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

Comparison of the modelled hydraulic impact of multi-legs and one leg geothermal well in the Dogger reservoir in the Paris area

Morgane Le Brun, Anne-Lise Gille, Pierre Chouet

3 avenue Claude Guillemin, BP46429, 45064 Orleans Cedex 2

Morgane.lebrun@cfg-geo.fr

Keywords: Modelling, multi-leg wells, hydraulic impact, Dogger

ABSTRACT

The Dogger reservoir is a deep carbonate reservoir (top at more than 1500m depth vertical) used extensively for district heating in the Paris area. The heat of the reservoir is mined using the doublet design, with a production well pumping the hot geothermal water (60-80°C) which is then reinjected colder (25-40°C) in an injection well after releasing its heat to the surface network via a heat exhanger. Few geothermal sites use the triplet design with two injection wells and one production well before transitioning to a fully new doublet when the wells productivity gets too low.

New projects are being carried out in less productive areas of the reservoir using new well designs to ensure a better productivity/injectivity of the wells despite the lower permeability. One of these design uses oil&gas multi-legs design with one slanted leg and two U-shaped legs to produce fluid from the most productive layers of the reservoir.

Modelling the hydraulic impact of this innovative doublet design can be challenging given the small scale of these legs (400m with a 7'' diameter) compared to the extension of the reservoir that needs to be taken into account (100m thickness and 100 km² horizontal extension). Different approaches are used by the different consultancies working on this reservoir, one approach represents the legs as linear drains in a permeable layer of a multi-layers model. Comparison of this multi-legs design with classical one leg design show that the multi-legs design improves the productivity/injectivity index of the wells but the hydraulic impact of this multi-leg design is more important on nearby (2 km) other geothermal operations.

Given the current 1 bar hydraulic impact accepted by the regulators for new geothermal operations on existing geothermal operations, this might mean that the geothermal projects targeting these less productive areas of the reservoir will need to be more spread out to limit hydraulic interference. A comparison of the results of the different modelling approaches might help reduce the uncertainty on the hydraulic impact of this multi-legs design and thus help the development of the mining scheme in these new development areas. This comparison will be done in an upcoming project lead by the BRGM in 2025.

1. INTRODUCTION

The Dogger reservoir is a carbonate reservoir located deeper than 1500m vertical depth under the Paris region and is used extensively for district heating network (Lopez et al, 2010). With a push for increase in heating capacity via geothermal energy, more geothermal projects are being planned in the Paris region, in areas of the Dogger reservoir which are less known. With less wells drilled in these untapped areas of the reservoir, the uncertainty on the permeability and thickness of the reservoir is higher. To reduce the risk of low productivity wells resulting in higher pumping costs and lower maximum flowrate, innovative well architectures (subhorizontal wells and multiradial/multi-legs wells) used in oil&gas have been tested in lower permeability areas of the reservoir (Ungemach et al, 2024) as alternative solutions to the conventional design of a slanted well.

This multi-legs design (also called multi-radial design) was tried for the first time on the Velizy project (Boissavy, 2021) and consists in one slanted leg and two U-shaped legs producing fluid from the most productive layers of the reservoir. These U-shape legs can be about 400m long with a diameter of 7'' spanning about 40 m of the formation vertically, the slanted leg acts more like a rathole and extent about 60m into the reservoir.

This architecture increases the surface of exchange of the well with the productive layers of the reservoir and thus increases the productivity of the well even with a low permeability formation. This increase in productivity helps reduce the pressure impact around the well compare to a classical slanted well design. Nevertheless, the multi-leg design has a bigger imprint in the reservoir compared to the one-leg conventional design and this could lead to higher pressure impacts on nearby wells.

Modelling the hydraulic and thermal impact of these unconventional architecture is done by consultancies to design the well spacing of a project, the well architecture and comply with the regulation of less than 1 bar impact on nearby wells. Different approaches are used by each consultancy and described in the regulatory documents, they often consider the same conceptual model for the reservoir (sandwich model, described in Le Brun et al, 2011) but differ in how they spread the hydraulic load in the productive sections of the reservoir.

One approach is presented in this study, spreading the flowrate over the whole length of the legs, an upcoming project lead by the BRGM will compare the different approaches and evaluate the sensibility of the hydraulic and thermal results to these different approaches.

This study compares the hydraulic and thermal impact of a multi-radial well with the impacts of a conventional design.

