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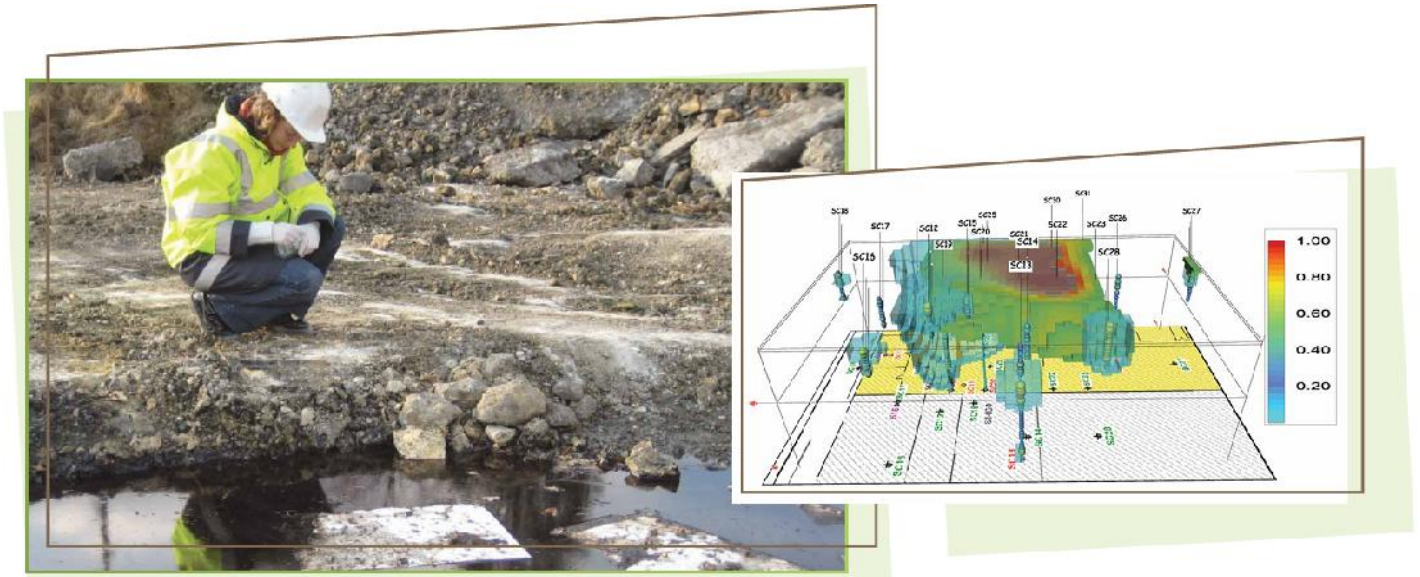
Sara Godoy del Olmo

Calculation of contaminated soil volumes : Geostatistics applied to a hydrocarbons spill Lac Megantic Case



Modélisation 3D d'une pollution aux chlorés

CONTEXT OF THE STUDY

This study was conducted for **pedagogical purposes**

In June 2014 a geostatistical training was performed for the Environmental Ministry of Quebec and for other public and private companies in order to better understand the Geostatistical method and its applications to the contaminated sites

The data set obtained in the Lac Megantic first characterizations was used for performing the study case during this training

Petroleum Hydrocarbons

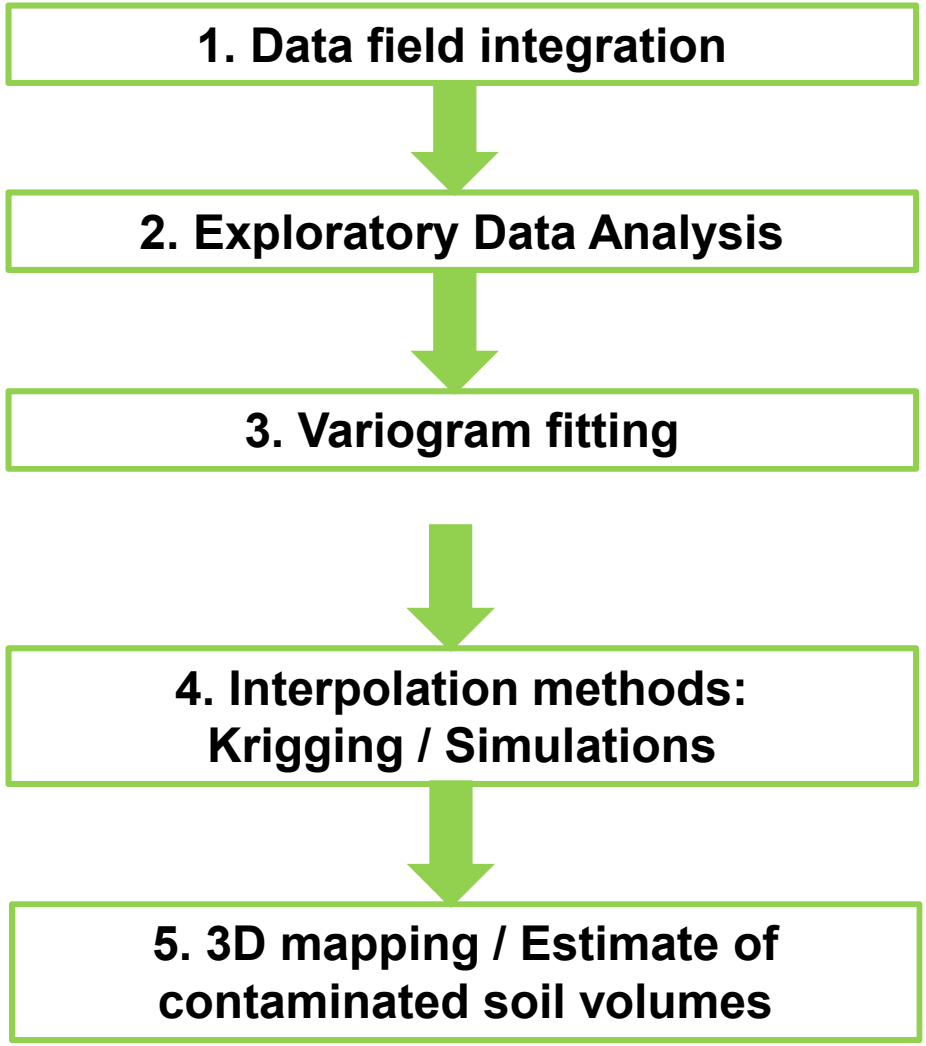
OBJECTIVES OF THE GEOSTATISTICAL STUDY

The geostatistical treatment has been performed in order to:

- Accurately understand the contaminants' behaviour in soil (correlations between contamination and depth/topography/geology…)
- Once the behaviour of the contamination is established, we perform a contamination mapping in order to visualize the pollution migration
- Delineate, if possible, the pollution extent and the volumes of contaminated soil affected by the PH spill

Remember:

A geostatistical study is conducted as follows:



1. Integrating the field data

Laboratory data

- In total, 450 PH laboratory analyses
- Preferential sampling performed in surface fills
- Maximum sampling depth = 8 m

Field Data: geology

- Fills layer (0-2m) and natural soil (silt and clay) until 8 m depth

Remediation threshold

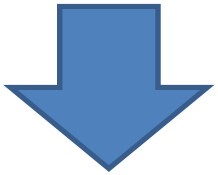
700 ppm for the PH

Field data must be geo-referenced in a coordinate X Y Z system

2. Exploratory Data Analysis

Objectives:

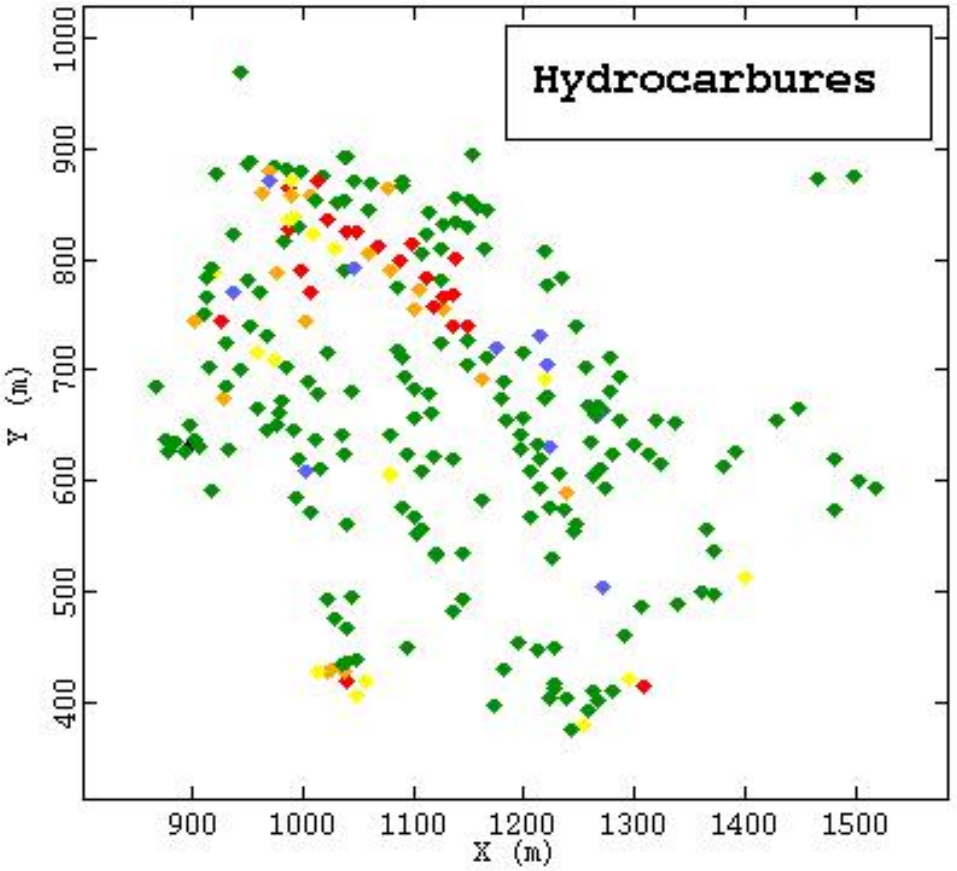
- Geological study,
- Contamination base map,
- Quick statistics, histograms
- Correlations between concentration and depth/geology,

