Sustainable Combination Heating: An Innovative Approach for In Situ Thermal Remediation in Challenging Lithology

RemTech 2018
Fairmont Banff Springs Hotel
Banff, Alberta

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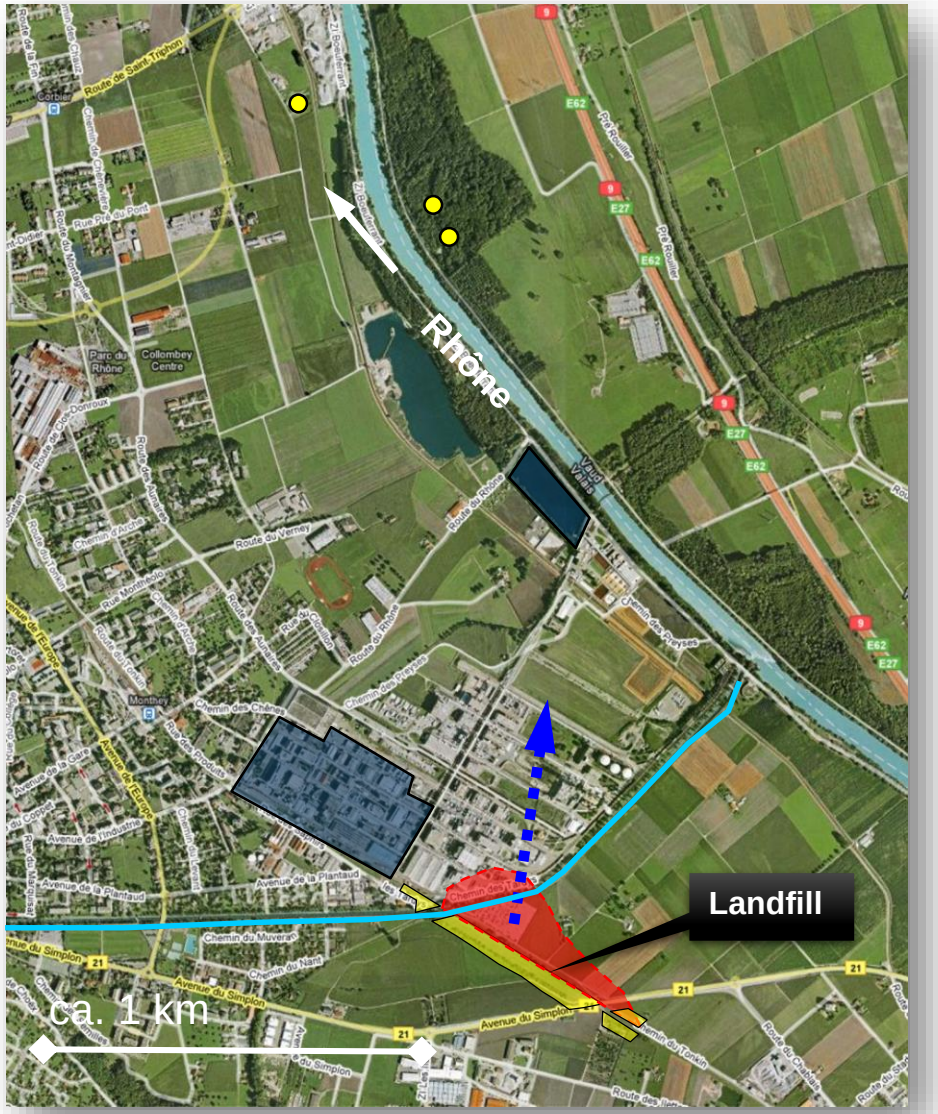
Date: 11 October, 2018

The business of sustainability

ERM

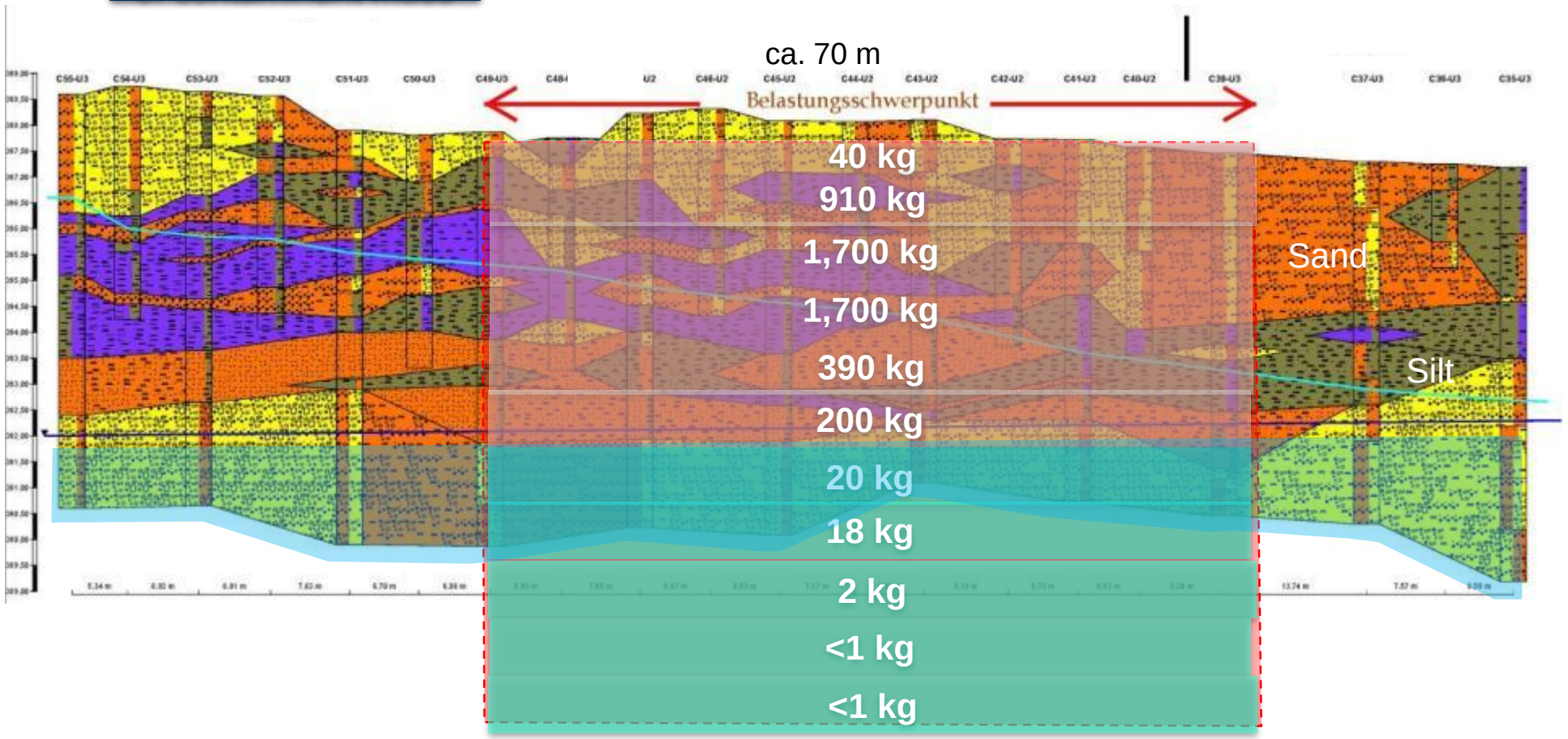
Switzerland Site Setting

- 70,000 m³ waste, 50,000 m³ soil
- Complex Inventory of Contaminants (chlorobenzene, anilines, chlorinated solvents, pesticides and heavy metals)
- Wide Range of Contaminant Concentration
- Swiss law enforced remediation by:
  - Complete excavation of waste
  - Soil & groundwater remediation
- Rigorous remediation targets
- Stringent Schedule



