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# Injection of slurries – 20 years of lessons learned

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# Presentation Layout / Agenda

- Ejlskov / RPI Group Structure and Project Approach - Overview
- Remediation Design and Implementation
- Case Studies
- Q&A Session

# RPI Group and Activated Carbon - Why?

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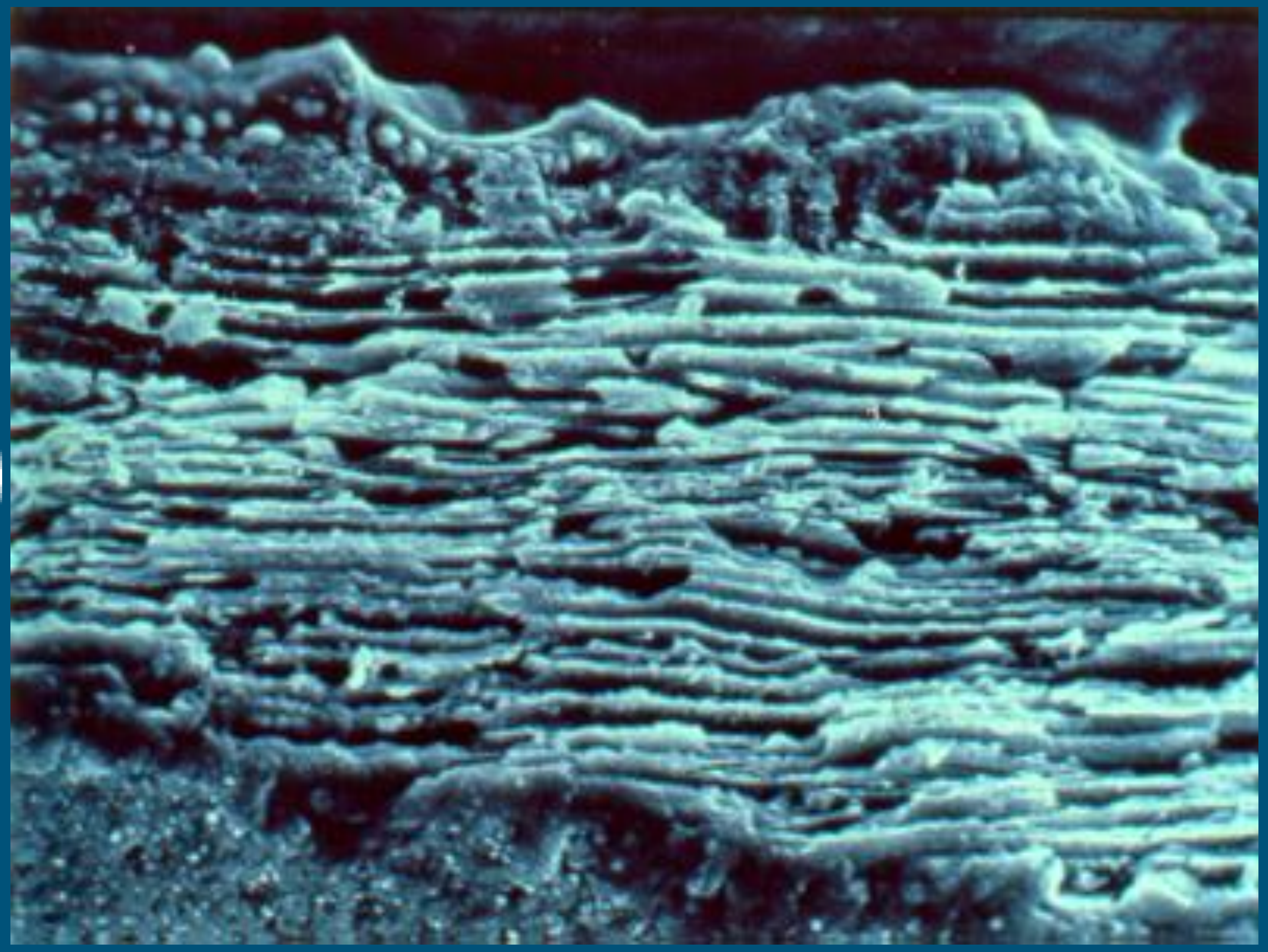
- Use well known in the industry
- Highly flexible for in-situ applications
- Applications can be made predictable when designed correctly
- AC use needs to be combined with a treatment mechanism prior to injections – adsorption alone will not work
- Some pores transport and some adsorb (think highways and parking lots)
- Size matters – granular vs. powdered vs. colloidal (microbial growth suffers as particle size decreases) – RPI Group works with GAC and PAC based products
- Virgin ☑ vs. Regenerated ☒

5 grams of carbon has an internal surface area equivalent to the surface of a professional football field

# RPI Group / Ejlskov – In a nutshell

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- RPI Laboratory has supported clients and projects with analyses of 150,000+ soil and GW samples (free of charge)
- Hundreds of years of combined experience in design and injection of slurries / solid amendments
- Over 6,000,000 kg of GAC and PAC products installed since 2002 (~7-8% installed by Ejlskov since 2010)
- An estimated additional 30% of supplemental solid amendments have been installed in the same period across the same projects
- 40 to 50 million liters of slurries injected
- 1000+ completed sites – more than 90% of clients who have used RPI approach and technologies once have come back at least one more time to complete a project
- Injections completed in 15 countries globally, 5 continents and across more than 90% of the US

# RPI Group / Ejlskov "End to End" Plan

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### 1. Site Review

- Review available historical data and define the Remedial Design strategy

### 2. Remedial Design Characterization

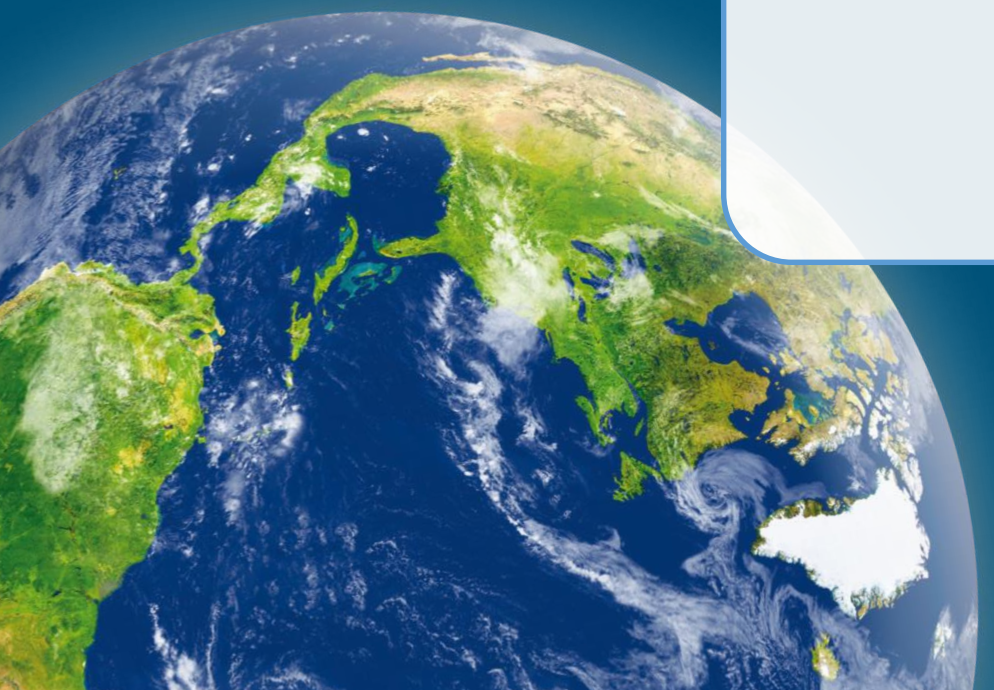
- Conduct high resolution investigation (RDC) to define lateral, vertical extent of the contamination and total contaminant mass distribution
- Refine final Remediation Plan
- Define remediation criteria

### 3. Active Remediation

- Conduct remediation / injection works
- Use of RDC data allows for efficient use of remediation budget

### 4. Performance Monitoring

- Soil and groundwater data to be compared against baseline values based on agreed monitoring programme



# Remedial Design Characterization (RDC)

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- Move focus from compliance data to remedial design data – site is contaminated (good to know) – RDC will tell you how much and where
- High frequency qualitative and quantitative data used to establish contaminant mass distribution (transition zones, thin layer of low/high permeability soils can easily be missed)
- In saturated soils, the estimated contaminant mass based on groundwater data only, can be under-estimated by 80-90% compared to an estimate based on high-frequency soil data
- Understand the link between soil contaminant mass (volume/distribution) migration pathway and most efficient injection design to reach criteria
- RDC effort allows to understand drilling conditions at the site – injection technique, possible issues and alternative solutions can be planned up front based on information gathered on site – field technician experience / understanding of injection design is critical
- A proper RDC campaign will require between 5 and 15% of the preliminary REM budget

