PHOTON WATER

NANOIRON
FUTURE TECHNOLOGY

NEXT GENERATION OF NANOREMEDIATION:

nZVI application enhanced by DC electric field

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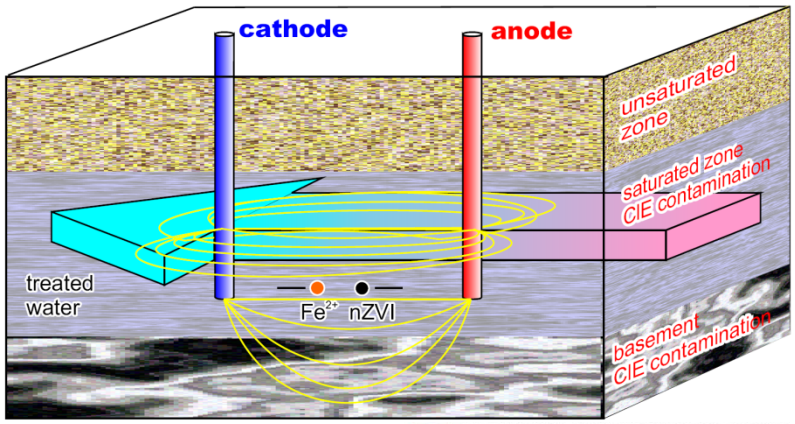
Basic principles

- Chemically supported reductive de-chlorination of CIE is inherently a substitution of chlorine protons, while the electrons are consumed by the equation: $Cl_2C{=}CCl_2 + 4H^+ + 8e^- \longrightarrow H_2C{=}CH_2 + 4Cl^-$

- For the successful running of the reaction it is necessary to create a significant excess of protons and electrons in a geochemical system. Both of these conditions are virtually assured by for example **Fe^0** reaction with water.

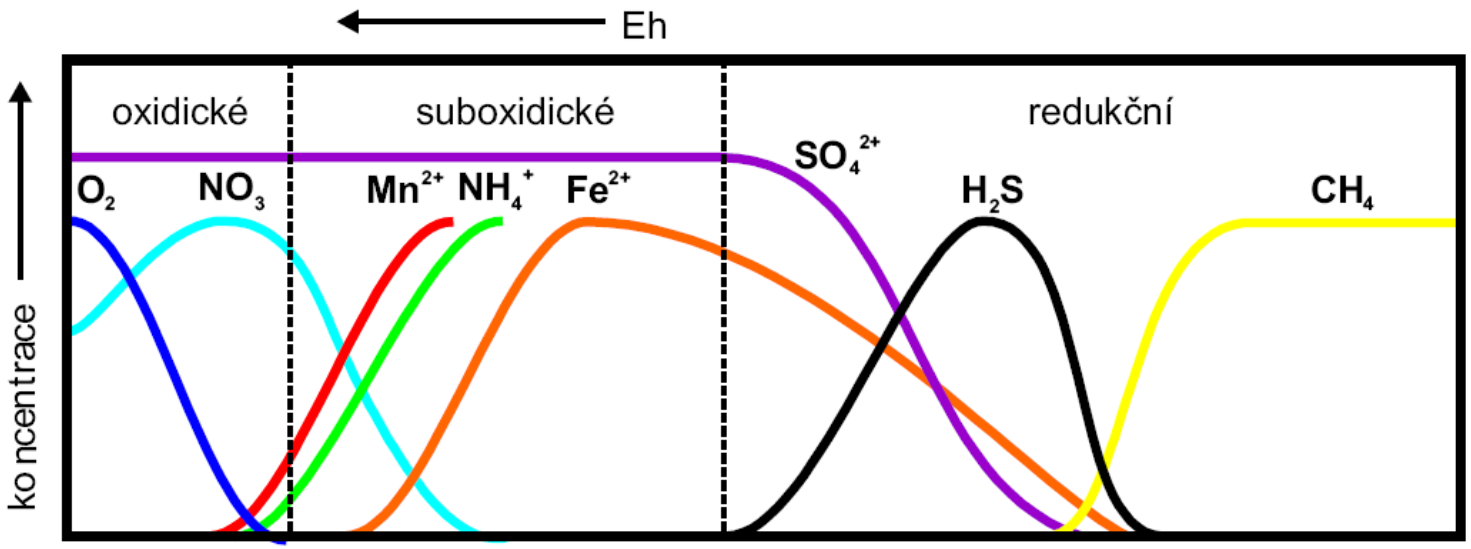
$$5H_2O + Fe^0 \longrightarrow Fe^{3+}(OH)^-_3 + H_2 + 2OH^- + 3H^+ + 3e^-$$

- A similar effect can be achieved by providing electrons into the reorganized structure using the DC electric field. During the appropriate current density the decomposition of water occurs. This process creates hydrogen and the environment gets overfed by e^- for the process of reductive de-chlorination of CIE.



Basic principles

- Decrease of ORP by DC before the injection of nZVI
  - -400 mV, reduces DO, nitrates, Fe^{3+}, sulphates
  - Increase of reactivity of nZVI
  - Prolongation of lifetime of nZVI

