Nanoscale Zero Valent Iron for Groundwater Remediation.

Christian Macé – cmace@Golder.com

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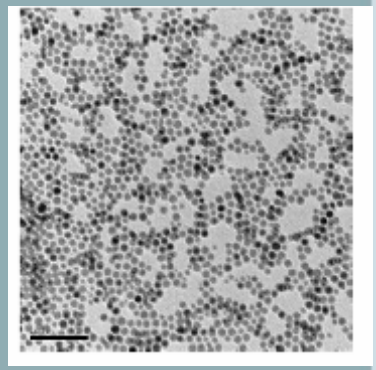
Iron Nanoparticles



- Chemically precipitated (bottom up) or Mechanically grinded (top down)
- Ideal size 50-100 nm
- More reactive than microscale particles as smaller (larger exchange surface)
- Reactivity can be enhanced by adding a coating of noble metal (BNP-Bimetallic Nanoscale Particles)
- Aqueous slurry from production to injection

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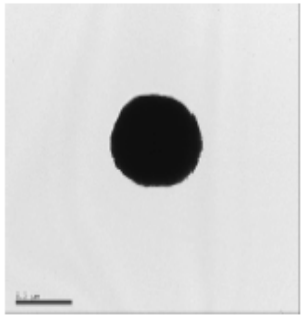
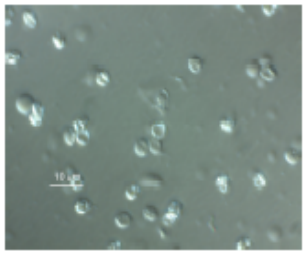
Size Comparison





Cryptosporidium	~5-10 μm
Staphylococcus	~2 μm
E. Coli	~1 μm
Ebola virus	~0.2-1 μm
Rotavirus	~100 nm
Poliovirus	~50 nm

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History

- 1995, Dr. Zhang starts to publish about nanoparticles
- 1999, First publication by Dr Zhang about successful VOCs and PCBs reduction by using NZVI
- 2003, Golder publication on first NZVI test in fractured bedrock context
- 2004, National Nanotechnology Initiative, federal US R&D program. First USEPA ROD for NZVI use at a superfund site
- 2005, EPA workshop on Nanotechnology and environment. Technology used by Golder in US, Canada, Europe, and Australia.
- 2006, over 20 pilot tests done. Large research effort in the US to develop the technology
- 2007, full scale treatments on-going

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Intellectual Property

- Waterloo patent (1993): Applicable to any iron body placed in the ground by any mean (PRB, reactive zone, etc.). EnviroMetal Inc (Adventus) exclusive license.
- NASA (2003): EZVI = Emulsified Zero Valent Iron. Colloidal iron in oil emulsion (DNAPL)
- Zhang (2005): Production and use of NZVI for groundwater remediation. International Long Term (10y) IP agreement signed between Golder and Lehigh University.

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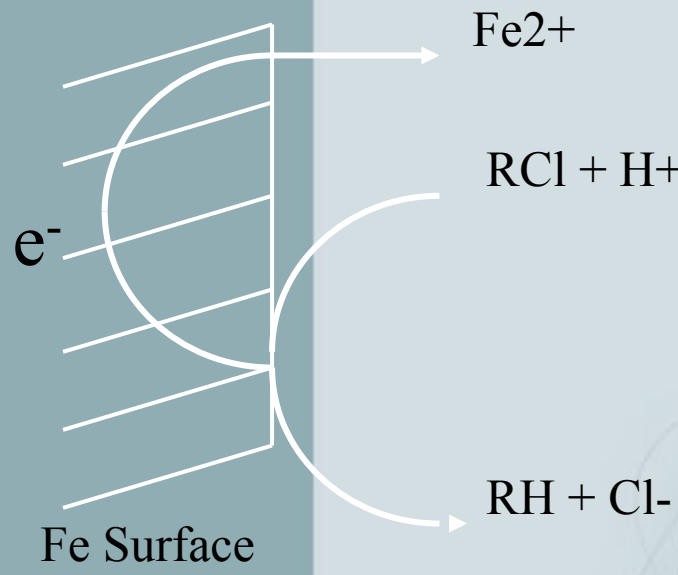
Theoretical action

- Beta-elimination (TCE->Acetylene)
- Hydrogenolysis (TCE->DCE->CV->Ethene)



