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DPT Practitioner's Guide: Best Practices for Successful DPT Injection of Solid Amendments in Sand Aquifers

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ATV Jord og Grundvand

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Document Scope & Purpose

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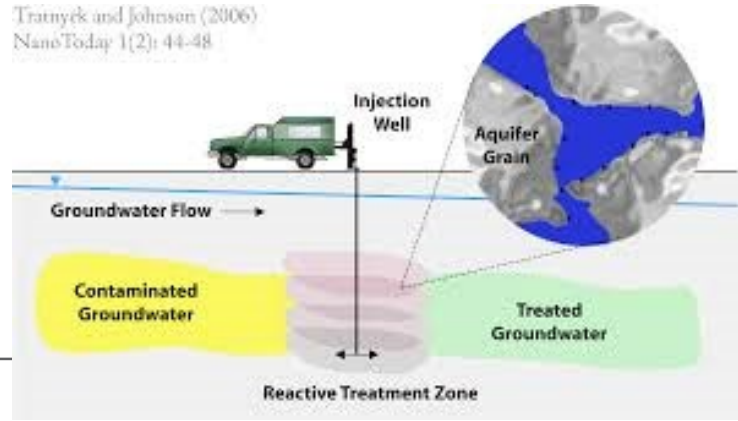
- Focus – Direct Push Injection (DPI) of **solid amendments** for in situ treatment of groundwater contaminants in **sand aquifers,** e.g.,
  - Microscale zero valent iron (mZVI)
  - Colloidal activated carbon (CAC)
  - ZVI-carbon composites (e.g., EHC, Provect-IR)
- Draw experience from U.S. and DK collaborators to develop a best practice-based guidance for remediation practitioners in DK
- Improve design and implementation of DPI and achieve desired project outcomes
- Best practices, and expectation management
- Review of Danish DPT case studies
- Not addressed: injection in clay till / enhanced fracturing*

* See presentation by ND Durant @ 14.40 today (it's going to be fantastic)

Motivation

- DPI is potentially cost-effective, common, easy-to-use
- Aim: **maximize injection and treatment success**
- **Expectations** for DPI can be over-rated. We must set appropriately
- DPI may fail when:
  - practitioners lack sufficient experience with DPI equipment and/or heterogeneous geology,
  - unsuitable injection tooling or injection parameters (e.g., pressures and flow rates) are applied,
  - subsurface conditions are not properly understood during design
  - and/or best practice protocols are not followed
- Success metrics: injection quantity, distribution…. vs.. Treatment. Soil and groundwater quality improvement are ultimate measure
- Effective **treatment performance depends on contact** – how to achieve best results?



Danish & Swedish DPT Case Studies Reviewed

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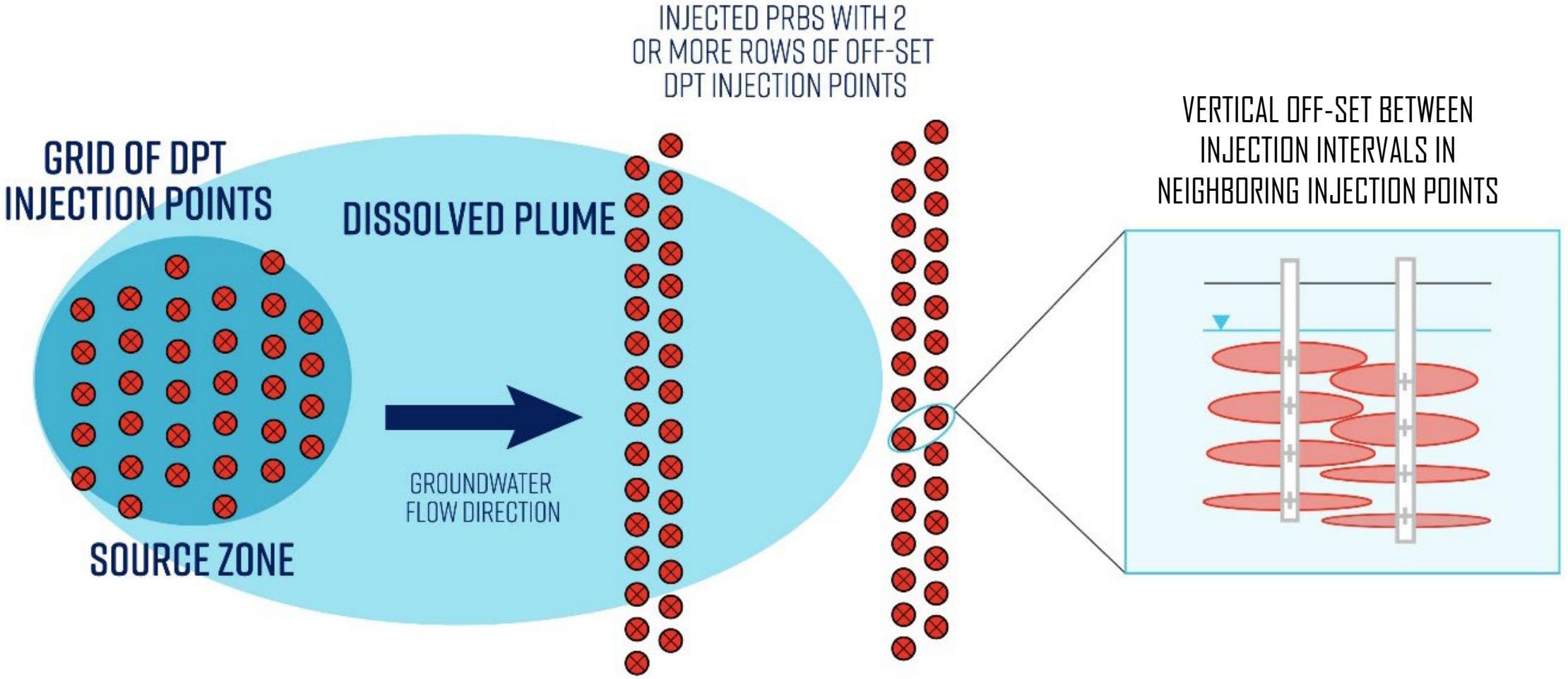
Site Address	Source	Injection Technique	Reagents
Rugmarken 42, Farum, DK	GEO	DPT and Injection wells	Molasses + nZVI + KB-1
Borupvej 35, Hillerød, DK	GEO	DPT and Injection wells	nZVI, Molasses + nZVI
Roskildevej 544, Brøndby, DK	GEO	DPT	Molasses + KB1
Zakrisdal, Karlshavn, SE	GEO	DPT	Regenesis 3DMe, HRC
Industrivej 2, 3540 Lynge, DK	Ramboll	DPT	Colloidal Act carbon + KB-1
Hagfors, SE	NIRAS	DPT	mZVI
Boden, SE	NIRAS	DPT	mZVI + Bioaug
Pennehave 13-15, Hoersholm, DK	NIRAS	DPT	EVO, KB-1
Ahornvej 3A-D, 2970 Hoersholm, DK	COWI	DPT	EVO, KB-1
Rungstedvej, 19, 2970 Hoersholm, DK	COWI	DPT	EVO, KB-1
Rugårdsvej 234, Odense, DK	COWI	DPT	mZVI (Ferox Flow)
Hvedemarken 3-5, 3520 Farum, DK	COWI	DPT	Provect-IR + KB-1
Ørnegårdsvej 2, Gentofte, DK	GEO	Injection wells	Molasses
Esrumvej 72, Helsingør, DK	GEO	Injection wells	Molasses, nZVI, EOS, KB-1

