Assessment of the integrated urban water management and representation of the hydrological response through modelling

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PhD project: PEPR NEO

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VILLE DURABLE
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COLLEGE DOCTORAL BRETAGNE
ECOLOGIE GEOSCIENCES AGRONOMIE ALIMENTATION

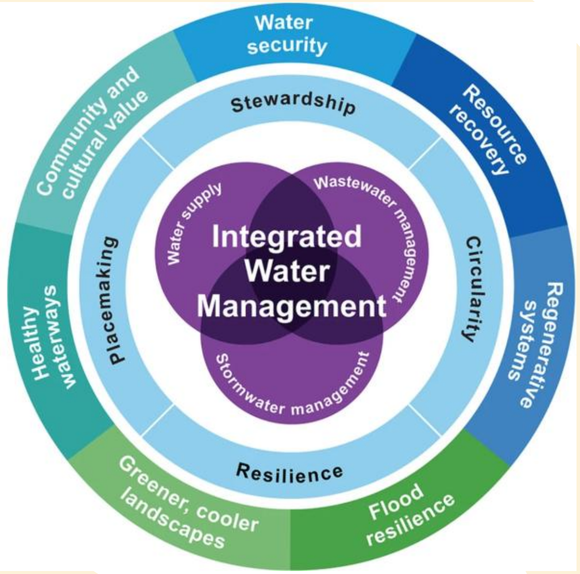
1. Context

a) Urbanization effects on the water cycle and environment

Bechet et al., 2017	Fletcher et al., 2013	Shuster et al., 2005	Hamel and Fletcher, 2014	Attard, 2017	Lalonde et al. , 2023	Akbari et al. , 2016
- Alteration and segregation of habitats - Physicochemical changes in soil - Disruption of hydrological cycle - Poor biological activity and biodiversity in soils	- Reduces infiltration and evapotranspiration - Increases surface runoff	- Increases transfer velocities - Causes risk of flooding in downstream areas	- Contributes to limitation of groundwater recharge	- Introduces local deformations of the piezometric level, modifying hydraulic gradients, then impacting flow speed and fragmenting natural flow systems	- How does urbanization modify rainfall?	- Increases the urban heat island effect during the warm season

b) Integrated urban water management

IUWM constitute a set of strategies to ensure access to water and sanitation infrastructure and services, manage rainwater, wastewater, stormwater drainage and runoff pollution, control waterborne diseases and epidemics; and reduce the risk of water-related hazards, including floods, droughts, and landslides, while preventing resource degradation (Bahri, 2012).



https://nzwaterreview.co.nz/integrated-water-management-a-systems-based-approach-to-urban-water/

1. Context

b) Integrated urban water management

- Source control

  Decentralized

  Increases Infiltration, groundwater recharge (Pophillat et al., 2022; Lit et al., 2025) and evapotranspiration (Hoghooghi et al., 2018).

  Controls Flood risk by temporal storage (Sage et al., 2017) and Surface runoff generation (Petrucci, 2012; Sage et al., 2017).

- Water reuse

  Rainwater harvesting (RWH) and **greywater reuse** (GWR).

  Diversifies water resources (Rodrigues et al., 2023),.

  Reduces water volumes conducted to water networks and treatment plants (Zhang et al., 2009; Penn et al., 2012; Lopez Zavala et al., 2016).

  Is beneficial for water quality and **serves** as a relatively constant water provision throughout the year (Leong et al., 2018)

https://metricaconsulting.co.uk/hydrology/sustainable-drainage-systems-suds/

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1. Context – Thesis objectives

Quantitative assessment of the integrated urban water management practices at different scales, in various urban contexts across the french metropolitan hydropedoclimatic gradient.

- Improve modelling workflows and spatial data processing to facilitate operational deployment.
- Optimization of stormwater, wastewater and reuse management strategies using performance indicators.
- Give scientific recommendations for the hydrologic modelling to support climate-resilient urban development.

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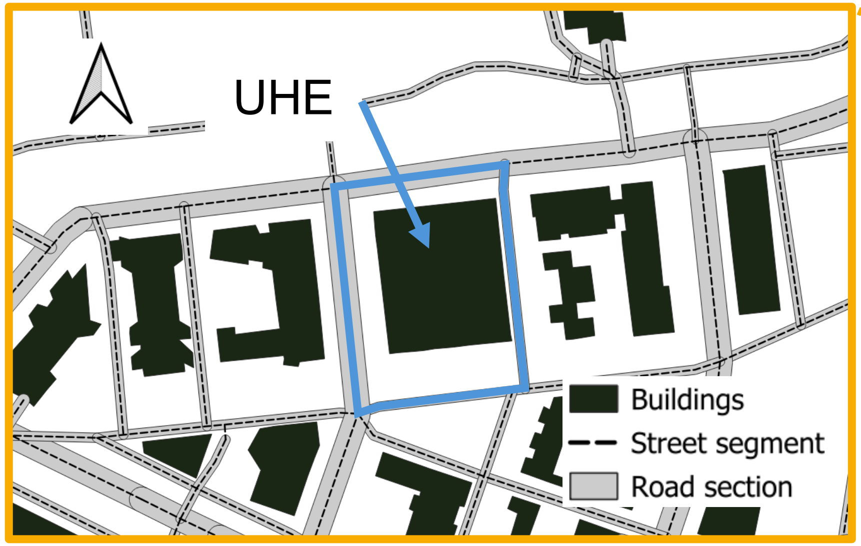
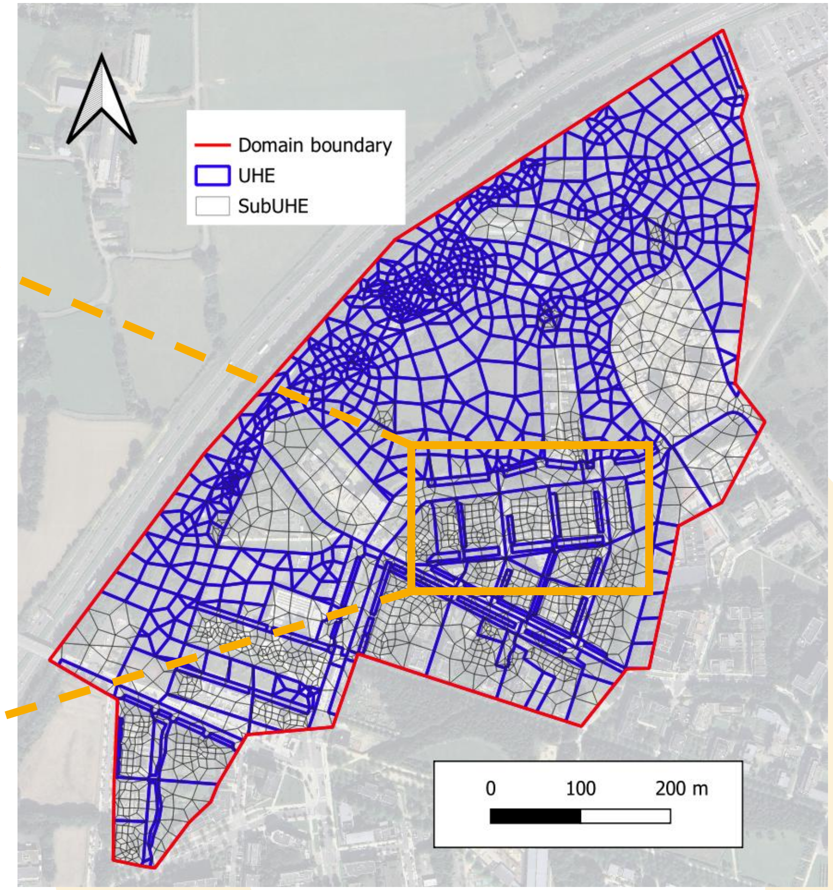
2. Hydrological response representation through modelling

