Production history modelling of a low enthalpy geothermal reservoir used for district heating: example of the Paris sedimentary basin

Joris Popineau[1], Theo Renaud[1], John O'Sullivan[1] and Julien Gasser Dorado[2]

[1]Geothermal Institute, University of Auckland, 70 Symonds Street, Grafton, Auckland, 1010, New Zealand

[2] Geofluid, 165 rue Belle Etoile, 95700 Roissy-en-France

j.popineau@auckland.ac.nz

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ABSTRACT

Exploitation of the geothermal energy in the Paris sedimentary basin started in the early 1970's, accessing the hot brine contained in the mid Jurassic carbonate rocks series, the Dogger. More than a hundred wells have been drilled to depths ranging from 1400 to 2000 meters, often using the doublet or triplet technology. Decades of production and reinjection have resulted in variations of the aquifer pressure and temperature in some areas. The characterization of the Dogger heterogeneities and the understanding of potential interconnections between the doublets areas of influence are essential to define sustainable management plans for current and future geothermal developments.

While the integration of a full-scale refined geological model into a reservoir model needs heavy computational resources, a simplified model gathering the main productive areas into one or two layers surrounded by sealed formations can be used to efficiently investigate the aquifer characteristics in a zone operating one or several doublets. Due to the high density of geothermal operations in the Paris sedimentary basin, regional numerical approaches are needed to assess potential interactions between doublets.

With this aim, the modelling of 13 doublets and 1 triplet intersecting the Dogger reservoir in the South part of Paris (Cachan/Orly) is performed, using a conventional double layer approach to simulate the natural state and production history of the area with the numerical simulator Waiwera from the University of Auckland in New-Zealand. The history matching to available production data is used to capture variations of the reservoir behaviour caused by natural and anthropogenic fluid flows in the heterogeneous Dogger reservoir. The geothermal reservoir properties and the production timeline are investigated during the calibration process, which uses a robust modelling workflow and a fast simulation to handle complex production history data.

Modelling a large scale geothermal field is valuable for understanding the pressure and temperature response in the productive areas, to suggest better monitoring of the geothermal resources, and to define future strategies for operating the reservoir in a sustainable way.

1 INTRODUCTION

The Dogger aquifer in the Paris Basin has been used for more than 40 years to supply heat, generally using a combination of one production well and one injection well, i.e., the "doublet" concept. More than 50 geothermal district heating systems have been completed, with 38 in operation in 2016. Wellhead production temperatures around 75°C and at injection of 40 °C in average are monitored (Hamm 2017, Lopez et al. 2010). The total installed capacity in 2000 reached 227 MW_{th} (Ungemach 2004). The first wells drilled were vertical but were then followed by deviated wells at around 40-60°. One of the latest doublet in Cachan, south of Paris, shows sub-horizontal trajectories, with deviations up to 85 to 95° (Ungemach et al. 2019). Their operational lifetime is mainly constrained by the thermal breakthrough, i.e., the decrease of the produced fluid temperature ranging from 0.5 °C, to up to 3-4°C, following economical parameters (Ignatiadis et al. 1998).

The Paris Basin is a large intracratonic sedimentary basin of 110,000 km² in the northern part of France (Figure 1). The deposit of sediments during the Triassic and Jurassic periods over the primary crystalline formations reaches a maximum of 3 km, where the subsidence rate was the highest. The Dogger formation is mostly composed of mid-Jurassic carbonate rocks, i.e. limestone and dolomite with thick oolithics layers related to barrier reef facies from a warm sea during the Bathonian period (Rojas et al. 1987). The Bathonian age deposit gathers three units: the cyclical unit with marine limestone and marl; the Oolithe Blanche unit corresponding to oolitic limestone and calcarenites and the Comblanchian unit, made of lagoon sediments with wackestone, mudstone and muddy limestone of various thicknesses. (Lopez et al. 2010, Rojas et al. 1989). The high variability of the deposits highlights the transition between various marine environments, from the outer shelf and reef barrier to a lagoon environment.

The water temperatures at the top of the aquifer at depths ranging from 1450 m to 2000 m vary between 55 and 80°C, with a high fraction of salt (6-35 mg/l) and dissolved gases including H_2S, inducing corrosion and scaling issues (Lopez et al. 2010). High horizontal transmissivities are observed (2-110 Dm) with an average porosity of 15 % for the productive layers. A natural lateral flow with a velocity below 50 m/years is mentioned (Aubertin and Ballin 1984) and is probably closer to 10-15 m/year in terms of Darcy velocity (Marsily et al. 1985, Rojas et al. 1989). This regional flow is suggested to come from the South-East part of the aquifer A global homogenous heat flux of around 60 to 90 mW/m² is calculated, with a local positive temperature anomaly observed in the south-east of Paris (Bonte et al. 2013, Papachristou et al. 2013). This anomaly can be interpreted as a consequence of this regional flow carrying hotter fluids

from deeper horizons or due to a local heat flux variation (Rojas et al. 1989).

Several productive layers are identified in the wells, mostly in the Oolithe blanche unit (Rojas et al. 1989), representing approximately 10 % of the total aquifer thickness. As the spatial correlation between the productive layers cannot be accurately performed, several modelling methods have been discussed. Indeed, the conceptual representation of the stratification key to model the reservoir performances accurately by considering enough complexity from the sedimentary context (Boissier et al. 2009, Papachristou 2013).

