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Full-Scale Demonstration of DPT-Jet Injection with Microscale ZVI to Remediate a Chlorinated Solvent Source Area in Clay Till at Møllevej 9, Nivå

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ATV JORD OG GRUNDVAND

Workshop on Injection of Remediation Agents
Copenhagen, 3 November 2022

DPT Jet Injection Technology Development Team

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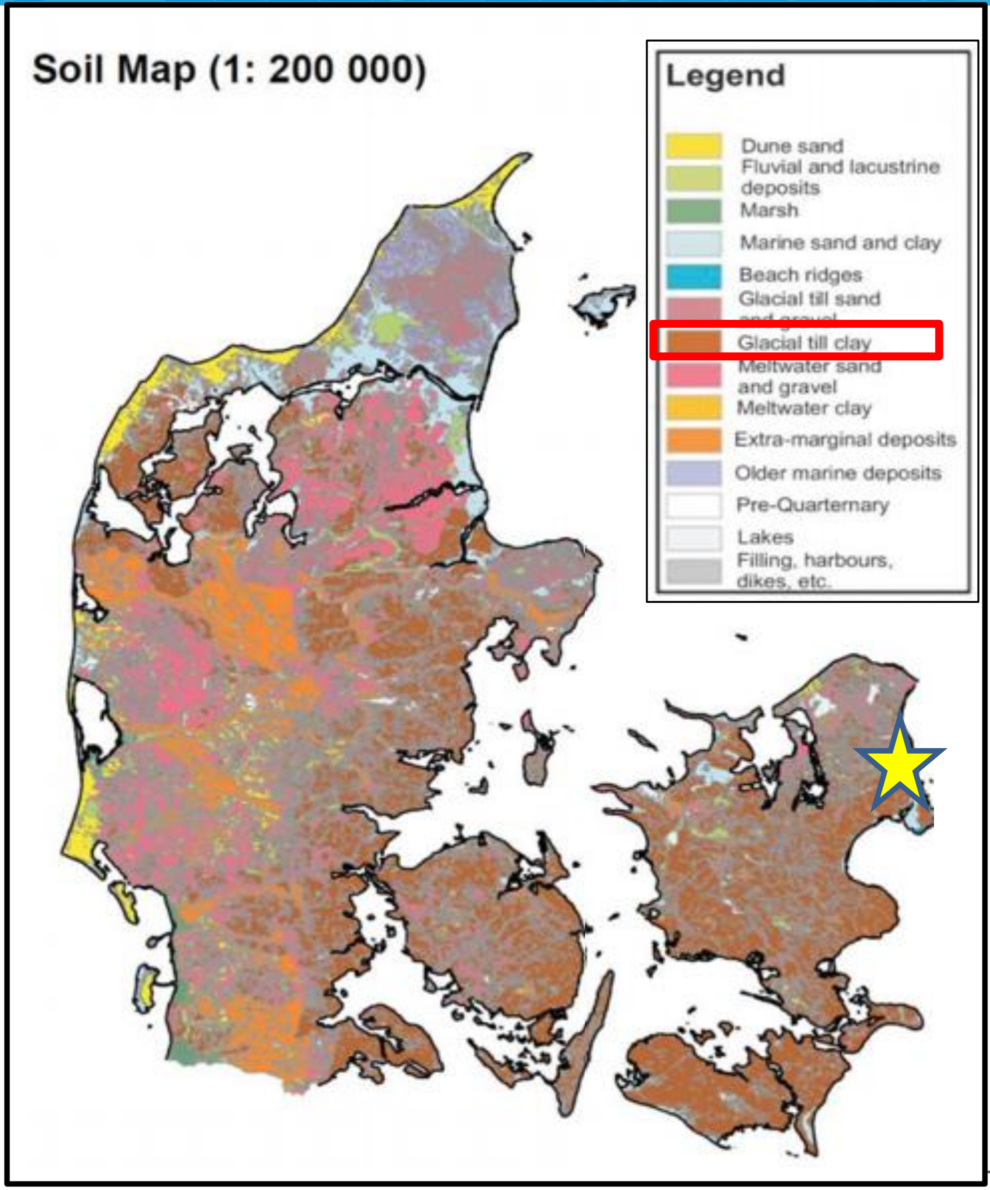
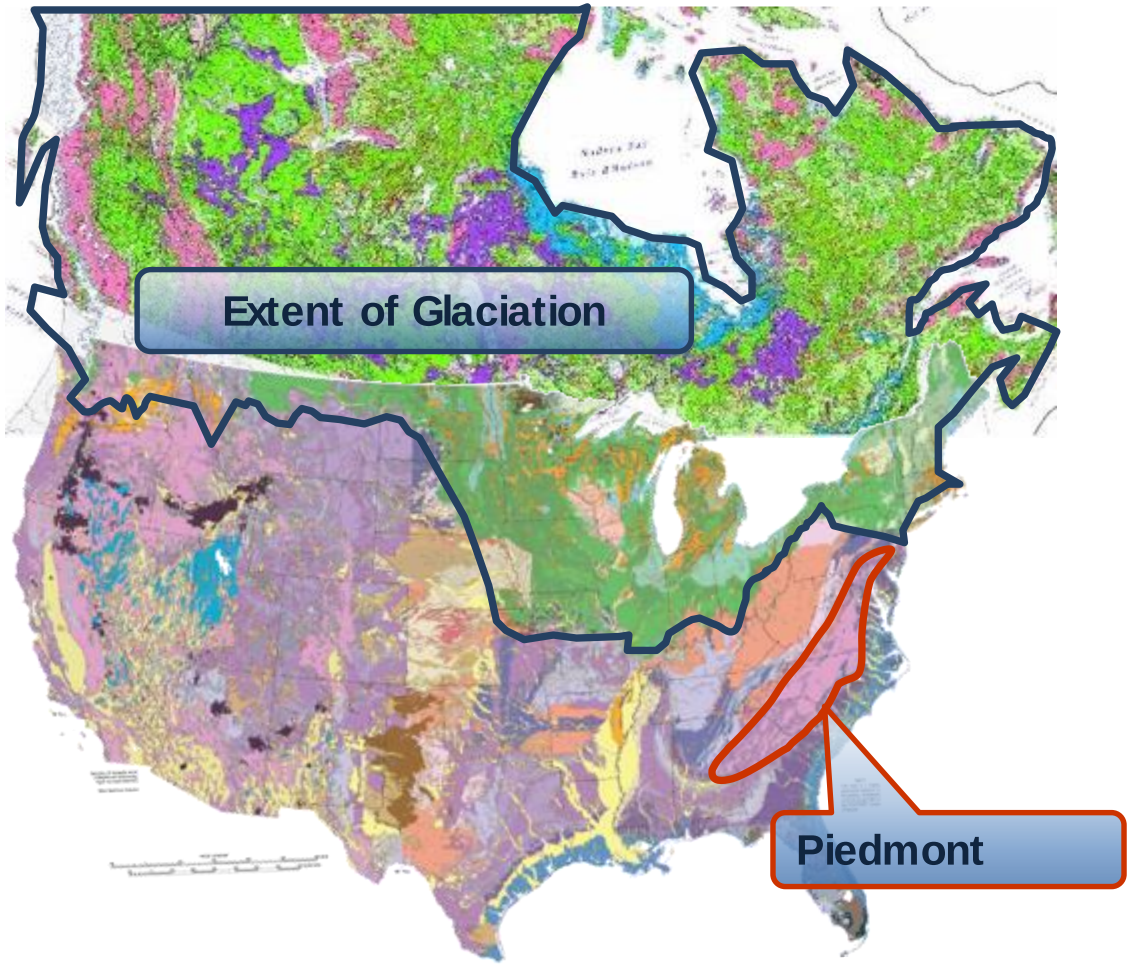
- ❖ Peder Johansen, Nina Tuxen, Mads Terkelsen — Region Hovedstaden
- ❖ Neal Durant, Dylan Eberle — Geosyntec consultants
- ❖ Bill Slack, Doug Knight, Chapman Ross — FRx
- ❖ Torben Højbjerg Jørgensen, Morten Dreyer — COWI

Problem, Part 1:
40% of Denmark is Covered in Clay Till



….glacial clay is also common in North America



Source: Karin Margarita Frei (2012) Exploring the potential of the strontium isotope tracing system in Denmark, Danish Journal of Archaeology, 1:2, 113-122, DOI: 10.1080/21662282.2012.760889

Problem, Part 2: Chlorinated Solvents released into clay till diffuse into the clay matrix, making remediation costly and challenging

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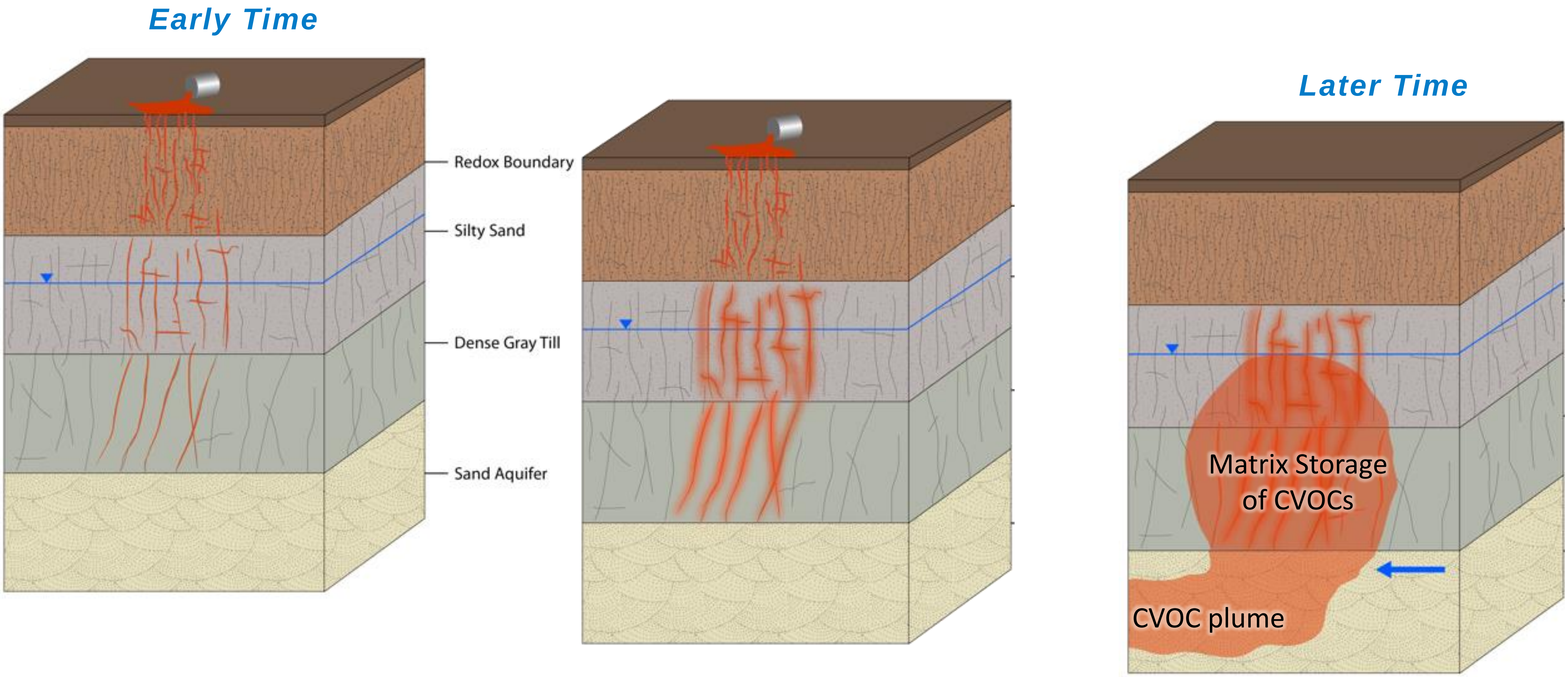

