Semi-analytical model of brine and CO2 leakage through an abandoned plugged well. Applications for determining an Area of Review and CO2 leakage rate.

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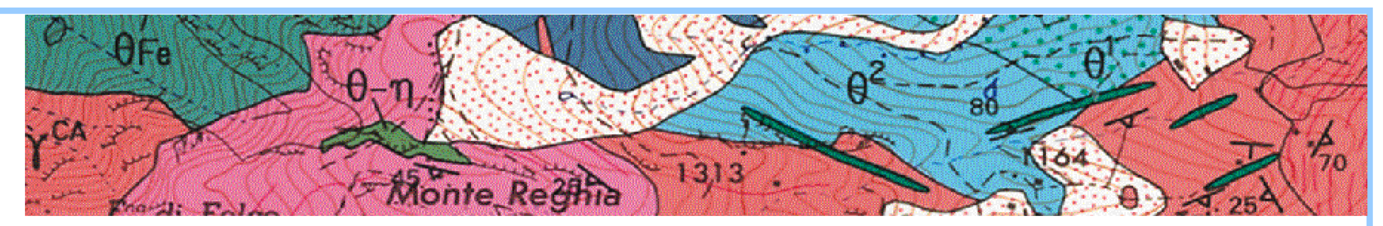

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Introduction

> Many CO_2 storage projects target **deep saline aquifers** located in sedimentary basins. In these regions, historical oil & gas operations have often left abandoned wells with sometimes undetermined plugging records

> The risk of **leakage through abandoned wells** should therefore be assessed, notably for preventing two adverse effects: **(i) the pollution of overlying fresh water aquifers** through the migration of saline brine, and **(ii) the emission of large fluxes of CO_2 in the atmosphere**. The present model may be used for describing both

Position of the model

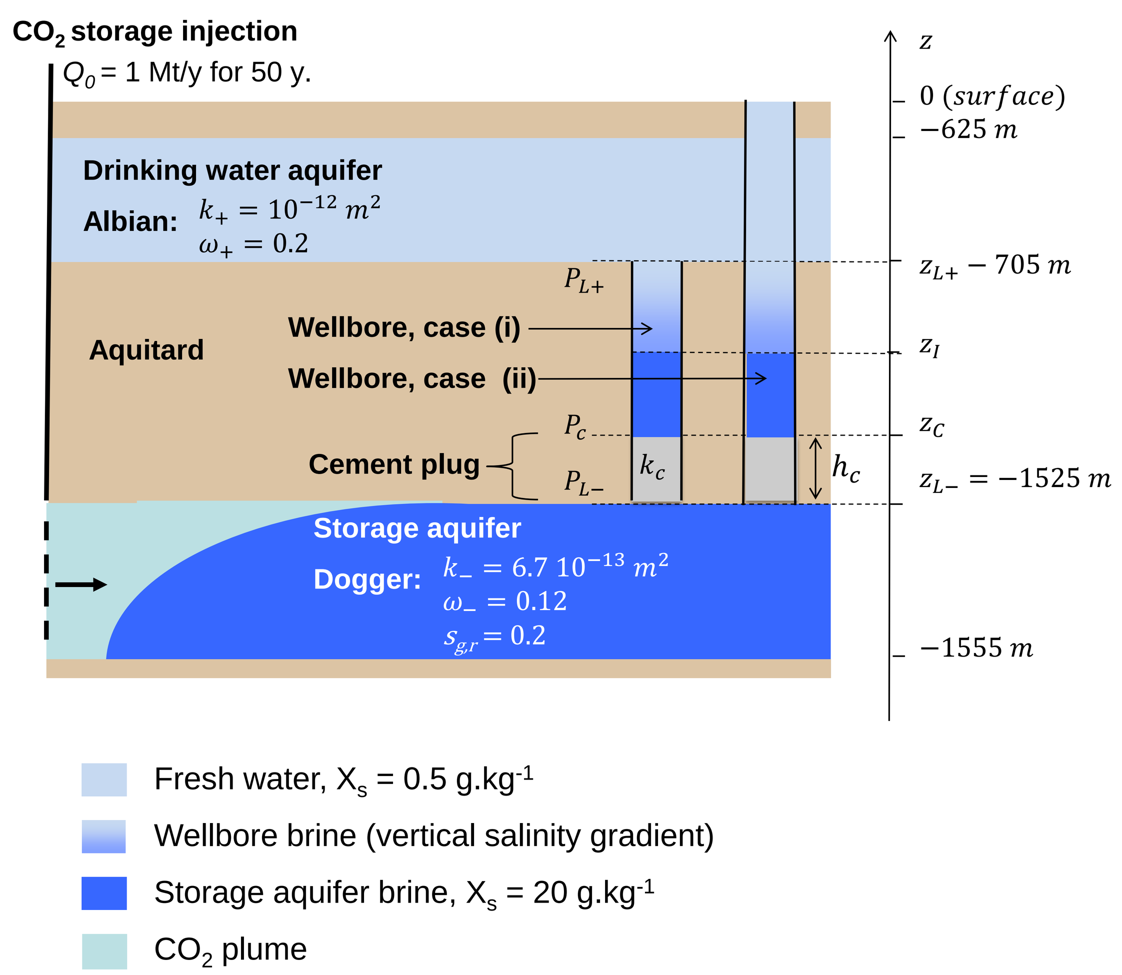
> Existing **semi-analytical models** can estimate the leakage flow rate of brine, possibly followed by CO_2, from the storage aquifer to overlying ones (cf. publications by Nordbotten, Celia and co-authors, 2004-2009)

