Supercritical CO_2 leakage Modeling for Well Integrity in Geological Storage Project

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COMSOL Conference

November 4-6, 2008

Outline

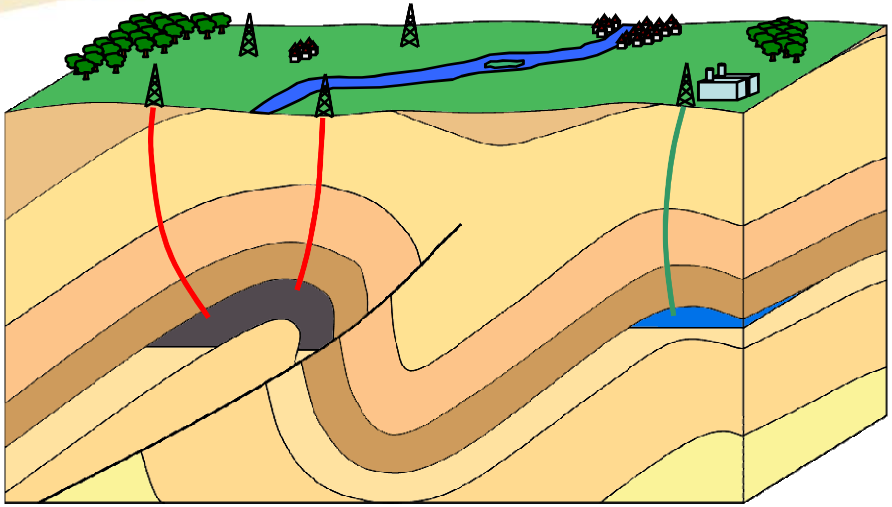
- ✓ **Context**
  - *Geological storage project*
    - ➢ **OXAND's activities: Well Integrity Risk Analysis**
- ✓ **Modelling**
  - *Governing equations*
    - ➢ **Porous media flow, biphasic system**
- ✓ **Results**

Context

- ✓ **Confirmation of global warming**
  - *Kyoto agreement*
- ✓ **CO_2 market**
  - *legal framework, taxes*
- ✓ **EOR**
  - *Enhanced Oil Recovery*

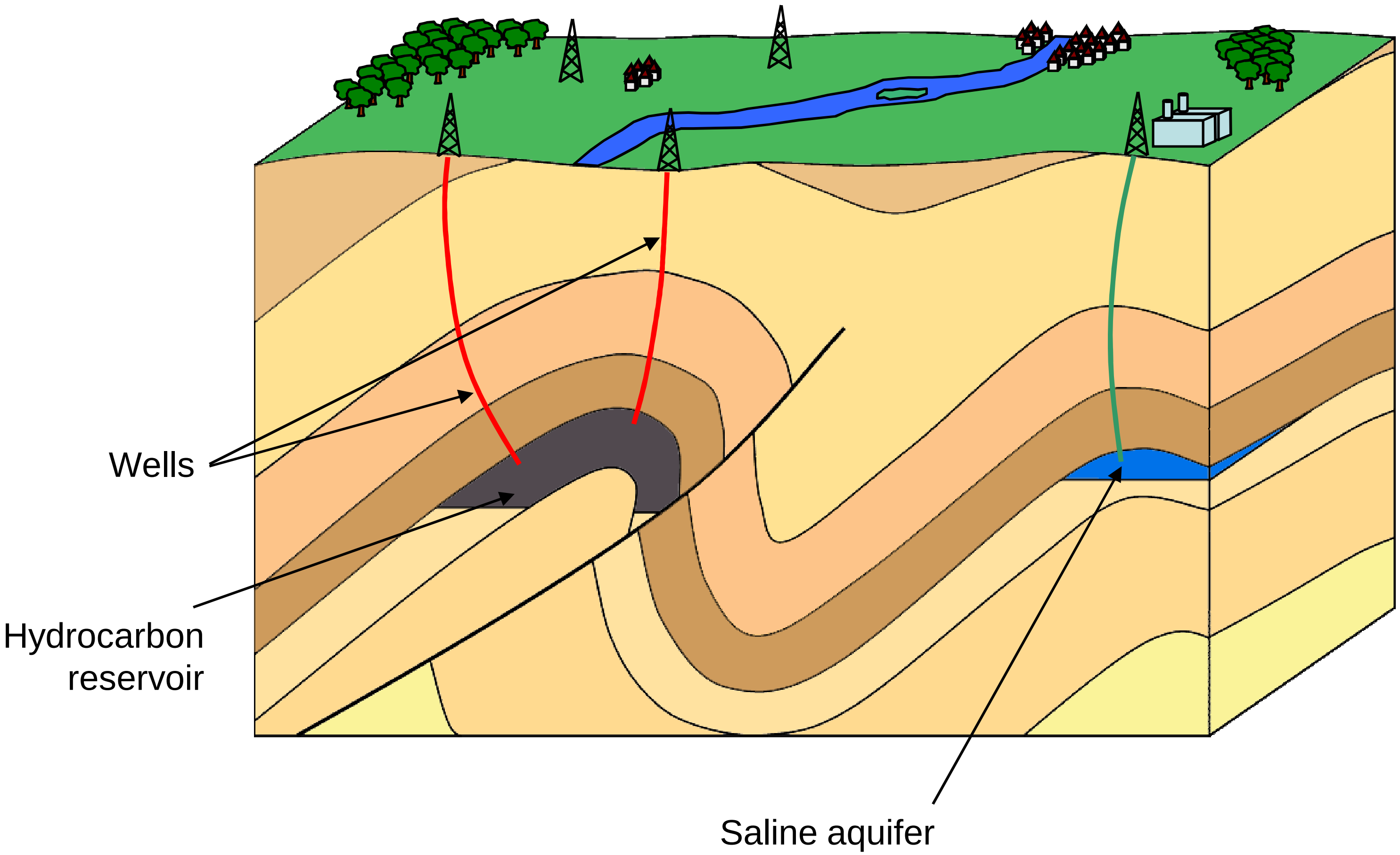
Growing interest for CO_2 geological storage as a feasible and relevant solution

Geological storage project

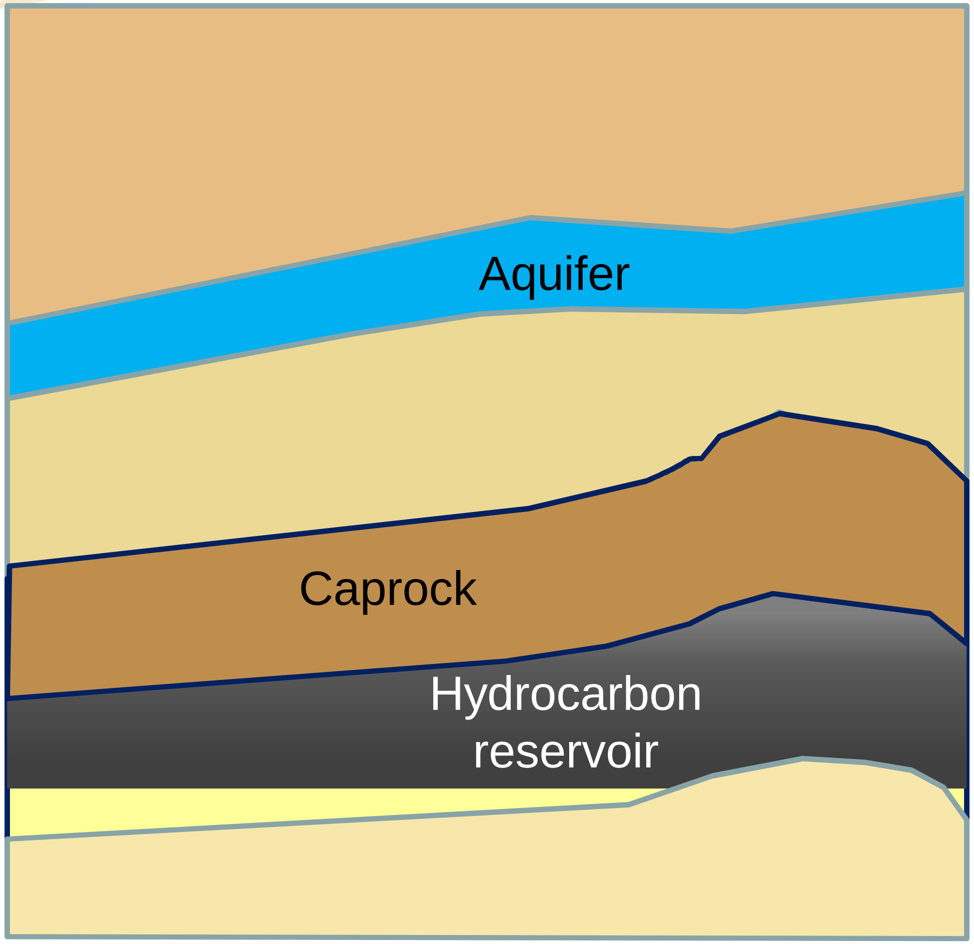


- **CO_2 Injection and long-term geological storage in:**
  - *Hydrocarbon reservoirs*
  - *Saline aquifers*
  - *Coal-bed*

