Industrial experience feedback of a geostatistical estimation of contaminated soil volumes

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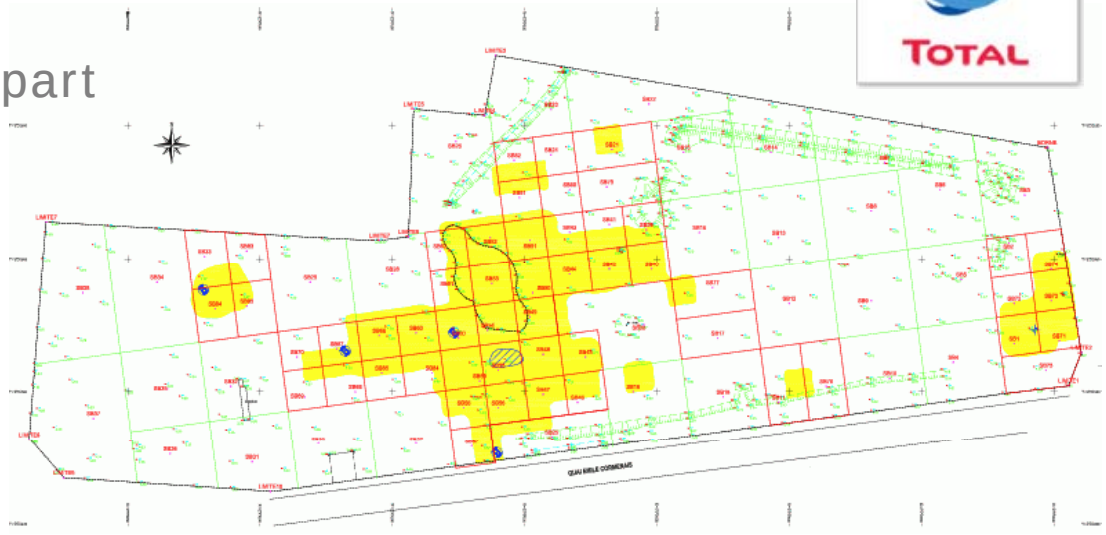
Context

- Former TOTAL oil deposit in France

High hydrocarbon grades in the lower part of a backfill layer

Detailed risk evaluation in 2002:

- Remediation threshold for THC: 2500 ppm
- Suspected contaminated surface: 7 775 m² (in yellow)
- Corresponding contaminated volume: 11 650 to 15 550 m³ (1.5 to 2 m depth)



Red: December 2005 sampling
Yellow: suspected contaminated areas

- Part of demonstration studies carried out for GeoSiPol and with the financial contribution of Ademe.

Since 2004, GeoSiPol (http://www.geosipol.org/) aims at promoting the use of geostatistics for the characterization of contaminated sites.

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Contents

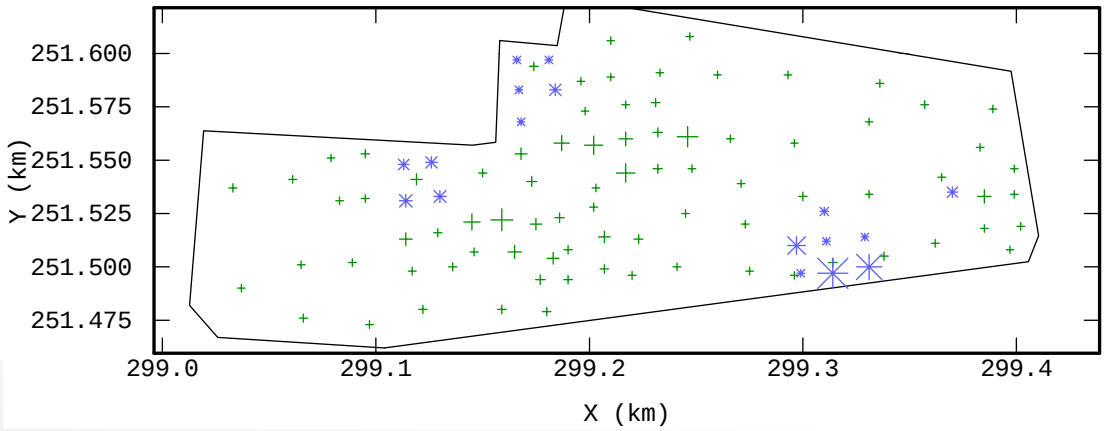
- Objectives:
  - Quantify and locate the contaminated volumes
  - Estimate the volumes to be excavated

- Key points:
  - Consideration of all available data
  - Iterative geostatistical approach & sampling recommendation
  - Quantification of the uncertainty
  - Consideration of remediation constraints

Available data: two campaigns

- December 2005:
  - Systematic sampling of potentially contaminated areas with a 15 m mesh
  - 82 boreholes: 2 samples taken between 0 and 1 m and 1 and 2 m, depending on organoleptic observations
  - → First geostatistical study in 2006
- June 2006:
  - 17 complementary boreholes, in uncertain areas
  - → Update of the geostatistical study

+ 82 initial boreholes
✳17 complementary boreholes



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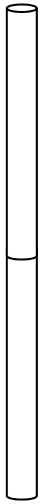
Available data