Problem, Part 3: We need a better mousetrap for clay till

In Situ Thermal Desorption

- High remediation efficiency, but expensive
- Was expensive before the energy crisis. And now….
- Environmental sustainability?
- Requires secondary, additional treatment at ground surface

Conventional DPT Injection

- Low permeability limits effectiveness of delivery
- Low radius of influence
- Poor control of placement
- High tendency for short-circuiting to ground surface

DPT-JI Technology Demonstration
Full-scale Source Area Remediation at Møllevej 9, Nivå

Project Phases and Timeline

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2011	2012 - 2013	2014	2015 - 2020	2021
Phase 1 - Taastrup Pilot Test	Phase 2 – Innovation / Redesign	Phase 3a – Møllevej 9 Injection Demonstration	Phase 3b - Møllevej 9 Treatment Demonstration	Phase 4 - Cost & Performance Report
• Clay till • Nanoscale ZVI • Rhodamine dye • Conventional hydraulic fracturing • Excavated injection test plot • Fracture mapping • Fracturing not controlled (unsuccessful)	• Developed DPT fracturing method • 3D printed prototype • Pilot tests in Ohio and South Carolina	• DPT. Jet Injection of mZVI • Clay till, chlorinated solvent source • Test: controlled & consistent emplacement of fractures • Fracture mapping	• DPT. Jet Injection of microscale ZVI • Clay till, chlorinated solvent source area • 6 to 12 m bgs • 50 tonnes mZVI • 121 fractures	• Hypothetical clay till site • Chlorinated solvent source area • Compare cost of DPT-JI to ISTD, EK-BIO, and ISS

DPT- Jet Injection: A Solution for In Situ Remediation of Clays, Silts and Saprolite

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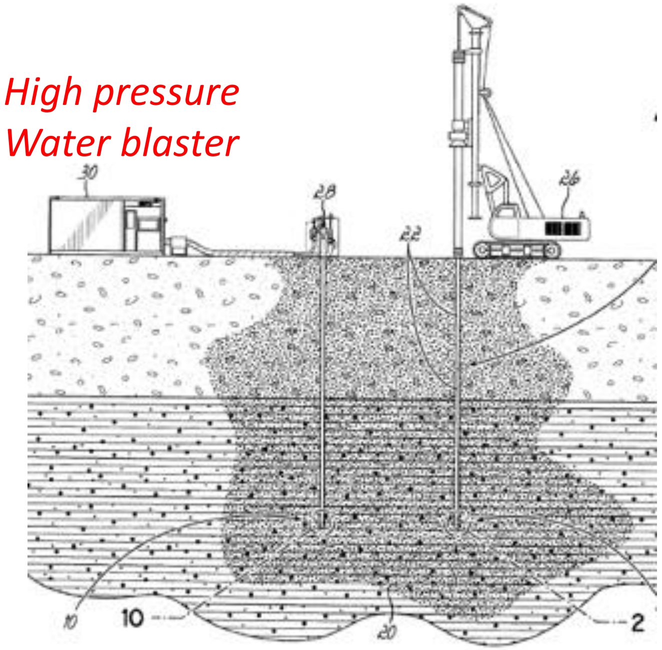
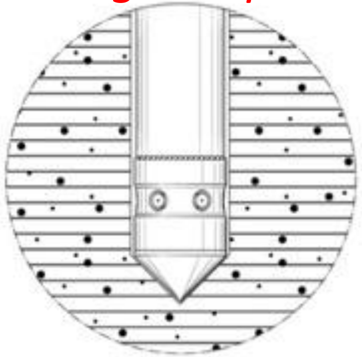
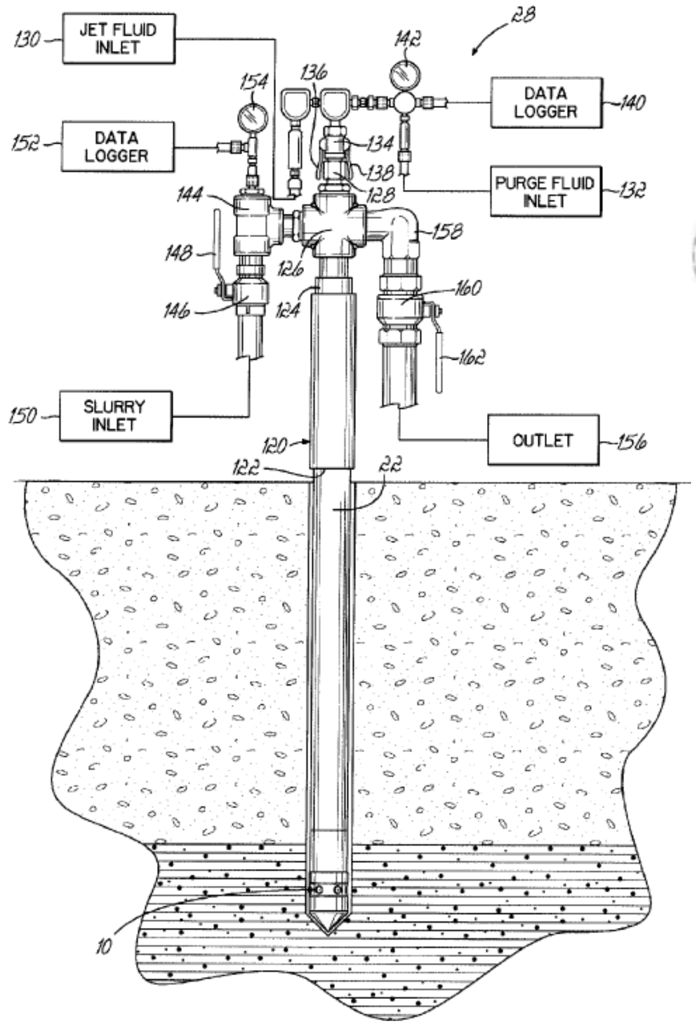
High pressure Water blaster



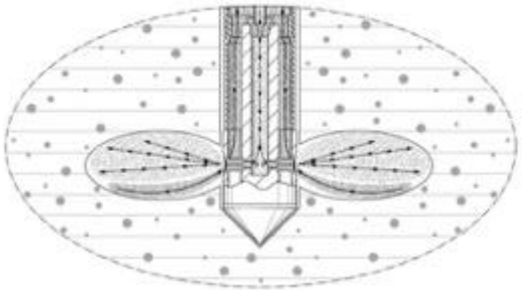
Push to target depth



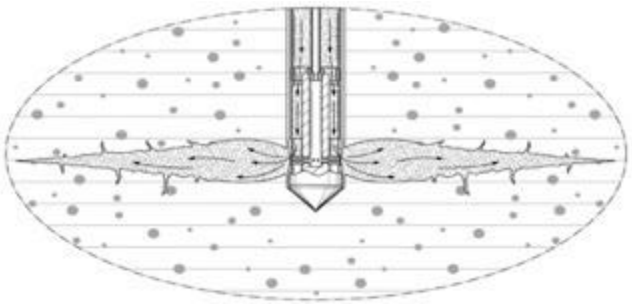


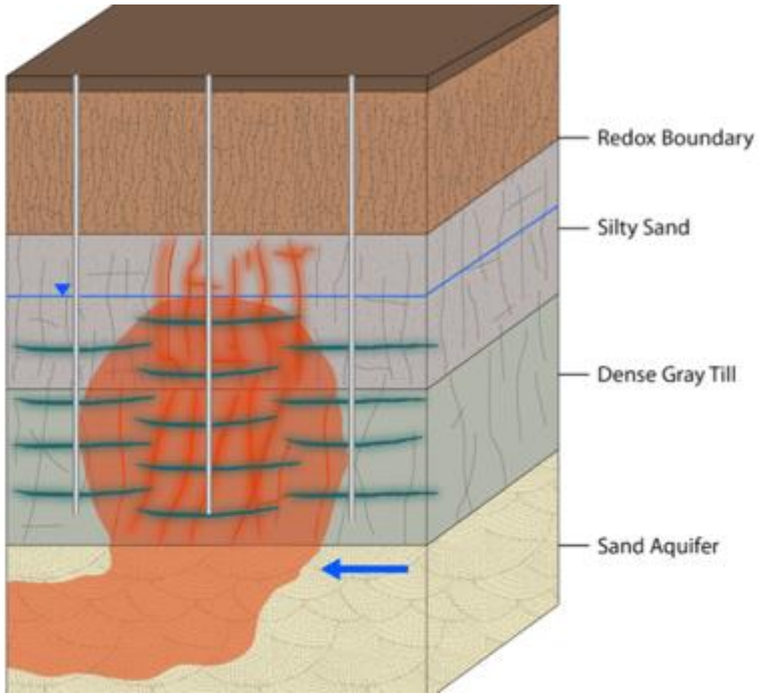
(10) **Patent No.:** **US 10,471,484 B2**
(45) **Date of Patent:** **Nov. 12, 2019**

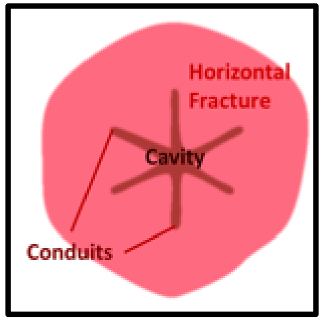
690 bar (10,000 psi) jetting – cuts conduits