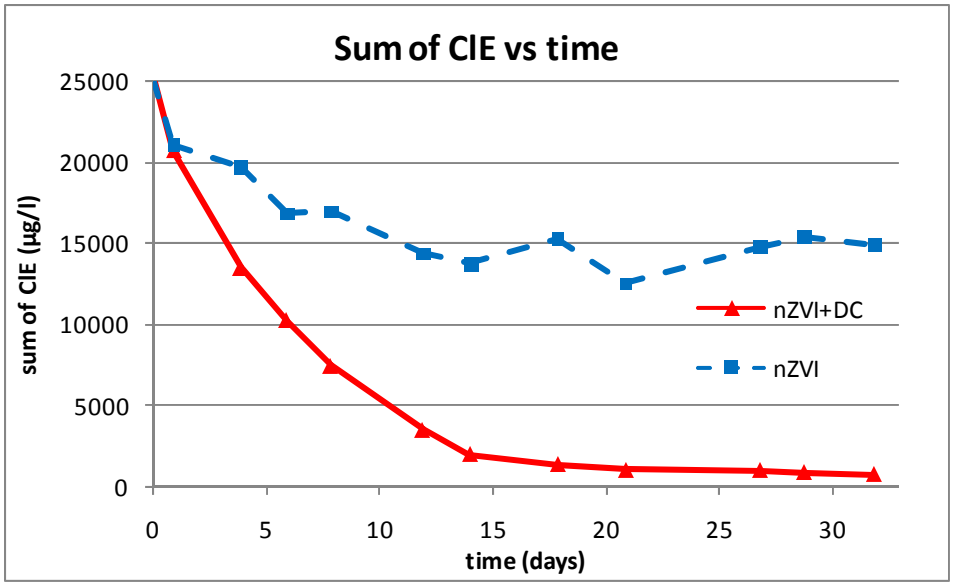


Redox processes in the aquifer

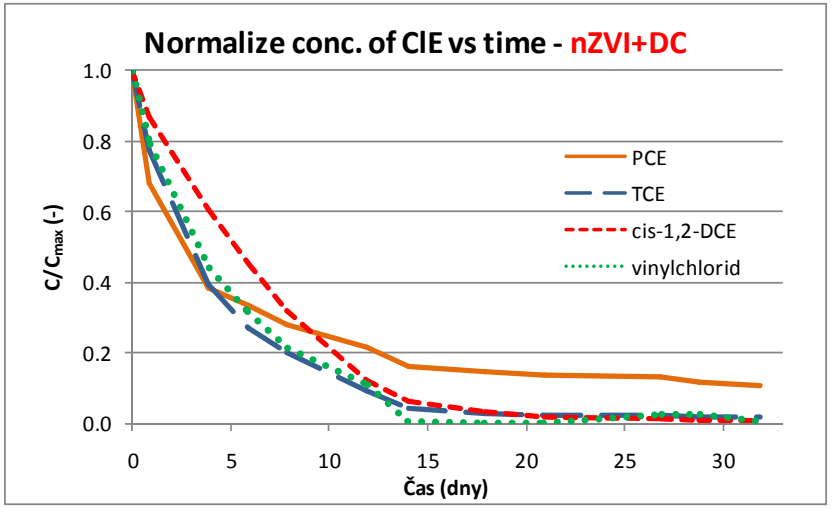
Laboratory tests

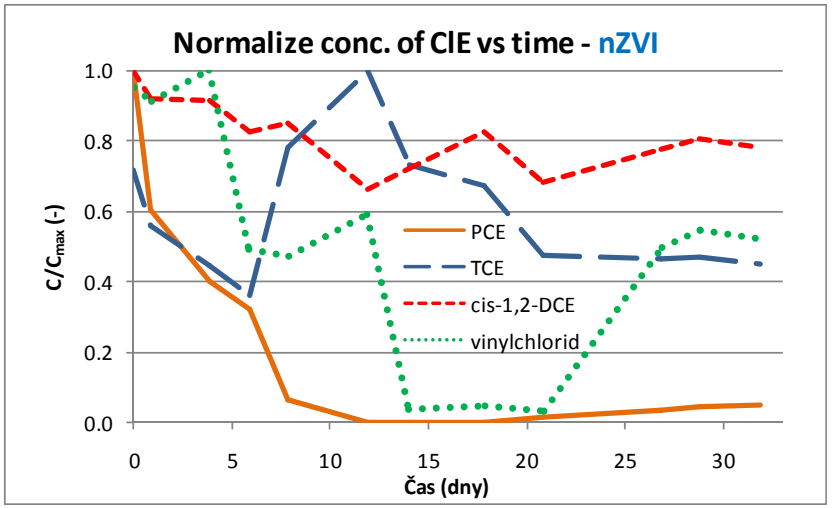
- *2 reactors (2.5 l)*
  - ***nZVI+DC***
  - ***nZVI***
- *ClE total 25 mg/l, app. 70% of cis-1,2-DCE*
- *nZVI concentration 0,5 g/l*
- *30 days*
- *pH, ORP, ClE, conductivity, anions*

Laboratory tests

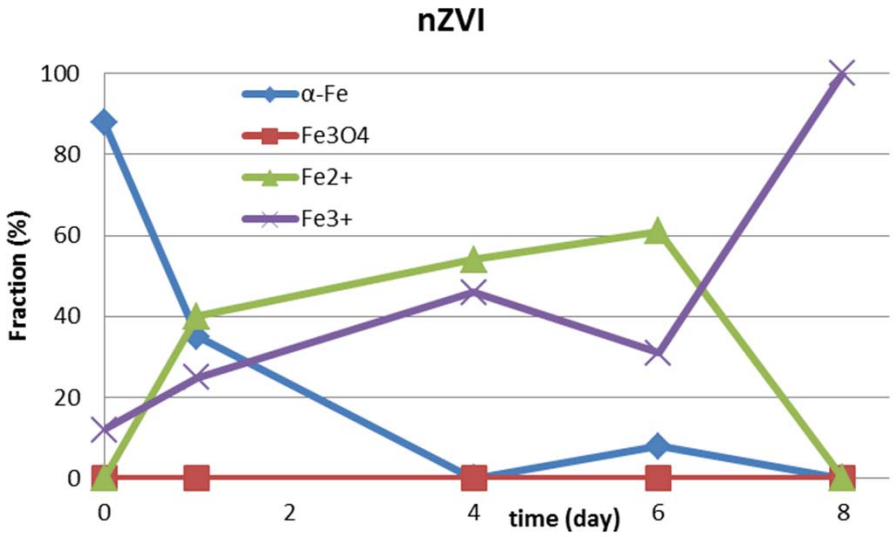


- common application of nZVI and DC current reduce 97% of the sum of ClE (alone nZVI app 40%)