Functioning of the URBS Model

(Rodriguez et al, 2008; Pophillat, 2022)





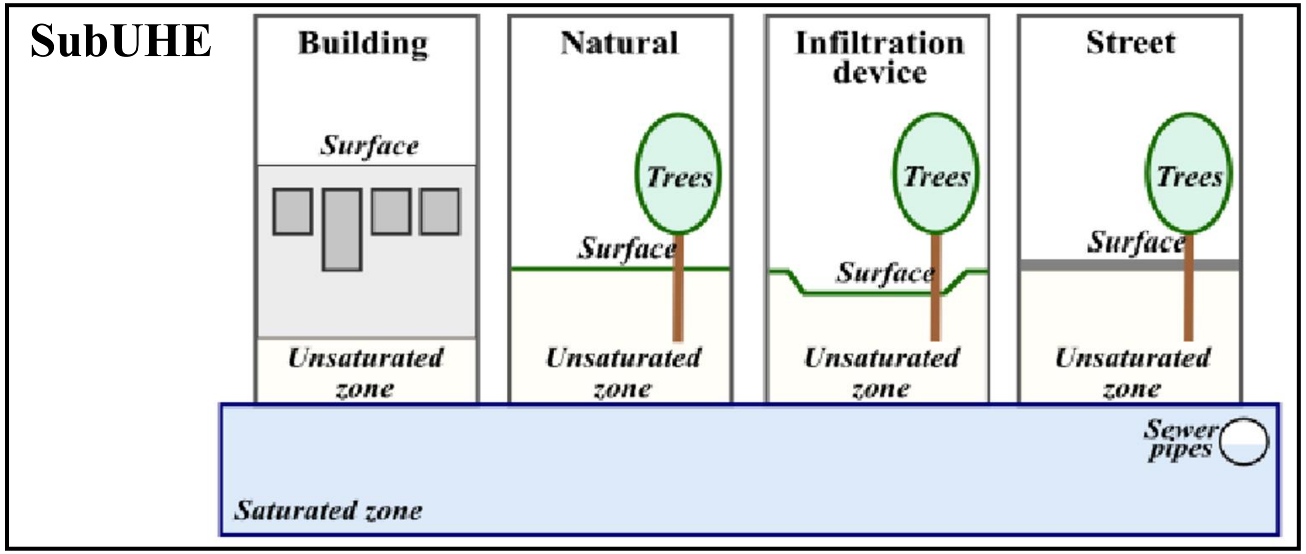
- Domain divided in UHE and SubUHE (Urban Hydrological Elements)
- Finite element approach
- Unstructured mesh
- Local refinement

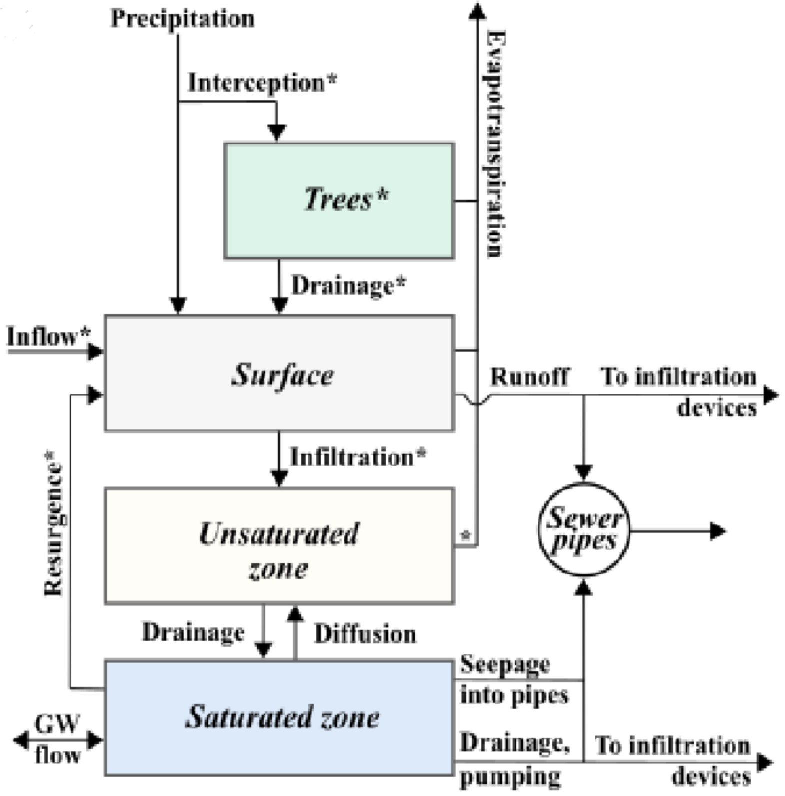
2. Hydrological response representation through modelling

Urban hydrological modelling approaches

Functioning of the URBS Model

(Rodriguez et al, 2008; Pophillat, 2022)





Schematization of the computation within the (sub)UHEs in the URBS model.
Division of a (sub)UHE according to the land use profiles - Fluxes computed within a profile (*except for buildings) (Pophillat, 2022).

