Remediation and Management Strategies for Redevelopment of a Former MGP Site

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SHEEBA AB

Sixth International Symposium on Bioremediation and Sustainable Environmental Technologies
Austin TX - May 9, 2023

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Project Background

This project is a collaboration between multiple parties, incl City of Stockholm, PEAB, Golder, Elander Miljöteknik, RGS, Sheeba, Arkil, Evonik, Geomind

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- Former MGP site located in Stockholm Sweden
- The area is being redeveloped into a residential area
- Soil and groundwater impacted by coal tar residue, incl. Polycyclic Aromatic Hydrocarbons (PAHs)
- Overarching goal with soil and groundwater remediation is to limit vapor intrusion to new residential buildings
- A series of bench and pilot testing of various technologies performed 2017-2020
- Full-scale implementation started March 2021 and first phase anticipated to complete in 2023

Aerial View of Stockholm Royal Seaport

- Part of one of Europe's most extensive urban development areas
- A total of 12,000 new homes and 35,000 new workplaces are planned for greater Royal Seaport Area
  - 1,500 new apartments planned at the former MGP area
- One of the city's designated sustainability profile areas
  - Sustainable remedial approach treating soil in place

Residential Development Completed along the Channel

Aerial view from 2013

Current view

Remediation Area – Area Next to Former Tar Factory

And this is what is planned..
1,500 new apartments being built in the area.

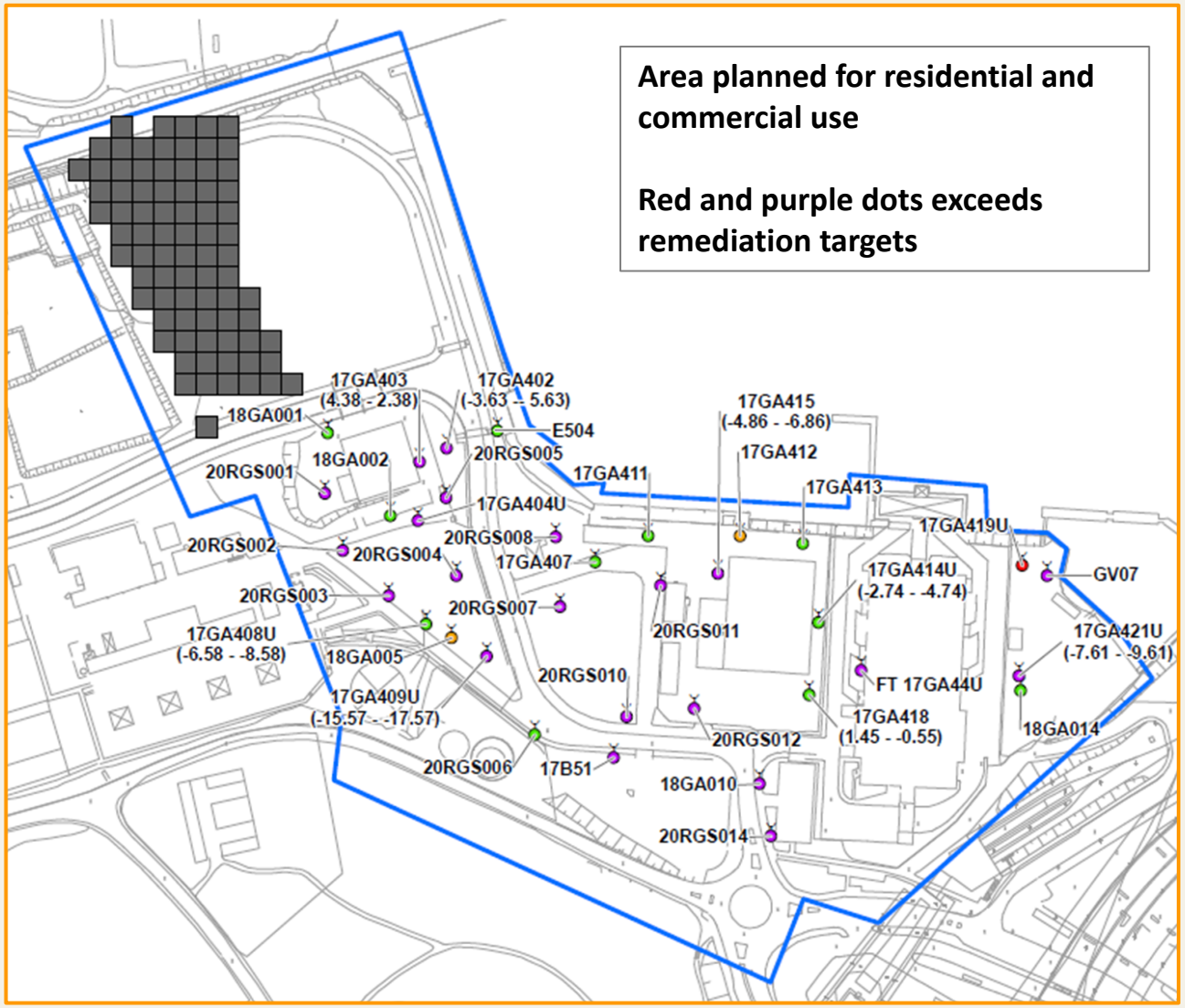
Pictured: An early-stage visionary illustration of the final Stockholm Royal Seaport district.

