Semi-analytical model of brine leakage through an abandoned plugged well to determine the Area of Review for CO_2 geological storages

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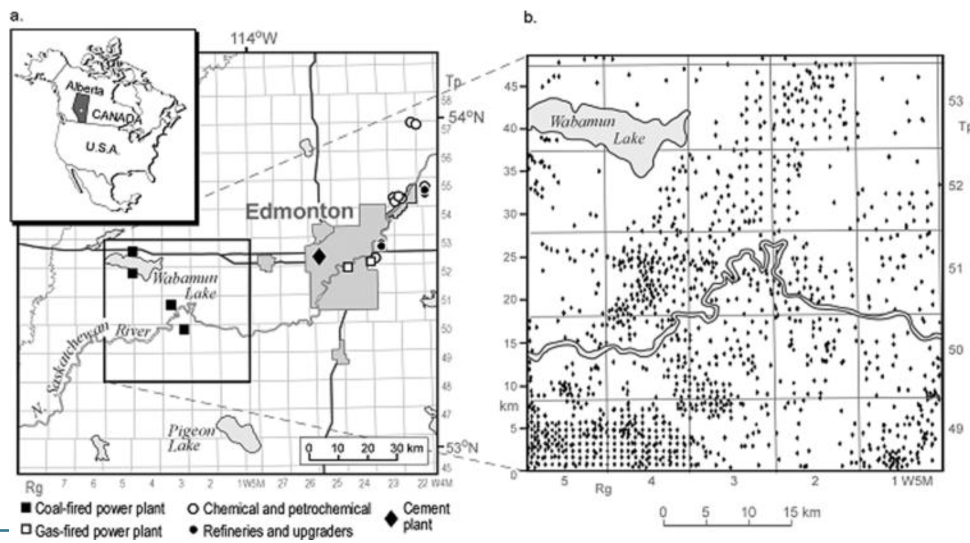
Risk division

Abandoned wells review – context overview

- **Many CO_2 storage projects target deep saline aquifers located in sedimentary basins**
  - Possible historical oil & gas operations
  - Abandoned wells with sometimes unknown plugging records
- **By leaking through abandoned (plugged) wells, the saline brine risks to leak into overlying fresh water aquifers**

→ wells in the area where this is possible should be reviewed (“Area of review”)

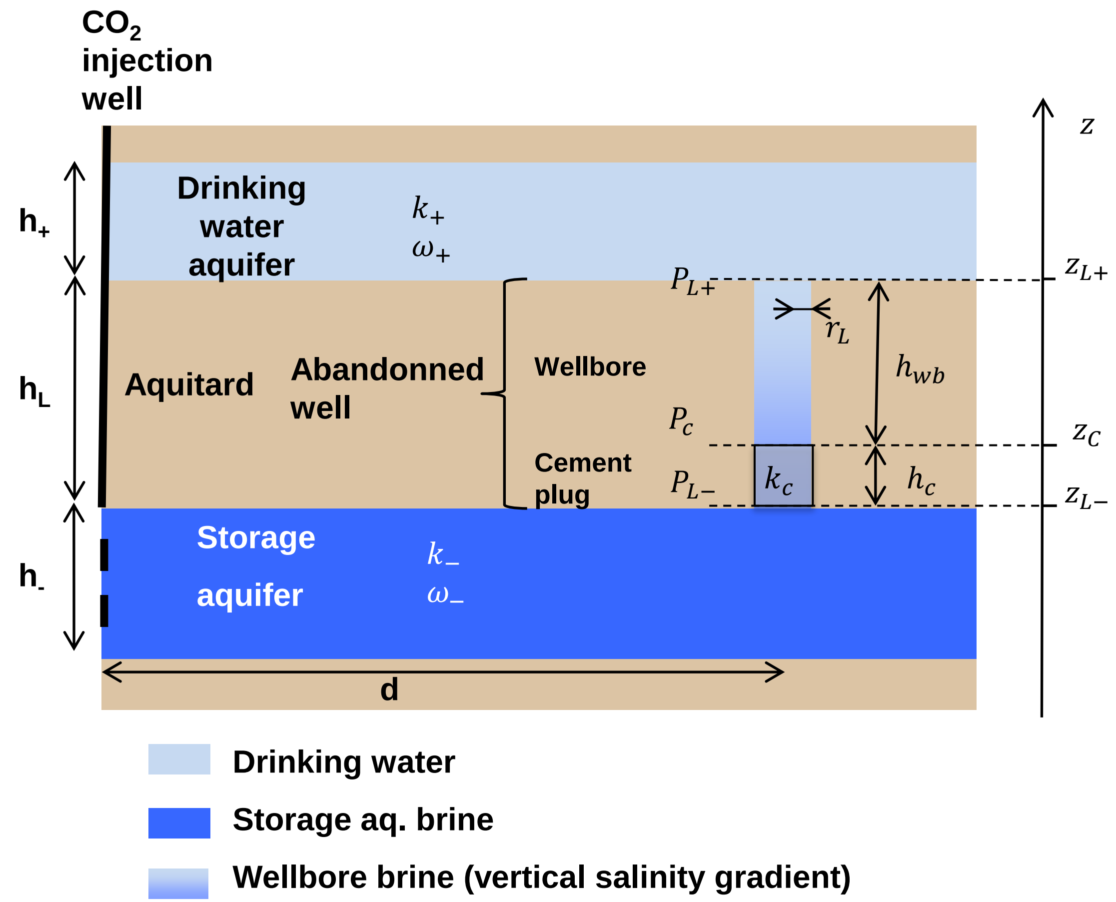
→ This model enables to prioritize the areas to review supposing minimum plug parameters



