



HAL
open science

Assessment of deep aquifer complexity by long period numerical path lines

Olivier Douez, Alain Dupuy, Olivier Atteia, Michel Franceschi

► **To cite this version:**

Olivier Douez, Alain Dupuy, Olivier Atteia, Michel Franceschi. Assessment of deep aquifer complexity by long period numerical path lines. International FEFLOW User Conference, Sep 2006, Berlin, France. pp.99-106. hal-00963682

HAL Id: hal-00963682

<https://hal.science/hal-00963682>

Submitted on 25 Mar 2014

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Assessment of deep aquifer complexity by long period numerical path lines

Olivier Douez
douez@egid.u-bordeaux.fr

Alain Dupuy
dupuy@egid.u-bordeaux.fr

Olivier Atteia
atteia@egid.u-bordeaux.fr

Michel Franceschi
franceschi@egid.u-bordeaux.fr

Institut EGID-University of Michel de Montaigne, Bordeaux, France

ABSTRACT: In the large sedimentary basins such as the Aquitain Basin (Southwest of France), the hydrogeological behaviour of the multi-layered aquifer system is complex. The hydrodynamic and isotopic chemistry coupled data can bring some answers on the main flow and the recharge of the whole system.

The confrontation of hydrodynamic parameters with isotopic geochemical data was carried out on the Infra-Molassic Sands (IMS) groundwater of the Aquitain Basin where the apparent water age, for most of the samples, ranges from -15 000 to -35 000 years BP. Moreover, this main upper aquifer is located in a regional multi-layered aquifer system.

The solution adopted to analyse the behaviour of this system consists in heuristic numerical modelling of this aquifer in order to carry out "numerical" path lines over several thousands years. The variability of the depth of the aquifer of the IMS (from + 300 down to - 2000 meters) needs to take into account the thermal parameters. The model so generated covers a surface of approximately 32 000 km².

In a first step, we investigated a model with a recharge only on the outcrops areas and a flow model by "piston" effect in a mono-layer system. The calculated water's age distribution obtained by this model of horizontal flow does not agree with the observed age data.

In a second step, the aquifer of IMS was integrated into a multi-layered system. The results obtained highlighted the principle of a recharge of the groundwater of the IMS by vertical leakage on long transient regimes through the overlying aquitard formation. These models allowed to show the respective importance of vertical and horizontal flows on a regional scale, and thus to better understand the behaviour of this system.

INTRODUCTION

The hydrogeological behaviour of the multi-layered aquifer system in the large sedimentary basin of Aquitaine (Southwest of France) is complex. To have a better comprehension of this functioning, it seems interesting to confront the hydrodynamic and isotopic data in a numerical model.

This study was made on the Infra-Molassic Sands (IMS) aquifer, the upper aquifer of the multi-layered system. This IMS aquifer undergoes a strong anthropic pressure related to its use in various economic sector such as drinking water supply, irrigation, spa which used warm springs located alongside the structures, geothermal and gas storage. That is why it is necessary to have a better understanding of this aquifer and in particular of its recharge.

The use of particles tracking with isochrone markers in a numerical model is the solution which was adopted. The depth variations of this deep aquifer require to take into account the geothermic effects. Two models have been studied, a first one with a mere piston effect and a more complex one in which the IMS aquifer is included in the multi-layered system.

THE IMS AQUIFER DESCRIPTION

The IMS aquifer is located in southern France in the Aquitain Basin (figure 1). The study area covers approximately 50,000 km² of which the half of this surface is covered by the aquifer of IMS. This aquifer is bordered to the south by the North Pyrenean Front, by the Montagne Noire and the Massif Central to the East. To the west, around the latitude of Mont-de-Marsan, the sand formation changes facies and it is not an aquifer anymore.

The Ypresian and Lutetian sandy formations of the Eocene compose this aquifer, these sands originally come from the Massif Central and Pyrenees erosion. The major outcrops are located to the south-east of Pau at the near of the Pyrenean front and to the extreme east at the near of the Montagne Noire. The surface of these outcrops is very reduced.

