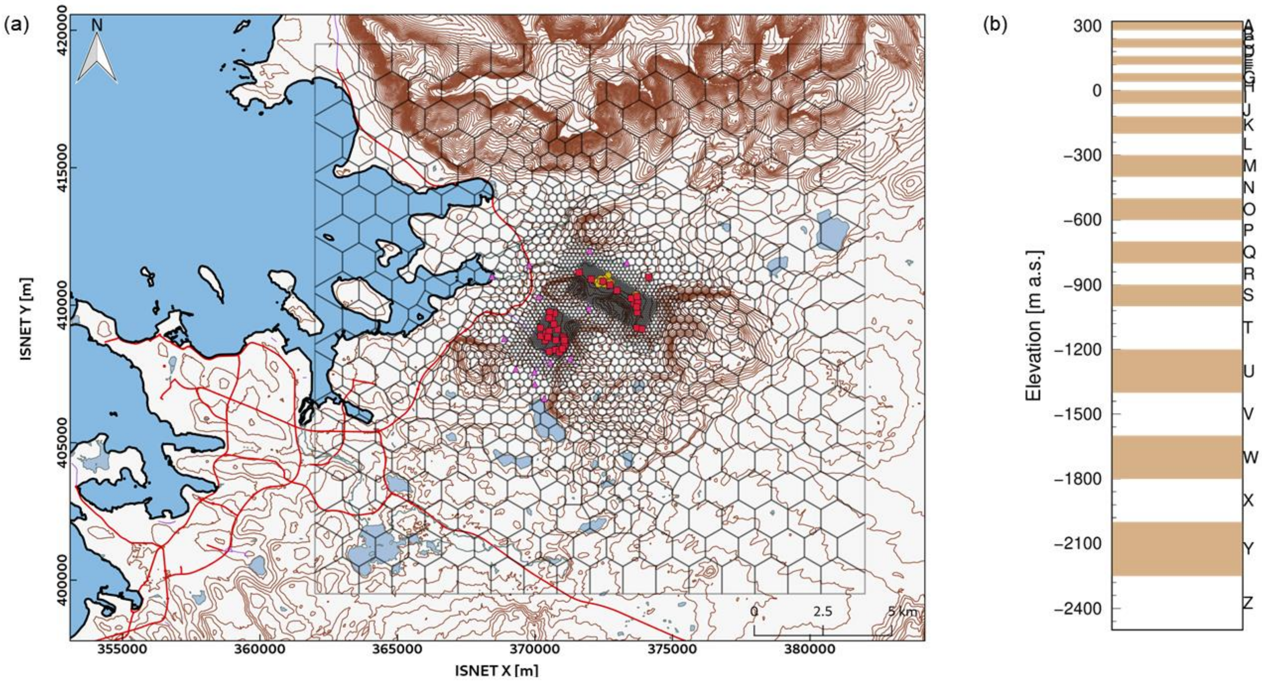

Figure 4: (a) Plan view of the numerical grid for the Reykir/Reykjahlíð area; the grid is refined around the production zones, production wells are shown with red squares, red thick lines depict main roads and thin brown lines depict elevation contours (b) the layering structure of the model; the white and beige colors show the thickness of the layers and the letters on the left are used to identify each layer (Data Source: Reykjavík Energy and Nation Land Survey of Iceland).