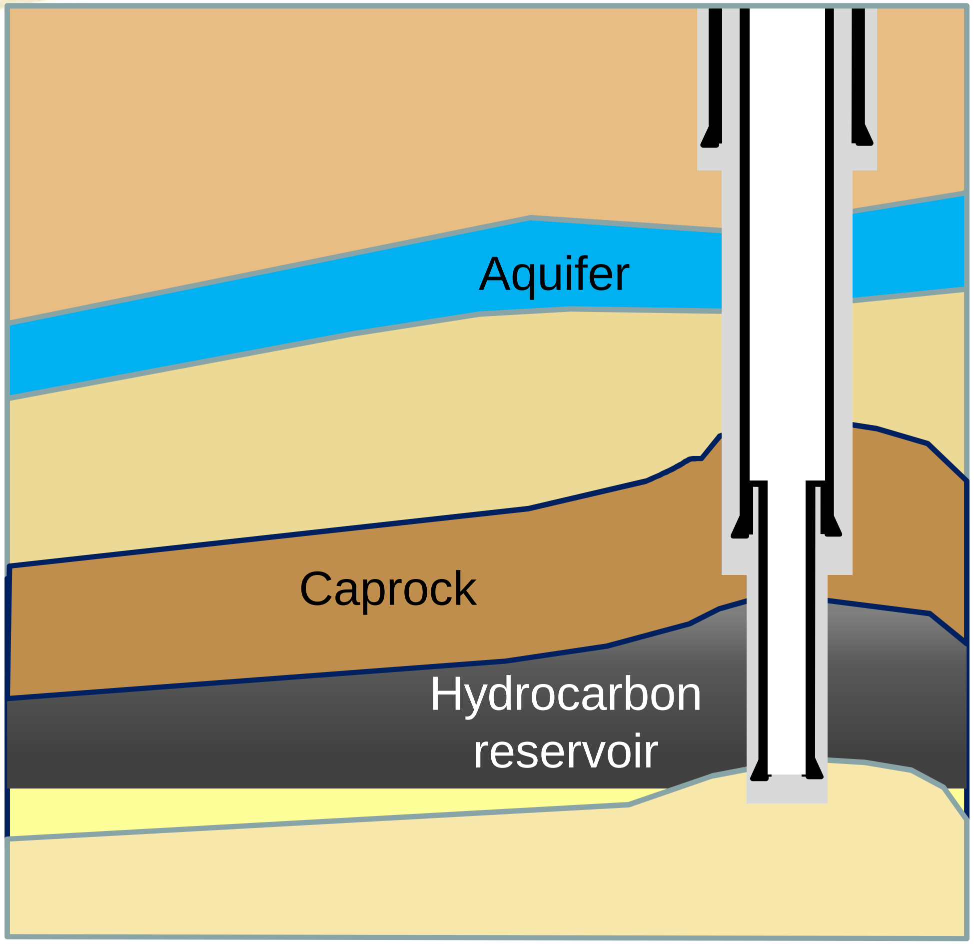
Geological & Biosphere system



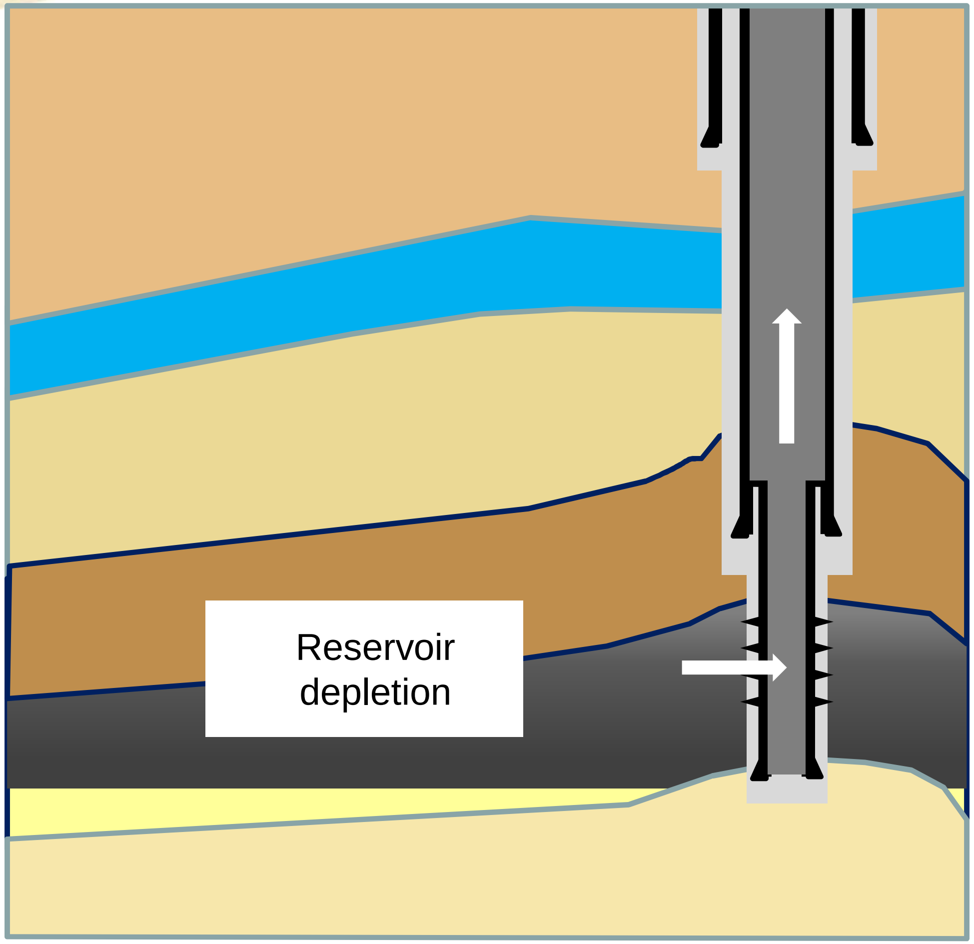
Geological system



Well Integrity Risk Analysis



Well Integrity Risk Analysis



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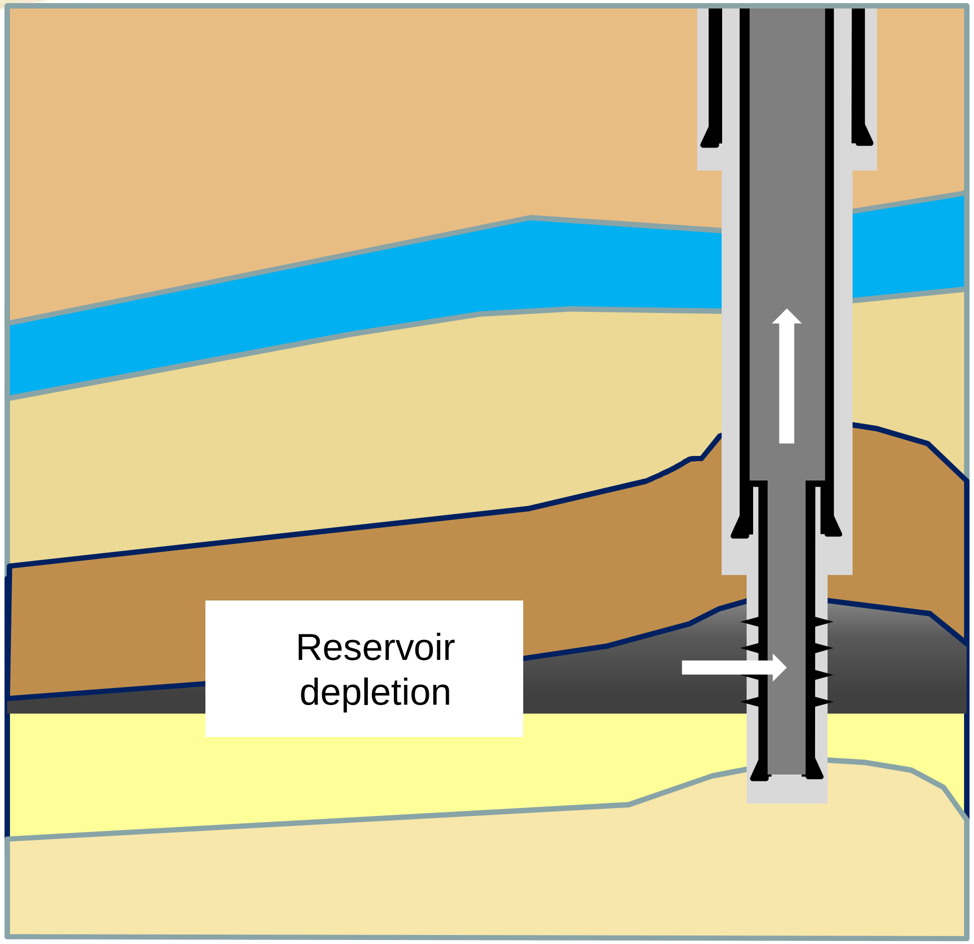

