Challenges of Conducting an Environmental Site Investigation in Aquifers with Low-permeability Zones

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June 03rd 2024

RAMBOLL

Bright ideas.
Sustainable change.

Trick Question

WHEN shall we detail the conceptual site model of a contaminated area???

During the Investigation steps, before the real completion of the CSM

After the investigation and before the beginning of the Remediation activities

During and throughout the development of the Remediation activities

Any other option???

Agenda

Characterization of the Site and Previous Activities

Field Activities

Results

Conclusions, Learning & Next Steps

Characterization of the Site

- Former **industrial activities** involving **tyre valve manufacturing for the automotive industry**, including rubber production, cleaning of parts, adhesive, application and vulcanization of rubber, assembly of the core valves.

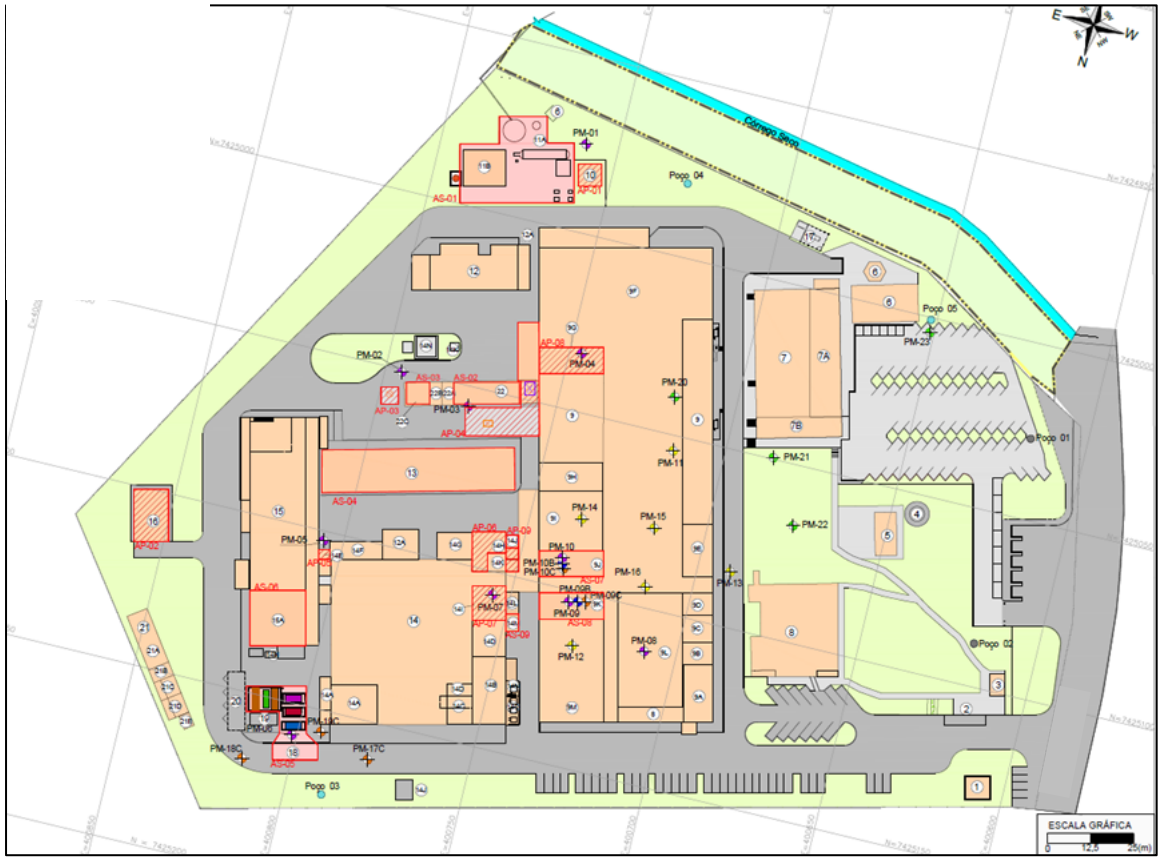
- The former factory facilities cover a total area of 45,000 m², with approximately 17,000 m² of built or paved areas.

- Main areas of interest: **Former Degreasing Room** (AS-07) and **Former Galvanizing Area** (AS-08): used from the 1980s until 2013 for degreasing operations, use of Tetrachloroethene (PCE); and electroplating, which involved the use of chromic acid.

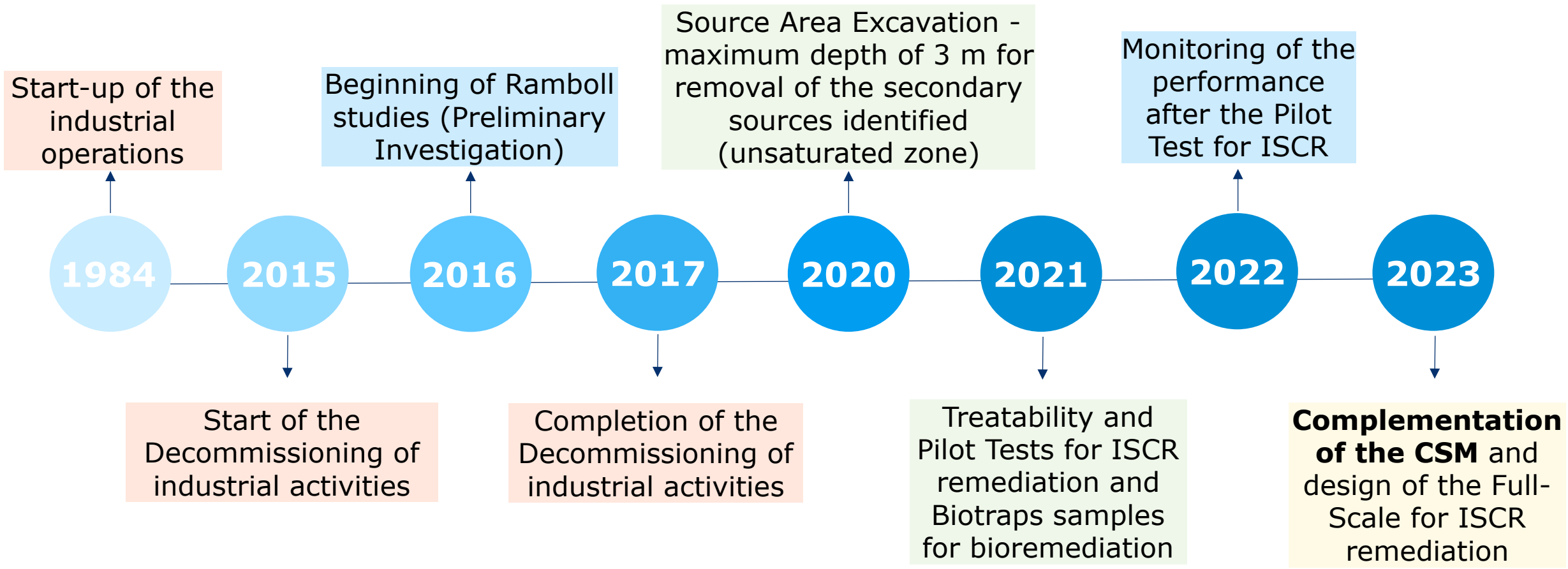
- Currently, the area of study (the former production areas) is occupied by a **logistics warehouse.**

Characterization of the Site

- The soil and groundwater samples indicated the presence of **tetrachloroethene** (PCE) and their degradation products: **trichloroethene** (TCE), **1,1-dichloroethene**, **cis-1,2-dichloroethene** (cis-1,2-DCE) and **vinyl chloride** (VC), at concentrations above the screening levels in the areas AS-07 and AS-08, where PCE handling occurred in the past;
- Highest groundwater concentrations before remediation: PCE (~140,000 ug/L), DCE (~20,000 ug/L) and VC (~15,000 ug/L);
- Groundwater level close to 6.0 mbgs;
- Current **monitoring network**:
  - **36** Multi-level monitoring wells (level A, B and C)
  - **14** Sub-slab monitoring wells
  - **04** Ambient air monitoring points

