PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

Conceptual and Numerical Models of the Laugarnes Geothermal Field, Reykjavík Iceland

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Keywords: Low-temperature, formation cooling, conceptual model, numerical model

ABSTRACT

The Laugarnes field is a low-temperature geothermal resource used for space heating in Reykjavik since the 1930s. Despite production averaging approximately 160 L s^{-1} over the past five decades, reservoir water levels and production temperatures have remained stable. This study examines the factors contributing to this stability in pressure and temperature to improve understanding and prediction of long-term reservoir behavior. A detailed review of historical static temperature surveys reveals "top-down" cooling in the upper few hundred meters of the system, which we interpret as indicative of cold recharge from near-surface formations. In the new conceptual model, this recharge is assumed to extract heat from the formation as it percolates into deeper, more productive sections of the reservoir. Numerical simulations successfully reproduced both the natural state and production history of the field, relying solely on basal conductive heat flux as the heat source and incorporating the effects of shallow recharge. The simulations also captured the temperature decline in the shallow formation and the near-stable discharge temperatures from the wells. These results suggest that shallow recharge and the associated top-down heat extraction mechanism sustain production in Laugarnes and offer an alternative framework for understanding reservoir processes in the field and other low-temperature geothermal systems.

1. INTRODUCTION

The Laugarnes geothermal field is one of three low-temperature fields (<150 °C) located within the Reykjavík area in southwest Iceland, the other two being Seltjarnarnes and Elliðaár (Figure 1). These systems are situated along the southern edge of the extinct Viðeyjar caldera, with Laugarnes located where caldera rim intersects the NW-SE trending fissure zone (Gunnlaugsson et al., 2000; Arnórsson, 1995). Although these systems are in close proximity, hydrologic tests and geochemical studies have suggested that these fields are separate hydrothermal systems, likely by impermeable barriers consisting of NW-SE oriented dykes (Thorsteinsson and Eliasson, 1970; Árnason and Tómasson, 1970; Tómasson, 1993). In addition to these three systems, two more low-temperature fields – Reykir and Reykjahlíð – lie 3 km to the northeast, while two high-temperature co-generation plants, located 30 km away, also supply the district heating systems in Reykjavík and surrounding municipalities (Thorbergsson et al., 2023).

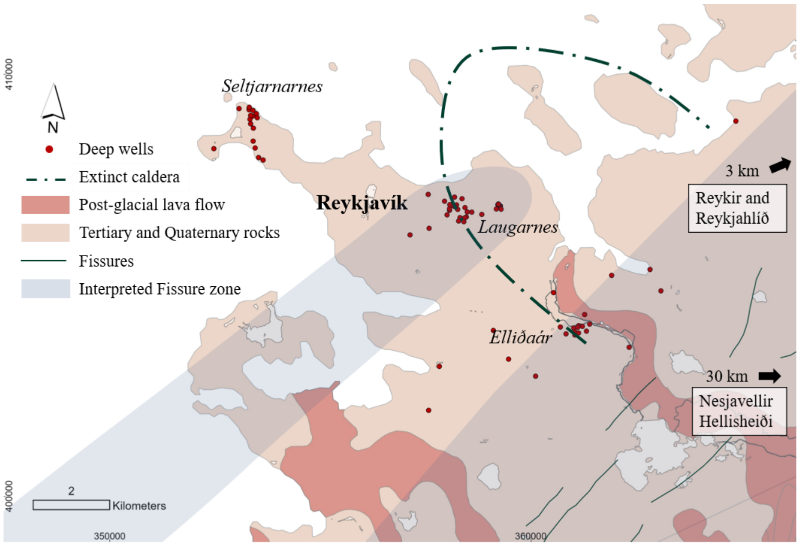

Figure 1. Location of low-temperature geothermal systems used for the district heating of Reykjavik and nearby municipalities.

The Reykjavik area is mostly covered by Plio-Pleistocene and Tertiary rock formations with post glacial lava flow along the Elliðaár valley that flowed some 5600 years ago (Tómasson, 1993). The stratigraphic sequence at Laugarnes, based on drill cuttings analyzed by Thorsteinsson and Eliasson (1970) and later by Fridleifsson (1990), consists of alternating layers of basalt flows, pyroclastics, and sediments, extending to depths of up to 2.2 km. The largest feed zones are primarily located at the boundaries between these lithologic layers (Tomasson et al., 1975). Alteration mineralogy studies from wells in both Laugarnes and the nearby Elliðaár field reveal high-temperature alteration, suggesting that temperatures exceeded 230 °C in the past (Tómasson, 1993; Fridleifsson, 1982; Kristmannsdóttir, 1975).

The production history of Laugarnes is summarized in Figure 2. Before its extensive utilization, the hot springs in the area discharged approximately 5-10 L s^{-1} of water at temperatures ranging from 80 to 90 °C. Shallow wells (<250 m) were drilled near the hot springs starting in 1928, increasing the discharge to 15-20 L s^{-1}, which was then piped to nearby buildings and houses (Axelsson et al., 2010). By the 1950s, rotary drills were used, allowing the construction of larger-diameter and deeper wells. These wells enabled the installation of downhole pumps, which led to a sharp increase in production (Gunnlaugsson, 2004). Production peaked in 1980-1990 as more deep wells were drilled. However, this was subsequently reduced in the early 1990s following the initiation of hot water production from the Nesjavellir power station and to mitigate the effects of observed groundwater influx (Gunnlaugsson et al., 2000; Fridleifsson, 1990). Over the next three decades, production at Laugarnes stabilized at an annual average of 160 L s^{-1} at 120-130°C. Seasonal fluctuations in water production, driven by higher demands during the winter than in the summer, are also seen in Figure 2.

