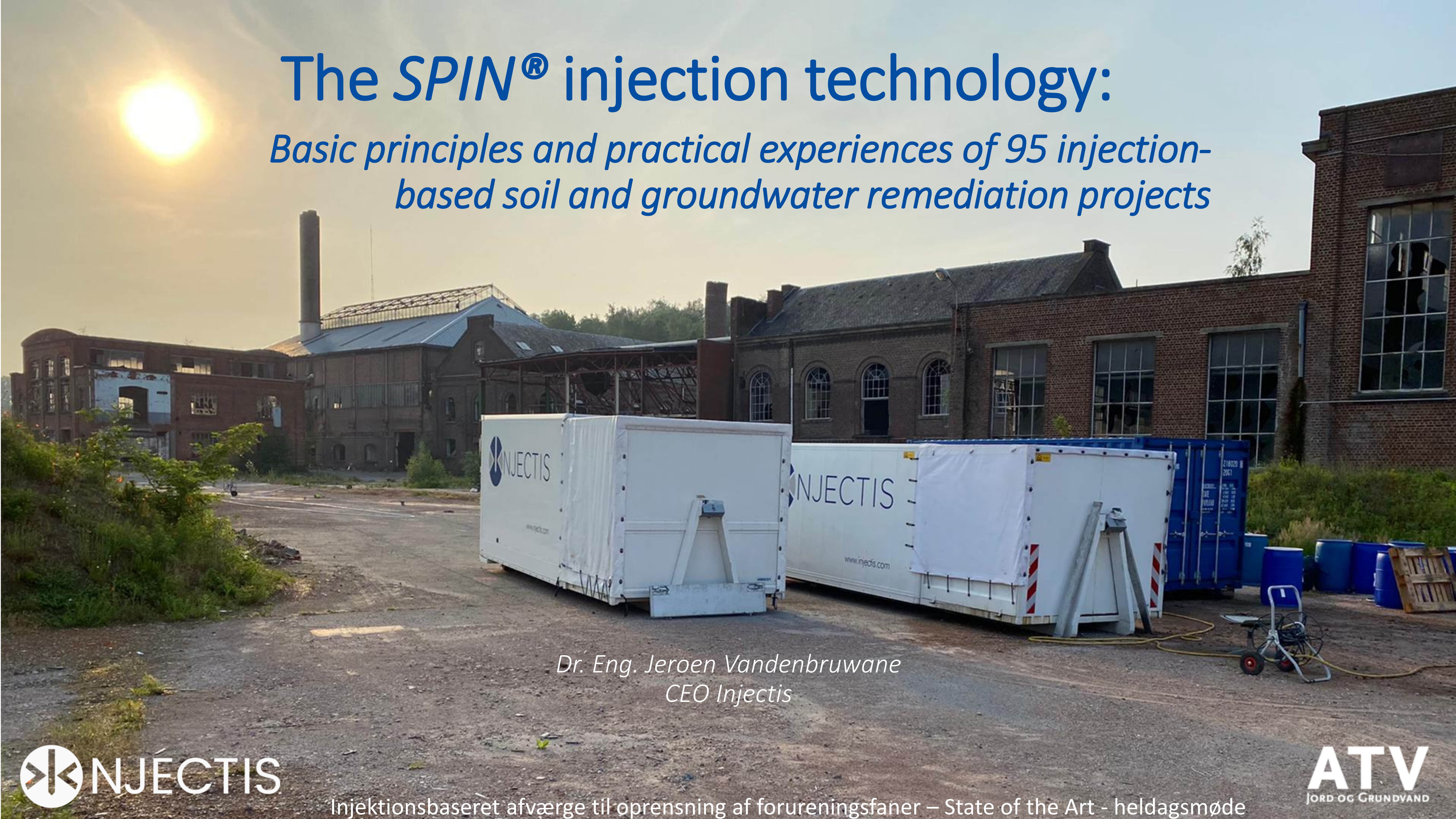

The *SPIN®* injection technology:

Basic principles and practical experiences of 95 injection-based soil and groundwater remediation projects

Dr. Eng. Jeroen Vandenbruwane
CEO Injectis

NJECTIS

ATV
JORD OG GRUNDVAND

Injection-based soil remediation:
How to hit the bullseye ?

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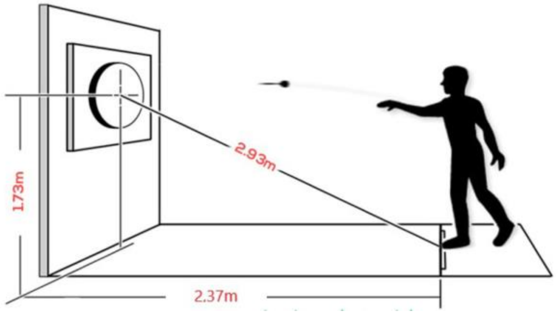
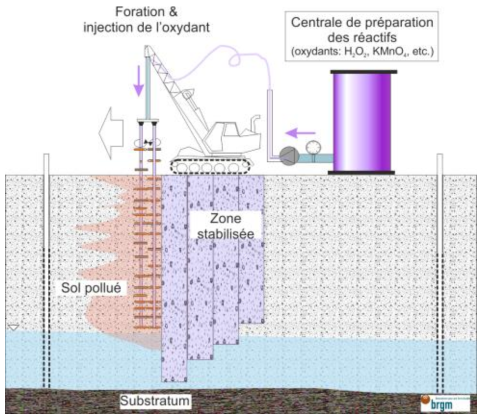
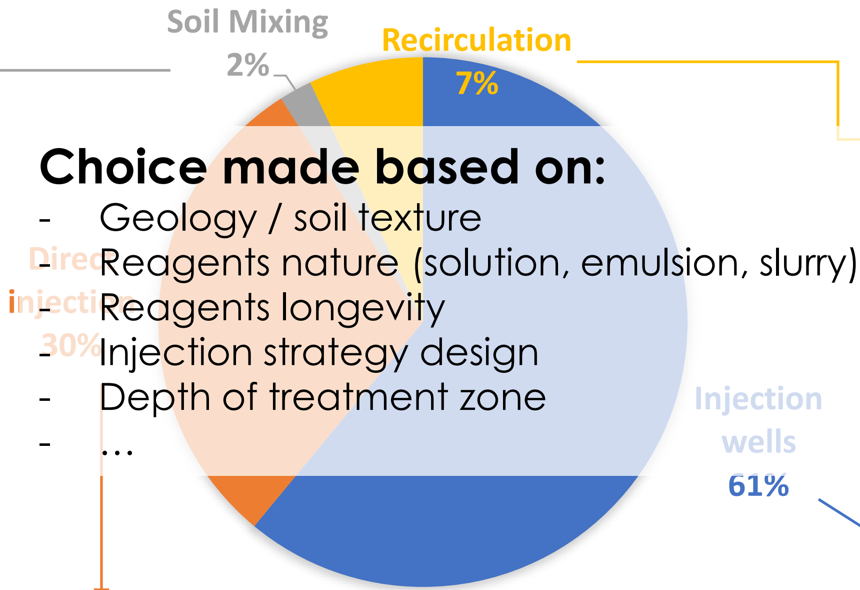
Injection-based soil remediation: *How to hit the bullseye ?*

Injection-based soil remediation: *How to bullseye ?*

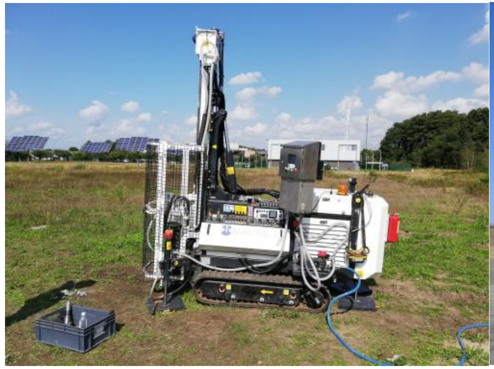


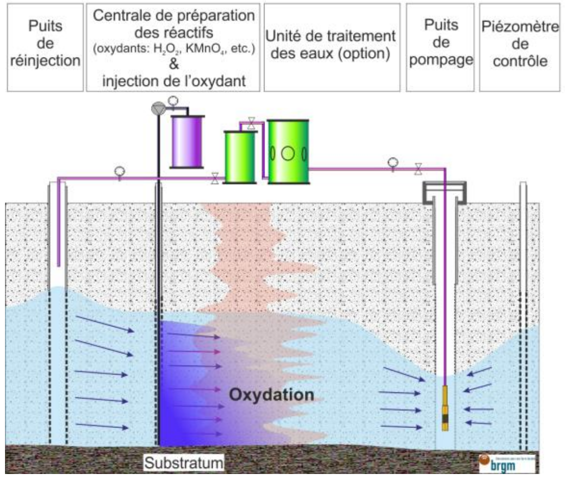




Choice made based on:

- Geology / soil texture
- Reagents nature (solution, emulsion, slurry)
- Reagents longevity
- Injection strategy design
- Depth of treatment zone
- …





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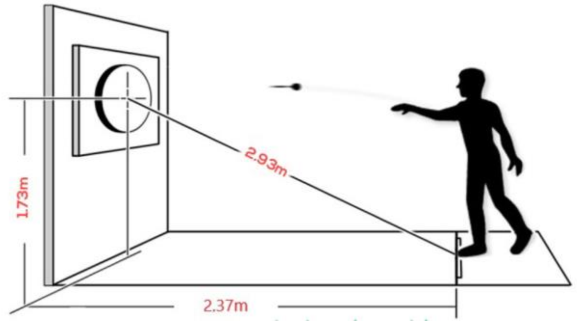
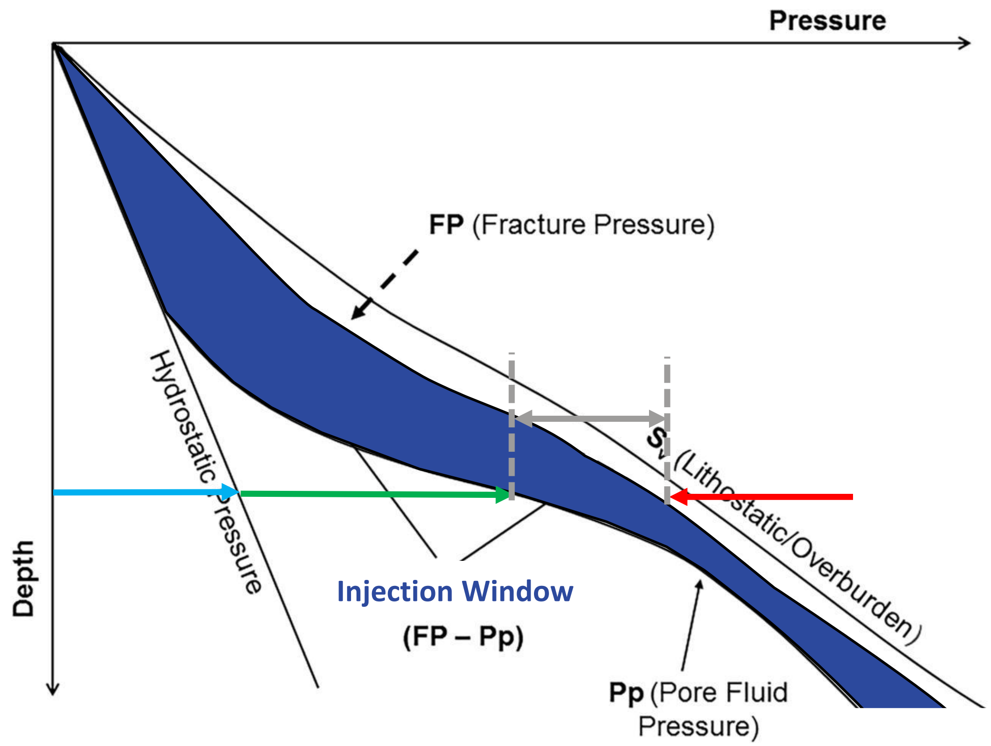
***Source graph:** Technical Report TR-NAVFAC-EXWC-EV-1303, "Best practices for injection and distribution of amendments", Battelle Memorial Institute and NAVFAC Alternative Restoration Technology Team, March 2013

Injection-based soil remediation: *How to bullseye ?*



Pollutants present in and adjacent to natural soil pores

➔ Reagents to be injected in this porosity



<u>Injection pressure window is function of :</u>

Soil depth

Groundwater level

Pore size distribution (soil texture)

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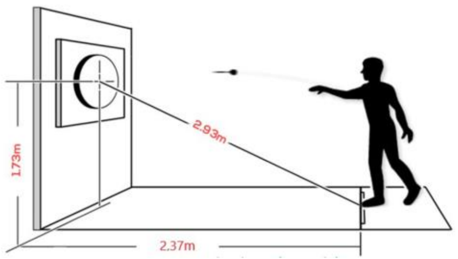
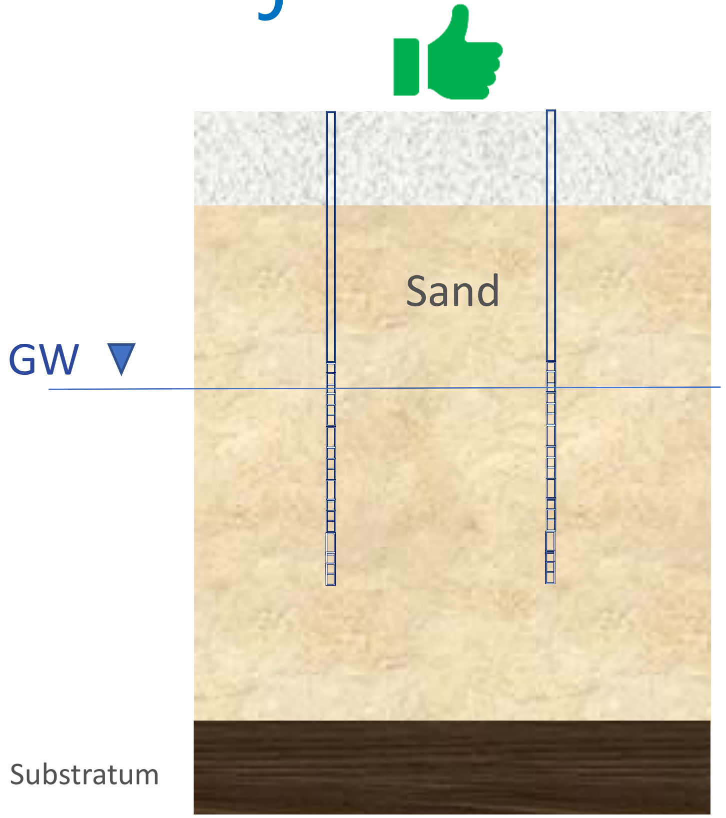
Injection wells & recirculation systems





- In SANDY aquifer (homog.)
- High VOLUME injected
- Low COST

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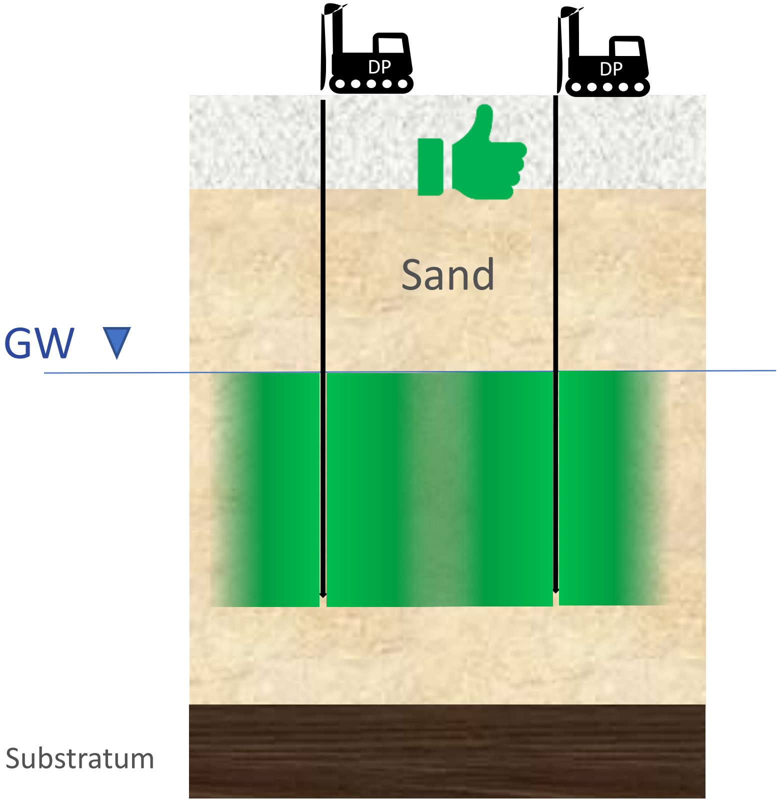
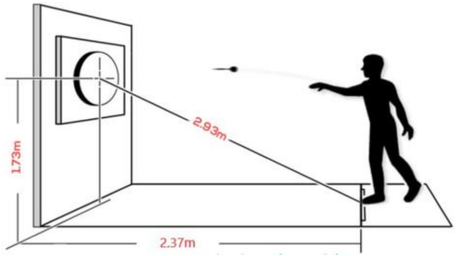
Conventional *direct-push* injection





