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DPT Jet Injection for Remediation in Clay Till:

Full-Scale Case Study Results from 4 Years of Treatment

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11 October 2018

Partners in Developing DPT Jet Injection

Geosyntec consultants

Region Hovedstaden

FRx

COWI

Geosyntec consultants

Two Key Take Home Points

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DPT Jet Injection Provides:

- Better Control: Flat Fractures and Limited Surfacing
- Competitive Cost: $60-150/CY for ZVI treatment

Problem Statement: Develop Better Injection Technology to Treat Contaminants in Clay

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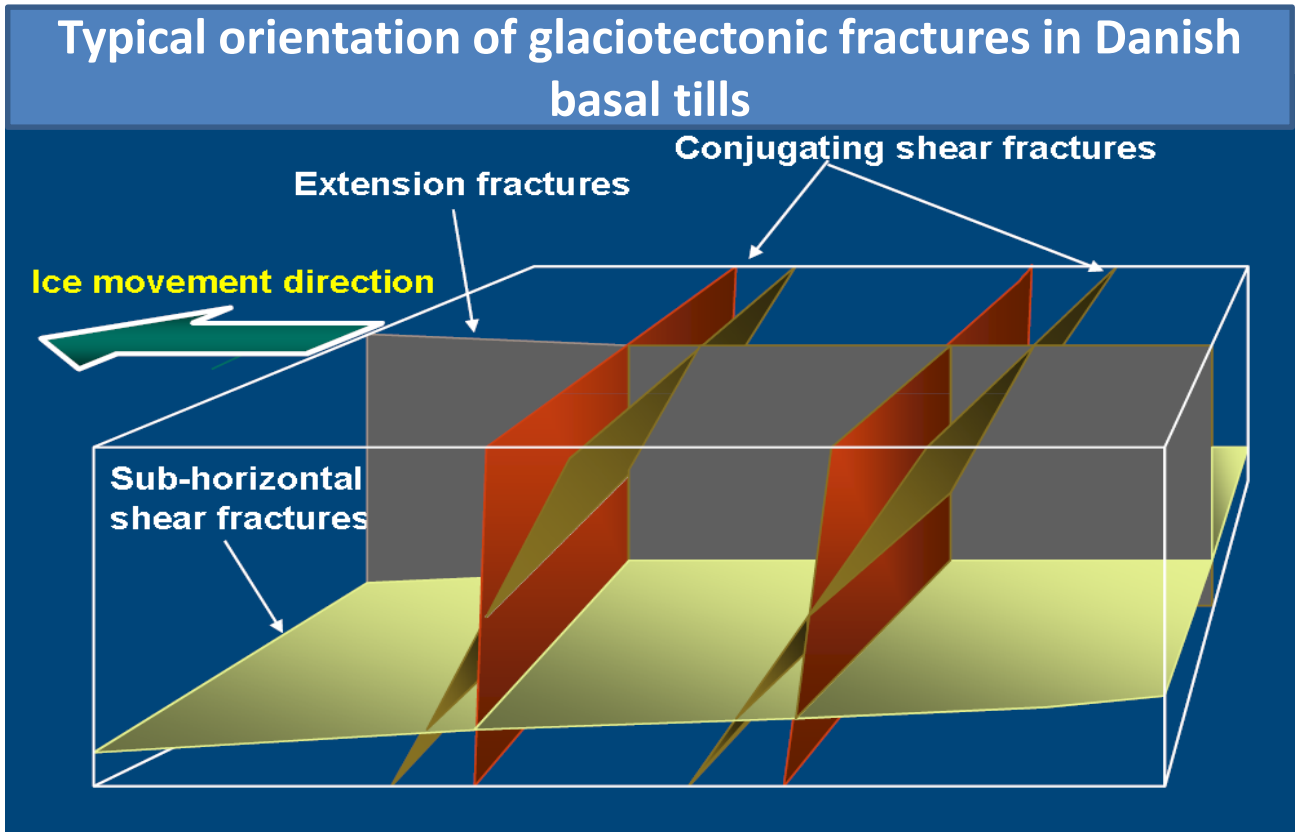
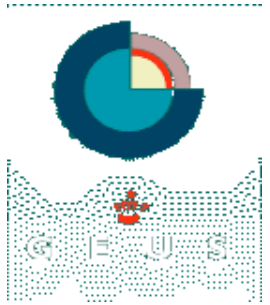
Method development partially funded by Danish government. Why?

- 40% Denmark covered in highly fractured clay till.





Problem Statement: Develop Better Injection Technology to Treat Contaminants in Clay

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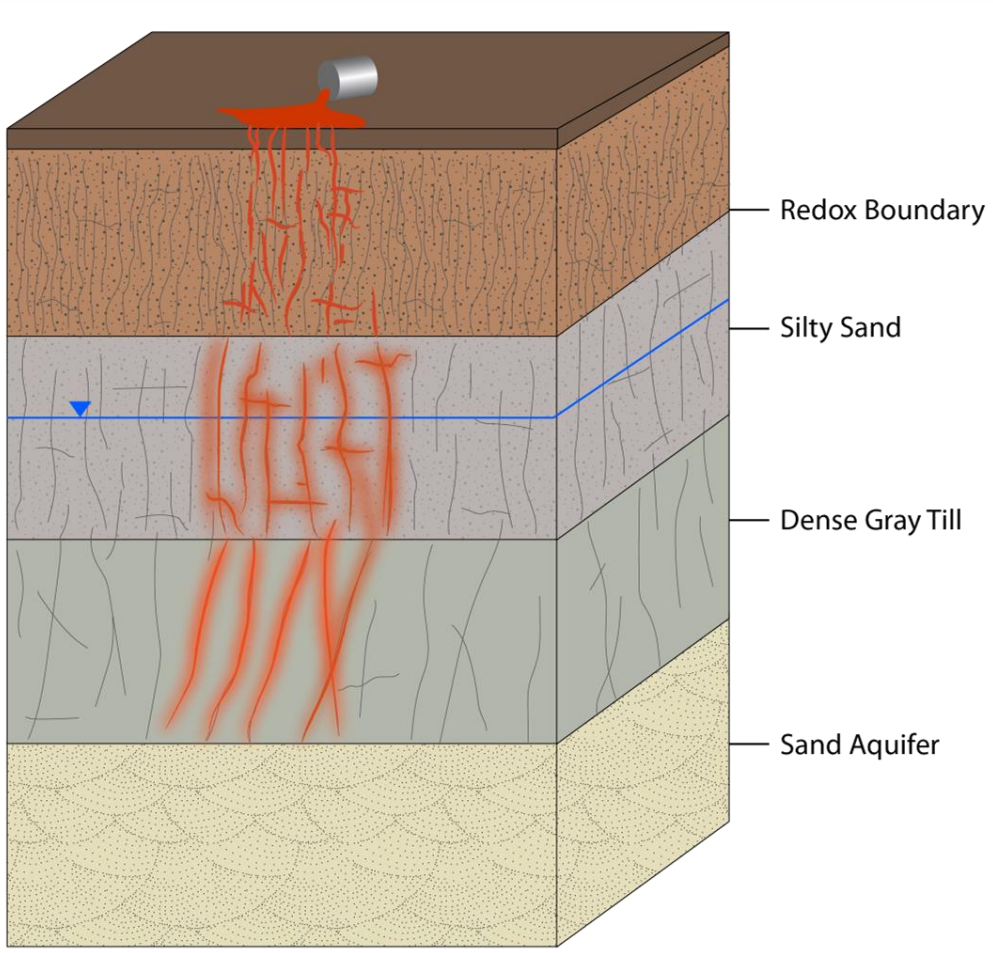
Method development partially funded by Danish government.

Why?

- 40% Denmark covered in highly fractured clay till.
- Hundreds of chlorinated solvent sites.

Clay till + solvents =

long-term source zones



Applicability in US and Canada

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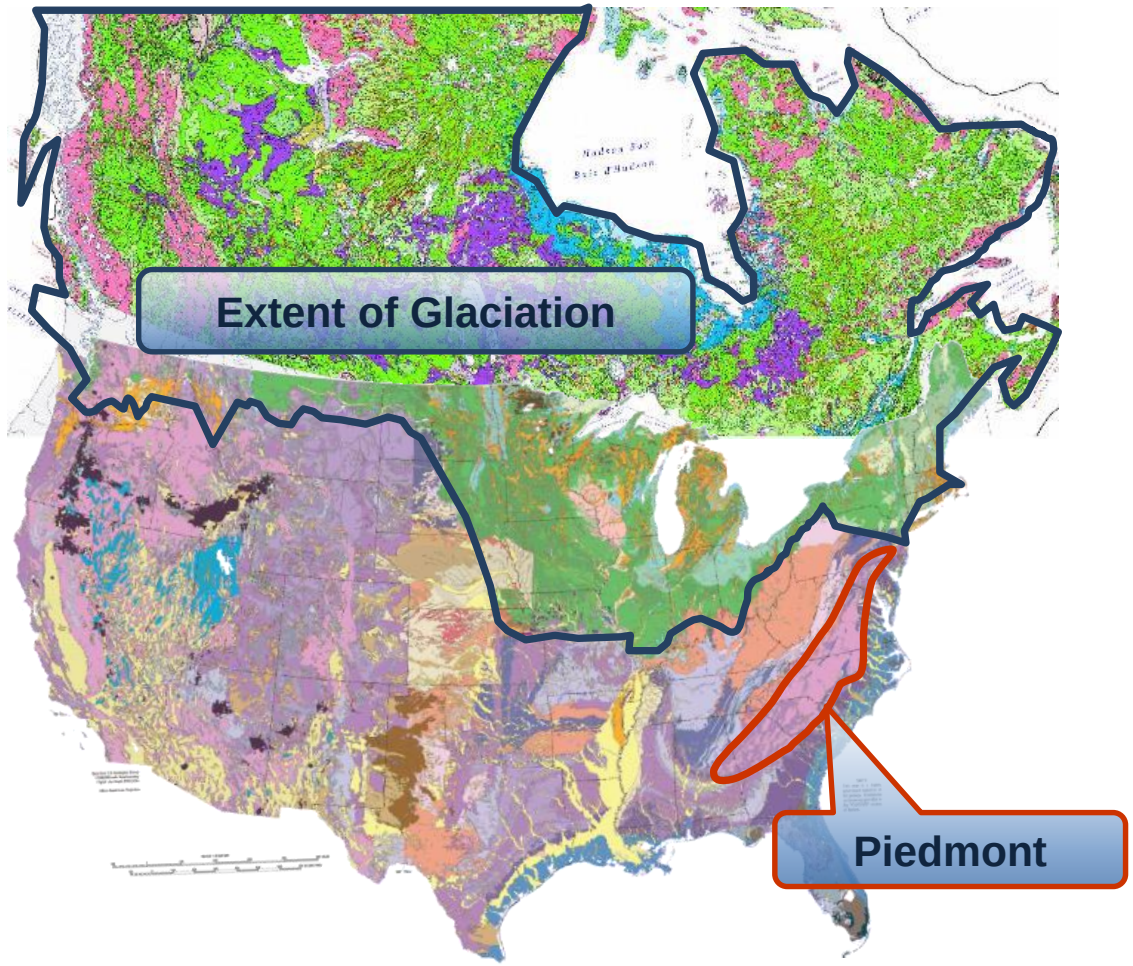
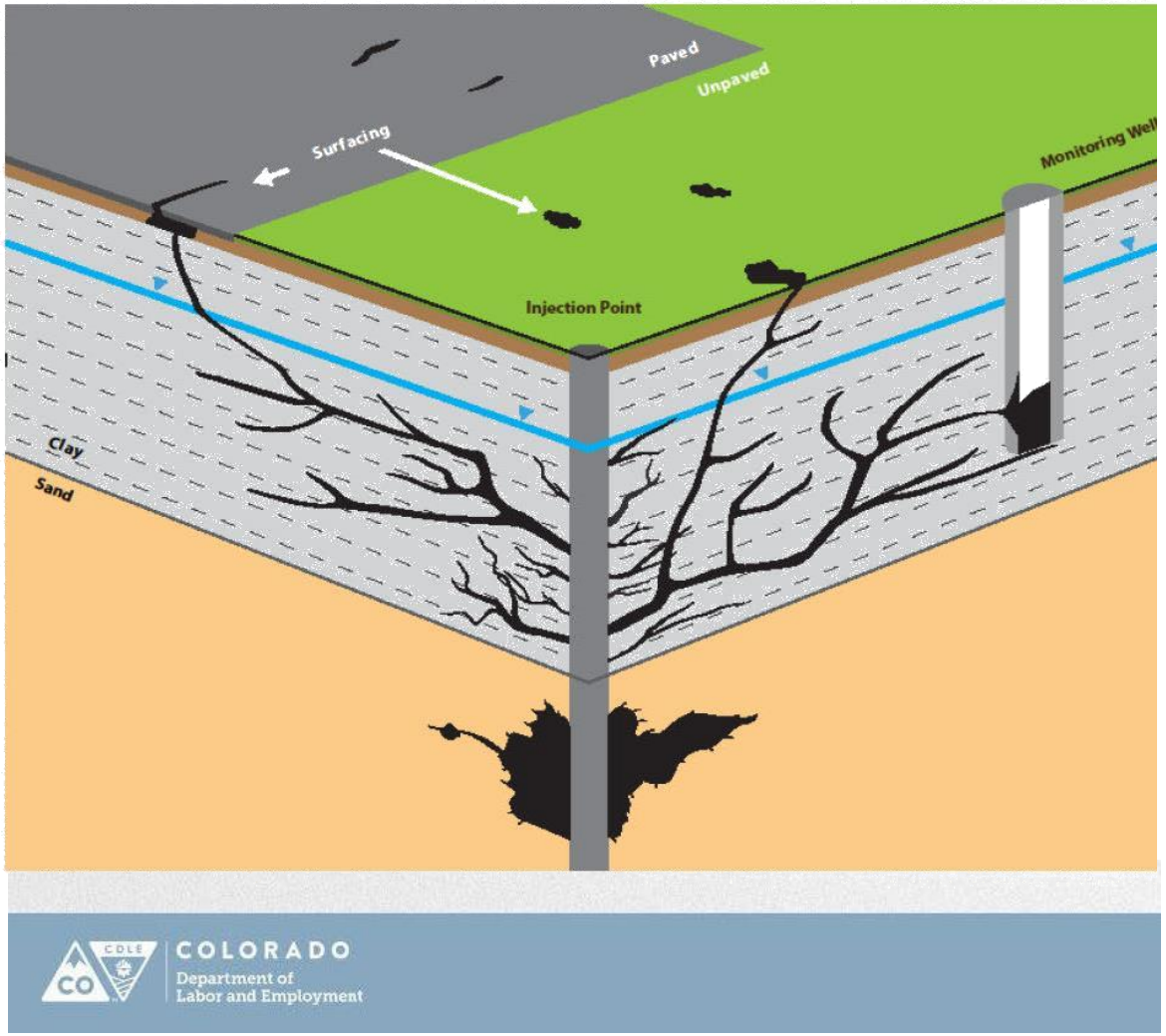
Remediating low-permeability sites is a major challenge for US and Canadian Sites.



Surficial Geology of North America

Source:
http://ftp.maps.canada.ca/pub/nrcan_rncan/publications/ess_sst/295/295462/gsccgm%5f195%5fb%5f2014%5fmn01p1.pdf
http://pubs.usgs.gov/of/2003/of03-275/USGS_OFR03-275.pdf

Jet Injection Compared to Traditional DPT Injections

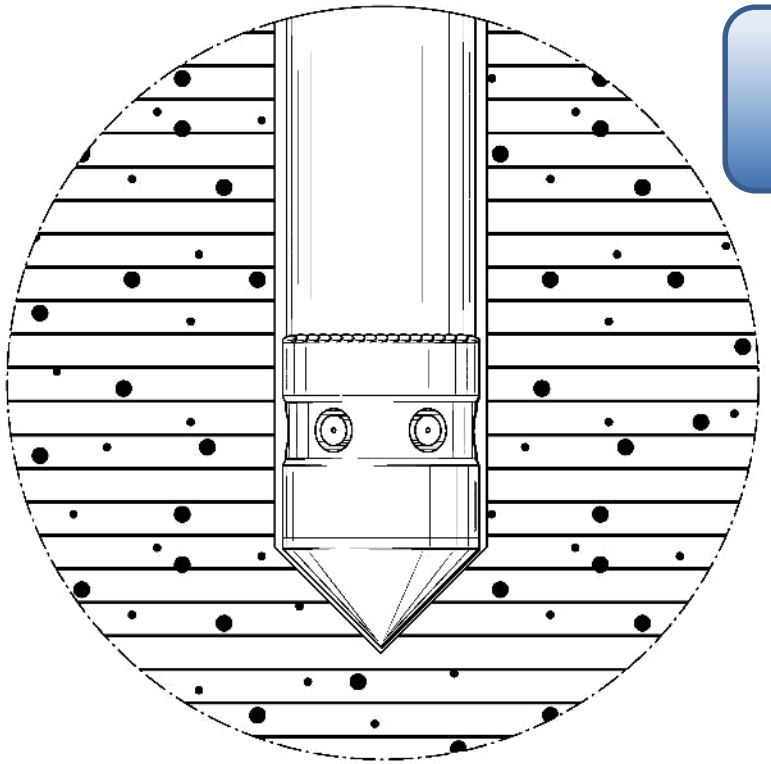


Injecting remediation amendment slurries using traditional direct push methods often results in uncontrolled fracturing of the subsurface.

DPT Jet Injection overcomes this limitation.

DPT Jet Injection – How does it work?

DPT Jet Injection – How Does it Work?



Direct push tooling advancement

DPT Jet Injection – How Does it Work?

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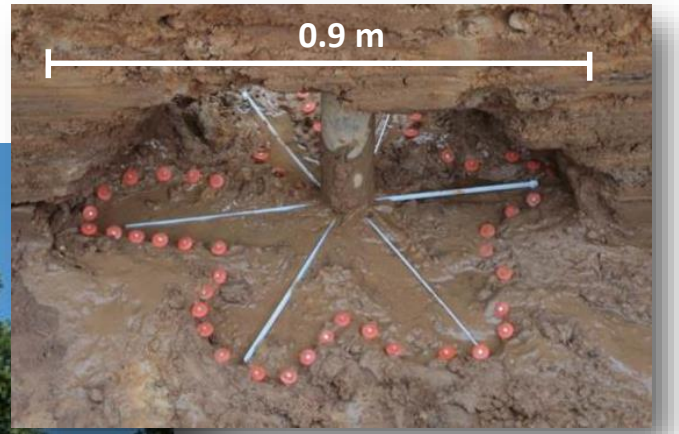

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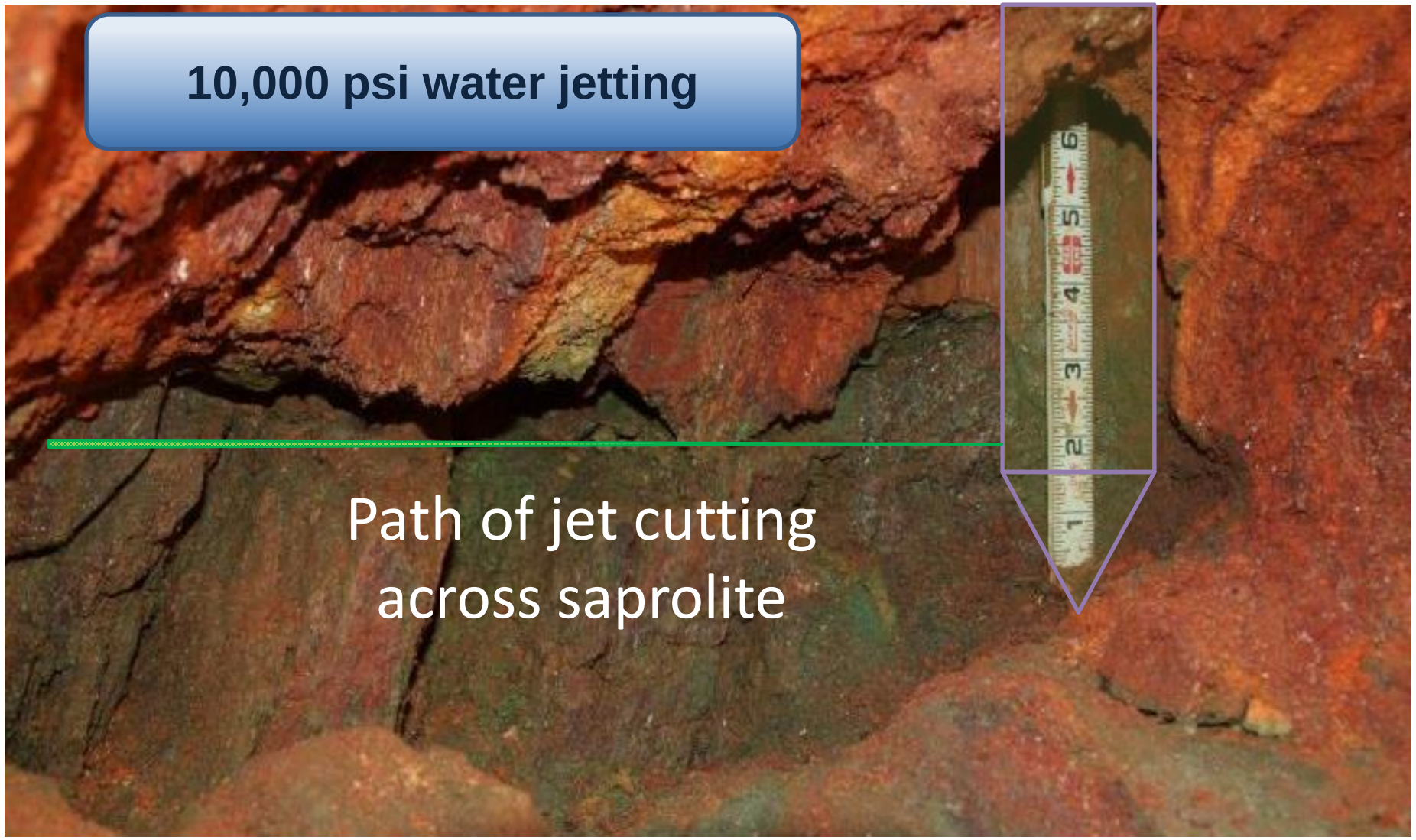

