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# Flexible Operation of a Dually Fed District Heating System in Iceland's Capital Region: Improving Overall Resource Utilization

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## ABSTRACT

Veitur Utilities operate a dually fed district heating system in the capital region of Iceland. About half of the district heating system is fed by low temperature wells in three geothermal fields in the capital region while the other half is fed by heated groundwater from ON Power's two geothermal power plants in the Hengill area. Historically, the mixing of these two types of waters has been problematic due to scaling, resulting in Veitur Utilities operating two parallel district heating systems in the capital region with waters that cannot be mixed. In the summer of 2020, the neighborhoods in the capital region that normally receive low temperature geothermal water were switched to heated groundwater resulting in all of the capital region being temporarily fed by heated groundwater. The aim of this operation was to rest the low temperature fields in the capital region to be better prepared to meet the demand for hot water in the city over the wintertime. The duration each geothermal field was rested ranged from 8 to 17 weeks. During this rest, the response of the low temperature fields in the city was carefully monitored. Continuous logging of the water level, temperature and well head pressure was carried out in designated monitoring wells, weekly hand measurements of the water level were done in various other wells and the possible occurrence of surface manifestations was monitored with field visits. In addition, the district heating system was extensively monitored by chemical analysis of water samples, pH measurements and monitoring of oxygen and hydrogen sulfide levels.

Chemical monitoring showed that the changes to the operation of the district heating system caused no significant scaling events or operational problems. However, a delayed recovery of magnesium and calcium ions was observed, which might indicate ion-exchange processes on pipe surfaces. A record seasonal water level increase was observed in all three geothermal fields. In one of the fields, Laugarnes, the water level reached a record high since pumping from the field began more than half a century ago. The overall gain resulting from this operation will however not become apparent until the coming spring when the lowest yearly water levels are reached.

## 1. INTRODUCTION

From the beginning of geothermal utilization for district heating in Reykjavík, the demand for hot water has increased from year to year due to population growth and industrial expansion. Up until 1990 this demand was met with the development and utilization of three low temperature geothermal fields located within the city limits. These fields are the Laugarnes, Elliðaárdalur and Reykir/Reykjahlíð fields. The geothermal water from the fields is used directly in the district heating system. In 1990 the Nesjavellir combined heat and power plant in the Hengill area, about 40 km east of Reykjavík, started producing heated groundwater for the city. In 2010 the thermal production capacity was further expanded with the addition of the Hellisheiði combined heat and power plant in the same area (see e.g. Gunnlaugsson and Ívarsson, 2010; Gunnlaugsson, Ívarsson and Friðriksson, 2015; Ívarsson et al., 2019). The heated groundwater and the hot water from the low temperature geothermal fields have different chemical compositions and cannot be mixed due to the precipitation of magnesium silicate, resulting in Veitur essentially operating two separate district heating systems in and around Reykjavík (Hauksson et al., 1992). As the city expanded, the additional water supply from the power plants was used for newer neighborhoods and the neighboring towns of Kópavogur, Garðabær and Hafnarfjörður while Mosfellsbær and the older parts of the city continued to use water from the low temperature fields. With increased tourism in central Reykjavík and the city's current emphasis on urban densification rather than expansion, the demand for low temperature geothermal water is increasing with limited capacity for growth in production from the low temperature fields. In order to meet increased demand during winter, Veitur decided to rest the low temperature fields through the summer period and provide the entire capital region with heated groundwater from Hellisheiði and Nesjavellir. This action called for increased production of heated groundwater, which was easily met as there is a surplus of hot water produced at the power plants in the summer months. This is because the power plants produce base load electricity all year round. The action also called for extensive changes in the operation of the district heating system, e.g. a change in the operational pressure for the part of the district heating system that generally receives hot water from the low temperature geothermal fields, and the reversal of flow in a few of the main transport pipes in the district heating system.

The main goals of this operation were:

1) Resting the low temperature fields in Reykjavík, thus raising the water levels in the fields and increasing the production capacity in the winter.
2) Improving resource utilization by ceasing injection of excess heated groundwater produced at the Nesjavellir power plant which normally takes place in wells located between Nesjavellir and Reykjavík.
3) Improving the environmental impact of power production at Nesjavellir by ceasing surface disposal of heated groundwater.
4) Demonstrating the flexibility of the district heating system and establishing a method of utilizing the low temperature fields more sustainably in the future.

