Thermal Conductive Heating and Steam-Enhanced Extraction

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New England Waste Management Officials' Association

In-Situ Thermal Remediation Workshop

June 13, 2012 – *Quinebaug Valley Community College in Danielson, CT*
June 14, 2012 - *Westford Regency Inn and Conference Center in Westford, MA*

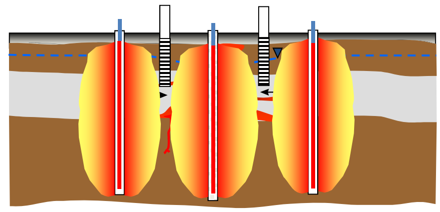
ISTR Technology Alphabet Soup

- Steam-Enhanced Extraction (SEE)*
- Electrical Resistance Heating (ERH)*
  - Electro-Thermal Dynamic Stripping Process (ET-DSP™)
- In Situ Thermal Desorption (ISTD)*
  - Thermal Conduction Heating (TCH) + Vacuum Recovery
- Combinations*: ISTD/SEE (ET-DSP™/SEE)
- Radio Frequency Heating

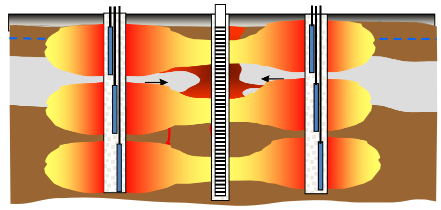
Focus of Talk

***Offered by TerraTherm, Inc.**

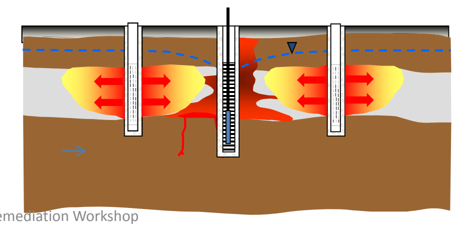
ISTD/TCH* - Heating governed by **thermal conductivity** (*f*~3) nearly uniform



ERH/ET-DSP* - Heating governed by **electrical conductivity** (*f*~200) may require stacked electrodes



SEE* - Heating governed by **hydraulic conductivity**
non-uniform steam flow



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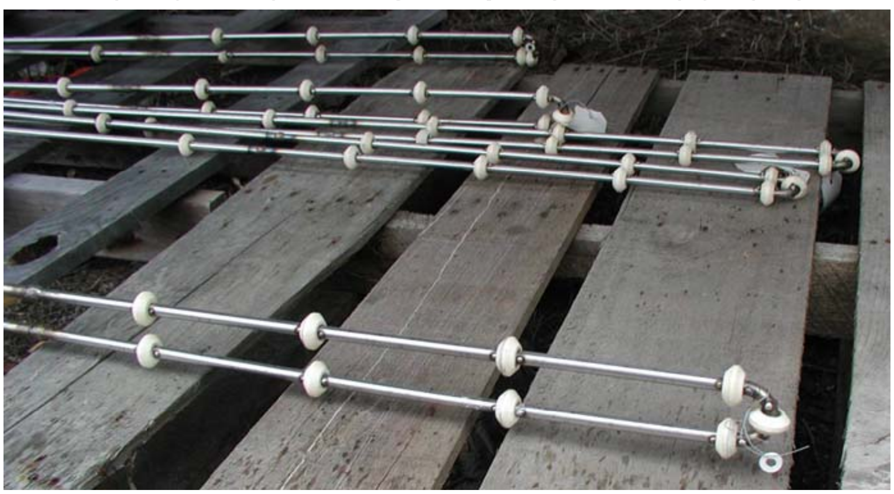
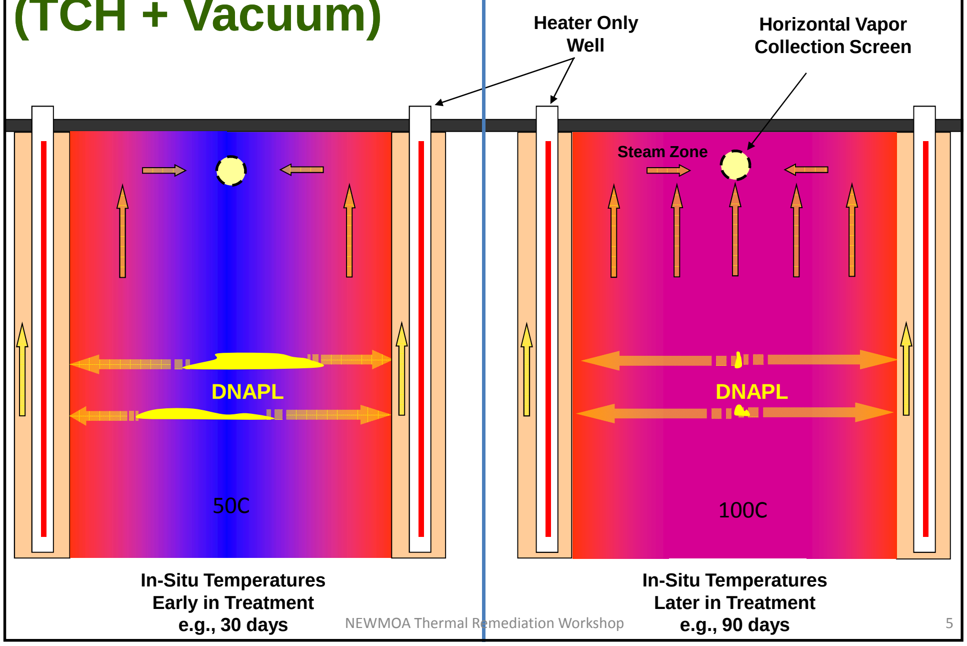
TerraTherm ISTD/TCH Heaters

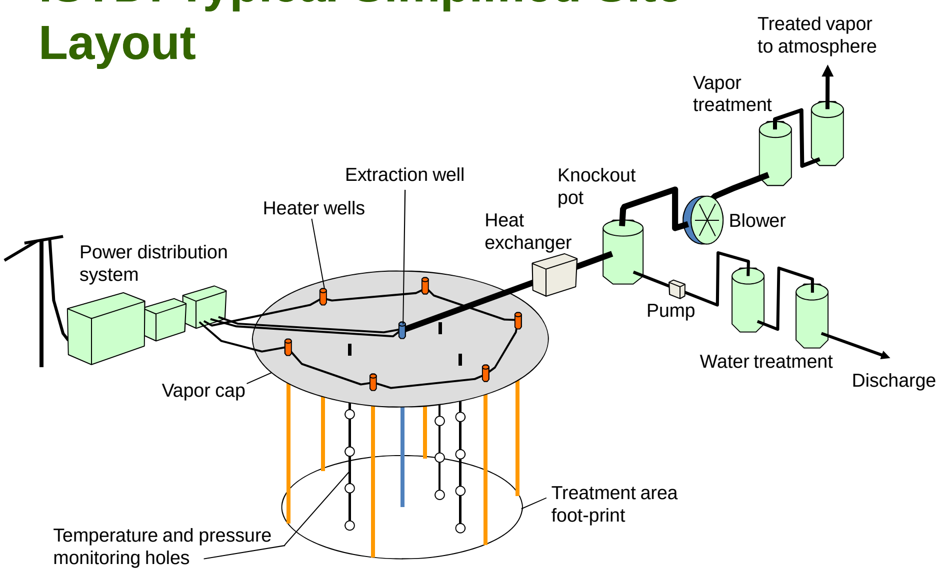


Covered by one or more of the following: U.S. Patent Nos. 5,190,405, 5,318,116, 6,485,232 and 6,632,047. International patents (e.g., EPC 1272290).

