Hydraulic impact of the access ramps and shafts of the French Cigeo deep radioactive waste disposal on the above aquifers of the Meuse/Haute-Marne site

H. Benabderrahmane[1], J. Kerrou[2], L. Tacher[3], P. Perrochet[2]

[1] Andra, 1-7 rue Jean Monnet, 92298 Châtenay-Malabry Cedex, France
[2] Centre of Hydrogeology and Geothermics (CHYN), University of Neuchâtel, Rue Emile Argand 11, 2000 Neuchâtel, Switzerland
[3] Ecole Polytechnique Fédérale de Lausanne, Laboratoire de Mécanique des Sols (EPFL - LMS), CH - 1015 Lausanne

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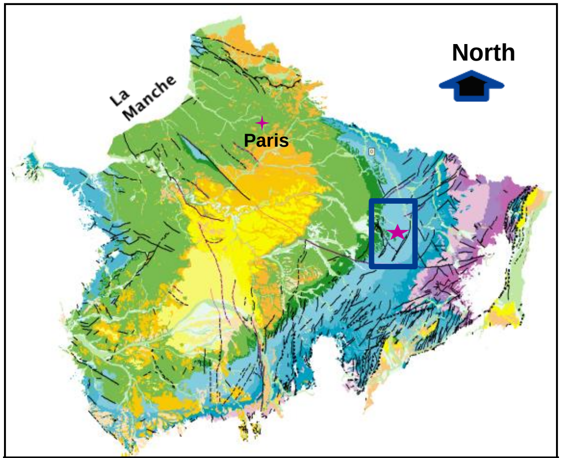
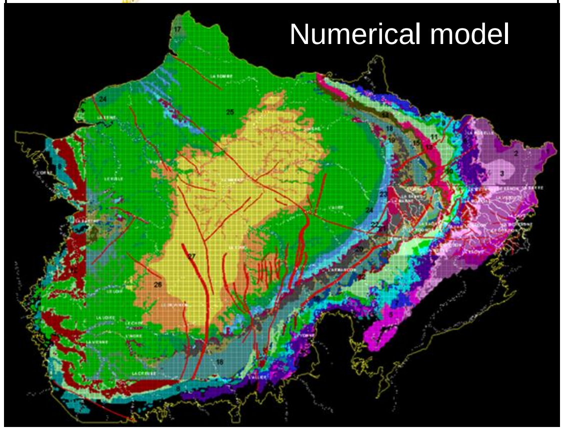
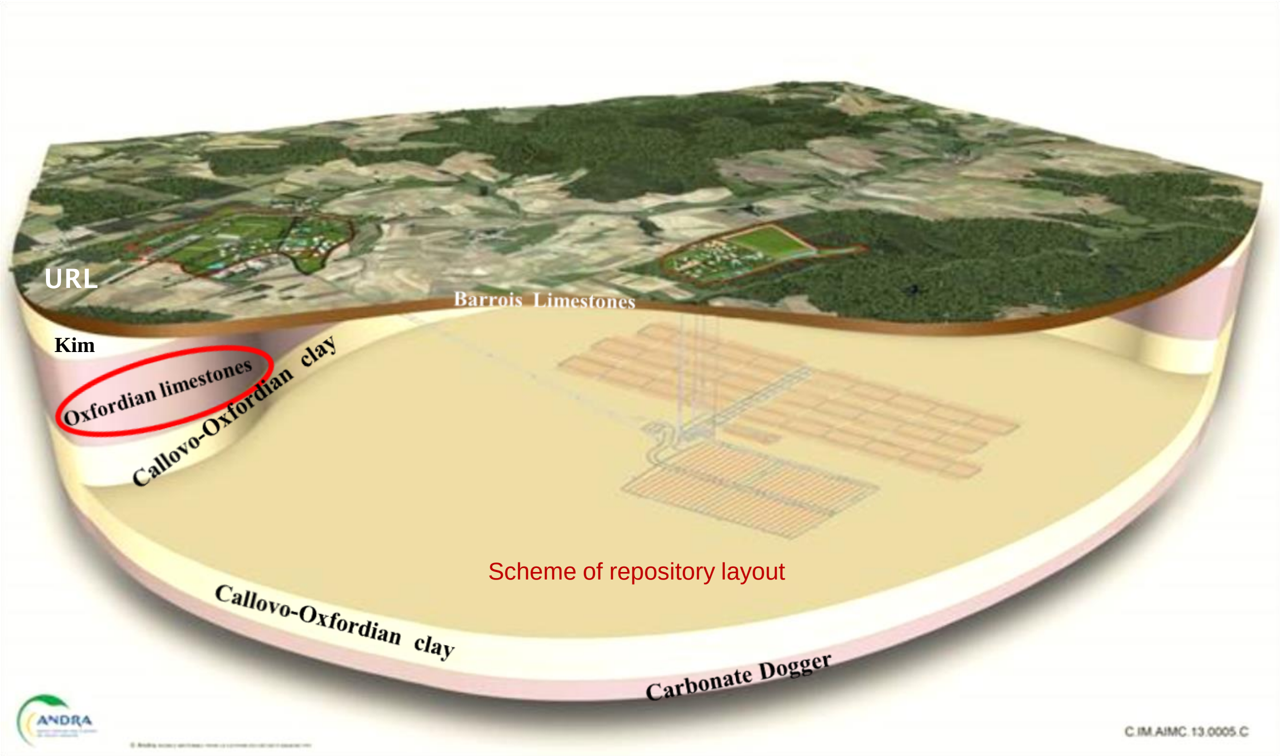
Cigèo Project: Hydro-geological multilayered aquifer system and planned repository concept (engineered structures)