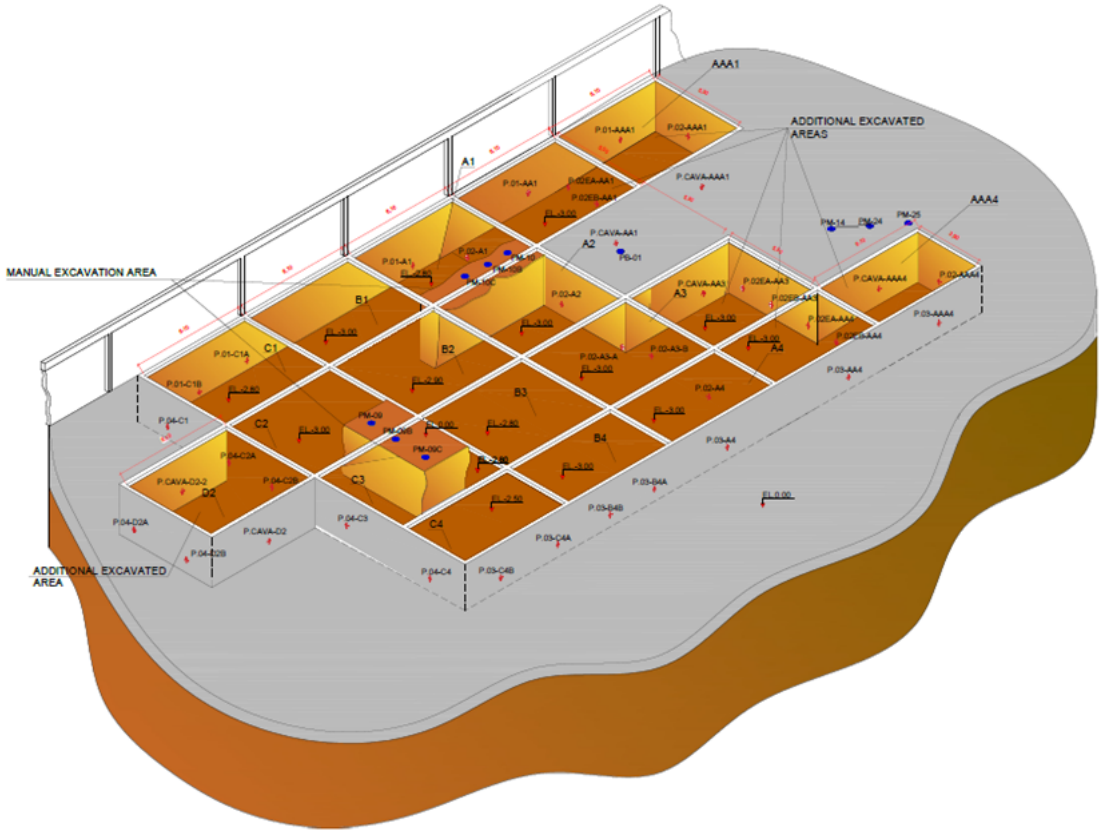


Characterization of the Site



Previous Activities

Source Area Soil Excavation (2020)



- Excavation total area of **450 m²** at 3.0 meters depth
- Excavated total volume of **1,887 m³**
- Excavated total soil mass of **2,464 t**
- Soil treatment: thermal destruction by co-processing

Previous Activities

More Details?
POSTER Section Today
Session G1

Remediation Preliminary Tests (2021-2022)

- Pumping Well installation (PB-01) for hydraulic tests;
- Installation of Biotraps to evaluate the applicability of the bioremediation technique;
- Chemical Analysis for QuantArray-Chlor (DNA) and DHC functional genes in the Biotraps samples;
- Treatability Tests for ISCR using ZVI and Sodium lactate amendment;
- Pilot Test for ISCR – Direct Push Injections in 3 locations downgradient of source area.

Previous Activities

However…

- ✓ During the evaluation of the ISCR Pilot Test data, a new hot spot area was "discovery", almost 10-15m downgradient of the main source area (already excavated).
- ✓ Groundwater contamination was found in deep levels resulting in an important change on previous CSM.
- ✓ Also, the results of the ISCR Pilot Test did not show any decrease in PCE concentrations. No impacts on physical-chemical data were observed.
- ✓ Conclusion: need to complement the investigation and update the CSM before move to full-scale remediation…

Field Activities

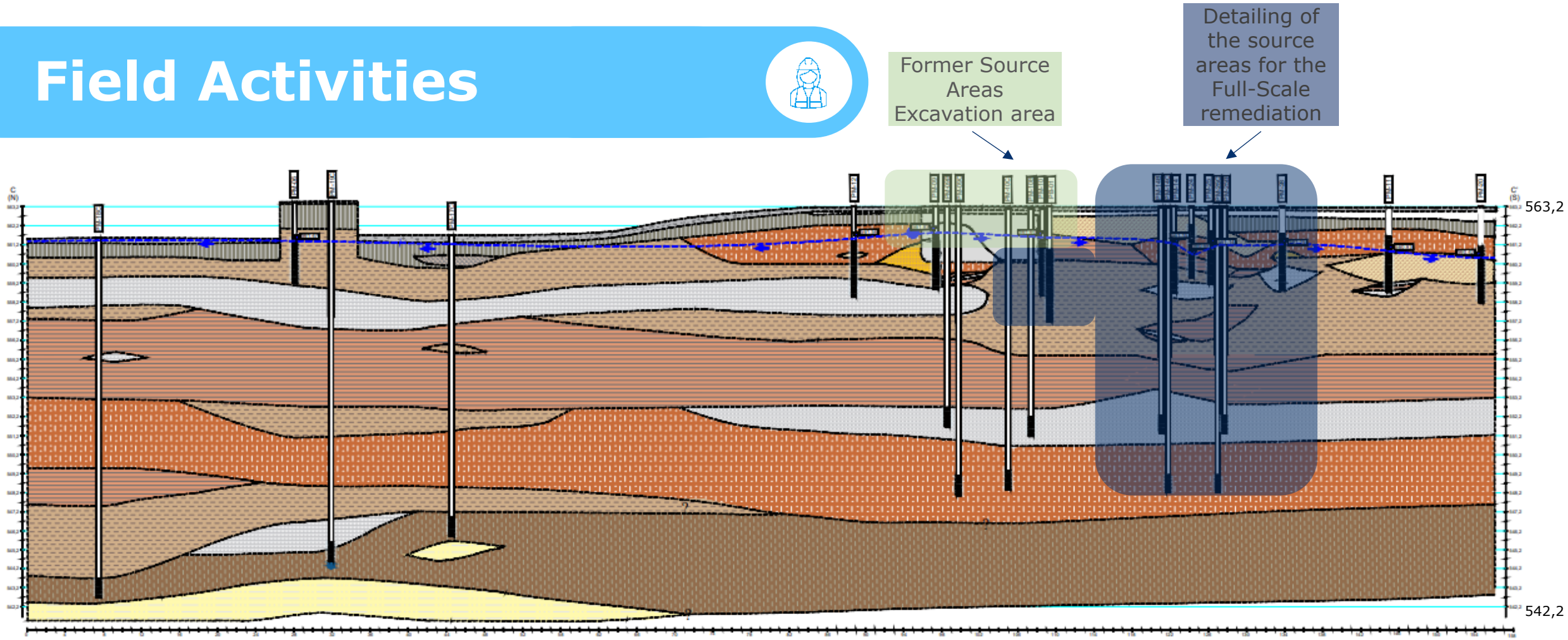
Main Goals

i. Conducting a **Complementation of the Conceptual Site Model** for the Full-Scale remediation, to identify active residual sources (secondary sources) in **saturated** and unsaturated zones after the excavation and pilot tests performed.

ii. Detailing of the source areas impacted by the compounds of interest and generating data to implement the Full-Scale remediation in the area.

iii. Determine the **low permeability and retention zones** and quantify the compounds present in the aquifer in the saturated and unsaturated zones.

Field Activities



The unsaturated zone (up to 2.5 m depth) is characterized by different soil layers composed of slightly sandy clay, medium to coarse sand and silty clay, sometimes containing coarse sand.

Subsequent layers present in the saturated zone up to a depth of 20 meters are composed of silty clay and organic clay (up to approximately 8 meters) and sandy soils with fine to coarse grain size (sometimes containing gravel).