- ✓ In SANDY aquifer (homog.)
- ✓ Depth Adapted injection
- ✓ Relatively low COST

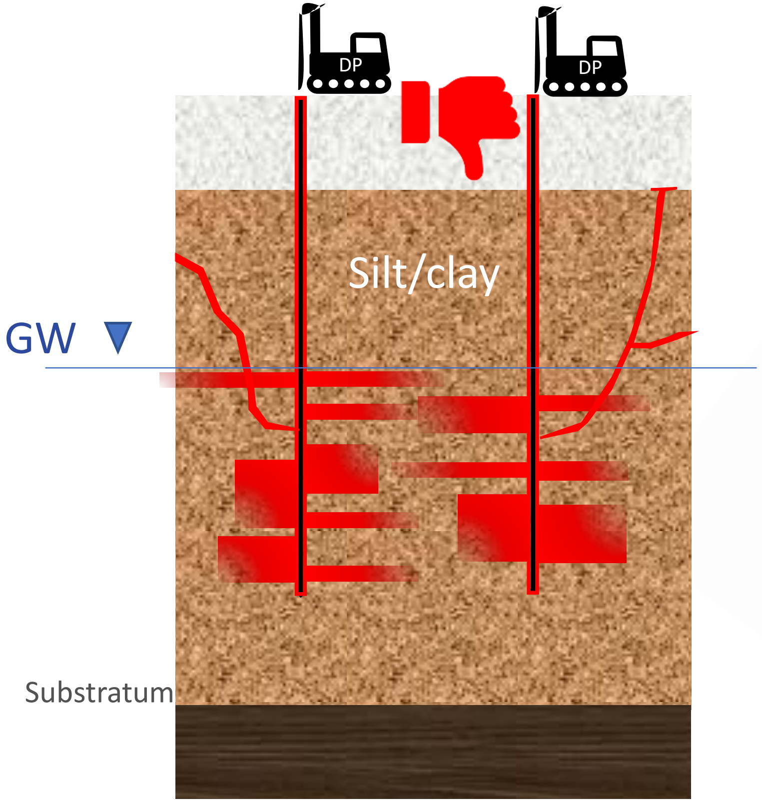
Other advantages:

- ✓ Fast
- ✓ No permanent infrastructure

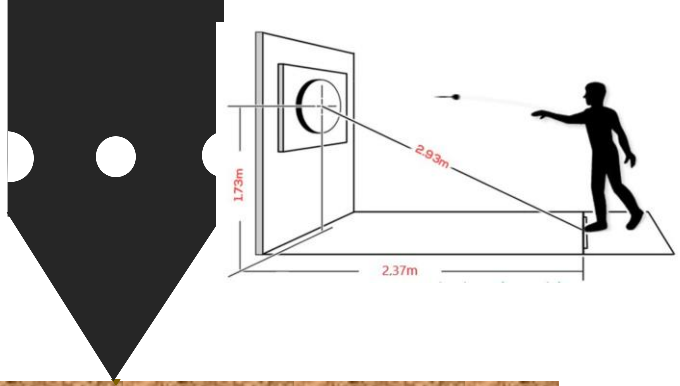
Other limitations:

- ⊘ Reflux of product after withdrawal
- ⊘ Blow-out of product along the rods
- ⊘ Fracturing > preferential flow paths

Conventional *direct-push* injection



$A_{contact\ DP}$ is very small



1.SMEARING OF THE SOIL

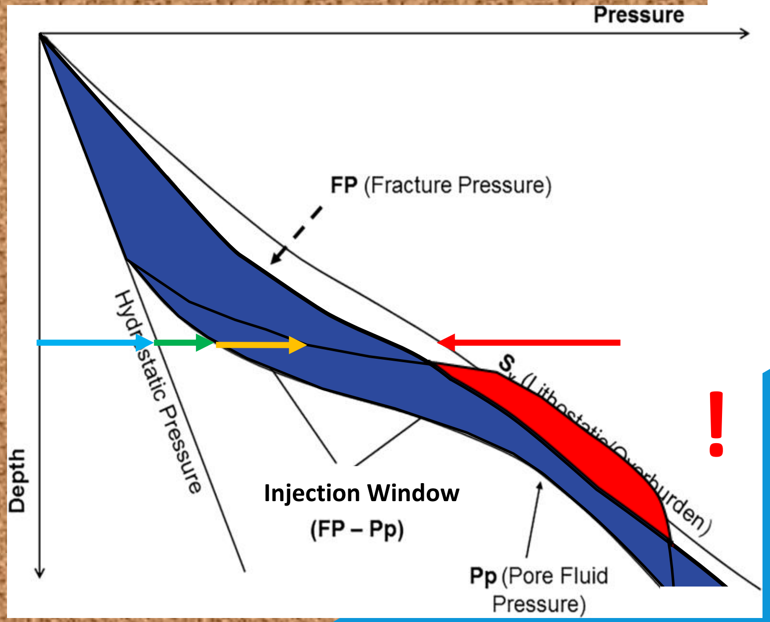
➔ Permeability (K_{sat})↘↘

2.COMPACTION

➔ Permeability (K_{sat})↘↘

$$Q_{inj} \approx K_{sat} \cdot P_{inj} \cdot A_{contact}$$

P_{inj} ↗↗



$P_{injection} > P_{critical,fracturation}$ to maintain Q_{inj}

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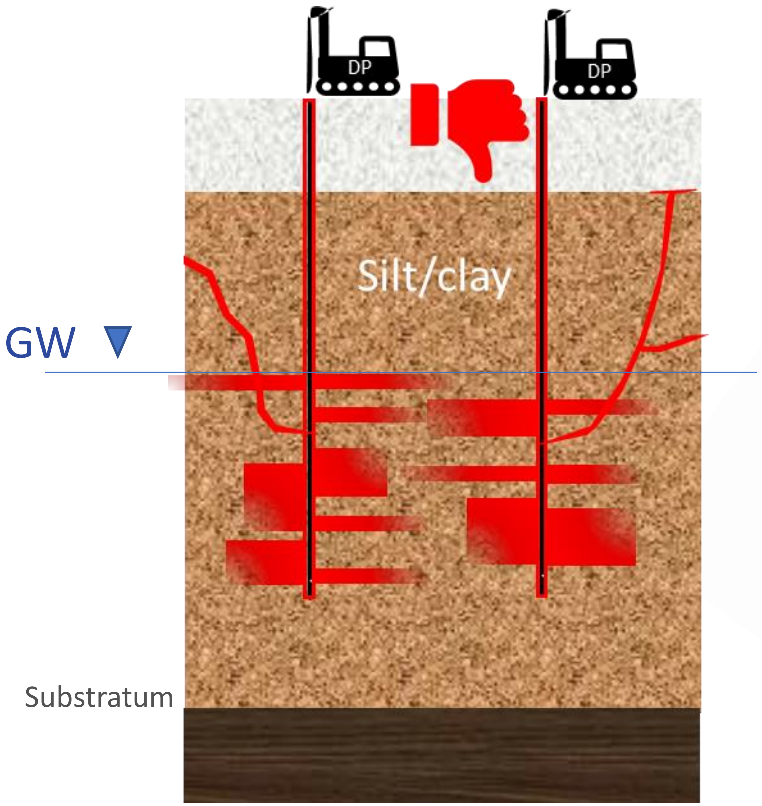
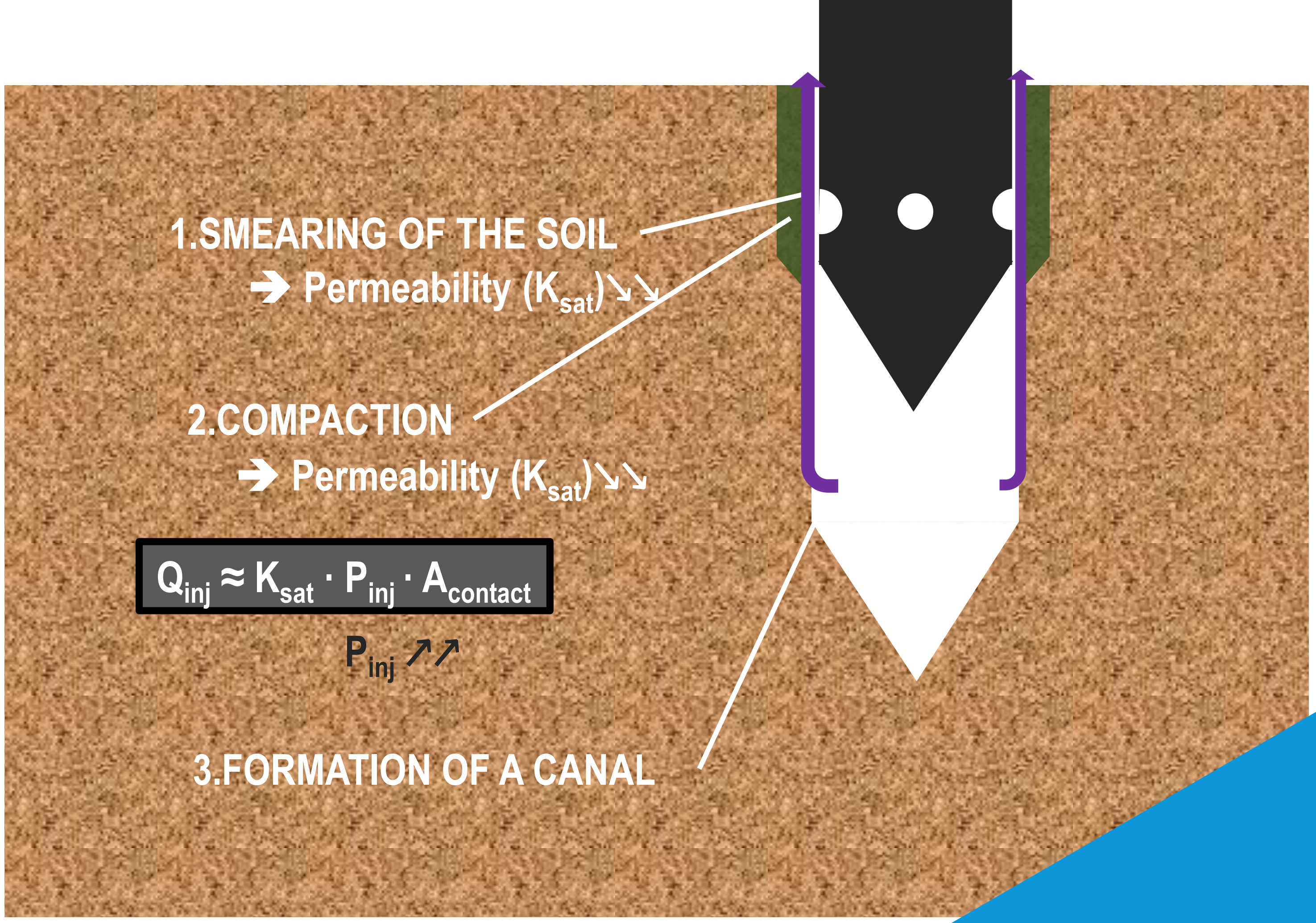
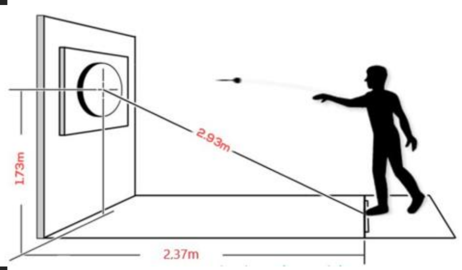
Conventional *direct-push* injection







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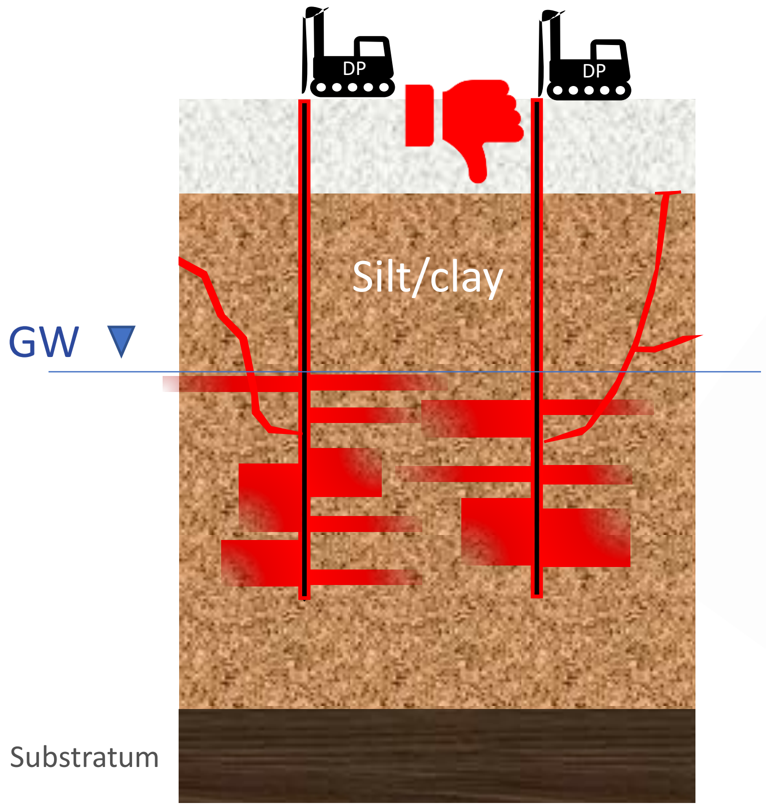
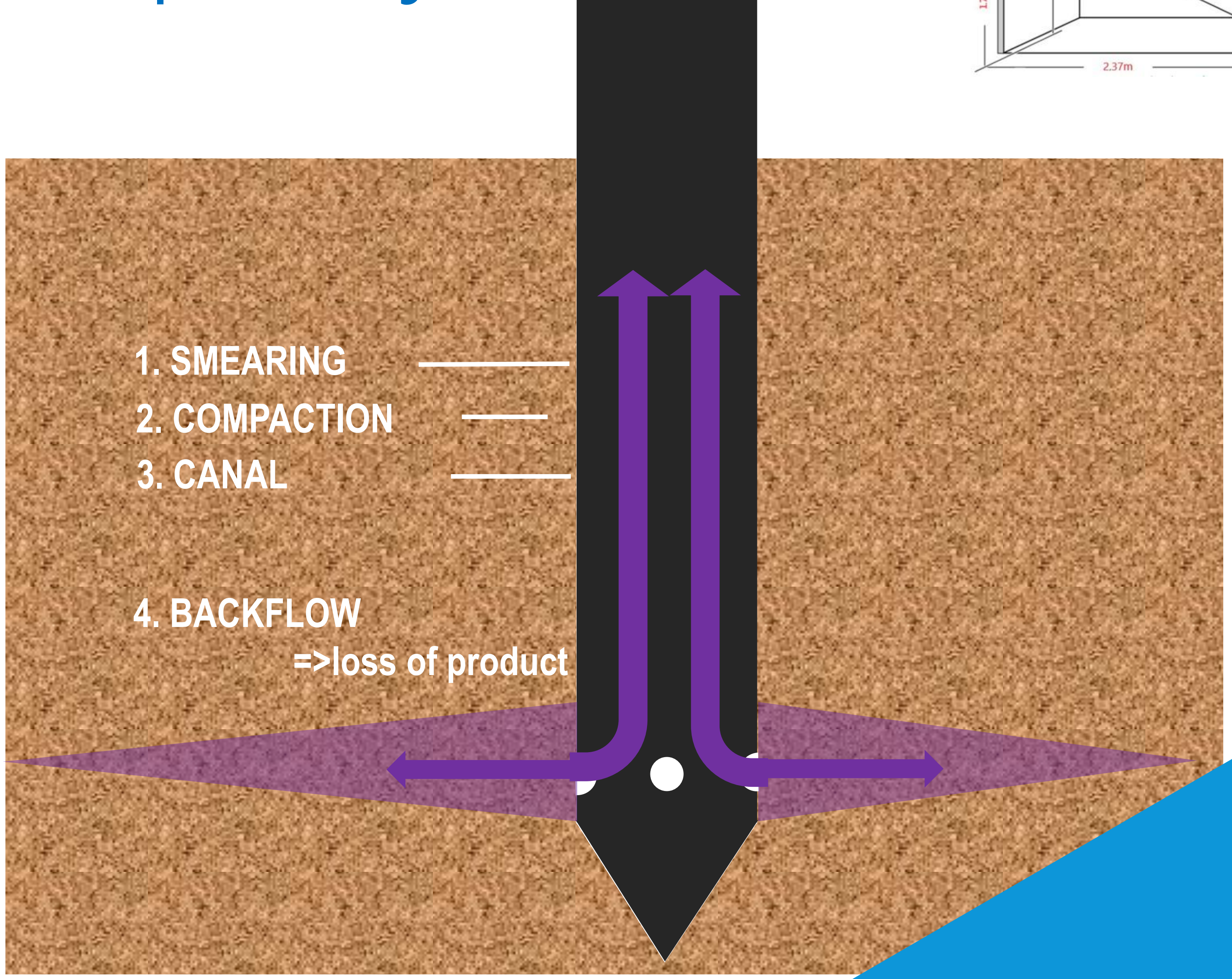
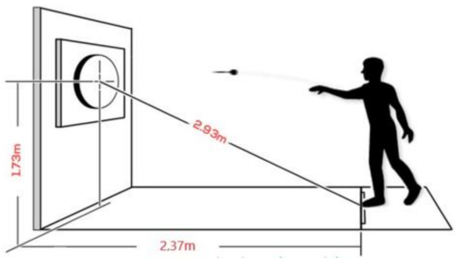
Conventional direct-push injection