Example in Alberta, Canada: 508 wells in a 30km x 30 km area.
from Bachu and Celia, 2009

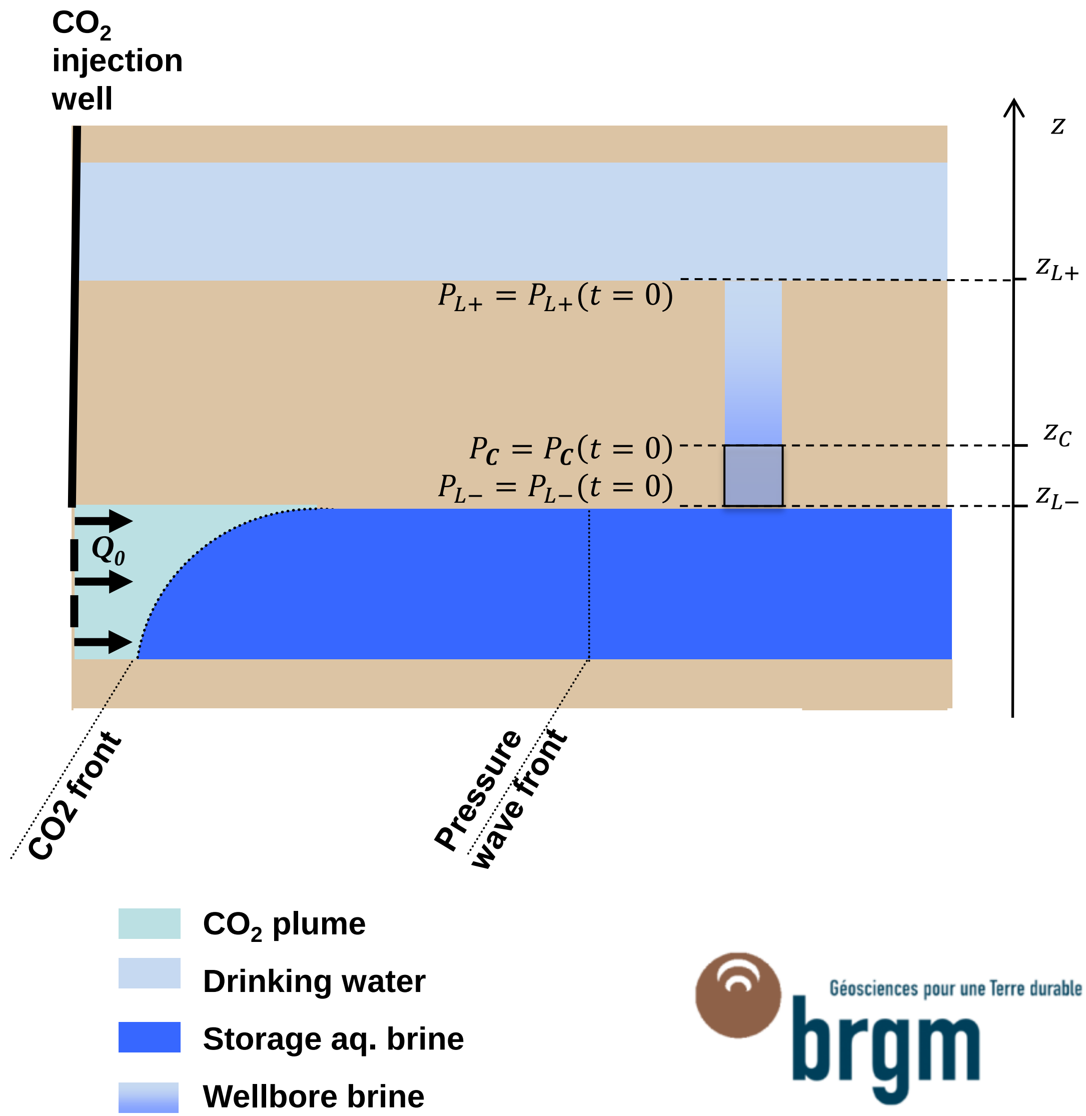
Schematic layout of the model

- **1 active injection well**
- **1 passive abandonned well, or « Leak »**
  - $z_c = z_{L-}$: wellbore only
  - $z_c = z_{L+}$: porous column only
  - $z_{L-} < z_c < z_{L+}$: plug & wellbore



