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Modeling Gas Transport in the Shallow Subsurface in Maguelone Field Experiment

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Abstract

In this paper, TOUGH2/EOS7CA model is used to simulate the shallow injection-monitoring experiment carried out at Maguelone, France, during 2012 and 2013. The ultimate objective of the work is to improve our understanding of gas transport in the shallow subsurface as well as to develop and validate the model to monitor it. This work represents first results towards modelling the nitrogen and CO_2 injection experiments carried out. The pressure data from the first injection experiments in summer 2012 is used as basis for comparison. Work is presently going on to incorporate the experimental data into the numerical simulation further.

"Keywords: gas transport, shallow subsurface injection, leakage, modeling"

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1. Introduction

One of the issues that need to be addressed in CCS projects is the possibility of leakage from storage reservoir to upper layers. Leakage of CO_2 to the near surface aquifers may constitute a risk to humans and environment. Developing reliable monitoring techniques to detect and characterize CO_2 leakage is

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necessary for the safety of CO_2 storage in reservoir formations. The availability of qualified methods for the detection and monitoring of potential CO_2 leakage in any depth is important in the risk assessment framework [1].

Many studies have been done to investigate different geophysical and geochemical monitoring techniques to detect CO_2 release in the shallow subsurface. In some studies, monitoring techniques directly measure the CO_2 concentrations by extracting CO_2 through hollow push probes or CO_2 surface flux [2-6]. In other studies, indirect monitoring of leakage is accomplished by application of geophysical data acquisitions [7-8].

To test and cross-validate different monitoring techniques, a series of shallow gas injection-monitoring experiments (SIMEx) has been carried out at the Maguelone, along the Mediterranean lido of the Gulf of Lions, near Montpellier, France. The experimental site is documented in Lofi et al [9]. At the site, a series of nitrogen and one CO_2 injection experiment have been carried out during 2012-2013 and different monitoring techniques have been applied [10]. A downhole hydrodynamic observatory is installed to measure pressure and temperature and collects samples for further investigations. Time-lapse monitoring by induction logging and vertical electrical resistivity methods have been applied to estimate the gas saturation and gas dissolution by evaluation of geological electrical resistivity of the injection site. The other approach is used is seismic time-lapsed monitoring which is implemented in both surface and downhole. The geophysical monitoring methods have being used to quantify changes in the target formation. Combination of these methods has led to improvement of the spatial and temporal resolution of monitoring. In addition to monitoring approaches, applying numerical simulation for different leakage scenarios would help to provide and successively develop efficient techniques for detecting and monitoring of CO_2 release in shallow aquifers [11-12].

In this study, the multiphase and multicomponent TOUGH2/EOS7CA model has been used to simulate gaseous nitrogen transport in the experiments carried out so far. The objective is both to gain understanding of the system performance based on the model analysis as well as to further develop and validate modelling approaches for gas transport in the shallow subsurface, against the well-controlled data sets. Numerical simulation can also be used for the prediction of experimental setup limitations. We expect the simulations to represent the breakthrough time for the different tested injection rates. Based on the hydrogeological data beneath the lido, we also expect the vertical heterogeneities in grain size distribution to create an effective capillary barrier against upward gas transport in numerical simulations.

Table 1. Geological layers at the Maguelone test site along with the model parameters

Layer No.	Sediment characterization	Average thickness of sediment layer (m)	Porosity (-)	Permeability (m^2)	van Genuchten α (cm^{-1})	van Genuchten m (-)
H3	sands	0.0 – 4.7	0.3	1.72×10^{-11}	0.0166	0.513
H2	clay, silty clay with shells	4.7 – 8.2	0.6	2.76×10^{-16}	0.0138	0.178
H1	shell fragments with milimetric gravels	8.2 – 9.2	0.3	1.72×10^{-11}	0.0166	0.513
P4	clays and carbonates	9.2 – 12.3	0.6	2.76×10^{-16}	0.0138	0.178
P3	sands, silts and clays	12.3 – 13.5	0.38	3.16×10^{-16}	0.0116	0.178
P2	sands, gravels and pebbles	13.5 – 16.5	0.25	1.72×10^{-11}	0.0081	0.513
P1	clays	16.5 – 20.0	0.6	2.76×10^{-16}	0.0138	0.178

