# Hydrological data analysis and groundwater flow modelling at a former uranium mine in France

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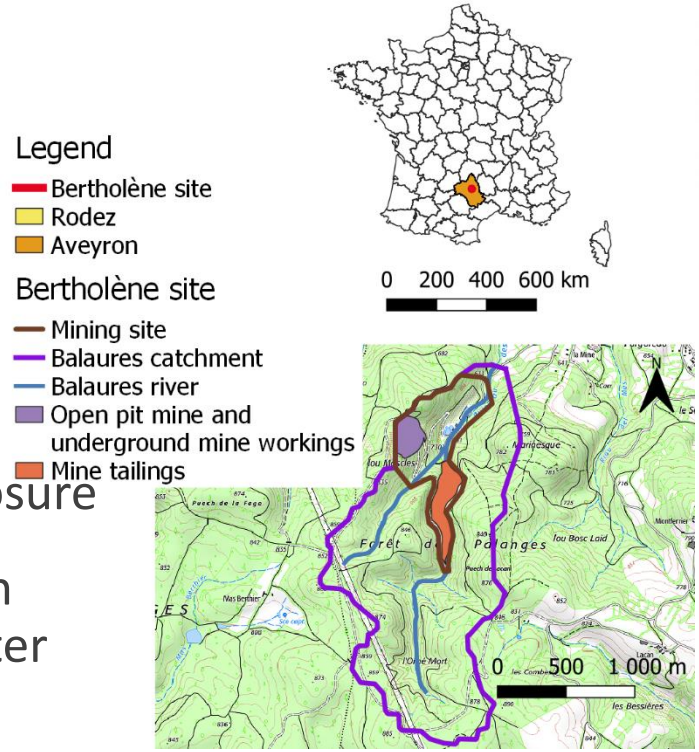
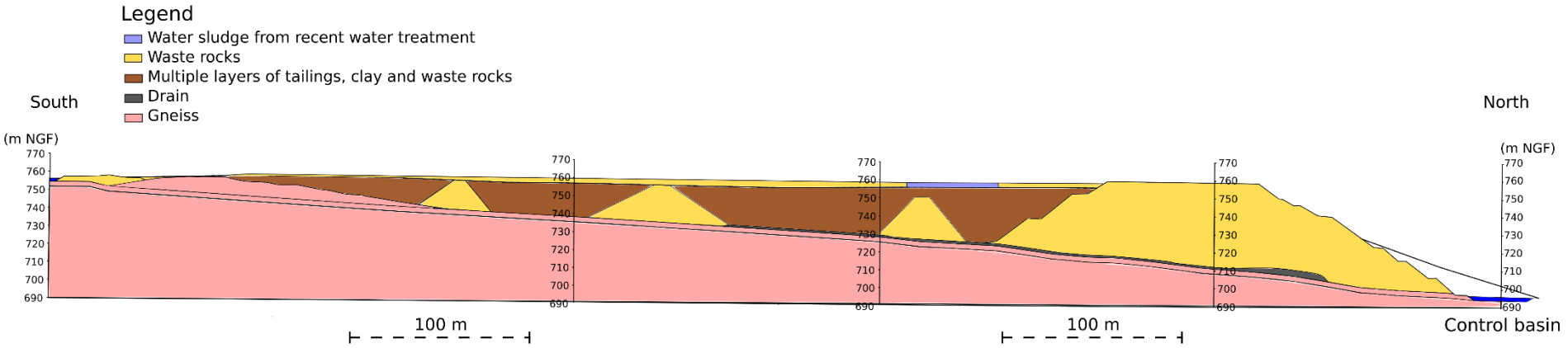
# Context of former mine

- Aveyron: South of Massif Central
- Uranium mining from 1977 to 1995: 750 tons of natural Uranium
- Heap leaching treatment on site
- Remediation and decommissioning after the mine closure
- Mine tailings, waste rocks → stored in isolated cells in a natural valley with a drain underneath to collect water in the control basin
- Acid mine drainage: gypsum + oxygen + water
- Water treatment and site monitoring by ORANO Après-Mines




