Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Power to the Operators: Further Development of a Robust Modelling Tool for the Management of Low- and Intermediate-Temperature Geothermal Reservoirs

Gautason B[1,5*], Halldórsdóttir S[1], Miecznik M[2], Magnússon R L[1], Marteinsson K[1,3], Þorgilsson G[1,4], Pierzchała K[2], Tyszer M[2], Bellot A T E[1,4], Aðalsteinsson S M[1], Kępińska B[2], Tulinius H[1] and Axelsson G[1]

ÍSOR (Iceland GeoSurvey), Kópavogur, Iceland[1*], Mineral and Energy Economy Research Institute, Polish Academy of Sciences, Kraków, Poland [2], Carbfix, Reykjavík, Iceland[3], Reykjavík University, Reykjavík, Iceland[4,] Breiðdalsvík Research Centre, University of Iceland[5],

*bjarg@hi.is

Keywords: Lumped parameter modeling, pressure changes, forecasting, low-temperature systems, Lumpfit++, Lumpfit, Botn, Hjalteyri, Syðra-Laugaland.

ABSTRACT

A new version of Lumpfit has been developed under the name Lumpfit++. Lumpfit++ can handle more complex systems than previous versions. Thus, a larger number of tanks (volumes) are permitted, and there is more freedom in defining connections between tanks. This added complexity allows users to more faithfully mimic production from geothermal fields where several wells are utilized for mass extraction, and the pressure response in the system is monitored from non-producing wells. A GUI has been added to the program to reduce the learning threshold for using the program effectively, and to facilitate the building of reservoir models. Our goal is for developers to adopt the software and incorporate it into their regular operations. This, in turn, will drive home the need for regular and careful collection of production data as a key component in the sustainable utilization of the resource.

1 INTRODUCTION

In this paper we report on work carried out within the EEA & Norway Grants-funded GeoModel project. GeoModel is the result of a collaboration between Iceland (primarily ÍSOR) and Poland (primarily MEERI PAS). The project commenced in late 2022 and was completed in early 2025. One aspect of the work dealt with developing further the well-known Lumpfit software that has been available to the geothermal community for decades. It is used to model and predict reservoir pressure changes (water-level changes) resulting from geothermal utilization. Here we summarize the history and outline the theoretical background of Lumpfit. We then demonstrate, with examples from low-temperature fields in Iceland, the use of this newly updated tool now known as Lumpfit++.

The motivation for developing Lumpfit++ can be summarized as follows: For one, we wanted to bring a robust but user-friendly modelling tool to the operators of geothermal fields. Our hope is that operators will adopt this, or similar tools, in their regular operations. In doing so, we expect that the importance of carefully collected and curated production data will become crystal-clear to them. The regular use of software of this nature may also lead to better and more sustainable field management.

Additionally, the increase in energy production from many geothermal fields in the last decades has led to more complex field management. A greater number of wells are utilized from a given field, each with its own characteristics. Furthermore, dedicated water-level monitoring wells are increasingly being used for field monitoring. Such monitoring wells may be poorly connected to the system, and response to pressure changes may be sluggish. There is a need for a modelling tool that can mimic these more complex production scenarios.

This is in stark contrast to the 1980s and 1990s when the Lumpfit program was developed based on a simple linearized model with production from a single well with water level data obtained from the production well. The newly developed program allows the user to model simultaneously water levels in multiple production wells, as well as dedicated observation wells.

Lumped parameter modelling of pressure response data has been applied to many low-temperature geothermal reservoirs in Iceland and elsewhere. The Lumpfit method simulates the pressure response of a reservoir by using a small number of connected homogeneous volumes. Originally, the method required very little computing time compared to more detailed numerical modelling. The method has proven to be very successful in predicting pressure change in liquid-dominated geothermal systems. It has been applied as a tool for resource assessment and field management for more than four decades. The most recent implementation is limited to a single source

of production and has a limited number of connections between reservoir volumes. Increasing hot water consumption in Iceland over the last decades has led to increased production from geothermal fields and an increased number of wells per field. The increased complexity of reservoir geometry calls for a new software tool based on the methodology for solving a general lumped parameter model presented by Axelsson in 1985 and 1989.

Lumpfit++ extends a previously developed program, Lumpfit, that utilized a solution to a linearized lumped parameter model. The original Lumpfit code was developed by Axelsson and Arason (1992). It was based on a preliminary version from Axelsson's thesis work (Axelsson,1985). The Lumpfit program was developed further and maintained at the National Energy Authority (Orkustofnun). Later, it was maintained and updated at ÍSOR (Iceland GeoSurvey). Lumpfit was, and still is, used as a teaching and training tool at the Geothermal Training Program for many years. In 2014 Lumpfit was implemented in Python and published with a graphical user interface (Gylfadóttir et al., 2024). The latest version of the program, referred to as Lumpfit v3 (or simply Lumpfit) was described in some detail by Gylfadóttir et al. (2024), who also outlined briefly its functionality. The latest incarnation, Lumpfit++, differs from previous versions in that it can handle more complex problems. For example, water level and production rate data from more than one well may be considered. It can also handle more complex connections between reservoir volumes. This is important for the modern-day management of geothermal reservoirs.

2 THEORETICAL FRAMEWORK

Axelsson (1989) described the mathematical model that the lumped parameter method is based on. Lumped parameter models of geothermal reservoirs consist of tanks connected by conductors. A commonly used analogy is the electrical circuit where several capacitors (tanks) are connected by resistors/conductors. Each tank simulates storage in different domains of the reservoir, whereas the conductors represent the permeable pathways between these domains (Figure 1).

