Interreg CENTRAL EUROPE

AMIIGA

European Union
European Regional Development Fund

Milano, 12 giugno 2019

AMIIGA

Luca Alberti

Politecnico di Milano – Dipartimento di Ingegneria Civile e Ambientale

INTEGRATED APPROACH TO MANAGEMENT OF GROUNDWATER QUALITY IN FUNCTIONAL URBAN AREAS

Interreg CENTRAL EUROPE AMIIGA

European Union European Regional Development Fund

AMIIGA project tackles the issue of complicated groundwater contamination crossing administrative borders.

In 6 Central European countries, representing the typical groundwater contamination problems, AMIIGA project is testing advanced investigation and assessment tools:

- statistical analysis to explore large monitoring datasets
- numerical modelling to spatially delimit the boundary of the plumes
- CSIA (Compound Specific Isotope Analysis) to distinguish between contaminant's sources and demonstrate degradation processes
- BMT (Biological Molecular Tool) to evaluate the capability of indigenous microbial consortia to degrade contaminants in situ.

This transnational cooperation project is funded by **Interreg CENTRAL EUROPE** and aims to improve sustainable use of natural heritage.

12 project partners
8 regions
7 pilot actions
18 outputs
2.9 million EUR Project budget
2.4 million EUR ERDF funding

GIG | Jaworzno | STUTTGART | TECHNICAL UNIVERSITY OF LIBEREC www.tul.cz

Regione Lombardia | POLITECNICO MILANO 1863 | Comune di Parma | GeoZS Geološki zavod Slovenije | VODOVOD KANALIZACIJA

WORK PACKAGES

WP M	Management [PP1 GIG]	Start: 09.2016 End: 08.2019
WP1	Tools for remediation and pollution management in FUA [PP7 PoliMi]	Start: 10.2016 End: 12.2018
WP2	Groundwater remediation - from conceptual model to realization [PP5 TUL]	Start: 09.2016 End: 08.2019
WP3	Management plan [PP3 Stuttgart]	Start: 10.2016 End: 08.2019
WP C	Communication [PP8 Parma]	Start: 10.2016 End: 08.2019

http://www.interreg-central.eu/AMIIGA
This project is supported by the Interreg CENTRAL EUROPE Programme funded under the European Regional Development Fund.

2.959.471,74 Project budget in EUR
2.444.589,52 ERDF funding in EUR
01/09/2016 - 31/08/2019 Project duration

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ACTIVITIES

WP1	Tools for groundwater pollution assessment and remediation in Functional Urban Areas (FUAs)	Start date: 10.2016 End date: 12.2018

Activity A.T1.1	FOKS tools amendment and adaptation to FUA scale	Start date: 10.2016 End date: 10.2017
Activity A.T1.2	Innovative CSIA TOOL for pollution and remediation assessment	Start date: 12.2016 End date: 10.2018
Activity A.T1.3	Innovative BMTs TOOL for natural and enhanced bioremediation implementation	Start date: 12.2016 End date: 10.2018
Activity A.T1.4	Harmonizing of innovative tools CSIA with previously amended FOKS tools	Start date: 09.2017 End date: 12.2018
Activity A.T1.5	Trainings and internships for improving technical skills and cooperative development of tools	Start date: 02.2017 End date: 09.2018

INTRODUCTION

Activity A.T1.1	FOKS tools amendment and adaptation to FUA scale	Start date: 10.2016 End date: 10.2017

The tools developed during the previous FOKS project were designed to be applied at the scale of a single contaminated site

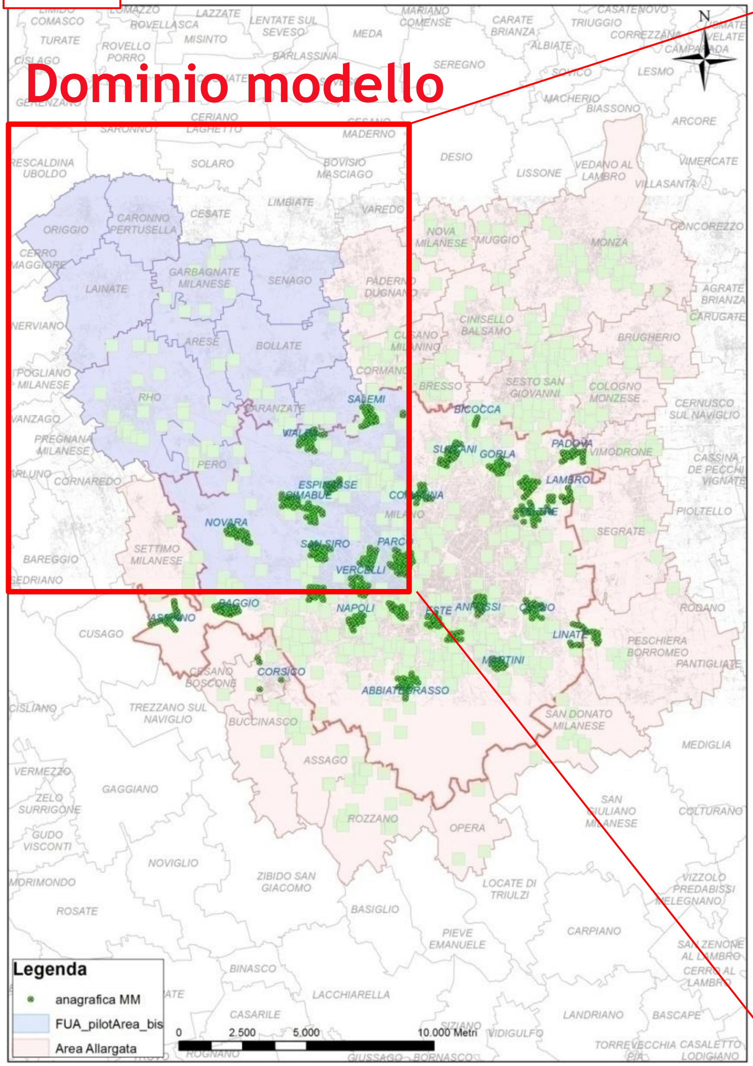
In order to be applied at FUA scale they needed to be adapted considering the existence of 2 kinds of contamination:

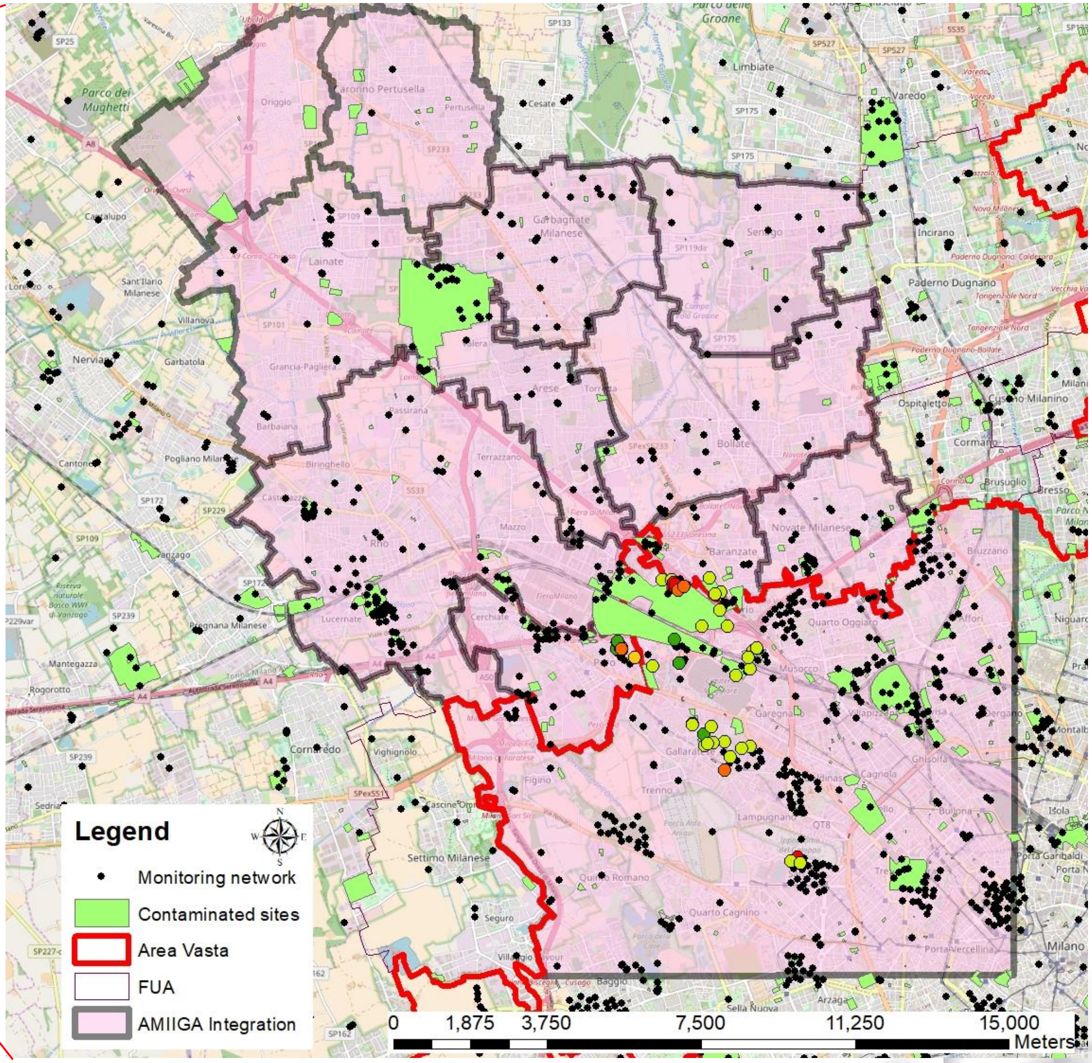
Point Sources (PS), responsible of medium-high concentration plumes