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Urban hydrological modelling approaches

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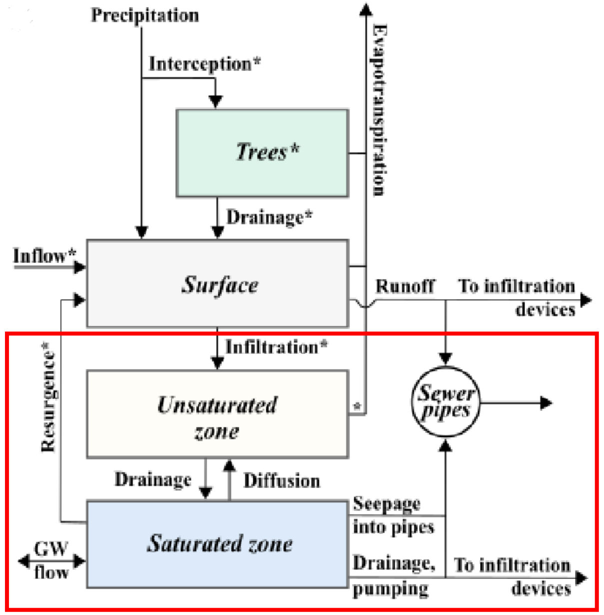
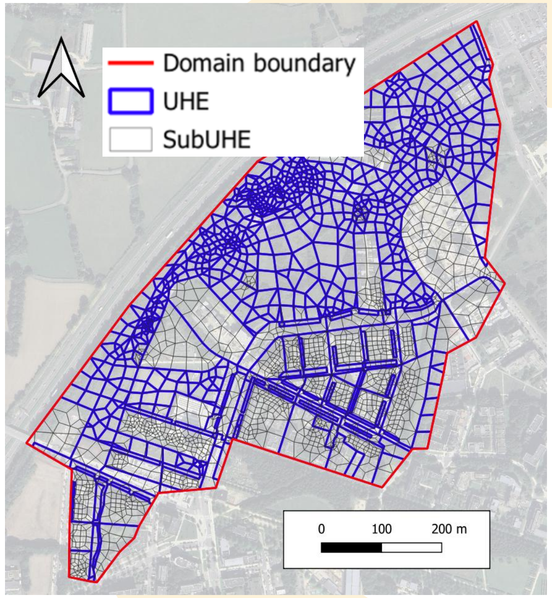


Schematization of the computation within the (sub)UHEs in the URBS model. Division of a (sub)UHE according to the land use profiles - Fluxes computed within a profile (*except for buildings) (Pophillat, 2022).

Boundary conditions:

- **Neuman (BCN):** represents lateral inflows in m^3/s **(Fixed)**
- **Dirichlet (BCD)**: represents hydraulic head in m **(Variable)**
- **Cauchy-type (BCC):** models a seepage, depends on the computed groundwater level and soil's bed elevation **(Dynamic)**



3. Assessment of hydrological response representation through modelling

URBS model implementation

Beauregard neighborhood (ZAC Rennes) case study

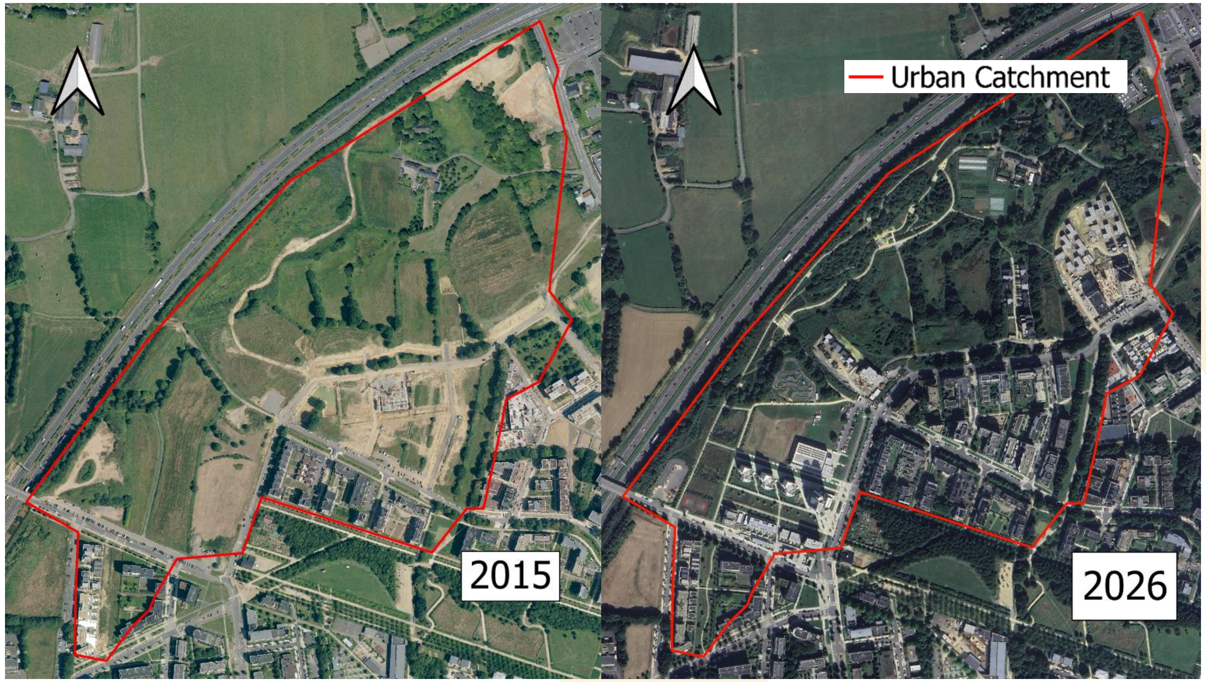
a. **Urban catchment description**
b. Hydrological data
c. Evaluation of model calibration

3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

a. Urban catchment description

- Peri urban catchment
- Surface area: ~35 Ha
- IUWM practices in place
- Impervious surface: ~26% at final developed state
- Source control devices: Swales and infiltration basins