Paris Basin Geological Background





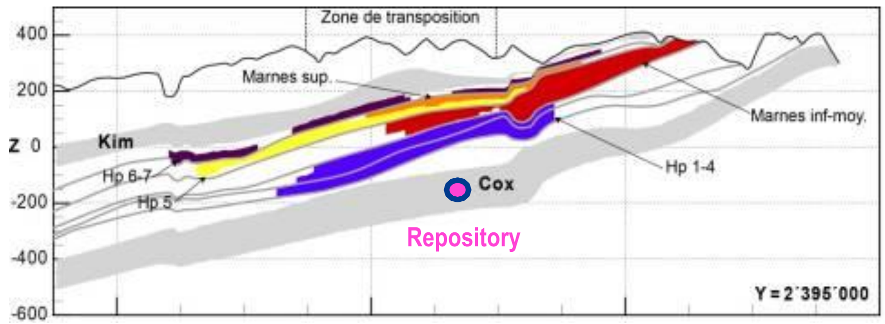
URL and Planned Repository site



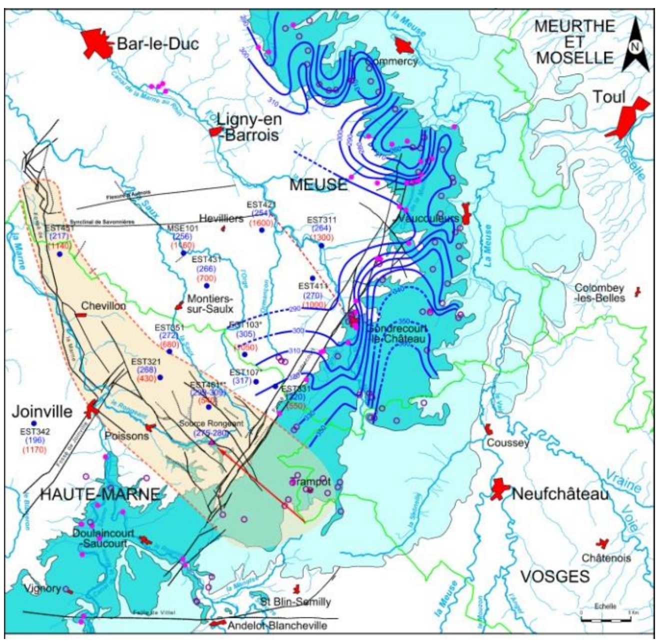
- Host layer : Callovo-Oxfordian clay - Age: 165 10^6 years - Thickness: 130 m - Depth: 500 m
- Overlying Multilayered aquifer system:
  - **Oxfordian Limestones (280 m)**
  - Kimmeridgian marles (100 m)
  - Barrois limestone (100 m)

Hydrogeological concept of the Oxfordian limestone aquifer

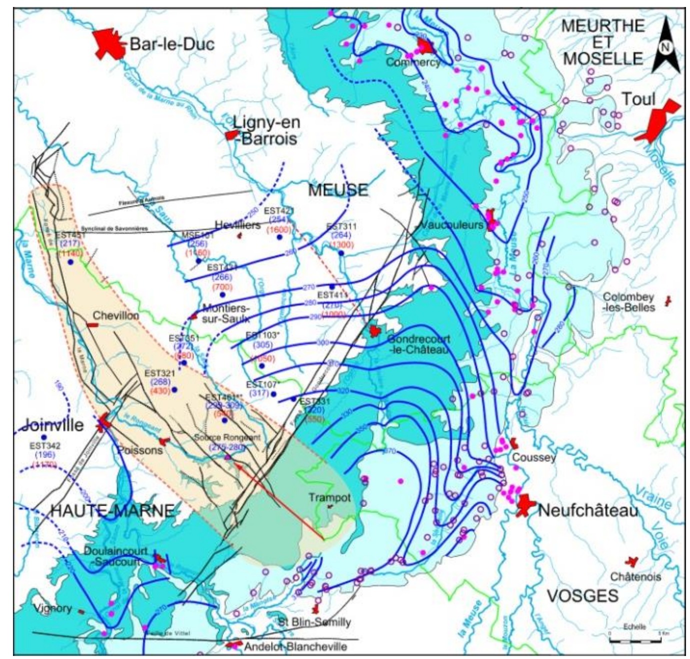
- Hydrogeological structure of the Oxfordian aquifer system
  - Oxfordian limestone aquifer is structured into two aquifer units NE of the site and just one unit in the rest of the domain
  - 7 Macropore zones gathered into 4 aquifers units (Hp1-4, Hp5, Hp6 and Hp7)
  - Hydraulic conductivity ranges from 10^{-9} m/s to 10^{-7} m/s