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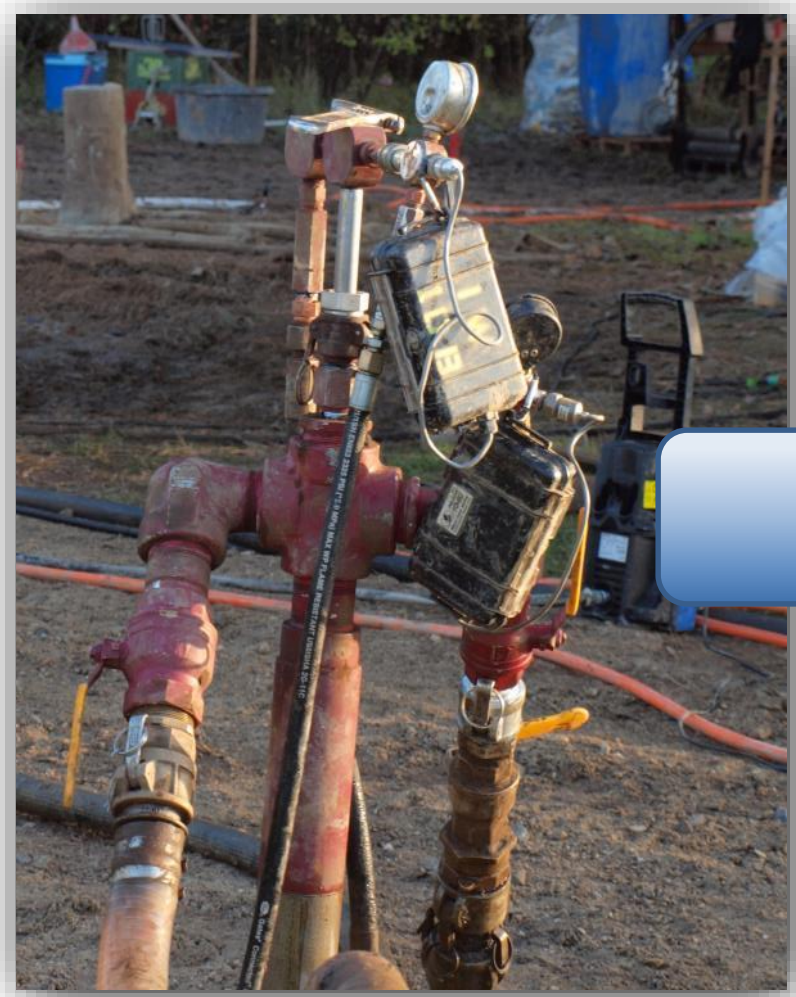

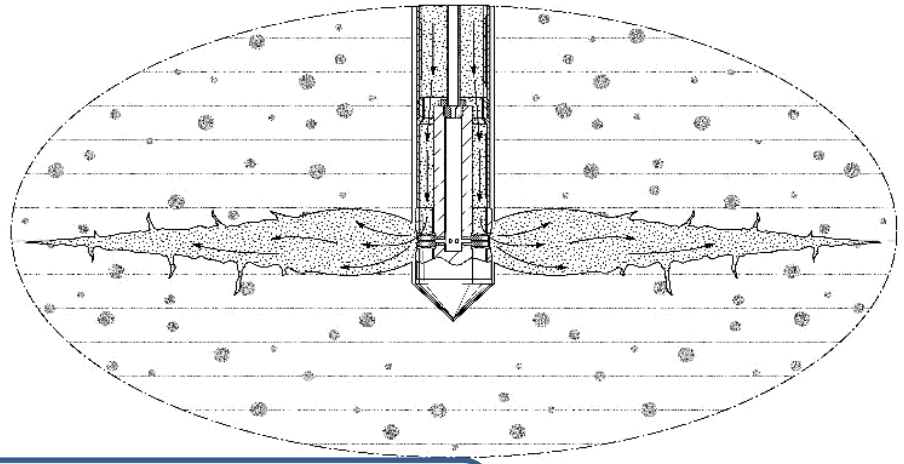

100 to 400+ psi slurry injection

DPT Jet Injection – How Does it Work?

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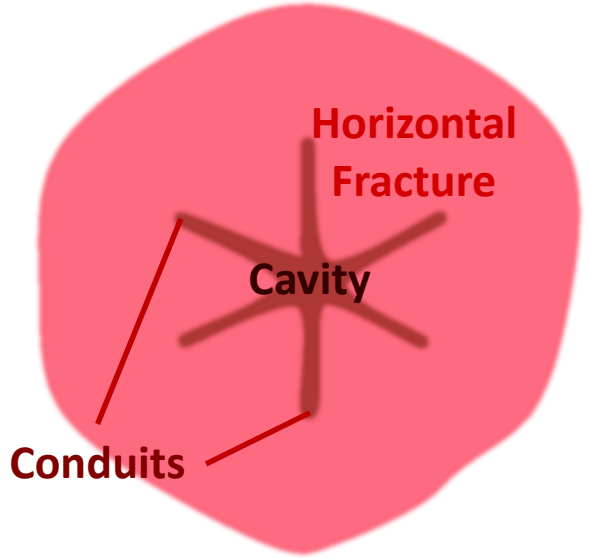
Slurry contains solid proppant which is emplaced to create a reactive and more permeable zone.



DPT Jet Injection – Applications

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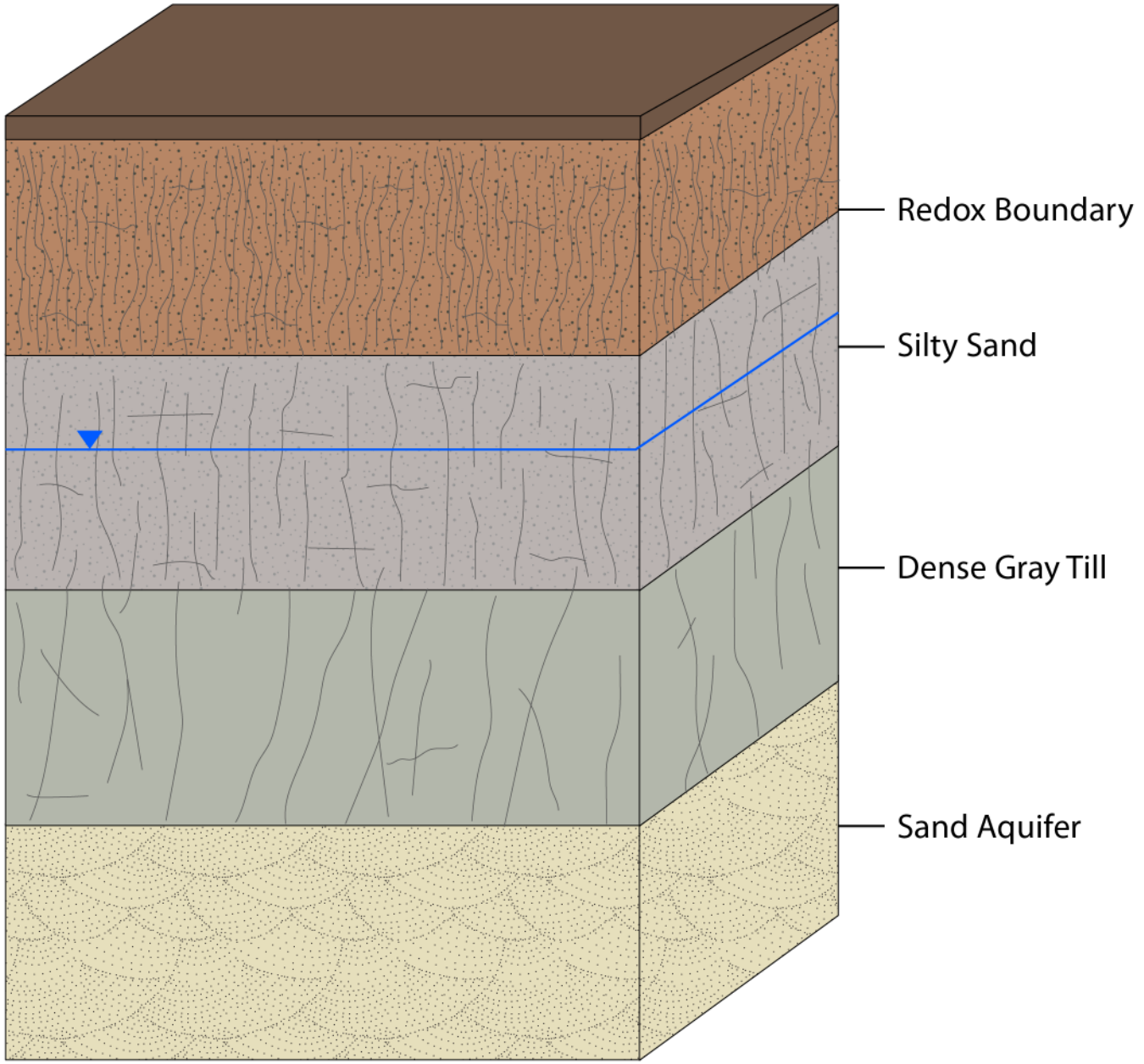
- Demonstrated in clay till (Maine, Ohio, Denmark), silt and clay (Louisiana, New Jersey, North Carolina) and saprolite (Georgia and South Carolina)
- Effective in heterogeneous low-permeability formations
- Capable of emplacing wide range of powdered, granular, and liquid amendments:
  - nZVI, mZVI, Granular ZVI
  - Solid and Liquid-Phase Electron Donors
  - Persulfate, Permanganate
  - Apatite II (metals stabilization)

Conceptual Model – Treatment with DPT Jet Injection



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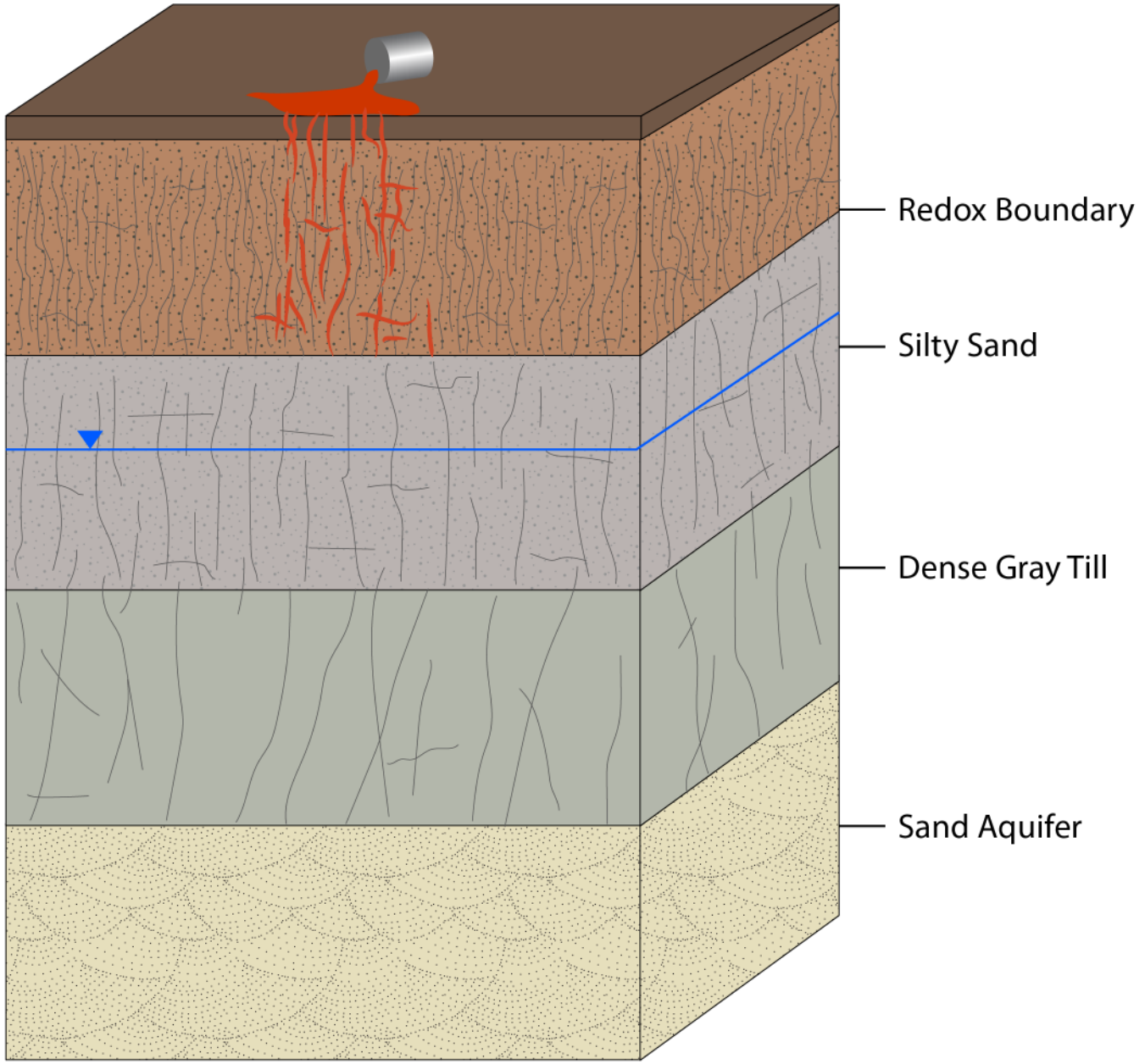

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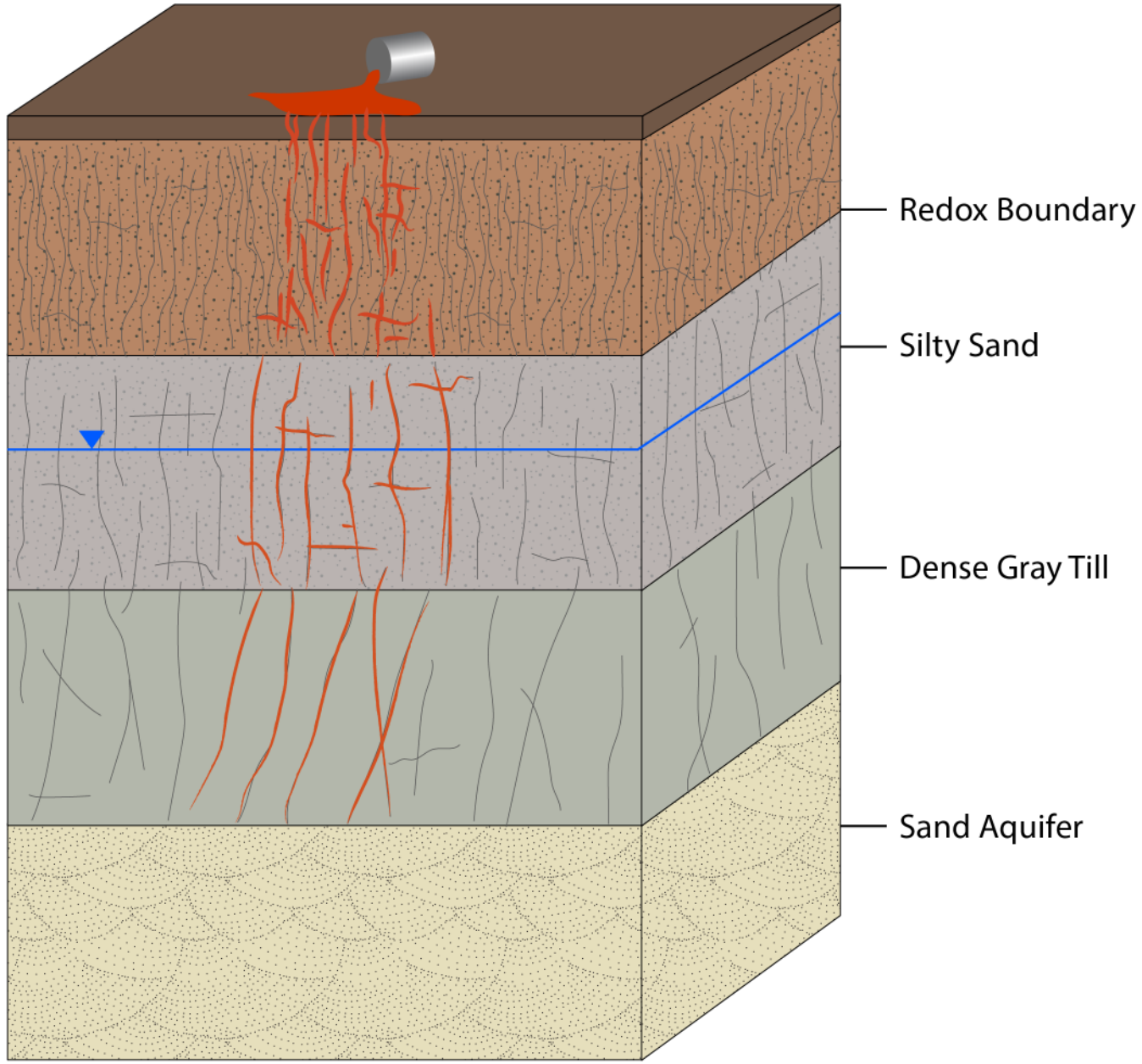

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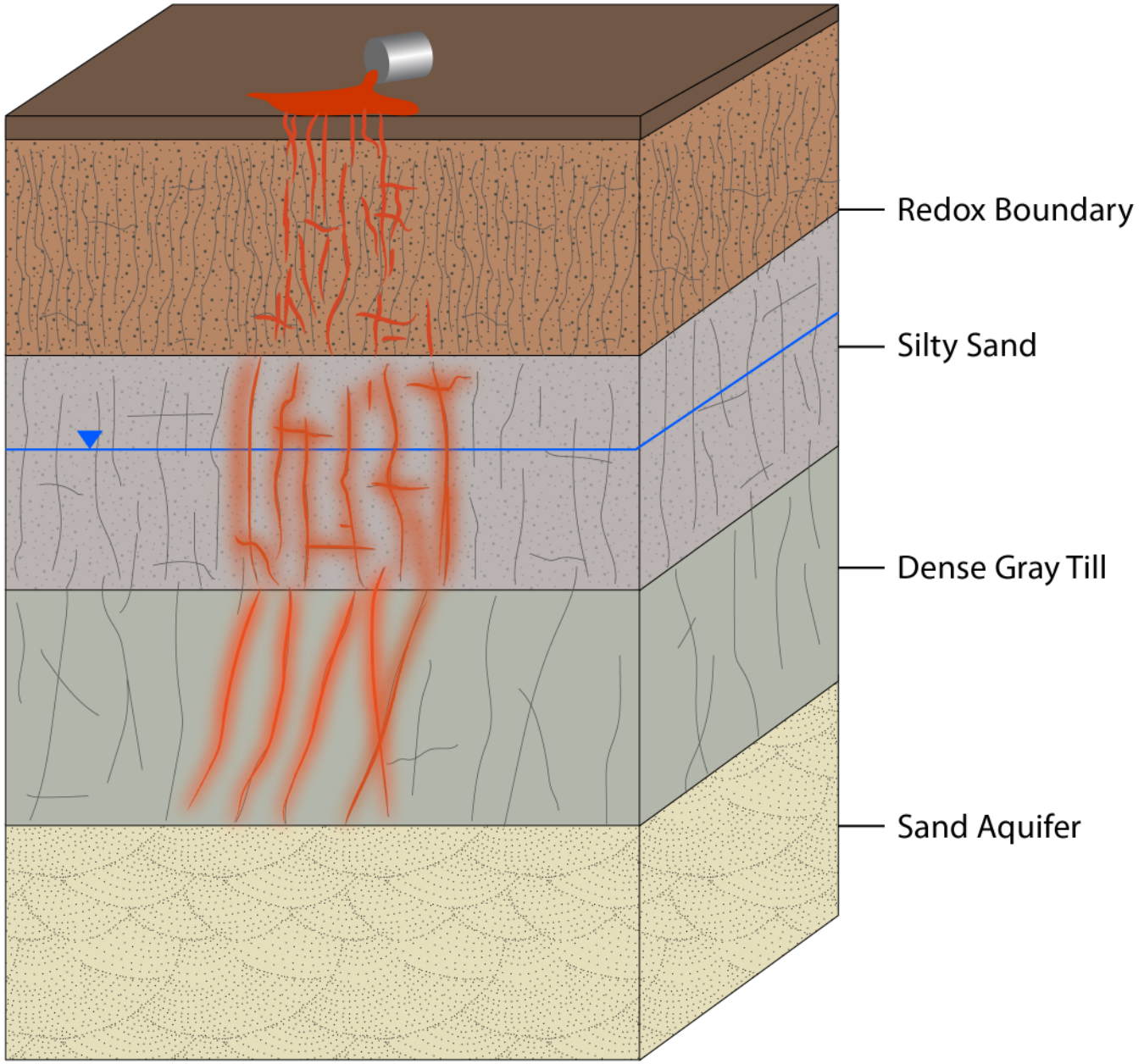