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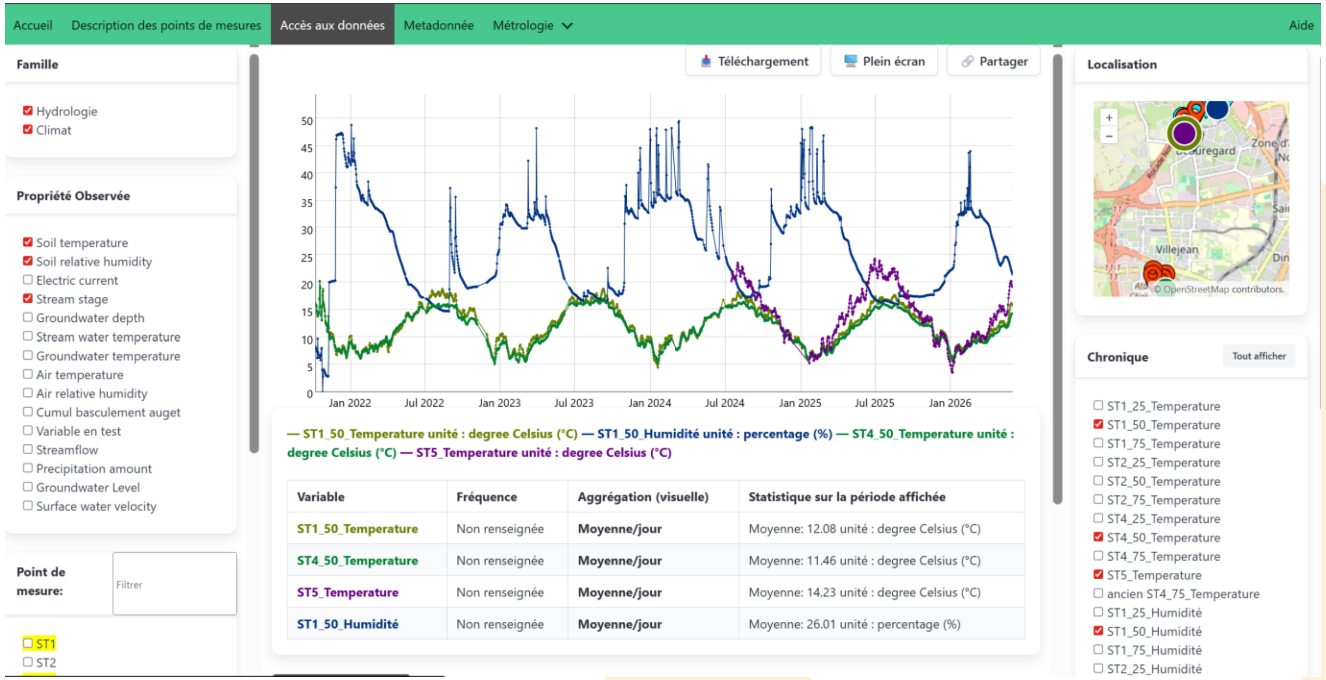
3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

b. Hydrological data

Work by Tom Lorée

Observatoires:
Site Urbain Rennais (SUR)
Station hydro météo Institut Agro



Variable	Fréquence	Agrégation (visuelle)	Statistique sur la période affichée
ST1_50_Temperature	Non renseignée	Moyenne/jour	Moyenne: 12.08 unité : degree Celsius (°C)
ST4_50_Temperature	Non renseignée	Moyenne/jour	Moyenne: 11.46 unité : degree Celsius (°C)
ST5_Temperature	Non renseignée	Moyenne/jour	Moyenne: 14.23 unité : degree Celsius (°C)
ST1_50_Humidité	Non renseignée	Moyenne/jour	Moyenne: 26.01 unité : percentage (%)

https://geosas.fr/stav_test/espace/telechargement/?config=https%3A%2F%2Fgeosas.fr%2Fstav_test%2Fconfig%2Fsur-rennes.json

3. Assessment of hydrological response representation through modelling

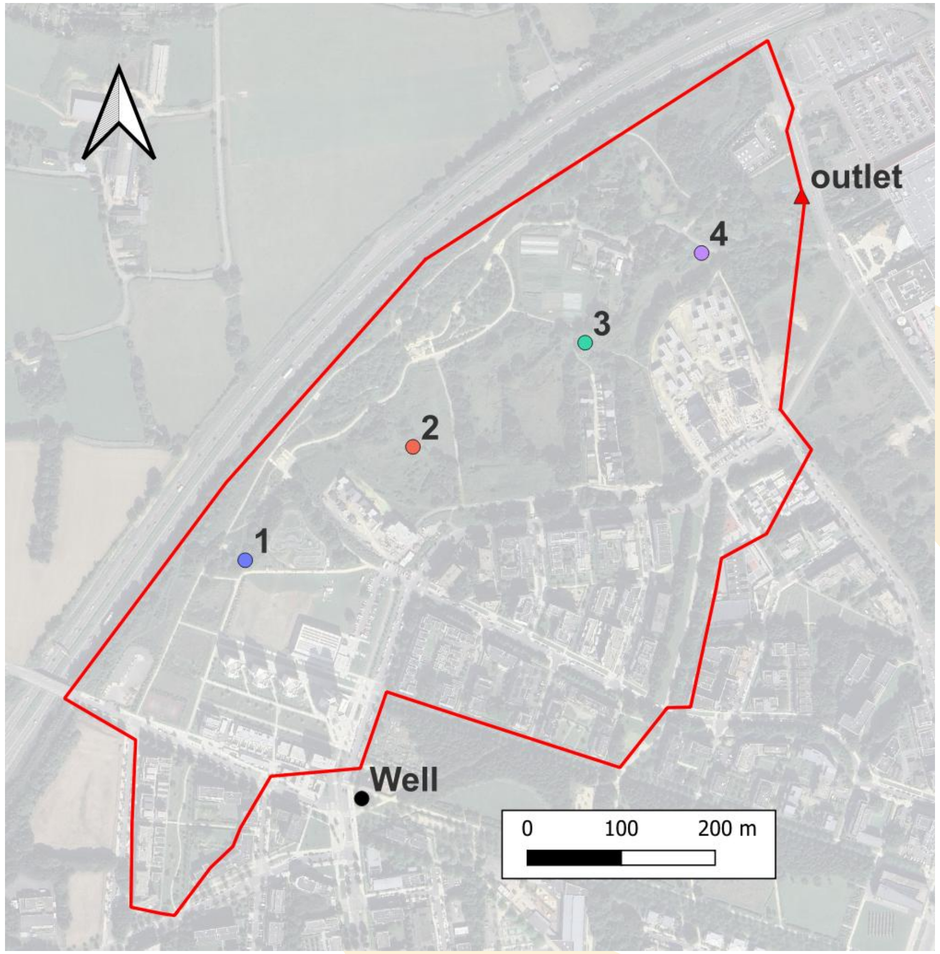
Beauregard neighborhood case study

b. Hydrological data

Site Urbain Rennais (SUR)