Site localisation




Longitudinal cross section of the waste rocks/tailings storage

# Site issues

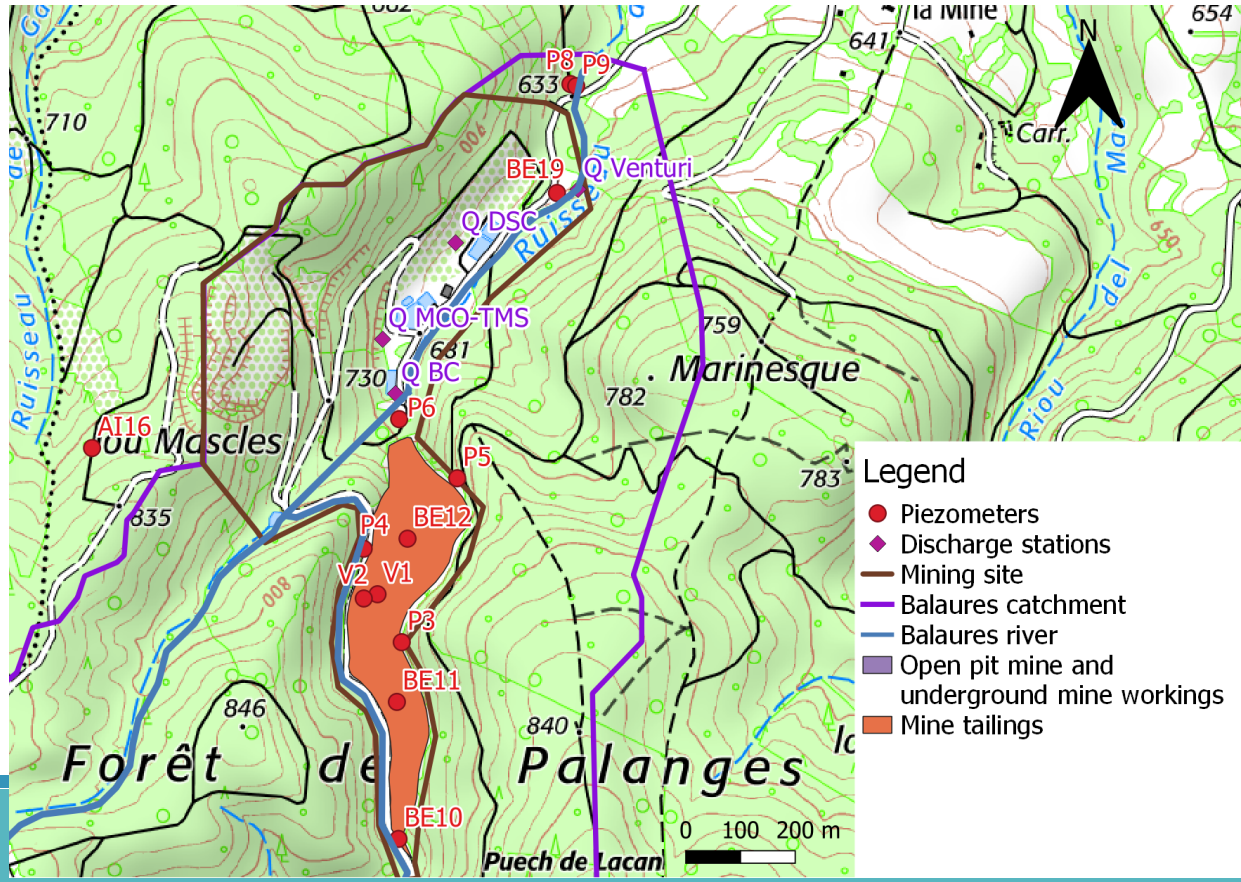
- Understanding of groundwater flows at the basin scale
- Identification of the sources of water within the tailings storage area
- Interaction between water table and tailings under extreme events
- Testing potential decommissioning scenarios

Waste rocks on the storage during a geochemical sampling in piezometer V2

In part backfilled open pit mine

# Data: groundwater and surface water monitoring

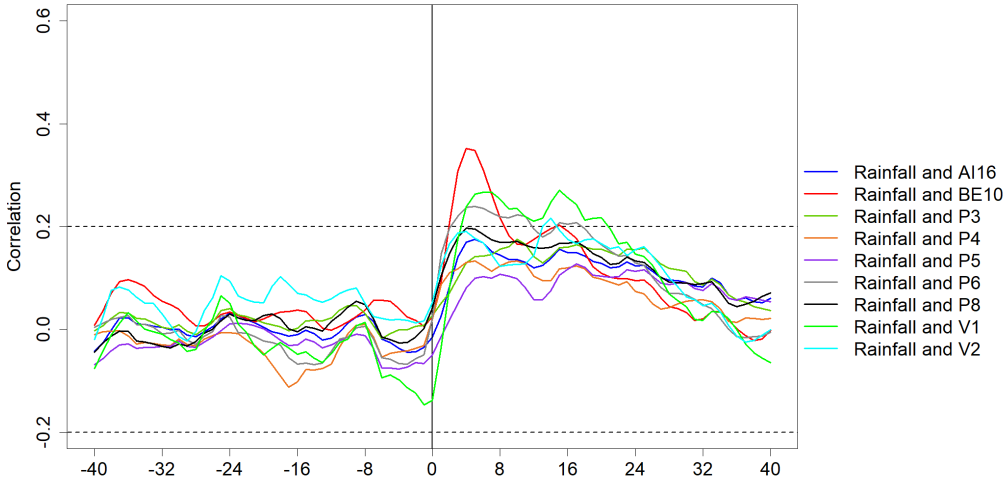
- Historical data: 20 years on 17 points (water levels, discharges at the control basin and the basin outlet)
- Implementation of 2 new piezometers
- Daily water level monitoring: since June 2018 (9 piezometers)
- Meteorological data at Rodez Météo-France station (20 years)