- Examples of boreholes



A

H_A = 0.6 m
THC_A= 160 mg/kg_{MS}

H_A = 0.8 m
THC_A= 190 mg/kg_{MS}

H_A = 0.6 m
THC_A= 1100 mg/kg_{MS}

B

H_B = 1.7 m
THC_B= 220 mg/kg_{MS}

H_B = 0.7 m
THC_B= 3200 mg/kg_{MS}

H_B = 0.3 m
THC_B= 4200 mg/kg_{MS}

Thickness of the potentially contaminated layer (threshold = 1000 ppm):

⇩ ⇩ ⇩

Thickness: 0 m

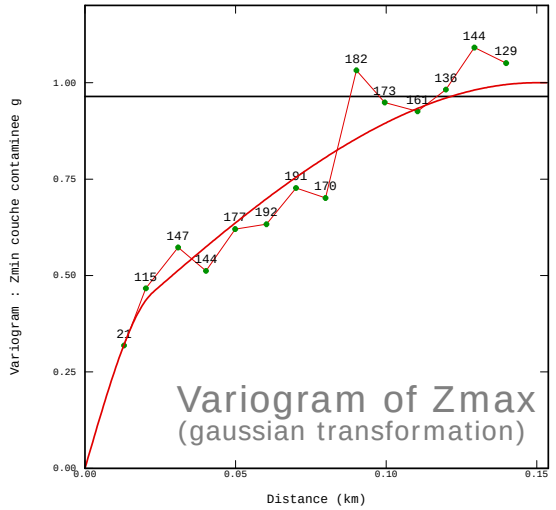
Thickness: 0.7 m

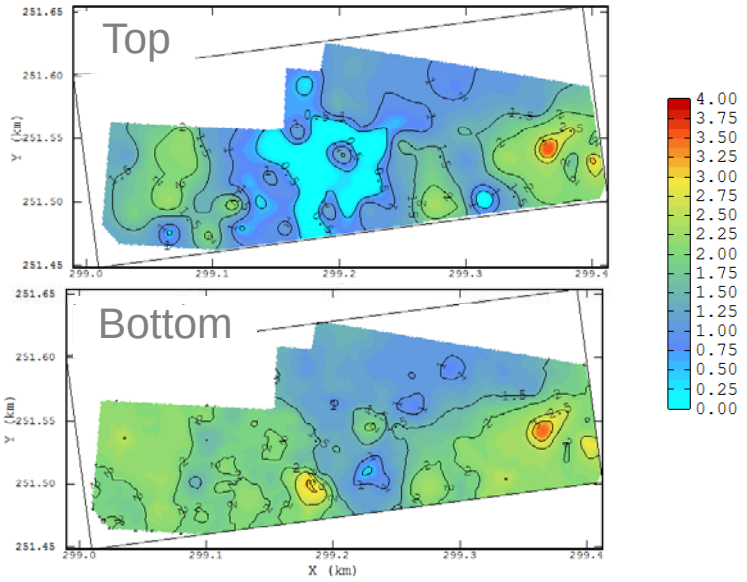
Thickness: 0.9 m
THC_{mean} = 2133 mg/kg_{MS}

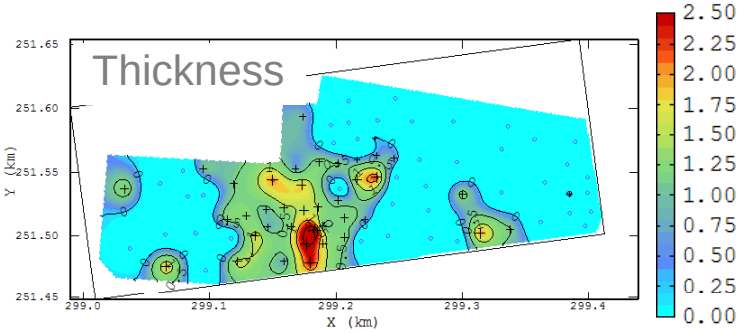
- Two steps procedure given the conditions of investigation:
  - Geometric estimation of the potentially contaminated layer
  - Estimation of the grades inside this layer (2D)

Modeling the geometry of the target layer

- Geometry of the potentially contaminated layer
  - Modeling of the top, the thickness and the bottom of the layer
  - Geostatistical simulations, quantification of the uncertainty (mesh: 1 m)
- 50% quantiles for:







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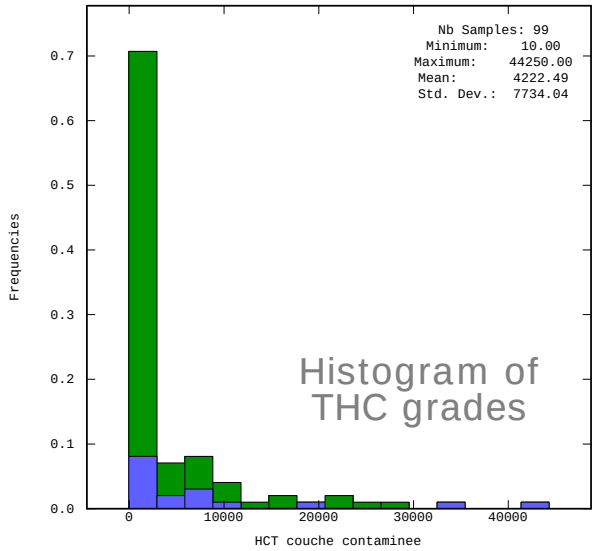
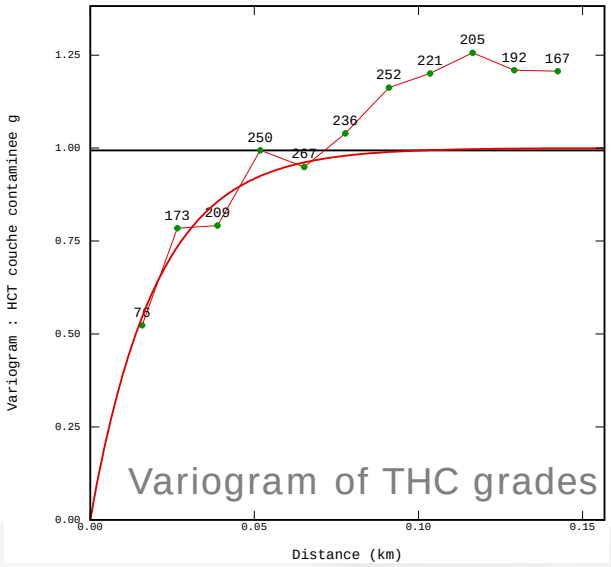
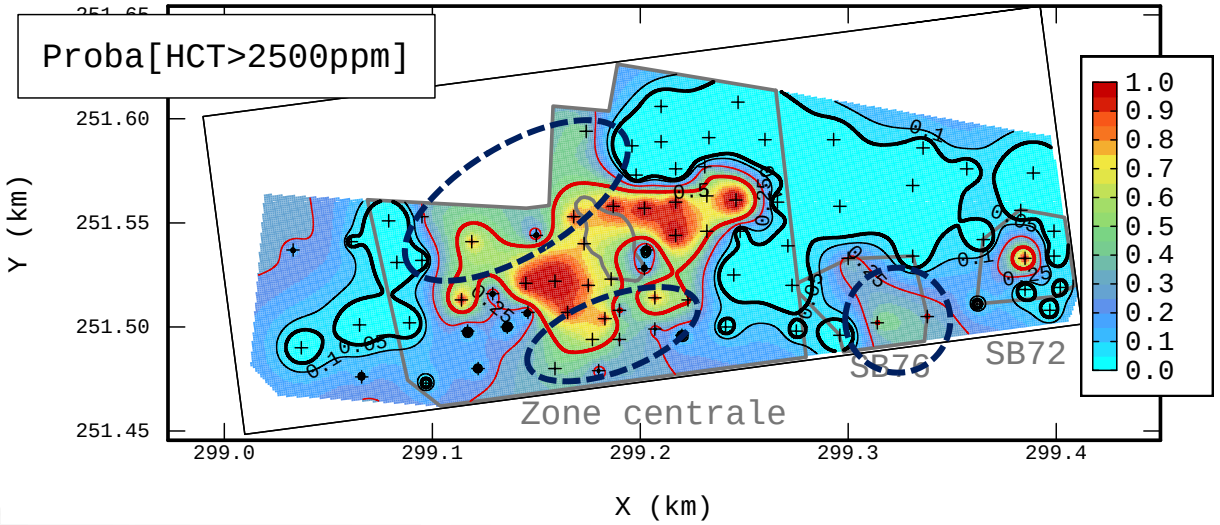
Modeling of the THC grades

- First geostatistical study using the 82 initial boreholes:
  - Simulation mesh: 1x1m
  - 3 target areas
  - 2D Map of the probability to exceed the 2500 ppm threshold







→ Uncertain areas

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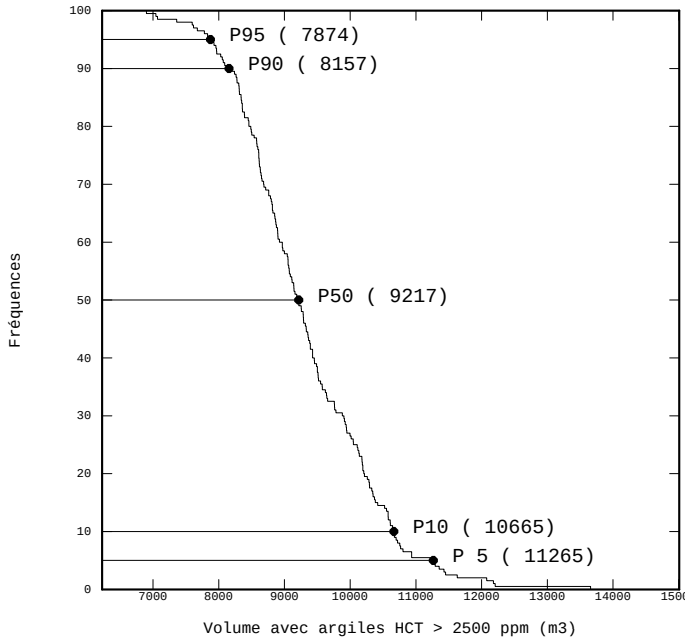
Contaminated soil volumes

- Computation of the total contaminated volume over the three target areas using:
  - Simulations of the contaminated layer thickness
  - Simulations of the grades inside the layer



Most probable volume: 9 217 m^3

$CI_{90\%}$ = [7 874 ; 11 265]

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Volume to be excavated

- How much should we excavate to remove all the contamination?