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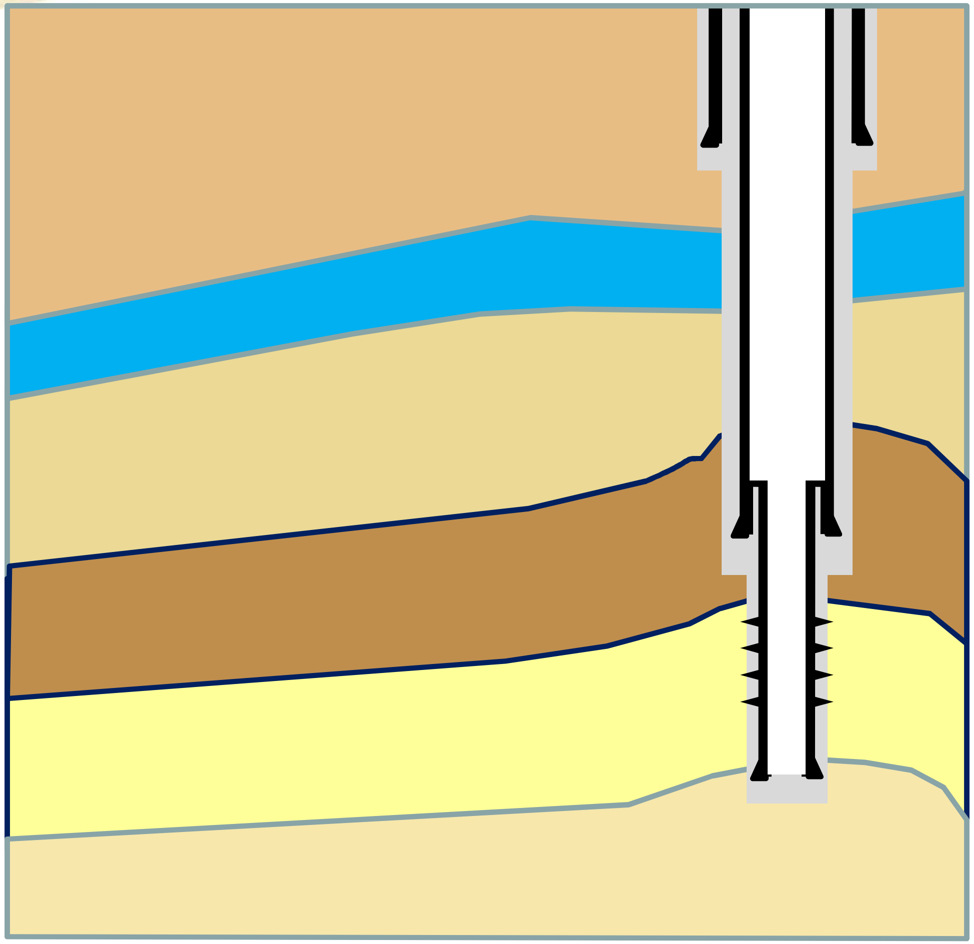
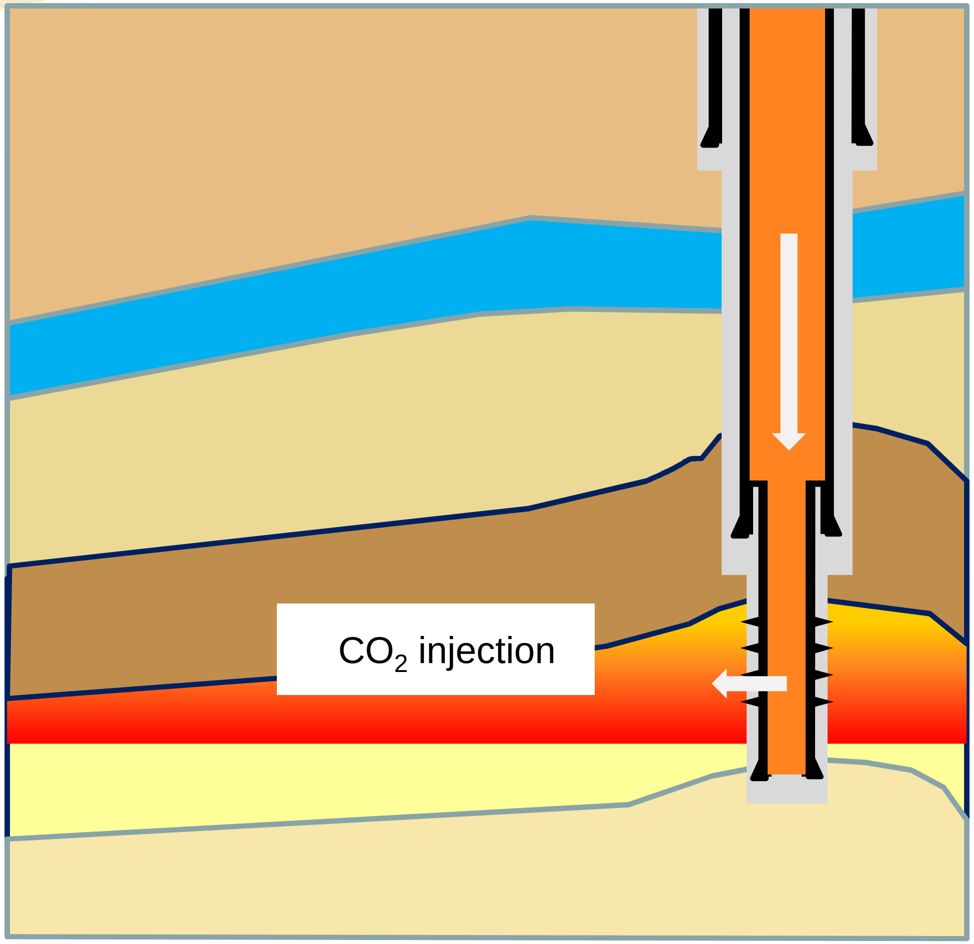