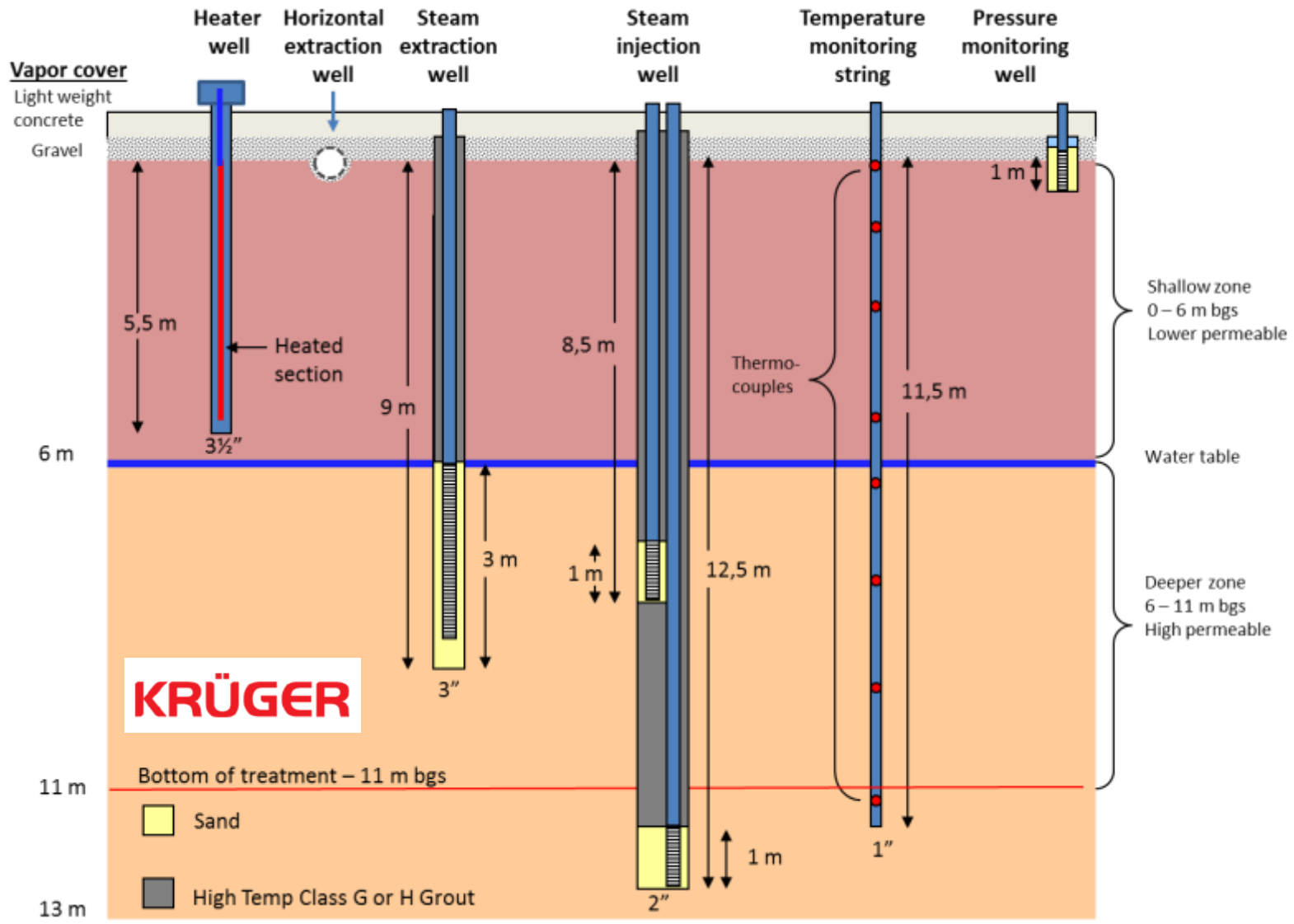
Underground Contraints

Forecast: ca. 5,000 kg of contaminant mass



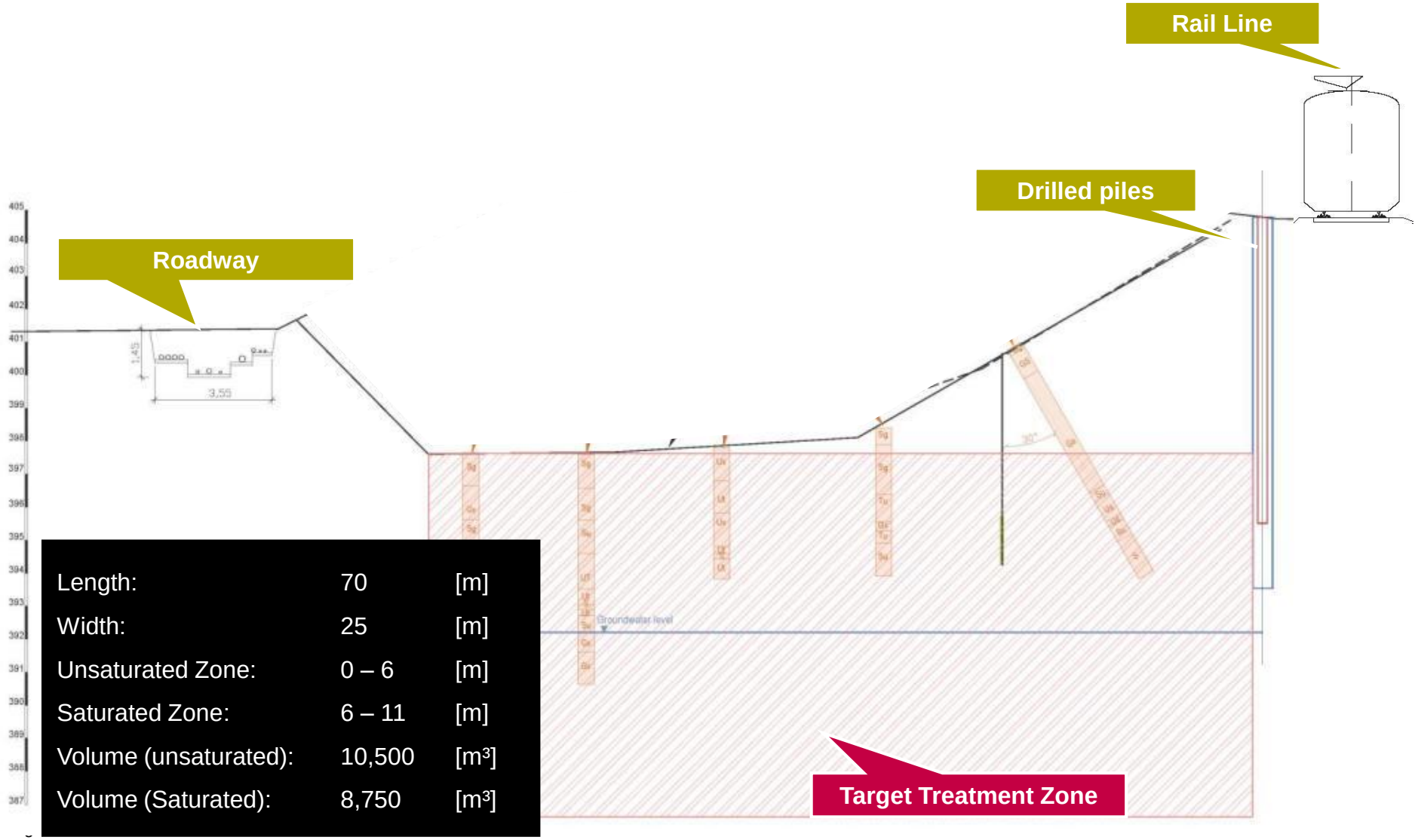
Remediation Target Area

Implementation-Design elements



provided by Krüger/TerraTherm

Boundary Conditions – sensitive infrastructure