2. DESCRIPTION OF THE MODEL

2.1 Software used for the simulation

The software COMSOL Multiphysics, module Earth Science was used to model the hydraulic and thermal impact of a geothermal doublet. The numerical equations are solved using finite elements, hydraulic impacts are solved in 2D or 3D, thermal impacts are modelled in 3D.

2.2 Conceptual model of the reservoir

The Dogger reservoir is composed of different geological units representing different deposit environment of a carbonate shelf (Lopez et al, 2010): the Cyclical unit at the bottom of the sequence contains porous layers and clayey layers (outer shelf), the Oolith units above contains high energy deposits of oolithic clasts displaying a relatively high porosity (reef), the top unit Comblanchien shows indurated marly carbonate layers with few oolithic clast (inner shelf, lagoon).

The flowing PTS logs performed after the drilling of the wells indicate that feedzones are present in these three units, with the Oolithic unit being the most prolific. These feedzones are only few meters thick and rarely extend laterally to the other wells, thus wells 1km away from each other can display a tenfold difference in their transmissivity.

To perform hydraulic and thermal numerical simulations within a reasonable computational time, the structure of the reservoir is simplified. One conceptual model is often used, called the sandwich model, which takes into account the thermal buffer effect of the non-productive layers within the reservoir.

This sandwich model is made of:

- One intermediate non-productive layer grouping all the non-productive layers of the reservoir but acting as thermal buffers.
- Two productive layers above and under the non-productive layer where the hydraulic impact and the thermal convection effect are being calculated.

To reduce the time of computation, a symmetrical axis is implemented in the middle of the intermediate non-productive layer, that reduces the size of the mesh. Thus, only the top half of the productive layer and half of the intermediate non-productive layers are integrated in the model (figure below).

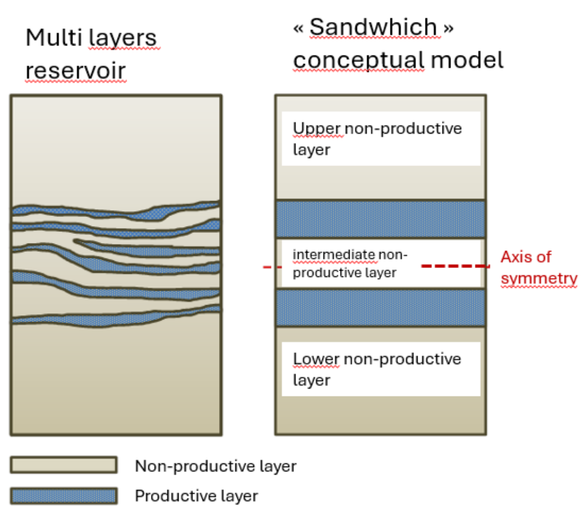

Figure 1: Conceptual model of the reservoir

2.3 Geometry of the model

This study focuses on one geothermal doublet, changing its design with two modelling scenarios. One scenario considers a multi-radial design, the production well and the injection well have three legs, one slanted leg (GMEU) with a length of about 110m, two U-shaped legs (GMEU-ST) of about 350m long. Another scenario considers a conventional design with one slanted leg (GMEU) with a length of about 110m. The flowrate is 400 m3/h with a reinjection temperature of about 24°C.

The model encompasses 6 other geothermal wells with a conventional design to evaluate the impact of the GMEU doublet on nearby wells.

To take into account the GMEU doublet and the 6 other geothermal doublets, the conceptual model described above is translated into a model geometry that presents a strong horizontal stretch. The model is thus 10km on the X-axis and 10 km on the Y axis, the vertical extension of the productive layer is 9m. This stretch prevents the use of a triangular mesh that enables more control of the size of the mesh vertically. The mesh is then composed of free tetrahedrals with the size smaller around the wells (figure below).