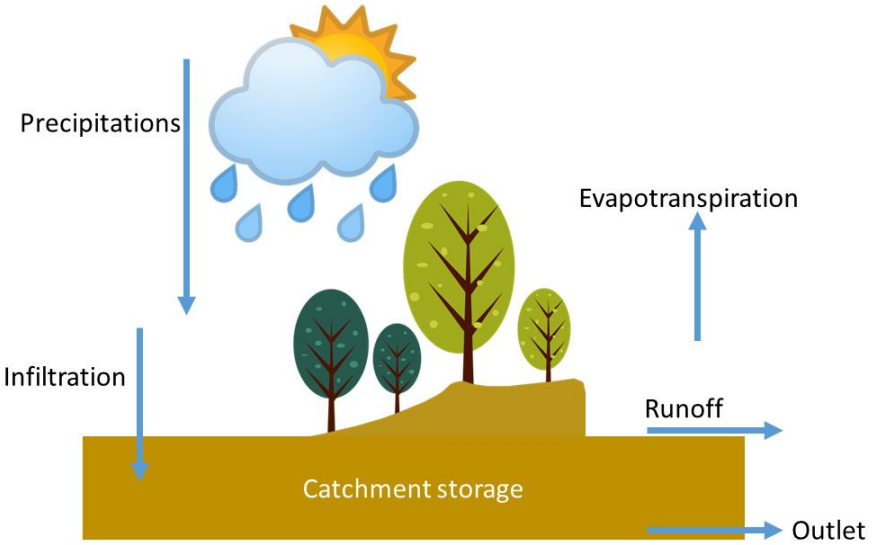

Localisation of monitored points

# Methods

- Auto and cross correlations (rainfall with water levels and discharges)
- Water balance at basin scale and at the tailings outlet
- 3D modelling with MODFLOW at the basin scale
- Impact of extreme events on water levels



