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FROM RESEARCH TO INDUSTRY

# Using geostatistical methods to help optimizing an existing groundwater monitoring network

22<sup>nd</sup> June 2022 – Surface and subsurface hydrology session

Nathalie COURTOIS (CEA), Claire FAUCHEUX (Geovariances)



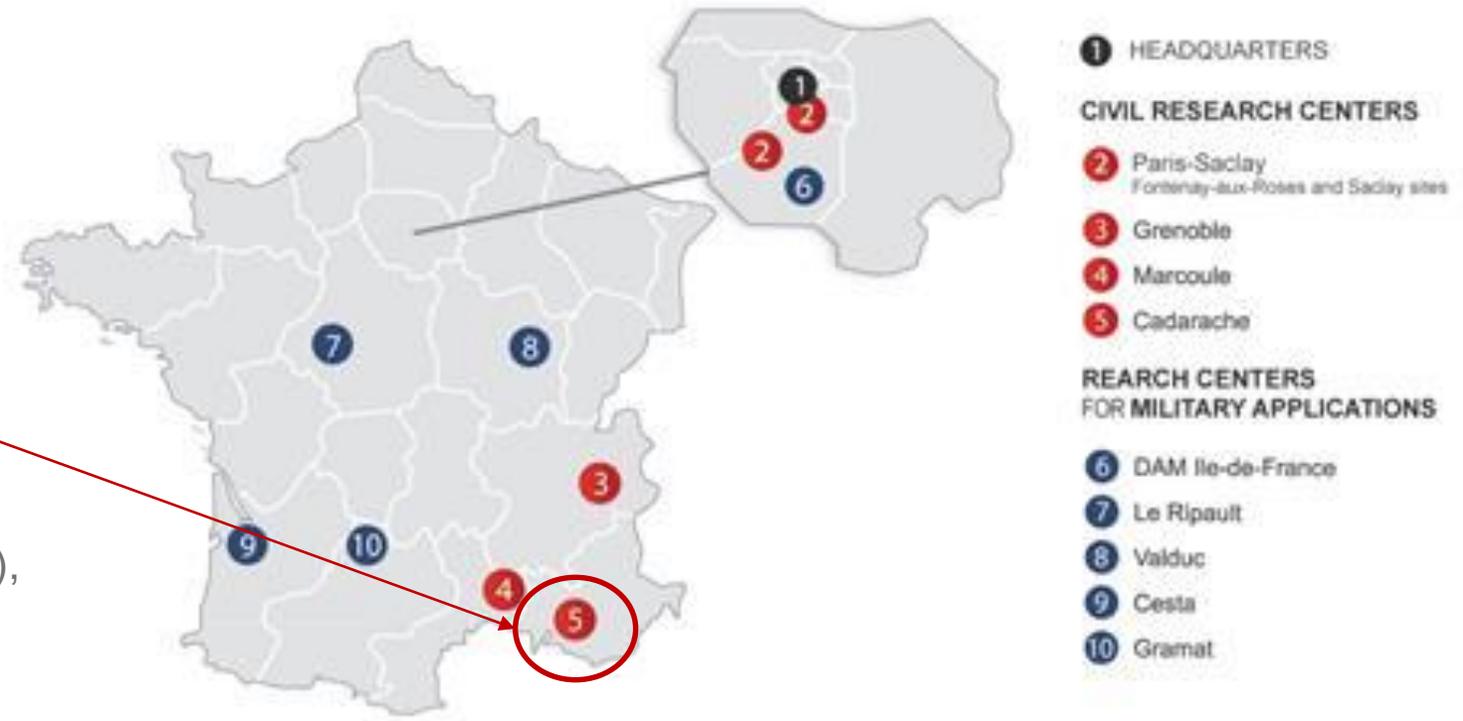
- French Alternative Energies and Atomic Energy Commission (**CEA**) is a key player in research, development and innovation in **four main areas**:
  - ▶ defense and security,
  - ▶ low carbon energies (nuclear and renewable energies),
  - ▶ technological research for industry,
  - ▶ fundamental research in physical sciences (matter and universe, climate and environment), health and life sciences.

- 9 research Centres**

- ▶ 20 181 employees
- ▶ 39 joint research units

- Study concern: Cadarache, South-East**

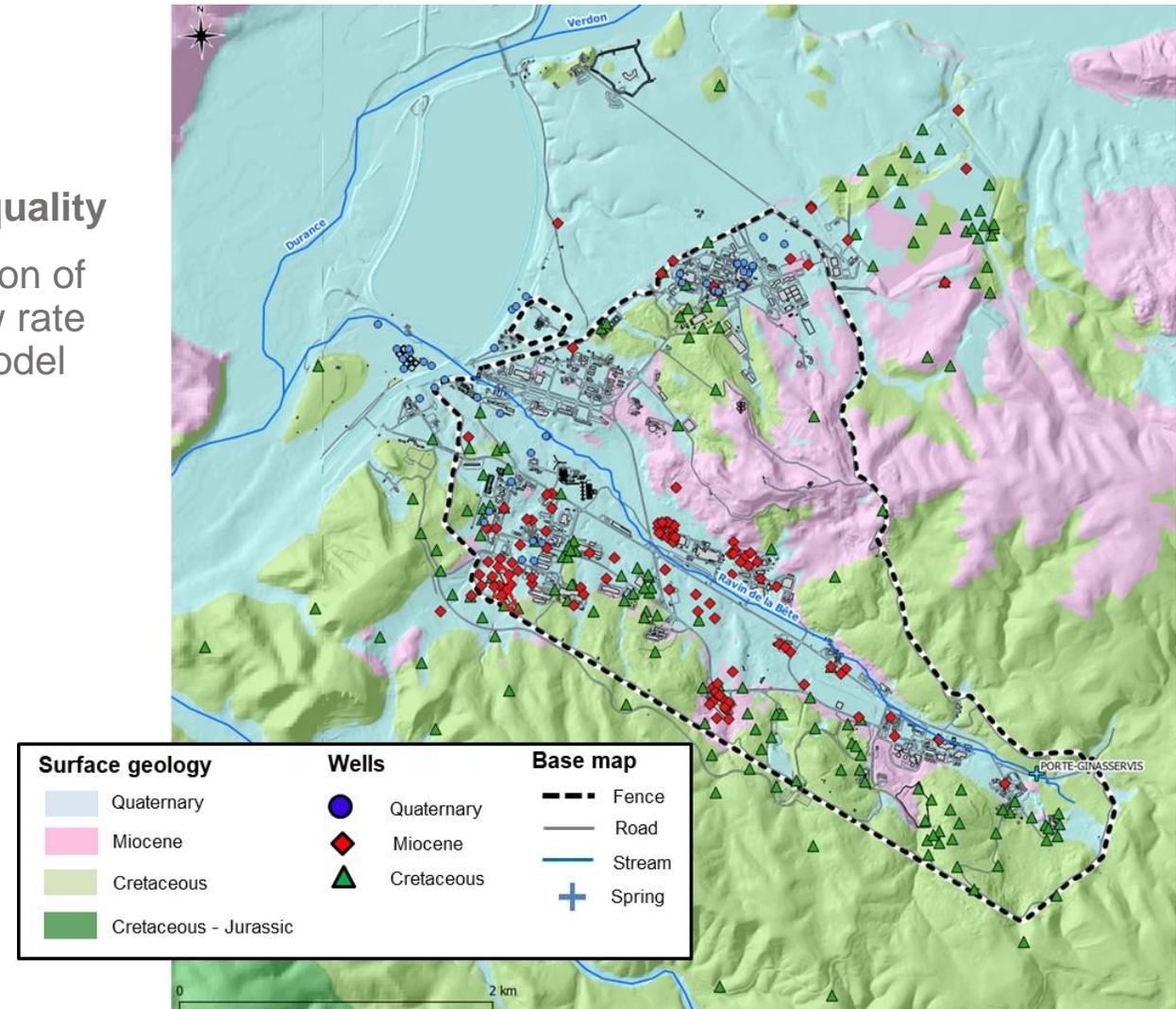
- ▶ Creation in the 60's
- ▶ A vast research Centre (900 fenced hectares), mixing natural areas and industrial activities
- ▶ ~ 40 facilities (Classified for Environment Protection and Nuclear)



- ❑ A complex geological and hydrological context: **3 superimposed aquifers** (Quaternary, Miocene and Cretaceous)
- ❑ A quite dense **groundwater monitoring network**...
  - ▶ Currently: ~ 400 wells
  - ▶ Dedicated to the survey of both groundwater **levels** and **quality**
  - ▶ Which has continuously evolved since the 60's as a function of different needs: survey of new facilities, knowledge of flow rate and directions, improvement of the 3D hydrogeological model used for flow and transport simulations, etc.
- ❑ ... to be **optimized!**
  - ▶ Number and spatial distribution
  - ▶ (Too?) dense near facilities, lack in certain areas



