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Andrzej Zuber
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Ewa Kmiecik

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Origin of mineral and thermal waters

title: **Modelling of a pumping test conducted in the mixing zone between a thermal aquifer and a surface aquifer using physico-chemical parameters monitoring**

author(s): **Jean-Yves Josnin**
Laboratoire EDYTEM UMR CNRS 5204 Université de Savoie, France,
jean-yves.josnin@univ-savoie.fr

Stéphanie Gallino
Laboratoire EDYTEM UMR CNRS 5204 Université de Savoie, France,
stephanie.gallino@univ-savoie.fr

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INTRODUCTION

The hydrodynamic behaviour of deep aquifers is often characterised using pumping tests that are interpreted with the petroleum engineering formalism (pressure instead of hydraulic head, artesian tests, permeability instead of hydraulic conductivity, etc.) (Bourdarot, 1996; Miller, 1979, Murphy et al., 1999). Moreover, for both petroleum pumping tests and geothermal pumping tests, only the temperature is measured in addition to the pressure variation (linked to the drawdown). We propose here to use both electric conductivity and temperature monitoring during a pumping test in order to obtain some information about the hydrodynamic characteristics and the position of a deep water plume emerging into a shallow aquifer. Indeed, the mixing between deep waters with thermal characteristics and surface water is common in French alpine regions. In the case of thermal spa of Aix-Marlioz (Fig.1), thermal waters from a “thermosiphon” diffuse, after crossing an aquitard, into a more or less karstified superficial aquifer. The thermal plume outlet in the urgonian low karstified limestone corresponds to the upper part of an overthrusting anticline (Fig. 2). The spa draws their waters from a well that catches water at the bottom of the urgonian series on the western flank of the anticline.

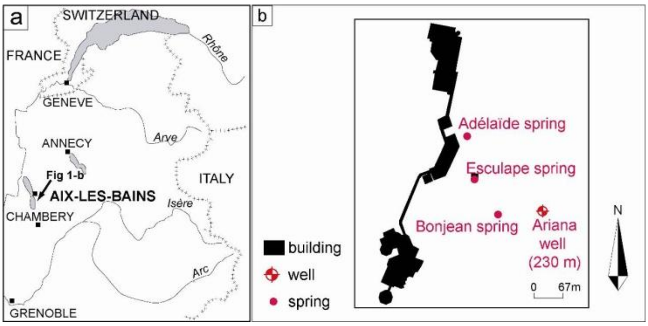

Figure 1. Location of studied area: a) regionally; b) on the locality of Aix Marlioz.

The physico-chemical characteristics of the deep flow are χ = 1000 µS·cm^{-1} and T > 17°C, whereas the shallow water ones are χ = 680 µS·cm-1 and T = 11°C. The mixing of two poles, in steady-state flow, has a conductivity of χ = 740 µS·cm^{-1} and a temperature of 17°C (Fig. 2).

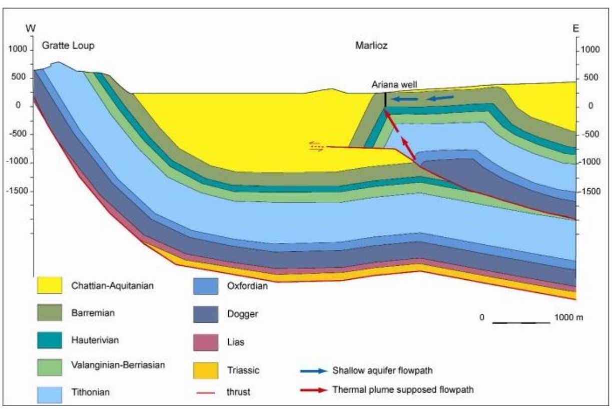

Figure 2. East-west geological cross-section of the Aix-les-Bains overlapping anticline through the locality of Aix Marlioz.

The surveys carried out prior to implantation drilling are insufficient to determine whether the thermal plume is diffuse or arrive concentrated in the base of the aquifer. The final aim of this study is to reproduce the plume behaviour, using a pumping test in which the drawdown, temperature, conductivity were monitored simultaneously. This approach aims to obtain a maximum of information from a unique pumping test performed into a single well. It is the opposite of the integral pumping tests (Bayer-Raich et al., 2006), that use a maximum of piezometers in order to obtain the characteristics of a pollution plume.

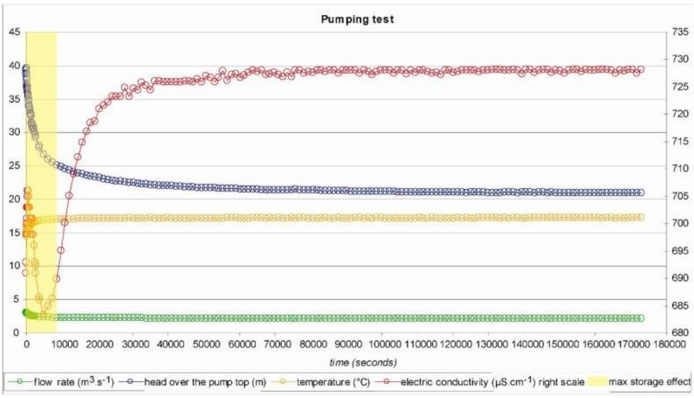

Figure 3. Plot of drawdown and electrical conductivity and temperature monitored during the pumping test on Ariana well at Aix Marlioz locality.