Before Construction can Begin the Soil Needs Treatment

- Soil and Groundwater impacted by MGP residual contamination including Polycyclic Aromatic Hydrocarbons (PAHs)

- PAHs present in three subsurface units:
  - Fill material down to 3-4 m bgs
  - Clay unit down to ~7 m bgs
  - More permeable “Moraine” layer (sand, gravels, and rock) beneath the clay

  - Total Area / Volume:
    - ~50,000 m^2
    - ~500,000 m^3



Site Specific Remedial Targets

Site Specific Remedial Targets developed to prevent vapor intrusion

Clay unit:

- PAH-16 <250 mg/kg
- Fluoranthene <4 mg/kg (key driver)

Groundwater:

- Naphthalene <6,200 ug/L
- Fluoranthene <12 ug/L
- Benzene <300 ug/L

16 Priority PAH (PAH-16)

PAH-L	PAH-M	PAH-H
naftalen	fluoren	benso(a)antracen
acenaften	fenantren	krysen
acenaftylen	antracen	benso(b)fluoranten
	fluoranten	benso(k)fluoranten
	pyren	benso(a)pyren
		dibens(ah)antracen
		benso(ghi)perylen
		indeno(123cd)pyren

Pilot Testing: Round 1

Screening of Several In Situ Technologies for the Saturated Zone 2017-2018

2017 - 6 DPT points per test:

Chemical oxidation:

- RegenOx
- PersulfOx
- Hydrogen peroxide 10 %

Enhanced desorption:

- PetroCleanze

Biological degradation:

- PermeOx
- ORC Advanced

2018 - Expanded pilot test with Activated Persulfate (PersulfOx):

500 m^2 area

2 injection rounds

- 80-90% redution in PAH-16
- >90% reduction in benzene
- >90% reduction in naphthalene
- Limited reduction in fluoranthene (dose/contact time)

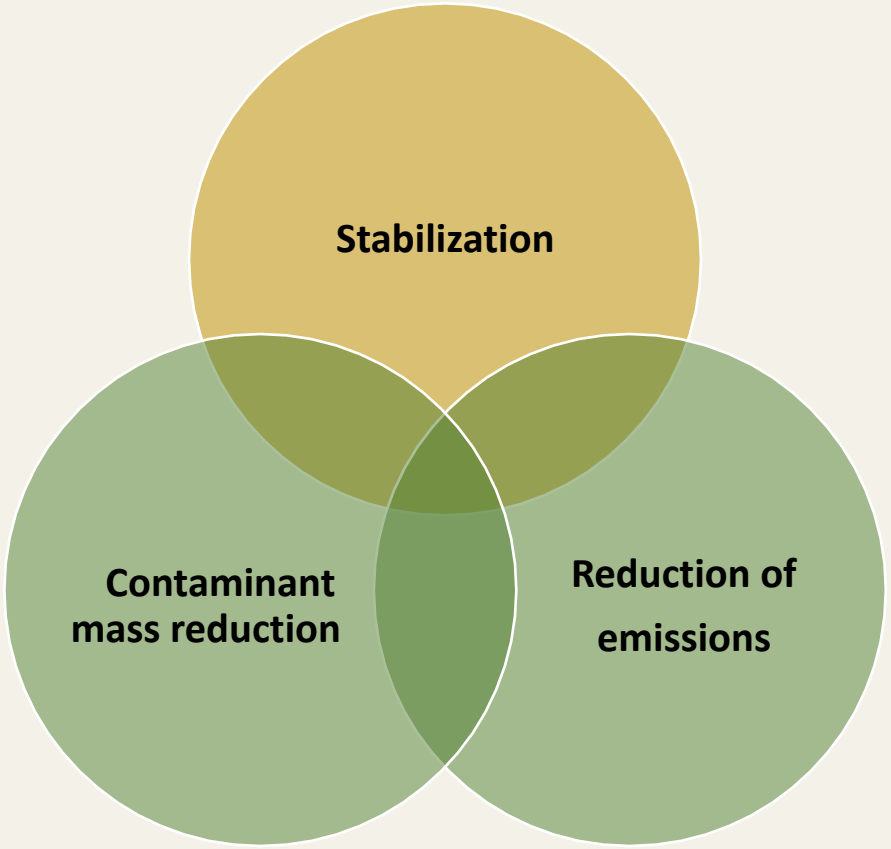
→ Activated Persulfate selected as primary remedial approach for saturated zone

Selected Remedial Strategy Overview

- **Excavate contaminated soil down to 3-4 m and replace by clean fill (vadose zone)**

- **Clay layer below this depth treated with ISCO-ISS (~50,000 m^3)**
  - Combined treatment and stabilization
  - Soil mixing effective for low permeability soils
  - ISS increases clay compressive strength to allow for above ground construction of roads and buildings

- **Underlying moraine layer treated with persulfate injections (~70,000 m^3)**
  - Rocks prevents soil mixing
  - Injection strategy more effective in more permeable soils
  - Possible polishing with aerobic bioremediation / colloidal activated carbon