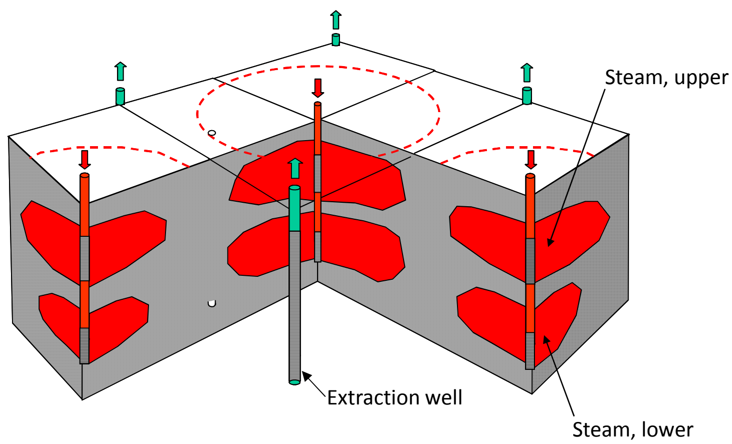
ISTD (TCH + Vacuum)



ISTD: Typical Simplified Site Layout



SEE
Typical Layout



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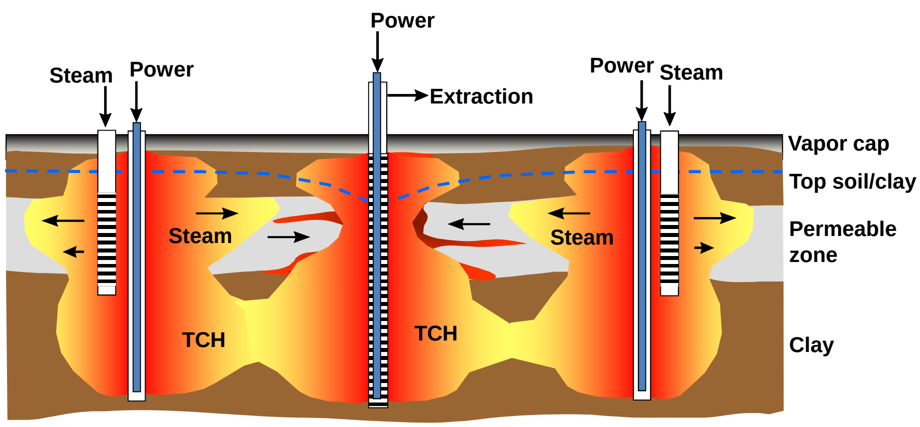
Steam Injection Manifold

ISTD+SEE in Complex Stratigraphy

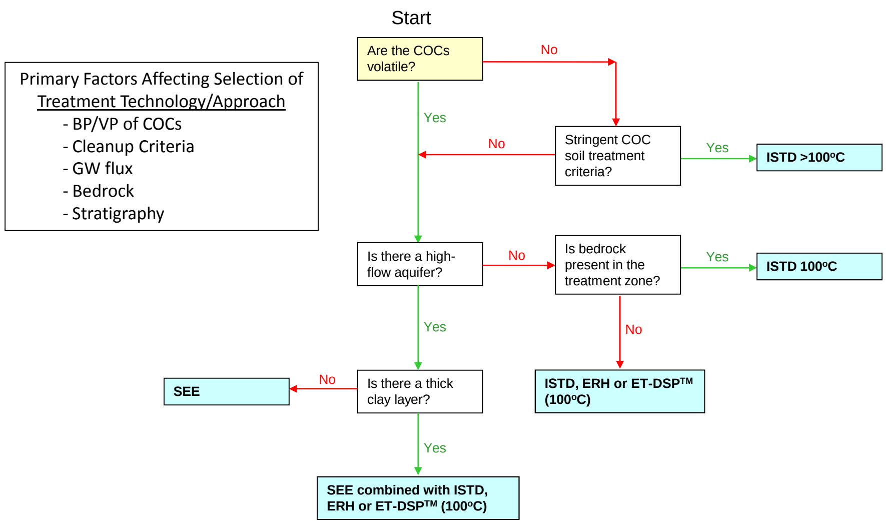


TCH	CVOC	BTEX	Chloro-benzenes	Gasoline	Diesel	Oils > 50 cp	Creosote, 10-100 cp	MGP coal tar, viscous
Sand, vadose	Green	Green	Green	Green	Green	Green	Green	Green
Sand, saturated	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Silt, vadose	Green	Green	Green	Green	Green	Green	Green	Green
Silt, saturated	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Clay, vadose	Green	Green	Green	Green	Green	Green	Green	Green
Clay, saturated	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Crystalline rock	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Cemented sedimentary rock	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Organic rock	Yellow	Yellow	Yellow	Yellow	Pink	Pink	Pink	Pink

SEE	CVOC	BTEX	Chloro-benzenes	Gasoline	Diesel	Oils > 50 cp	Creosote, 10-100 cp	MGP coal tar, viscous
Sand, vadose	Green	Green	Green	Green	Green	Green	Green	Yellow
Sand, saturated	Green	Green	Green	Green	Green	Green	Green	Yellow
Silt, vadose	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Silt, saturated	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Clay, vadose	Red	Red	Red	Red	Red	Red	Red	Red
Clay, saturated	Red	Red	Red	Red	Red	Red	Red	Red
Crystalline rock	Yellow	Yellow	Yellow	Yellow	Pink	Pink	Pink	Red
Cemented sedimentary rock	Pink	Pink	Pink	Pink	Pink	Pink	Pink	Red
Organic rock	Pink	Pink	Pink	Pink	Pink	Red	Red	Red

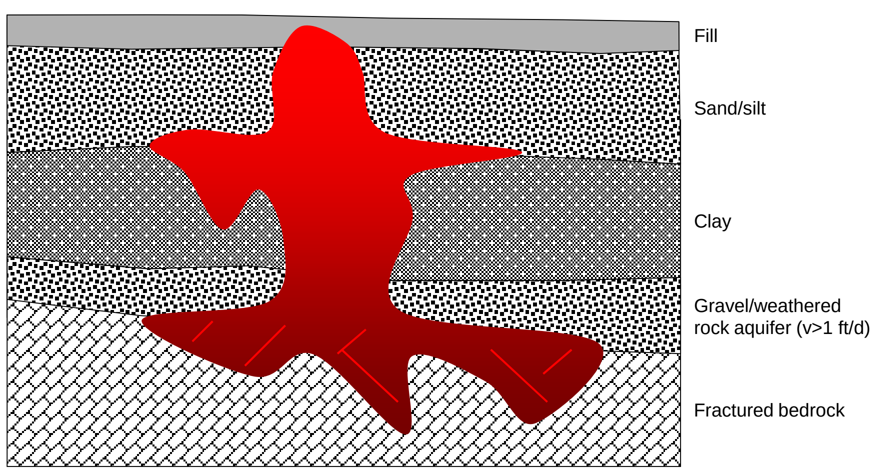
TCH+SEE	CVOC	BTEX	Chloro-benzenes	Gasoline	Diesel	Oils > 50 cp	Creosote, 10-100 cp	MGP coal tar, viscous
Sand, vadose	Green	Green	Green	Green	Green	Green	Green	Green
Sand, saturated	Green	Green	Green	Green	Green	Green	Green	Green
Silt, vadose	Green	Green	Green	Green	Green	Green	Green	Green
Silt, saturated	Green	Green	Green	Green	Green	Green	Green	Green
Clay, vadose	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Clay, saturated	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Crystalline rock	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Cemented sedimentary rock	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Organic rock	Yellow	Yellow	Yellow	Yellow	Pink	Pink	Pink	Pink

Green	Effective
Yellow	Promising/site specific
Pink	Problematic/unproven
Red	Will not be effective