A tank in a lumped model is characterized by its mass storage coefficient, κ, defined as the ratio between the liquid mass in the tank, m, and the pressure, p, i.e. $\kappa = m/p$. A conductor between two tanks in a lumped model is characterized by its mass conductance σ, defined as the ratio between the mass flow rate in the conductor, q, and the pressure difference between the connected tanks, Δp, i.e. $\sigma = q/\Delta p$. The pressure (water level) in the tanks simulates the pressure in different parts of the reservoir, whereas production from the reservoir is simulated by the withdrawal of liquid mass from one or more of the tanks (Figure 1).

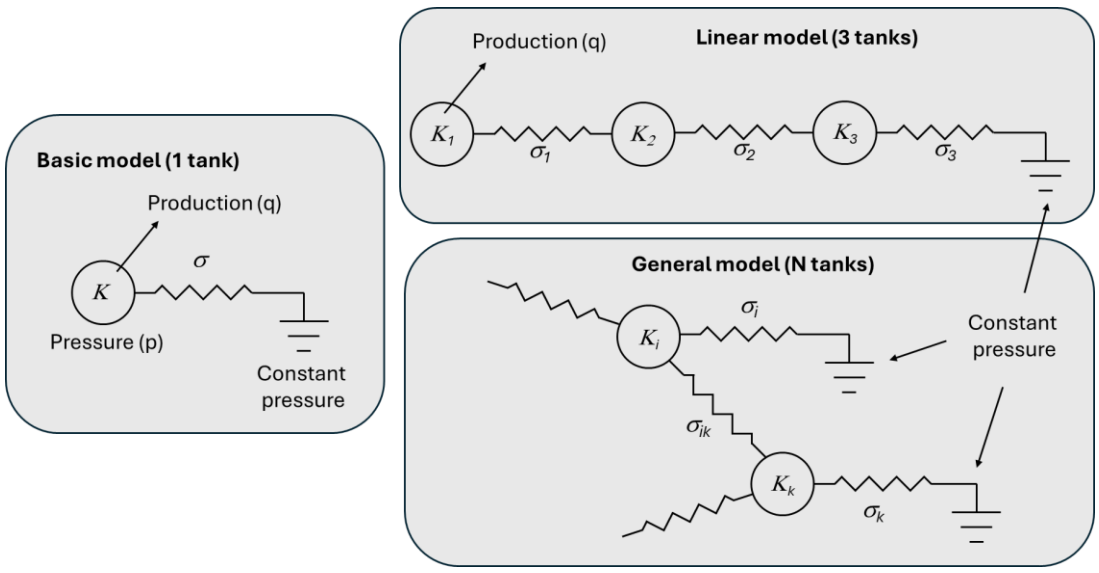


Figure 1. A schematic illustration of a basic one-tank model (left), a linear three-tank model (upper right) and a general N-tank model (lower right). The tanks (K) are linked together with conductors (σ). All are shown supported by a constant pressure boundary (open model). Alternatively in a closed model the kth tank is not supported by a constant pressure boundary (adapted from Axelsson (1989)).

The theoretical Lumpfit model can be related to a conceptual model for a particular geothermal system. Tying the conceptual model and the Lumpfit model together is a useful exercise and may contribute to improvements in either the simulations or the conceptual model. In a fault-related, fracture-dominated system one can speculate that the fault core constitutes one tank, which is supported by the relatively permeable damage zone around the fault core that constitutes the second tank. Both tanks are supported by the country-rock tanks three and four that provide the infinite (constant-pressure) support for the system (Figure 2).

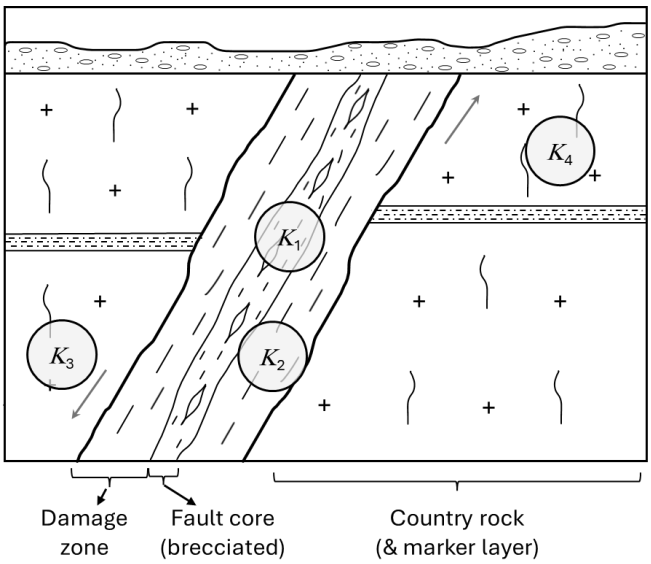


Figure 2. Potential relationship between a theoretical Lumpfit model and a conceptual model of a fracture-dominated (fault-related) geothermal system (figure redrawn and adapted from Gudmundsson 2013).