## 2. BREAKDOWN OF OPERATIONS

Ceasing production in the low temperature fields and making changes in the district heating system to feed the entire capital area with heated groundwater was an extensive operation that was performed over a two month period at the start of the summer. Production in the Elliðaárdalur field was stopped on April 30th, production in the Laugarnes field was stopped on May 18th, and in Reykir the production was stopped on June 11th. The production in Reykjahlíð was never completely stopped but it was reduced to ~20% of normal production on June 11th. The production was kept at a minimal rate to supply Kjalarnes and rural Mosfellsdalur during the summer rest. The system changes that were made following the ceasing of production from the geothermal fields were as follows:

1. The neighborhoods of Árbær, Ártúnshöfði, Fossvogur and Múlar switched from low temperature geothermal water to heated groundwater; May 27th.
2. The rest of the eastern part of Reykjavík which was fed by low temperature geothermal water switched to heated groundwater; June 10th.
3. The western part of Reykjavík switched to heated groundwater; June 11-12th.
4. Mosfellsbær switched to heated groundwater June 19th.

These steps are illustrated in Fig. 1. On June 19th, the switching operation was finished, and the entire capital region received heated groundwater from Nesjavellir and Hellisheiði while the low temperature fields in Elliðaárdalur, Laugarnes and Reykir/Reykjahlíð were rested. On August 21st, the operation was reversed, production from the low temperature fields was gradually resumed and the district heating system was returned to business as usual operations. Production from Reykir and Reykjahlíð was returned to normal on August 21st, the Elliðaárdalur field resumed production on August 28th, and production from the Laugarnes field commenced on September 5th. The fields were rested for different time periods ranging from 8-17 weeks.

The summer rest and accompanying changes in operation of the district heating system were a large and complex undertaking. It involved storage tanks, heating systems with return water from space heating and neighborhoods that have never received heated groundwater before. Detailed planning ensured a smooth transition and minimal mixing of the two waters to prevent magnesium silicate scale formation during the operation.

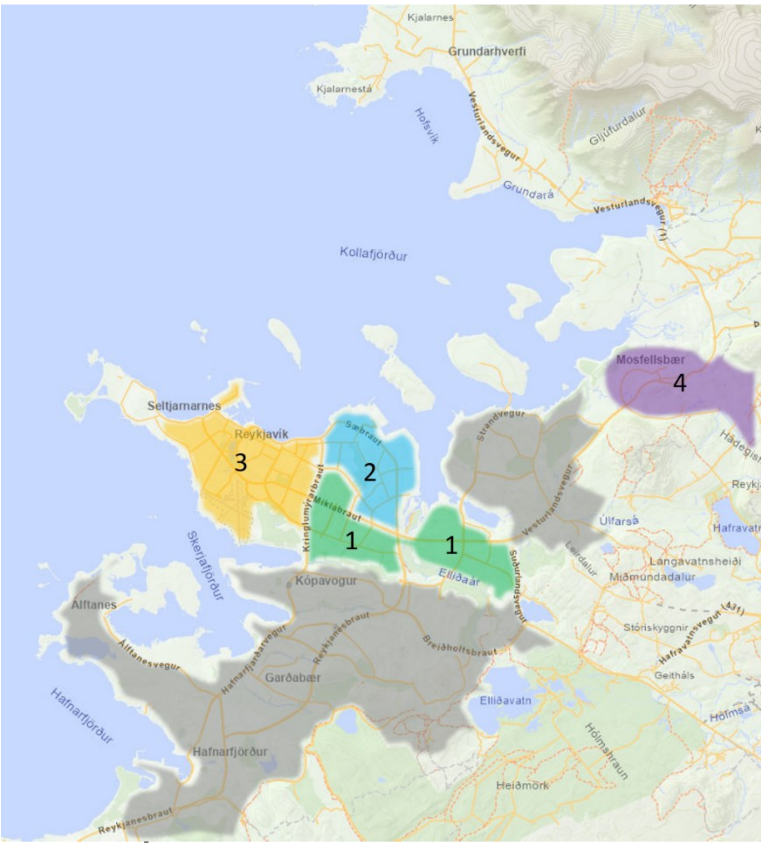


**Figure 1: Visual breakdown of the operation's timeline. Grey areas receive heated groundwater all-year round. The green area was switched from low temperature geothermal water to heated groundwater on May 27th, the blue area was switched on June 10th, the yellow on June 11-12th and the purple on June 19th.**

## 3. MONITORING AND RESULTS

### 3.1 Water level monitoring and results

Water level in all three geothermal fields that Veitur utilize in the capital region has been declining in recent years. The reason for this is increased production due to increasing demand for hot water. As previously mentioned, the aim of the summer resting of the geothermal fields was to allow the fields to recover from heavy winter production. In addition, the hope was to collect more hot water reserves than in normal operations which could in turn increase the production capacity the following winter.