Multiple Point Sources (MPS), constituted by multiple small and unidentifiable sources responsible of an anthropogenic diffused contamination

WEBGIS

link


Dominio modello
Legenda
anagrafica MM
FUA_pilotArea_bis
Area Allargata
0 2.500 5.000 10.000 Metri

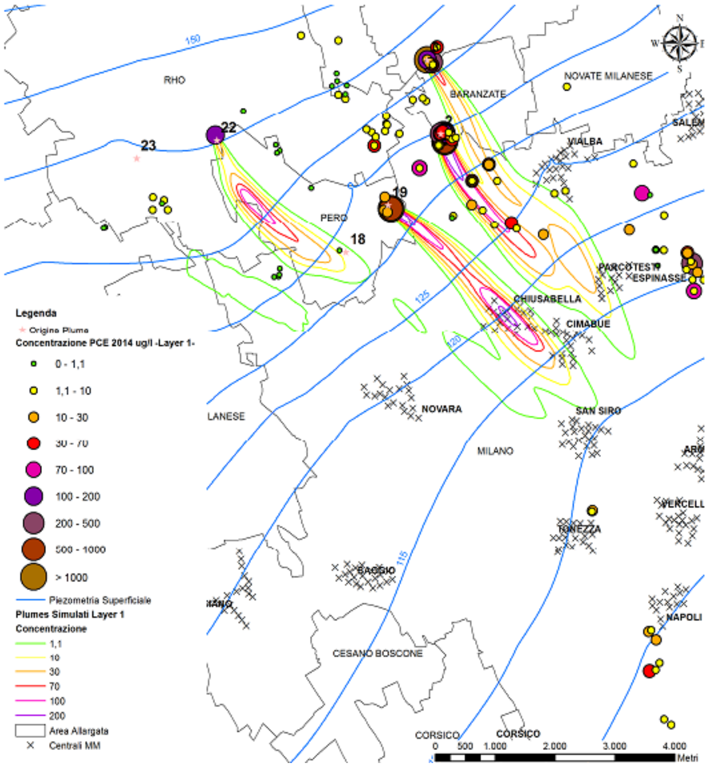

Legend
Monitoring network
Contaminated sites
Area Vasta
FUA
AMIIGA Integration
0 1,875 3,750 7,500 11,250 15,000
Meters

HOW TO LOCATE SUSPECTED SOURCES?

Milano FUA had a long industrial history since the 50ies.
Many Chlorinated Hydrocarbons plumes are still present and they hit some public wells.
Often, as in many industrial districts, plumes with high concentrations are detected but the contaminant source position (PS) is unknown.
As Milano aqueduct is fed only by groundwater the Public Authorities are asking:

HOW CAN WE DISTIGUISH THE DIFFUSE CONTAMINATION FROM THE POINT SOURCES CONTAMINATION?

HOW CAN WE IDENTIFY THE AREA WHERE THE PUNCTUAL SOURCES ARE POSITIONED?



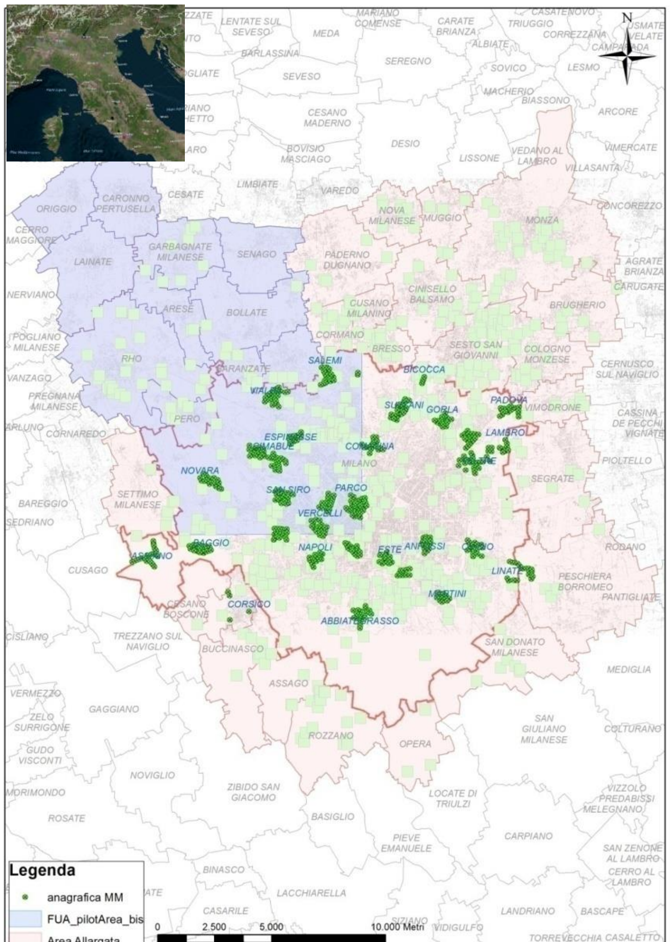
TOOLS DEVELOPMENT

Activity A.T1.1	**FOKS tools amendment and adaptation to FUA scale**	**Start date: 10.2016** **End date: 10.2017**

Deliverable D.T1.1.1	Web-GIS tool development for groundwater database management and open-access consultation	Delivery date: 10.2017 concluded
Deliverable D.T1.1.2	Guideline for statistical method and geostatistical analysis for GW quality studies at FUA	**Delivery date:** 03.2017 concluded
Deliverable D.T1.1.3	GW contamination modeling at FUA: “inverse iterative modeling” guideline for implementation and use	Delivery date: 04.2017 concluded
Deliverable D.T1.1.4	Technical protocol for statistical analysis coupled with transport modeling for GW pollution assessment	Delivery date: 05.2017 concluded

STATISTICAL TOOL

In AMIIGA one of the aims of WP1 is to develop and test a methodology to answer these questions



HYDROCHEMICAL DATA SET (2003-2014) AVAILABLE IN MILANO FUA (TCE,PCE,CLF)

Cluster analysis

Hot-spot location

Groundwater Transport model (Modflow-MT3D)

PLUME extension in FUA

GEOSTATISTICAL analysis (cleaned dataset)

Factor and Multivariate analysis

Diffuse contamination MAPS and assessment

Stochastic modelling for particle backtracking

Probabilistic MAPS of PS position

METHODOLOGY

1st RESULT

METHODOLOGY

2nd RESULT

STATISTICAL TOOL

Once hot spots have been identified a groundwater transport model has been applied to assess the PCE plume extension

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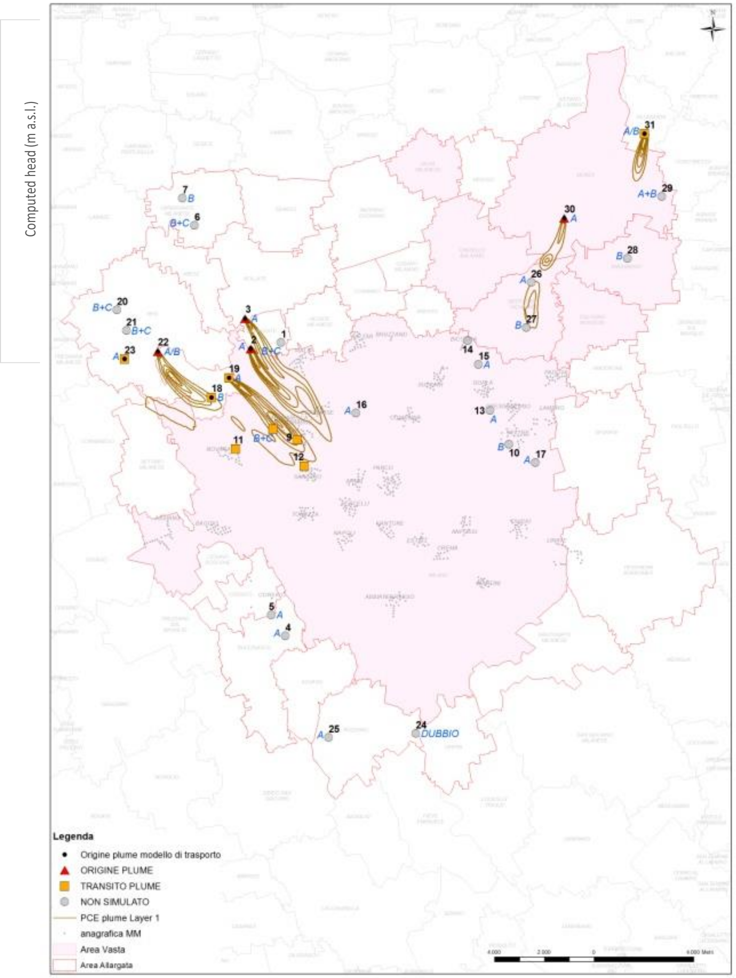
PLUME extension in FUA

