



FRAC-IN



In-situ soil remediation at
low permeability sites using the
hydraulic/pneumatic fracturing
(FRACIN) approach

Ondřej Lhotský





FRAC-IN Concept

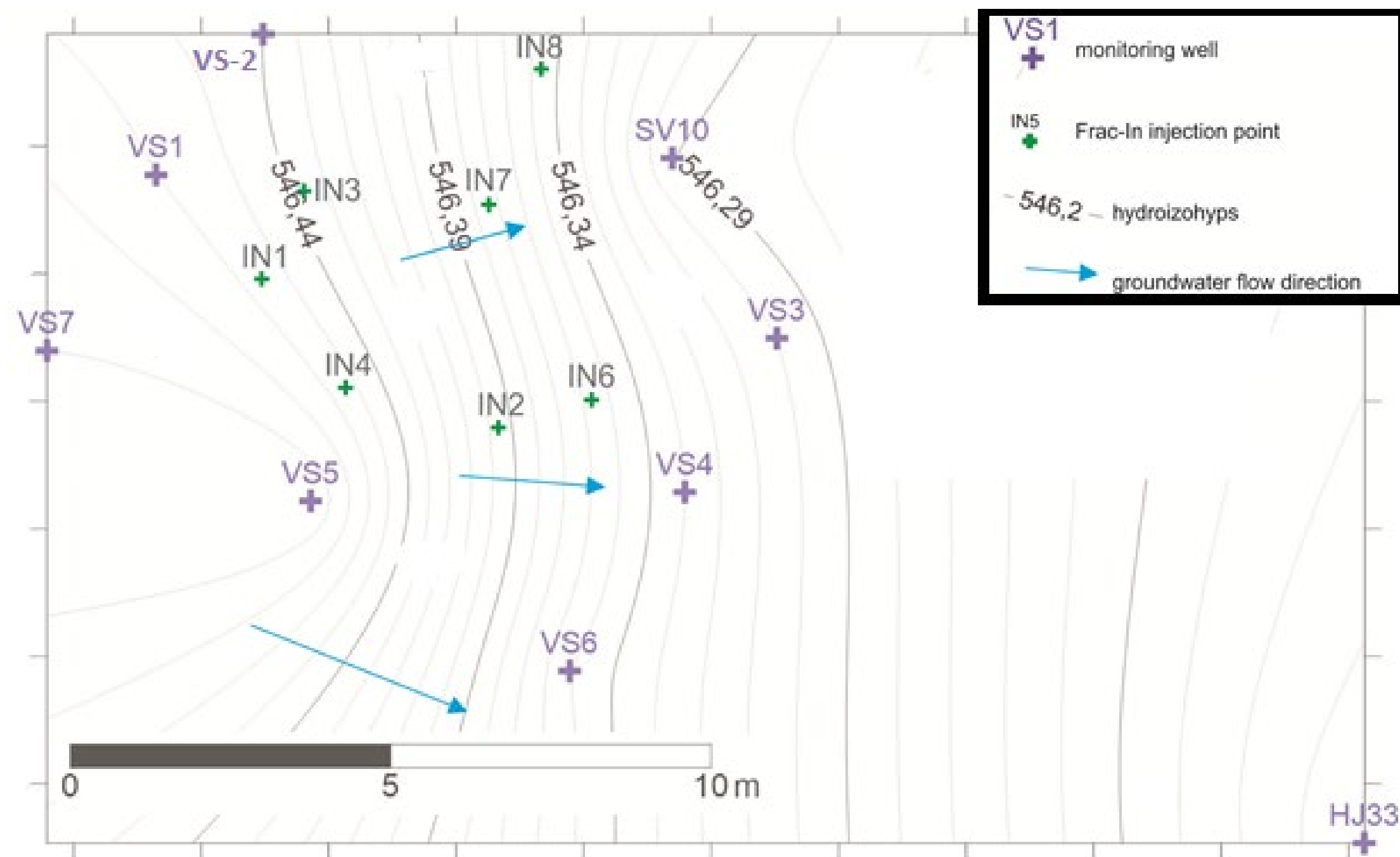




FRAC IN Injections – Pilot test on the site in Western Czechia

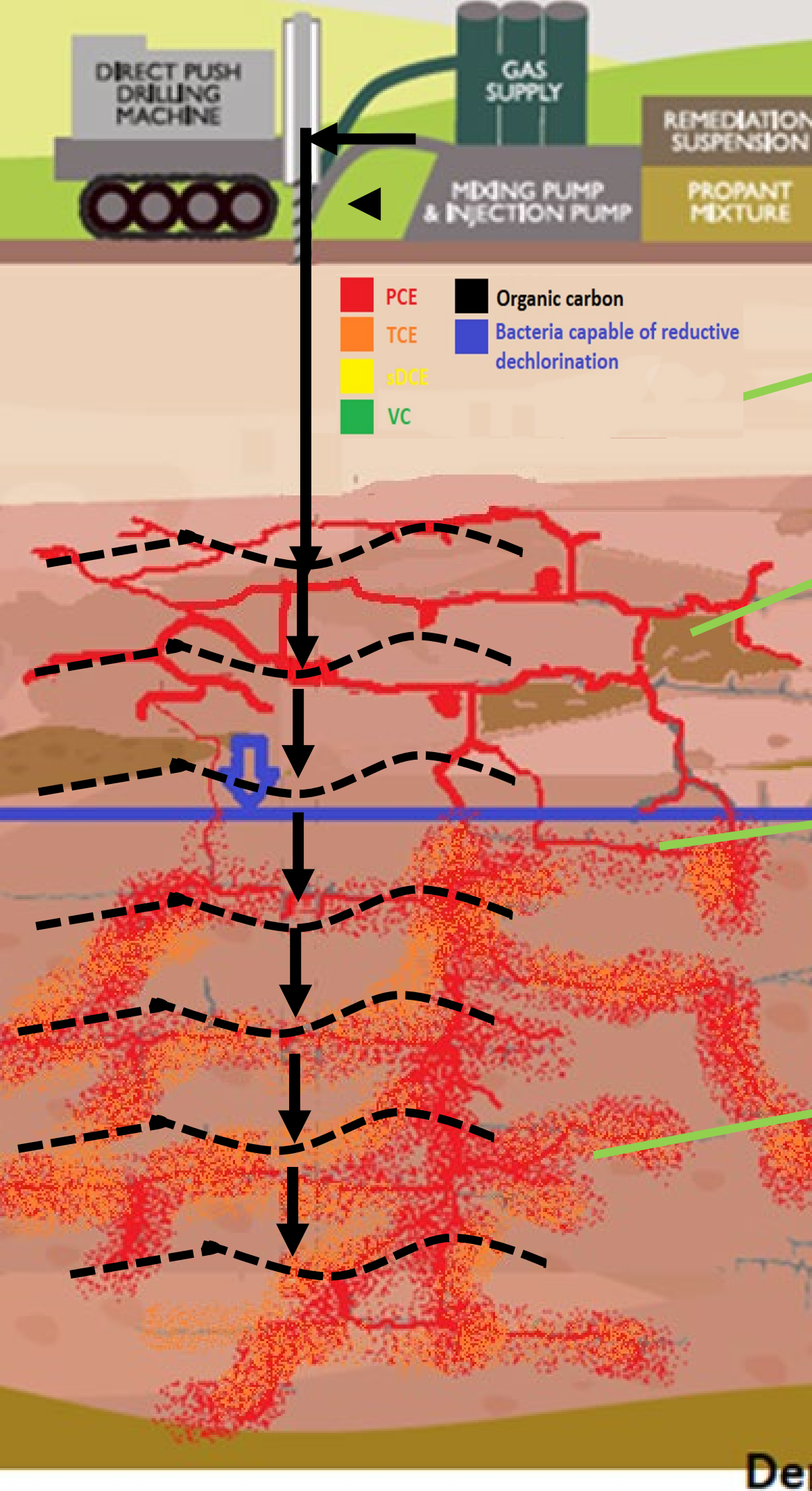


- Old metalworks with chlorinated ethenes (**PCE** is dominant) contamination in both unsaturated and saturated zone
- **Complex geology** – quaternary deposits formed by a mixture of loamy to sandy clays with a significant amount of existing preferential flow paths with the **permeability in range of 10^{-5} to 10^{-6} m/s**