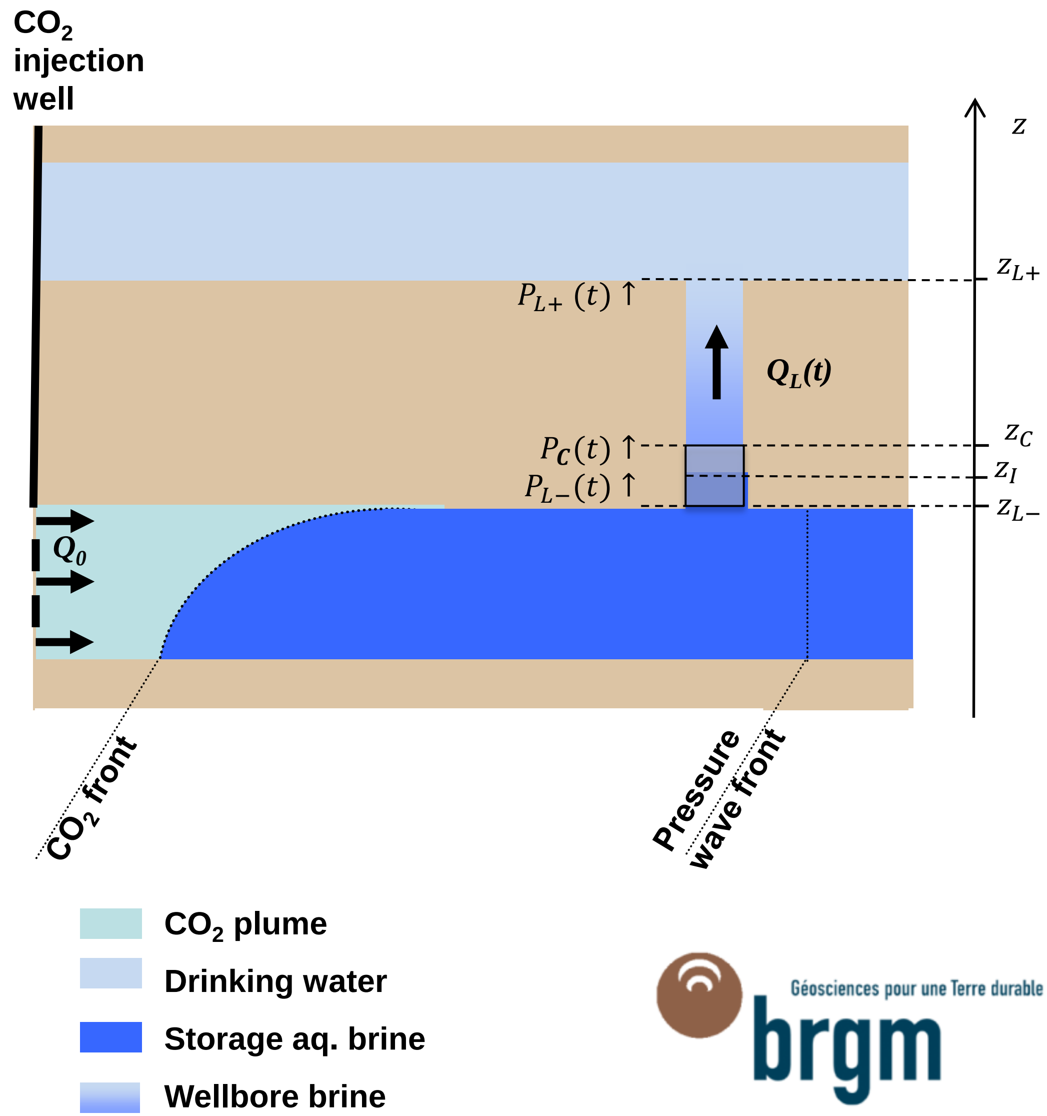
Beginning of CO_2 injection

> **Constant CO_2 injection flow rate starts (Q_0)**



Brine leakage during CO_2 injection

- Dense storage aquifer brine starts filling the leak up to z_I
- The « wellbore brine » is pushed up
- Pressure increases in the abandonned well



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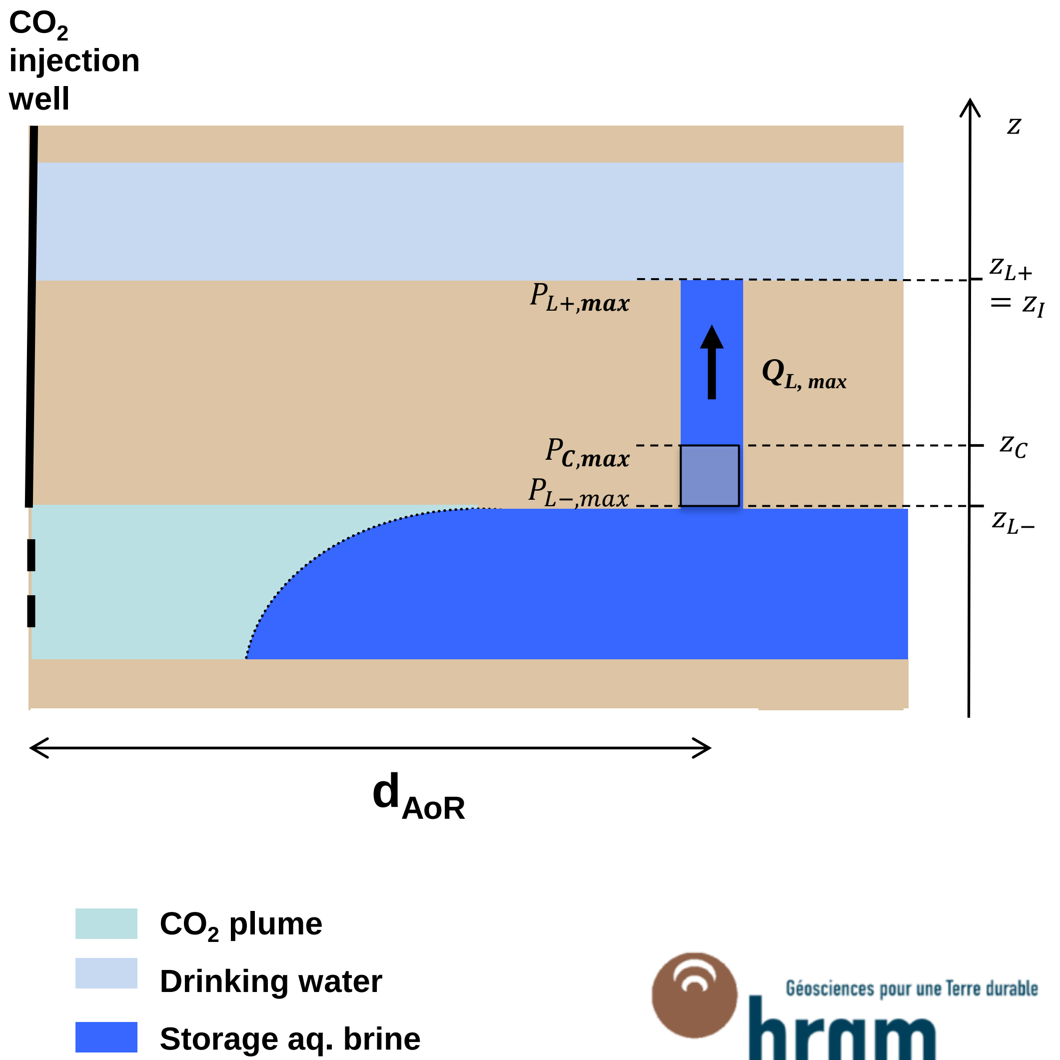
End of the CO_2 injection & « AoR »