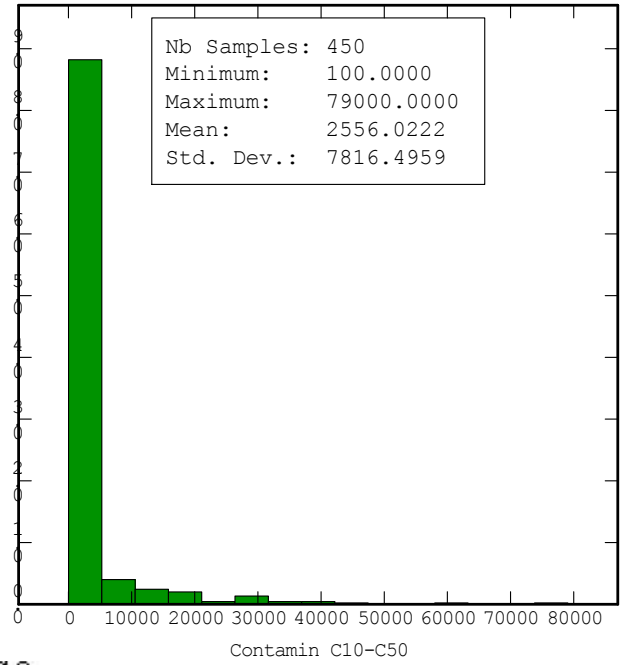


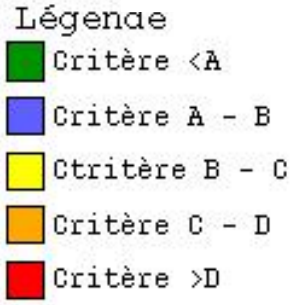
Experimental variogram construction

2. Exploratory Data Analysis

Contamination base map

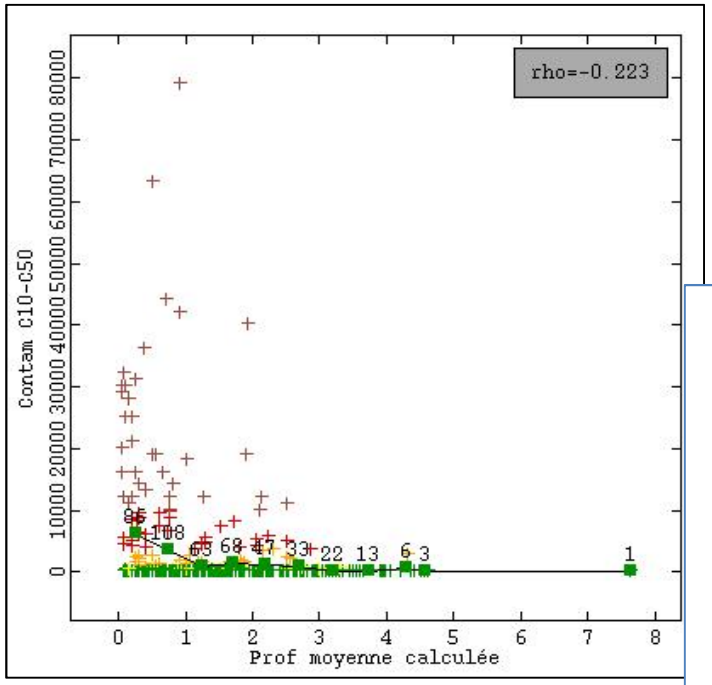




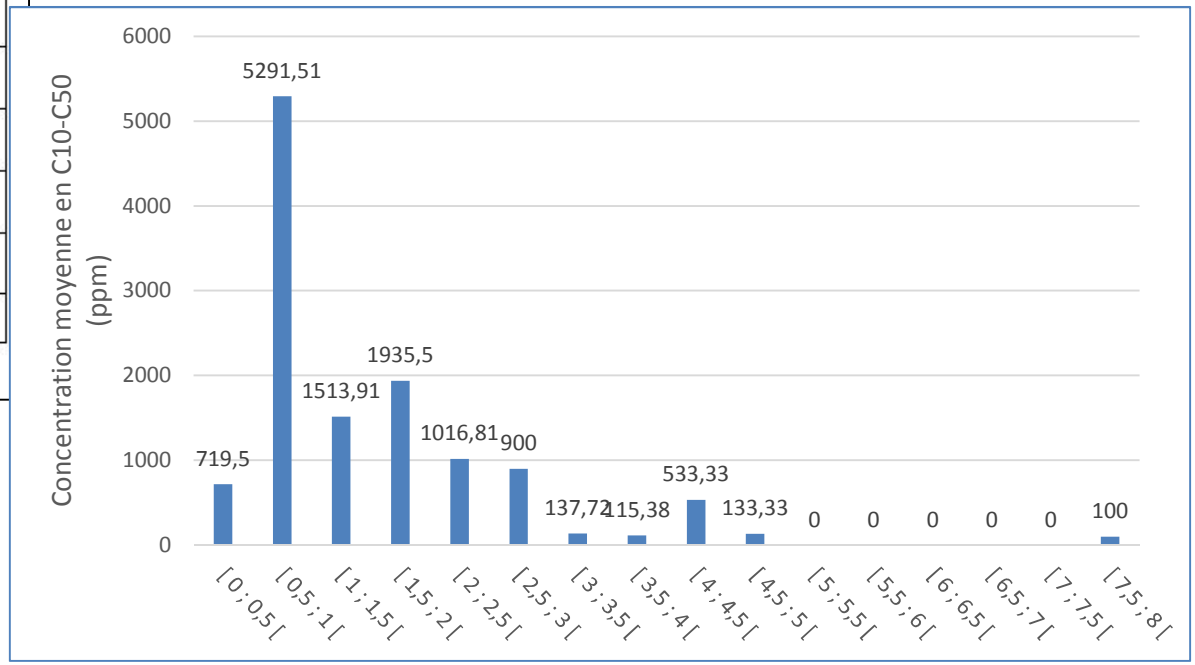


2. Exploratory Data Analysis

Correlation between concentration and depth

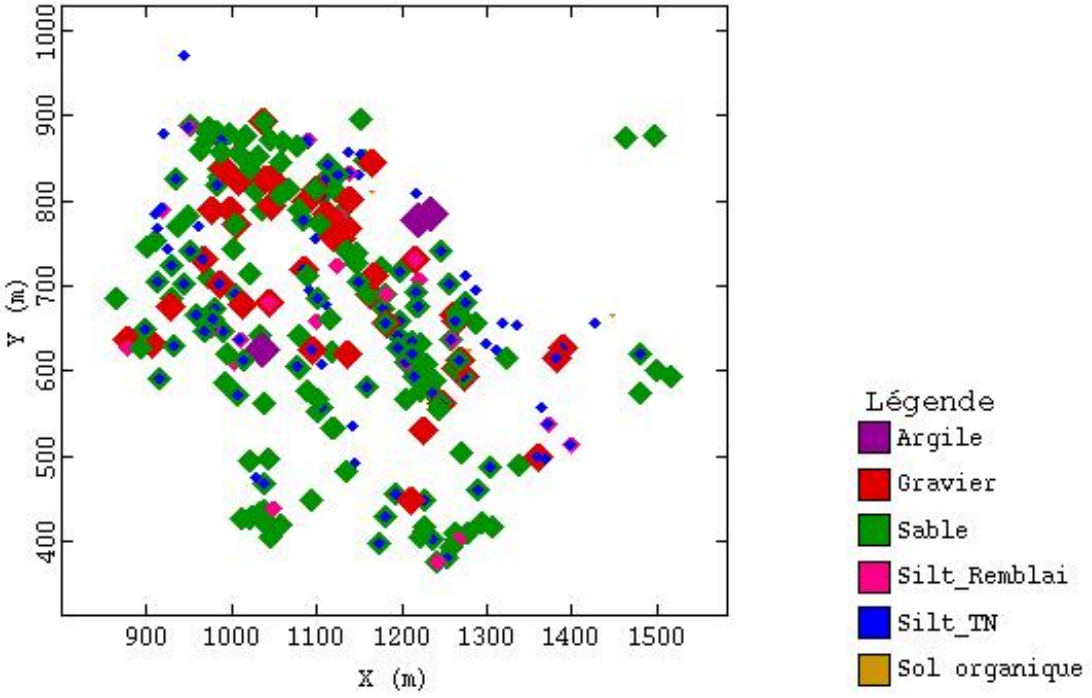


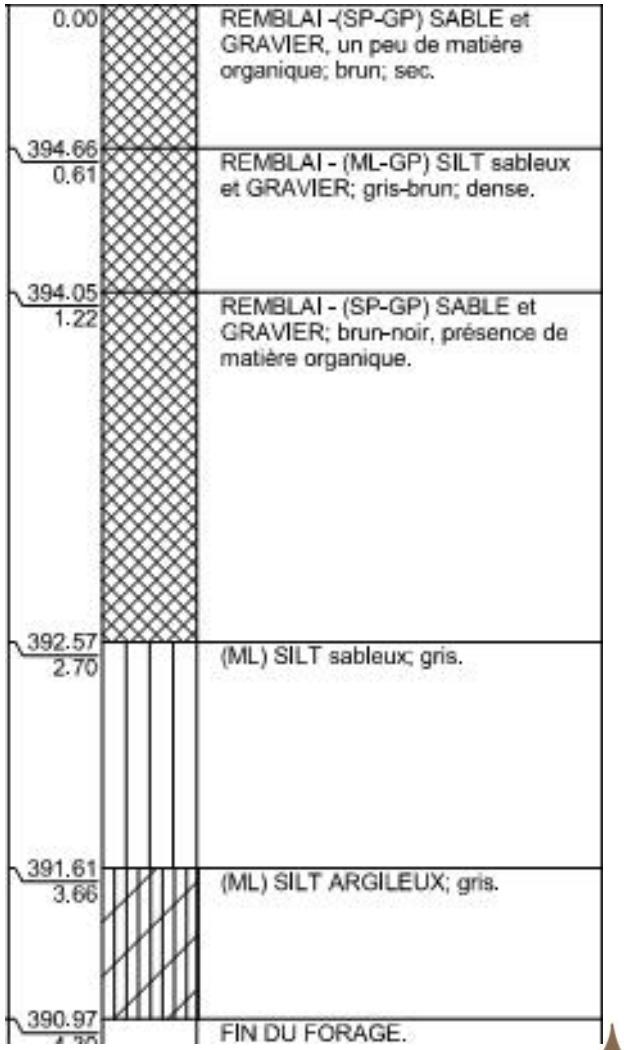
The highest concentrations are measured between 0.5 and 1 m depth



2. Exploratory Data Analysis

Sampling

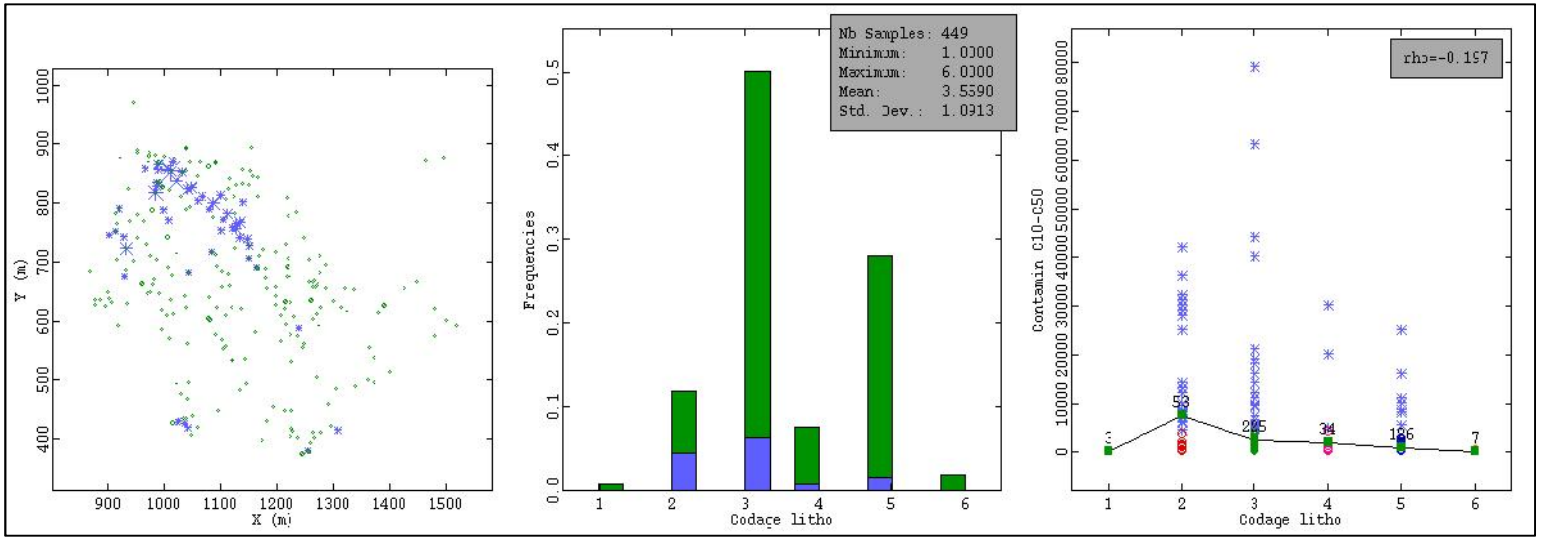




fills	**Sand, gravel, Silt-F**
Natural soil	**Silt-NS, clay, organic matter**

2. Exploratory Data Analysis

Correlation between concentration and geology

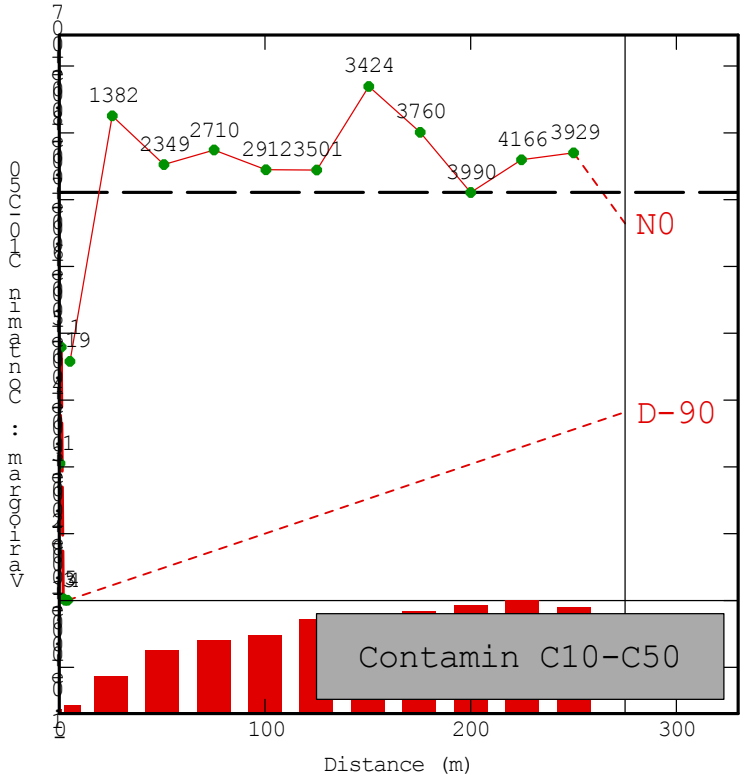


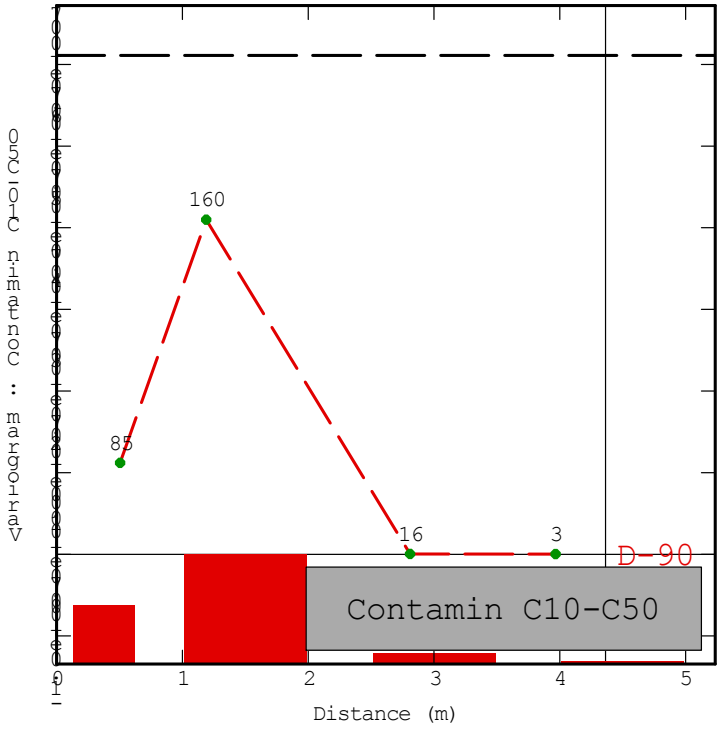
Lithology	Code	Frequency	Effective	Mean (PH ppm)	Minimum concentration	Maximum concentration
2. Gravel	2	11,8	53	7584,53	100	42018,9
3. Sand	3	50,2	225	2539,87	100	79019,9
4. Silt_F	4	7,6	34	1904,41	100	30005,4
5. Silt_NS	5	28,1	126	870,95	100	25004,1
1. Clay	1	0,7	3	100	100	100
6. Org Matter	6	1,6	7	137,14	100	281,07