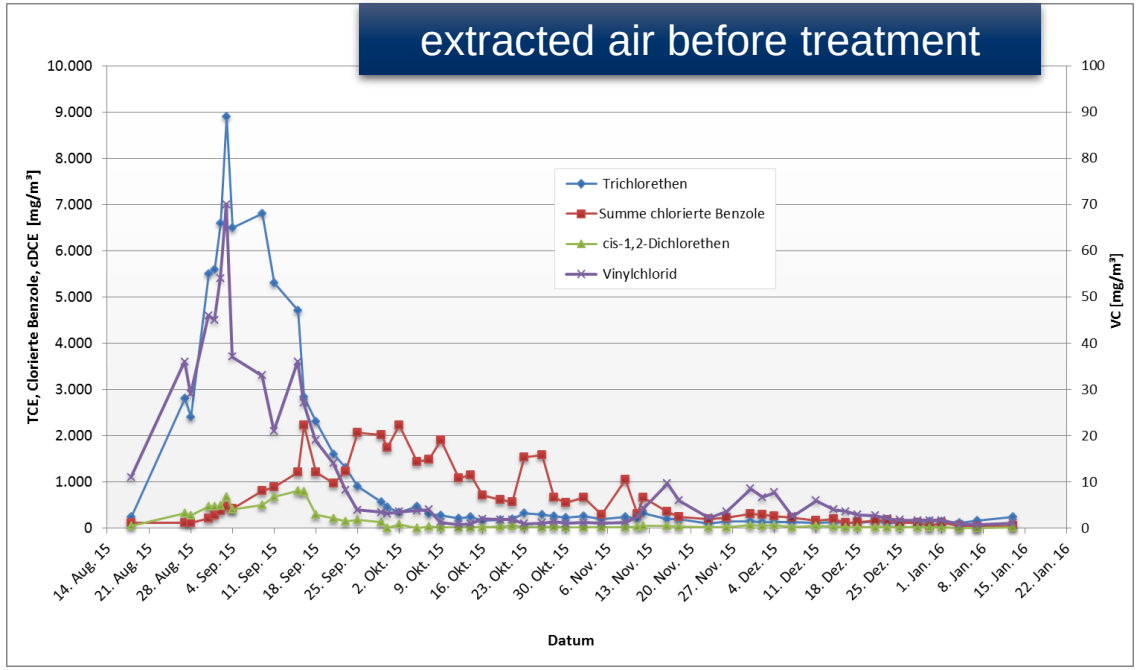
Length:	70	[m]
Width:	25	[m]
Unsaturated Zone:	0 – 6	[m]
Saturated Zone:	6 – 11	[m]
Volume (unsaturated):	10,500	[m³]
Volume (Saturated):	8,750	[m³]

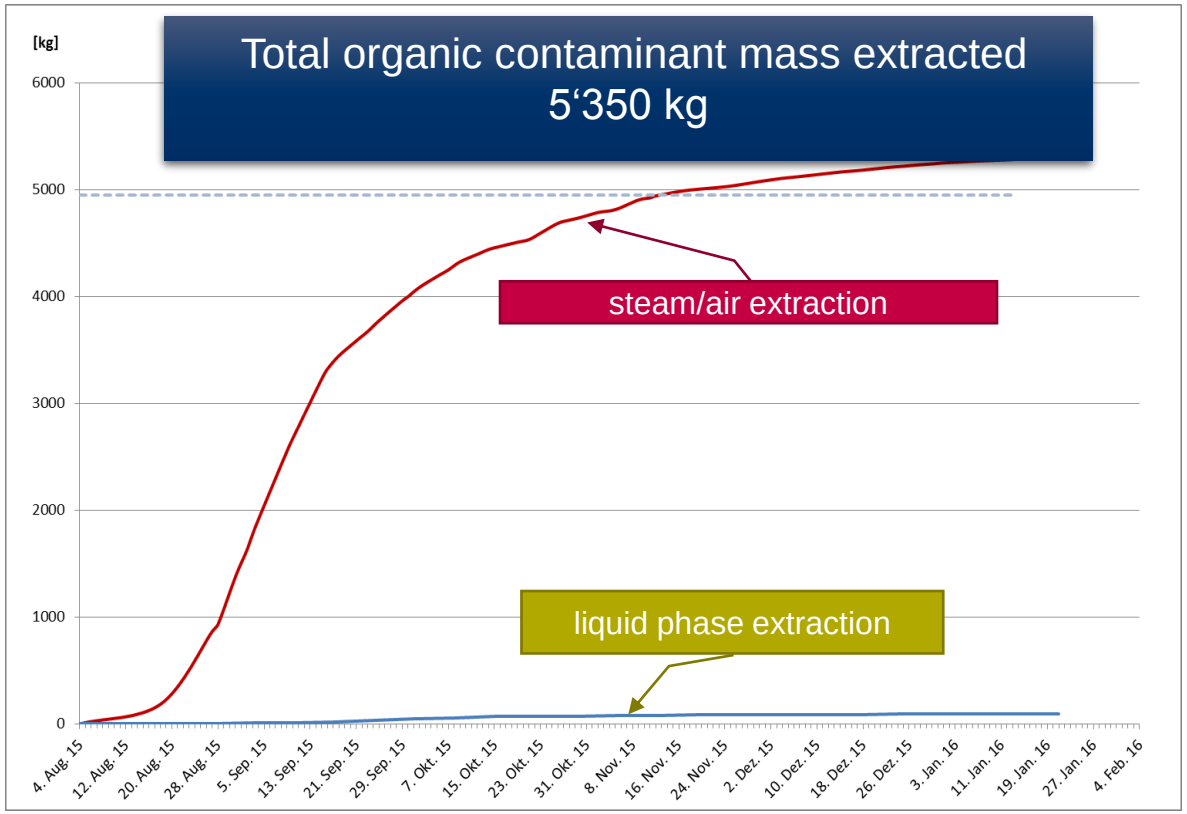
Phase II – Soil & Groundwater Remediation