Development of a **specific** and **original geostatistical methodology**



## □ Principal data

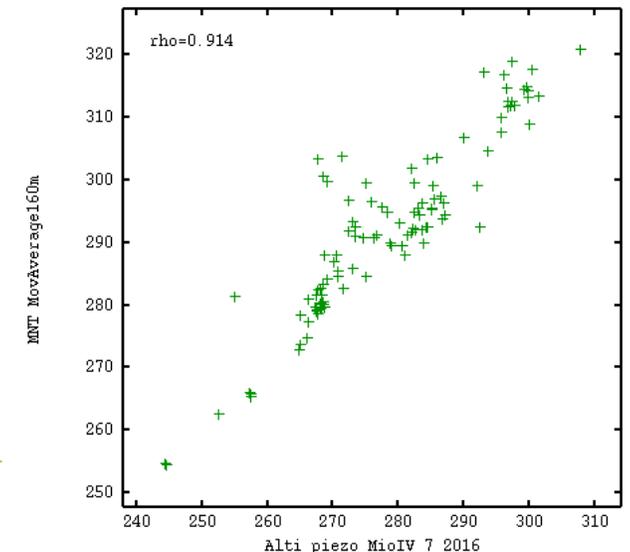
- ▶ **11 years** of annual/biennial **hydraulic heads data**, covering a large panel of hydrological conditions: low to high water levels.
- ▶ **Digital Elevation Model** (mesh 20 x 20m)
- ▶ **3D geological model**: top/bottom of geological formations

## □ Optimization objectives and criteria

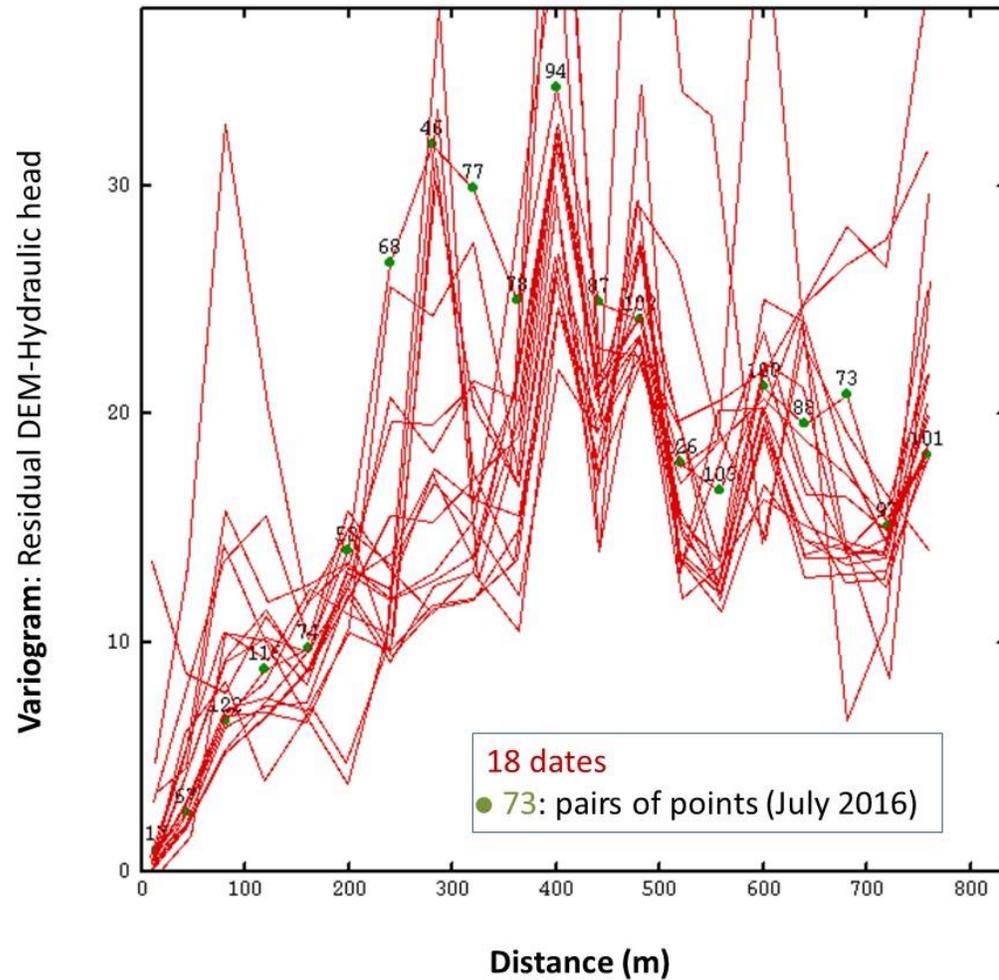
- ▶ Better knowledge of the piezometry at site's scale → **Reducing uncertainties** linked to **hydraulic heads estimation**
- ▶ Monitoring network able to detect an eventual pollution and its migration → **Focus on downstream from facilities**
- ▶ Optimize the number and spatial distribution of wells

## □ Based on kriged piezometric maps

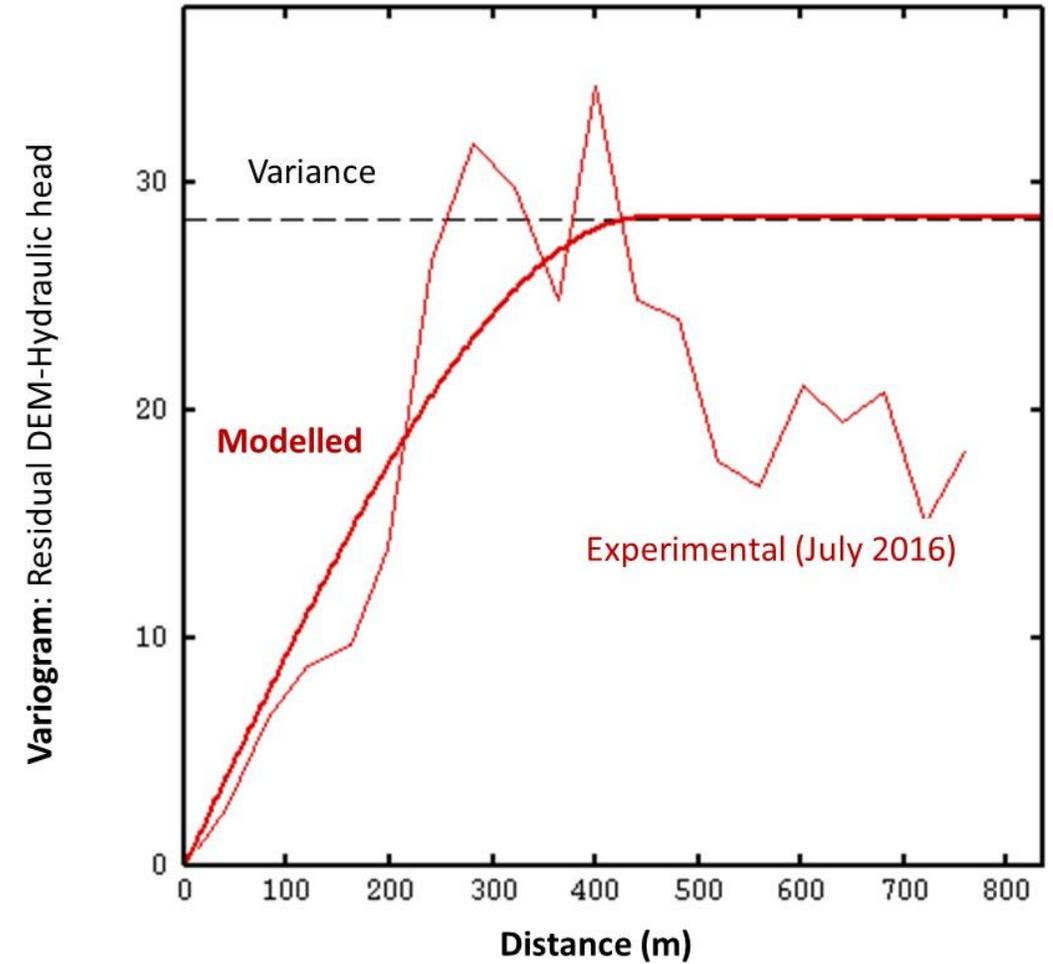
- ▶ **Variograms** calculated on hydraulic heads surveys for **18 dates**
- ▶ Corresponding head distributions constructed by **kriging**, mesh 2 x 2 m.
- ▶ For Quaternary/Miocene aquifers, as hydraulic heads and elevations are correlated, **smoothed Digital Elevation Model** is used as **external drift**.
- ▶ Residual variable: DEM – hydraulic head (m)