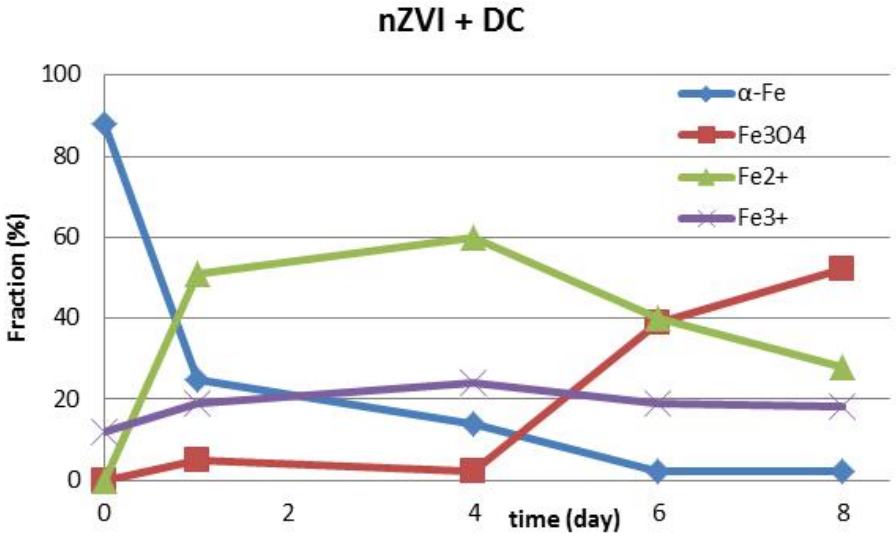


Laboratory tests



nZVI only

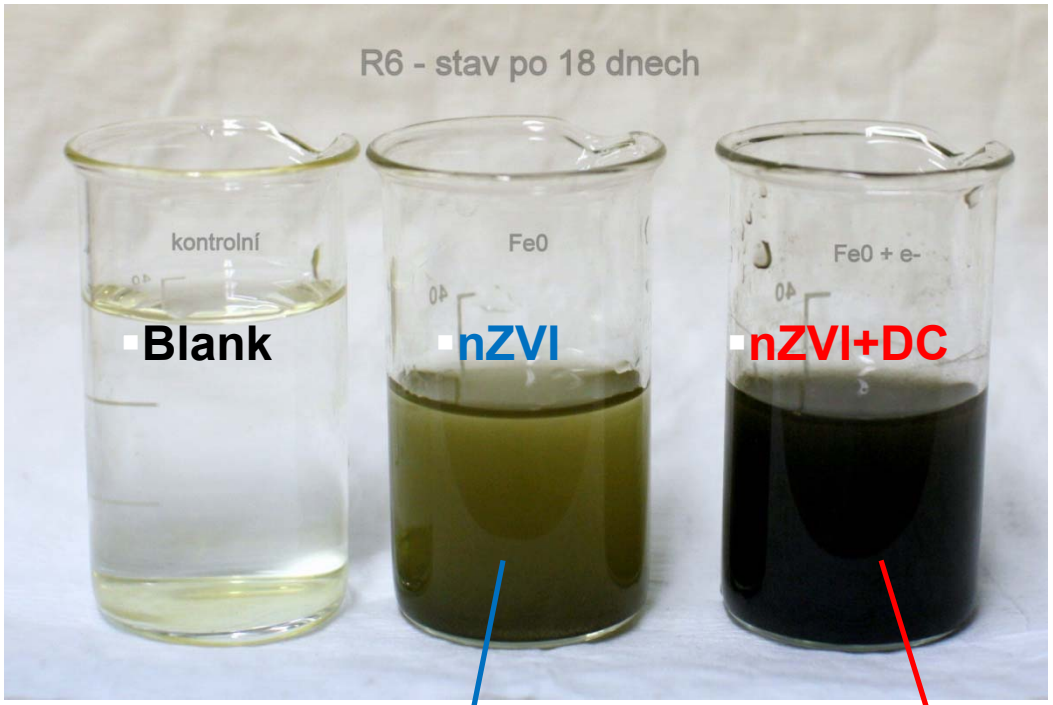
0% of Fe^0
0% of Fe^{2+}
0% of magnetite
100% of Fe^{3+} - goethite