Field Activities

- Drilling of **20 soil boring**

(6.0m up to 15.0m / 5m x 5m mesh)

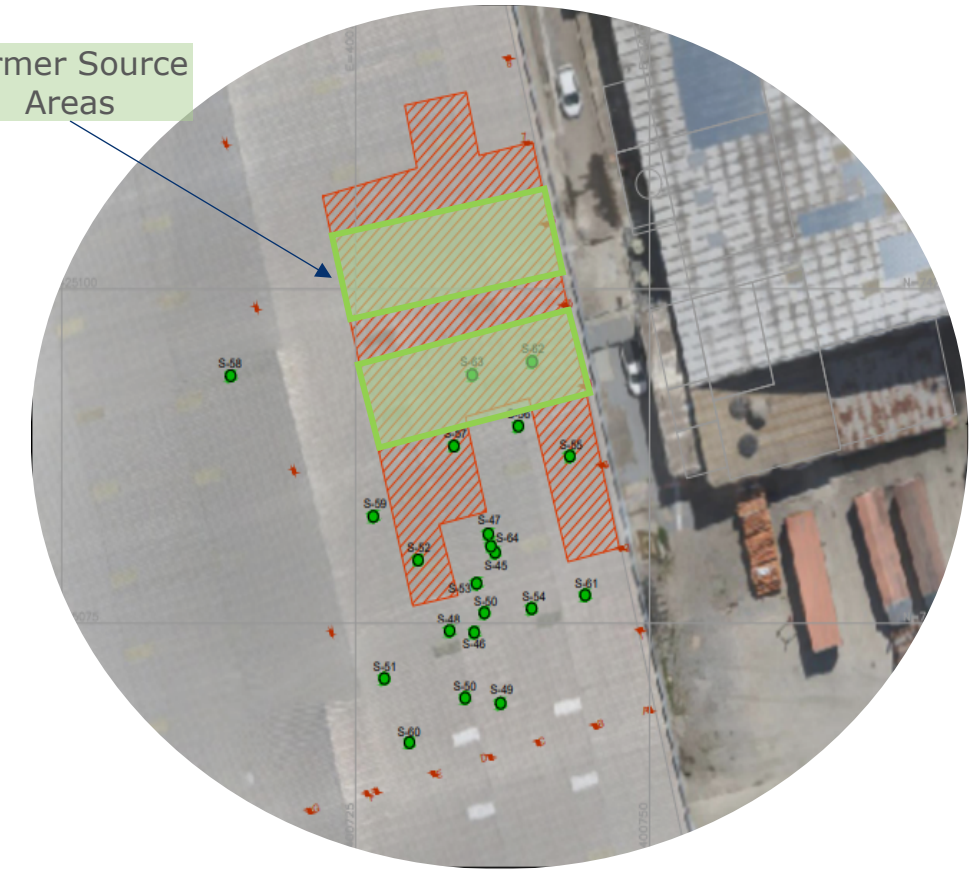
◇ Volatile gas readings with portable photoionization detector (PID) every 20 cm along the lithological profile

◇ **85 soil samples**

VOC

◇ **25 undisturbed soil samples**

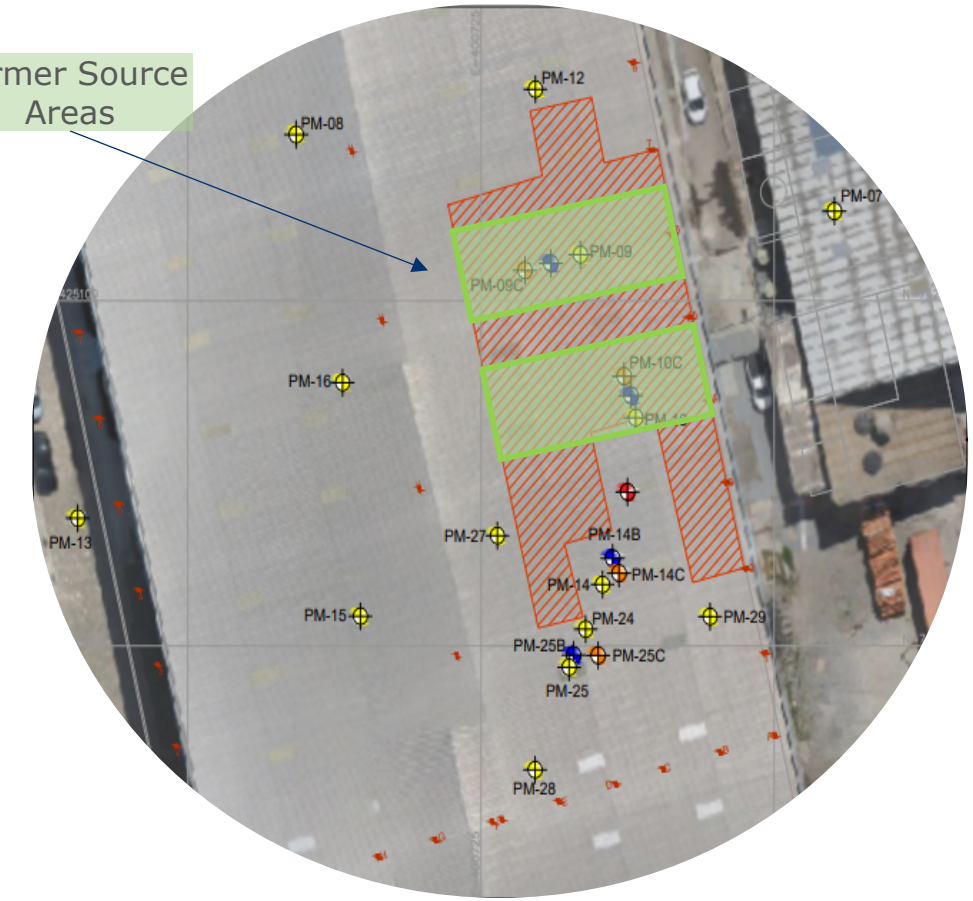
Granulometry, macroporosity, microporosity, fraction of organic carbon (foc) and vertical hydraulic conductivity



Field Activities

- Installation of **07 groundwater monitoring wells**:
  - ◇ 03 monitoring wells at the shallow level of the aquifer;
  - ◇ 02 monitoring wells at the intermediate level of the aquifer (level B);
  - ◇ 02 monitoring wells at the deep level of the aquifer (level C).

- Collection of **02 discrete groundwater samples** (grab samples).



