

# Optimisation of remediation volumes by inverse analytical modelling

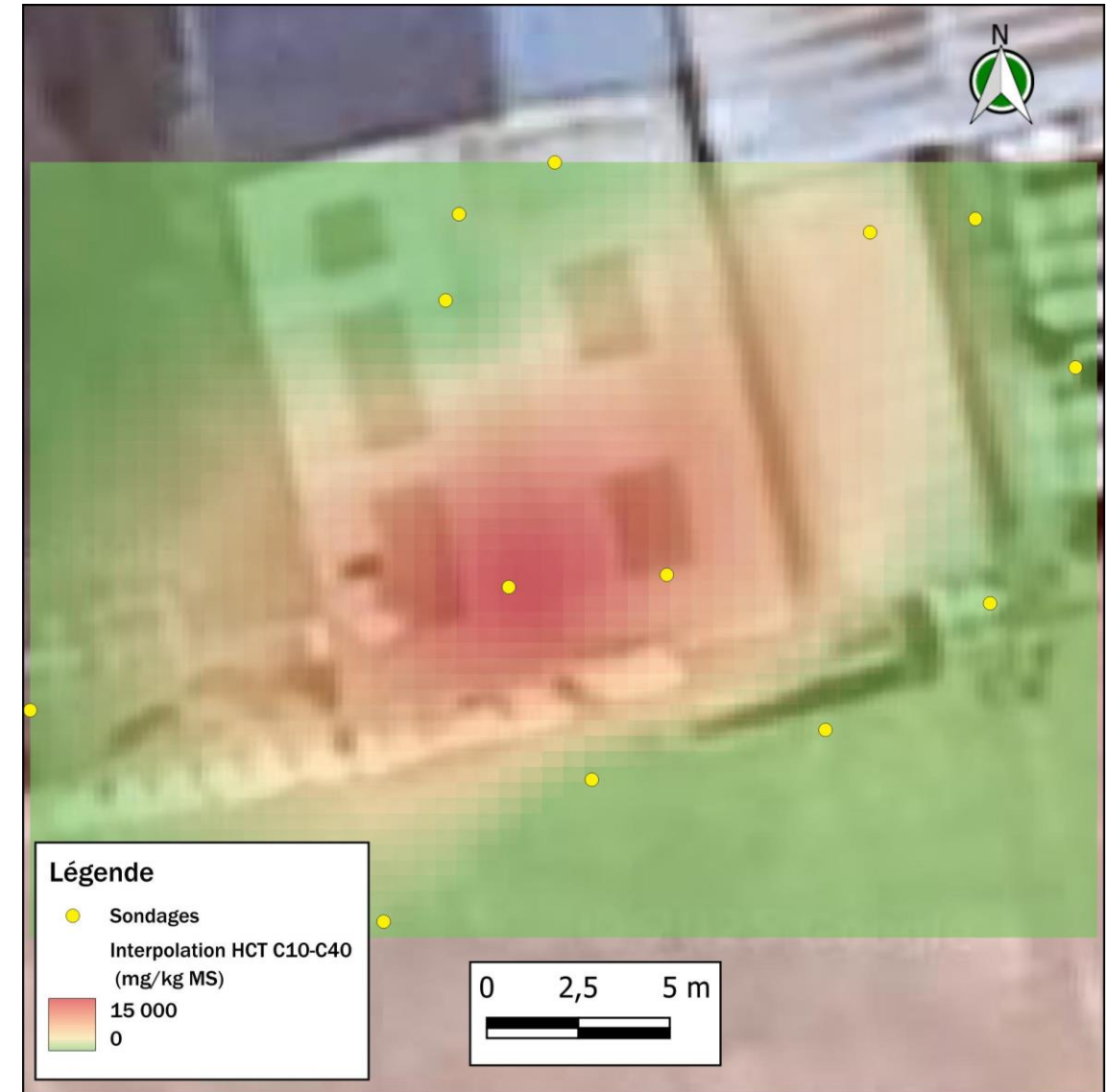
Alexis GRIS - 3rd year of thesis

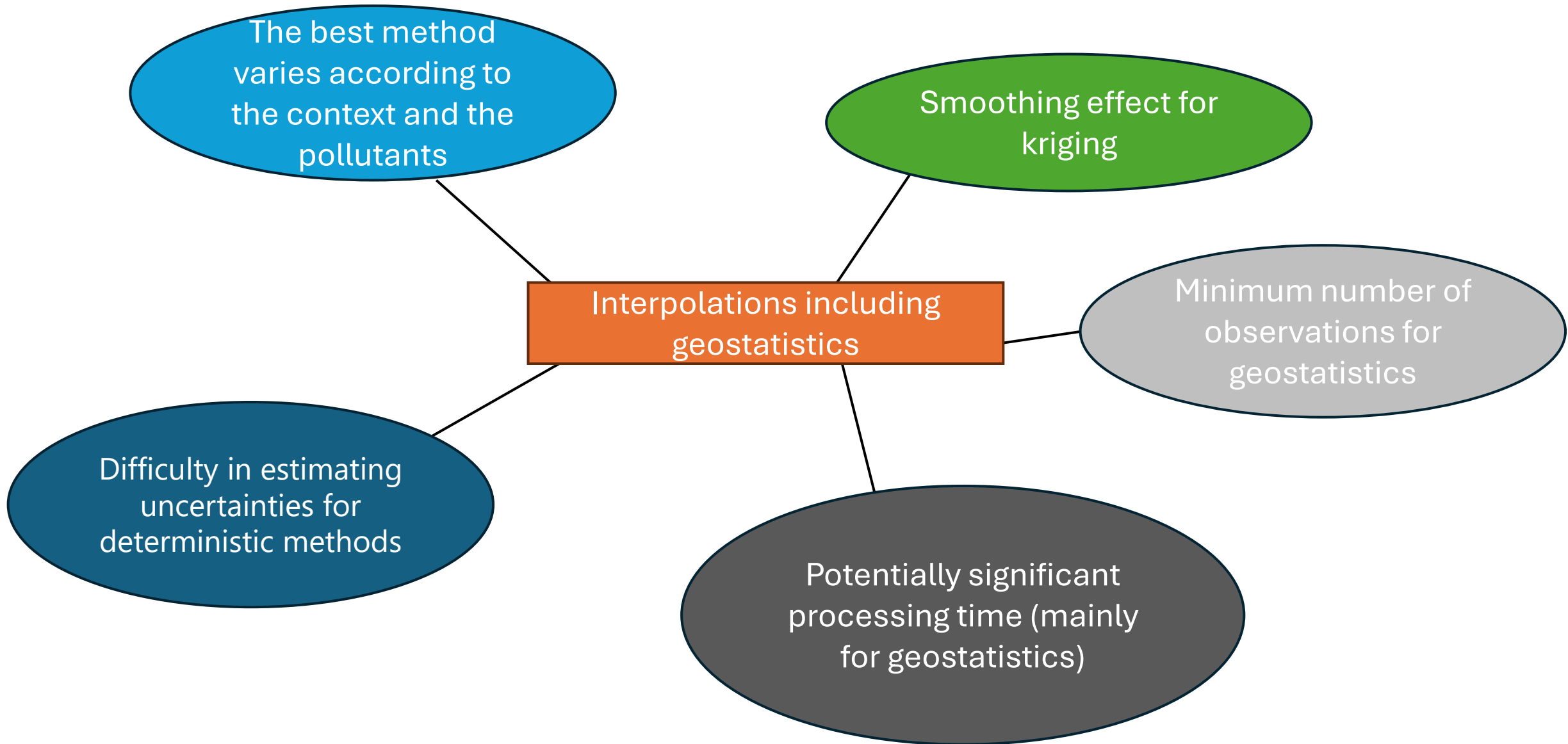
Under the supervision of Jacques BODIN and Laurent CANER

Estimating the volume of polluted soil is a major challenge in limiting the financial, health and environmental impacts.