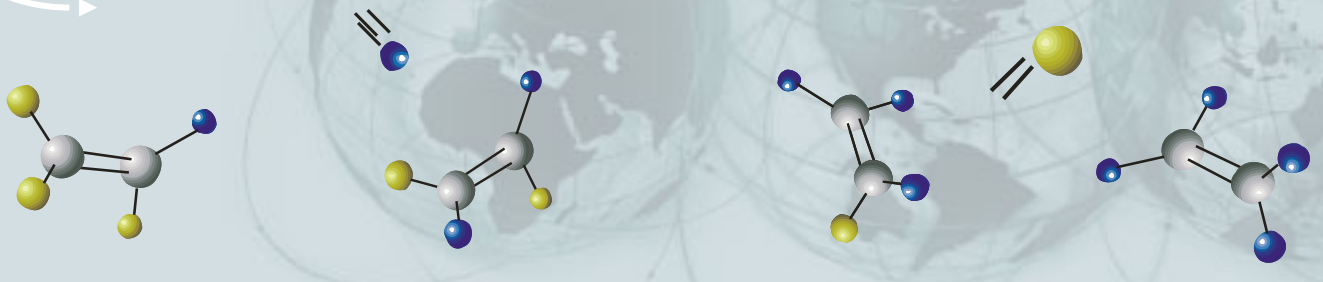
Partial reaction

$Fe^0 \rightarrow Fe^{2+} + 2e^-$

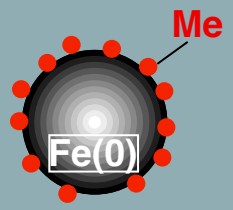
$C_2HCl_3 + 2e^- + H^+ \rightarrow C_2HCl_2 + Cl^-$

Complete reaction (TCE to Ethene)

$3Fe^0 + C_2HCl_3 + 3H^+ \rightarrow 3Fe^{2+} + C_2H_4 + 3Cl^-$



Potential use



- Dechlorination:
  - Chlorinated solvents (PCE, TCE)
  - PCBs - PCP- Pesticides
  - Dioxins
- Adsorption/precipitation
  - Metals (Cd, Co, Ni, Sn, Pb, Cu, Hg, Cr)
  - Arsenic
- pH stabilization (acid mine drainage)
- Surface water treatment – adsorption of viruses, bacteria and metals, treatment of nitrates, sulfates, and organics.

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Injection setup

NC, USA

2003

Injection setup

Ontario, Canada

2004

Injection setup

Czech Rep.

2005

Injection setup

NJ, USA

2005

Injection setup

Italy

2005

Parametric sensors

Data logger

Trench for cables

Injection System

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Injection setup

Germany

2006

Injection setup

FL, USA

2006

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Injection setup

NY, USA

2007

Injection setup

OH, USA

2007

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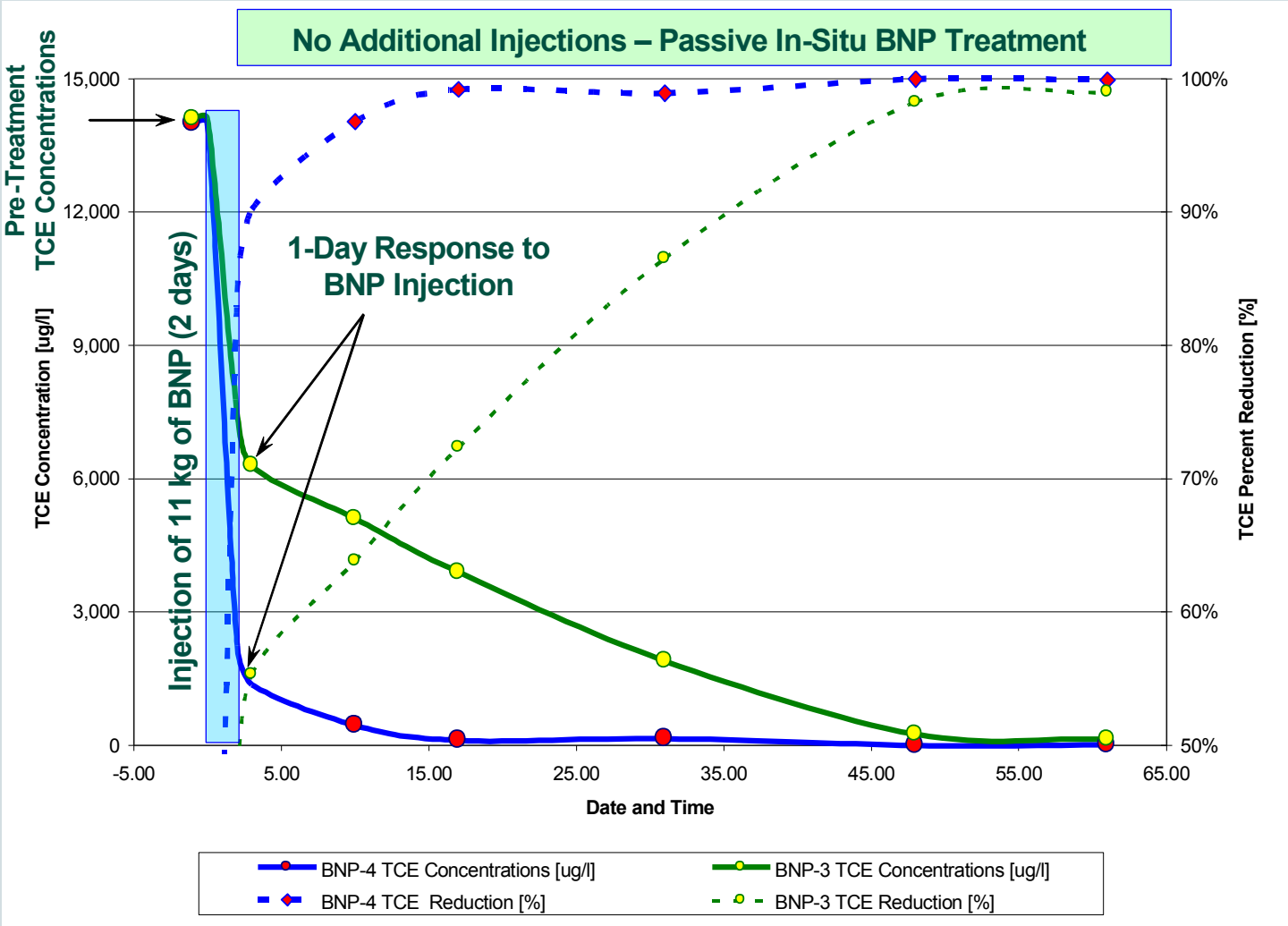
Results