Well Integrity Risk Analysis



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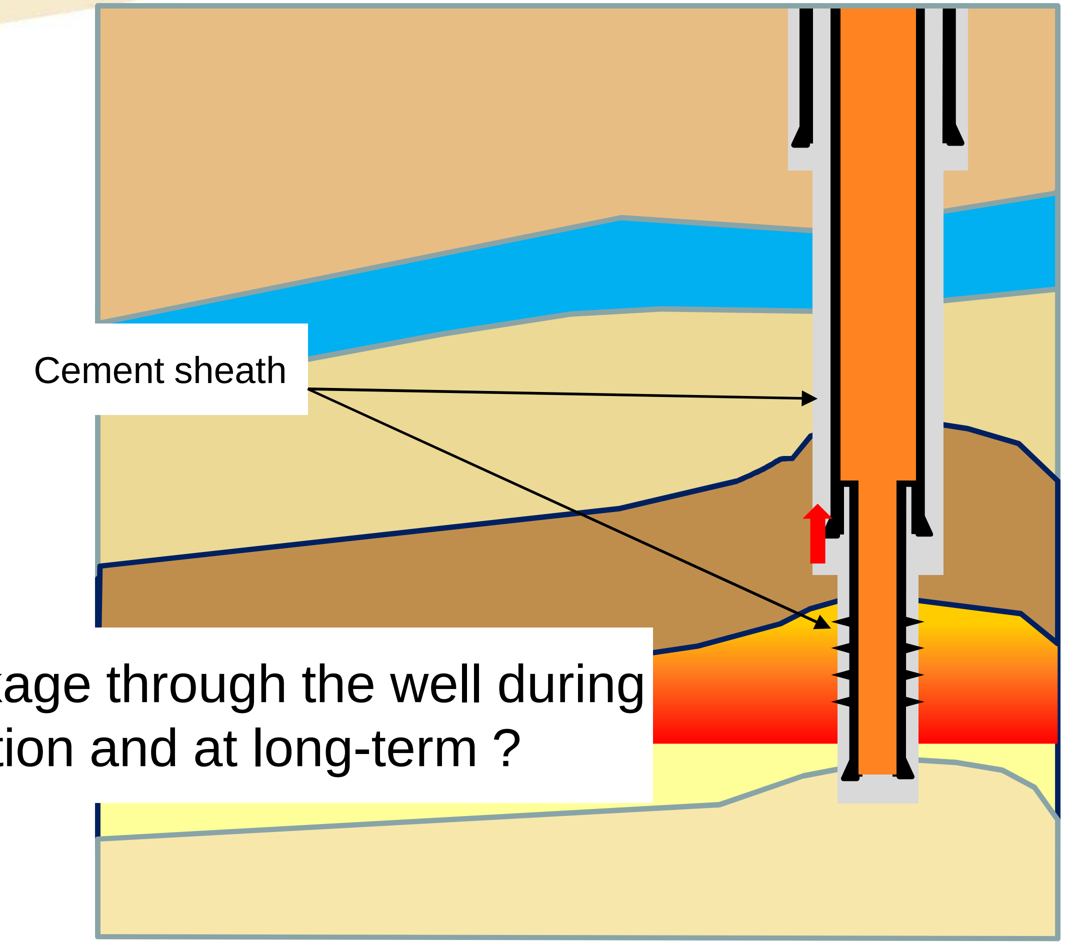
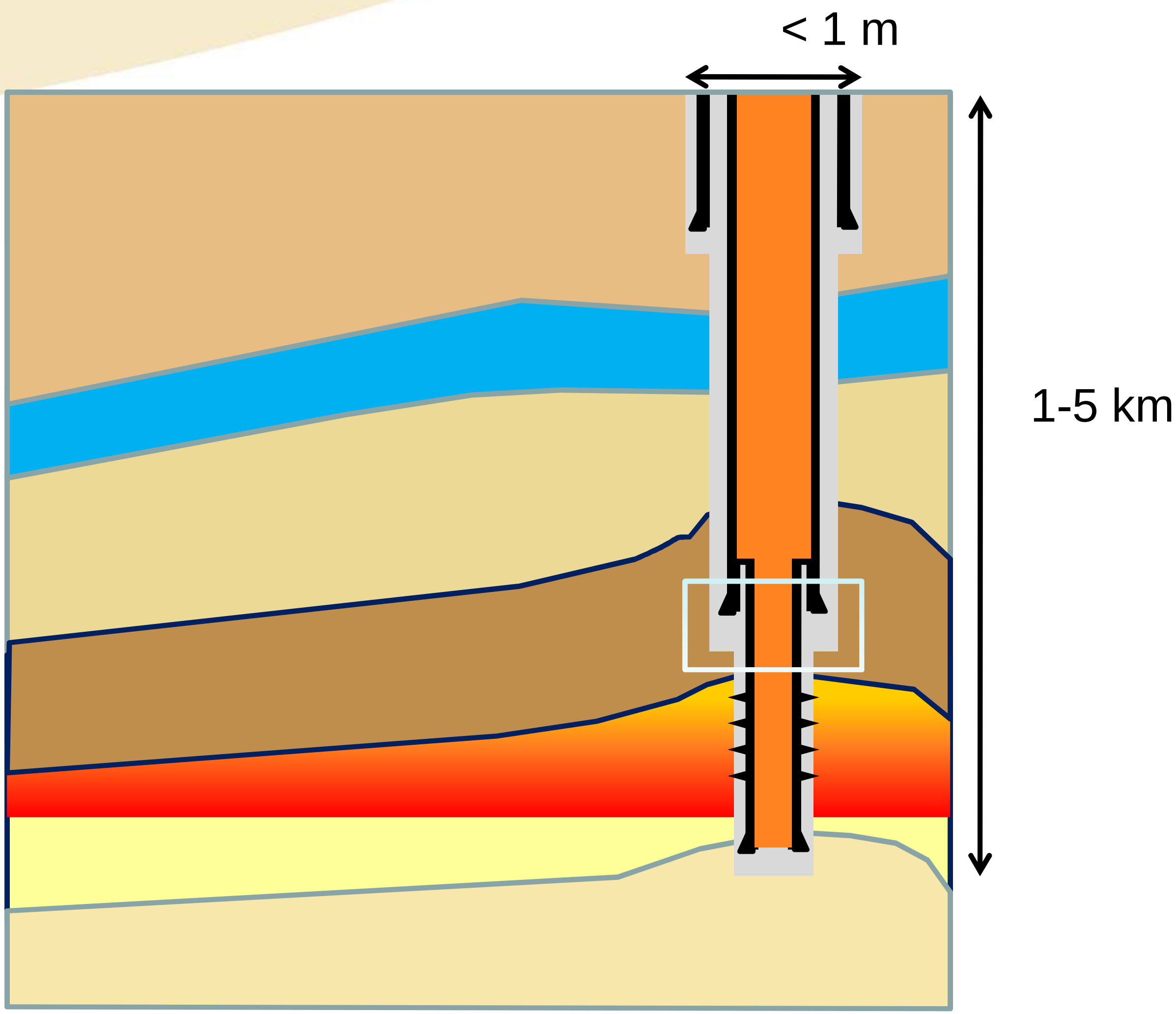
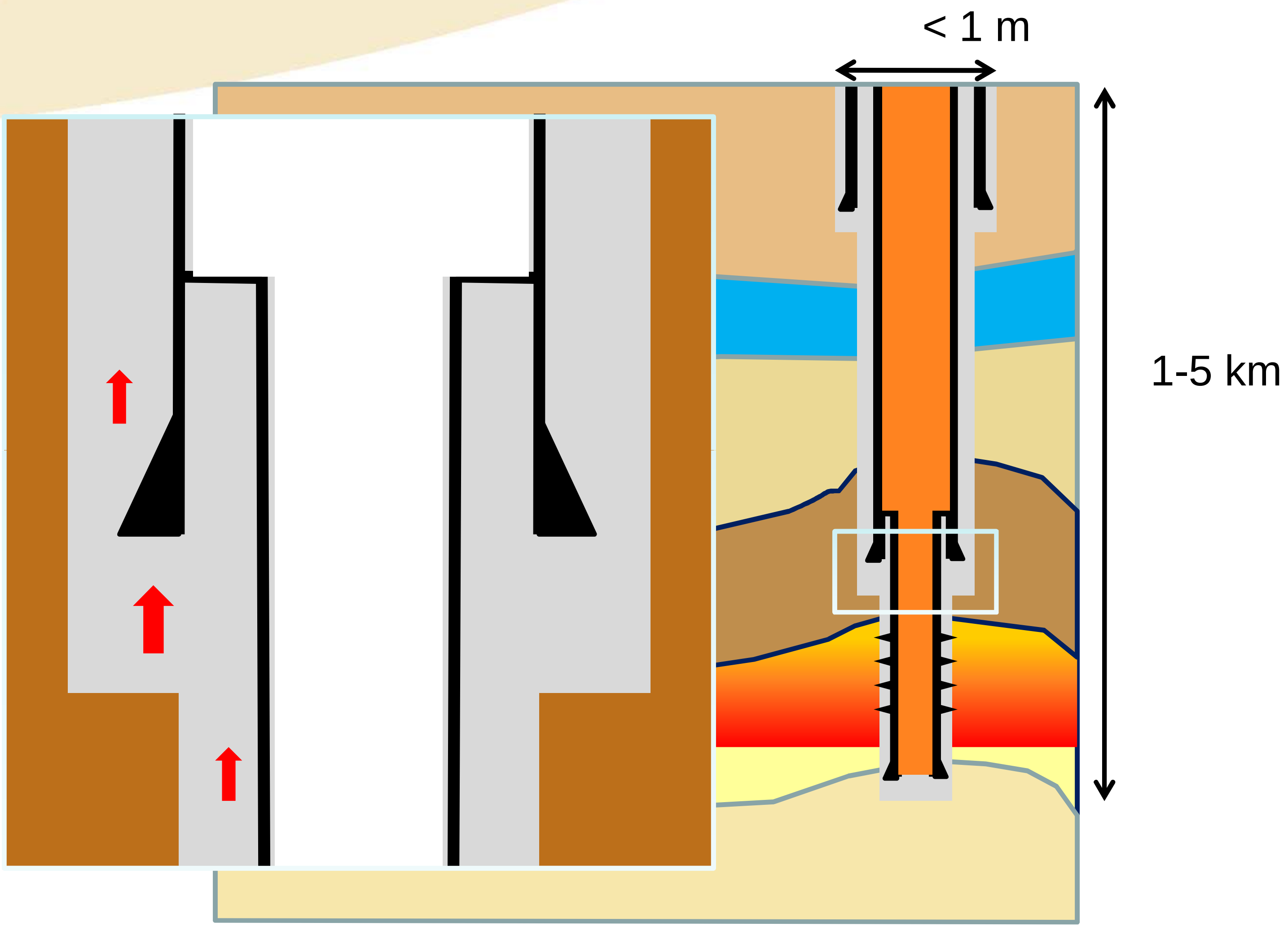


CO_2 leakage through the well during the injection and at long-term ?