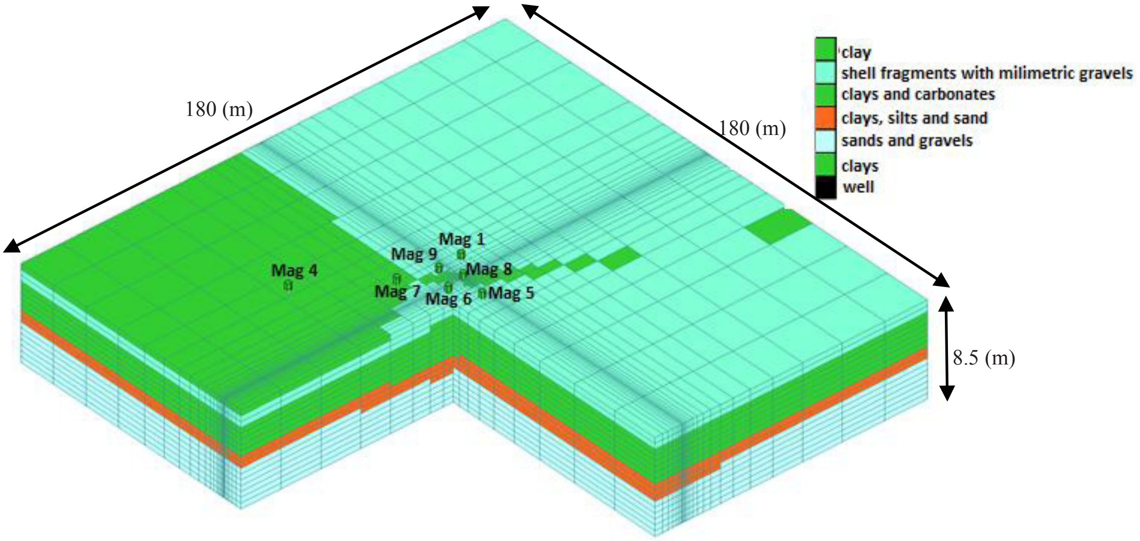

Fig. 1 View of 3D model of the Maguelone test site used in TOUGH2 simulations

2. Maguelone experiment site

The Maguelone experimental site is located beside the Mediterranean beach of the Gulf of Lions, 10 (km) to the south of Montpellier. The site area is restricted to the north by the Prevost coastal lagoon and to the south by the Mediterranean Sea. Continuous geological samples and geophysical data from shallow boreholes at Maguelone have led to detailed geological structure model of the test site. The geological data and structure model is described in detail by Lofi et al [9]. According to the collected data two depositional sequences are identified. In near surface (0-9 m) a skinny late-Holocene sequence (< 5000 yrs B.P.) is constituted with three soil layers from top to bottom: (1) grey shelly beach sands, (2) impermeable dark green clay, and (3) a thin layer of gravel/shells. From 9 (m) to the base of boreholes (50 m), it is Pliocene sequence. Pliocene sequence mainly consists of fined grained continental deposits (clay, silt and silty clay) which make the deposits poorly permeable. In the Pliocene sequence, a single remarkable depositional unit is located from about 13.5 to 16.5 meter below ground level (mbgl) and consists in a porous and permeable conglomerates and sands interpreted as fluvial deposits. Geophysical measurements and hydrological testing indicate a high hydraulic conductivity (4.0×10-3 m/s) of this layer and salinity (34 g/l) of formation water [9]. This depositional layer is used for the gas injection experiment. The layers in the Pliocene sequence from top to bottom are: (1) clay, (2) silt and sand, (3) sand and gravel and (4) clay (table 1).

The water table in the site is about 0.8 (mbgl). Formation conductivity logs data indicates a brackish to salty water unit from 0 to 32 (mbgl) [10]. The piezometric records of the site show that the water level is not considerably affected by the tide. The groundwater flow is influenced by rainfall in that region. There is no specific groundwater flow direction in the aquifer and the direction of flow changes with seasons and periodically changes with tide. In this study we simplify the modelling works by excluding the groundwater flow and water table and boundary pressure fluctuations.