Expanded Bench & Pilot Testing - 2019-2020

- Goal is to optimize reagent blends, dosing and application strategies for soil mixing and injection applications

ISCO bench

- SOD & BBC testing
- Screening of multiple activation methods:
  - Alkaline activation (NaOH / $Ca(OH)_2$)
  - Iron activation (Fe-lactate)
  - Silica (PersulfOx)
- Screening of different persulfates:
  - Klozur SP (sodium persulfate)
  - Klozur KP (potassium persulfate – extended release - flouranthene)
  - PersulfOx (sodium persulfate with built-in activator)

ISCO injection pilot

- Same list of technologies as bench
- Focus on distribution and injection properties:
  - Injection via DPT
  - Injection via TAM-tubes
- Evaluation of Injection Radius of Influence (ROI) & Injection Volumes:
  - ROI of ~3 m targeted
  - 600 L/m injection solution

ISCO-ISS bench & pilot

- Bench test to evaluate dose response and different cement and slag blends with persulfate:
  - Stabilization – UCS & K
  - Contaminant destruction
  - Effect on pore vapors
- Pilot test looked at implementability in the field:
  - Two different auger techniques evaluated

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Reagent Blends & Application Strategy Selected for Full-Scale Implementation

ISCO Injections for Moraine

- Alkaline Activated Persulfate:
  - Primary: Klozur® SP and NaOH solution (ease of injection)
  - Secondary: Extended Release Klozur® KP slurry (fluoranthene)
- Injection via TAM tubes:
  - Easy reapplication
- Dosing strategy:
  - Vary reagent dose based on baseline contamination levels across area

ISCO-ISS for Clay

- Installation via large diameter augers found succesful (Arkil)
- Area Subdivided into 50 m^2 Treatment Cells
  - Use OIP probe to determine remedial need
- Minimum ISCO-ISS Dosing Determined by Bench and Pilot:
  - Slag Cement: 4-8 wt%
  - Klozur® SP: 1.8 wt%
  - Water: 4-7 wt%

Full-Scale Installation of ISCO-ISS to Clay Unit - 2021-2023

Soil mixing using large diameter augers – 2 rigs in operation

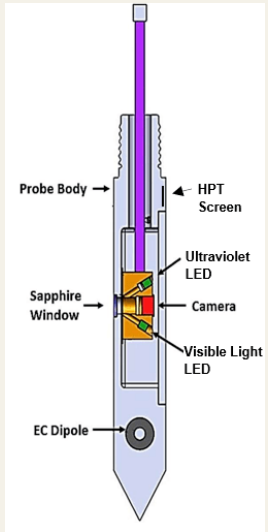
Klozur® SP + Cement Mixing Station

Pre-Screening with OIP to Determine Need for ISCO Addition

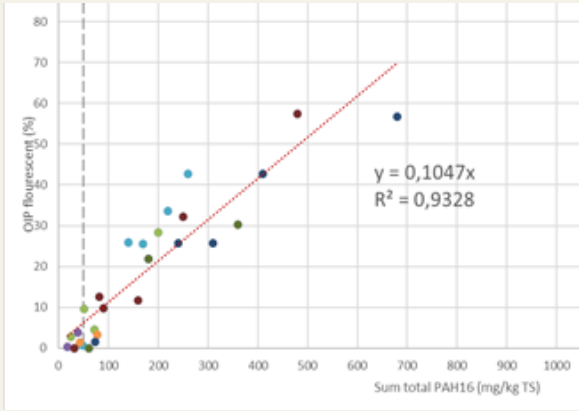
- Area divided in to 50 m^2 cells and screened with Optical Imaging Profiler (OIP) probe

- Remedial goal:
  - Main driver: Flouranthene < 4 mg/kg
  - Based on PAH mix correlates to ~225 mg/kg PAH-16
  - Correlates to 26% fluorescence

- If OIP result < 26% fluorescence, cell did not required treatment:
  - ~60% of cells could be excluded
  - Some cells still needed ISS application for stabilization



Correlation between Fluorescence & PAH-16 in soil:



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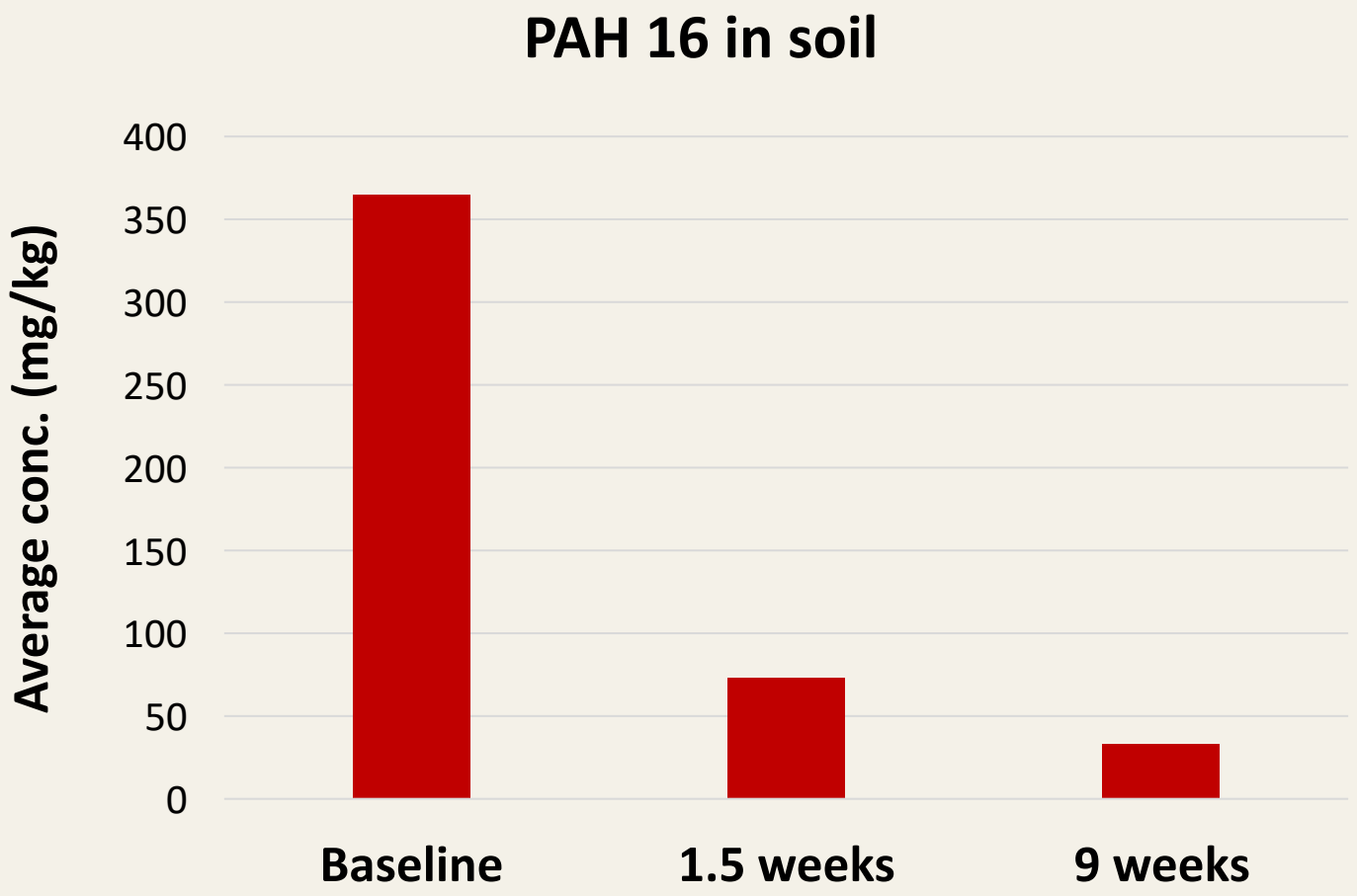
Full-Scale Results – Contaminant Destruction – PAH 16



PAH 16 concentrations:

Baseline:

- Average: 365 mg/kg
- Range: 1-2700 mg/kg

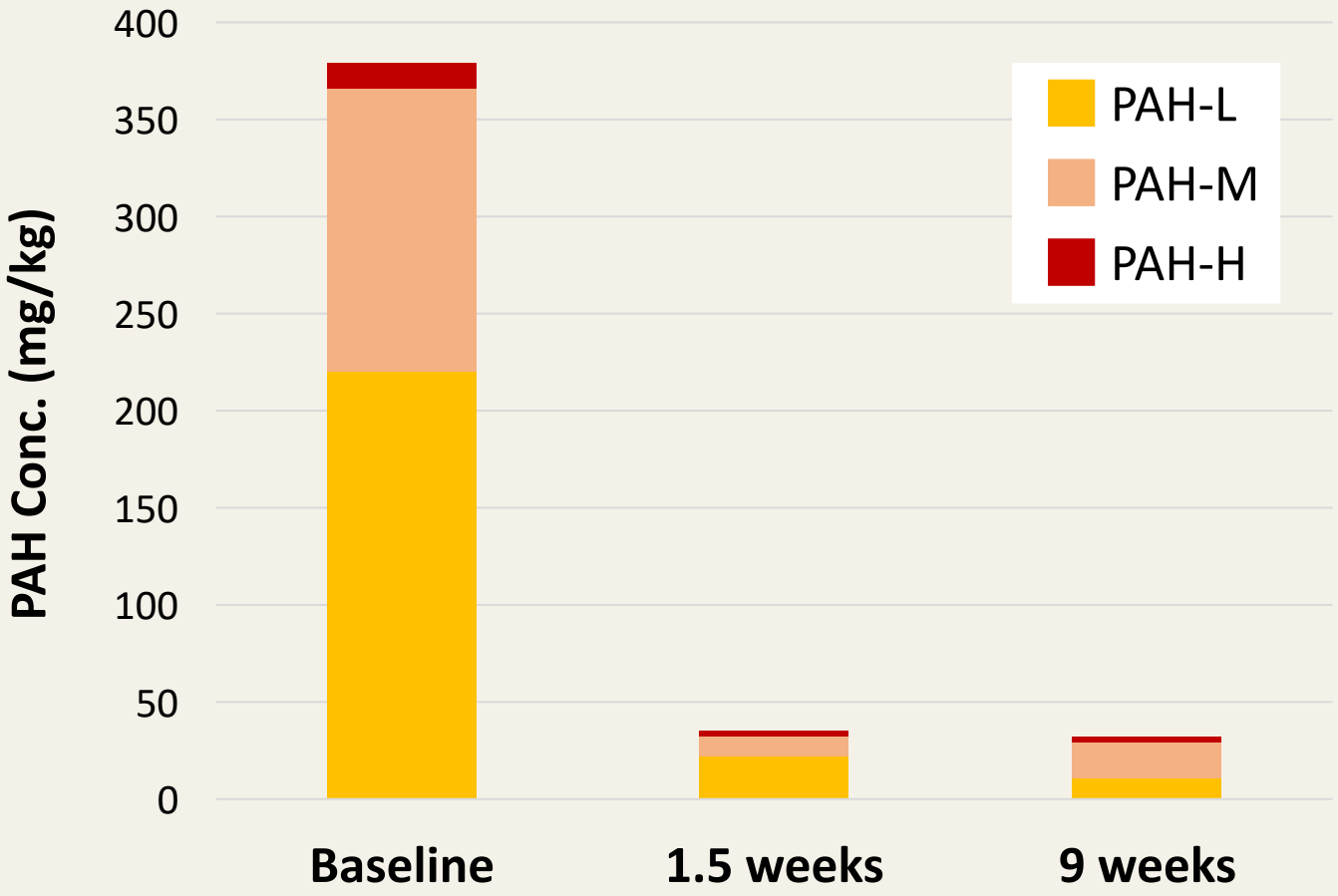
9 weeks post treatment:

- Average: 33 mg/kg
- Range: 5-120 mg/kg
- All samples below remedial goal of 250 mg/kg

Significantly larger variation in untreated clay.

Reference: Uppföljning av föroreningshalter i pelare efter stabilisering och kemisk oxidation av lera (ISS-ISCO), Golder, Jan 2022

Full-Scale Results – Contaminant Destruction



Reduction in PAH conc. following 9 weeks:

- ~95% reduction in PAH-L
- ~90% reduction in PAH-M
- ~80% reduction in PAH-H

Higher % reduction in lower molecular weight PAH fractions.

No significant continued treatment after 2 weeks.

Reference: Uppföljning av föroreningshalter i pelare efter stabilisering och kemisk oxidation av lera (ISS-ISCO), Golder, Jan 2022

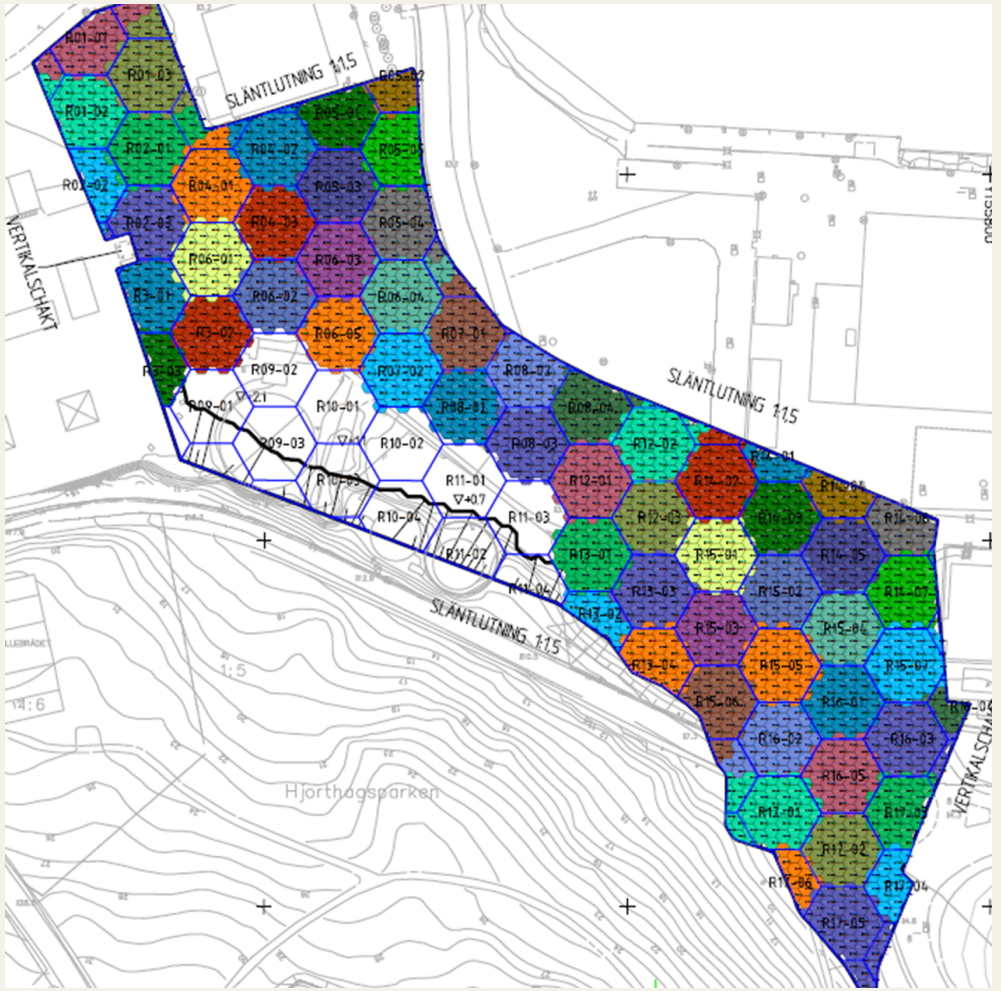
Moraine Layer: Injection Area Strategy

- Area subdivided into cells (350 m^2 per hexagon)
  - 32 injection locations per cell
- One monitoring well installed at the center of each cell
- Based on results, each area treated with different reagent dose
- Multiple applications were planned for higher conc. cells