> « Area of review » d_{AoR}:

Area where the pressure changes due to the injection can drive the reservoir brine up to a shallower aquifer of interest



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Equations of the model

> **Static pressure equation in the abandonned well**

> **Pressure under the leak in the storage aquifer**

> **Pressure over the leak in the overlying aquifer**

> **Mass conservation**

> **Darcy flow in the cement plug**

> **Semi-analytical resolution**

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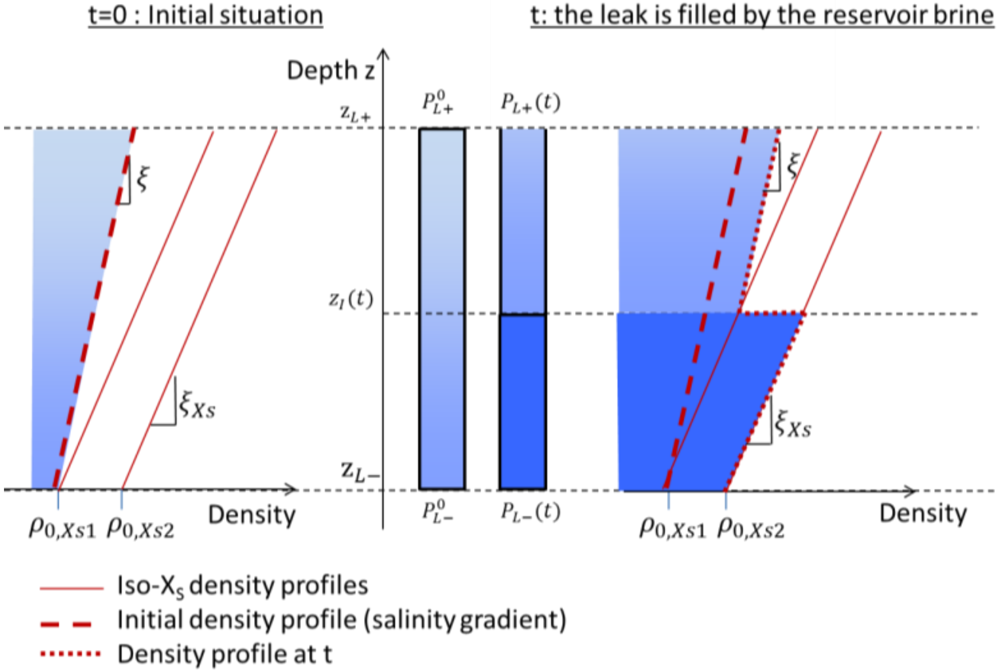
Static pressure equation in the abandonned well

> Well bore pressure gradiant

$$\nabla P = \nabla P_{grav} + \nabla P_{fric} + \nabla P_{acc}$$

- « frictional and inertial pressure gradients contributing typically a few percent or less.” (Pruess, 2006, for geothermal wells)
- $\rightarrow \nabla P = \nabla P_{grav}$



$$P_{L-}^{static} - P_{C}^{static} = \Delta P_{cp}^{0} + \Delta P_{cp}^{1}(z_I)$$
$$P_{C}^{static} - P_{L+}^{static} = \Delta P_{wb}^{0} + \Delta P_{wb}^{1}(z_I)$$

> Thermal equilibrium

(Oldenburg & Rinaldi 2011)