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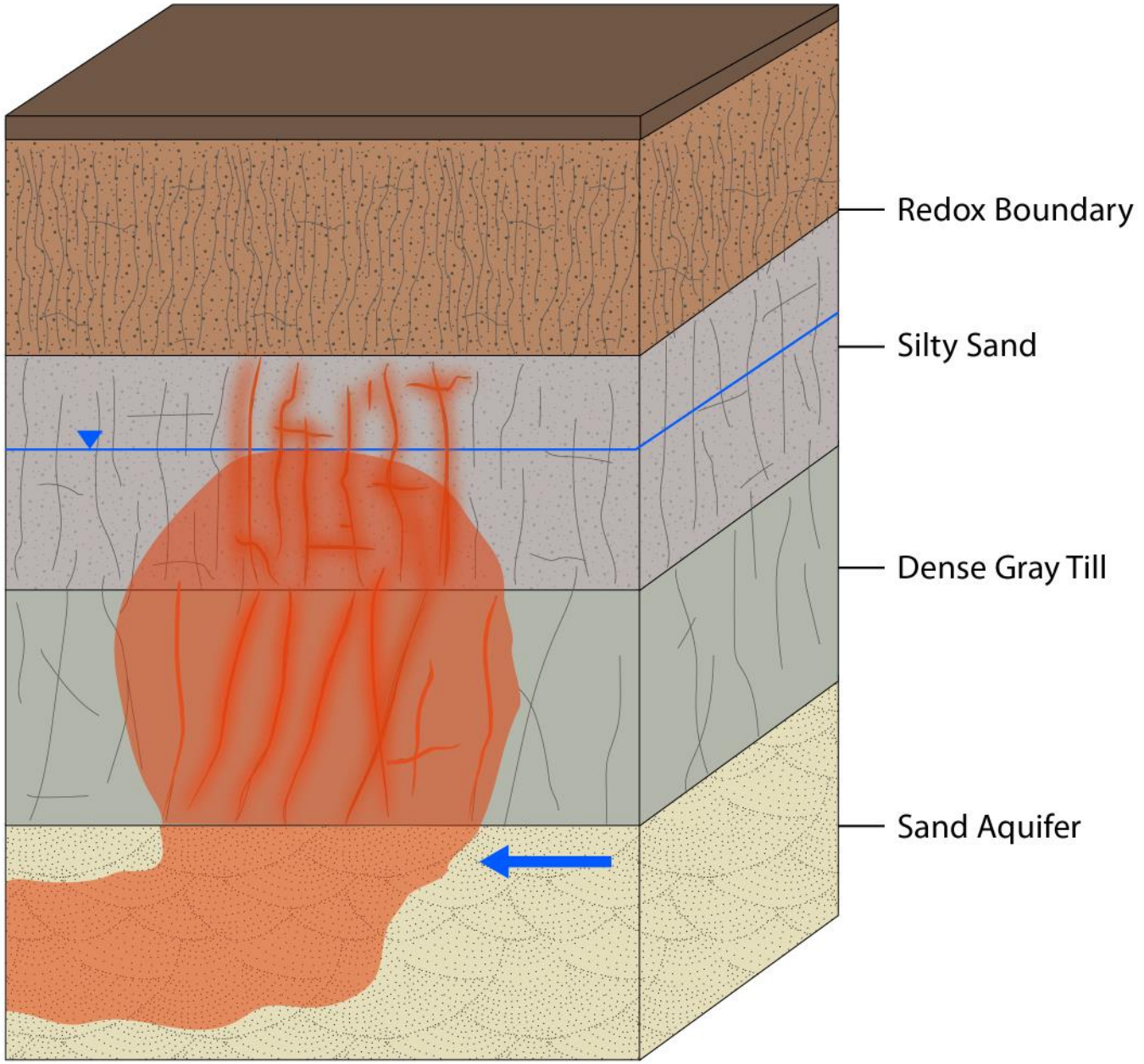

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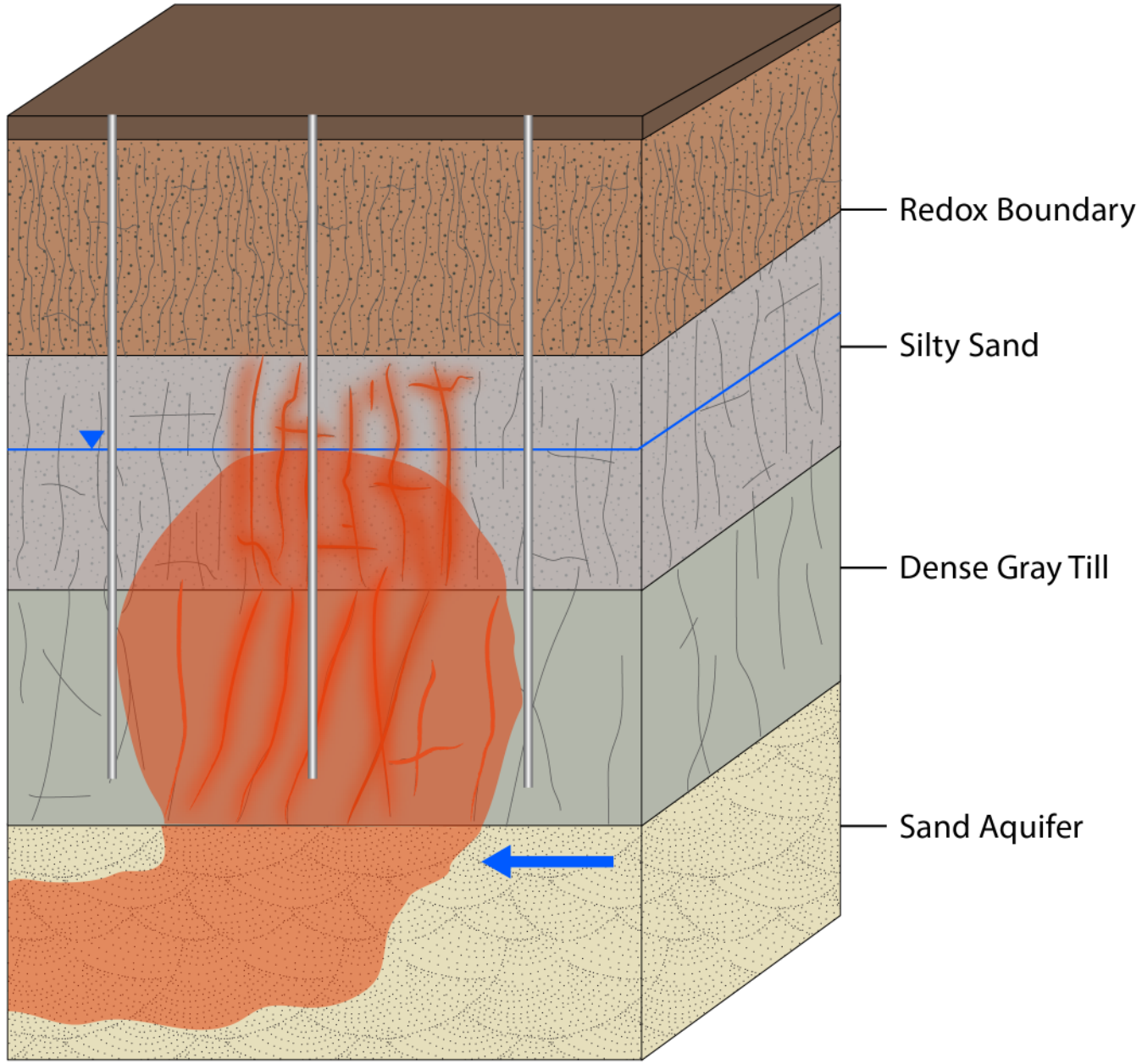

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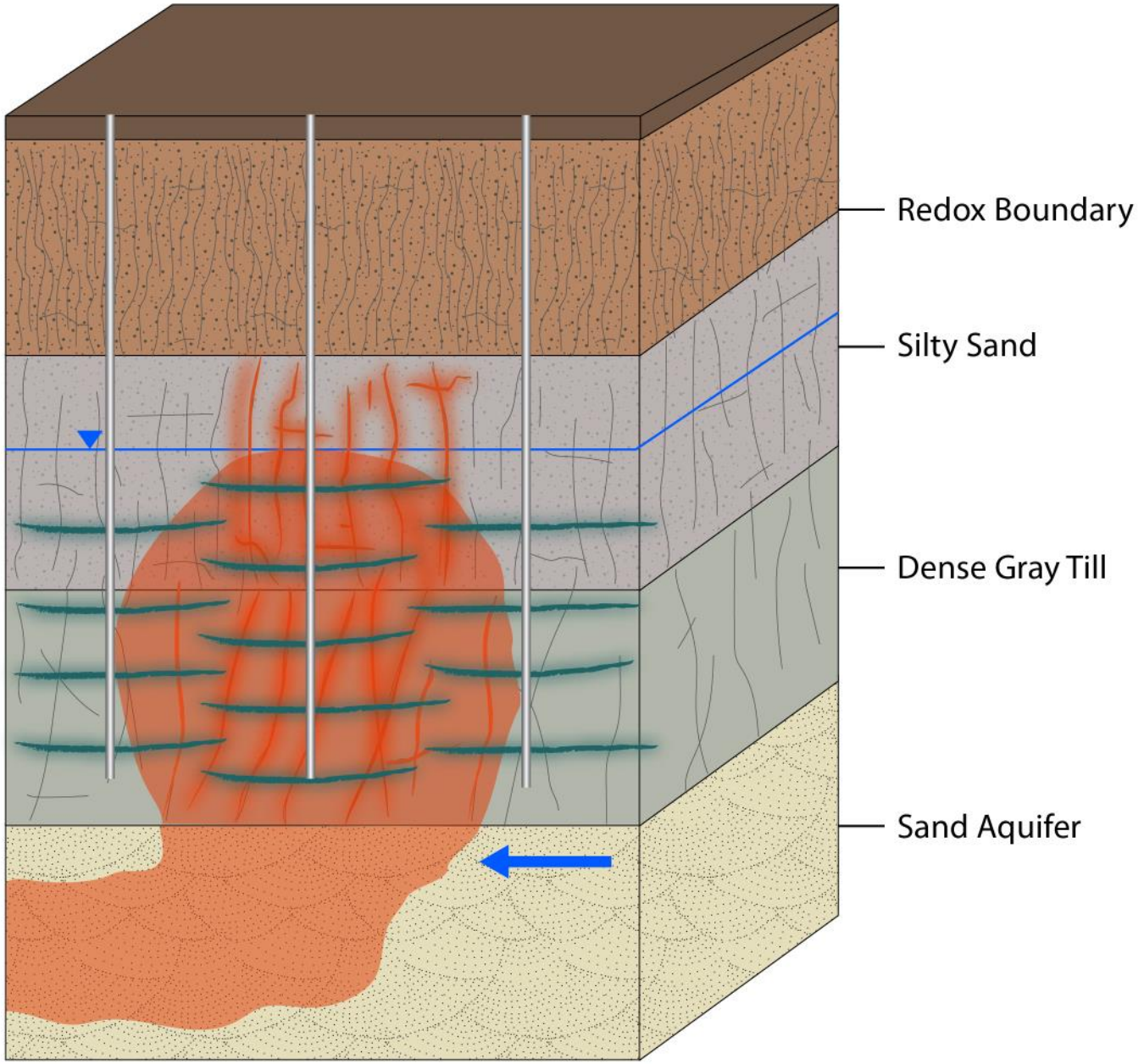

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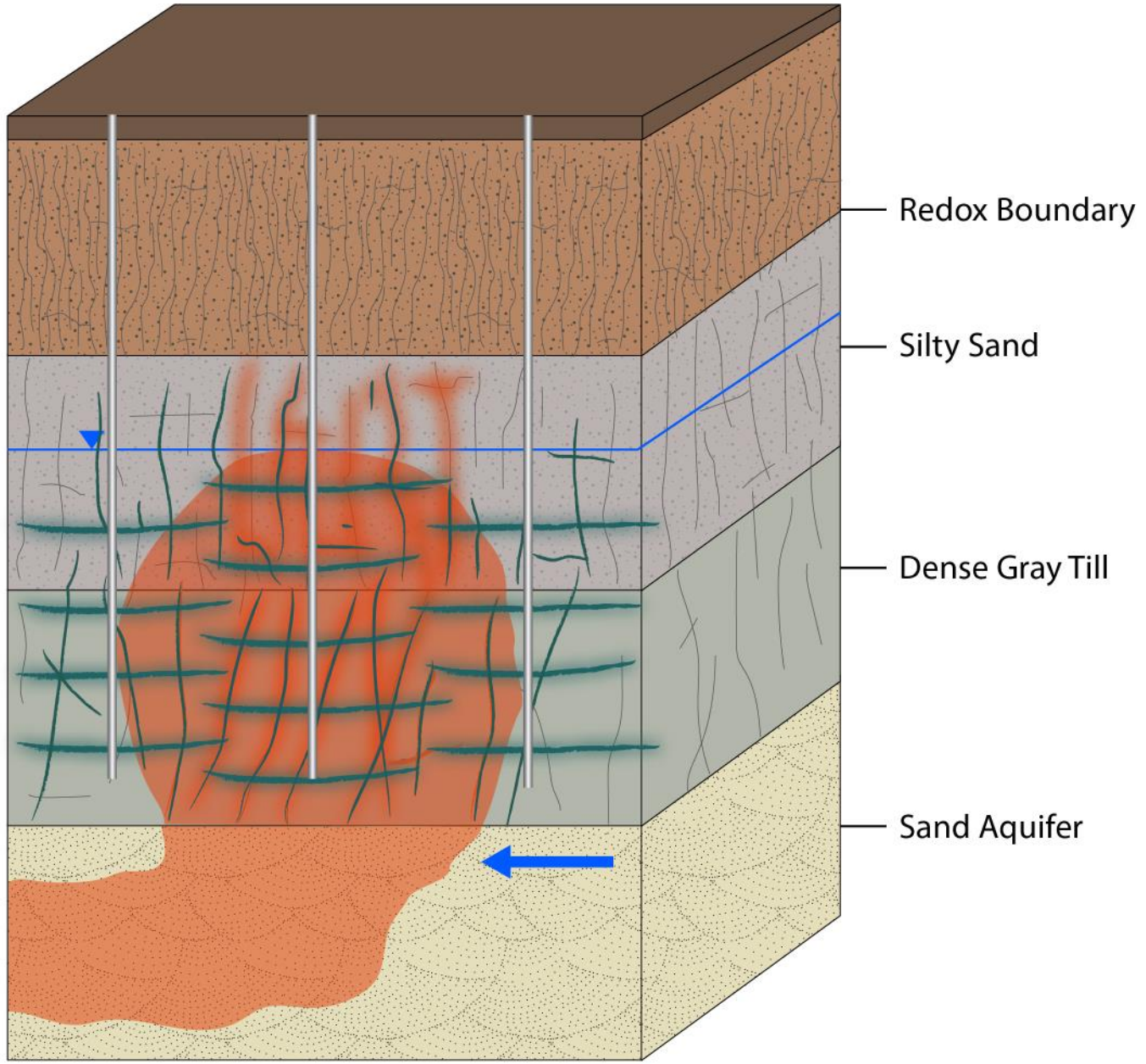

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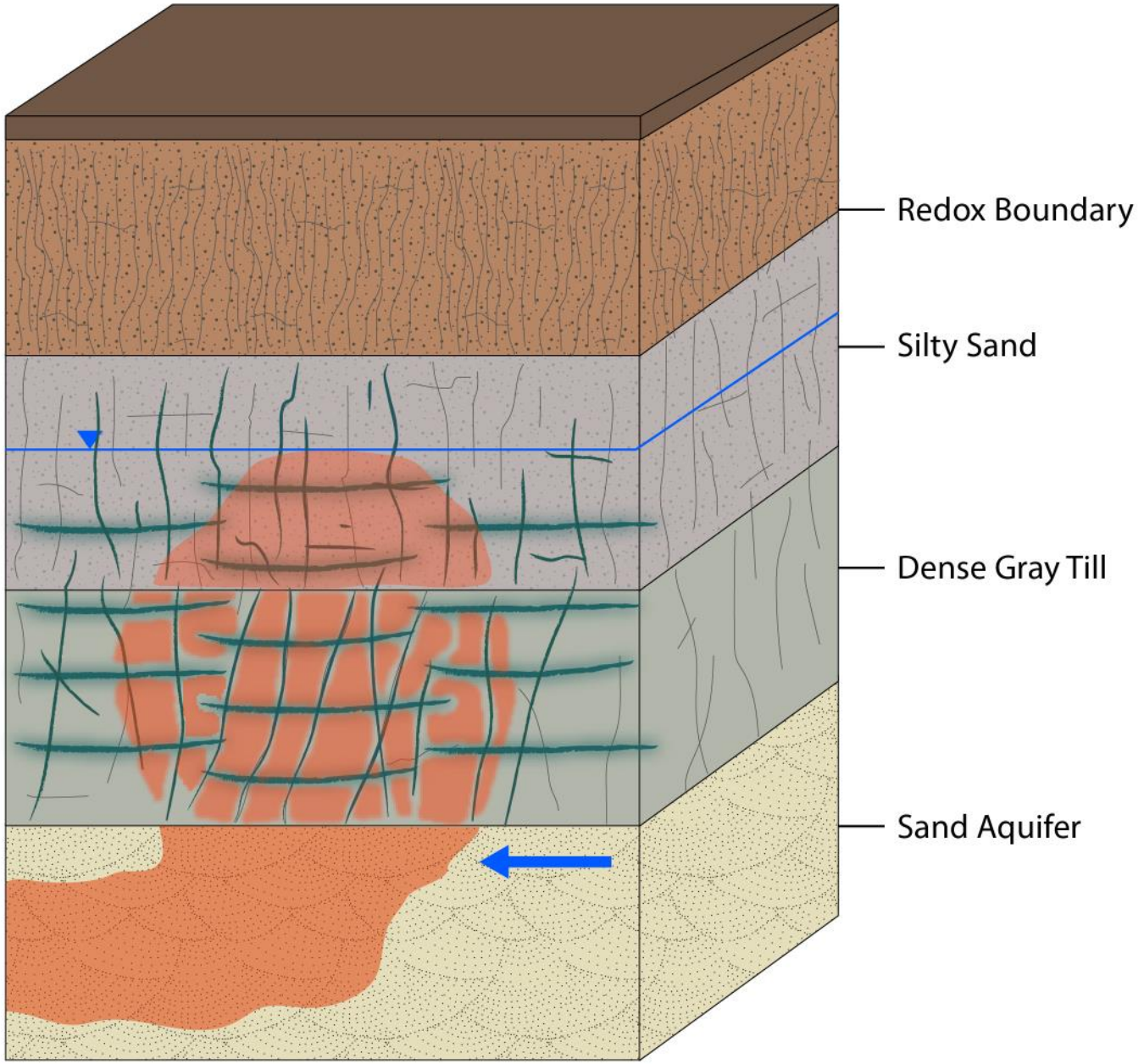

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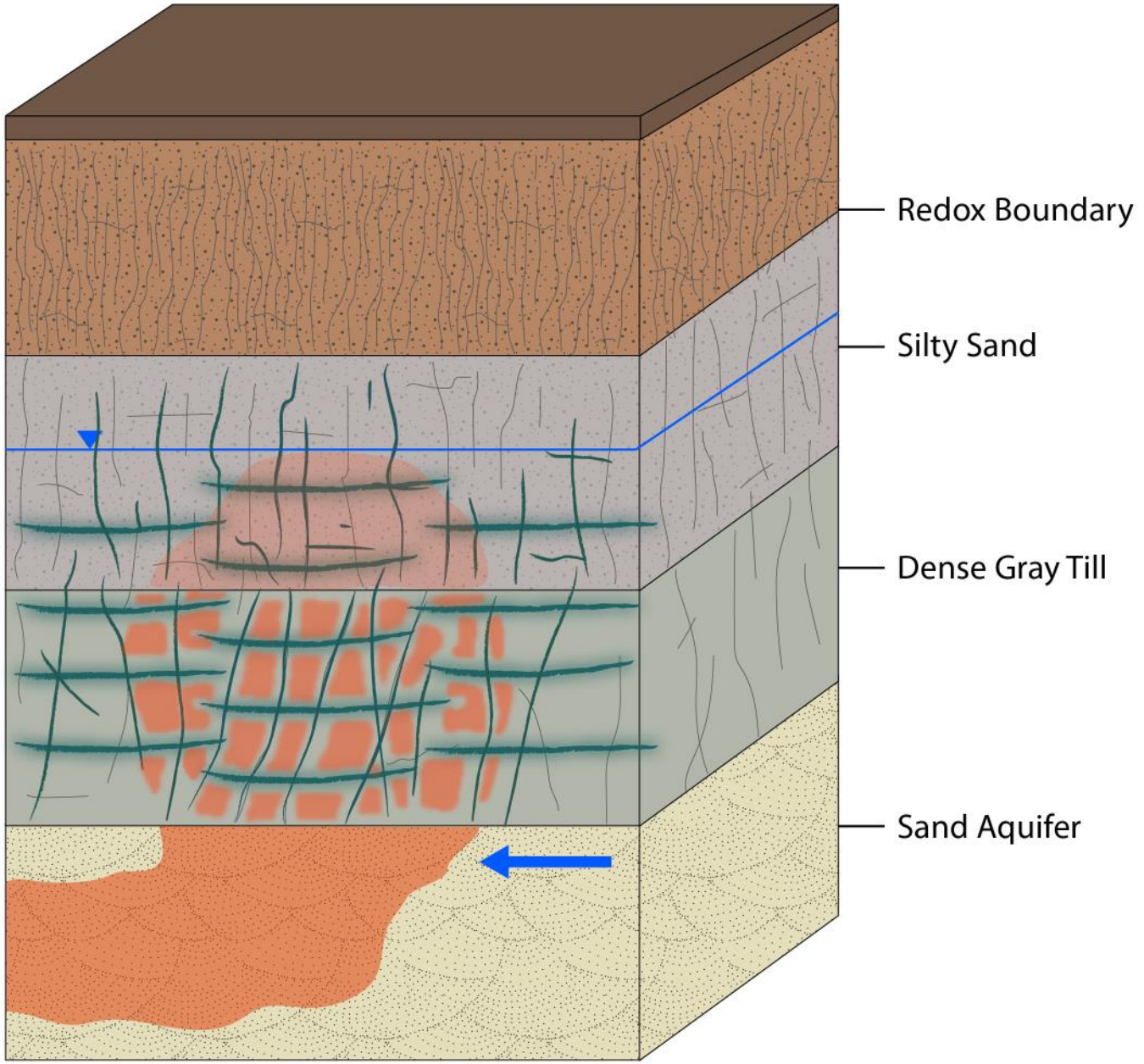