nZVI + DC

2% of Fe^0
28% of Fe^{2+}
51% of magnetite
19% of Fe^{3+} - goethite

Laboratory tests

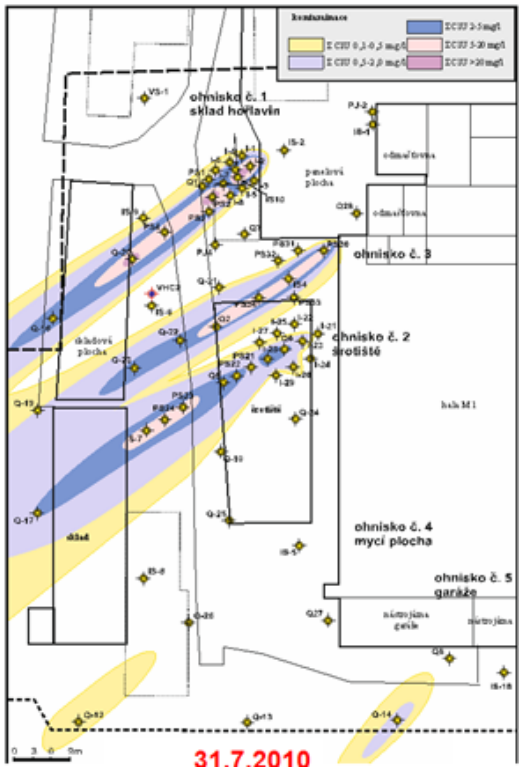


90% goethite
10% magnetite

80% magnetite
20% $Fe(OH)_2$

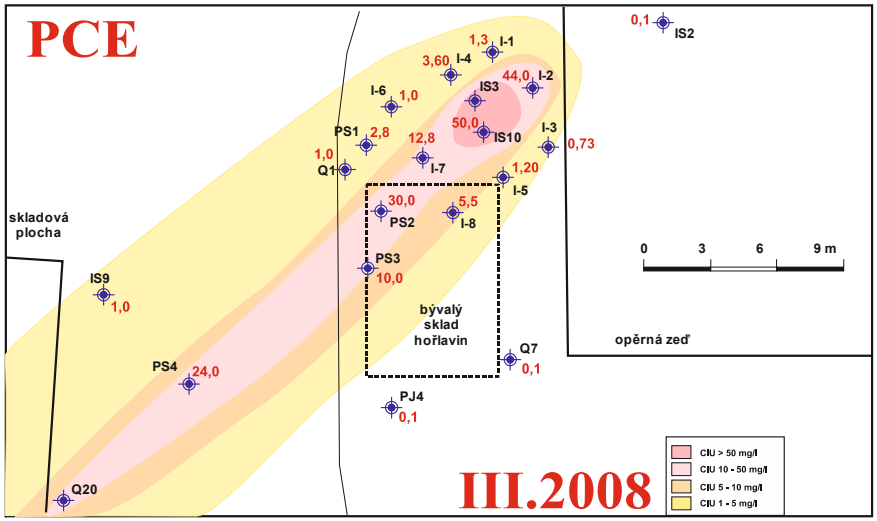
Field verification – Site Hořice

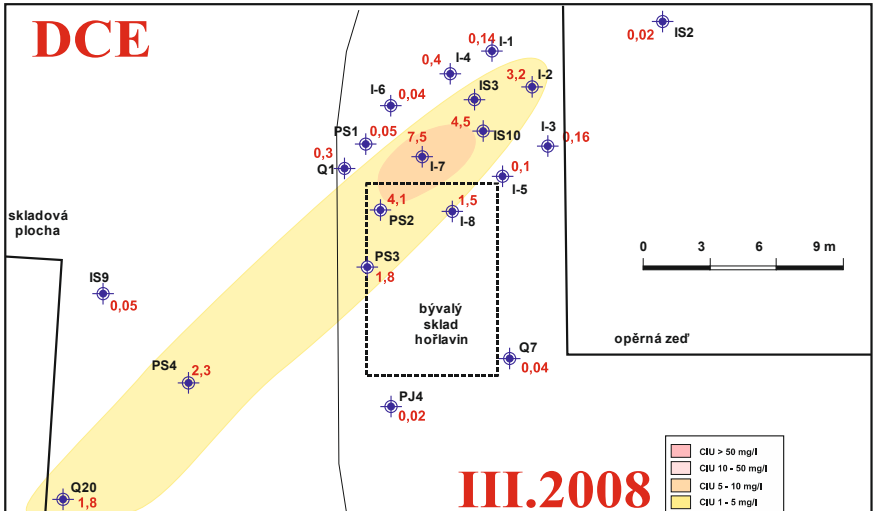
- Quarternary aquifer – sandy silts to clays
- Hydraulic conductivity 10^{-7} m/s
- PCE contamination, daughter products
- 3 tons of nZVI (TODA, NANO IRON) in several injection campaigns
- Direct-push