METHODOLOGY



STATISTICAL TOOL

Once the plumes extension is simulated the monitoring points hit by them can be canceled from the dataset

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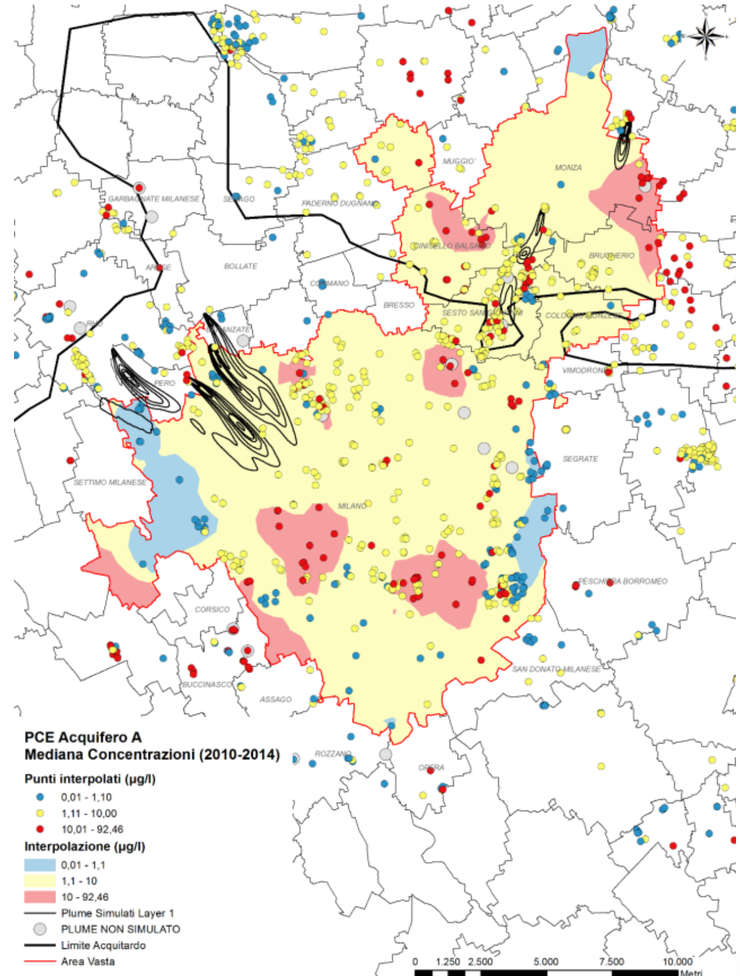
GEOSTATISTICAL analysis (cleaned dataset)

Diffuse contamination MAP

METHODOLOGY

RESULTS



STATISTICAL TOOL

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Diffuse contamination map showed that is incorrect to define a single PCE diffuse value for the entire study area. Then Factor and Multivariate analysis have been applied to define the proper value in each of the areas (yellow and read) where concentrations are higher than the Italian threshold limit (1,1 μg/l)

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Hot-spot location

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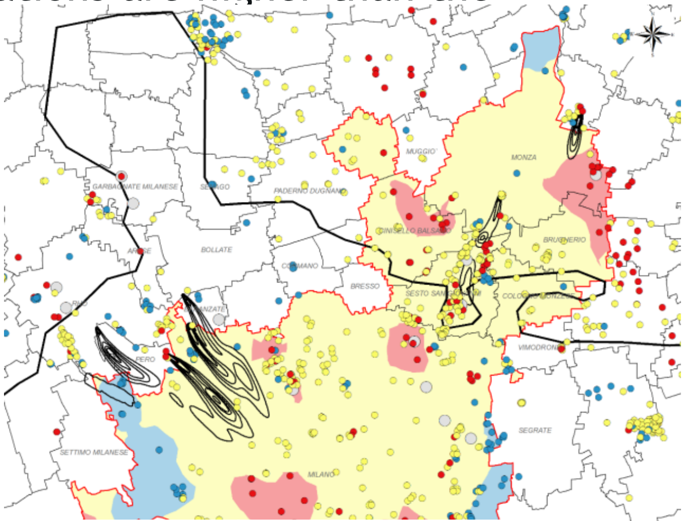
METHODOLOGY

RESULTS



	Multivariate analysis	
	Principal cluster	
	YELLOW (50° Perc.)	RED (75° Perc.)
Aquifer (A)	8	12.75
Aquifer (B)	7.1	15
Not separated (A, A+B, B)	3	6

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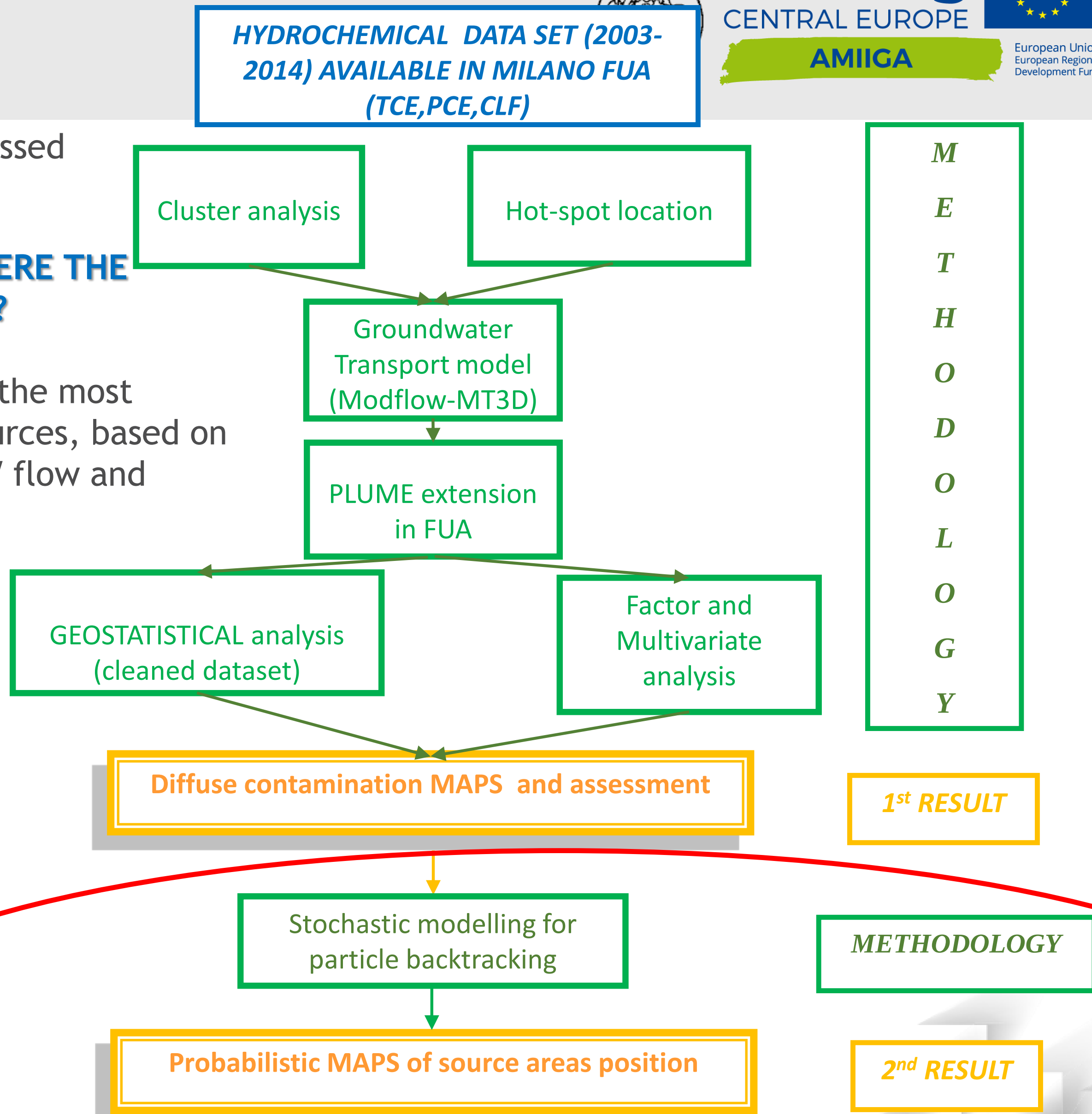
PS POSITIONING

Once the diffuse contamination is assessed and separated from the plumes…..

HOW CAN WE IDENTIFY THE AREA WHERE THE PUNCTUAL SOURCES ARE POSITIONED?