More largely, there are a lot of expectations worldwide on developing geothermal projects in deep stratigraphic sedimentary contexts for direct-use or power generation. Some examples of coming or existing projects can be found in Australia (Pujol et al. 2010, Bahadori et al. 2013, Pujol et al. 2015), in the USA (Allis et al. 2016) or in China (Wang et al. 2013, Pang et al. 2015). This work aims to provide modelling solutions at any steps of such projects.

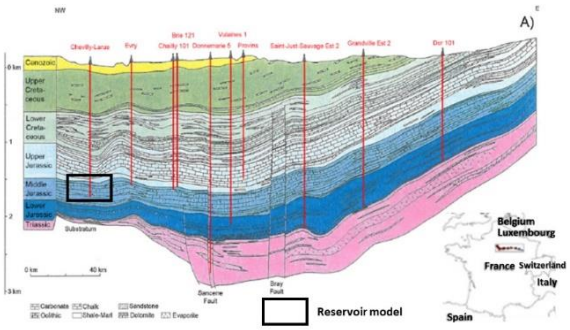

Figure 1: Location of the study area in the litho-stratigraphic east-west section of the eastern part of the Paris sedimentary basin (modified from Dentzer et al. 2016)

2 HISTORICAL RESERVOIR MODELLING BACKGROUND IN THE DOGGER

Single, multilayered or sandwich layered models results in slight variations for the calculated thermal breakthrough, which is mainly controlled by the flow rate and injection temperature (Antics et al. 2005, Hamm et al. 2011). The methods converge to similar results for long simulated times in thesouth-East of Paris. (Le Brun et al. 2011, Papachristou et al. 2013). Despite limitations, the sandwich layer approach gives a satisfactory compromise for modelling the Dogger and simplify the model settings. Generally, the thermal breakthrough is prevented with a high thickness and thermal conductivity value for the impermeable layers (Hamm et al. 2011).

Efforts for modelling either one doublet or an area including several doublets have been conducted (Rojas et al. 1989, Lopez et al. 2010, Le Brun et al. 2011, Papachristou et al. 2013, Goyénèche et al. 2014). The geothermal simulators TOUGH2, Marthe, METIS, SHEMAT, Comsol have notably been used. The models considered an infinite horizontal layer with two impermeable layers at top and bottom of the reservoir. At the doublet scale, different conceptual models are used to capture a range of results. Due to strong local heterogeneities, the modelling of the deep geothermal aquifer is very challenging, especially as large lateral and vertical variations in the geological units are expected (Rojas et al. 1989).

In late 2010, due the high density of operating doublets, the southeast of Paris (Val de Marne) started to observe thermal interferences between doublets (Cachan I, II, L'Hay-les-Roses, Fresnes, Chevilly-Larue; Thiais; Orly I, II, Maisons-Alfort I, II, Alfortville, etc.) (Goyeneche et al. 2014). The modelling and the observed data confirmed some slight cooling at the wellheads in the Val de Marne area, with a provisional temperature drop of 2°C between 2012 and 2020 observed at Alfortville for example. Concerning the pressure response to the production and reinjection regimes, pressure test analyses have been carried out between five doublets in the Southeast of Paris and suggest the existence of a continuous and homogenous reservoir (Hamm et Giuglaris 2015). Nonetheless, the pressure distribution and its trend over a bigger area on a longer term is not something that has been modelled and investigated since the production started in the Dogger. Analysing and modelling the pressure and the temperature response can help in characterising the reservoir parameters (e.g. porosity, permeability) to better describe the well connectivity.

Data have been collected to gather the pre-production state (or natural state) of the Dogger and also the production data from the operating facilities which enable to investigate the history matching for several doublets (Hamm 2020).

This study presents an update of a 3D numerical reservoir approach that represents multiple production and injection wells in a deep sedimentary basin (Popineau et al. 2022). Thanks to decades of available data, the history matching of the temperature and pressure is performed. The analysis of the resulting petrophysical, hydraulic and thermal reservoir parameters needed to match the data can help in understanding the doublets hydraulic connectivity and the Dogger's aquifer extension and performances. Thus, this model is a preliminary study to improve the accuracy of long-term assessments to design new facilities and sustainably manage a deep sedimentary geothermal resource against thermal breakthrough and hydraulic head losses.

3 DEEP SEDIMENTARY BASIN MODELLING

3.1 Conceptual model

The main objective is to base the numerical model on most of the concepts and local parameters representing the reservoir behaviour of the Dogger since the start of production. While the initial conditions of previous Dogger models is interpolated via kriging from petrophysical data and measurements (Hamm et al. 2011, Papachristou et al. 2013), the present study establishes a steady state simulation with specific boundary conditions and formations parameters, all described in Section 4.1.2. The studied area is located in the Southeast of Paris around the city of Cachan. Our model considers 29 wells (thirteen doublets and one

triplet), all shown in

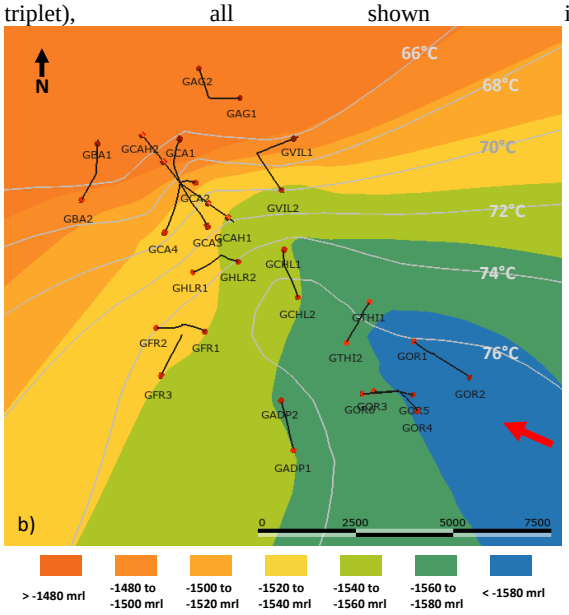

Figure 2 and Figure 4. Public available data have been collected from an open data base called Sybase (Hamm et Maurel, 2020), notably the total productive thicknesses, the impact elevations of the Dogger and productive zones (or feedzones), the initial temperatures and pressures at depth before production, and production and reinjection schedule with fluid temperature and well head pressure.