The most commonly used methods for estimation are

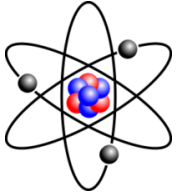
- Interpolations (nearest neighbor, radial basis function, modified quadratic Shepard's, etc.) ;
- Geostatistics (kriging, simulations)







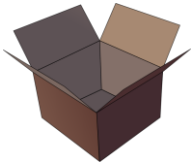
Objective: New method for estimating potentially polluted volumes



Based on the characteristics of the site / pollutant



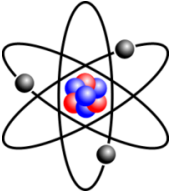
Easy to use



With a limited amount of data available



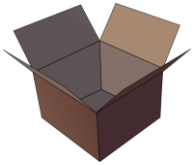
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Easy to use



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Use of an analytical solution

## Analytical solution



Exact solution of a pollutant transport equation without numerical approximation

Allows many phenomena to be reproduced (advection, dispersion, flow, volatilization, sorption, degradation, diffusion, etc.)

Potential 3D estimate



Most of the parameters (soil, sites and pollutants) are unknown.

Based on a simplifying assumption of strong spatial homogeneity of the environment

## Analytical solution



Exact solution of a pollutant transport equation without numerical approximation

Allows many phenomena to be reproduced (advection, dispersion, flow, volatilization, sorption, degradation, diffusion, etc.)

Potential 3D estimate



Most of the parameters (soil, sites and pollutants) are unknown.

→ Inversion of parameters in possible ranges.

Based on a simplifying assumption of strong spatial homogeneity of the environment

→ Application to subsets of observation points (Delaunay triangulation).

Regarding the inversion, the two main points are:

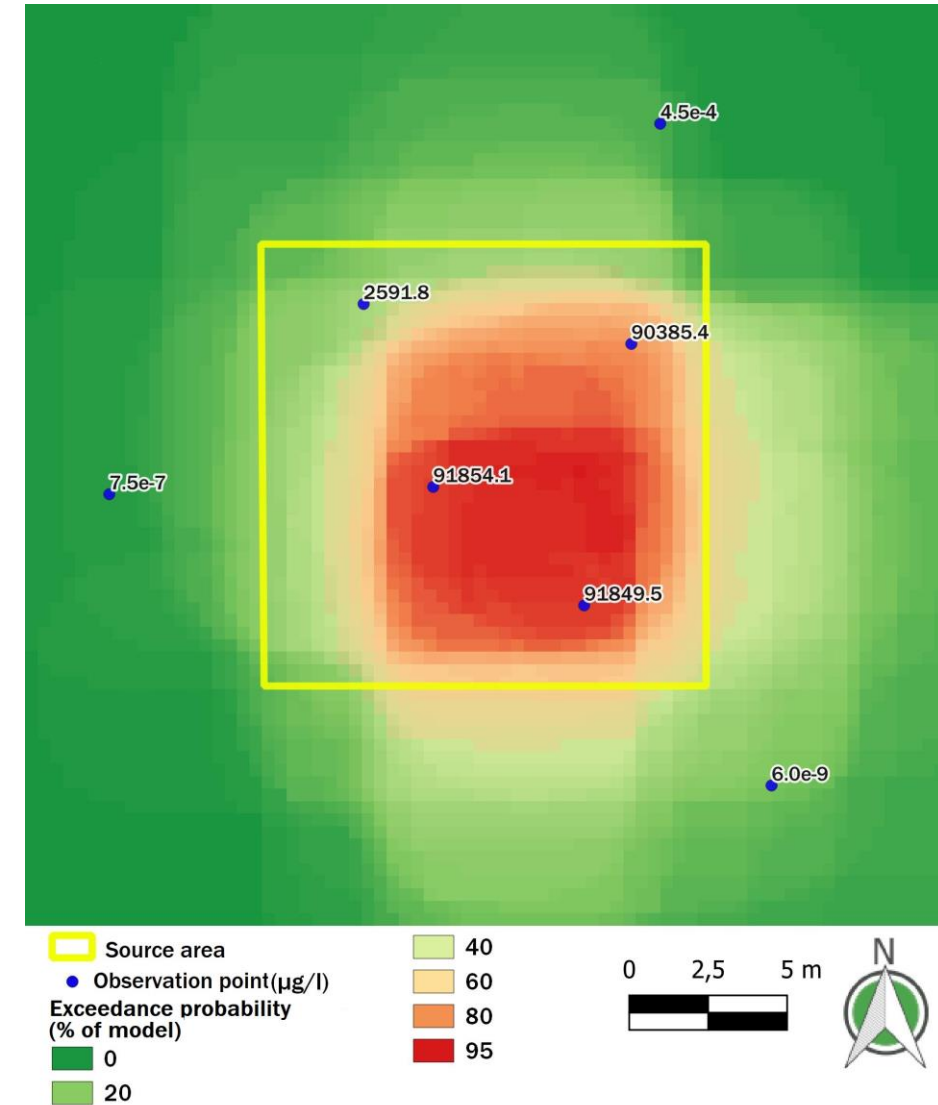


The inversion is very sensitive to the initial values taken into account. → random parameter selection



Problem of non-uniqueness of the solution → 10 models are inversed by Delaunay triangle

Combination of the models to obtain a threshold overrun % map.