PRE-REMEDIAL DESIGN – October 2017

POST-REMEDIAL DESIGN – October 2018

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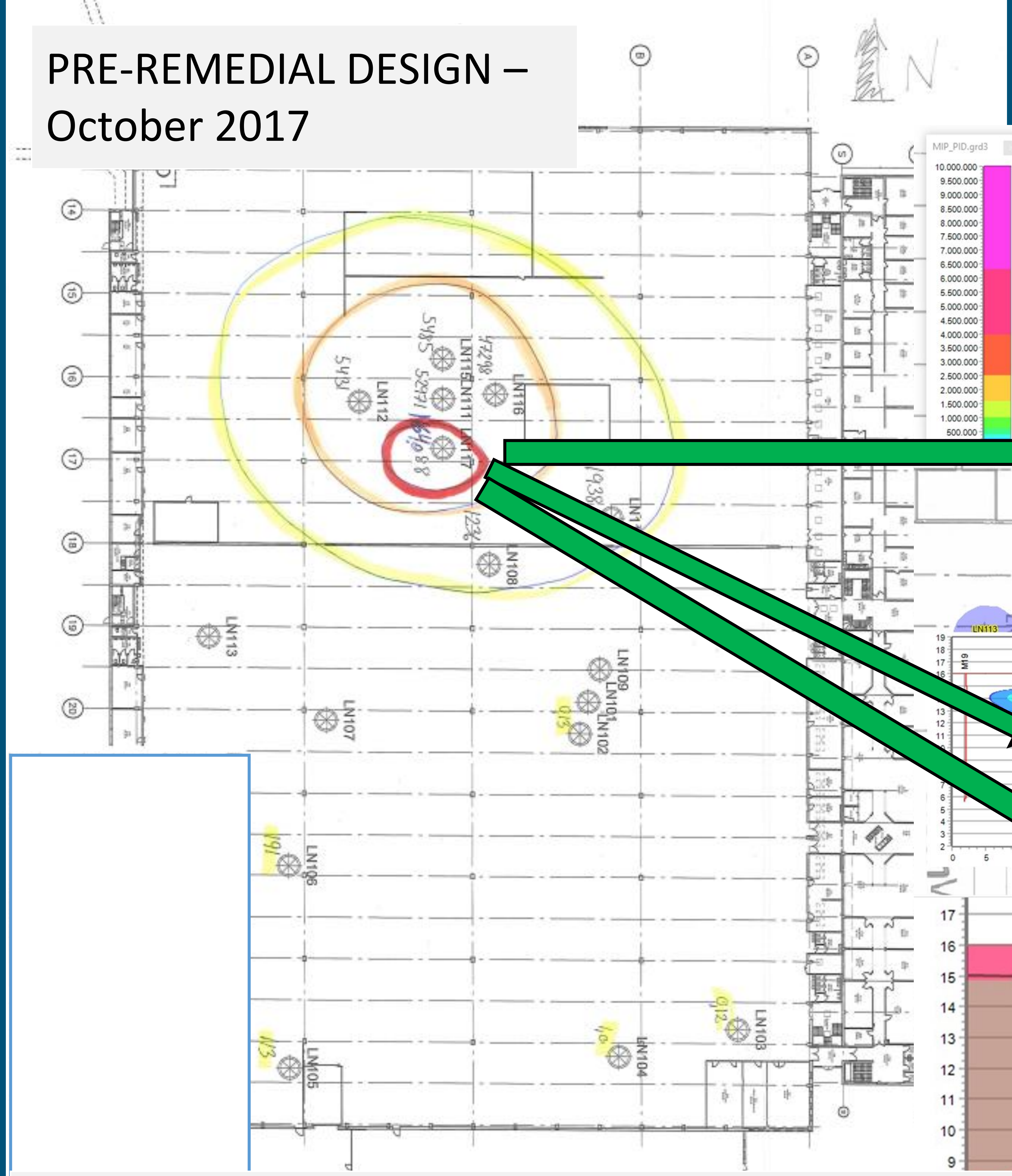
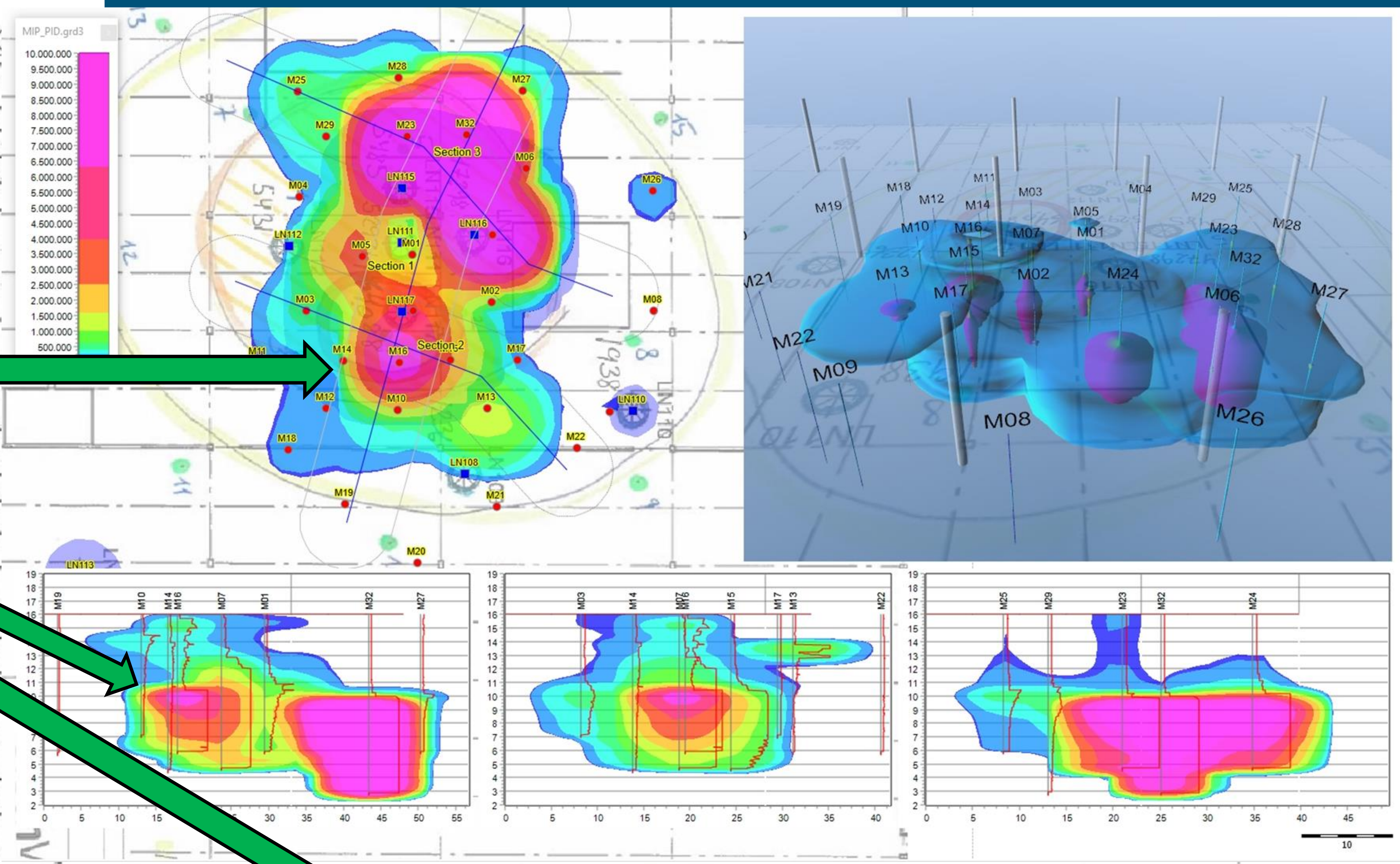
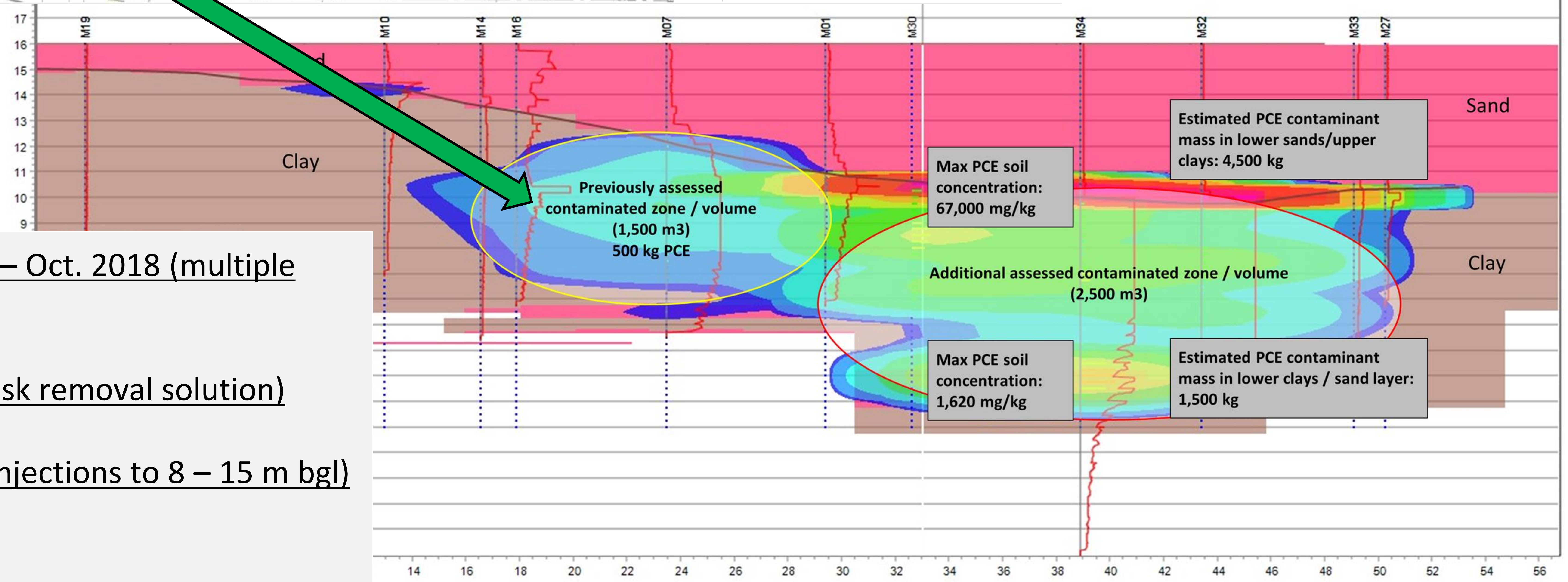
# Remedial Design (Case Study)








- Approx. 300 soil samples analysed free of charge – Oct. 2018 (multiple DNAPL zones)
- In-situ remediation completed in January 2019 (risk removal solution)
- Single application by Direct Push injections (400 injections to 8 – 15 m bgl)
- 80%+ PCE Reduction in groundwater at Q2 2022