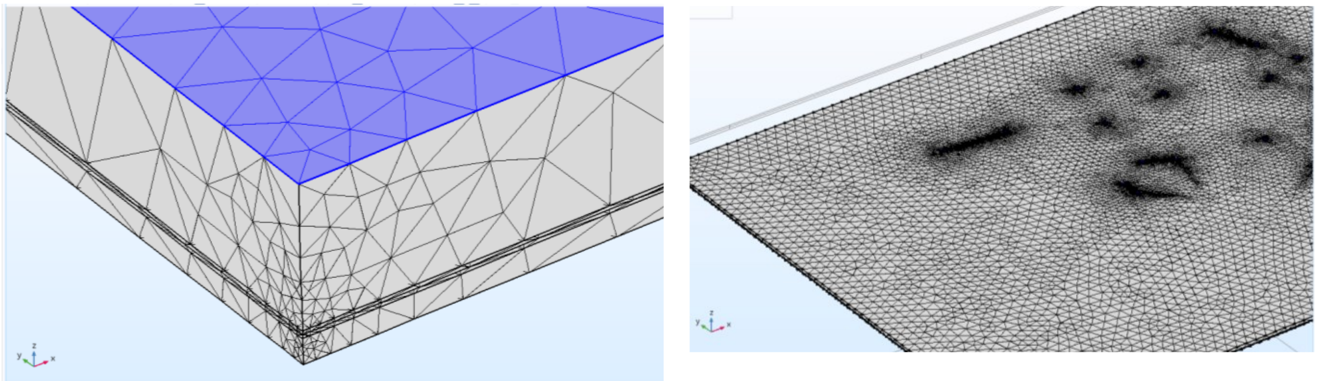

Figure 2: Mesh used in the model

For the mutli-radial design, the U-shaped legs (Leg 1 and leg 2) are integrated in the model as polygons on a horizontal plan located in the middle of the top productive layer, the slanted leg is a vertical polygon located over the whole length of the top productive layer. For the conventional wells, the slanted leg is the vertical polygon only (figure below).

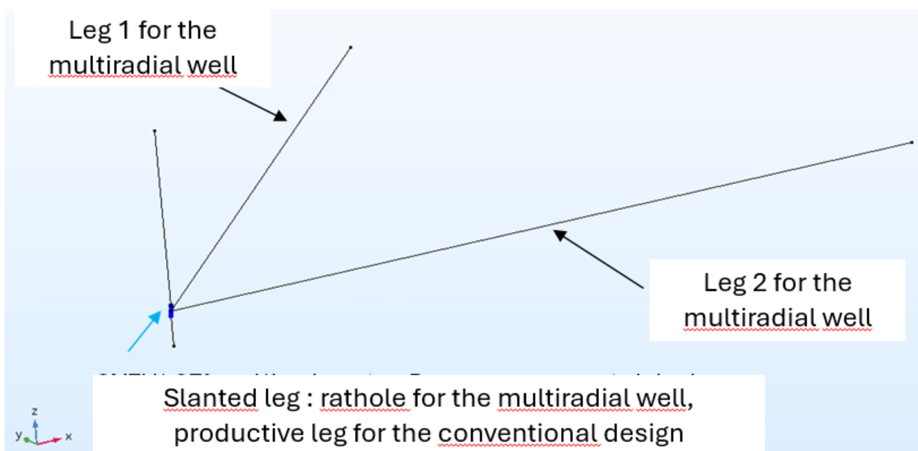

Figure 3: Geometry of the multiradial well in the model

The flowrate of the well is set as a ratio kg/s/m , by dividing the flowrate by the productive thickness for the slanted leg. For the horizontal drains, this ratio is obtained by dividing the flowrate by the thickness of the reservoir and the length of the drains multiplied by 4 to take into account the axis of symmetry.

2.4 Reservoir parameters

The main parameters of the model are described in the table below.

Table 4: Summary of the reservoir parameters

Type	Value
Thickness Intermediate non-productive layer	31 meters
Mean porosity	17 %
Rock density	2800 kg/m^3
Average fluid density	1004 kg/m^3
Average fluid viscosity	0,5 cp
Average fluid salinity	14 g/L
Fluid heat capacity	4,18 MJ/kg/K
Fluid thermal conductivity	0,6 W/m/K
Reservoir heat capacity	2,5 $MJ/m^3/K$
Non-productive layer heat capacity	2,1 $MJ/m^3/K$
Reservoir thermal conductivity	2,5 W/m/K
Reservoir storage	$1{,}01.10^{-10}$ Pa^{-1}

3. MODELLING RESULTS

3.1 Hydraulic impact

3.1.1 At the scale of the well

For the multi-radial design, the production of 400 m3/h of fluid causes an averaged drawdown of 18 bar on each leg (GMEU1 and GMEU1-ST1), which corresponds to a productivity index of 22 m3/h/bar With the conventional design, the pressure drawdown is -57 bar at the salnted leg (GMEU1), which corresponds to a productive index of 7 m3/h/bar (figure below).

The multi-radial design improves the production and injection capacity of the doublet by about 3 times.