Continuous water level data loggers were placed in monitoring wells in all three fields in the summer of 2019. These were wells RG-07 and RG-34 in the Laugarnes field, well RG-27 in the Elliðaárdalur field, wells SR-32 and MG-01 in the Reykir field and well MG-28 in the Reykjahlíð field. The location of the utilized geothermal fields and the monitoring wells is shown on Fig. 2. Before the loggers were put in place, water level measurements in these wells were performed manually on a monthly basis. These wells are cased down to the geothermal reservoir and the water level they portray thus reflects the system pressure and not the shallower colder groundwater system that lies above the geothermal system. The new loggers record values every 10 minutes and visualize the data on a website that is available to both operators and researchers monitoring the fields. This new equipment allowed for careful monitoring of changes in water level resulting from operational changes during the summer resting.

Fig. 3 shows water level measurements in three of the monitoring wells from the beginning of 2006 until the 5th of September 2020 when production from the Laugarnes field started again. The water level in all fields shows seasonal fluctuation due to seasonal differences in demand. A sharp water level rise was seen in all areas in the beginning of the summer of 2020 when the production was turned off or decreased, as was the case for the Reykjahlíð area which maintained ~20% of normal summer production. About 2 weeks after the production was stopped in each area, the rate of the water level rise decreased and stabilized.

The Elliðaárdalur system is by far the smallest of the three fields and water level in that field has often reached the surface during normal summer operations in the past. The water level reached the surface in well RG-27 in the beginning of July and stayed there until production was started again at the end of August. Water level in the Elliðaárdalur field is very responsive due to the small size of the system and it dropped fast when production was started up again. Because of this, the Elliðaárdalur system does not seem to benefit much from summer resting operations. Water level rose fast in well RG-07 in Laugarnes for the first two weeks but then stabilized at between 0.1-0.6 m water level rise per day. The temperature in the Laugarnes system is higher than in the other systems (produced temperature of fluid from the system is ~120 °C to 130 °C). Past experience had shown that wells there could erupt when water level reached shallow depths (~20 m depth below wellhead). Because of this, the water level rising was monitored in detail, pressure sensors were placed on three production wells and regular field visits were carried out to monitor the status of well heads and possible surface manifestations. In the end, the water level in well RG-07 reached 10.7 m below the wellhead at the end of the summer resting operations on the 5th of September and no eruption occurred nor did surface manifestation appear. This was a historic maximum in the reservoir water level since production started from the Laugarnes field. The behavior in the Reykir/Reykjahlíð system was similar with a stabilized daily water level rise of 0.1-0.7 m. This system is by far the largest system and water level lies at a greater depth from the surface. Water level in monitoring well MG-01 reached 29 m below the surface at its highest point during the summer resting. The system would have benefitted from a longer rest. Even though this elevation was not a historic maximum it was the highest point in the last 10 years, despite increasing production over that period.