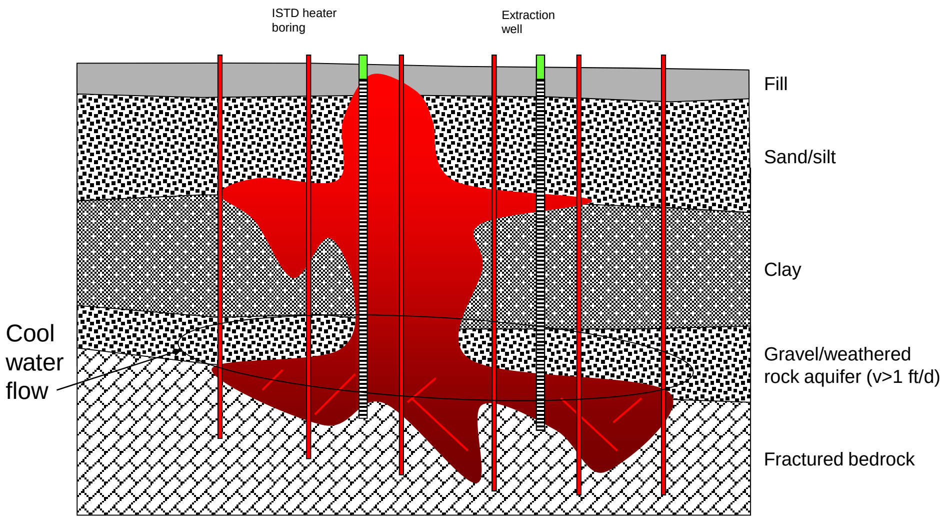


Simplified decision tree for identifying applicable thermal technologies for a site

Example Source Area DNAPL and VOC Distribution



ISTD



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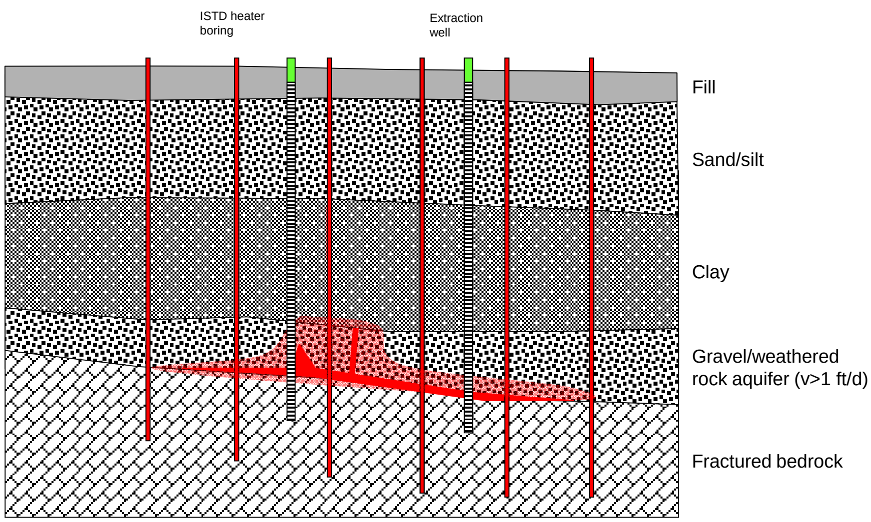
ISTD – Result



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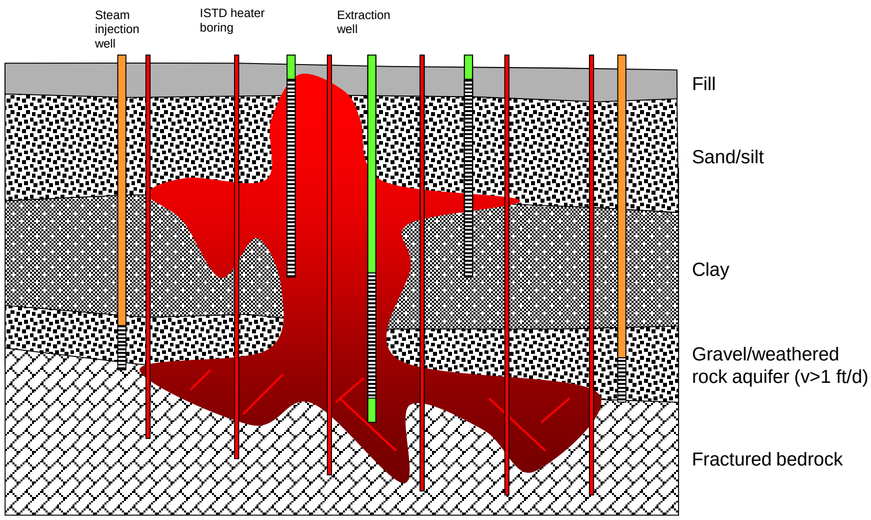
ISTD - SEE Combination



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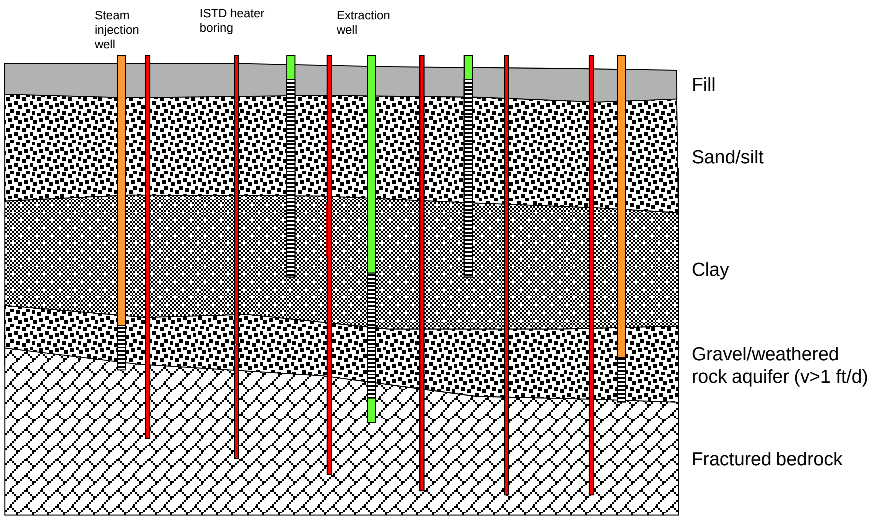
ISTD - SEE Combination – Result



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Data Needs

- Good Conceptual Model
  - Definition of treatment zone
  - Comprehensive list of COCs, concentrations, and mass estimates
  - Geology and Hydrogeology (stratigraphy, permeability, hydraulic gradients, gw flow velocities)
- Treatment Objectives
- Site Constraints

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Why stay and listen?

- DNAPL source zone "removed" – does it make a difference?
- How to use thermal in tight spaces under buildings
- Use of steam and conductive heating together – the site conditions should determine which method, not what the vendor says
- Thermal is cool!