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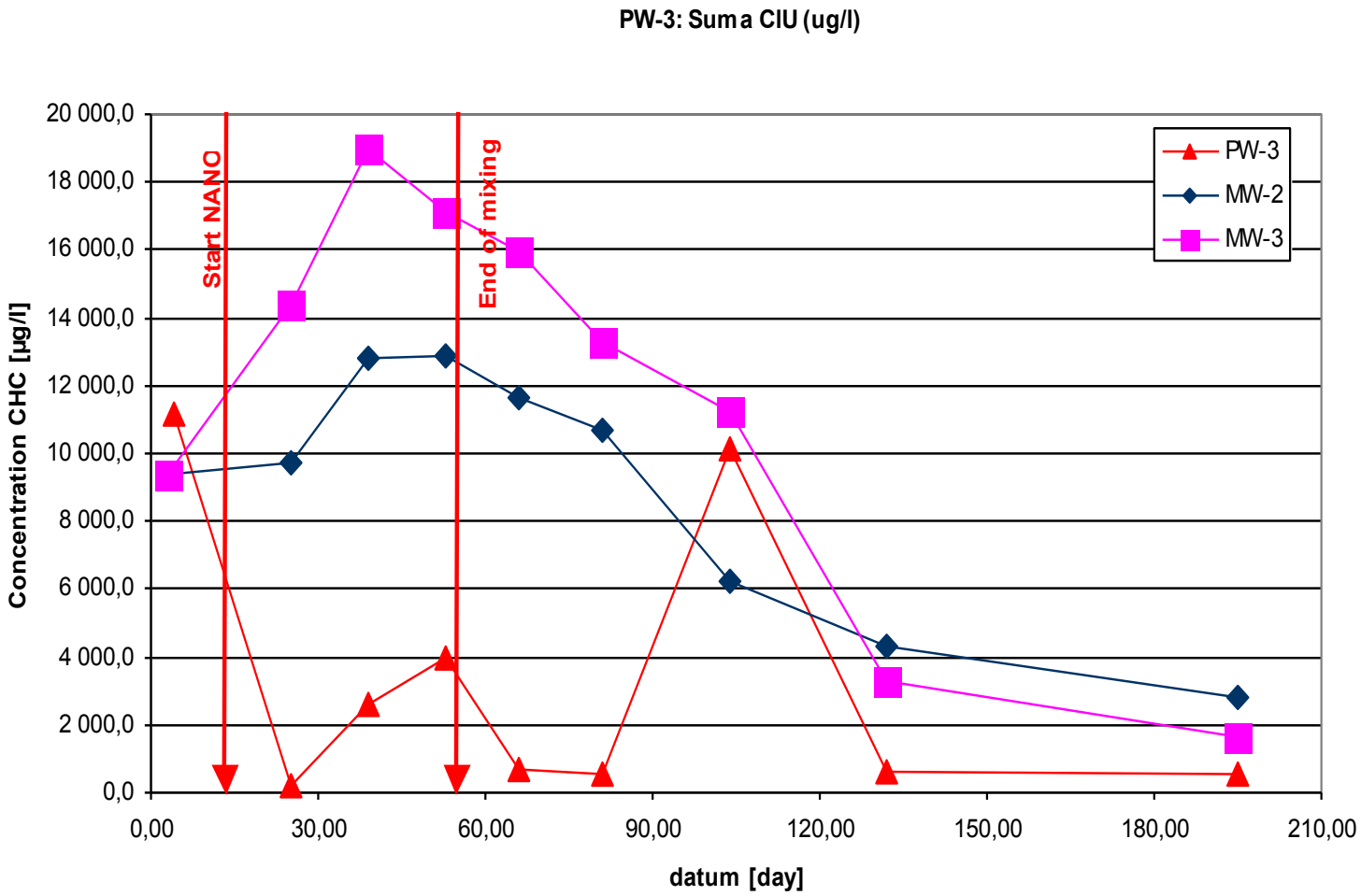
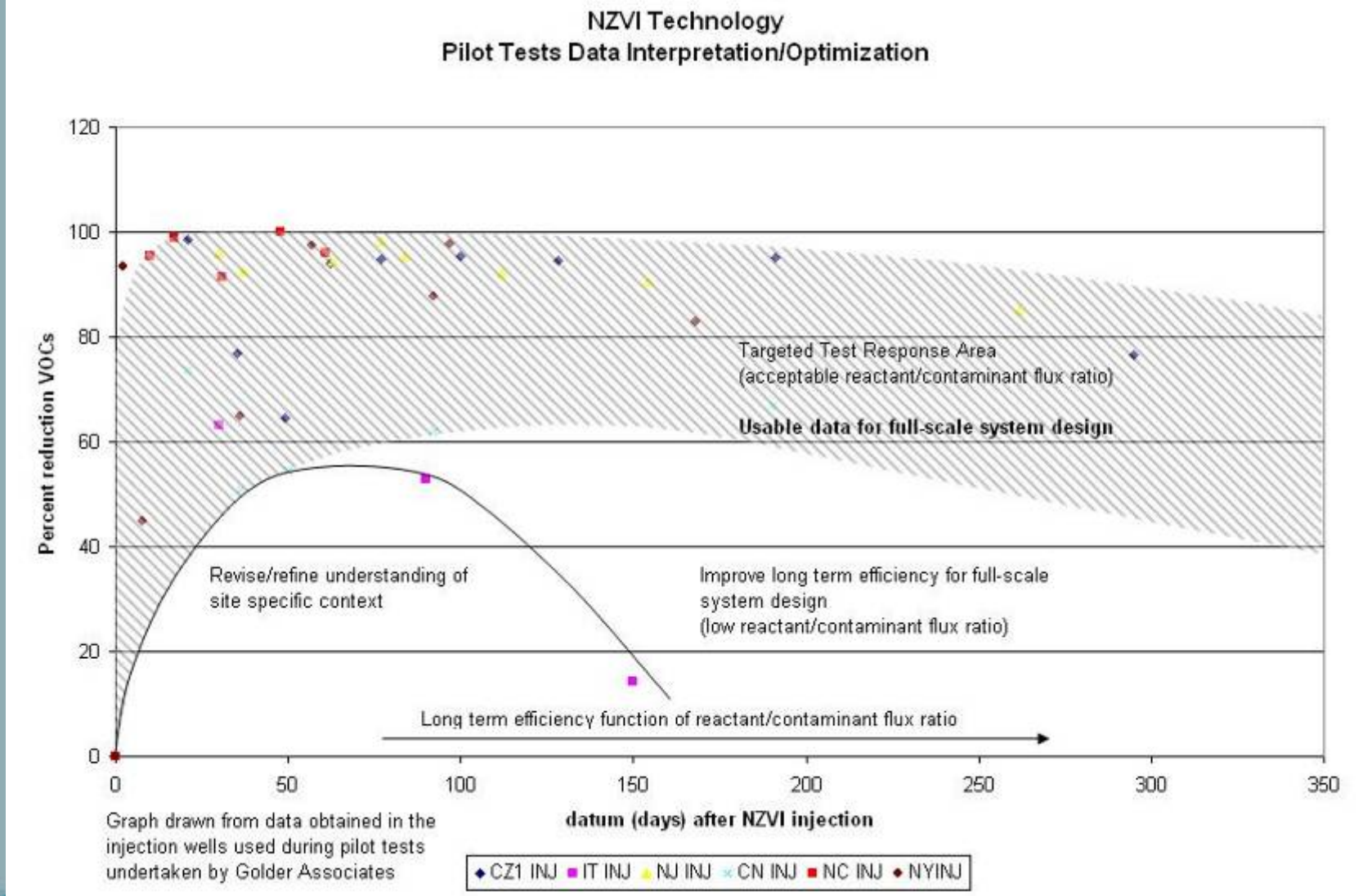
Results