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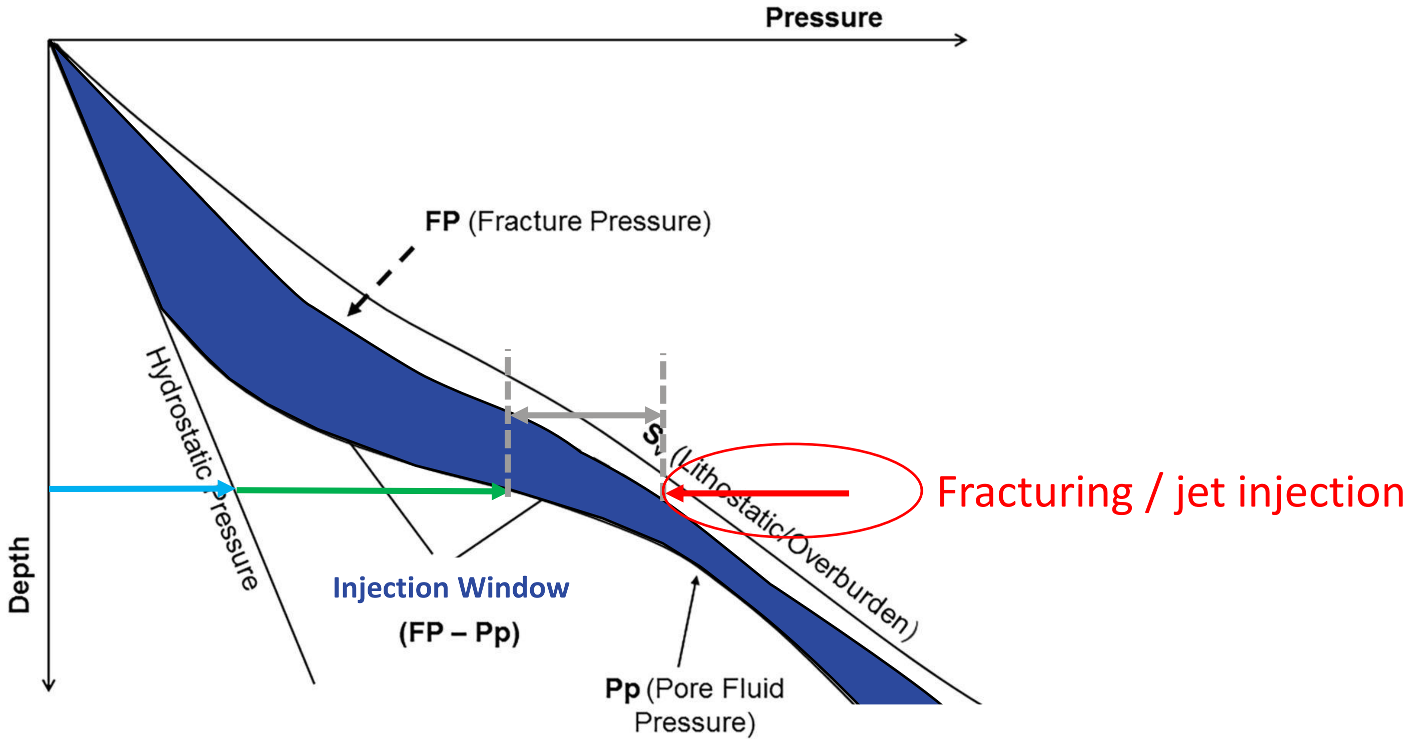
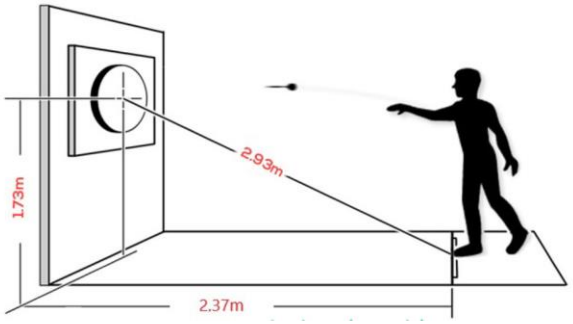
Fracturing / jet injection

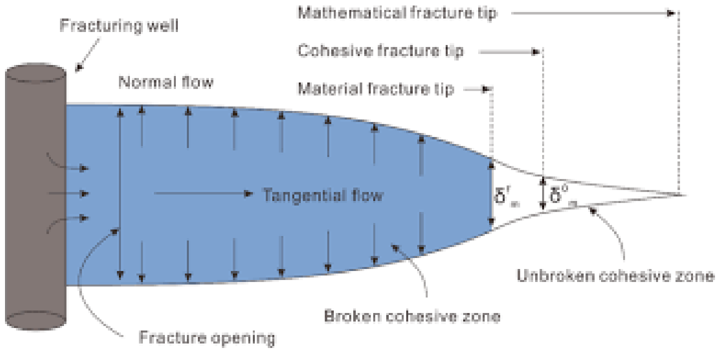
$$Q = -K_S\, A\, \frac{dh}{dz}\ (Darcy's\ law)$$

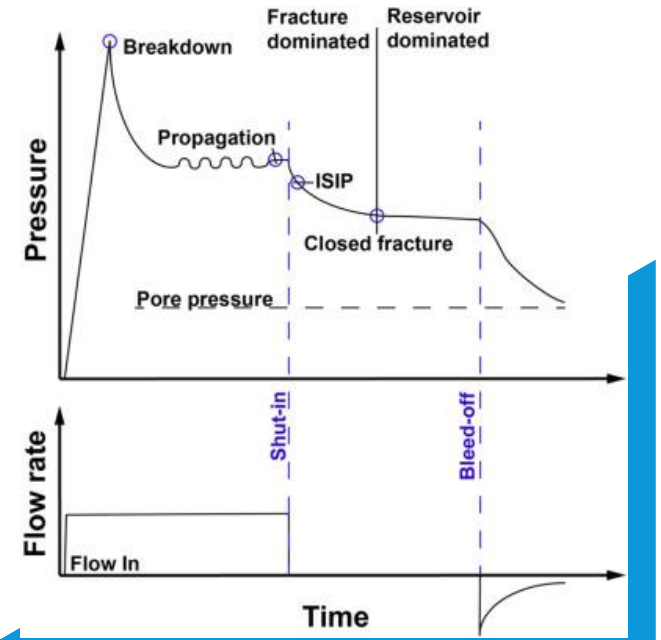
When and why fracturing or jet injection :

- Accidentally by DPT in low perm soils (compaction around injection head)
- Accidentally by increasing injection pressure to maximize injection flow rates (time!)
- To achieve (economically) feasible injection flow rate (Q_{inj}) in low perm. soils
- To "inject" slurries in fine textured soils ($d_{particle} > d_{pore}$)





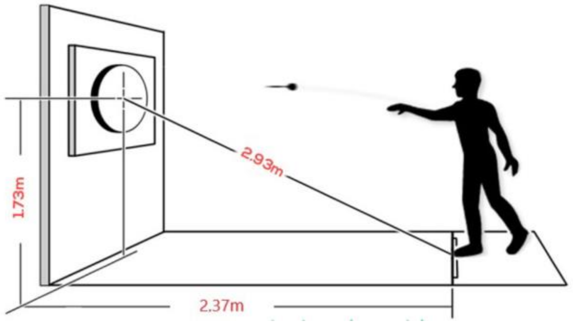


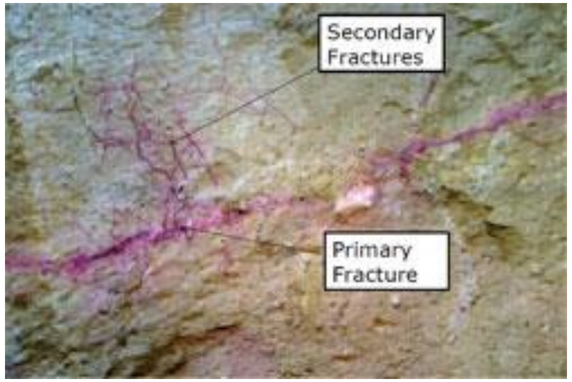


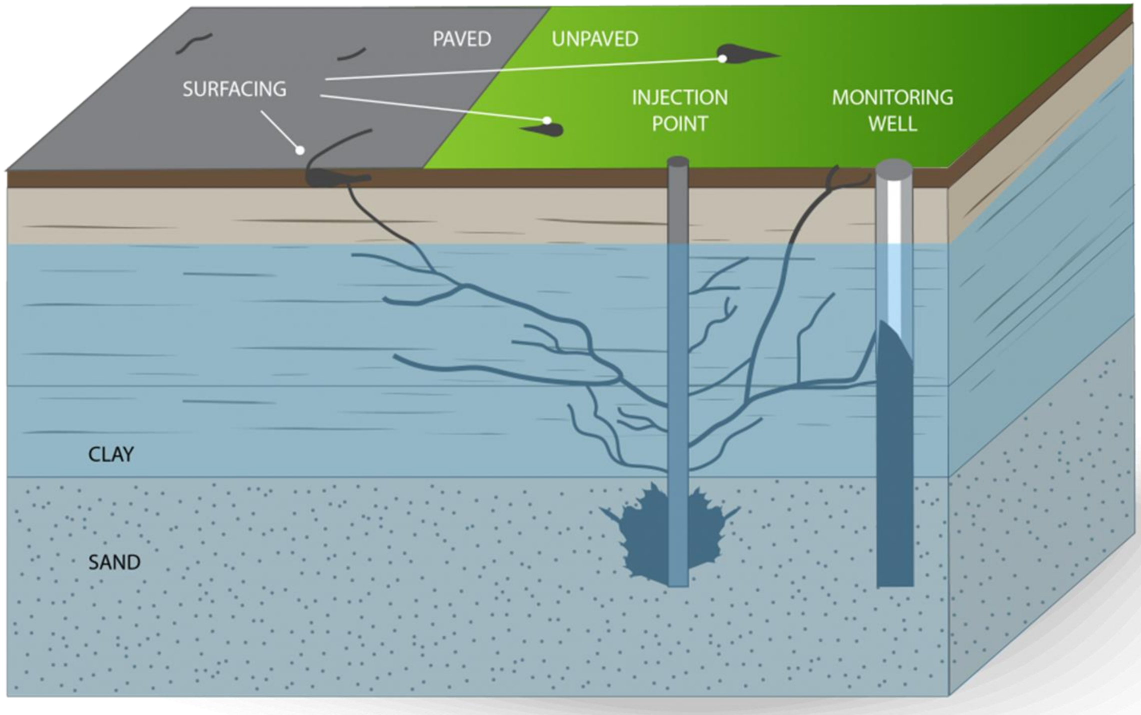
Fracturing / jet injection

Points of attention with fracturing / jet injection :

- By definition: reagents injected in "artificial" cavities, not (directly) in natural porosity
- Time needed for diffusion into natural "inter-fracture" porosity (cfr. longevity)
- In case of slurry; particles do not move in natural soil porosity (compaction, $d_{pores} \Leftrightarrow d_{particles}$)
- Poor control on fracture direction (path of least resistance)
- Reagents loss (surfacing, arrival in non-polluted zones, short-circuiting to wells,…)
- Bleed-off / refluxing after retraction of injection head (cfr. DPT in low perm soils)
- Heavings might be an issue







After T. Fox Petroleum Remediation Using In Situ Activated Carbon, 2015, Proceedings of the 25th National Tanks Conference, Phoenix Arizona