10 to 27 bar (400 psi) slurry injection to complete fracture







Geologic Profile for Møllevej 9 Area

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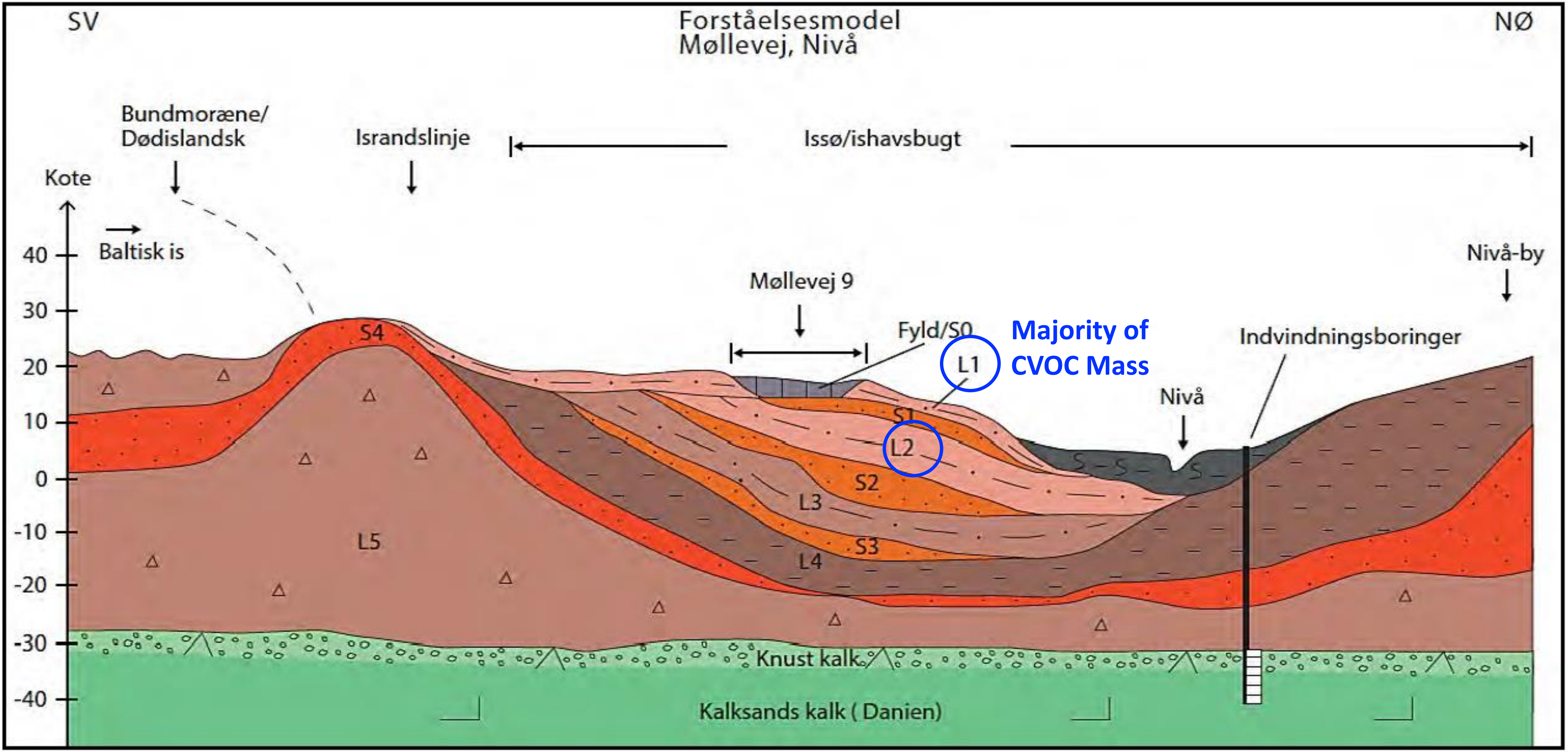

DPT-JI mZVI Remedial Design, Møllevej 9

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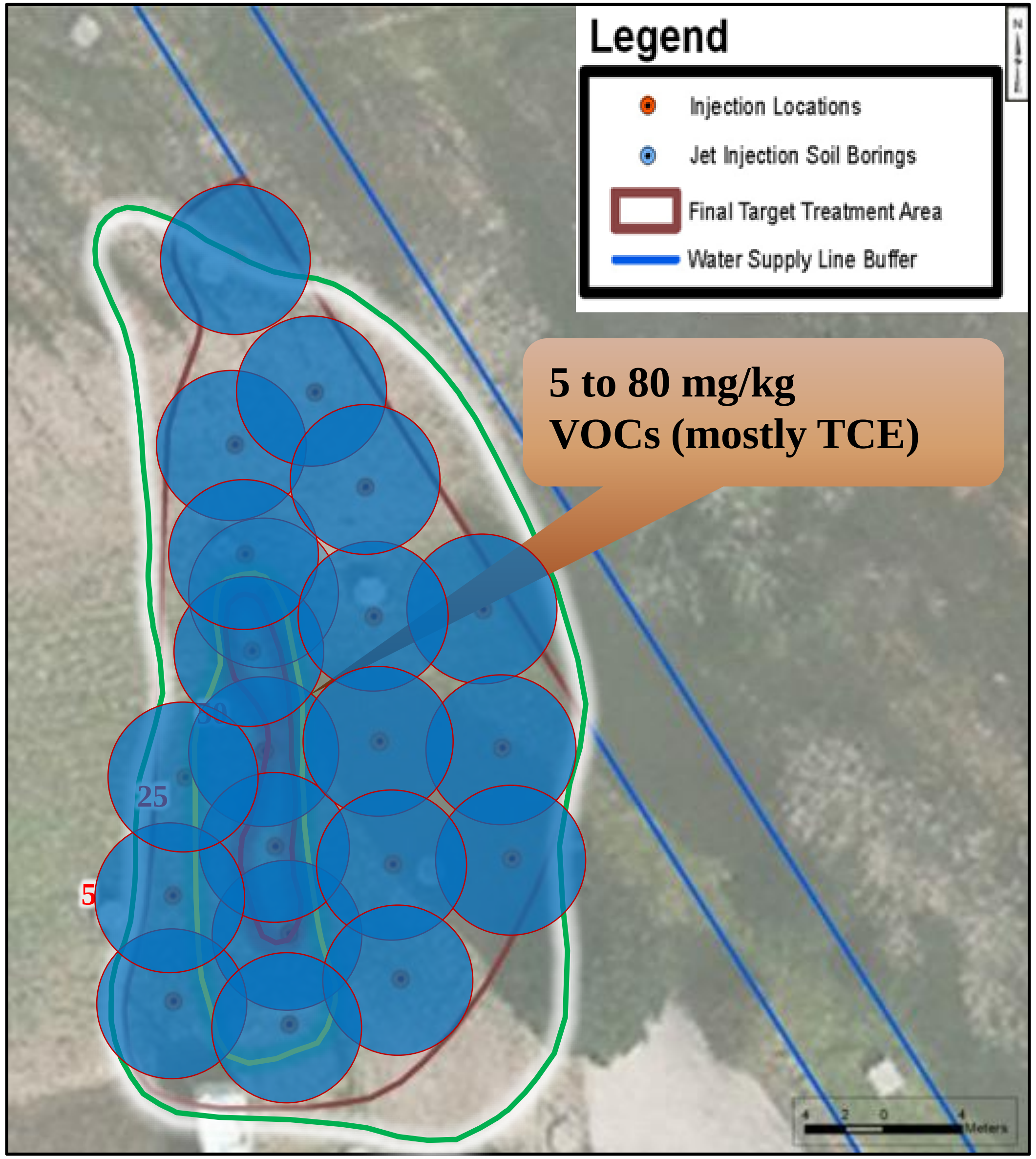
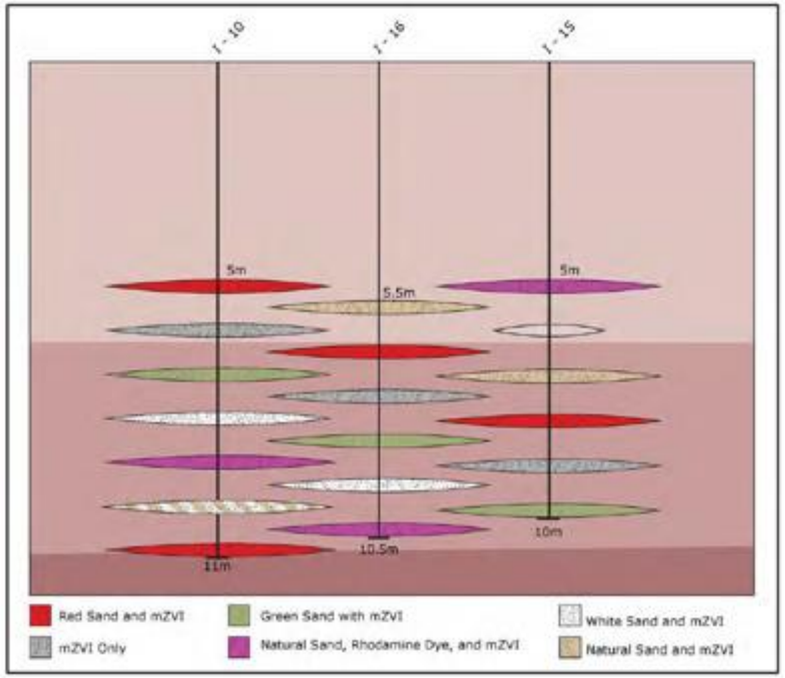
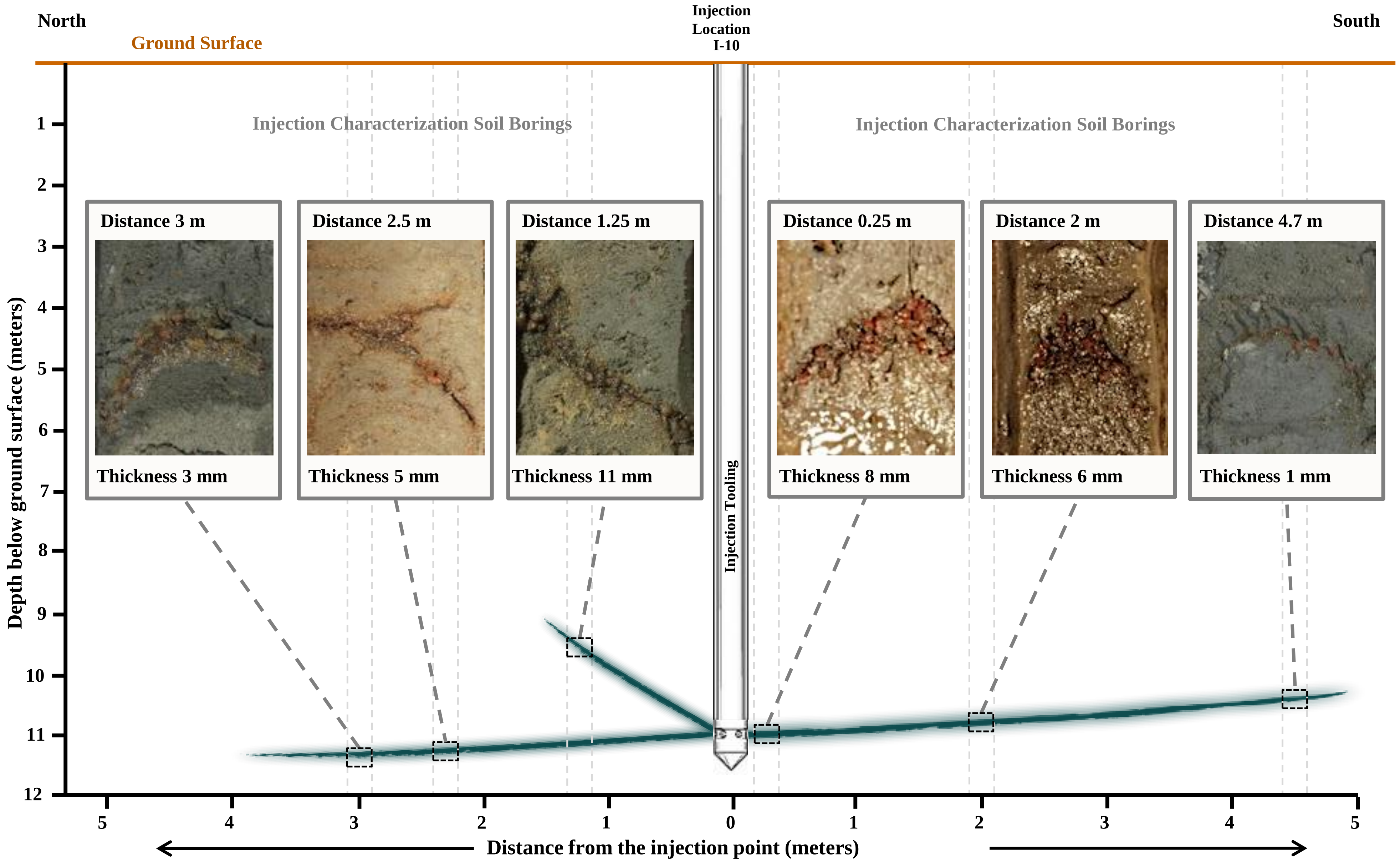