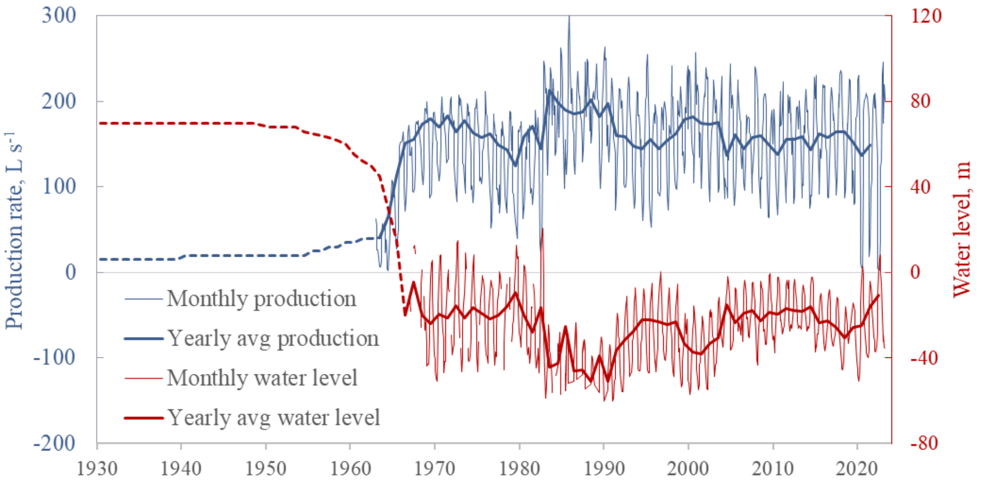

Figure 2. Historical production and water levels in the Laugarnes geothermal field; dashed line estimated from Axelsson (2010), solid lines from Orkuveitan.

The extraction of hot water from Laugarnes resulted in significant pressure drawdown, as shown in Figure 2. At the start of production, the springs and wells were self-flowing and the reservoir's hydrostatic pressure was estimated at 6-7 bar, equivalent to a water column of 60-70 m above sea level. Intensified water pumping during the late 1960s caused a dramatic drop in water levels. At the peak of production, the water level had declined to 60 m below sea level (BSL), equivalent to a total decline of 120 m from pre-production level. Despite this significant drawdown, the water level remained stable as the production was maintained. The correspondence of water level with production rate is also evident on the seasonal production. This suggest that the reservoir reaches quasi-equilibrium with its recharge (Axelsson, 2010), as otherwise, the pressure would continue to drop.

While the reservoir pressure of the Laugarnes field responded accordingly with the total production rate, temperature measurements have remained remarkably stable over the past decades. Discharge temperatures from production wells have stayed nearly constant, despite fluctuations in production levels (Bravo, 2024). Additionally, static wellbore surveys have indicated that rock temperatures in the deep, productive sections of the reservoir have also remained steady. Previous conceptual models (Björnsson et al., 1999 and 2000) interpret a deep flow of hot water from the northeast supporting the production of the field.

Due to the observed stability of temperatures in Laugarnes, quantitative studies of the field (Thorsteinsson and Eliasson, 1970; Bodvarsson and Zais, 1981; Axelsson, 1989; Fendek, 1992; Sarak, 2005; Changhong, 2012) have primarily focused on predicting and forecasting the pressure (water level) response to production. Many of these studies interpret the reservoir as unconfined to explain the stability of water levels relative to production rates. Combined with interpretations of stable reservoir temperatures, this boundary condition suggests the presence of a constant-pressure heat source at the base of the field. Consequently, these interpretations imply that the field could sustain production indefinitely under modeled future scenarios. However, this assumption underscores challenges in predicting the sustainability of Laugarnes, as the field's limits are not yet clearly defined. This highlights the need to revisit and refine interpretations of temperature stability.

In this study, we reexamine downhole temperature measurements from the field to identify changes in formation temperatures. The findings will be used to identify recharge zones and highlight the major reservoir processes occurring in the field. These processes will then be quantitatively tested through the development of a numerical model.

2. TEMPERATURE CHANGES AND HEAT BALANCE

Historical wellbore surveys from the wells in Laugarnes were retrieved from the Icelandic National Energy Agency (Orkustofnun) database. Surveys extending beyond 200 meters in depth were selected for further evaluation to determine their suitability for interpreting formation temperature changes. Initially, temperature surveys displaying instability – such as those conducted within a few months of well completion – were excluded. Surveys affected by dynamic processes, including flowing surveys or those with cross-flow, as well as surveys containing erratic data, were also removed. Among the remaining surveys, wells with more than one stable temperature survey were selected for detailed analysis.