Figure 2 shows the conceptual understanding of the area at its natural state where the top elevation of the Dogger suggests a clear dip to the Southeast with the axis of a synclinal object observed from the centre area of the model to its Southeastern corner. Noticeable differences, compared to uniform temperatures and hydrostatic gradients, are seen from the temperature and pressure contours (obtained from field data before production or at its early stage). Incursion of higher temperatures and pressures are measured toward the Northwest, which can be explained by a natural lateral hot fluid flow (red arrow) and variable bottom heat flux (seen in Section 1). More details are given in Section 4, which details the boundary conditions used to obtain a robust initial state model.

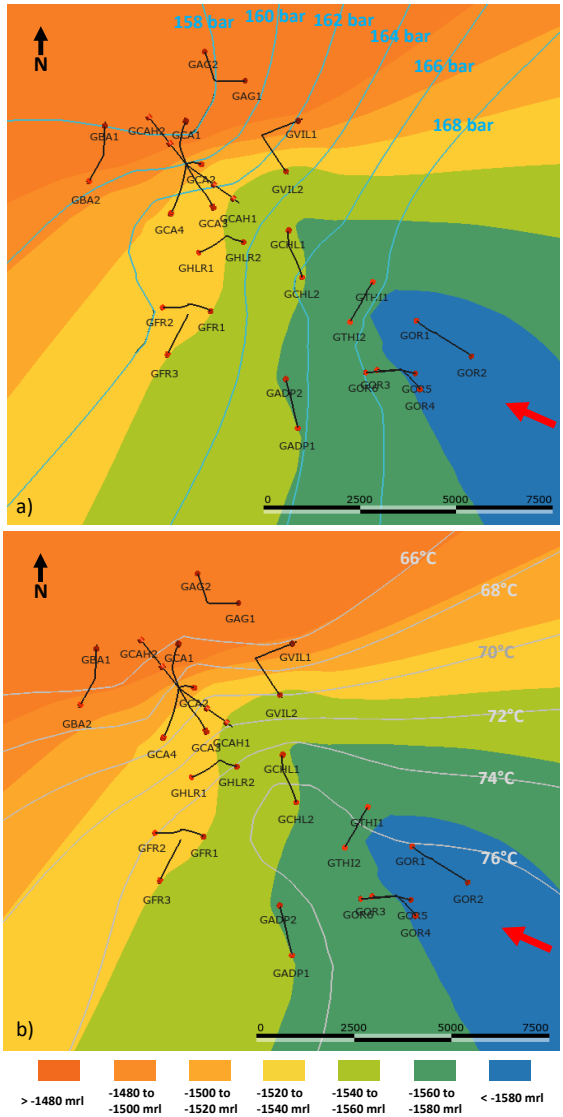

Figure 2: Cachan area with the 29 wells and their production zones (red disk), with the Dogger top impact elevation map, the pressure contours (blue lines) in a) and the temperature contours (grey lines) in b) measured near the production zones. The red arrow indicates the natural lateral flow

To reduce computational resources but keeping a valid representation of the thermal and hydrodynamics parameters of the sedimentary basin, the sandwich layer method is chosen to define the reservoir rock-types in the model. Figure 3 shows the conceptual scheme of the simplification from several productive layers into the sandwich model. The sandwich model aims at considering the total vertical thickness "h" of the productive zones, divided into two layers separated by an intermediate impermeable layer that stores and supplies heat to the producing layers by conductivity (Antics et al., 2005).

Extra flexibility during the calibration process is brought through the definition of the reservoir top and bottom layers (in orange) representing the remaining thickness of the Dogger reservoir. This corresponds to the layer between the Dogger top elevation measured from the well logs but not

explicitly considered as productive in the literature. A maximum vertical thickness of 140 m for the Dogger is set to implement the interface between the reservoir bottom and the wall.

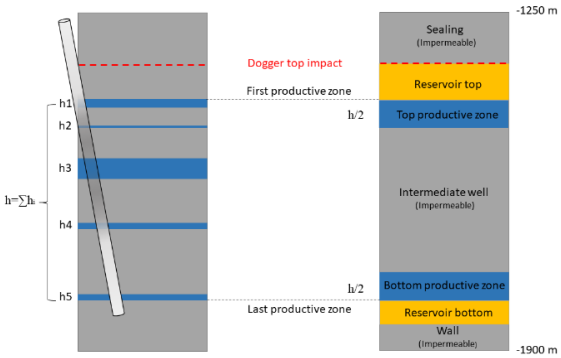

Figure 3: Sandwich layer method used to create the vertical rock-type discretization of the reservoir model (Popineau et al. 2022).

The conceptual scheme in the right column of Figure 3 is defined for each well and based on their data collected from sybase (see Popineau et al. 2022). Then continuous layers between the wells have been generated using Leapfrog® Geothermal, resulting in a 3D layer-based model considered to populate the reservoir grid with different rock-types.