- 714 m^2 Target Treatment Area (TTA)
- Injection depth range: 6 to 12 m bgs
- 3,985 m^3 treatment volume
- 0.5 to 1.0 m injection intervals
- 4 m design ROI
- 21 injection locations with 121 individual injections
- 50 tonnes mZVI (Hepure Ferox Flow)
- 25 tonnes sand



Tracing Individual Fractures



Lateral Distribution of Horizontal Fractures – North / South Cross Section

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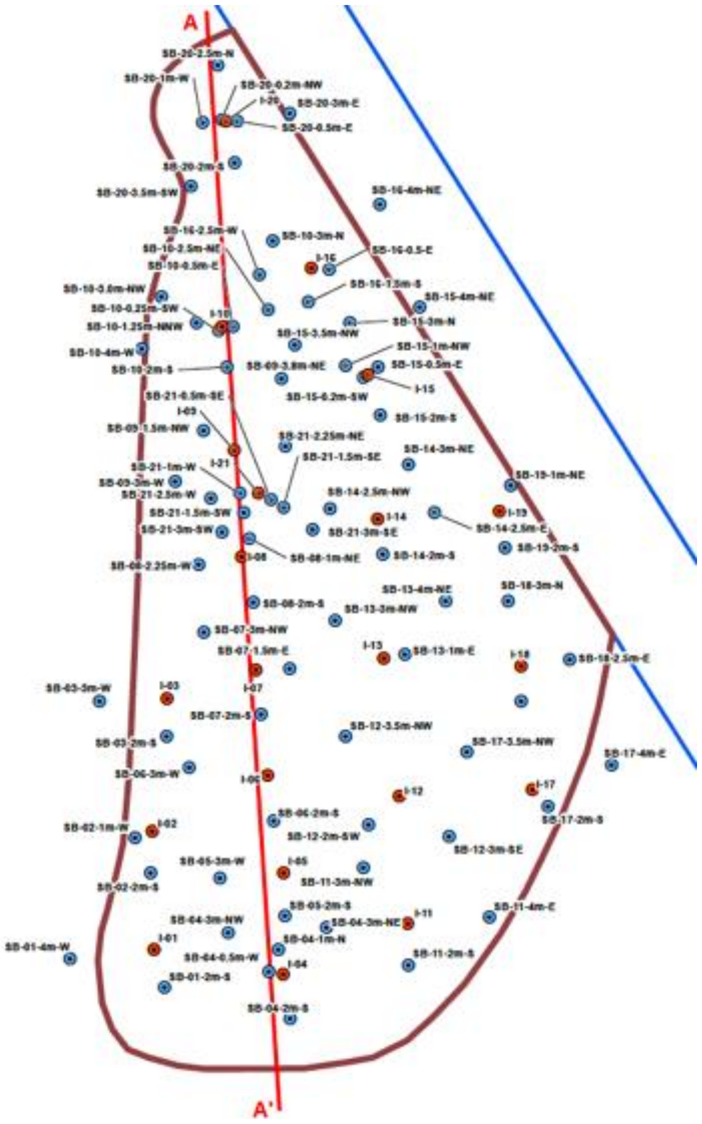
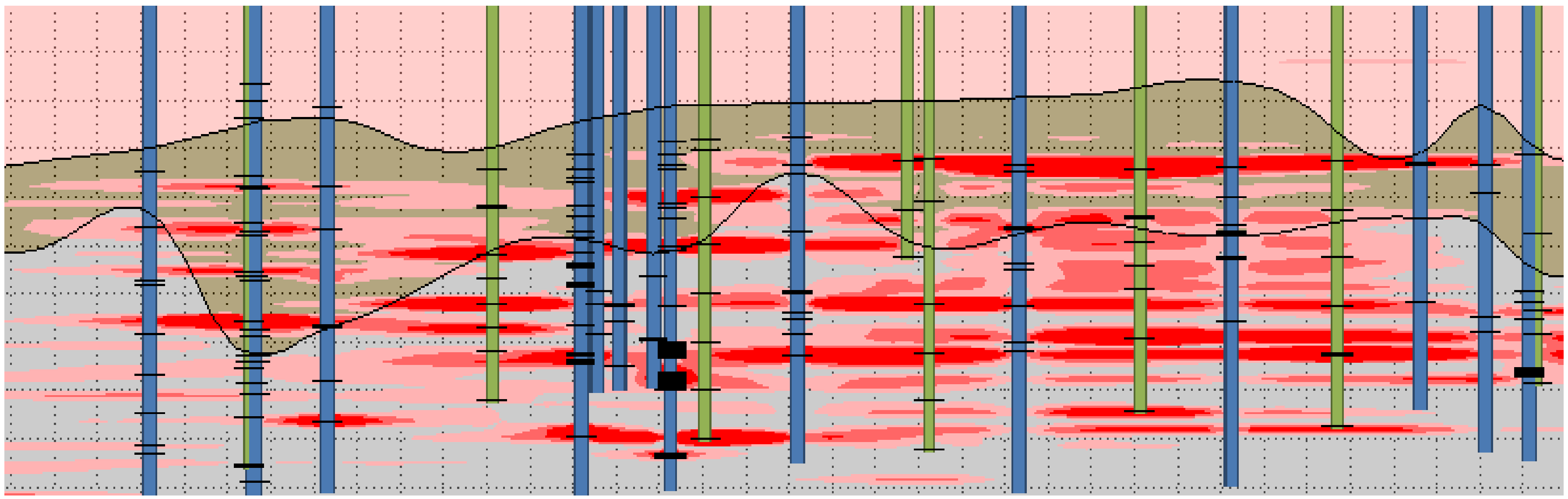
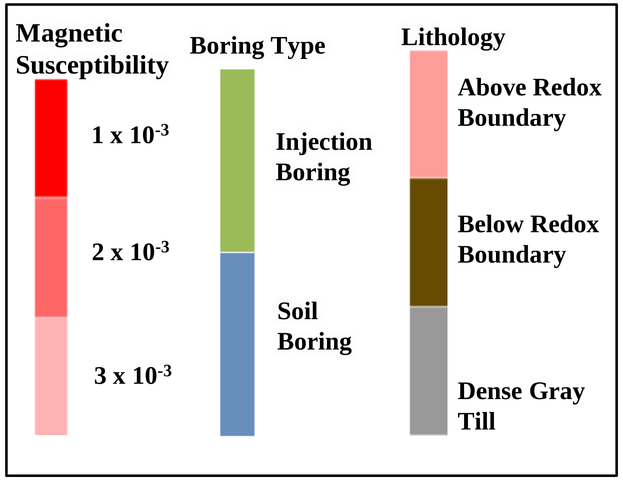


North

South





Black tick marks are visual ZVI observations in soil borings
(3D model verification)