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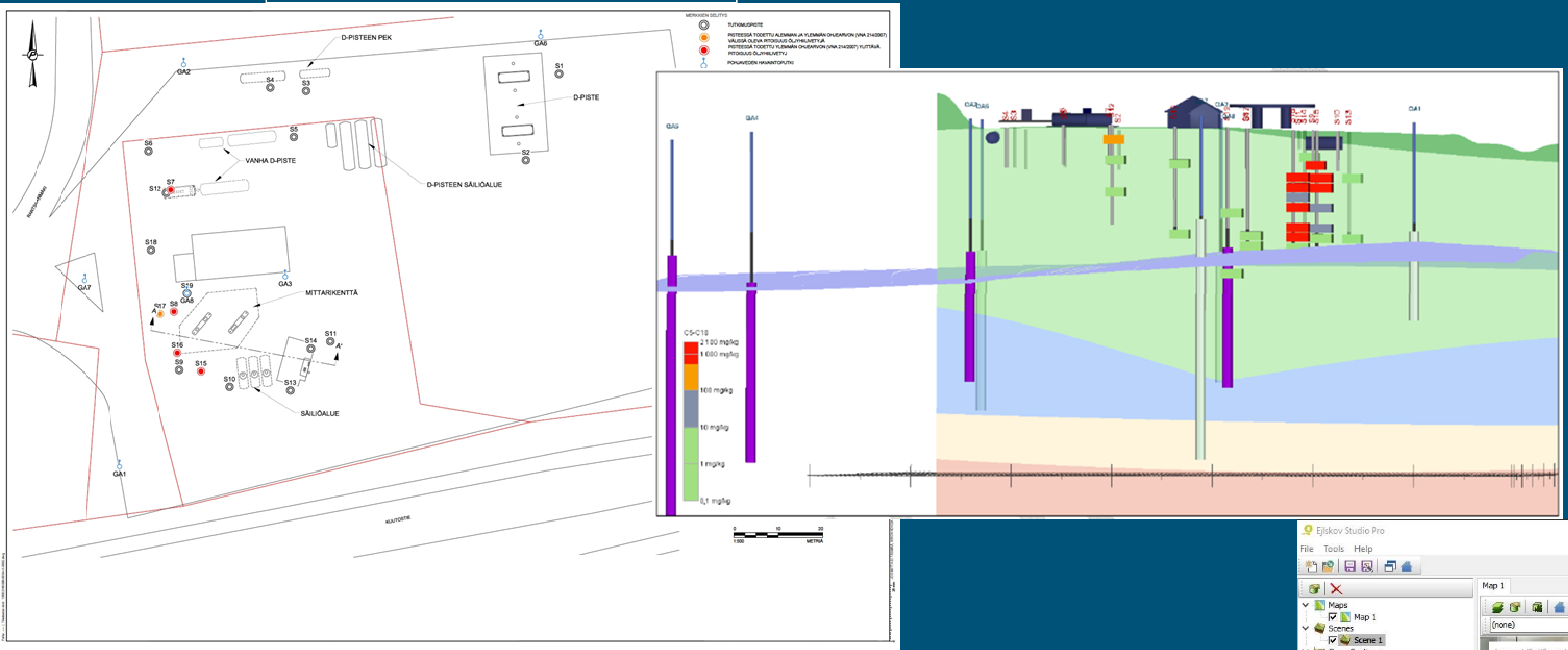
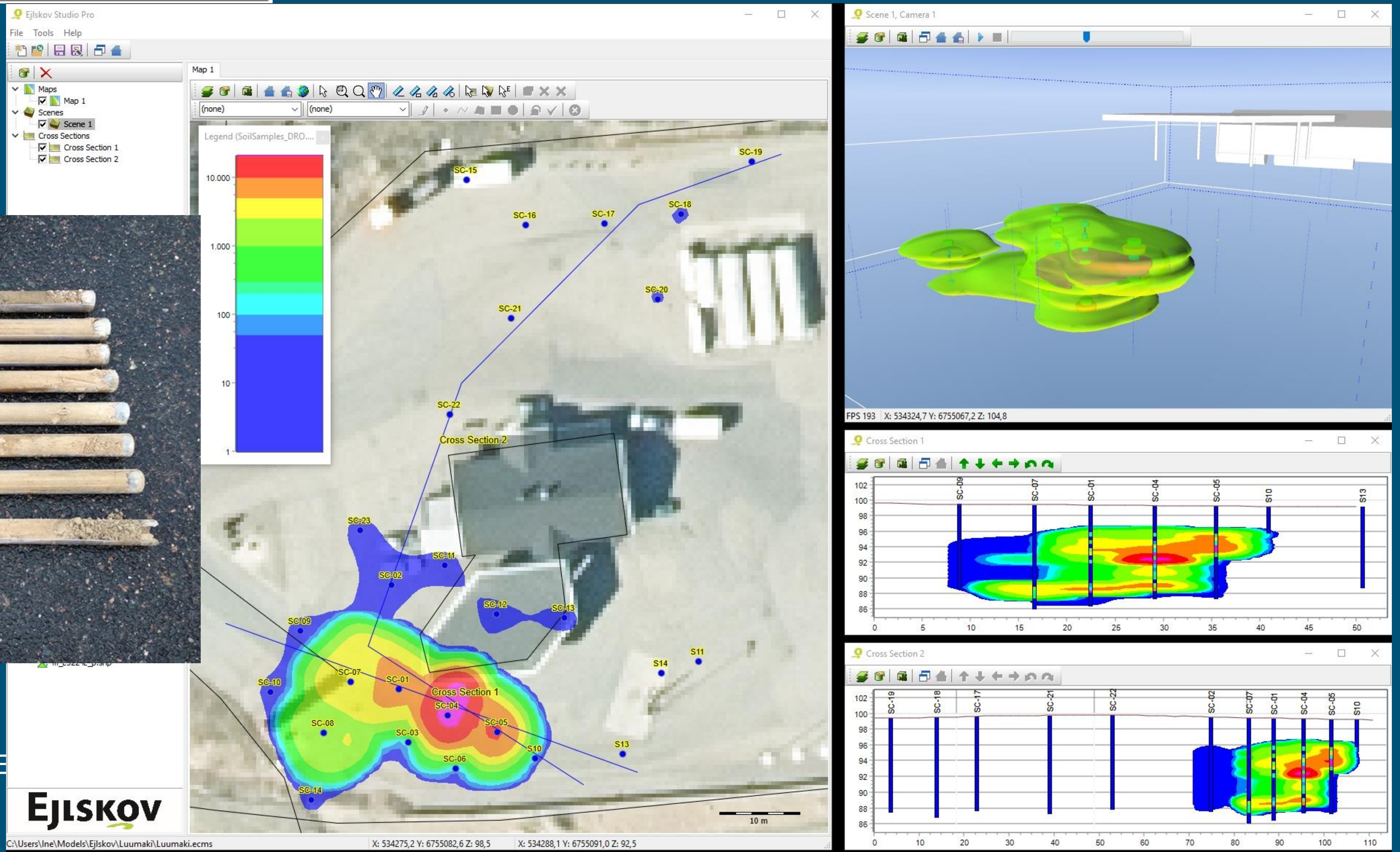
# Remedial Design (Case Study)

PRE-REMEDIAL DESIGN




- 425 soil samples analysed free of charge – Sept 2017
- In-situ remediation completed in May - June 2018
- Pre-drilling followed by Direct Push injections (11 m of dry sands to go through)
- Site closed in Q2 2021