- Pilot spot selected and monitoring system (consisting of 9 wells) installed based on previous MIP survey and other works



Conceptual site model

Typical MIP profile (XSD)

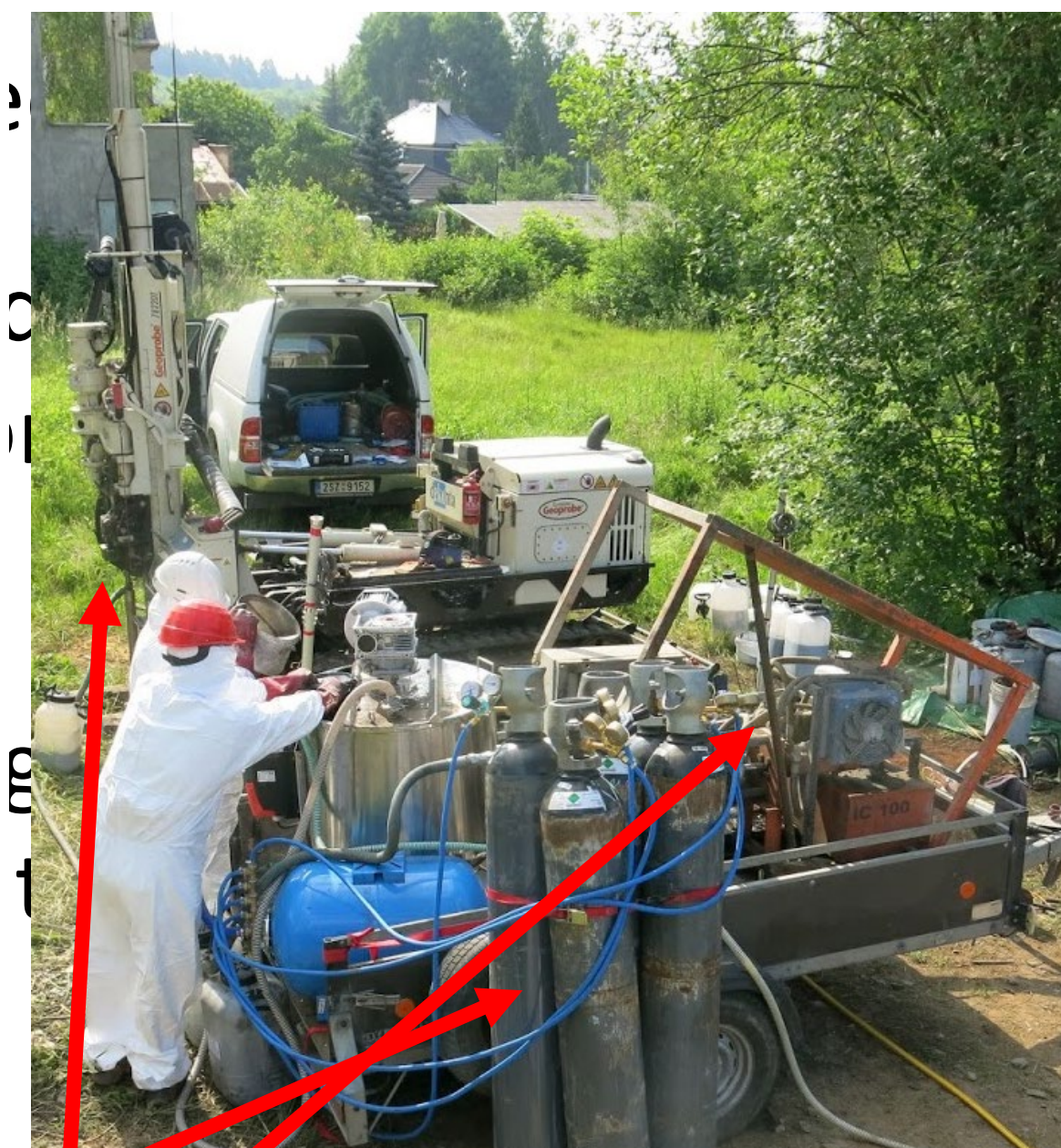


Frac In injections in to both unsaturated and saturated zone in order to widen current fracture system and fill it with reactive materials

Nitrogen used for pneumatic fracturing

Mixture of sand, milled iron and sulfidized nZVI used to fill the fractures

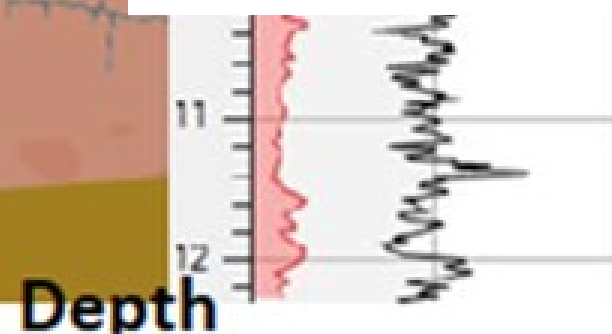
Dried whey injected afterwards in to the fractures to provide carbon source for bacteria