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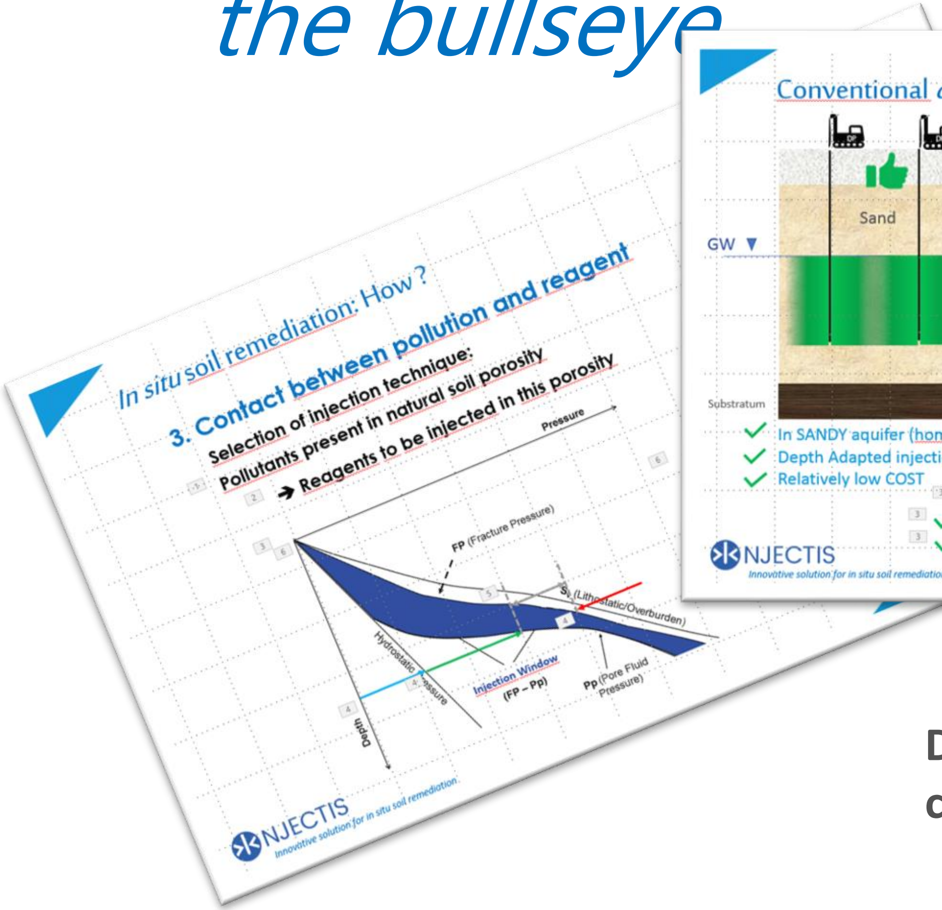
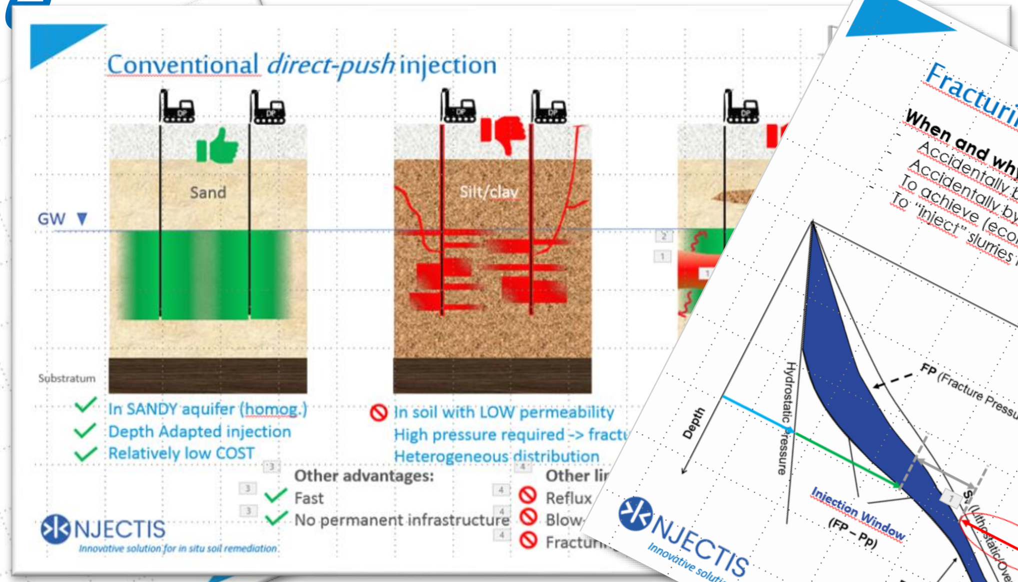
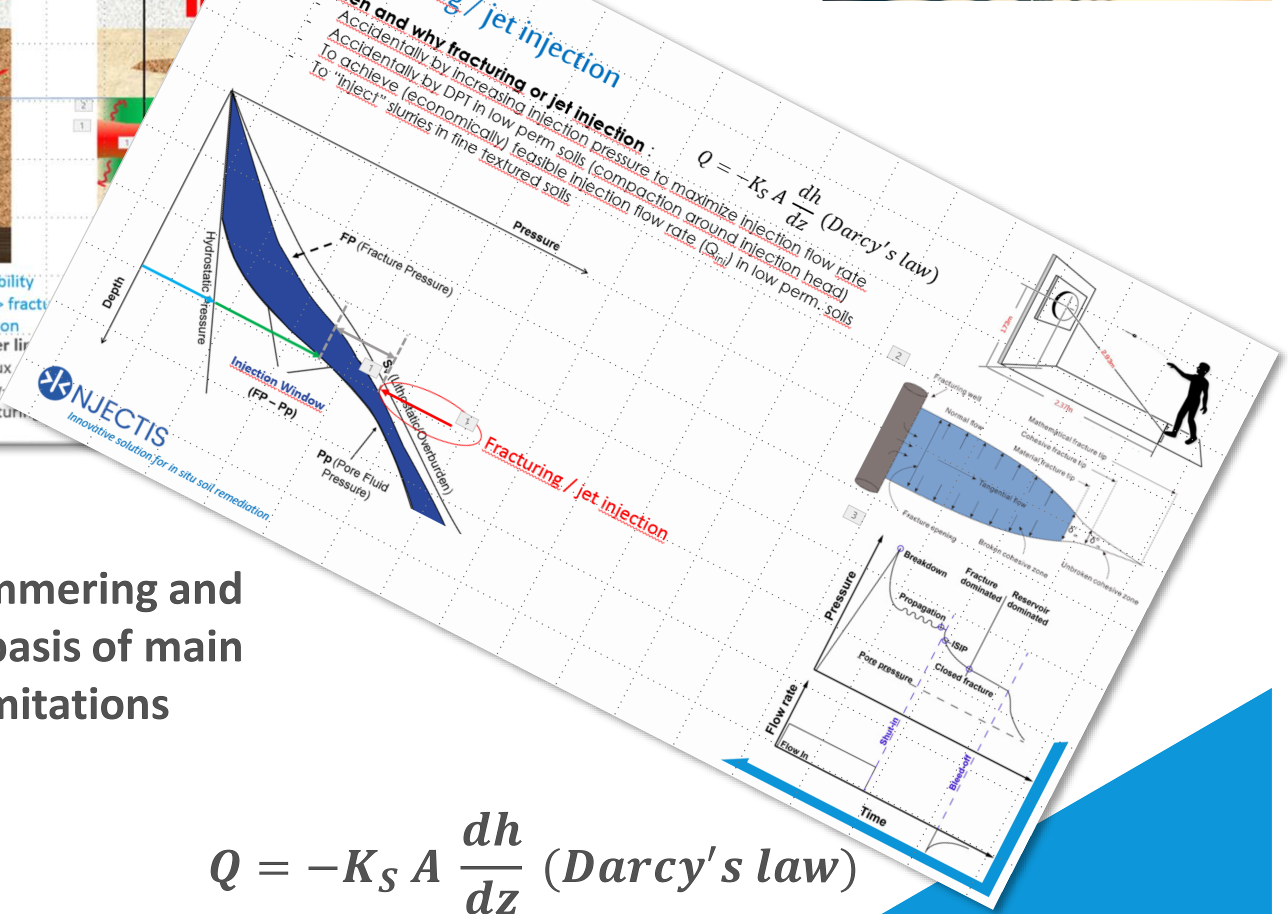
Innovative solution for in situ soil remediation

SPIN® injection technology:

How we thought to hit the bullseye

(anno 2015)

SPIN® injection technology: *How we thought the bullseye*

Injection pressure is the key parameter

Direct-push: hammering and compaction on basis of main problems/limitations

$$Q = -K_S\,A\,\frac{dh}{dz}\ (Darcy's\ law)$$

Keeping K_s as high as possible, increasing the A and maximizing the dh/dz, but < $P_{fracture}$

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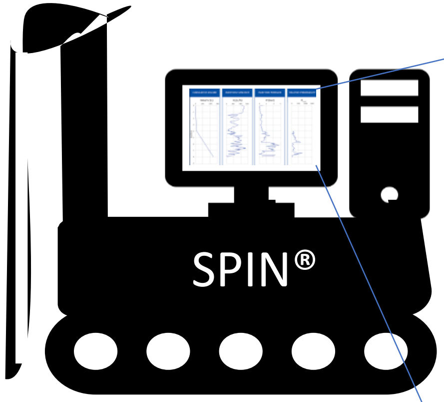
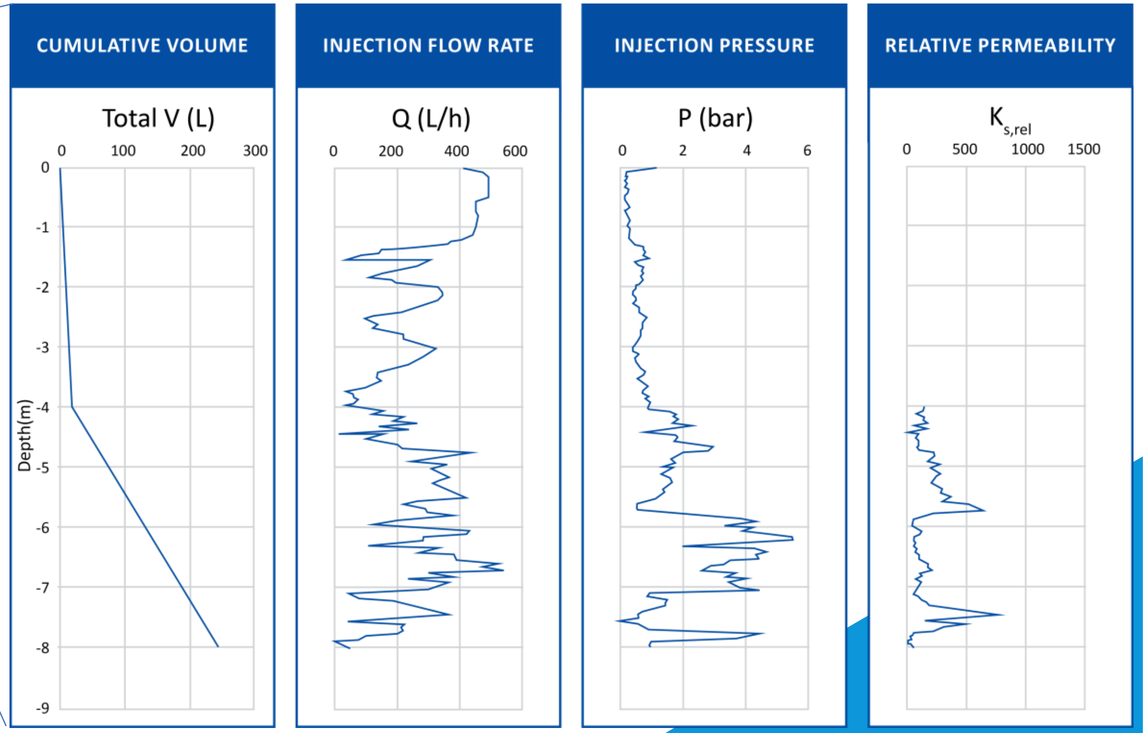
Innovative solution for in situ soil remediation

SPIN® injection technology: *How to hit the bullseye*

2. Coupled to a processor and pressure control system

- ✓ Can detect hydraulic conductivity in real time
- ✓ Can adapt the pressure cm/cm to the geology
- ✓ More certainty about a homogenous distribution





1. A new patented head

- ✓ Avoids compaction of the soil
- ✓ Avoids channel formation (hammering)
- ✓ Opens the soil progressively
- ✓ K_{sat} not altered
- ✓ Increased contact surface A
- ✓ Allows working at low pressure
- ✓ Close the injection point (no backflow)

$$Q = -K_S\, A\, \frac{dh}{dz}\ (Darcy's\ law)$$

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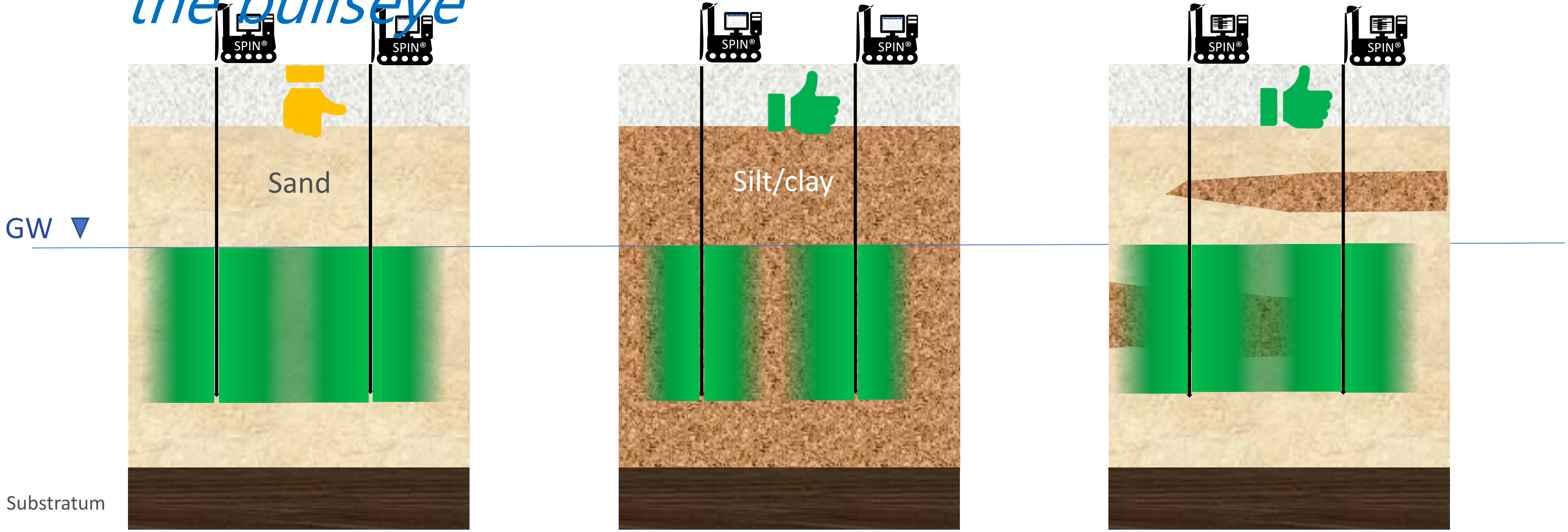
SPIN® injection technology: *How we thought to hit the bullseye*



- In SANDY aquifer (homog.)
- Depth Adapted injection
- No significant advantage

- In soil with LOW permeability
- Low pressure > without Fracture
- Homogeneous distribution

- In HETEROGENEOUS soil
- Homogeneous distribution

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Practical experiences:
How we hit the bullseye
(2015 – 2022)

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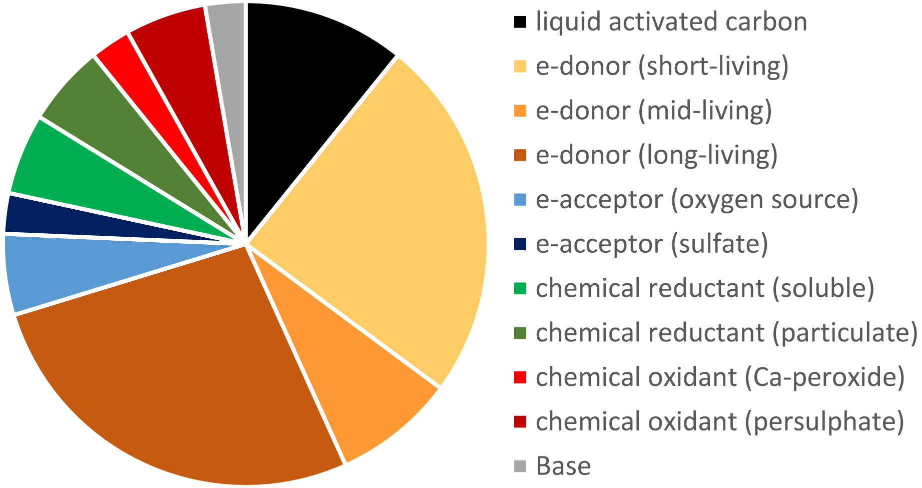
Practical experiences 2015- 20

General statistics:

- ✓ 95 injection projects (44 pilot tests, 51 full scale)
- ✓ Belgium, France, Spain, Germany, the Netherlands, Denmark, Sweden
- ✓ 2.083 injections between 0 and 30 m-bgl
- ✓ 21.399 meters injected
- ✓ 5.061.584 liters injected (2 Olympic swimming pools)
- ✓ All reactions, nearly all reagents
- ✓ 100 % heterogeneous and low permeability aquifers
- ✓ 45% other injection techniques tested but inadequate