## □ 18 experimental variograms



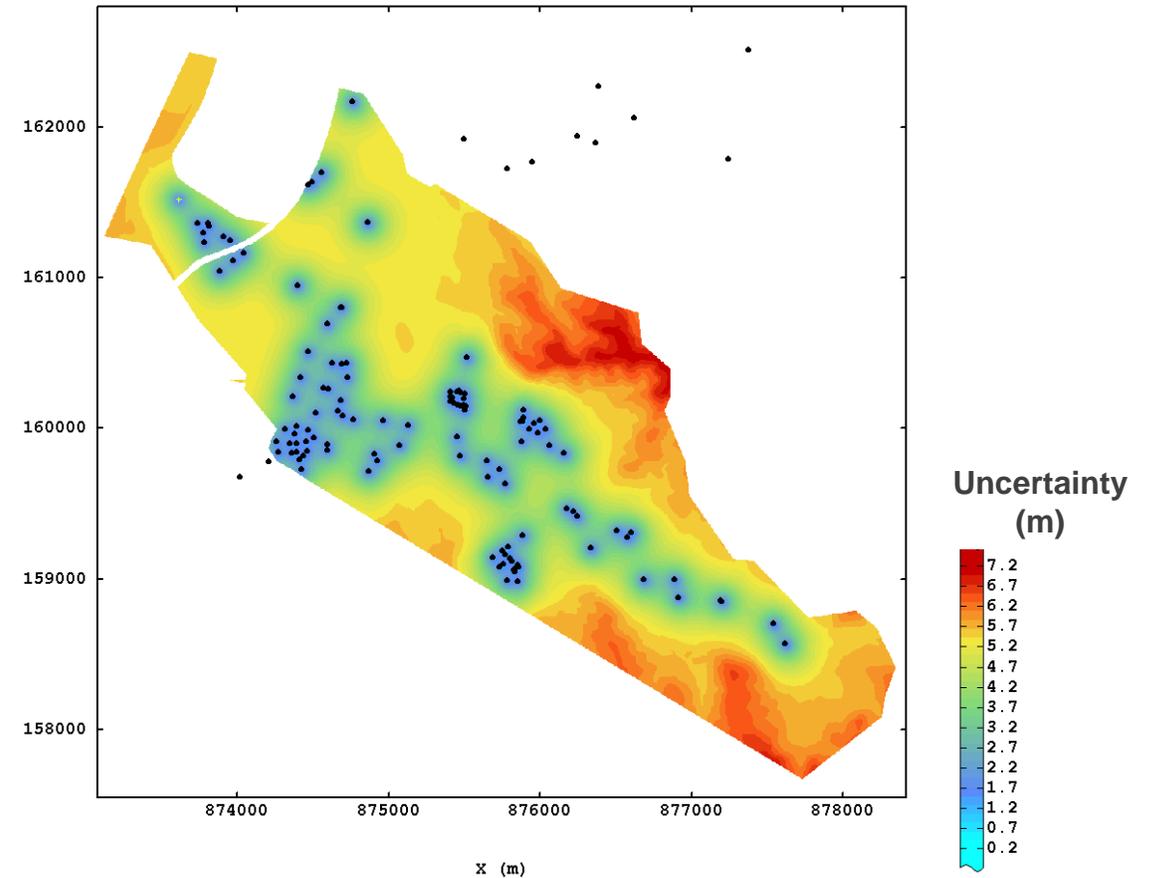
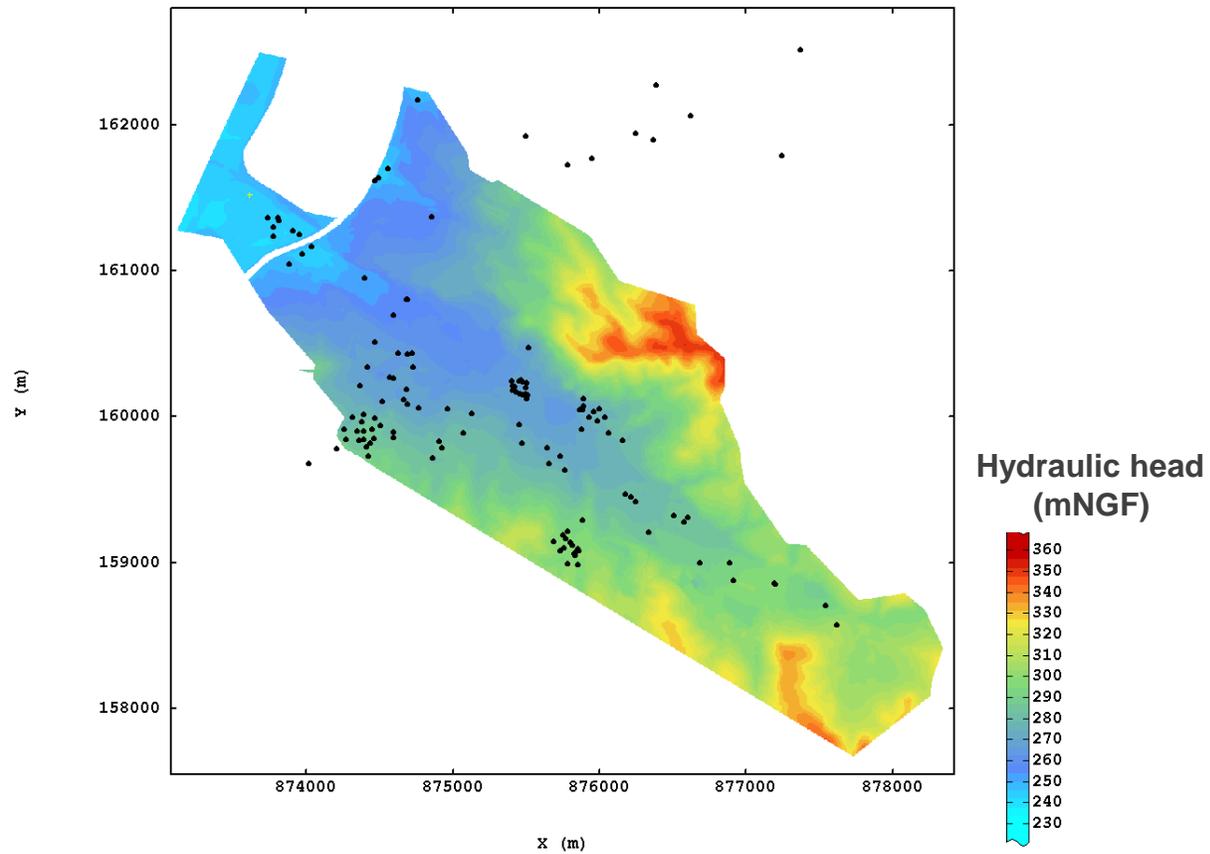
## □ One model



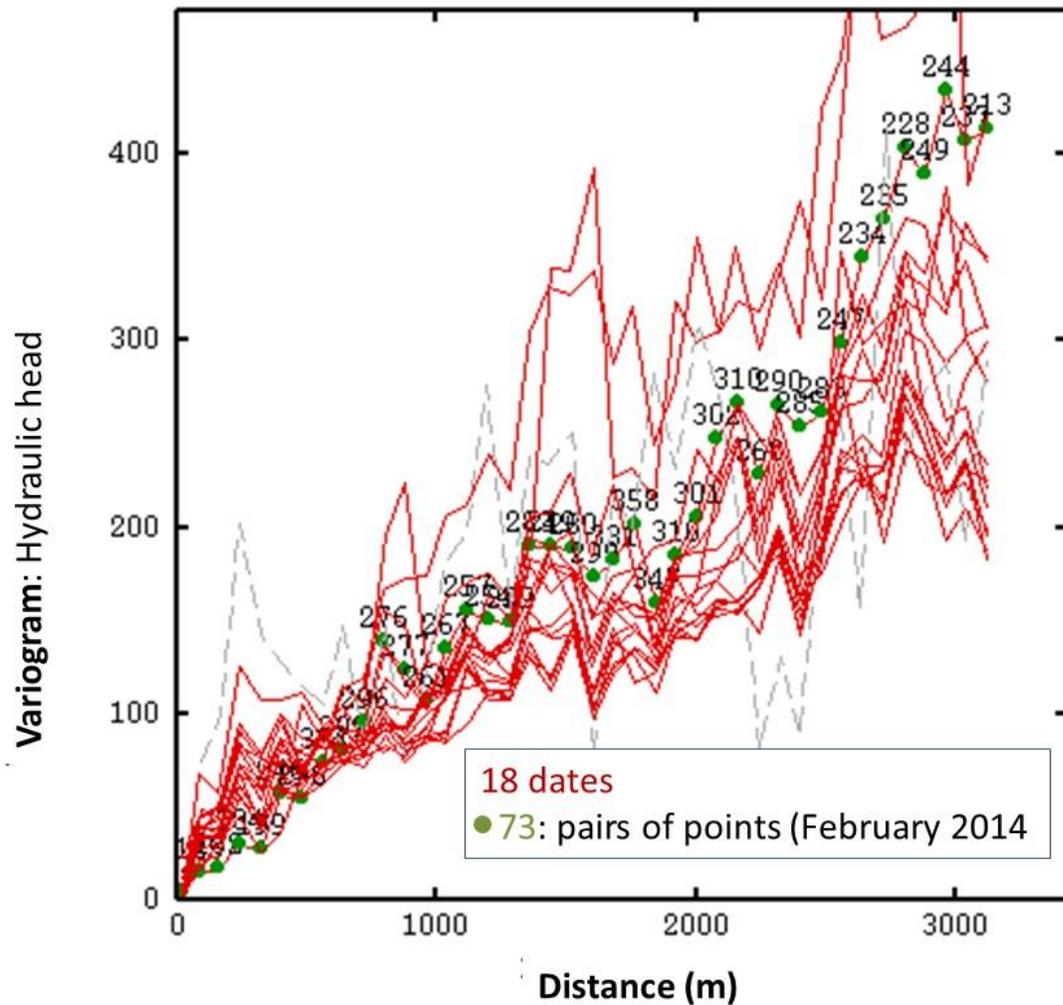
□ 18 kriged piezometric maps...