Pneumatic system with nitrogen

Injection pump

Injection hose connected to the injection rods





FRAC IN Injections



Approx. 50% of material injected in to the unsaturated zone

D (m)	N	S (L)	W
4,8	OK	100	150
6	OK	100	100

IN_P
+

VS7
+

D (m)	N	S (L)	W
3,5	OK	100	100
4,5	OK	100	120
5,5	OK	100	40
6,5	X	X	X
7,5	OK	100	130
7,5	OK	100	100
8,5	OK	100	100

VS2
+

D (m)	N	S (L)	W
3	OK	100	100
4	OK	200	200
5	OK	100	100
6	OK	200	200
7	OK	100	100
8	OK	200	200

IN_3
+

D (m)	N	S (L)	W
4	OK	200	
4,5	OK		100
5	OK	100	200
6	X	X	X
7	OK	200	230
8	OK	100	200
9	OK	100	300

IN_4
+

VS5
+

D (m)	N	S (L)	W
2,5	OK	100	100
3,5	OK	100	100
4,5	OK	100	200
5,5	OK	100	100
6,5	OK	100	100
7,5	OK	100	100
8,5	OK	100	100

IN_5
+

IN_7
+

D (m)	N	S (L)	W
3,5	OK	100	100
4,5	OK	100	50
5,5	X	X	X
6,5	OK	200	100
7,5	X	X	X

IN_2
+

D (m)	N	S (L)	W
3,5	OK	100	100
4,5	X	X	X
5,5	OK	100	100
6,5	OK	200	200
7,5	OK	100	100
8,5	OK	200	200
9,5	X	X	X

IN_6
+

D (m)	N	S (L)	W
3	OK	100	100
4	OK	100	50
5	X	X	X
6	X	X	X
7	OK	200	150
8	OK	100	100
9	OK	100	100

VS4
+

D (m)	N	S (L)	W
3	X	X	X
4	OK	200	100
5	OK	100	100
6,1	OK	200	100
7,2	OK	200	100
8,1	OK	50	x

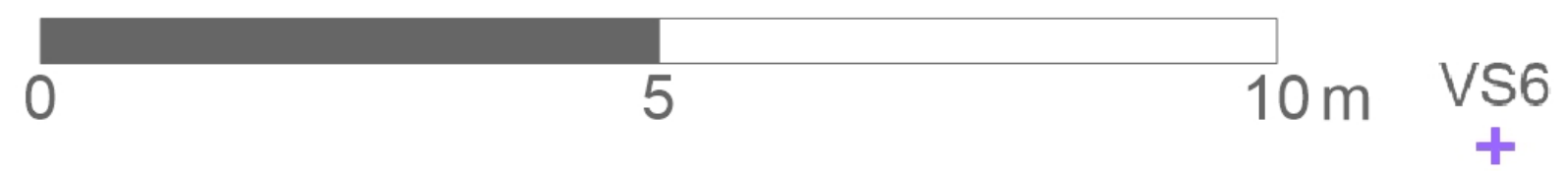
IN_8
+

SV10
+

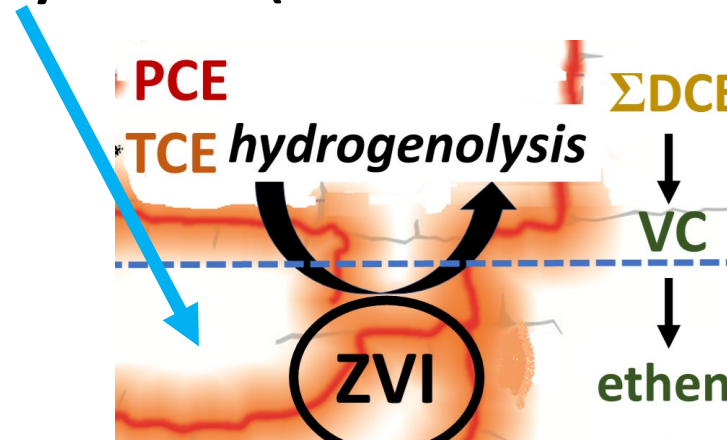
VS3
+

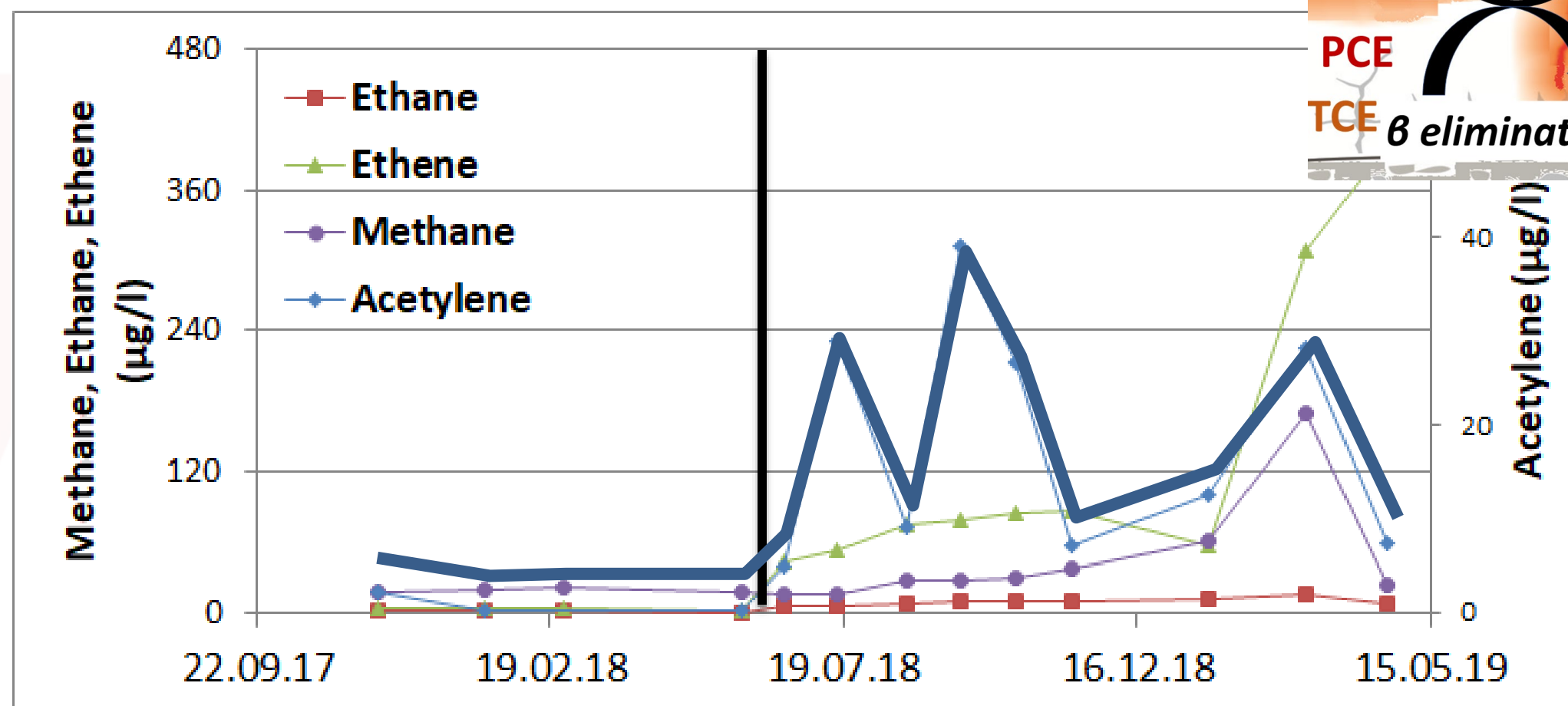
- In total:
9 injection points
45 successful injection horizons
5,5 m³ of suspension
1700 Kg of milled Fe and sand
35 Kg of SnZVI
5,5 m³ of hydraulic/rinse fluid
300 kg of dried whey with pH stabiliser

- Based on the results the radius of influence varied from 2 to 6 m, with typical **ROI around 4 m**