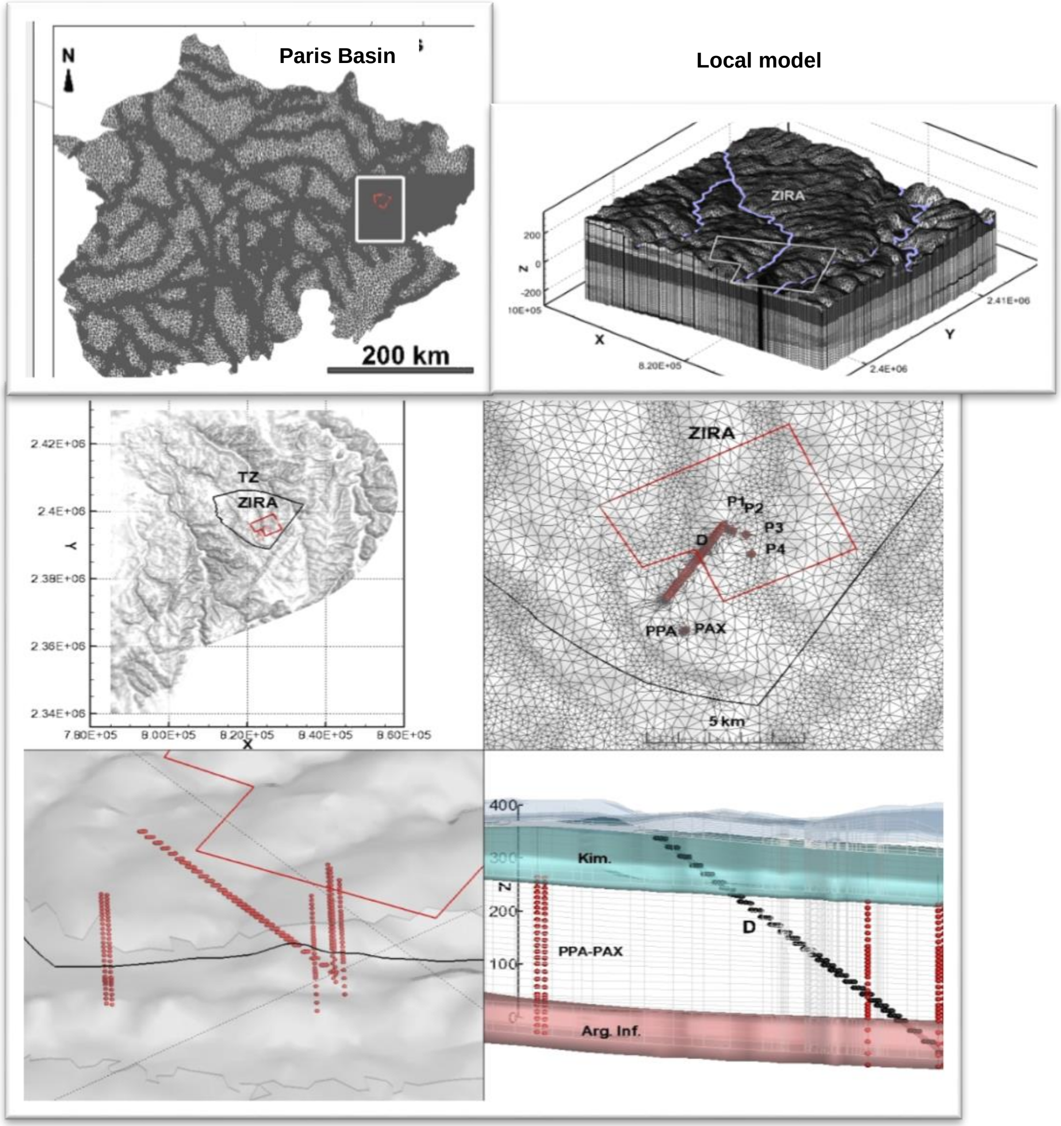
Late Oxfordian



Middle Oxfordian



Numerical solution of variably saturated flow (Modified Richard's equation) : Finite Element Mesh

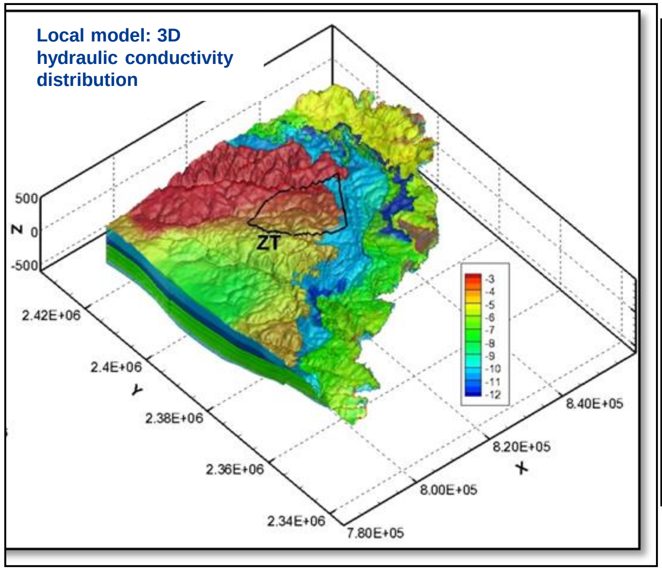


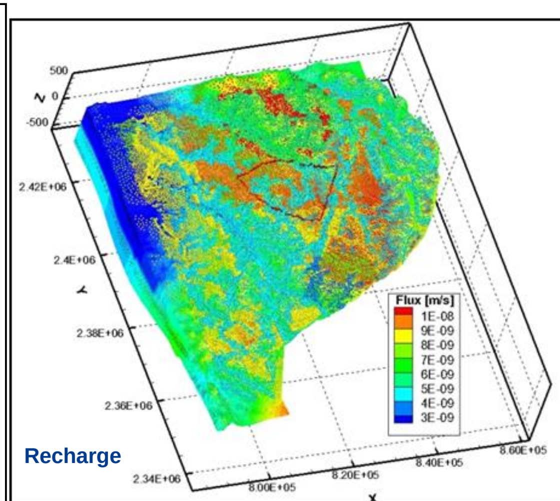
- Mathematical formulation (modified Richard's equation for variably saturated flow)

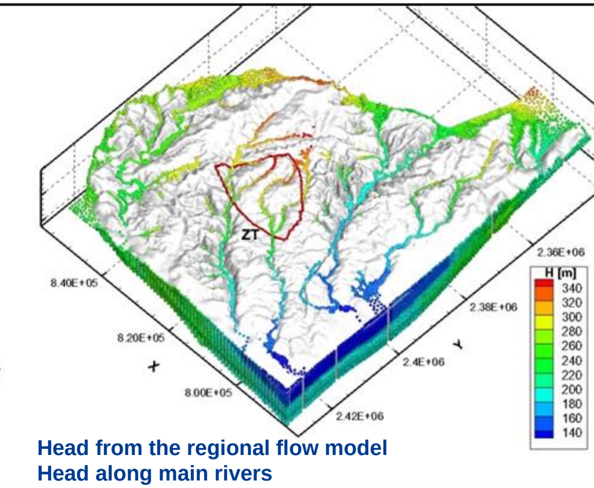
$$\frac{\partial \theta}{\partial t} = \nabla . k_r K \nabla(\psi + z) - \Delta Q$$

- Finite Element Mesh (EPM approach)
  - 3,2 10^6 nodes
  - 10,3 10^6 elements (2 m to 200 m)
  - Vertical refinement, numerical layers : 53
- GroundWater FEM computer code (Chyn University of Neuchâtel)