Typical DPI Treatment Zone Configurations



Some Best Practice Questions Answered

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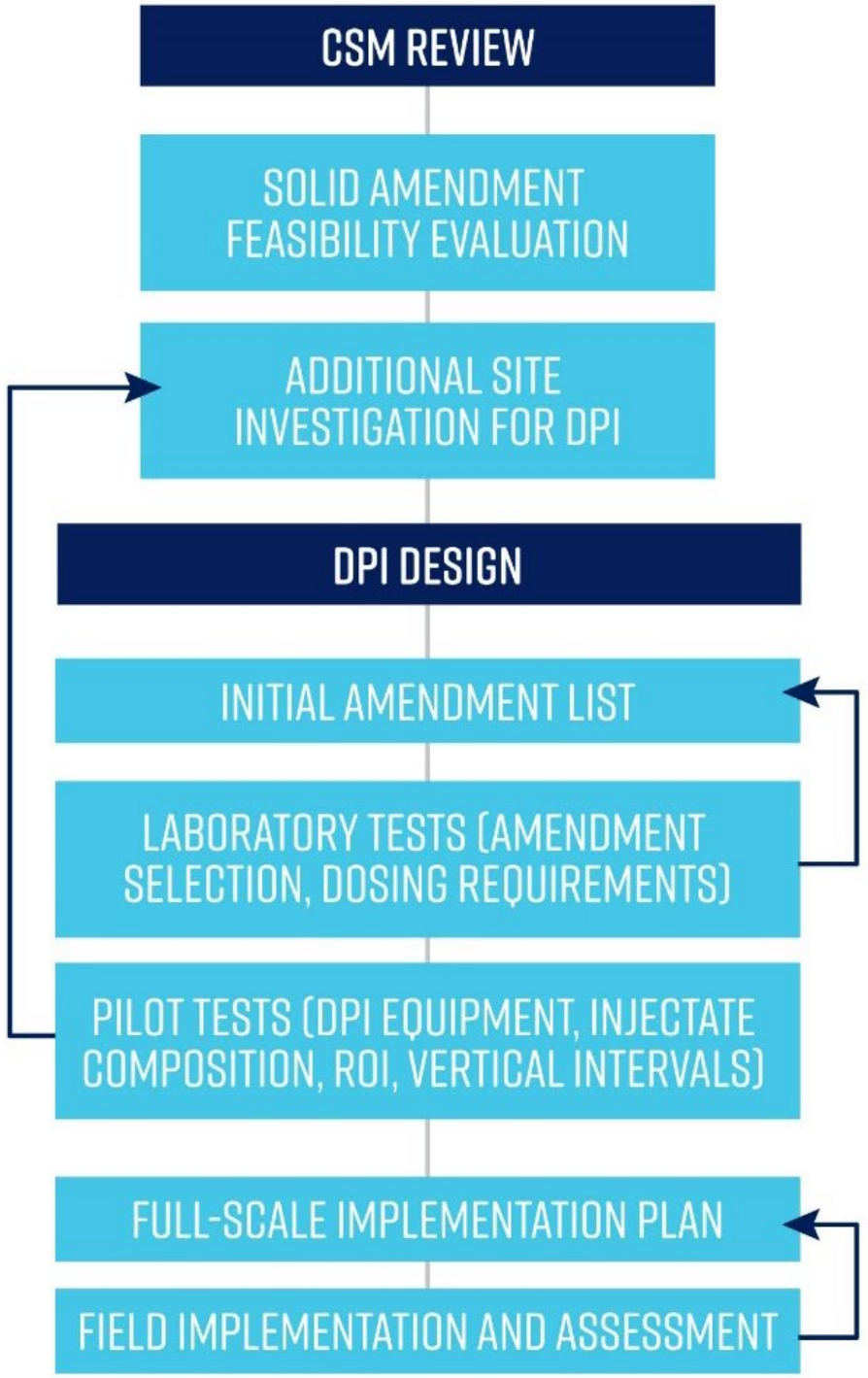
- Which amendments to use for which contaminants?
- Amendment dosage?
- Amendment longevity?
- Will reinjection be necessary in the future?
- Injection point spacing, ROI, laterally / vertical spacing?
- Injection mode: top-down? bottom-up? When?
- Injection pressures?
- How to avoid short-circuiting / daylighting?
- How to avoid uncontrolled, unintended delivery?
- What about clogging of injection equipment?
- What can we expect from DPI?