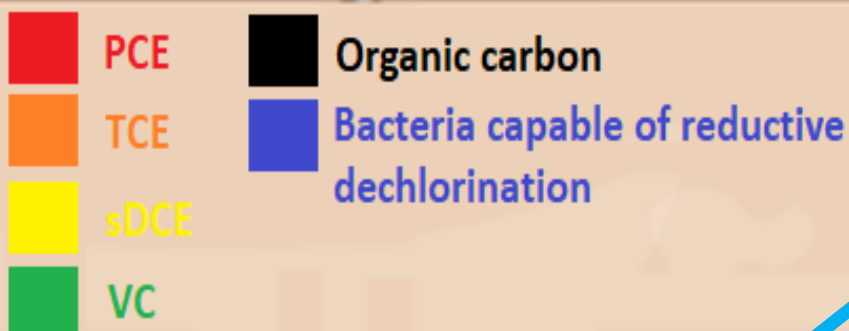
PCE
 TCE
 sDCE
 VC
 Organic carbon
 Bacteria capable of reductive dechlorination

- Low bacterial abundance
 - DCE and VC in low concentrations
 - Existing network of cracks widen and partly filled with iron which reacted with PCE to generate acetylene (abiotic processes were dominant)
 - High organic carbon concentration
 - PCE mobilized and partly dechlorinated
- 
- The diagram illustrates the chemical processes occurring at the ZVI (Zero-Valent Iron) site. A blue arrow points from the text 'Existing network of cracks widen and partly filled with iron which reacted with PCE to generate acetylene (abiotic processes were dominant)' to the diagram. The diagram shows a cross-section of the ground with a dashed blue line representing the water table. Above the water table, PCE (red) and TCE (orange) are present. Below the water table, ZVI (Zero-Valent Iron) is shown in a circular area. The process of 'hydrogenolysis' is indicated by a curved arrow between the ZVI area and the PCE/TCE plume. To the right, a vertical flow of chemicals is shown: ΣDCE (red) at the top, followed by VC (green) in the middle, and ethene (green) at the bottom, with downward arrows indicating the flow.

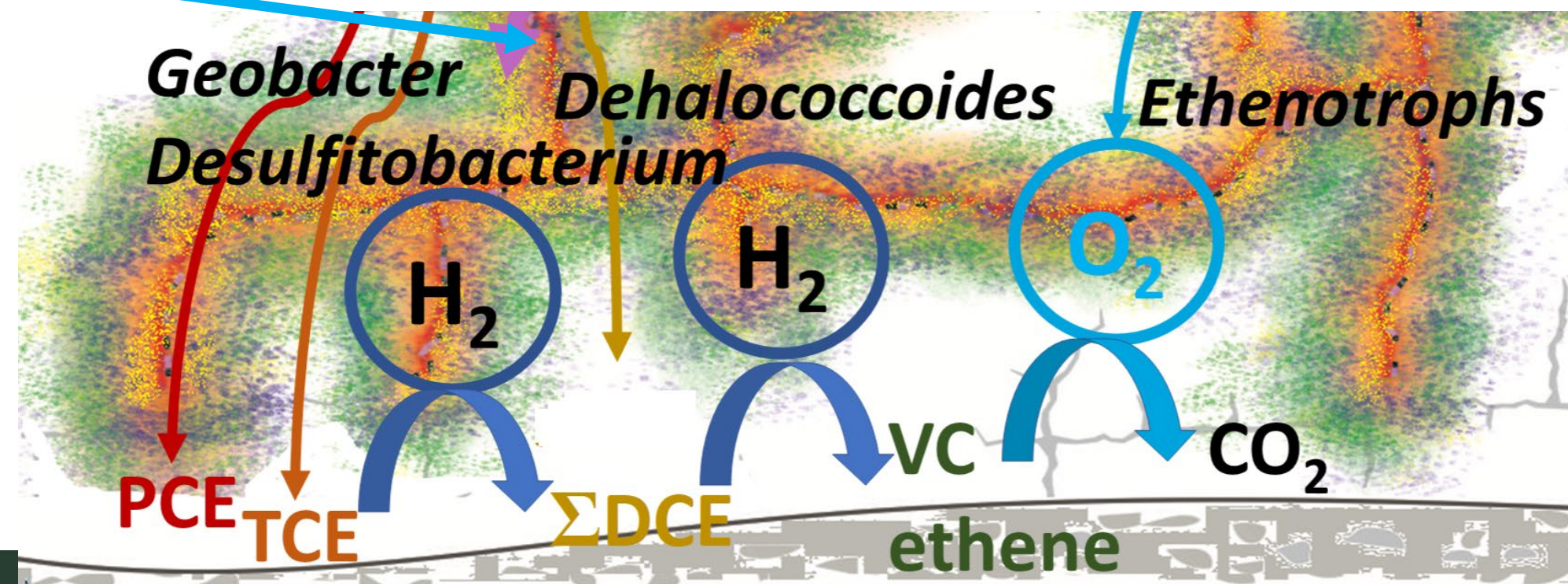


The diagram illustrates the ZVI cycle for PCE and TCE remediation. A central circle labeled 'ZVI' is surrounded by a blue dashed line. To the left, a blue arrow points down towards the ZVI circle. Above the ZVI circle, the text 'PCE' and 'TCE' are shown, followed by 'hydrogenolysis'. Below the ZVI circle, the text 'PCE' and 'TCE' are shown, followed by ' β elimination'. To the right of the ZVI circle, a vertical flow of species is shown: Σ DCE at the top, followed by VC, then ethene, and finally acetylene at the bottom. Arrows indicate the flow of these species: a downward arrow from Σ DCE to VC, a downward arrow from VC to ethene, and an upward arrow from acetylene to ethene. A curved arrow also points from the ZVI circle up towards the Σ DCE/VC interface.

Results – Conceptual site 2.5 years after the injection



- Precipitation seeps into treated fractures → significant decrease in unsaturated zone contamination → most of the PCE phase reduced to DCE → runoff to groundwater
- High activity of anaerobic and aerobic CVOCs degrading bacteria in groundwater
- A significant decrease in PCE and TCE conc. in groundwater
- DCE dominant CVOC → concentrations gradually decrease
- VC is not accumulated probably due to the activity of ethenotrophic bacteria
- Biotic degradation of the CVOCs is a dominant process

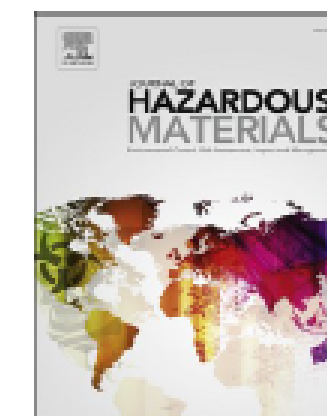


- The performed injections led to an increase in the permeability of the site
- In the first phase after the injections, the abiotic reduction of ClE on the supplied iron particles dominated
- Successive increases of dechlorinating bacteria → removal of accumulated DCE
- 2.5 years after the injections, a significant decrease in the mass of ClE present and dechlorination of most of the PCE
- The triggered processes will continue → significant improvement in the condition of the site