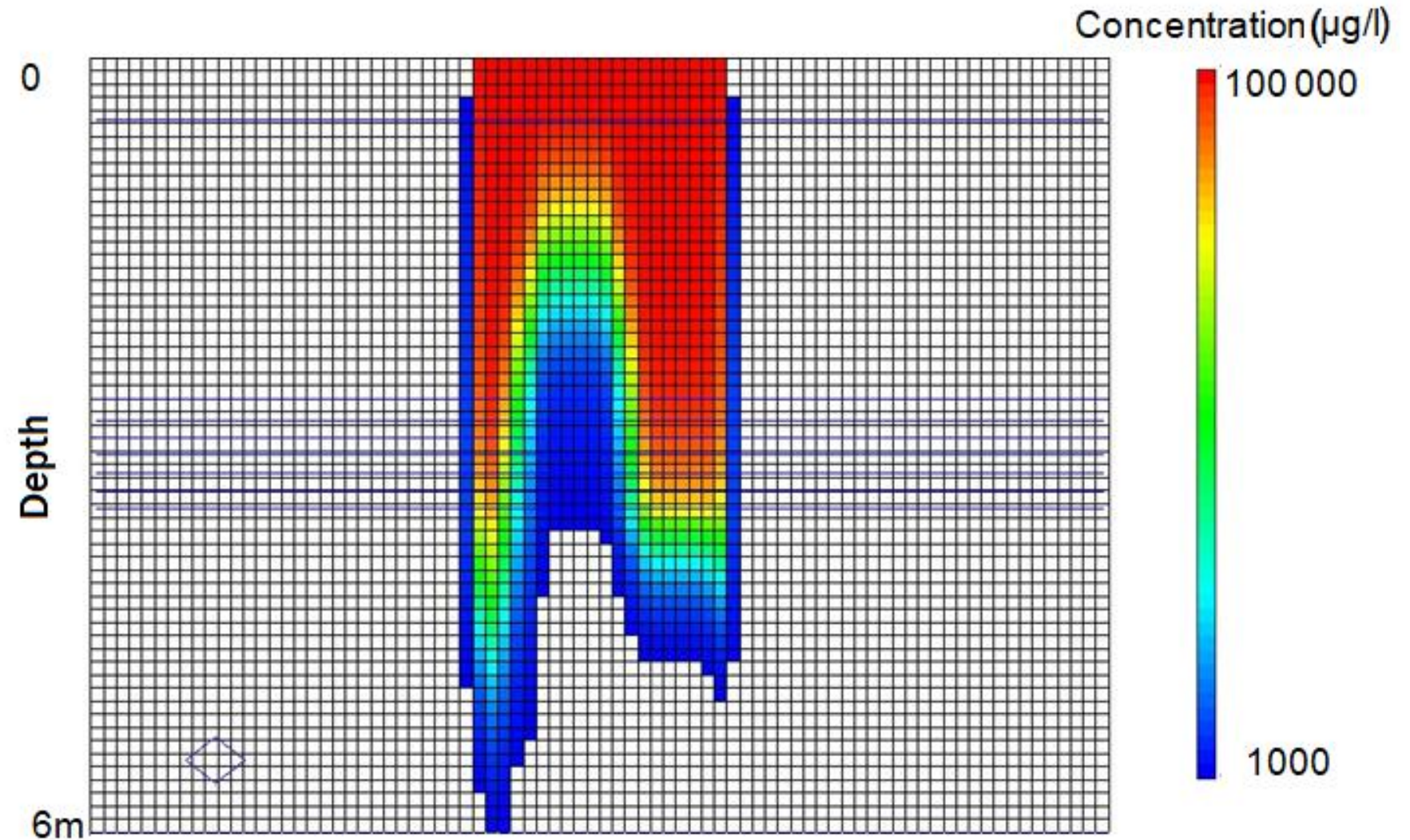


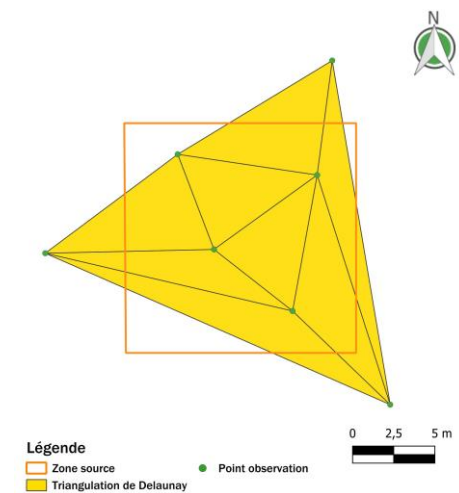
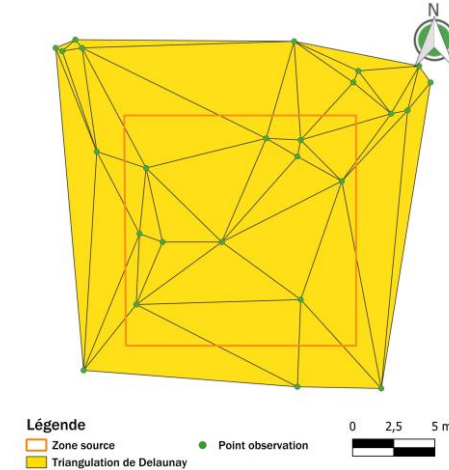
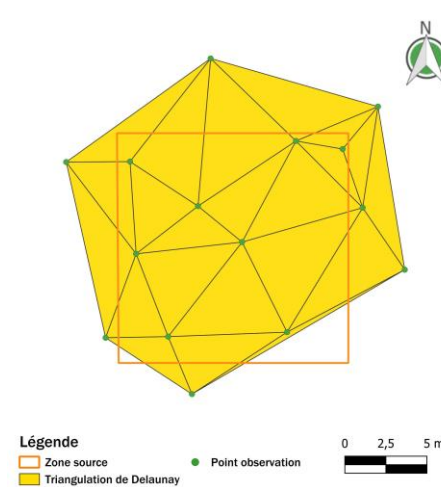
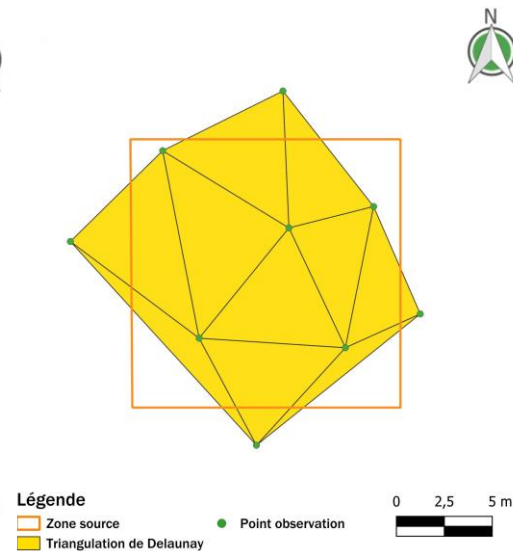
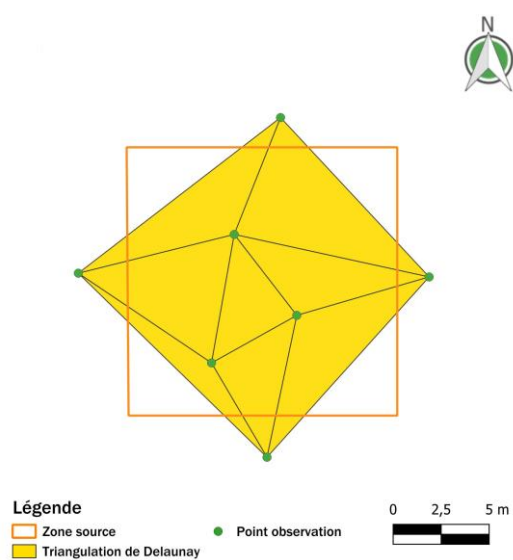
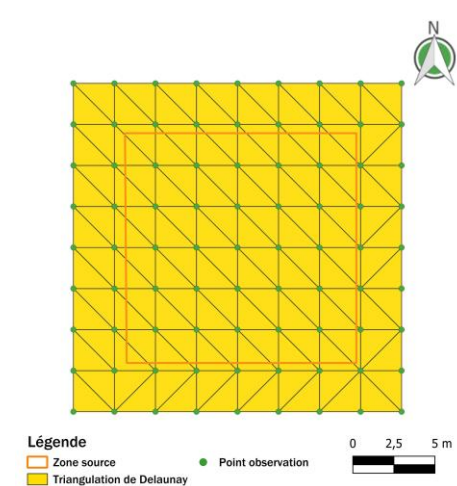
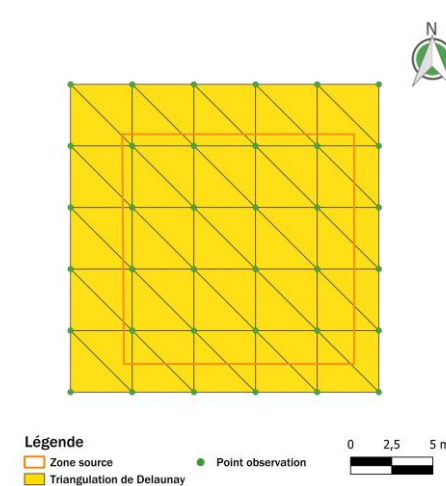
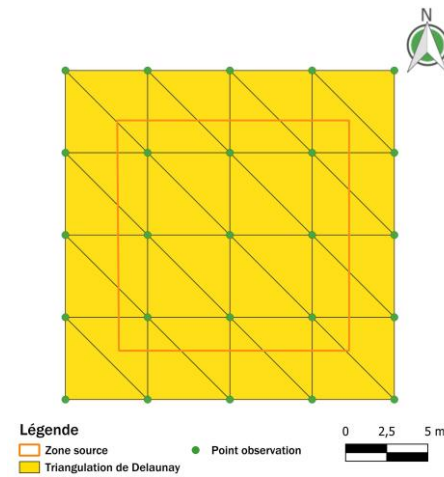
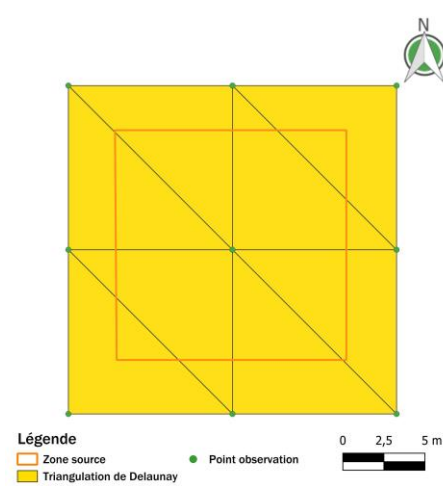
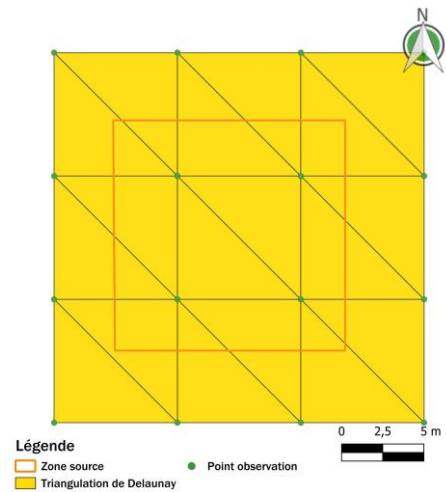
Flow and transport modeling in ZNS on MODFLOW USG