  Because of:

  - Uncertainty about depth and thickness of the contaminated layer
  - Spatial variability of the grades inside this layer

  → Volume to be excavated > Contaminated volume

- Several scenarios:

Z_{min} Quantile (Top)	Z_{max} Quantile (Bottom)	THC Quantile	Volume to be excavated
Q50 (probable)	Q50 (probable)	Q50 (probable)	8 674 m^3
Q50 (probable)	Q50 (probable)	Q10 (safe)	18 108 m^3
Q25 (safe)	Q75 (safe)	Q10 (safe)	33 755 m^3

Excavation

- Main steps of the site remediation

June 2006: 17 complementary boreholes (recommendations after the first geostatistical study)

Evaluation of the contaminated volume based on the analytical results (without geostatistics): 8 300 m^3

Summer 2006: Excavation and sorting of 22 347 m^3 of soil, of which 13 171 m^3 are contaminated

→ Contaminated volumes roughly computed from analytical results clearly underestimate the amount of pollution

Comparison with geostatistical prediction

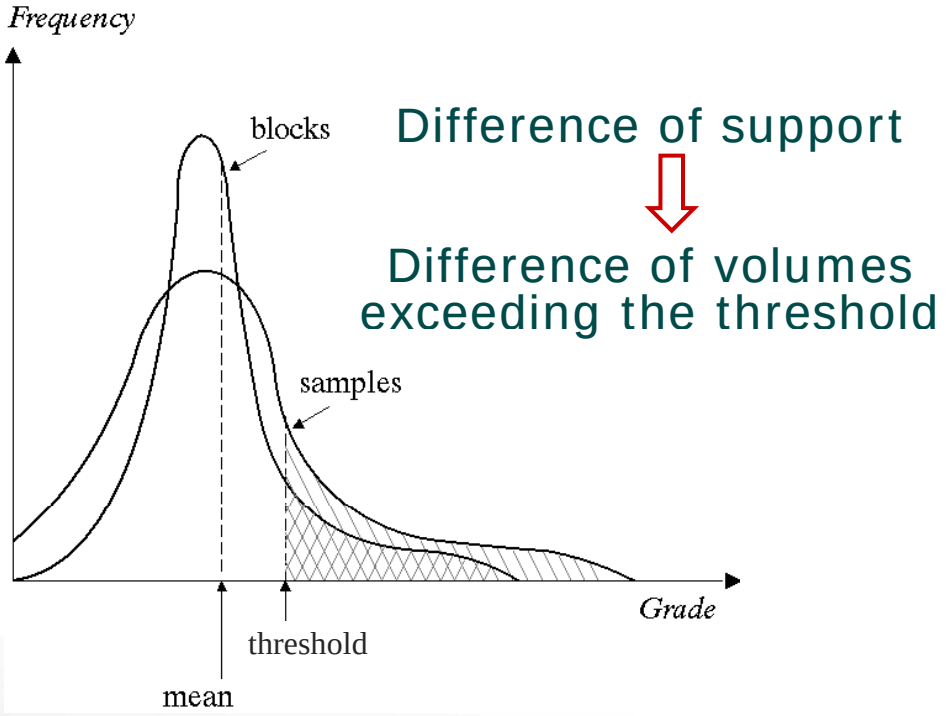
Remediation: 13 171 m^3 of contaminated soils…

…to be compared to the 9 217 m^3 obtained during 1st geostatistical study – $CI_{90\%}$=[7 874 ; 11 265 m^3]

→ Underestimation of 30%

→ True value not even comprised in the confidence interval

- Two main reasons:
  - Difference of support:
    - simulations (1x1 m mesh)
    - excavation (15x15 m mesh)
  - The 17 complementary boreholes of June 2006 (before excavation) are not yet integrated in the study



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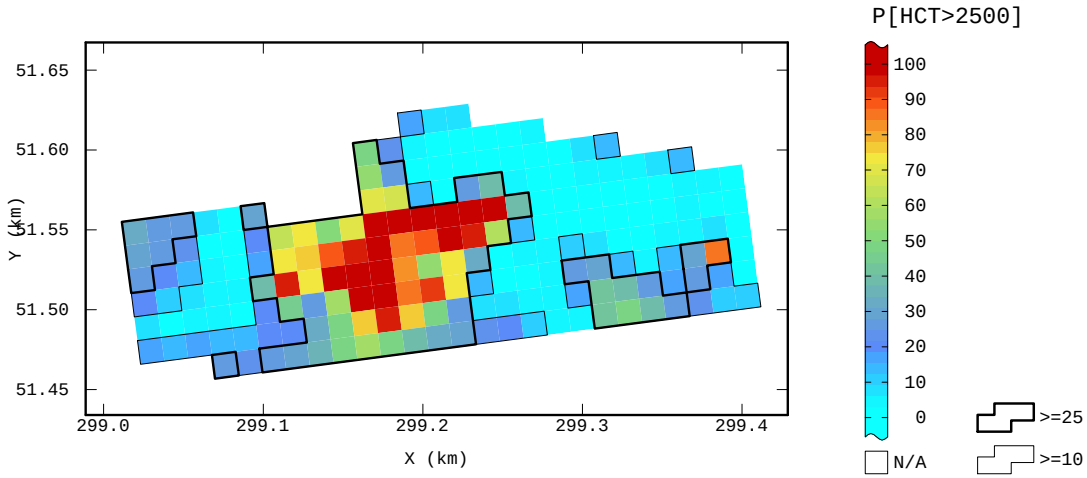
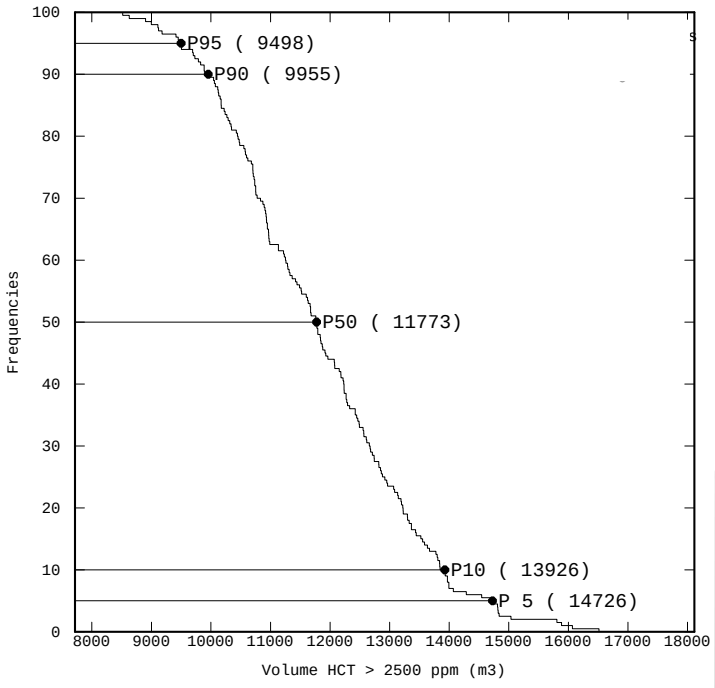
Taking the remediation support into account