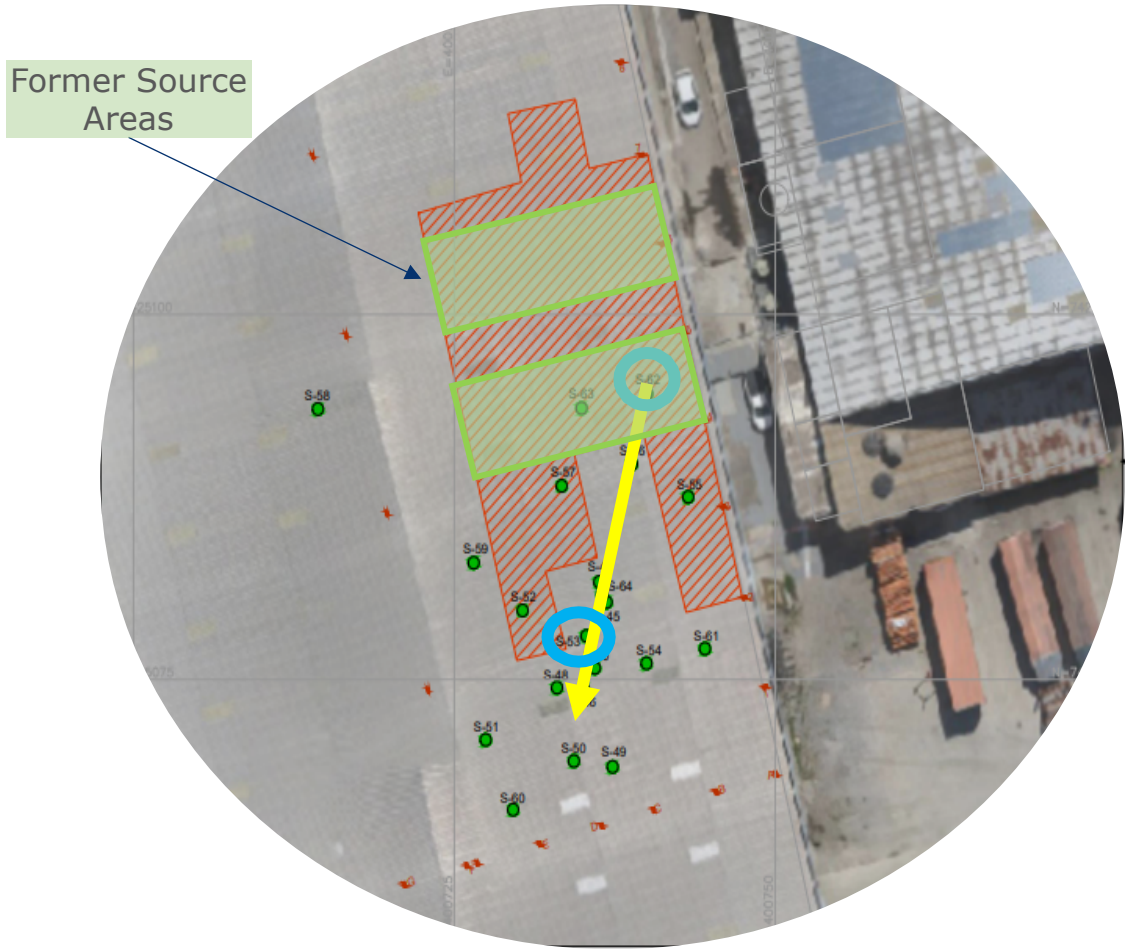
Results

Analytical Results

- The results of the PID readings added to the soil samples for the VOC analysis indicated the existence of a well-defined axis where changes in soil quality occur:
  - ◇ Soil borings S-62, S-56, S-45, S-46, S-47, S-48 and S-53
  - ◇ same direction of migration of the tetrachloroethylene groundwater plume
  - ◇ Depths vary between 2.0 and 6.0m: main concentrations in the saturated zone of the aquifer.
  - ◇ Highlighting the results of samples:

S-53@5.5m (9,810.20 mg/kg)

S-62@4.5m (1,814.75 mg/kg)



Results

S-45 Soil Profile

Former Source Areas

Sondagem: S-45 / Poço de monitoramento: PM-14C

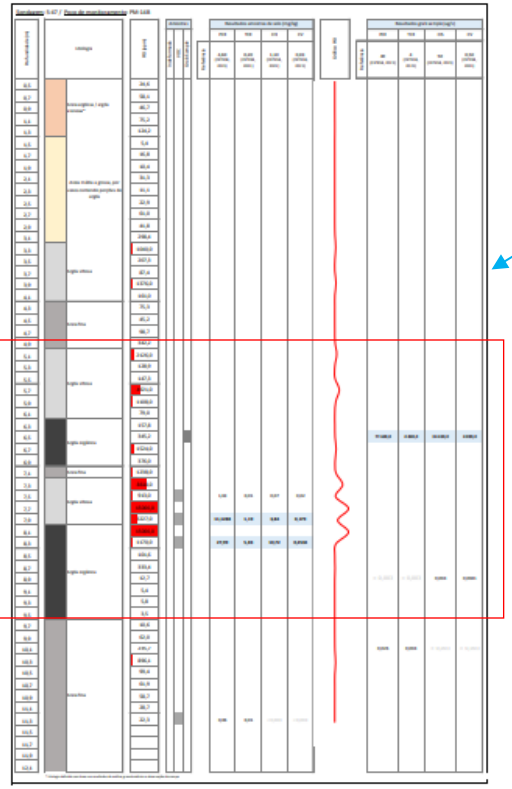
Profundidade (m)	Litologia	PID (ppm)	Amostras: Indeformada	Amostras: VOC	Amostras: Grab Sample	Resultados amostras de solo (mg/kg)	PCE	TCE	CIS	CV	Gráfico PID	Análises geotécnicas: Porosidade Efetiva (%)	Análises geotécnicas: Condutividade Hidraulica Vertical (cm/s)	Análises geotécnicas: FOC (%)
						Referência	4,60 (CETESB, 2021)	0,20 (CETESB, 2021)	1,10 (CETESB, 2021)	0,03 (CETESB, 2021)				
5,3	Argila siltosa	1957,0												
5,5		272,0												
5,7		2463,0												
5,9		11107,0					**9,88**	0,27	**107,41**	**4,060**				
6,1		5552,0												
6,3	Argila orgânica	2971,0												
6,5		11432,0					3,602	1,27	**95,06**	**0,963**				
6,7		99,7												
6,9		122,3												
7,1	Argila siltosa	1726,0												
7,3		21,9												
7,5		29,3												

Results

S-47 Soil Profile

Sondagem: S-47 / Poço de monitoramento: PM-14B

Profundidade (m)	Litologia	PID (ppm)	Amostras: Indeformada	Amostras: VOC	Amostras: Grab Sample	Resultados amostras de solo (mg/kg)	PCE	TCE	CIS	CV	Gráfico PID	Resultados grab sample (ug/L)	PCE	TCE	CIS	CV
						Referência	4,60 (CETESB, 2021)	0,20 (CETESB, 2021)	1,10 (CETESB, 2021)	0,03 (CETESB, 2021)		Referência	40 (CETESB, 2021)	4 (CETESB, 2021)	50 (CETESB, 2021)	0,50 (CETESB, 2021)
5,1	Argila siltosa	2126,0														
5,3		128,9														
5,5		147,3														
5,7		4921,0														
5,9		1108,0														
6,1		79,0														
6,3	Argila orgânica	157,8														
6,5		345,2			■								77.638,0	2.869,0	32.430,0	2.089,0
6,7		1524,0														
6,9		376,0														
7,1	Areia fina	1238,0														
7,3	Argila siltosa	8618,0														
7,5		913,0		■			1,63	0,01	0,07	0,02						
7,7		15000,0														
7,9		3227,0		■			**11,1288**	**1,19**	**3,84**	**0,179**						
8,1	Argila orgânica	15000,0														
8,3		1170,0		■			**27,99**	**5,83**	**10,72**	**0,2534**						
8,5		101,6														
8,7		333,4														
8,9		12,7											< 0,003	< 0,003	0,004	0,0041
9,1		5,4														
9,3		5,8														
9,5		3,5														



Former Source Areas

Results

S-53 Soil Profile

Sondagem: S-53

Profundidade (m)	Litologia	PID (ppm)	Amostras: Indeformada	Amostras: VOC	Amostras: Grab Sample	Resultados amostras de solo (mg/kg): Referência	PCE	TCE	CIS	CV	Gráfico PID	Análises geotécnicas: Porosidade Efetiva (%)	Condutividade Hidraulica Vertical (cm/s)	FOC (%)
						4,60 (CETESB, 2021)	0,20 (CETESB, 2021)	1,10 (CETESB, 2021)	0,03 (CETESB, 2021)					
1,9	Areia média a grossa, por vezes contendo porções de argila	1,8												
2,1		3,7												
2,3		92,0												
2,5		100,1												
2,7		18,3												
2,9		14,1												
3,1		84,4												
3,3	Argila siltosa	386,0												
3,5		485,0												
3,7	Areia fina	2277,0												
3,9		2303,0					19,98	0,23	0,46	0,003				
4,1		2712,0					9,64	0,02	0,04	< 0,0030				
4,3		362,0												
4,5		346,0												
4,7	Argila siltosa cinza	597,0					138,60	0,98	1,46	0,056		3,00	6,E-06	2,30
4,9		82,0												
5,1		11,7												
5,3		5,5												
5,5		12000,0					9.810,2	18,48	31,46	0,096		1,90	1,E-05	2,32
5,7	Areia fina	1000,0					3,87	1,00	3,36	0,004				
5,9	Argila orgânica	213,0												
6,1	Areia fina	227,0												
6,3	Argila orgânica	47,0												
6,5		123,0												

Former Source Areas

Results

S-62 Soil Profile

Sondagem: S-62

Profundidade (m)	Litologia	PID (ppm)	Amostras: Indeformada	Amostras: VOC	Amostras: Grab Sample	Referência	PCE	TCE	CIS	CV
							Resultados amostras de solo (mg/kg)			
							4,60 (CETESB, 2021)	0,20 (CETESB, 2021)	1,10 (CETESB, 2021)	0,03 (CETESB, 2021)
0,5	Pó de Brita									
0,7										
0,9										
1,1										
1,3										
1,5										
1,7										
1,9										
2,1										
2,3										
2,5		5,7								
2,7	Argila siltosa	12,3								
2,9		76,9								
3,1		55,4								
3,3		297,0								
3,5		15000,0								
3,7		15000,0					**15,71**	0,17	0,49	0,019
3,9		2677,0								
4,1		15000,0					**25,32**	0,05	0,09	0,003
4,3	Areia fina	3801,0								
4,5	Argila siltosa	15000,0					**1.814,75**	**3,15**	**3,86**	**0,147**
4,7		2192,0								
4,9	Areia fina	115,3								
5,1	Argila siltosa	35,2					**10,09**	**1,19**	**2,51**	**0,669**
5,3		224,1								
5,5	Areia fina	22,3								
5,7	Argila siltosa	49,7								
5,9		67,1								
6,1	Argila orgânica	21,1					3,59	**0,21**	**3,77**	**1,061**