ISTR Installation

Operation: August 2015 – January 2016

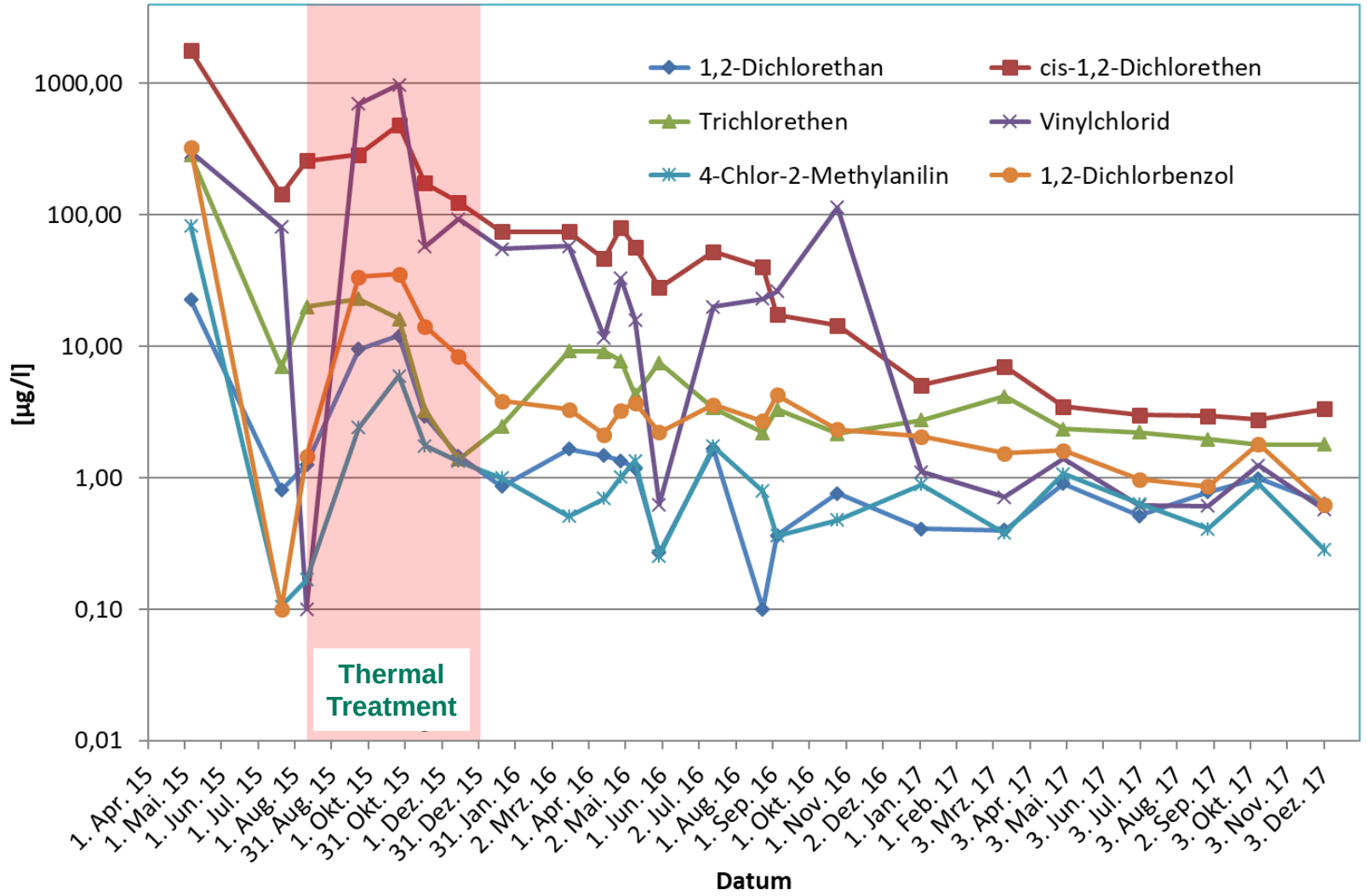
Performance & Achievements of Soil Remediation





Rebound??

Post Remediation Monitoring (20 m downgradient from TTZ)



Performance & Achievements of Soil Remediation

Remedial Sucess

	Soil		Groundwater	
11 Target Compounds with remedial objectives	**Max Soil Conc. before ISTD [mg/kg]**	**Remedial Success [%-Reduction]**	**Average Conc. before ISTD [µg/L]**	**Remedial Success [%-Reduction]**
Trichhloroethene	**834**	**99.9 %**	**1,595**	**98.0 %**
1,2-cis-Dichloroethene	**109**	**99.9 %**	**3,685**	**98.3 %**
1,2-Dichlorethane	**19.8**	**~100 %**	**293**	**99.8%**
Vinyl chloride	**2.8**	**99.6 %**	**750**	**99.5 %**
1,2-Dichlorobenzene	**2,855**	**99.8 %**	**3,176**	**99.3 %**
1,4-Dichlorobenzene	**34.6**	**99.8 %**	**69**	**100 %**
Chlorobenzene	**719**	**99.6 %**	**1,480**	**99.4 %**
Anilines	**111**	**95,0 %**	**624**	**99,8 %**
Metobromuron	**1.13**	**99.1 %**	**11**	**99.8 %**
Fluometuron	**2.10**	**99.5 %**	**92**	**99.8 %**
Bisphenol A	**417**	**56.4 %**	**21,664**	**99.8 %**