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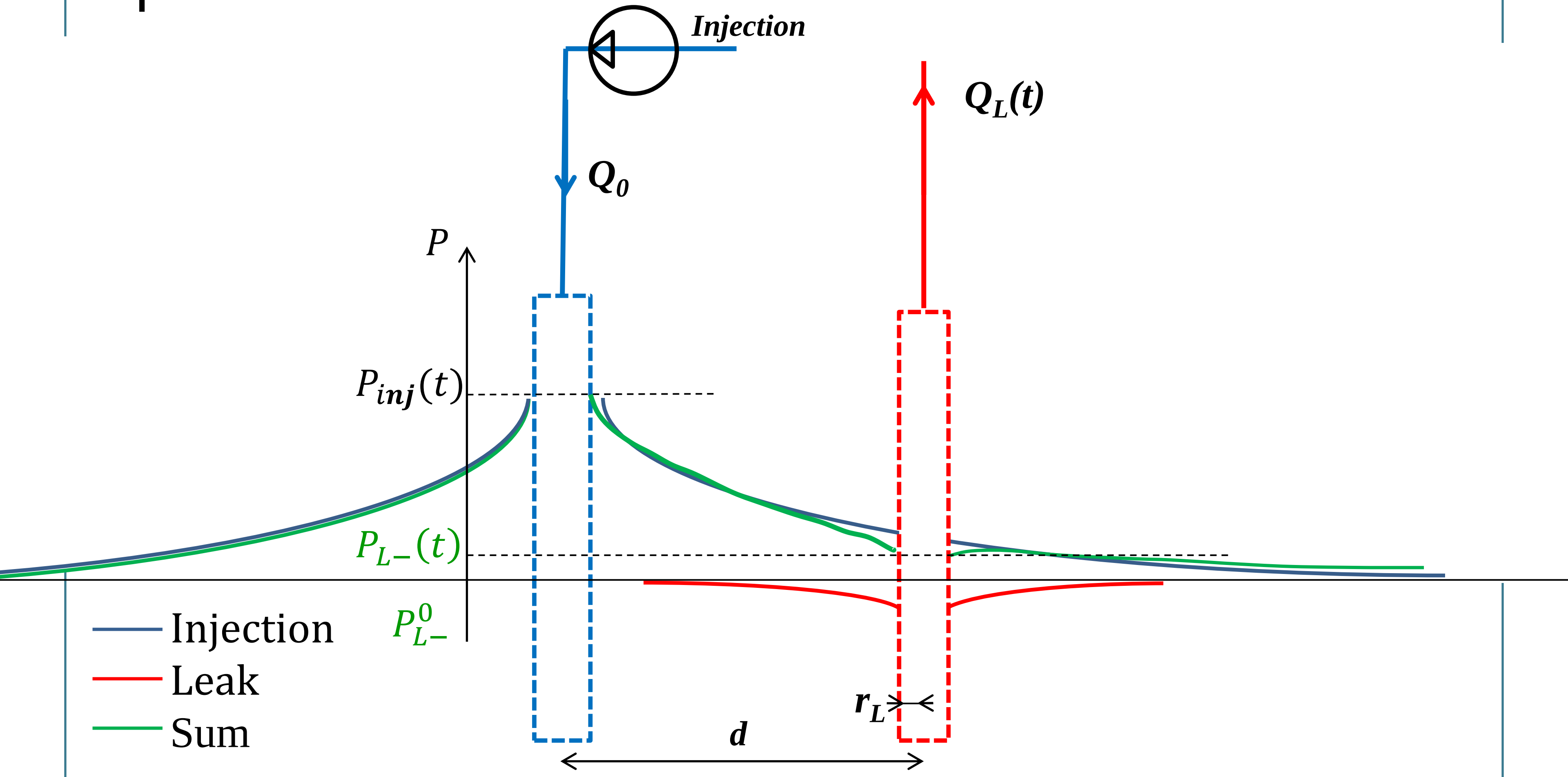
Pressure under the leak in the storage aquifer



$$P_{L-}(t) - P^0_{L-} = \frac{\mu_-}{4\pi k_- h_-}\left[Q_0 E_1\left(\frac{d^2 S_-}{4T_- t}\right) - \int_0^t \frac{dQ_L}{dt'} E_1\left(\frac{r_L^2 S_-}{4T_-(t-t')}\right) dt'\right]$$