POST-REMEDIAL DESIGN

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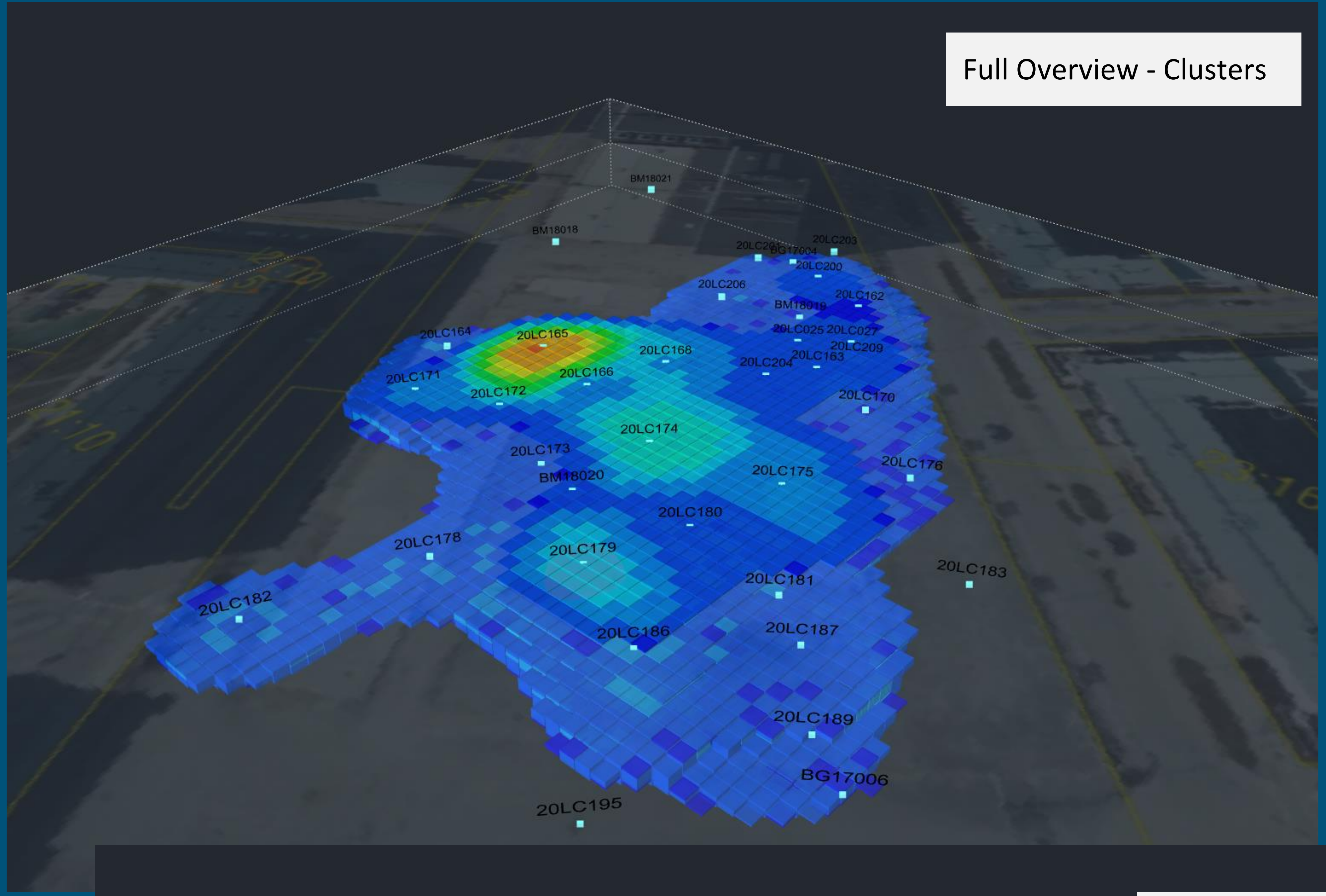
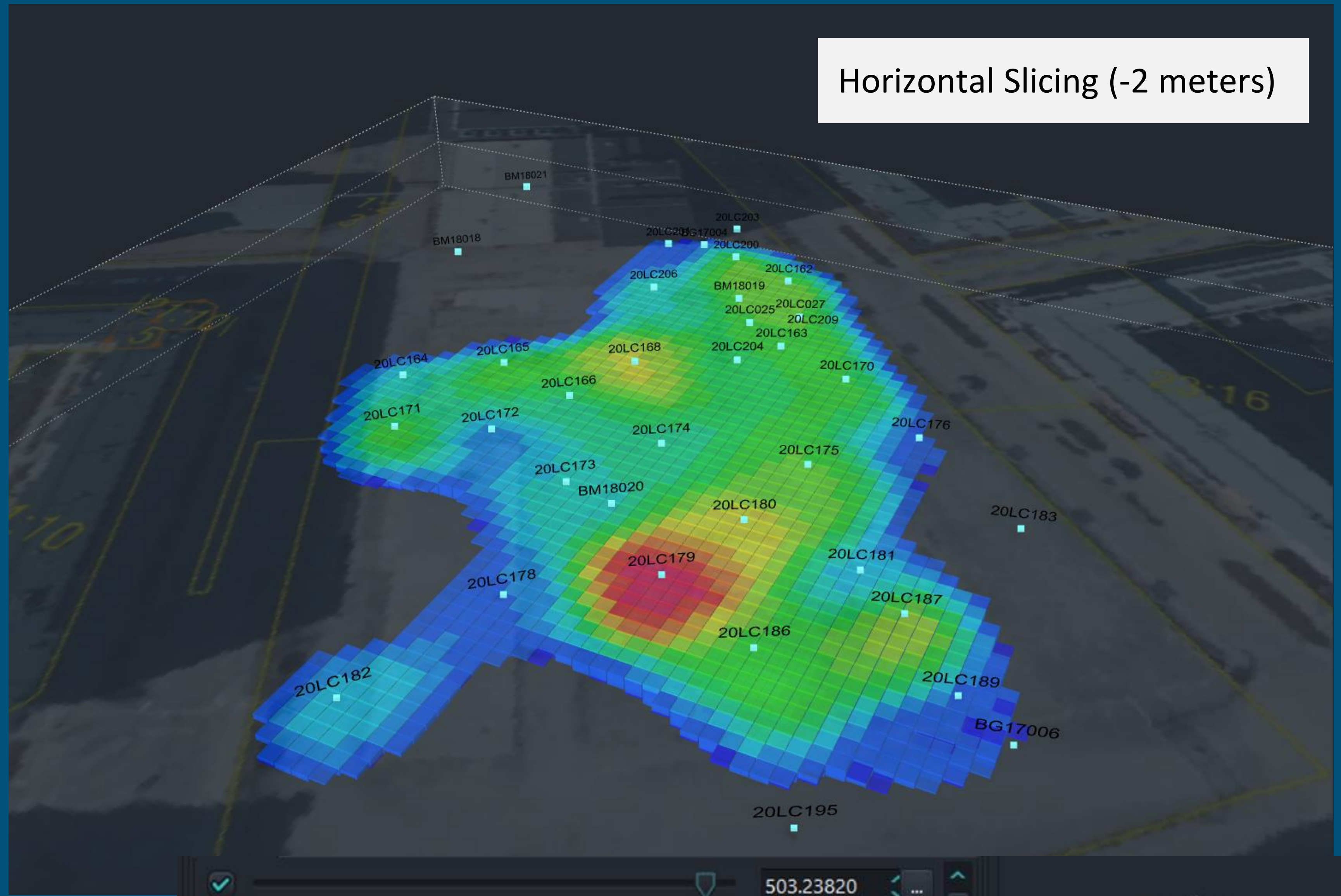
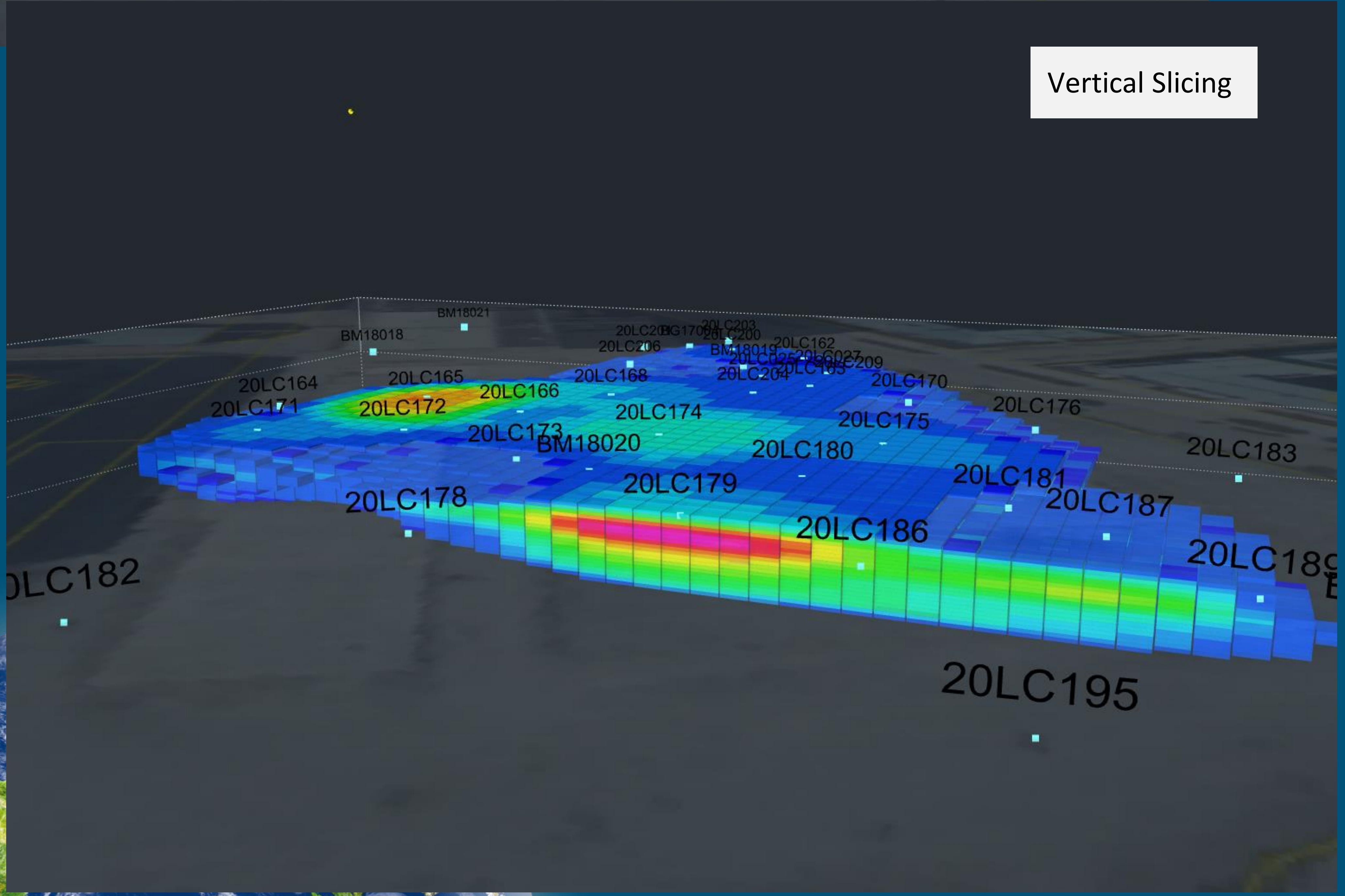
# Remedial Design - Output





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# Evolution of injection equipment – early 2000s



Early days issues included:

- Maintain slurry in suspension while mixing – how to create homogenous slurries
- Avoid loss of product from injection pump to injection nozzle
- Manage daylighting