This improvement is of the same magnitude of what is described in the end of drilling report for the multi radial geothermal doublet of Velizy, which indicates a productivity index of 4 m3/h/bar for the well with only a slanted leg and a productivity index of 19 m3/h/bar for the well with the 2 U shaped drains. This represents a fivefold improvement, which is higher than what is modelled but this improvement is also due to the different acid jobs that were performed before the production test of the well.

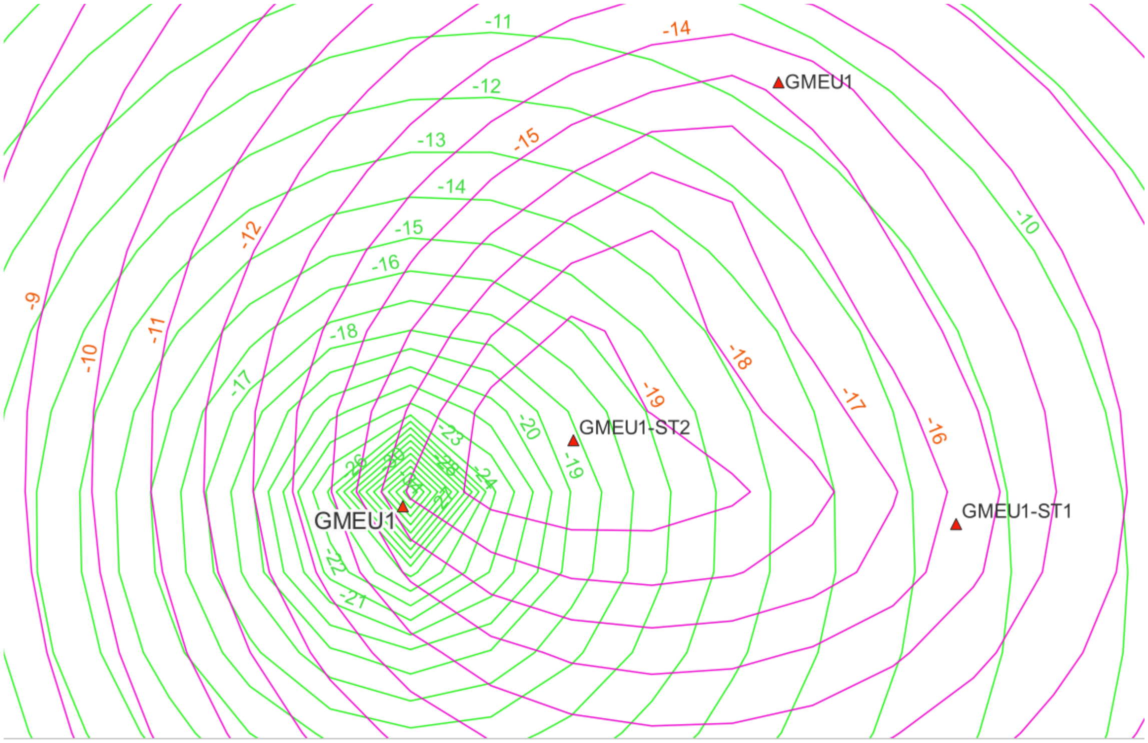

Figure 5: Hydraulic impact on two well designs: in pink for the multi-radial well design, in green for the conventional slanted well (unit in bar)

3.1.2 Impact on neighboring wells

The hydraulic impact on another geothermal doublet 2 km away from the multi-radial well is -2,6 bar on the production well (GFAR-1) and -3,6 bars on the injection well (GFAR-2).

For the conventional design, the hydraulic impact on these wells is 2,2 bar on the production well (GFAR-1) and -3 bars on the injection well (GFAR-2).

This innovative multi-radial design seems to create a bigger impact on the neighboring wells than the conventional design, it increases the drawdown by -0,4 and -0,6 bar on wells located about 2 km away.

The difference is less for wells further away from the multi-radial well, with an increase of the drawdown of about 0,2 bar on wells about 3 km away from the well (-1,4 bar on the production well GBA-2 and -0,8 bar on the injection well GBA-1 bar with the multi-radial well, -1,2 bar and -0,7 bar with the conventional design).