The test was performed by injecting nitrogen through the well Mag 8 (Fig.1). The design and implementation of the injection experiment is described in the Pezard and Denchik [10]. This work presents the simulations of the injection test performed on 7th June 2012. 144 (m3) of nitrogen in gas form injected in 13-16 (mbgl) and in the next day 38 (m3) was injected. In numerical simulation we used the first rate of injection. Fig.1 shows location of the monitoring wells relative to the injection well (Mag 8). In Fig.1, Mag 5 is used as hydrodynamic observatory based on a multi-packer completion from WestBay (SWS), Mag 6 as a time-lapse logging hole, Mag 7 and Mag 9 as a downhole electrical observatory imaGeau and finally Mag 1 as a seismic observatory downhole [10].

3. Numerical Modelling

The numerical simulator TOUGH2 [13] and Module EOS7CA [14] is used for modelling Nitrogen (N_2) and CO_2 release into the shallow subsurface. The Module EOS7CA is including the equation of states to treat a two phase flow (gas and liquid), five components (water, brine, CO_2 or N_2, a gas tracer, and air) system in near ambient pressure/ temperature conditions [14].

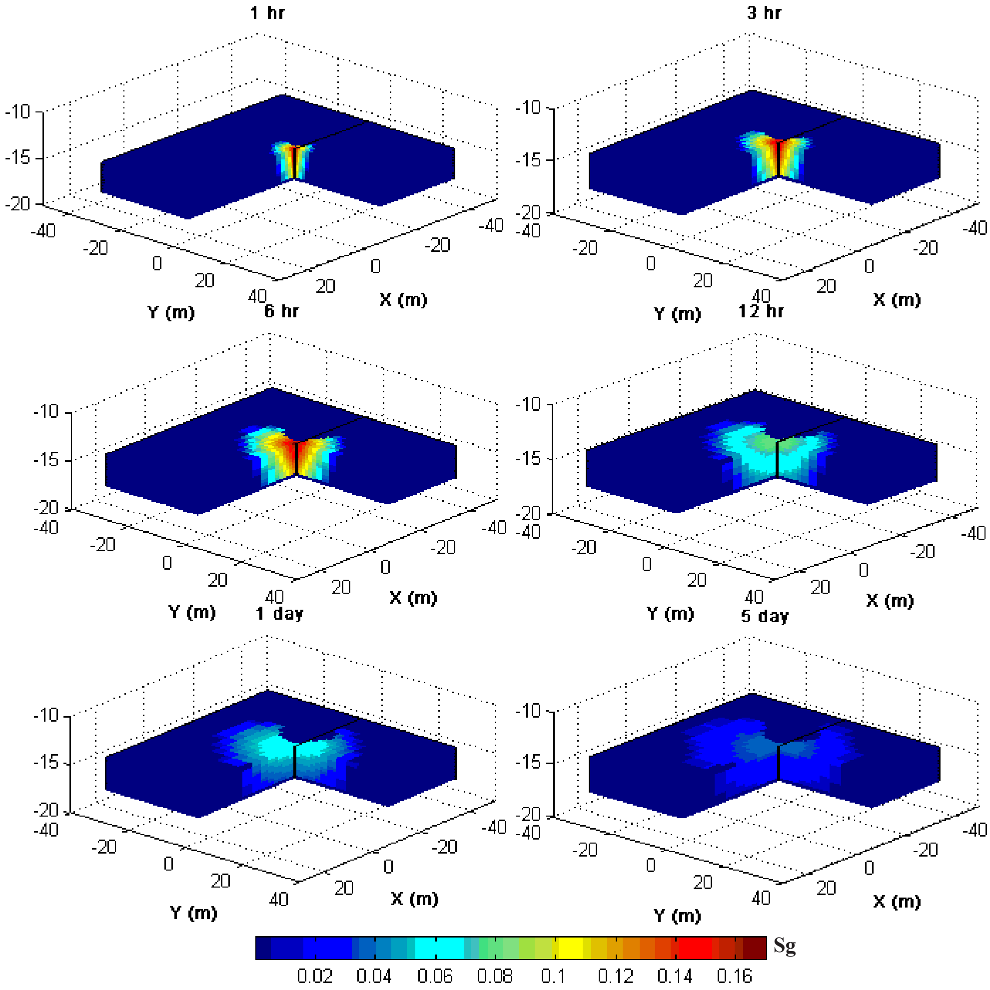

Fig. 2 N_2 plume evolution for Base scenario model during gas injection (0 to 6 hr) and after the injection period (until 5 days)

In the simulations presented here, the processes of advection and diffusion are considered. The dissolution of the gas is also included regarding the influence on electrical resistivity measurements. The chemical reaction between rock minerals and gaseous phase that could cause the change in pH and electrical resistivity of soil are not considered in this model. In all simulations in this study, the heat transport is neglected and it is assumed that the experiment was done in the isothermal situation.