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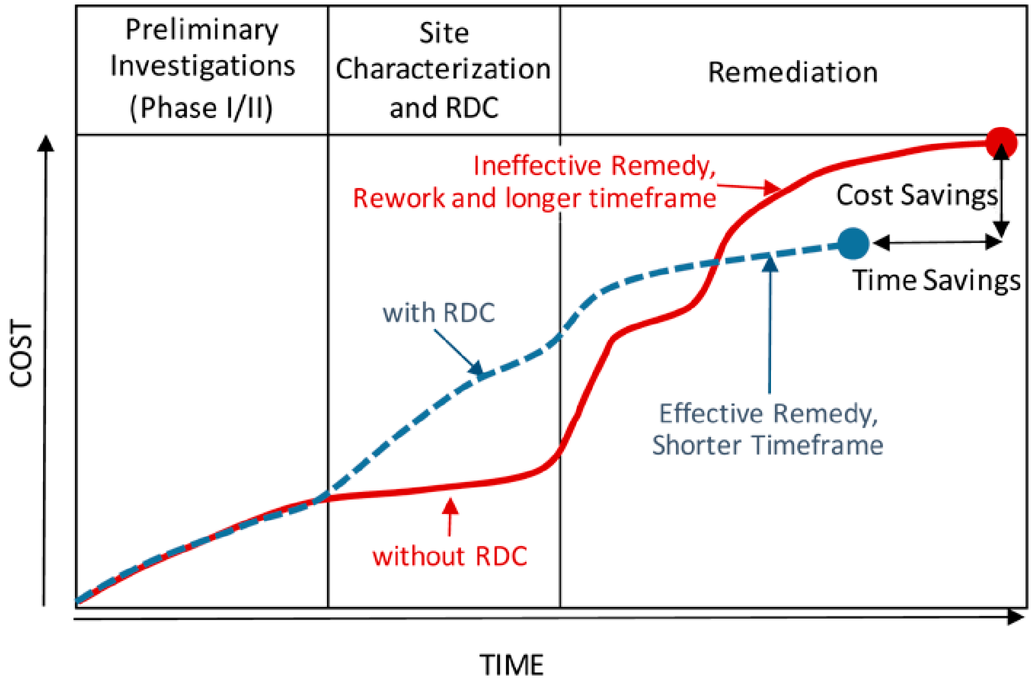
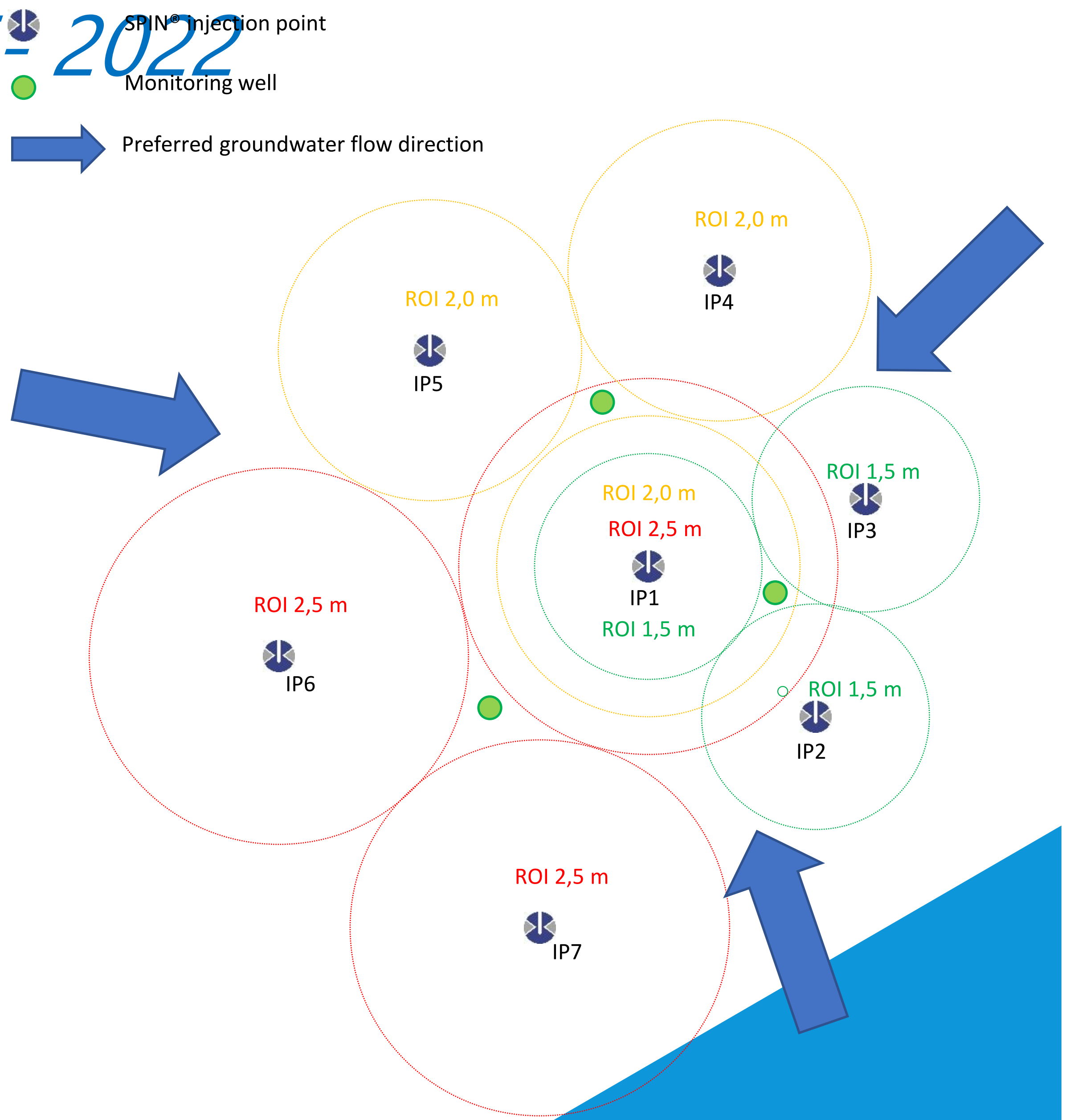
Practical experiences 2015 - 2022

Pilot test design (as part of RDC):

- ✓ Maximize information with minimum # injections
- ✓ 7 injections in certain geometric configuration
- ✓ 3 (clusters of) monitoring wells
- ✓ Average price: ± € 20.000

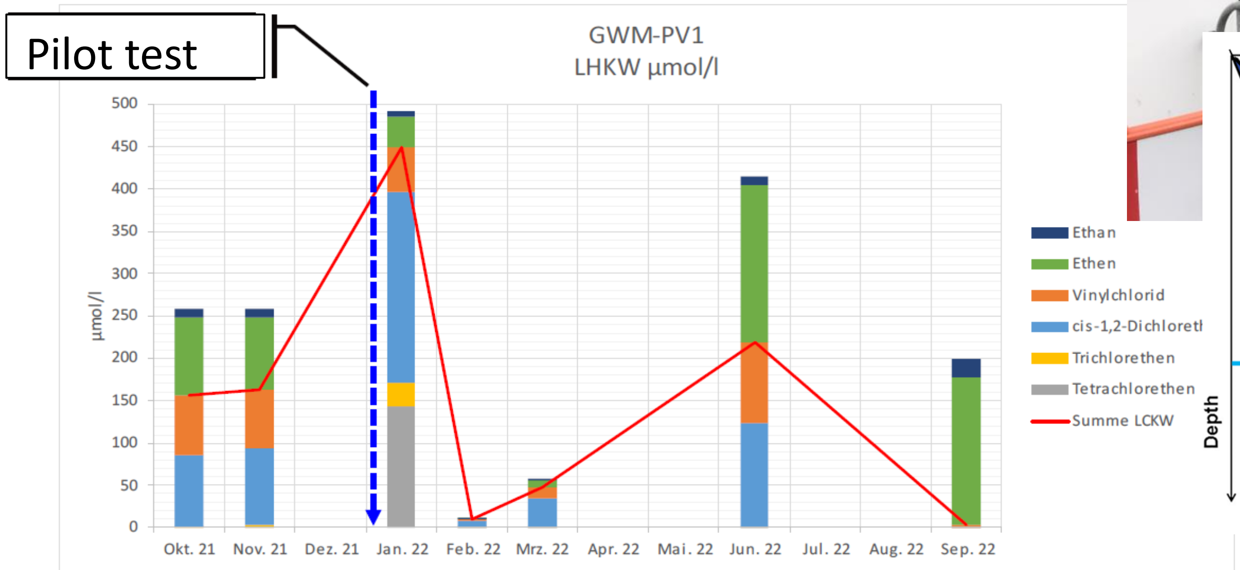


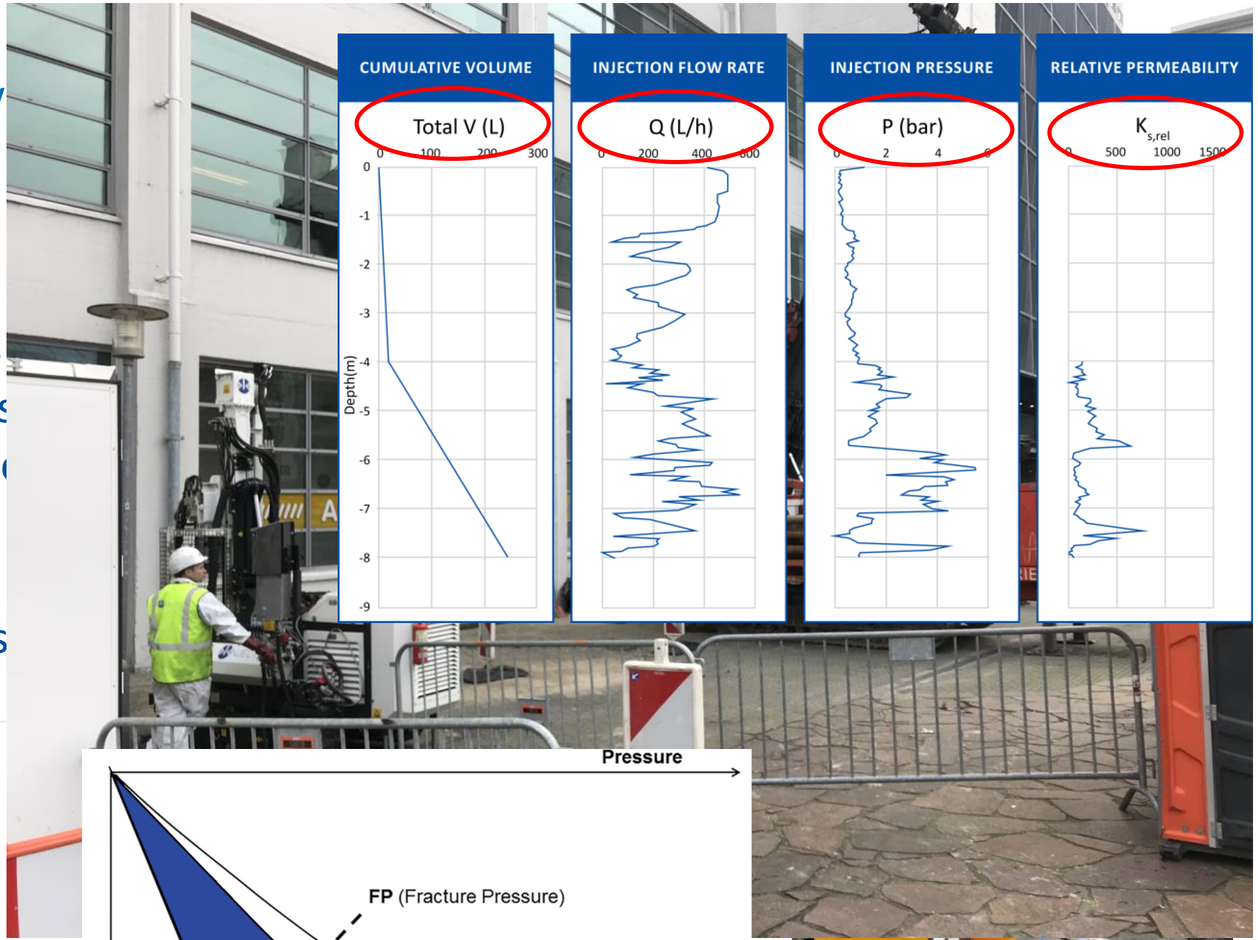


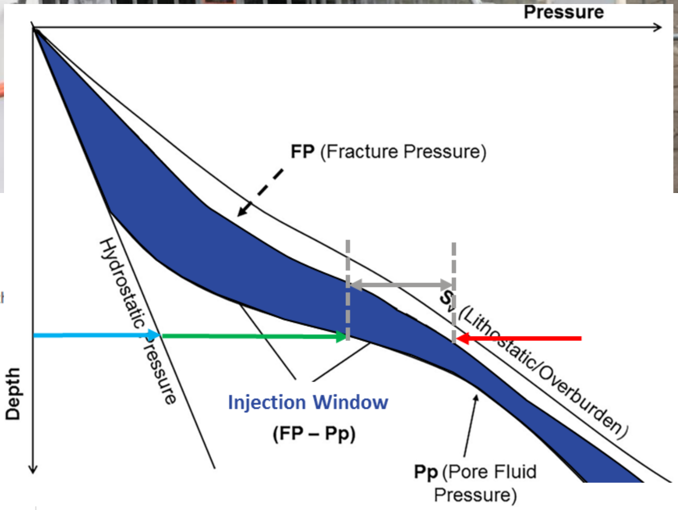
Practical experiences 201

Information from pilot tests:

- ✓ Can we reach the desired depths ? (size doesn't matter)
- ✓ Geology "injectable" at an economically feasible Q_{inj} ? (≈3
- ✓ Can the selected reagent be injected at non-fracture press
- ✓ Desired volume be injected homogeneously over the selec
- ✓ ROI in different layers (arrival in MWs) ?
- ✓ Desired reaction observed short-/mid-term ?
- ✓ Longer term: rebound versus inflow from outside pilot tes







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Innovative solution for in situ soil remediation

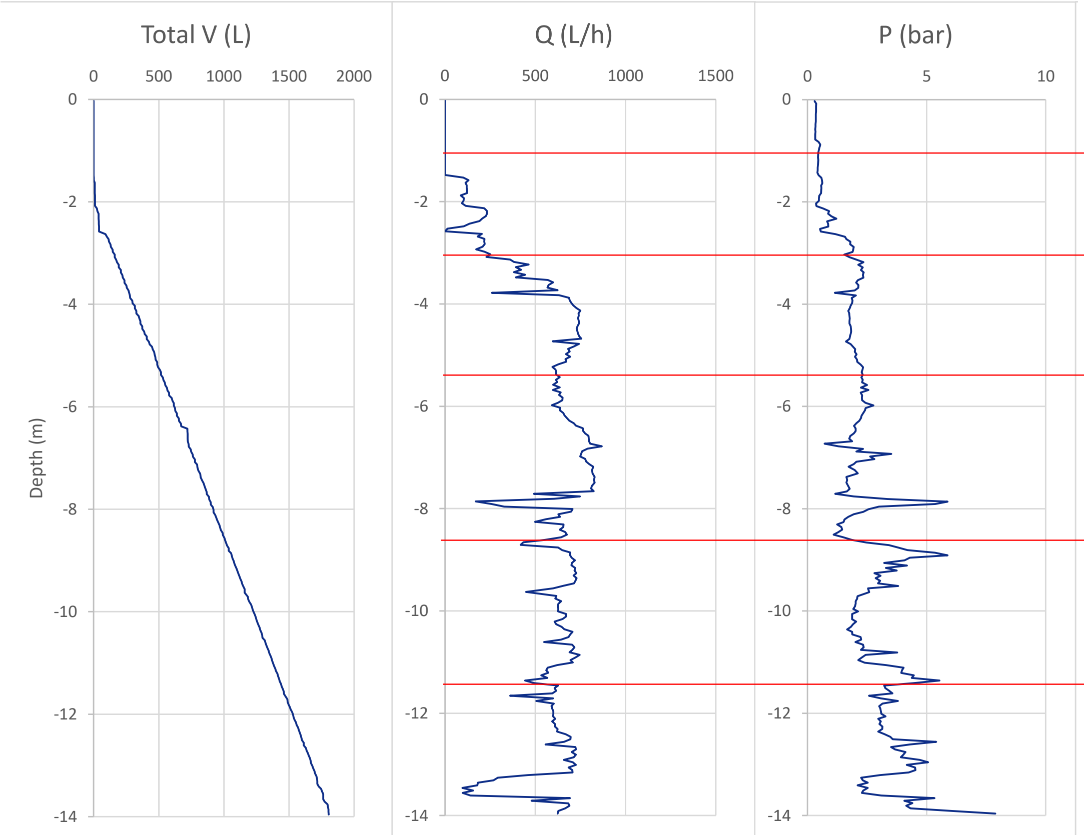
Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Injection pressure *versus* injection flow rate