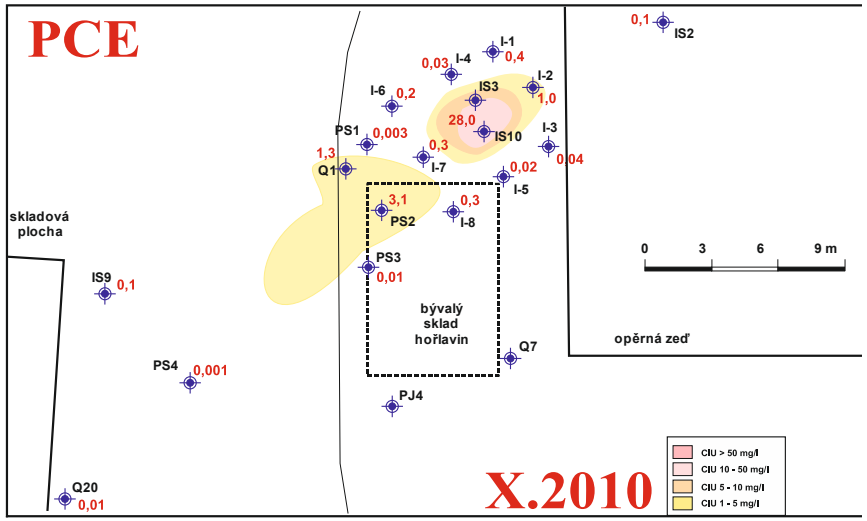
Field verification – Site Hořice

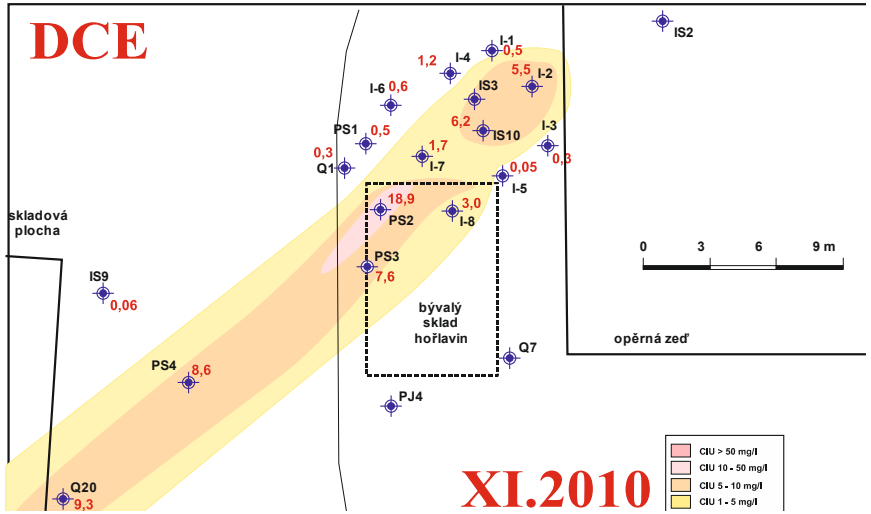
Beginning of remediation





State after 2nd nZVI appliaction





Field verification – Site Hořice

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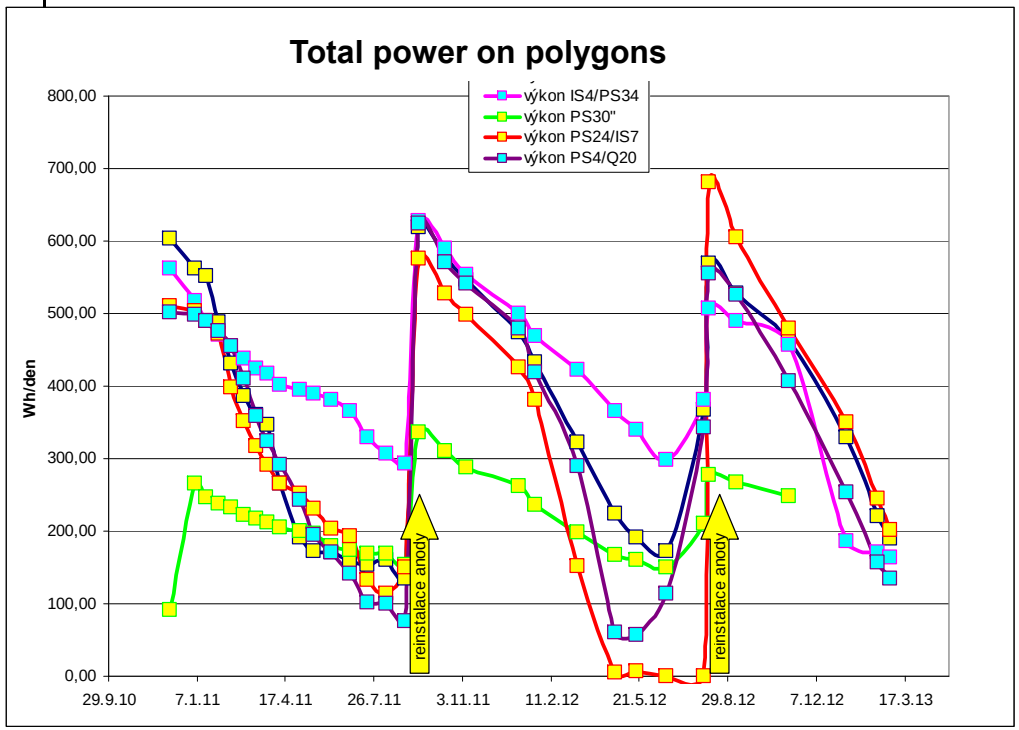
Oxidation-decomposition of anodes

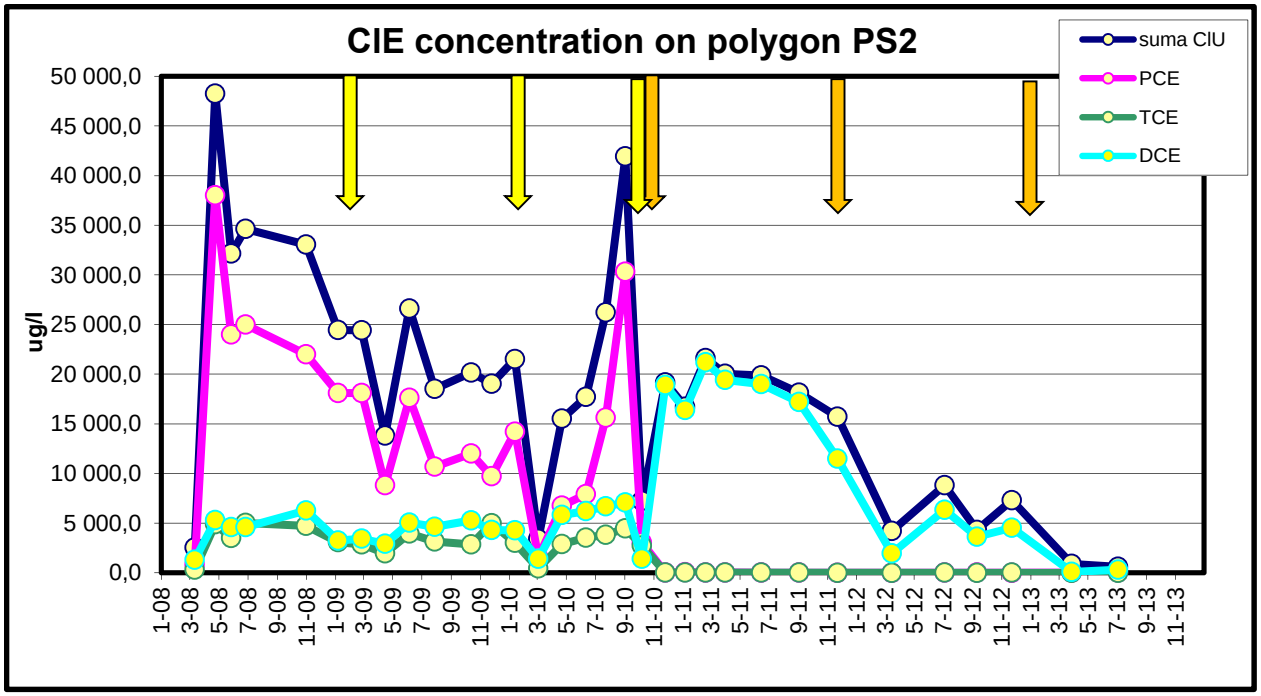
- >> reinstallation each 6-9 months
- From **12/2009** runs 2 polygons, from **10/2010** 9 polygons



Field verification – Site Hořice

ClE concentration

- On all 9 polygons decreasing of ClE concentration
- After nZVI injection (yellow arrow) dechloration from PCE to DCE
- Stagnancy period – after DC current connection (orange arrow) rapid decrease of sum of ClE (even DCE, VC)