Parametrization and boundary conditions

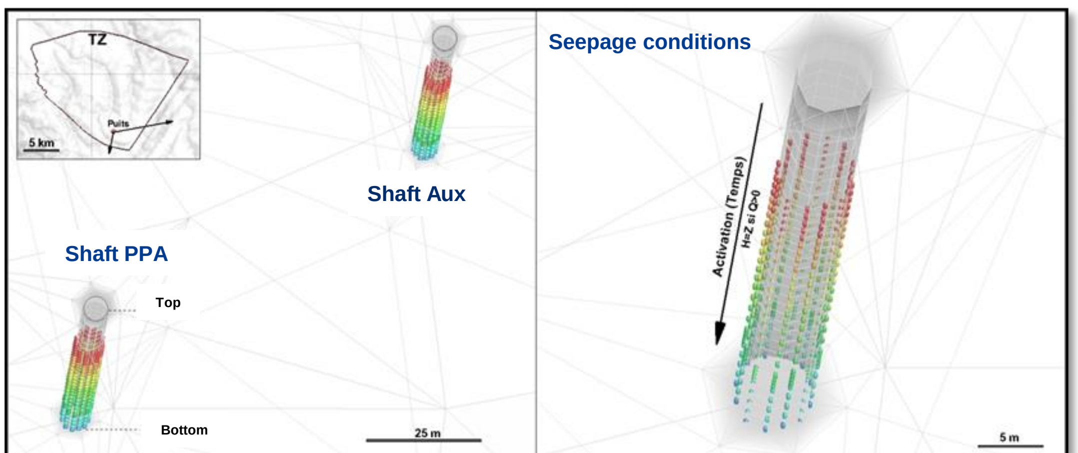




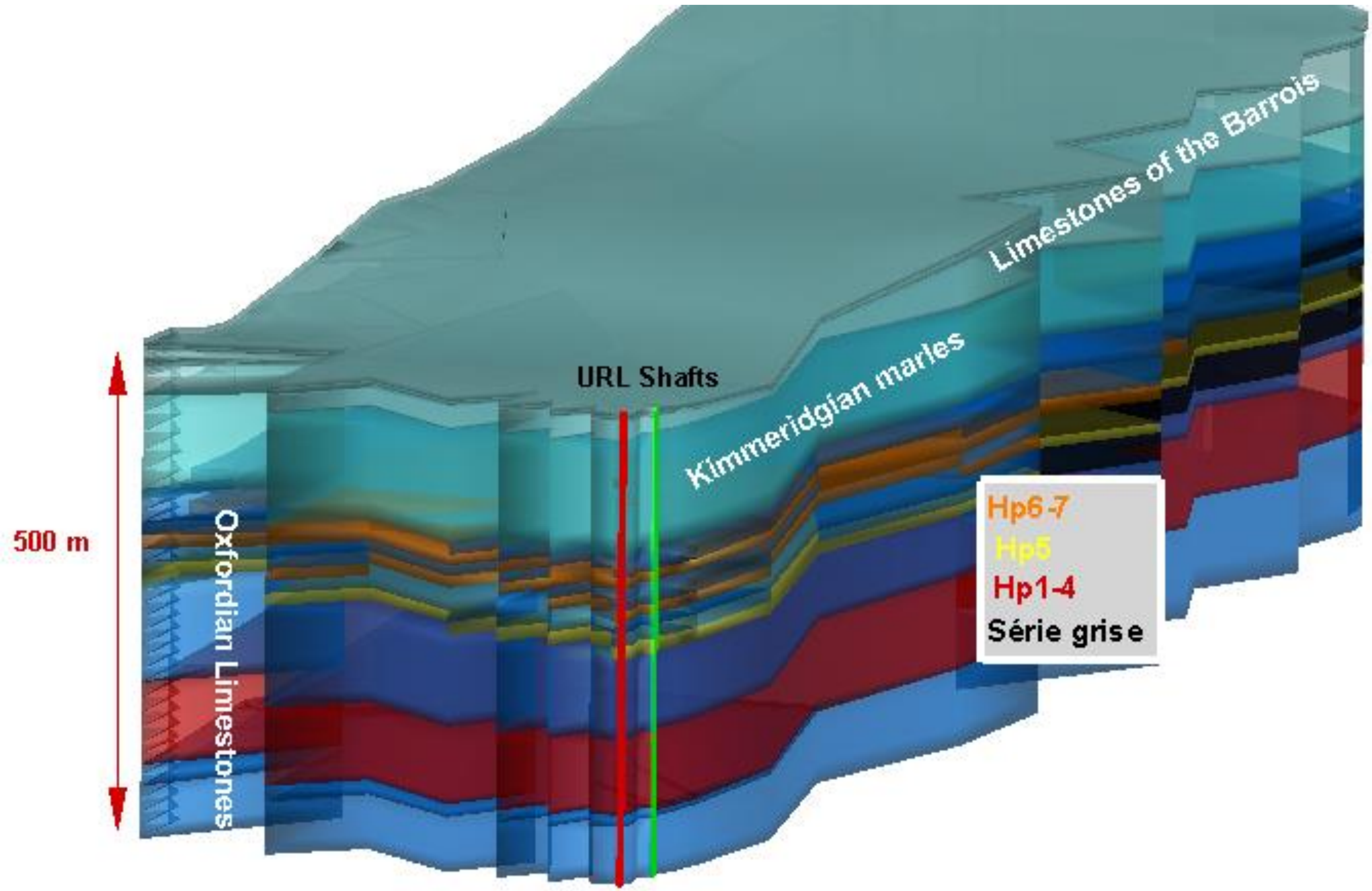


- Permeability distribution of the refined multilayered aquifer system extracted from the integrated Paris Basin/Sector
- Unsaturated zone: dependency between relative permeability, capillary pressure and water saturation is controlled by Mualem (1976) et Van Genuchten (1978) formulation

- Neumman boundary condition type: specified flux on the top surface
- Dirichlet boundary condition type along the river network, the shafts and the ramp
    - Elevation of the rivers beds
    - Seepage condition: on the shafts and ramp)



URL Monitoring data for transient flow modelling: (i) pressure in boreholes and (ii) drained water into the shafts

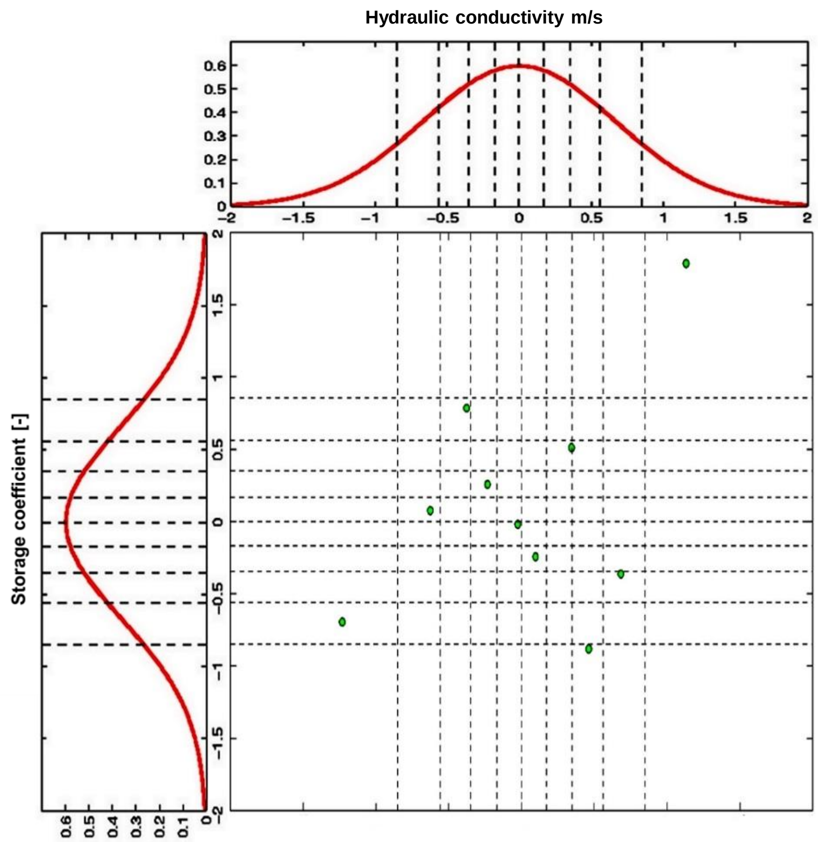


Sensitivity analysis based on LHD sampling (1)