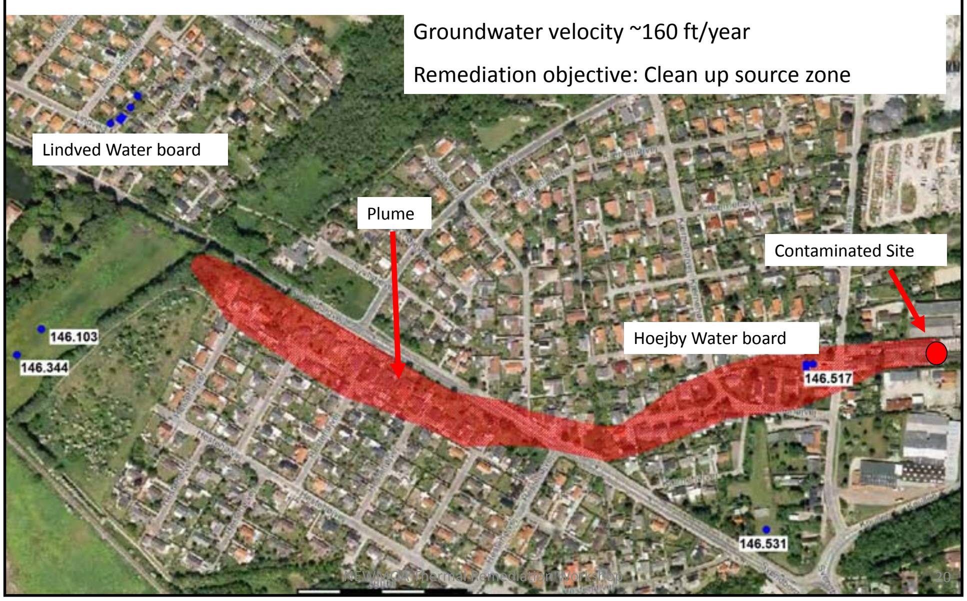
Why clean up?

Plume length >3,300 ft

Two municipal wells downgradient of site – supplying more than 100,000 citizens

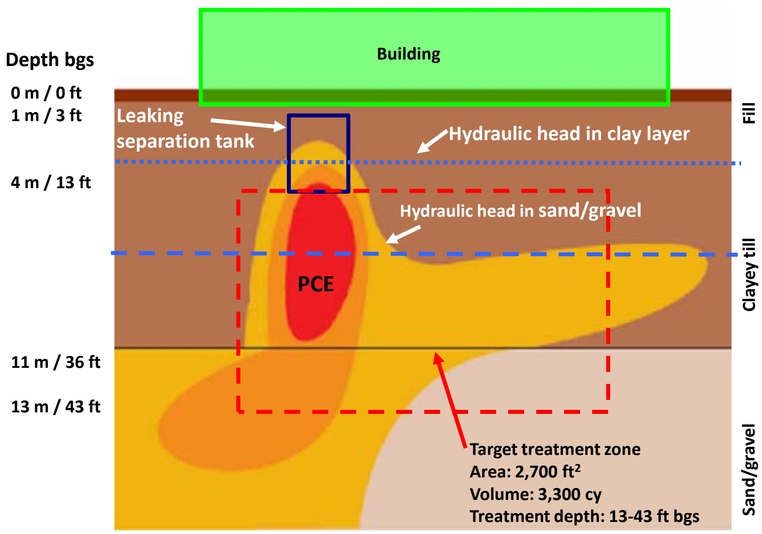
Groundwater velocity ~160 ft/year

Remediation objective: Clean up source zone

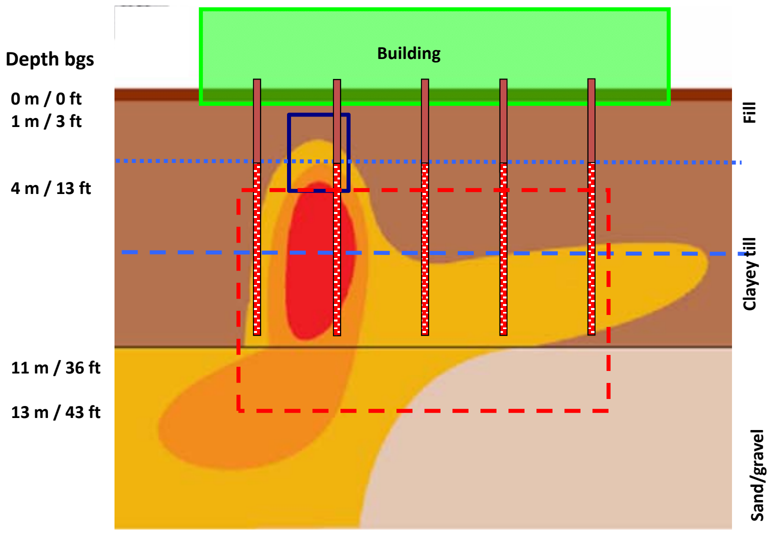


Source zone location

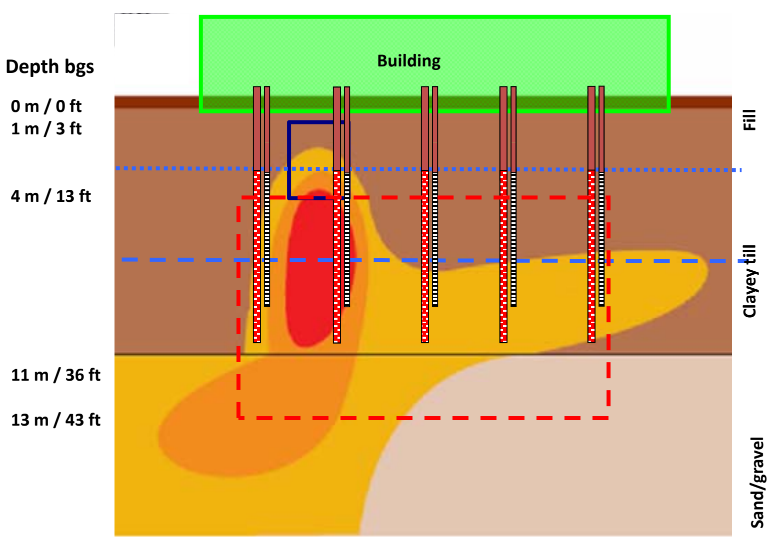
Contaminant distribution, geology and hydrogeology



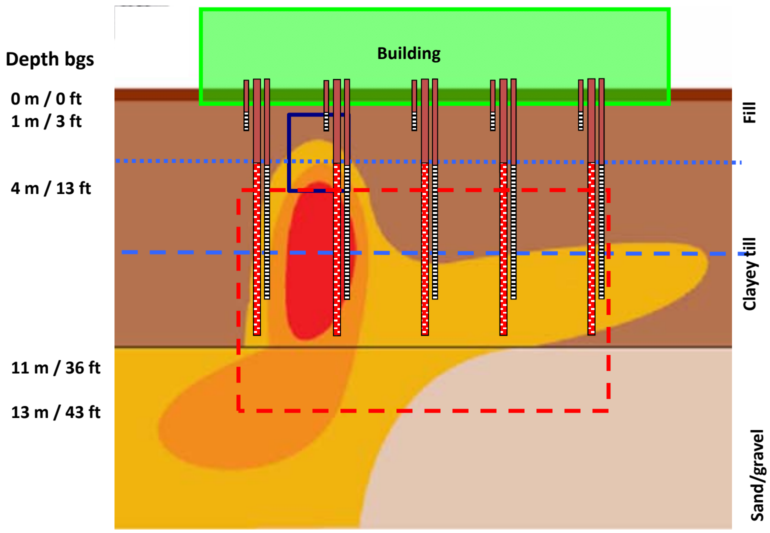
Thermal Concept (SEE and TCH)



Thermal Concept (SEE and TCH)



Thermal Concept (SEE and TCH)