According to the site information two basic scenarios were defined. The first scenario which is called Base scenario was simply defined as injection occurs in permeable layer in the Pliocene sequence with high conductivity (P2, sands, gravels and pebbles) which is confined in top and bottom by two impermeable layers. It is expected that there is no leakage through the silt and clay layer in top (P3). Presence of fairly small slope (~2 %) in the top of sand and gravel layer is also included in the simulation. The second scenario, Leaky scenario; is defined by considering leakage through the injection well to the upper layer. The leaky well scenario is defined to study the influence of leakage on monitoring measurement. Unpacked injection well connects two permeable layers of P2 and H1 in test site.

The boreholes data from the field site provides a conventional 3D numerical grid (Fig. 1). The 3D numerical grid contains of 18513 cells (33×33×17) with refinement near the injection well. The soil layers properties were allocated as shown in Table 1. The parameters were estimated based on the soil types and materials in this preliminary modelling study. We used the van Genuchten characteristic curves of capillary pressure and relative permeability. These parameters were determined by the ROSETTA database based on the material properties [15].

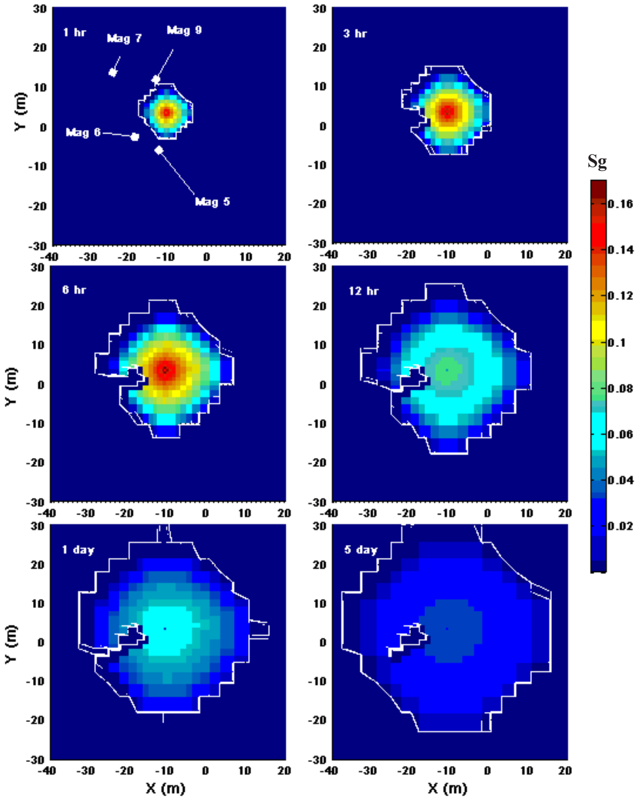

Fig. 3 Top view of gas saturation at 13.8 (mbgl), Base scenario at different time interval

4. Results and Discussion

4.1. Base Scenario

Results show the evolution of the nitrogen (N_2) plume in the injection domain as well as change in pressure. Fig. 2 shows the development of the N_2 plume in the model domain for the injection rate of 30 (kg/hr). The evolution of the gas plume is continuous with time and after five days the N_2 is transported over a longer distances (almost 25 m far from the injection well). Gas saturation is continuously increasing until the end of the injection. After the injection is stopped, the Sg (gas saturation) contents are reduced and after 5 days the maximum Sg in domain is less than 0.02 (2%). Presence of heterogeneities in the top layer appears to show no considerable effects on plume shape. Fig. 3 shows the plume in the top of the sand and gravel layer (P2) where the pressure and gas saturation monitoring was done. Due to the position of the monitoring wells relative to injection well, the monitoring wells Mag 5, 6, and 9 are affected by gas injection after 3 hours. But the monitoring well Mag 7 is not affected in the injection period. The N_2 reaches to the Mag 7 after 12 hours after the injection is started.