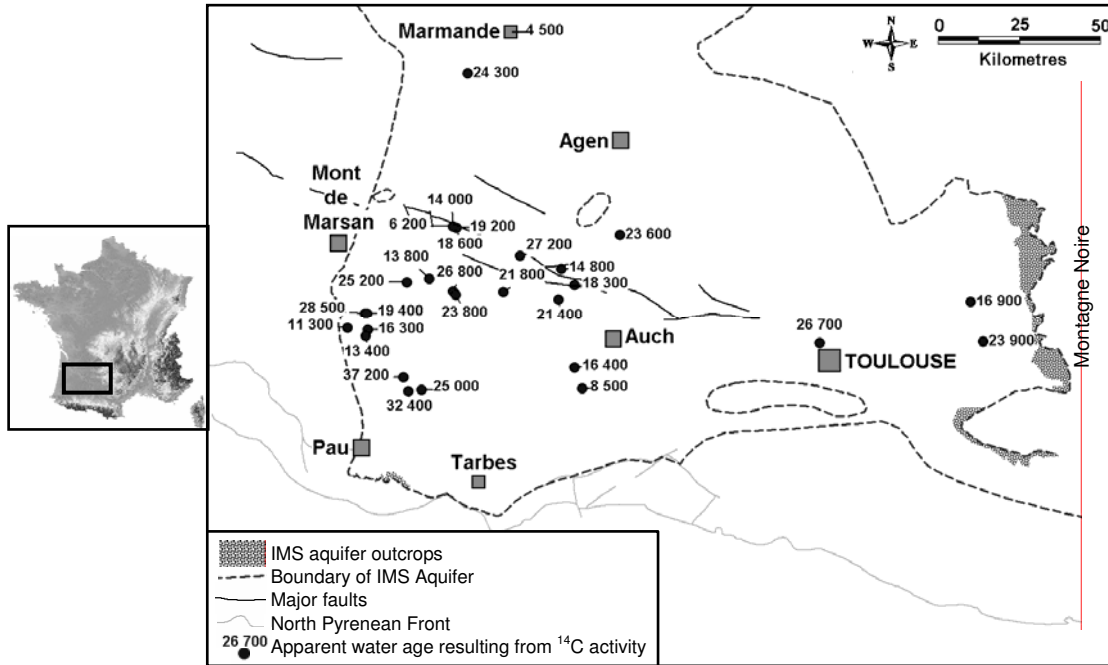


Figure 1: Geographical situation

The IMS aquifer is the upper aquifer of a multi-layered deep aquifer system (figure 2). It is a confined aquifer below the molassic sediments which can reach a thickness from 200 to 1,000 meters. This molassic formation has a low permeability.

The average permeability of this aquifer, estimated from aquifer testing and modelling results, is 10^{-5} m.s^{-1} (Labat, 1998). The specific storage is about 10^{-6} m^{-1} and the porosity ranges from 20 to 35% (Housse & Maget, 1977).

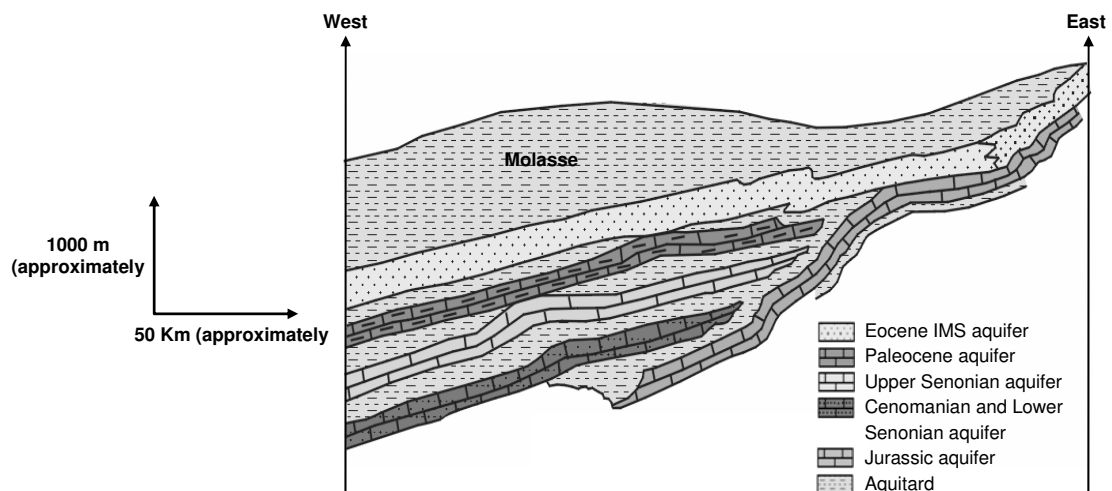


Figure 2: Simplified geological cross section of the multi-layered deep aquifer system of the Aquitaine Basin (Besbes & al., 1978, modified)

The apparent age of the water ranges from – 5,000 and – 40,000 years before present. This apparent age of the water of IMS results from ^{14}C activity, using the Pearson & Hanshaw method. Most of the data varies from around –15,000 to -35,000 years (figure 1).