- New maps and quantification of contaminated soils considering a 15x15 m mesh

Probability map to exceed the threshold of 2500 ppm





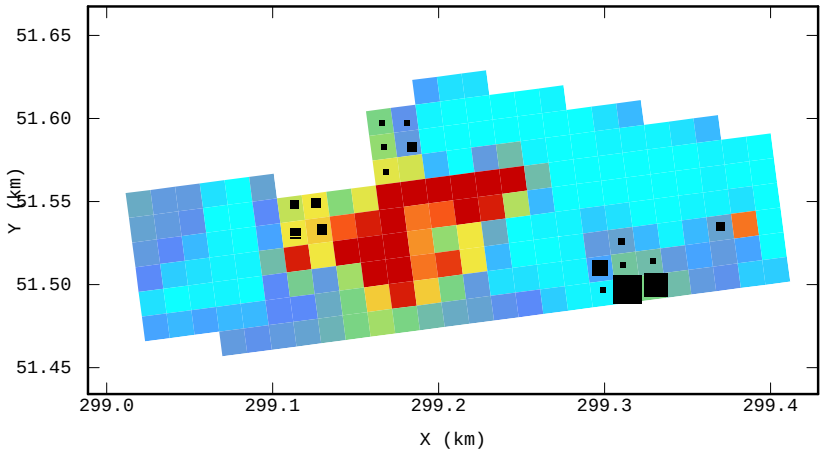
Most probable volume: 11 773 m^3

$CI_{90\%}$ = [9 498 ; 14 726]

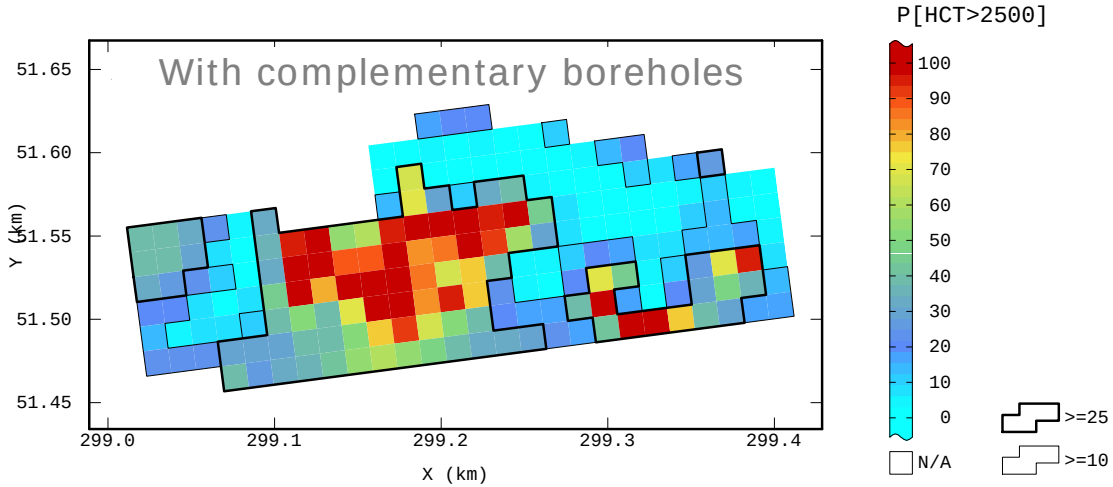
→ Underestimation of 10,6%

→ True value comprised in the $CI_{90\%}$

Taking complementary boreholes into account



New boreholes, located in uncertain areas (following the 1st geostatistical study)