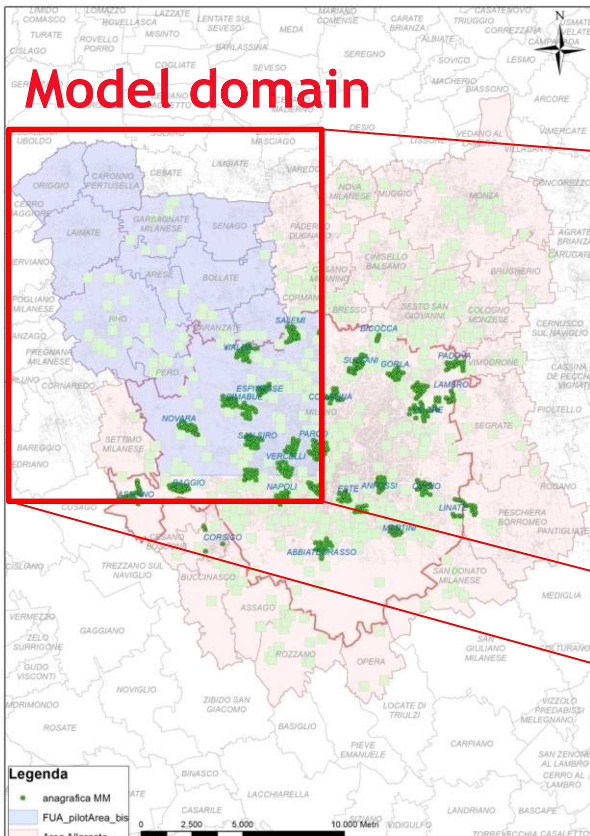
We are proposing a method to identify the most probable position of these Punctual Sources, based on inverse numerical simulation of the GW flow and advective transport

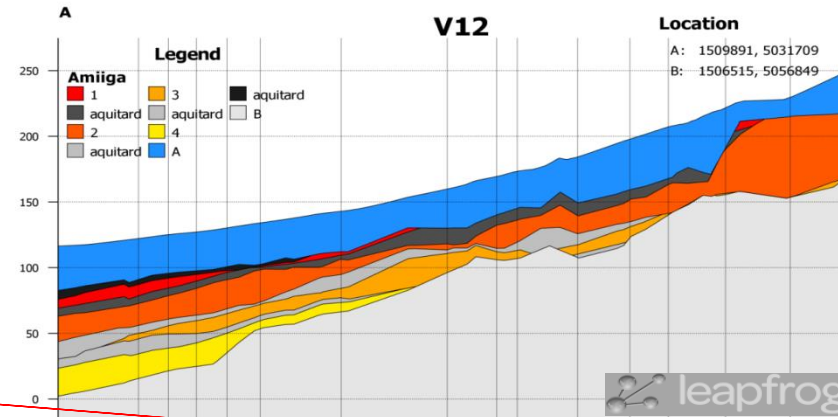


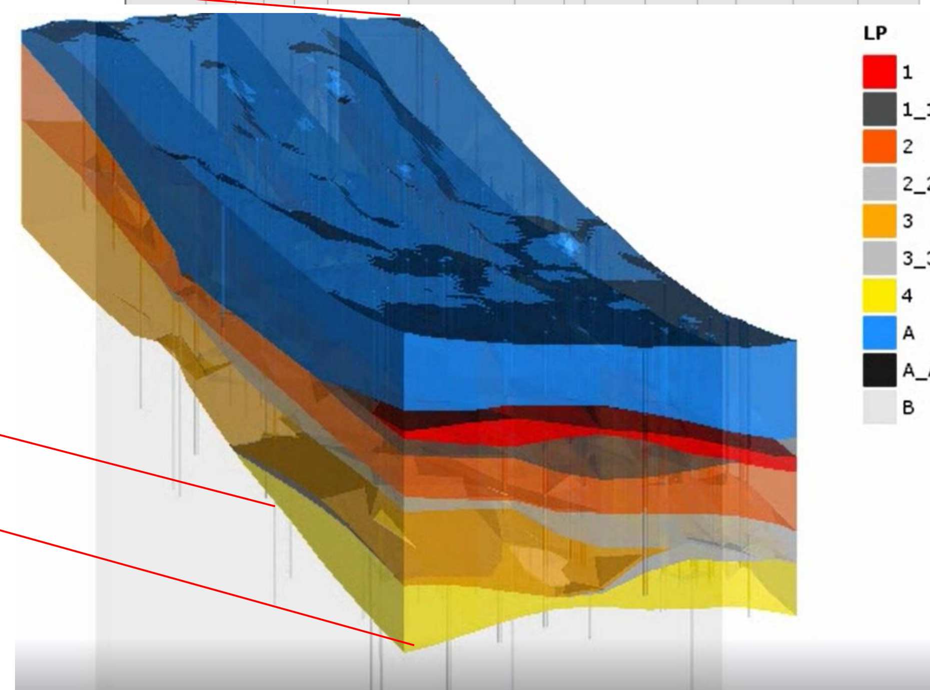
1- DETERMINISTIC MODEL

First a GW flow model was implemented and calibrated for the Milano Pilot Area

MODFLOW 2005
19x 21 Km
255.320 cells
From 100 m to 50 m
9 layers







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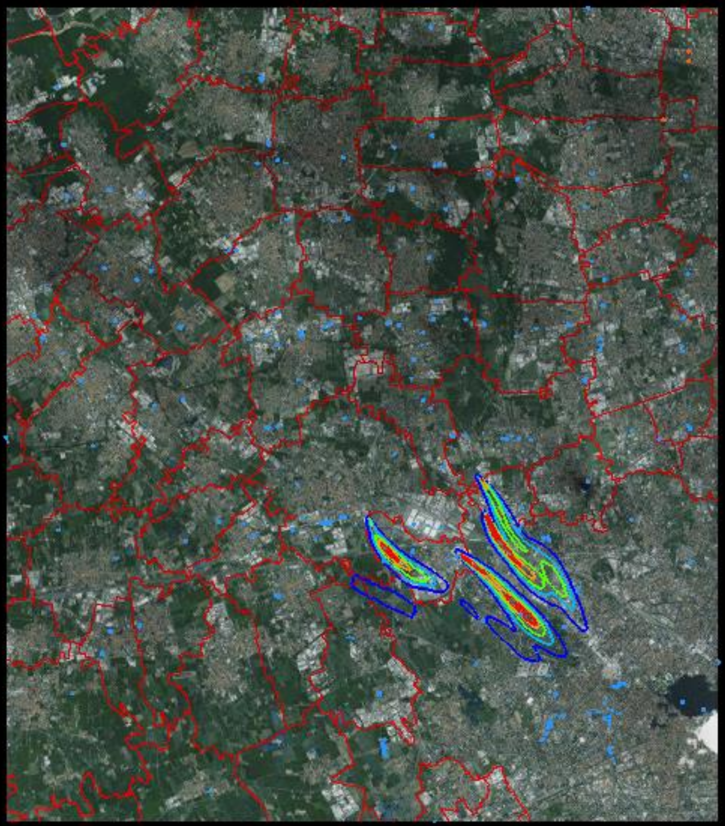


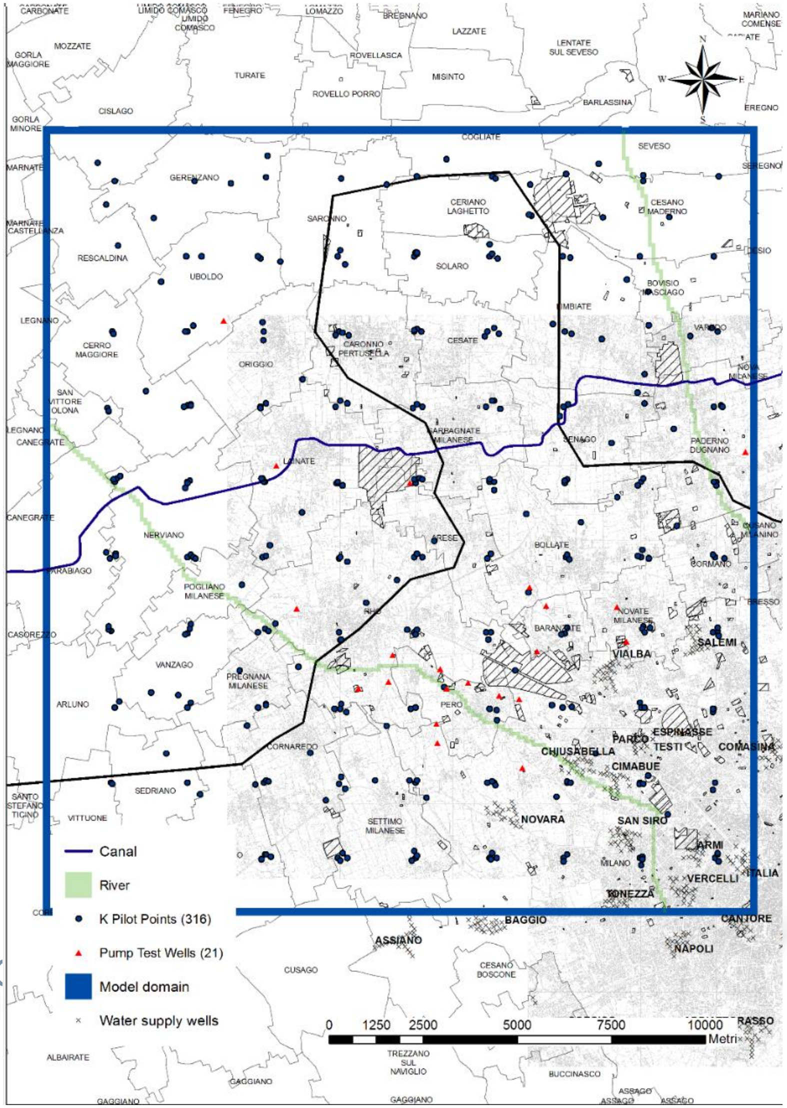
Aquifer
Aquifer A
Aquifer B1
Aquifer B2
Aquifer B3
Aquifer B4
Aquitard