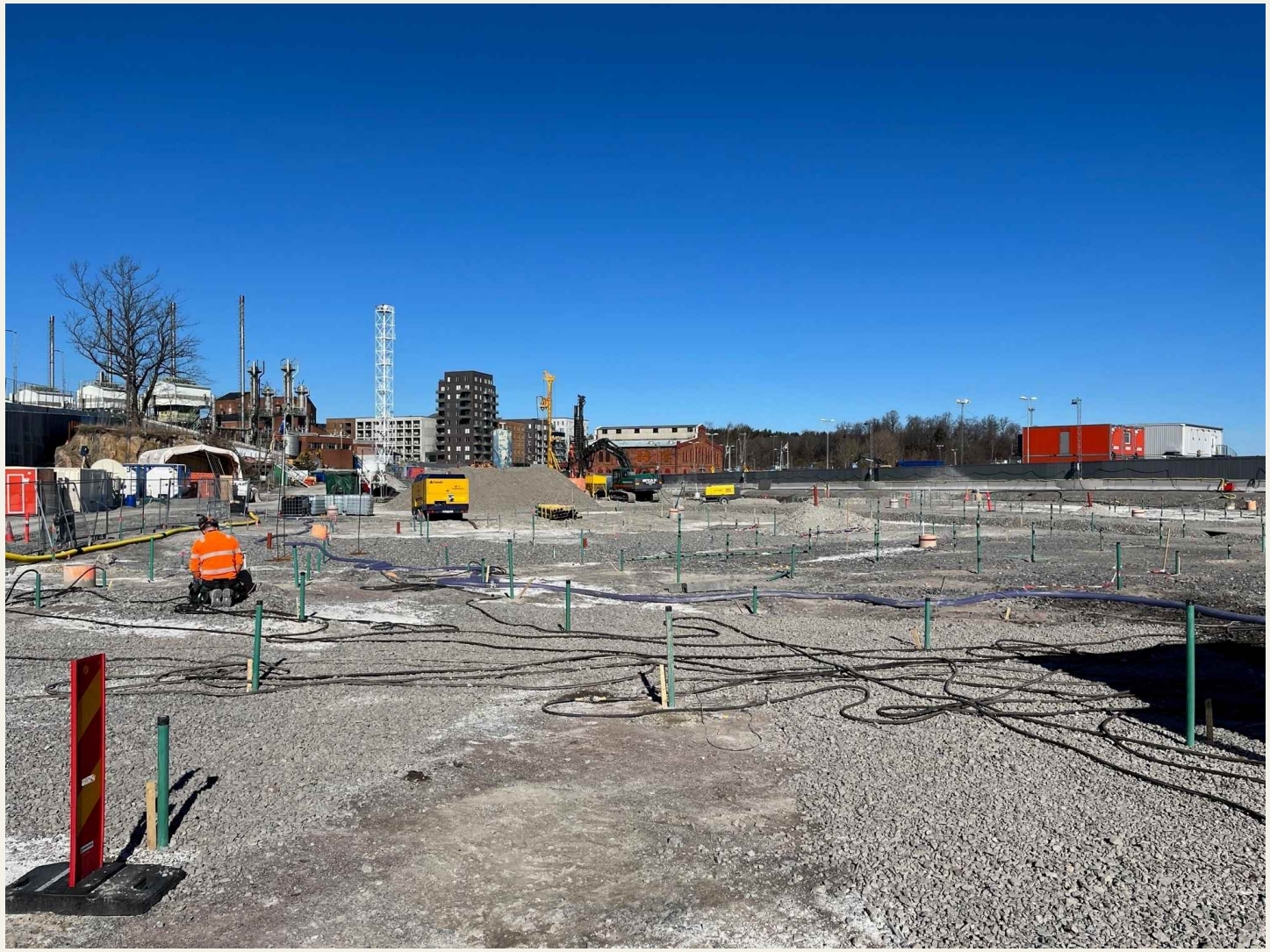
		No Treatment*	Low dose	High Dose**
Naphthalene	µg/L	<3,100	3,100-3,800	>3,800
Fluoranthene	µg/L	<6	6-54	>54
Benzene	µg/L	<150	150-1,000	>1,000