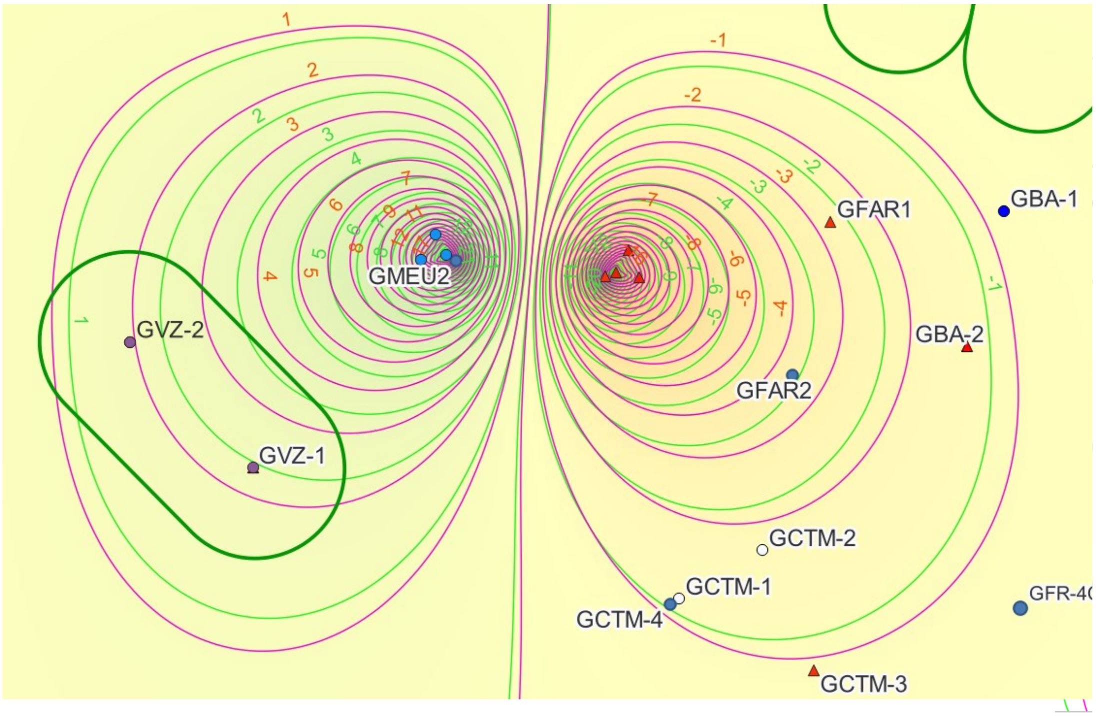

Figure 6: Hydraulic impact on neighboring wells: in pink for the multi-radial well design, in green for the conventional slanted well (unit in bar)

3.2 Thermal impact at the scale of the well

The thermal impact is compared between the multi-radial well design and the conventional slanted well after 28 years of production (figure below).

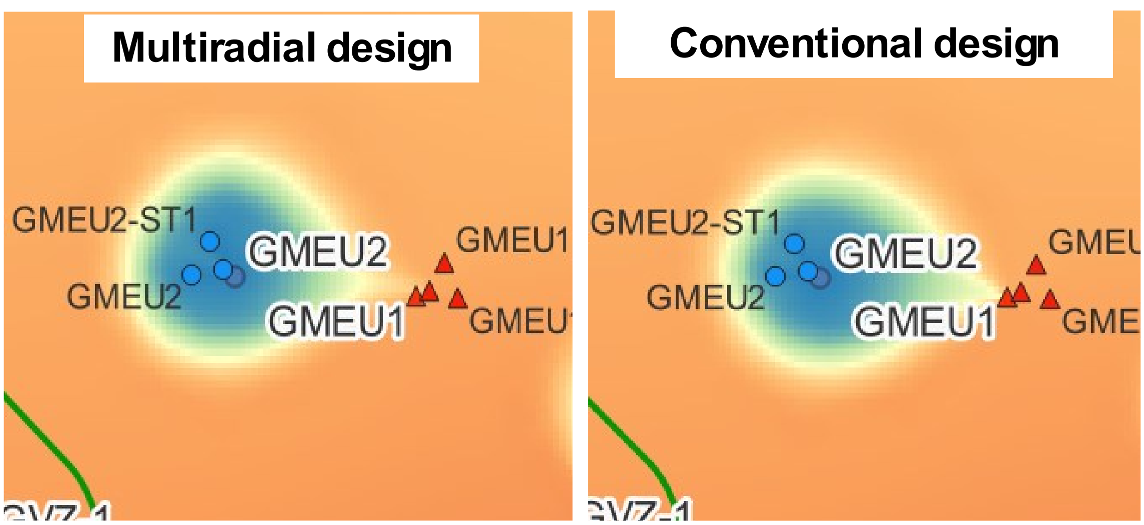

Figure 7: Thermal impact at the scale of the doublet: left image for the multi-radial design, right image for the conventional design (dark blue 24°C, red color 70°C)

The temperature evolution for each leg of the production well is extracted from the model as an average over the length of the legs for each scenario (with drains and without drains). The multi-radial well design seems to slow down the cooling front from the injections well (figure below), except on one leg where it is accelerated (-1°C less after 28 years of production on GMEU1-drains).