3 THE LUMPFIT++ USER INTERFACE

Lumpfit++ provides a simple GUI for running simulations. The interface prominently features a graph for displaying water level and production data. Above the graph are two important dropdown menu options for the program's functionality, *File* and *Properties*. The *File* drop-down menu has easy-to-understand *Read*, *Save* and *Quit* options. The *Properties* menu is for building the actual model (Figure 3). It will be described in more detail below. Underneath the graph are two key functions, i.e. *Displayed tank* and *Invert*. The former allows the user to select which tank's water-level and production-data is displayed on the graph. The latter function uses a least-squares minimization algorithm to invert the model to the data.

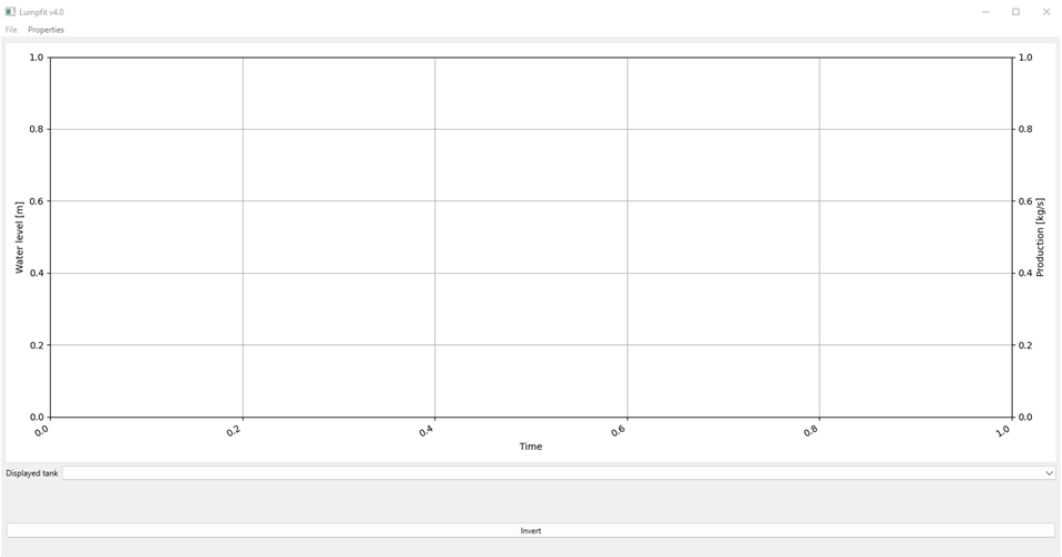


Figure 3. The Lumpfit++ user interface, prior to reading in a data file.

3.1 Input

Input files are text files with a header (1st row only) that the program ignores when reading the file. Rows with data start with a timestamp (YYYY-MM-DD HH:MM:SS) followed by data pairs consisting of water level (m) and pumping or flow (kg/s) from each well used in the model (Figure 4). Only water-level data is provided for monitoring wells. Missing data, denoted "-999", is ignored by the program. Data entries are separated by tabs or white space.

```
Date, waterlevel 1, prod. 1, waterlevel 2, prod. 2, waterlevel 3, prod. 3, waterlevel 4, prod. 4,
2019-01-02 00:00:00     63.1    -999    57.98   55.31   62.8    98.45   -999    -999
2019-01-09 00:00:00     63.4    -999    57.99   54.51   61.1    97.99   -999    -999
2019-01-16 00:00:00     62.9    -999    57.7    54.58   61.2    96.62   -999    -999
2019-01-23 00:00:00     62.2    -999    57.74   55.24   61.1    98.29   -999    -999
2019-01-30 00:00:00     62.3    -999    57.8    55.09   61.3    98.72   -999    -999
2019-02-05 00:00:00     64.08   -999    57.57   -999    61.2    -999    -999    -999
2019-02-06 00:00:00     -999    -999    -999    55.14   -999    99.08   -999    -999
2019-02-11 00:00:00     63.9    -999    57.79   -999    61.6    -999    -999    -999
2019-02-12 00:00:00     64.8    -999    57.99   -999    59.38   -999    -999    -999
2019-02-13 00:00:00     -999    -999    -999    55.57   -999    99.03   -999    -999
2019-02-18 00:00:00     62.0    -999    58.01   -999    61.7    -999    -999    -999
2019-02-19 00:00:00     63.9    -999    57.8    -999    61.9    -999    -999    -999
```

Figure 4. Input files are text files consisting of a timestamp followed by tabbed (or spaced) data pairs (water level and pumping) for each well. The file has a single header line that Lumpfit++ ignores.

The first step in any model is always to read in a data file, which activates the *Properties* menu (Figure 5). The next step is to determine the number of tanks. This is done with the *Tanks* option in the *Properties* menu. A reasonable starting point is to have one more tank than the number of production wells. Next, the user decides the capacitance (kg/Pa) of each tank and the initial water level (m). Default values are given for the capacitance. Then, the user selects the *Connections* option to determine the connections between tanks and their conductance. Default values are given for the conductance. Finally, under the *Wells* option, users assign wells to the appropriate tanks and name each well. After setting the parameters, a model that fits the data is simulated by pushing the *Invert* button at the bottom of the program screen. Some tweaking of the parameters will be needed to obtain a reasonable fit (Figure 6).