Fig. 4a shows the comparison of simulated gas saturation at 13.9 (mbgl) depth for different rates of injection at monitoring well (Mag 5). As expected, the gas saturation is reduced by reducing the injection rate. Fig. 4b shows a comparison of the measured and modelled pressure change in 13.9 (mbgl), indicating only a small change in the measured pressure change while the numerical modelling shows a sharp increase in pressure at this point. The effect of different injection rates was tested as well. The difference in measured and modelled pressure response indicates that the gas plume has not reached at the monitoring well at 13.9 (mbgl) during the field experiment. Therefore, our first conclusion is that leakage is happening in this system so the leaky scenario is considered in the next simulation.

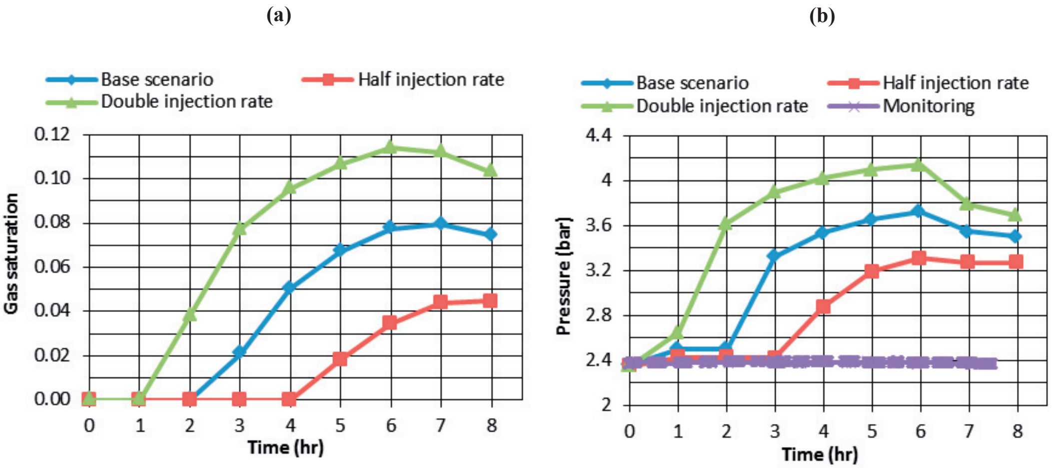

Fig. 4 (a) Gas saturation (b) Simulated pressure for 3 injection rate and monitored pressure at the observatory well (Mag 5) at depth of 13.9 (mbgl) (total amount of N_2 injection 144 (m^3) in Base scenario, 72 (m^3) in Half injection rate and 288 (m^3) in Double injection rate)