- **Experimental Design and identification of the sensitive parameters**
  - **14 parameters (Hydraulic conductivity and Storage associated to 7 Oxfordian layers and macropores zones (Hp1-4, Hp5, Hp6 and Hp7)**
  - **Factor intervals**
    - **Hydraulic conductivity: [0.02 , 50.]**
    - **Storage coefficient: [0.02 , 50.]**
  - **Latin Hypercube parameters sampling**
    - **Gaussian parameters Distributions**
    - **300 numerical simulations/Experiments**
  - **Response/Target : Objective Function**

$$OF_{gw} = \sum_{t=0}^{tn} \left| \frac{H^k_{obs}(t) - H^k_{sim}(t)}{H^k_{obs}(t)} \right| + \sum_{t=0}^{tn} \left| \frac{Q^l_{obs}(t) - Q^l_{sim}(t)}{Q^l_{obs}(t)} \right|$$

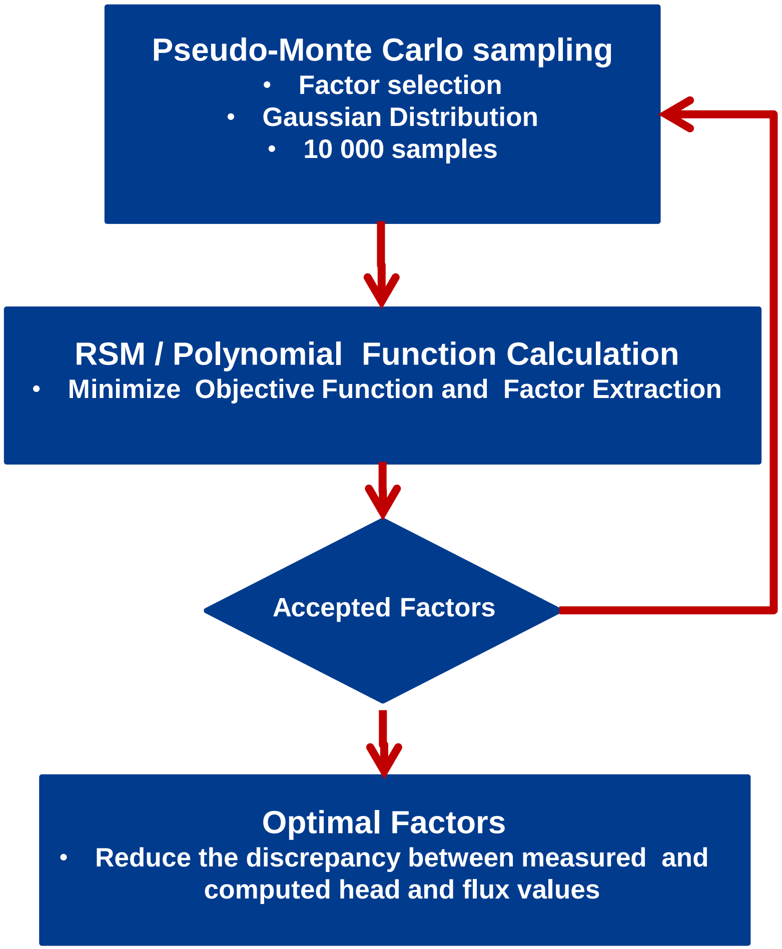
Latin Hypercube Sampling
300 sampling intervals of equal probability

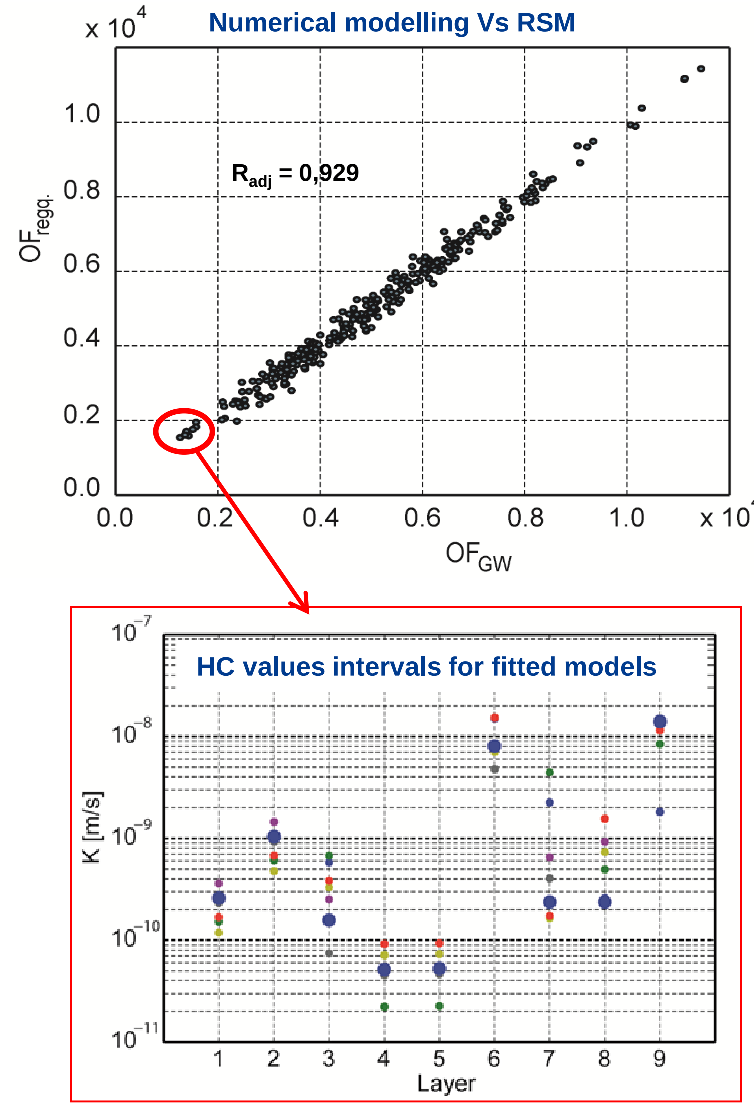


- **Response surface Model**
  - **K1, K2, S5, S7 the less sensitive parameters**
  - **Resulting regression model (polynomial Function) includes 37 terms (linear and second order effects)**
  - **R^2= 0,975**
  - **Optimized Polynomial function: 37 terms including constant**

Calibration using Polynomial function (RSM) (1)