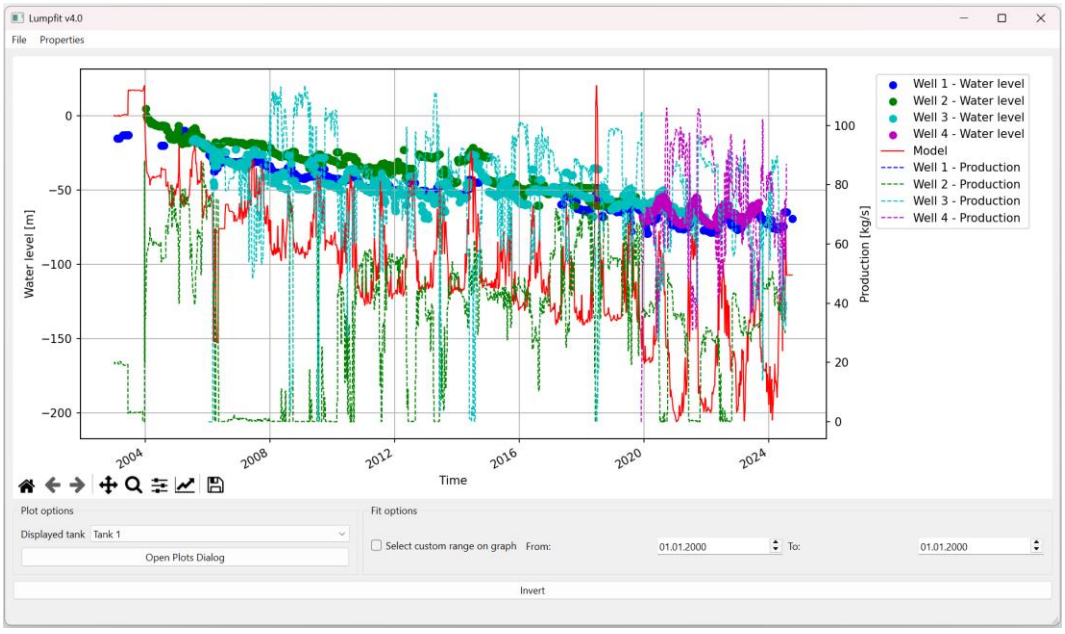


Figure 5. Program screen after data has been loaded using the *File > Open Datafile* menu.

3.2 Forecasting

Preparations for forecasting are made using the *Prediction* dialog under the *Wells* drop-down menu. The panel provides a setting for the forecast period (in years) with a default value of 20 years. Sub-panels, equaling the number of tanks, are provided to define the production rate for each well and the annual production increase from each tank.

The *Seasonal Variation* panel enables users to establish relative seasonal variation in monthly production rates for each month of the year. In the *Variation Function* panel, users can define a function to establish variation in the monthly production rates. The default type is a cosine function, where the user can set the relative amplitude, and offset, of the cosine function. After changing the preset values, the *Seasonal Variation* panel should be updated by pressing the *Calculate* button.

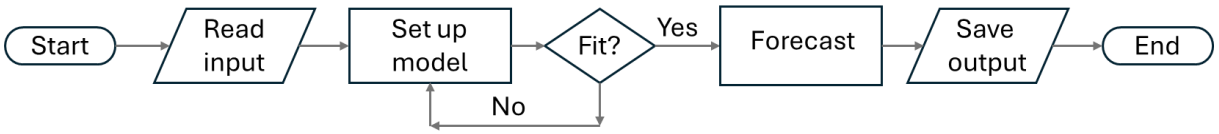


Figure 6. A simple flow diagram showing the key steps in using Lumpfit++ for modelling well data.

4 APPLICATION OF LUMPFIT++ TO DEMO SITES IN NORTH ICELAND

As part of the project, Lumpfit++ tool was tested on demo sites located in central north Iceland (Figure 7). All three sites are fields operated by Norðurorka, the district heating company for Akureyri and surrounding areas. Hjalteyri is located on the western shore of the Eyjafjörður fjord about 25 km north of Akureyri, and Syðra-Laugaland and Botn are both located about 12–13 km south of Akureyri in the Eyjafjörður valley. A summary of the fields and fluids extracted is presented in Table 1.

A relatively simple classification scheme is used in Iceland to divide geothermal systems into two main categories, “high-temperature systems” and “low-temperature systems”, based on the regional geothermal gradient (dT/dZ). The geothermal systems discussed here are all classified as “low-temperature” systems since the formation temperature at 1 km depth is below 150°C (dT/dZ < 150°C/km) (e.g. Arnórsson, 1995 and references therein). In high-temperature systems the formation temperature is above 200°C at 1 km (dT/dZ > 200°C/km).

The depleted signature of the water isotopes ($\delta^{18}O$ and δD) in the geothermal fluid in these systems demonstrates that the fluids originate as precipitation. The total dissolved solids are typically very low in these fluids (200-300 ppm) and the pH values are high (~ 10 ± 0.5). This is thought to be a result of the fluid donating protons to the bedrock formations in exchange for cations leached from the rock. The concentrations of anions are affected by the composition of the country rocks that the fluids interact with and the residence time of the fluids in the crust (Arnórsson, 1995).

Table 1. Key information about the sites in North Iceland.

Geothermal fields (test sites)	Operated since	No. of production wells	Average prod. in 2023 [L/s]	Temp. of fluid (°C)	pH of fluid at Temp	~TDS [ppm]
Botn	1981	2	25.3	81-86 °C	9.90 @ 21.5°C	200-280
Hjalteyri	2003	3	170.6	86-87 °C	10.1 @ 21.6°C	250-310
Syðra-Laugaland	1978	3	48.6	94-95 °C	9.90 @ 16.1°C	200-250

The prevailing conceptual model for these low-temperature systems can be summarized as follows (Björnsson, et al. 1995 and references therein). The systems are associated with deep vertical or sub-vertical fractures or fracture sets. Convection in these systems results in heat mining at depth (Bodvarsson, 1982, 1983; Halldorsdottir et al., 2023). Heat is brought towards the surface in upflow limbs. The upflow produces localized thermal gradient anomalies. Therefore, prospecting geothermal resources with thermal gradient wells has been quite successful. This phenomenon is well illustrated by comparison of three temperature profiles from a production well (e.g. HJ-21 in Figure 7): the measured temperature, the inferred formation temperature, and the theoretical background gradient.