2- STOCHASTIC MODELING

The deterministic model was based in a single distribution of the hydraulic conductivity (K)
In order to explore the uncertainty link to the K distribution an inverse calibration through PEST was done using the Pilot Points technique

- **316 K-pilot points where regularly placed in the model domain (10^{-5}-10^{-2} m/s for aquifer layers, 10^{-8}-10^{-6} m/s for clay lenses)**
- **21 aquifer tests where associated with Pilot Points**
- **44 observations (head targets) placed in different layers based on screened levels**

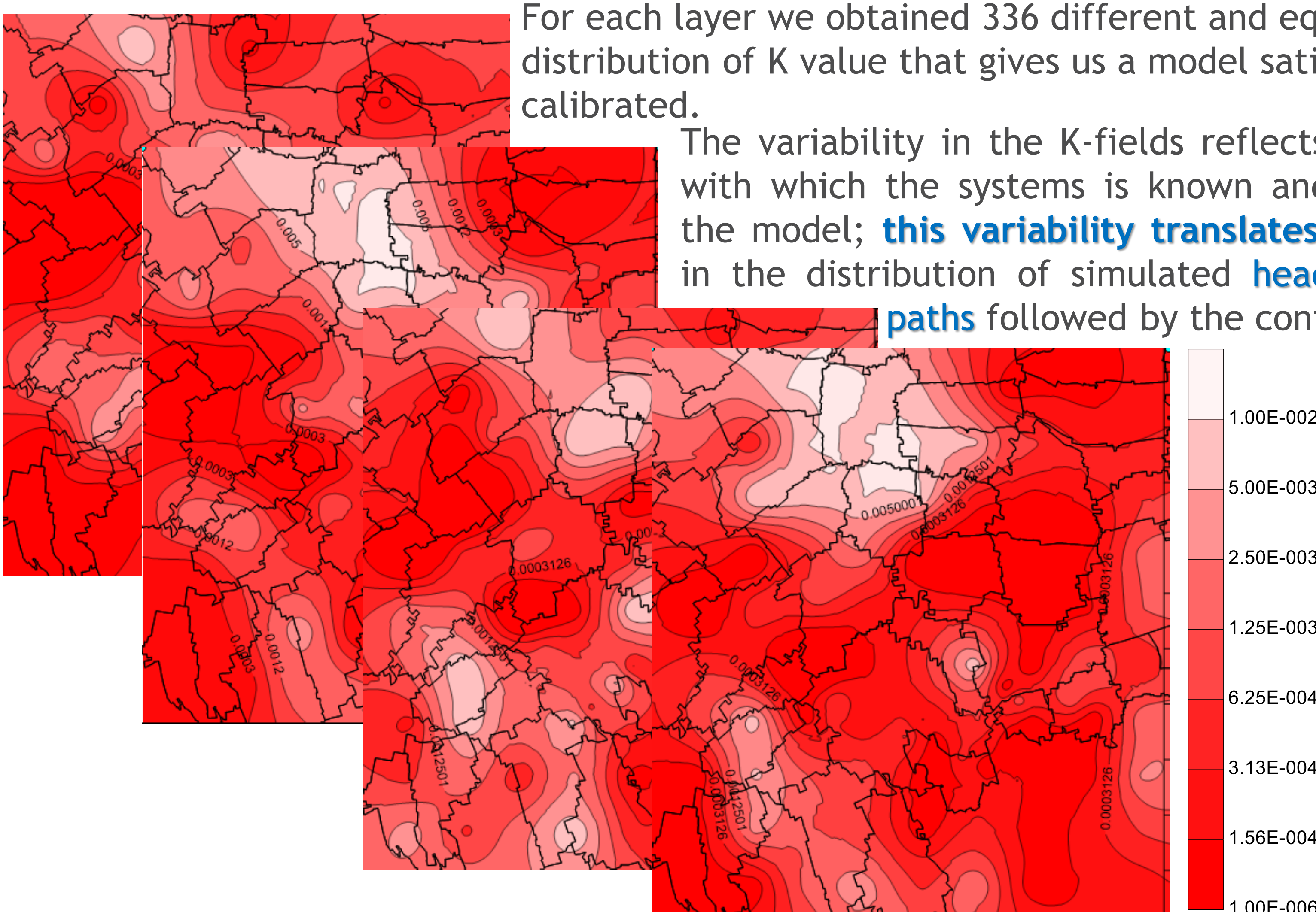
Starting from the deterministic calibrated model, we randomly generate 400 different realizations of K-fields. Only them that were able to provide a satisfactory fit to observations were kept for the next step



2- STOCHASTIC MODELING

For each layer we obtained 336 different and equally possible distribution of K value that gives us a model satisfactorily calibrated.

The variability in the K-fields reflects the uncertainty with which the systems is known and represented by the model; **this variability translates into** differences in the distribution of simulated **heads**, hence in the **paths** followed by the contaminants.



3- PARTICLE BACK-TRACKING

MONTE CARLO APPROACH

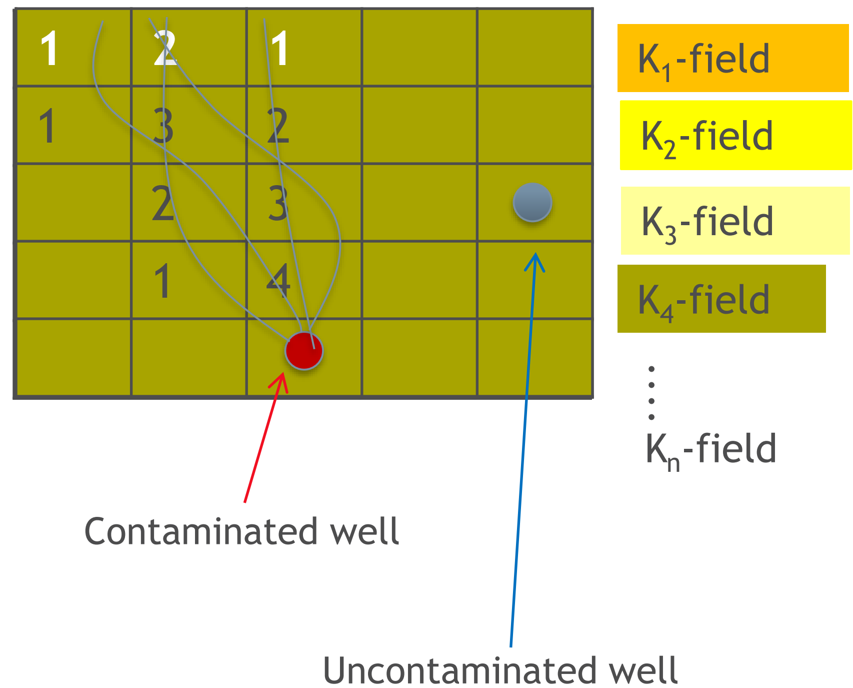
In each well having a concentration > 10 µg/l particles were added

Then particles were traced backward for each of the 336 previously calibrated simulations

Particles follow different paths in each simulation depending on the selected K-field, but some path are followed more frequently

The number of particle passing in each cell is counted for the 336 simulations

Cells with an high number of passages have an high probability to contain the source responsible of the contamination



336 POSSIBLE K-FIELDS → 336 BACKWARD PARTICLE TRACKING (MODPATH)

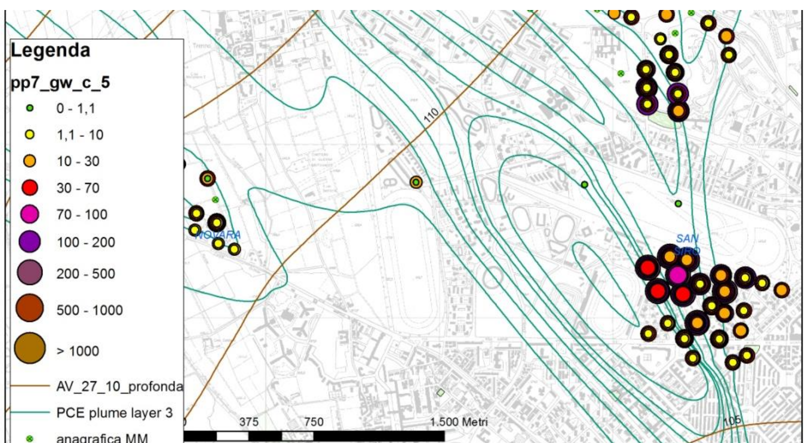
MONTE CARLO APPROACH

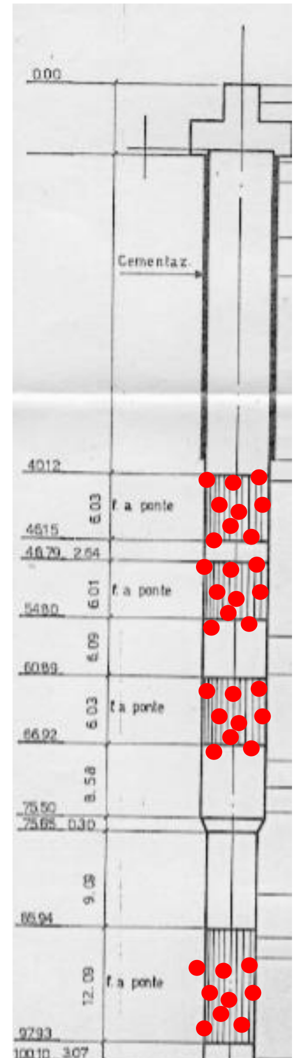
San Siro public wells suffer a PCE contamination since at least 30 years. Recently concentration raised till 300 μg/l. Many industrial sites located up-gradient could be considered responsible of this contamination.