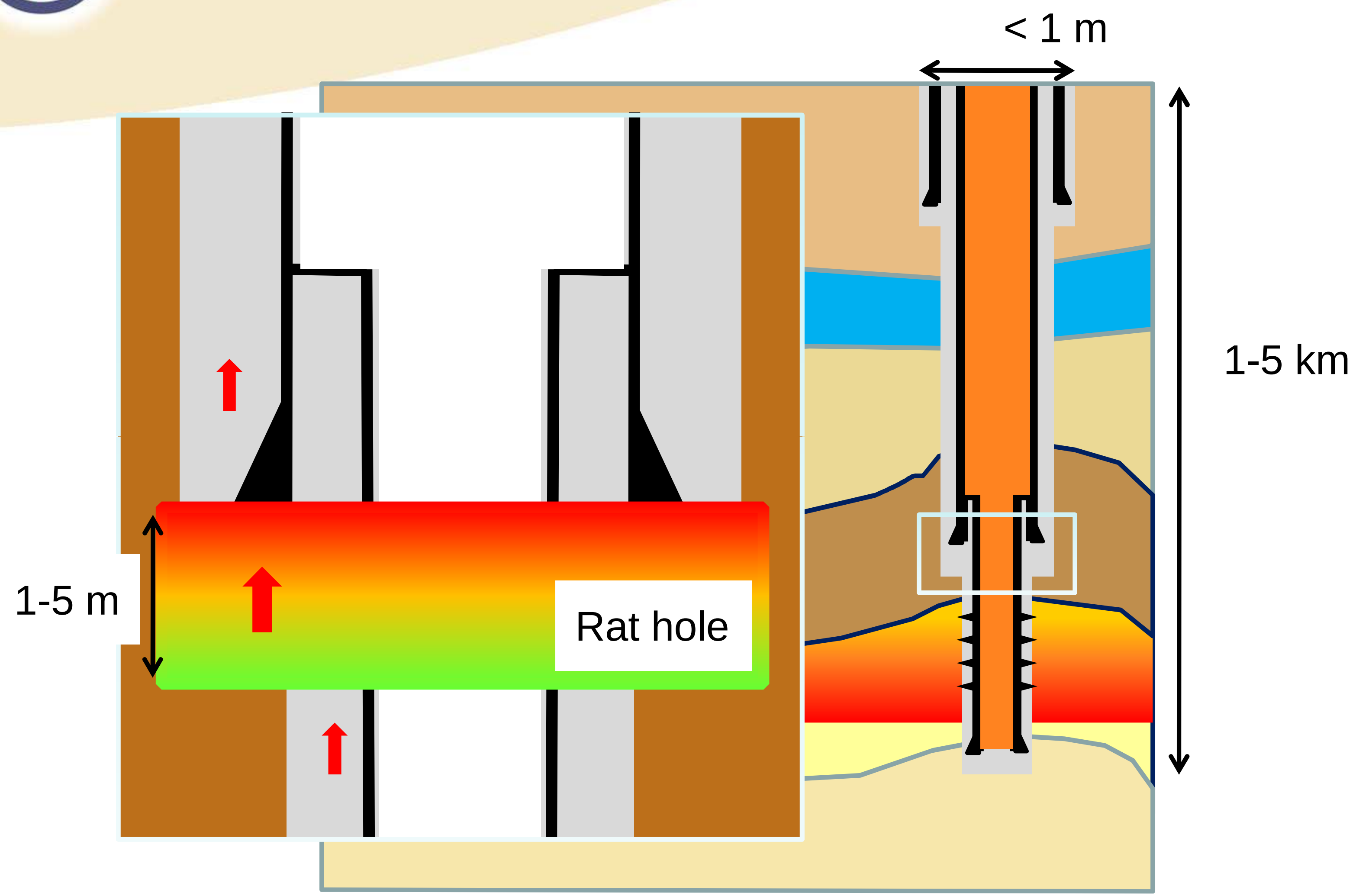
Well Integrity Risk Analysis



Well Integrity Risk Analysis



Well Integrity Risk Analysis

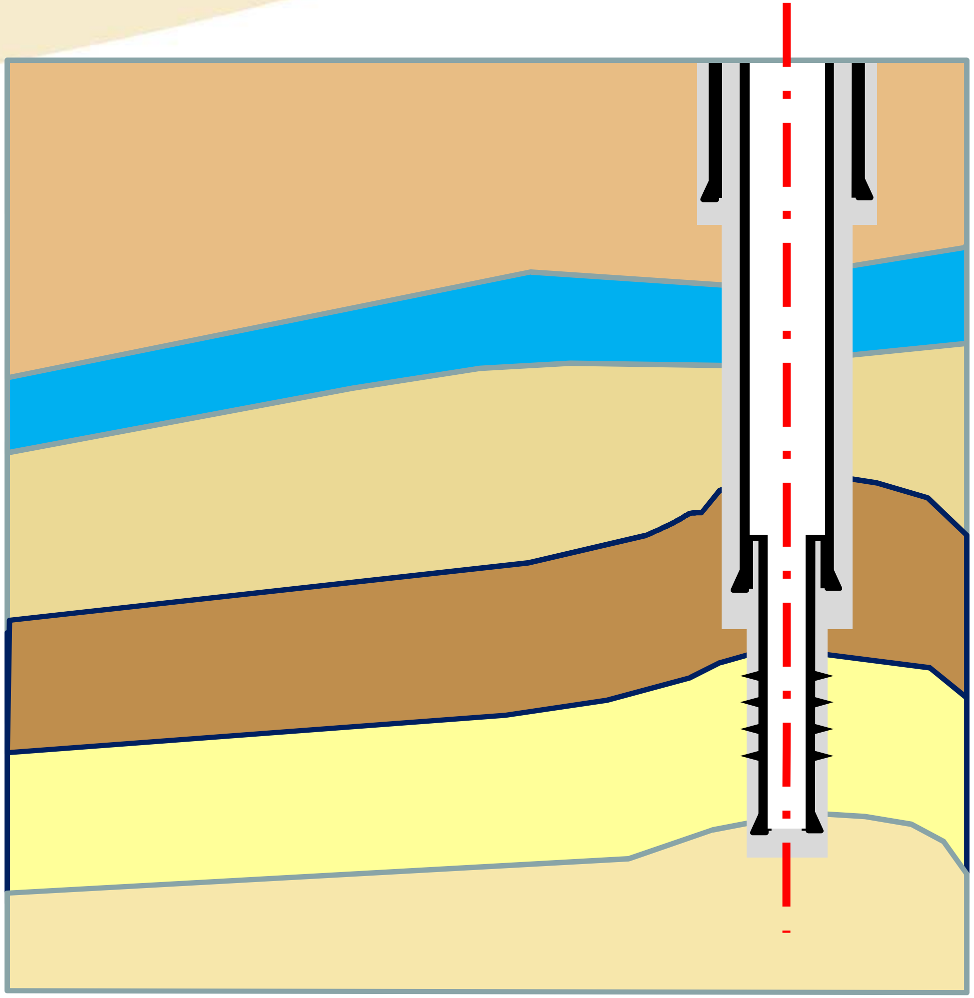


Rat hole represents key element in the CO_2 leakage simulation

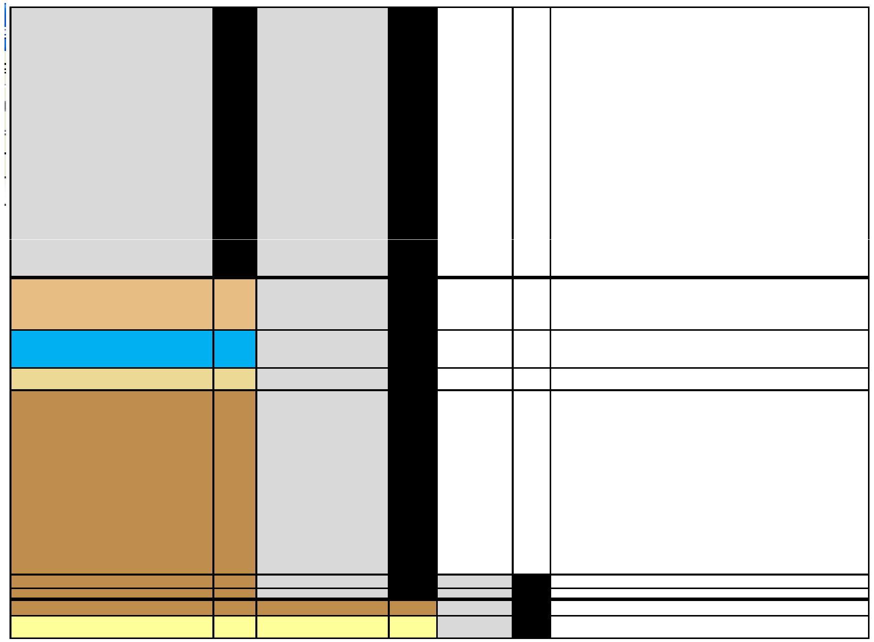
Modelling

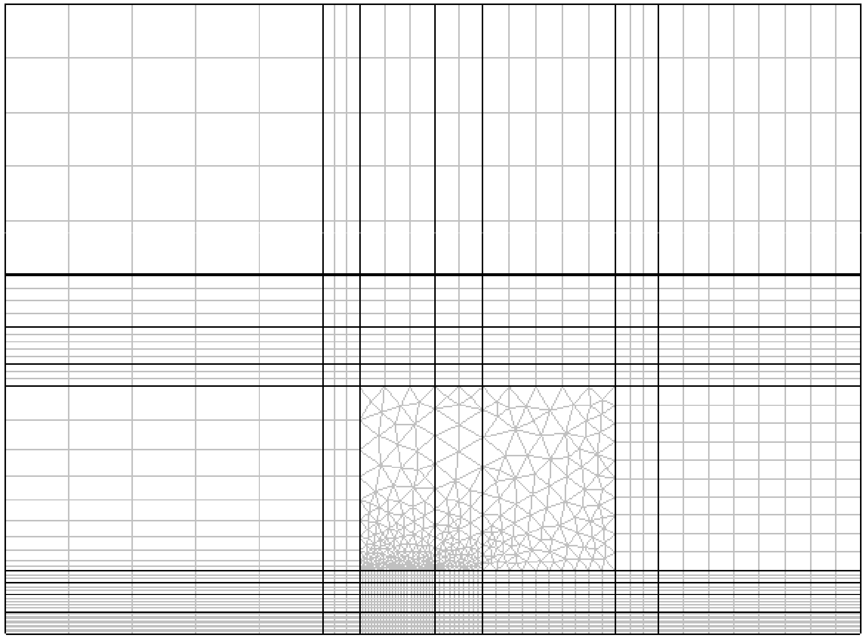
- ✓ **Biphasic flow model**
  - *Water + Supercritical CO_2*
  - *Incompressible phases*
    - **Fluids properties at p, T bottom injection reservoir**
- ✓ **Well modelling**
  - *Well is assumed as a concentric system*
    - **Cylindrical coordinates**

Meshing



Meshing





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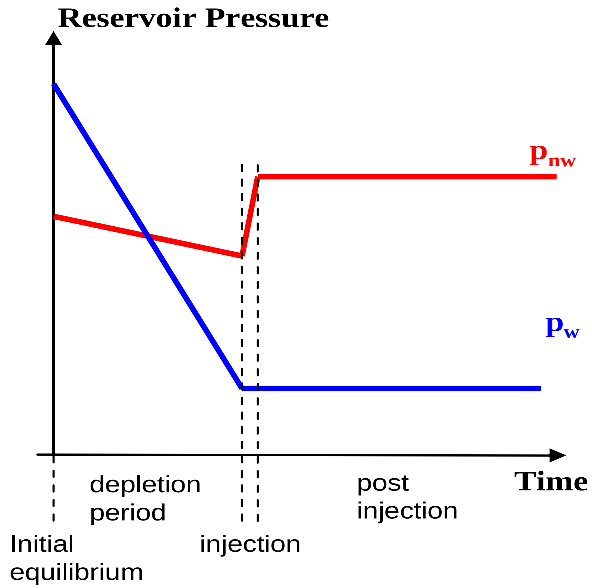
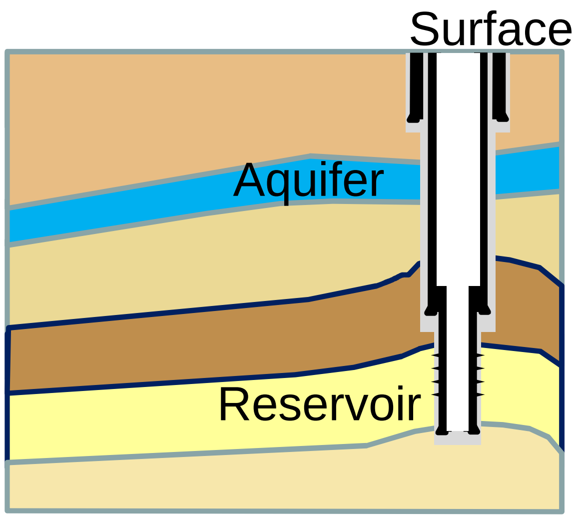
Computation stage

- ✓ **Initial condition:**
  - *Initial equilibrium*
  - *Depletion period*
  - *Injection*



- ✓ **Boundary condition**
  - *Aquifer connection*
    - ➢ water
  - *Bottom reservoir connection*
    - ➢ CO_2
  - *Surface connection*
    - ➢ atmosphere, water



Governing Equations

✓ **Wetting phase:**

$$\delta_S \frac{\partial S_w}{\partial t} + \nabla \cdot \left[-\frac{k \cdot k_{r,w}}{\eta_w} \nabla (p_w + \rho_w g H) \right] = 0 \qquad \textbf{(1)}$$