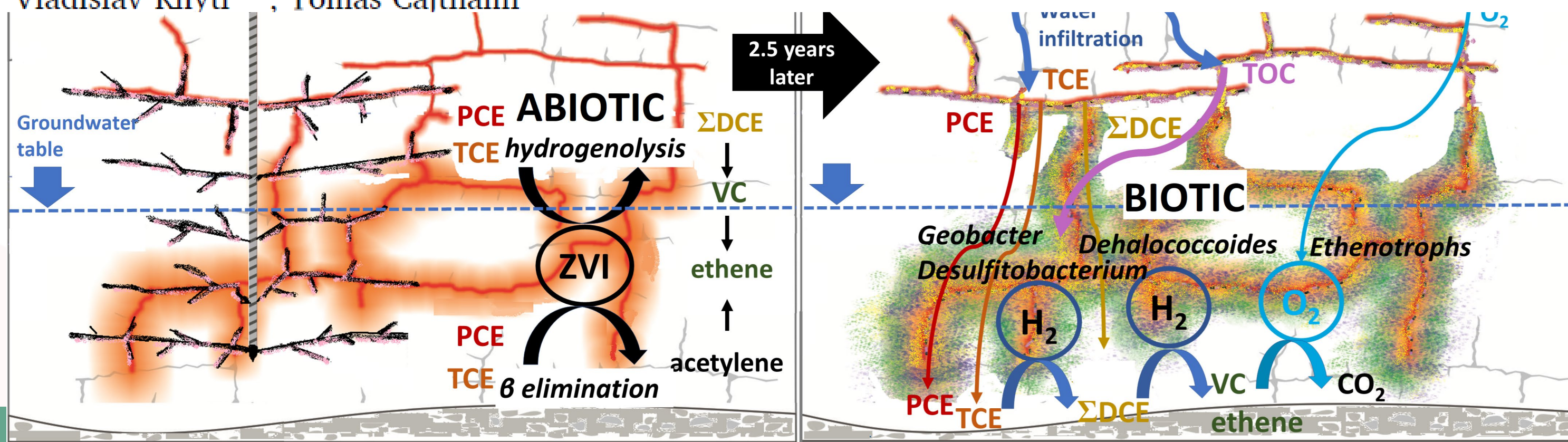
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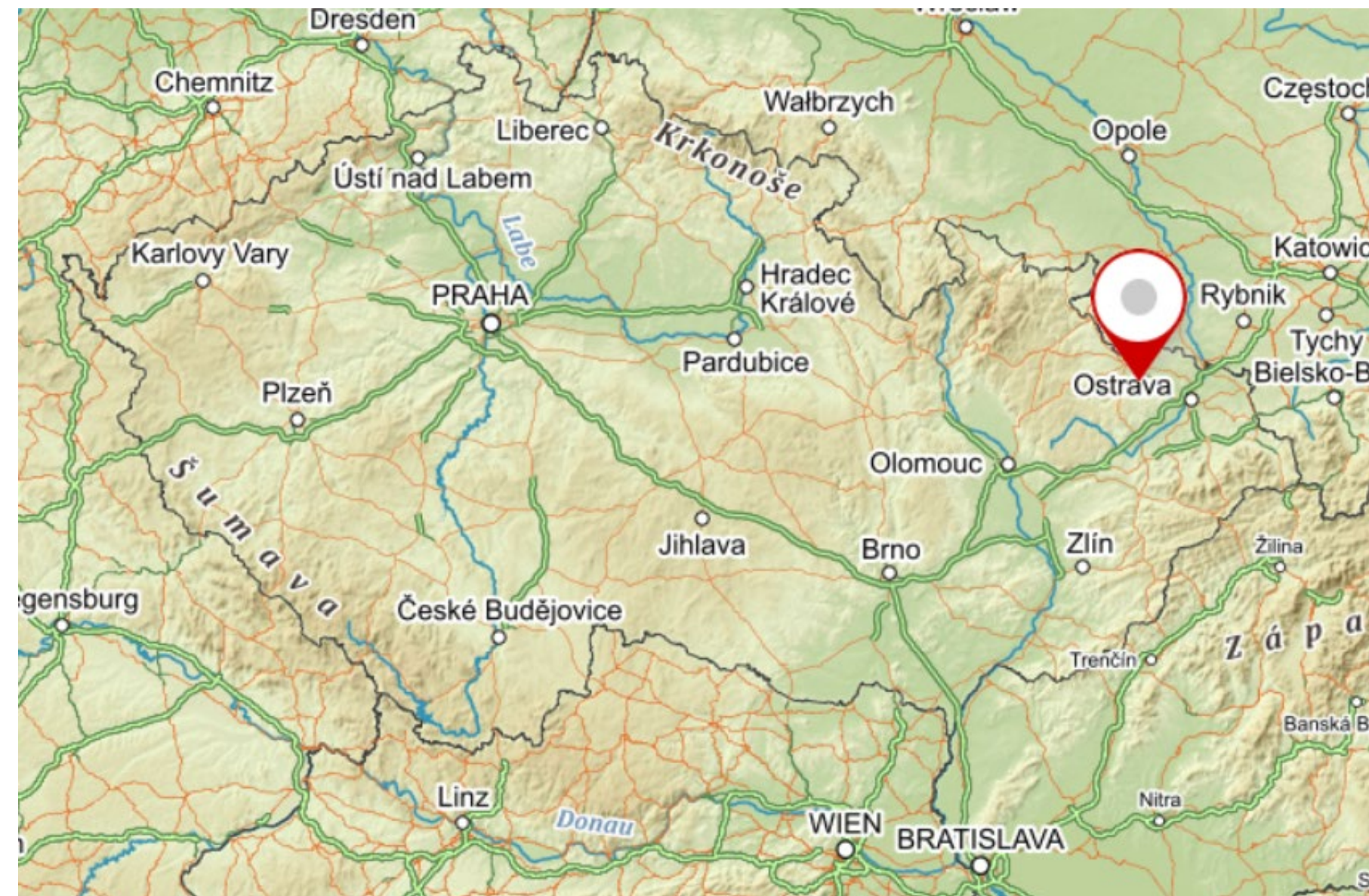
The effects of hydraulic/pneumatic fracturing-enhanced remediation (FRAC-IN) at a site contaminated by chlorinated ethenes: A case study

Ondřej Lhotský^{a,b}, Jan Kukačka^a, Jan Slunský^c, Kristýna Marková^d, Jan Němeček^d,
Vladislav Knytl^{a,b}, Tomáš Cajthaml^{b,e,*}