3.2 Model parameters

The models have been integrated with the parallel open-source geothermal flow simulator Waiwera (Croucher et al. 2020). which allows fast computational times for highly refined grids(O'Sullivan et al. 2019).

3.2.1 Grid design

Figure 4 shows the grid set up to represent the reservoir. The area covers 17 km by 13 km which includes a minimum space of 3 km between any well production zone and the side boundaries. It is composed of 339 877 blocks distributed from – 1250 mRL down to -1900 mRL, with a minimum resolution of 125 meters horizontally and 5 meters vertically. The small block sizes allow the grid to accommodate the slight dips of the different rock-types defined in Figure 3 but also the pressure and temperature variations between the wells (e.g., pressure interferences, temperature breakthrough, etc.). All wells feedzones are connected to 5 meters grid layers to avoid any undesirable production or reinjection effects in larger blocks.

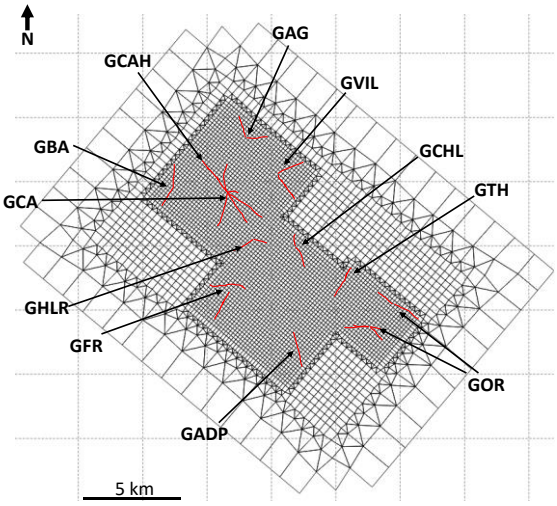

Figure 4: Plan view of the model grid with the refined areas of 125 meters blocks all around the 29 wells (Popineau et al. 2022).

3.2.2 Boundary conditions

The implementation of sensible boundary conditions allows the system to reach the correct steady state and help to reproduce the temperature and pressure responses during the production history. To represent the conceptual model described in Section 3.1, three main boundary conditions are defined: a variable heat flux at the bottom of the model, associated with the corresponding temperature boundary at the top of the model, a constant hydrostatic pressure at the top of the model, considering an average surface elevation of 60 mRL, and side boundary conditions to implement the natural lateral fluid flow described by Rojas et al. (1989).

The lateral flow is implemented in the model on the South-East and North-West sides of the grid with constant pressure and temperature conditions on blocks of rock-types "reservoir" and "productive zones". Their intensity and distribution can be manually adjusted to match the natural state of the system. Table 1 presents the models used to investigate the effect of the bottom heat flux and the lateral recharge on the natural state conditions. The results and the discussions can be found in section 4.1.

Table 1: Model numbers investigating the effects of the boundary conditions

Model number	Boundary conditions investigated
001	Homogeneous heat flux No lateral recharge
002	Homogenous heat flux Lateral recharge
003	Heterogeneous heat flux No lateral recharge
004	Calibrated model Heterogeneous heat flux Lateral recharge

3.2.3 Rock-types assignment

A detailed lithology of the Dogger and its associated rock parameters are not explicitly defined by using a stochastic method in this model. The idea is to start from simple and known average values observed at the wells (e.g., porosity,

permeability, etc.), that are applied to the main rock-types defined vertically in Figure 3. Mapped on the grid, it gives seven layers shown in Figure 5. Thus, to obtain the complexity needed to represent the regional or local heterogeneities of the sedimentary basin, more rock-types have been implemented in the model. Additionally to the sandwich layer rock-types previously defined in Popineau et al. 2022, two other concepts were introduced in the rock typing process to allow a maximum of flexibility during the history matching.

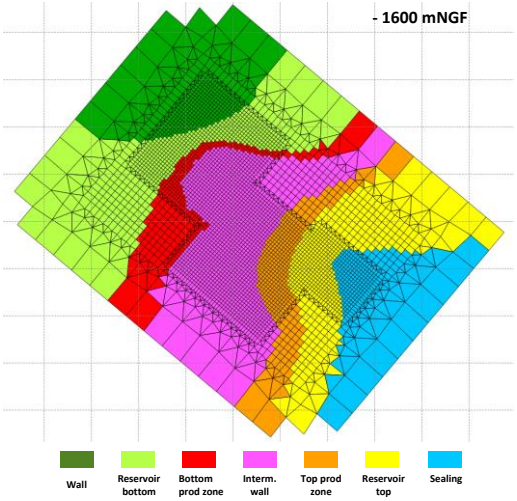

Figure 5: Sandwich layer rock-types distributed on the reservoir grid at – 1600 mRL (Popineau et al. 2022).

These two concepts, detailed and illustrated in Popineau et al. (2022), consist into a first rock category to better constrain the flows between wells (based on a Voronoï diagram), and a second rock category to control the rock parameters in the well vicinity (based on 500m pills around each doublet/triplet). With all these superimposed, it is 822 rock-types that give flexibility and freedom to the calibration process. High rock-type heterogeneity does not necessarily mean variability is rock parameters. For this reason, rock-type names have been carefully chosen to identify the above categories (see Popineau et al. 2022 for naming construction details). For the first simulation run, the rock-types were all assigned permeabilities of 100 mD for permeable rocks units and 0.01 mD for impermeable rock units. The porosity has been set to 12% and the rock thermal conductivity is 2.7 $W.m^{-1}.K^{-1}$.