New map of the probability to exceed 2500 ppm

→ Decrease of the uncertainty in the new sampled areas

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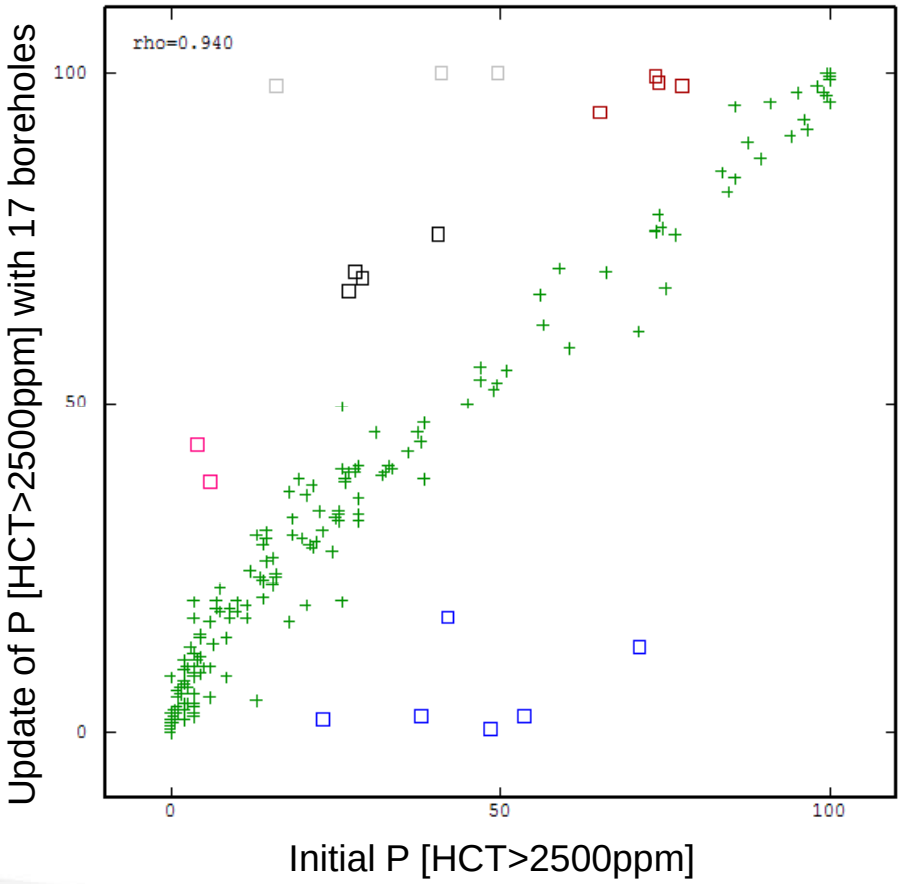
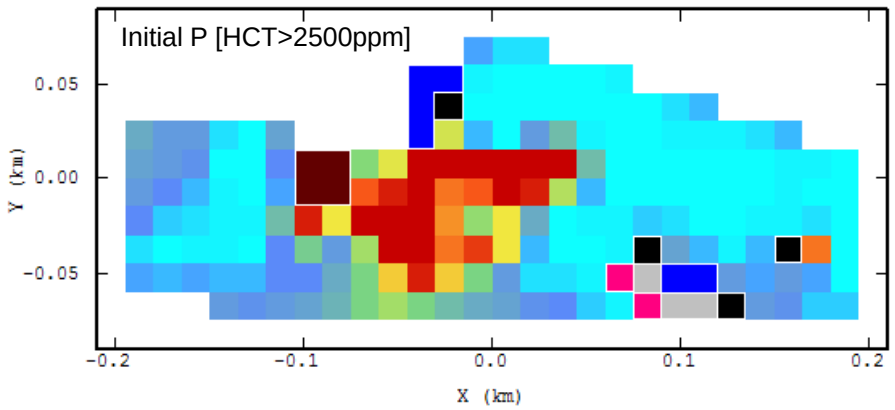
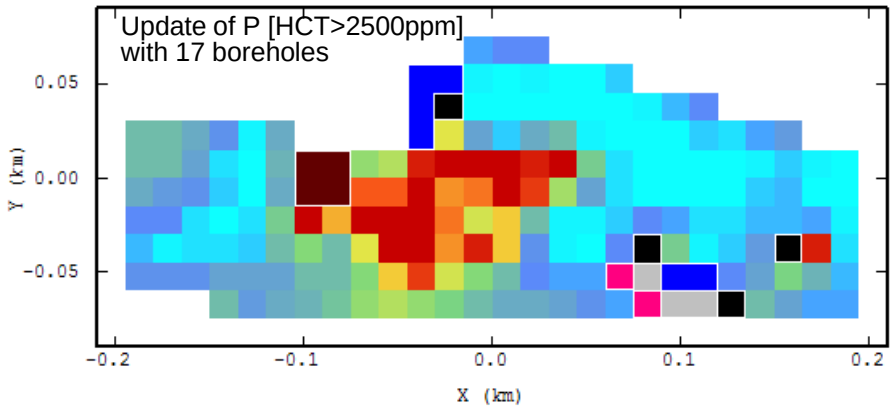
Taking complementary boreholes into account

- Comparison of P[HCT>2500 ppm] maps before and after integration of the 17 new boreholes