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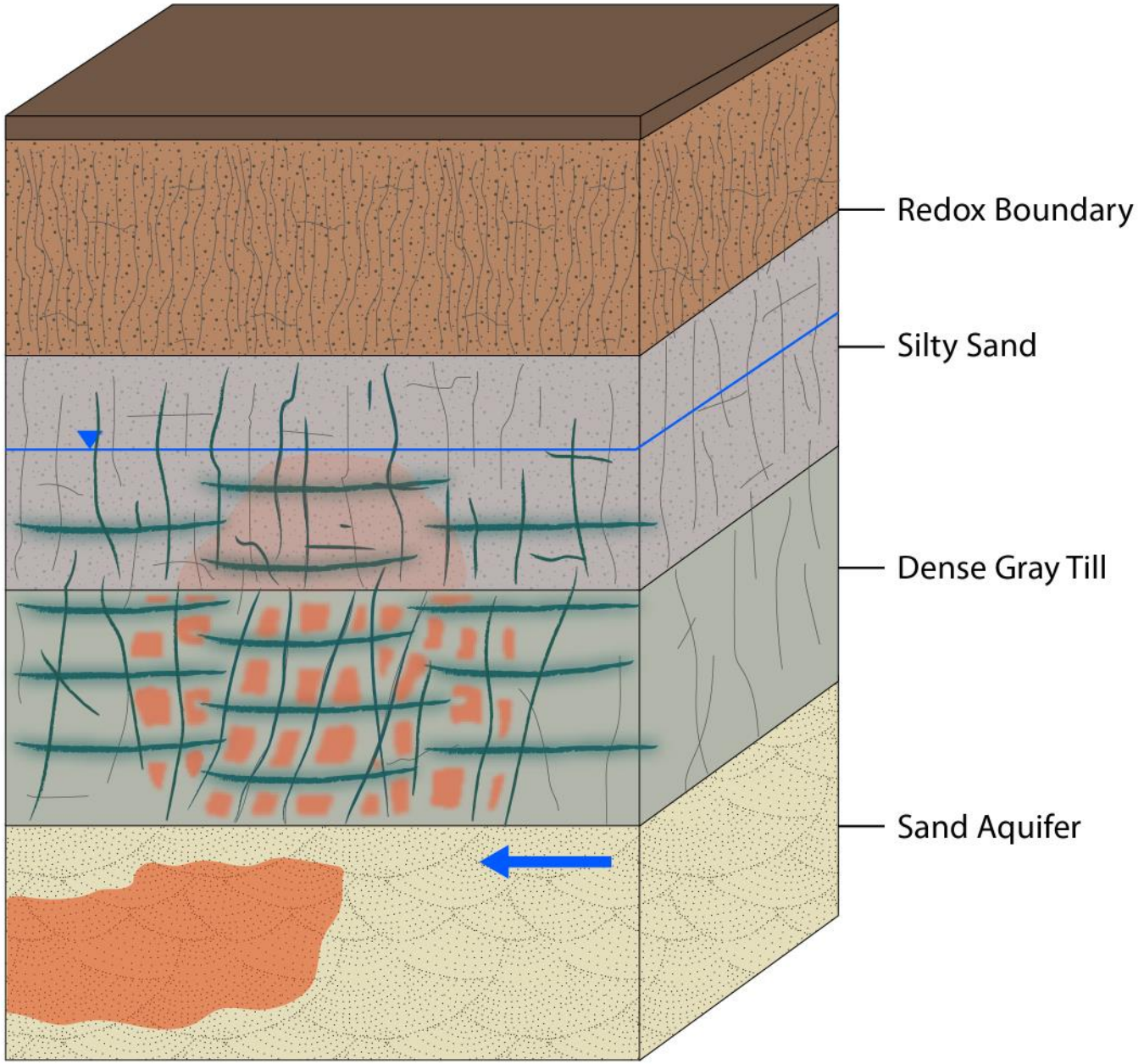

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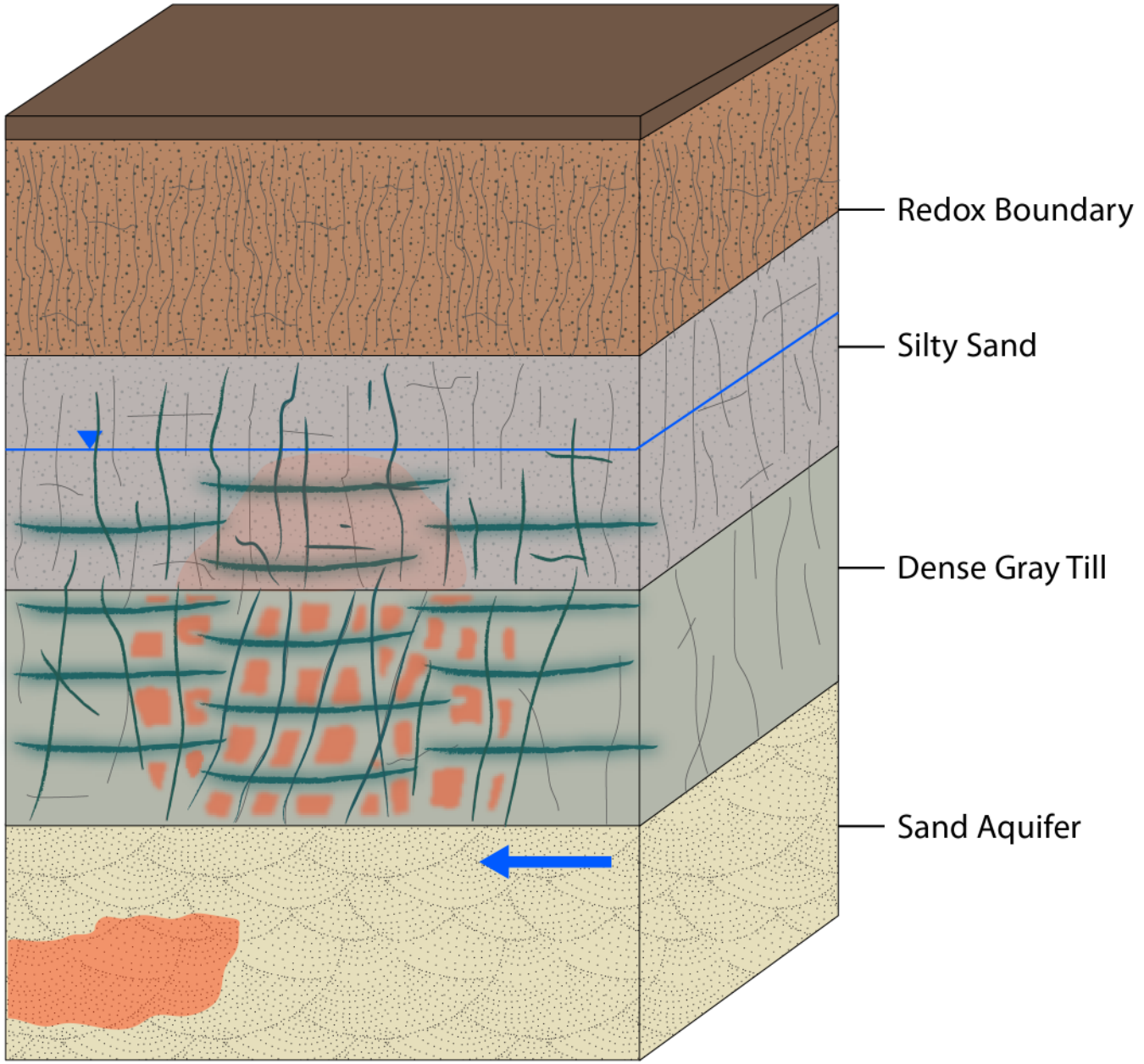

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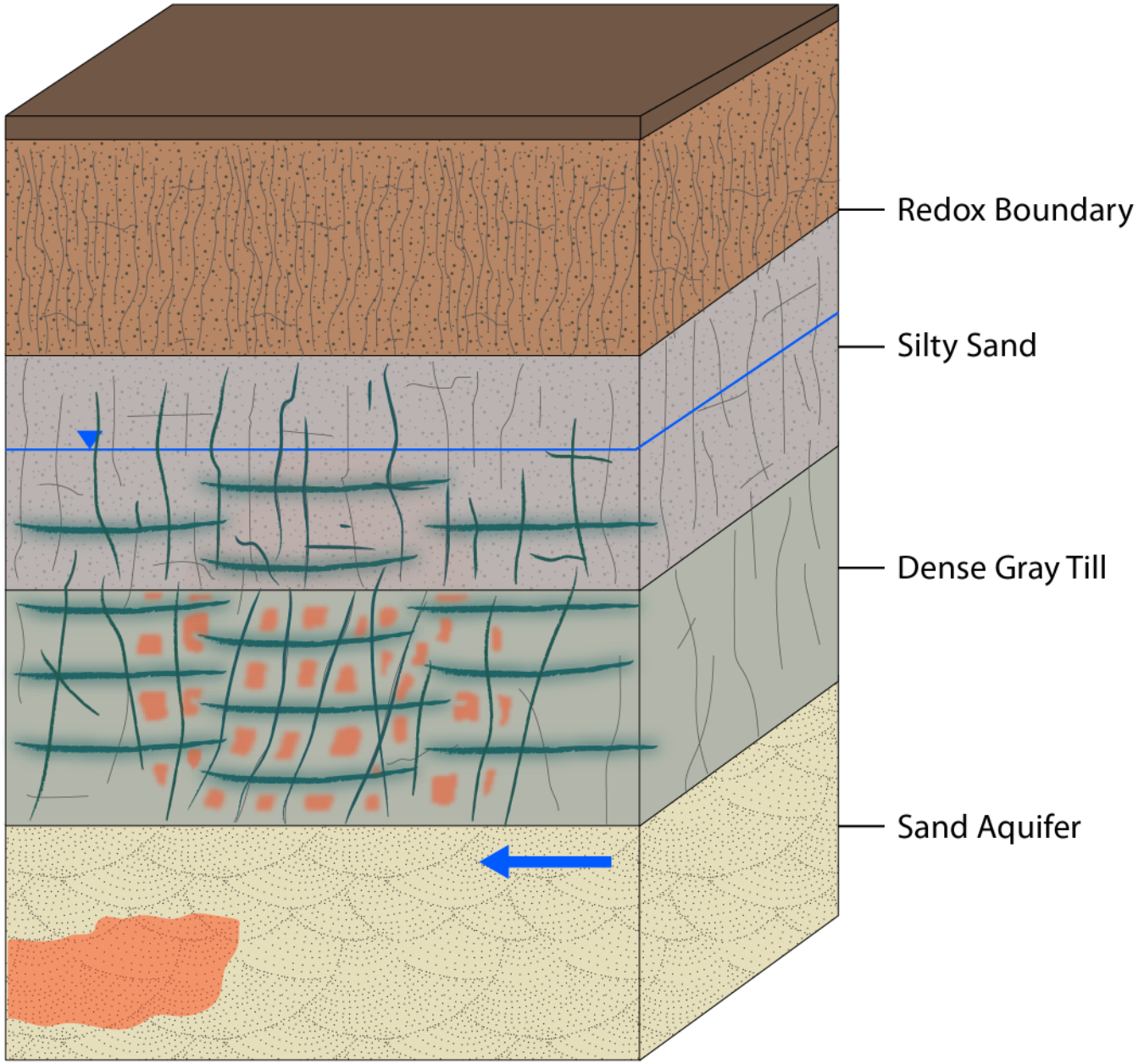

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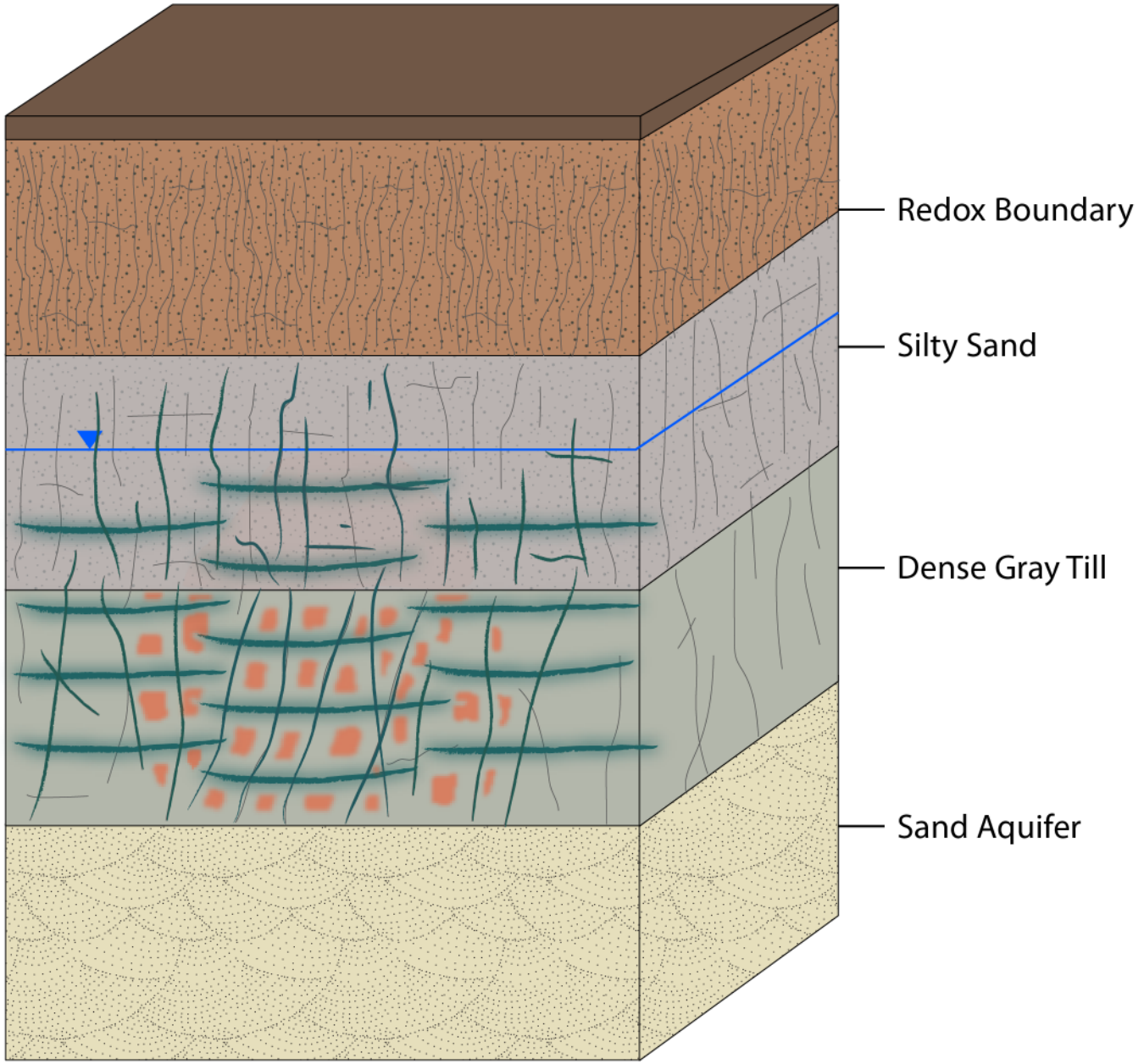

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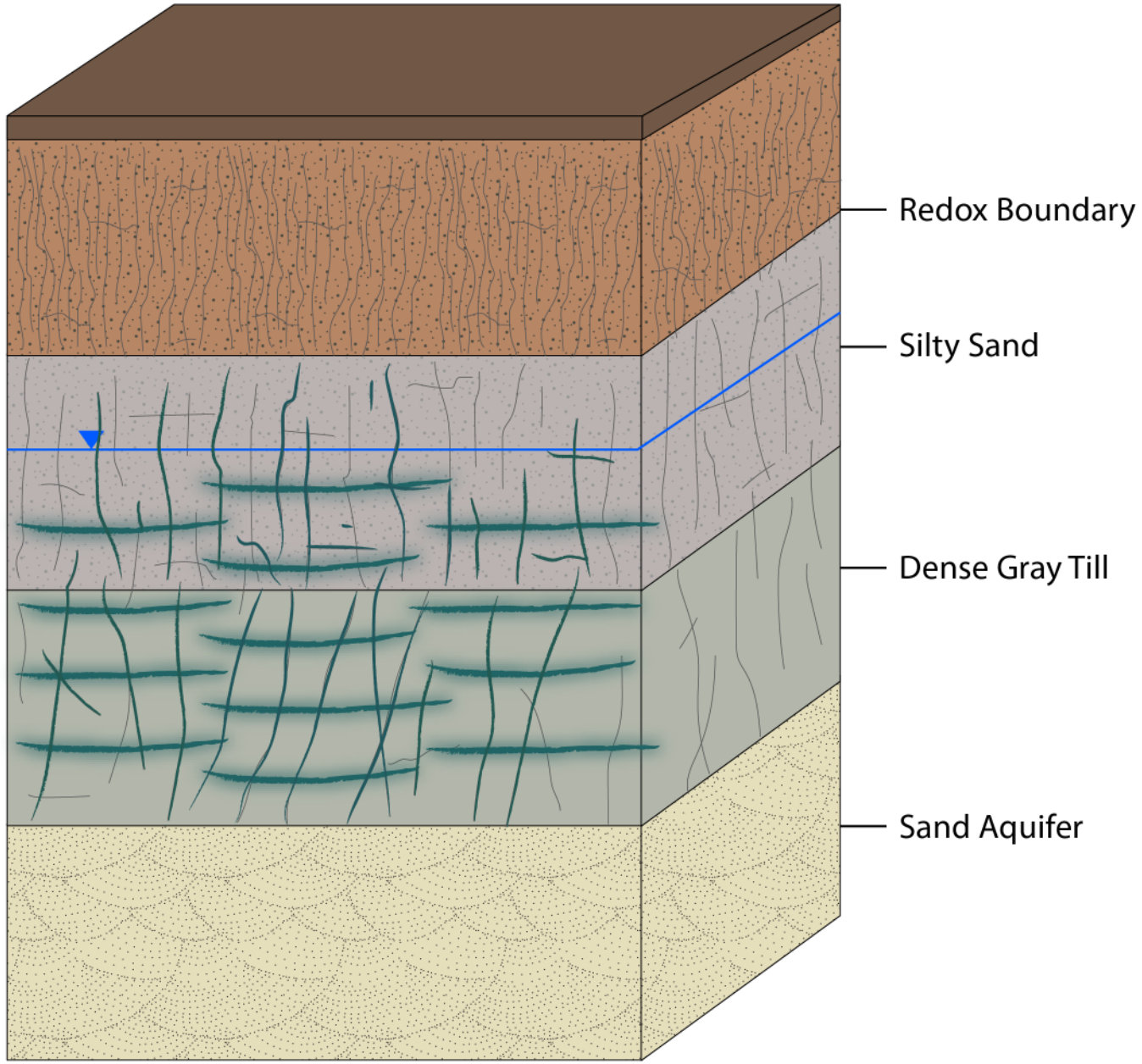

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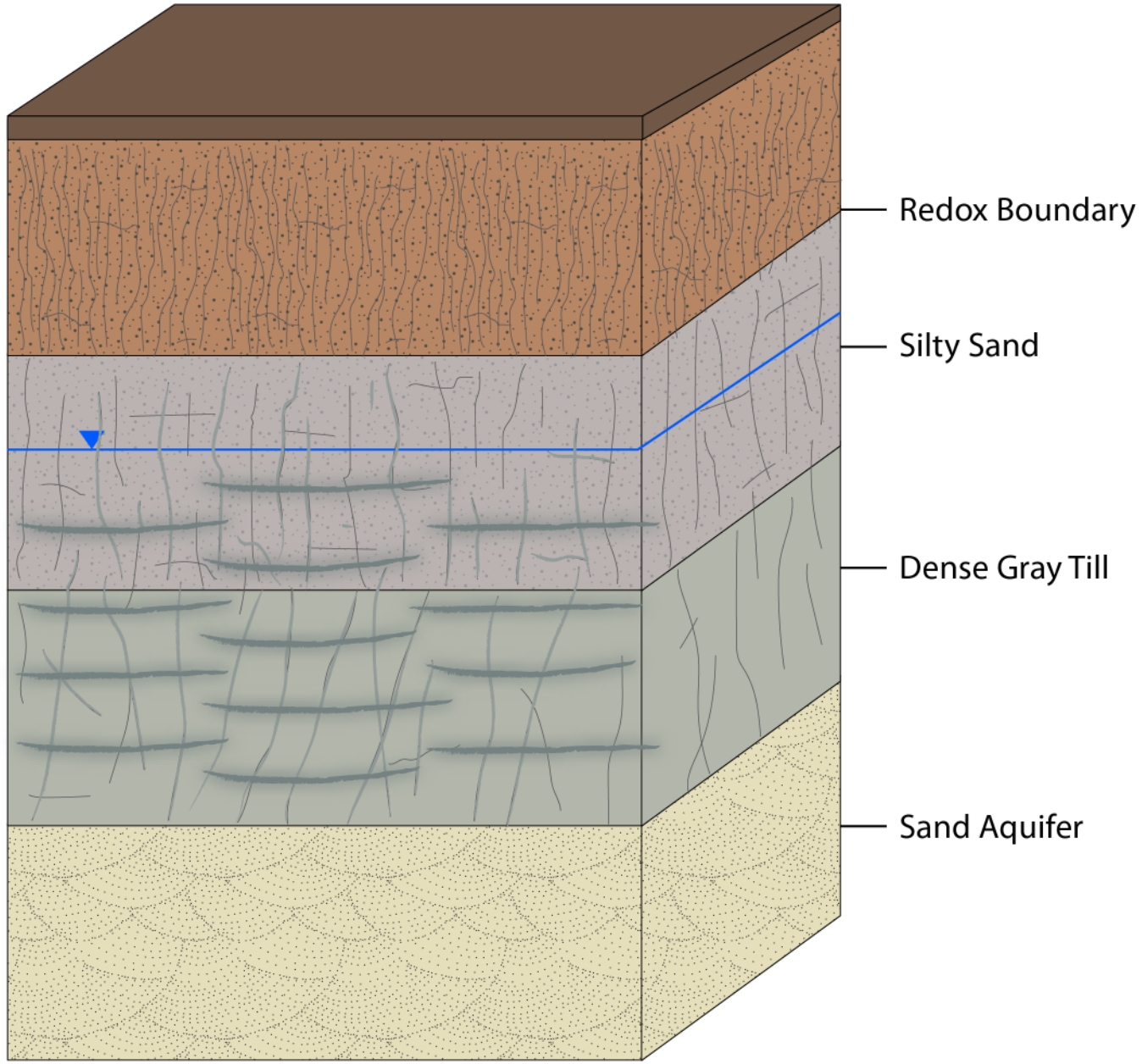