✓ **Non-wetting phase:**

$$\delta_S \frac{\partial S_{nw}}{\partial t} + \nabla \cdot \left[-\frac{k \cdot k_{r,nw}}{\eta_{nw}} \nabla (p_{nw} + \rho_{nw} g H) \right] = 0 \qquad \textbf{(2)}$$

Pressure form

✓ **Wetting phase:**

$$C_{p,w}\frac{\partial(p_{nw}-p_{w})}{\partial t}+\nabla\cdot\left[-\frac{k\cdot k_{r,w}}{\eta_{w}}\nabla(p_{w}+\rho_{w}gH)\right]=0 \quad \textbf{(3)}$$

✓ **Non-wetting phase:**

$$C_{p,nw}\frac{\partial(p_{nw}-p_{w})}{\partial t}+\nabla\cdot\left[-\frac{k\cdot k_{r,nw}}{\eta_{nw}}\nabla(p_{nw}+\rho_{nw}gH)\right]=0 \quad \textbf{(4)}$$

Specific capacity

- ✓ **Specific capacity**

$$C_{p,w} = -C_{p,nw} = \frac{\delta_s \partial S_w}{\partial p_c}$$

- ✓ **Relationship between effective water saturation and specific capacity**

$$C_{p,w} = \frac{\alpha m}{1-m}\phi\left(1-S_{r,w}\right)\Theta^{1/m}\left(1-\Theta^{1/m}\right)^{m}$$

Porous media

✓ **Capillary pressure**

$$p_c = p_{nw} - p_w$$

✓ **Relationship to close biphasic flow model (Van Genuchten):**

$$\left(1+\left(\frac{p_c}{p_{ec}}\right)^N\right)^M = \frac{1}{\Theta} \qquad \textbf{(7)}$$