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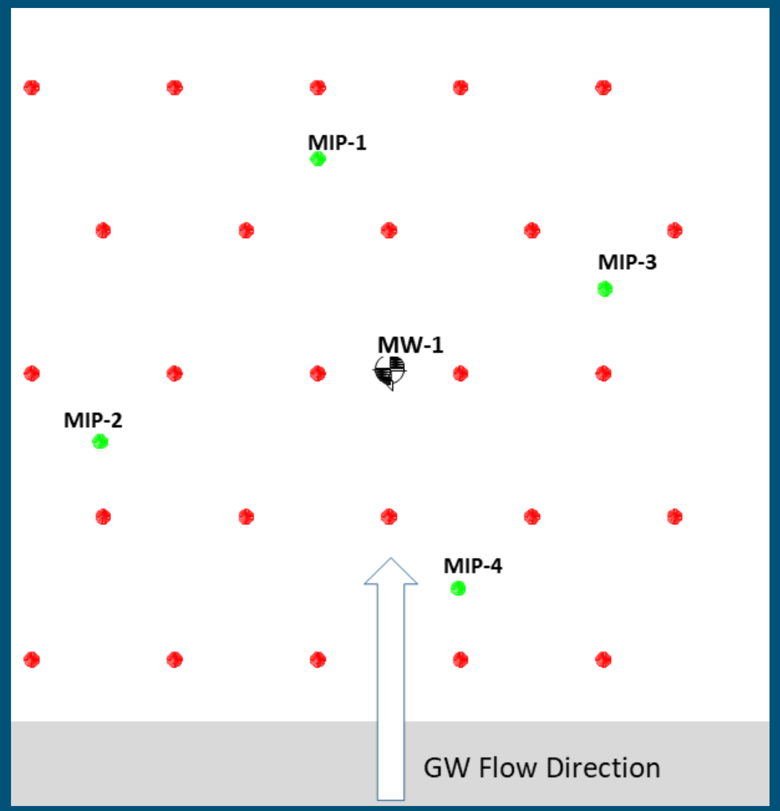
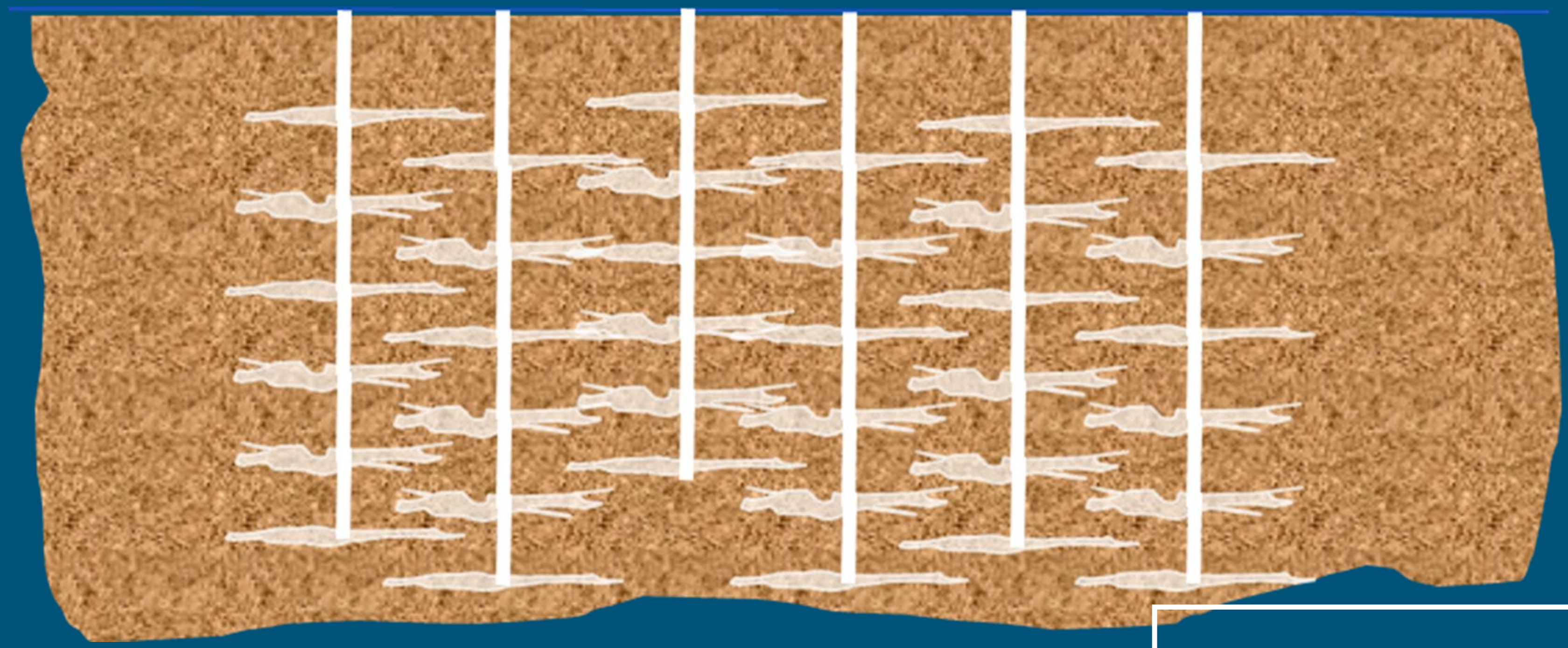
# Evolution of injection equipment – early 2020s

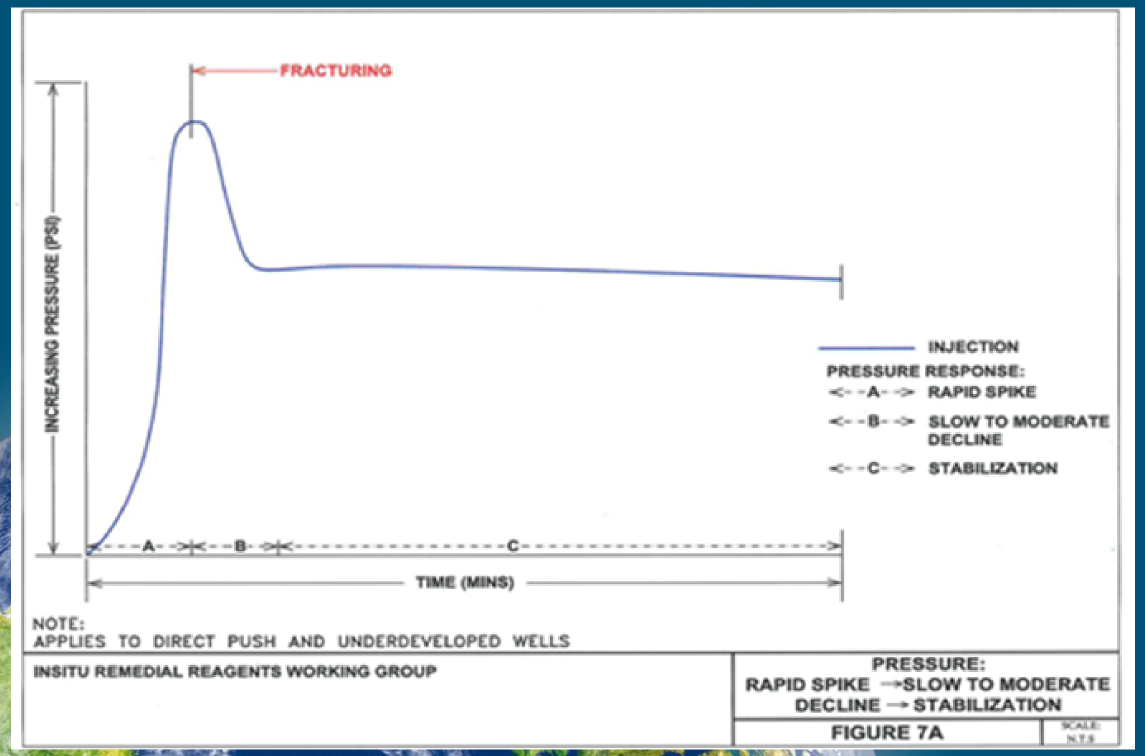
# Installation / Injection Features – Key to success




- Mixing of slurry on site
- Top down injections - one for every 0,5-0,6 meter
- Different system pressure settings from 0 to 170 bar and flow rates varying from 30 lpm to 920 lpm
- Nozzles set ups allowing for 40 to 220 km/h exit velocity
- Soil separation (clayey soils) vs. turbulent mixing (sandy soils)
- Injection Hoses – no loss of product in rod joints



- Pressure
- Flow & Exit Velocity
- Injection Volume vs. Slurry Density




- Injection grid spacing is a function of lithology, contaminant distribution, volumes and amount of products to inject
- Never exceed with volumes by enlarging the injection grid (risk of daylighting and poor distribution)
- Consider pre-drilling if geology conditions require
- Geophysics investigations for bedrock applications

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# Injection evidence

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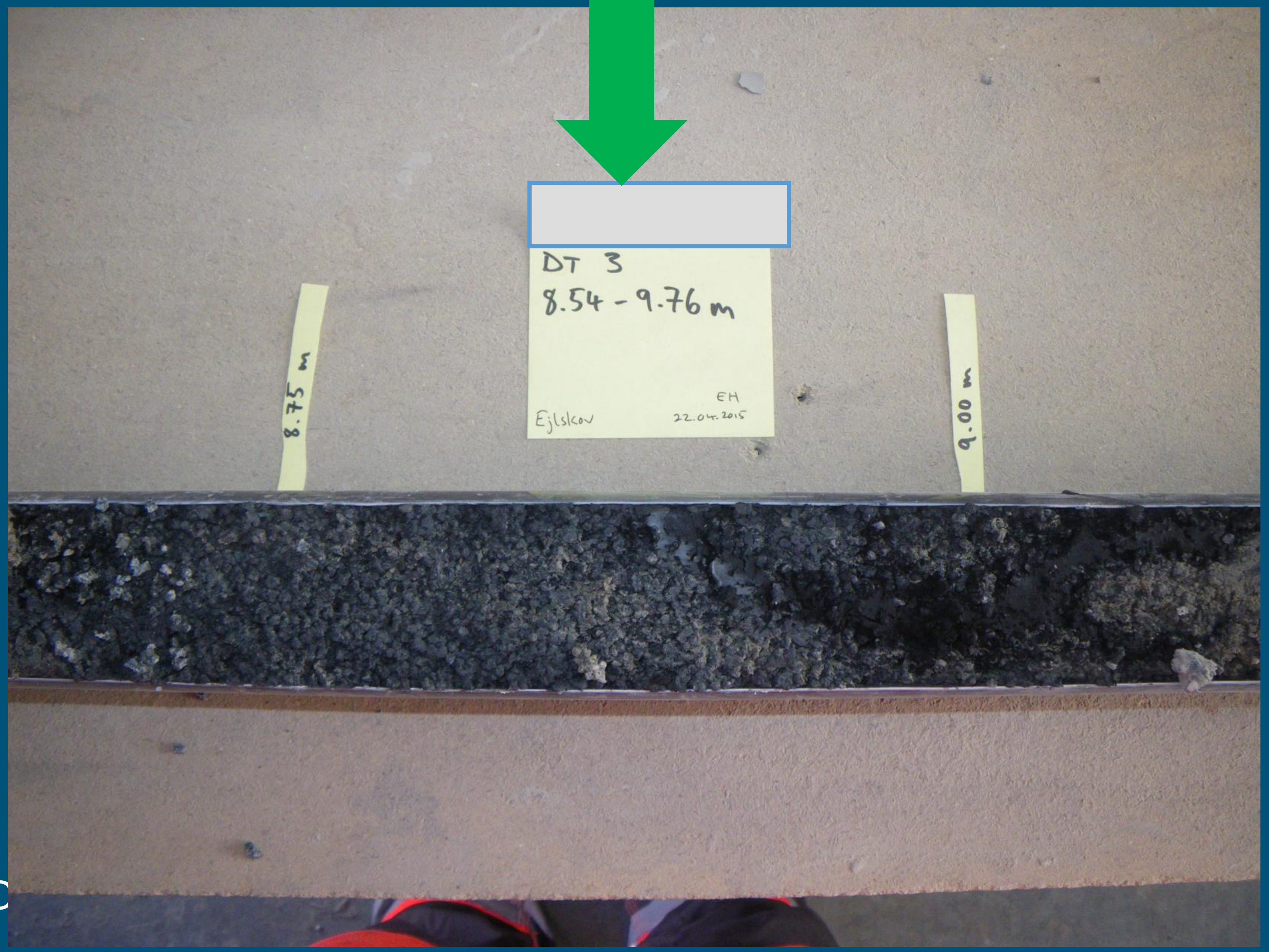