2. Exploratory Data Analysis

Experimental Variogram Construction

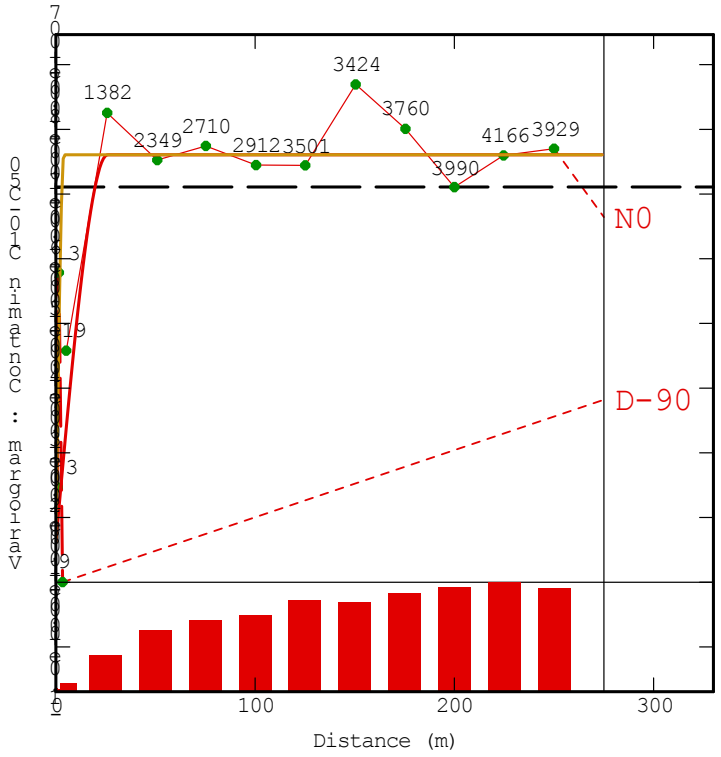
B.1/ Isotrope Directional Variogram– NO/D90

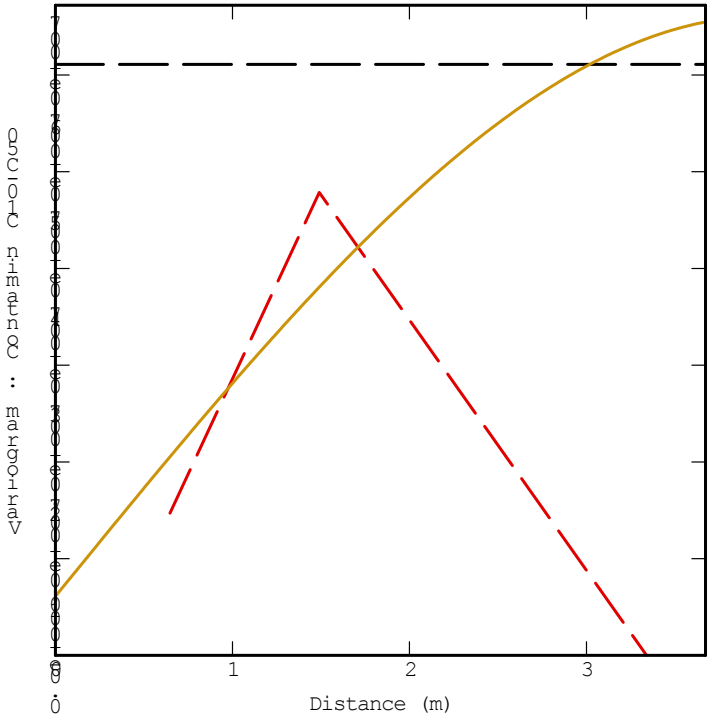




3. Variogram Fitting

B.1/ Isotrope Directional Variogram– NO/D90





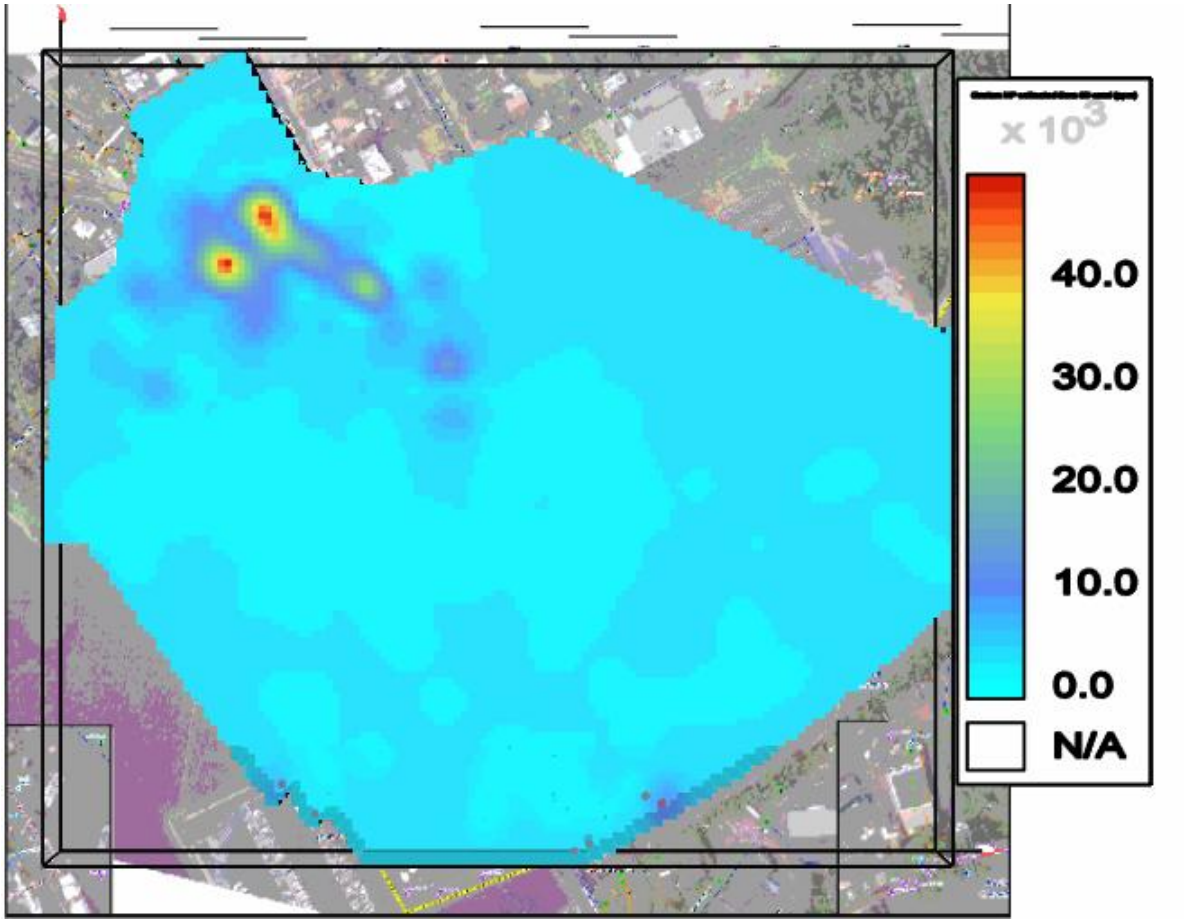
3. Variogram Fitting

Cross Validation

		Mean	Variance	Percentage of robust data	Correlation Coefficient Z/Z*
3D Variogram	Error	-44.55817	29886681.8726	98.6	0.687
	Standard error	-0.00355	0.96465		

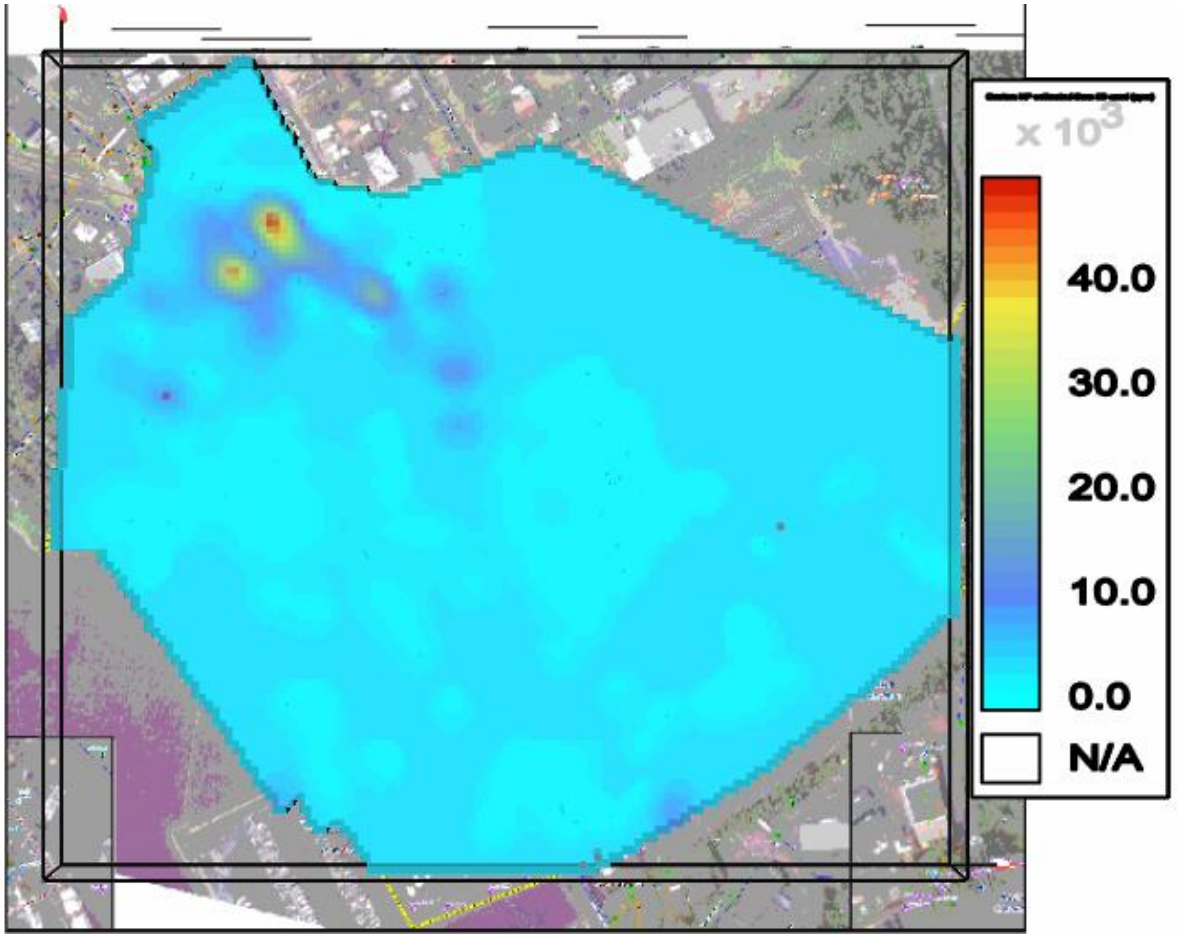
4. Interpolation method: ordinary krigging

Petroleum Hydrocarbons 0-2 m



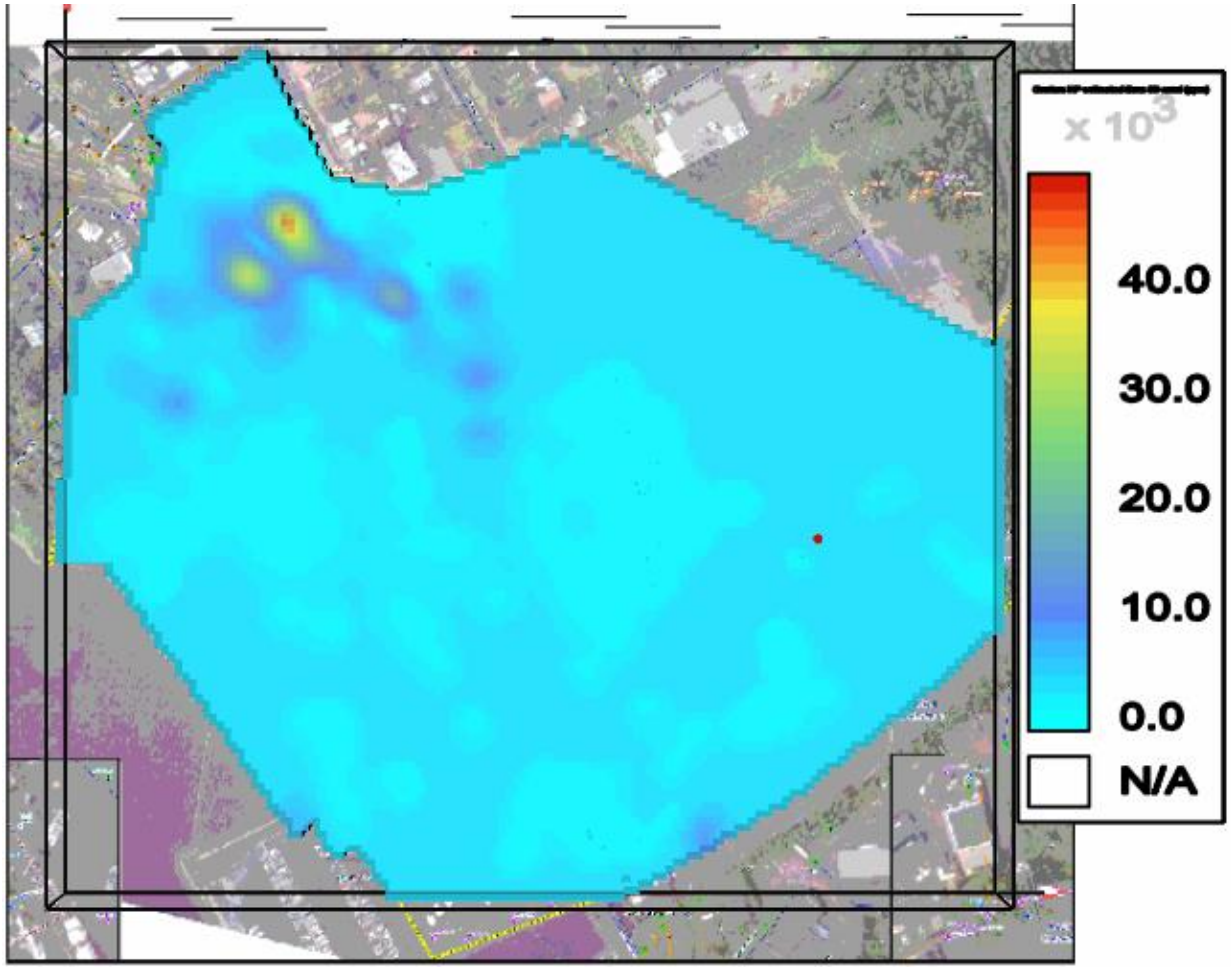
4. Interpolation method: ordinary krigging