- *the effective saturation of wetting phase*

$$\Theta = \frac{S_w - S_{rw}}{1 - S_{rw}}$$

- *the capillary pressure p_c*
- *the capillary pressure head p_{ec}*

Main Results: Effective Water Saturation

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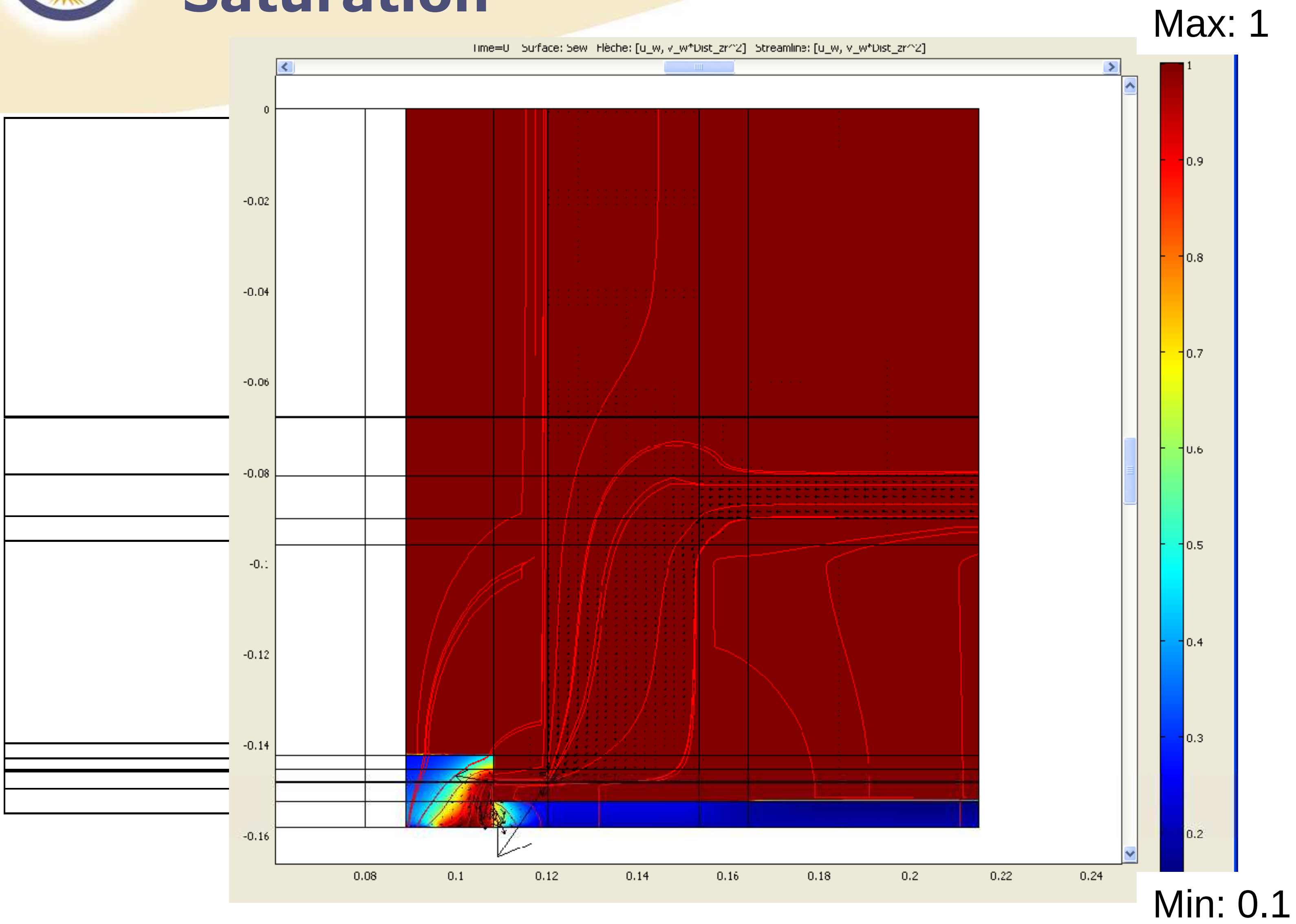
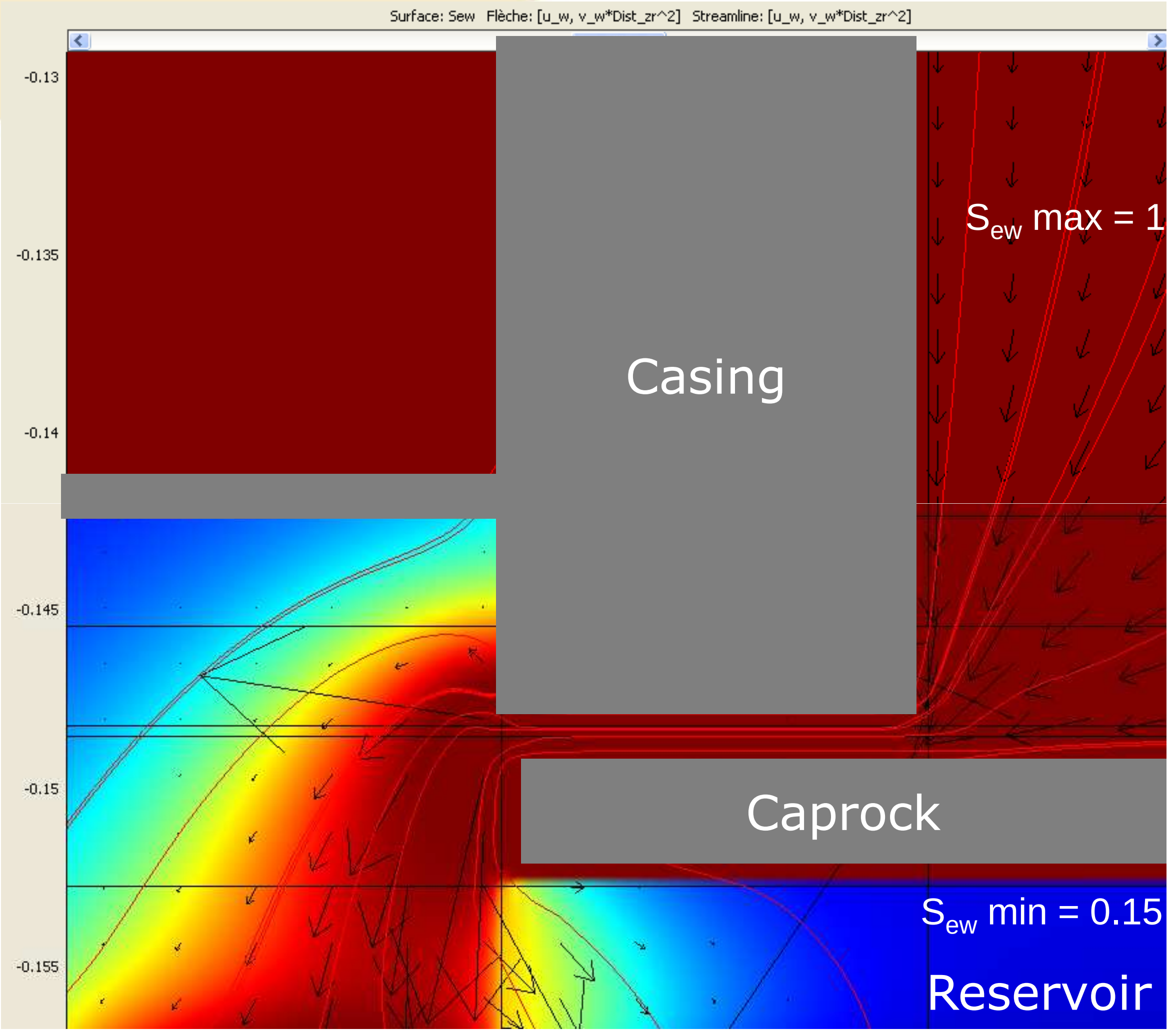
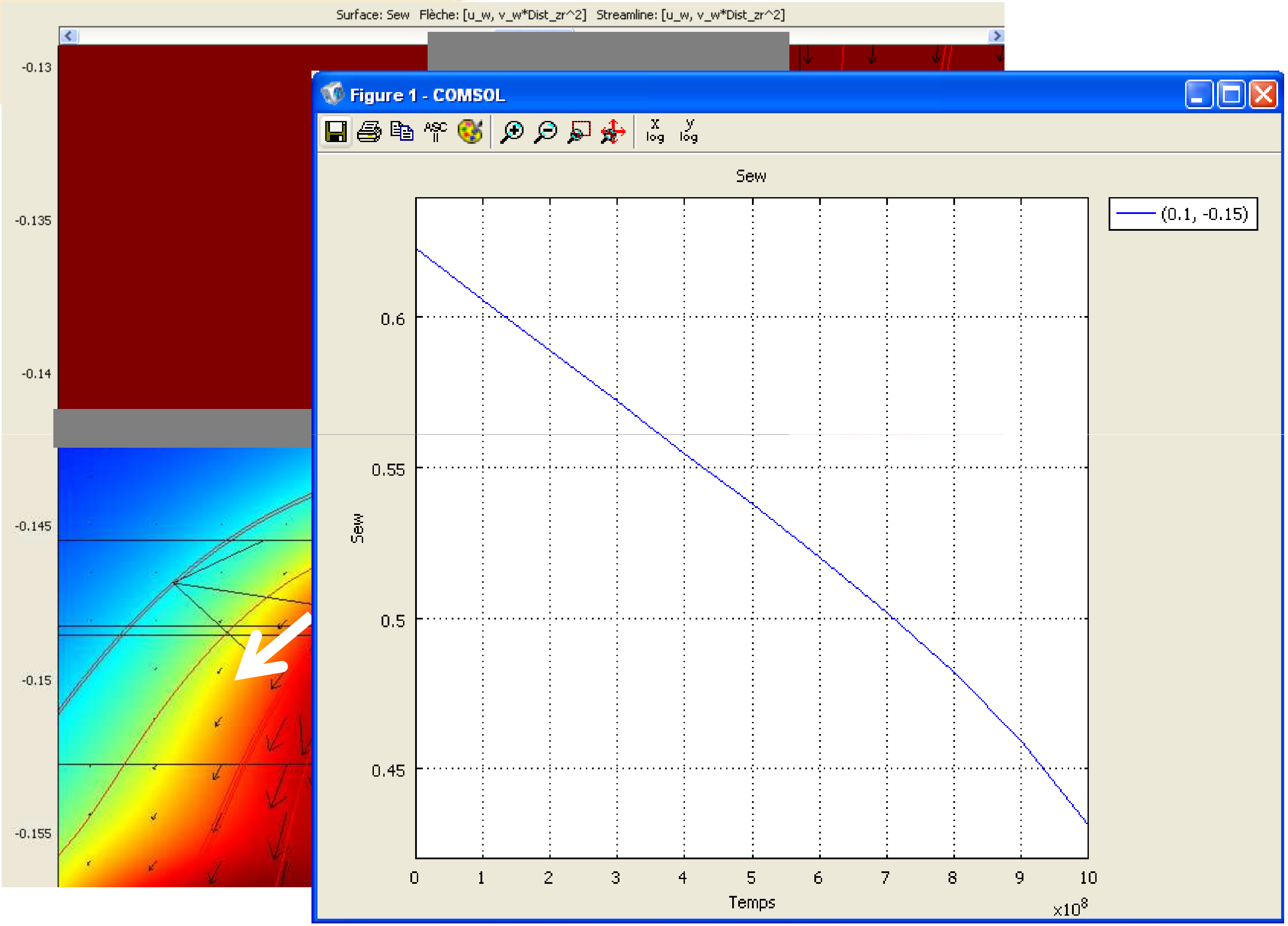