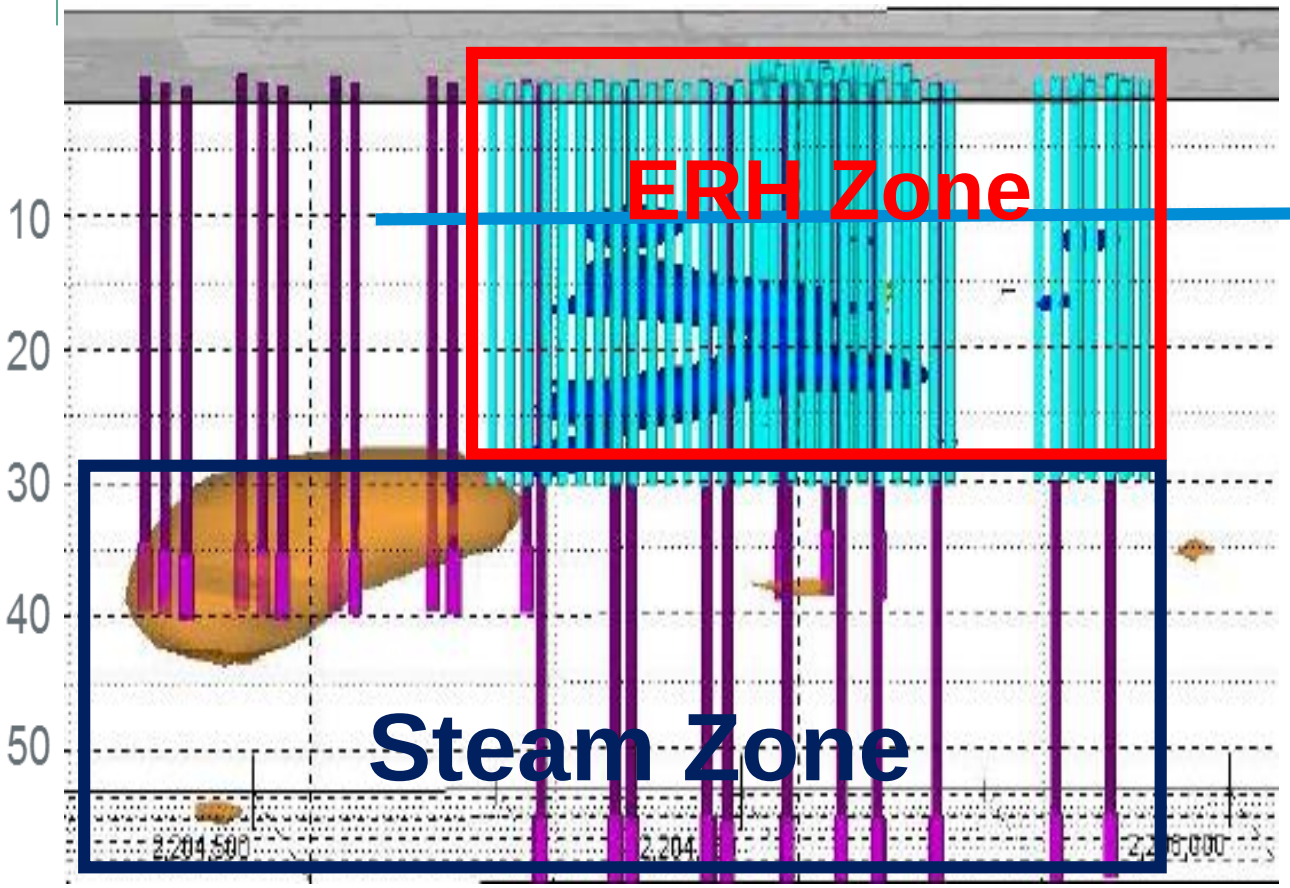
California Site Background

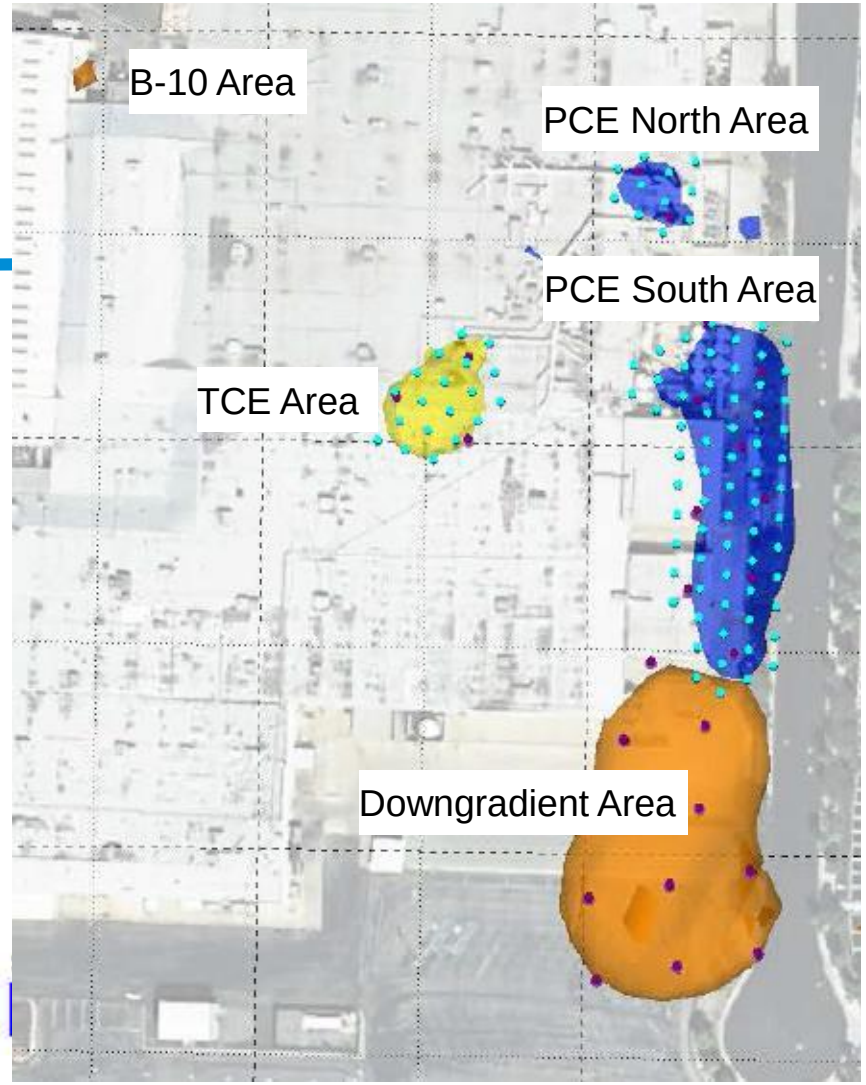
- Former aerospace manufacturing facility
- TCE and PCE impacts from degreasing operations
- Site planned for sale and redevelopment for industrial/commercial reuse.
- Lithology
  - Shallow unit - relatively low permeability clays and silts to approximately 25 to 30 feet bgs.
  - Intermediate unit
    - Sand A - Sand and gravelly sand from 30 to 40 feet bgs.
    - Sand B - Sand and gravelly sand. Slightly more permeable than Sand A. 40 to 70 feet bgs

Summary of Remediation

- Remedial Strategy
  - Implement Electric Resistance Heating (ERH) to heat fine-grained Shallow Unit soils.
  - Implement Steam Enhanced Extraction (SEE) to heat A and B Sands.
  - Raise soil and groundwater temperatures to above VOC co-boiling and boiling points:
    - **PCE = 88°C (co-boiling)**
    - **TCE = 73°C (co-boiling)**
    - **1,4-Dioxane = 78°C (co-boiling)**
    - **cis-1,2-DCE = 60.1°C (boiling)**
    - **VC = -13.8°C (boiling)**
  - Achieve asymptotic mass removal.
  - Reduce soil concentrations to below risk based Environmental Screening Levels
    - PCE 0.6 mg/kg
    - TCE 1.2 mg/kg
  - Reduce groundwater concentrations

Extent of Impacts





Implementation Sequence

Building Demolition

Well electrode installation

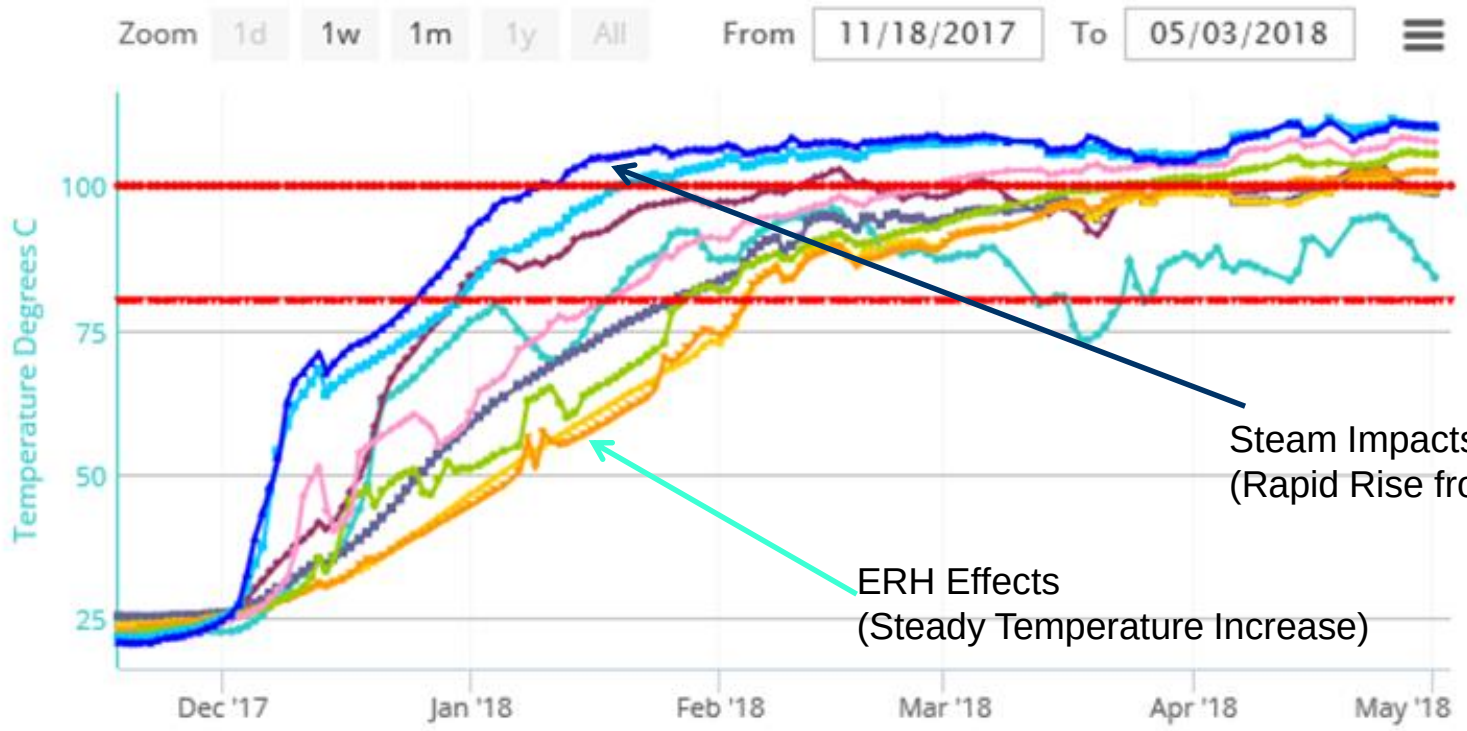
Electrode installation

Vapor Cap Construction

Piping and electrical construction

Boiler and Treatment Compound

Subsurface Temperatures (Temperature Graphs)