SPIN INJECTION LOG	
Injection point	IP1

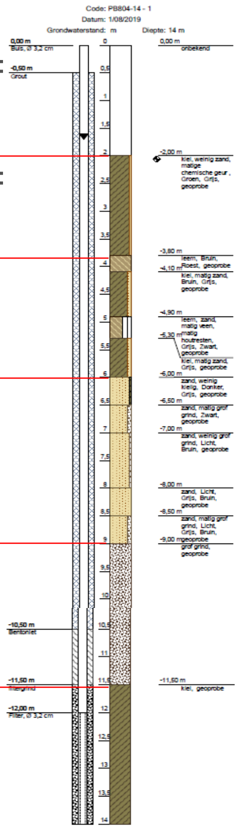
	Date	Hour
Start	20/08/2019	11:05:47
End	20/08/2019	16:03:25



$$Q = -K_S\, A\, \frac{dh}{dz} \ (Darcy's\ law)$$

$= \ldots rel\ P_{inj}$

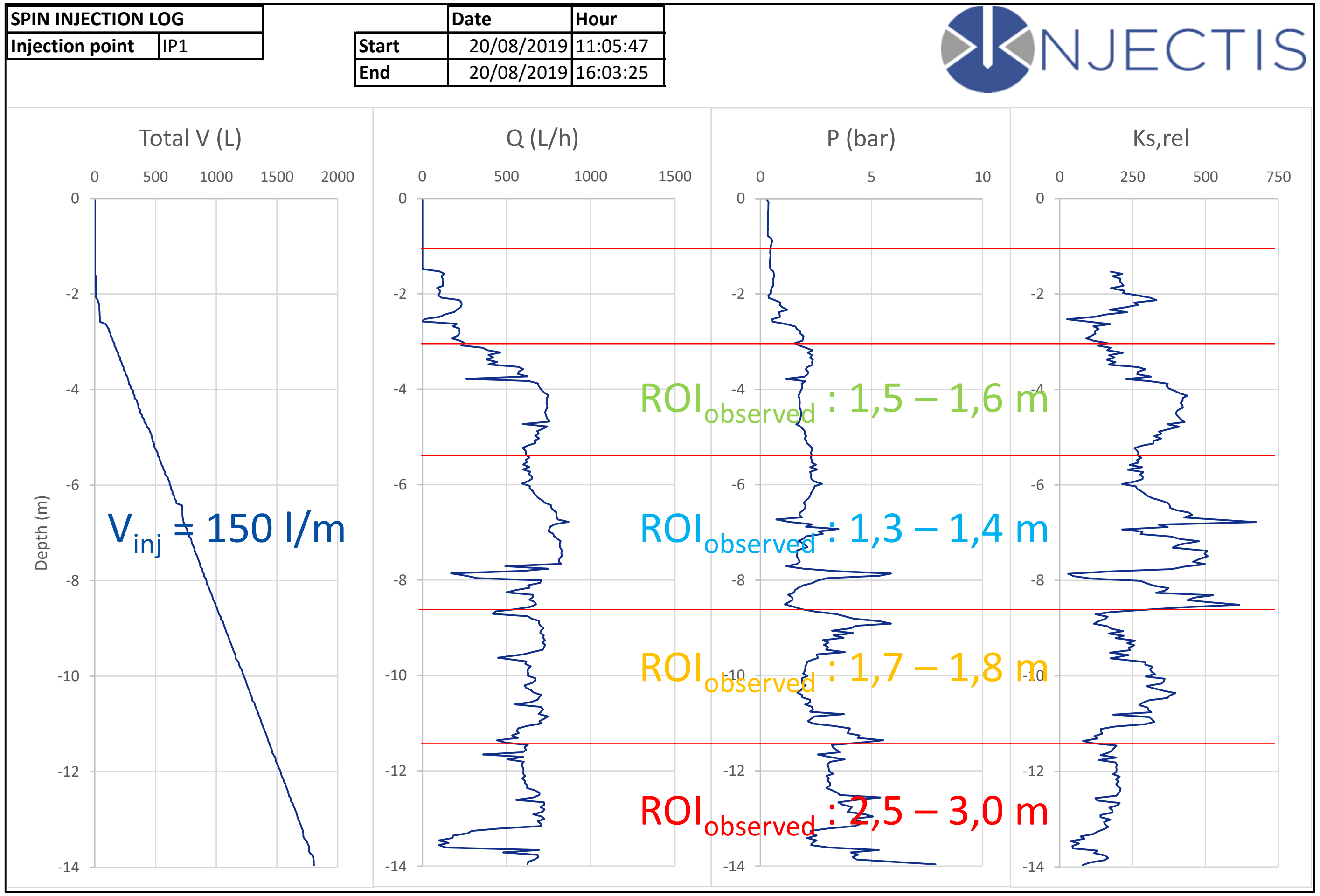
$= \ldots rel$



Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Injection volume *versus* ROI *versus* soil texture



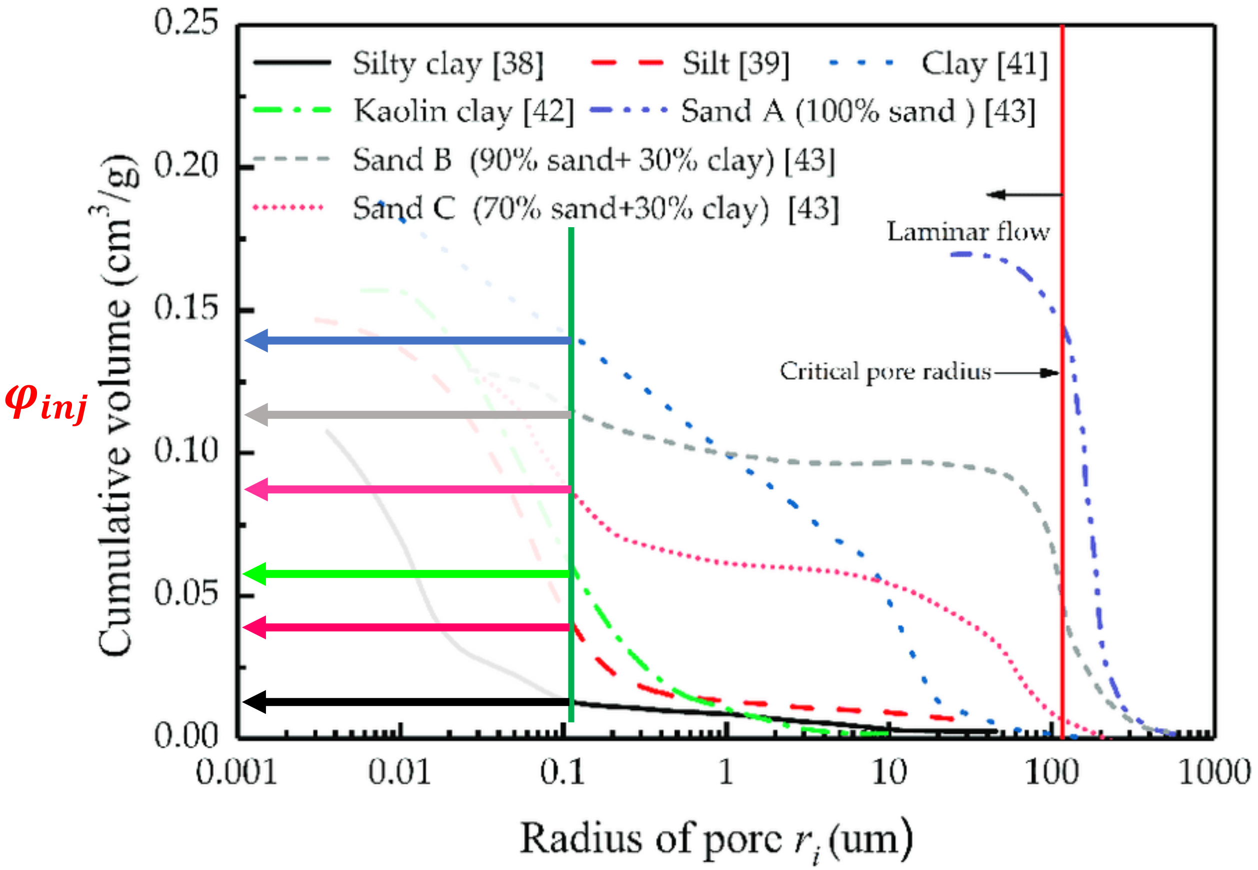
$$\text{ROI} \approx \frac{1}{K_{s,rel}}$$

Low pressure injection
=> Injection in macropores

Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Injection volume *versus* ROI *versus* soil texture



$$\text{ROI} \approx \frac{1}{K_{s,rel}}$$

Low pressure injection

⇒ Injection in macropores

⇒ % MP depend on soil texture

$$\text{ROI} = \sqrt{\frac{V_{inj}}{(\pi \cdot \varphi_{inj})}}$$

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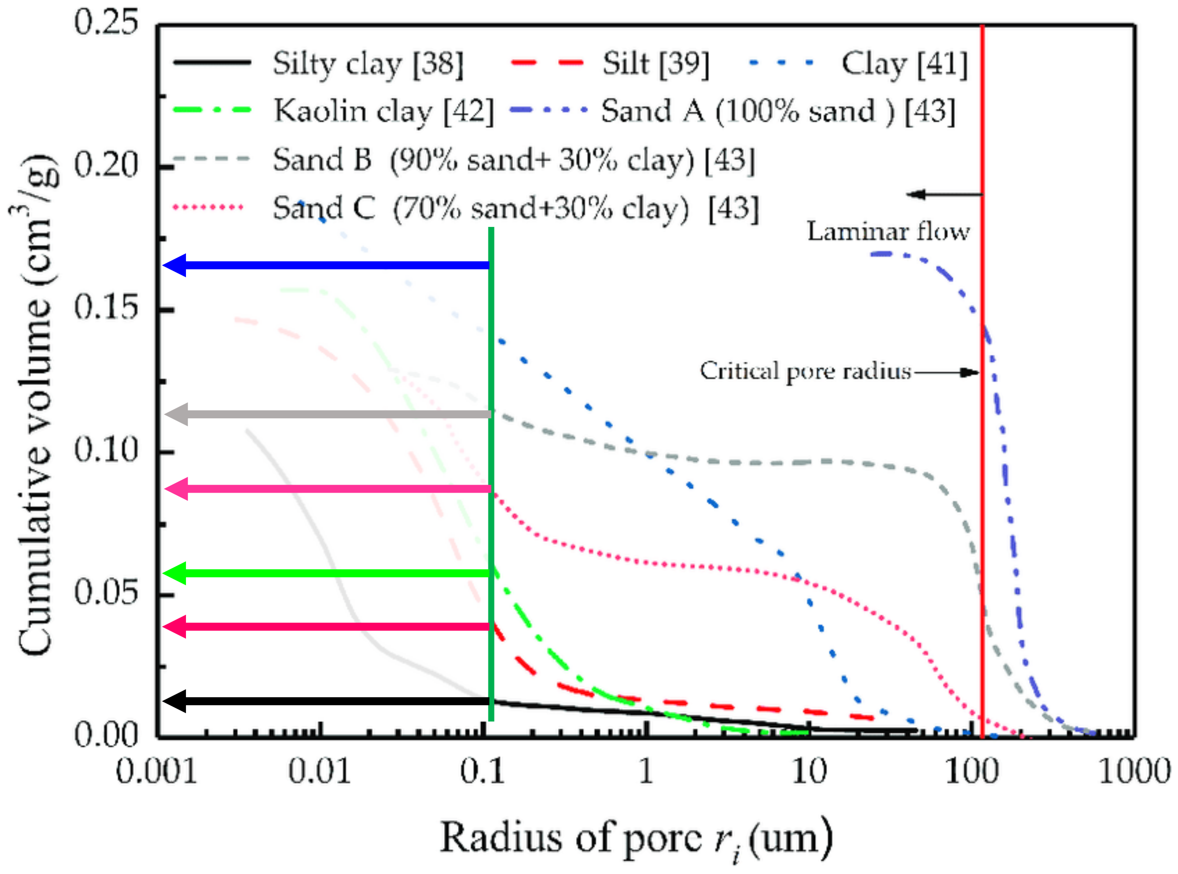
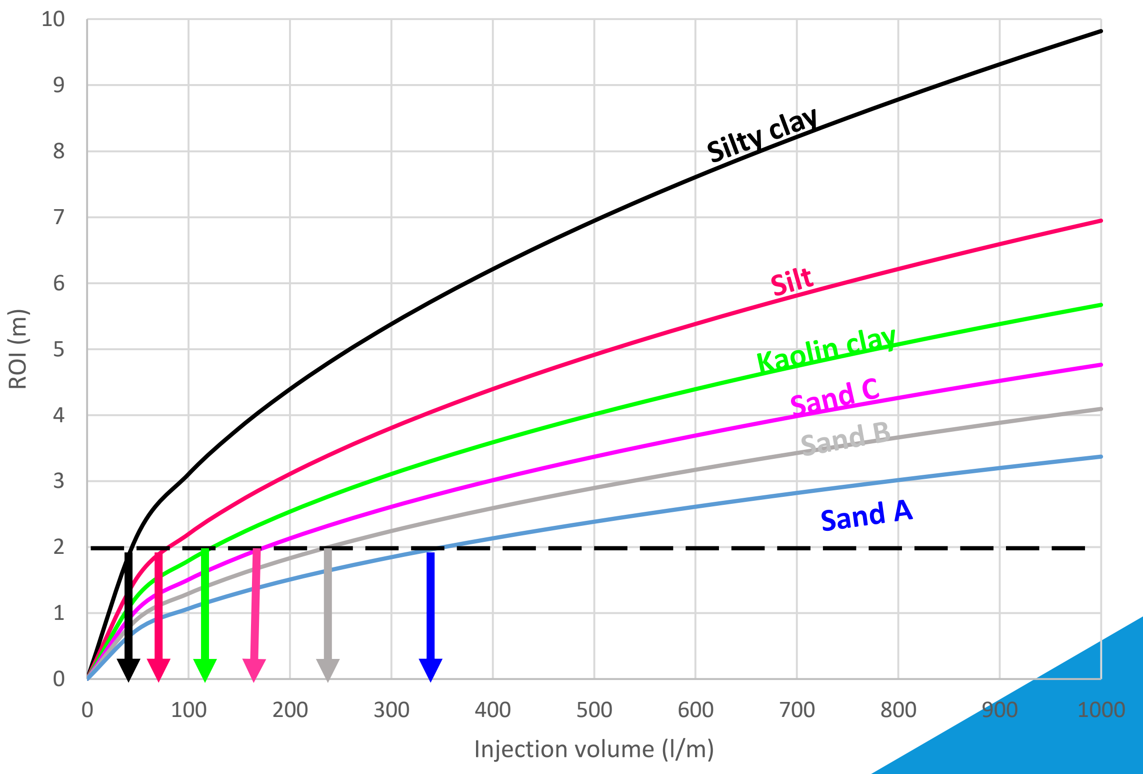
Innovative solution for in situ soil remediation

Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Injection volume *versus* ROI *versus* soil texture