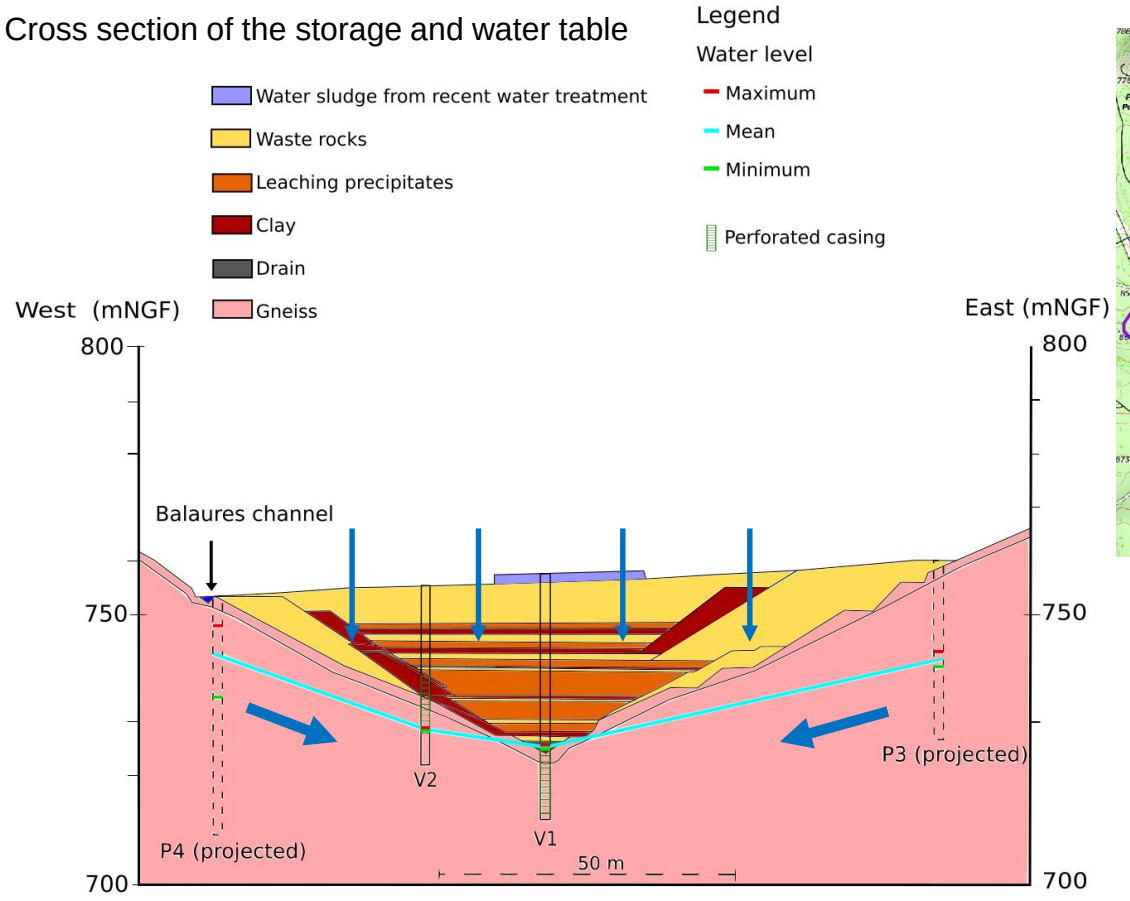

Cross correlation between daily rainfall and water levels

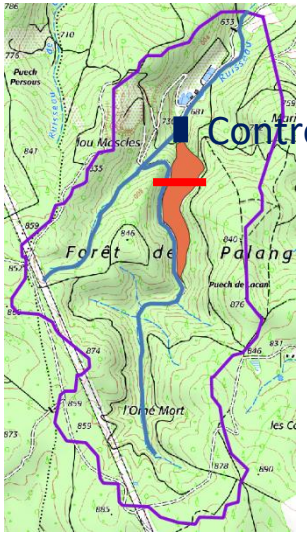



Water balance

# Hydrological conditions within the tailings-gneiss complex

- Fast hydrological response at the control basin: 5 to 8 days
- Unsaturated conditions and no perched groundwater within the tailings
- No water contribution from gneiss aquifer to the tailings storage