> Based on these approaches, this work includes several novelties:

- It considers the **pressure increase** under the leak when the **dense saline brine** from the storage reservoir progressively fills in the leak and replaces the native fluid of the wellbore, and then its decrease when the **lighter $CO_{2,g}$** breaks through
- The leak is composed of an **open wellbore** and **a porous column of varying height & permeability**, which may represent various leaks, from an empty wellbore to a flow in a porous media such as the annular cementation. It either reaches the surface or an overlying aquifer

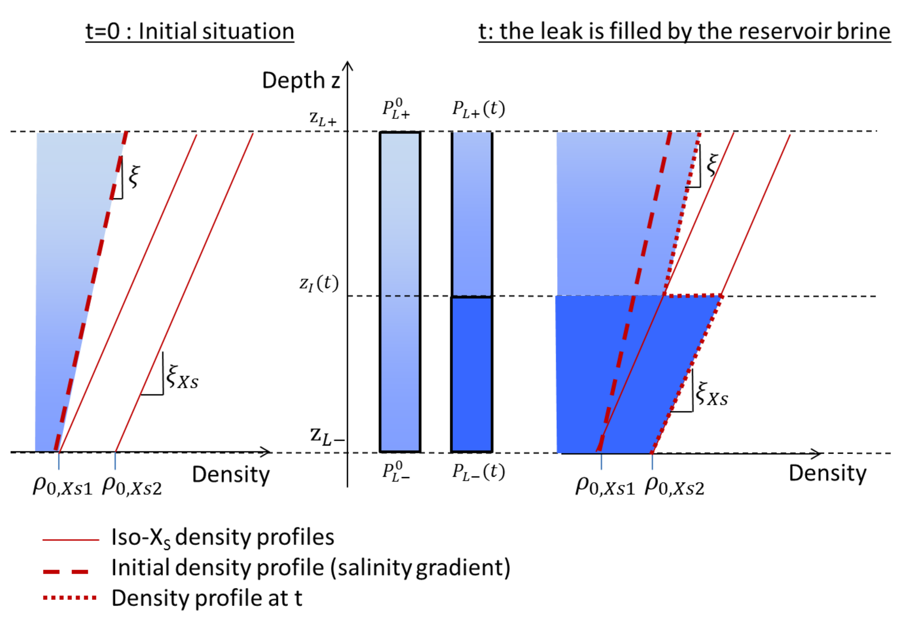
Schematic layout

& Paris basin case main data



Pressure under the leak modeling

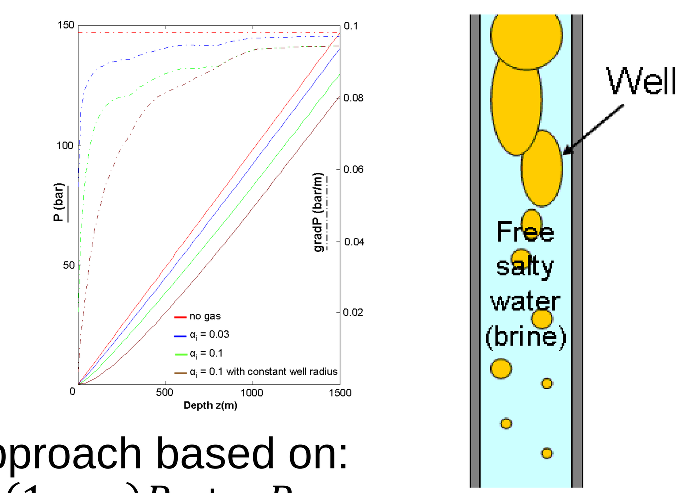
> During the brine leakage