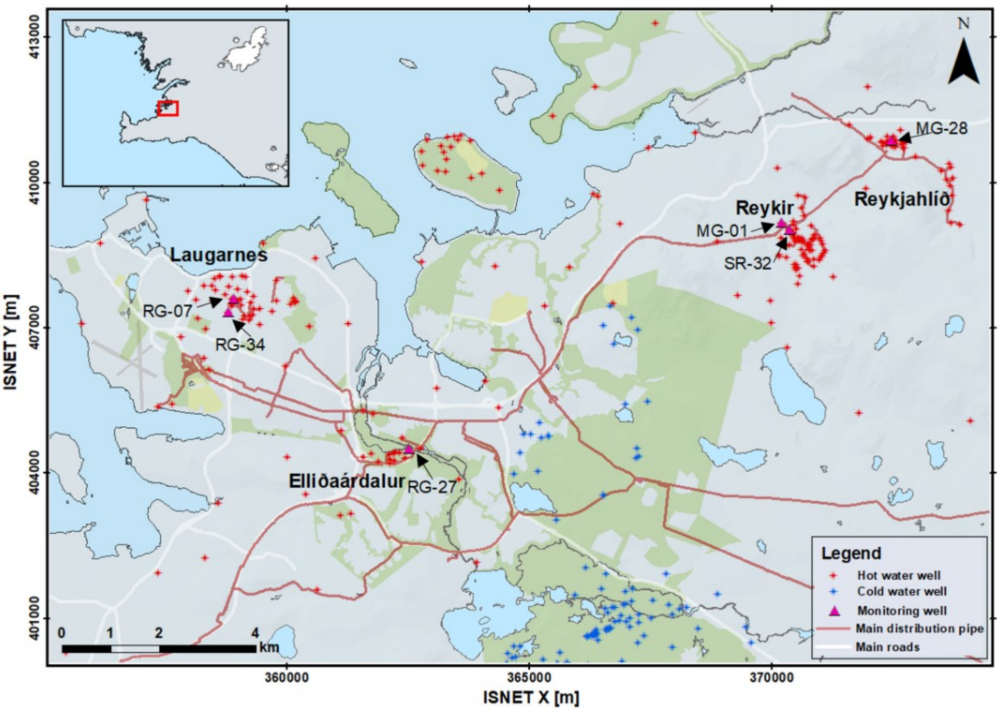


**Figure 2: Map of the capital region showing hot and cold water wells, main distribution pipes for hot water and main roads. The monitoring wells that continuous water level data loggers were placed into in 2019 are shown with triangles (Data source: National Land Survey of Iceland and Reykjavík Energy).**

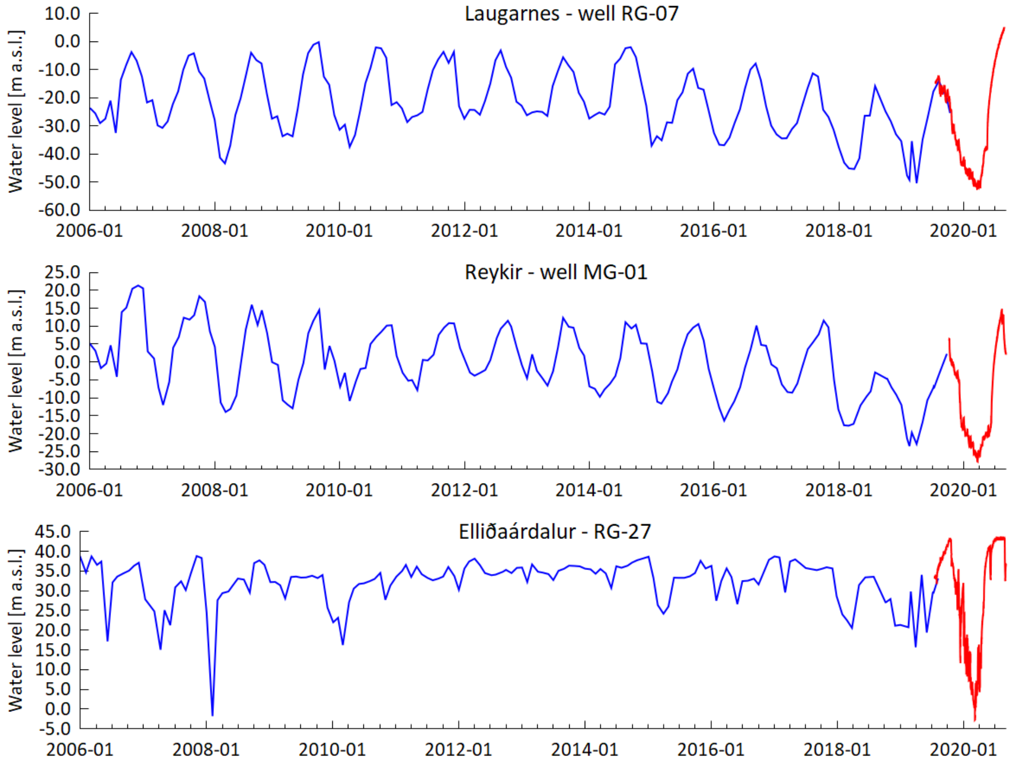


**Figure 3: Water level changes in monitoring wells RG-07 in Laugarnes, MG-01 in Reykir and RG-27 in Elliðaárdalur from the beginning of 2006 until the 5th of September 2020. Manual measurements are shown in blue and continuous logger measurements that started in 2019 in red. The water level is shown in reference to sea level (m a.s.l.).**

The water level rise from the lowest point in winter to the highest point in summer in 2020 was a record for both the Laugarnes and the Reykir/Reykjahlíð systems. It remains to be seen whether this operation will result in greater reserves towards the end of winter. But while the effects last, higher water levels increase the production capacity of the utilized low temperature fields and therefore the security of supply of the district heating system.