PW-3: Suma ClU (ug/l)
Concentration CHC [µg/l]
20 000,0
18 000,0
16 000,0
14 000,0
12 000,0
10 000,0
8 000,0
6 000,0
4 000,0
2 000,0
0,0
0,00
30,00
60,00
90,00
120,00
150,00
180,00
210,00
datum [day]
Start NANO
End of mixing
PW-3
MW-2
MW-3

Interpretation



Challenges

- Socio-technological context (No Asbestos or GMO-like mistake)
- Optimize and control the spread of particles into the aquifer
- Flux and migration of injected particles measurement
- Particles quality optimization

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Particles spread

- Difficult in low permeability porous media

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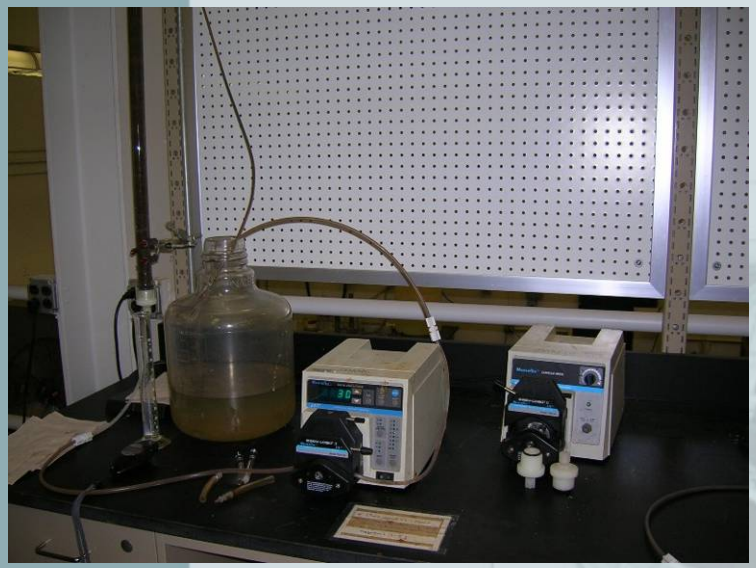
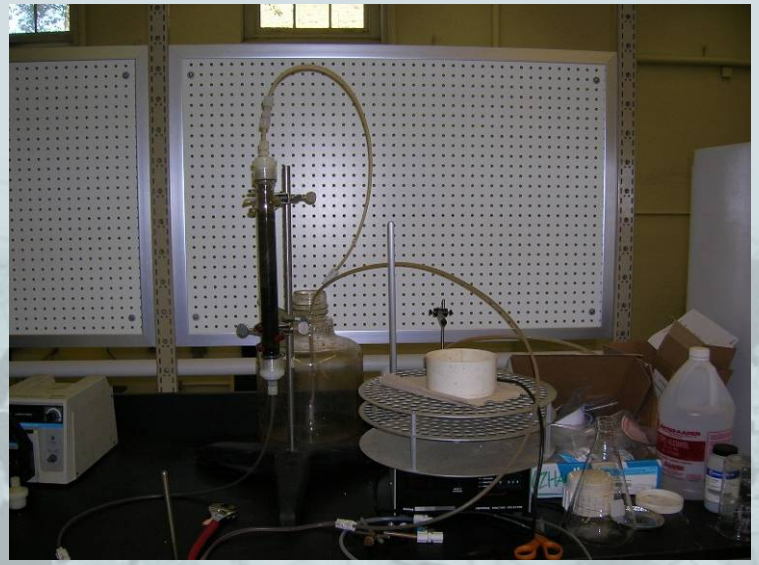
Particles spread

- Numerous Colum tests done in 2006 : identification of a food-grade additive for injection in porous media





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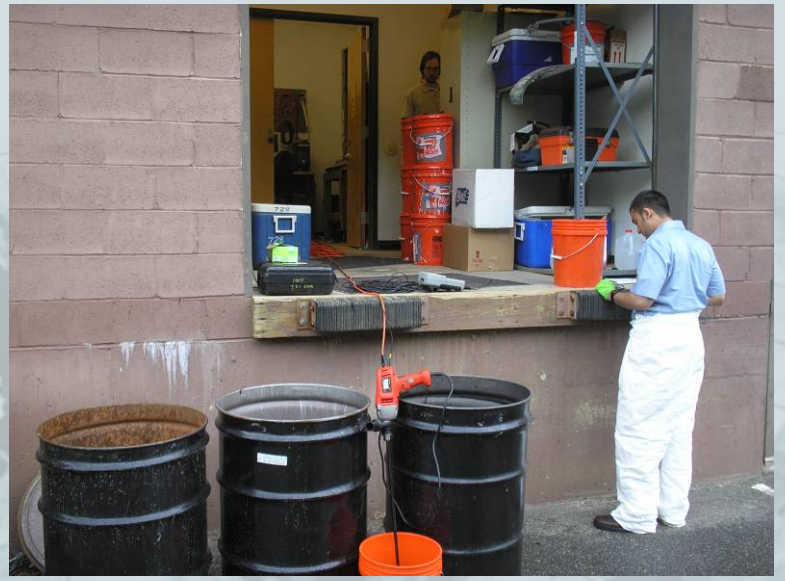
Particle quality optimization

- Source selection
- Project-specific design in function of reactivity needed and type of contaminant(s) to treat