Pollution between 0 and 6 meters deep

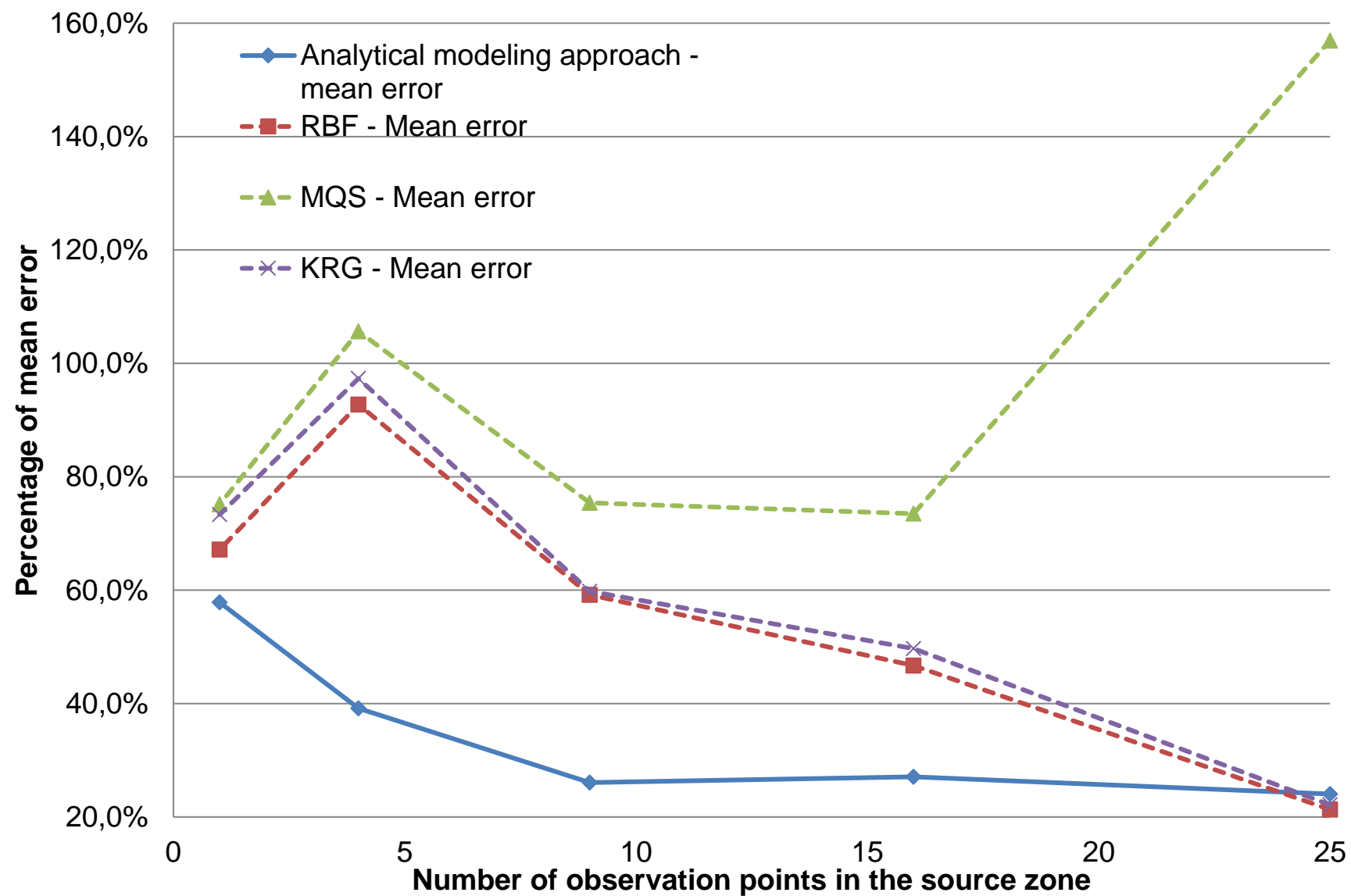
Known volume (synthetic case)