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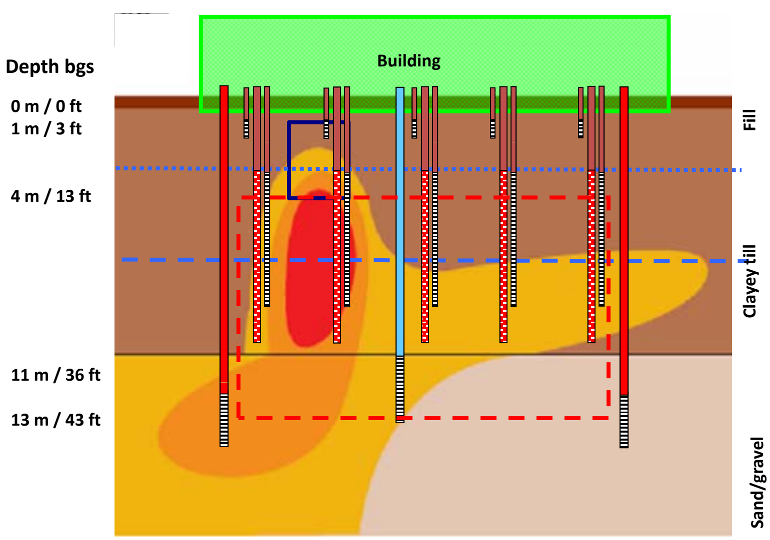
Thermal Concept (SEE and TCH)



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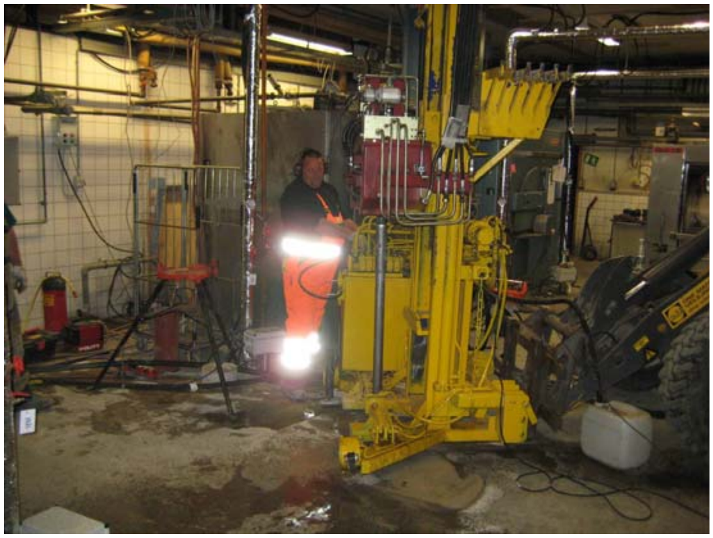
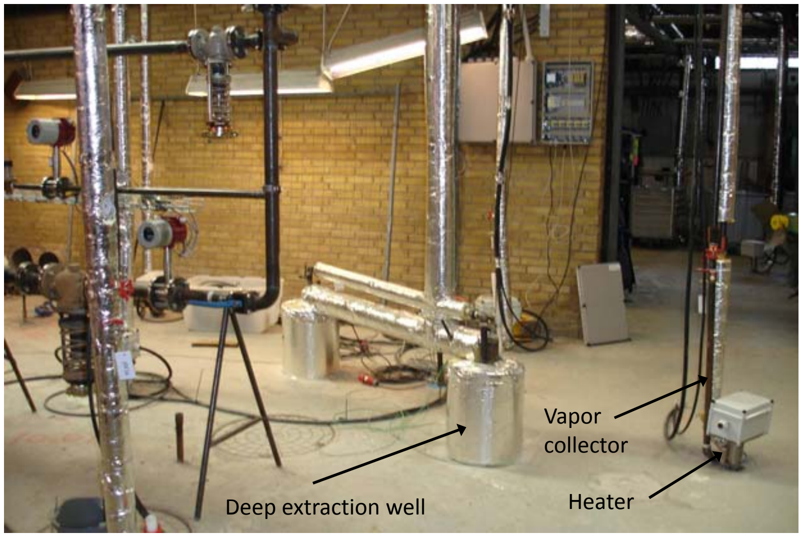


Drilling between dry cleaning machines, walls, cables and pipes

Indoor heater installation



Wells

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Treatment system in two levels due to limited space at site

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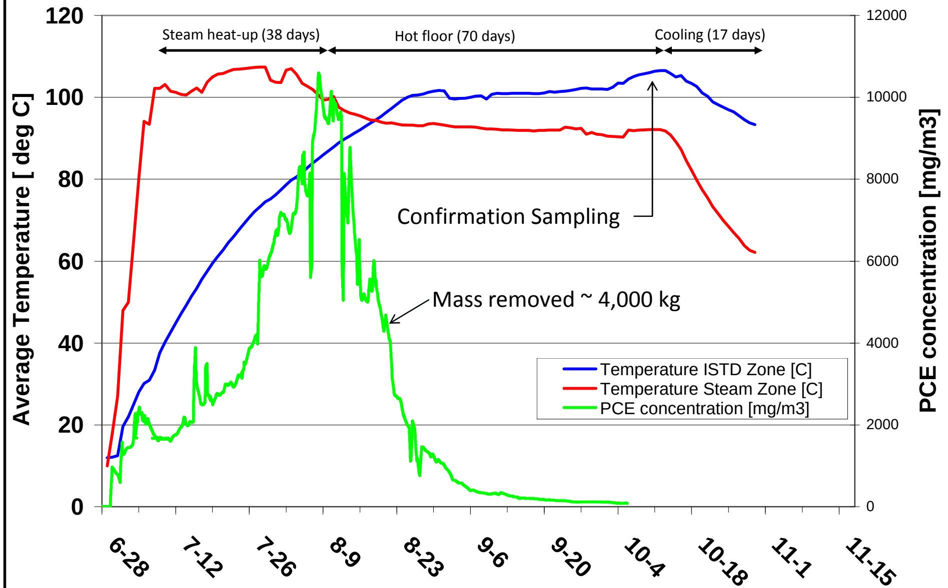
Average Temperature and Concentration



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Hot Soil Sampling - Equipment

- Intact core samples are needed to minimize vaporization of CVOCs during sampling
- Samples typically collected using a core barrel-type sampler equipped with stainless steel or Teflon sleeves
- Lengths and diameter of sample tools may vary from driller to driller

Hot Soil Sampling - Sample Collection

- The core barrel sampler and sample sleeve are assembled and advanced to the desired depth
- Samples are collected
- Full recovery not always possible

- Standard drilling equipment utilized

Hot Soil Sampling - Sample Collection (Cont.)

- Once removed from the borehole, the core barrel is disassembled and the sample sleeve is removed
- The ends of the sample sleeve are immediately covered with Teflon tape and capped

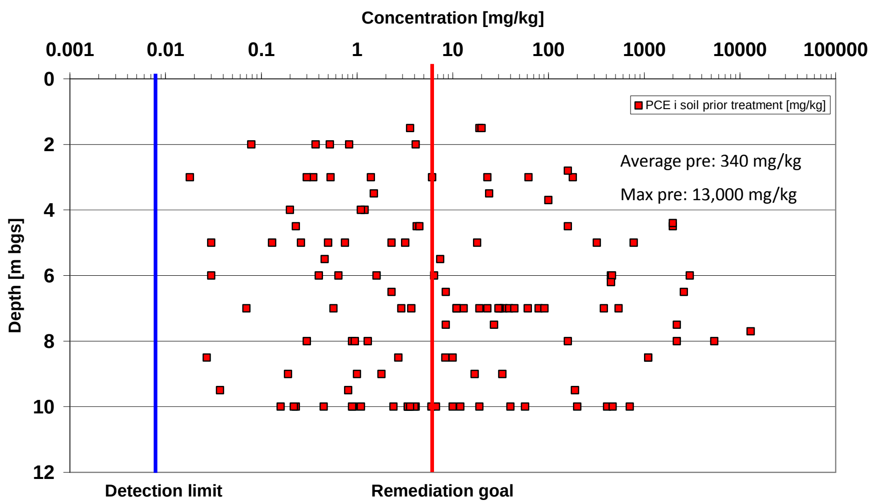
Hot Soil Sampling - Sample Collection (Cont.)