- Constant research effort
- numerous reactivity test done on CrVI and VOCs



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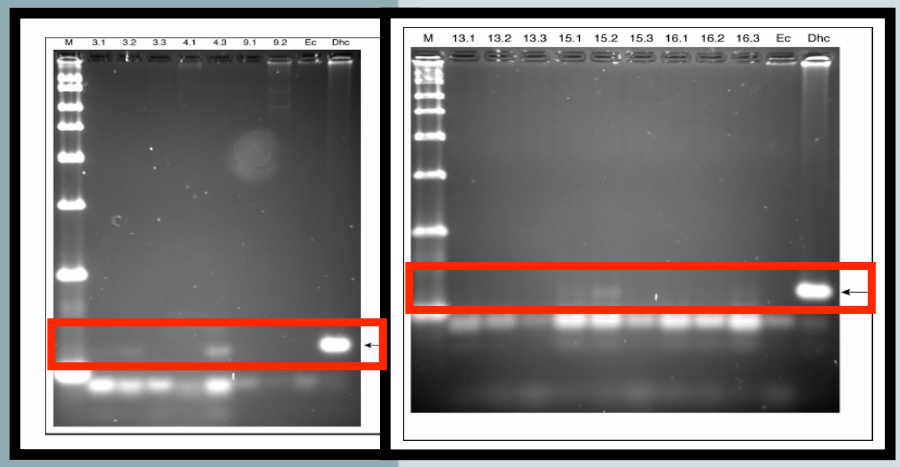
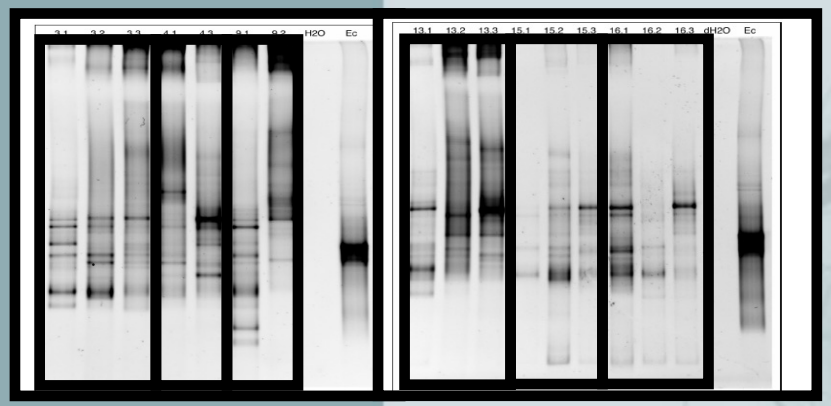
Interpretation



Denaturing Gradient Gel Electrophoresis – DGGE

Polymerase Chain Reaction - PCR



- Over 90 % reduction of contaminants is possible in field conditions
- Results depend on particles reactivity and proper injection setup
- Additive mandatory in porous media
- No buildup of degradation products despite strong biodegradation enhancement

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Advantages

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Advantages

Sustainable development

- Highly cost-effective
- Low risk
- Environment-friendly

Suits sustainability approach.