Heterogeneity in porosity and water content

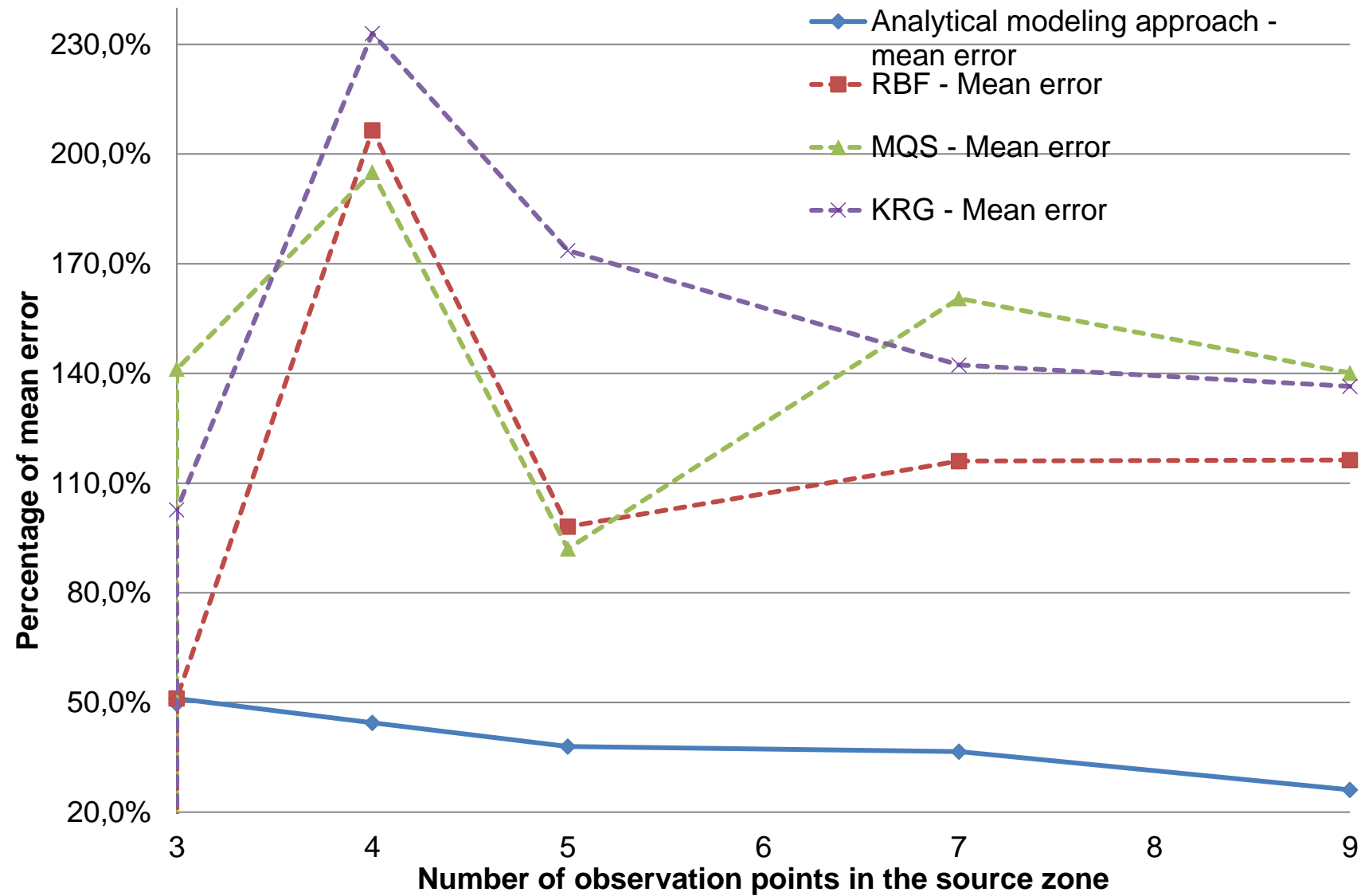




Distribution of observation points for the synthetic case



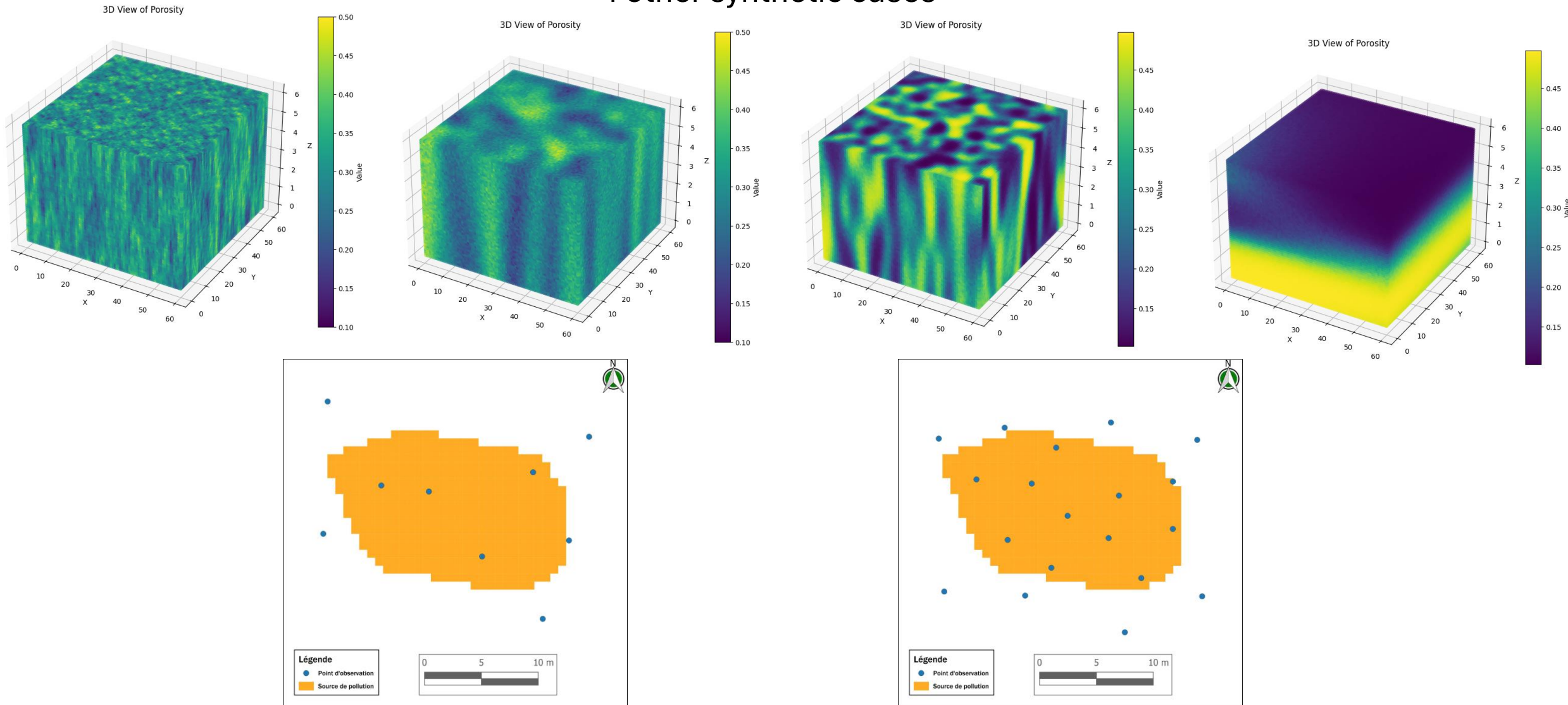
Results regular distribution of points

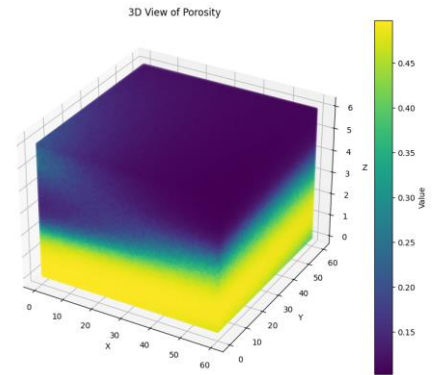
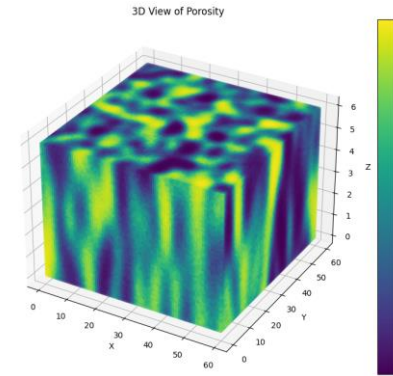
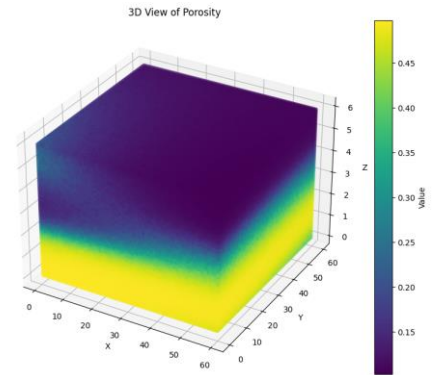
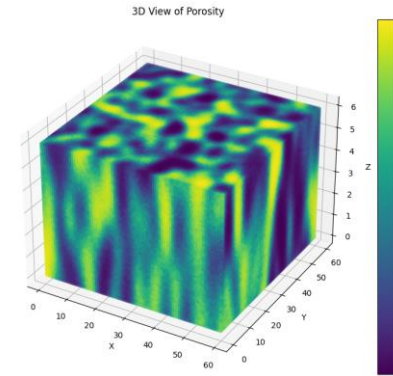
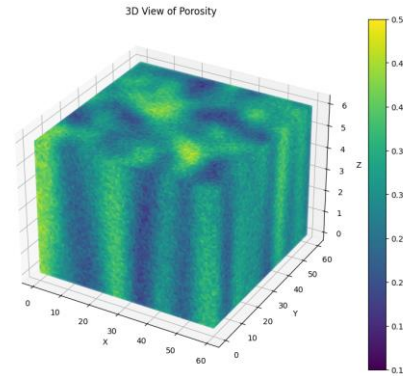
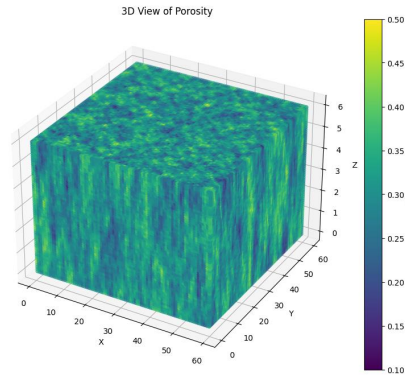