Formation temperature changes (ΔT_r) in the Laugarnes wells, based on at least two stable static temperature surveys, are shown in Figure 3. The data suggests that the deeper, more productive sections of the reservoir (below 1000 meters) have remained stable. This stability is confirmed by surveys from wells R12, R16, and R18, which penetrate these depths and align with earlier interpretations of constant reservoir temperatures. In contrast, the shallow sections of several wells show significant cooling, with formation temperatures decreasing by up to 10 °C at 500 meters below sea level (BSL) in some cases. These observations vary in magnitude across wells. However, there is an inconsistency in the timeframe for calculating temperature changes. Some wells have surveys conducted decades apart, while others have surveys only a few years apart. This limitation arises from the sparse availability of temperature surveys and underscores the need for more frequent temperature measurements to better evaluate and quantify these changes.

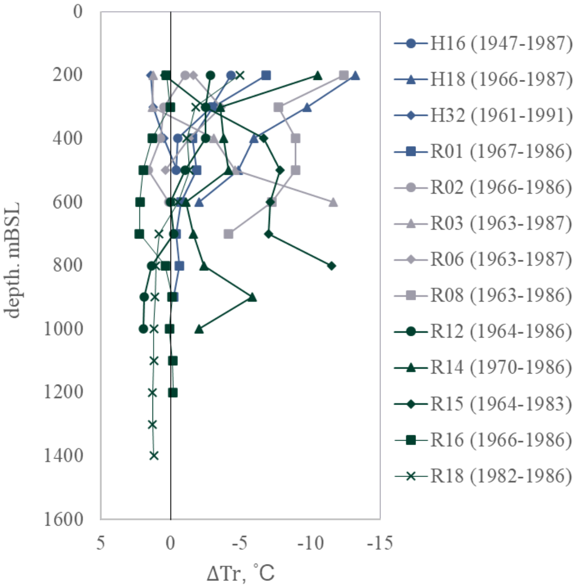

Figure 3. Calculated temperature decrease in Laugarnes wells based on repeated static temperature measurements, where the years correspond to the dates of the surveys.

The temperature changes shown in Figure 3 suggest the presence of a cold, shallow recharge that extracts heat as it percolates into the deeper sections of the reservoir, where the major feed zones of the wells are located. At the recharge location, the temperature change is more pronounced, potentially explaining the greater decline observed in the shallower sections. As the recharge heats up, its temperature increases, reducing the potential for further heat exchange. The deep production zones in Laugarnes likely account for the discharge temperatures remaining largely unaffected by the observed cooling in the shallower sections. However, this cooling may eventually reach the deeper sections, which could impact production temperatures over time. To examine these processes, a 3D numerical model was developed, allowing shallow recharge to percolate into the reservoir.

3. NUMERICAL MODEL

3.1 Numerical model setup

To evaluate whether the decline in formation temperature is sufficient to sustain Laugarnes and assess the possibility of replicating production-induced cooling, we developed a numerical model of the field. The Brynhild module of the Volsung Software Package version 2.2.20240815 (Clearwater and Franz, 2019) was selected for its simplicity and user-friendliness. A geological model of the area was created using Leapfrog™ Geothermal, incorporating a digital elevation map from the National Land Survey of Iceland (Landmælingar Íslands) and lithostratigraphic data from Laugarnes and Elliðaár, simplified based on Thorsteinsson and Eliasson (1970) and Tómasson (1993).

A 20 km by 20 km by 3 km numerical grid was constructed with Laugarnes at its center. This grid was oriented at a 45° azimuth to align with the interpreted flow paths in prevailing models. The grid was refined using PyTOUGH (Croucher, 2011) to achieve finer block sizes at the center and upper sections. At the grid's center, blocks have dimensions of 0.5 km in both length and width, increasing to 1 km in the outer regions. The block thicknesses were set to 100 m in the first kilometer, 250 m in the second kilometer, and 500 m in the outermost zone. The final numerical grid is shown in Figure 4a, and a cross-section showing the layer thicknesses in Figure 4b.