METHODOLOGY

To apprehend the behaviour of the IMS groundwater and more particularly the amount of recharge according to the aquifer, the solution consisted in using a numerical modelling in order to carry out pathlines with isochrone markers over several thousand years. These results are then compared with the apparent water ages. The study being done on stream tubes, the mixing of waters is not taken into account. The extension of the model is equal to 32,660 km² (figure 3). The model is composed of 7 layers including 3 aquifers: IMS, Paleocene and the Upper Senonian ones (figure 4). A refined zone was established in the east part for a best use of the particles tracking method.

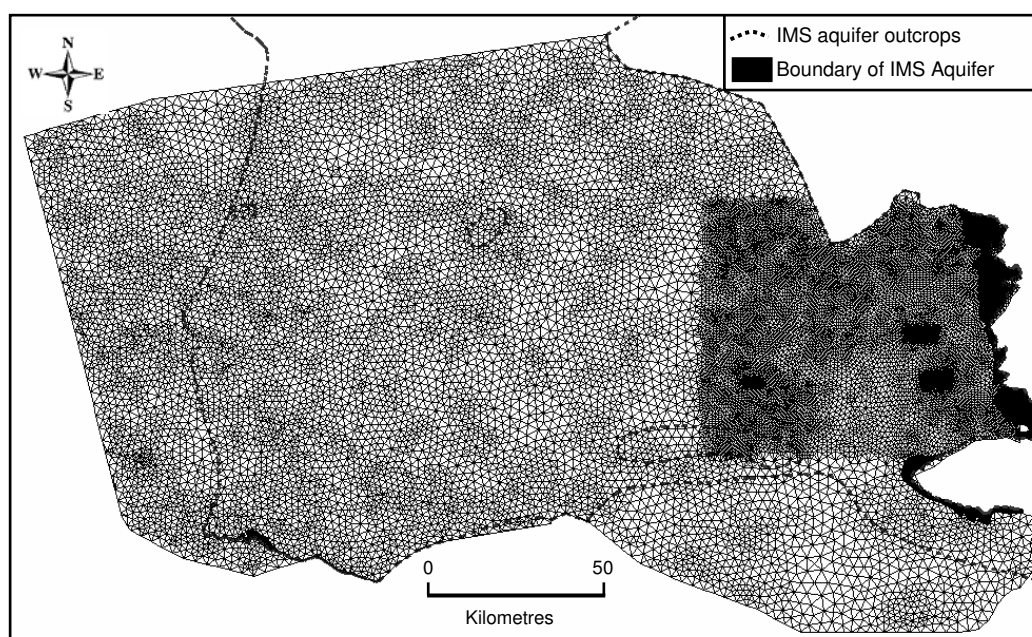


Figure 3: Extension of the numerical modelling

In the aquifer, the depth can reach more than 1,000 metres, this is required to take into account the geothermic data in the models.

The method used was to impose a grid of temperature on the surface level and on the level of the continental platform in order to establish a realistic geothermic gradient, that is to say between the first and the last slice of the numerical modelling. The surface temperature corresponds to the average atmospheric temperature. The calibration of the temperatures was carried out with no flow in a steady state (figure 5). The results were then injected into the models. To simplify the problem, the flow effect on the temperature was ignored.