3.3 Production history parameters

To determine the well production elevations, well data from Sybase (Hamm et Maurel, 2020) has been previously analysed and thus included into the production history model. A summary table of these for each well is available in Popineau et al. (2022). Figure 6 highlights the type of data transient collected from Sybase to implement the production and reinjection schedule. The data have been monthly averaged in the model to keep a fast but detailed time-stepping calculation. The seasonal variability is strongly observed due to lower heat demand during summer season and higher in winter. These production and reinjection data are implemented in the model for each wells at the different feed blocks. These feed blocks are determined by using the feedzones elevations mapped on the grid (O'Sullivan et al. 2019). Most of the feed blocks are located in the "top productive zone" or "bottom productive zone" rock-types shown in Figure 3, and some other intersects the "reservoir top" or "reservoir bottom" rock-types.

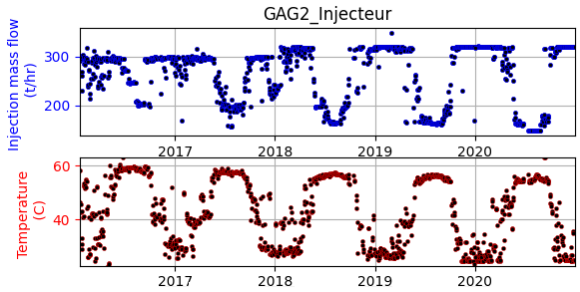

Figure 6: Example of raw reinjection data used for the production history in well GAG2.

The production and reinjection proportions going into the two model feedzones of each well have been adjusted manually to reproduce the temperature and pressure responses observed during the production history. For most of the wells, the top feedzone contributes more in the production based on the well drilling reports found in the literature. Simultaneously, the rock types parameters were also modified to obtain a more sensible match to the transient data and its trends. While keeping a good match to the natural state, the calibration process of the production history has involved small adjustments to the boundary conditions (temperature gradients and lateral recharge); the rock-type properties (mainly porosity and permeability); the proportion of fluid produced/reinjected in the top and bottom feedzones for each well. An example of production well history calibration is detailed in section 4.2 with well GOR6.

Parameters like boundary conditions and rock-type properties (except porosity) also affect the natural state, if they are adjusted the natural state model is run again to obtain the initial pressure and temperature distribution. These changes remain conceptually and physically acceptable and good match to the natural state data is kept. The results shown in section 4.1 for the natural state results from this iterative process.

To better represent the modelled fluid temperature compared to the temperature observed at the well head, the wellbore heat losses from the feedzones to the well head based on the well design and mass flow data have been analytically calculated using Ramey's equations described and applied to production wells (Horne et Shinohara, 1979).

4 RESULTS

4.1 Calibration of the Natural State

Calibrating the natural state conditions of the system enables to initiate the beginning of the production history. To match the initial temperature and pressures measured in the wells, the parameters detailed in Section 3.2 and discussed in the literature are adjusted.

The temperature and pressure well measurements are taken at a certain elevation in the Dogger reservoir. Early measurements in the 1980s or in the 1990s are preferably chosen for the calibration to avoid any thermodynamic

changes due to the beginning of the production and reinjection (e.g. formation of "cold bubble", see section 4.2).

However later well measurements are also considered by keeping in mind that past reinjection and production have potentially affected the local initial temperature and/or the pressure values. In this section, the implementation of the natural flow recharge and heterogenous heat flux values are discussed to match both temperature and pressure data. An updated calibrated model is shown with its rock parameters detailed. Relation to the depth is an important factor to consider while viewing the results as well measurements across the field are made at different elevations.

4.1.1 Effects of the lateral recharge

An overall hydrostatic pressure gradient is applied to the top of the model at – 1250 mRL, by using the parameters detailed in the Table 2. Figure 7 shows field and modelled temperature and pressure data for the natural state when the lateral recharge is implemented (002) or not (001). The linear regression of the two sets of data highlights the critical contribution of the lateral recharge.

Nonetheless, the implementation of the lateral recharge has been critical to better match the initial temperatures and pressures. The lateral flow enables to support the higher pressure values observed in the deeper zones compared to a normal pressure gradient. This recharge provides an average flow of 12 m/year (Darcy velocity), by applying higher pressures of 1 to 2 bars on the South-East boundaries (red arrows in Figure 9) with a fluid hotter by 5°C to 10°C on the boundary.

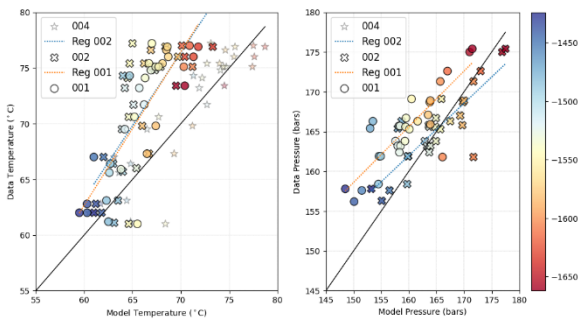

Figure 7: Effect of the lateral recharge on the temperature and pressure distribution at the natural state. The elevation in meter above sea level is set in the color bar.