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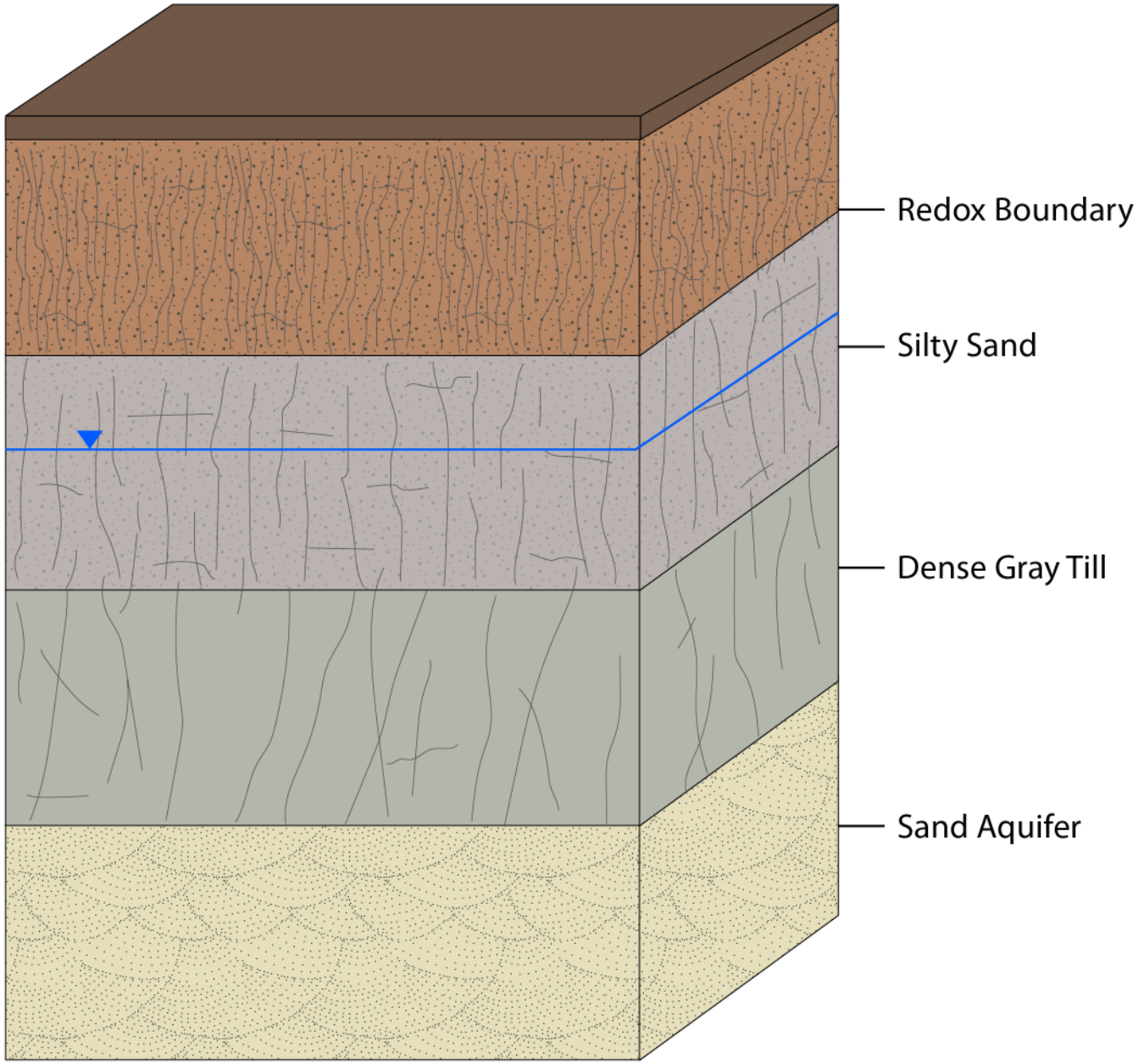
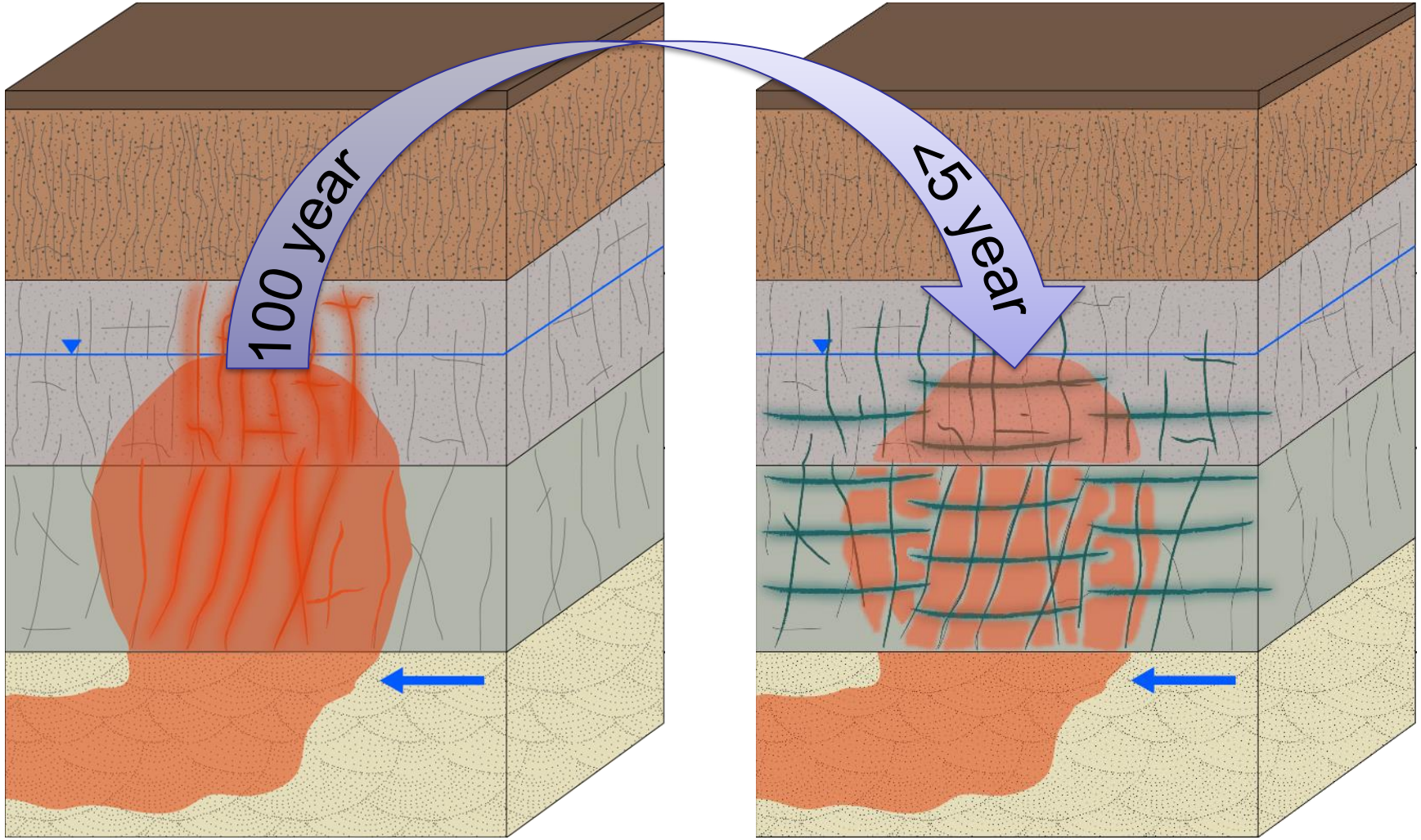


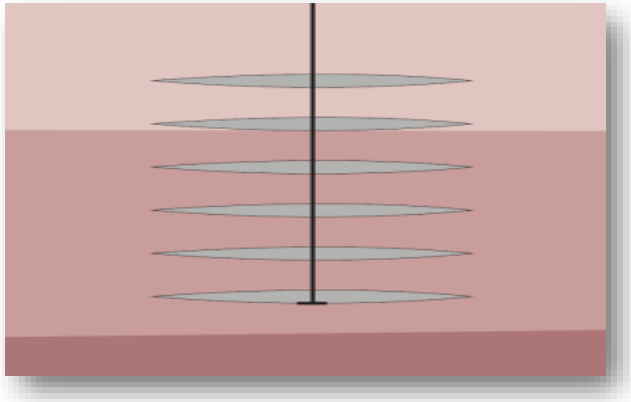
Objective

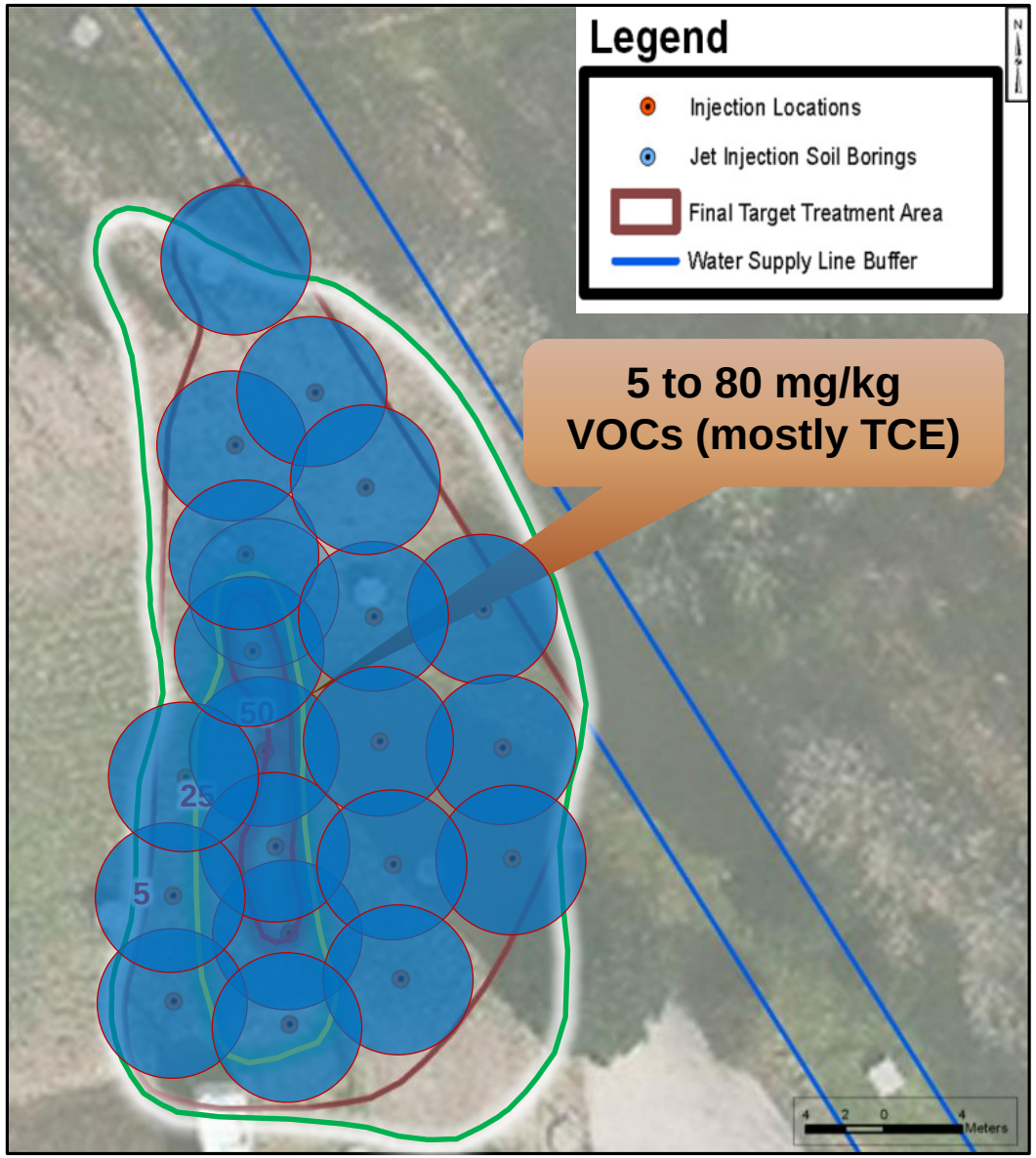


CASE STUDY: Full-scale Source Treatment in Denmark

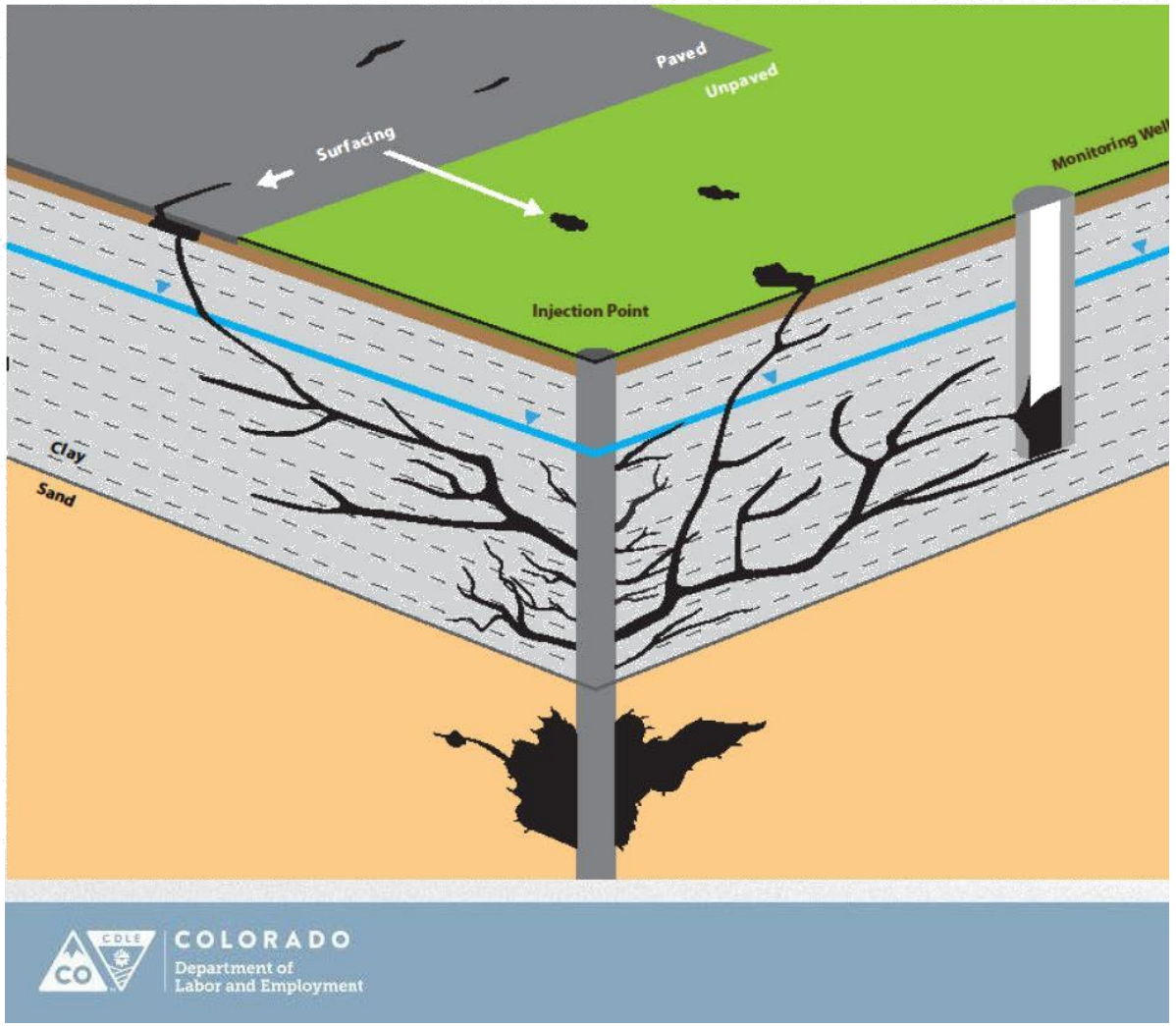
Case Study – Remedial Design

- 700 sq meter Target Treatment Area (TTA)
- 4 m design ROI
- 21 injection locations with 121 individual injections
- 5-7 discrete injection depths
- 50 tonnes mZVI (Hepure Ferox Flow)
- 25 tonnes sand





Case Study – Surfacing



Surfacing during injection was limited to 4 known historical borings and 2 other locations during 121 injections.

Surfacing during slurry injection can be controlled!!

CASE STUDY: Denmark – ZVI Distribution

Case Study – Lateral Fracture Distribution

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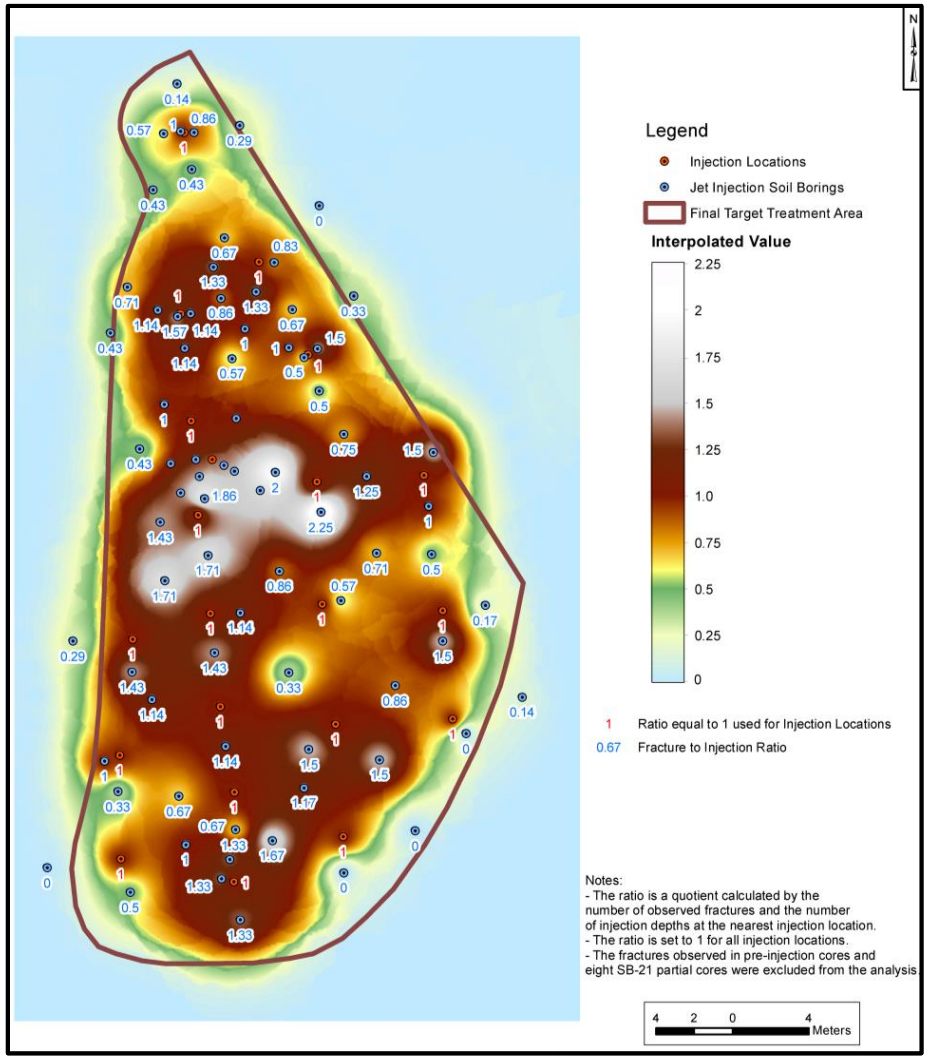
- Advanced 80 borings in TTA
- Confirmed that we met our 4 m design ROI