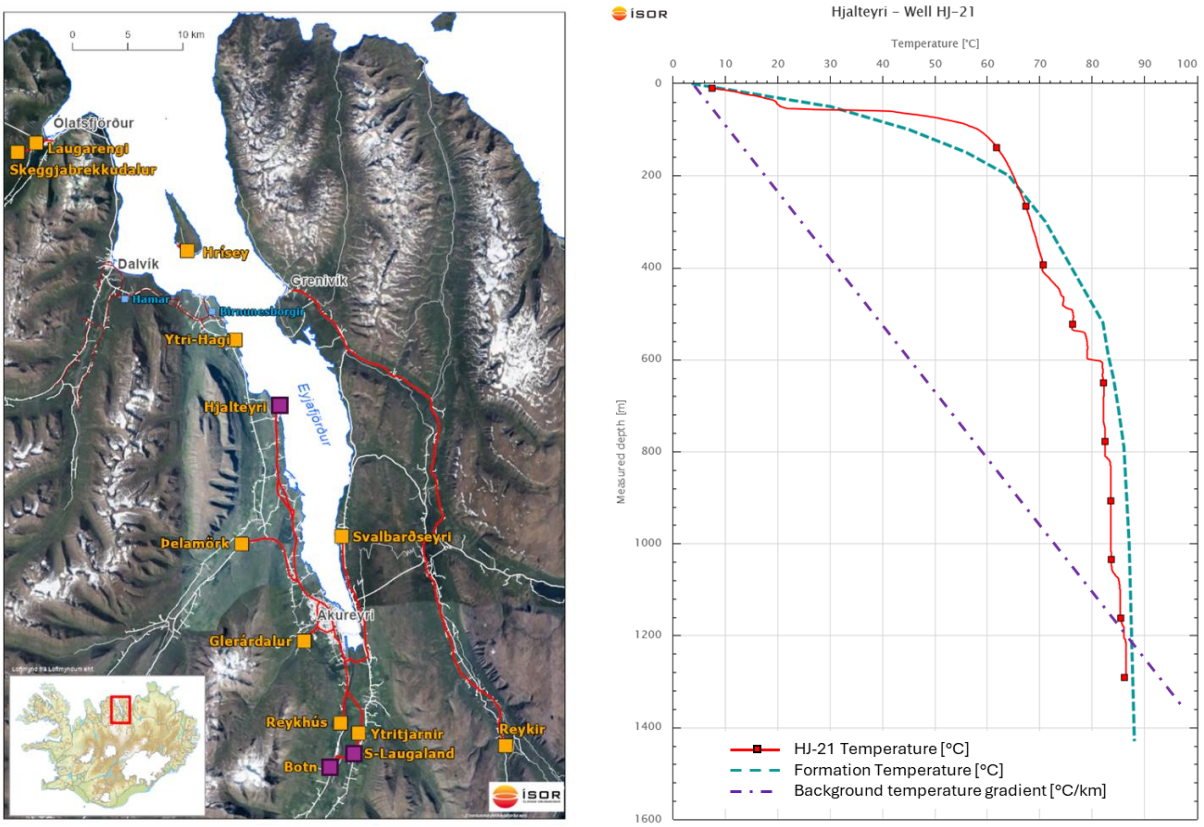


Figure 7. Left panel: Map showing the main features of Norðurorka's district heating system for Akureyri and the surrounding areas. Location of demo sites are shown as purple boxes. Other geothermal fields operated by Norðurorka are shown in orange. Two fields operated by the Dalvík district heating company are shown in blue. Right panel: Temperature log from a production well (HJ-21, at Hjalteyri). Also shown are the formation temperature (greenish blue) and the theoretical background gradient (purple). Note an extensive region of near-constant, high (80-88°C) temperature controlled by convection in nearby fractures. Also note that at shallow levels (<200 m) the local gradient is higher than the background gradient. At depth (>1200 m), however, the background gradient is higher than the measured temperature in the well. Hence, heat mining occurs at depth.

4.1 Hjalteyri case study

For the Hjalteyri geothermal system, Halldórsdóttir et al. (2025) applied Lumpfit++ to analyze the reservoir response to varying production rates using a general five-tank model. The simulations reproduced the measured drawdown trends at the monitoring well HJ-18 and predicted that the water level would stabilize around 70 m for a total production rate of approximately 160 kg/s. When compared to earlier modelling with Lumpfit v3 (a linear three-tank "open" model), the updated approach yielded consistent results, stabilization between 70–75 m for 150 kg/s and 90–100 m for 200 kg/s, but provided an improved fit to the observed data and more reliable well-specific pressure predictions (Figure 8). These results indicate that the Hjalteyri reservoir can likely sustain production rates of up to ~200 kg/s with limited long-term drawdown, supporting its potential for continued geothermal utilization.