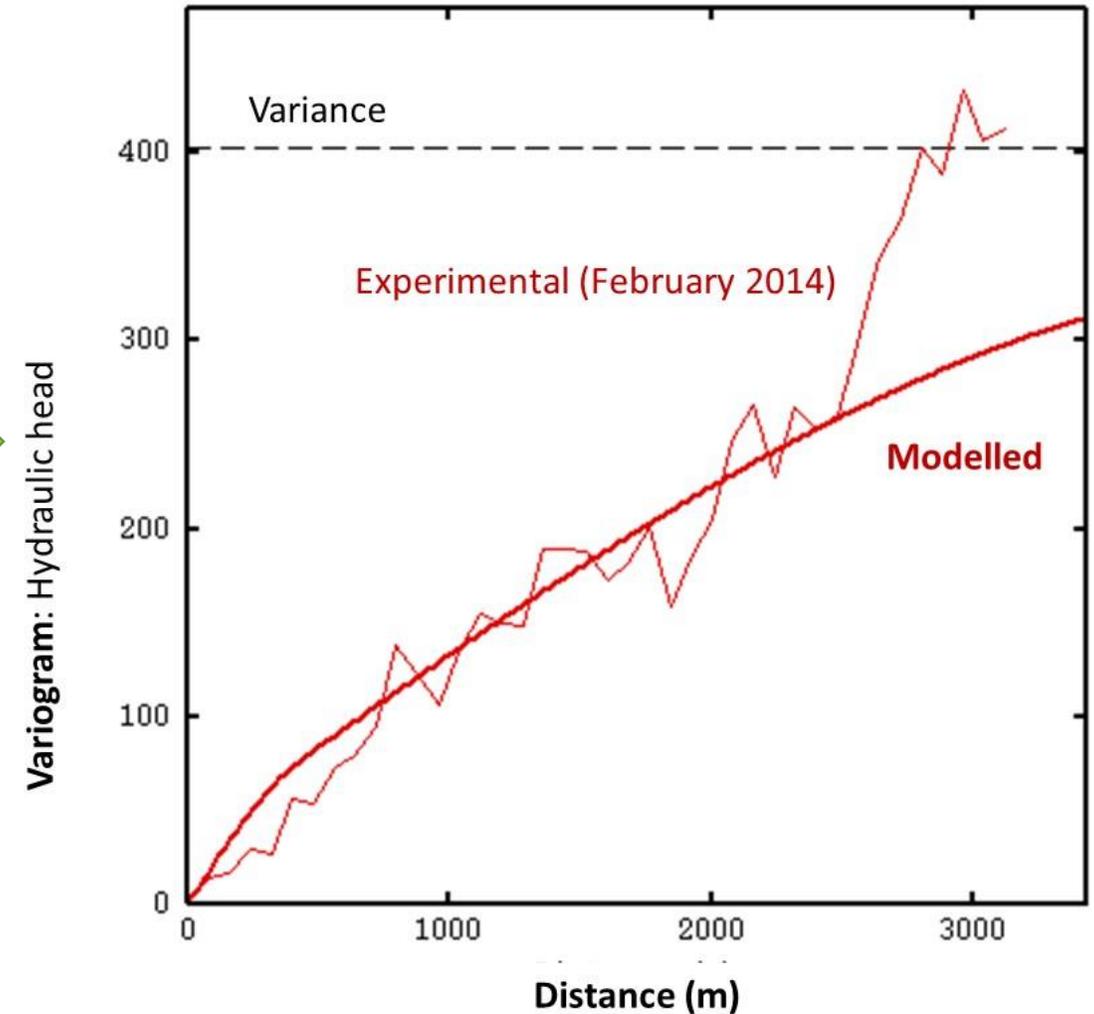
□ ... and 18 kriged uncertainties maps...



□ 18 experimental variograms



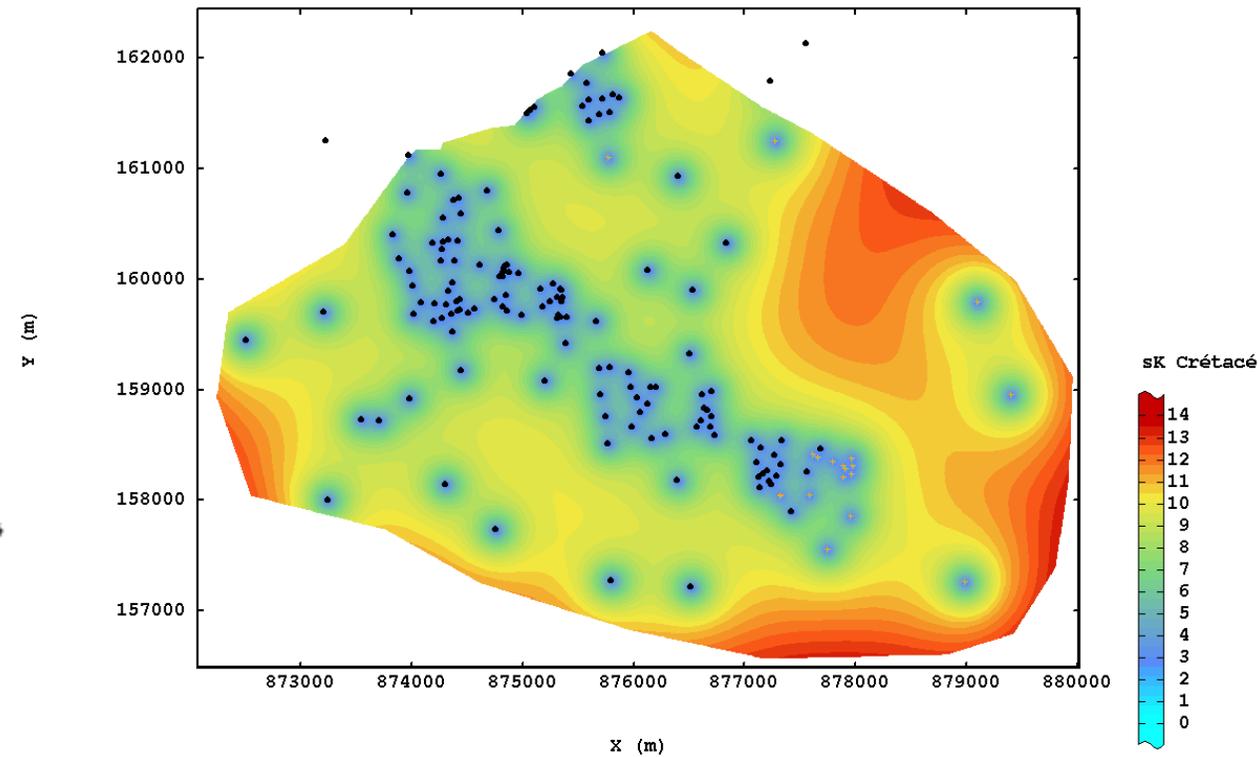
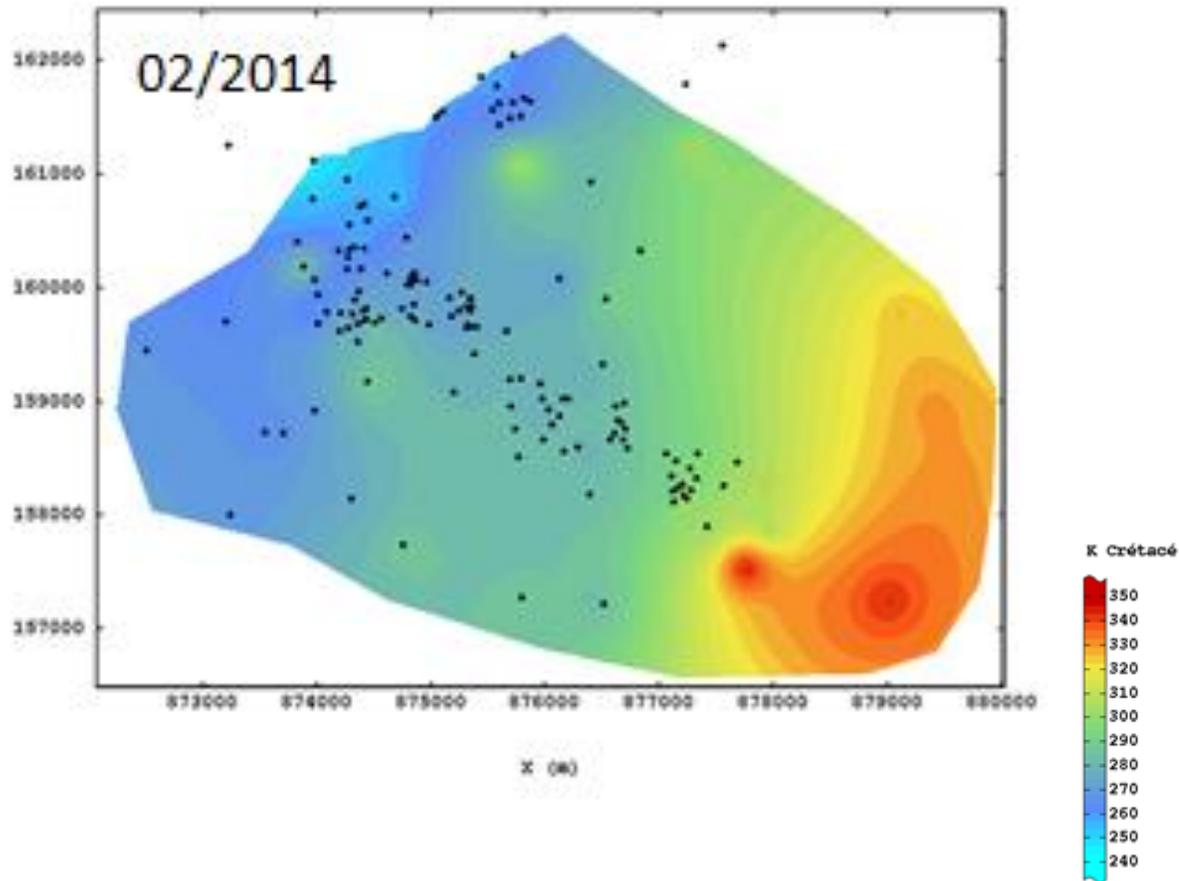
□ One model