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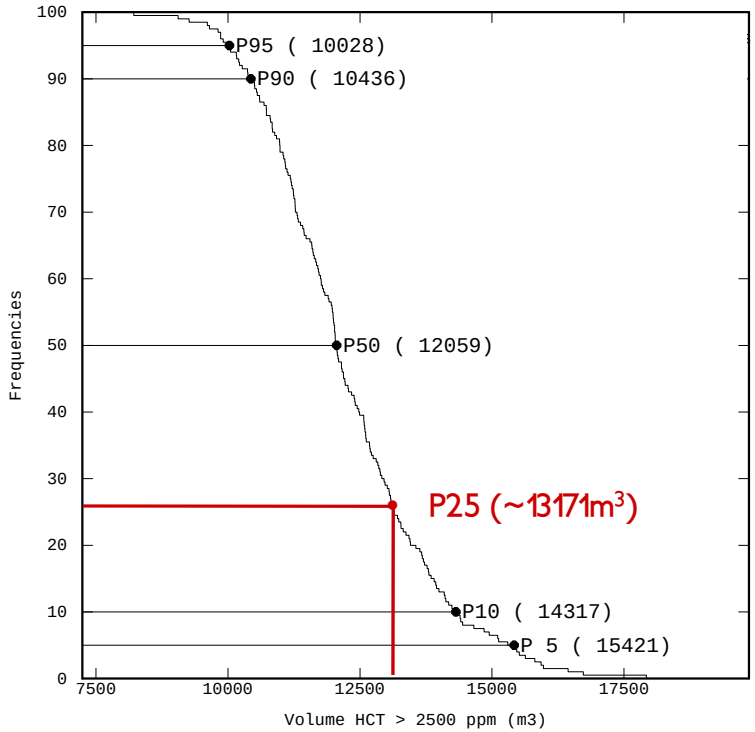
Update of the contaminated volumes

- New quantification of contaminated volumes over the three target areas, taking into account:
  - The 15x15 m remediation mesh
  - The 17 complementary boreholes



Most probable volume: 12 059 m^3

→ Underestimation of 8,4%

$CI_{90\%}$ = [10 028 ; 15 421]

→ True value included

The true contaminated volume of 13 171 m^3 corresponds to the 25% quantile

Rem: Evaluation of the contaminated volume based on the analytical results (without geostatistics): 8 300 m^3

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Update of the volumes to be excavated

- Using geostatistics, prediction of how much soil should have been excavated to remove all the contamination?

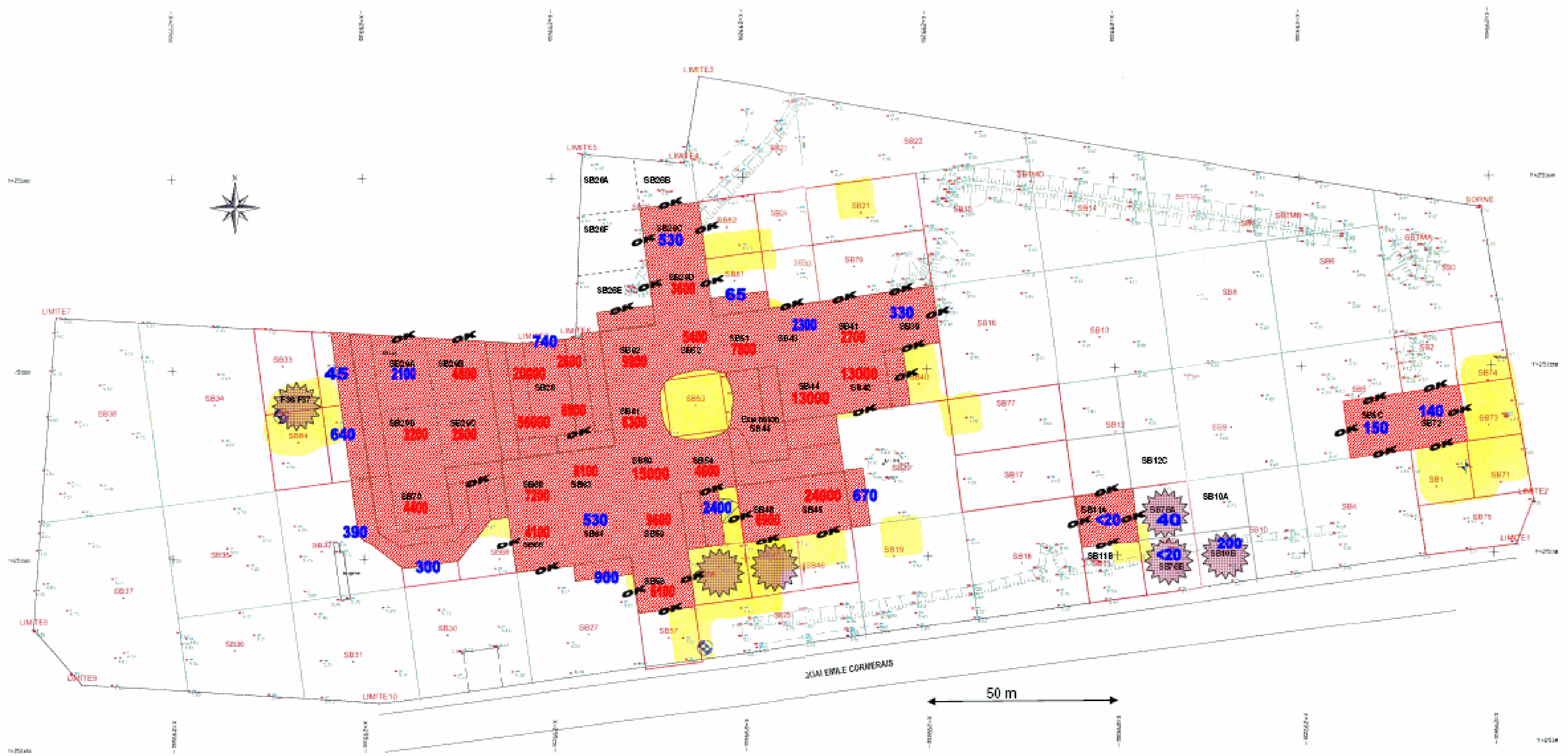
Z_{min} Quantile (Top)	Z_{max} Quantile (Bottom)	THC Quantile	Volume to be excavated
Q50 (probable)	Q50 (probable)	Q50 (probable)	14 112 m^3
Q25 (safe)	Q75 (safe)	Q25 (safe)	31 239 m^3

... to be compared to the real excavated volume of 22 348 m^3.