### 3.2 Chemical monitoring

Introducing a new water source to the district heating system presented challenges to its operation. To understand how the system reacted, chemical monitoring was performed with the goal of answering two key questions:

1) How long does it take to flush out the existing water and replace it with the new source?
2) To what extent is there mixing of the two waters and is it extensive enough to cause scaling?

Water samples of return water from space heating were taken throughout the district heating system from key distribution centers in areas where it is collected. Samples were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES) for the main cations and anions, but those of principal interest are sodium, magnesium, and calcium. On-site pH measurements were performed using a portable Metrohm pH meter. Table 1 shows a typical chemical composition of low temperature geothermal water and heated groundwater in the district heating system.

**Table 1: Chemical composition of water used for district heating in the capital area**

| | Heated groundwater (mg/kg) | Low temperature geothermal water (mg/kg) |
|---|---|---|
| Na | 15,08 | 46,10 |
| K | 2,14 | 0,87 |
| Mg | 3,58 | 0,01 |
| Ca | 8,53 | 2,29 |
| $SiO_2$ | 38,06 | 81,90 |
| Fe | 0,01 | <0,005 |
| Al | 0,04 | 0,15 |
| B | 0,07 | 0,02 |
| $SO_4$ | 18,54 | 48,50 |
| Cl | 12,28 | 15,00 |
| pH *(@25°C)* | 8,35 | 9,54 |
| $H_2S$ | 0,18 | 0,80 |

The best indicator of how water switching operations progress is sodium, a cation that is unreactive and has different concentrations in the two water sources. Sodium values of 43-47 mg/kg indicate low temperature geothermal water from Reykir and Reykjahlíð while values of 14-16 mg/kg point to heated groundwater from Hellisheiði and Nesjavellir. An intermediate value suggests a mix of the two and that the water switching period is ongoing. Other ions mostly follow suit, but magnesium and calcium display curious behavior that will be discussed specifically in this section.

During normal operation, bi-weekly manual monitoring of $O_2$ and $H_2S$ levels in the district heating system is performed. This monitoring was increased in frequency to twice a week during the summer rest. Keeping the water oxygen free prevents pipe corrosion and surplus $H_2S$ concentration ensures any oxygen entering the system reacts to form sulfate ions. $H_2S$ occurs naturally in geothermal water, but a small concentration of $H_2S$ is added to heated groundwater at the power plants. Additionally, precipitation plates were placed in three locations in the district heating system to monitor potential scaling during the water switching period. No scaling was observed on any of the plates so they will not be discussed further.

As the water switching operation begins, heated groundwater starts to flow along the main branches of the district heating system at roughly the speed of walking, flushing out the low temperature geothermal water. Therefore, the new water reaches the distribution centers in only a matter of hours. A better representation of when the water switching is finished for the entire district heating system and its users, however, is found in the return water from space heating as it comes back to the distribution centers. As seen in Fig. 4 below, the concentration of sodium in the smaller Reykjavík neighborhoods, Árbær and Fossvogur, drops to typical groundwater values one day after the start of operations. The rate of return depends on space heating demands due to outside temperature and varies between neighborhoods due to size and complexity. Nevertheless, larger neighborhoods show heated groundwater values after at most four days and likely sooner, but due to infrequent sampling, faster return could not be verified.

While the concentration of sodium indicates that heated groundwater has replaced any low temperature geothermal water in the system, the concentrations of magnesium and calcium tell a different story. Magnesium concentration lags significantly behind and does not reach groundwater levels until 7-9 days after water switching. This indicates that magnesium is forming scale within the system. Contrarily, calcium concentration shoots up and exceeds the levels typically found in either of the two water types, suggesting that existing calcium scaling is dissolved and flushed out.

Judging from these values only, however, it is difficult to assess the exact reactions taking place. One possibility is magnesium and calcium undergoing an ion exchange process involving pre-existing scale in the district heating system. The two cations are both bivalent and of similar size and reactivity, so as magnesium is bound to the preexisting scale, calcium ions are liberated. The alternative would be the formation of new magnesium silicate scaling and simultaneous dissolution of calcium carbonates. Due to variability of silica concentration in the two heated groundwater sources and due to the difficulty of measuring dissolved carbonates, the scaling reactions cannot be verified.

The opposite behavior was observed when summer resting of the geothermal areas concluded and the district heating system was returned to its normal operating state, with low temperature geothermal water replacing heated groundwater. While sodium concentrations rose to the expected value in 3-4 days, dissolved magnesium ions were detected in the water up until 10 days later. Calcium concentration dipped below its expected value for low temperature geothermal water, indicating scaling or ion exchange reactions. While the exact reaction mechanisms are unknown, the overall scaling effect due to water switching operations is minimal. The period where mixing of the two types of water occurs is short, no scaling was observed on precipitation plates placed in the water flow in pipes in the district heating system and most of the ions that are lost during the water switching operations are recovered in the reverse operation. Further research will include extensive monitoring of a single neighborhood during water switching operations to work out the exact rate of return of each ion and to correlate that with flow data and potential scaling.