□ 18 kriged piezometric maps...



□ ... and 18 kriged uncertainties maps...

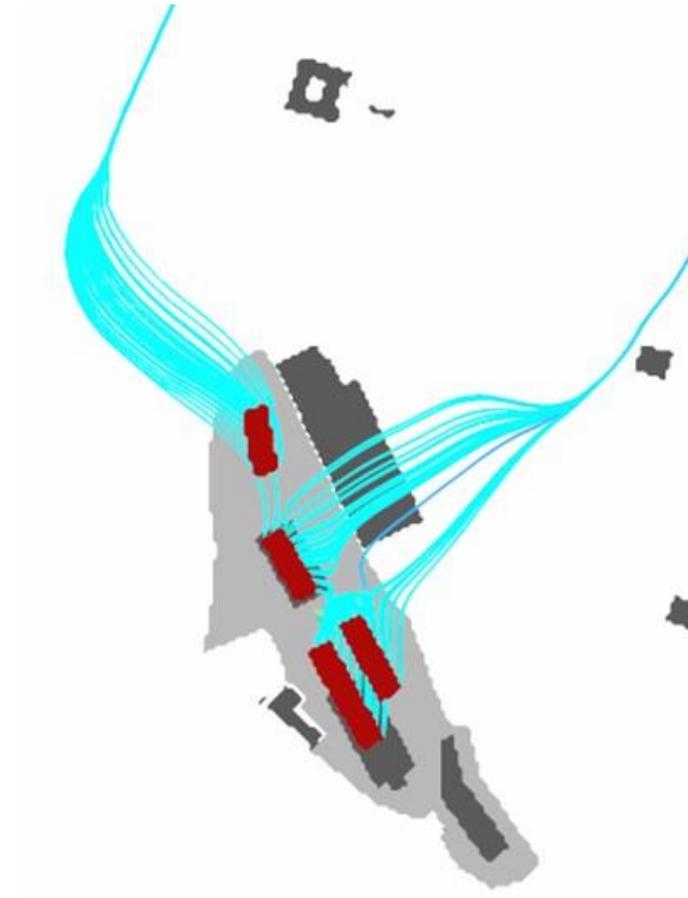


### □ Objective:

- ▶ Monitoring network able to detect an eventual pollution and its migration
- ▶ Having a better knowledge of the flows (directions and dispersion) downstream from facilities

### □ Principle: Use of “drops” trajectories

- ▶ Virtual “drops” put down on areas of interest (facilities, buildings, etc.)
- ▶ Calculation of the trajectories of these drops down to the kriged piezometric map (medium supposed to be homogeneous, constant velocity, no boundary conditions)
- ▶ Trajectories are calculated for each date (18) → ~ “dispersion” due to different hydrogeological conditions
- ▶ Number of drop passages are counted on the regular kriged grid



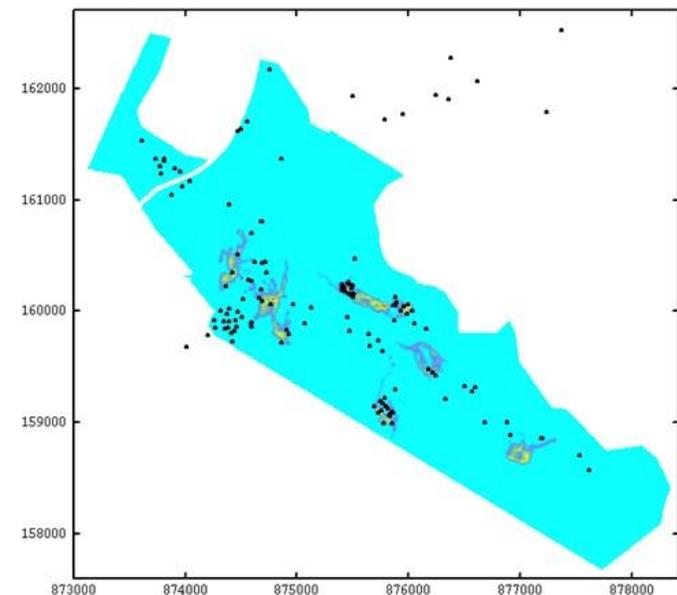
Trajectories of “drops” starting from buildings



Number of “drops” passages

❑ **Synthetic and multi-criteria maps to help for optimizing the existing monitoring network**

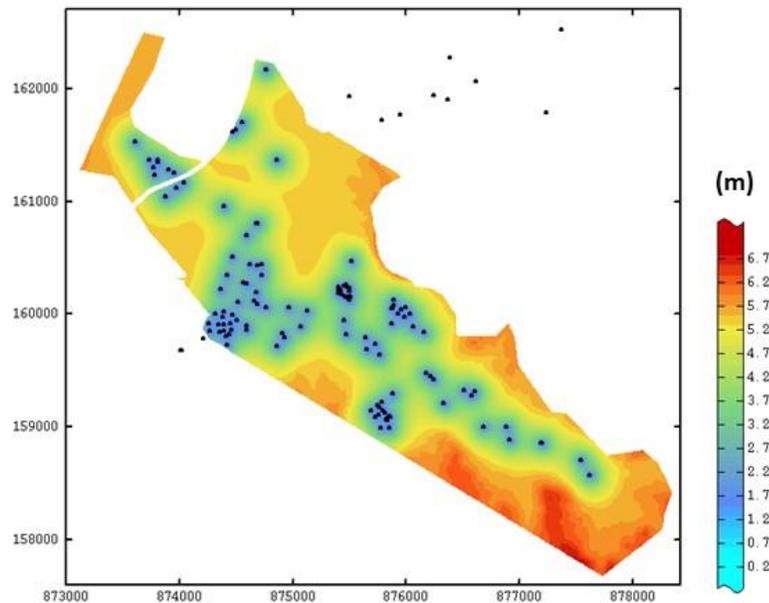
- ▶ **Criteria 1:** Map of trajectories (~ flow direction and dispersion) from facilities of interest
- ▶ **Criteria 2:** Map of uncertainties on hydraulic head
- ▶ **Criteria 3:** Map of distance from facilities