3.2 Model development and setup

Due to the fractured and altered nature of the system, the basalt/hyaloclastite stratigraphy does not realistically represent the system's permeability structure. Therefore, simplifications are made on the stratigraphic structure of the model. Water level measurements and temperature profiles from surrounding wells, temperature distribution maps as well as results from previous modeling studies (Verkfræðistofan Vatnaskil, 2000) are used to estimate the extent of the geothermal system. The parts of the model that lie outside the geothermal system are assigned other rock types than the parts of the model that lie within it. Based on water level measurements, well HS-35 on the SW edge of Reykir for example falls outside of the geothermal system rock types. Due to a different water level in shallower wells in the area and the shape of formation temperature profiles in production wells, the system is assumed to be separated from a colder groundwater system above it by a lower permeability layer. The geothermal system itself is split up into the subsections Helgafellssvæði, Vestursvæði and Austursvæði according to the division presented by Thorsteinsson and Einarsson (1990) based on pump test results. The subsections are then further split up into two depth intervals. The system inflows from the southwest and the northeast are assigned other rock types as well. A plan view of the general rock type distribution within the system is shown on Fig.5.

The model elements that lie above the elevation of the water table are assigned an atmospheric rock type which has a constant pressure of 1 bar and a temperature of 4°C. The elevation of the water table in each element is approximated by interpolating between shallow groundwater elevation contours (Verkfræðistofan Vatnaskil, 2017) and extracting the value in the element center. The shallow water level is assumed to be constant and with a temperature of 4°C. The initial pressure profile is hydrostatic. Generally, a temperature gradient of 60°C/km is applied but within the geothermal system, the temperature in the bottom layer is extrapolated from rock temperature curves. The conditions in the bottom layer are assumed to be constant. Sufficient permeability and temperature in the bottom layer cause convection within the geothermal system.