INITIAL INTERPRETATION OF THE PUMPING TEST

The pumping test was performed in a 230m depth well (Ariana well) with a casing from top to 171m depth (the last deeper part remains in borehole).

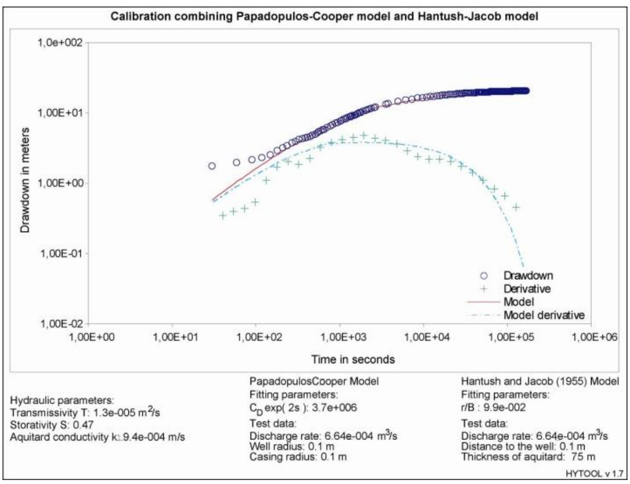

Figure 4. Diagnostic plot of the drawdown data combining the Papadopulos-Cooper model (well-bore storage effect) and the Hantush-Jacob model (leakage) showing that this interpretation is possible from a theorical point of view although the greater transmissivity of the aquitard vs the aquifer transmissivity is unrealistic.

The results of monitoring are presented on Fig. 3. As expected (karst low developed), the drawdown can be explained as an essay in porous media with a well-bore storage effect due to the depth of the well (Papadopulos-Cooper) combined with a drainance (Hantush-Jacob) (see Fig. 4). This classical interpretation from drawdown was carried out using Hytool (P. Renard, Hytool, user manual, 2003) (see Fig. 4). However, the hydraulic conductivity obtained for the aquitard is greater than that obtained for the aquifer, which is illogical. This is probably because the aquifer is not clearly identified as a both fractured and weakly karstified aquifer (failure of calibrations type Warren and Root). The interpretation of the pumping test using the drawdown only led to an unsatisfactory result from a hydrodynamic point of view.

It may be noted on Fig. 3 that conductivity and temperature showed different behaviours at the beginning of pumping. In particular, the temperature is stabilized 8 hours before the electrical conductivity. This cannot be due to the well-bore storage effect because its duration is less than 1h30. The phenomenon observed on the electric conductivity curve is then related to the water mixing in the media. On Fig. 3, the maximal time (beyond the theory) of the well-bore storage effect duration is shown in yellow.

THE MODEL

Considering that we have frequently obtained differences between total mineralization behaviour and temperature behaviour with identical transport and hydraulic parameters, we focus in the present abstract on the modelling total mineralization behaviour. The software used to perform the modelling is Feflow (Diersch, 2002), which permits both flow, mass and heat transport in saturated and unsaturated media. The calculations are done into finite element mesh (Fig.5).

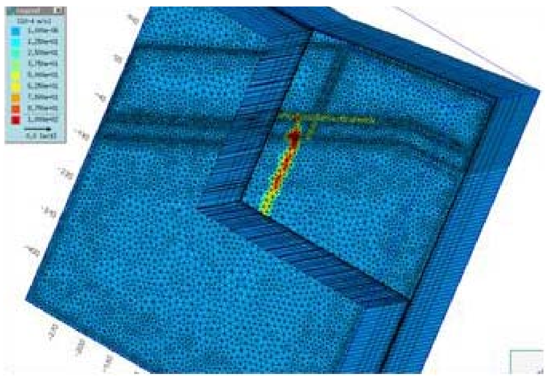

Figure 5. 3D finite element model of the Aix Marlioz locality around the Ariana well.

The information given during the drilling indicates a more fractured and productive zone between 170 and 180 m depth in the borehole. The information given by the field indicates that the thermal plume can potentially be located downstream to the well in lateral position. Indeed, the spring located upstream to the well (to the east) has chemical and thermal characteristics of the shallow aquifer, when the springs located downstream (to the west) show intermediate chemical facies that become closer to the thermal one from South to North.

RESULTS AND DISCUSSION

The simulations shown on Fig. 6 have been realised using the same set of hydrodynamic and transport parameters. Only the thermal plume position is moving. The goal here is the reproduce qualitatively the shape of the electrical conductivity curve obtained during the pumping test (in red on Fig. 3). This curve is characterised by a first increase (short in time) of the electric conductivity immediately followed by a drawdown. At the end of the curve, a new increase appears, that finishes with a stabilisation at relatively high level of electric conductivity. This shape described just above is our reference for the curves obtained on Fig. 6. In the present abstract, only one of the representative sets of parameters used is shown. The final calibration in order to reproduce more exactly the electric conductivity behaviour will be performed from the Fig. 6c thermal plume location (see after). In Fig. 6, the simulated TDS concentrations were converted into electrical conductivity.