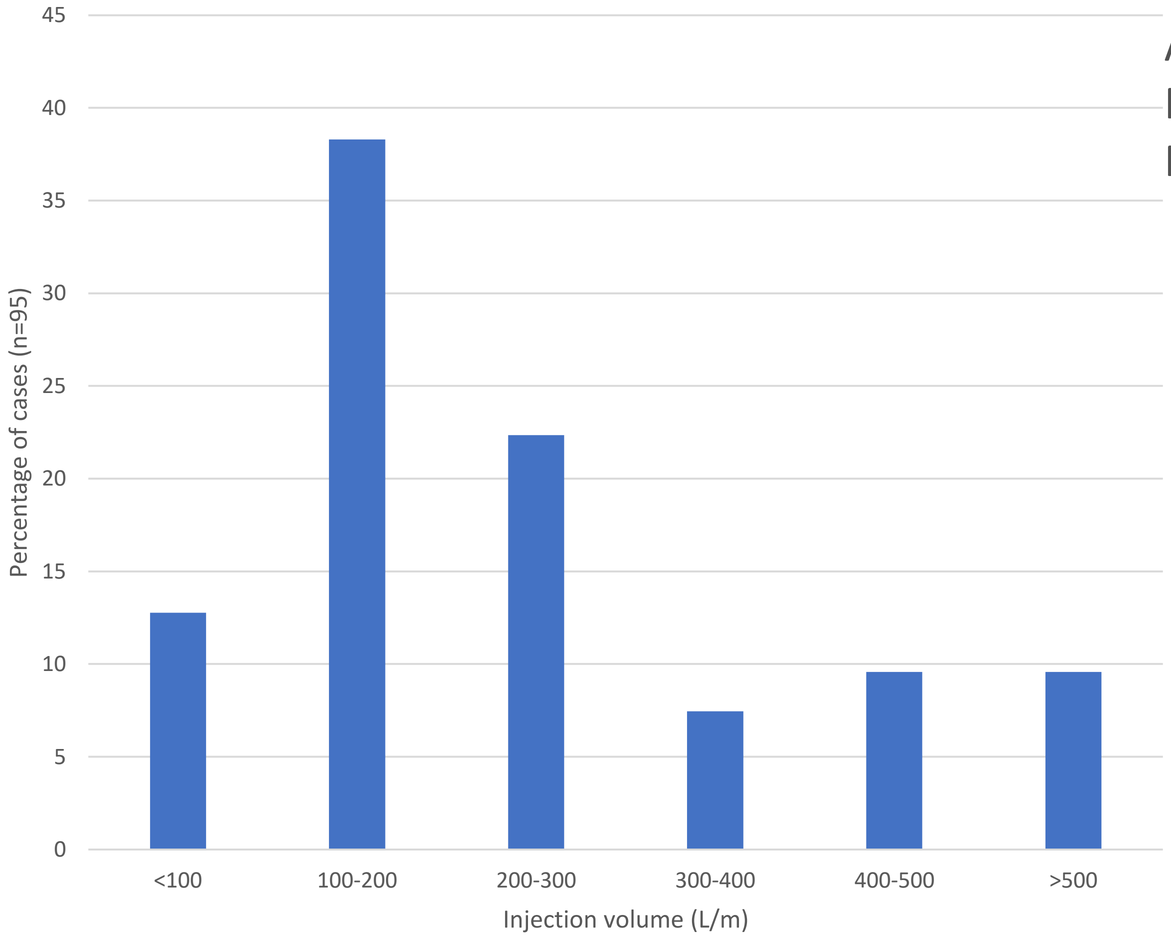




Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Injection volume *versus* ROI *versus* soil texture

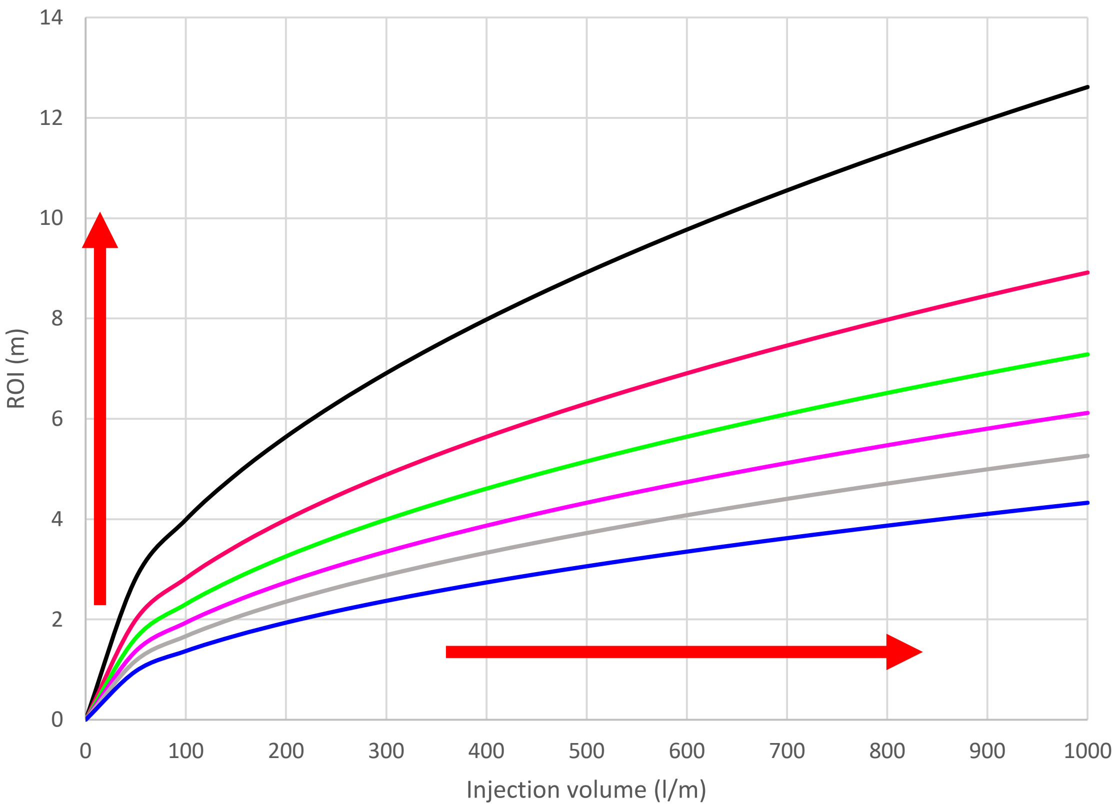


Average = 253 L/m
Min = 24 L/m (2016)
Max = 1.550 L/m

Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Number of injection points *versus* injection volume per injection



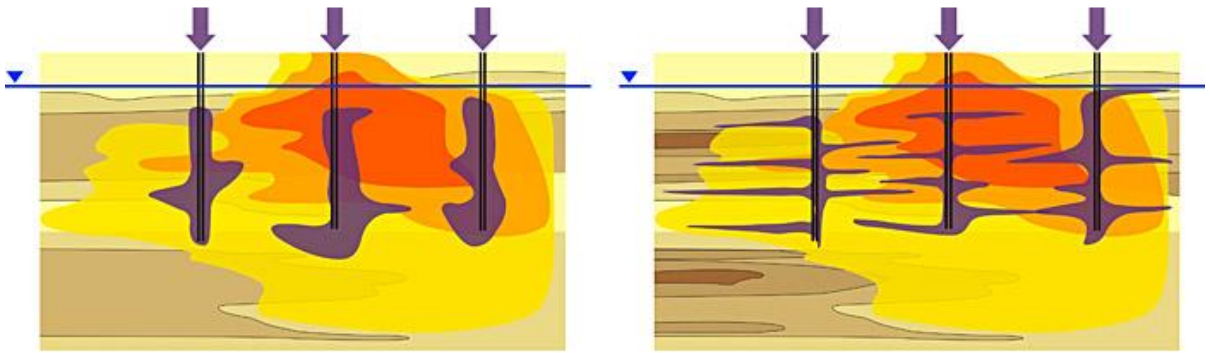
Maximizing V_{inj} per injection point

⇒ Maximize ROI per injection point

⇒ Reduces # injection points

But…

Rarely perfect "cilinders"

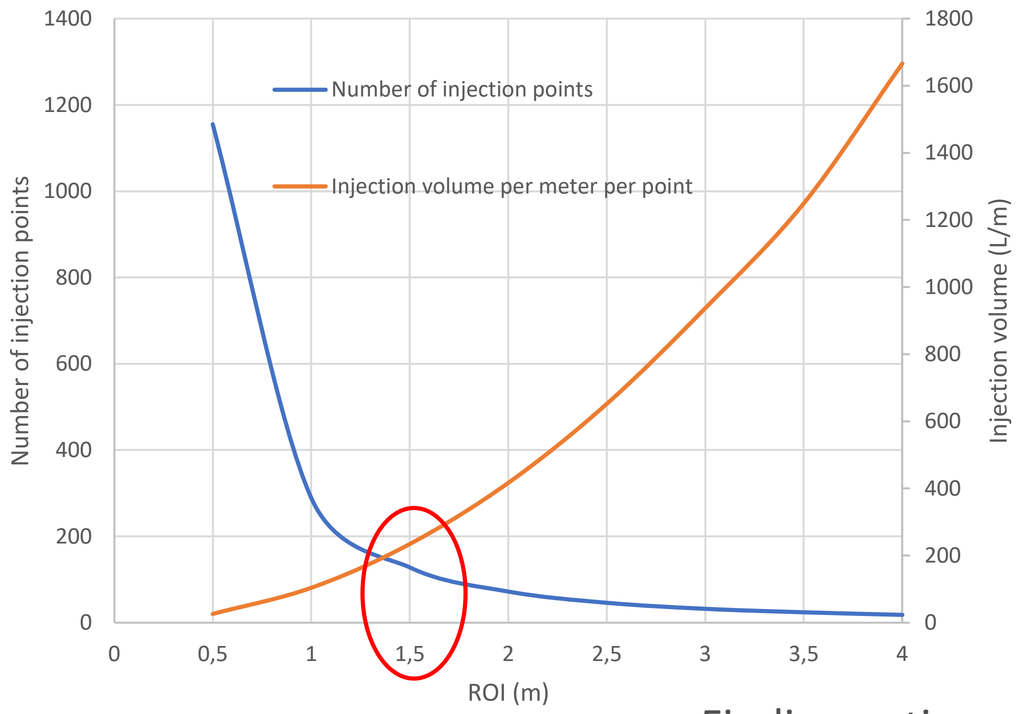


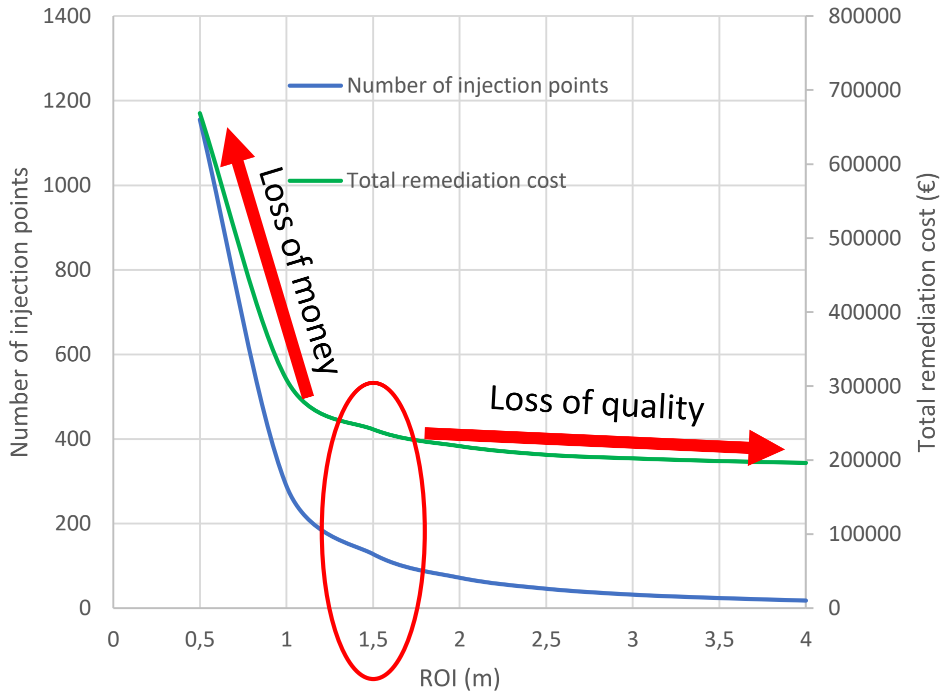
Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Number of injection points *versus* injection volume per injection

Exemple: 1.000 m², 1-11 m-bgl, 3% vol





Finding optimum between
qualitative distribution
and total cost

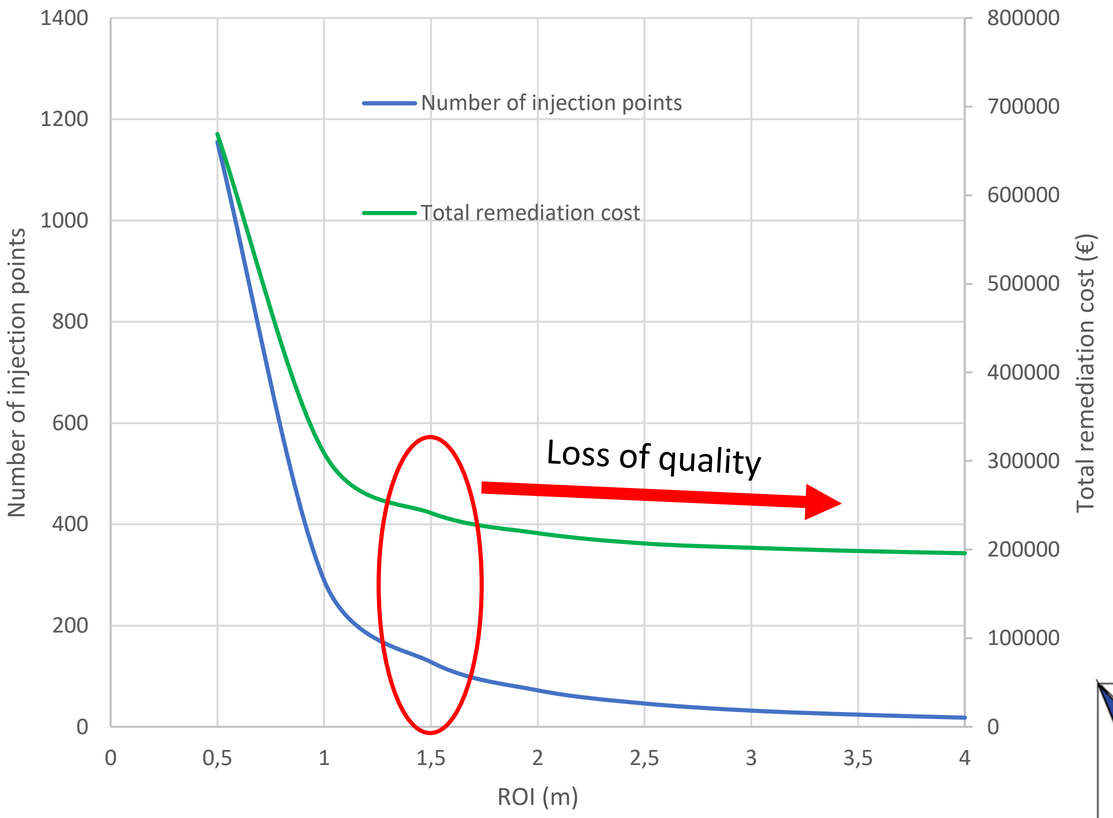
NJECTIS

Innovative solution for in situ soil remediation

Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Cost *versus* quality



How can overall remediation cost be reduced ?

$$\begin{cases} V_{inj} = Q_{inj} \cdot t_{inj} \\ Q_{inj} = K_{s,rel} \, P_{inj} \end{cases}$$

$$\Rightarrow V_{inj} = K_{s,rel} \cdot P_{inj} \cdot t_{inj}$$

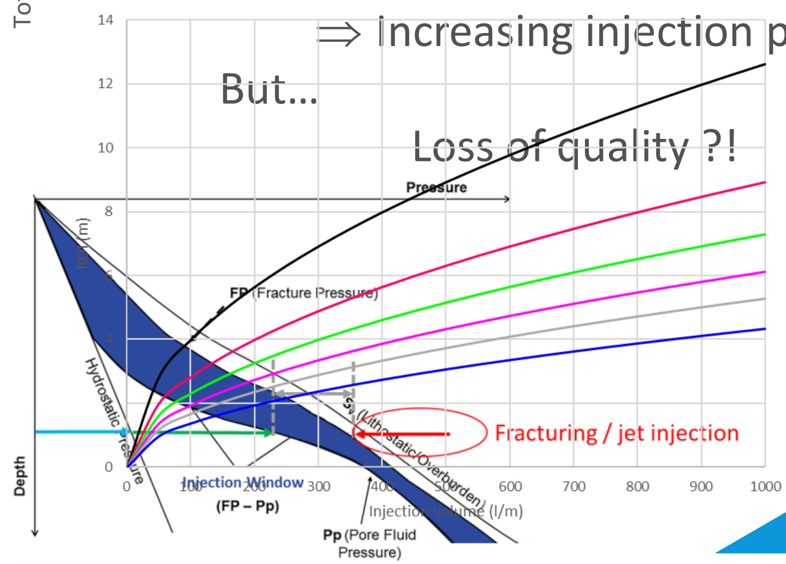
$\Rightarrow$ Minimizing injection time (t_{inj})

$\Rightarrow$ Reducing injection volume (V_{inj}) or

$\Rightarrow$ Increasing injection pressure (P_{inj})

But…

Loss of quality ?!