* Half of remedial target value

** >10% of theoretical solubility indicates presence of “free phase” (NAPL)



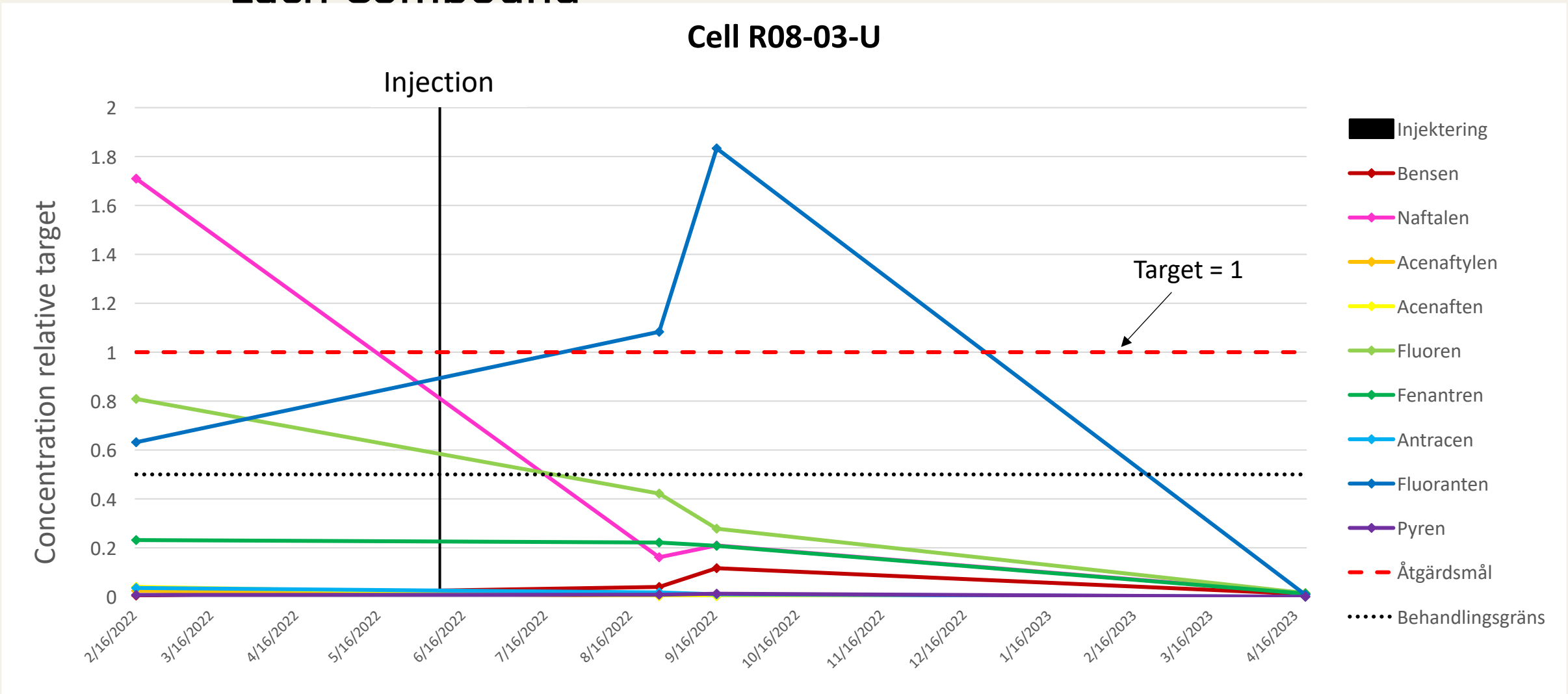
Injection of Klozur® SP + NaOH Solution to Moraine Layer via TAM-tubes – 2022 to ongoing



Automated pump station allowing for injection at multiple points simultaneously

Sleeved TAM-tube

Example Results Following ISCO Injections Plotted Relative Remedial Targets for Each Compound