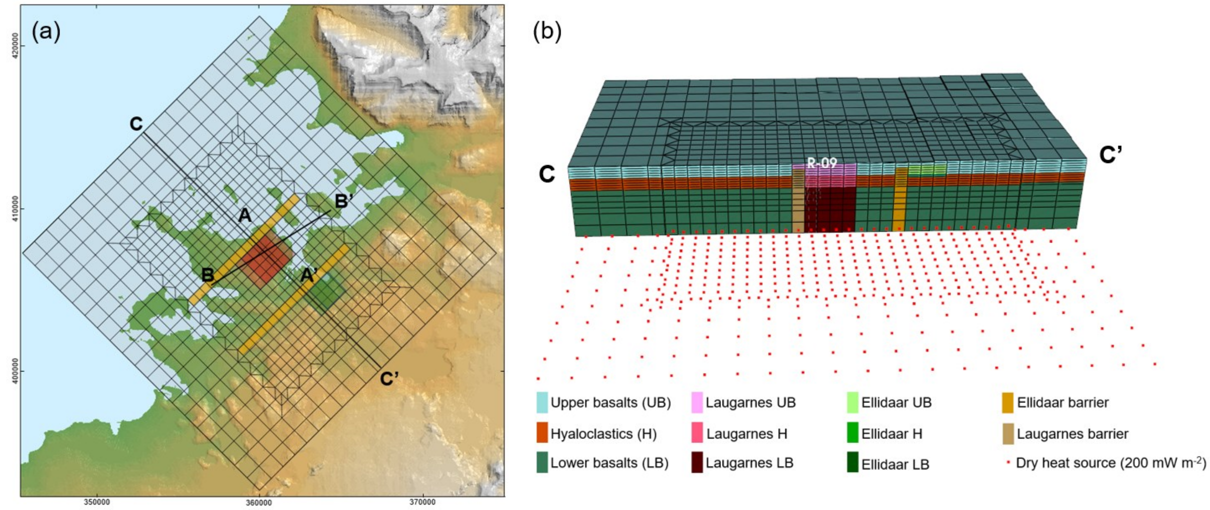

Figure 4. (a) Numerical model grid with Laugarnes at the center and (b) NE-SW (CC') cross-section showing layer thicknesses and the lithologic units.

To simplify the permeability calibration of the reservoir and surrounding rocks, new rock types based on the background lithologic units were defined to represent the reservoirs at Laugarnes and Elliðaár. Each reservoir consists of three lithologic layers with thicknesses aligned with the background lithologies. Additionally, the two hydrological barriers separating Seltjarnarnes, Laugarnes, and Elliðaár were implemented as distinct lithologic units. A NW-SE (CC') cross-section through the center of the grid, shown in Figure 14b, illustrates all the units.

Two boundary conditions were applied to the model. At the base, a dry heat source with a constant energy rate was implemented, providing conductive heat input equivalent to 0.2 W/m^2. This reflects the elevated geothermal gradient in the area, as reported by Bodvarsson (1982) and Flóvenz and Saemundsson (1993). At the surface, the top blocks were connected to an atmospheric block maintained at constant pressure and temperature. Blocks representing the sea were also assigned a constant temperature, with pressure values corresponding to the average sea depth based on bathymetric data.

3.2 Numerical model calibration

The calibration of the numerical model was achieved by implementing a two-step iterative process based on the method outlined by O'Sullivan and O'Sullivan (2016), refining the anisotropic permeabilities (k_x, k_y, k_z) of the various lithologic units. First, the natural-state calibration was performed by matching the formation temperatures obtained from well surveys with the corresponding reservoir blocks. A natural state was deemed established when the mass and energy balance equations were resolved satisfactorily for a time step of at least 3 million years (10^{15} s), indicating steady-state conditions. The second step focused on production history calibration, further refining rock permeabilities to achieve a reasonable match with historical water levels recorded in monitoring wells. Although the model was calibrated to water level measurements, it does not directly provide water level outputs. Instead, water levels for each column were derived from the pressures of the underlying blocks. First, the pressure for each block n under column a were converted to their equivalent hydrostatic head ($\boldsymbol{H_{a,n}}$):

$$H_{a,n} = \frac{P_n}{\rho g} - z_n \qquad (1)$$

where P_n is the pressure, ρ is the water density at 120 °C (940 kg/m^3), g is the gravitational constant, and z_n is the block center depth from sea level. The water level (H_a) is then taken as the average hydrostatic pressures of the underlying blocks:

$$H_a = \frac{\sum H_{a,n} \Delta h_n}{\sum \Delta h_n} \qquad (2)$$

where Δh_n is the block thickness. In calculating the water level, only blocks 4 ($z_n = 250\ m$) through 13 ($z_n = 1325\ m$) were considered as these blocks already account for the majority of the feed zones in the reservoir (~95%).

The numerical model was deemed calibrated after achieving a sufficient match between two data sets: natural state temperatures and historical pressures. The calibrated permeabilities required to achieve this are summarized in Table 1, alongside estimated permeabilities from previous analytical models.

Table 1. Calibrated permeabilities of the rock types in the numerical model and permeability estimates from analytical models.

	k_x, m^2	k_y, m^2	k_z, m^2
Laugarnes UB	1.45e-14	1.8e-14	8.5e-15
Laugarnes H	1.45e-14	1.8e-14	8.5e-15
Laugarnes LB	1.35e-14	1.5e-14	7.0e-15
Upper Basalts	1.2e-14	1.3e-14	3.0e-15
Hyaloclastics	1.2e-14	1.3e-14	3.0e-15
Lower Basalts	1.1e-14	1.2e-14	2.7e-15
Laugarnes Barrier	1.0e-16	1.0e-15	1.0e-16
Elliðaár Barrier	1.1e-15	1.0e-15	5.0e-16
Bodvarsson and Zais, 1978	1.7E-14		
Björnsson et al., 1990	1.2E-14		
Changhong, 2012	1.2E-14		

The calibrated natural-state thermal structure in the numerical model, shown in Figure 5a, highlights the upflow feature beneath Laugarnes. This temperature distribution closely aligns with the measured formation temperatures from the field wells, as illustrated in Figure 5b, where block temperatures are compared with measurements from two deep wells (R34 and R40). The temperature distribution also shows a decrease in temperature further away from the field.