In Fig. 6a and 6b, the pumping well and the thermal plume are in the same cross-section parallel to the natural flow into the superficial aquifer. In Fig. 6a, the plume is in upstream position regarding to the pumping well. In Fig. 6b, the plume is in downstream position regarding to the pumping well. It appears on Fig. 6a that only the first increase of the electric conductivity appears, followed by a long drawdown (too long to be reduced enough after calibration). On Fig. 6b, only a correct drawdown of the electrical conductivity appears. The first peak and the final stabilisation are missing. On Fig. 6c, all the characteristics expected are present. This last test is obtained with a thermal plume located in a downstream position regarding to the pumping well, but not exactly in the cross-section of natural flow that intersects the well. The plume is into a flow section in a lateral position. When we modified the hydrodynamic parameters or the transport parameters, we often obtain a curve of electrical conductivity with this shape. It indicates that such position correspond probably to the position of the plume regarding to the well. Moreover, we know that the spring with the physico-chemical characteristics closer to the thermal plume is really in such a position regarding to the pumping well. In the present example, the monitoring of the electric conductivity really permits to give more indications on the position of the thermal plume into the shallow aquifer (more that the single interpretation of the drawdown curve).

CONCLUSION

We have therefore tried to use both the electrical conductivity data and the temperature data to reduce the scope for interpretation of a pumping well. In the present case, the test is successfull only after the electric conductivity data qualitative interpretation. We need now to confirm this first result by a complete model including temperature data, and if possible, give a quantitative solution to the problem and not only a qualitative one as presented here.

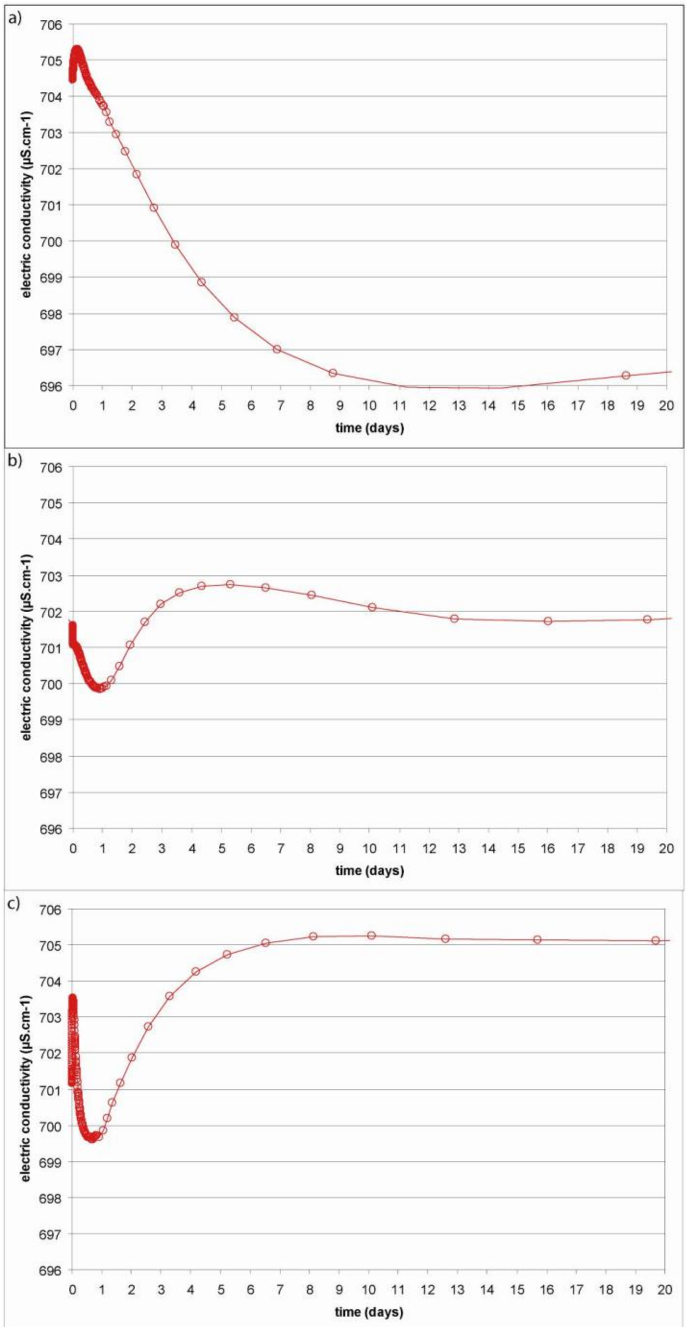

Figure 6. Results of simulations made in the two hypotheses: a1 concentration when the thermal plume is located upstream to the well; a2 temperature when the thermal plume is located upstream to the well; b1 concentration when the thermal plume is located downstream to the well; b2 temperature when the thermal plume is located downstream to the well.

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