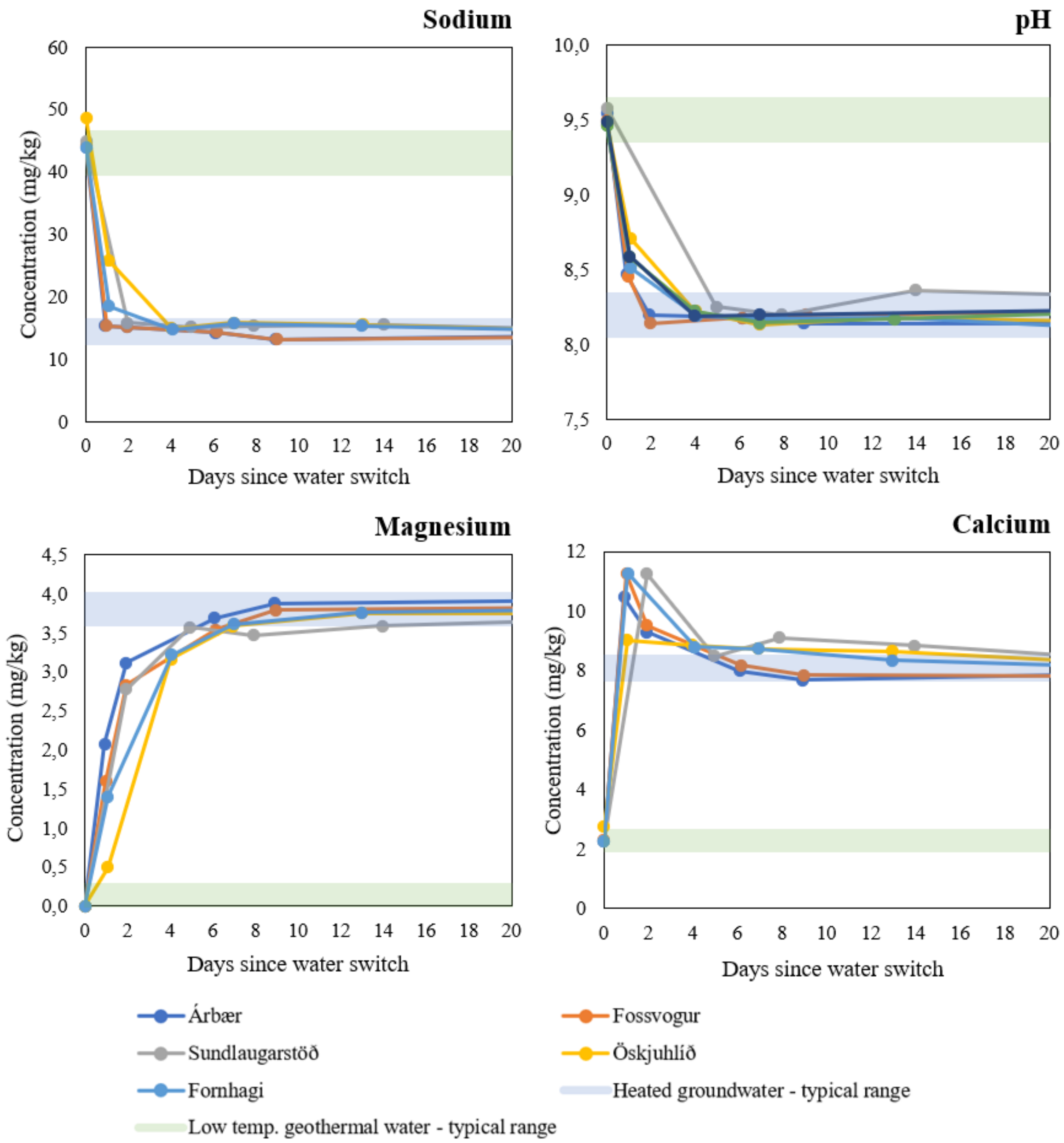


**Figure 4: Four graphs showing the concentration of sodium, magnesium, calcium and pH of return water in five distribution centers of the district heating system in Reykjavík, following the water switch from low temperature geothermal water to heated groundwater. Typical ranges of low temperature geothermal water and of heated groundwater are shown in green and blue shading, respectively.**