RSM calibration process

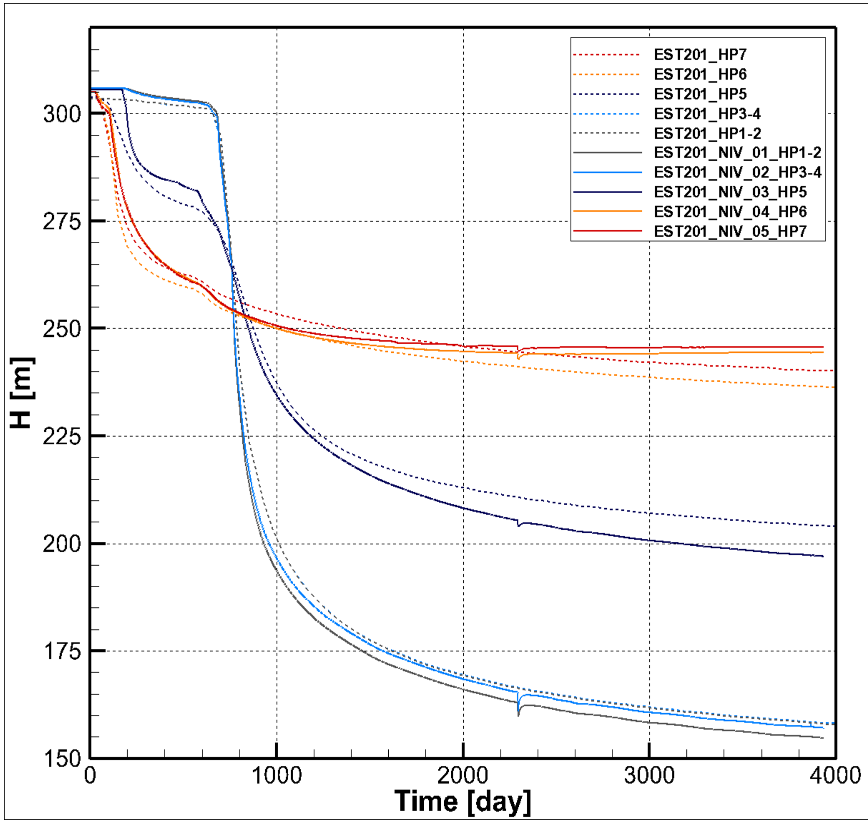




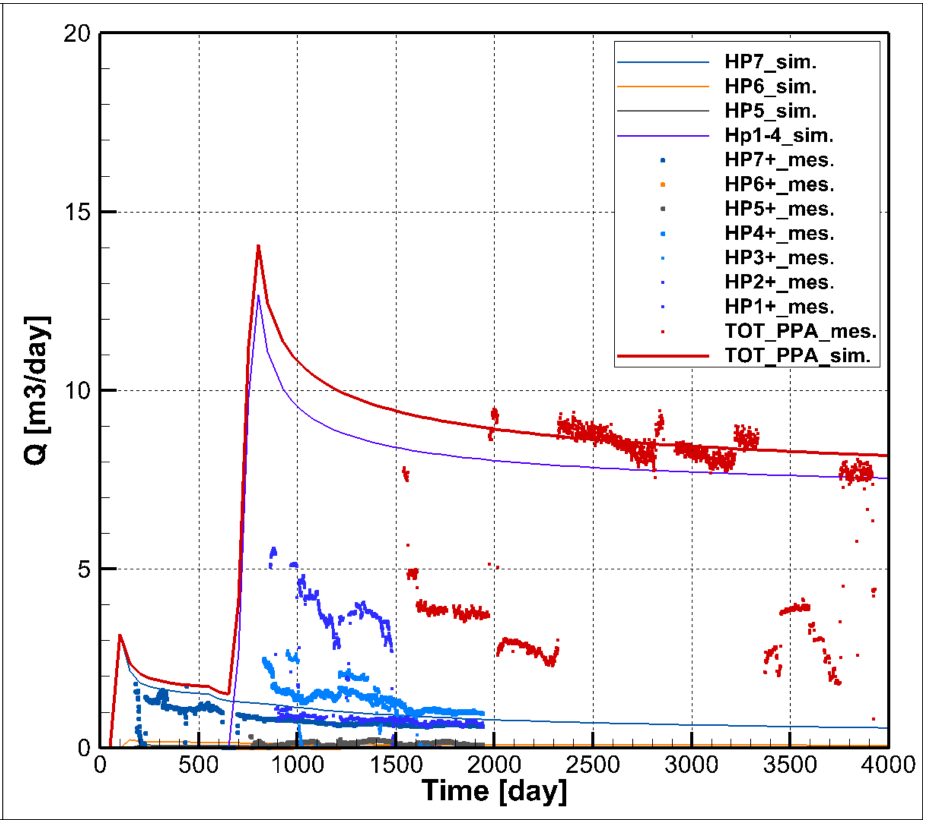
Calibration of the transient local flow inferred by the URL (2)

Matching the near field monitoring results of the Oxfordian aquifer (transient flow calibration)
Calibration parameters: Hydraulic conductivity and Specific storage (Hydraulic diffusivity : 2 10^{-4} – 5 10^{-2} m^2/s)