Case Study: Tracing Single Fractures

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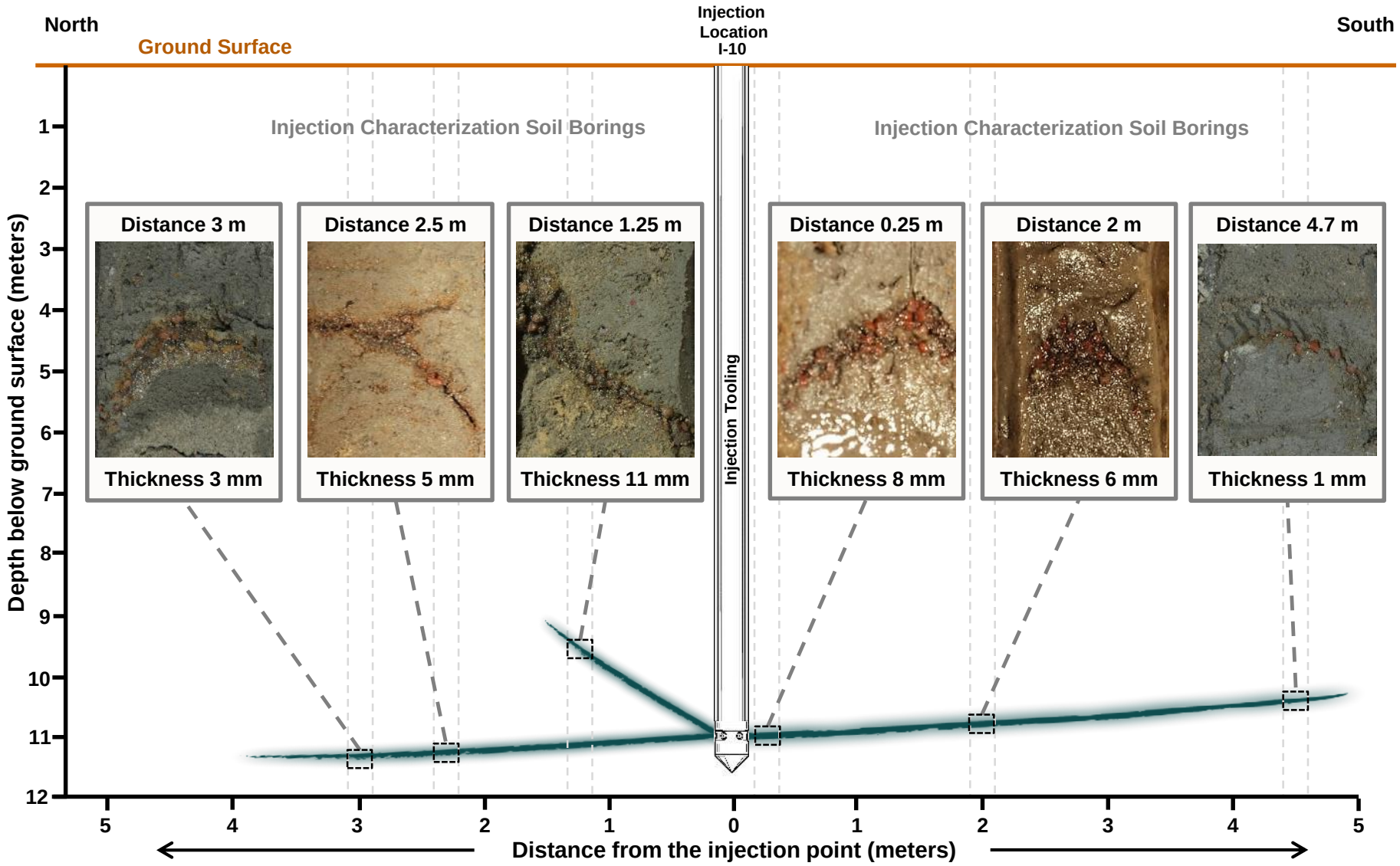

Case Study: Mapping Overlap w/ Multiple Tracers

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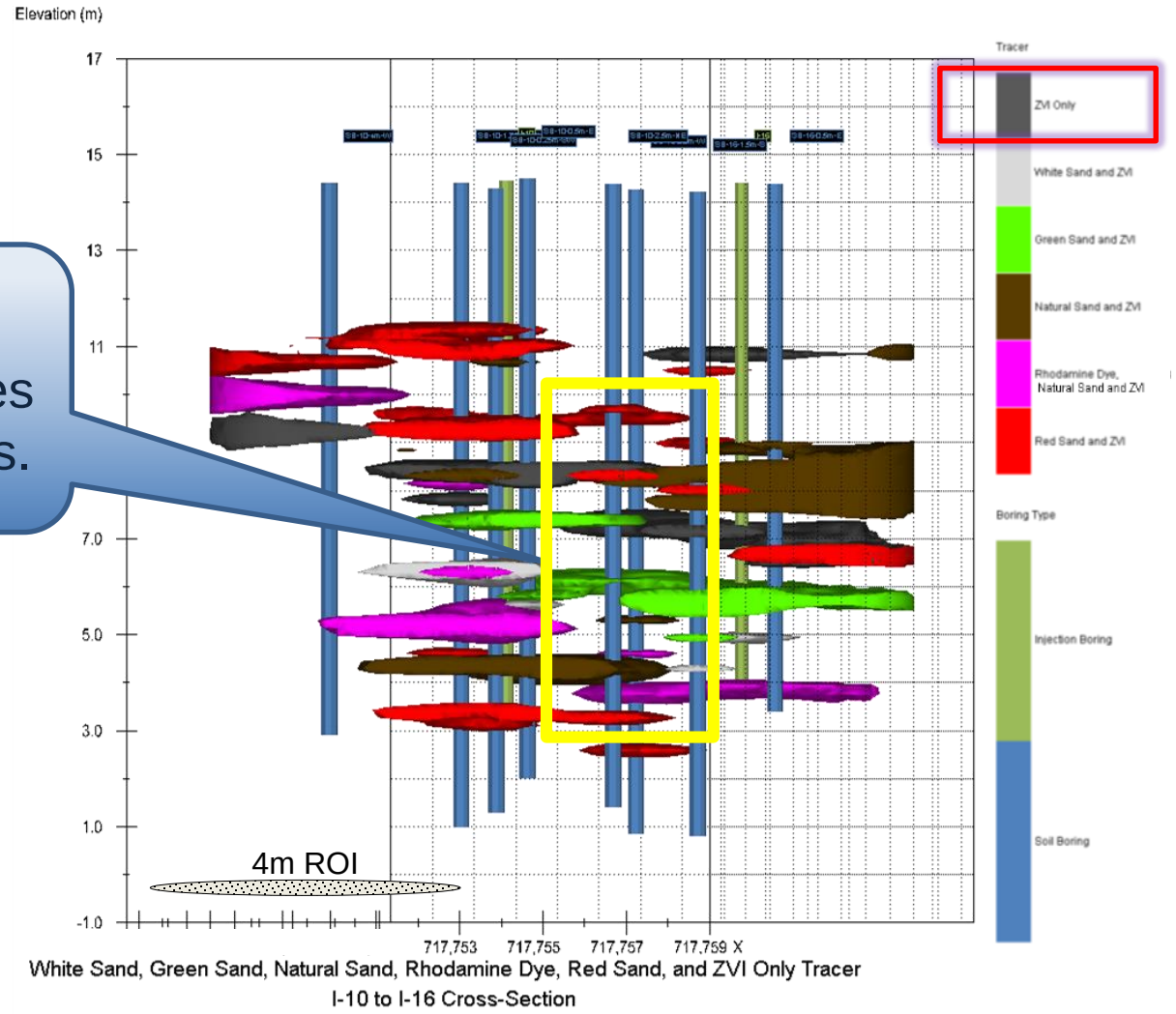
Documented multiple overlapping ZVI-filled zones between injection locations.



White Sand, Green Sand, Natural Sand, Rhodamine Dye, Red Sand, and ZVI Only Tracer
I-10 to I-16 Cross-Section

Case Study: Distribution of Fractures – 3D Modeling

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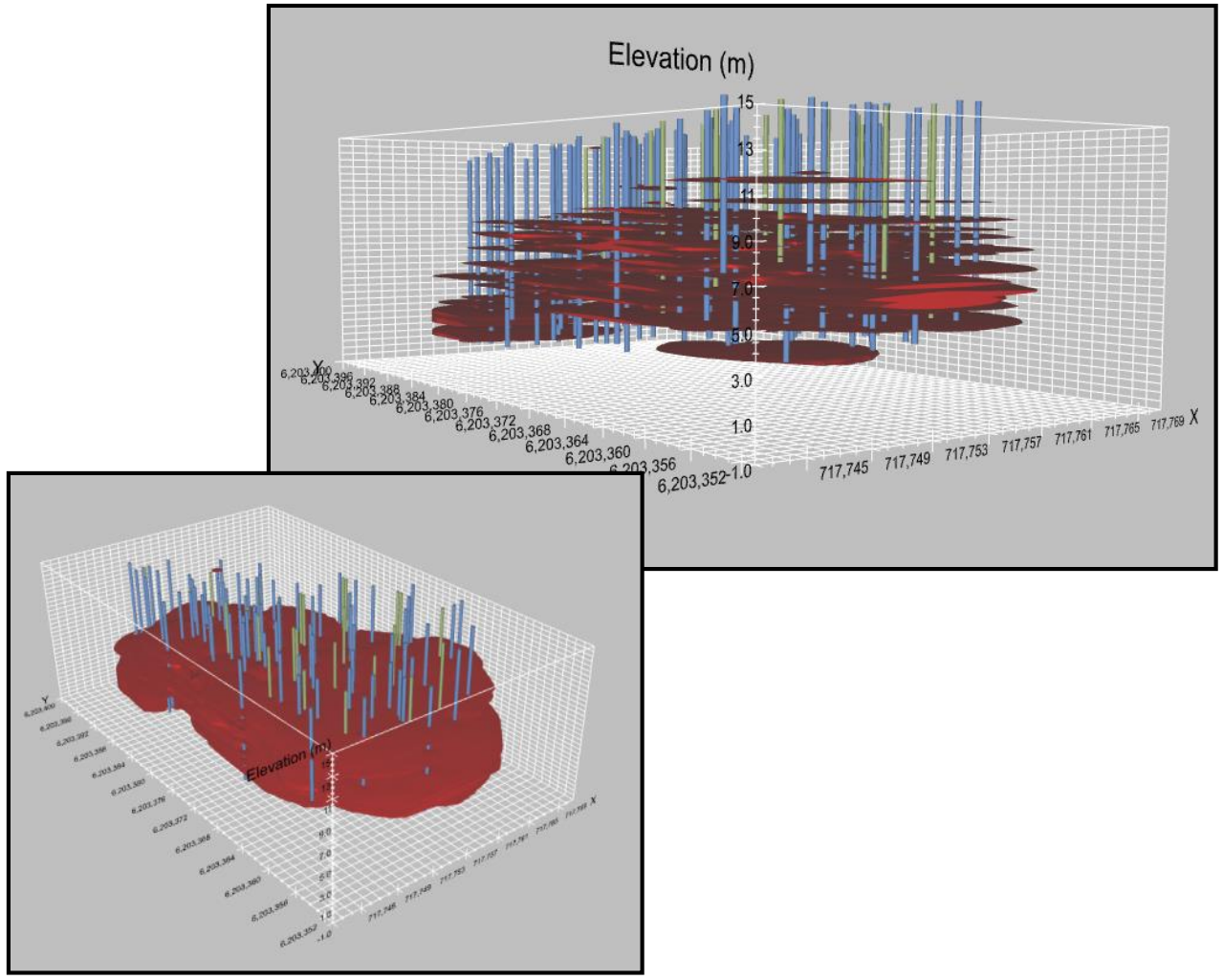
METHODOLOGY

- 3D modeling (EVS software) was utilized to interpolate magnetic susceptibility (MS) readings.

- Interpolated MS readings >1x10^{-3} were generally co-located with visual identification of ZVI-filled fractures.



Lateral Distribution of Horizontal Fractures – Cross Sections

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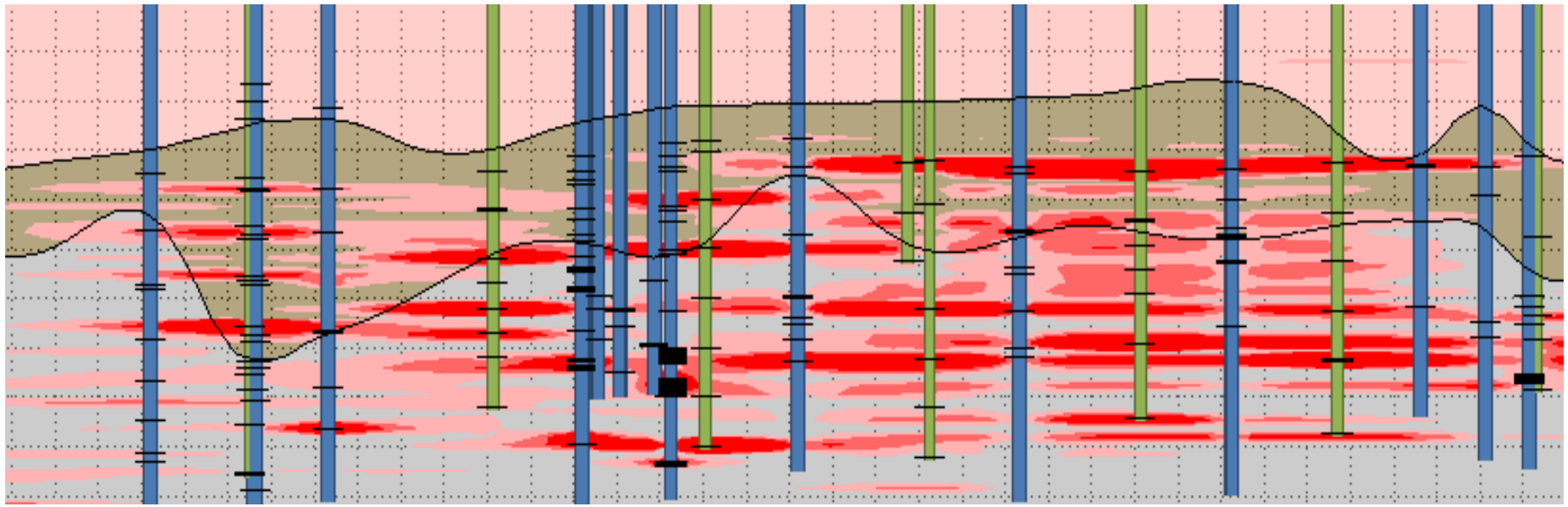
North **South**



Magnetic Susceptibility

- 1 x 10^{-3}
- 2 x 10^{-3}
- 3 x 10^{-3}

Boring Type

- Injection Boring
- Soil Boring

Lithology

- Above Redox Boundary
- Below Redox Boundary
- Dense Gray Till

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

4m ROI

North-South 2 Cross-Section

Møllevej 9, Nivå, Denmark

Geosyntec consultants

Columbia, Maryland | March 2015

Case Study – 3-D Print of Distribution

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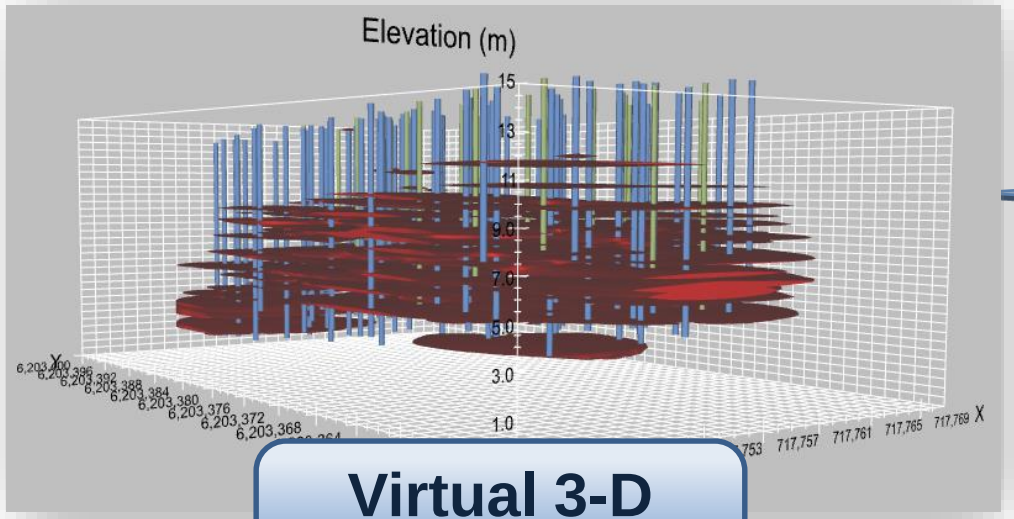
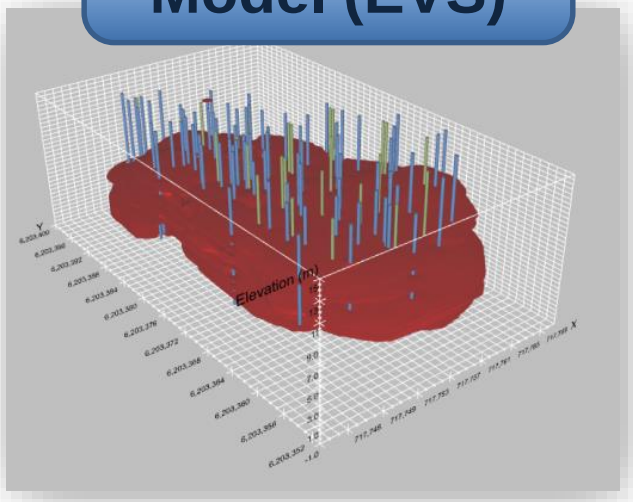


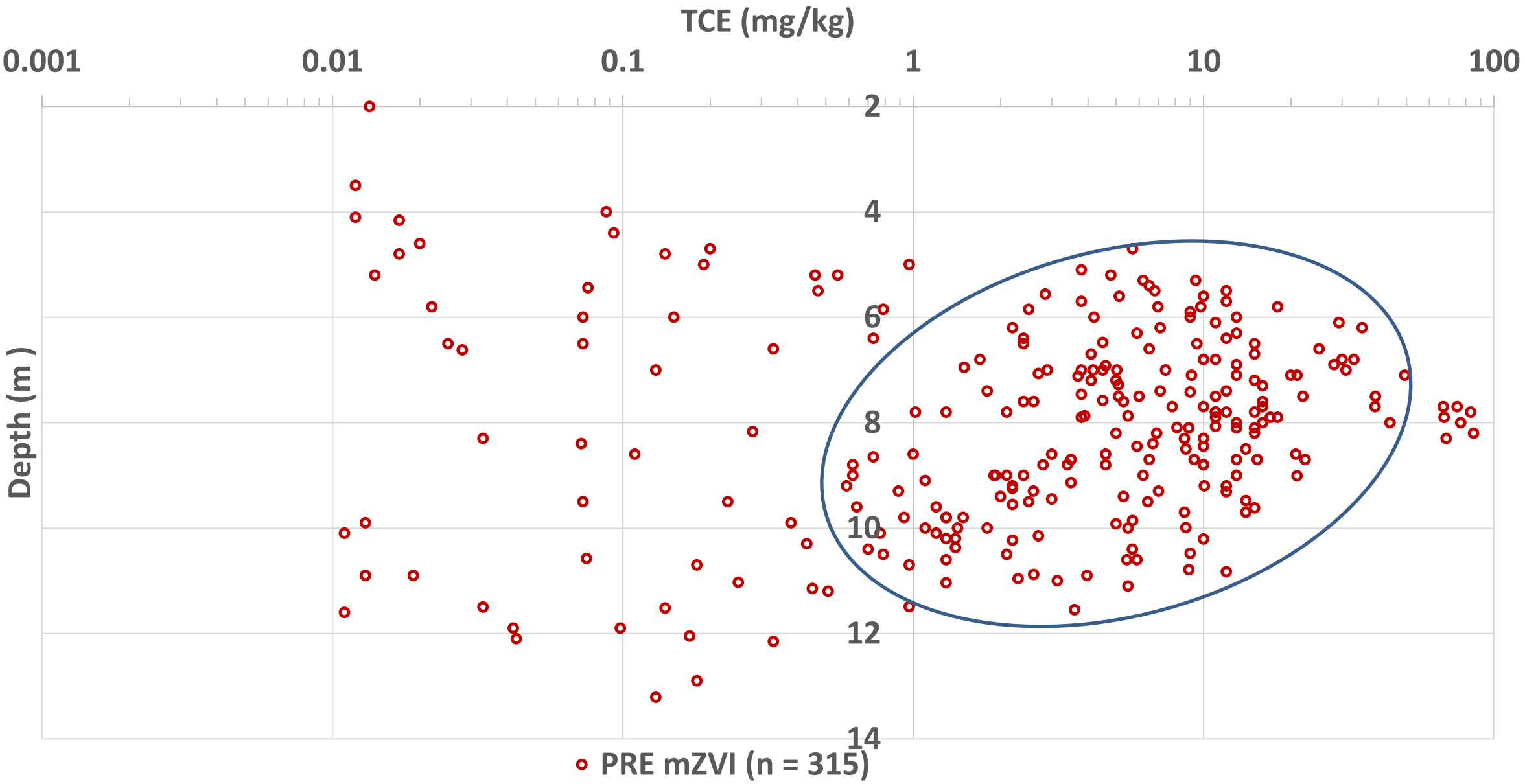
Virtual 3-D Model (EVS)