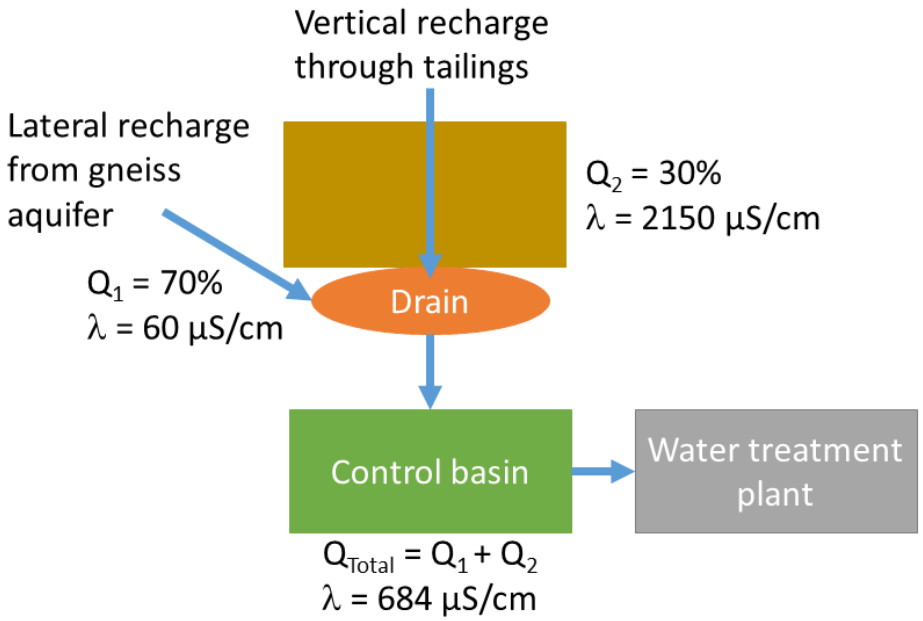


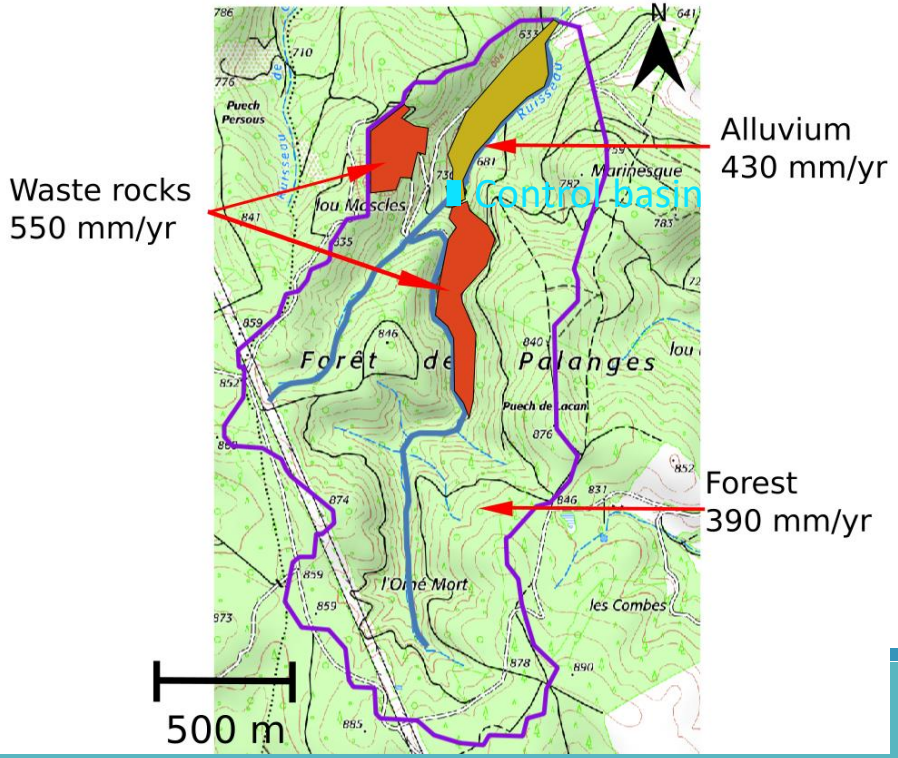
# Water balance at site scale

- Calculation of mean annual recharge: 400 mm/yr  spatialized into 3 zones according to the type of surface
- Uncertainties on site discharges
- Sub-catchment of tailings storage:
  - 70% of groundwater + 30% water percolating through tailings
  - Validation with electrical conductivities

Sub-catchment of tailings storage water balance

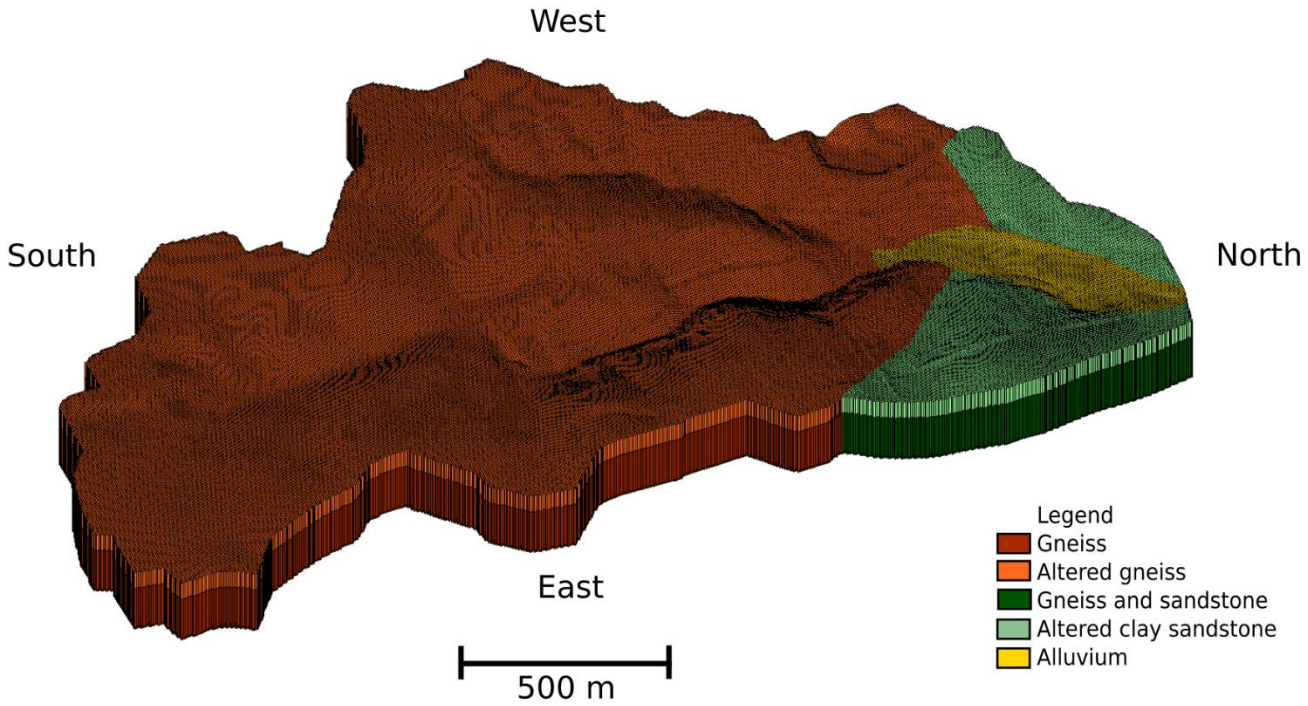



Recharge on site



# Modelling with MODFLOW

- Simplified model: 2 layers, 5 m long meshes
- Steady state
- Gneiss and sandstone aquifer
- Recharge from water balance
- No flow at the catchment limits except for the river output
- Specified head for river and intermittent creeks