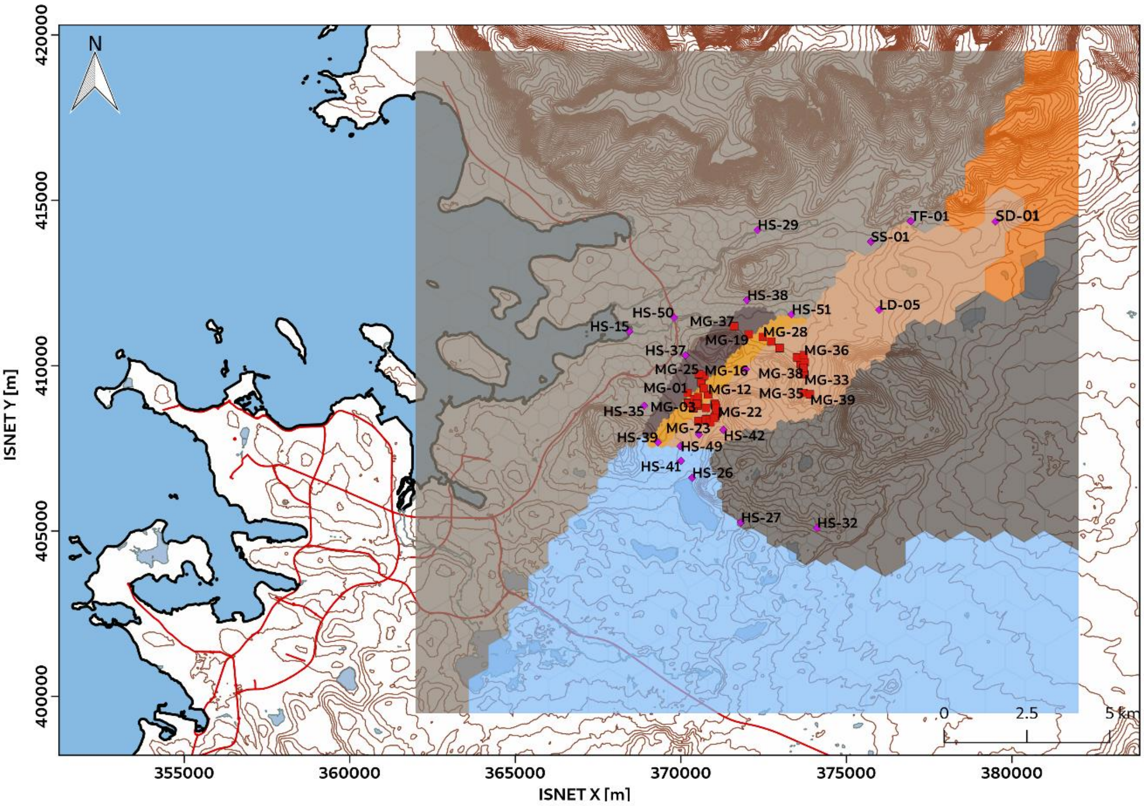

Figure 5: Overview of rock type distribution within the model layers covering the geothermal system. Inflow from the NE is shown in dark orange, inflow from the SW in blue, less permeable edges in grey, the system and its subsections in dark gray, light orange and beige. Wells are shown with red and pink markers (Data Source for map data: Reykjavík Energy and National Land Survey of Iceland).

3.3 Model calibration

The model is allowed to reach steady state before the production is simulated. This is standard procedure in geothermal modeling (O'Sullivan et al., 2001). Formation temperature profiles from wells are used to calibrate the initial state of the model. The production history is calibrated against reservoir pressure draw-down in the geothermal system and the temperature of produced fluid. The horizontal and vertical permeability in the different rock types is varied to get a good match. Rock density, thermal conductivity and heat capacity are kept constant. This is an iterative process that requires multiple runs to get a satisfactory match both with regards to initial state and production history and system response.

A vertical Southwest-Northeast slice through the central part of the model showing steady state temperature distribution is shown in Fig.6 along with four examples of formation temperature comparisons in production wells. Fig.7 shows calculated and measured reservoir pressure draw-down derived from water level measurements for 3 monitoring wells; SR-32, MG-01 and MG-28. Data for pressure drawdown in monitoring wells is used to monitor the response of the system to production. These wells are cased down to the geothermal reservoir and thus reflect the system pressure. A good fit is obtained for formation temperature and pressure draw-down in many of the wells. The poorest fits are for the wells located closest to the system edges (see e.g. well MG-16 in Figure 6). This is due to lack of wells towards the edges and further away from the production areas. Data from such wells would give a more accurate representation of the temperature distribution away from the production areas. For the same reason, comparison between measured and simulated changes in the temperature of produced fluid in wells close to the edges gives the poorest results. Temperature distribution in the model outside the geothermal system itself needs to be better represented in order to model cooling which has been observed in some of these wells, especially wells located at the southwestern edge of the Reykir field.

Calibration of the model to available data shows that the system is very permeable. From current calibration runs, the horizontal permeability values for the geothermal system rock types range from $5\cdot10^{-13}$ to $2\cdot10^{-12}$ m^2 and the vertical permeability from $2\cdot10^{-14}$ to $6\cdot10^{-14}$ m^2. With a functional numerical model, different production and injection scenarios can be simulated.