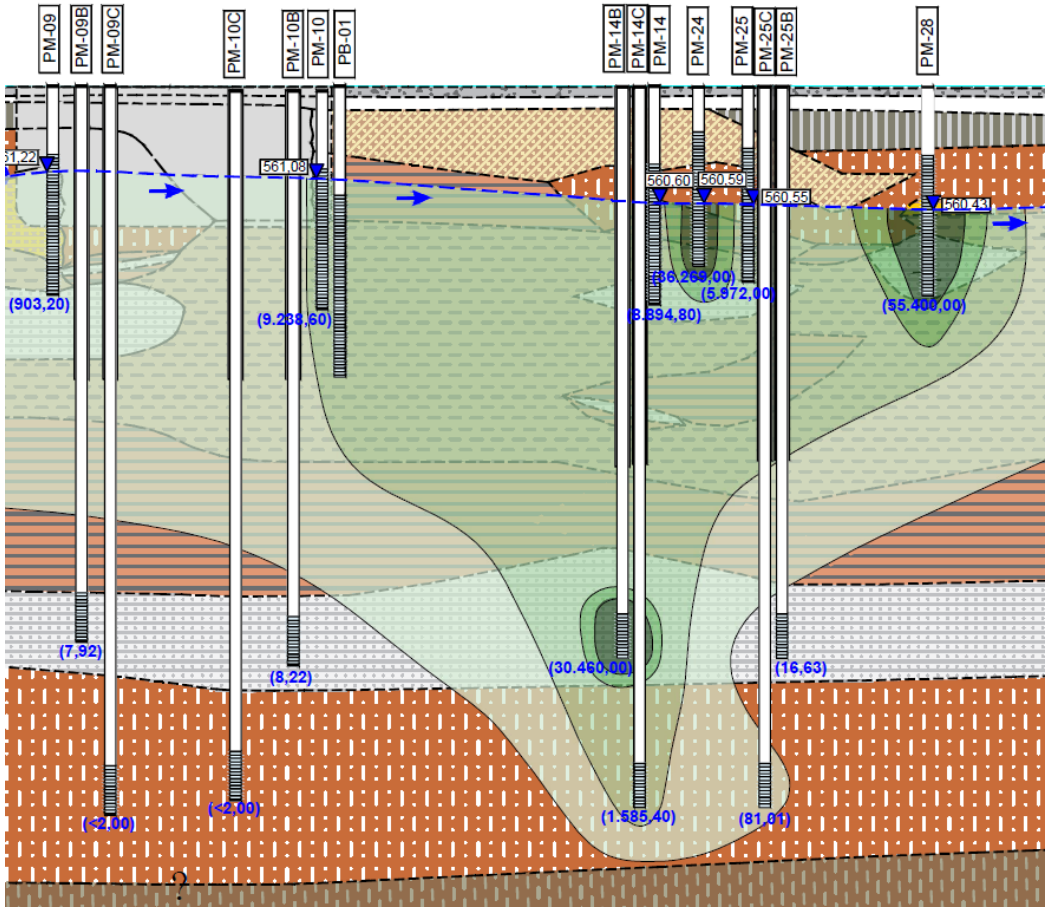
Gráfico PID

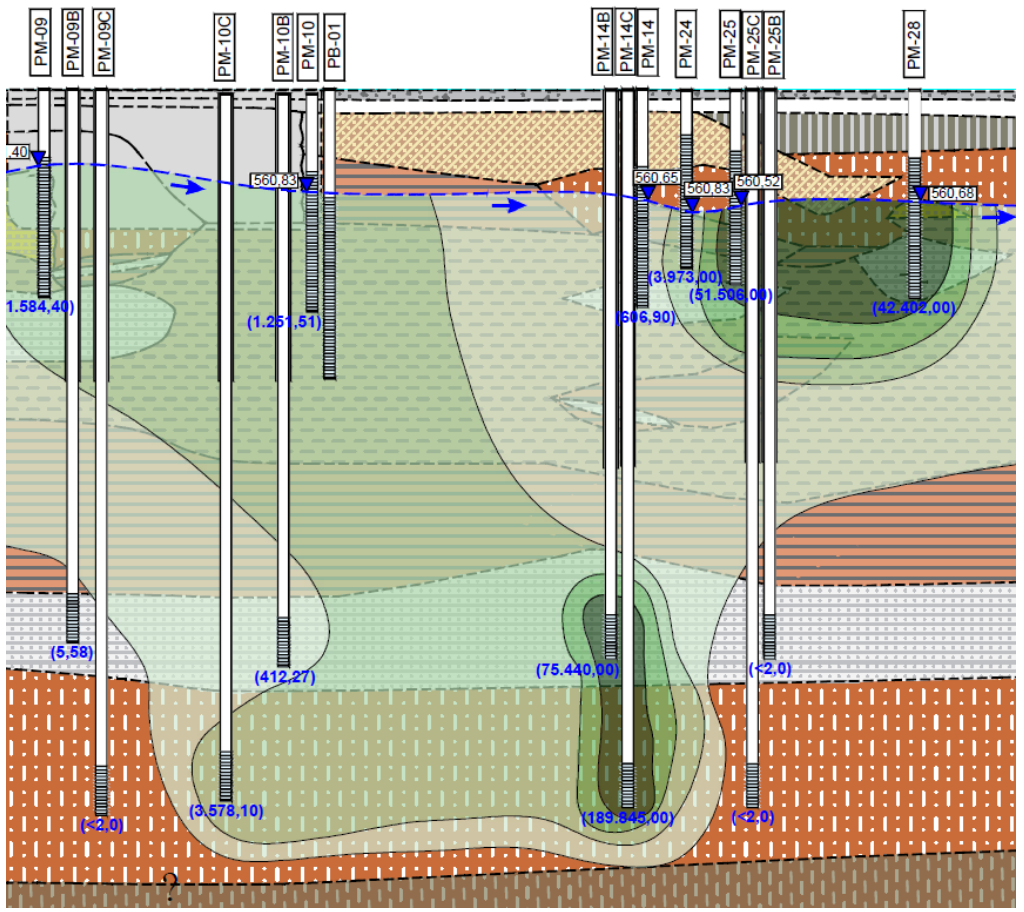
Former Source Areas

Results

Before first event of ISCR injection ⟷ **After first event of ISCR injection**

September 2023 → **March 2024**

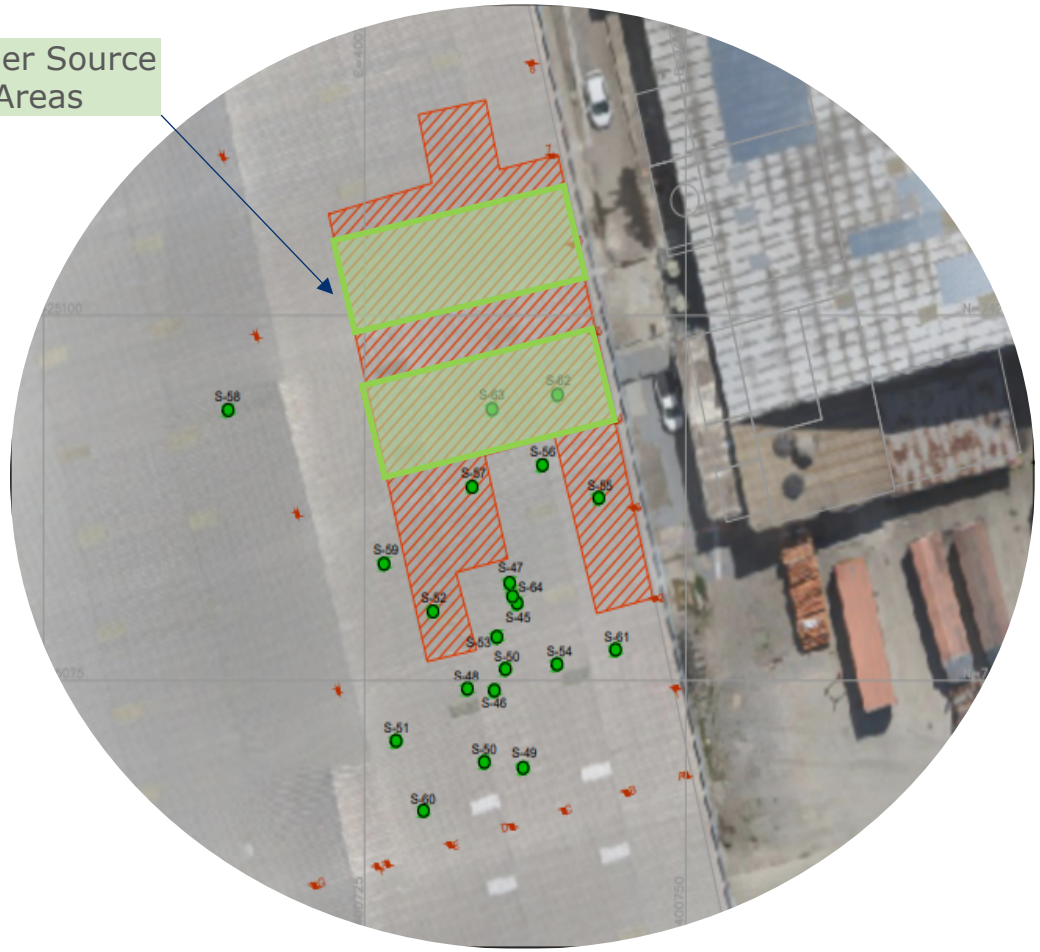




Results

Geotechnical Results

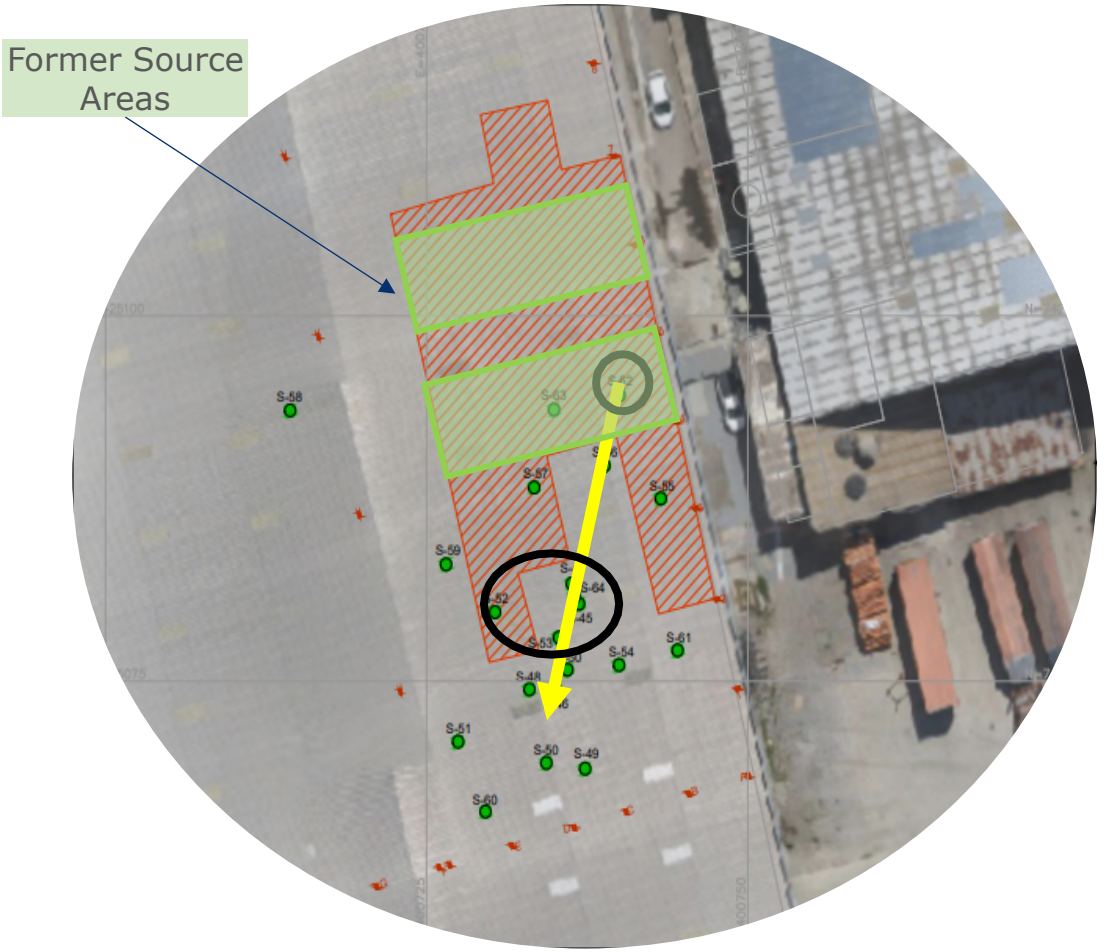
- The geotechnical results corroborated the lithological profiles described in previous works, where the local aquifer is composed of:
  - clayey, silty and sandy soils with variation in the sandy particle size profile and presence of gravel;
  - higher hydraulic conductivity from 8 meters depth (sandy soils);
  - low effective porosity (macroporosity), with an overall average of 2.97%, providing the aquifer **low permeability**, low transmissivity or ability to transmit fluid;
  - **Fraction of organic carbon (foc)** ranging from 0.08% to 9.98% and an overall average of 2.4%, providing a high concentration of organic matter (soils containing peat and organic clay);
  - Based on the results, it was concluded that the local aquifer has a high retardation coefficient (R).