Flow Chart of DPI Design and Implementation Process



Summary of Contaminants Treatable by Common Types of Solid Amendments

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Treatment Mechanism	Commercial Injectable Solid Products	Target Contaminants				
		Chlorinated hydrocarbons	Petroleum Hydrocarbons	Reducible metals (e.g., Cr, As, Se)	Phenols, cresols, and PAHs	Pesticides
Abiotic reduction	nZVI, mZVI	✓		✓		
Microbial oxidation	BOS-200®	P	✓		P	
Microbial reduction	mZVI-C (EHC®, Provect-IR®, EVO-ZVI mixtures)	✓		✓		
Sorption	CAC, PAC	✓	✓	P	P	P

P- potentially treatable, depending on COC type, concentrations, and background geochemistry

Common Commercial Injection Tools Used in DPI

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DPI Particle Emplacement Methods

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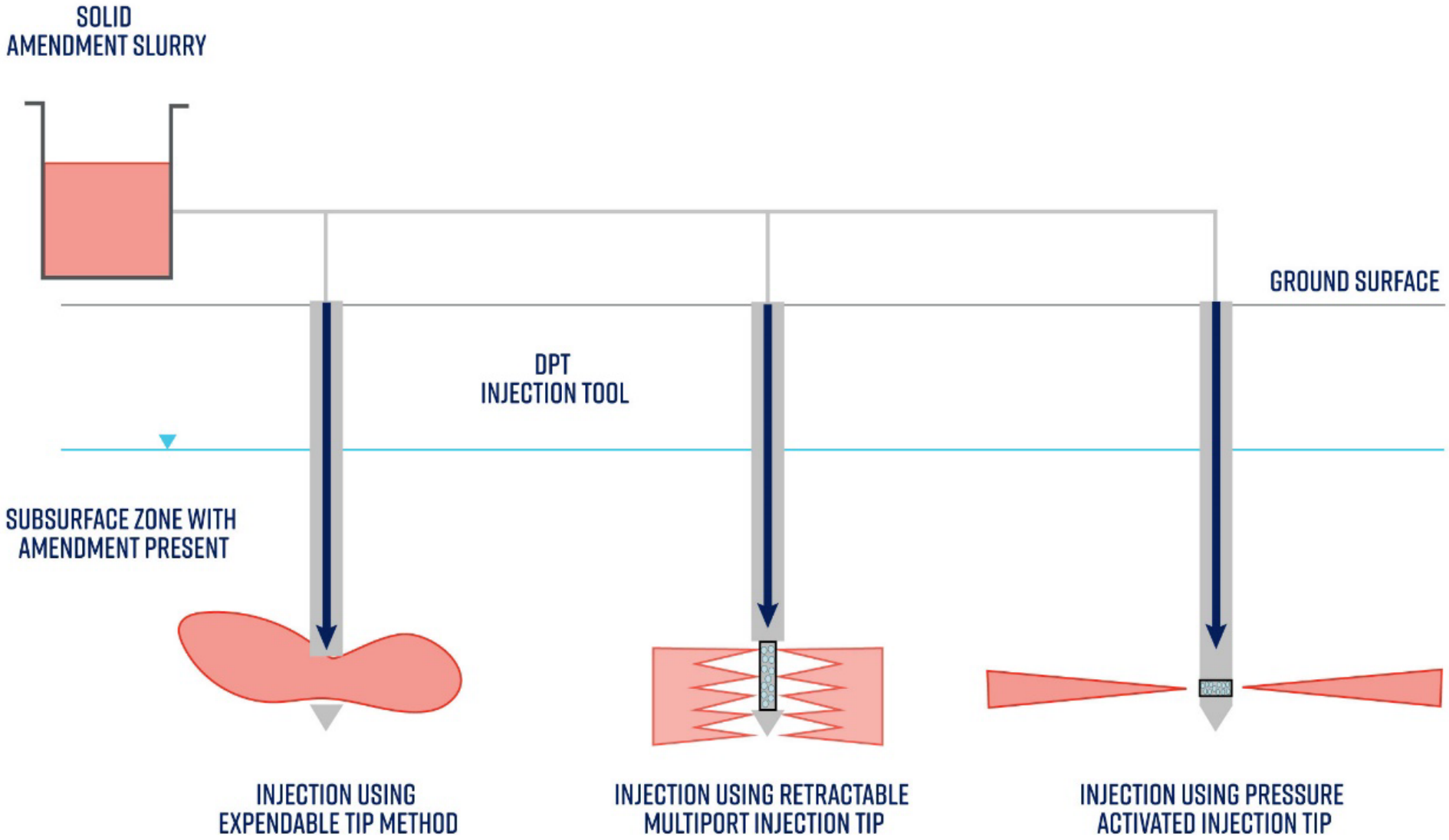