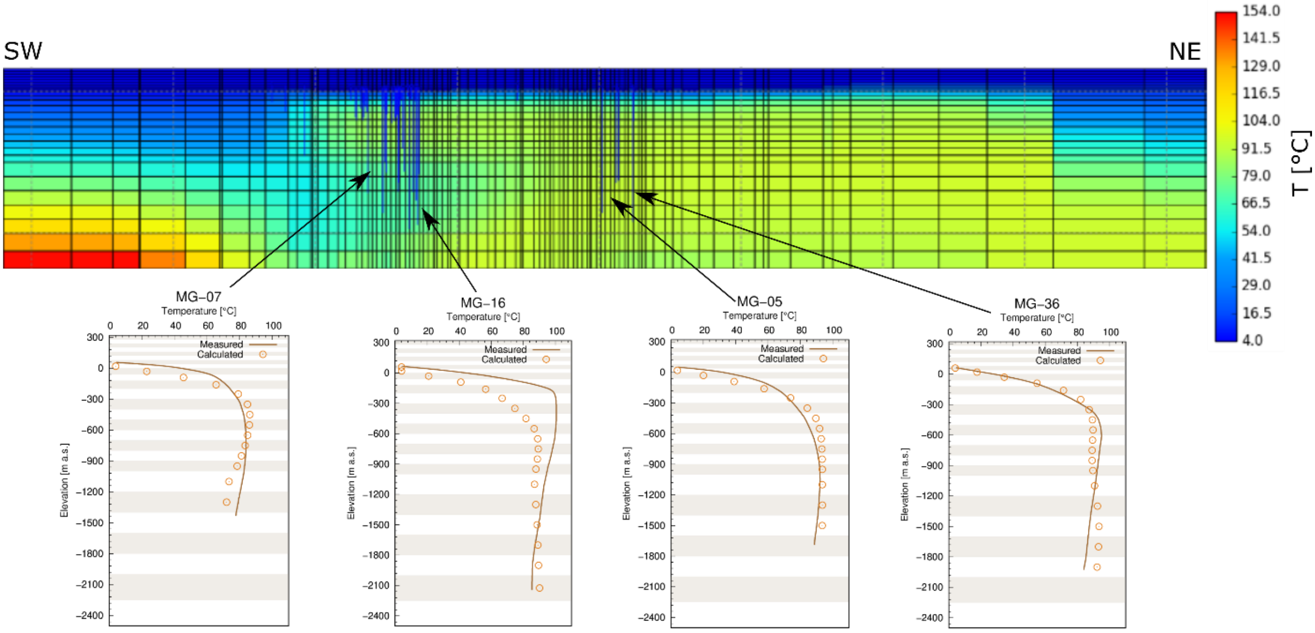

Figure 6: A vertical Southwest-Northeast slice through the central part of the model showing steady state temperature distribution along with a comparison between formation temperature and calculated temperature for wells MG-07, MG-16, MG-05 and MG-36.