- Samples are placed into an ice bath for cooling containing drains to allow melt water to freely drain
- Once cooled to a temperature no higher than 10°C (50°F) the sample is ready to be containerized

Hot Soil Sampling - Sample Collection (Cont.)

- Samples are sealed tightly in a plastic bag for shipment to the laboratory
- Laboratory will extrude the soil
- Alternatively, the cooled samples may be processed in the field
- Commercial systems like the En Core® sampler may also be utilized

Soil concentrations before remediation



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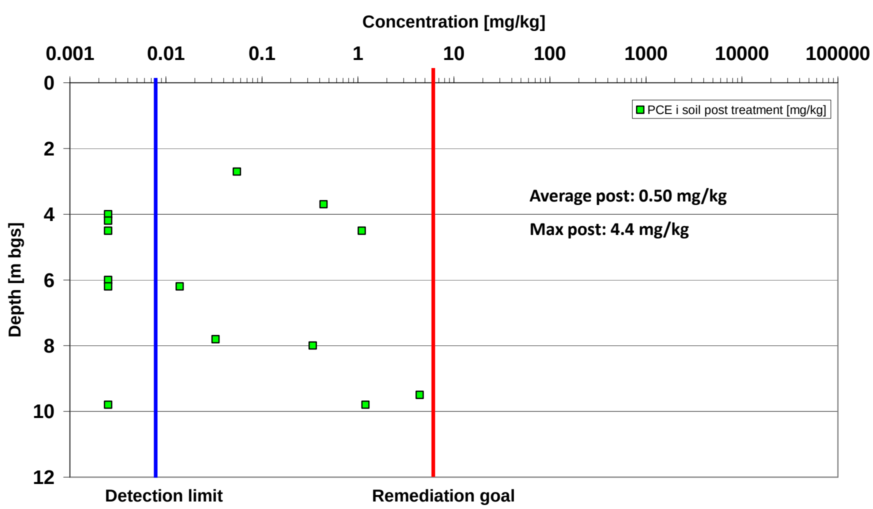
Soil concentrations after remediation



Mass remaining in source zone: **10 kg (22 lbs)**. Removal efficiency: **99.75%**

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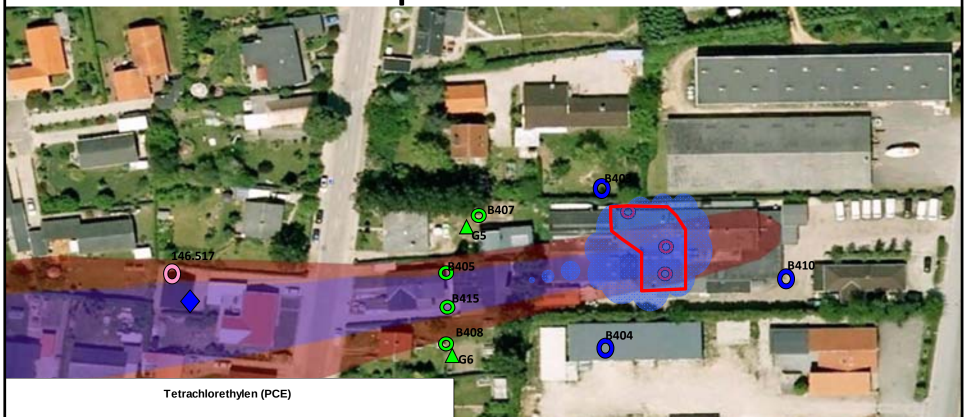
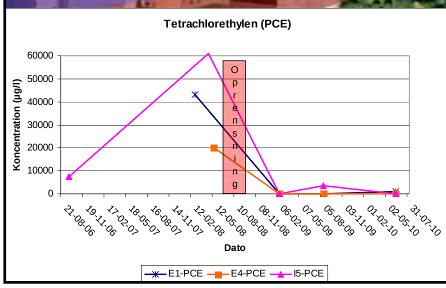
Effect on plume?

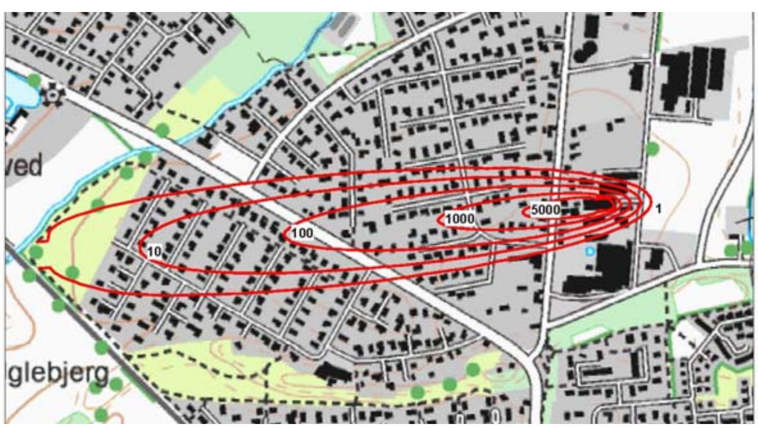




- Mass discharge reduced following thermal treatment

Predicted PCE Plume - Without Source Removal

- expected to reach municipal wells



Predicted PCE Plume - With Source Removal

- mass flux significantly reduced
- natural degradation attenuates plume
- municipal drinking water wells protected

Conclusion

- 4000 kg of DNAPL were removed – 10 kg left
- Mass discharge reduced by ~ 300-800 times
- Plume has started shrinking
- Long-term benefit predicted – no need to treat groundwater for drinking purposes

Fractured Rock Site in Southeastern US

- Focused Cleanup of TCE Source Zone
  - DNAPL
  - Above and below the water table
  - Saprolite, weathered bedrock, and fractured bedrock
- Leave groundwater plume for MNA and/or Enhanced Bio
- November 2006 to July 2007
- Active Manufacturing Facility

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Fractured Rock Site - Plan View

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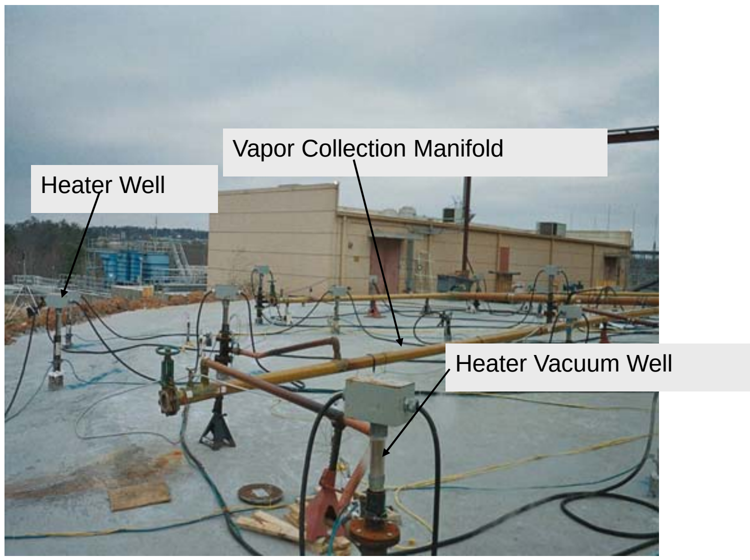
ISTD Wellfield