Typical Design Parameters and DPI Equipment Used for Common Types of Solid Amendments

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Parameter	Colloidal Amendments		Microscale Amendments	
	nZVI	CAC	mZVI/C-mZVI	GAC/PAC
Product Form	Concentrated suspension		Dry powder	
Dosing Rate	< 0.1%	0.5 – 2% soil wt	0.25 – 1.5% soil wt	0.5 – 2% soil wt
Injectate Concentration	< 2 – 10 g/L	< 200 g/L, adjustable	100 – 300 g/L	50 – 200 g/L
Additives	Stabilizers included in commercial nZVI suspensions	Proprietary polymer stabilizer	Guar gum (5 – 6 g/L) in C-mZVI)	None
ROI	1 – 3 m		0.5 – 2 m	
Type of DPI Injection Tool	Retractable tool		Pressure activated	
Type of Injection Pump	Air diaphragm or progressive cavity		Progressive cavity or high-pressure piston	
Injection Volumes	Targets 25% to 50% effective pore volume		Controlled by the selected dosing rate, the ROI and injectate concentration	
Injection Pressures	< 5 bars		4 – 40 bars	
Injection Flow Rates	3 – 10 L/min		5 – 30 L/min	

Potential Problems with DPI of High Viscosity Amendments

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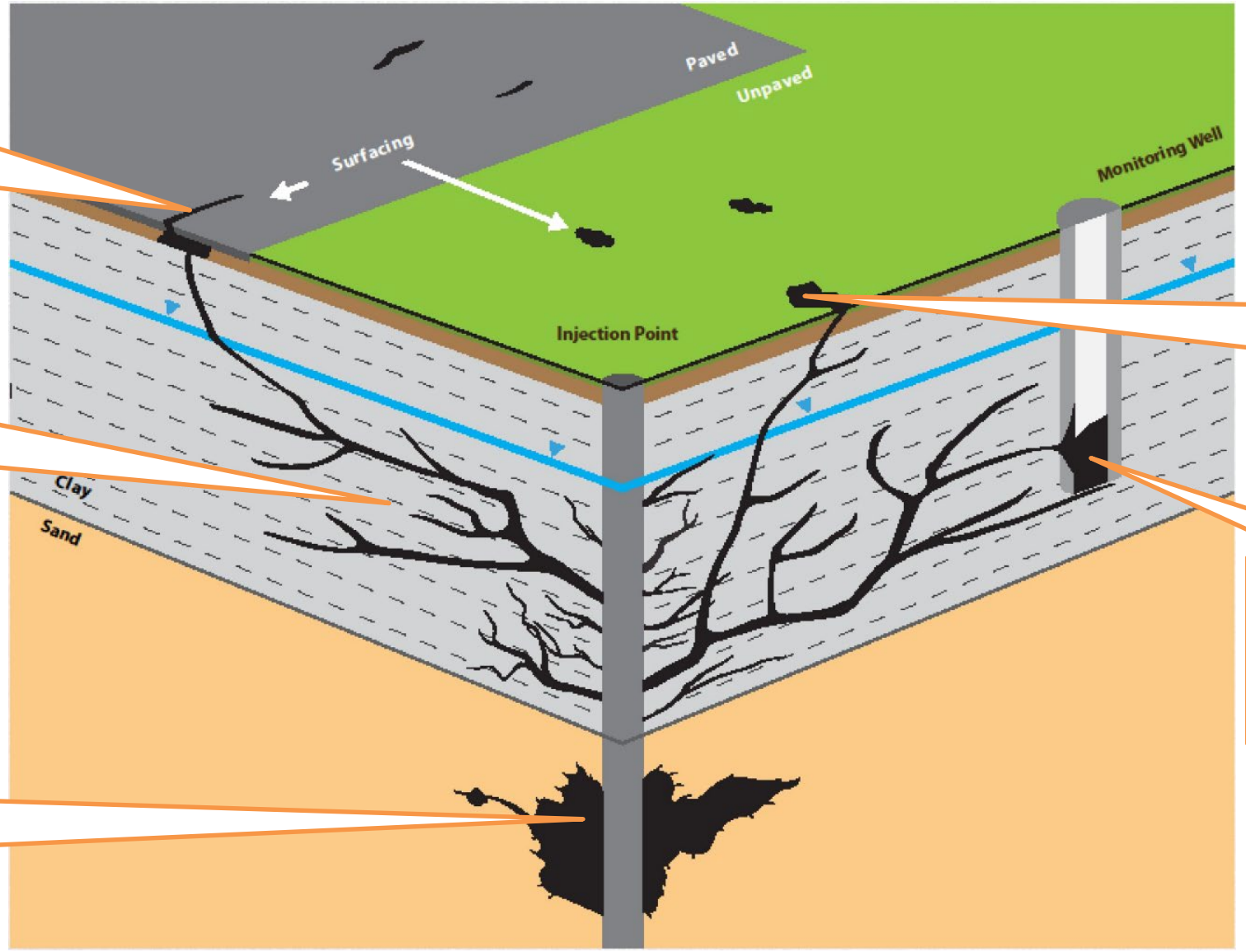
Damage to asphalt