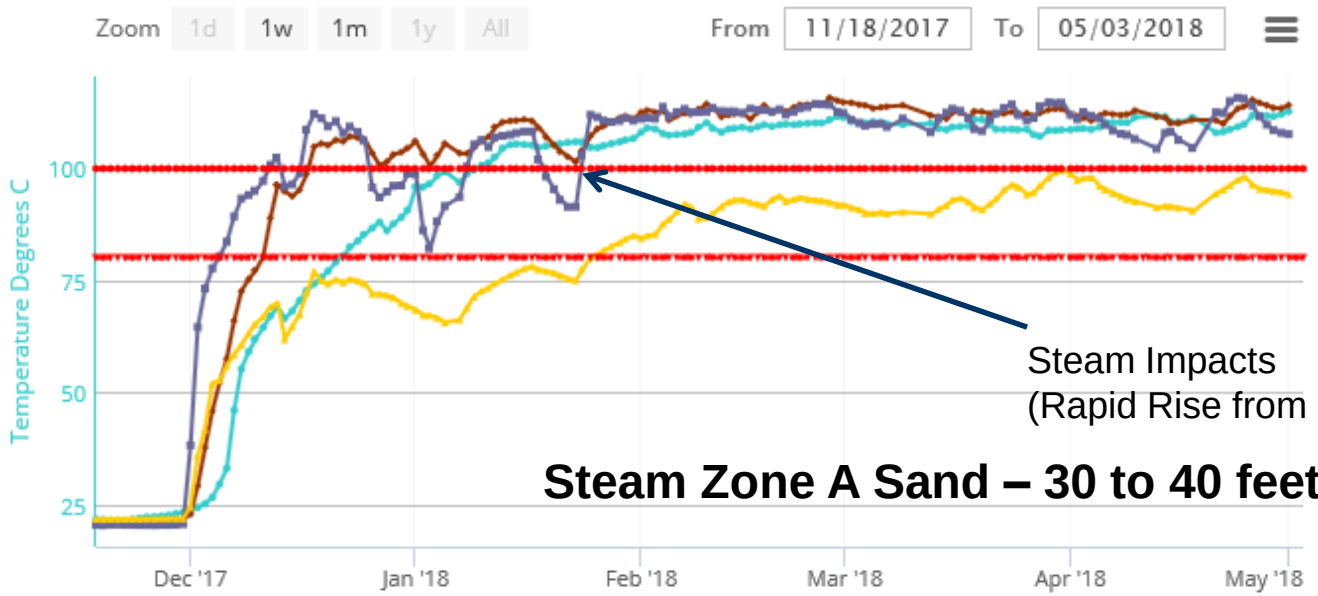
Co-boiling point

Steam Impacts in ERH zone (24 to 30 feet bgs)
(Rapid Rise from Steam Contact)

ERH Effects
(Steady Temperature Increase)

ERH Zone – 3 to 30 feet bgs

Subsurface Temperatures (Temperature Graphs)



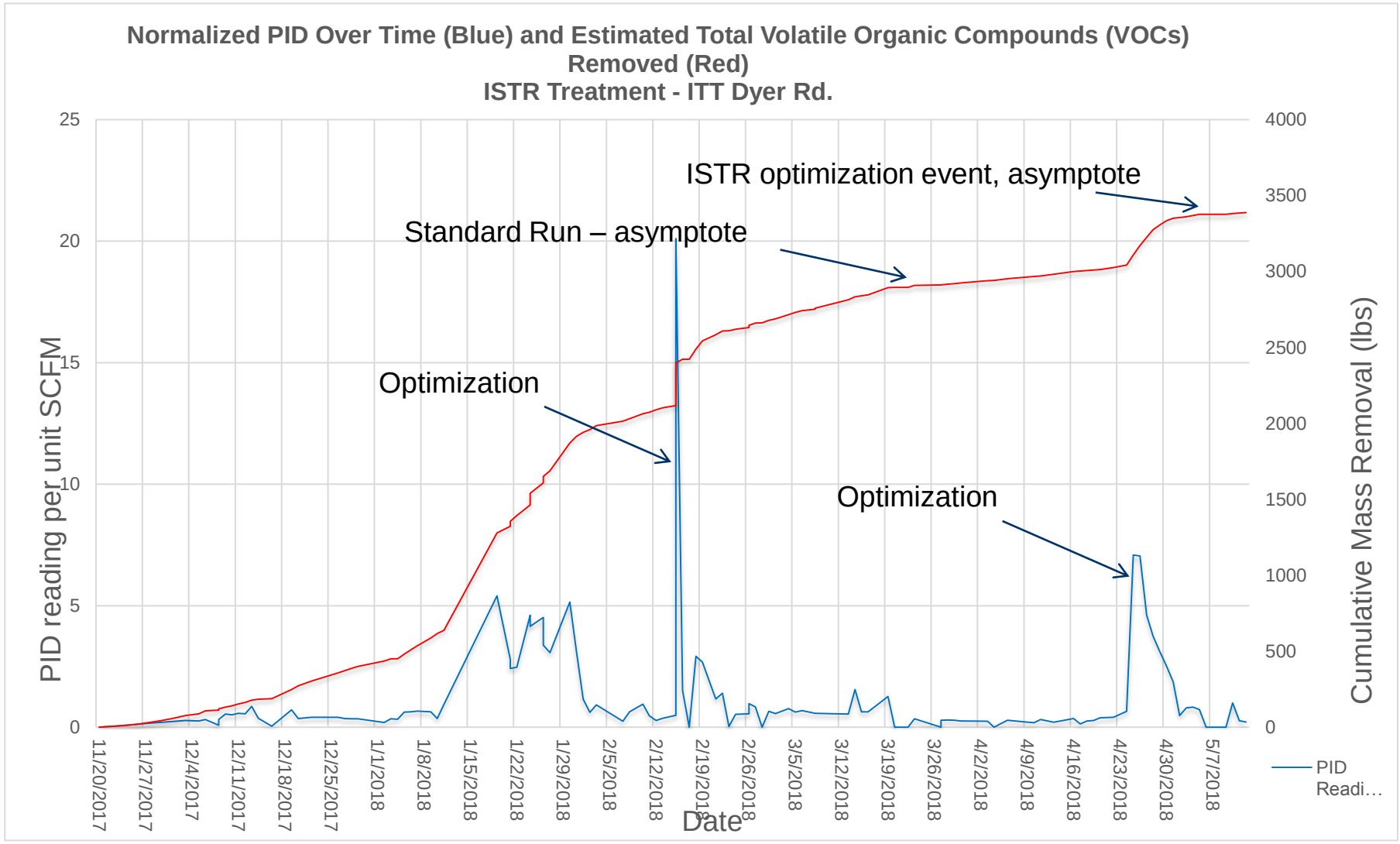
Co-boiling point

Steam Impacts
(Rapid Rise from Steam Contact)