Petroleum Hydrocarbons 2-2.5 m



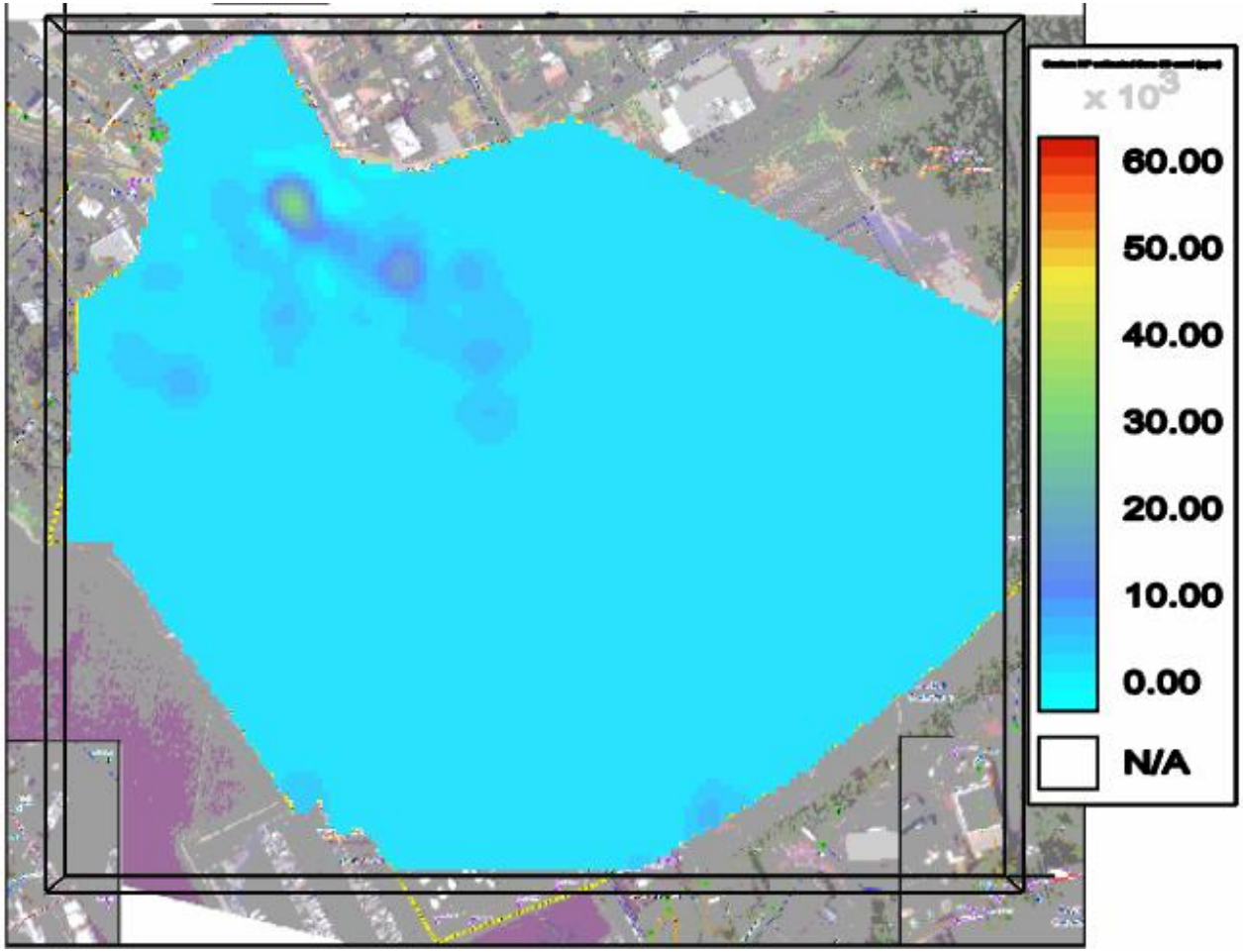
4. 4. Interpolation method: ordinary krigging

Petroleum Hydrocarbons 2.5-5 m



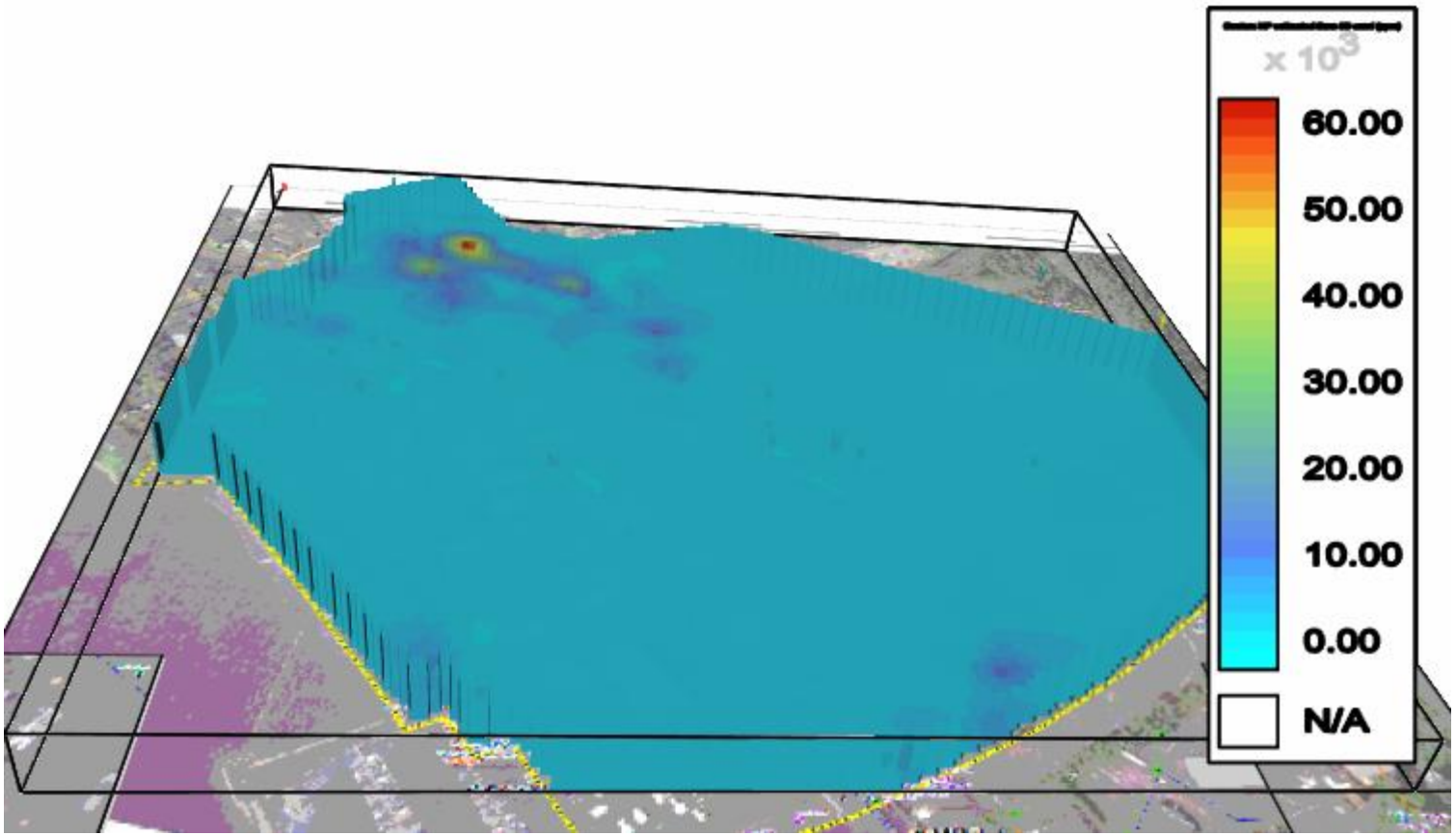
4. Interpolation method: ordinary krigging

Petroleum Hydrocarbons 5-8 m



4. Interpolation method: ordinary krigging

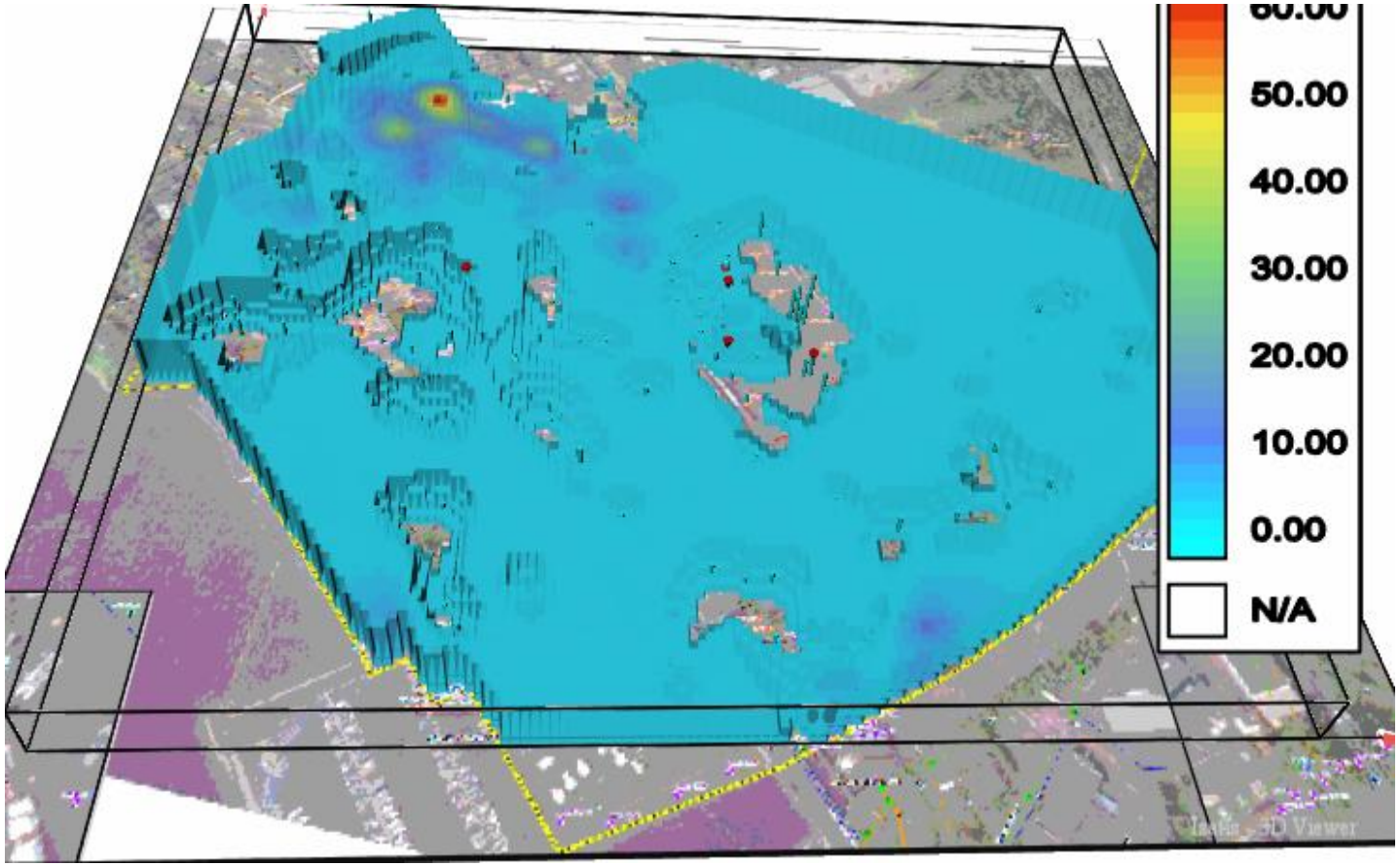
Petroleum Hydrocarbons – 3D view



4. Interpolation method: ordinary krigging

Petroleum Hydrocarbons Concentrations > 700 ppm - 3D view

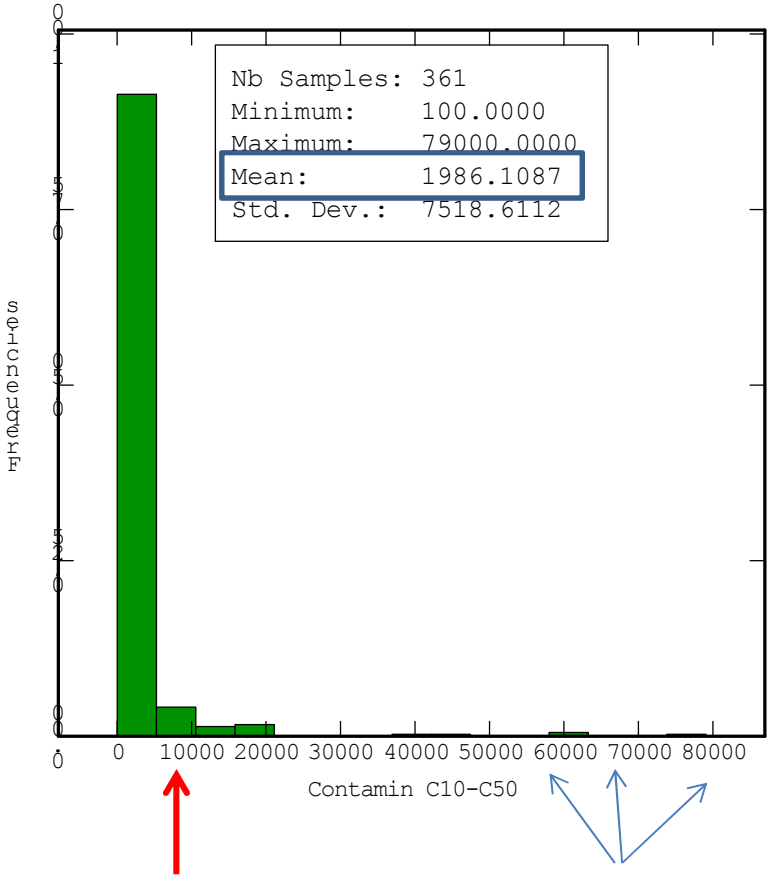
Is the whole site contaminated? Why?