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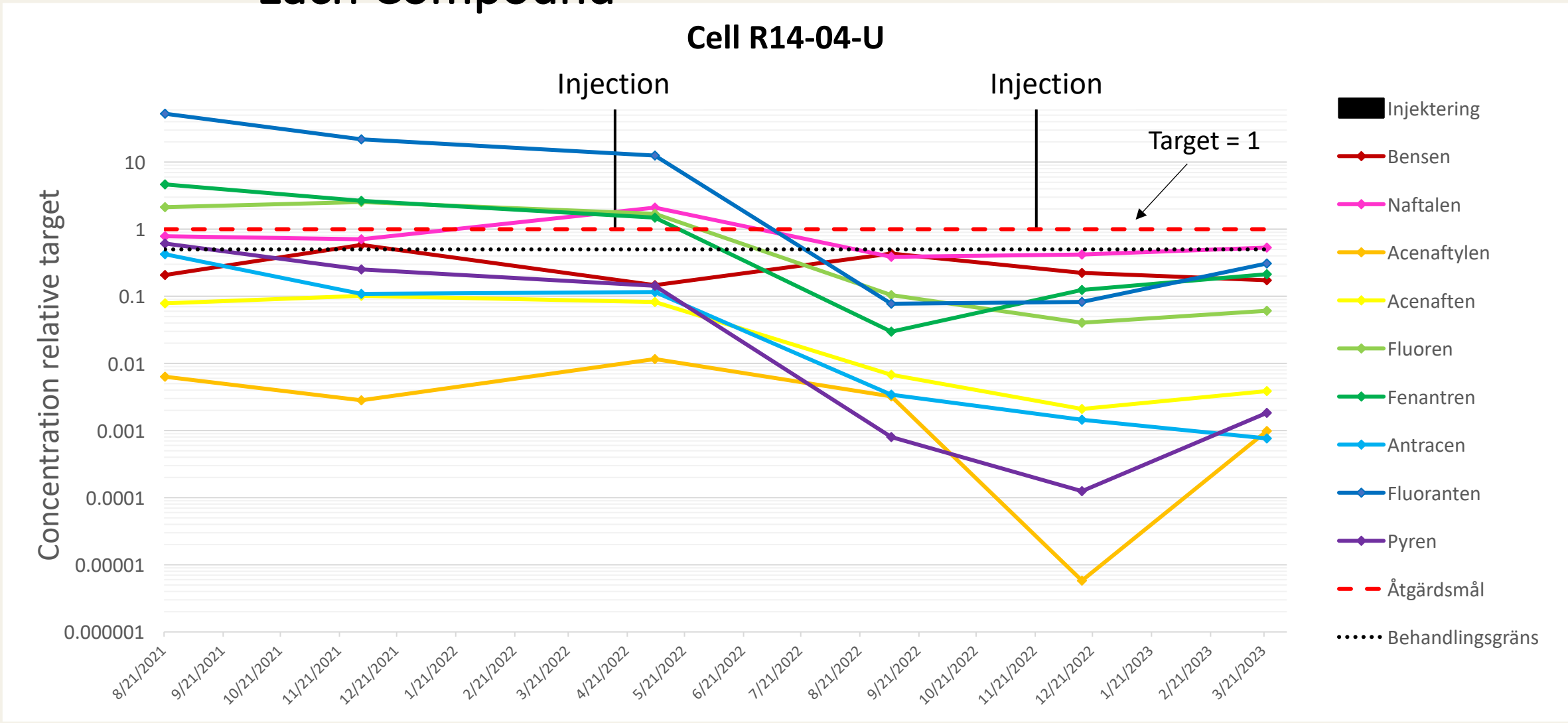
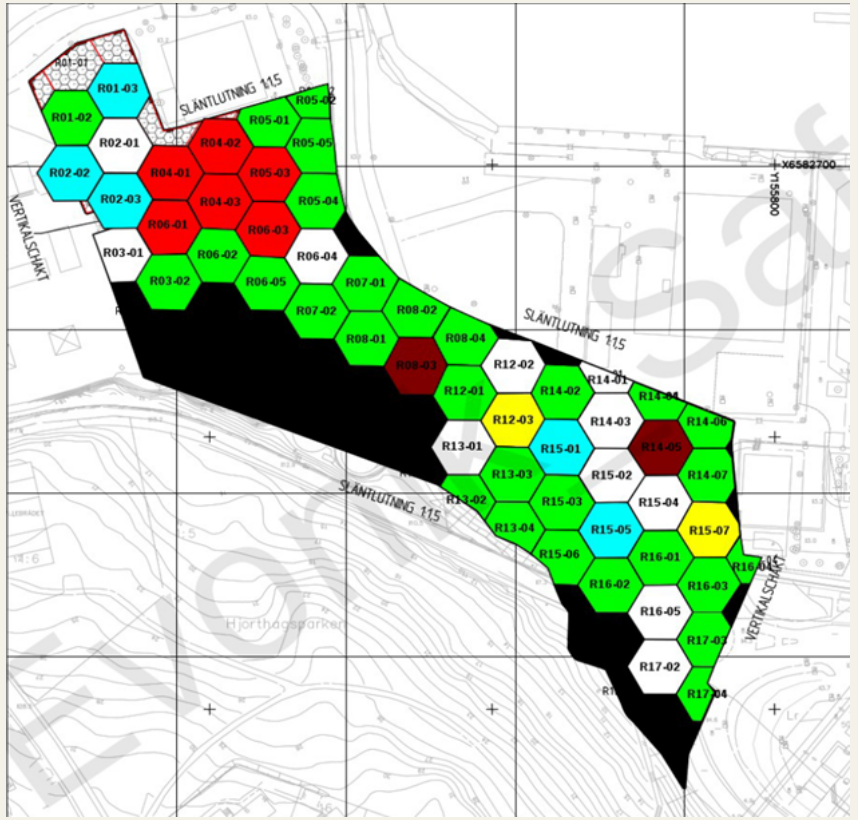


Conclusion - Current Status & Next Steps

- ISCO-ISS completed in spring 2023 – targets achieved
- ISCO injections expected to be completed in 2023
  - Green cells - confirmed clean in 3 monitoring events over 6 months
  - Blue cells – targets met at 6 weeks & 3 months, awaiting final 6-months confirmation sampling
  - Yellow cells – results met at 6 weeks, awaiting additional confirmation sampling
  - White cells - awaiting monitoring results
  - Two cells (brown) - requiring re-injection
  - Red cells – new areas – last monitoring discovered elevated contamination in 6 cells previously deemed clean (recent earth work)



Strategy found successful for meeting site targets and additional work is planned for adjacent areas using the same general remedial approach

Thank you!

Questions are welcome.

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