Borehole EST201



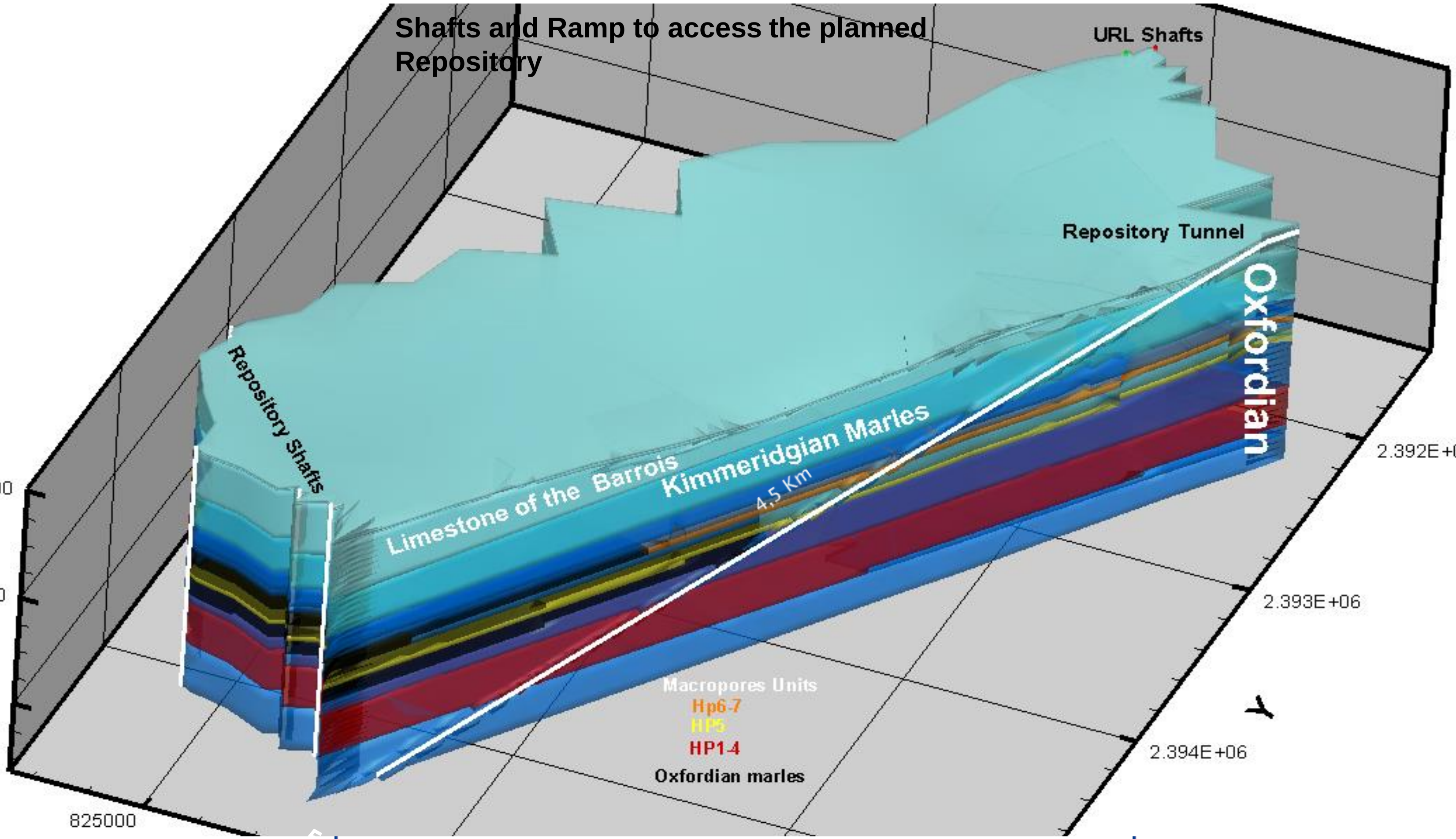
Discharge into the main Shaft (PPA)



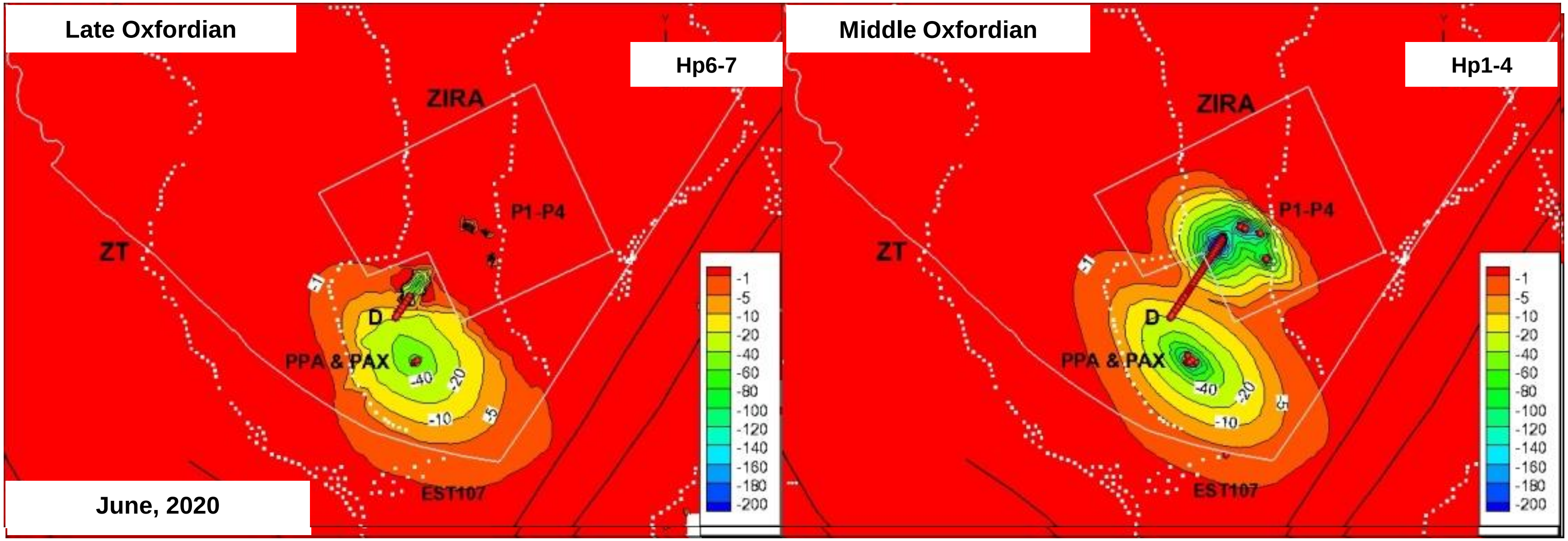
Head/discharge time series

Repository concept, construction time schedule and initial flow field

- **Initial flow field:**
  - January 2019
- **Construction time schedule:**
  - January to September 2019: ramps and two first shafts
  - October 2019 to March 2020: two last shafts



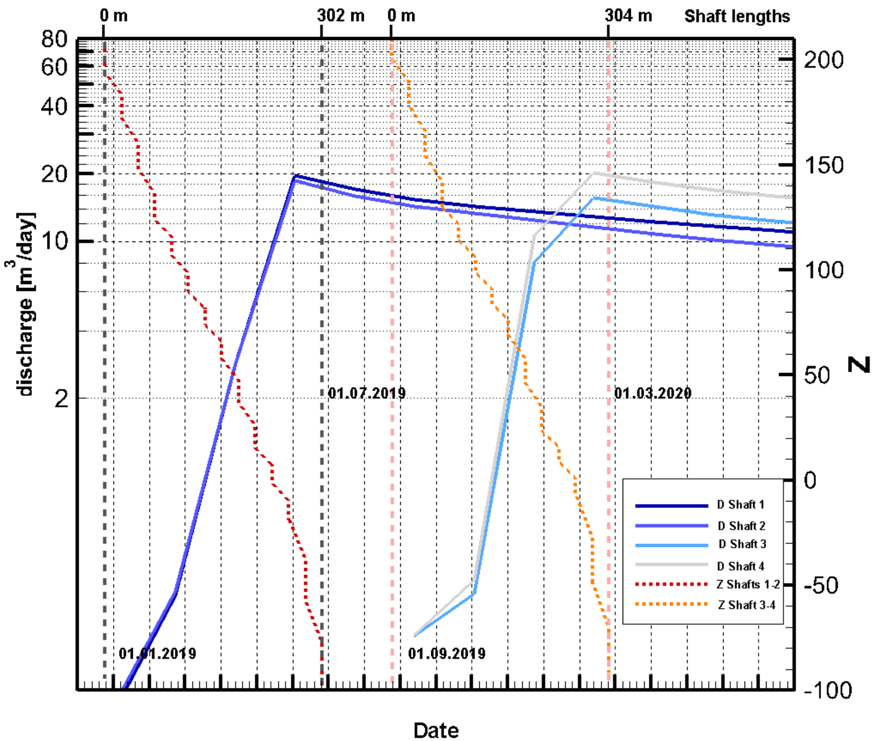
Evolution of the hydraulic perturbations during the construction phase