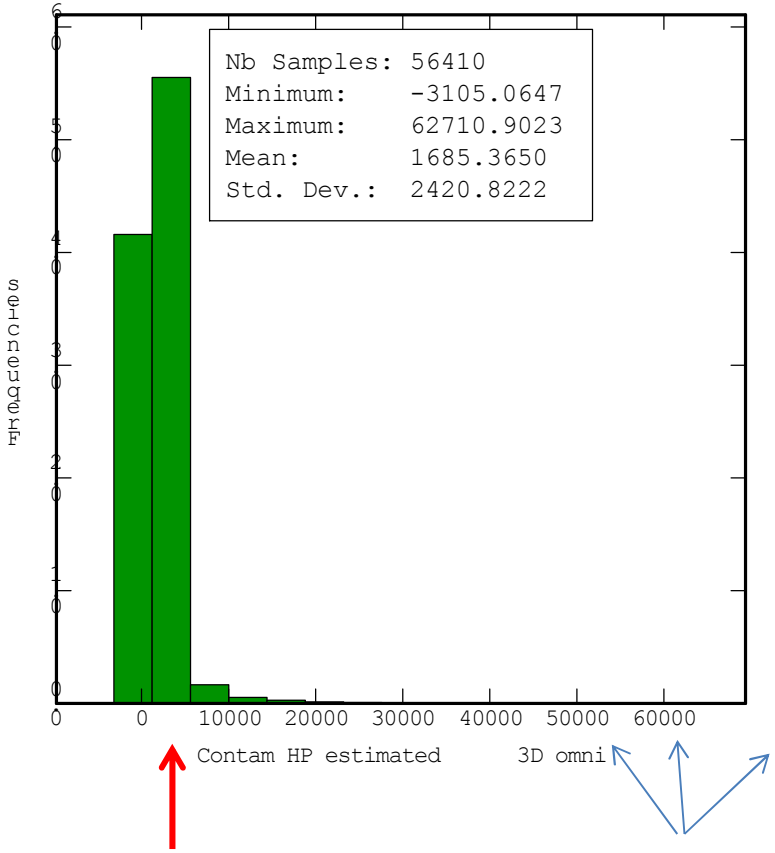
4. Interpolation method: ordinary krigging

Krigging reproduces the expected value of the distribution: estimates are strongly influenced by the mean value of the distribution

Original data histogramme - PH



Krigging histogramme- PH



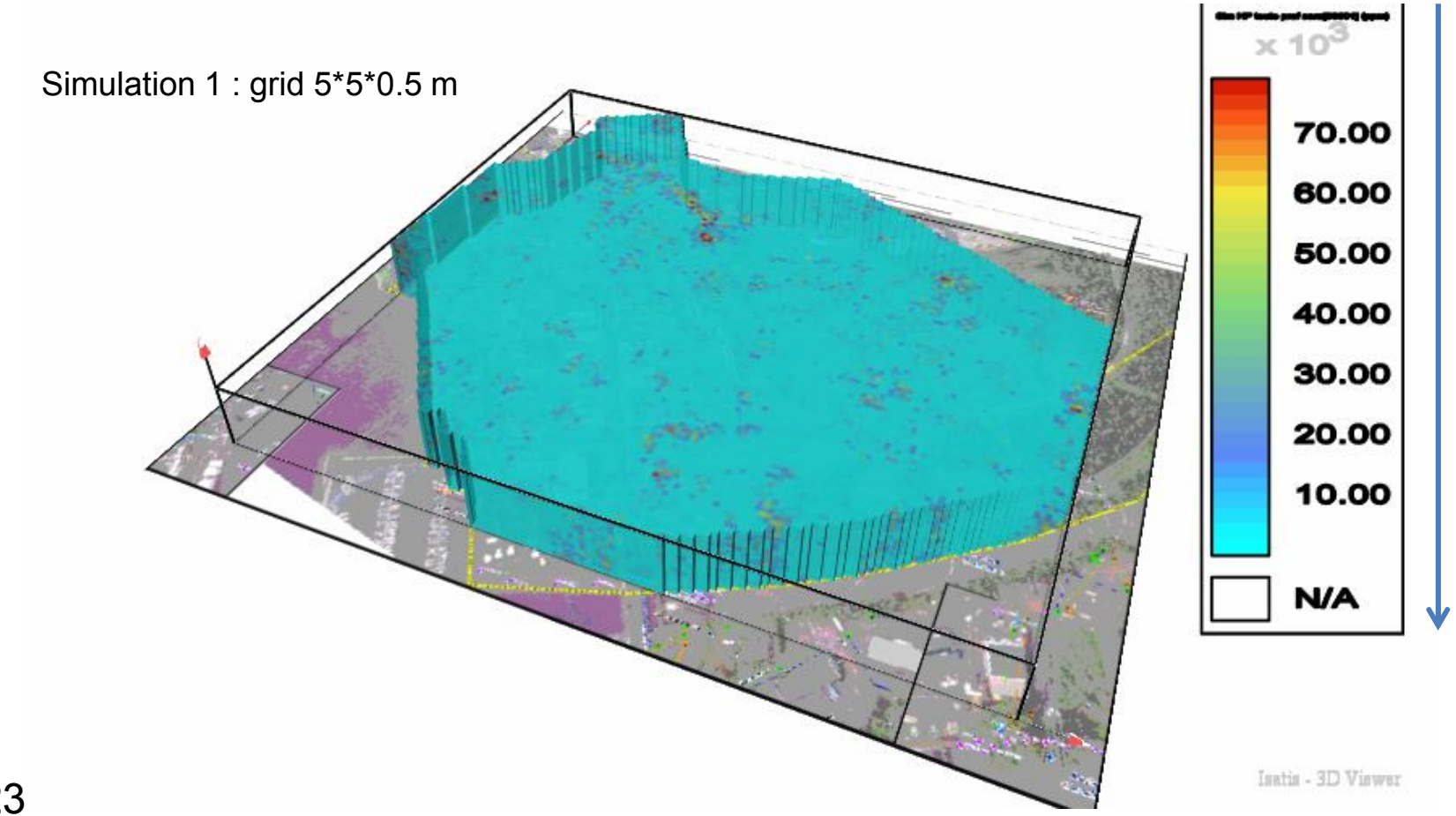
5. Interpolation Methods: Conditional simulations

Krigging	Conditional Simulations
Krigging allows reproducing the expected value of the distribution: estimates are strongly influenced by the mean value	Each simulation respects the values observed in the sample points. Mean and variance are preserved in each realization
Several random fonctions whit the same mean and variance can have the same variogram	Simulations can reproduce the statistics of order 1 (histogram) and 2 (variogram)
Allows only one mapping of the contamination	Performing a large number of simulations allows to better reproduce the real diversity of possible cases, especially if we are considering a random variable.
Quantifying the uncertainty is not possible	The uncertainty is quantified so it is possible to asses the risk of the project

5. Interpolation Method: Conditional Simulations

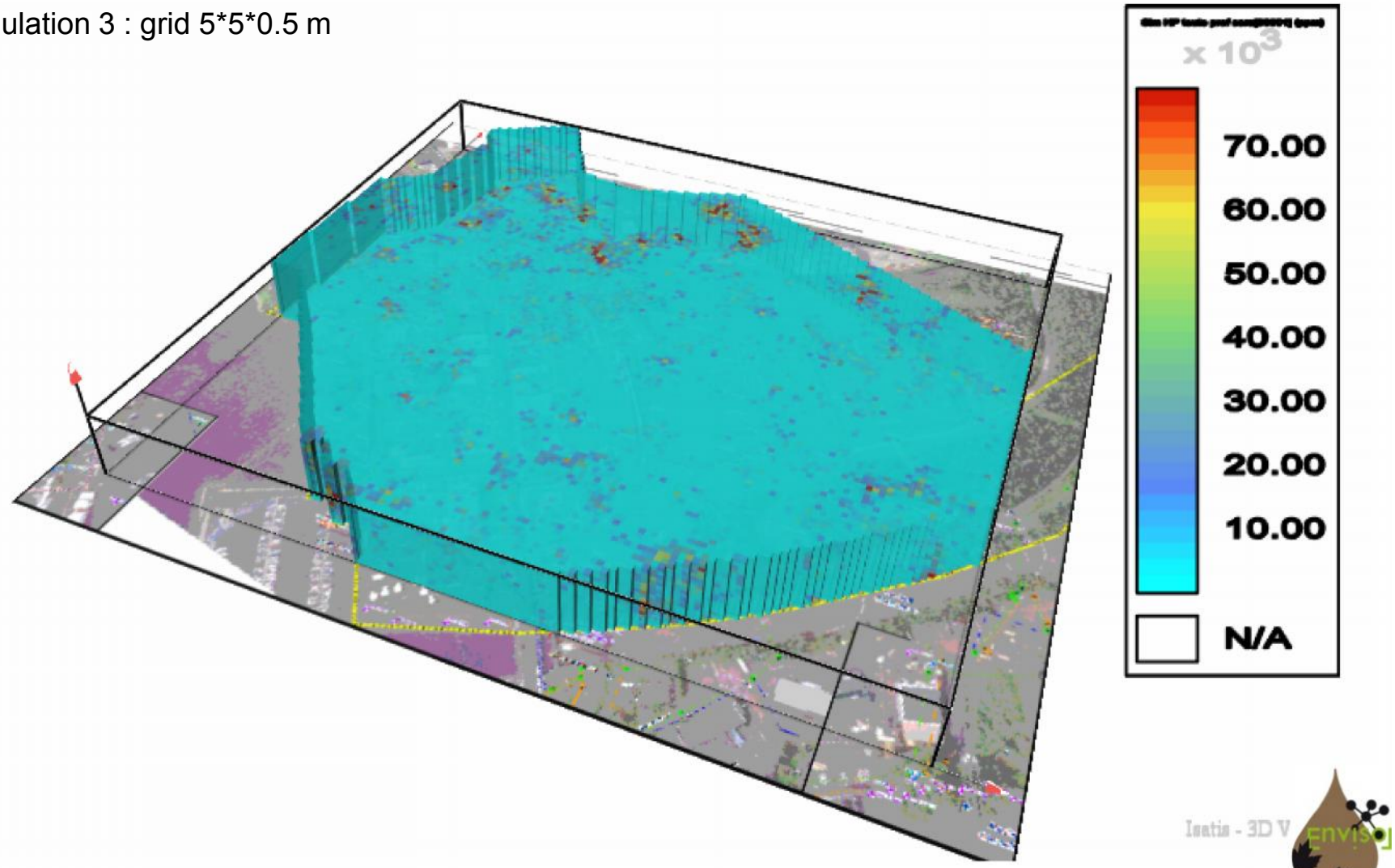
Conditional simulations allow us to perform several charts (with equal probability) to better reflect the diversity of real possible cases