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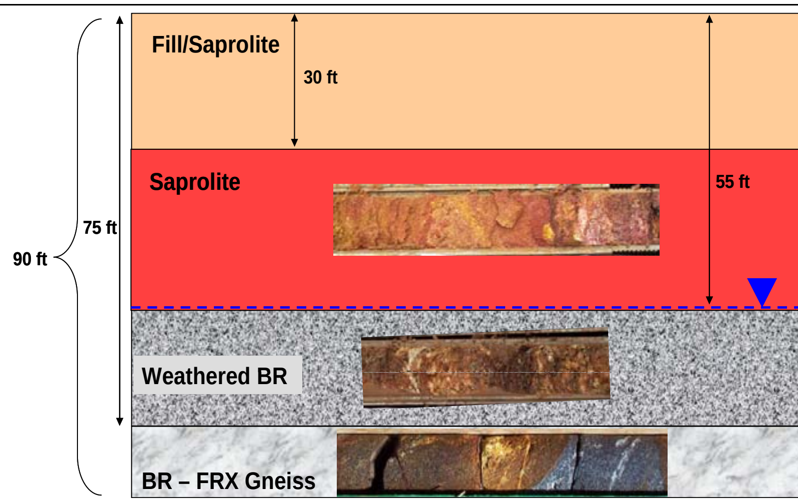
Conceptual Cross-Section Through Treatment Zone



Treatment zone = 8,700 cy

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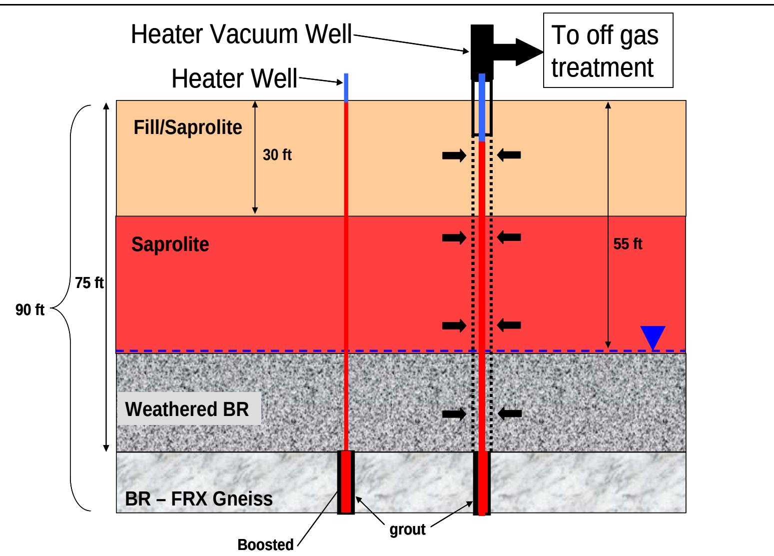
ISTD Thermal Wells



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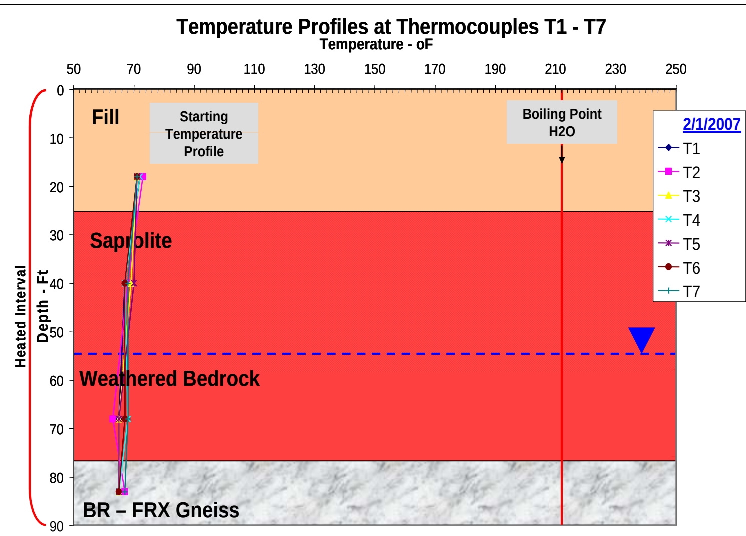
Starting Temperature Profile



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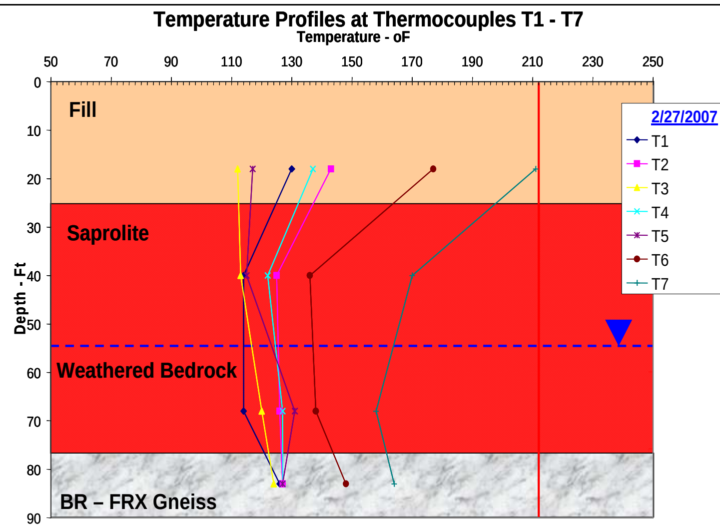
Temperature Profile at 4 Weeks



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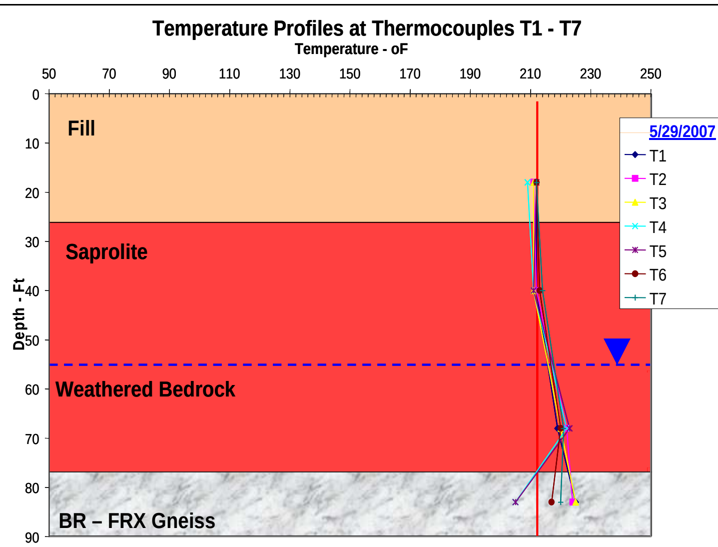
Final Temperatures within Treatment Zone



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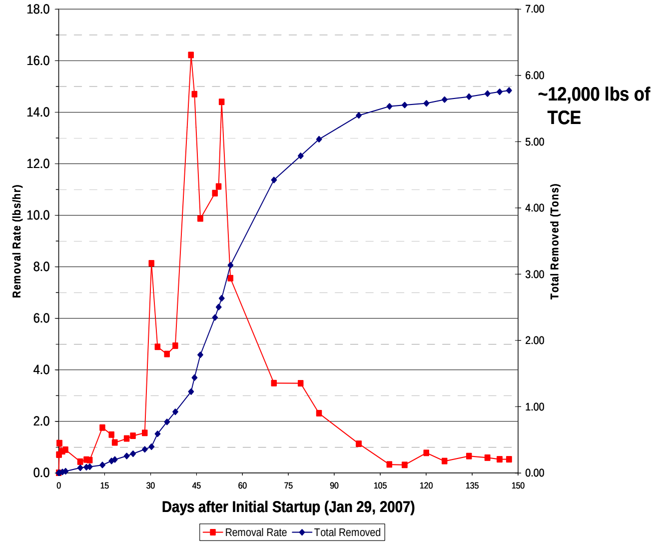
Mass Removal During ISTD Treatment