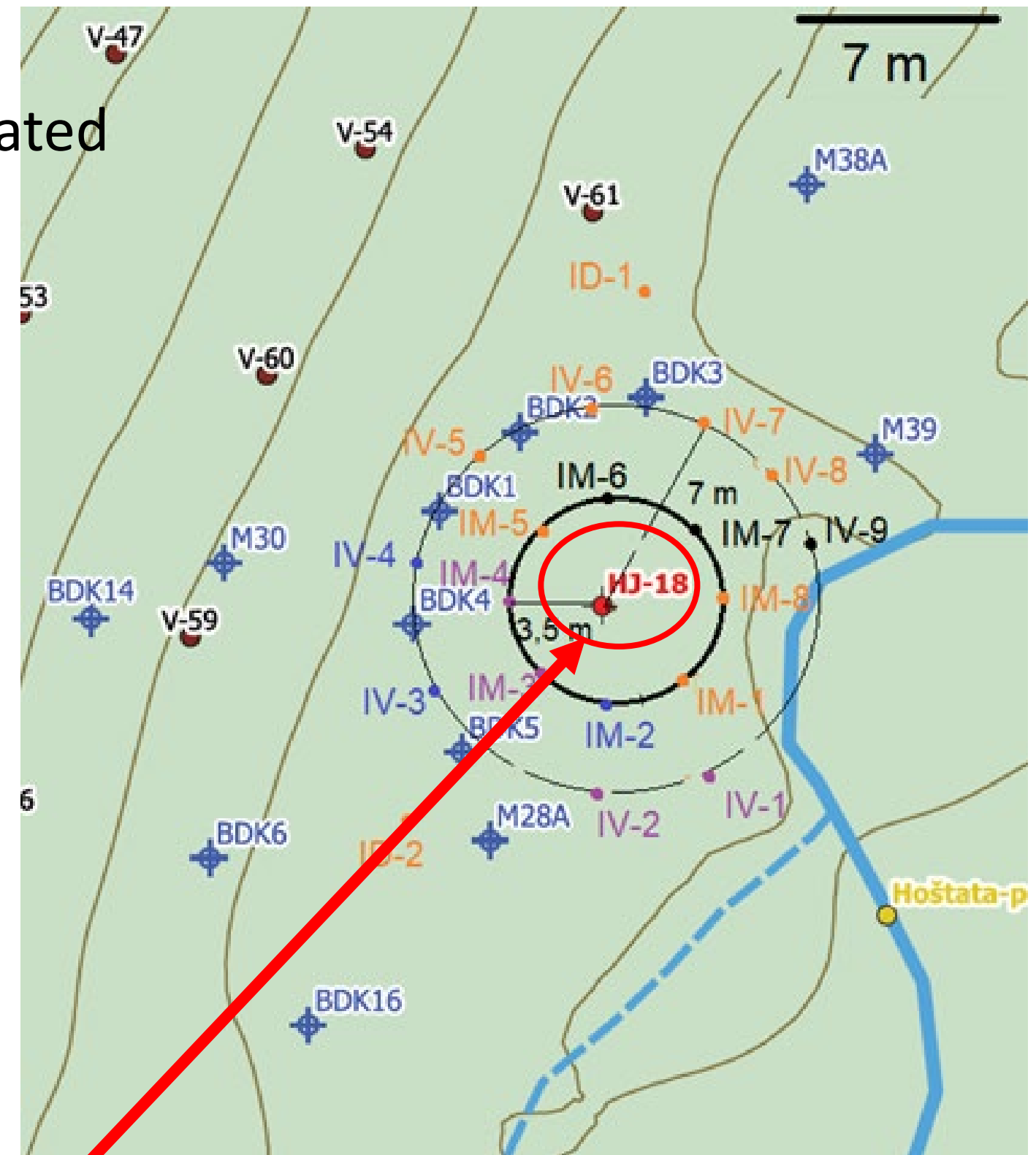
Development of
FRAC-IN-OX technology
and pilot test on the
Březinka site in Silesia



Frac-In-Ox upgrade

- Frac-In-Ox technology combines direct-push drilling with pneumatic fracturing and the subsequent hydraulic emplacement of **strong oxidation agents**
- The technology is suitable for treating poorly permeable or heterogeneous sites contaminated with organic contaminants that are treatable **via in-situ chemical oxidation (ISCO)**
- The technology enables the injection of highly-concentrated and, thus, **highly-corrosive solutions** of strong oxidation agents
- The upgraded Frac-In-Ox set up provides allows for the remote operation of the system, thus significantly **enhancing the safety** of the procedure