Unplanned, uncontrolled fracturing

Poor ROI, injectate stuck around bottom of point



Injectate daylighting at ground surface

Injectate impacts at neighboring monitoring well

Figure source: Tom Fox at the Colorado Department of Labor and Employment – Division of Oil and Public Safety
https://www.neiwpcc.org/tanks2015old/tanks2015presentations/3-Tuesday/Carbon-Based%20Injections/fox.carbon_injection.tuesday.pdf

Example DPI Implementation Problems and Potential Solutions

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Problem	Example Solution (Partial List)
Difficulty advancing DPT injection rod	• Use a more powerful DPT rig. • Use smaller diameter rods. • Increase injection flow rate. • Use a different drilling method to advance through refusal zones
Injection tool plugging	• Increase concentration of sheer-thinning fluid (guar gum). • Increase injection flow rate. • Flush tooling after each injection interval.
Injectate daylights to ground surface	• Avoid subsurface utilities such as sewer, water, electric, and fiber optic cables • Skip the shallowest interval • Decrease the volume of slurry injected per point in the shallow intervals. • Lower injection pressures.
Insufficient volumes of slurry injected due to backpressure	• Increase the number of injection points • Increase the slurry concentrations to lower injection volumes. • Increase injection pressures. • Replace injection nozzle with a smaller port size (increases injection velocity)
Excessive wear of injection tools	• Use equipment capable of handling solid suspensions with characteristics of the selected amendment. • Inspect tools after each location and replace as necessary.

Injection sequence – some best practices

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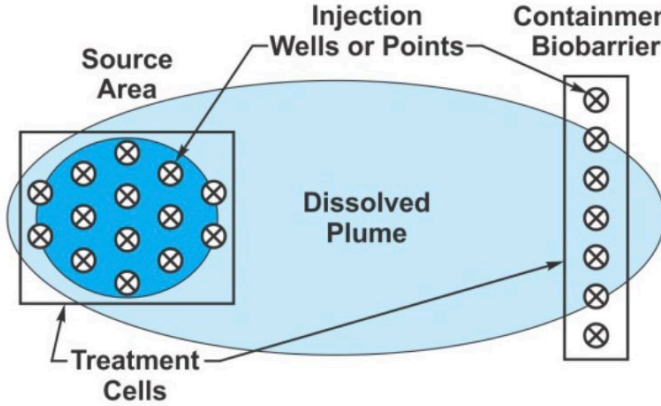
- ✓ Both top-down and bottom-up injection have been used
- ✓ top-down succeeds more often
- ✓ Pressure-activated tip is more successful with top-down approach; prevents plugging during advancement between injection intervals
- ✓ Bottom-up approach creates preferential pathway for downward migration of injectate during retraction of the rods, resulting in pyramid-shaped distribution
- ✓ Bottom-up may be successful when target formation permeability decreases with depth
- ✓ Work from outside -> in. From low concentration areas, toward high concentration areas
- ✓ With grid injection designs, avoid consecutive injections into adjacent locations; move to give geologic formation pressures time to dissipate