### 3.3 Impact on thermal production at power plants

Typically, heated groundwater makes up 42-55% of the total supply for the district heating system in the summertime but this year, with the low temperature fields being rested, heated groundwater accounted for 87% (Fig. 5). As a result, the need for disposal of heated groundwater with injection into shallow wells located between Nesjavellir and Reykjavík was drastically decreased, to only 10-16% of what was injected in the last four years. This injection is carried out over the summertime to dispose of excess heated groundwater produced at the Nesjavellir power plant in response to the annual demand fluctuation for space heating. The impact on thermal production at Hellisheiði power plant was hard to discern since the thermal capacity was increased by 50% this year. Any increase in production would result only in lower temperature brine that is reinjected, and no heated groundwater is disposed on the surface or using shallow injection.

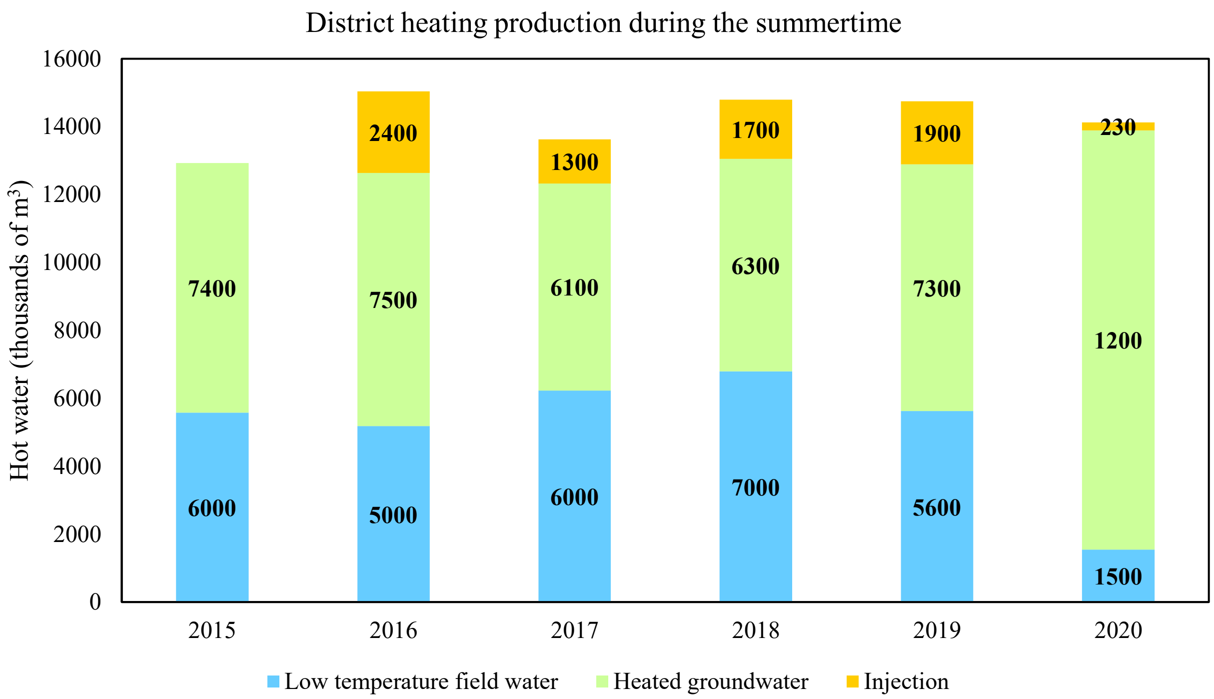


**Figure 5: Comparison of hot water production for the capital area in the summertime from 2015-2020 (May 27th - August 21st). In 2020 the increased use of heated groundwater reduced both the production from low temperature fields and the need for injection into shallow wells located between Nesjavellir and Reykjavík.**

The purpose of this operation was not only to collect hot water reserves in the low temperature fields but also to improve the overall resource utilization of the available resources for the district heating system. The annual fluctuation of space heating demand coupled with the operation of the Nesjavellir and Hellisheiði combined heat and power plants for base load electrical production prompts the disposal of excess water over the summertime. With this operation, the disposal of excess heated groundwater in shallow wells between Nesjavellir and Reykjavík was greatly reduced. However, surface disposal of pre-heated groundwater (heated in the condensation process prior to heat exchange with geothermal fluid) at Nesjavellir was only slightly reduced and at the same time, production of heated groundwater was more than doubled compared to previous years (Fig. 6). This was due to operational changes at the power plant. In the coming years, the surface disposal of pre-heated groundwater could be greatly reduced with the summer resting operation through careful planning and cooperation between the power plant operator ON Power and Veitur Utilities that operates the district heating system.