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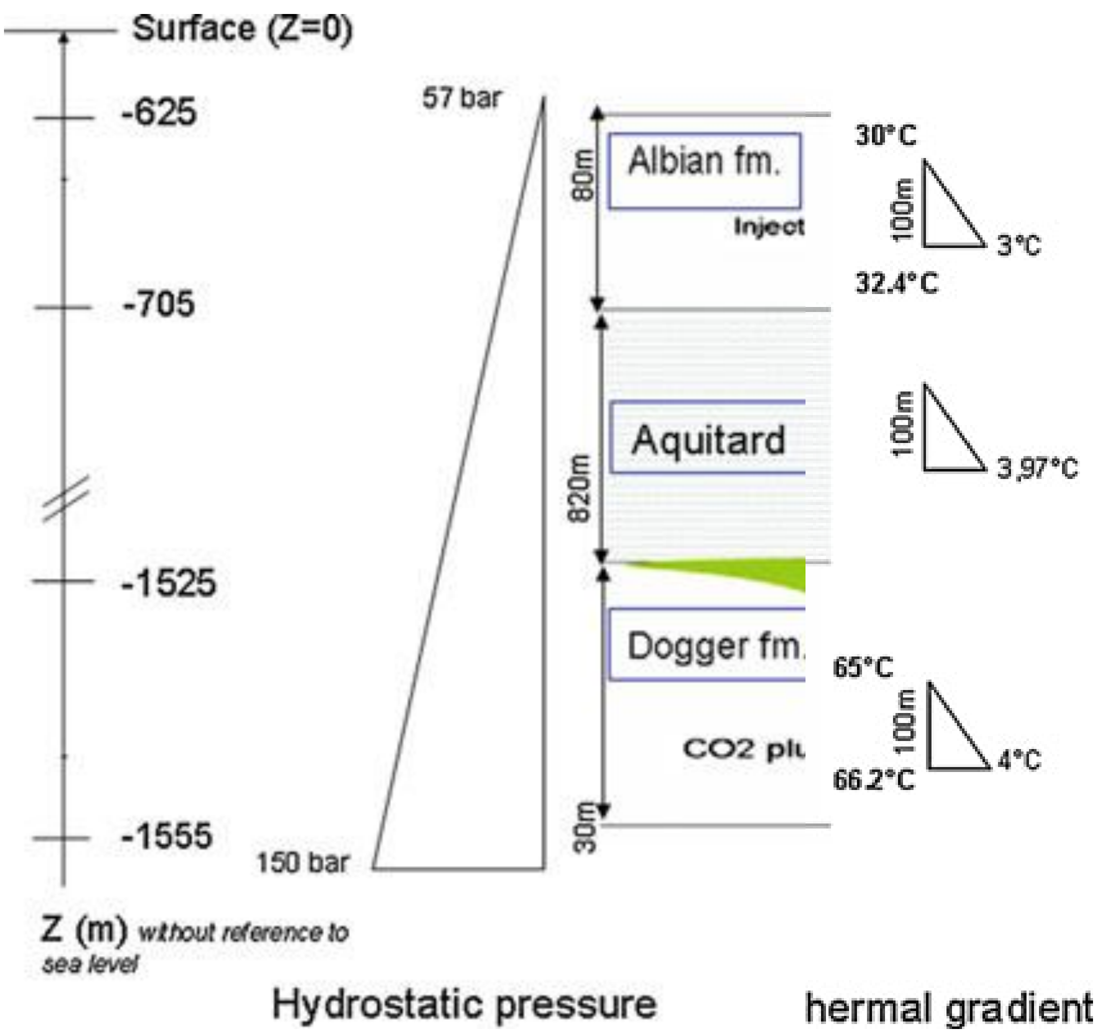
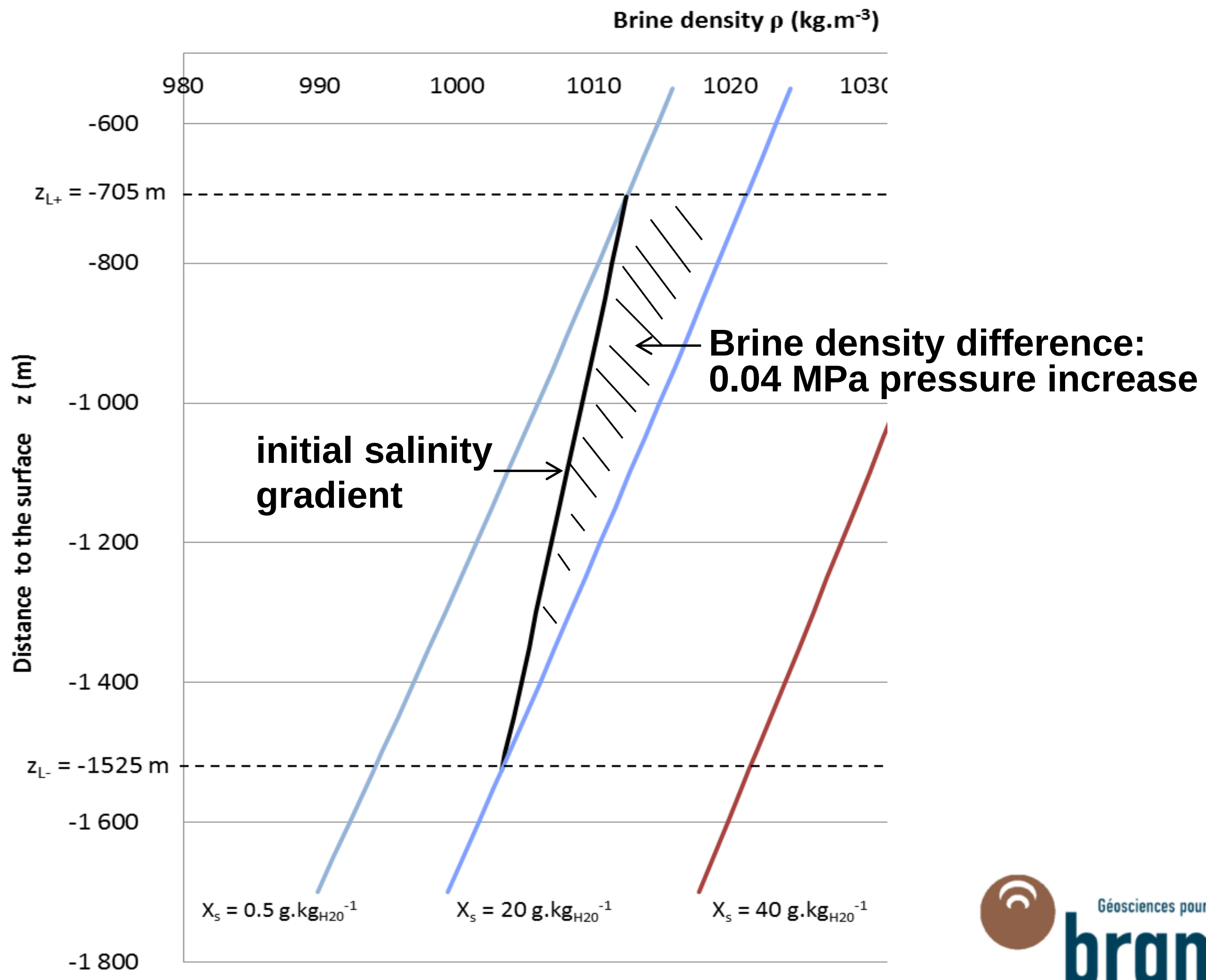
Application to the « PICOREF » sector, Paris basin



P, T, X_S **correspond to the Paris basin context as presented in Humez et al. (2011).**