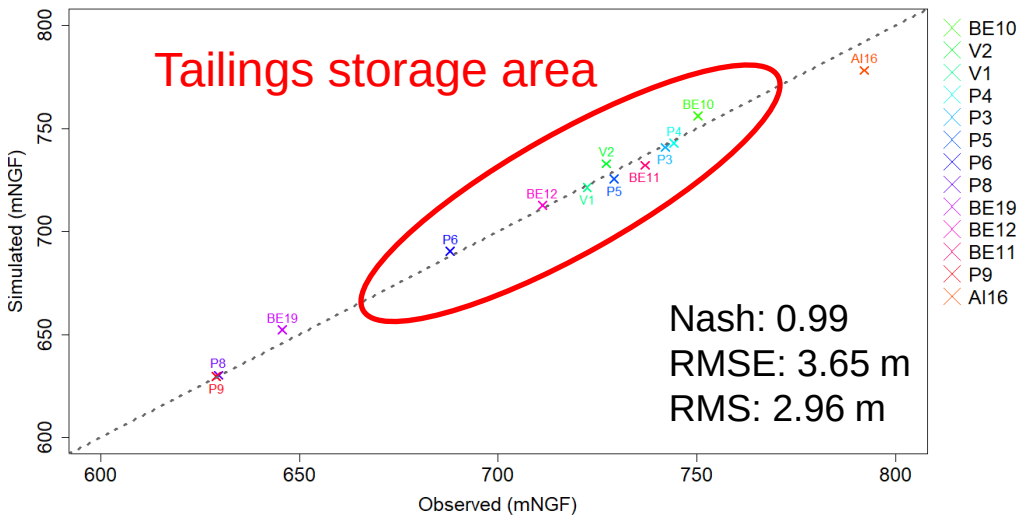



3D representation of the modelling

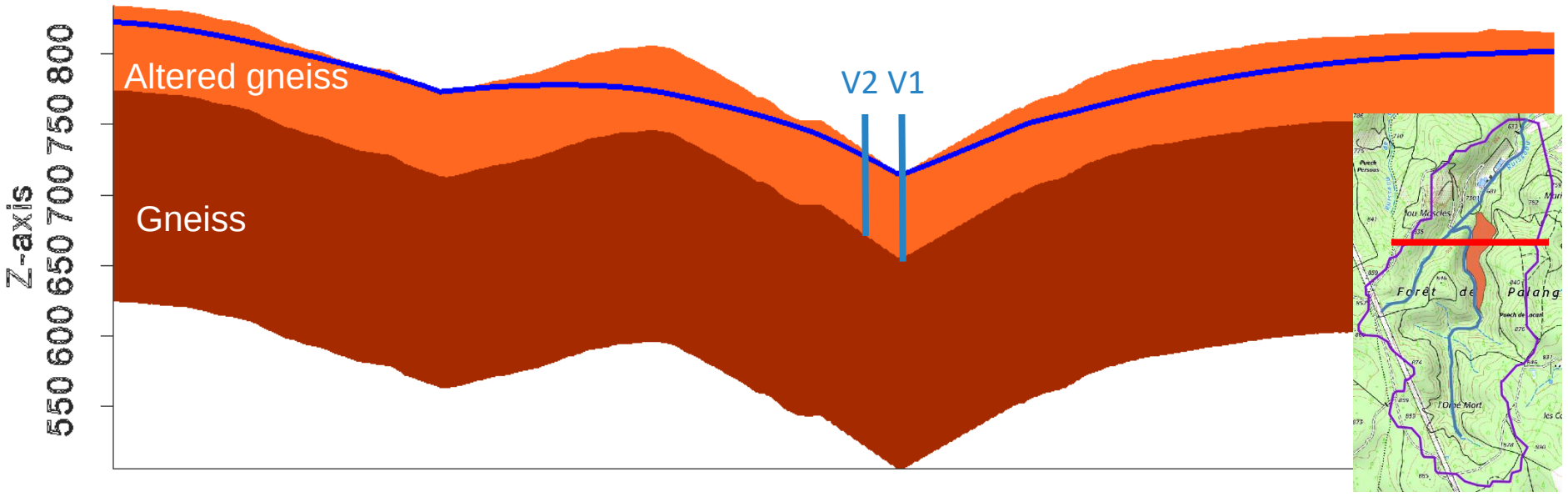
# Modelling with MODFLOW

- Reproduces water levels correctly
- Reproduces correctly:
  - Water levels within the tailings storage
  - Discharge at the basin control (+6.5%)