-particles weighted on concentration,

(i.e **1 particle every 10 μg/l**) where added to 6 contaminated wells

-for each well particles are equally distributed in all the layers screened





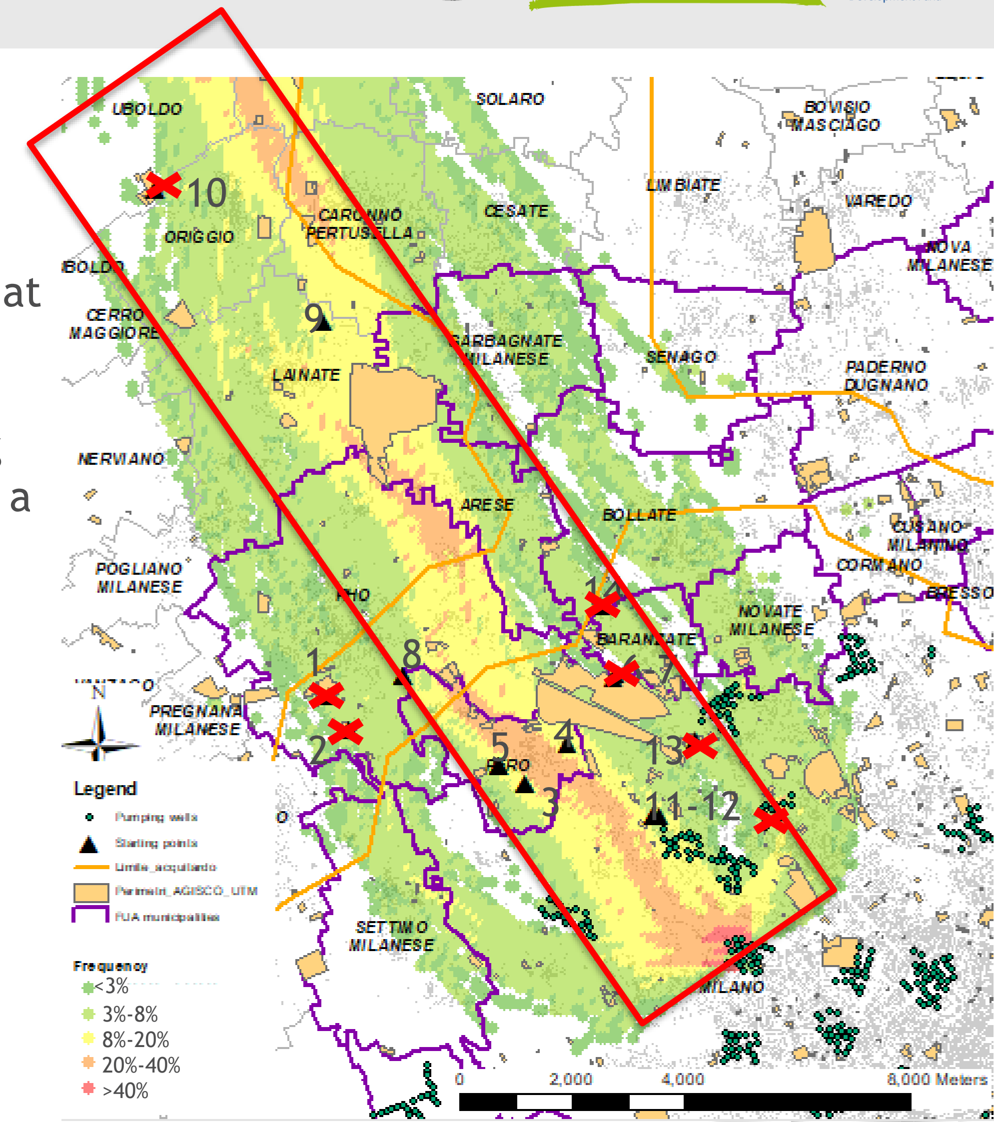
EXAMPLE San Siro well 3
PCE =90 μg/l
Screens in 4 layers
9 particles in each layer

3- PARTICLE BACK-TRACKING

MONTE CARLO APPROACH

We obtained a probabilistic map showing the likelihood of each cell to contain the source that hit the San Siro public wells

Overlapping this map with the layer containing the industries position it is possible to prepare a ranking lit of the areas that need to be deeply investigate



RESULTS ANALYSIS

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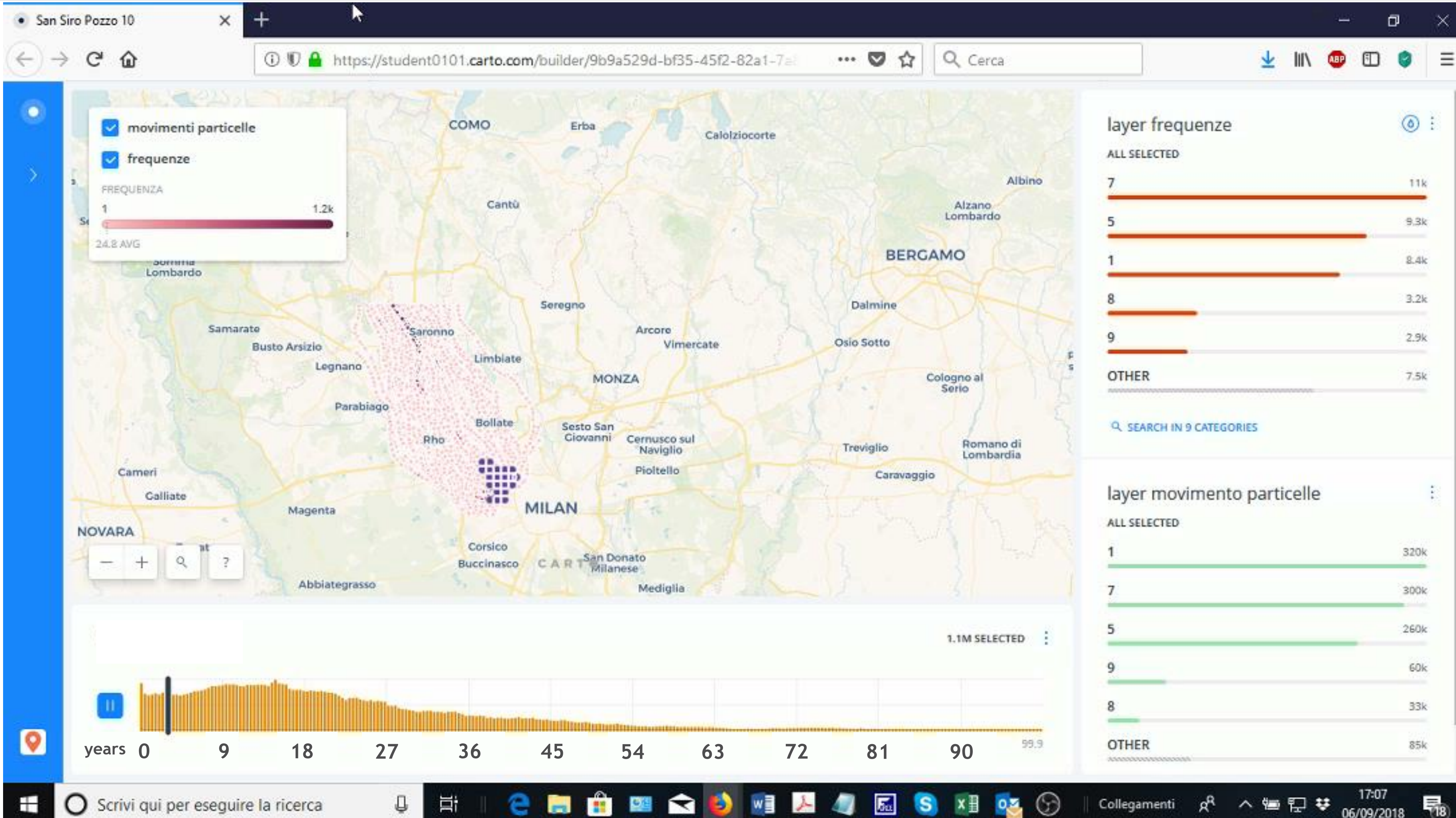