3-D Printed Model

CASE STUDY: Denmark – Treatment Results

TCE in Soil – Baseline



TCE in Soil – 6 months Post-Treatment

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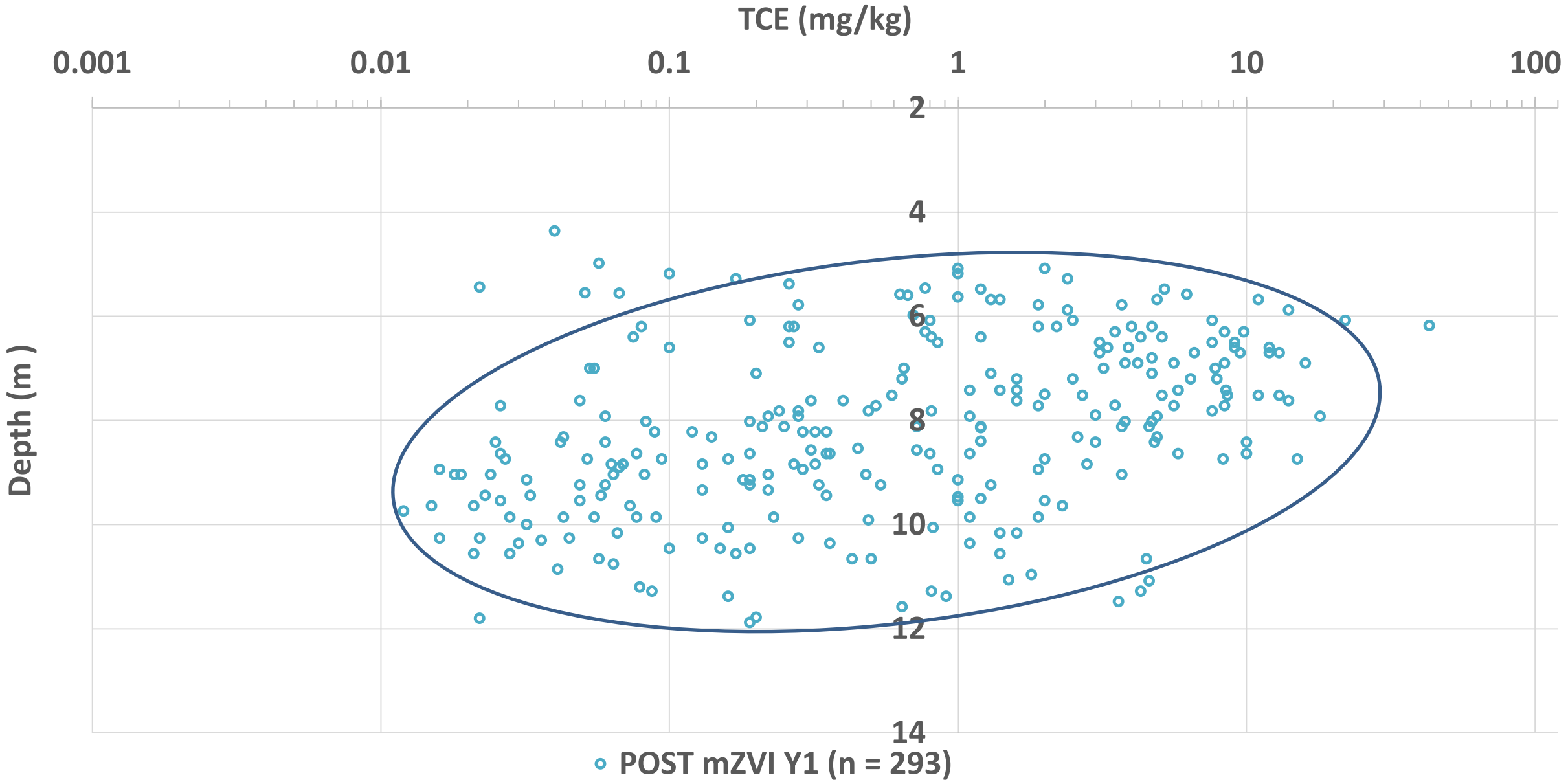

TCE in Soil – 18 month Post-Treatment

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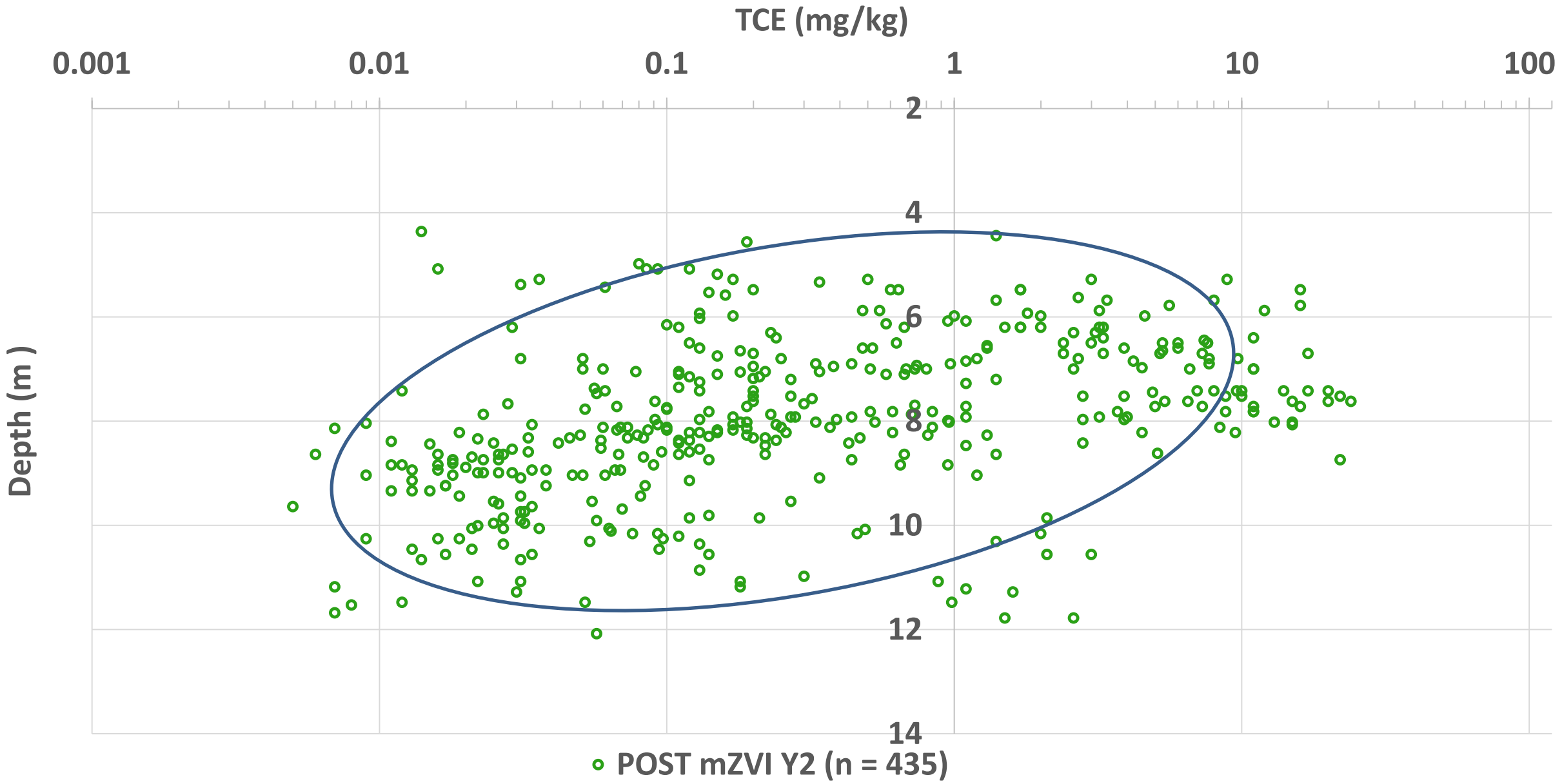

TCE in Soil – 30 month Post-Treatment

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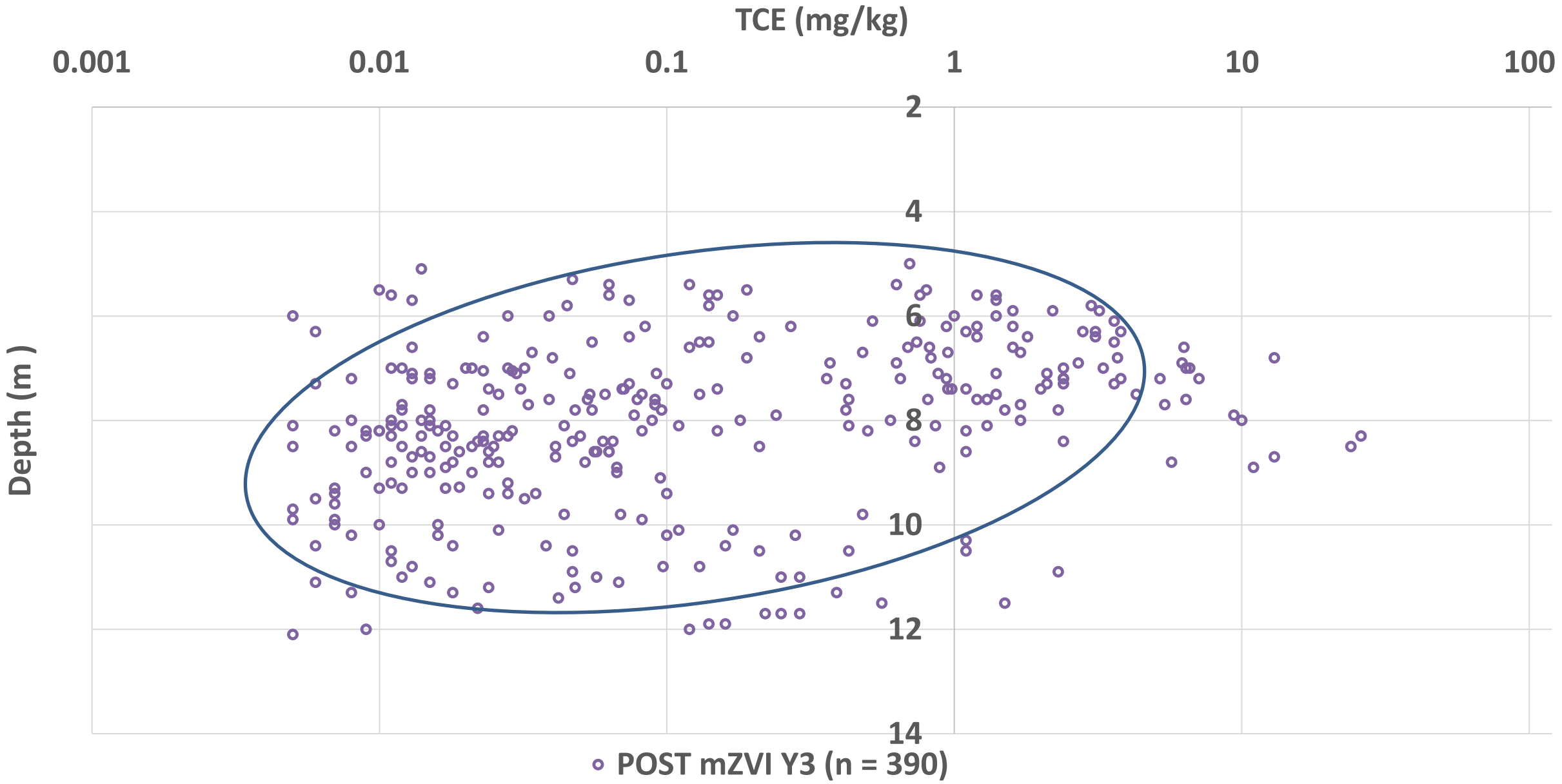

TCE in Soil – 4 years Post-Treatment

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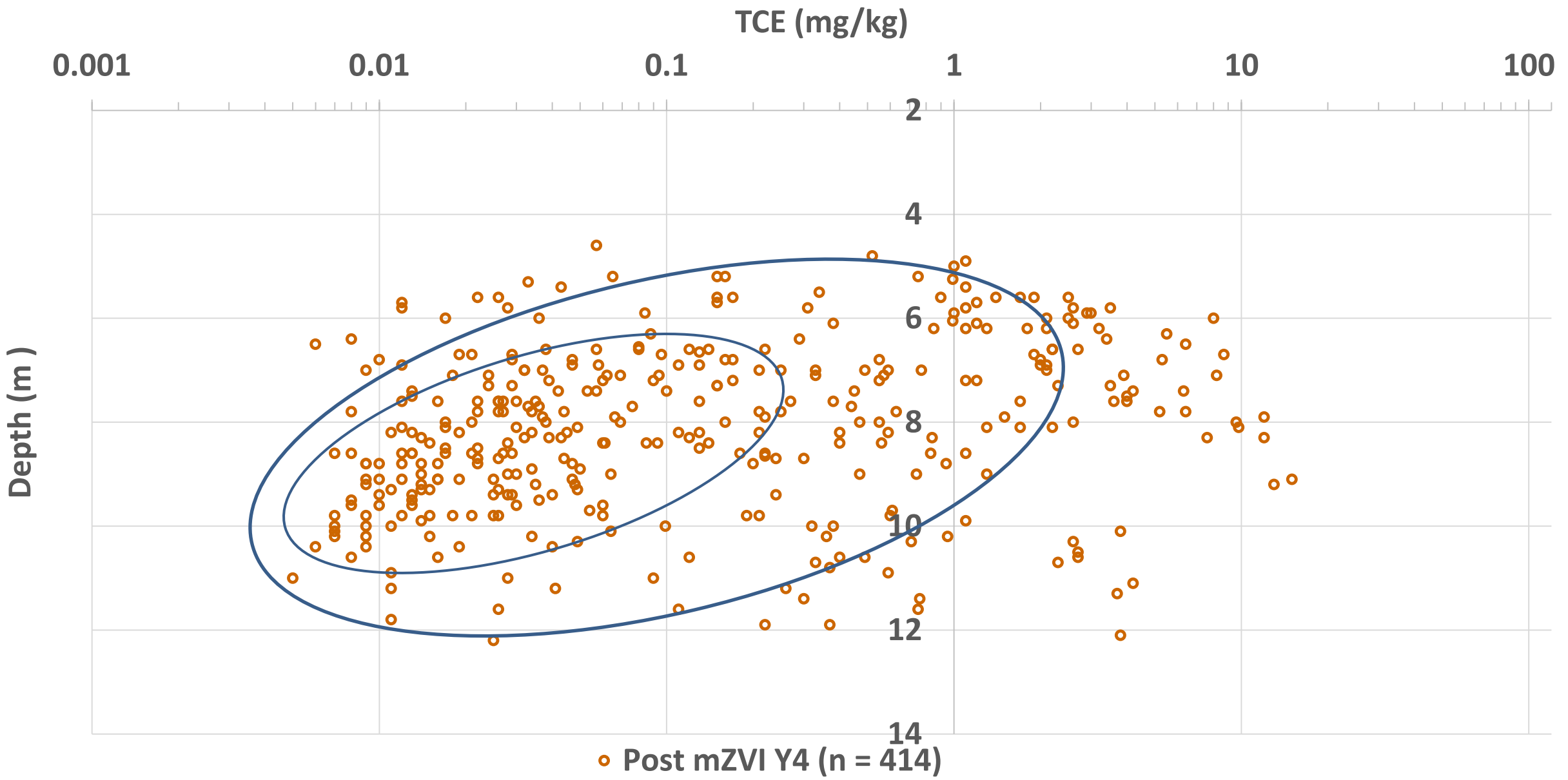

Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

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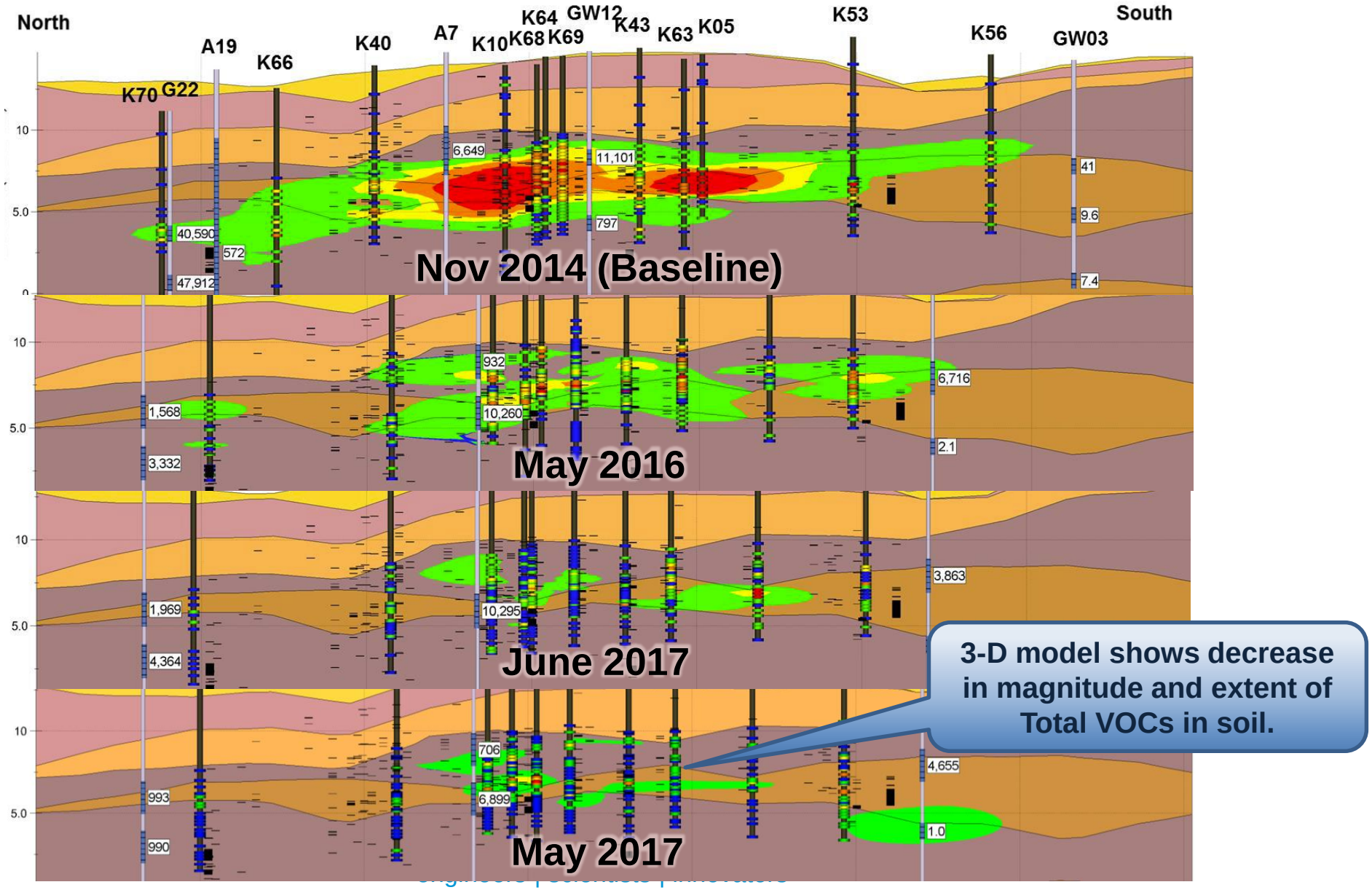

Distribution of Total VOCs in Soil – 4 years Post-Treatment

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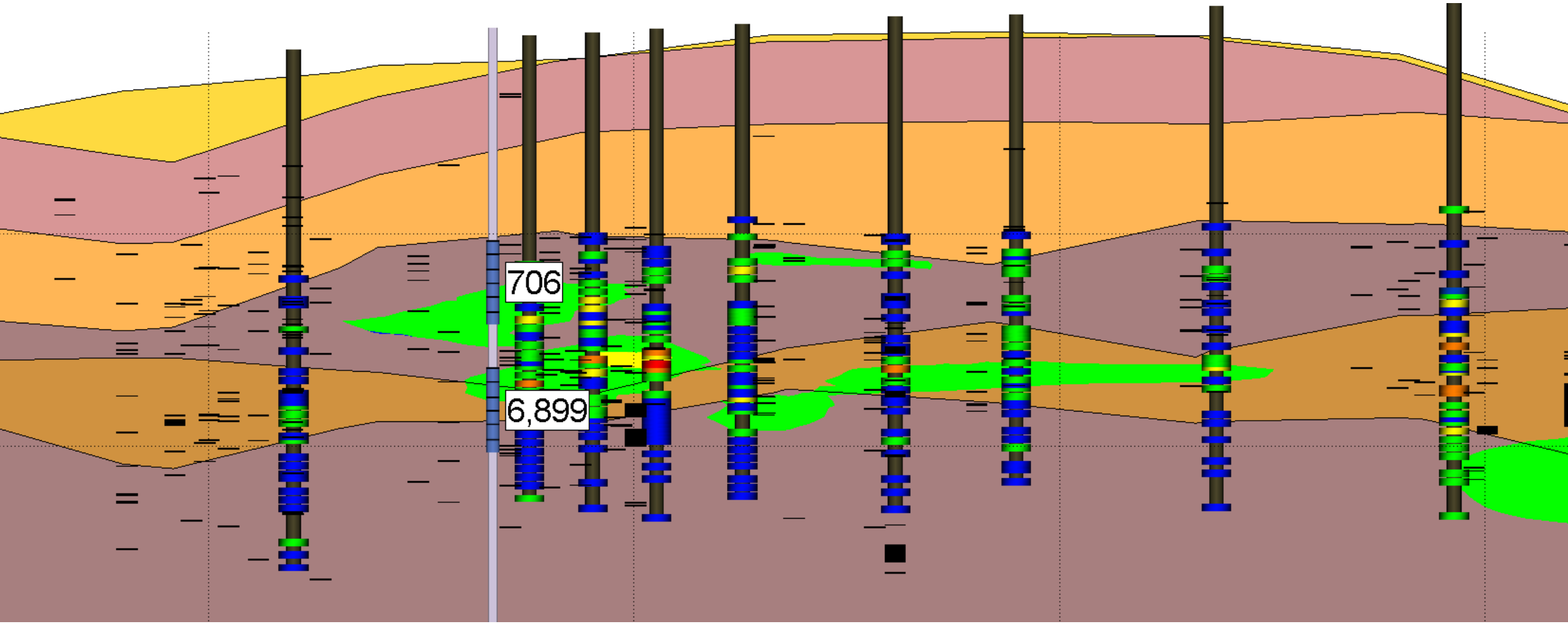