> During the brine leakage, a pressure increase under the leak $P_{L-}(t)$ is considered due to the **density difference** between native and reservoir brine salinities.

> Paris basin case: when the Dogger brine reaches the Albian aquifer, P_{L-} has increased of 0.04 MPa

> During the CO_2 leakage



> First approach based on:

$$P_{L-}(t) = (1-\alpha)P_1 + \alpha P_2$$

where:

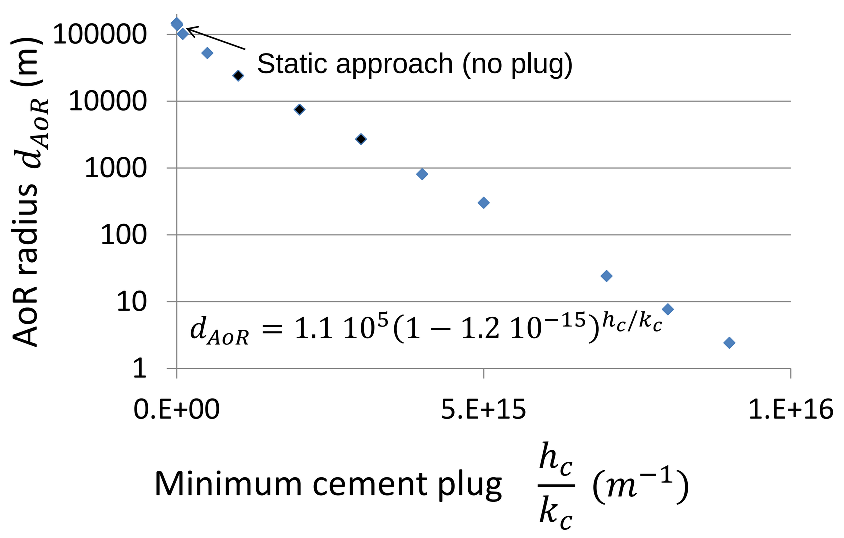
- P_1, P_2 are the pressure for the column entirely filled with brine resp. CO_2
- $\alpha \in [0,1]$ is a coefficient proportional to the leakage rate Q_{L,CO_2} and inversely proportional to the CO_2 uprising speed in the wellbore (assumed to be 0.16 m.s[-1] in average). Cf. Wertz, F., Audigane, P., Bouc, O., 2009, CO_2 -Thermodynamic Model in a Leaking Well, En. Procedia 1 (2009) 1791-1798