Brine density profile



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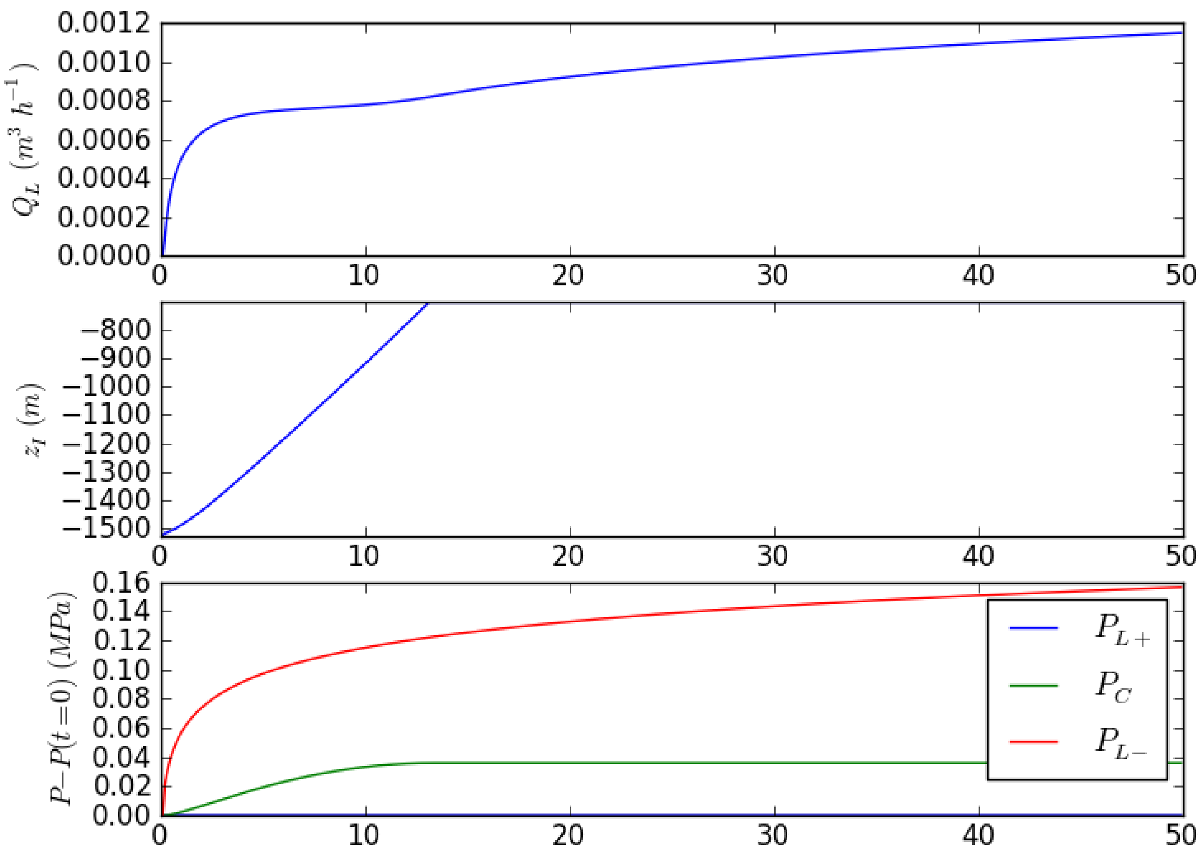
Example of brine leakage

- CO_2 injection scenario: 1 Mt/y for 50 years
- D=6.7 km from the injection to the abandonned well
- Cement plug: 10 m high, weak permability of $10^{-13} m^2$



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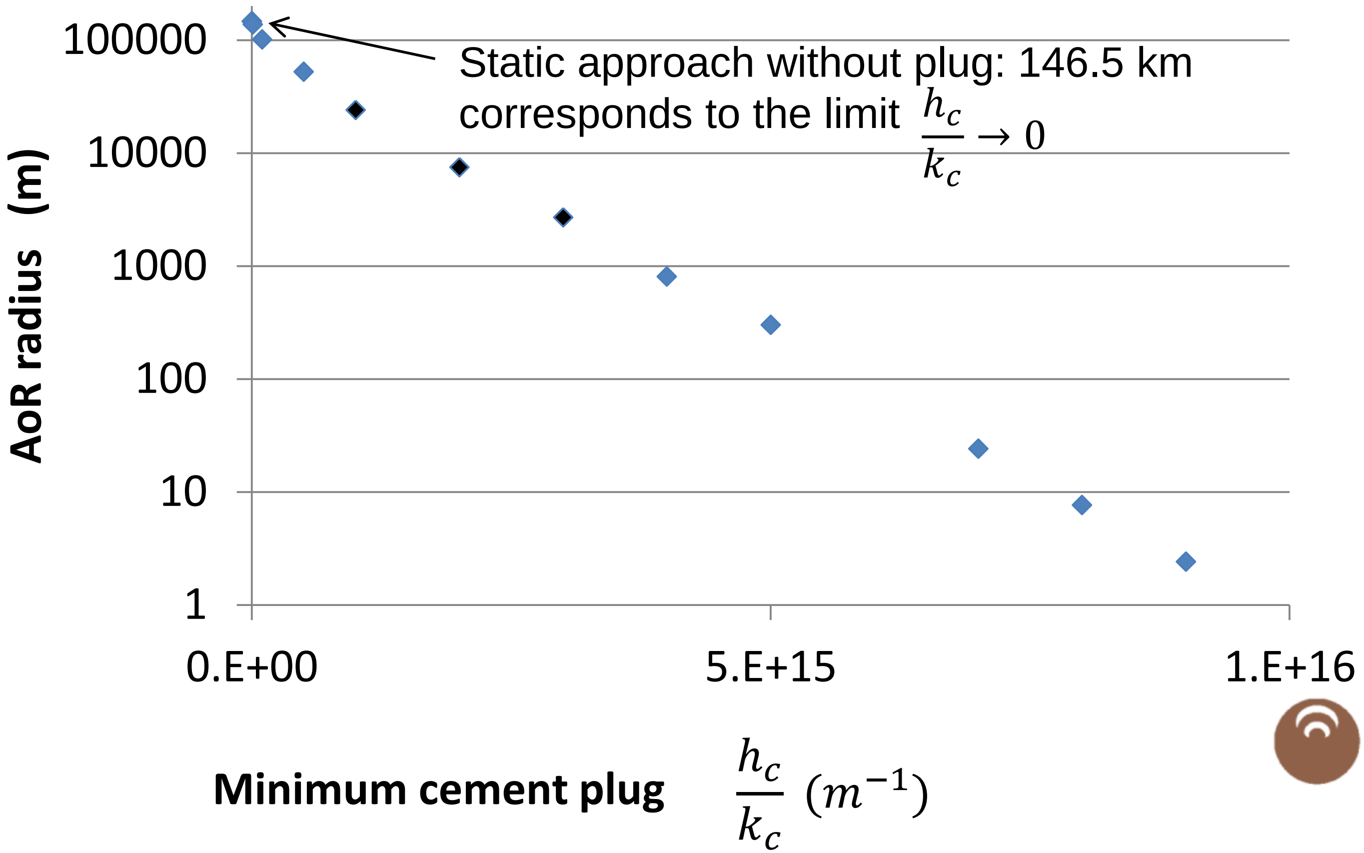
Area to review for a minimum cement plug height on permeability ratio