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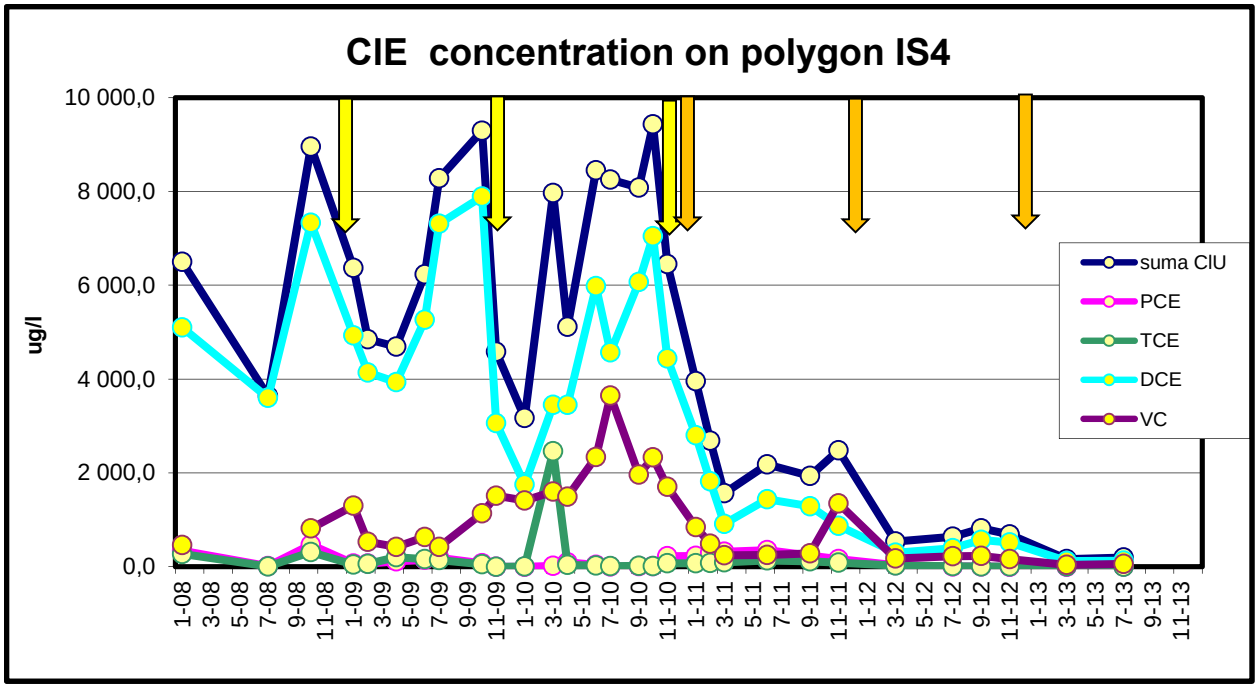
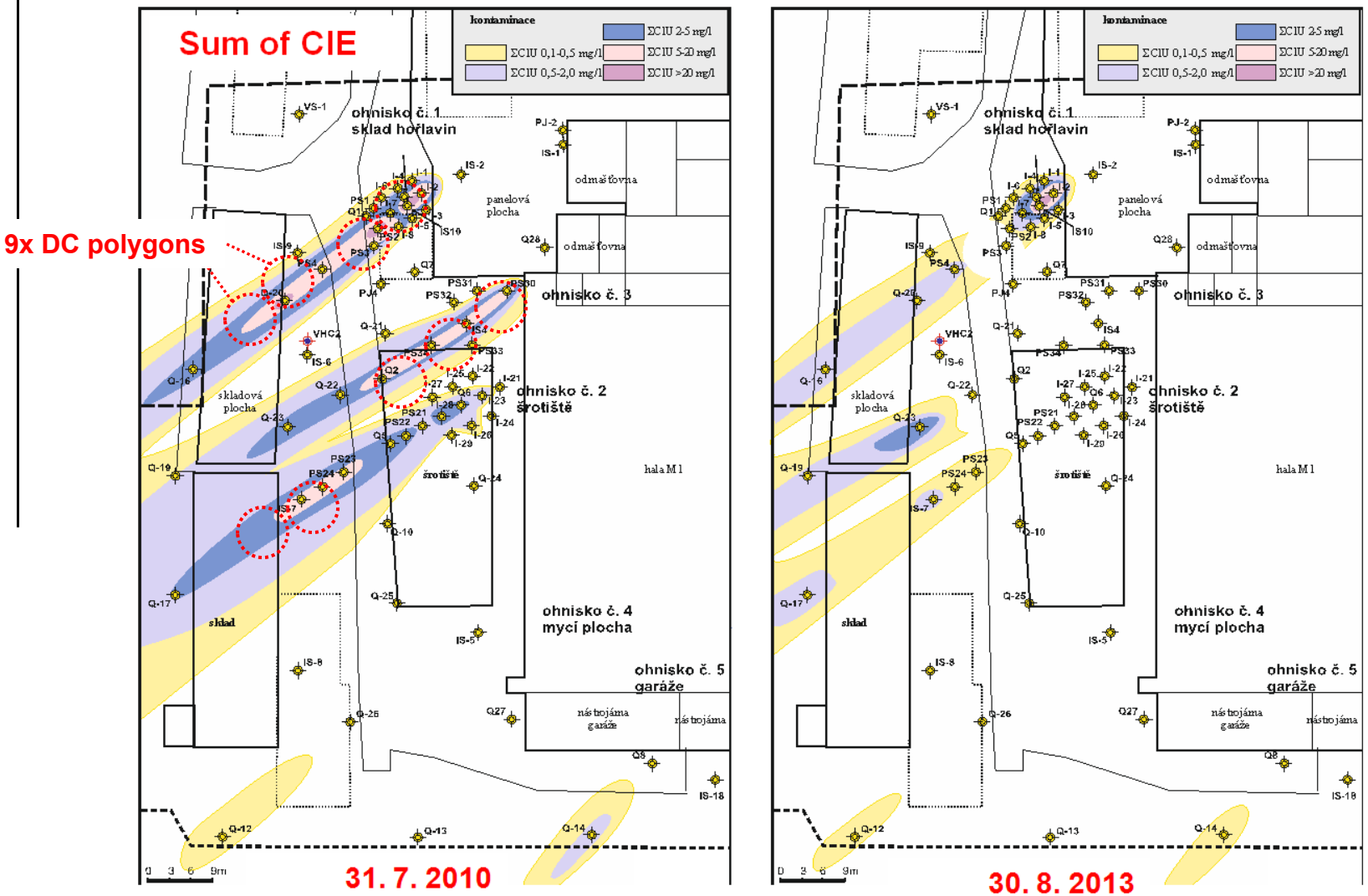