Simulation 1 : grid 5*5*0.5 m



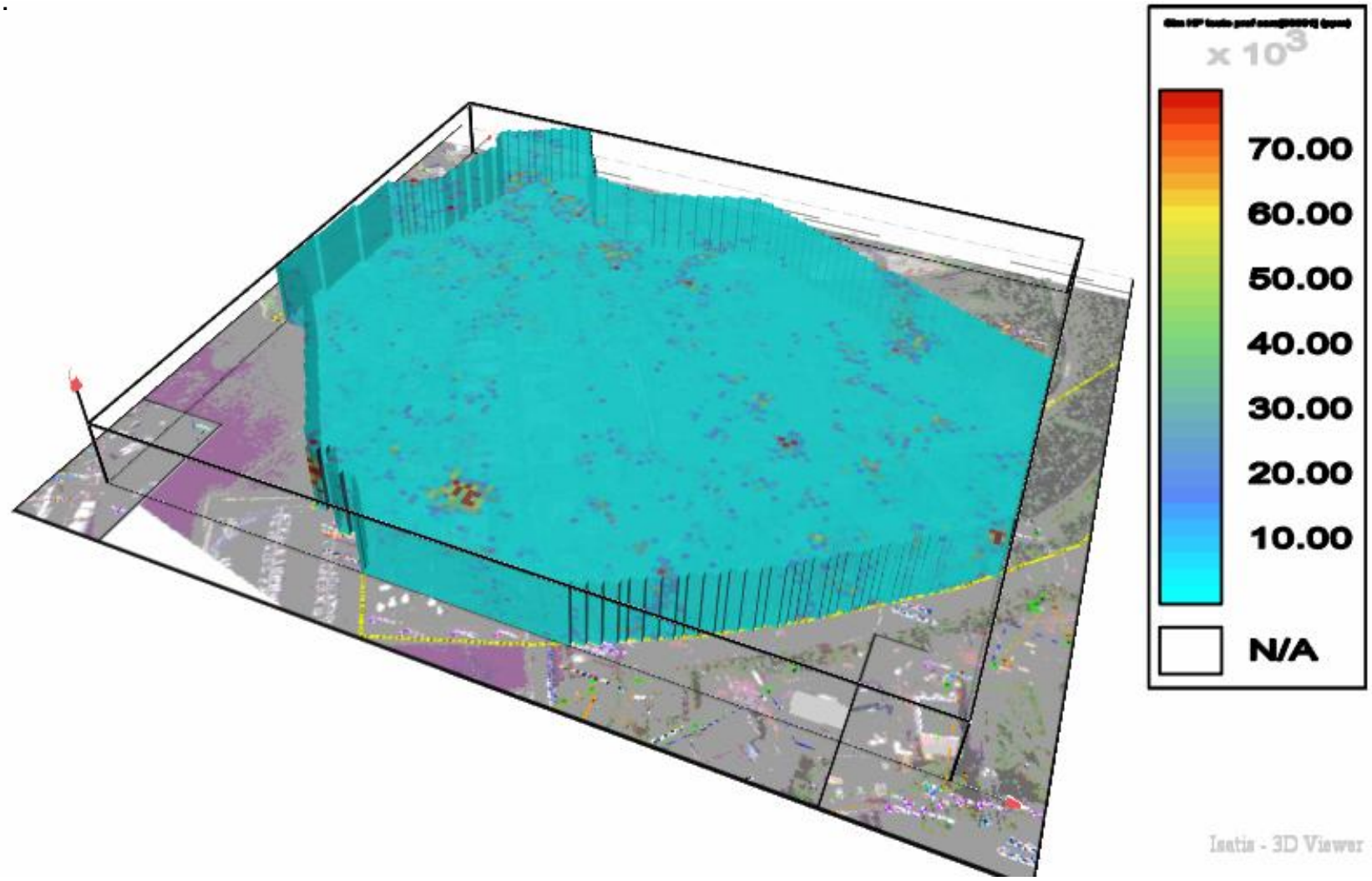
5. Interpolation Method: Conditional Simulations

Simulation 3 : grid 5*5*0.5 m



5. Interpolation Method: Conditional Simulations

Simulation 250: grid 5*5*0.5 m
etc…



5. Interpolation Method: Conditional Simulations

Performing a post-treatment of conditional simulations allows to ask the following questions:

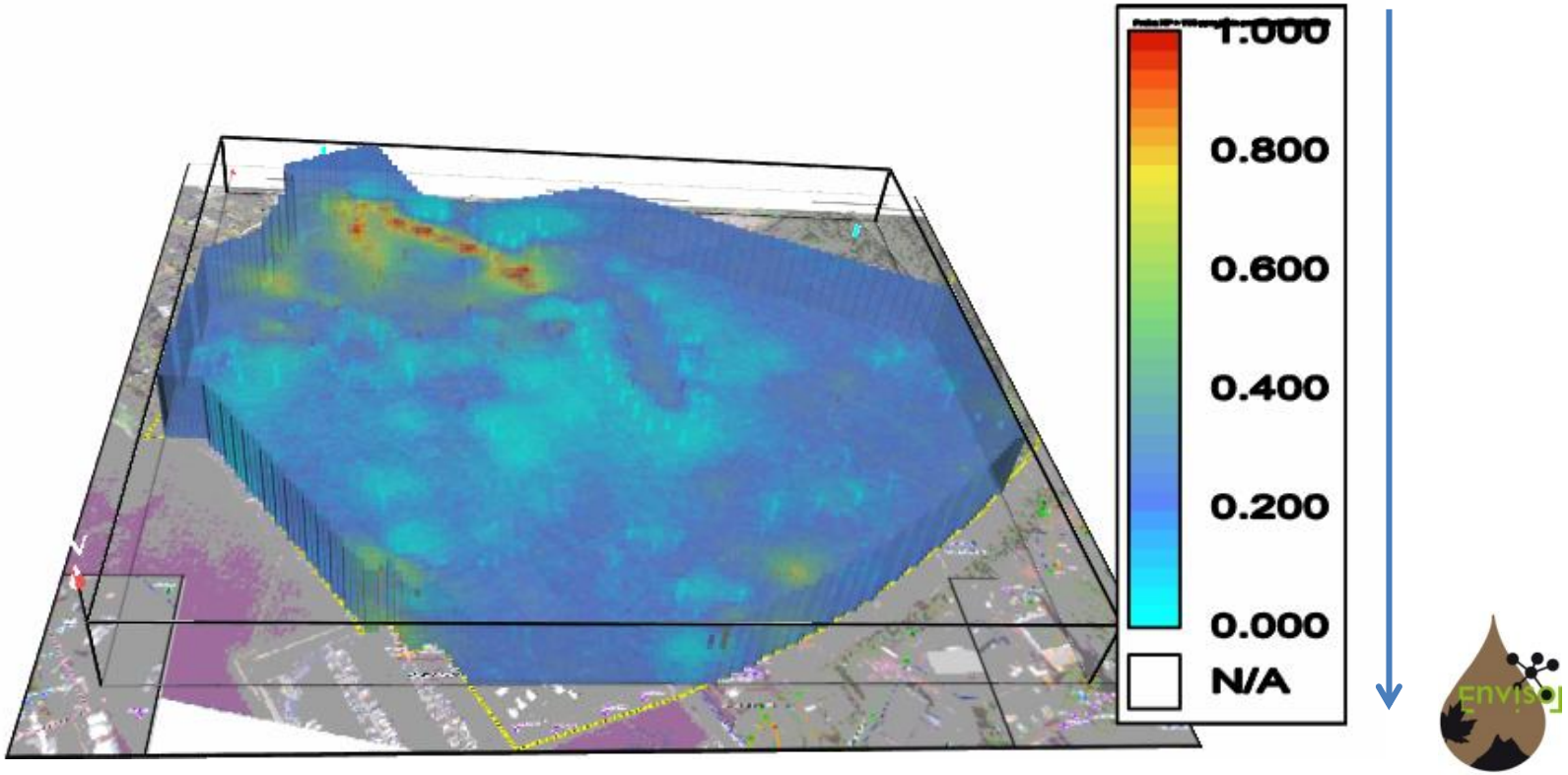
- Where are the contaminated areas? This question is used to **locally** estimate the risk of exceeding the remediation threshold
- What is the volume of contaminated soil ? This question is used to estimate the **overall** level of contamination in the study area

How to answer these questions ???

5. Interpolation Method: Conditional Simulations

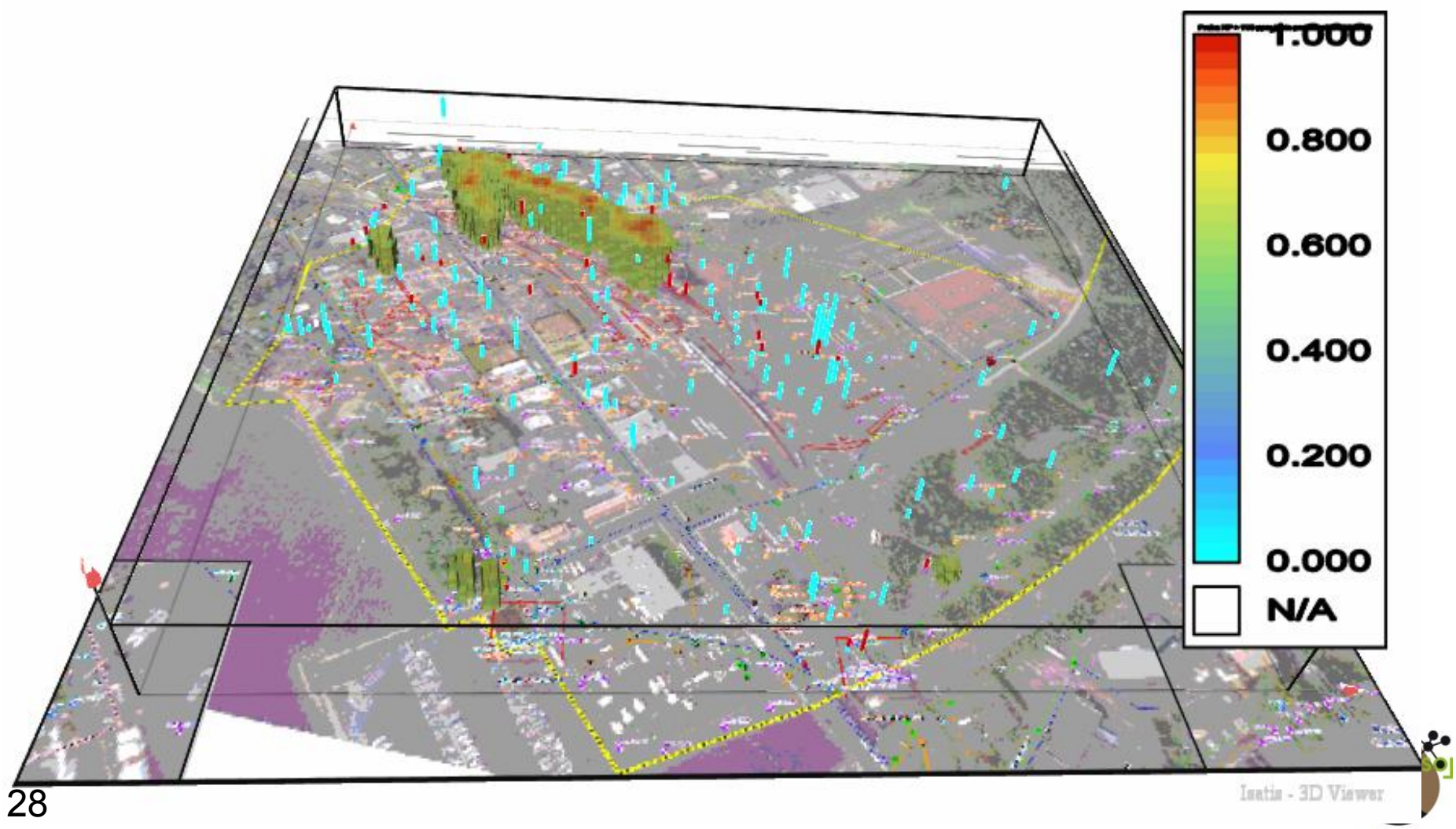
Where are the contaminated areas? This question is used to **locally** estimate the risk of exceeding the remediation threshold

Setting a remediation threshold → probability map for the occurrence of PH in soil (for each bloc) in concentrations higher than 750 ppm



5. Interpolation Method: Conditional Simulations

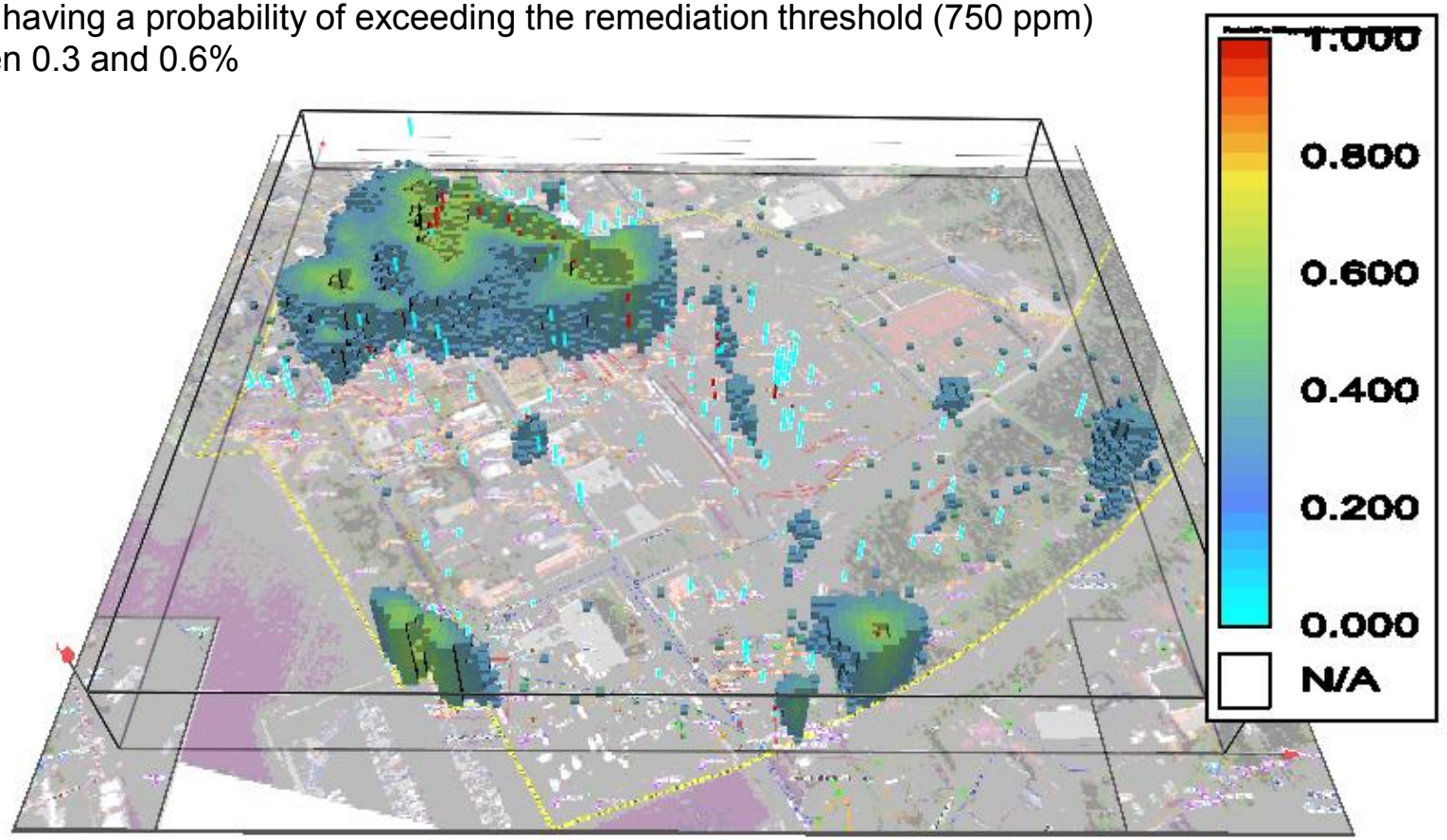
Blocks showing a probability of exceeding the remediation threshold greater than 0.6%