4.1.2 Bottom heat flux adjustments

Figure 8 presents the contribution of the heterogeneous heat flux (003) compared to a homogenous heat flux (001). While no major effects is observed on the pressure distribution, the implementation of variable bottom heat flux helps to heat up the deeper wells. The model 004 results from a combination of the heat flux and recharge flow as Figure 9 shows. The background heat flux implemented into three zones of different intensities (77 mW/m², 83 mW/m² and 99 mW/m²) to set up temperature gradients across the model match the initial measured temperatures at the different wells. Note that Figure 7 and Figure 8 include all the available natural state data, regardless of the dates of measurements. The following section discusses the calibrated model obtained, including the analysis of the natural state data.

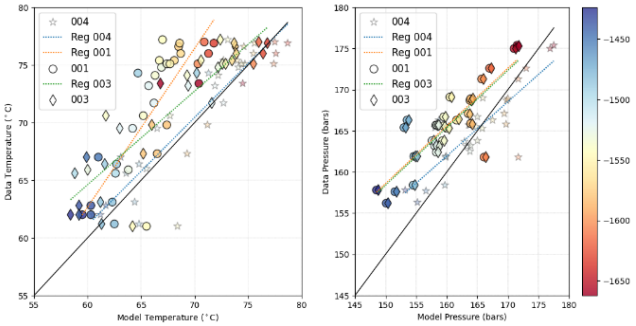

Figure 8: Effect of the heterogeneous heat flux on the temperature and pressure distribution at the natural state.

4.1.3 Calibrated model

Good match to the measured field temperature and pressure data has been obtained through the calibration process for the initial state conditions. For temperatures, most of them are within plus or minus 2°C, showing a similar temperature distribution to the one in

Figure 2 with hotter fluid located in the South at – 1600 mRL. More investigation of the surrounding parameters of the wells can be done during the production history matching to better define their connectivity to the system. Measured temperatures coming from the two horizontal GCAH wells have been discarded as they were observed in 2018 and they show cold temperatures that have been affected by the production or reinjection of the four others nearby Cachan wells GCA.

Concerning the pressure match, an overall good representation of the pressure distribution has been obtained. This is mainly due to the implementation of a lateral South-East recharge (see section 4.1.2), as a homogeneous hydrostatic gradient only does not allow a good representation of the initial pressure conditions measured at the wells.

Much smaller pressures are observed in the model near the GVIL doublet, once again attesting that the connectivity to the overall system needs more investigation. Pressure values from 2018 of the horizontal Cachan GCAH wells have also not been considered for the same reasons as before.

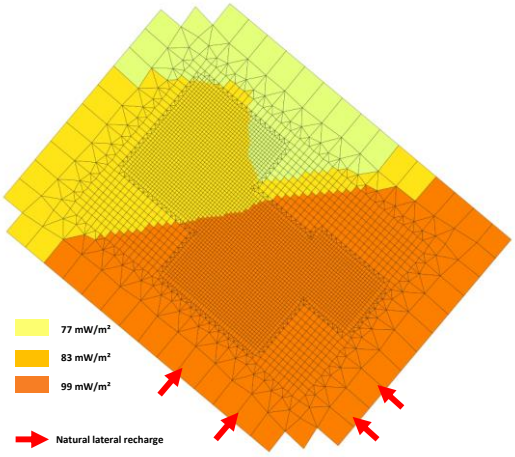

Figure 9: Plan view of the heat flux distribution through the model (updated from Popineau et al. 2022)

Table 2 summarizes the calibrated parameters used in the current model. Local changes to the permeability and porosity fields that have been done during the production history calibration are not being detailed in that table.

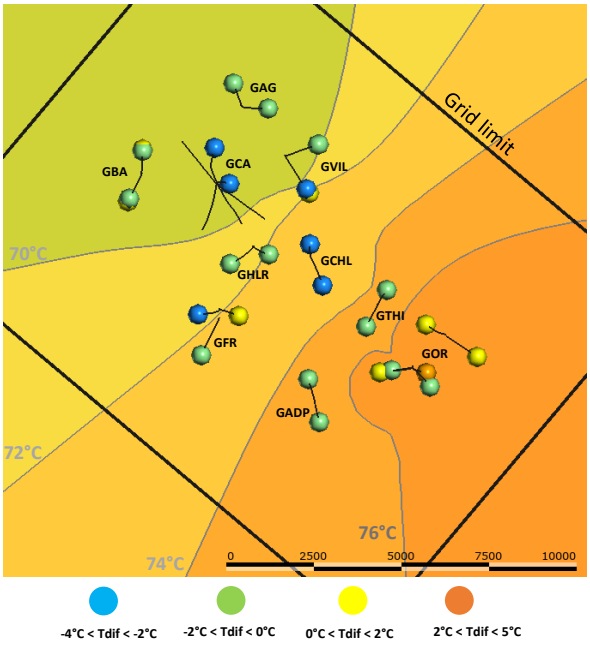

Figure 10: Plan view of the model temperature distribution at -1600 mRL obtained after the calibration. Temperature difference (T model – T measurement) at the measured data elevation are shown with the colored balls for each well.