Results

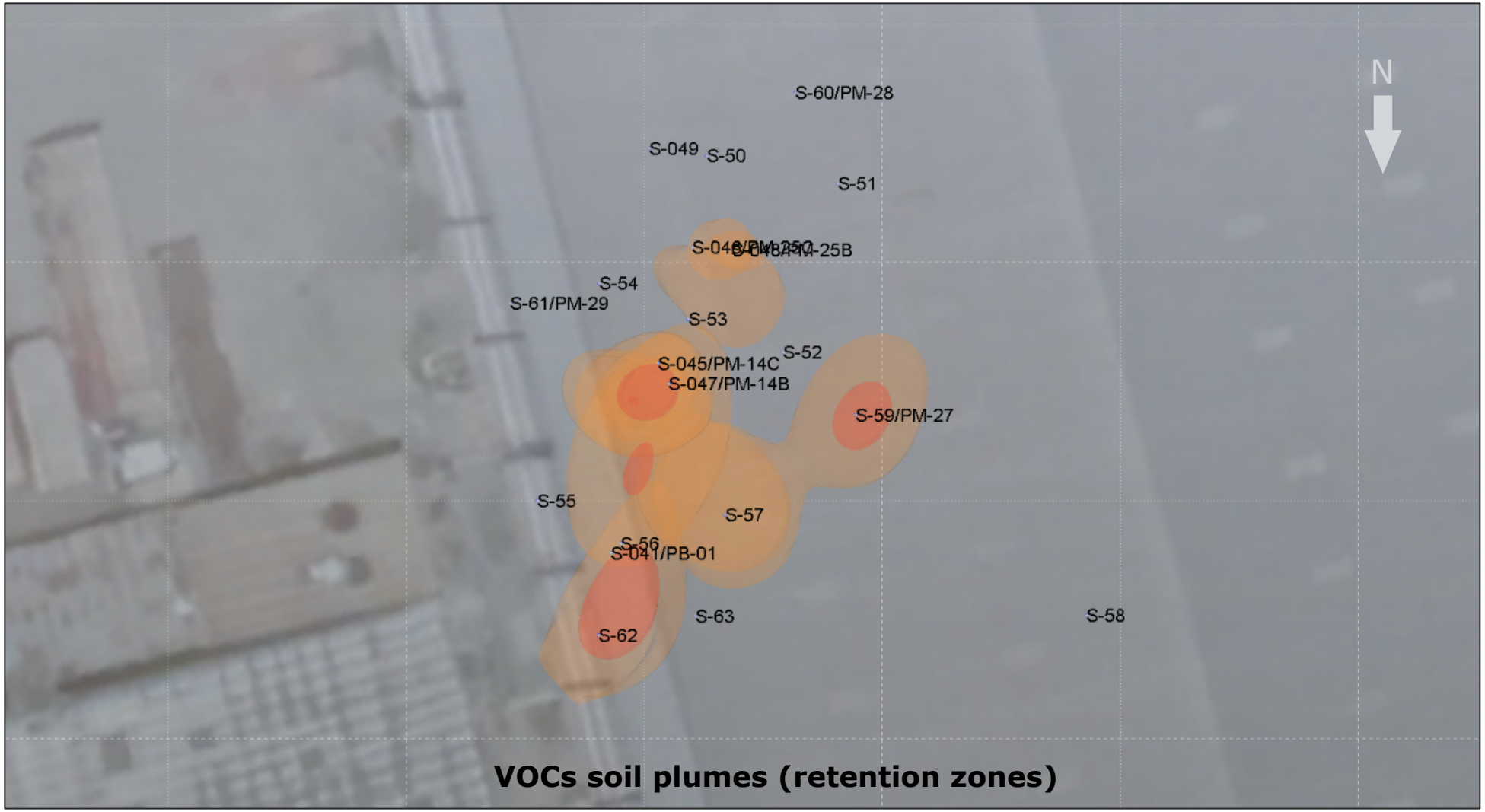
Retention Zones

- Regions characterized by areas of low permeability
- Most of the contaminant mass is in the retained, adsorbed or residual phase
- Correlation between the analytical results and the geotechnical results of the undisturbed samples:
  - granulometry/lithological profile, vertical hydraulic conductivity, fraction of organic carbon (foc) and effective porosity;
  - predominantly clayey soil, ranging from silty clay to organic clay, with vertical hydraulic conductivity between 10^{-6} and 10^{-5} cm/s, effective porosity between 1.9% and 2.9% and foc between 2.32% and 9.98%;
  - 04 main identified retention zones are located at soil borings S-45 (5.9 m e 8.7 m), S-52 (4.9 m), S-53 (4.7 m e 5.5 m) and S-62 (4.5 m).



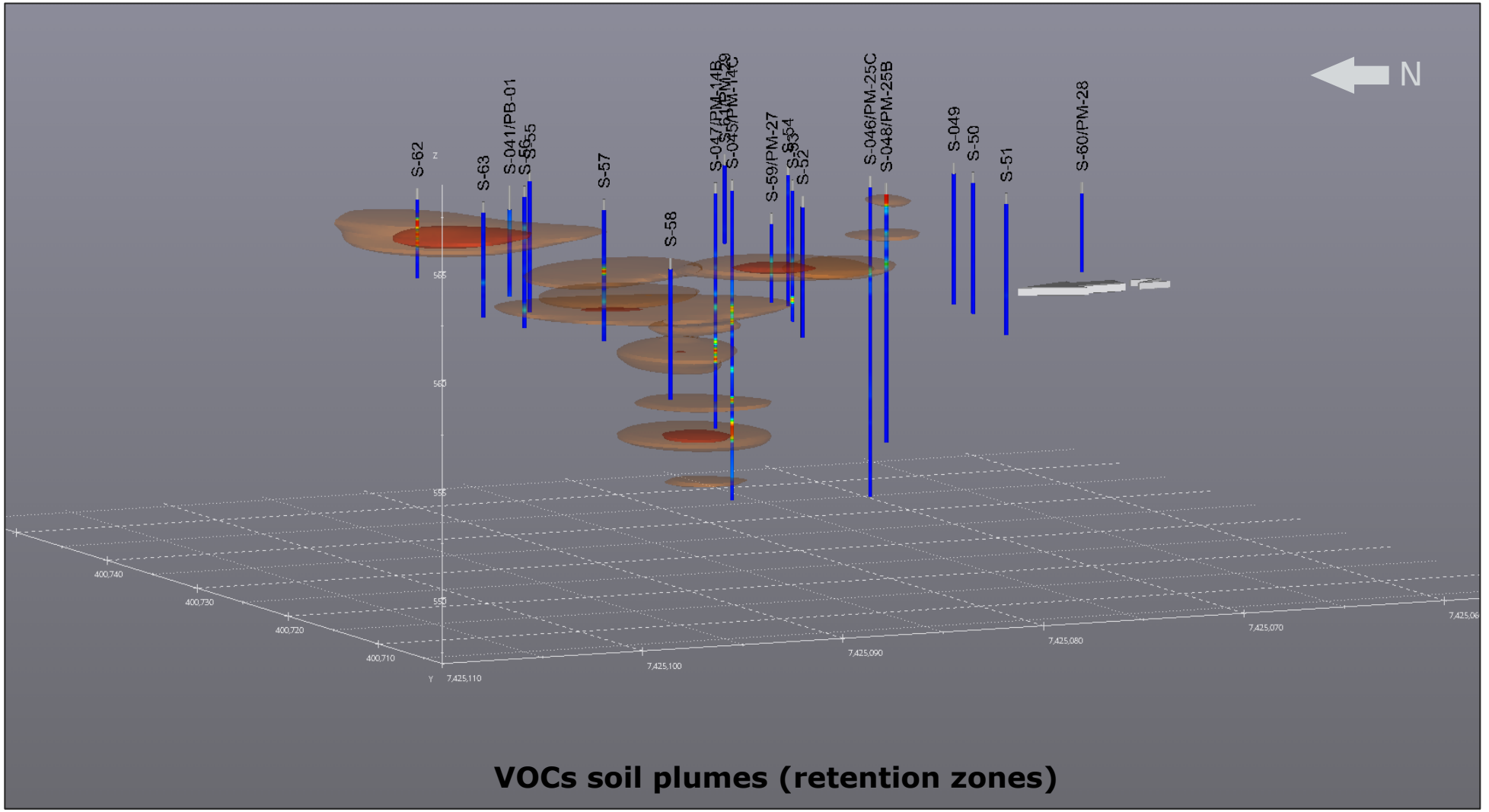
- ✓ 04 soil borings represent **98.8% of the mass of PCE detected in the soil**;
- ✓ Tetrachloroethylene concentrations **above 100 mg/kg**;
- ✓ Samples S-45, S-52, S-53 e S-62 represent 98% of the total mass of volatile organic compounds (VOCs) detected in the soil.

Results (3D Model)



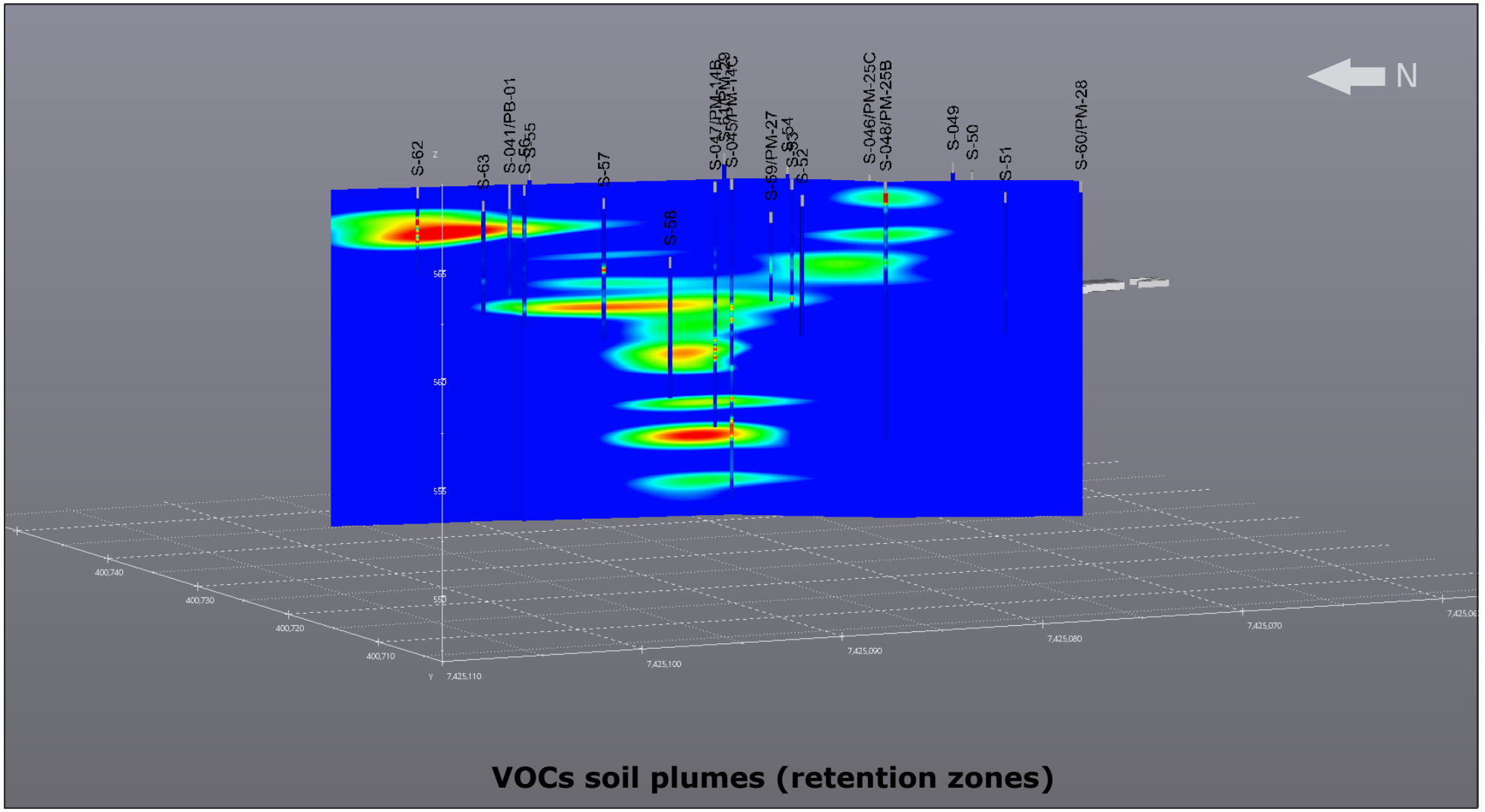
VOCs soil plumes (retention zones)