Number of "drops" passages

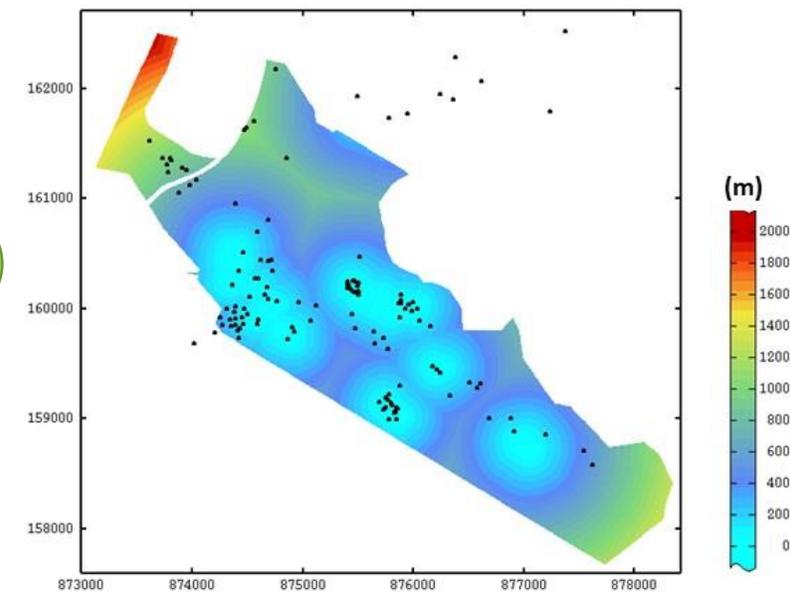
-  +

X



Hydraulic head uncertainty

X



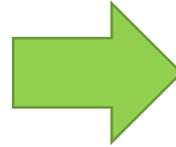
Distance from facilities

### □ To final synthetic map

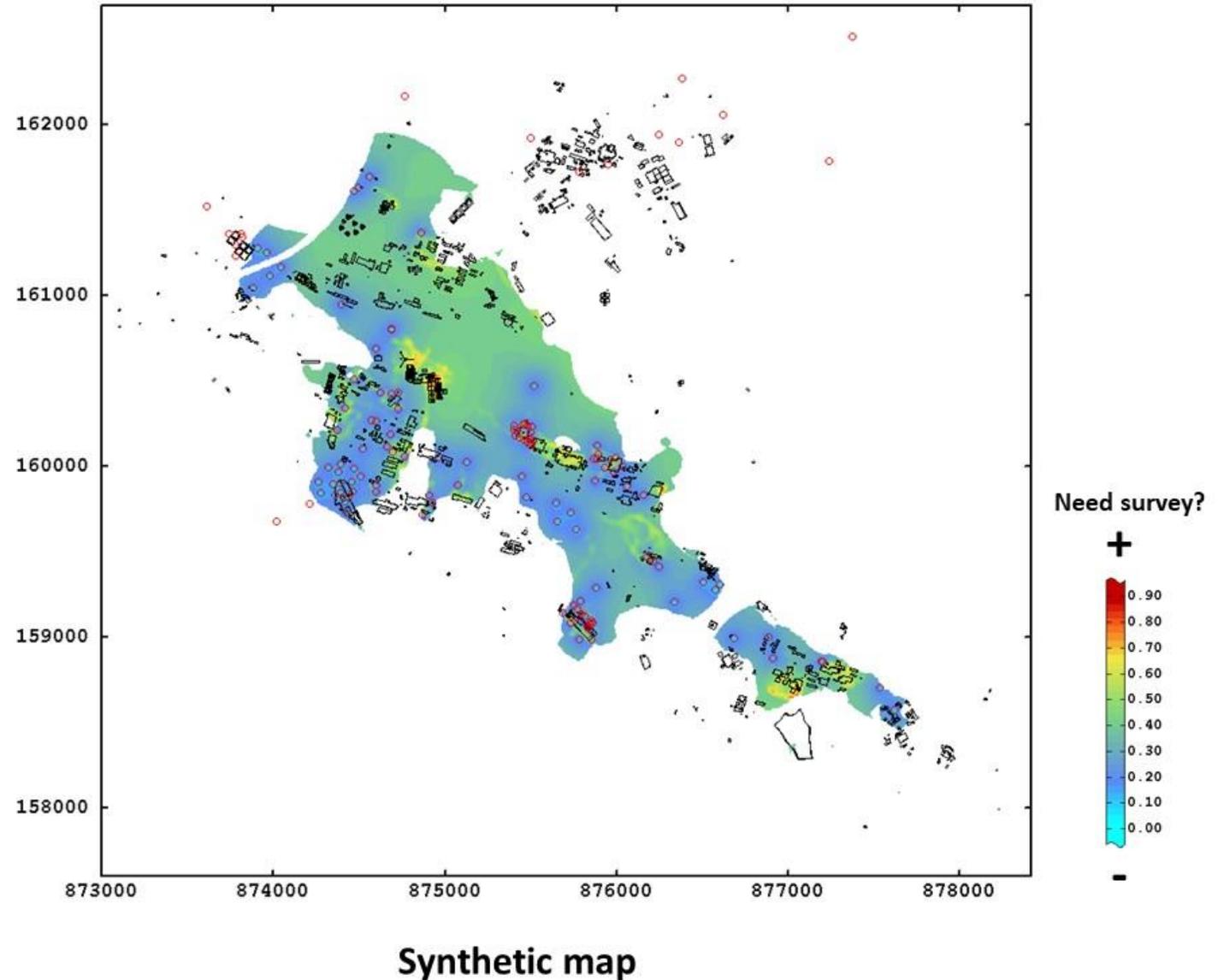
- ▶ Criteria are normalized to 1
- ▶ Test of different criteria weightings



$$0.45 \times \text{Trajectories} + 0.5 \times \text{Uncertainties} + 0.05 \times \text{Distance (if distance} < 400\text{m)}$$



- ▶ Highlighting the survey need
- ▶ Decision-making support



### Criteria for adding new wells

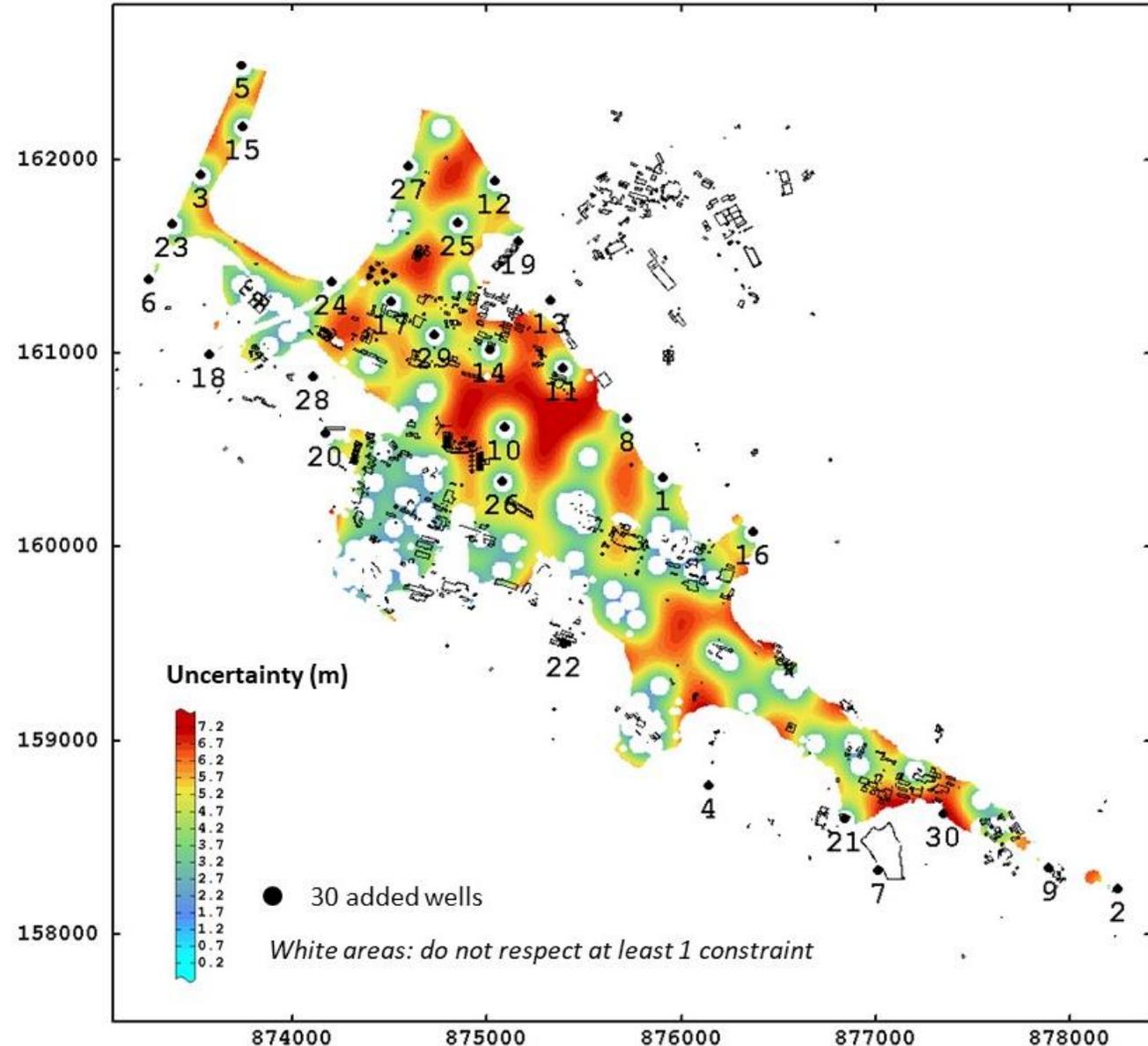
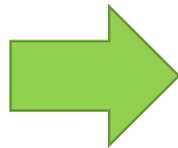
- ▶ Sequential implantation
- ▶ Priority in areas with high uncertainty on hydraulic head
- ▶ Objective: decreasing the uncertainty on hydraulic head in zones with few information