Location	Groundwater level	Water content	Streamflow
1	X	X	
2	X	X	
3	X		
4	X	X	
Well	x		
Outlet			X

- ➢ Continuous measurements time series
- ➢ Manually measured data
- ➢ Data correction and evaluation

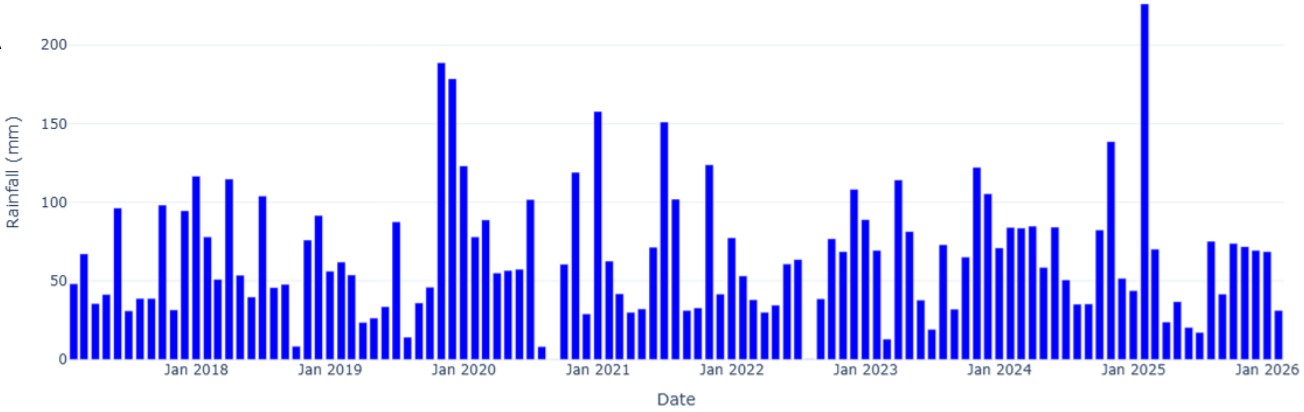


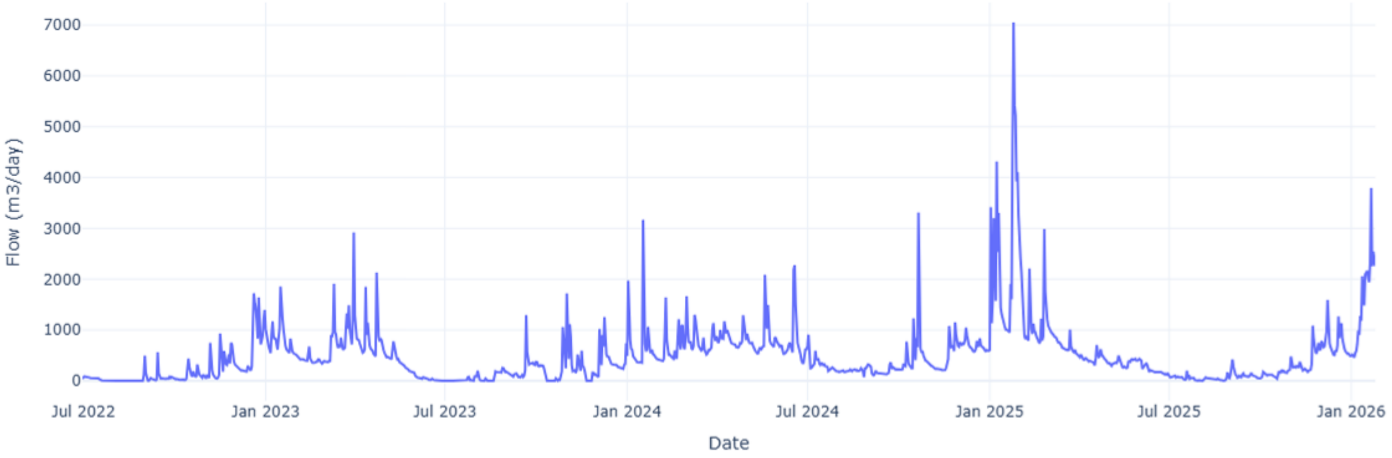
3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

b. Hydrological data

- Rainfall depth at Institut Agro Rennes-Angers
- Streamflow at catchment outlet





Year	Cumulative rainfall (mm)
2018	767
2019	873.8
2020	812.2
2021	797.8
2022	661.6
2023	803.8
2024	832.8
2025	795