Results (3D Model)



VOCs soil plumes (retention zones)

Results (3D Model)



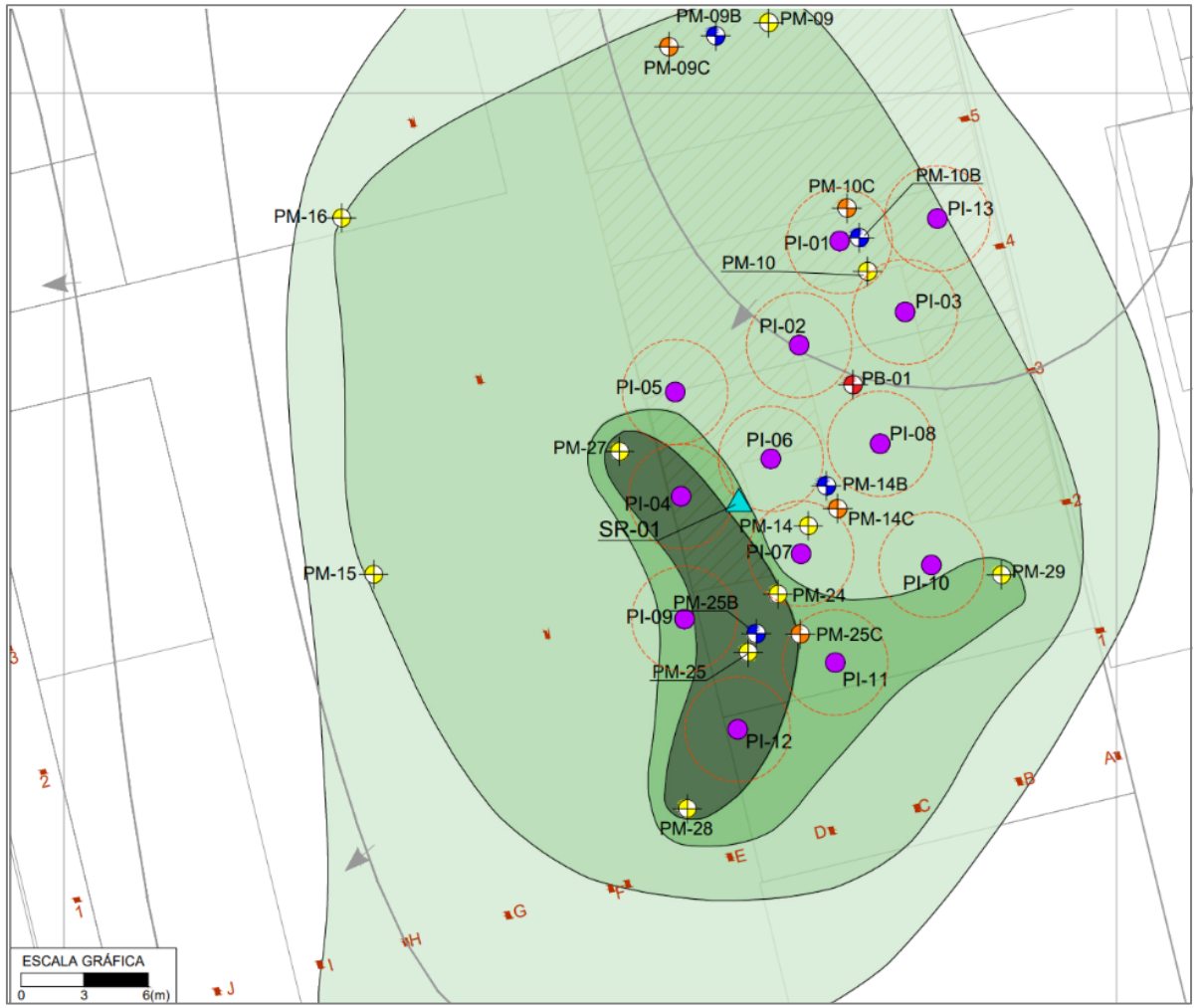
VOCs soil plumes (retention zones)

Conclusions & Learning

- The conceptual site model should be robust enough to identify secondary sources and low permeability and retention zones, especially in the saturated zone of the aquifer.
- High-Resolution Techniques are essential to identify the contamination sources and retention zones.
- Three-dimensional models are excellent tools for visualizing the data collected in the field, and essential for future decision-making (investigation, remediation, etc.).
- The execution of the field work shall be dynamic, with real-time decision-making.
- In general, studies indicate that the saturated zone of the aquifer is responsible for containing more than **80%** of the contamination in the retained or adsorbed phase in soil (secondary sources).
- In this case study, the detailing of the conceptual site model was done late… but better late than never…

Next Steps

ISCR Full-Scale Remediation – Injection points for 2023 Actions (horizontal distribution)



Injection points
(2.5m R.O.I.)

13 Injection points – 330 m^2 total area

PCE Concentration (µg/L)

< 40
40 - 1.000
1.000 - 10.000
10.000 - 20.000
> 20.000

PCE 2023 March Plume

Next Steps

ISCR Full-Scale Remediation – Injection points for 2023 Actions (vertical distribution)

- 13 injections points in the first event (2023)
- 2 to 6 meters deep
- 3 vertical intervals
- According to vertical distribution of the retained mass interpolated by EVS (3D Model)
- Estimated Injection Volume of 1,320 m³
- Remedial Product (ISCR-IR® - Provectus)
  - Total mass of 6 tons - Total Volume of 14.4 m³

In 2024, a new (and final) injection will be done, to decrease the concentrations in some specific areas…

Please, wait **BATTELLE 2026** for more details…

ISCR-IRM (kg)	440	470	475	490	420	500	470	475	470	510	510	450	320	6000
Water (L)	1056	1128	1140	1176	1008	1200	1128	1140	1128	1224	1224	1080	768	14400

Flow rate: 20-25 LPM

Depth (m) BGS	PI-01	PI-02	PI-03	PI-04	PI-05	PI-06	PI-07	PI-08	PI-09	PI-10	PI-11	PI-12	PI-13
0													
0,1													
0,2													
0,3													
0,4													
0,5													
0,6													
0,7													
0,8													
0,9													
1													
1,1													
1,2													
1,3													
1,4													
1,5													
1,6													
1,7													
1,8													
1,9												150	
2							130		130				
2,1			175					175				360	
2,2							312		312				
2,3			420					420					
2,4	140	150		150	120	150							
2,5													
2,6	336	360		360	288	360							
2,7													
2,8													
2,9													
3										175	175		
3,1													
3,2										420	420		160
3,3													
3,4			150				170	150	170				384
3,5												140	
3,6			360				408	360	408				
3,7												336	
3,8	150	160		170	150	175							
3,9													
4	360	384		408	360	420							160
4,1													
4,2													384
4,3													
4,4										175	175		
4,5													
4,6										420	420		
4,7													
4,8			150					150					
4,9													
5			360					360					
5,1													
5,2	150	160		170	150	175							
5,3							170		170				
5,4	360	384		408	360	420							
5,5							408		408	160	160		
5,6												160	
5,7										384	384		
5,8												384	
5,9													
6													

Thank you!!!

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