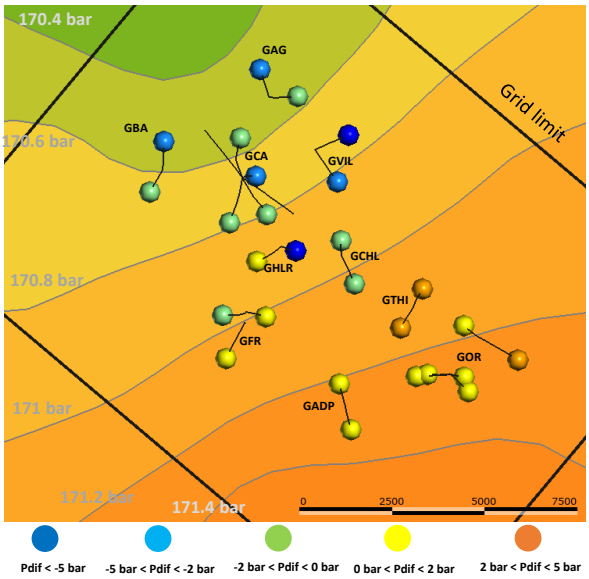

Figure 11: Plan view of the model pressure distribution at -1600 mRL obtained after the calibration. Pressure differences (P model – P measurement) at the measured data elevation are shown with the colored balls for each well.

Table 2: Model parameters set for the current calibrated model

Parameter	Assigned value
Surface temperature	13°C
Surface pressure	101 325 Pa
Rock conductivity	2.7 $Wm^{-1}K^{-1}$
Deep heat flux (3 zones)	77, 83 and 99 $mW.m^{-2}$
Lateral recharge pressure boundary	+ 1 to 2 bar
Lateral recharge temperature boundary	+ 5 to 10°C
Background permeability (reservoir and productive zones rock-types)	horizontal: 2D vertical: 1 D
Background permeability (intermediate wall rock-type)	horizontal: 1 D vertical: 0.1 mD
Background permeability (sealing and wall rock-types)	horizontal: 1 mD vertical: 0.001 mD
Background porosity	12%

4.2 Production History results

The full production history of the area has been modelled using the calibrated natural state model as a starting point for the temperature and pressure distribution, the associated top and bottom boundary conditions and the SE-NW lateral recharge. From 1985 to 2021, the historical production and reinjection data of each well is applied. Figure 12 shows the total production and reinjection mass flow for all wells in the considered area.

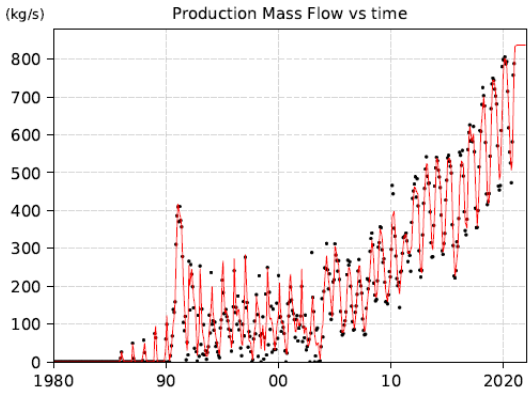

Figure 12: Total production and mass flow for the 29 wells with the back dots for the field data and the solid line for the model mass flows (the same amount has been reinjected) (Popineau et al. 2022).

For each well, a detailed representation of the production or reinjection regime associated with temperature and pressure responses have been represented and analyzed. The objective being to reproduce the exact same behavior as observed with the field data, which is mainly having the wells producing or reinjecting the right amount of fluid at the historic temperature. For example, well GOR 6 in Figure 13 shows the temperature match to the observed production data, where the green and blue lines respectively correspond to the top and bottom feedzones of the sandwich layer concept and the orange line to the modelled fluid temperature with heat loss. The model represents the produced fluid temperature and its trend. Temperature decreases from 75.5ºC down to 74.8ºC after 13 years of production, due to the breakthrough of cold fluid coming from the reinjection well (also called "cold bubble"). The calibration confirms that most of the fluid produced comes from the top productive zone at around -1595 mRL with average permeabilities of 7 Darcy.

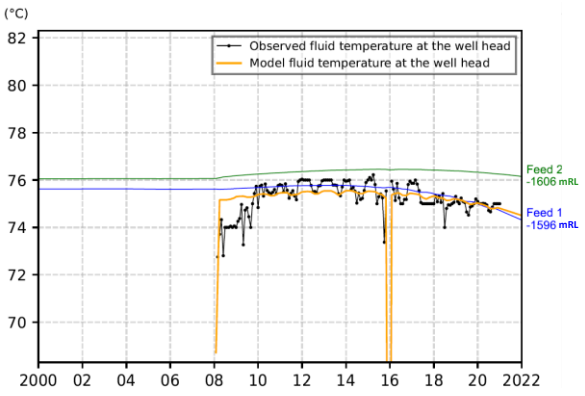

Figure 13: Production temperatures at well GOR 6 (Orly le Nouvelet) showing both field and model fluid temperatures at well head (black and orange) and fluid temperatures at the two productive feedzones (blue and green).

As previously cited for GOR6, the temperature decline corresponds to colder reinjected water which propagates over time and spreads around GOR5, with a preferred trend toward GOR6 as GOR6 produces and reduces pressure. Figure 15 shows the evolution of the temperature breakthrough represented by the orange volume (fluid temperature < 70ºC) that reaches a distance of 700 meters after 13 years of production.

To be noted, GOR4 previously reinjected cold water over 17 years which created a cold bubble next to GOR5 even before this one started. It tended to warm back up as the doublet GOR4/GOR3 stopped but new reinjection from GOR5 reactivated it. Reservoir pressures at the top and bottom productive zones are also extracted from the model to be analyzed, as Figure 14 shows. Before GOR 6 starts producing in 2008, the reservoir pressures at these elevations vary because interferences coming from production and reinjection activities of neighbor wells.