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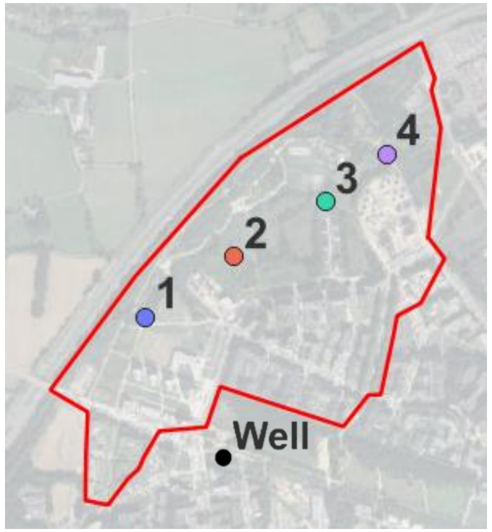
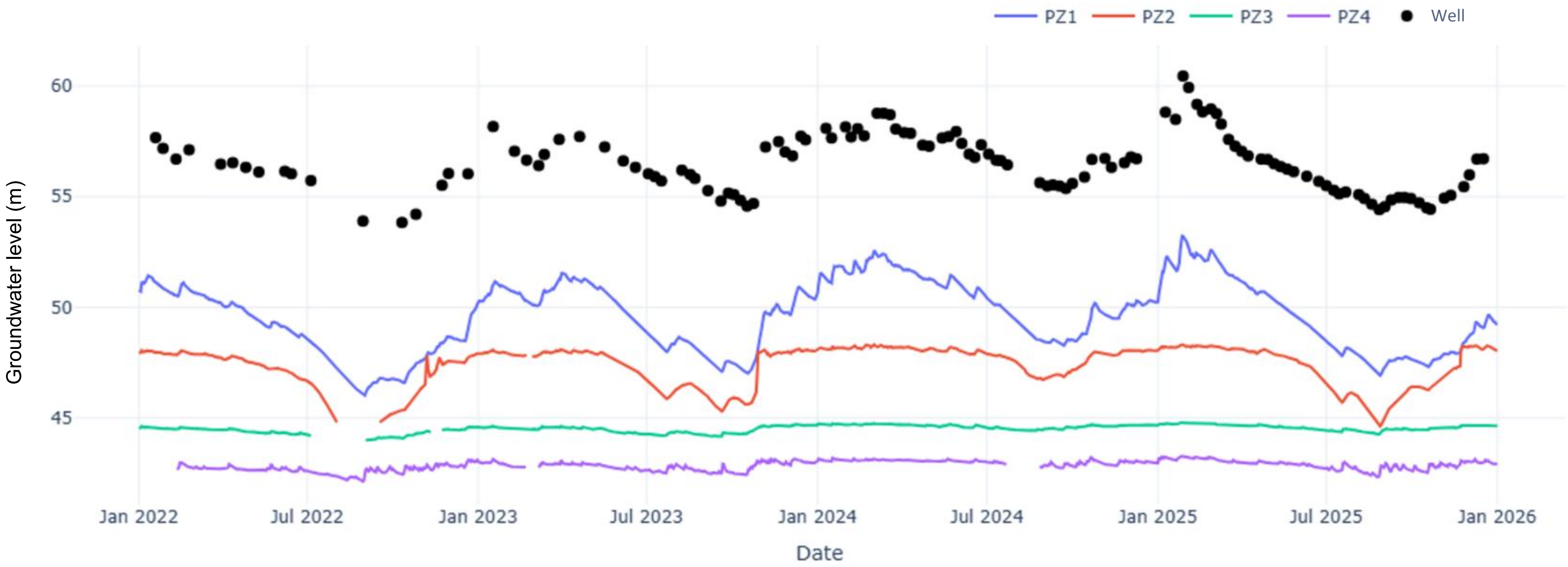
5. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

b. Hydrological data – groundwater level





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3. Assessment of hydrological response representation through modelling

URBS model implementation

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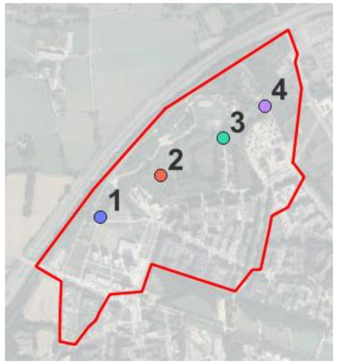
b. Hydrological data

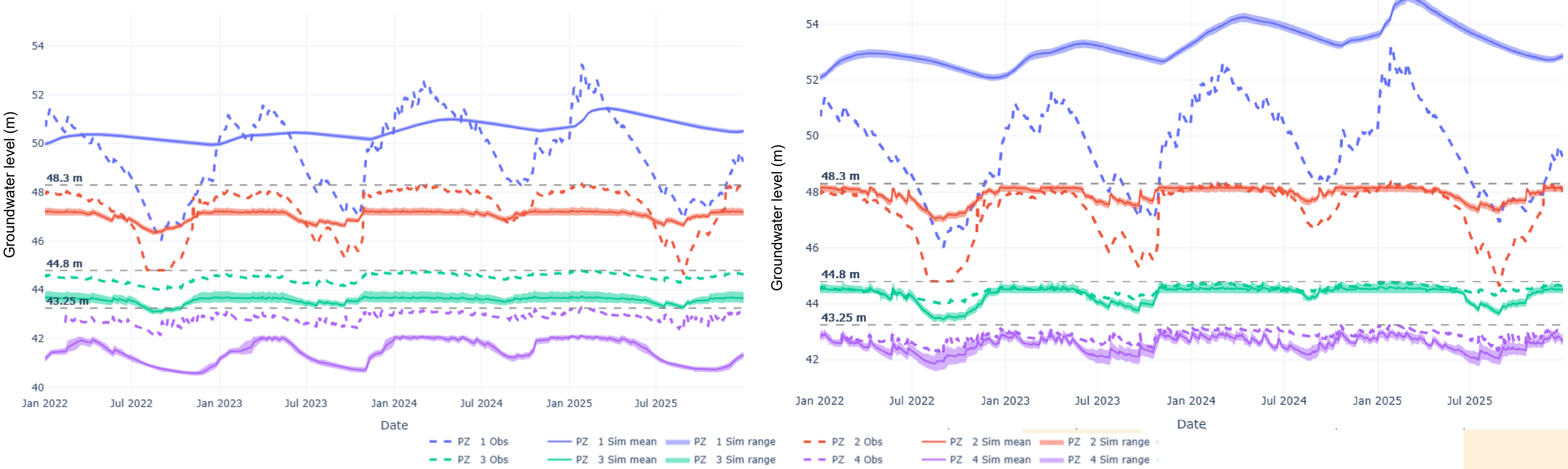
c. **Evaluation of model calibration**



3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

f. Evaluation of model calibration – Spatialized groundwater level improvements



Bias:

PZ1	PZ2	PZ3	PZ4
0.975	-0.296	-0.921	-1.394

r:

PZ1	PZ2	PZ3	PZ4
0.401	0.895	0.834	0.626

Bias:

PZ1	PZ2	PZ3	PZ4
3.674	0.586	-0.168	-0.317

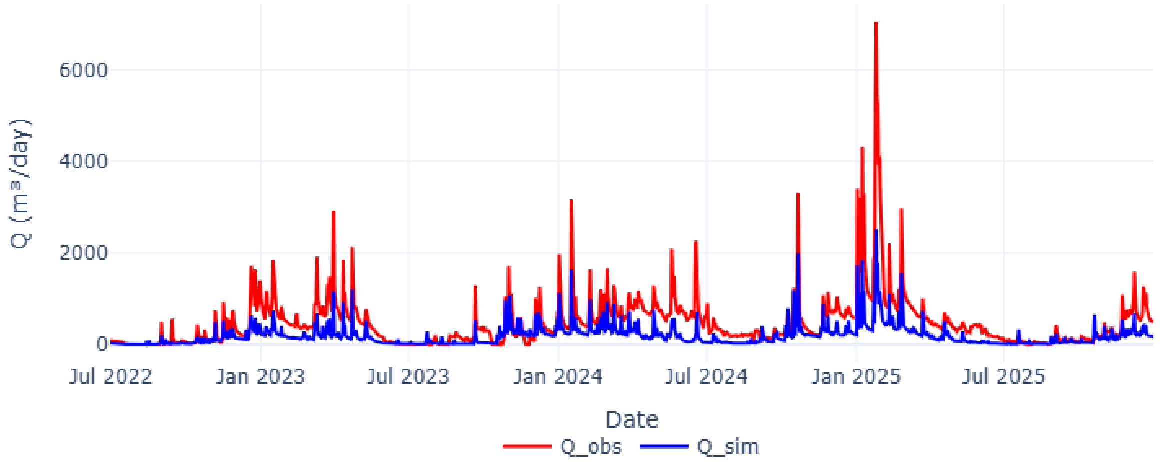
r:

PZ1	PZ2	PZ3	PZ4
0.548	0.909	0.832	0.876

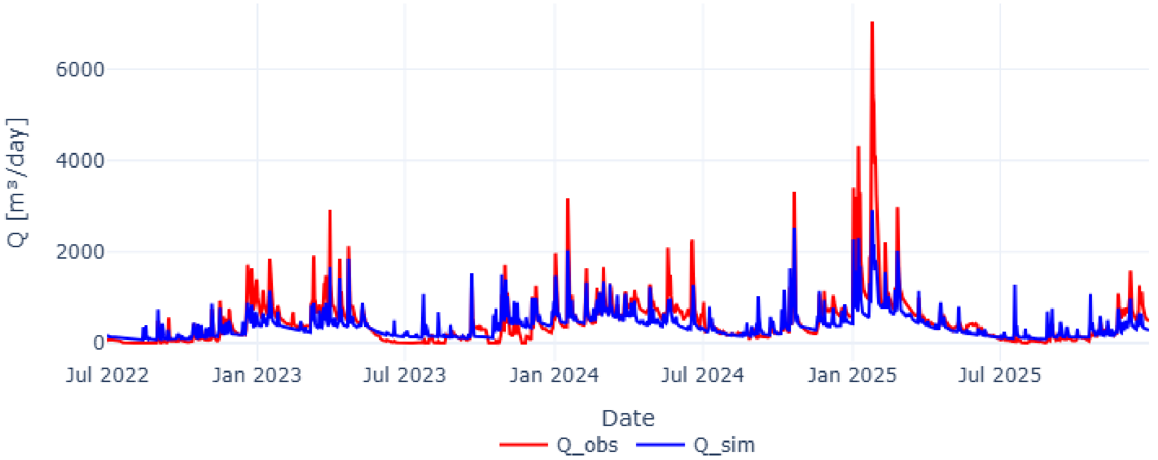
3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

f. Evaluation of model calibration – Streamflow improvements



Pearson r	R2	RMSE (m³/day)	Bias (%)	NSE
0.8745	0.7647	474.2385	-59.67	0.3054



Pearson r	R2	RMSE (m³/day)	Bias (%)	NSE
0.8716	0.7598	340.0549	-16.3	0.6428

4. Data mobilization – future developments

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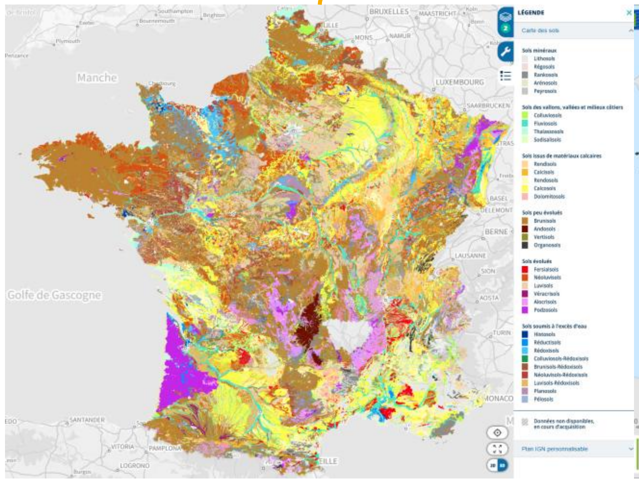
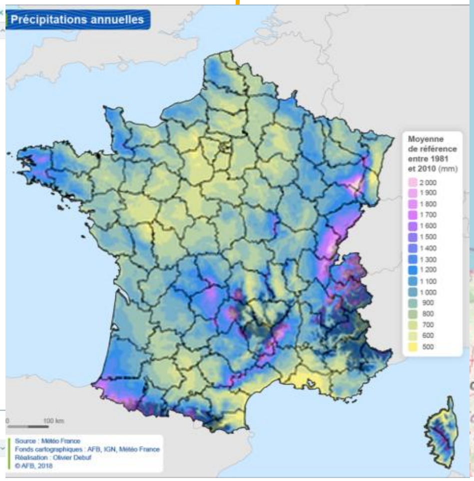
Study of the urbanization effects across the hydropedoclimatic gradient.