Results of random-semi-random sampling



## 4 other synthetic cases





	Case n°1		Case n°2		Case n°3		Case n°4	
Number of sampling points	10	20	10	20	10	20	10	20
% average error inverse analytical modeling	37%	27%	49%	43%	44%	25%	30%	17%
% average interpolation error	136%	69%	162%	80%	175%	63%	93%	59%
% reduction in error	73%	61%	70%	47%	75%	59%	67%	71%



Clayey sands



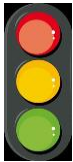
2 m deep



Leaking aboveground fuel oil tank



11 soundings and 13 samples



500 mg/kg MS in HCT C10-C40







Additional sounding with realization of composite samples by mesh



Volume of polluted soil estimated at  $735 \text{ m}^3$





## Interpolation (RBF 3D method)



Uncertainties in the north and in the south



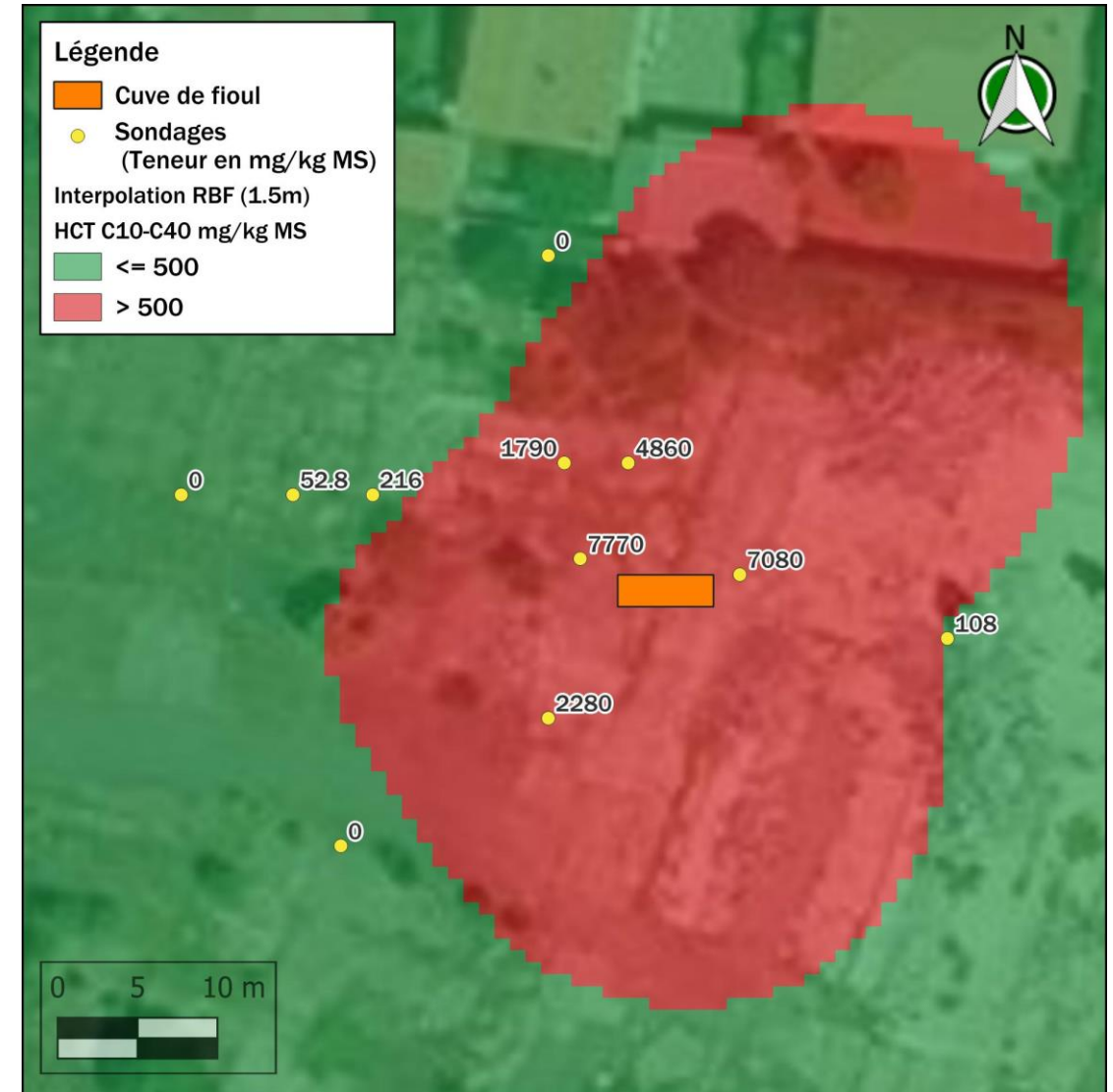
Volume of polluted soil estimated at 3064 m<sup>3</sup>