Steam Zone A Sand – 30 to 40 feet bgs

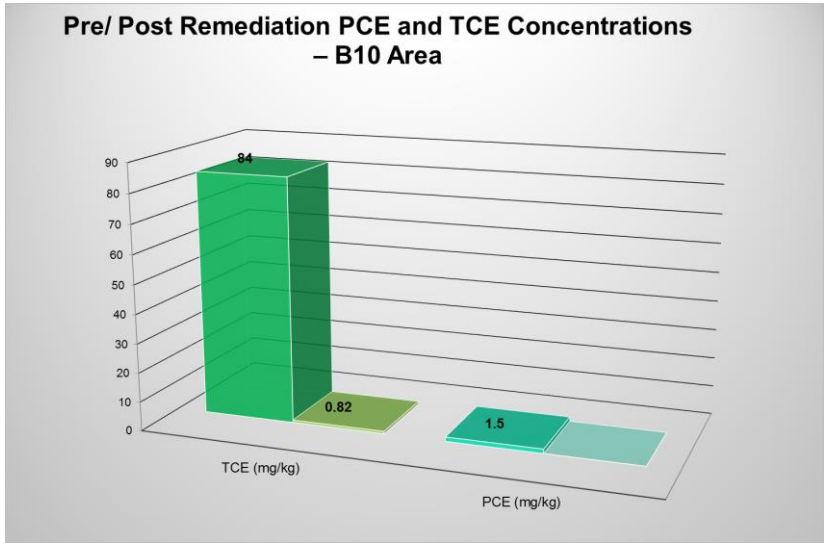
Steam Zone B Sand – 40 to 60 feet bgs

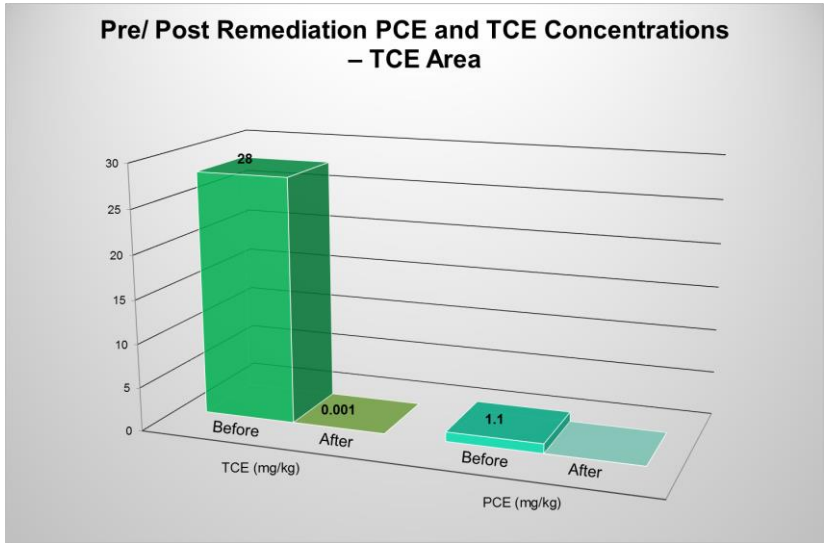
Asymptotic Mass Removal

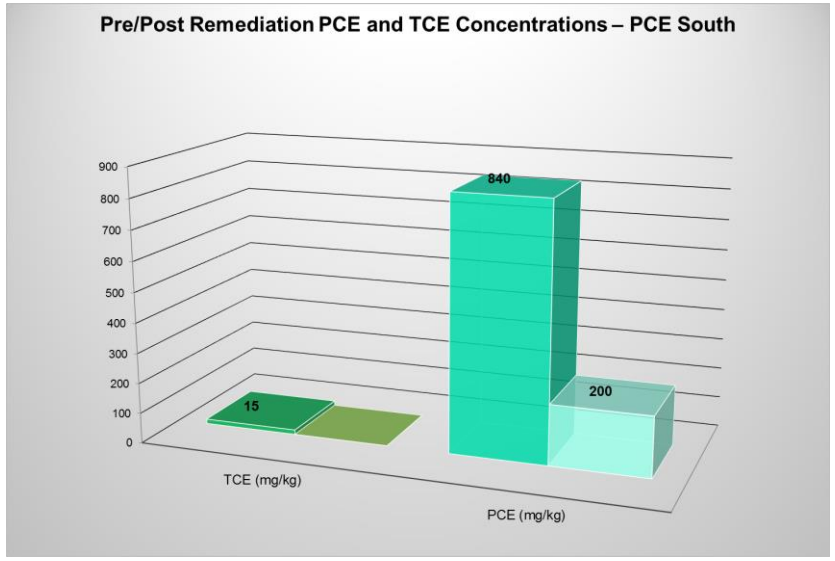


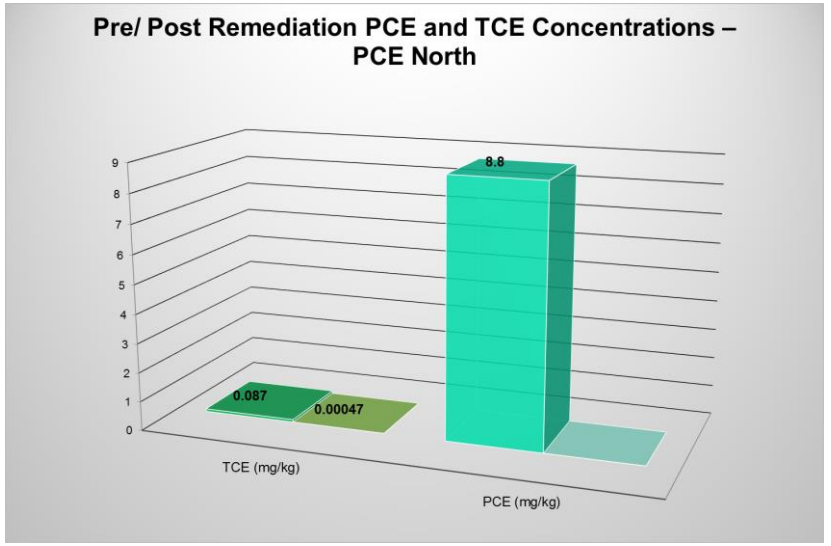
Asymptote determined by Sigmoidal model

Performance Monitoring - Soil

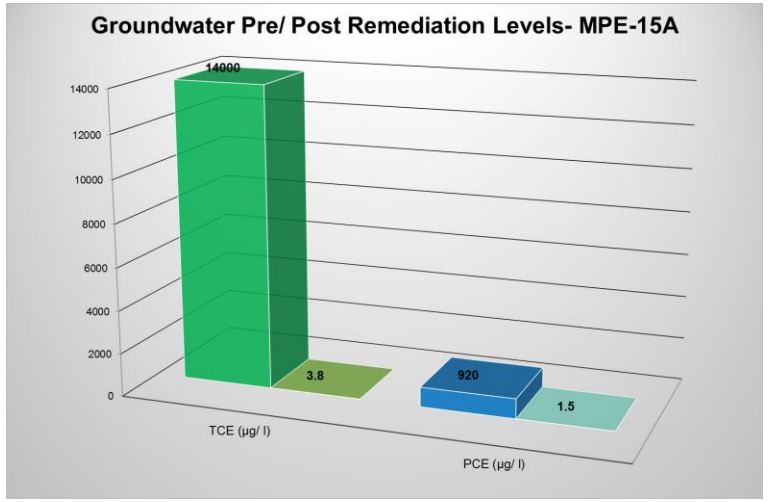


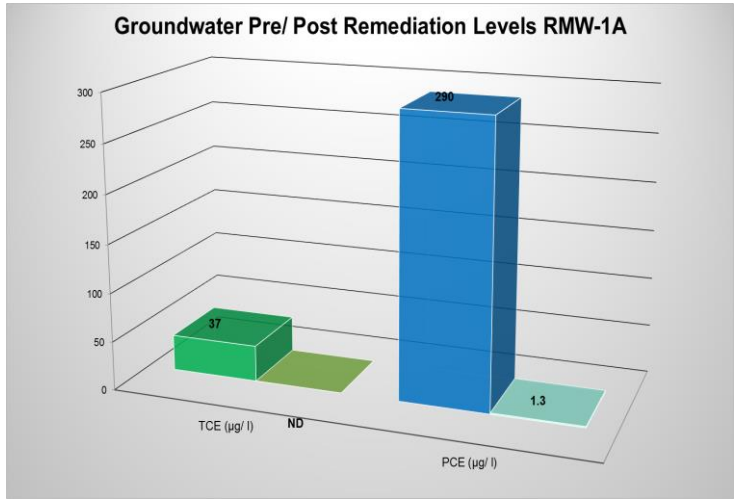


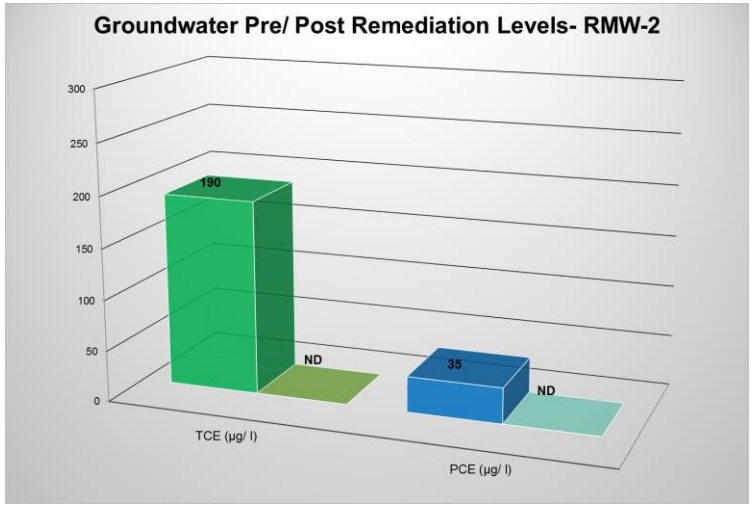


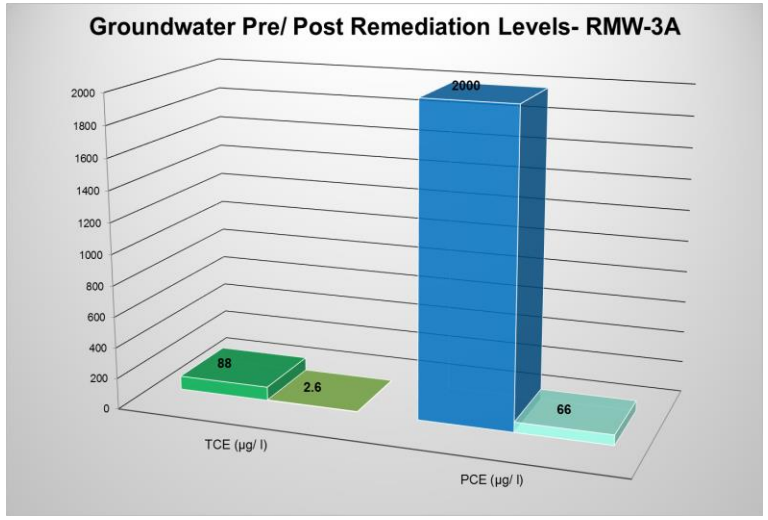


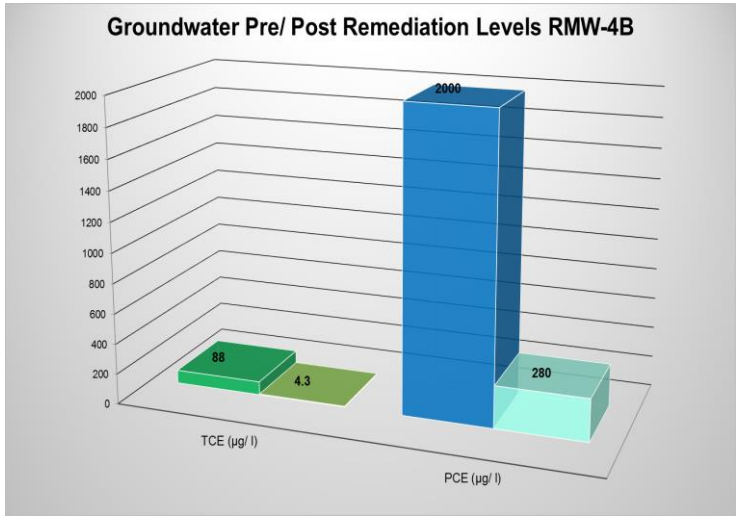
Performance Monitoring - Groundwater

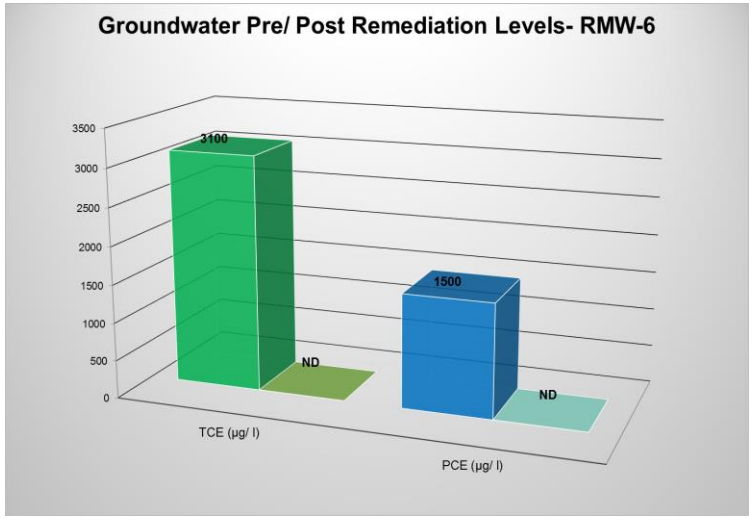






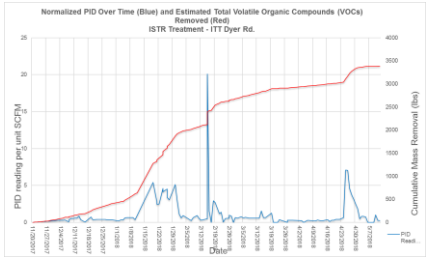