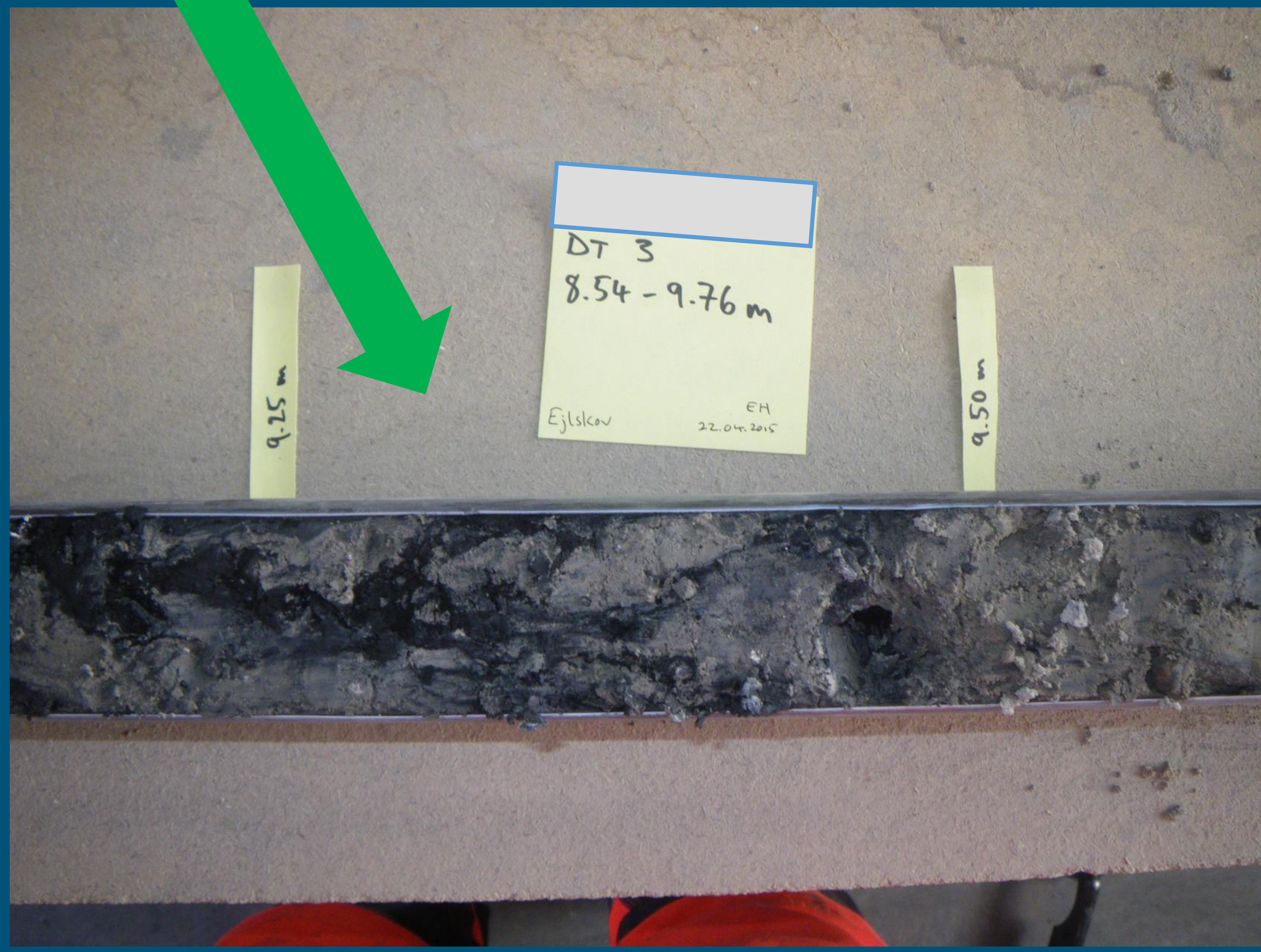

# Daylighting – how to interpret and understand it?

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- IT WILL HAPPEN AND YOU HAVE TO LIVE WITH IT and IT IS NOT ALWAYS BAD
- Assess daylighting dynamics – instantaneous vs. delayed
- Try completing the injection point and re-evaluate approach
- JUST… DO NOT skip intervals or lower the flow rate – remember how the CSM looks like and which migration pathways must be addressed
- Verify previous boreholes conditions in the vicinity of the injection points (soil cores, GW wells, injection points)
- If needed, over-drill old locations and seal them with bentonite
- Think at the large picture – it's not one injection point which guarantees success
- Re-evaluate injection volumes – do not alter amount of product (play with density)
- Re-evaluate grid spacing (volume and pattern)
- Re-evaluate installation sequence – scatter the injections
- Learn from all the above and find the best way forward
- **Teach drillers to seal holes and install GW wells properly (especially geotechnical surveys)**




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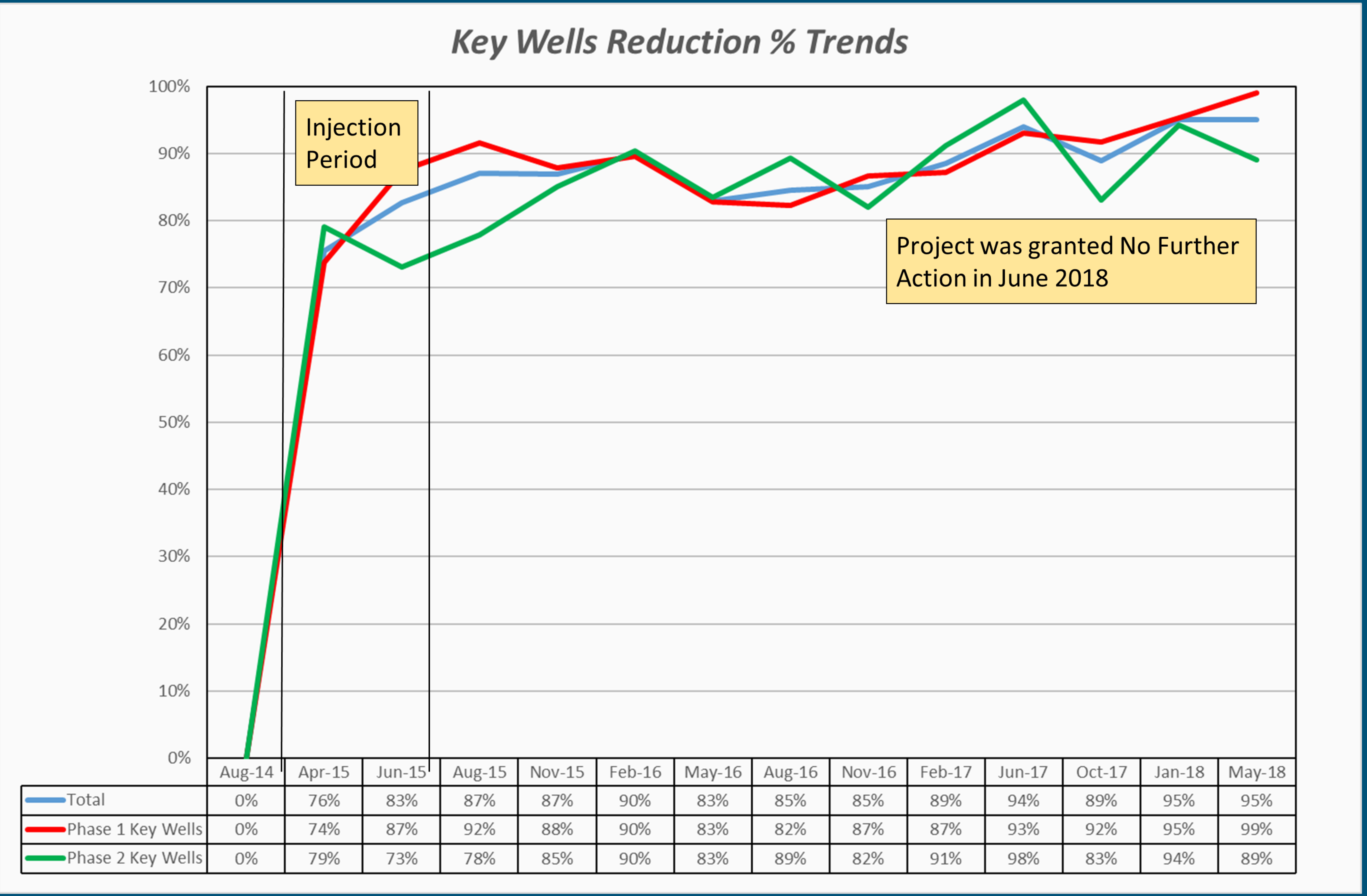