Simulated vs. Observed water levels

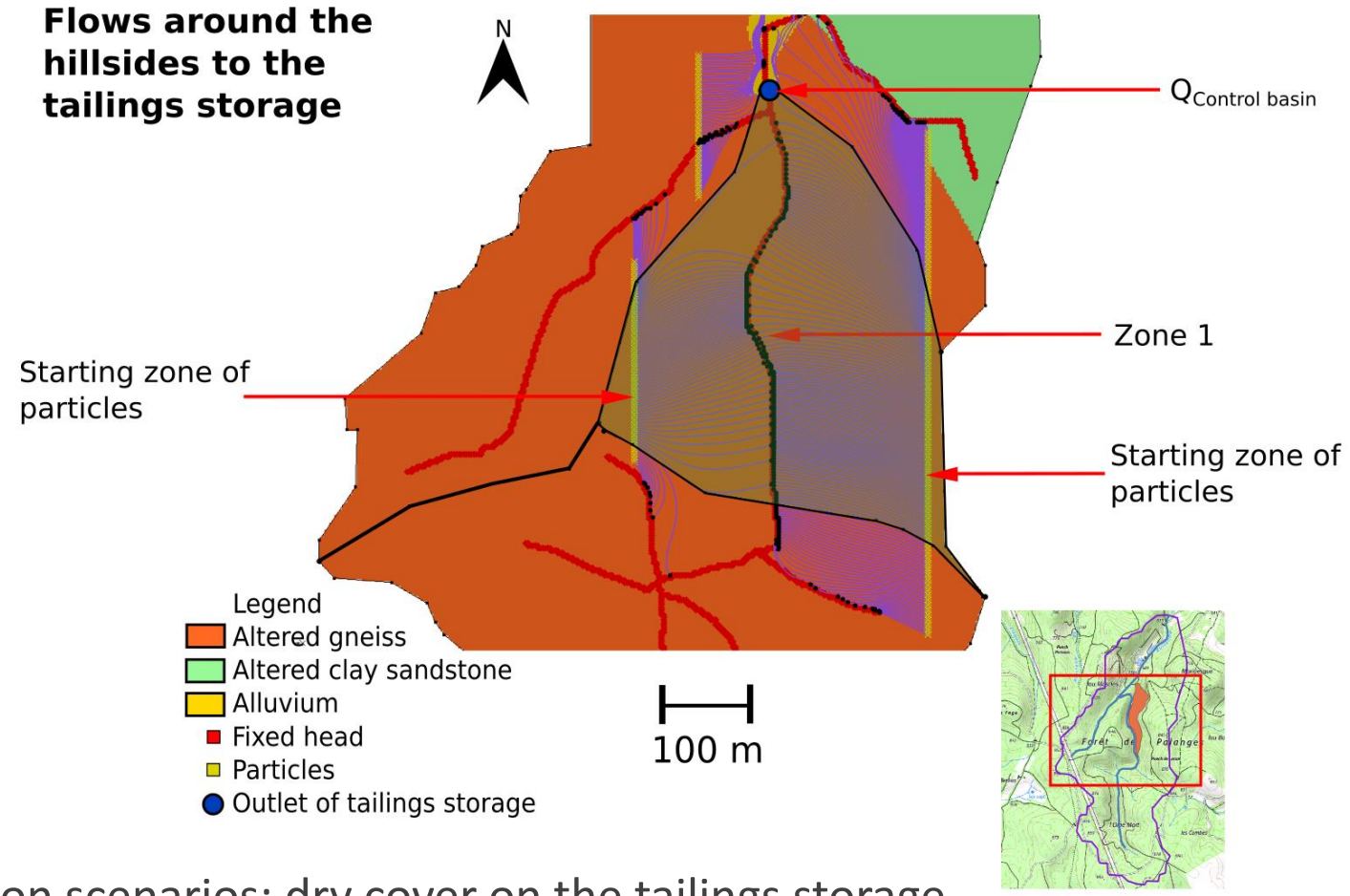



Cross section of the model with the simulated water table



# Modelling with MODFLOW

- Particle tracking allows visualizing lateral water transfers through gneiss aquifer