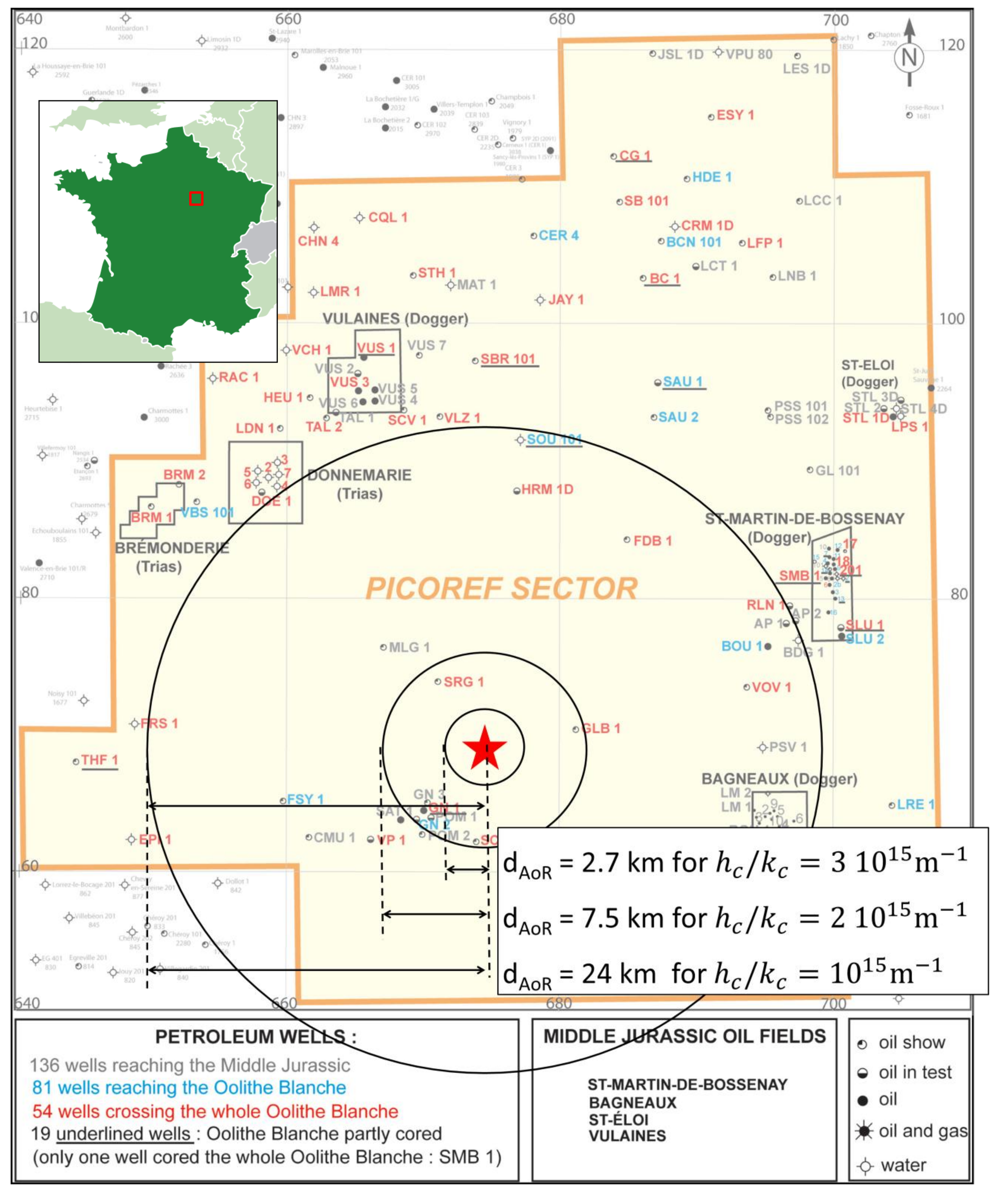
Application (i): Determining an Area of Review

> "Area of review "defined as the area where the pressure changes due to the injection can drive the reservoir brine up to a shallower aquifer of interest

> Application of the injection scenario to the PICOREF sector in the Paris basin (France). The Oolithe Blanche layer, or "Dogger", is used for CO_2 storage. 135 abandoned wells reach this layer and the overlying Albian aquifer in the sector.