North-South 2 Cross-Section

Møllevej 9, Nivå, Denmark

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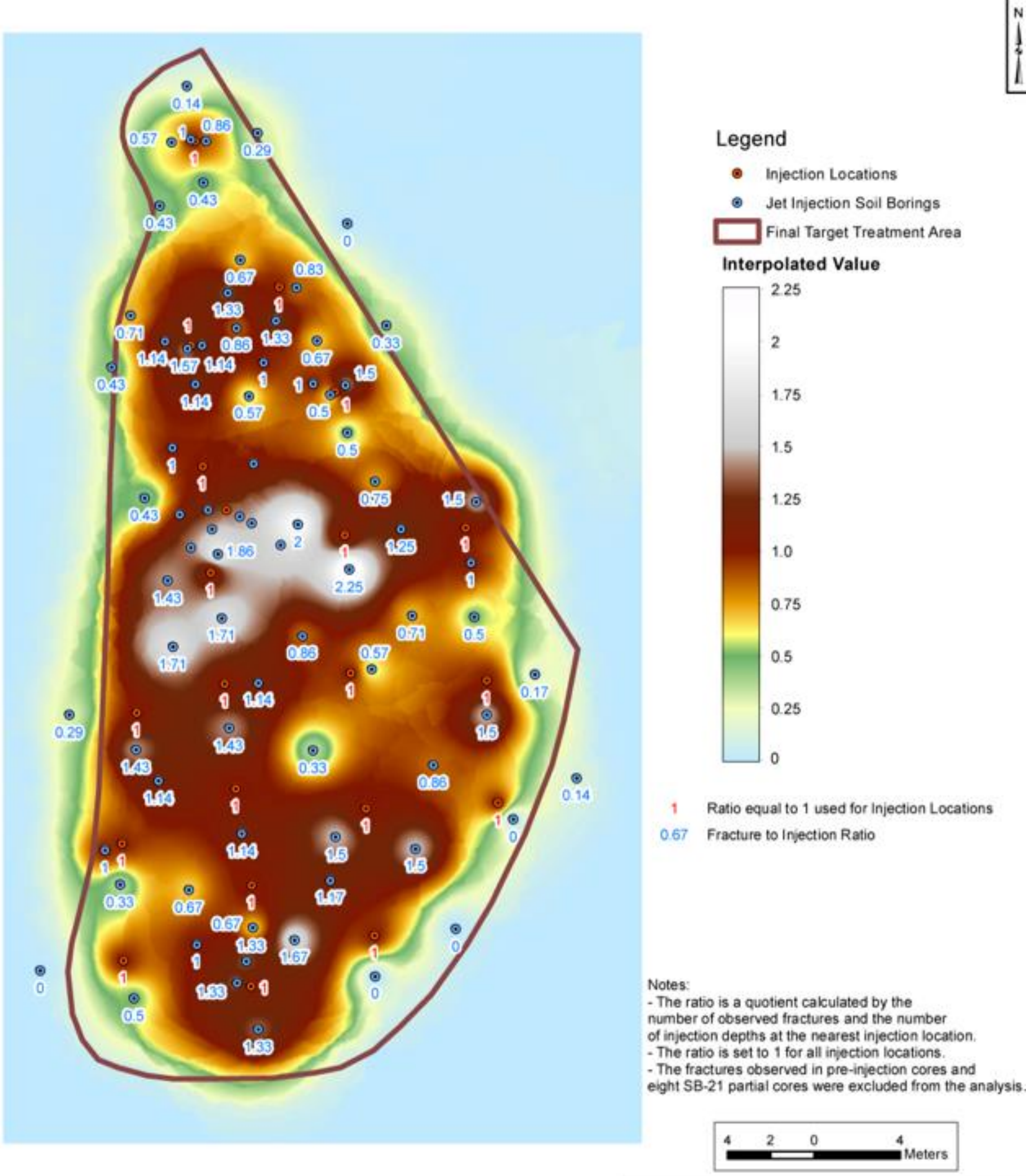
Columbia, Maryland | March 2015

Fracture Emplacement – Summary of Results

- DPT-JI process is faster than conventional hydraulic fracturing
- Daylighting observed at 4 locations (historical borings, unknown infrastructure)
- Emplaced fractures subhorizontal, overlapping, consistent with design
- mZVI-filled fractures detected 423 times
- Natural vertical fractures filled with mZVI observed at 22 locations
- Fracture thickness
  - range: 1 to 111mm
  - Typical: 2 – 4mm
- Fracture length / ROI
  - range: 1.7 to 5.7m
  - Typical: 3.5



mZVI Treatment Performance
Full-scale Source Area Remediation at Møllevej 9, Nivå

Measuring Performance of Remediation by mZVI

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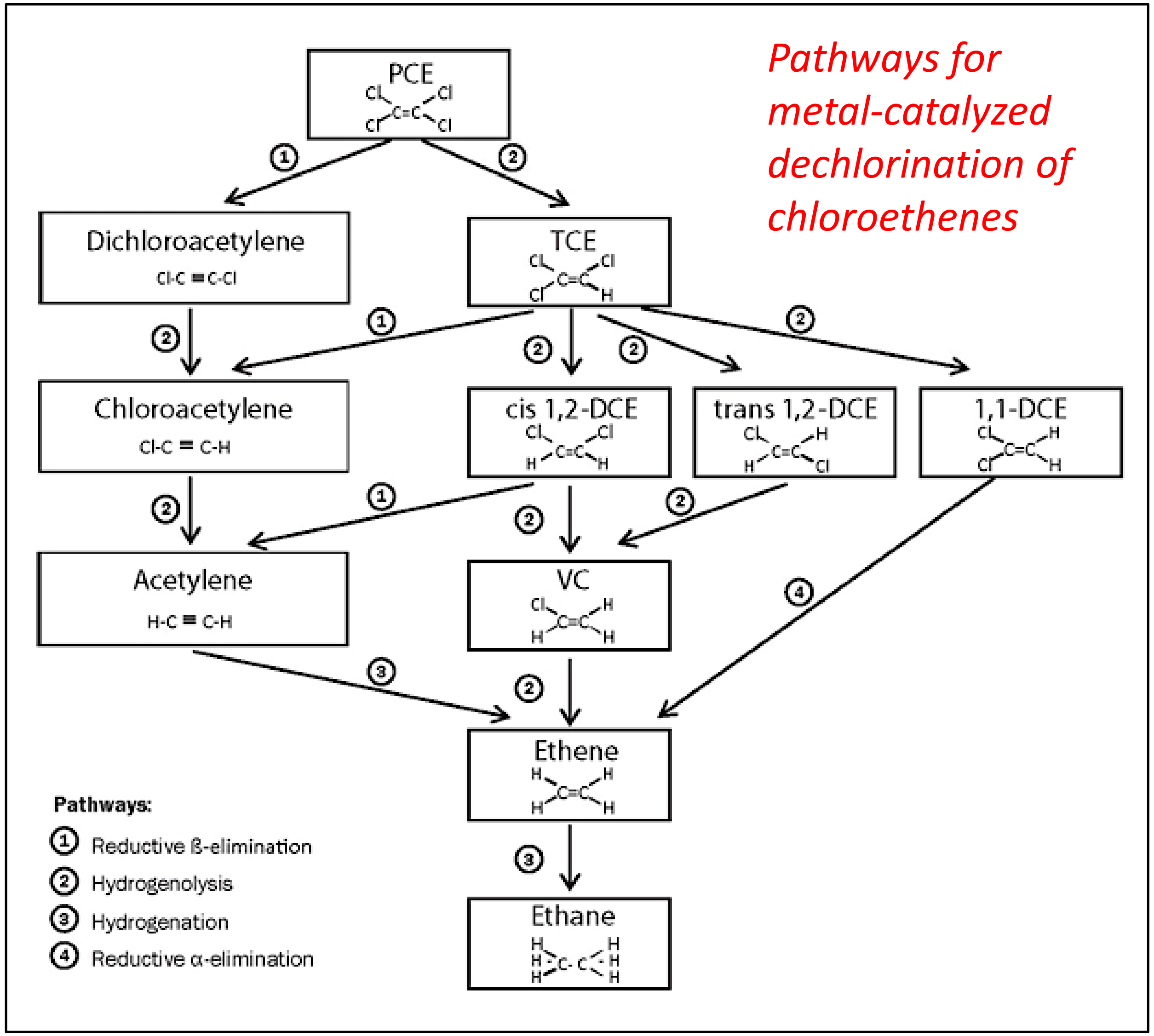
- Soil core sampling annually at 14 locations (1,951 soil samples)
- Development of EVS (Arcview/GIS) model to estimate CVOC mass in TTZ
- Groundwater sampling two times per year in Years 1-4; one sampling event in Year 5 and Year 6
  - at ~ 13 well clusters (3 wells per cluster)
  - 385 groundwater samples
- Estimation of CVOC mass discharge across transects
- MIP/HPT to inform soil boring locations
- CSIA – dual isotope $^{37}Cl/^{35}Cl$, $^{13}C/^{12}C$ to evaluate mechanisms
- Biomarkers for dechlorinating bacteria



Example Soil Results – TCE Baseline vs. Year 6
All Soil Samples

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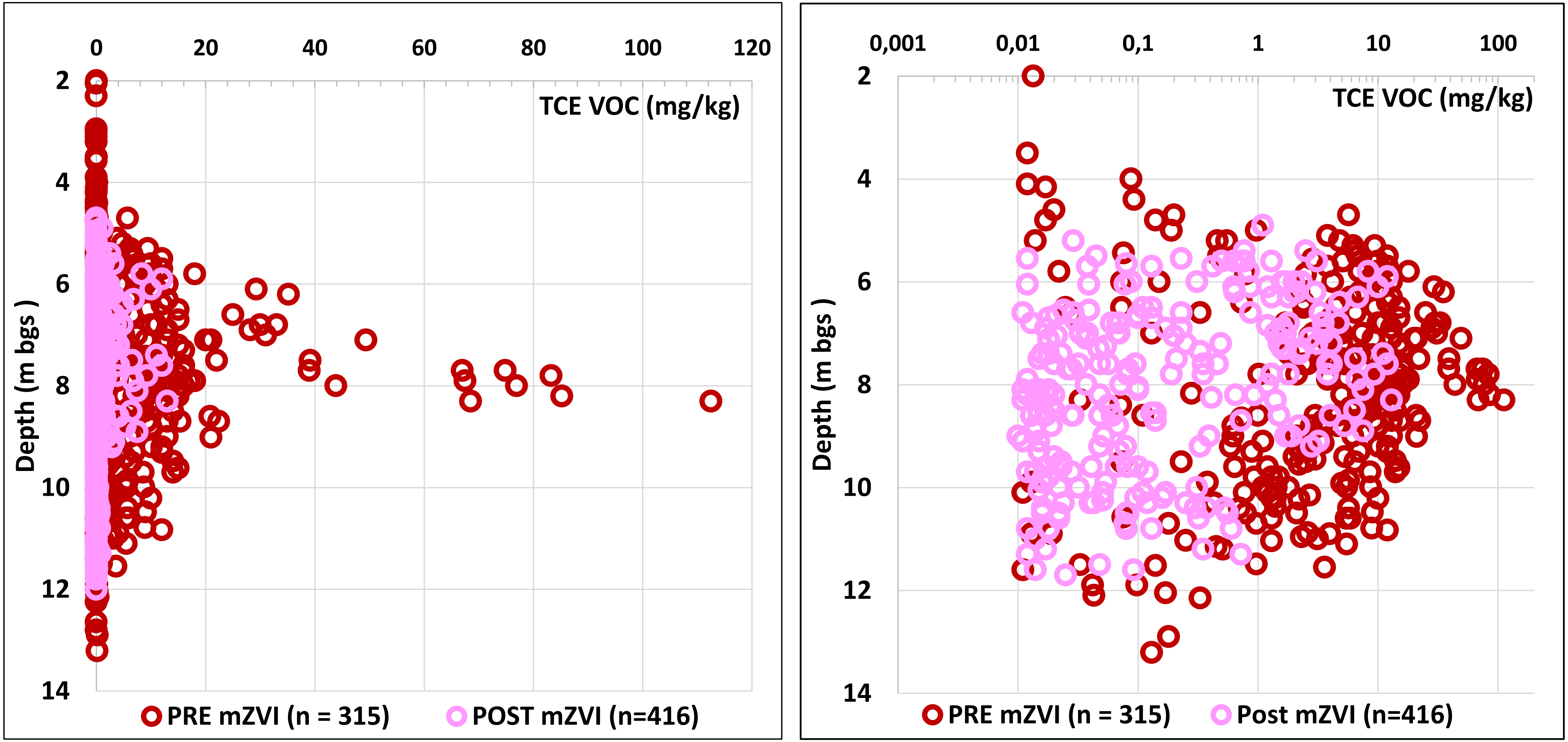