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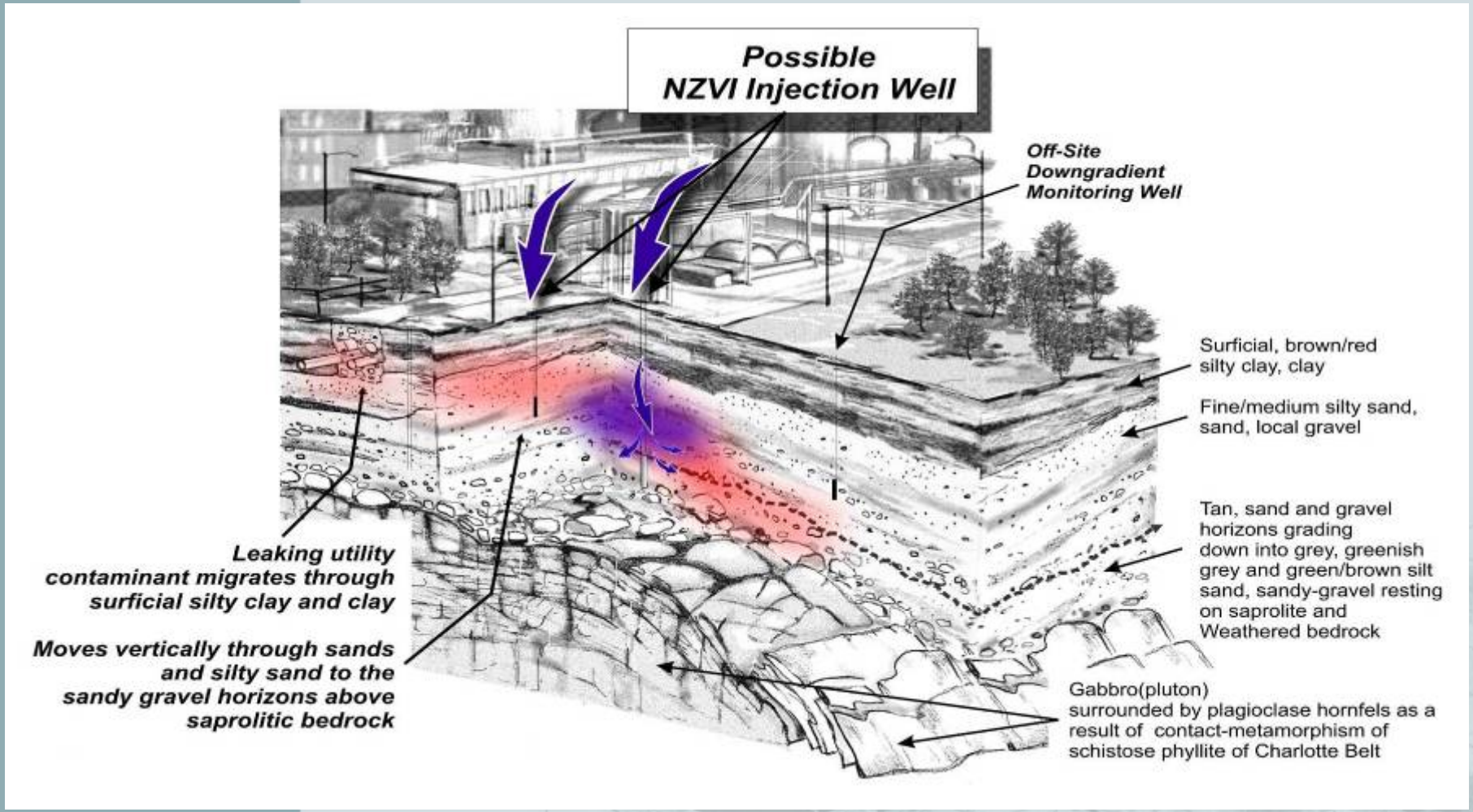