Injection point spacing and layout – best practices

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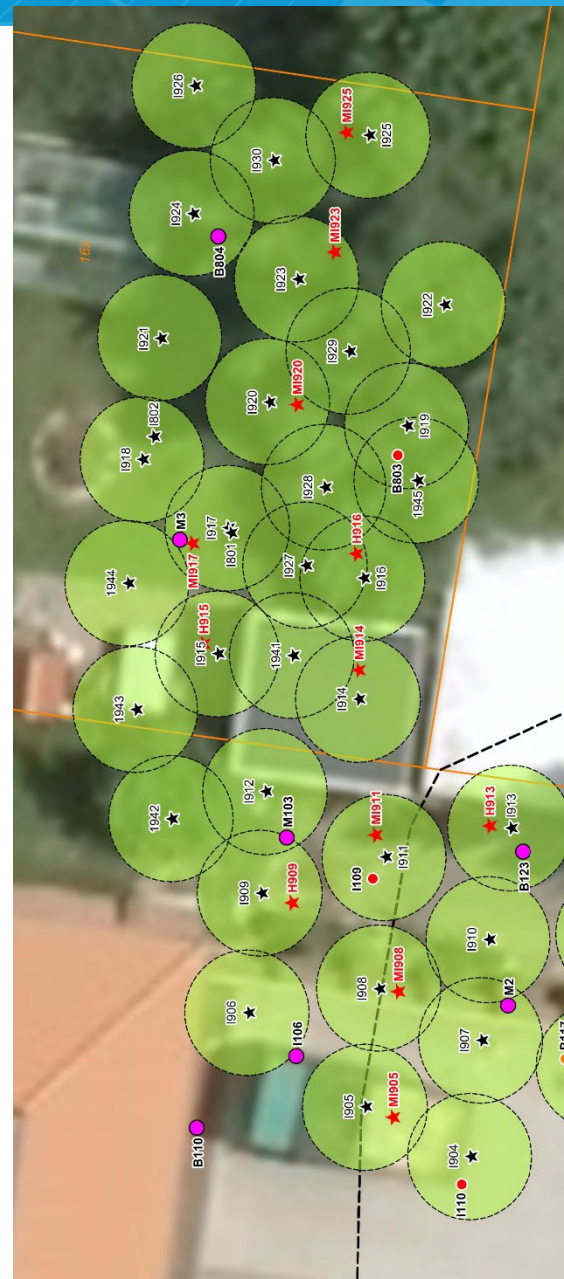
- ✓ Account for groundwater flow rate, groundwater geochemistry, and reagent consumption rates – consider objective residence time in treatment zone
- ✓ Apply a factor of safety in injection point / ROI coverage of target treatment area
- ✓ Overlap ROIs. Use denser grid spacing in higher COC areas
- ✓ Use multiple rows of injection points in PRBs
- ✓ At many sites, three or more rows may be needed to provide a sufficient residence time and treatment longevity.
- ✓ Alternate injection depths in adjacent injection points to improve coverage
- ✓ Select amendment dose that accounts for consumption/degradation by all reaction and physical processes



Injection Volume – Best Practices

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- ✓ Total injection volume is determined differently between high viscosity (e.g., mZVI) and low viscosity amendments (e.g., CAC, nZVI).
- ✓ For mZVI, amendment dosage drives volume - slurry volume is calculated by dividing total mass of amendment by the amendment concentration in the slurry
- ✓ For colloidal amendments (CAC, nZVI) that are injected as diluted and stabilized suspension using low pressure, the injection volume target is to 25% to 50% of effective PV.
- ✓ Pilot testing should be used to assess the ability of the target formation to accept the calculated injection volume.
- ✓ A delicate balance exists between injection volume, concentration, ROI, and cost
  - ➢ daylighting of injectate at the ground surface can occur if the injection volume exceeds the capacity of the geologic matrix in the TTZ. In this case, the amendment concentration in the injectate could be increased to reduce the overall injection volume.
  - ➢ If volume is decreased, ROI may also decrease, and injection spacing may need to decrease, and DPT cost may increase