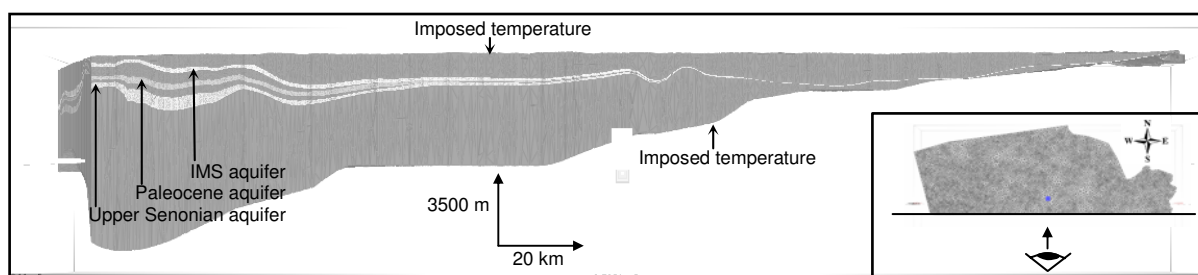


Figure 4: Cross section in the numerical modelling

The project was made in two steps:

The first step consisted in simulating the IMS aquifer as a mono-layer, and the recharge taking place only on the outcrops areas. The flow is then represented by a simple piston effect which corresponds

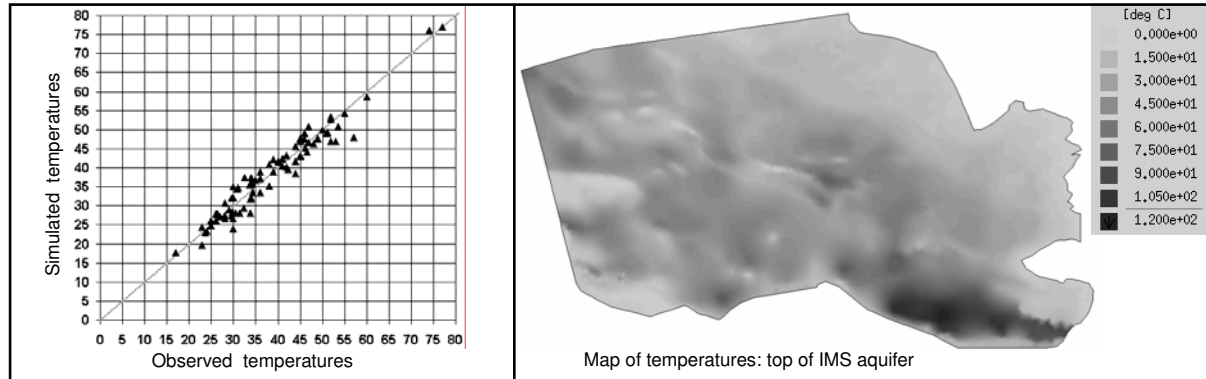


Figure 5: Calibration of the temperature

to a mere advection phenomenon. The boundary conditions are applied only to the IMS aquifer. The permeability fixed to all the formations is of $10^{-15} \text{ m.s}^{-1}$, except for the IMS.

The second step consisted in simulating the IMS aquifer as a part of the multi-layered system. Currently, only 3 points of data in the east part were studied. In the extreme east, fixed potentials are applied on a part of the first slice to study the vertical leakage between the surface and the IMS aquifer. These fixed potentials are equal to the topographic levels. The permeability of the molasse was set at 10^{-9} m.s^{-1} on the whole study area. The west part, more complex, is not studied in this paper.

RESULTS AND DISCUSSION

Mono-layered system

In the east part, the simulated time to reach backward the outcrops is superior to 40,000 years for two points whereas the measured ages are inferior to 30,000 years, is incompatible with a model by advection (figure 6).

In the west part, the central zone where the water ages range from 18,000 to 26,000 years was studied. The time to reach the outcrops is also incompatible with the apparent water ages observed (figures 7). Indeed, the isochrone markers show ages equal to 30,000 years before reaching the outcrops.