### 2 constraints all along the sequential process

- ▶ Distance to existing or new added wells  $> 50$  m
- ▶ Thickness of the geological layer (estimated with 3D model)  $> 10$  m

### Sequential addition of 30 wells

- ▶ Final synthetic map
- ▶ White areas: do not respect at least one constraint

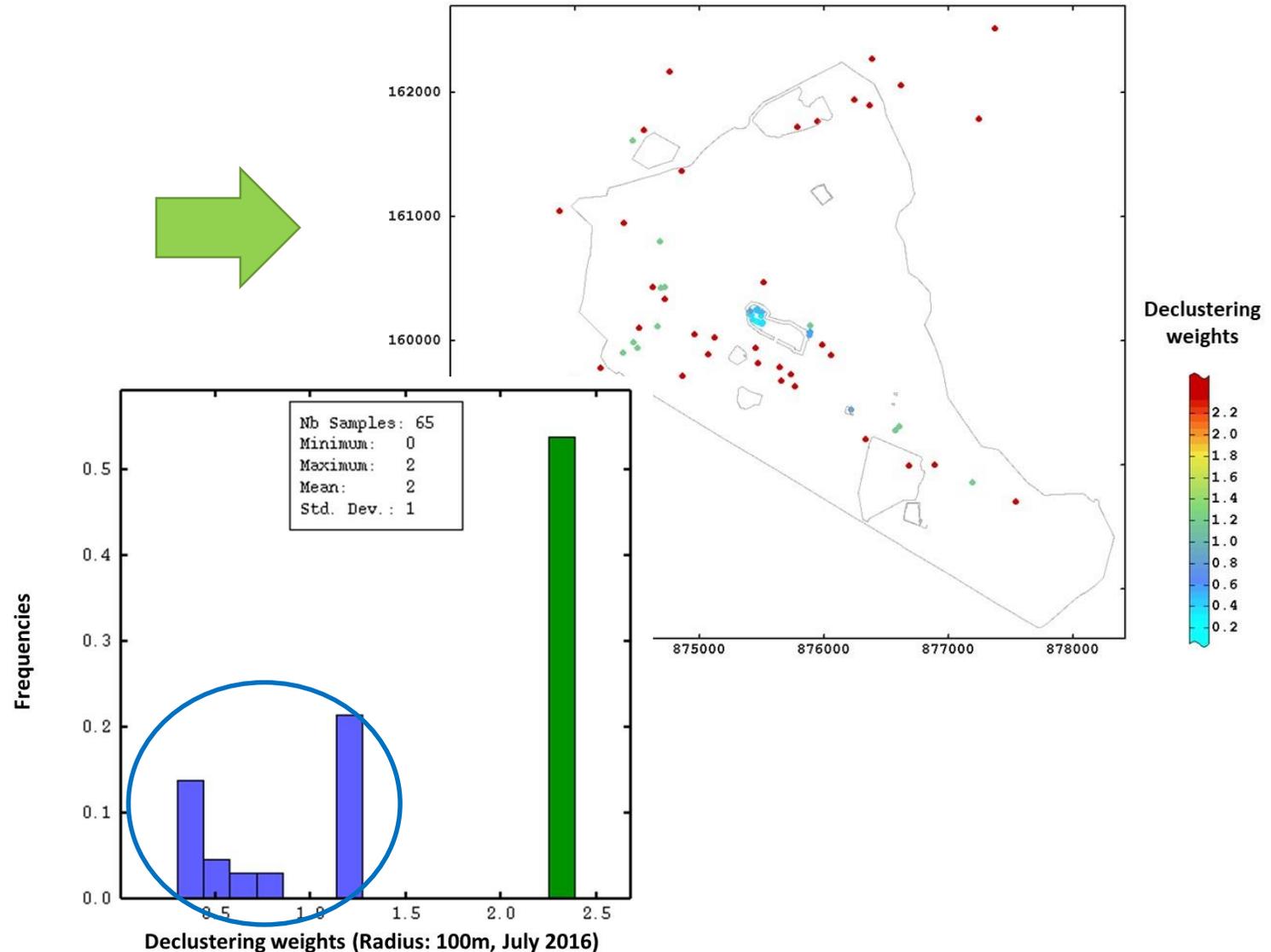


### Criteria for removing existing wells

- ▶ Sequential removal
- ▶ Criteria of **geometrical redundancy**
- ▶ Definition of **declustering weights**: all the more important as a well is isolated
- ▶ Test of different **declustering radius** (25 to 250 m) to **highlight wells groups** and **prioritize wells** to be removed