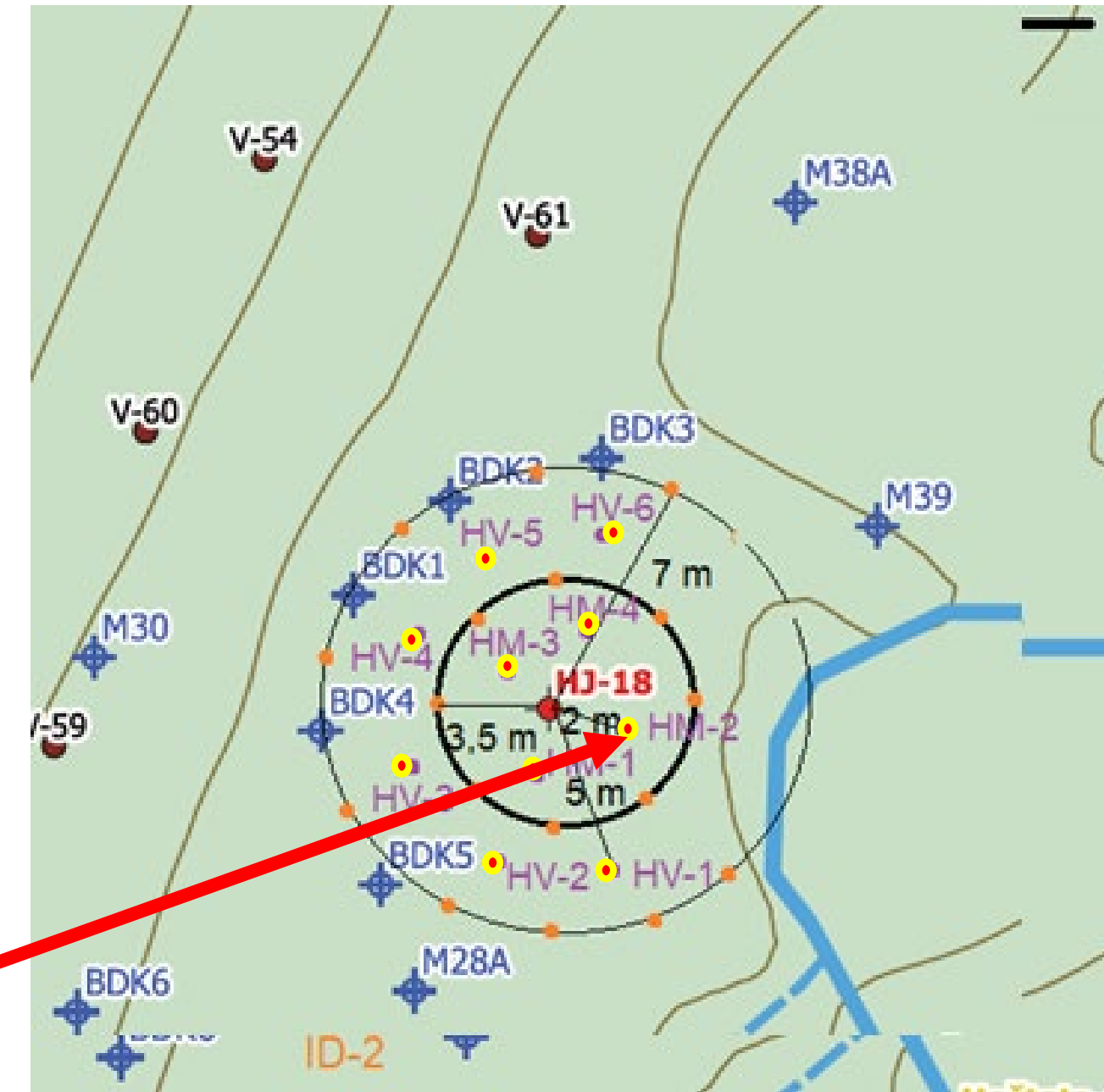
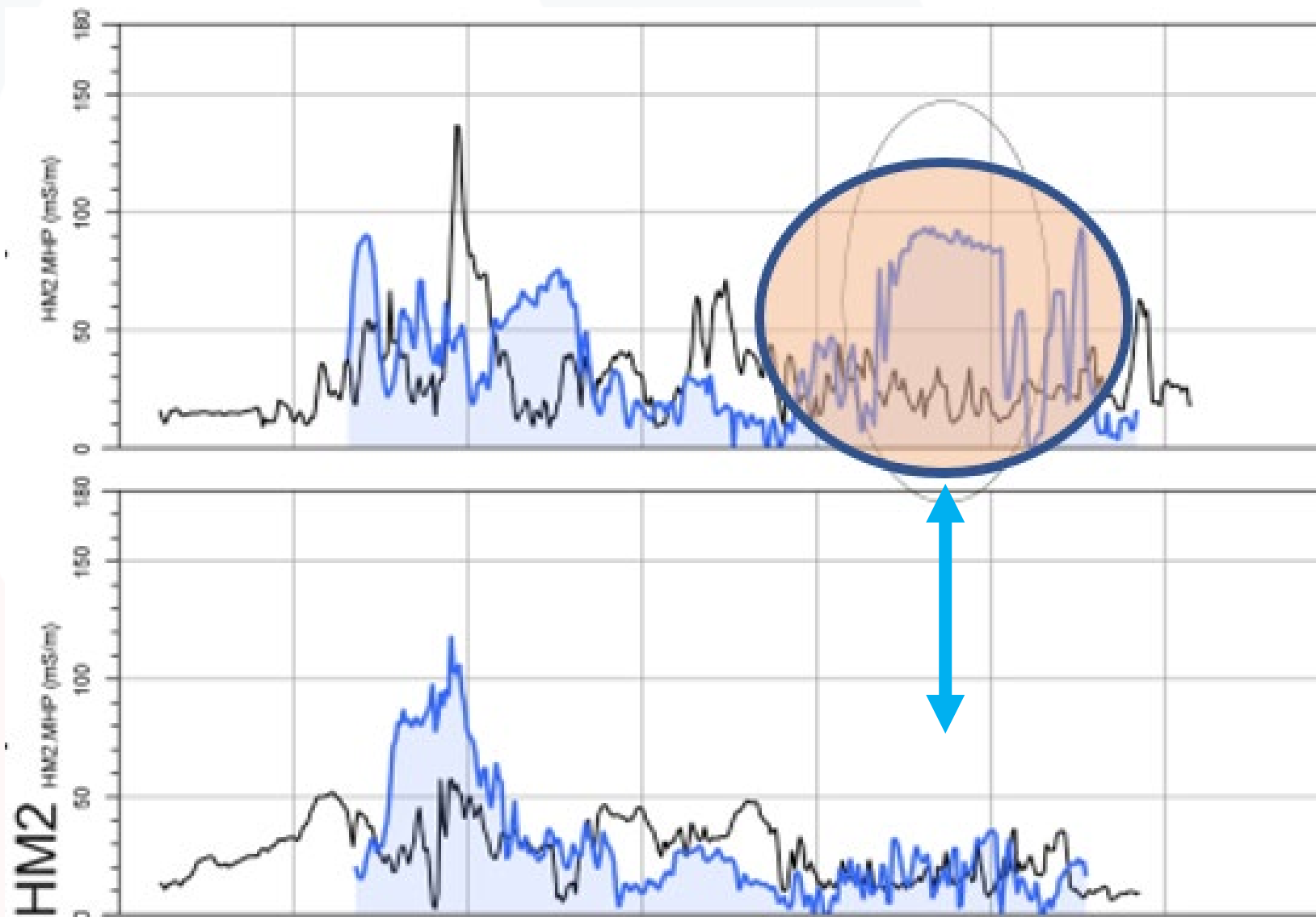
- The former landfill site used for dumping of waste paints, varnishes and solvents from the drug manufacturer located in a former sand quarry.
- Main contaminants are 1,2 dichloroethane, chloroform, dichloromethane, benzene, toluene and trichloroethene.
- The aquifer is composed of fine-grained sands with low permeability → problems injecting remediation as the injected materials tend to migrate upwards to the surface.
- The water table depth round 1 m b.g.l. Aquifer thickness round 4 m
- Main area for Frac-In-Ox injections in the close vicinity of the HJ-18 monitoring well