Example Soil Results – TCE Baseline vs. Year 6 Borings K68 & K69

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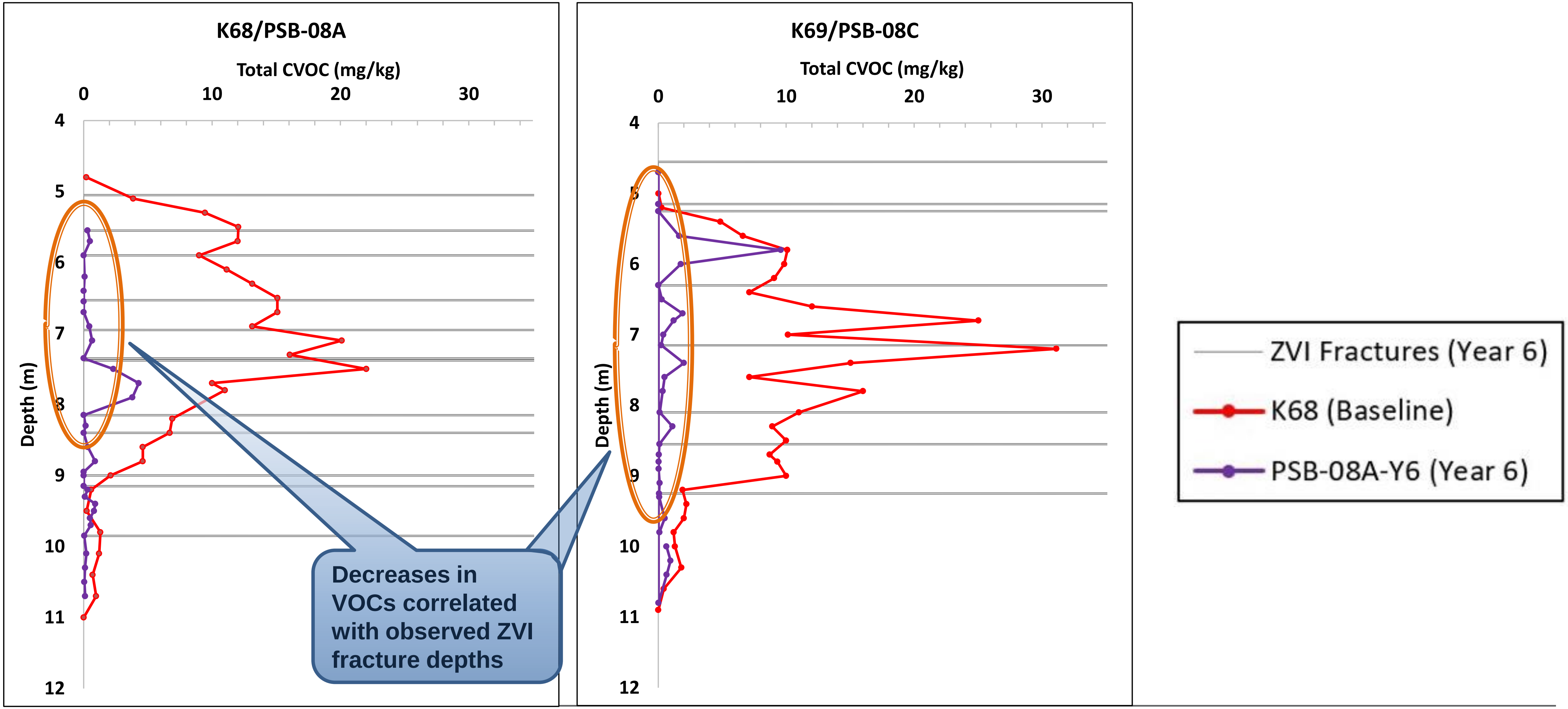

Change in CVOC Mass in Target Treatment Zone (TTZ) - (EVS (Arcview/GIS) Model Domain)

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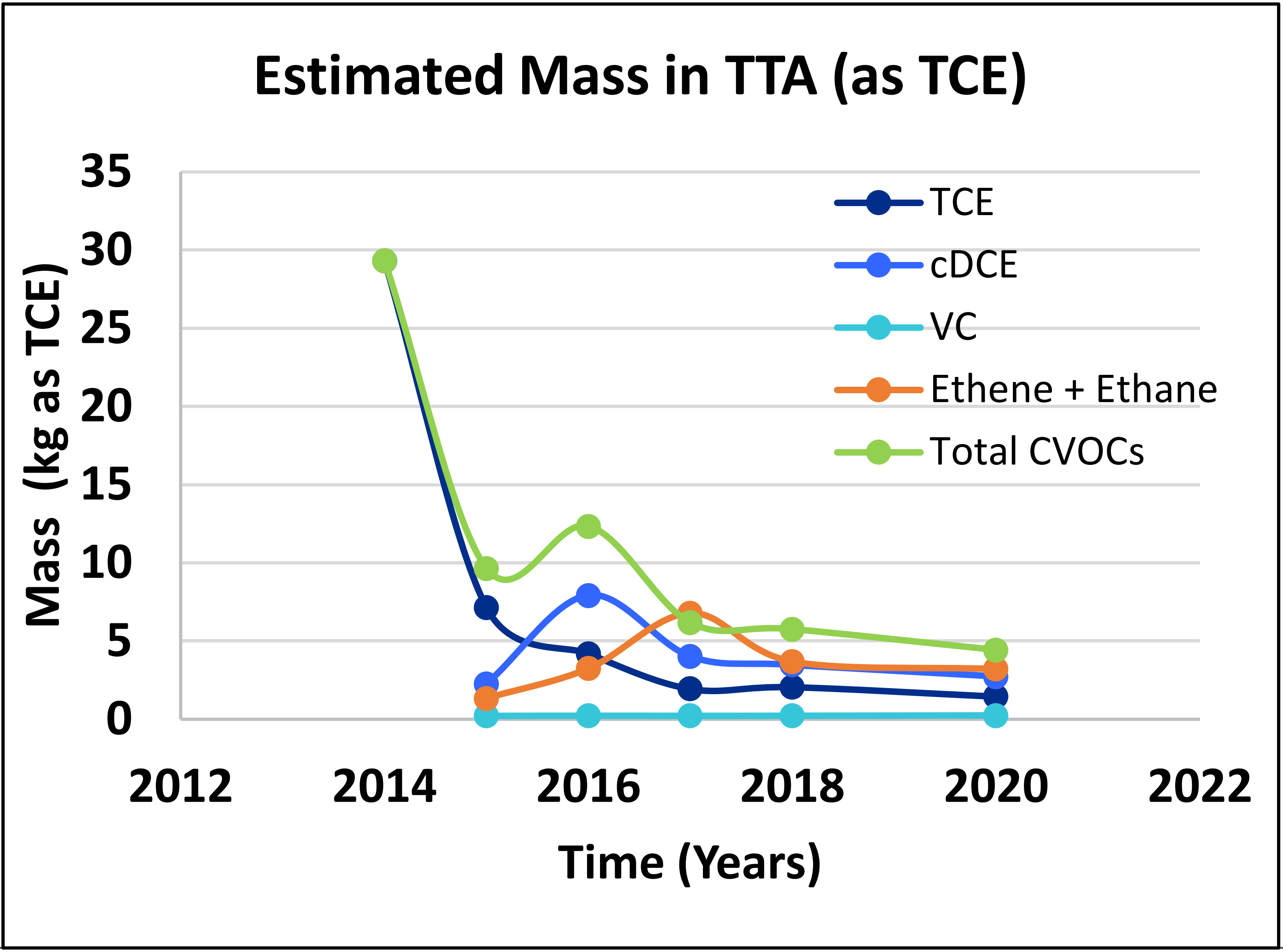
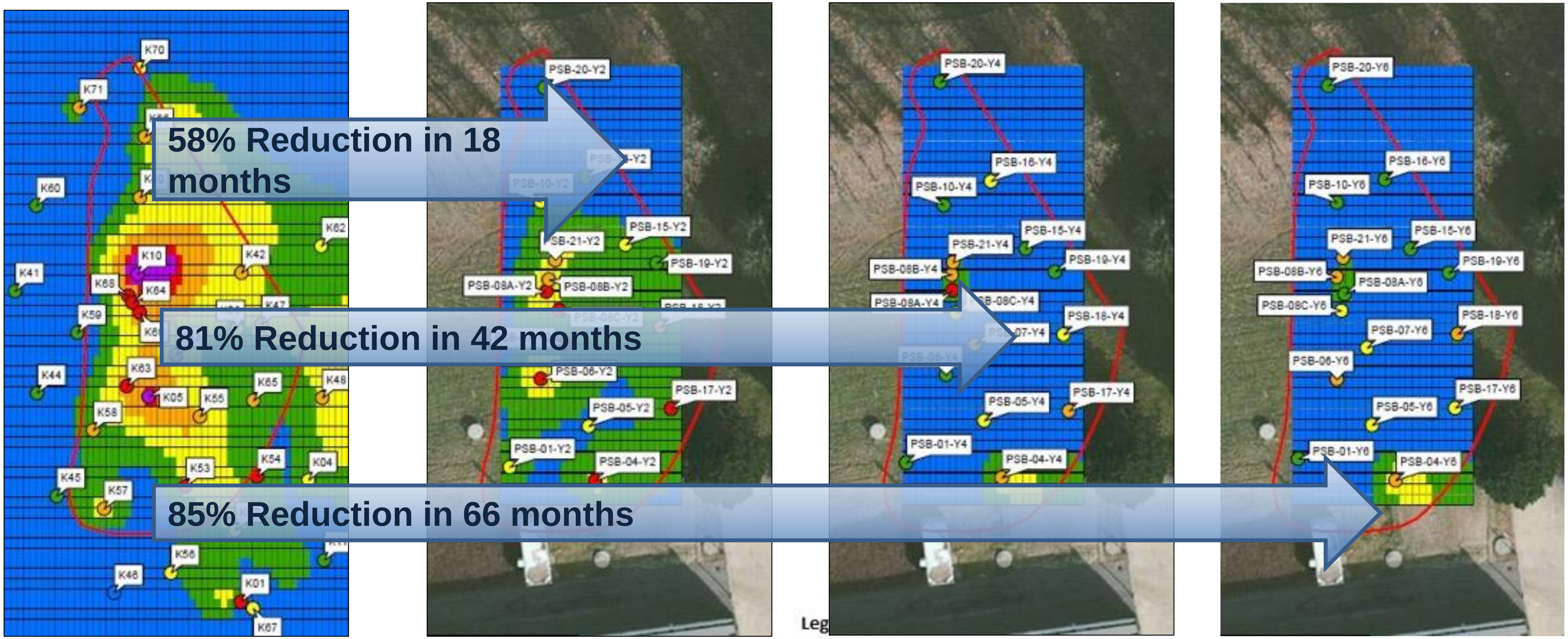