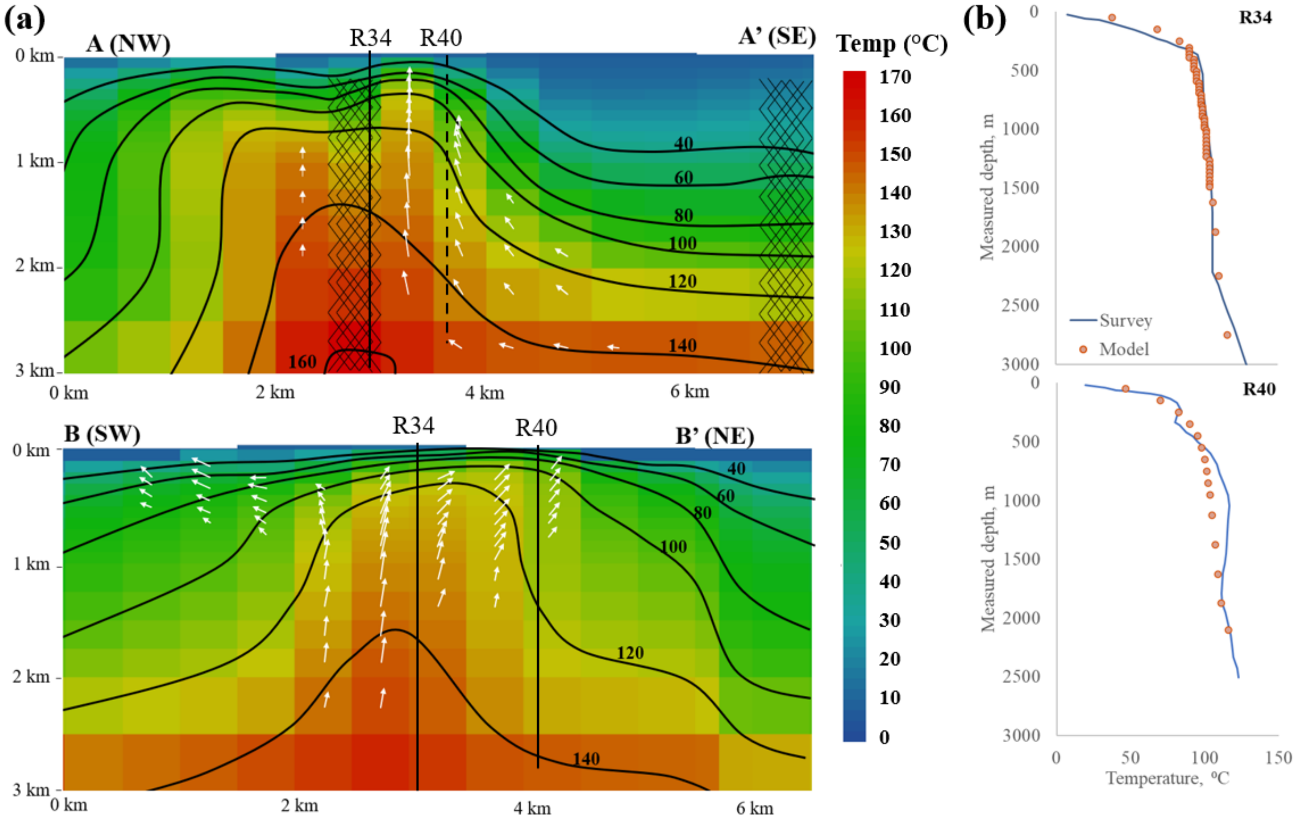

Figure 5. (a) AA' (NW-SE) and BB' (SW-NE) cross-sections through Laugarnes showing the calibrated natural-state temperature distribution and water flow velocity (b) comparison of modeled and measured well temperatures from R34 and R40 (refer to Figure 4 for AA' and BB' section lines).

Figure 5a also illustrates how the natural-state temperature distribution is primarily controlled by deep water flow, largely driven by the topographic relief in the area. The calibrated vertical permeabilities of the surrounding rocks are about four times lower than the horizontal components, enhancing the lateral flow of water. As the water flow towards the northwest, it gains heat until it reaches areas of higher vertical permeability at Laugarnes. The low-permeability structure perpendicular to this flow further promotes upward movement by restricting flow through it. This topography-driven flow of water contrasts with the prevailing conceptual model (Björnsson et al., 1999 and 2000), which interpreted a deep recharge flowing from the northeast beneath the sea. Despite these differences, the temperature distribution generated by the numerical model closely align with those of the prevailing model and field measurements. The outflow feature in Figure 5a (BB') may also explain the slight temperature reversal observed in R40.

Figure 6 illustrates the production history calibration of the numerical model, where the simulated water levels match the measurements from monitoring wells. In the initial state, the numerical model reproduced the overpressure, although higher by 10 m (1 bar). It also captured the pressure decline resulting from the production increase in the 1960s and the major fluctuations that followed. Additionally, the simulation replicated the observed stability in water levels following, without requiring a deep recharge boundary condition. This suggests that the recharge sustaining production primarily originates from the shallower blocks connected to the atmosphere.