> **CO_2 injection scenario: 1 Mt/y for 50 years**



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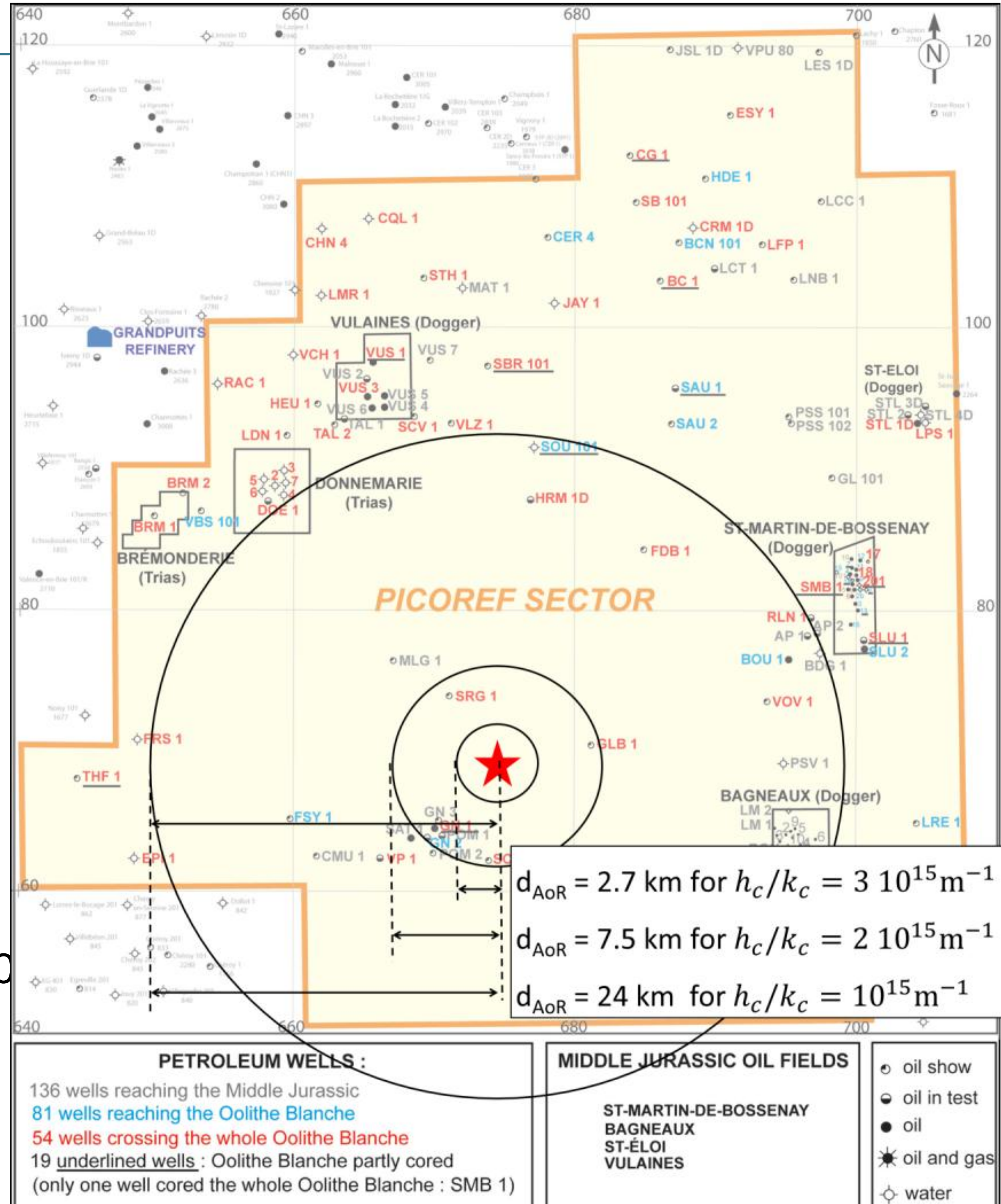
Prioritization of the wells to review



$$d_{AoR} = 2.7 \text{ km for } h_c/k_c = 3\ 10^{15} \text{m}^{-1}$$

$$d_{AoR} = 7.5 \text{ km for } h_c/k_c = 2\ 10^{15} \text{m}^{-1}$$

$$d_{AoR} = 24 \text{ km for } h_c/k_c = 10^{15} \text{m}^{-1}$$

Adapted from Delmas et al., 2010

> Conclusions

- The model describes the leakage of brine through the leak. Compared to the state of the art (Nordbotten, Celia and co-authors, 2004-2009), it adds the possibility of accounting for density change within the leak due to the incoming of dense brine
- It shares the advantages (immediate computation) and drawbacks (homogeneous layers) of semi-analytical models
- Compared to a static approach (Nicot et al., 2009), 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

> Next steps

- Inclusion of the CO_2 leakage
- Monte-Carlo analyses

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> Thanks!

> Acknowledgements

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