Distribution of Total VOCs in Soil – Baseline to Year 6

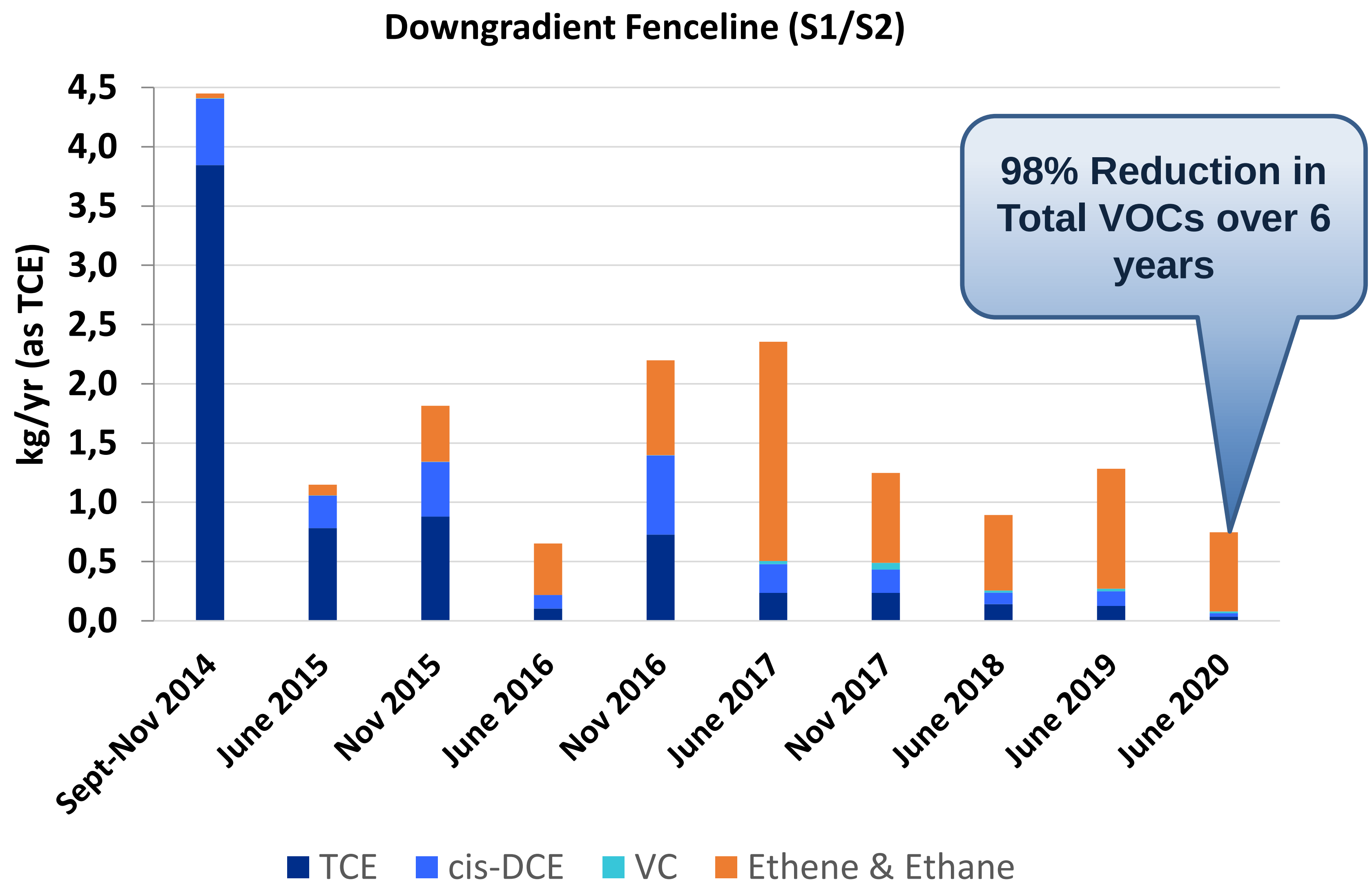
Nov 2014 (Baseline) | June 2016 | June 2018 | June 2020

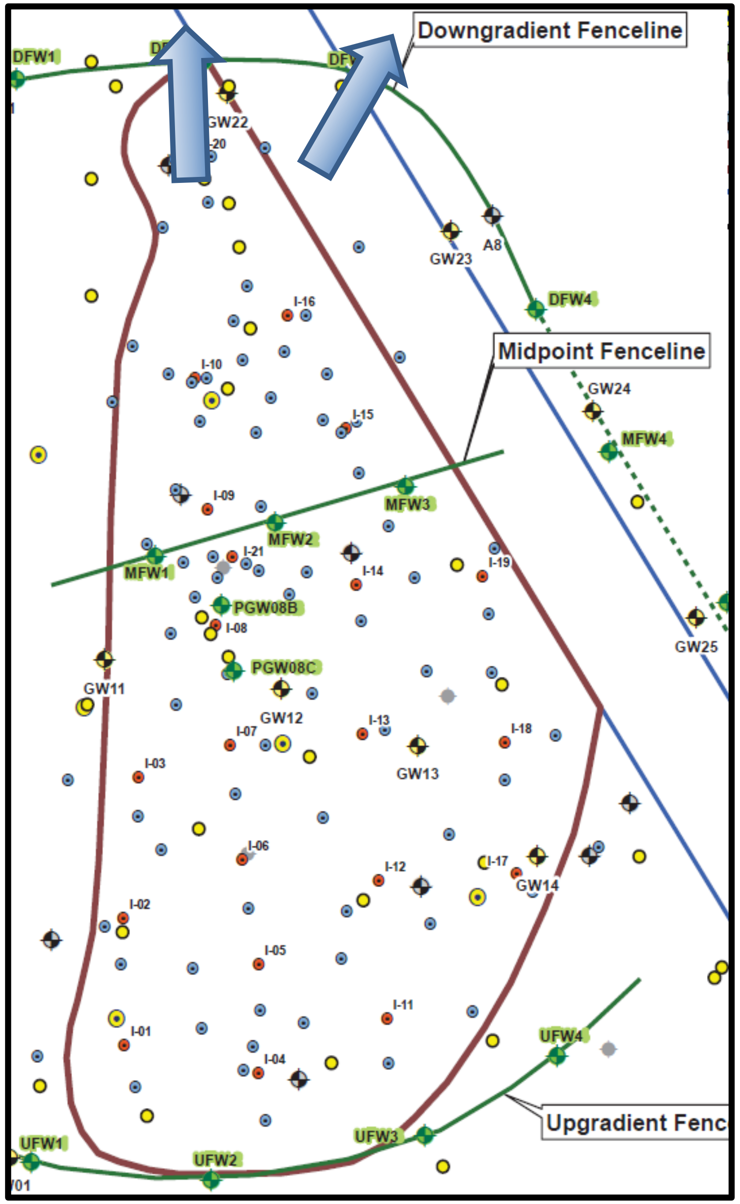


Leg

Total CVOC Concentration (mg/kg)	Sum total CVOC Mass/Grid Column (kg)
≤1	0.000000 - 0.001000
>1 and ≤5	0.001001 - 0.002000
>5 and ≤10	0.002001 - 0.004000
>10 and ≤20	0.004001 - 0.008000
>20 and ≤40	0.008001 - 0.010000
>40	0.010001 - 0.020000

Mass Discharge VOCs in Groundwater from TTZ





June 2020 CVOC Mass Flow in Treatment Zone

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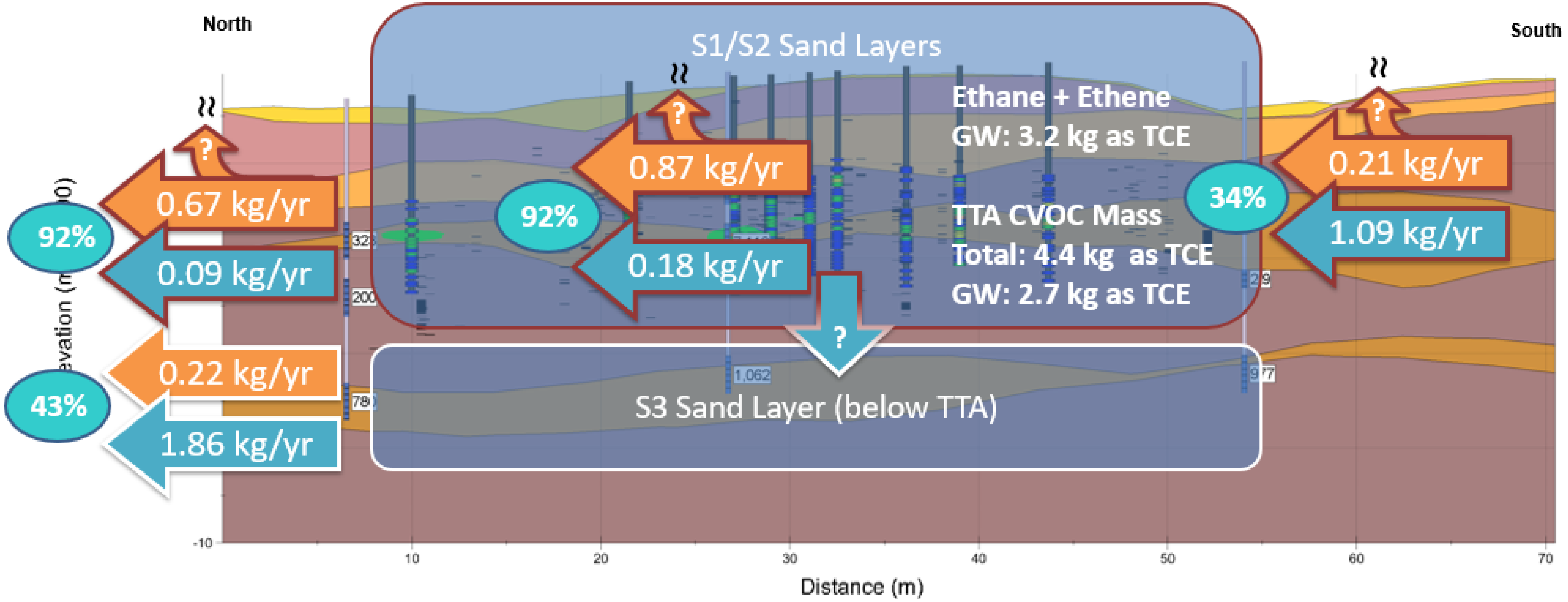
June 2020 Total Mass in TTA & Groundwater Discharge Through TTA