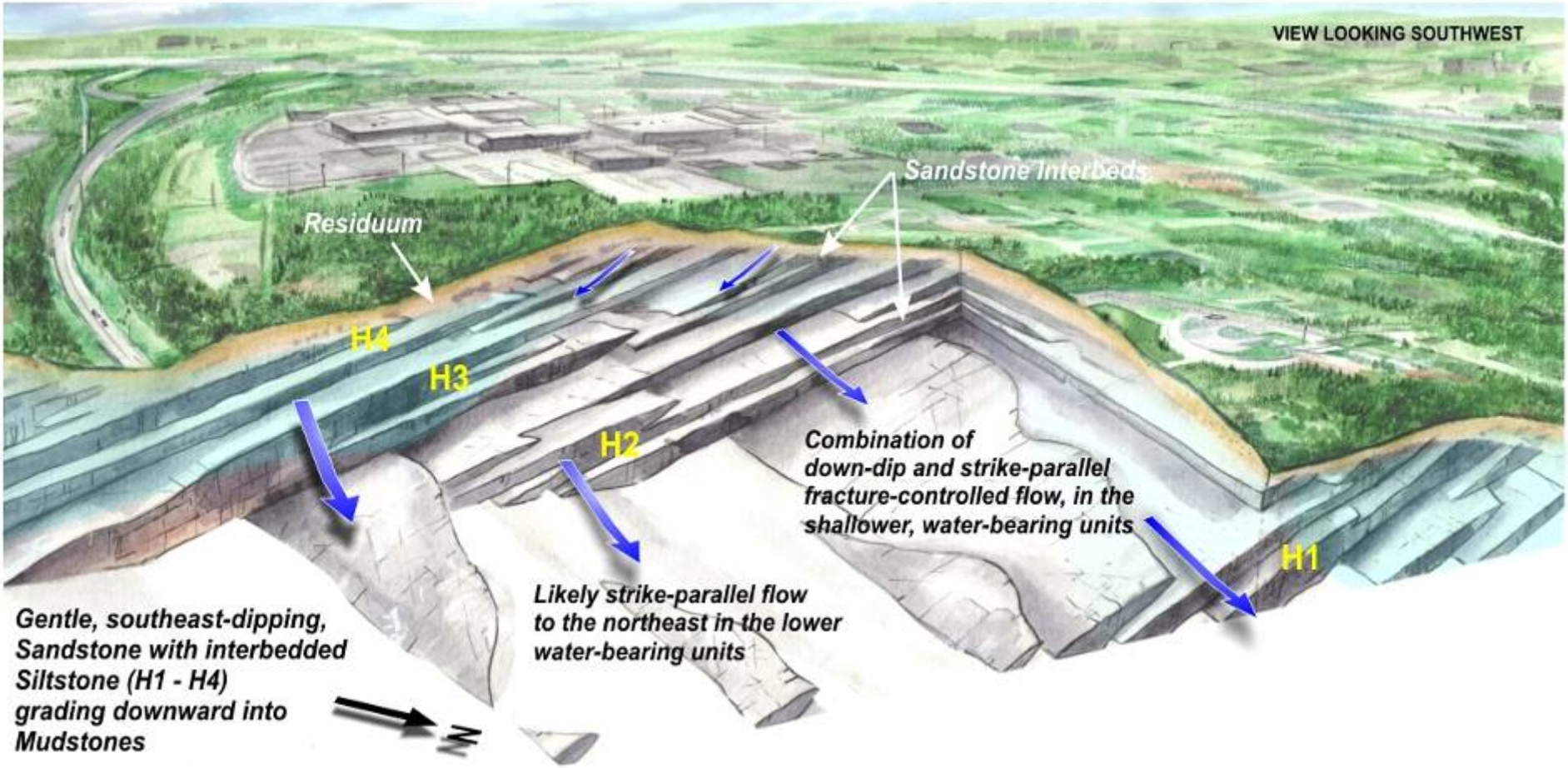
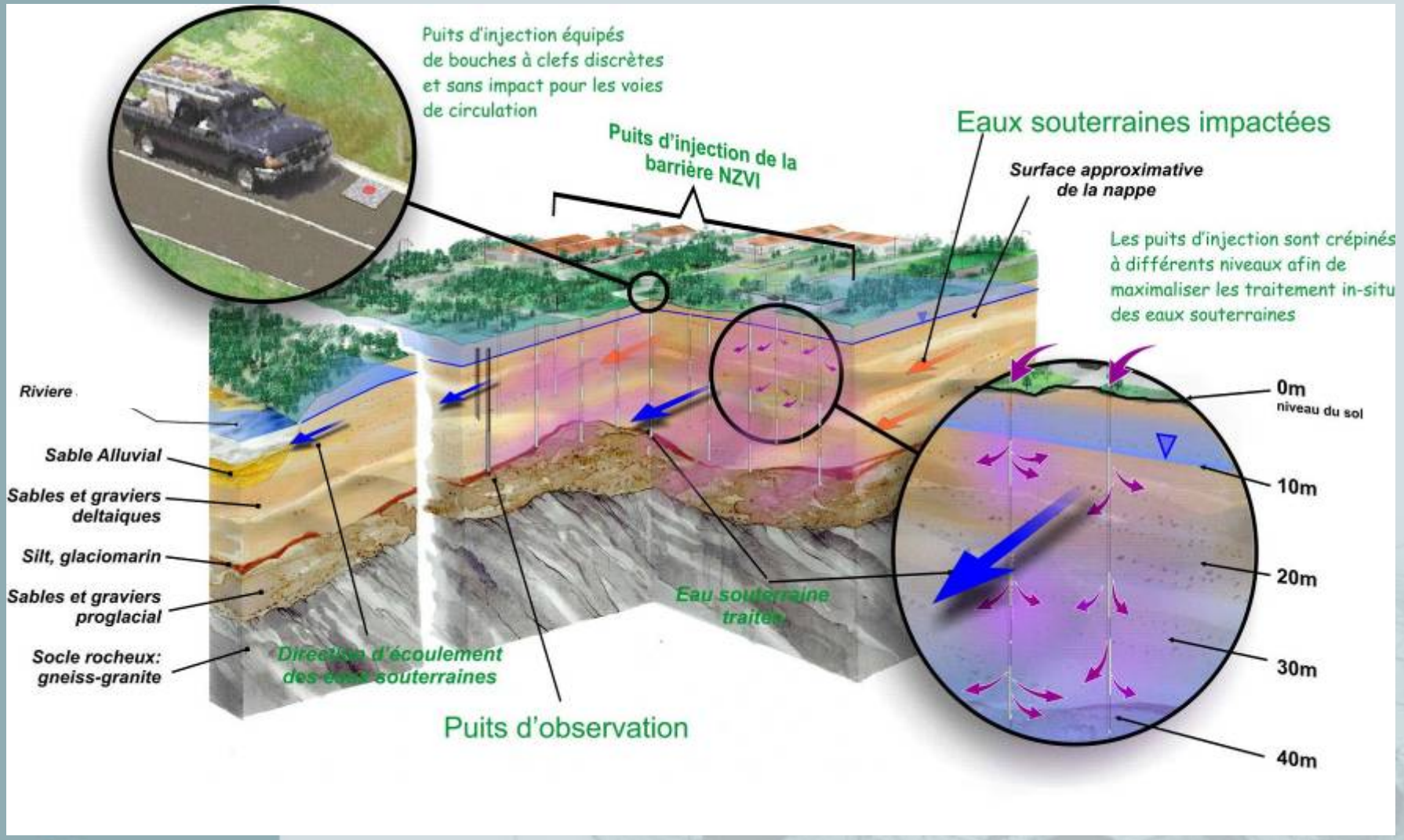