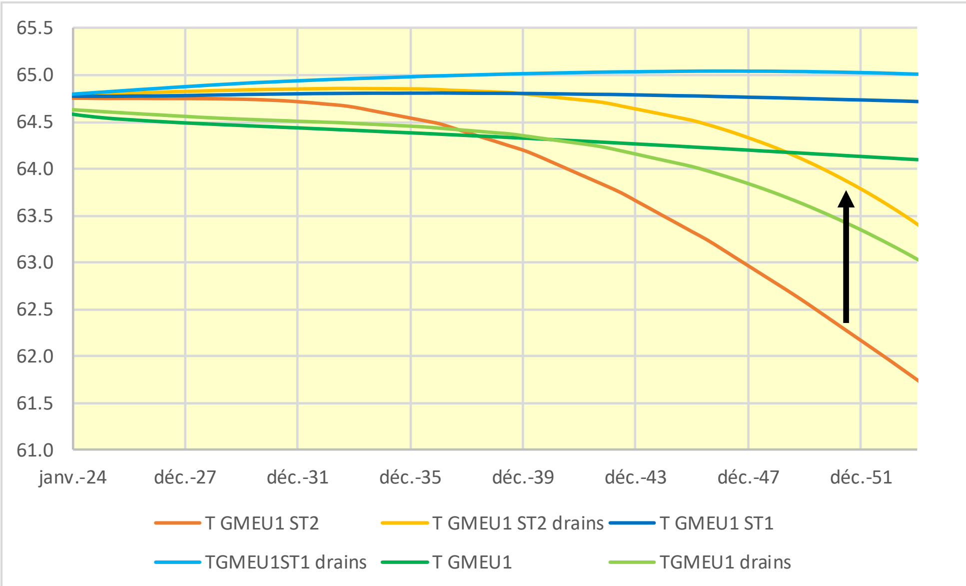

Figure 8: Thermal evolution at the different legs of the production well for the multiradial well scenario ("drains") and for the conventional scenario

4. CONCLUSION

Modelling the hydraulic impact of the innovative multi-radial design on a geothermal doublet can be challenging given the small scale of these legs (400m with a 7'' diameter) compared to the extension of the Dogger reservoir that needs to be taken into account (100m thickness and 100 km² horizontal extension). Different modelling approaches are used by the different consultancies working on this Dogger reservoir, this study represents the legs as linear drains in the productive layer of a "sandwich" model. Comparison of this multi-legs design with a conventional one leg design shows that the multi-legs design improves the productivity/injectivity index of the wells but the hydraulic impact of this multi-leg design is more important on nearby (2 km) geothermal operations.

Given the current 1 bar hydraulic impact accepted by the regulators for new geothermal operations on existing geothermal operations, this might mean that the geothermal projects targeting these less productive areas of the reservoir will need to be more spread out to limit hydraulic interference. A comparison of the results of the different modelling approaches would help reduce the uncertainty on the hydraulic impact of this multi-legs design and thus help the development of the mining scheme in these new development areas. This comparison will be done in an upcoming project lead by the BRGM in 2025.

REFERENCES

Le Brun M, Hamm V, Lopez S, Ungemach P, Antics M, Ausseur JY, Cordier E, Giuglaris E, Goblet P, Lalos P.: Hydraulic and Thermal impact modelling at the scale of the geothermal heating doublet in the Paris basin, France. Proceedings, 36th Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, (2011).

Lopez S, Hamm V, Le Brun M, Schaper L, Boissier F, Cotiche C, Giuglaris E.: 40 years of Dogger aquifer management in Ile-de-France, Paris Basin, France. Geothermics, 39, (2010), 339–356.

Ungemach, P., Antics M., Sarda D., Bethune, G., Gaillard, M.,: Multilateral wells. A key architecture in maximising geothermal exposure and multilayered reservoir performance. A review of Paris Basin well design achievements, Proceedings, 49th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2024)

Boissavy, C., Schmidlé-Bloch, V., Pomart, A., Lahlou, R.: France Country Update, Proceedings, World Geothermal Congress 2020+1, Iceland, (2021)