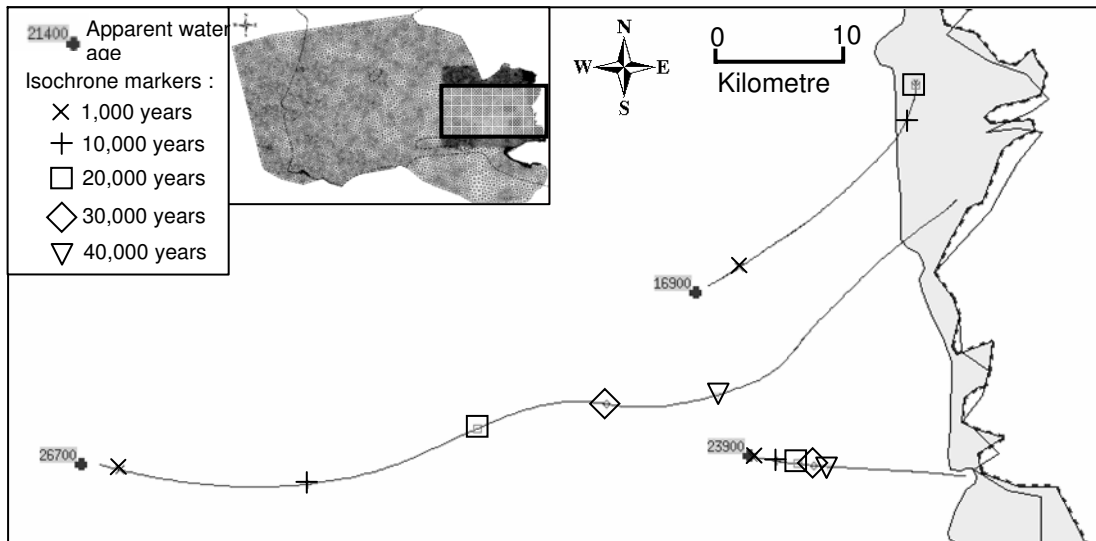


Figure 6: Backward particles tracking with isochrone markers in the east part

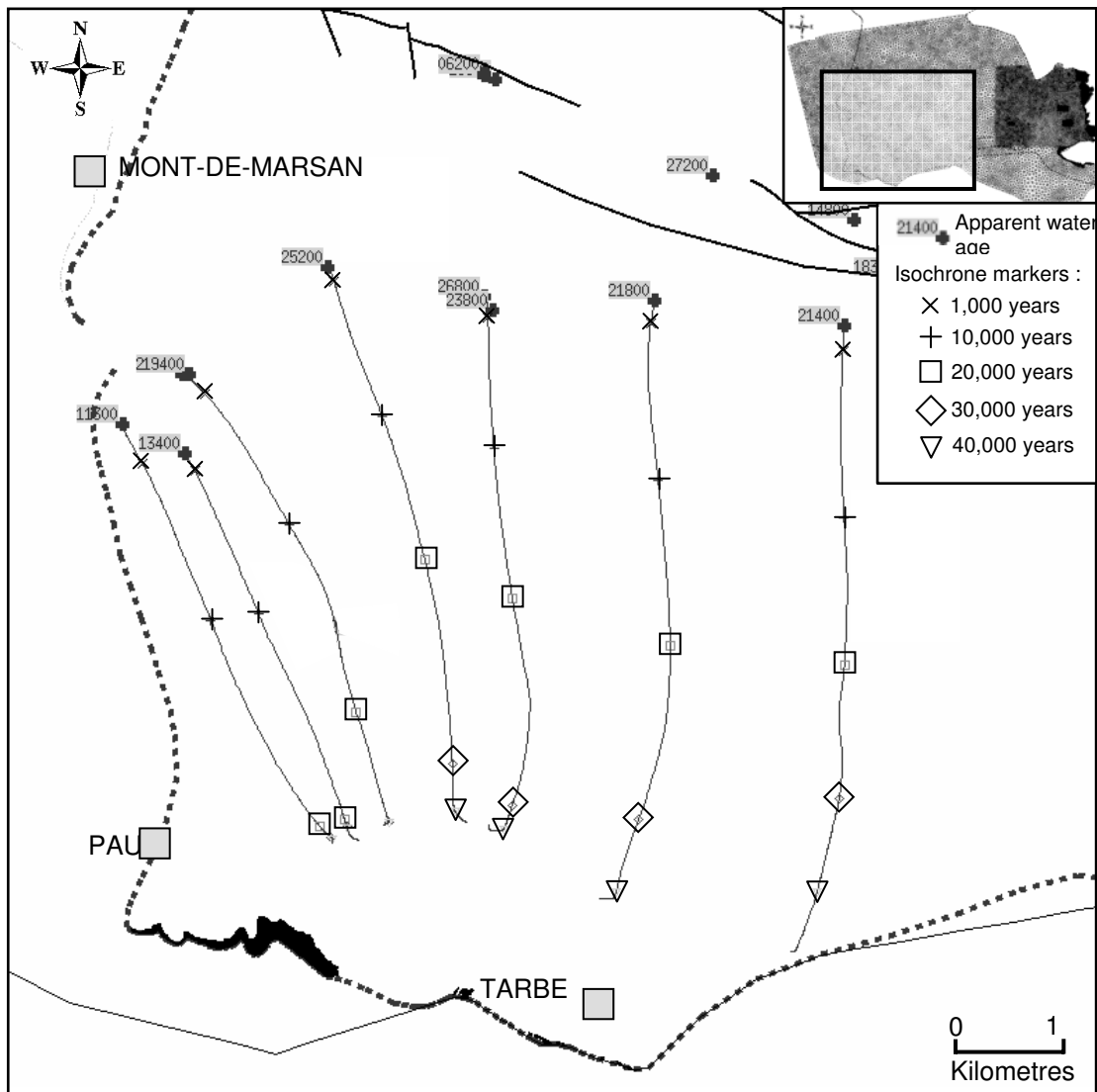


Figure 7: Backward particles tracking with isochrone markers in the west part

The age of water on the different studied parts of the aquifer have not been able to be adjusted by using the particles tracking with isochrone markers. The first results show that the functioning of the IMS aquifer is more complex than a mere piston effect. This aquifer must not be considered as a mono-layered system.

Multi-layered system

For the 3 points studied, the original area of the water does not correspond to the IMS outcrops. Indeed, the pathlines come from the molassic formation (figures 8, 9 & 10). The isochrone markers enable to restore the observed water ages with an error of 1,000 years maximum. This error is inferior to the uncertainty of the measure of the water age.

One part of the IMS groundwater would find its origin in the molassic formation. These first results on the multi-layer seem to show a pattern of recharge, at least in the east part, by downward vertical leakage on long transient regimes through the molassic aquitard.

These data seem to consolidate the results obtained on the geochemical and data parameters. Indeed, the mineralisation in the east part, and in particular the sulphate concentration, can be explained by the contribution of solutions coming from the upper molassic formation (André, 2002).