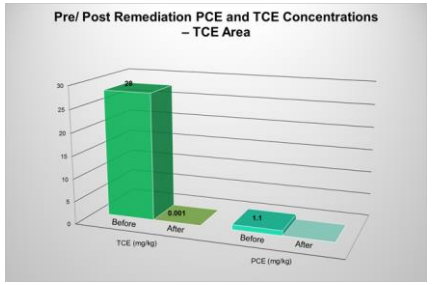


Conclusions

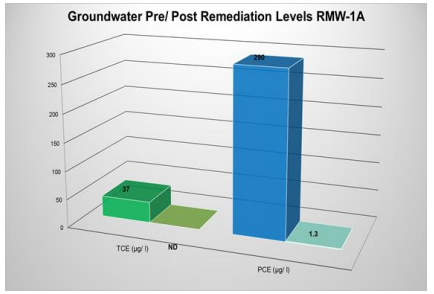
- Combined ERH and SEE achieved asymptotic mass removal.
- System removed more than 3,300 lbs. of VOC mass from soil and groundwater



- 175 of 178 soil samples collected were below ESLs.
- Remedial system in areas around 3 elevated samples was optimized by installing targeted steam injection wells and increasing steam injection mass flow rate.



- VOC concentrations in groundwater were reduced up to 4 orders of magnitude.
- VOCs in 6 of the 10 performance monitoring wells were reduced below MCLs (or non-detect)



Thank you

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