4.2 Application to Botn and Syðra-Laugaland

The two sites Botn and Syðra-Laugaland are located about 12-13 km south of Akureyri (Figure 7). At Botn, two production wells (HN-10 and BN-1) have been operated since the early 1980's and the water level has been monitored continuously in a nearby well (BY-3) since 1995. The production data from wells HN-10 and BN-1 and the water level data from well BY-3 were fitted using a 3-tank Lumpfit++ model with each well placed in a separate tank. A comparison between calculated and observed water level changes in BY-3 is shown in Figure 8. The comparison indicates that while the model captures the overall water level trend, it underestimates the water-level range associated with production lows and highs. The results are promising, and future work should focus on incorporating available water level observations from the two production wells into the modelling.

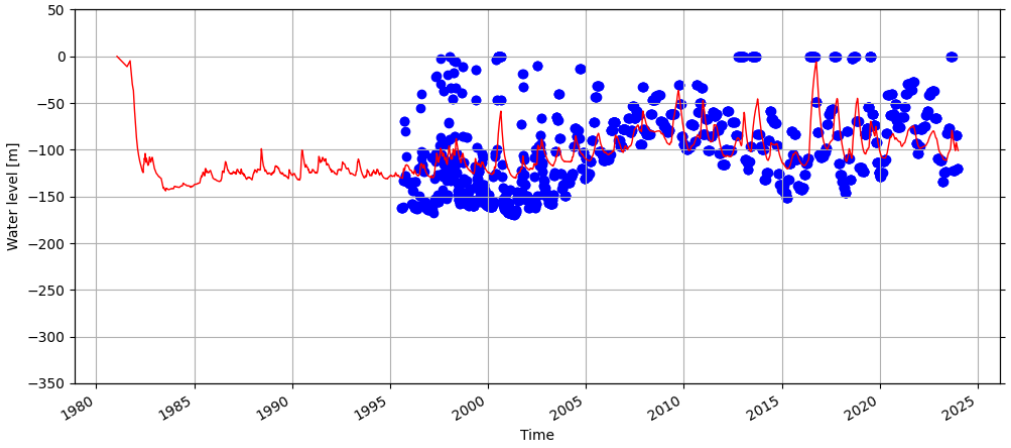


Figure 8. Observed and calculated water level changes in BY-3 in the Botn geothermal system. The data were fitted using a 3-tank Lumpfit++ model in which the production wells HN-10 and BN-1, as well as the observation well BY-3, were placed in separate tanks.

The water level data for Syðra-Laugaland is neither continuous nor from a single monitoring well (Figure 9). Until 1997, well LJ-8 was the main water monitoring well until it was converted into a re-injection well in late 1997. After that, there exists data from several production wells. There is continuous data from well GG-1 and therefore it is used as a reference well for modelling. However, well GG-1 is located too far from Syðra-Laugaland to be considered a sufficiently reliable monitoring well for the reservoir in the future (Egilson, 2024).

For the present work, only total production and re-injection data was available (Figure 9). For the modelling with Lumpfit++, wells LN-12 and LJ-8 were selected to represent a production well and a re-injection well, respectively. This approach assumes that both production and re-injection occur from a single well rather than multiple wells. This is true for re-injection. However, production is distributed across multiple wells. The fit between the model and the calculated water level data is promising (Figure 10).