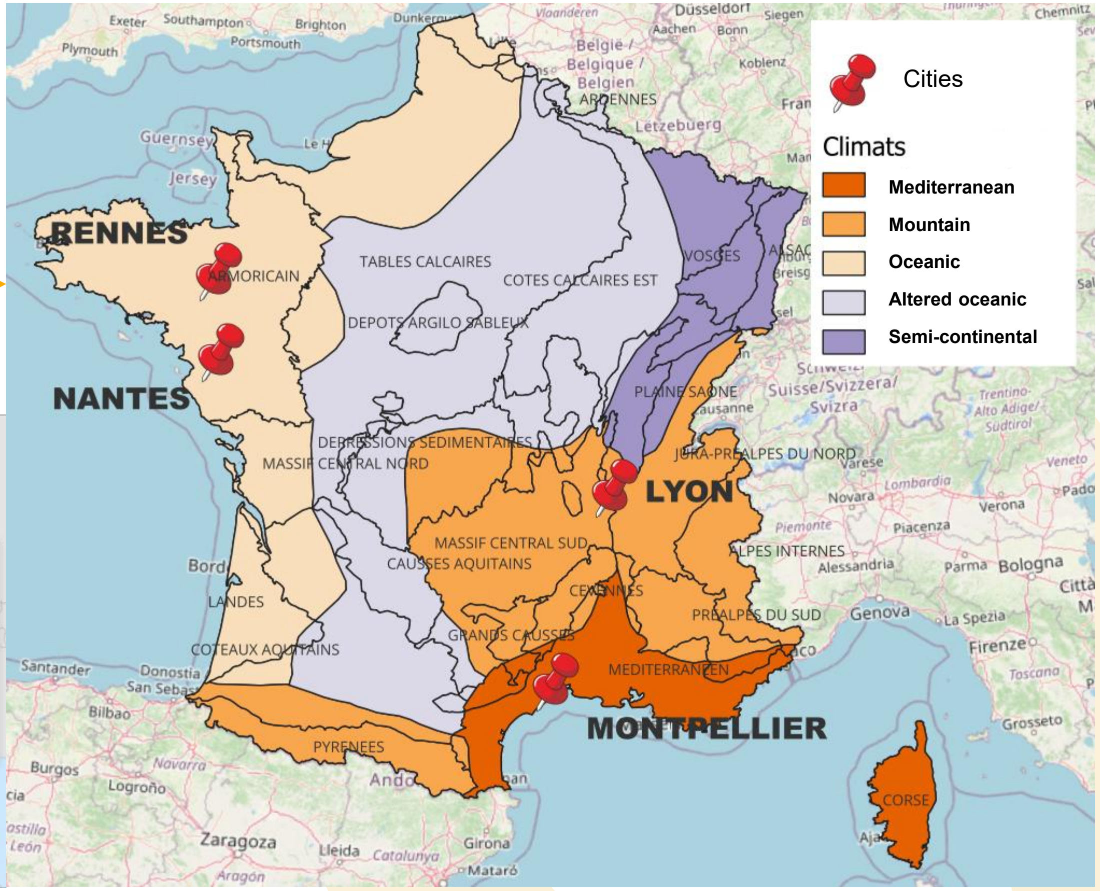
- 4 cities are potentially concerned
- Description of different hydrogeological and climatic conditions



https://www.geoportail.gouv.fr/donnees/carte-des-sols



https://www.eaufrance.fr/les-volumes-de-precipitations8



https://www.sandre.eaufrance.fr/definition/mdo/1.3/hydroecoregion1

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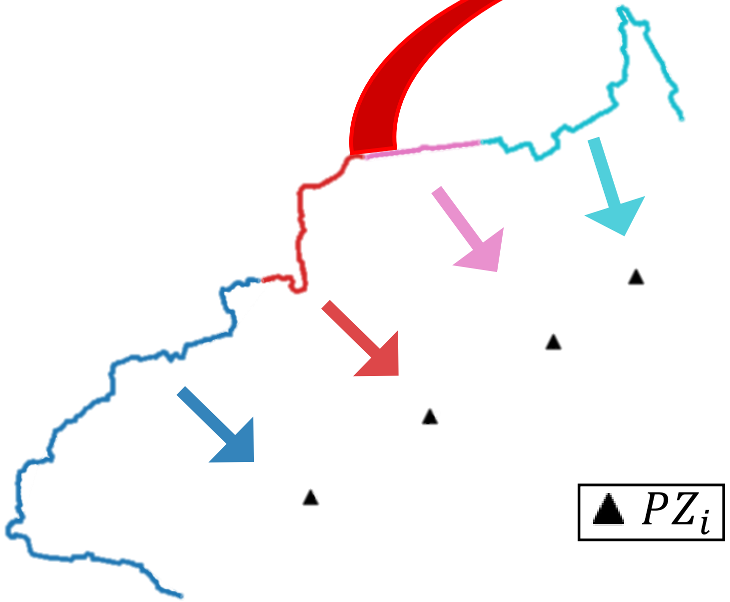
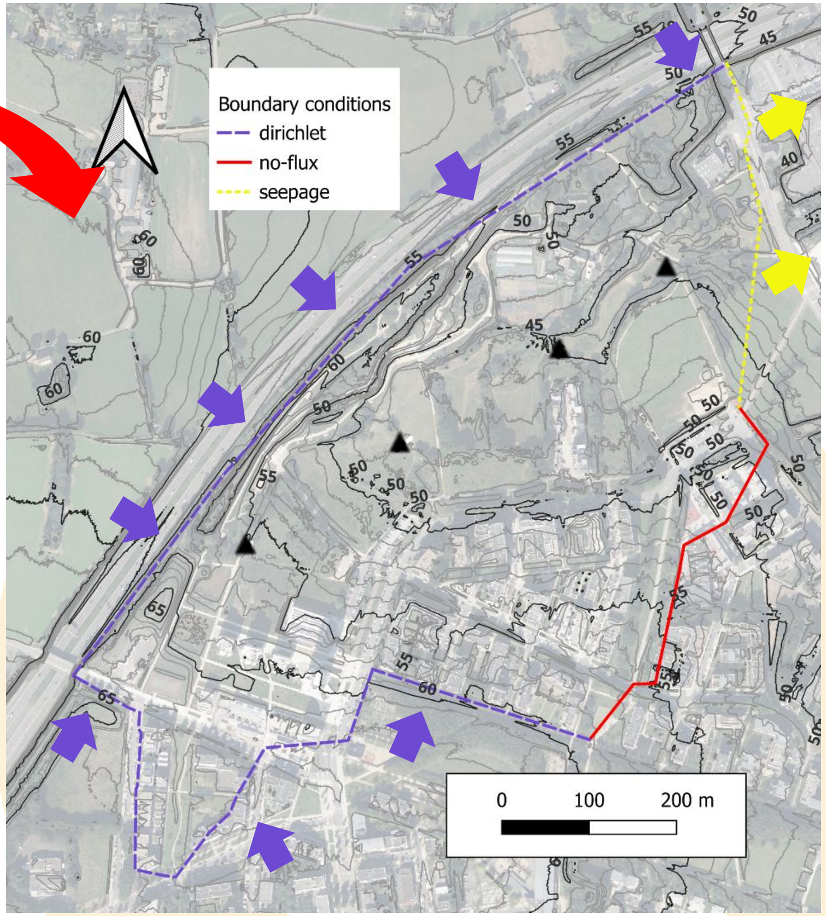
3. Assessment of hydrological response representation through modelling

Beauregard neighborhood case study

c. Boundary conditions





- Consideration of natural and urban catchments
- Groundwater level time series used for the introduction of variable boundary conditions (BC)

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c. Boundary conditions – function for variable hydraulic head boundary condition

Inflow Hydraulic gradients computing

↓

Build BC series for boundary elements

↓

BC file series reading function

↓

Date parsing function

↓

Element indentifying and BC updating function