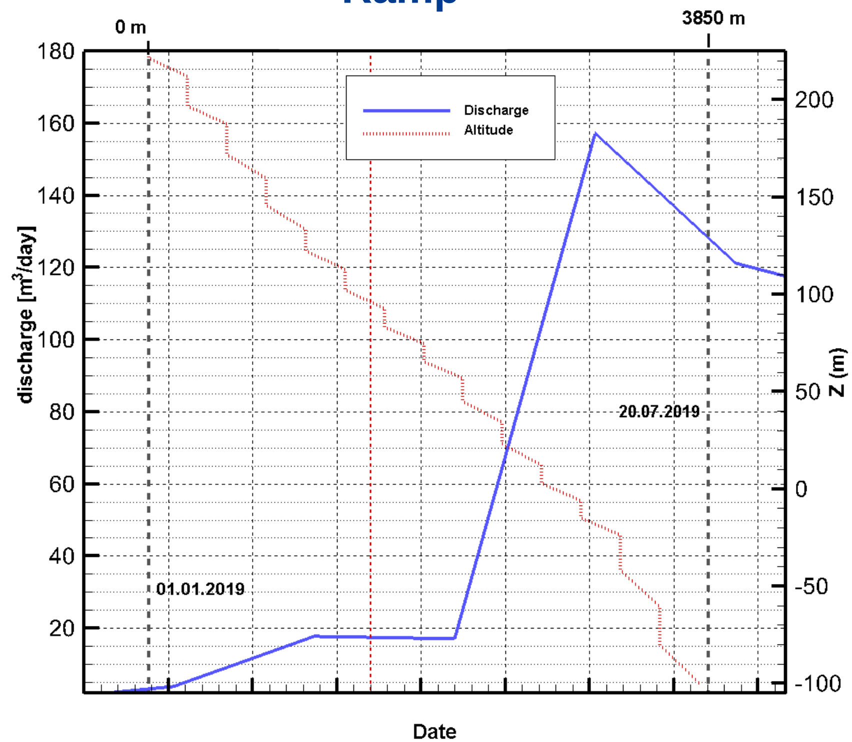
URL perturbation extension prior to the repository construction

Discharge prediction into the shafts and into the ramp during the construction phase

Shafts



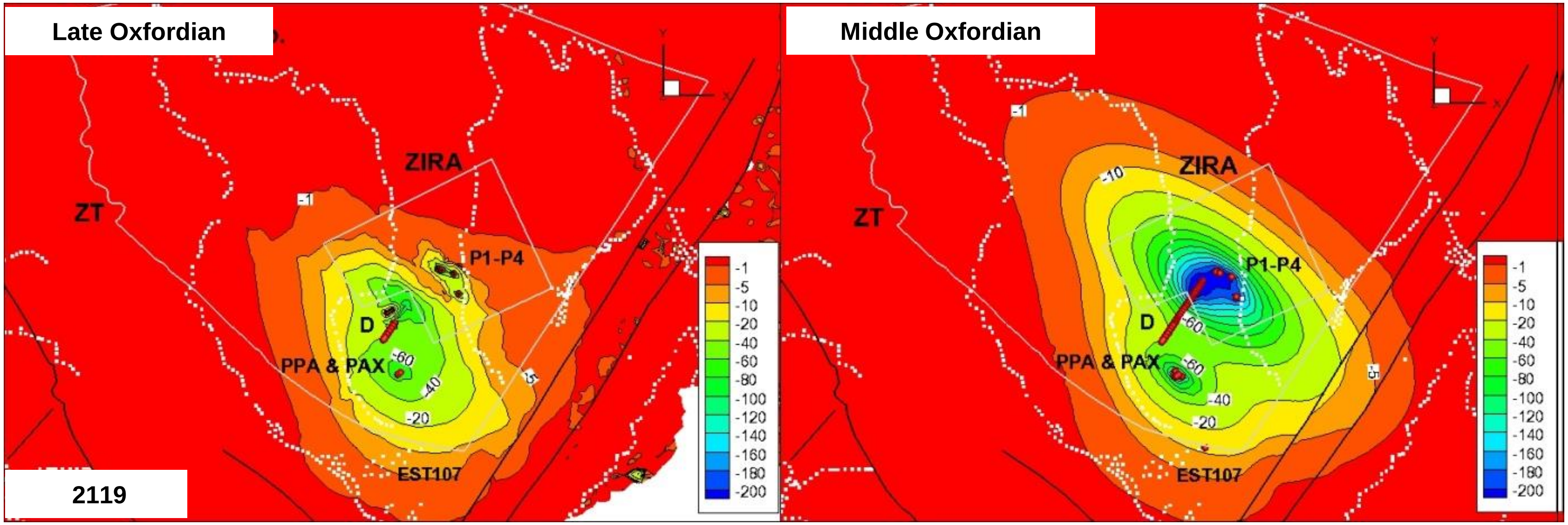
Ramp



Maximum discharge m^3/day

Shaft1	*Shaft2*	*Shaft3*	*Shaft4*	*Ramp*
20	18	16	21	155
230				

Evolution of the hydraulic perturbation during an operational phase of 100 years



Major results and perspective

- Results
  - Predicted hydraulic perturbation has lateral extension of about 40 Km^2
  - Maximum discharge is of 21 m^3/day in Shaft 4
  - Discharge of drained water into the ramp has maximum predicted value of 155 m^3/day
- Perspective
  - Reduction of the uncertainty of the layers geometry crossed by the ramps and the shafts by integrating the 3D seismic survey results of the repository area (ZIRA)
  - Constraining the transient flow calibration by the use of Kalmann filter technic
  - Predict and assess the hydraulic impact of the engineered structures on the Barrois limestones aquifer system
  - Map the unsaturated zone around Shafts and Ramp

THANKS TO THE MODELLING TEAM

THANKS FOR YOUR ATTENTION