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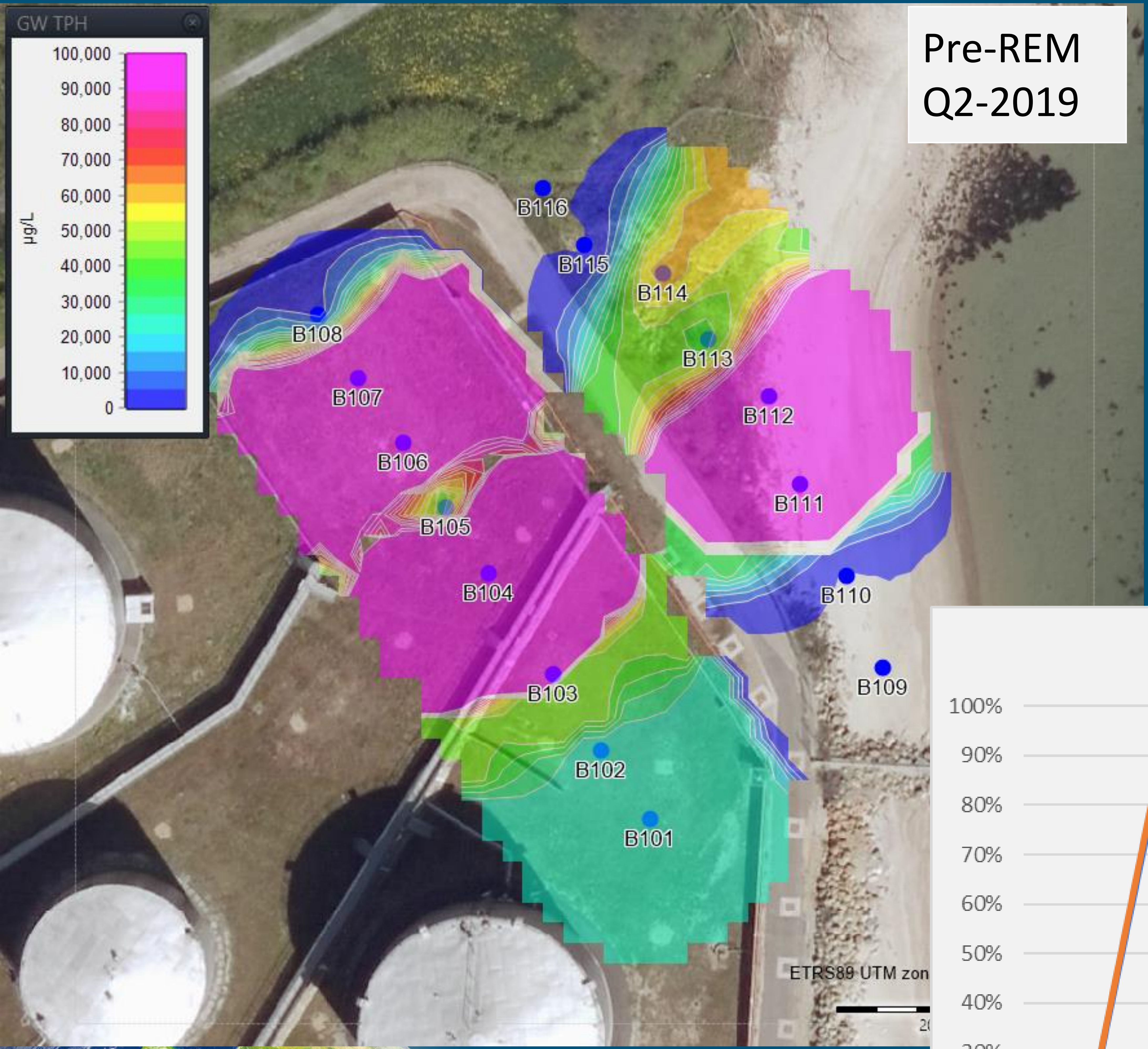
# Source and plume treatment - Copenhagen – Case Study

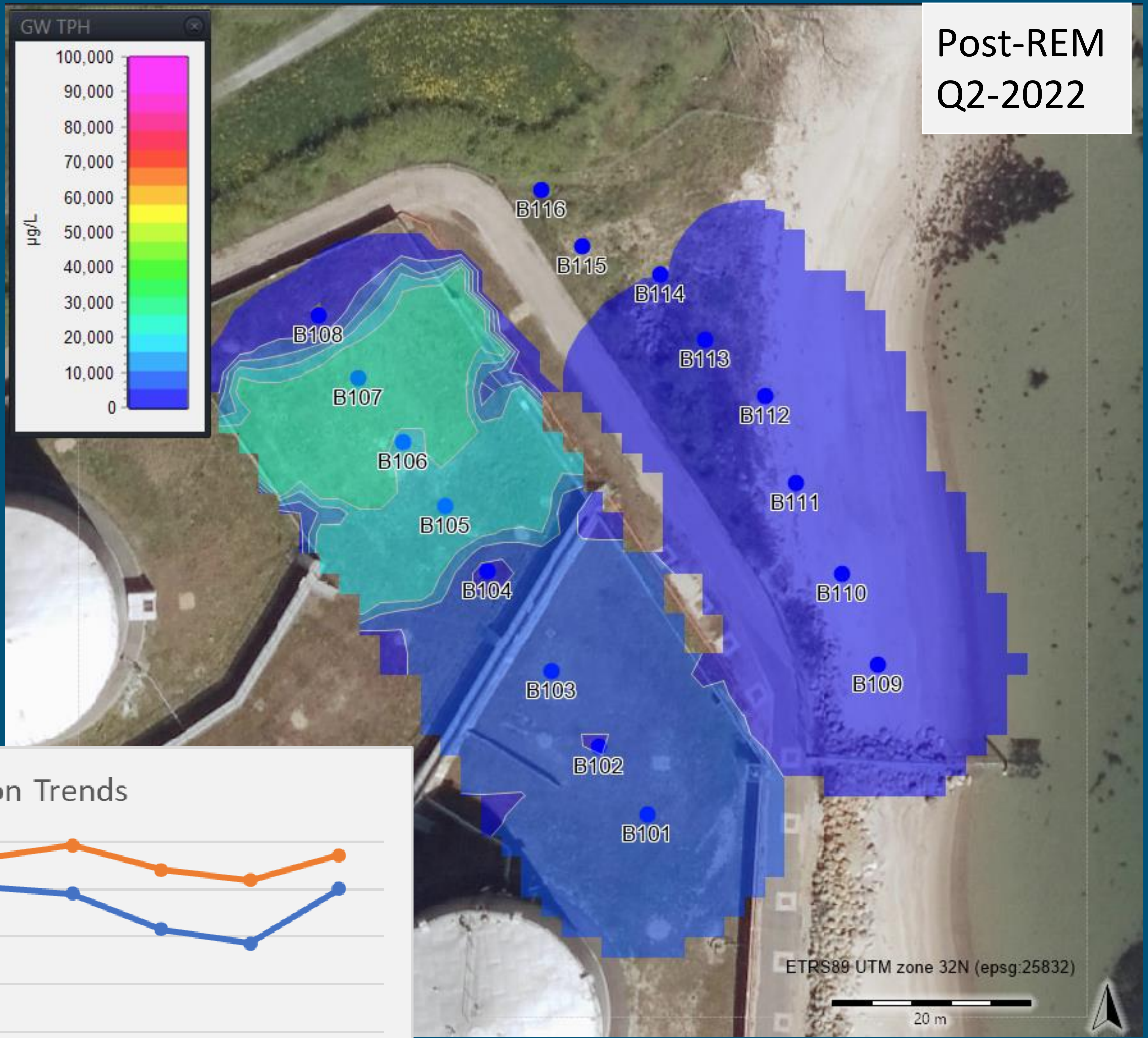
| Parameter | | Sum BTEX | Benzene | Toluene | Xylenes (o+m+p-Xylene +Ethylbenzene) |
|---|---|---|---|---|---|
| Quality Critera | | - | 1 | 5 | 5 |
| Well | Date | µg/l | µg/l | µg/l | µg/l |
| KB2-B | Feb 2013 | 4,321 | 4,200 | 2 | 119 |
| KB2-B | Mar 2013 | 4,900 | 4,800 | < 1,9 | 77 |
| KB2-B | May 2013 | 344 | 330 | < 1 | 14 |
| KB2-B | Aug 2013 | 385 | 373 | <1,2 | 12 |
| KB2-B | Nov 2013 | 264 | 260 | < 2 | 4 |
| KB2-B | Feb 2014 | 359 | 340 | < 2 | 19 |
| KB2-B | May 2014 | 221 | 210 | < 2 | 9 |
| KB2-B | Aug 2014 | 100 | 96 | 0.11 | 6 |
| KB2-B | Dec 2014 | 360 | 350 | 0.28 | 13 |
| KB2-B | Feb 2015 | 310 | 280 | 5.5 | 24 |
| KB2-B | Mar 2015 | 440 | 420 | 1 | 19 |
| KB2-B | Jul 2015 | 205 | 200 | < 3 | < 1,6 |
| *KB2-B* | *Aug 2015* | *105* | *98* | *< 5* | *< 2,4* |
| KB2-B | Feb 2016 | 48 | 42 | < 6 | < 3,8 |
| KB2-B | May 2016 | 12 | 10 | <2 | < 0,9 |
| KB2-B | Aug 2016 | 12 | 9 | < 2 | < 1,1 |
| KB2-B | Nov 2016 | 10 | 7 | < 2 | < 0,9 |
| KB2-B | Jan 2017 | 41 | 7 | 17 | 17 |
| KB2-B | May 2017 | 16 | 14 | 1 | 0.37 |
| KB2-B | Oct 2017 | < 0,01 | < 0,01 | < 0,01 | < 0,04 |
| KB2-B | Jan 2018 | 22 | 22 | 0.15 | 0.79 |
| KB2-B | May 2018 | 0.16 | 0.041 | <0.02 | 0.12 |

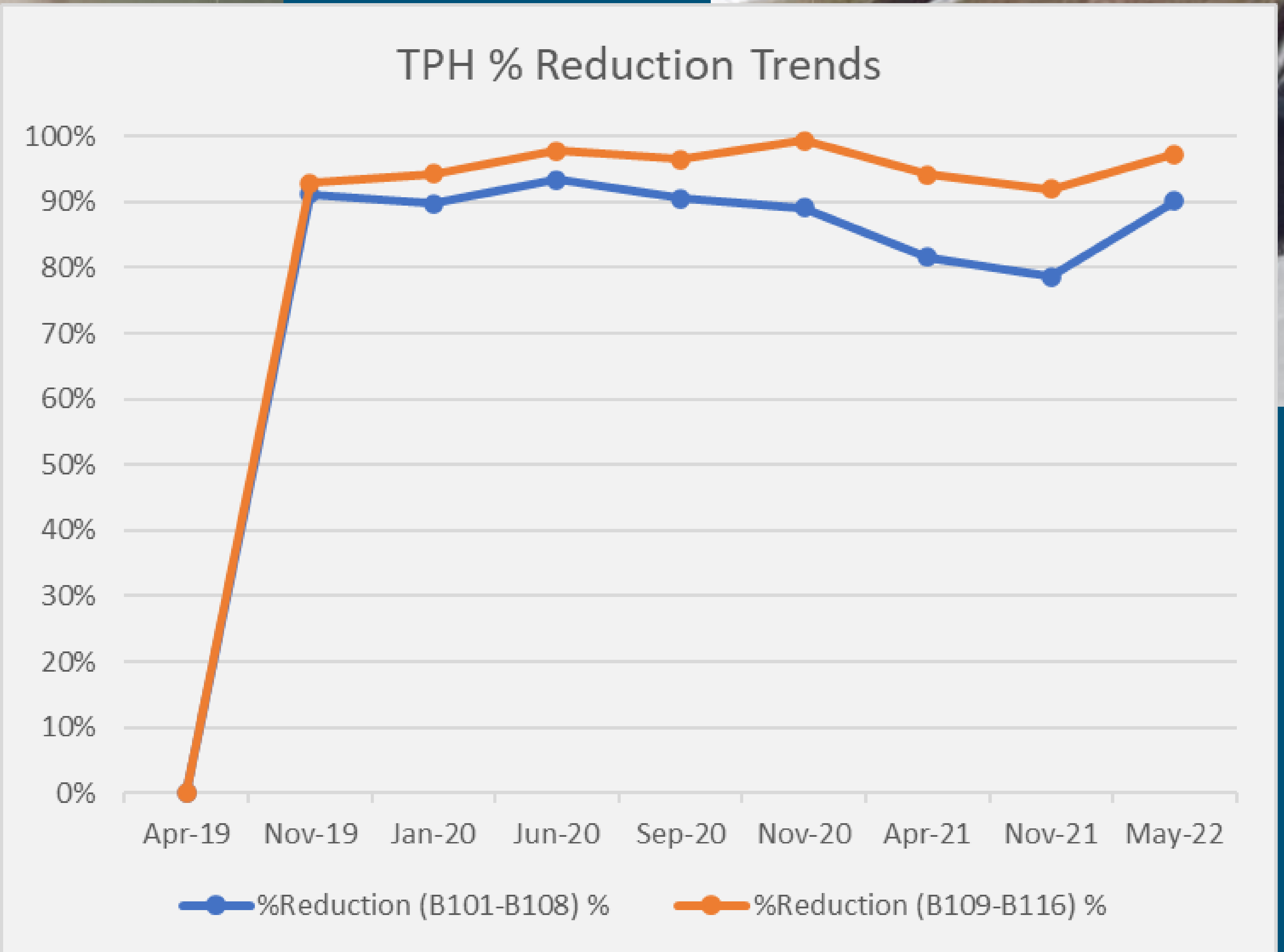
Above – overall trends of monitoring wells (Benzene % reduction trends are shown) part of the performance-based contract – from LNAPL concentrations to below site-specific criteria in less than 3 years