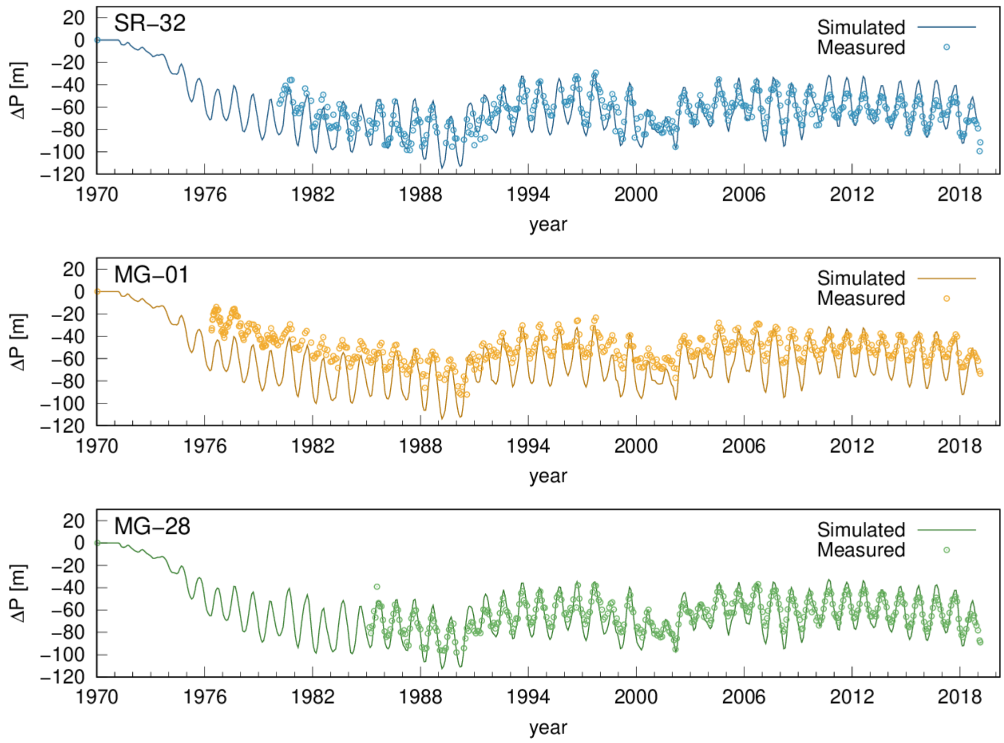

Figure 7: Simulated and measured draw-down for monitoring wells SR-32, MG-01 and MG-28 during the period 1970-2018. Wells SR-32 and MG-28 show a good fit but well MG-01, located at the edge of the production zone, needs some improvements.

4. INJECTION SCENARIOS

As mentioned above, surplus hot water is produced in Nesjavellir during the summer months. This water amounts to 250-300 L/s. The goal of this modeling work is to test different injection scenarios to see whether injection of this surplus water could provide pressure support in the system and decrease draw-down. Preliminary results from three different injection scenarios are presented here. In all scenarios, 250 L/s of 80 °C warm water is injected into a hypothetical injection well on the Southwestern edge of the system where hydrological connection with the production wells is known to exist. The location is shown with a star in Fig.8(a). The water is assumed to enter the system through two different feedzones, one at 500 m b.s.l. and one at 1500 m b.s.l. These depth values were chosen for this scenario as numerous feedzones are found around these depth intervals in the production areas. The amount is divided evenly between the feedzones. In these simulations, injection was started in the year of 2010 and the results were compared to simulations where no injection took place. The factor that varies between scenarios is the period of injection. In the first simulation set, injection is started in the middle of May and stopped in the middle of August each year (Fig.8(b)). In the second simulation set, injection starts in the middle of April and lasts until the middle of October each year (Fig.8(c)). In the third simulation set, injection is constant throughout the year (Fig.((d)). Figure 8 shows the changes in draw-down in monitoring well SR-38 which is the closest monitoring well to the injection location. Three lines are depicted; the dashed line is the draw-down when no injection takes place, the blue line is the draw-down when injection takes place and the orange line is the difference between them. The orange line thus illustrates the duration of the pressure support. The figures only show the period from 2010 until 2015 to better illustrate the pattern that forms, but the same pattern continues throughout the simulation time, that is until the end of 2018. The same pattern is seen for all monitoring wells but the amplitude of the support is the largest for SR-38 since that is the closest well. The smallest amplitude is seen for MG-28, which is the monitoring well in Reykjahlíð. A rise in pressure is seen immediately when the injection is started. The water level starts dropping once injection is stopped but pressure support still lasts until the end of the year in the three-month case and longer for the six-month case. The peak is very sharp for the three-month long injection but smoother for the six-month long injection. In the case of whole-year injection, a steady water level rise (i.e. pressure rise) of about 25 m is observed.