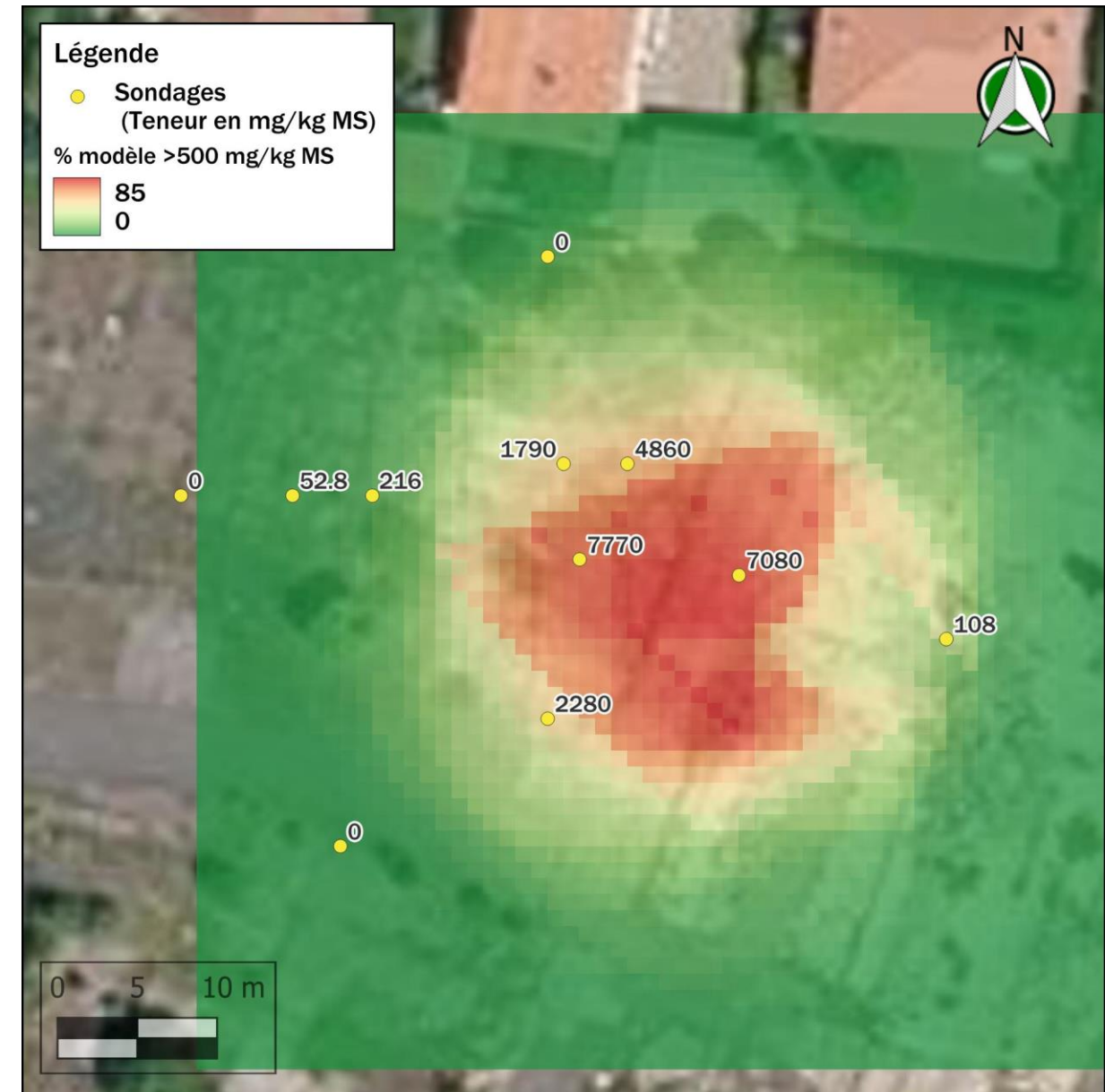
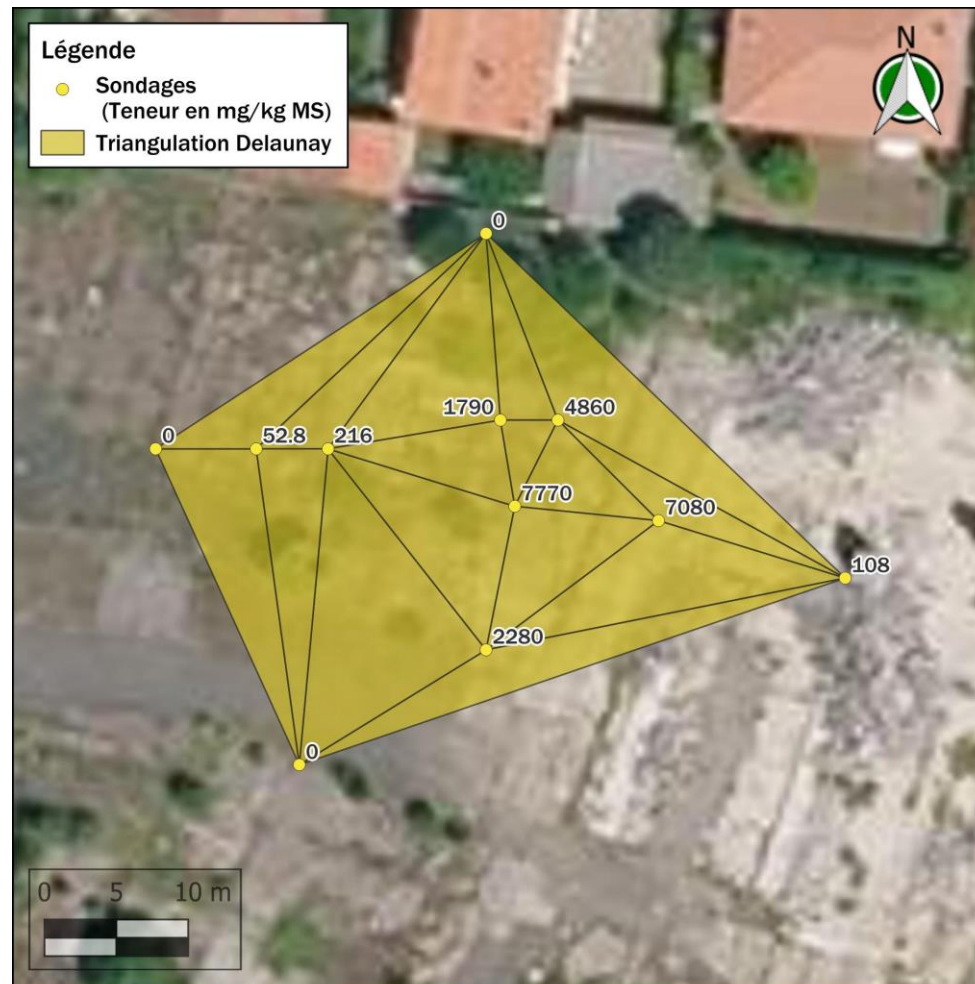
Volume probably overestimated



Error of approximately 147%  
(considering the size of the mesh  
presented above)