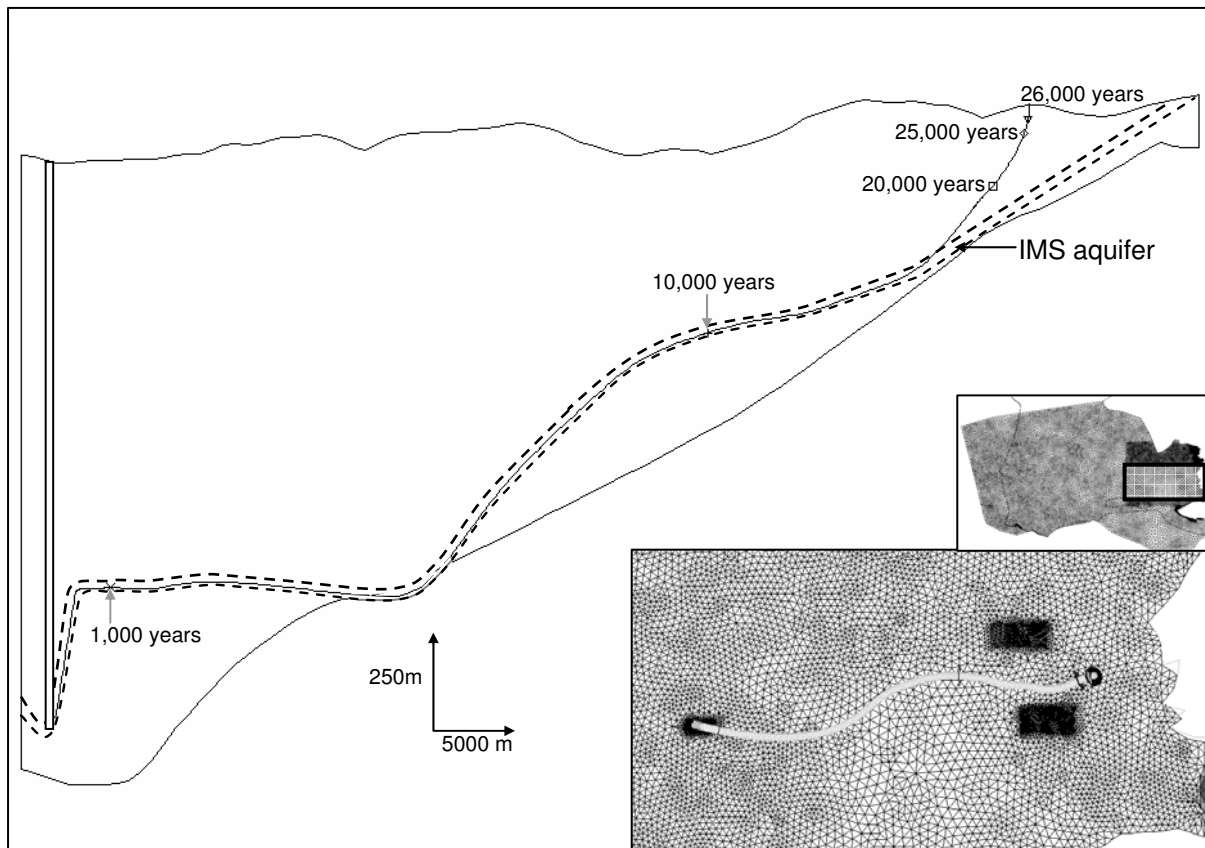


Figure 8: Pathline with isochrone markers, apparent water age observed 26,700 years

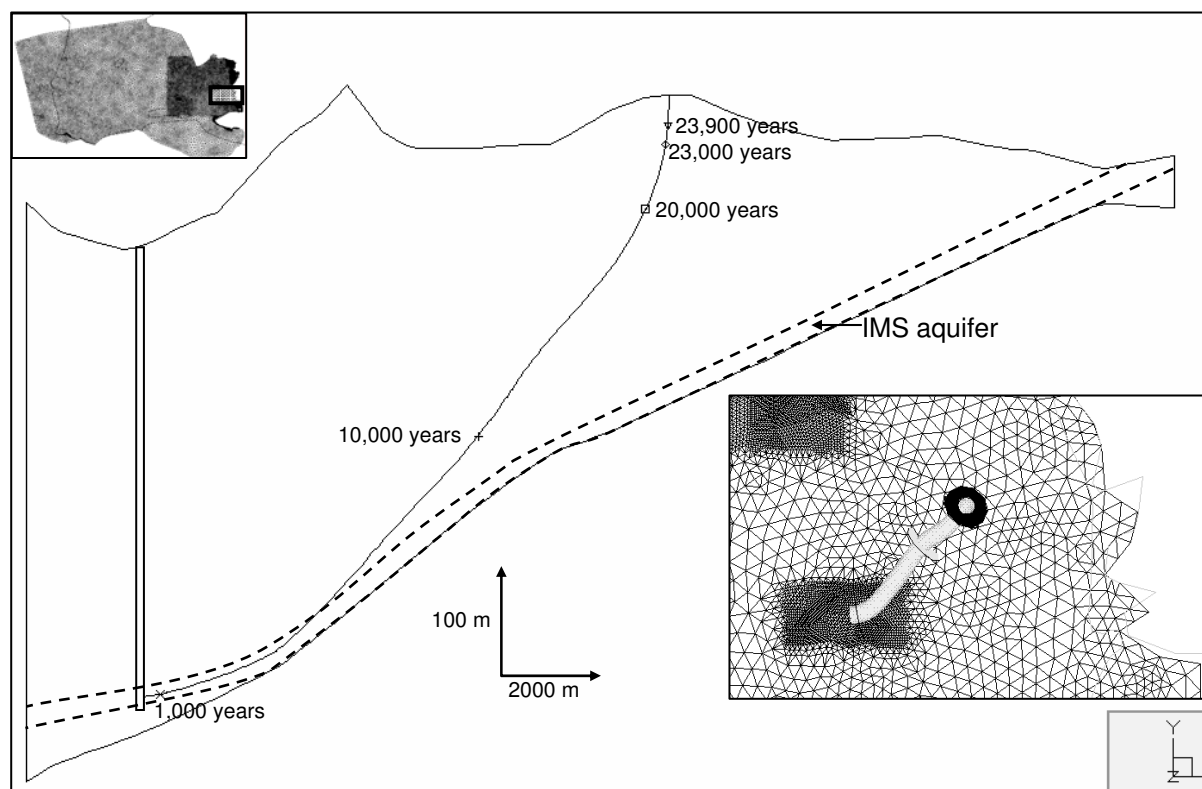


Figure 9: Pathline with isochrone markers, apparent water age observed 23,900 years