Effective Water Saturation



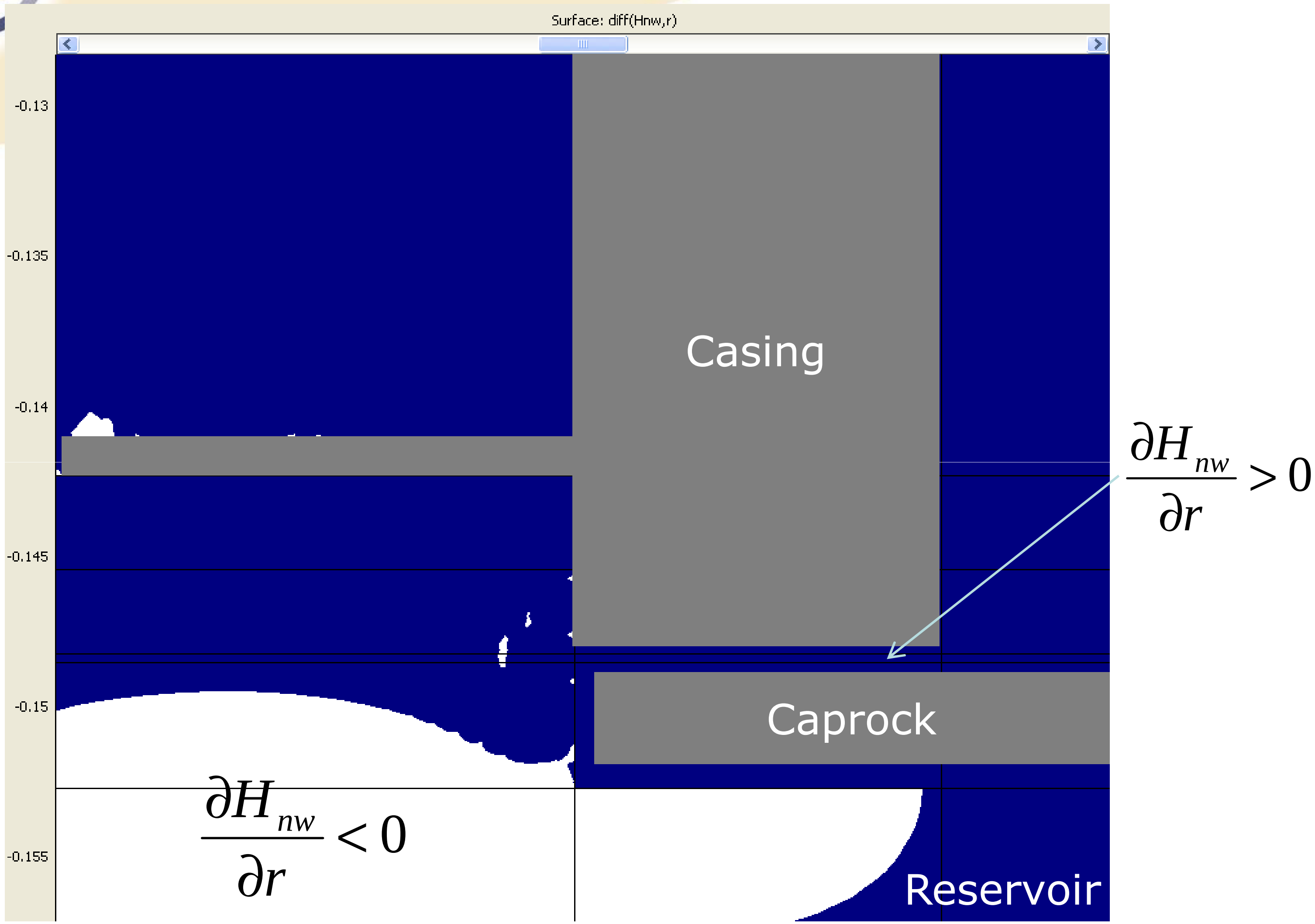
No CO_2 leakage with aquifer connection

Effective Water Saturation



No CO_2 leakage with aquifer connection

Radial pneumatic gradient



No possible CO_2 radial flow in the rat hole

Numerical difficulties

- ✓ **Space distortion**
  - *Radial size scale: <1 m*
  - *Axial size scale: 1000 m*

- ✓ **Permeability**
  - *Well cavity (5O D)*
  - *Caprock (0.001 mD)*
  - *Bad cement sheath (10 mD)*

→ Large ranges of values for parameters describing the well induce numerical difficulties

- ✓ **Capillary pressure head**
  - *Need values > 0,1 bar to converge*

→ Due to Van Genuchten model

Conclusions

- ✓ **Numerical simulations have highlighted the competition between the gas flow and the liquid flow in a specific area of a well**

- ✓ **The rat-hole zone constitutes a key element to consider in the long term integrity performance of a well**

- ✓ **An improvement of the knowledge of the flows in this specific area within the well will be a support in assessing the Performance and the Risks from a well integrity perspective**

Future works

- ✓ **Robustness analysis to be performed**
  - *To quantify the CO_2 leakage in the case of no aquifer protection*
  - *Improvements in the modeling to take into account the significant differences between some parameters values for two linked elements*

- ✓ **This study will have to be coupled to a macroscopic CO_2 leakage modelling within well system.**
  - *Essential into a quantitative well integrity risk analysis for CO_2 storage projects*