ACTIVITIES

WP1	**Tools for groundwater pollution assessment and remediation in Functional Urban Areas (FUAs)**	Start date: 10.2016 End date: 12.2018
Activity A.T1.1	FOKS tools amendment and adaptation to FUA scale	Start date: 10.2016 End date: 10.2017
Activity A.T1.2	**Innovative CSIA TOOL for pollution and remediation assessment**	Start date: 12.2016 End date: 10.2018
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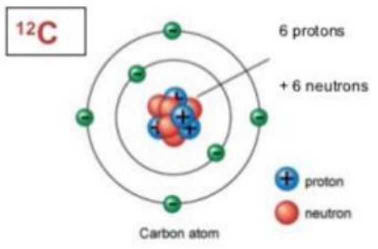
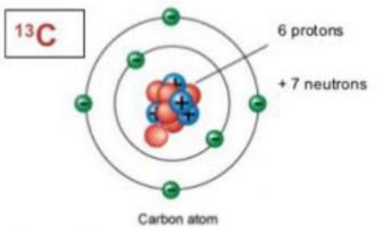
Activity A.T1.4	Harmonizing of innovative tools CSIA with previously amended FOKS tools	Start date: 09.2017 End date: 12.2018
Activity A.T1.5	Trainings and internships for improving technical skills and cooperative development of tools	Start date: 02.2017 End date: 09.2018

ISOTOPE FINGERPRINTING

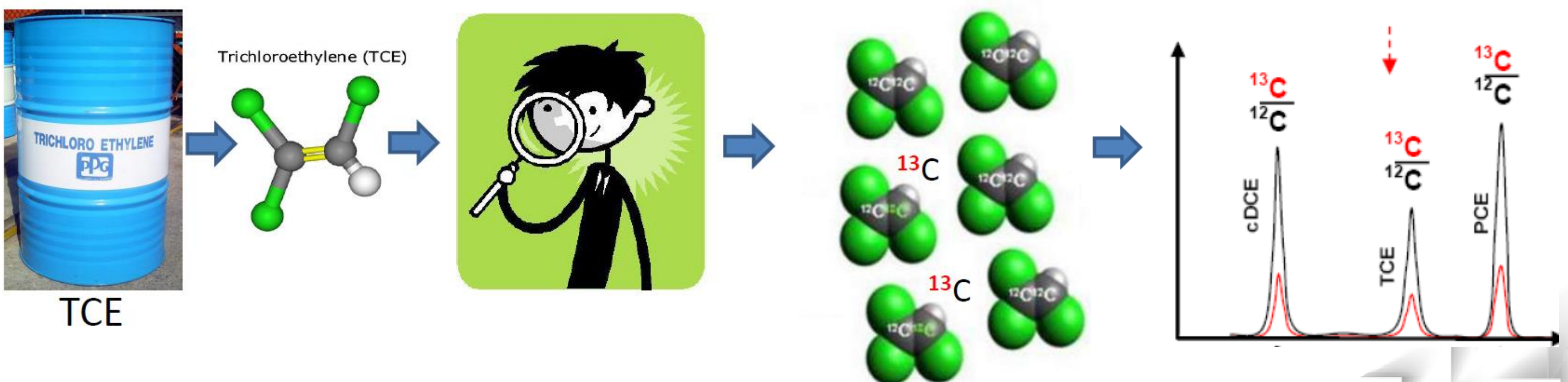
Another activity developed in the AMIIGA project is the application of **Isotope Fingerprinting techniques (CSIA)**



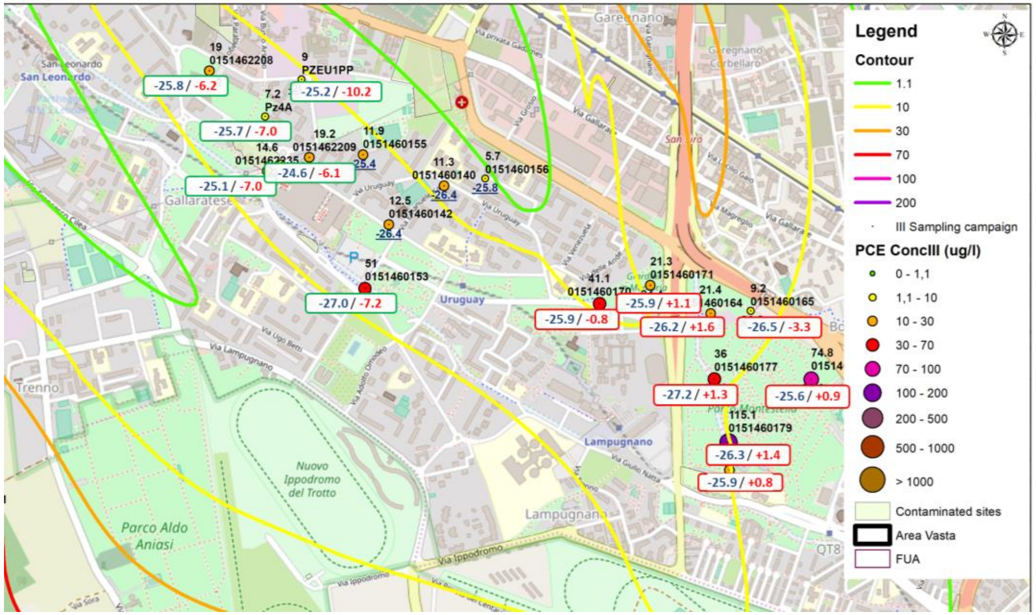
Politecnico di Milano has a research line dedicated to CSIA. Research development as analytical methods and field tests are developed in collaboration with **ENI** and **IT²E** laboratories and analysis for **$^{13/12}C$, $^{37/35}Cl$, $^{2/1}H$** are performed through GC-IRMS.



An isotope is an atom of a same chemical element (e.g. C) having the same atomic number but a different atomic mass: this because they have a different number of neutrons (e.g. ^{12}C and ^{13}C)

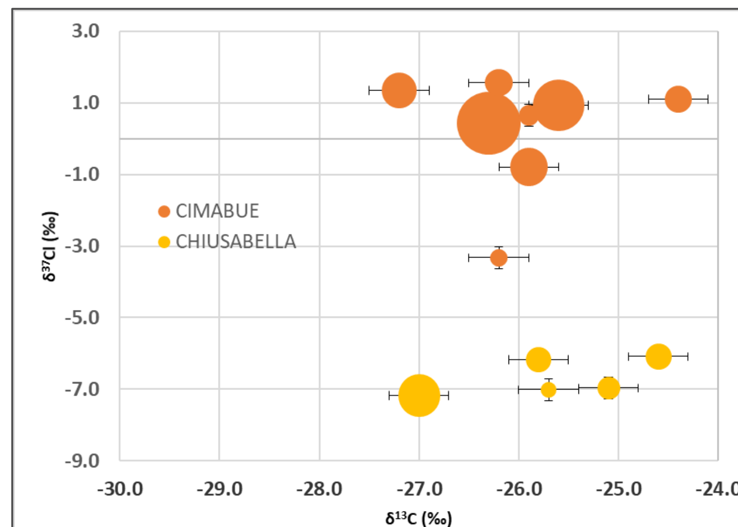


ISOTOPE FINGERPRINTING



In the AMIIGA project Compound Specific Isotope Analysis have been applied in in Italy, Germany , Poland and Czech Rep.
In Milano have been applied in order to verify the results of the groundwater and transport modeling and than confirm the developed conceptual model.

Analysis of $^{13/12}$**C**, $^{37/35}$**Cl** (dual isotope) allowed to confirm that the Chiusabella e Cimabue pumping stations are reached by 2 different plumes



ISOTOPE FINGERPRINTING

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Deliverable D.T1.2.3	Freeware software for CSIA data analysis for remediation assessment

groundwater pollutants with BIOCHLOR-ISO. Journal of Contaminant Hydrology, 2016

P. Höhener patrick.hohener@univ-amu.fr Version 4.2V with Cretnik-Correction

Aix Marseille Université-CNRS, Laboratoire Chimie Environnement UMR 7376, Marseille Runs on Excel 2010 or later

With decreasing rate constant

White cells	115	Enter value directly....or: if you want to calculate:
Blue cells	0,02	Use blue cells for calculating the white cell; formula is given under the arrow
Orange or	grey cells	Do not change anything in grey or orange cells

TYPE OF CHLORINATED SOLVENT: Ethenes

1. ADVECTION

Seepage Velocity	Vs	310,1	(m/yr)
or			
Hydraulic Conductivity	K	5,9E-04	(m/sec)
Hydraulic Gradient	i	0,005	(m/m)
Effective Porosity	n	0,3	(-)

2. DISPERSION

Alpha x	20	(m)
Alpha y	2	(m)
Alpha z	0,20	(m)

3. ADSORPTION

Retardation Factor* R_f

Soil Bulk Density, rho	1,7	(kg/L)		
FractionOrganicCarbon, foc	0,0010	(-)		
Partition Coefficient	Koc			
PCE	426	(L/kg)	3,41	(-)
TCE	130	(L/kg)	1,74	(-)
DCE	125	(L/kg)	1,71	(-)
VC	30	(L/kg)	1,17	(-)
				(-)
Common R_f (used in model)*			2,01	