> Prioritization of the areas to review supposing a minimum cement plug height on permeability ratio



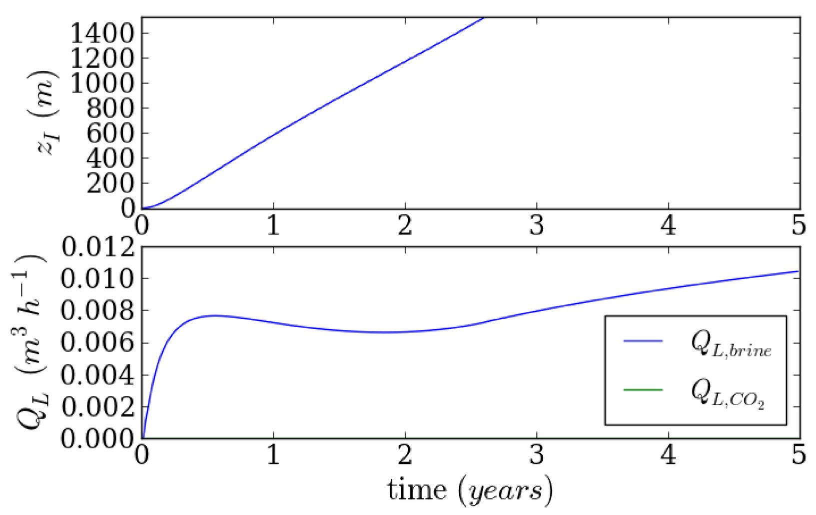


Adapted from Delmas, J., Brosse, E., Houel, P., 2010. Oil & Gas Sci. and Tech. Vol. 65 (2010), No. 3, pp. 405-434

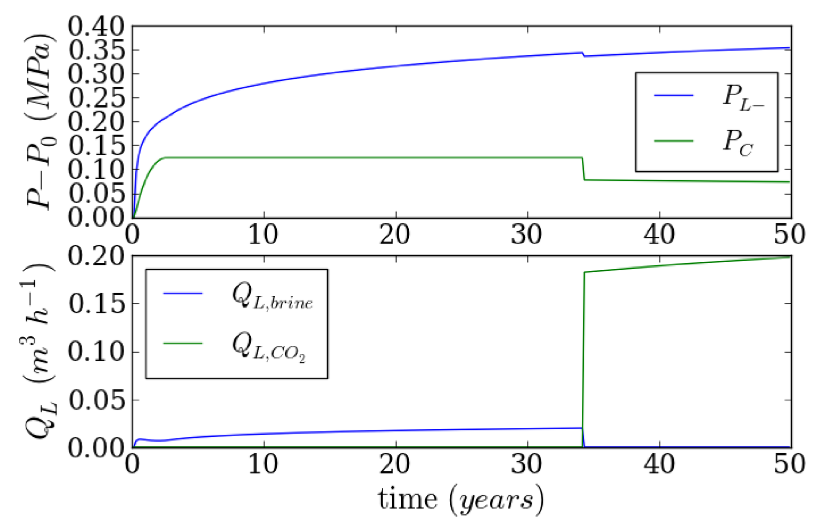
Application (ii): CO_2 leakage to the surface

> Same case study as Application (i), except that the leak directly connects the Dogger aquifer to the surface. A weak cement plug ($h_c = 1m; k_c = 10^{-13}m^2$) is considered in the leak, which is located 5 km away from the injection point

> Borehole filling until 2.6 years



> $CO_{2,g}$ breakthrough at 34 years



> Dense Dogger brine progressively fills the leak up to the surface; the pressure under the leak increases

> Visible cusp on the brine leakage rate due to the end of the pressure increase

> Visible decrease of the pressure under the column of fluid after its filling with a lighter mixture of brine and $CO_{2,g}$

> Due to the low CO_2 viscosity, the CO_2 leakage rate largely increases compared to the previous brine leakage rate

Conclusions

> The model describes the leakage of brine through the leak, and of $CO_{2,g}$ as a first approach. Compared to the state of the art, it adds the possibility of accounting for **density change** within the leak, due to either the incoming of **dense brine** or **light CO_2**

> It shares the advantages (immediate computation) and drawbacks (homogeneous layers) of **semi-analytical models**

> Compared to a static approach, this dynamic model enables less conservative estimation of the "Area of Review", by including effects of **cement plugs**, of **brine density differences** and of leakage-induced pressure effects

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