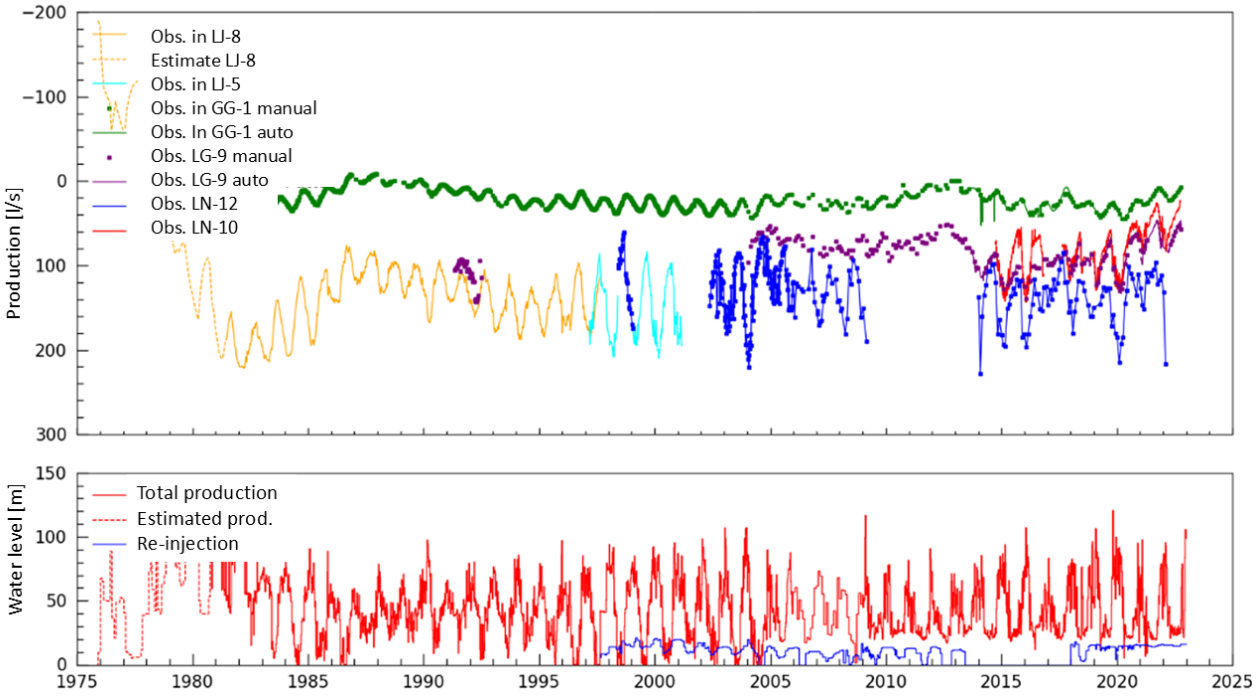
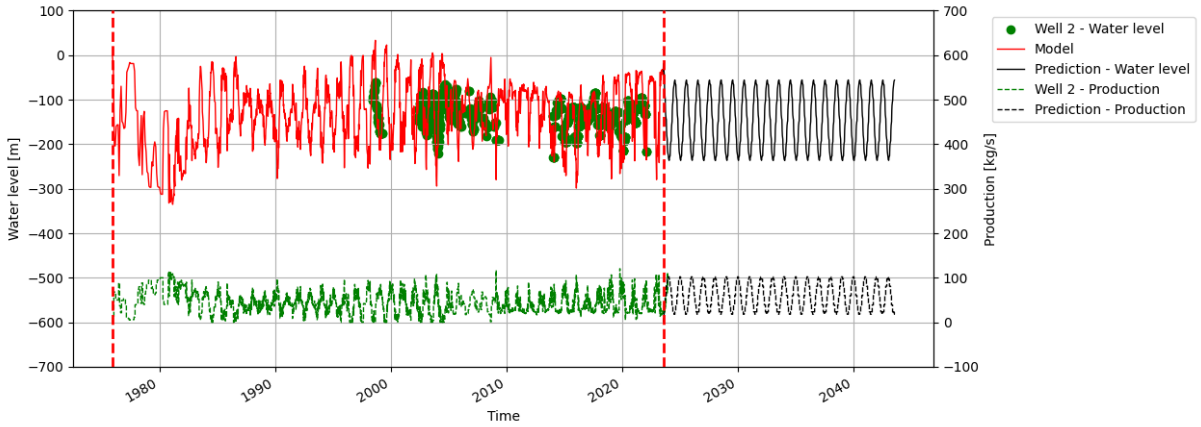
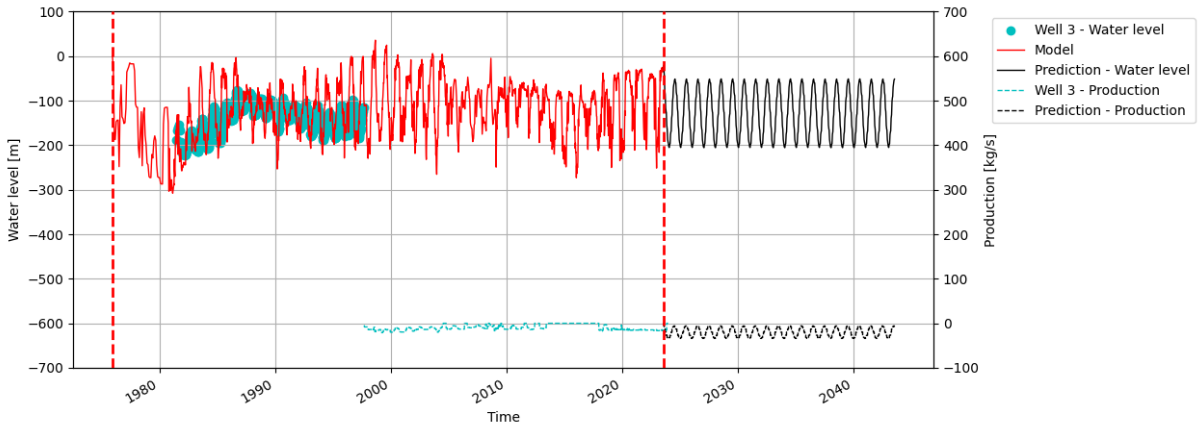


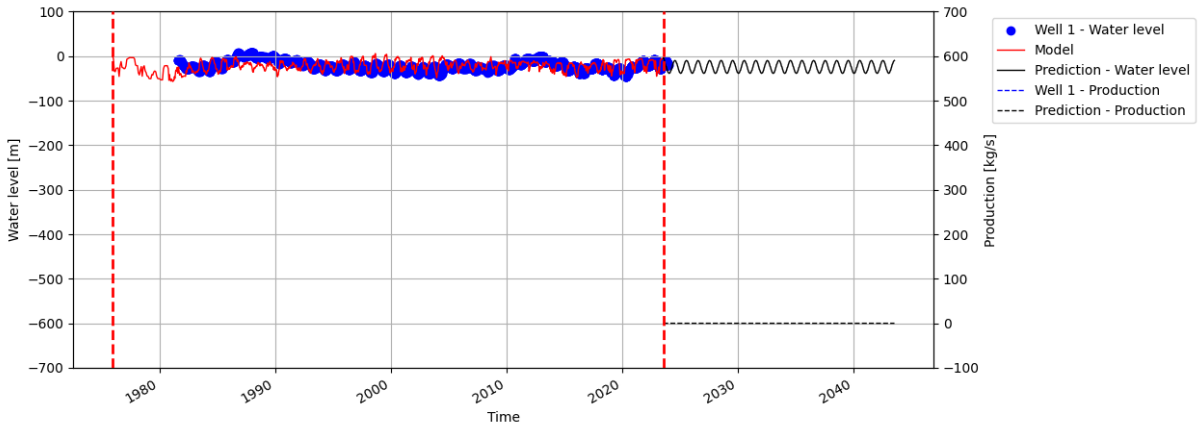
Figure 9. Available production history from the Syðra-Laugaland reservoir: Water level in several production wells and continuous water level in GG-1. The total production is shown, as is re-injection into well LJ-08 (from Egilson, 2024).