Distribution of Total VOCs in Soil – Baseline, 6 months Post-Treatment

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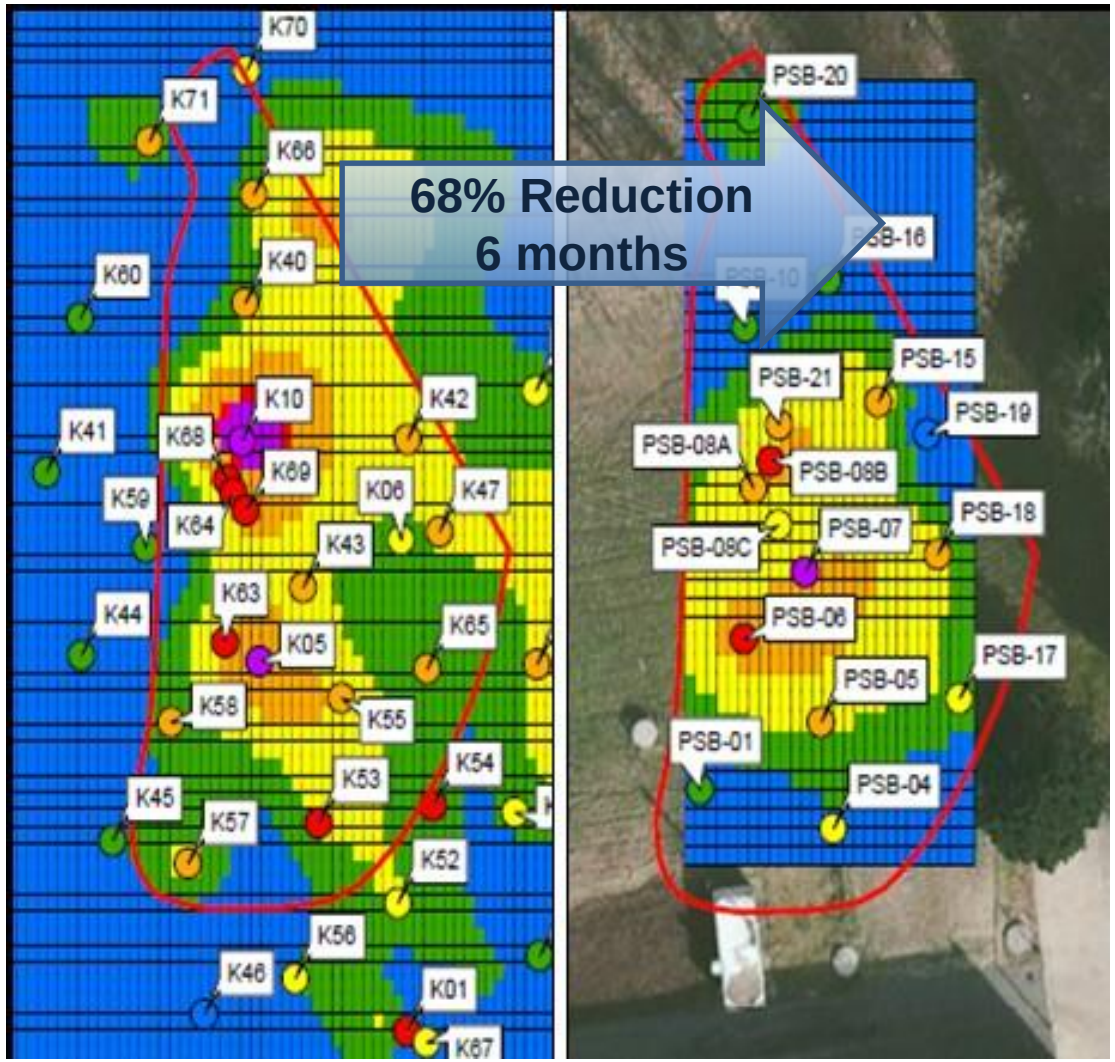
Nov 2014 (Baseline) June 2015



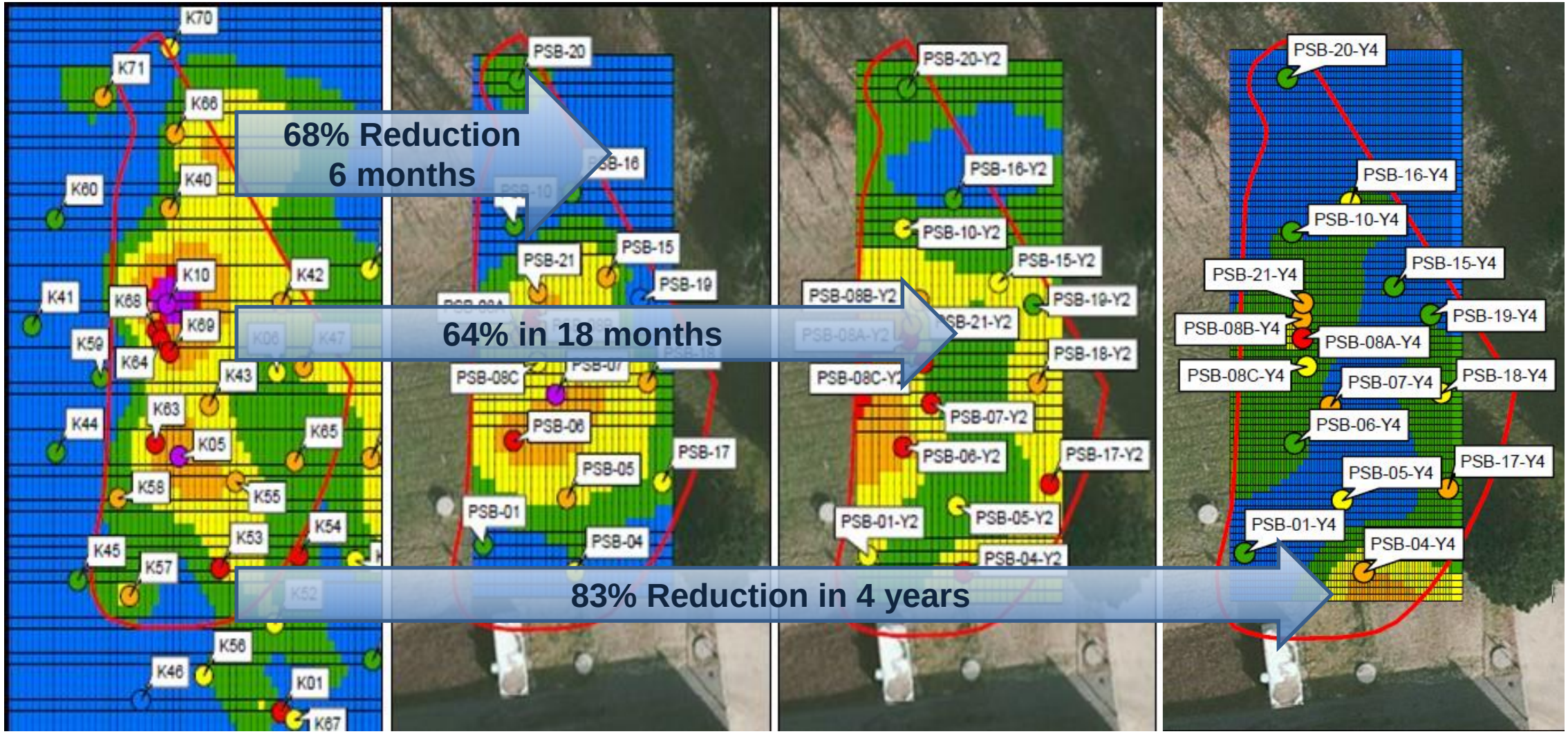
Legend:

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

Distribution of Total VOCs in Soil – Baseline to 4 years Post-Treatment

Geosyntec consultants

Nov 2014 (Baseline) | June 2015 | May 2016 | May 2018



Mass Discharge VOCs in Groundwater from TTA

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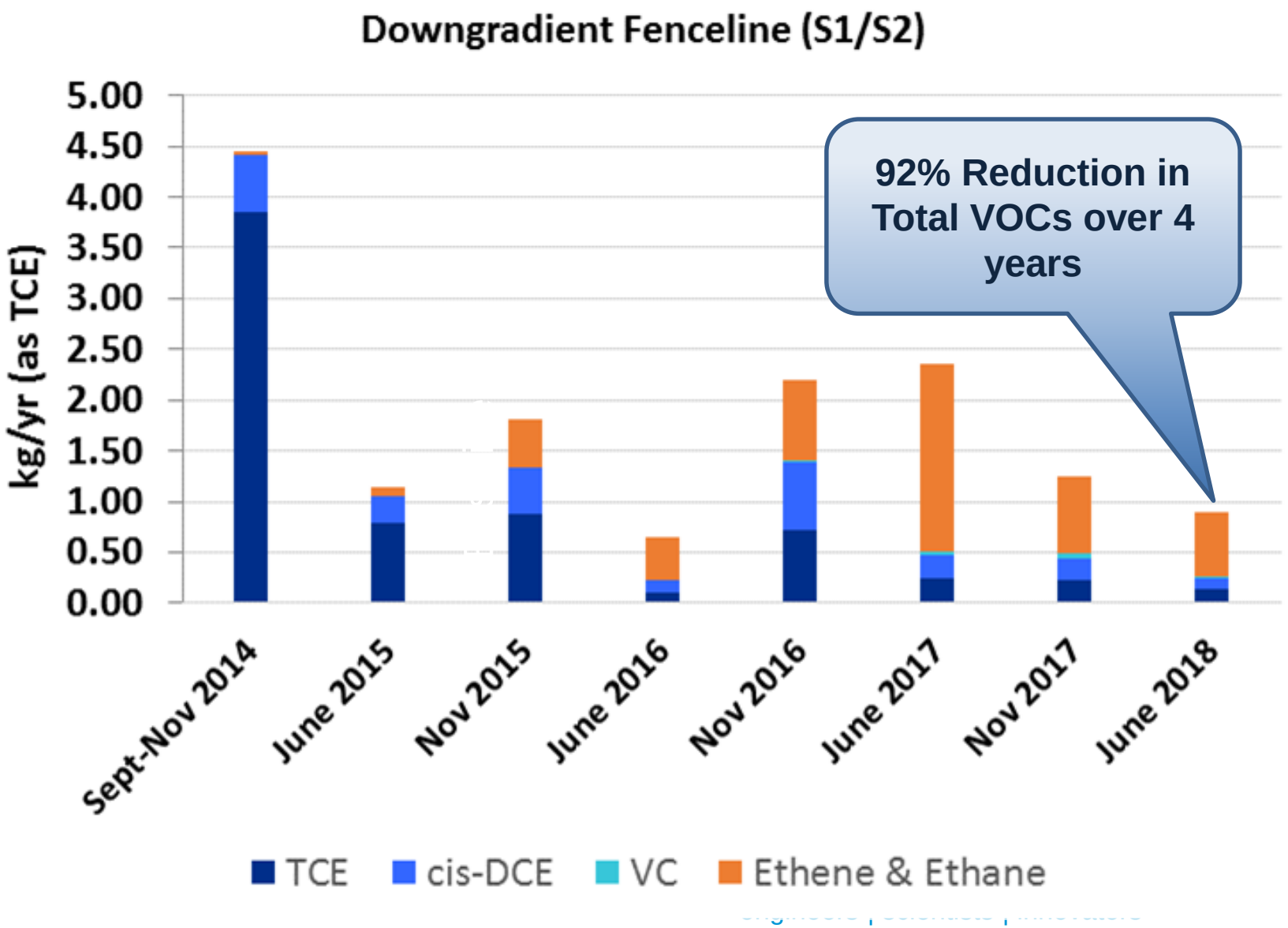

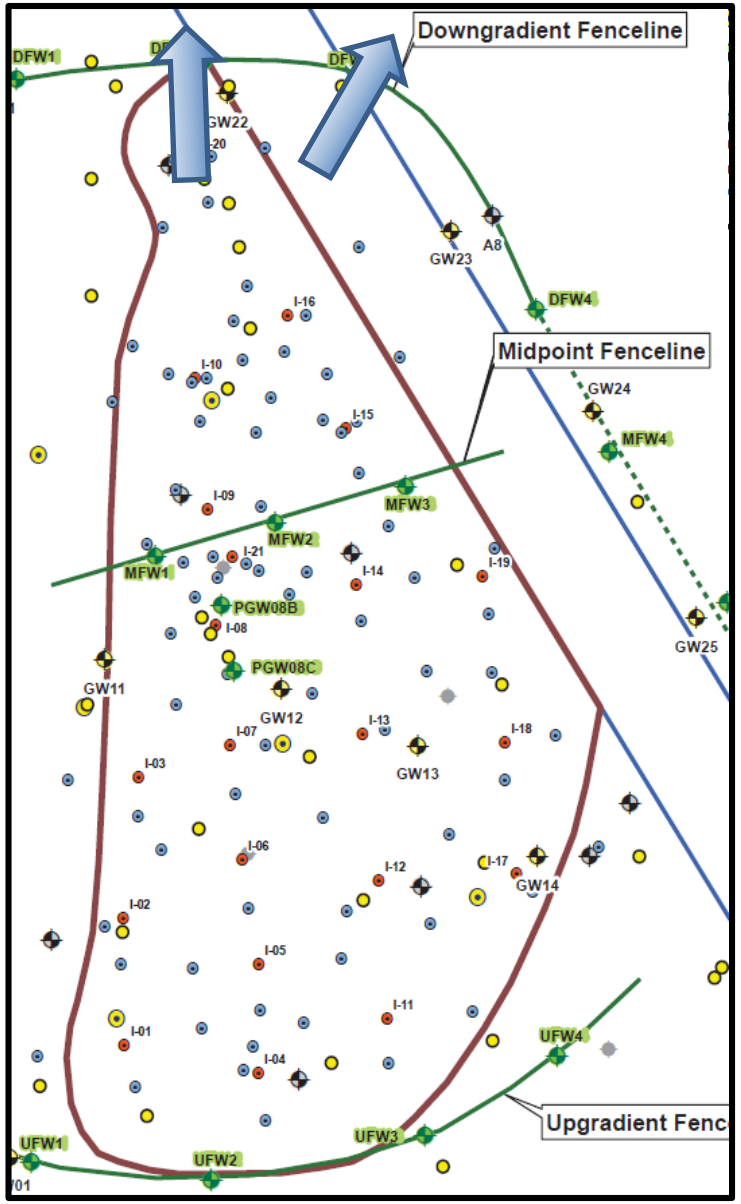

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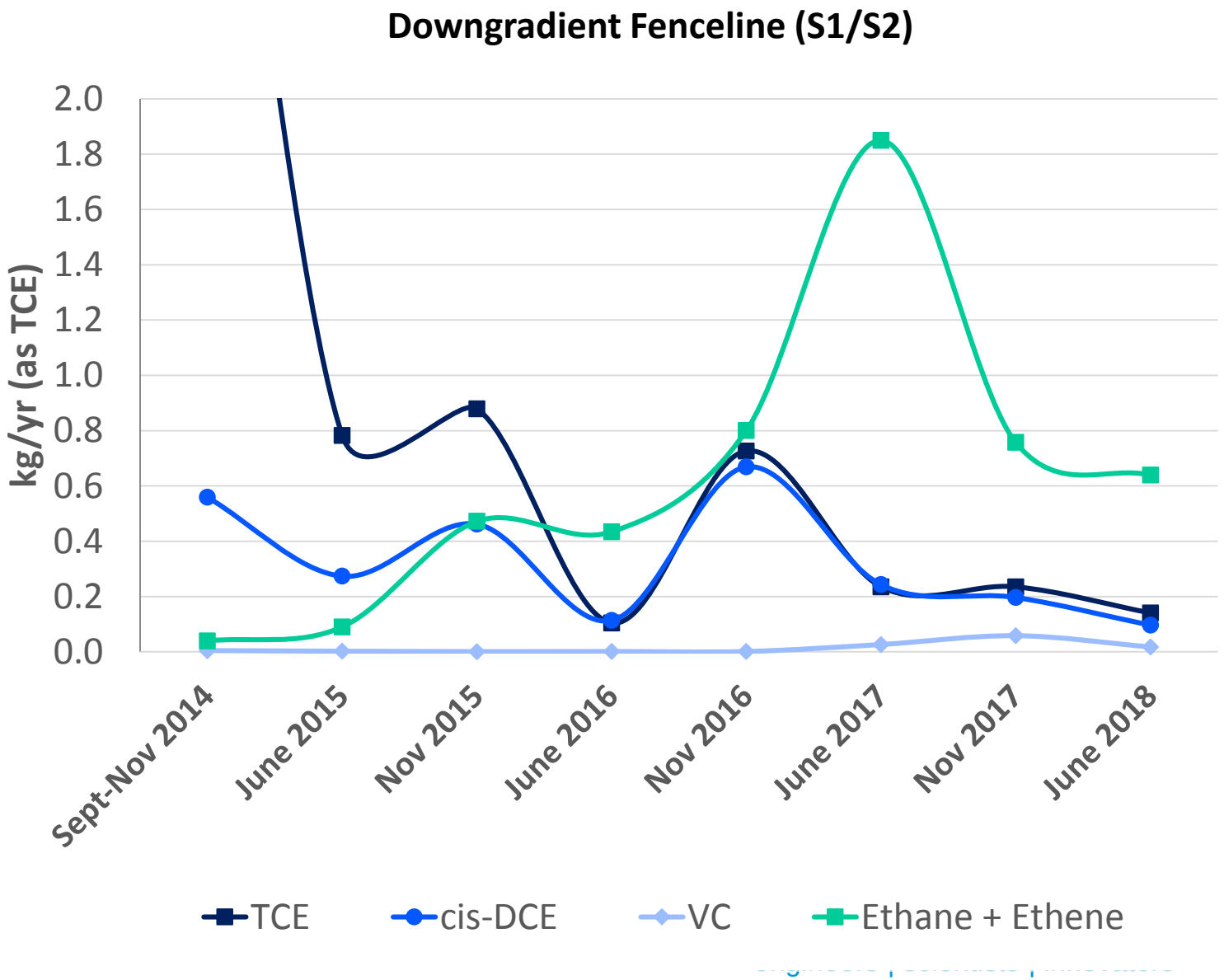

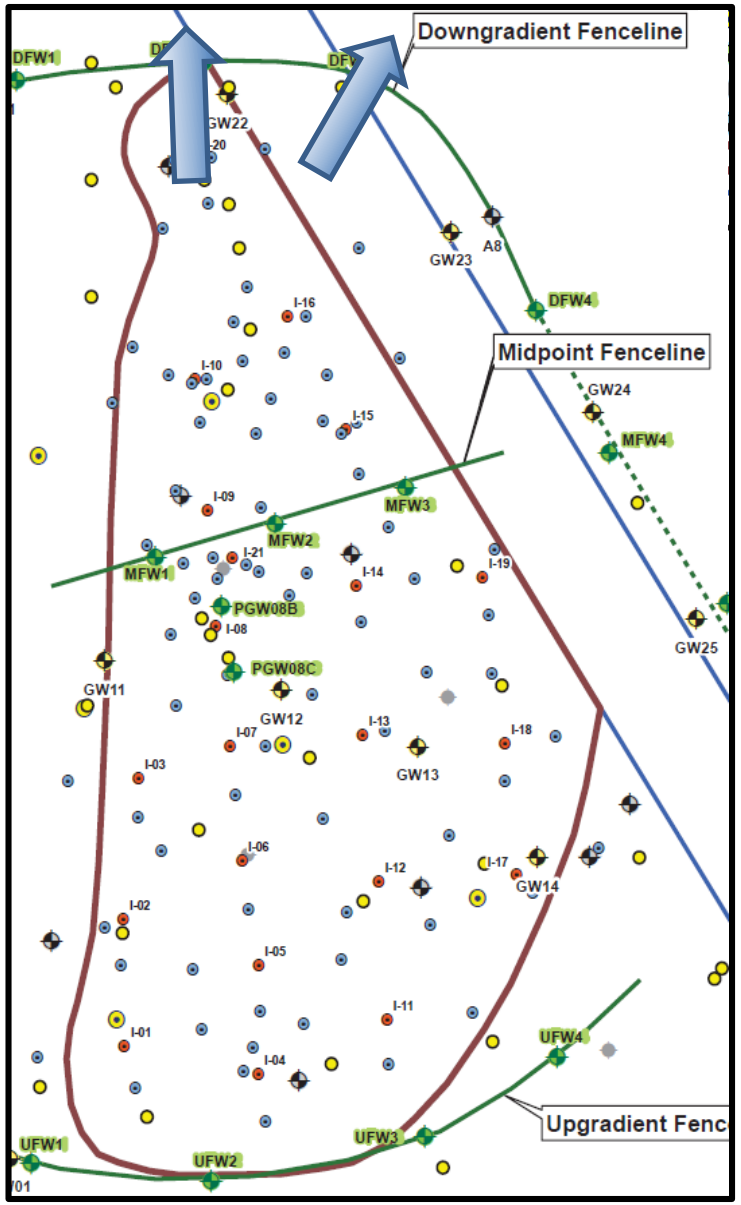

Case Study Conclusions

- DPT Jet Injection shown to be extremely effective for emplacing amendments in challenging low permeability formations.
- Total TCE mass in soil decreased by 92% after 4 years.
- Total VOC mass in soil decreased by 83% after 4 years.
- Total VOC mass discharge in groundwater decreased by 92% after 4 years.
- Increasing ethane/ethene concentrations demonstrate complete degradation (max. ethane conc. in 2018 = ~7 mg/L).
- Lesson Learned: Bioaugmentation at beginning could have provided faster complete treatment in the first 2 years, limiting cis-DCE formation.

Advantages of DPT Jet Injection

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- Better Control: Flat Fractures and Limited Surfacing
- Reduced Injection Time: Faster than standard DPT injection approaches
- Works reliably at shallow depths and in heterogeneous formations
- Injection of long-term amendments like ZVI can result in semi-passive treatment of long-term source zones
- Competitive Cost: When compared to other methods commonly used for treating low-permeability zones (e.g., thermal, excavation)

$60-150/CY for ZVI treatment

Questions?

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