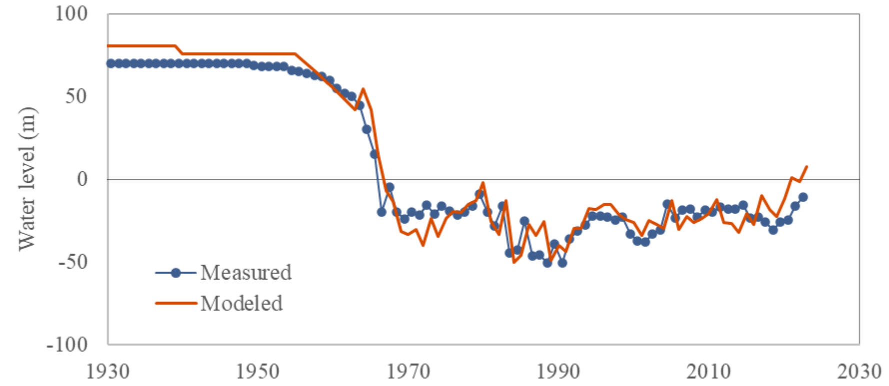

Figure 6. Production history calibration - comparison of water levels measured from monitoring wells and the simulated water levels from the model.

The calibrated model is then used to evaluate the impact of production on the formation temperatures. Figure 7a depicts the temperature evolution of a modeled well from year 1900 to 2020. No significant temperature decline is observed between 1900 and 1930, when production was restricted to springs, or between 1930 and 1960, when wells were self-flowing. However, a notable decrease in formation temperatures becomes apparent after 1960, particularly in the shallower sections of the field, coinciding with increased production through pumping. Figure 7b compares the modeled temperature decline from 1960 to 1990 with the measured decline shown in Figure 3. This period was chosen to match the timeframe of most temperature surveys in Figure 3. The results show that the model predicts a temperature decrease consistent with the measured data, as well as the "top-down" cooling pattern observed in many wells.

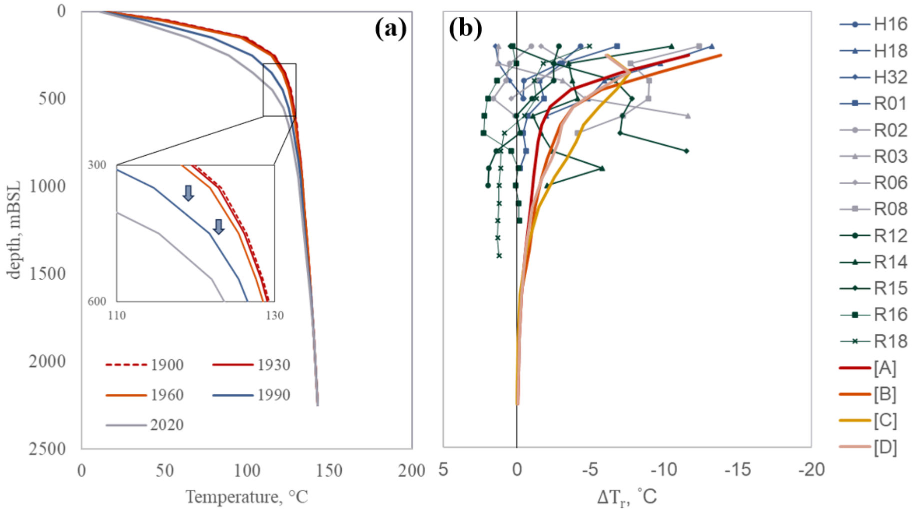

Figure 7. (a) Simulated evolution of formation temperatures of column A, where most production wells are located, illustrating the thermal decline induced by production since 1960, and (b) Comparison of the simulated formation temperature decline of column A and surrounding columns (B, C, D) from 1960 to 1990 with measured temperature changes from wells.

In the numerical model, the calibration of the reservoir's initial-state thermal structure and pressure history (Figure 5) was achieved by refining the anisotropic permeabilities of various lithologic units. Adjusting permeability values had contrasting effects on the two calibration parameters. Reducing permeabilities limited water convection, trapping more heat within the blocks and leading to higher natural-state temperatures. In contrast, during production calibration, lower permeabilities restricted mass exchange between blocks, resulting in a more significant decline in reservoir pressures. As a result, the permeability values needed to be low enough to accurately replicate natural-state temperatures, yet high enough to allow sufficient mass transfer between blocks to sustain water extraction. This underscores its importance in governing heat and mass transport during both the initial state and production states. The successful calibration suggests that the refined permeabilities, summarized in Table 1, adequately support heat and mass transport within the reservoir. Moreover, these calibrated permeabilities align well with estimates from earlier analytical and lumped-parameter models, as also shown in Table 1.

The calibrated vertical permeabilities (k_z) of the reservoir and surrounding rocks were set two to four times lower than their lateral permeabilities (k_x and k_y), promoting lateral water flow. In the natural state, this lateral flow enables water to travel and get heated, until it encounters zones of higher vertical permeability beneath Laugarnes. This permeability distribution likely reflects the depositional history of the rocks, where alternating subaerial and subglacial lava flows create layered structures (Thorsteinsson and Eliasson, 1970; Fridleifsson, 1990), with interlayer contacts acting as preferential pathways. Conversely, the increased permeability in Laugarnes may result from recent fracturing of the deposited rocks.

The lower lateral permeability may also explain how the reservoir develops overpressure in its natural state. This overpressure is driven by buoyant forces resulting from the density difference between the reservoir fluid and the cooler surrounding aquifers. This suggests that the vertical permeability is low enough to contain the pressure within the reservoir, even in the absence of a clay cap. However, the lack of a clay cap also means that shallow recharge can infiltrate the reservoir during production, which aligns with the open-boundary interpretations from earlier analytical models.