Field verification – Site Hořice

State before nZVI+DC start

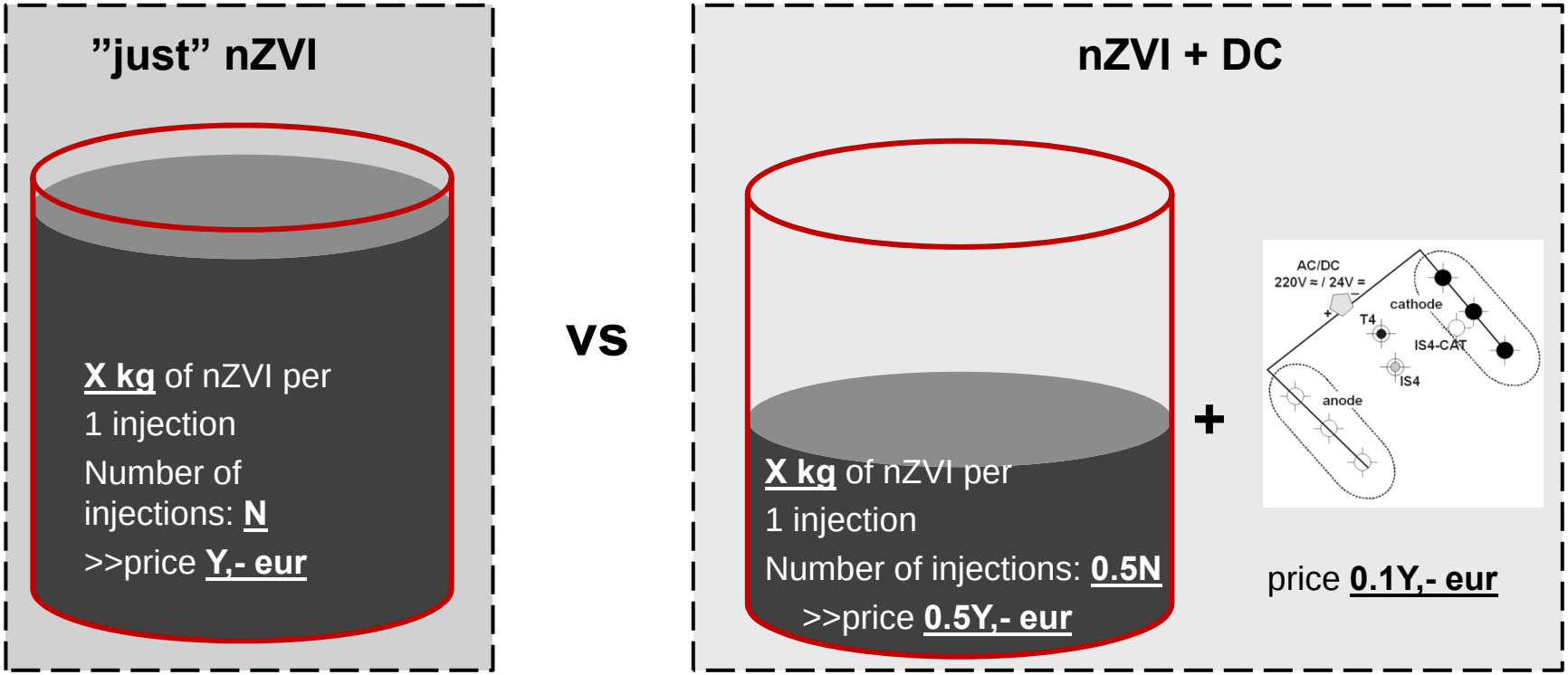
2013, until today



Economic comparison

- **<u>100% nZVI</u>** vs. **<u>100% of nZVI + 10% of DC system</u>** = double active time

  >> Less number of injections



Same reactivity + Double active time = 40% saved

Referneces 2010-2018

Site	Country	nZVI product	nZVI amount (kg)	Number of DC polygons	Remediation type
Hořice v Podkrkonoší	Czechia	TODA, N25S, NANOFER STAR	2 500	9	full scale
Spolchemie Ústí nad Labem	Czechia	NANOFER DC	1 500	4 - geoch. barrier	pilot
Písečná - OEZ Letohrad	Czechia	NANOFER DC	1 500 (3x)	5	full scale
Mars Svratka	Czechia	NANOFER DC	2 000	4 - geoch. barrier	full scale
Jablonné v Podještědí	Czechia	NANOFER STAR	500	2	pilot
Jablonné nad Orlicí	Czechia	NANOFER DC	250	2	pilot
Blehovsko	Czechia	NANOFER DC	550	4	pilot
Přelouč	Czechia	NANOFER DC	550	4	pilot
Bordeaux	France	NANOFER DC	80	1	pilot
Tian jin	P. R. China	NANOFER STAR	300		pilot
Aargau	Switzerland	NANOFER DC	250	2	pilot