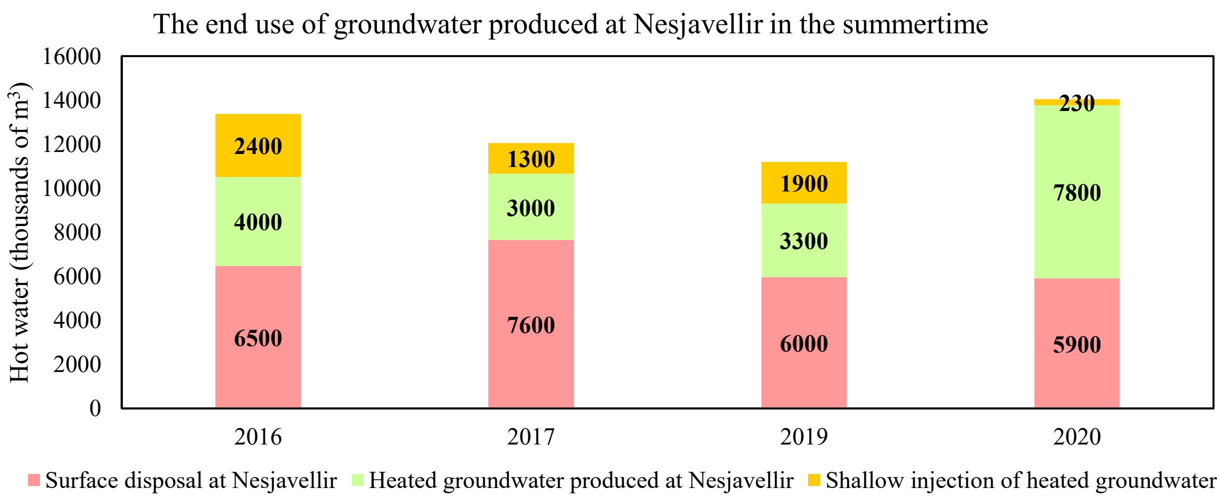


**Figure 6: Comparison of the end use of groundwater produced in Nesjavellir during the summer months. The pink columns represent the portion of groundwater that goes through condensers and is then immediately disposed of on the surface. The green columns represent the groundwater that goes through heat exchangers after the condensers and is used for district heating in the capital region. The yellow columns represent the portion of heated groundwater that is injected in shallow wells located between Nesjavellir and Reykjavík. Data from 2018 is missing from this graph due to a malfunction in the measurement of water produced at Nesjavellir that year.**

## 4. CONCLUSIONS AND RECOMMENDATIONS

In an effort to increase production capacity from utilized low temperature fields in the capital region in Iceland in the wintertime, Veitur Utilities turned off production from all fields feeding the capital region in the summer of 2020. This was an extensive operation that required switching entire neighborhoods that normally receive geothermal water over to a new water source, heated groundwater from combined heat and power plants in the Hengill area. The mixing of these two types of water has been problematic due to scaling, resulting in Veitur Utilities operating two parallel district heating systems in the capital region with water types that cannot be mixed. The duration each geothermal field was rested ranged from 8 to 17 weeks.

During this rest, the response of the low temperature fields in the city was carefully monitored. A record seasonal water level increase was observed in all three geothermal fields. In one of the fields, the Laugarnes field, the water level reached a record high since pumping from the field began more than half a century ago.

Chemical monitoring showed that the changes to the operation of the district heating system caused no significant scaling events or operational problems. However, a delayed recovery of magnesium and calcium ions was observed, which might indicate ion-exchange processes on pipe surfaces.

Overall, the operation was a success. However, the benefit for production capacity during the winter months will not become fully apparent until the spring when water level and demand data for the whole year is available to compare with previous years. Researchers at Reykjavík Energy are currently working on a regression model to simulate the water level in the geothermal fields with and without this operation to evaluate the effect it had on production capacity throughout the year.

In the coming years, an operation similar to this one will be performed every summer. A few key features will be in focus next year:

1) Maximizing the water level rise in each low temperature geothermal field.
2) Minimizing the injection of heated groundwater in shallow wells located between Nesjavellir and Reykjavík.
3) Minimizing the surface disposal of pre-heated groundwater at Nesjavellir.

Specifically, minimizing surface disposal at Nesjavellir should be easily achievable next summer.

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