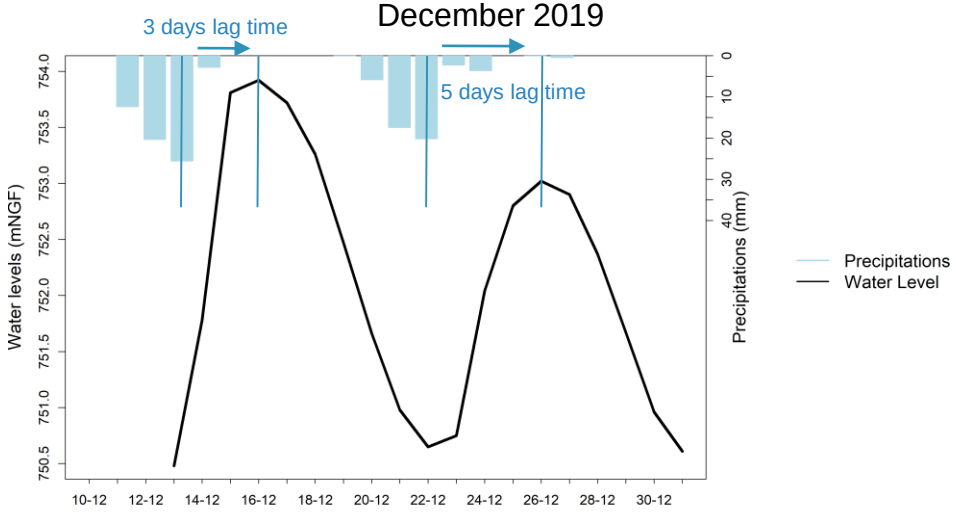



- Long-term evolution scenarios: dry cover on the tailings storage
  - 35% decrease of the discharge at the control basin ($Q_{BC}$)

# Impact of extreme events on water tables

- Event definition: 1 or more consecutive rainy days (> 2 mm)

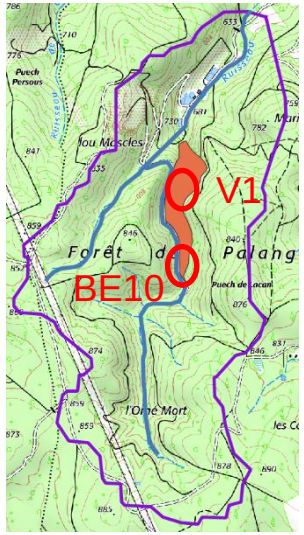
Water levels and daily precipitations in BE10 from 10 to 31 December 2019




Return period 2 years = 62 mm

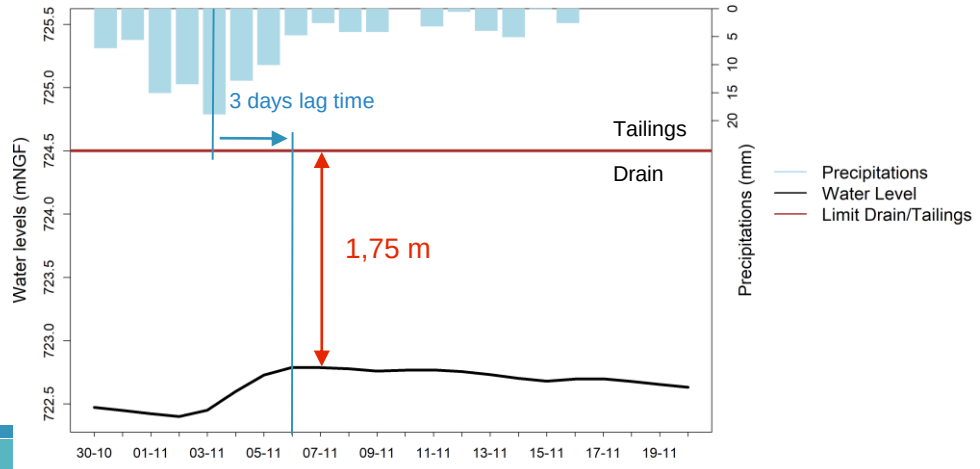
Fast increase of groundwater level with consecutive rainy days

Fast decrease of groundwater level: 5/6 days after the peak




- In 20 years of monthly water-level monitoring, water level never reaches the tailings
- In 2 years of daily water-level monitoring, no occurrence either
- The observation of the water level confirms the statistical approach

Water levels and daily precipitations in V1 from 30 October to 20 November 2019




Return period 5 years = 88 mm

# Conclusions

- Storage: unsaturated conditions, no perched aquifer
- At the outlet of the tailings ($Q_{BC}$) = 70% of water from gneiss aquifer (lateral flows) + 30% of water coming from vertical infiltration through tailings and waste rocks
- Groundwater modelling
  - Validation of recharge hypothesis
  - Groundwater flows at the basin scale
  - Validation of current functioning
- Extreme events
  - Water can be in contact with tailings less than 5 days with a period return greater than 20 years

# Perspectives

- AMD is expected to occur for 50 to 100 years (Beaucaire C. (2021)) even with a dry cover on the tailings storage
- Long-term decommissioning
- Impact of climate change on water tables and discharges on the site
  - Climate variable trends during the 100 next years
  - Evolution of extreme events: frequency and intensity

Beaucaire C. (2021). Modélisation géochimique du drainage acide minier au sein du stockage de résidus de Bertholène. Technical report ORANO Mining IDF-DT-009383.