Possible
NZVI Injection Well
Off-Site
Downgradient
Monitoring Well
Surficial, brown/red
silty clay, clay
Fine/medium silty sand,
sand, local gravel
Tan, sand and gravel
horizons grading
down into grey, greenish
grey and green/brown silt
sand, sandy-gravel resting
on saprolite and
Weathered bedrock
Leaking utility
contaminant migrates through
surficial silty clay and clay
Moves vertically through sands
and silty sand to the
sandy gravel horizons above
saprolitic bedrock
Gabbro(pluton)
surrounded by plagioclase hornfels as a
result of contact-metamorphism of
schistose phyllite of Charlotte Belt


VIEW LOOKING SOUTHWEST
Residuum
Sandstone Interbeds
H4
H3
H2
H1
Combination of
down-dip and strike-parallel
fracture-controlled flow, in the
shallower, water-bearing units
Likely strike-parallel flow
to the northeast in the lower
water-bearing units
Gentle, southeast-dipping,
Sandstone with interbedded
Siltstone (H1 - H4)
grading downward into
Mudstones
N


Puits d'injection équipés
de bouches à clefs discrètes
et sans impact pour les voies
de circulation
Puits d'injection de la
barrière NZVI
Eaux souterraines impactées
Surface approximative
de la nappe
Les puits d'injection sont crépinés
à différents niveaux afin de
maximaliser les traitement in-situ
des eaux souterraines
Riviere
Sable Alluvial
Sables et graviers
deltaiques
Silt, glaciomarin
Sables et graviers
proglacial
Socle rocheux:
gneiss-granite
0m
niveau du sol
10m
20m
30m
40m
Eau souterraine
traitée
Direction d'écoulement
des eaux souterraines
Puits d'observation