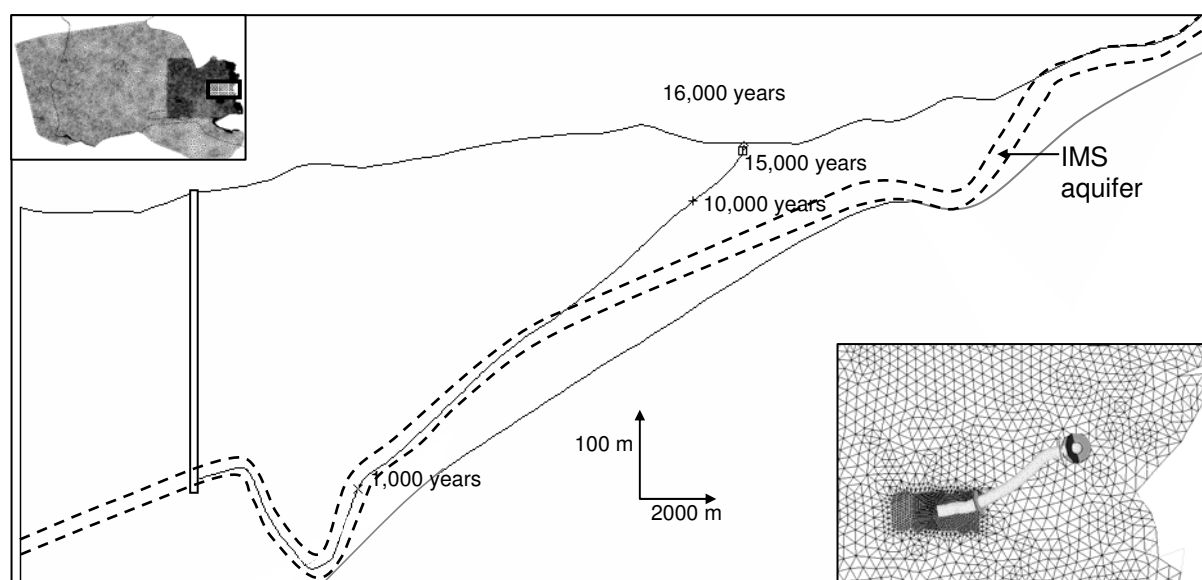


Figure 10: Pathline with isochrone markers, apparent water age observed 16,900 years

SUMMARY

The confrontation of isotopic data with hydrodynamic parameters by using a numerical model made it possible to have interesting information on the behaviour of the IMS aquifer. Thus, the use of the particles tracking with isochrone markers to simulate the time of the water flow brought a better knowledge as for the behaviour of this deep aquifer.

The first numerical model showed that the functioning of this aquifer is incompatible with a flow model by simple piston effect with recharge limited on the outcrops. Indeed, the groundwater age could not be calibrated by using the particles tracking.

The second model which includes the IMS in a multi-layered aquifer system gave better results. The water age could be calibrated in the east area with the particles tracking with a maximum error equal to 1,000 years.

These simulations allowed to show that the behaviour of this aquifer is complex, with a recharge by vertical leakage phenomenon on long transient regimes through the upper aquitard formation.

These last results are in agreement with the geochemical data and in particular the mineralisation of the water in the east part which can be explained only by the contribution of solutions coming from the molasse. In order to complete this work, it is necessary to study the complex west zone.

REFERENCES

- André L., Contribution de la géochimie à la connaissance des écoulements souterrains profonds. Application à l'aquifère des Sables Infra-Molassiques du Bassin-Aquitain, Thèse : Bordeaux 3 : 2002, 230 p.
- Besbes M., De Marsily G., Plaud M., 1978, Bilan des eaux souterraines dans le Bassin Aquitain In Hydrogéologie des grands bassins sédimentaires, Mém. Conférence de Budapest : mai-juin 1976, 829 p., Vol.XI, pp.294-303
- Housse B., Maget Ph., 1977, Potentiel géothermique du Bassin Aquitain, Levallois-Perret : BRGM, Elf Aquitaine (Production), 1977, 167 p., 38 pl.
- Labat N., 1998, Rôle de particularités sédimentaires et structurales sur le comportement des sables sous-molassiques soumis aux fluctuations induites par les stockages souterrains de gaz. Application à l'étude de leur influence sur l'hydrodynamisme des émergences locales, Thèse : Bordeaux 3 : 1998, 228 p.