5. Interpolation Method: Conditional Simulations

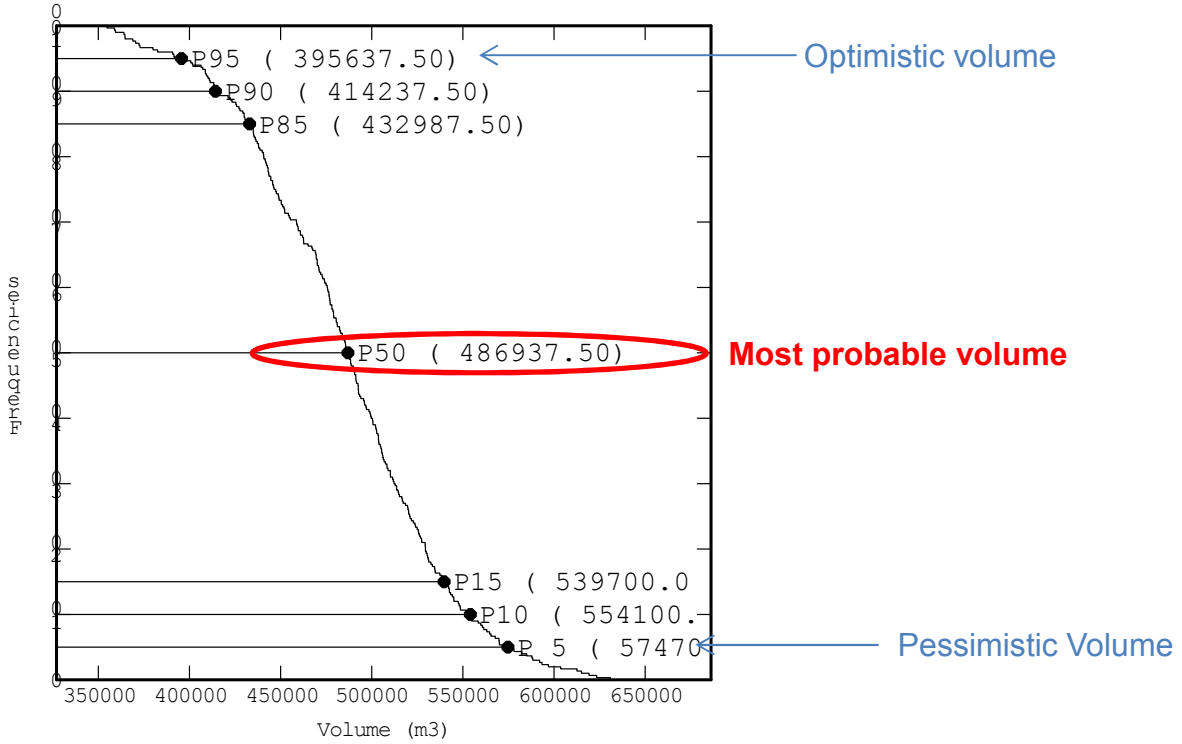
Which risk level are we willing to accept? How to manage blocks showing an uncertain estimate?

Blocks having a probability of exceeding the remediation threshold (750 ppm) between 0.3 and 0.6%



5. Interpolation Method: Conditional Simulations

What is the volume of contaminated soil ? This question is used to estimate the **overall** level of contamination in the study area



Risk curve

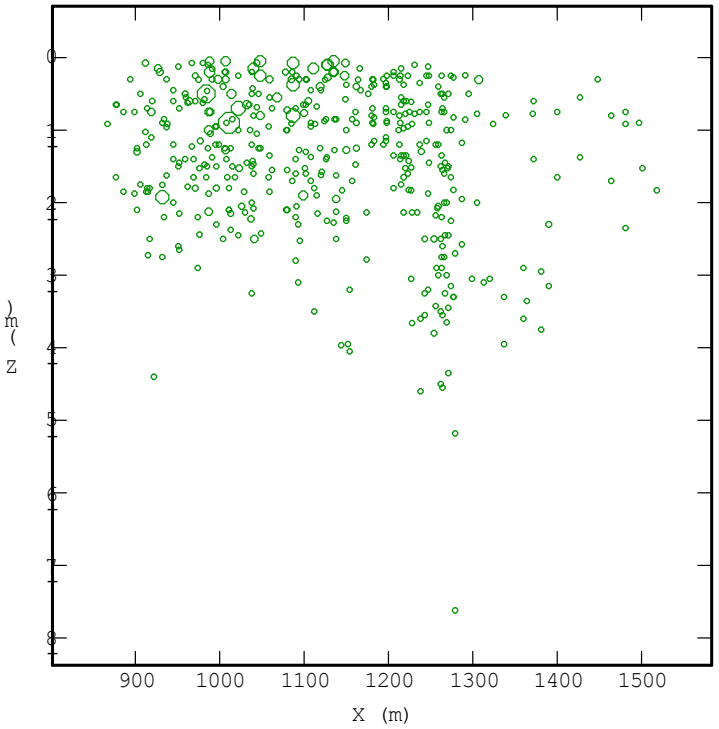
5. Interpolation Method: Conditional Simulations

Performing conditional simulations shows that:

- The estimated volume of contaminated soil is between 574 700 m3 (pessimistic volume) and 395 637 m3 (optimistic volume)
- The most probable volume is 486 937 m3, which corresponds to 25% probability of exceeding the remediation threshold (low risk)
- The uncertain volume (probability between 30% and 60%) represents a total volume of 237 787 m3
- This volume represents 48% of the most probable contaminated volume announced by the risk curve

5. Interpolation Method: Conditional Simulations

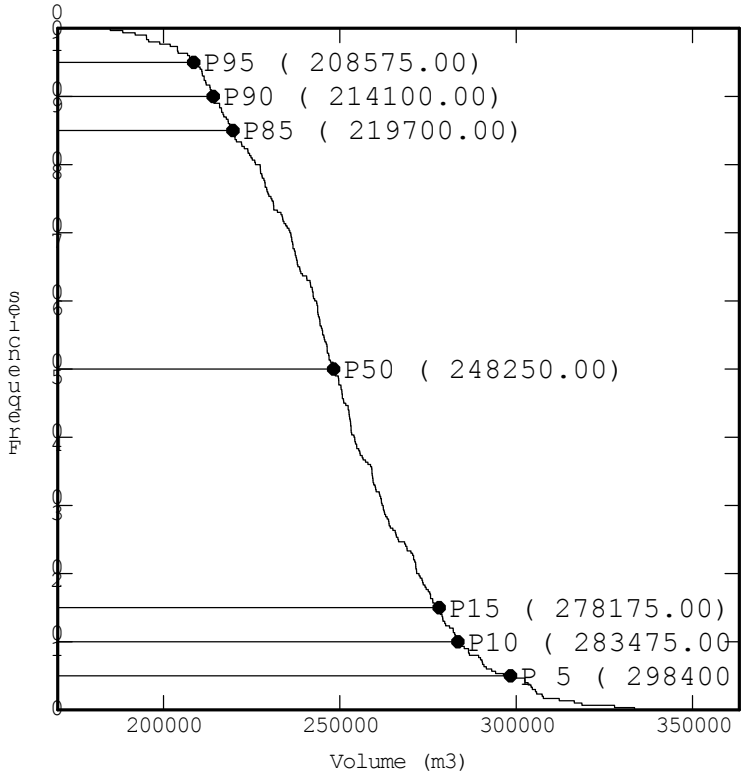
The calculations show a great uncertainty of the contaminated soil estimate



Sampling barely performed from 5 m depth

5. Interpolation Method: Conditional Simulations

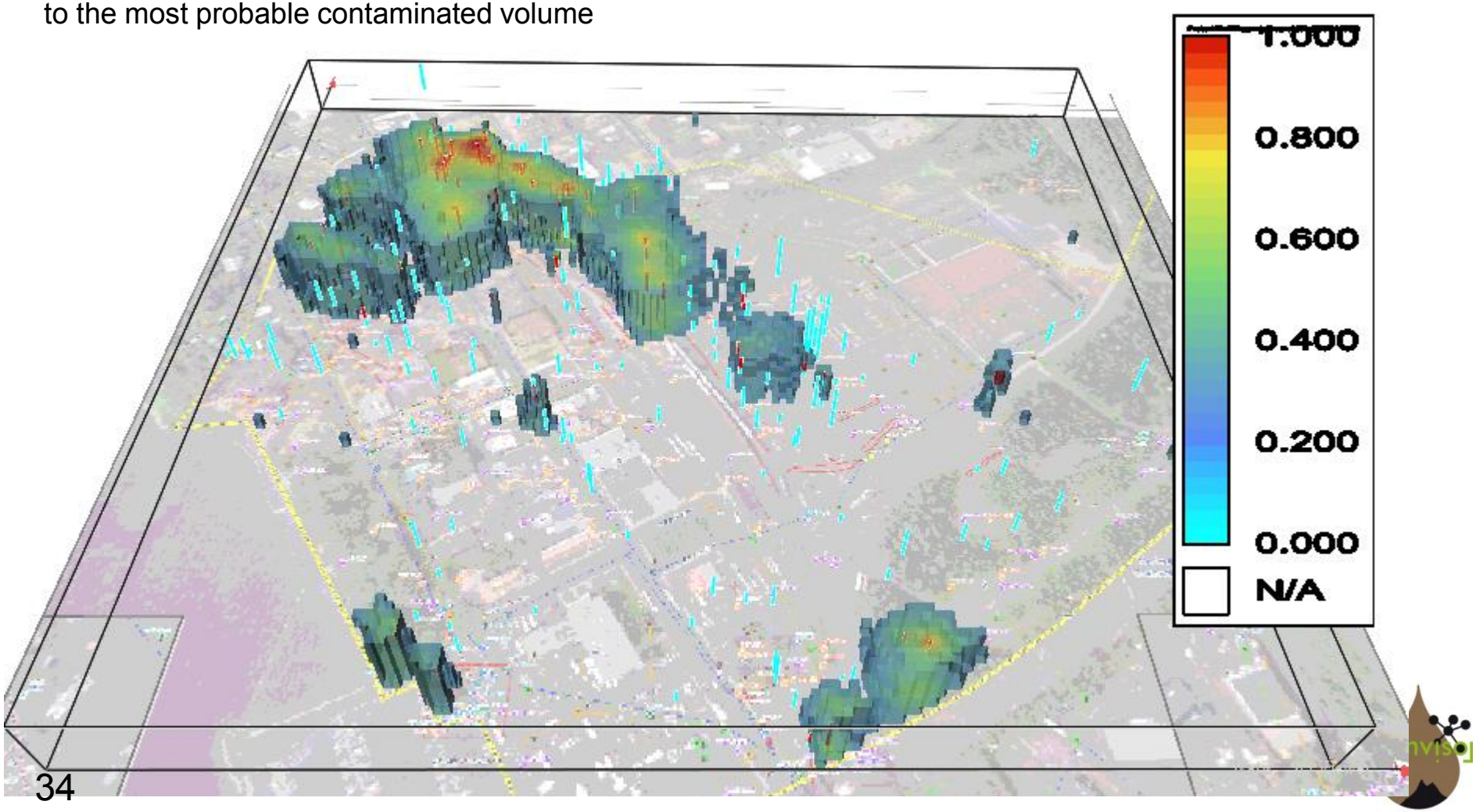
If the estimate is stopped at 5 m depth:



- The difference between the pessimistic and optimistic volumes is less important,
- The most probable volume is 248,250 m3, which is half of the uncertain volume calculated above, and corresponds to approximately 25% probability of exceeding the remediation threshold
- The volume of contaminated soil showing uncertain estimation (30% to 60% probability of exceeding the threshold) is 66 375 m3
- This volume represents 25% of the most probable contaminated volume (P50) announced by the risk curve