(a) Observed and calculated water level changes in LN-12 together with total production.



(b) Observed and calculated water level changes in LJ-8 together with total re-injection.



(c) Observed and calculated water level changes in GG-1

Figure 10. Comparison of observed and calculated water level in wells in the Syðra-Laugaland reservoir. The production history is fitted using a 4-tank Lumpfit++ model, with the predicted water level reflecting both production and re-injection at two sites, assumed to be wells LN-12 and LJ-8, respectively.

The data were modeled using a general 4-tank model. To predict water level changes, both the production and re-injection sites (each assumed to be a single well) and the reference well are assigned to individual tanks. A fourth tank is included to account for potential effects from the outer parts of the reservoir. The two vertical red dashed lines in the subfigures indicate the data range selected for model fitting.

While the results are promising, as they reproduce the same average water level, there are inconsistencies in the modeled seasonal maximum and minimum. Future work should focus on obtaining well-by-well production data, which will surely enhance the usefulness of Lumpfit++ for predicting water level changes.

5 CONCLUSIONS

A new version of Lumpfit has been developed under the name Lumpfit++. This new version can handle more complicated systems than previous versions. A larger number of tanks (volumes) are permitted, and there is more freedom in defining connections between the various tanks. This added complexity is needed to more accurately reflect production from geothermal fields where operators utilize several wells for mass extraction and monitor the pressure response in the system from non-producing wells.

A GUI has been added to the program to reduce the learning threshold for using the program effectively and to facilitate the building of reservoir models. The ultimate goal is that field operators will adopt the software and incorporate it into their routine procedures. Hopefully this will drive home the need for regular and careful collection of production data as a key priority in the development and production of the reservoir.

Lumpfit++ installer and User Guide can be downloaded free of charge from GeoModel website (https://geomodel.pl/en/download/)

Acknowledgements

The authors gratefully acknowledge support for the GeoModel project (https://www.geomodel.pl/) under the Fund for Bilateral Relations through the European Economic Area Financial Mechanism (EEA FM) and the Norwegian Financial Mechanism (NFM) 2014-2021.

We would also like to thank Norðurorka district heating service for allowing the use of their data from Hjalteyri, Botn and Syðra-Laugaland and for funding part of the work related to the development of the Lumpfit++ software.

Finally, we thank María Helga Guðmundsdóttir for her thoughtful comments on the manuscript.

REFERENCES

Arnórsson, S.: Geothermal systems in Iceland: Structure and conceptual models - II. Low-Temperature Areas. *Geothermics* **24**, (1995) 603-629.

Axelsson, G.: Hydrology and Thermomechanics of Liquid-Dominated Hydrothermal Systems in Iceland, Ph.D. Thesis, Oregon State University, Corvallis, Oregon, 291 p. (1985).

Axelsson, G.: Simulation of Pressure Response Data from Geothermal Reservoirs by Lumped Parameter Models, *Proceedings*, 14th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, (1989).

Axelsson, G., and Arason, P.: *LUMPFIT – A Computer Program for Simulating Pressure Changes in Hydrological Reservoirs*, Orkustofnun Report OS-92026/JHD-12, 32 p. (1992).

Egilson, Th.: Endurmat vinnslugetu jarðhitasvæðanna á Botni, Sydra-Laugalandi, Ytri-Tjörnum, Glerárdal, Laugalandi á Þelamörk og Hjalteyri í Eyjafirði, ÍSOR Report 2024/044, 46 p. (2024).

Gudmundsson A., De Guidi G. and Scudero, S.: Length–displacement scaling and fault growth. *Tectonophysics*, **608** (2013), 1298-1309.

Gylfadóttir, S.S., Axelsson, G., and Arason, P.: *Lumpfit Users' Guide* – Original PyLumpfit User Manual from 2014, ÍSOR Report 2024/031, 28 p. (2024).

Halldórsdóttir, S., Berre, I., Keilegavlen, E., and Axelsson, G.: Crustal Conditions Favoring Convective Downward Migration of Fractures in Deep Hydrothermal Systems, Geophysical Research Letters, 50(22), e2023GL105380 (2023). https://doi.org/10.1029/2023GL105380

Halldorsdottir, S., Marteinsson, K., Egilson, T., Gautason, B., Tulinius, H., Thorgilsson, G., Magnusson, R. and Axelsson, G.: Simulation of Pressure Response from Geothermal Reservoirs by an Updated Lumped Parameter Method – Hjalteyri Case Study, *Proceedings*, 50th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2025). SGP-TR-229.

Marteinsson, K., Halldorsdottir, S., Aðalsteinsson, S.M., Magnusson, R., Þorgilsson, G., and Gautason, B.: *Lumpfit++ Users' Guide*, ÍSOR Report 2024/030, 17 p. (2024).

Sarak, H., Onur, M., and Satman, A.: Lumped-parameter models for low-temperature geothermal fields and their application, *Geothermics*, **34**, (2005), 728–755.