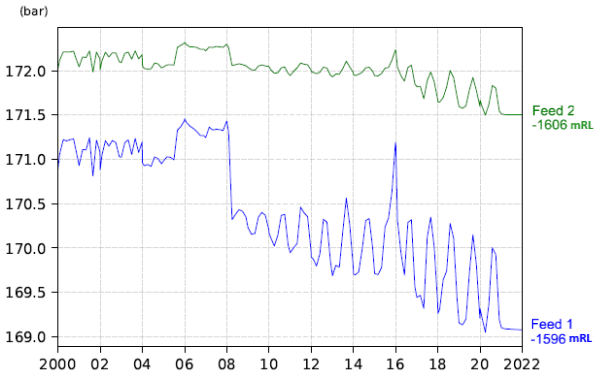

Figure 14: Production reservoir pressure modelled at the two productive feedzones for well GOR 6

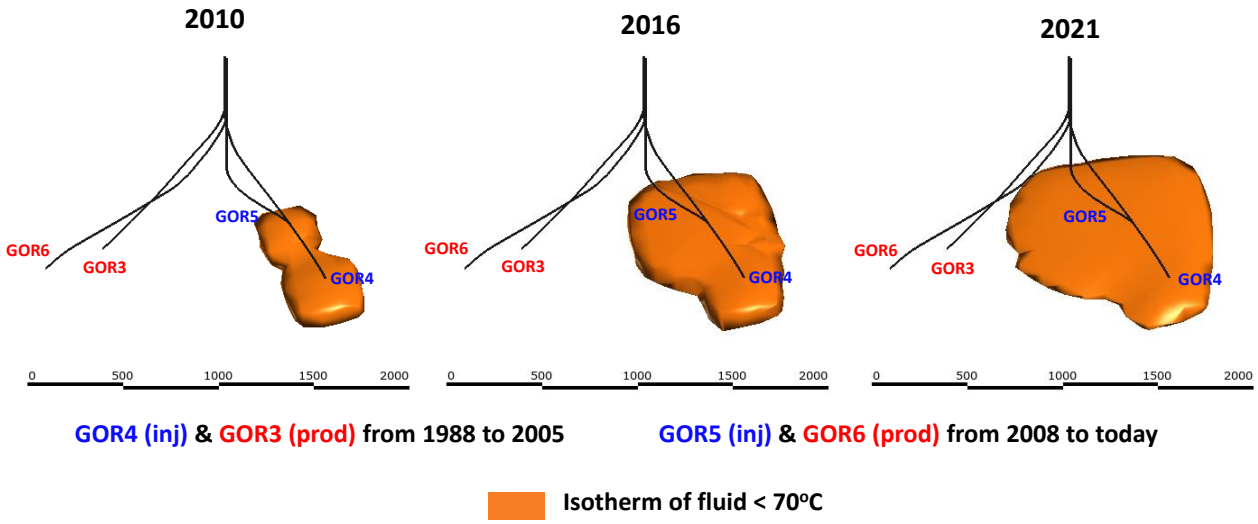

Figure 15: 3D representation of the cold bubble propagation for fluid temperature less than 70°C from 2010 to 2021 at Orly 2 le Nouvelet (GOR5 and GOR6)

After 2008, pressure keeps declining by around half a bar in the last four years, and this even if reinjection goes on. Reservoir pressure monitoring could help calibrating the model to better understand and predict the pressure response of the reservoir. To date, the reservoir pressures have not been compared with the well head measurements as no transient pressure data correlated to the reservoir is available.

4.3 Model outcomes

Replicating the geothermal production history of this area has allowed us to learn and understand a lot about the reservoir and its responses but also by simply analyzing the existing data. However, a reservoir model like this one can also provide key information that will be useful for future development strategies of the geothermal resource and its sustainability, like:

- Missing monitoring data needed to reinforce the model calibration (e.g. transient reservoir pressure)
- Quality check of the existing and future data
- Predicting productivity of existing wells in relation to the evolving reservoir conditions (e.g. better manage temperature or pressure declines, recovery of cold wells)
- Planning make-up wells in relation to the reservoir conditions and rock properties
- Input reservoir conditions and rock properties to stakeholders like production surface engineers, drillers, geoscientists or other useful modelling (wellbore, surface production design, uncertainty quantification, etc)

5 CONCLUSION

A production history model of the Dogger aquifer in the South-East of the Paris sedimentary basin has been set up and calibrated with measured field data at its initial state and during production history. The model design allows a high heterogeneity of the Dogger reservoir to carry out calibration of the model parameters against reservoir data. During the production phase, interferences in temperature and pressure are observed between the doublets on the field (e.g. GOR doublets). Large-scale modelling allows us to analyse these interferences between wells and doublets which will become more and more important as more doublets are added.

Gathering transient downhole pressure data in new wells can improve the calibration of such large-scale models and better understand well connectivity, in order to forecast more sustainable flow rates, avoid temperature breakthrough and reduce risks. The model is still being improved, e.g., more time needs to be taken on production history calibration to better constrain the model parameters around the doublets and triplets. A coupled wellbore model could be implemented to better represent the wells behavior and have strong correlation between the reservoir and the surface.

For future work, alongside forecasting future production based on a robust production history model, uncertainty quantification can be implemented to provide more confidence on future output such as production mass flow and production temperatures, temperature breakthrough or pressure decrease. Finally, model outcomes have been detailed to inform all stakeholders and management groups of the potential uses of such model. Modelling being relatively cheap and quick compared to other costs encountered during a geothermal project, it also reduces the risk and help for future decision making.

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