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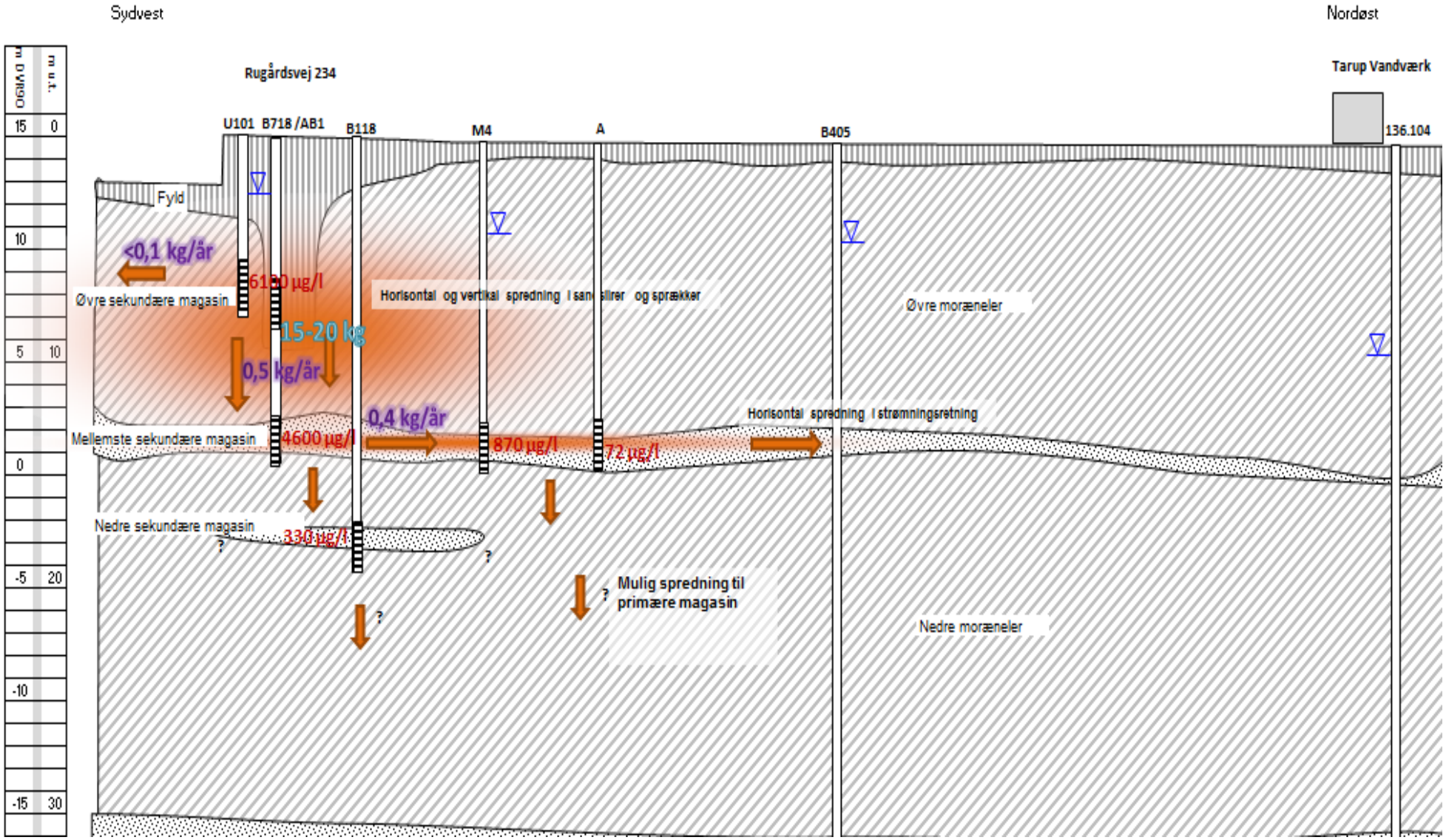
A Feel-Good Story Involving DPT
This is How We Do It