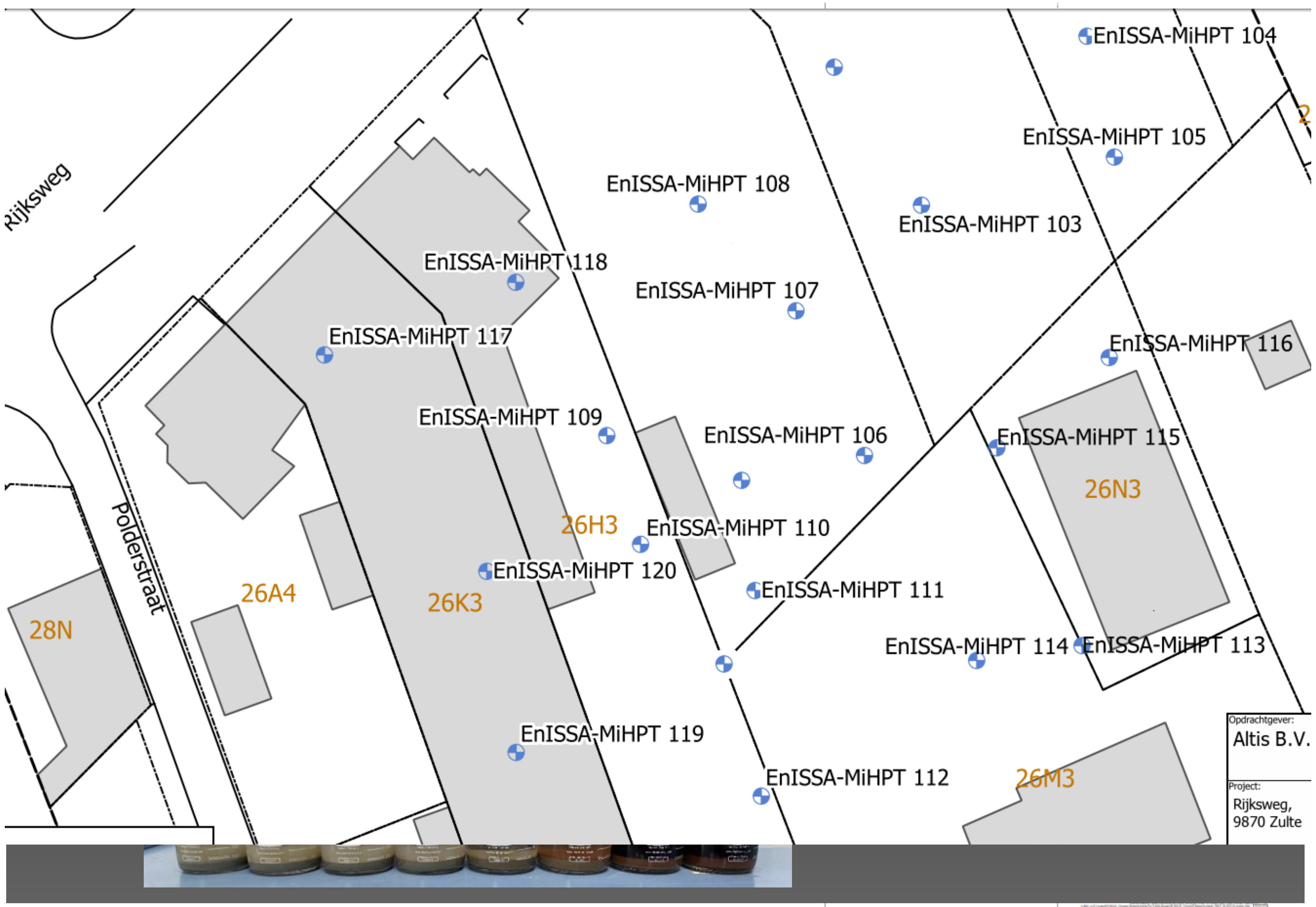
INJECTIS

Innovative solution for in situ soil remediation

Practical experiences 2015- 2022

Some interesting relationships (lessons learned):

✓ Cost reduction *versus* high resolution site characterization (HRSC)



Total estimated remediation cost: €1,2 Mio

RDC: ISCO with permanganate

lab tests: different dosages

⇒ Additional HRSC (23 Enissa-MIP drillings)

⇒ 3D-model

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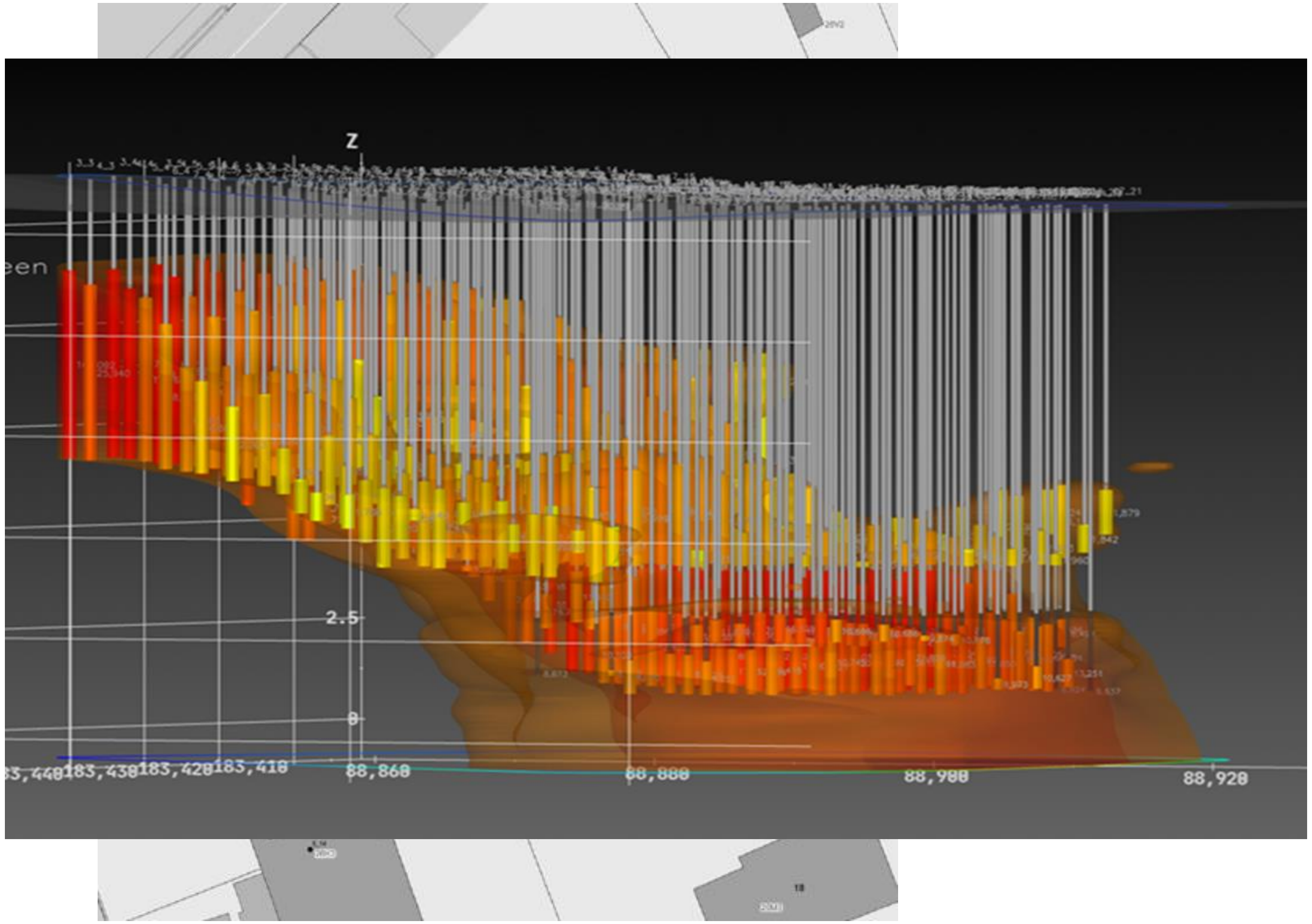

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RDC: ISCO with permanganate

lab tests: different dosages

⇒ Additional HRSC (23 Enissa-MIP drillings)

⇒ 3D-model

⇒ Overlay with injection points

Result:

- Injection trajectory exactly known
- Dosage exactly known (3D)

⇒ 50 % reagent saving

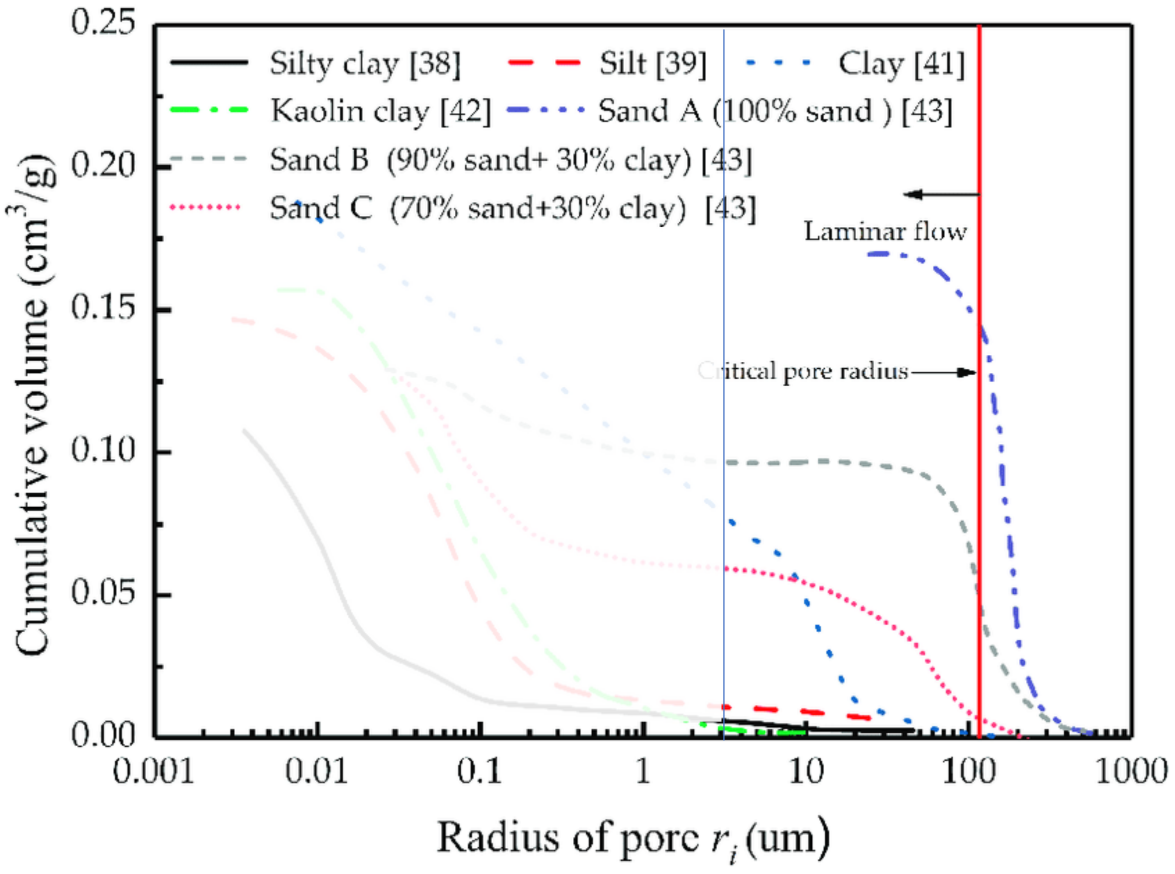
⇒ 30% overall cost saving

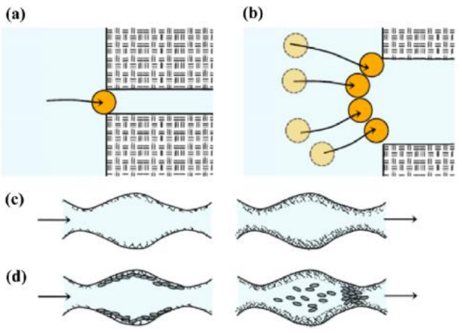
⇒ Time saving !

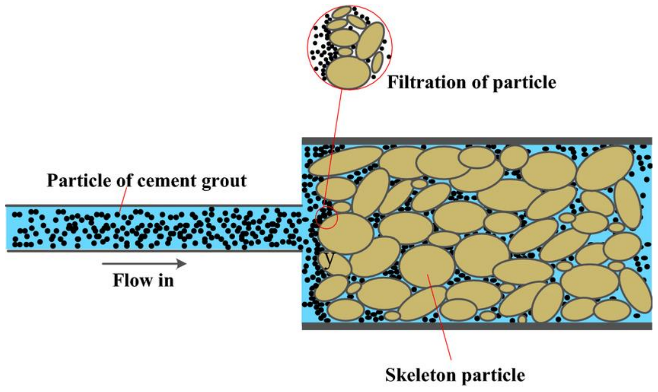
Practical experiences 2015-2022

Experiences with slurry injections :

✓ Yes, but…

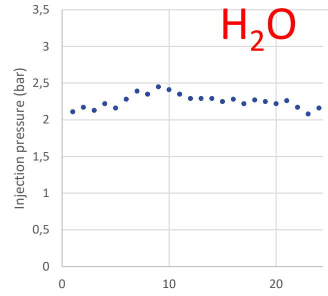




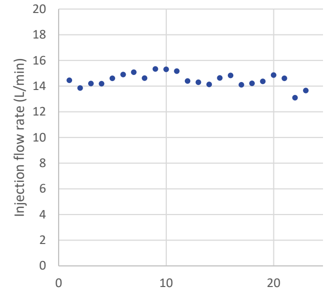


SPIN ® micro-data					
Injection point	IP1		Depth	12,31	m-bgl
Upper limit	12,0	m-bgl	Max. pressure	3,08	bar
Lower limit	20,0	m-bgl	Max. flow rate	17,33	L/min
Dosage	66,0	L/m	Total volume	5,76	L
Time step	2,00	#meas/sec	Average $K_{s,rel}$	4,28	(-)

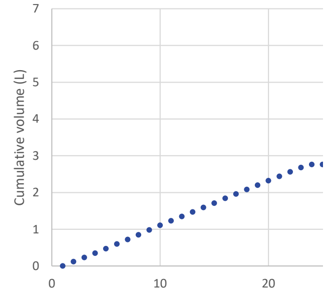
P_{inj}



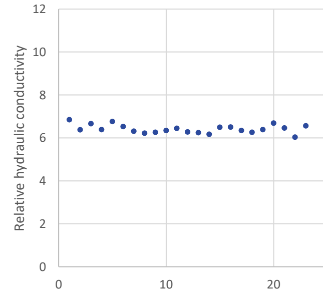
Q_{inj}



V_{inj}



K_s



<u>Sieving out around injection point ($d_{particle} > d_{pore}$) </u>:

- Clogging of soil pores (P_{inj}↑, Q_{inj}↓↓)
- No distribution of reagents (droplets, particles)

High pressure injection might be a solution,
but…

NJECTIS

Innovative solution for in situ soil remediation

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Thank you

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