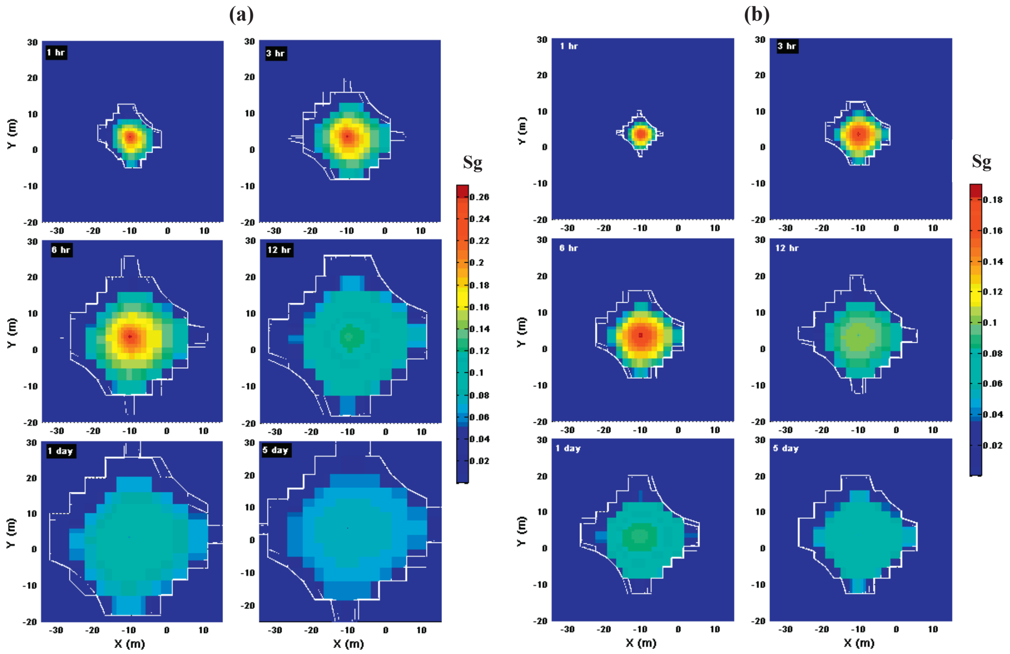

Fig. 5 Top view of gas saturation variation with time for Leaky scenario at (a) 8.3 (mbgl) (b) 13.8 (mbgl)

4.2. Leaky well scenario

A leaky well behaves as a connector between the two permeable layers in the test site. The injected N_2 in layer P2 moves through monitoring well and permeates to the layer H3. Fig. 5a and 5b show the top view of gas saturation in each layer (8.3 mbgl and 13.8 mbgl). Comparing the Fig. 3 and Fig. 5b shows the gas saturation with time is relatively less in Leaky scenarios than Base scenarios. The Sg contents in upper layer were increased (Fig. 5a). The reason for more gas saturation is density reduction. Presence of a leaky path may lead to higher gas saturation in shallower depth. Since the top layer (H3 at 8.3 mbgl) is relatively thinner than the bottom layer (P2 at 13.8 mbgl), the spreading of gas through the top layer is faster (Fig. 5).

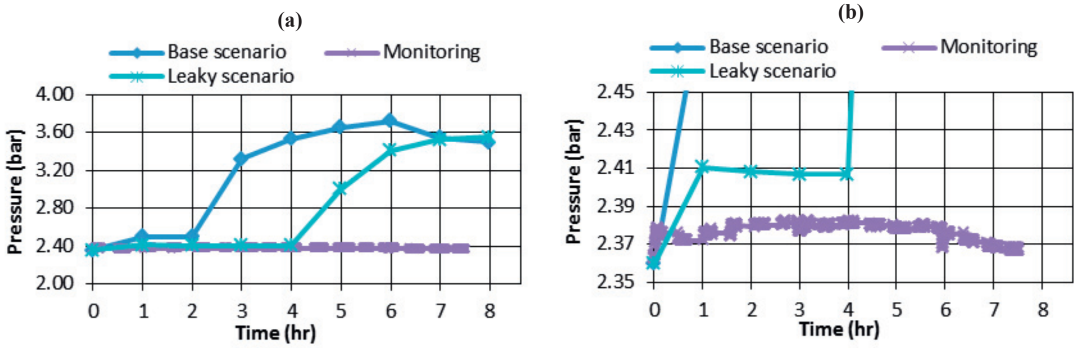

Fig. 6 (a) Simulated pressure (b) section of simulated pressure at observatory well (Mag 5) at depth of 13.9 (m)

Fig. 6 shows the comparison of the pressure in the monitoring depth of 13.9 (mbgl) by observatory well, Mag5; in two scenarios. The results show that the leaky scenario slightly improves the model agreement with the field observation but the difference is still significant. The agreement is better in layer P2, due to pressure reduction at the observatory well Mag 5.

5. Concluding remarks

Numerical simulation is an effective tool to study the gas transport through the shallow subsurface system. Data from full-scale field experiments is valuable and necessary information to validate such models. The Maguelone gas (Nitrogen and CO_2) injection experiments carried out between summer 2012 and December 2013 provide unique data that improve our process understanding as well enable such model validation.

This work represents first results towards modelling the nitrogen and CO_2 injection experiments carried out at the Maguelone site. The pressure data from the first injection experiments in summer 2012 is used as basis for comparison. The agreement in pressure response between the model and the first data set is not yet sufficient, the main hypothesis being that the leakage through one of the wells is not yet sufficiently accounted for. Some leakage has been sealed in the subsequent experiments and work is presently going on to further process the data from these experiments as well as to incorporate that into the numerical simulation. The improvement to the model will include consideration of heterogeneities of the site as well as leakage through wells more accurately.

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