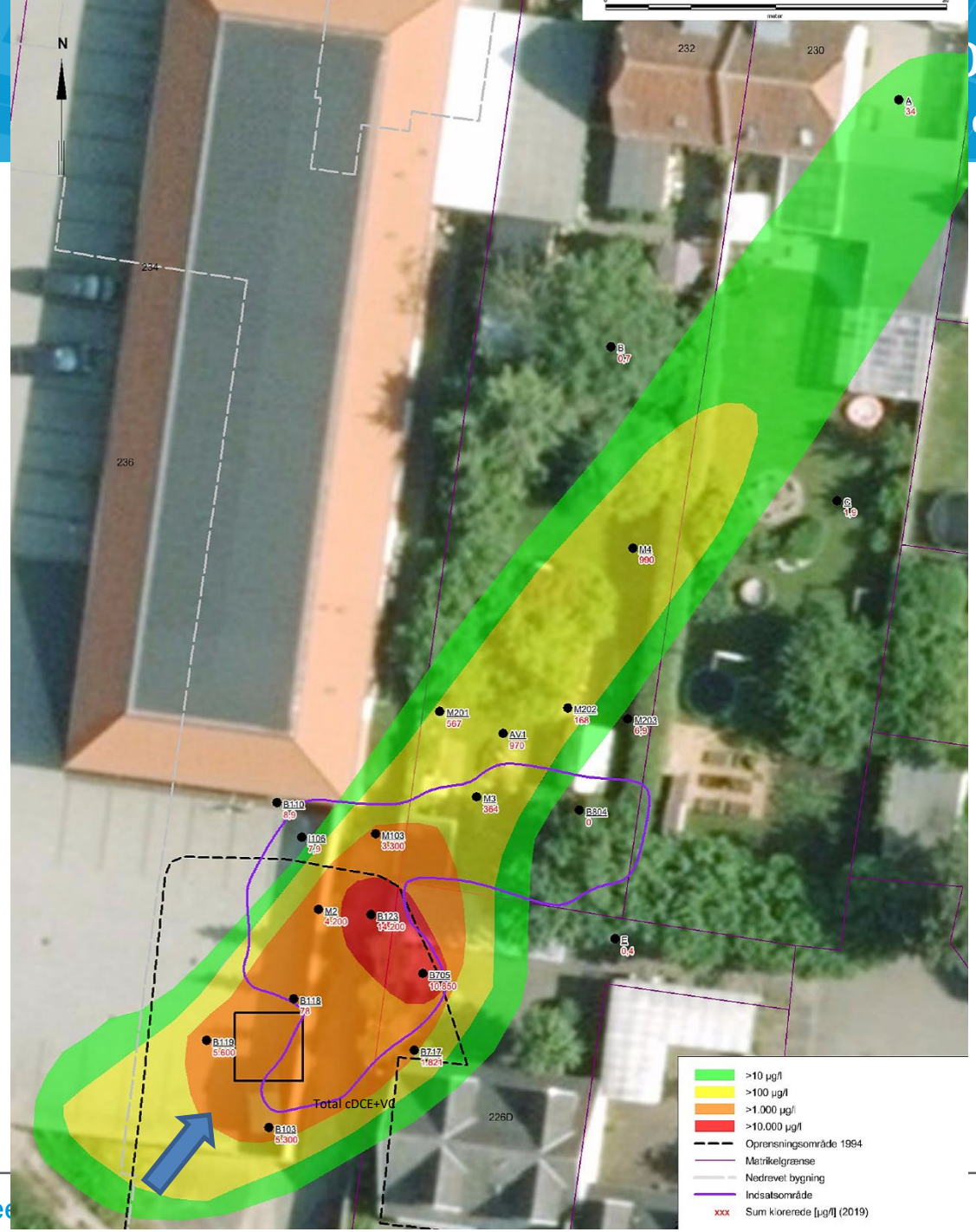
Conceptual Site Model



cVOC (cDCE + VC) in Sand Unit

Pre-remediation conditions:

- 15-m wide combined cDCE/VC plume.
- TCE present at trace concentration even in the source zone.
- Off-site plume migration to a well 100 m downgradient.
- The highest total VOC. concentration detected in the source zone 14 mg/L.
- GW velocity in sand estimated at between 0.24 m/d.



Design and Injection Point Layout

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- mZVI application dose: 1.5%wt to soil (5-7 ft thick sand layer, starting from 35 ft bgs).
- 40 DPT injection points 8 ft on center.
- 5 injection intervals in each DPT point (660 lb. mZVI per point).
- mZVI delivered in a guar gum slurry (300 g/L ZVI, 6 g/L GG), along with KB-1 (0.5 L per IP).
- DPT injection using a using a pressure activated tool (Geoprobe) and a high pressure grout pump.

mZVI Injection Process

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DPT Injection Tip

Plugging of the tip during top-down injection (settling of mZVI during transition between injection intervals). Change was made to flushing out the rods with anaerobic water before transitioning to the next lift.

5-yr Results of mZVI Remediation

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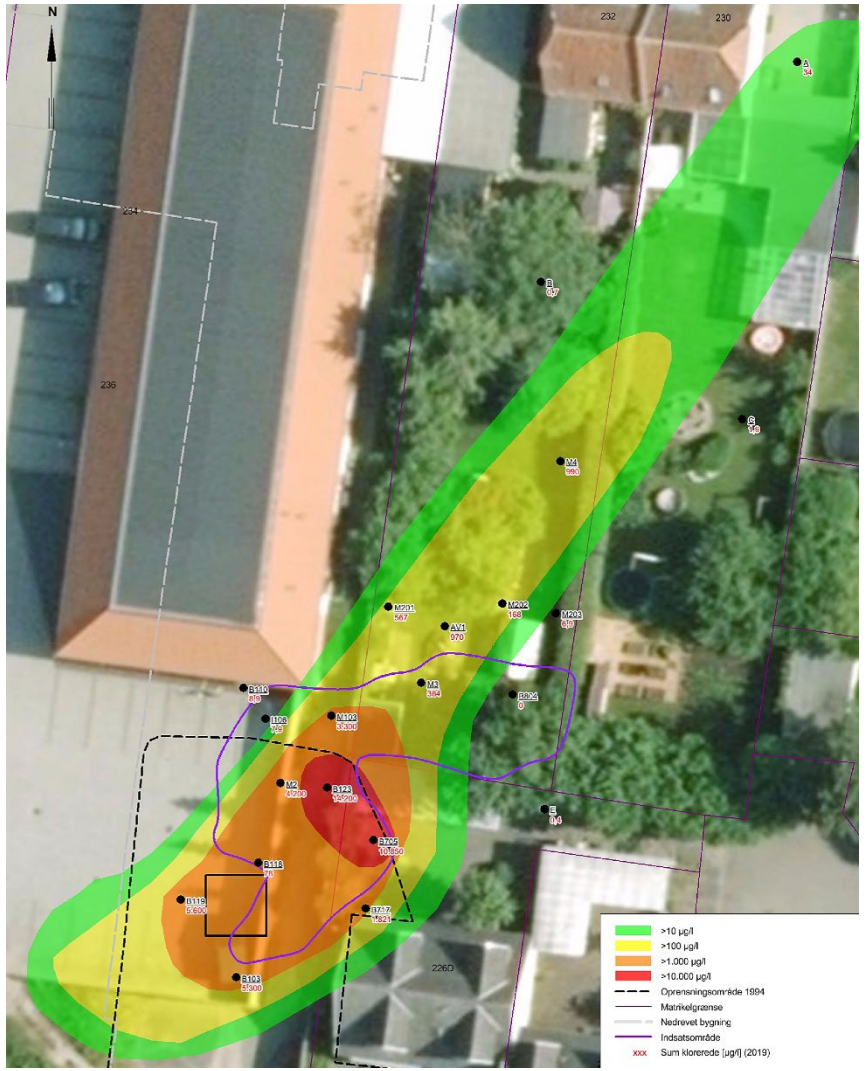
VOC plume prior to mZVI Injections



VOC plume 5 years after mZVI Injections

Thank you, Denmark!

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Want to learn more? Download the DPT Practitioner's Guide at:

https://kmiregh.kontainer.com/folder/267735