This connection to a shallow open boundary condition implies a critical balance in vertical permeability: it must be high enough to permit water infiltration into the system but low enough to result in slow thermal cooling. The historical pressure calibration in the numerical model (Figure 6) indicates that the recharge is sufficient. Similarly, the modeled temperature decline (Figure 7) demonstrates that the thermal cooling caused by cold recharge matches the observed cooling measured in wells. These results show that the calibrated permeability distribution achieves the necessary balance during production-history calibration, providing adequate recharge while minimizing the downward progression of a thermal front.

Despite the simulated shallow thermal front and the observed temperature decrease (Figure 7a and 7b), the discharge temperature simulations in Figure 8 indicate that production remains largely unaffected. In the numerical simulation, the discharge temperature of a well is modeled using the average field-wide feed zone distribution from Thorsteinsson and Eliasson (1970): 15% from 300–600 m, 80% from 600–1300 m, and 5% from 2000 m. The results show that discharge temperatures decline by about 5 °C during the initial 100 years of production, aligning with measured data from some of the wells, such as R05. Assuming the field-wide production remains stable, the discharge temperature is projected to decline by an additional 7 °C over the next 100 years. This prognosis, however, is based on a relatively simple model, so some statistical variation is expected. For example, R10 shows a relatively stable temperature compared to the modeled decline. Refinements in the model, such as incorporating a more detailed feed zone distribution in the wells, using smaller blocks, and extending the boundaries both laterally and at depth, could improve accuracy. Nevertheless, these findings suggest that while production is affected by cold water influx, the temperature decline may remain within acceptable limits, supporting the field's long-term sustainability.

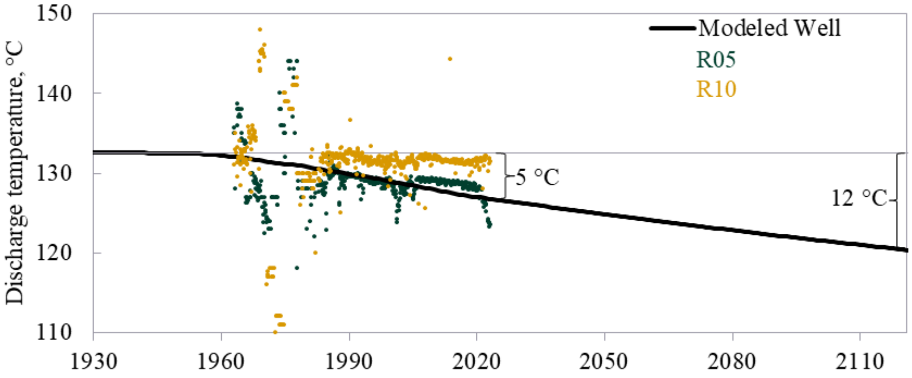

Figure 8. Simulated discharge temperatures and comparison with two production wells.

4. A REVISED CONCEPTUAL MODEL

The numerical model of Laugarnes demonstrates how the shallow recharge could reproduce the observed “top-down” cooling, as well as the how it could be the primary driver of heat and mass transport during production. Without deep mass inflow boundary condition, the production is largely sustained by the cold shallow recharge. Consequently, the heat is largely provided by the heat it extracts as it flows into the deeper section of the reservoir. We integrate this into the updated conceptual model of the field in Figure 9.