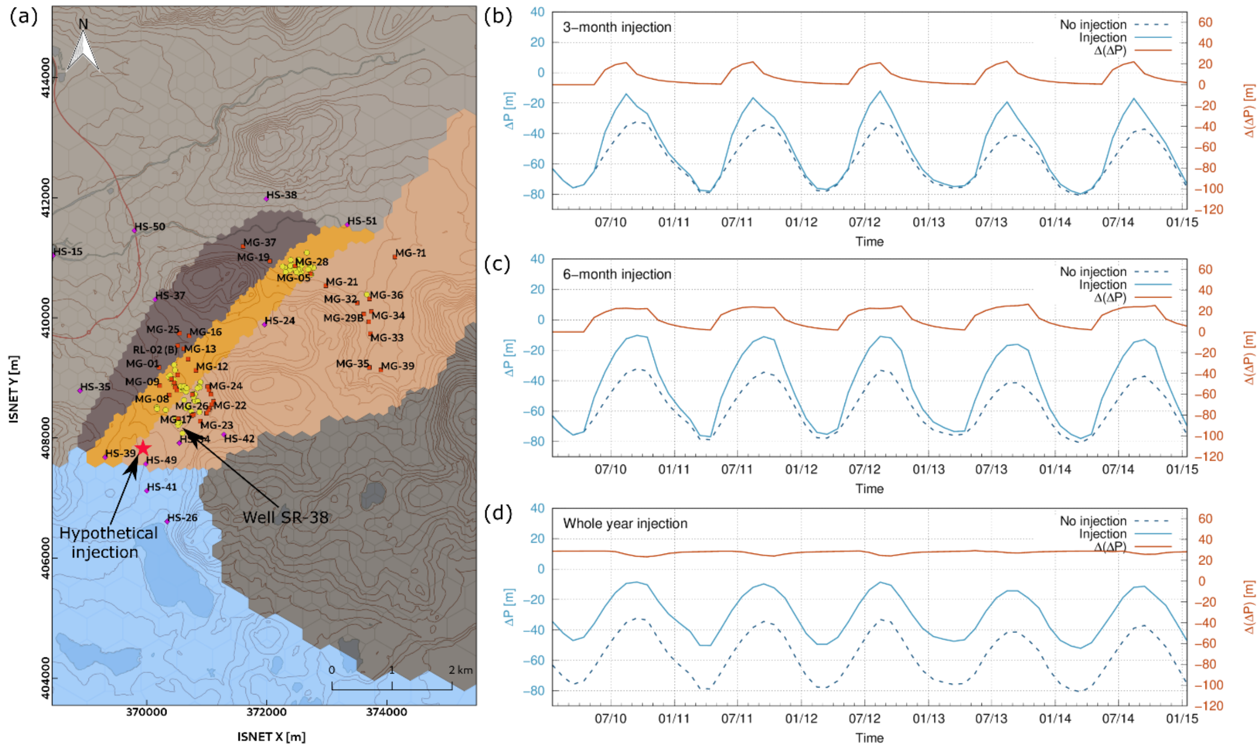

Figure 8: (a) The location of the hypothetical injection location and the location of monitoring well SR-38, the color scheme for the rock types is the same as in Fig. 5, (b-d) Comparison between simulated draw-down when no injection takes place (dashed line) and when injection takes place (solid blue line) and the difference between the two (orange line). (b) is for three month long seasonal injection, (c) is for six month long seasonal injection and (d) is for constant injection.

5. CONCLUSIONS AND RECOMMENDATIONS

With reduced energy waste in mind, the idea of seasonal injection of excess hot water from the Nesjavellir Power Plant into a utilized low temperature system in Reykjavík´s vicinity has been proposed. This summer injection could provide pressure support in the low temperature systems and possibly allow heat storage for the following winter when demand is higher than in the summertime. To estimate the feasibility of this idea, a numerical model of the Reykir/Reykjahlíð low temperature system has been developed. The Reykir/Reykjahlíð system was chosen as the first case study since that system is under heavy production. The numerical model was run using the TOUGH2/iTOUGH2 simulator. The model includes production history from the 1970s when deep production started until the end of 2018. The initial state of the model was calibrated against formation temperature profiles and the production history was calibrated against pressure draw-down and temperature of produced fluid. A good fit was obtained for formation temperature and reservoir pressure draw-down in many of the wells and the results show that the system is very permeable. A better representation of the temperature distribution on the edges and outside the geothermal system is needed to better represent cooling which has been observed in some wells due to recharge of colder water.

The model has been used to preform simulations of the injection of 250 L/s of 80 °C warm water into the Southwestern edge of Reykir. The results show that the system response is very fast, that is, pressure in the whole system rises immediately once injection is started. Pressure support lasts for a few months after injection is stopped. More scenarios and setups will be simulated using the model. Examples include other injection locations, decreased summer production and increased winter production. Furthermore, a simplified chemical model is being constructed to test the effect of injecting water with a different chemical composition into the system.

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