4. BIOTRANSFORMATIO First Order Decay Coefficients

	k (1/yr)	half-life [yrs]
PCE	0,69	1,00
TCE	0,69	1,00
DCE	0,69	1,00
VC	0,69	1,00

5. ISOTOPES

	ε C bulk	Initial δ¹³C	ε Cl bulk	ε offset Cl	Initial δ³⁷Cl
PCE	-1,00	-26,5	-2,0	na	0,0
TCE	-10,0	-30,0	-3,0	na	0,0
DCE	-10,0	-30,0	-2,0	-1,0	0,0
VC	-10,0	-30,0	-2,0	na	0,0

Switch for TCE-DCE → 1 0: Cretnik correction; 1: Standard approach

6. GENERAL

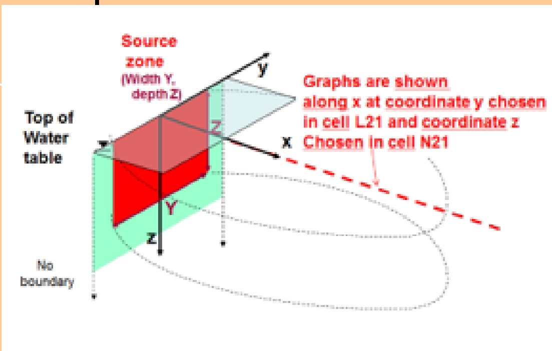
Simulation Time	50,0	(yr)	Used time 58,00
Modeled Area Width	na	(m)	Integ. Step
Modeled Area Length	1200	(m)	1,08875

7. SOURCE DATA

Source Thickness in Sat. Z 25 (m)

Width* (m) 50 Y

Compound	Conc. (mg/L)	Conc. (mM)	Threshold (mM)
PCE	4,0	0,024	
TCE	0,1	0,001	
DCE	0,1	0,001	
VC	0,0	0,000	
ETH	na	0	



8a. FIELD DATA FOR COMPARISON (in mg/L) y Coordinate 0 z Coordinate 0 Date: na

Dist. x from Source		0	125	176	200	444	931	1168			
PCE	mg/L	4,00	0,15	0,03	0,03	0,01	0,00	0,00			
TCE	mg/L	0,00	0,00	0,00	0,00	0,00	0,00	0,00			
DCE	mg/L	0,00	0,02	0,01	0,01	0,00	0,00	0,00			
VC	mg/L										
ETH	mg/L										
Chloride	mg/L										
Carbon isotopes											
PCE	δ¹³C	-26,5	-26,5	-23,1	-24,1	-25,0	-24,3	-24,0			
TCE	δ¹³C										
DCE	δ¹³C										
VC	δ¹³C										
ETH	δ¹³C										
Σ[CEs]	δ¹³C	-26,50	-21,27	-14,09	-13,64	-16,07	-20,74	-20,80			
Chlorine isotope											
PCE	δ³⁷Cl										
TCE	δ³⁷Cl										
DCE	δ³⁷Cl										
VC	δ³⁷Cl										

ACTIVITIES

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Activity A.T1.5	Trainings and internships for improving technical skills and cooperative development of tools	Start date: 02.2017 End date: 09.2018

BIOMOLECOLAR TOOLS

Deliverable D.T1.3.1	BMTs technical protocol for remedial implementation and performance evaluation (draft)	

University of Liberec is driving the Activity 1.3 and they prepared a protocol explaining how Biomolecolar Tools can be used in assessing Natural Attenuation processes in order to design remediation actions based on Enhanced bioremediation

- BMT = bio-molecular tools
  - **Assessing contaminant's biodegradation on polluted sites**
  - **Evidence of remediation rate**
- Type of material
  - Groundwater, soil, nanofiber carrier samples, ...
- Methods
  - Real-time PCR - specific bacteria or functional genes detection
  - Next-generation sequencing (NGS) - microbial composition

Biological molecular tools (BMT): a brief guideline about why and how to use BMT for characterization and remediation of contaminated sites in Europe

BIOMOLECOLAR TOOLS

Deliverable D.T1.3.2	Report on BMTs analysis from studies and remediation pilot actions	Delivery date: 05.2018 concluding

Biomolecolar analysis were performed in Parma, Stuttgart, Novy Bidzov and Jaworzno

Groundwater						
Primer	MR-1	MR-2	MR-5	MR-6	ZMS-4	ZMS-5
U16SRT						
bvcA						
vcrA						
DHC-RT						
Dsb						
Dre						
dsrA2						
nirK						

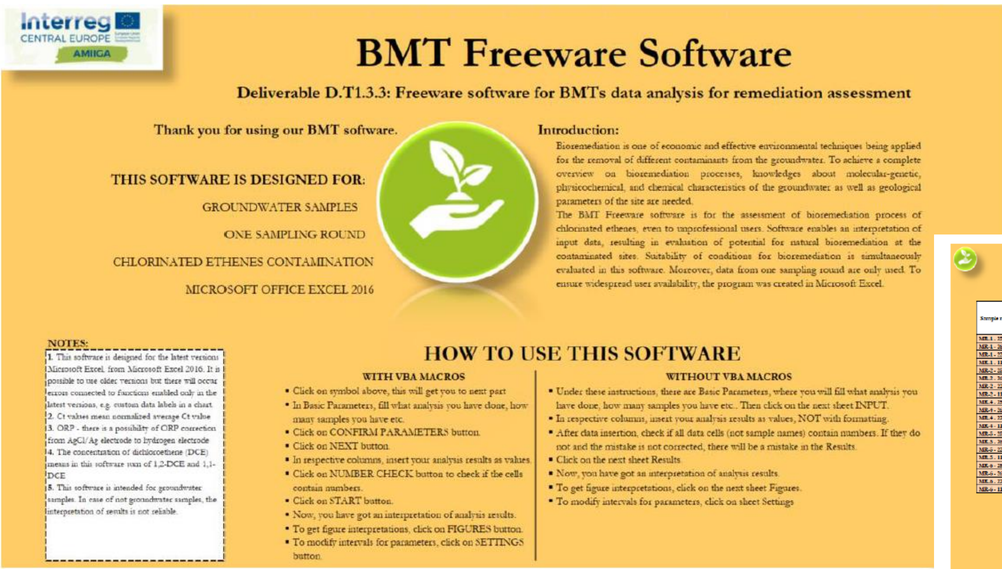
Nanofiber carriers					
Primer	B 72	B 373	FB 4neu	KE 3-4	KE 3-6
U16SRT					
bvcA					
vcrA					
DHC-RT					
Dsb					
Dre					
dsrA2					
nirK					
AlkB1					
etnE					
linA					

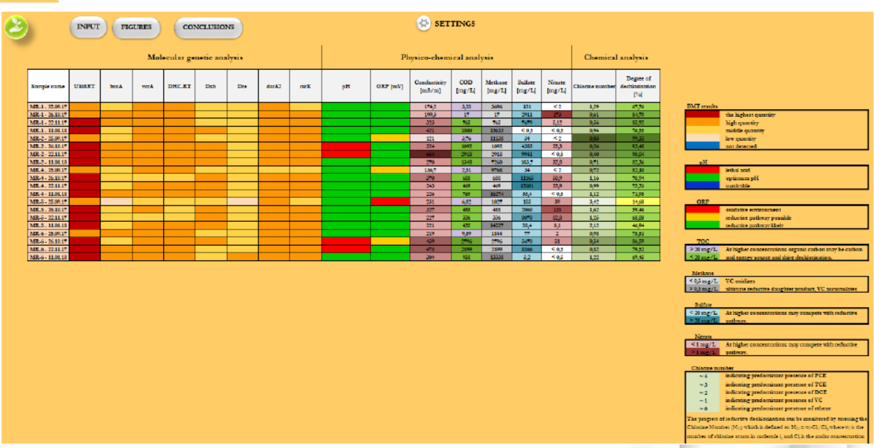
Groundwater						
Primer	PM3	PM5	PZ3	PZ4	PZ5	PZ8
U16SRT						
bvcA						
vcrA						
DHC-RT						
Dsb						
Dre						
dsrA2						
nirK						
linA						
DEF/G						
bssA						

BIOMOLECOLAR TOOLS

Deliverable D.T1.3.3	Freeware software for BMT's data analysis for remediation assessment	

An excel spreadsheet was created by Liberec University in order to give an overview of the contamination detected at the site and to assess the presence of a microflora suitable for CHC degradation





CONCLUSIONS

The tools settled in the AMIIGA project are improving the capacity to face the groundwater contamination at FUA scale:

Web-GIS, statistics, isotope fingerprinting and inverse modeling can be applied to evaluate the **diffuse contamination** level

Web-GIS, inverse modeling and isotope fingerprinting can be applied in order to find the most probable **position of Punctual Sources**

Isotope fingerprinting and biomolecolar tools can be applied at contaminated site scale in order to **evaluate Natural Attenuation** processes and the possibility to implement **Enhanced Bioremediation** actions