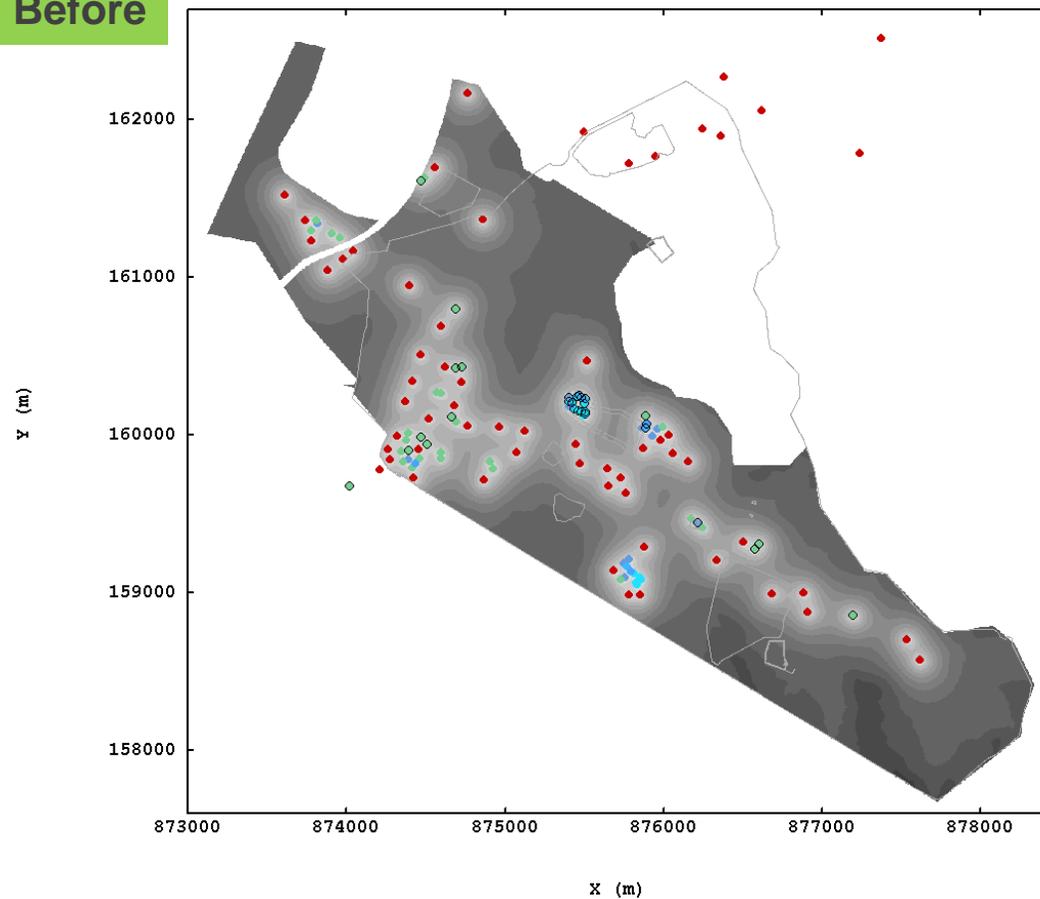
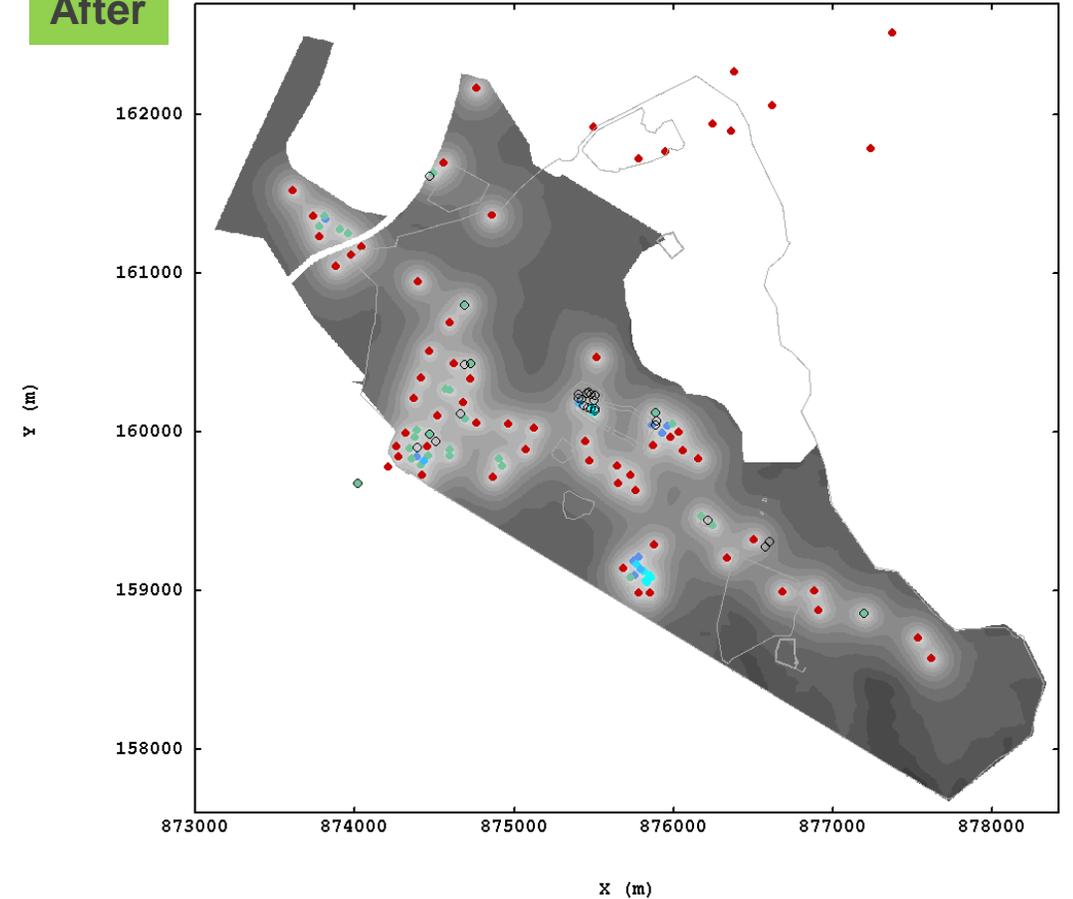
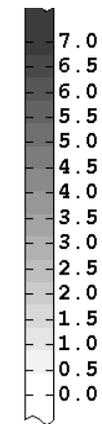
### Declustering process

- ▶ Declustering radius: 100m
- ▶ 65 wells identified
- ▶ **Low weight** → 30 wells proposed for removal



### □ Impact of ~30 wells' removal

- ▶ Kriging of hydraulic head is done again, without the removed wells
- ▶ Differences invisible on piezometry, very low on uncertainties

**Before****After****Uncertainty  
(m)**

### 3 principal results

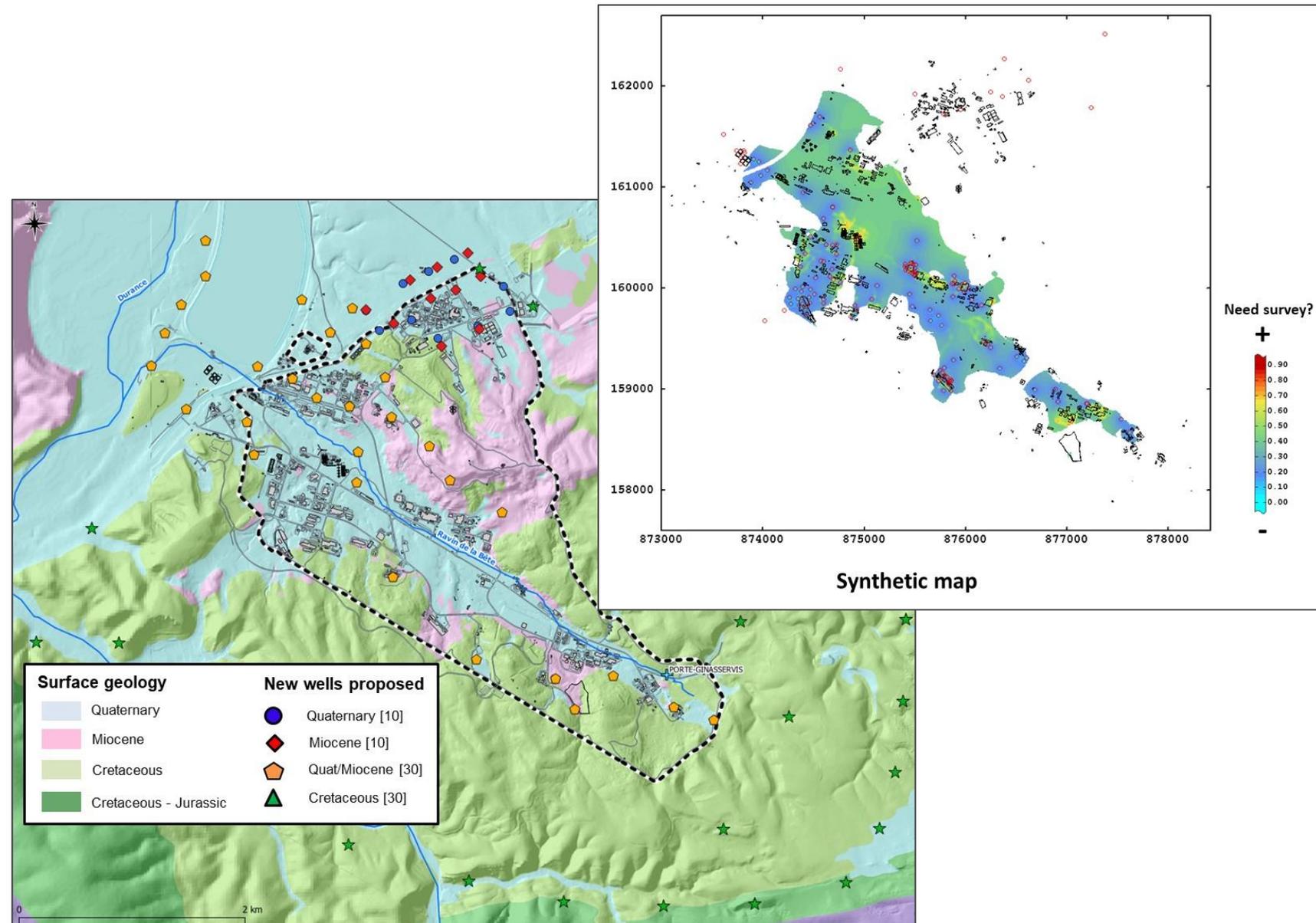
- ▶ Highlighting **survey need** linked to facilities (~ quality survey)
- ▶ Propositions for **adding new wells** (~ best knowledge of piezometry)
- ▶ Propositions for **removing existing wells** (~ limit redundancy)

### Interests of geostatistical methods

- ▶ Optimal utilisation of piezometric data in different flow conditions
- ▶ Automated and sequential process → test of different configurations and criteria

### Uses?

- ▶ Used to add new wells
- ▶ To be completed by hydrogeological expertise (faults, access for engine)





**Thank you for your attention!**

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