# Inverse analytical modeling



## Inverse analytical modeling

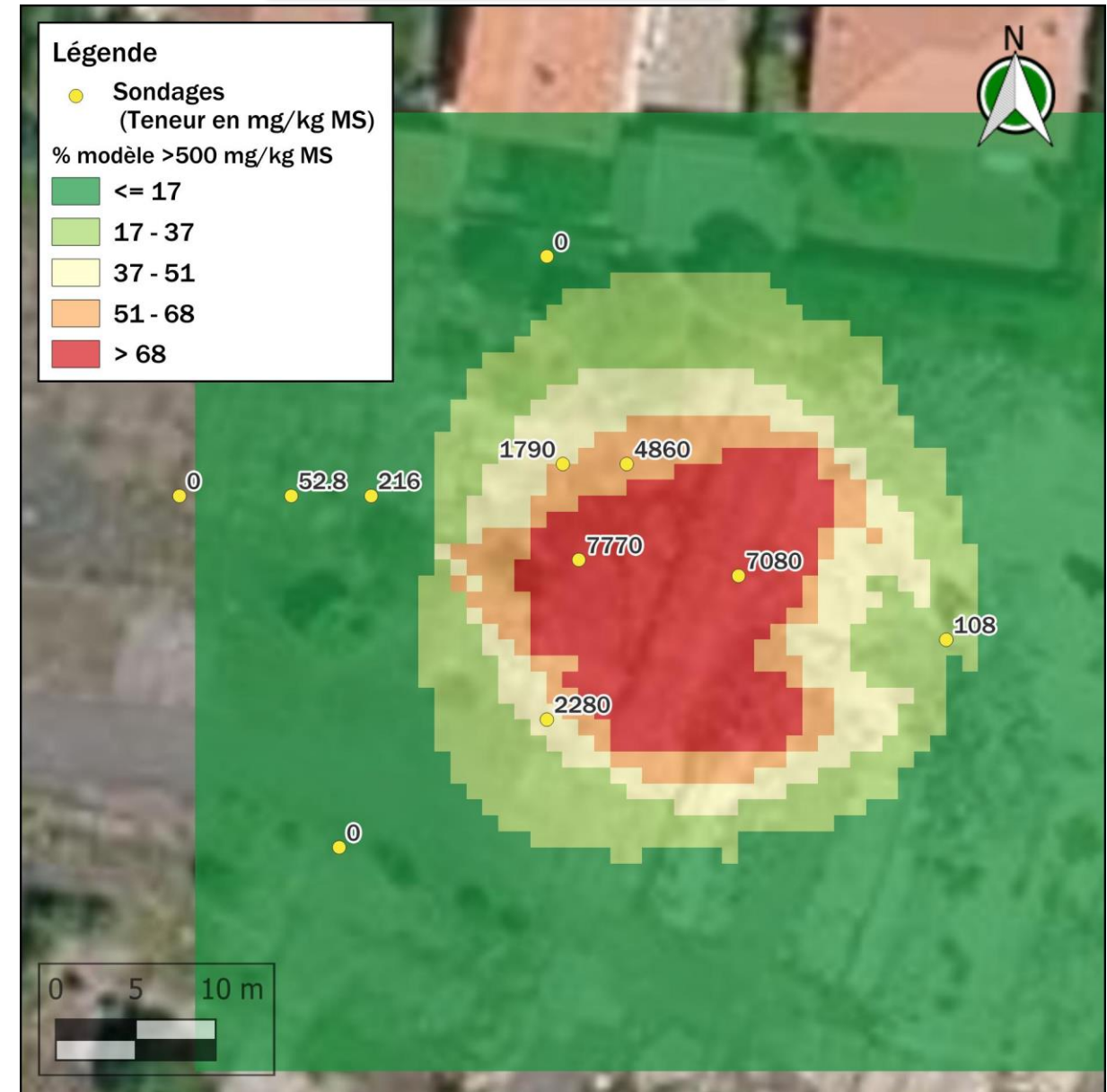


Volume of polluted soil estimated at between 880 and 1330 m<sup>3</sup>

Average (percentage of acceptable models) at 1104 m<sup>3</sup>



Error of approximately 67% (in relation to the mesh)





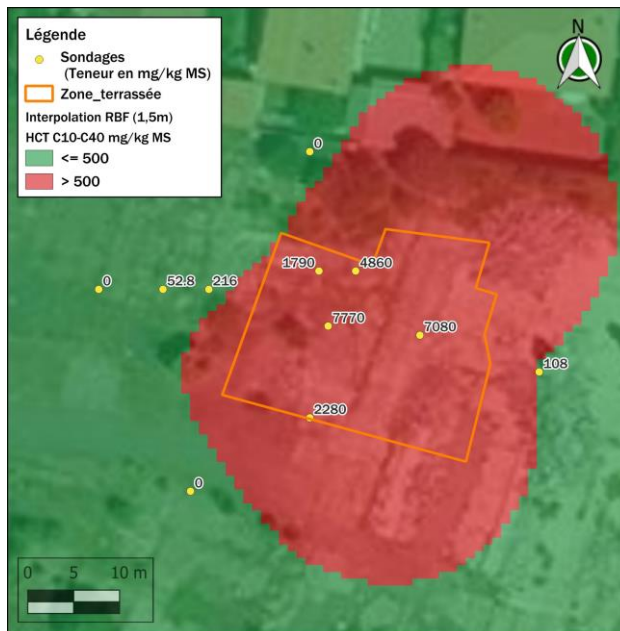
## After remediation work



Volume of polluted soil reduced to approximately 1060 m<sup>3</sup> (excluding embankments)



Interpolation error at approximately 80% (excavated area)



## After remediation work



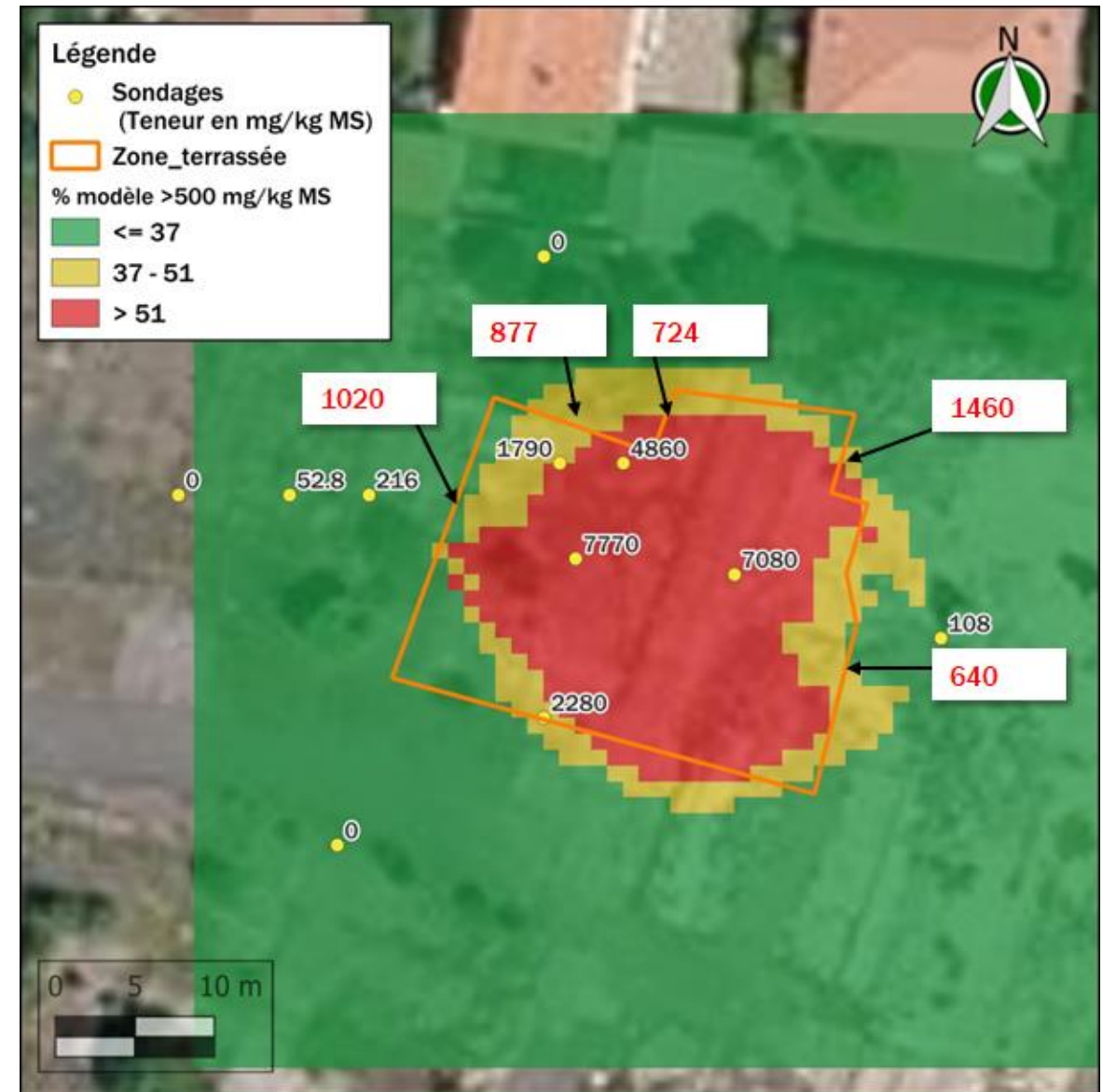
Error of approximately 26%  
(excavated area)



Error reduction compared to  
interpolation of 66%.



Compared with the initial program,  
three times the edges of the  
excavation had to be reworked.

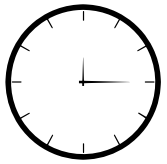




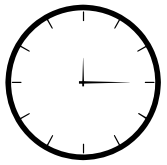
The results on the synthetic cases show a significant reduction in the average error compared to interpolation, regardless of the heterogeneity chosen.



The proposed method is of particular interest if the number of observations is low.



Application to a large number of real cases to identify the limits (presence of fills or additional sources).



The method could be applicable to the saturated zone and in particular to pollutant plumes.

**Thank you for your attention.**

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