On the right – the importance of removing a migration pathway. Limestone aquifer GW well not addressed by injections. Removal of contaminant migration pathway from the upper soils allowed passive reduction of BTEX concentrations

# Source and barrier treatment – South-East Jutland Case Study




- No Remediation Design performed
- Injection based on groundwater flux data mostly
- LNAPL observed in few wells prior to remediation start no longer observed

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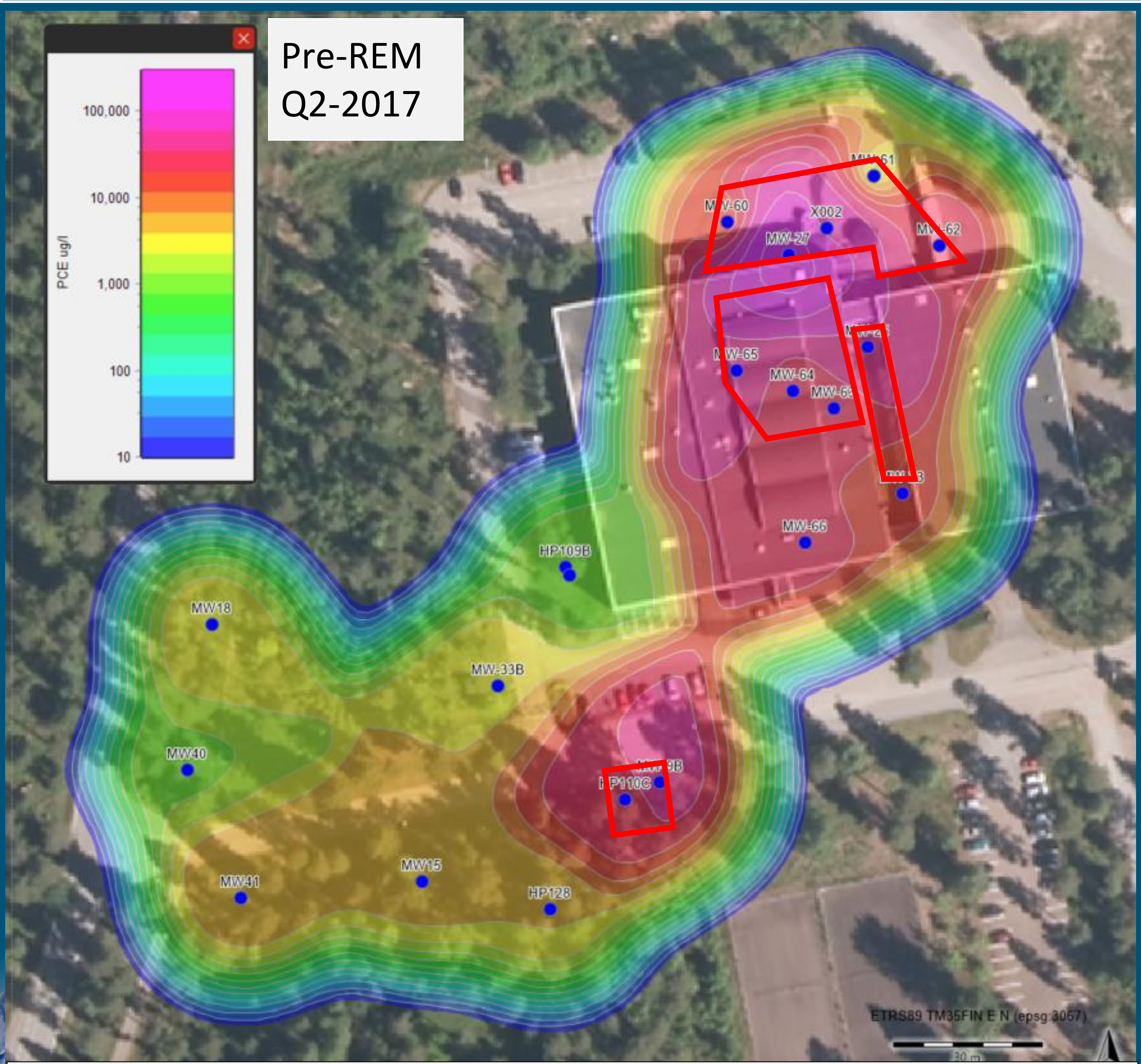
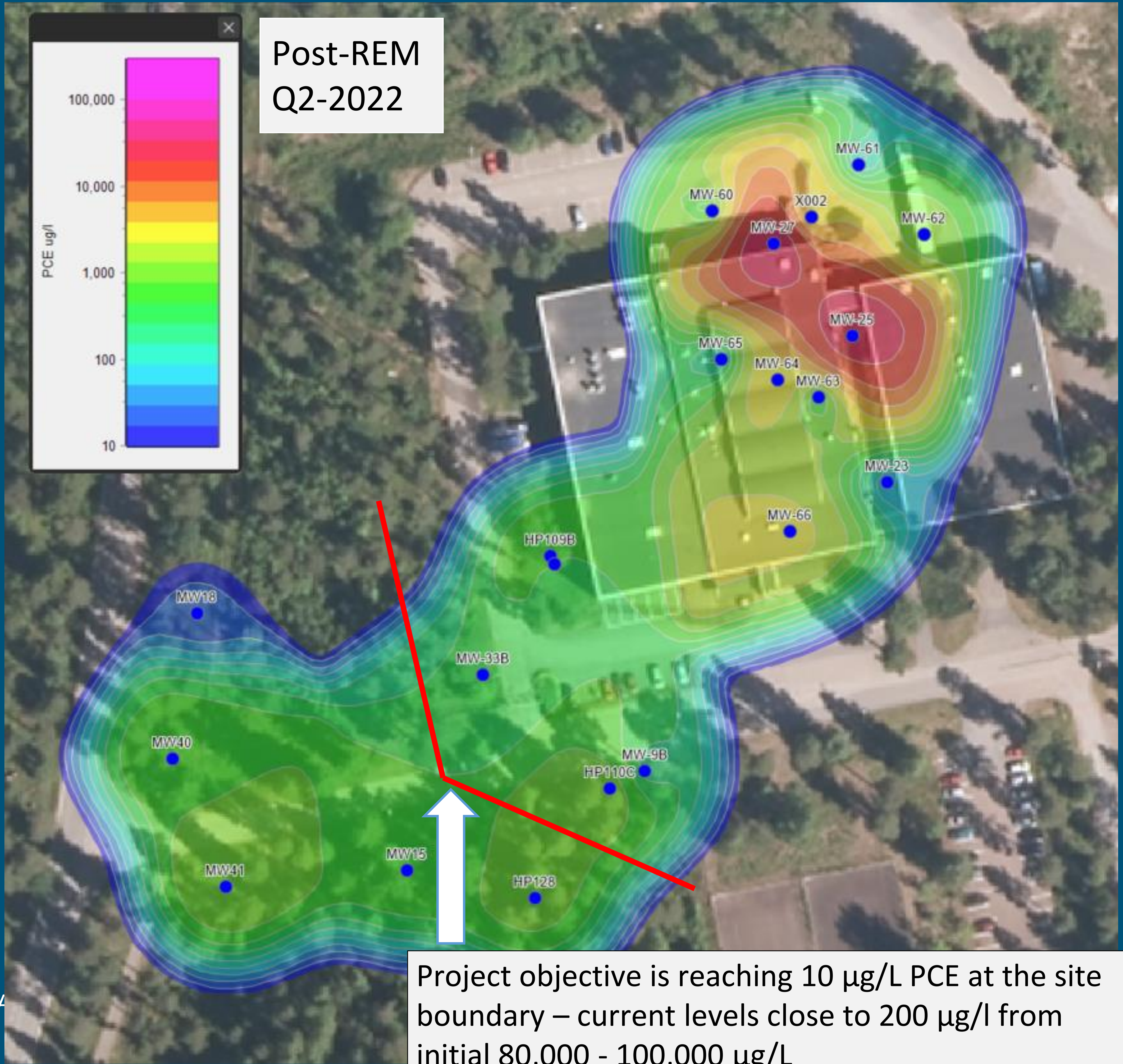
# Source and passive plume treatment – Confidential Site - Case Study




Pre-REM
Q2-2017




Post-REM
Q2-2022

Soil validation samples in 2022 showed 30-40% mass reduction from an initial 15,000 kg PCE in soil – DNAPL observed in source area well has not been observed since Q1 2021 (40 cm measured pre-injections) – Injection zones are marked in RED

Project objective is reaching 10 µg/L PCE at the site boundary – current levels close to 200 µg/l from initial 80,000 - 100,000 µg/L

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