5. Interpolation Method: Conditional Simulations

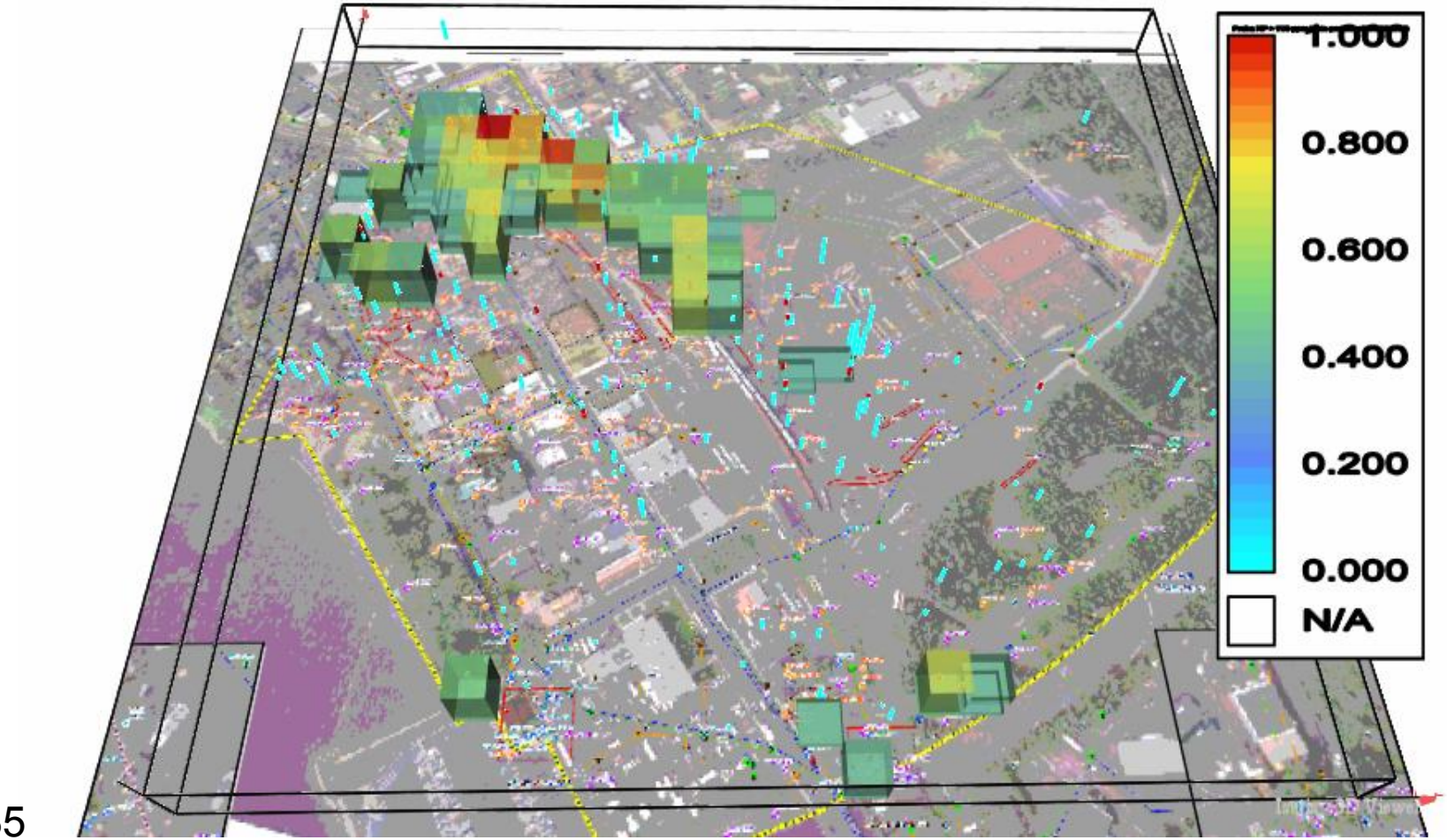
Mapping : Soil having 25% probability or more of being above the remediation threshold and corresponding to the most probable contaminated volume



5. Interpolation Method: Conditional Simulations

Changing the grid: blocks size = 25*25*1 m

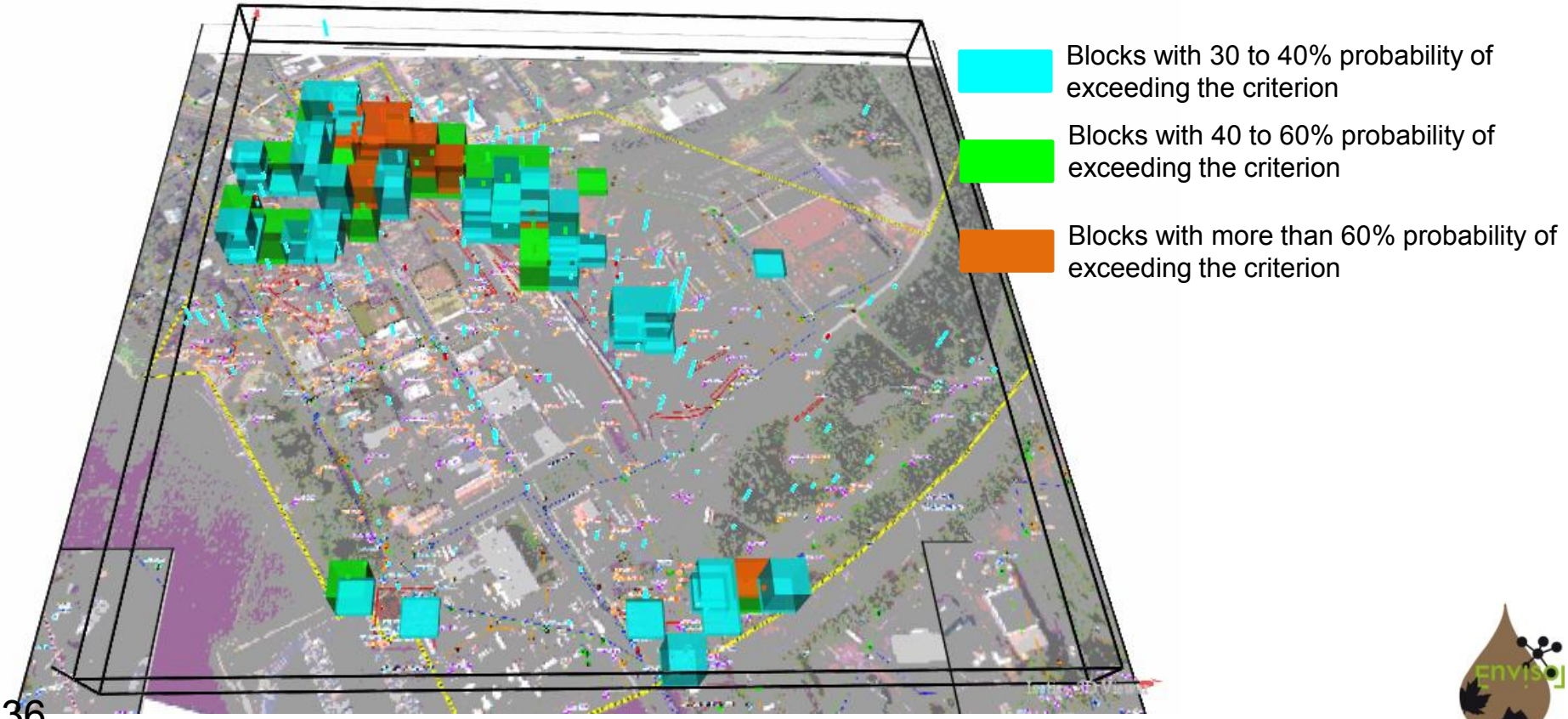
Blocks having a probability greater than 0.6% of exceeding 750 ppm



5. Interpolation Method: Conditional Simulations

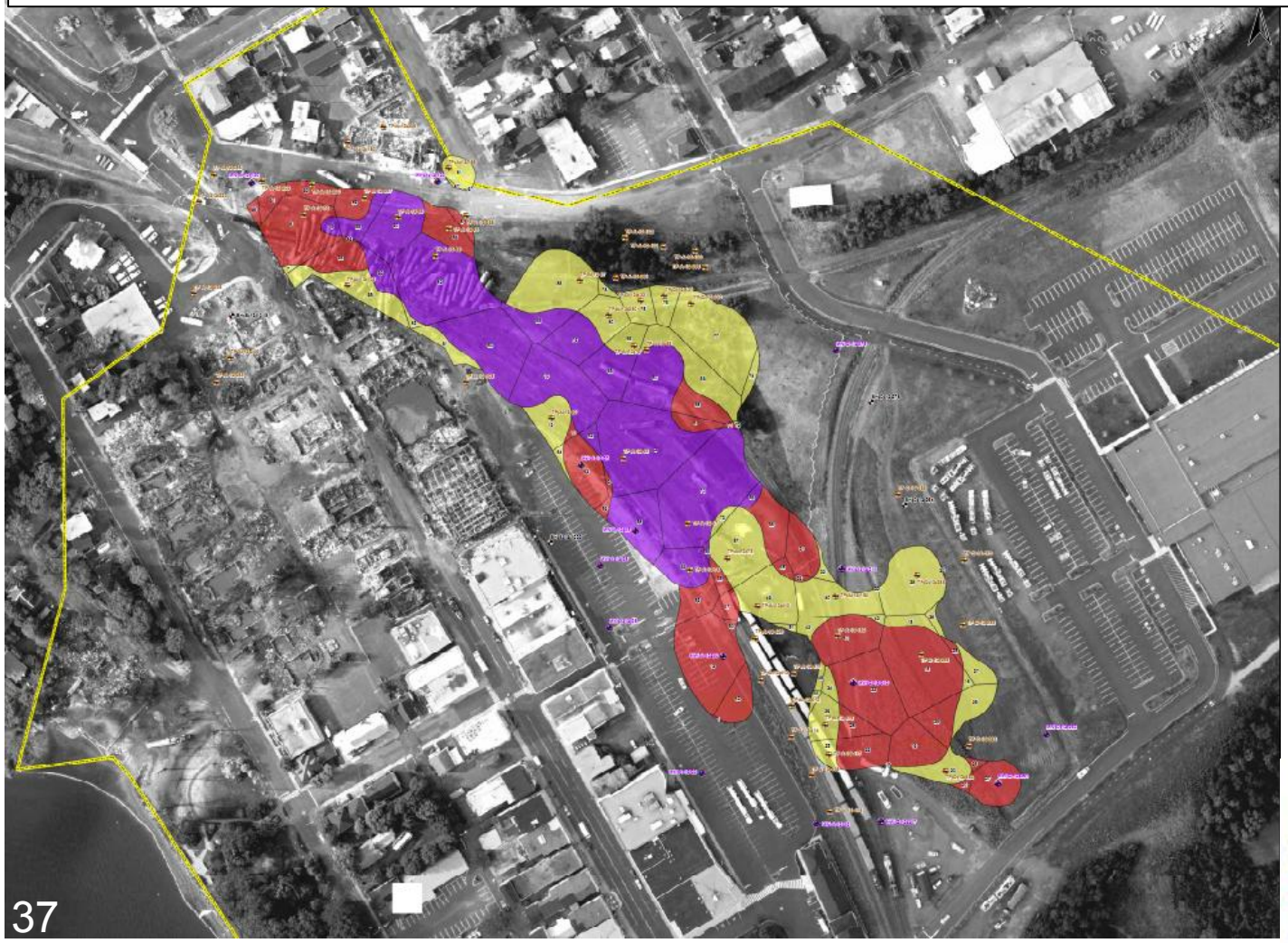
Changing the grid: blocks size = 25*25*1 m

It is possible to produce maps suitable for decontamination which will be based on the risk we are willing to take in order to define a real strategy for the remediation project



Comparison between different methods: Polygons vs Geostatistics

Polygons method performed according to the observed geology (thickness of the fills layer)

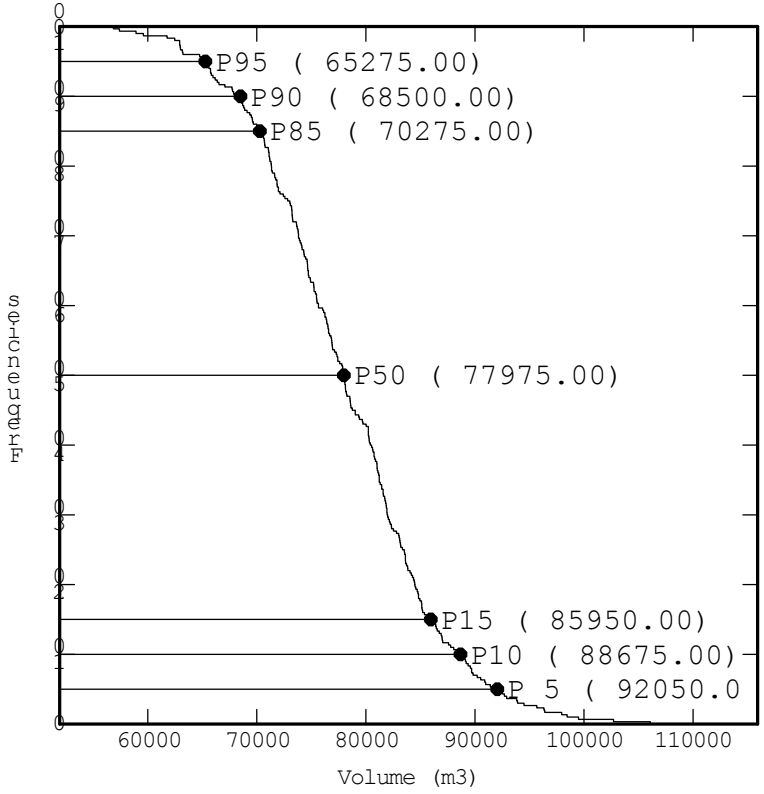


Total volume
103 000 m3
to 126 300 m3

Comparison between different methods: Polygons vs Geostatistics

Risk curve

Risk curve performed on the fills for the north area, along the railways



Conclusions

Performing the geostatistical study highligths the following information :

- Geostatistics provide a coherent analysis of data collected at each step of a contaminated site characterization by performing statistical processing of spatial data.

- Geostatistics' ultimate goal is to determine the uncertainties associated to interpolation methods in order to reduce the financial risks of remediation sites projects.

- The choice of the geostatistical method used for each project has a large influence when making estimates, especially if the original data does not show a clear spatial structure. To make relevant calculations, it is necessary to conduct a comprehensive analysis of the input data before integrating it into the geostatistical treatment. Each choice must be justified by the geostatistical theories but also judged by the experts working on contaminated sites.

Thank you for your attention