- These volumes can be reduced during the excavation as the sorting progresses and if visual/organoleptic observations of the areas to excavate are used.

Remediation in practice

- What has been done:



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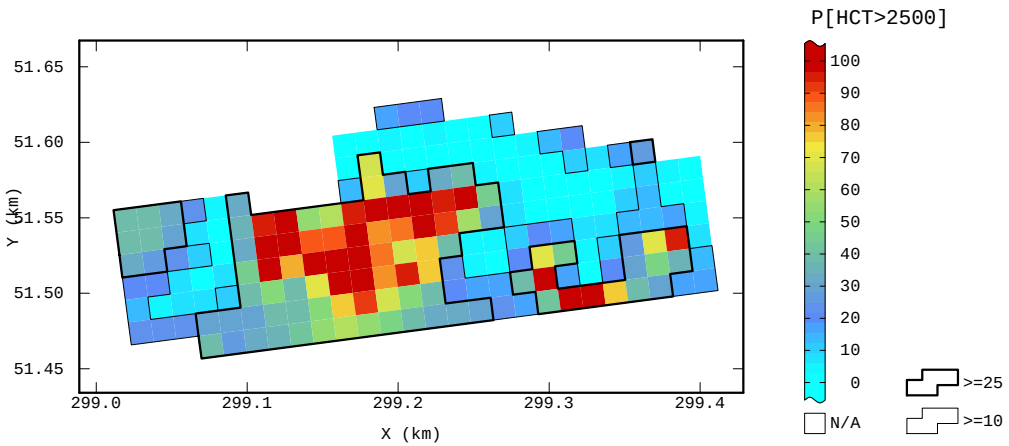
Remediation in practice: with geostatistics

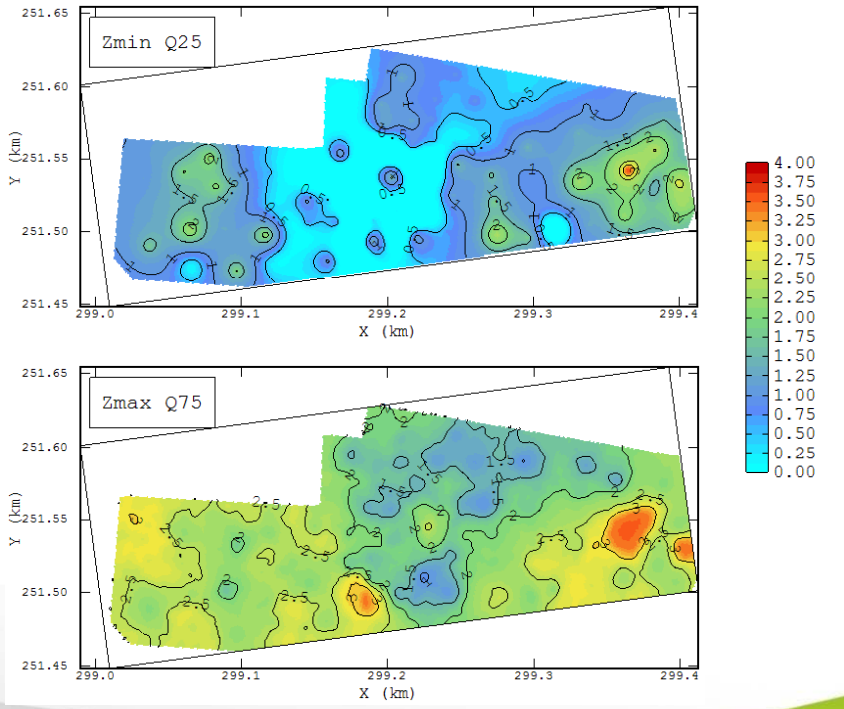
- What could have been done:

  After choosing a scenario for both geometry and THC grades, for example Q25/Q75/Q25:

  - Horizontal extension is given by the 25% isoline (bold) of the probability map to exceed 2500 ppm

  - Inside those areas, depths to remediate are obtained thanks to:
    - $Q_{25\%}$ map for top of layer
    - $Q_{75\%}$ map for bottom of layer





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Conclusion

- Geostatistics provide a relevant prediction of the contaminated volumes if remediation constraints are taken into account (15x15 m mesh)
- Advantages of the iterative approach:
  - Orientation for further investigations
  - Better final accuracy
  - Real integration of geostatistics in the remediation workflow
- Geostatistical approach outcomes:
  - Data quality control
  - Relevant estimates…

    …coupled with uncertainty quantification,

    …for both contaminated and excavated volumes.
  - Cost / benefit analysis

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Acknowledgments

- ADEME for financial support
- TOTAL for the authorization to present the results
- Other GeoSiPol members for their valuable contribution

... And thank you for your attention!

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Appendix

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