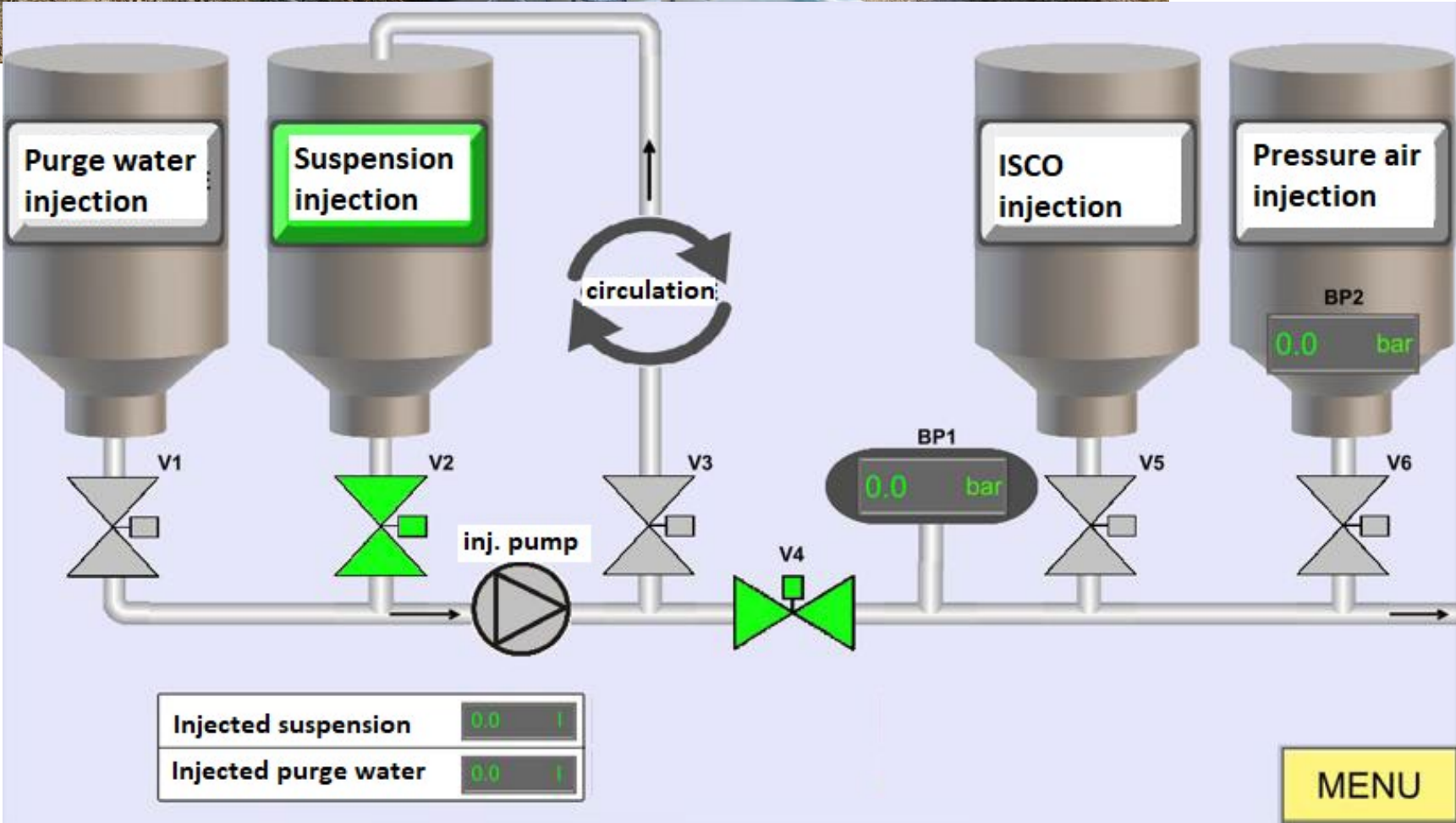
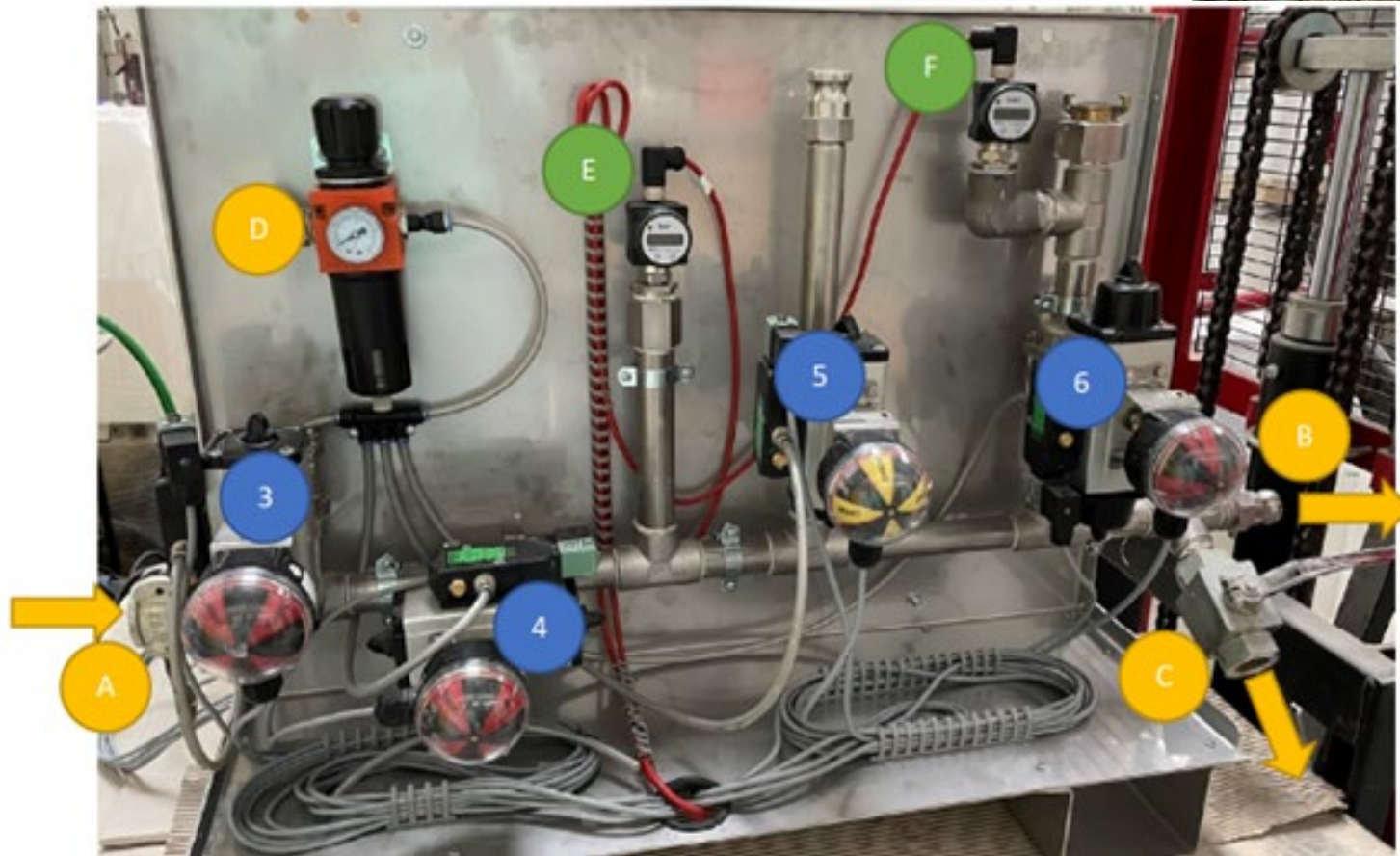
- 16 injection probes at the site were performed within the pilot test and two different remediation mixtures injected:
 - a. 9 probes with mixture using guar gum as the thickening agent for transporting sand into the created fractures, with subsequent injection of strong ISCO agents
 - b. 7 probes with mixture using hydrophilic fumed silica and calcium peroxide as thickening agent, with subsequent injection of strong ISCO agents
- A total of 1.4 t of sand, 1.4 t of sodium persulphate, 0.95 t of potassium persulphate and 0.56 t of calcium peroxide was injected.



- Surveys of the pilot site using the so-called Hydraulic Profiling Tool (HPT) were performed at the site prior to and following the injections indicated a significant increase in the hydraulic permeability of the aquifer



- It was proved it is possible to inject strong oxidizing agents via the upgraded Frac-In-Ox injection system using a remote control valve system enhancing the safety during injections
- The performed injections led to significant increase in the permeability of the site
- The monitoring of the groundwater quality both before and after the pilot testing served to prove the good distribution of the injected remediation agents and their long-lasting presence in the groundwater.
- A mean decrease of 62% in the sum of the volatile organic compound concentration was observed via the monitoring of boreholes 4 months following the injection campaign.





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Session 3c6 / Abstract title: The Utilisation of Innovative
Site Survey and Remediation Methods at the Duchcov
Site with Complex Conditions and Geology

Thursday 14:00-15:30 Room Z-I / 111





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dekonta

Thank you for your attention

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