Thank you for listening

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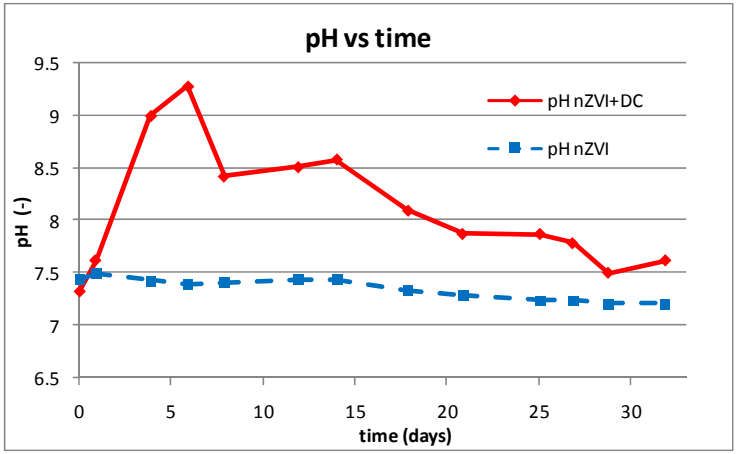
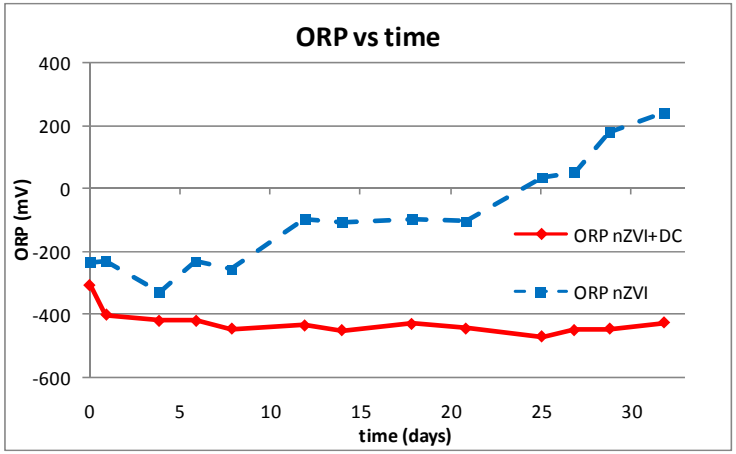
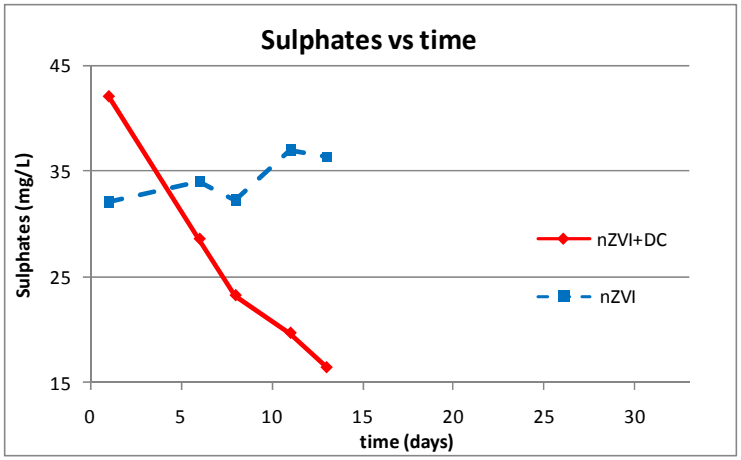
Laboratory tests

- *ClE total **25 mg/l**, app. **70% of cis-1,2-DCE***
- *Resctors: **nZVI+DC**, **nZVI***
- *nZVI concentration **0,5 g/l**, steel electrodes, **30 days***







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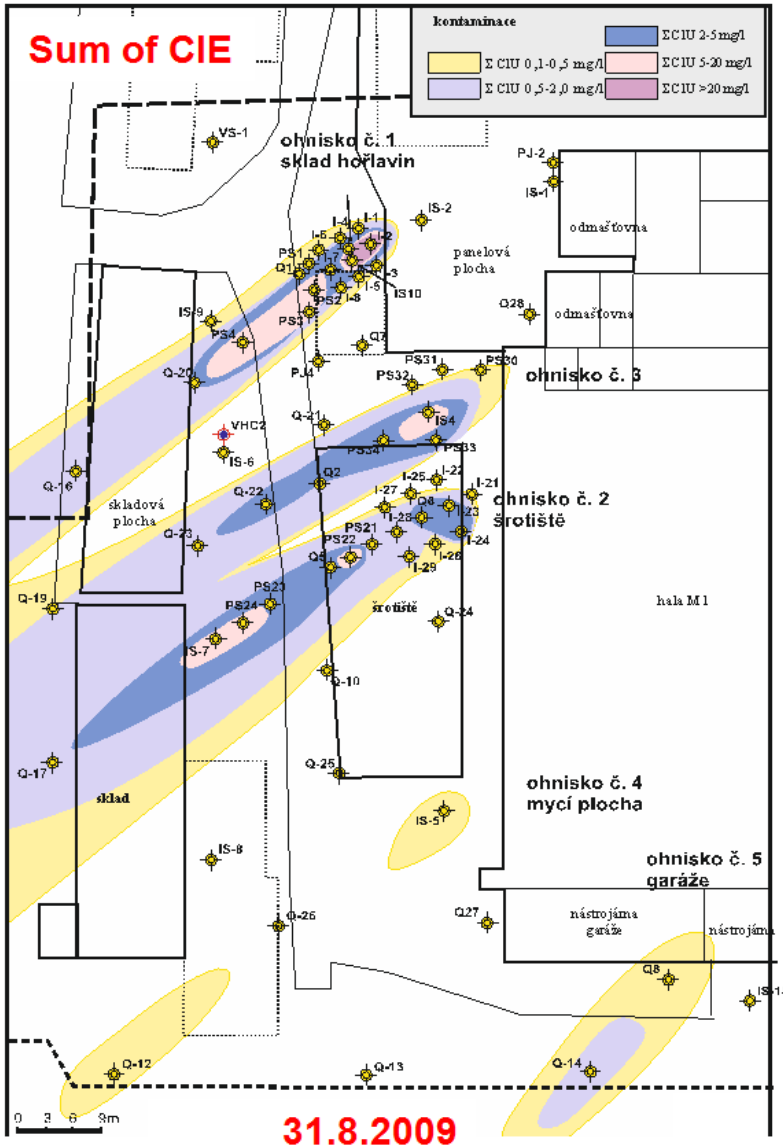

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