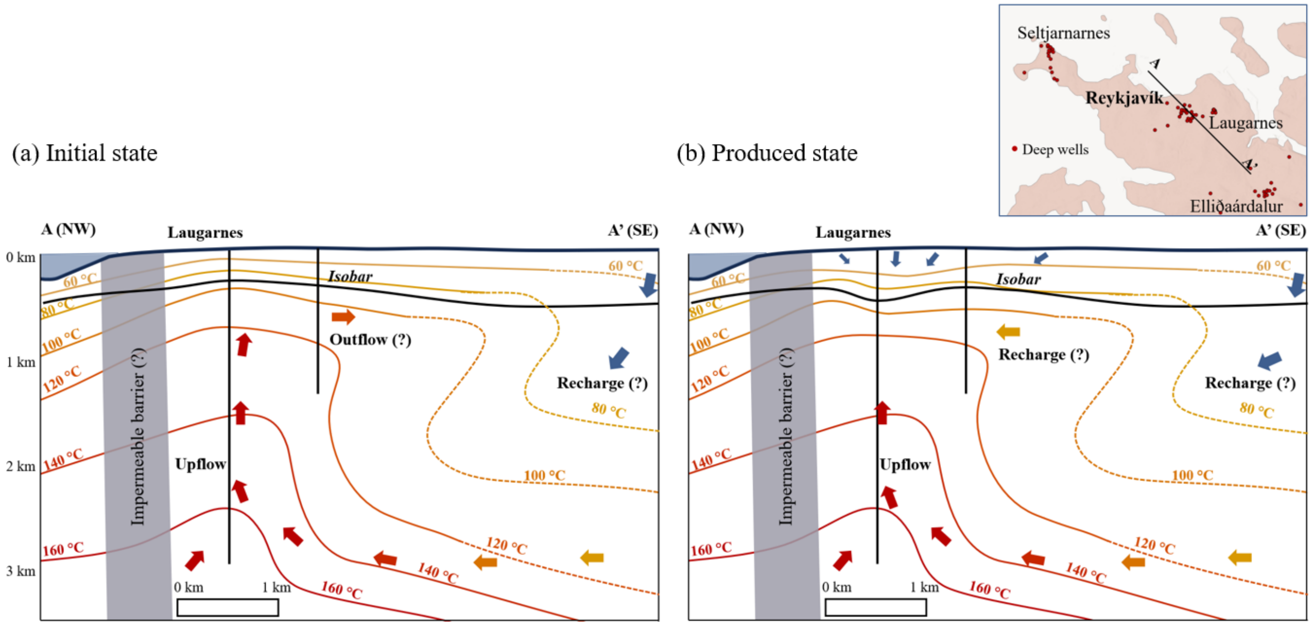

Figure 9. A revised conceptual model of Laugarnes in (a) the initial state and (b) the produced state.

The temperature distribution during the initial state (Figure 9a) highlights the upflow beneath Laugarnes and the deep topography-driven the southeast. In the numerical model, some of the hot water outflows eastward, explaining the temperature reversal observed in well R40. Extending this flow further to the east and southeast may also account for the temperature reversal recorded in the Elliðaár wells (see Tómasson, 1993). The overpressure beneath Laugarnes, driven by the buoyancy of hot water, is depicted as an isobar in Figure 9a.

As water is pumped from the field, the resulting drawdown generates a driving force for shallow, cold recharge to infiltrate the system. In Figure 5b, this is depicted by a local depression in the isobar. The drawdown may also reverse the direction of the outflow, which could act as a recharge pathway. Heat extraction associated with these recharge streams cools the formation, as shown by the isotherm depressions at recharge locations. This cooling effect may explain the temperature decline observed in the wells (Figure 3). Similar depressions in the isobar and isotherms are observed in Elliðaár, which may account for the recorded temperature decline in the wells (Bravo, 2024).

The model also emphasizes the importance of formation cooling as the primary heat source, with significant implications for the sustainability and longevity of the field as a hot water supply for the city. The process of cold recharge extracting heat from shallow formations suggests a downward-moving thermal front over time, which could eventually influence the deeper, more productive sections of the reservoir. However, forecasts from the numerical model indicate that, assuming current production levels are maintained, the discharge temperature is expected to decline by only 7 °C. This suggests that while some decline is inevitable, its impacts may remain within acceptable limits. Conversely, increasing production rates could accelerate the thermal front's movement, potentially causing a more pronounced temperature decline.

Despite these findings, we acknowledge the limitations of the current model and emphasize the need for refinements to improve predictions of future reservoir performance. For example, the most recent static temperature measurements were collected several decades ago, and updated measurements could help validate or challenge our findings. Furthermore, data from additional wells could provide a more detailed understanding of spatial temperature variations linked to production, potentially revealing the origins of larger recharge streams. Lastly, the numerical model could be enhanced by incorporating finer grid blocks and including nearby low-temperature fields in its calibration.

5. CONCLUSIONS

This study examined long-term production and field data from Laugarnes, leading to a reevaluation of the field's conceptual model based on the findings:

- Repeat static formation temperature measurements show "top-down" cooling, with more significant cooling in the shallower sections. This suggests that cold recharge from the shallow parts of the reservoir infiltrates into the deeper, more productive sections.
- To assess whether this shallow recharge can support production, a numerical model was developed. The initial-state temperature distribution and the production pressure history of the field were successfully calibrated using only basal conductive heat flux as the heat input. Additionally, the shallow formation cooling was well-replicated. These results suggest that shallow recharge is sufficient to sustain the mass and heat produced by the field.
- Forecasts from the numerical model indicate that, because most feed zones are located in the deeper sections of the field, discharge temperatures remain largely unaffected. The model predicts a temperature decline of approximately 5 °C over the first 100 years of production, consistent with data from some production wells. Furthermore, it predicts an additional 7 °C decline by the end of another 100 years.
- The conceptual model of Laugarnes was updated to integrate the shallow recharge mechanism as a key process in the reservoir's behavior during production.

The new conceptual models offer an alternative perspective on understanding heat flow in Laugarnes and, ultimately, its longevity and sustainability. Previous interpretations implied that the field could produce perpetually without significant thermal decline. Our reevaluation of reservoir data indicates production-induced thermal changes in the field, which are replicated in the numerical model as a downward-moving thermal front. Despite this, production remains largely unaffected due to the deep feed zones, with near-constant discharge temperatures, a trend also replicated in the model. However, significant changes in production – such as a substantial increase in pumping – could accelerate the movement of the thermal front, potentially leading to an excessive decline in discharge temperature. This highlights the importance of updating field data and delving deeper into these models to accurately predict the future performance of the field.

Finally, the results and key insights from this study could aid in understanding other low-temperature systems in Iceland. For example, Reykjahlíð exhibits similar pressure and discharge temperature stability. Elliðaár and Reykir also show pressure stability, though with a noticeable decline in discharge temperature (Bravo, 2024; Bjornsson and Steingrimsson, 1995). The mechanisms of shallow recharge and formation heat extraction may be applicable in modeling the responses of these fields, as well as other low-temperature fields in Iceland.

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