June 2020 Mass Discharge (kg/yr as TCE)

0.66 kg/yr Total CVOCs

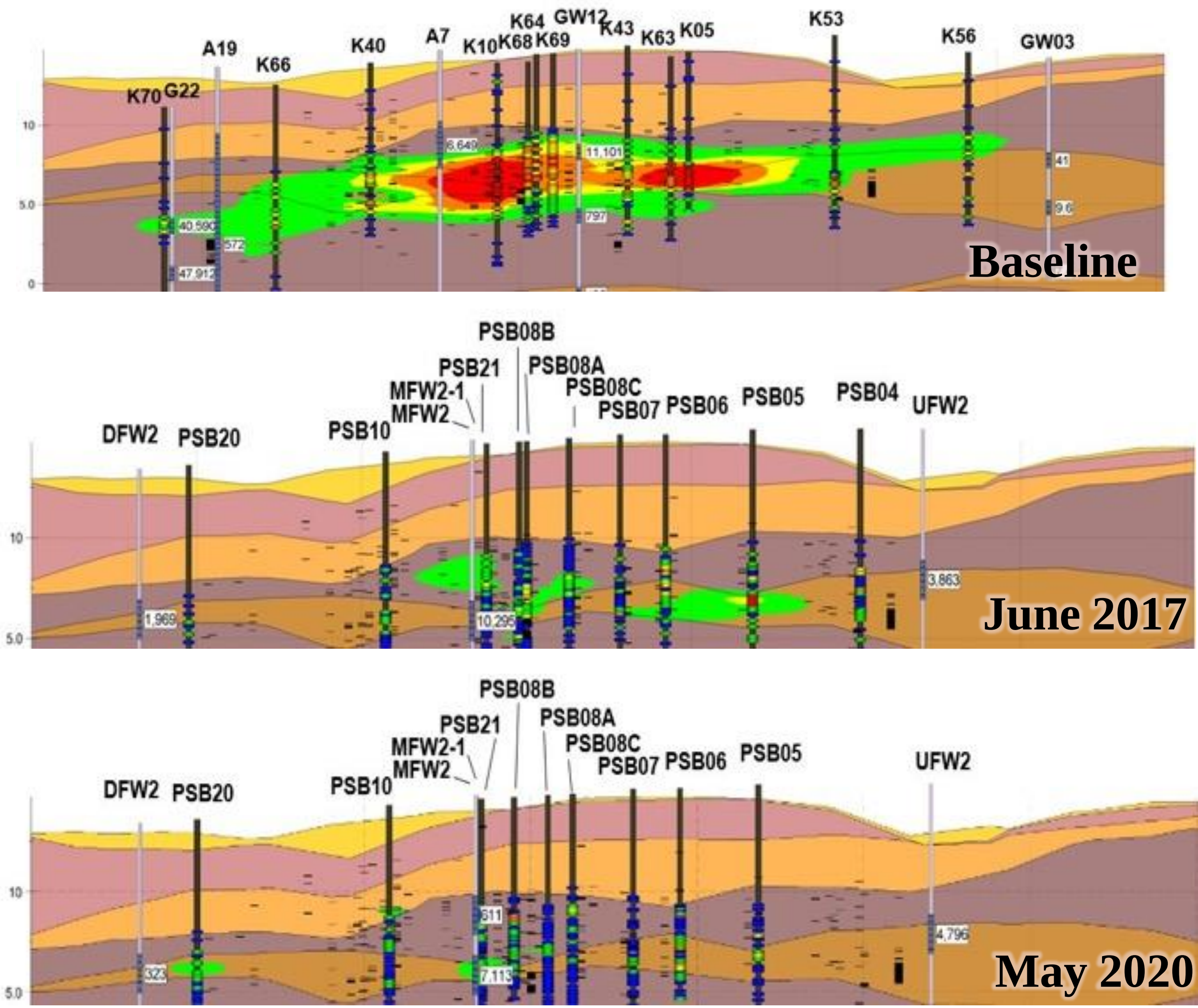
0.04 kg/yr Ethene & Ethane

Dechlorination Score (%)

70%

mZVI Treatment Performance – Summary of Results

- mZVI remedy reduced CVOC mass discharge by 98% in 6 years
- mZVI completely destroyed 95% of the initial baseline CVOC mass over 6 years
- CVOCs flowed from upgradient into the TTZ. The “extra” CVOCs reduced apparent CVOC mass destruction to 85% in 6 years
- Ethene + ethane are primary end products
- Biodegradation of guar likely stimulated biological reductive dechlorination (cDCE and VC production)



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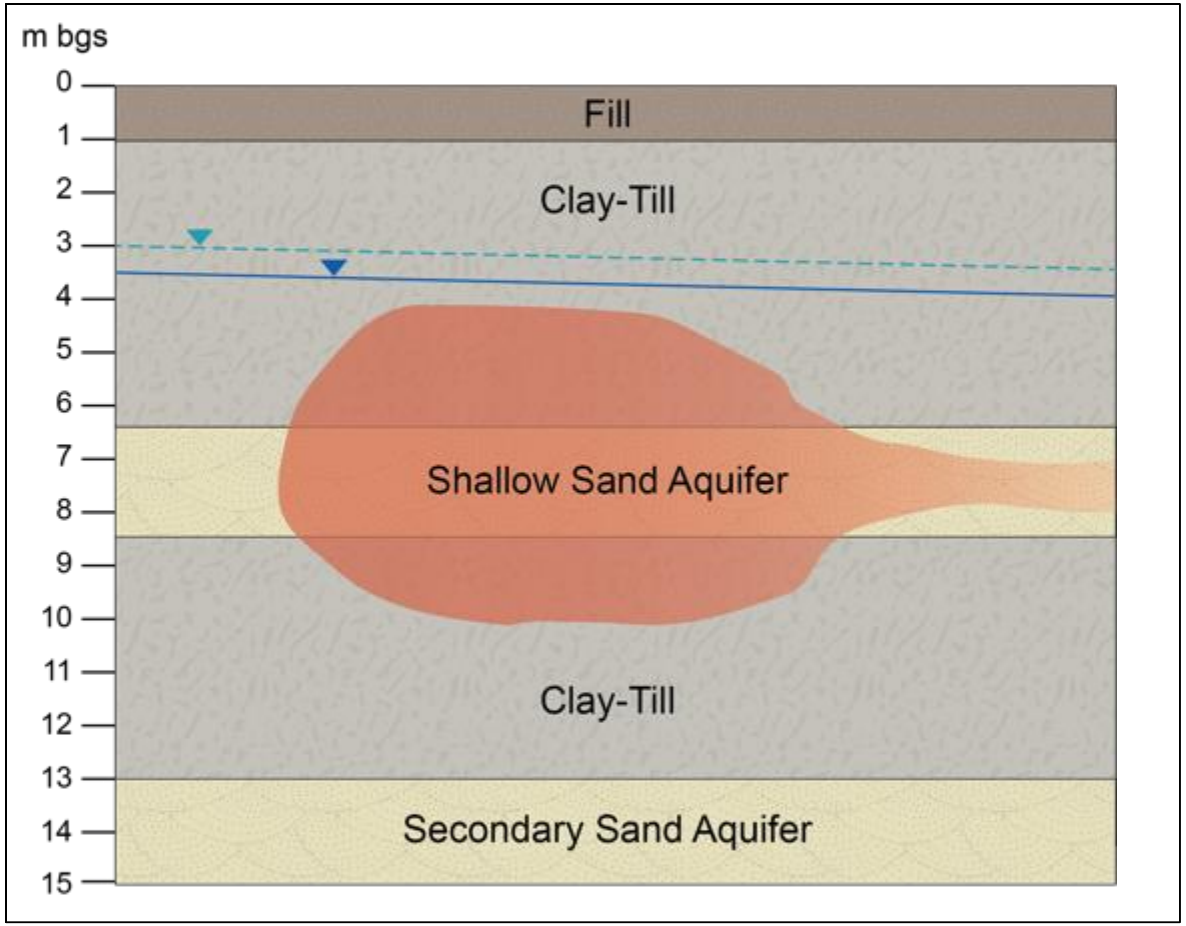
DPT Jet Injection
Cost & Performance Report

Model Site

Comparison of five remediation technologies appropriate for clay till

1. DPT-JI
2. Excavation
3. Electrokinetically-enhanced bioremediation (EK-BIO)
4. In situ thermal desorption (ISTD)
5. ISCO – in situ solidification/stabilization (ISCO-ISS)



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Model Site – Scoring of Remedial Alternatives

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Treatment Technology	Scoring Criteria (ranked from 1 to 5 with 1 being best)				
	Cost	Certainty	Duration of Remedy Implementation	Time of Remedy Completion	Sustainability/ Carbon Footprint
DPT-JI mZVI	1	3	1	5	1
ISS-ISCO	3	2	1	1	5
ISTD	3	2	3	1-2	3
Excavation	5	1	2	1	4
EK-BIO	5	3	5	3	2

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Key Take Home Points

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DPT - Jet Injection Provides:

1) Controlled delivery of remediation amendments in unconsolidated low-permeability geologic matrices:

- Clay till, saprolite, weathered bedrock

2) Competitive costs for treatment:

- 800-1000 DKK/m^3 for mZVI treatment of chlorinated solvent source areas in clay till
- Less expensive than ISTD, excavation, ISCO-ISS, and EK-BIO

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Questions?