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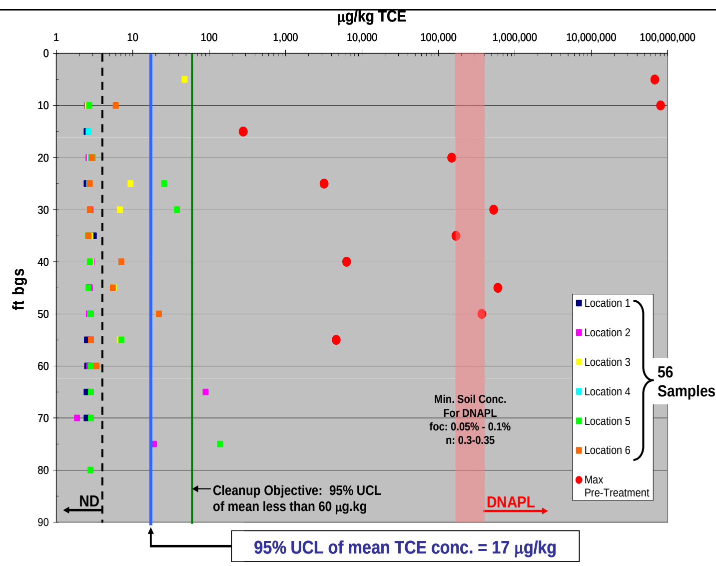
Confirmation Soil Data: ISTD Project in Fractured Rock



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Summary, ISTD Project in Fractured Rock

- Rock heats more readily than overburden (less water and porosity).
- Crystalline rock cleans up readily.
- Total project cost including power: ~$1.1M
- ~1.5M kWhr or 170 kWhr/cy.
- Unit cost including power: $125/cy (power: ~$12/cy)

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Summary

- ➡ Steam-Enhanced Extraction (SEE)*
- Electrical Resistance Heating (ERH)*
  - Electro-Thermal Dynamic Stripping Process (ET-DSP™)
- ➡ In Situ Thermal Desorption (ISTD)*
  - Thermal Conduction Heating (TCH) + Vacuum Recovery
- ➡ Combinations*: ISTD/SEE (ET-DSP™/SEE)
- Radio Frequency Heating

➡ Focus of Talk

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Think Thermal When…

- ✓ You have a Source Zone, or Hot Spots
- ✓ Site is Heterogeneous and/or Low in Permeability
- ✓ Stringent Cleanup Levels Must be Achieved, Quickly (or you just need to remove a lot of mass)
- ✓ Excavation is Ruled Out or Impractical

Thermal is Especially Well Suited if:

- ✓ The Treatment Zone is Deep
- ✓ There's a Mixture of Contaminants
- ✓ The Site is Complex, and/or
- ✓ Long-Term O&M is Too Costly

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SUPPLEMENTAL MATERIAL - HOT SOIL SAMPLING

Griepke-Nielsen, S., et al, Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA. 2012

Soil Sampling during and after Thermal – How and When?

Steffen Griepke Nielsen, Pia Juul Jensen (formerly NIRAS A/S, Alleroed, Denmark)
Gorm Heron (TerraTherm, Inc., Bakersfield, CA USA)
Jim Galligan and John LaChance (TerraTherm, Inc., Gardner, MA USA)
Peder Johansen (Capital Region of Denmark, Hillerød, Denmark)
Niels Ploug, Jesper Holm (Krüger, Gladsaxe, Denmark)

Key Questions

- How can one sample hot soil for reliable CVOCs concentration data?
- Will the thermally treated site experience rebound during the cooling period?
- Will it be necessary to repeat soil sampling once the site cools?

Sampling Equipment

- Intact core samples are needed to minimize vaporization of CVOCs during sampling
- Samples typically collected using a core barrel-type sampler equipped with stainless steel or Teflon sleeves
- Lengths and diameter of sample tools may vary from driller to driller

Equipment Decontamination

- Downhole equipment (augers, core barrels, drive rods, etc.) must be decontaminated prior to use
- Samples sleeves and end caps must be decontaminated if reused

Sample Collection

- The core barrel sampler and sample sleeve are assembled and advanced to the desired depth
- Samples are collected
- Full recovery not always possible

- Standard drilling equipment utilized

Sample Collection (Cont.)

- Once removed from the borehole, the core barrel is disassembled and the sample sleeve is removed
- The ends of the sample sleeve are immediately covered with Teflon tape and capped

Sample Collection (Cont.)

- Samples are placed into an ice bath for cooling containing drains to allow melt water to freely drain
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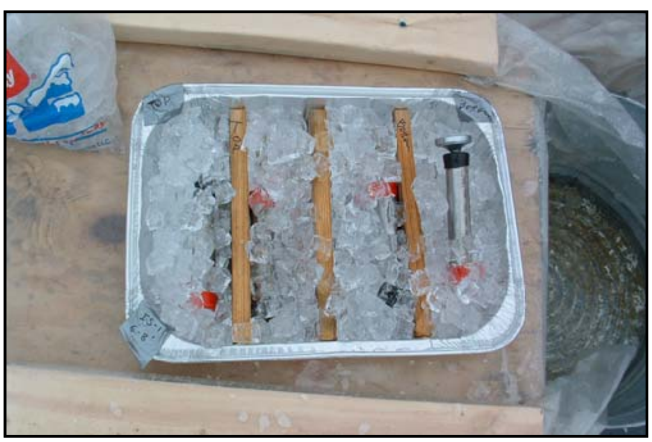
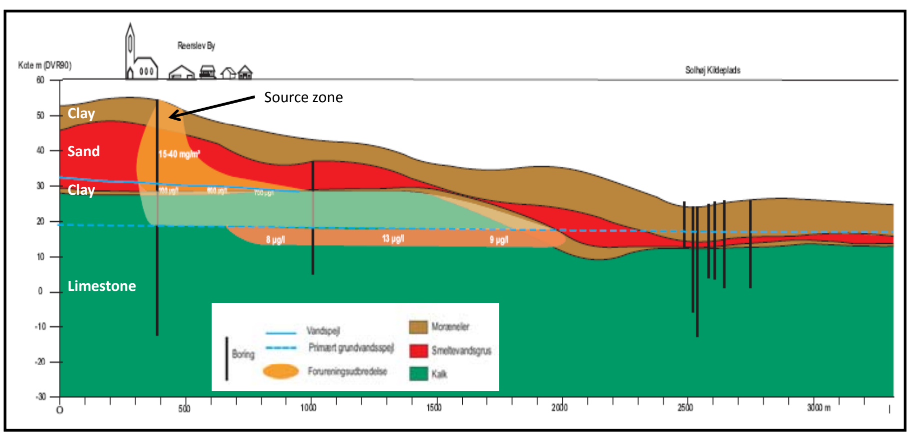


Sample Collection (Cont.)

- Samples are sealed tightly in a plastic bag for shipment to the laboratory
- Laboratory will extrude the soil
- Alternatively, the cooled samples may be processed in the field
- Commercial systems like the En Core® sampler may also be utilized

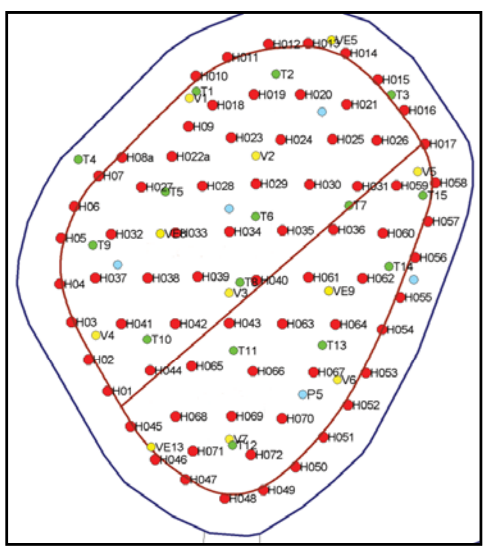
Reerslev – PCE Source Zone with Plume



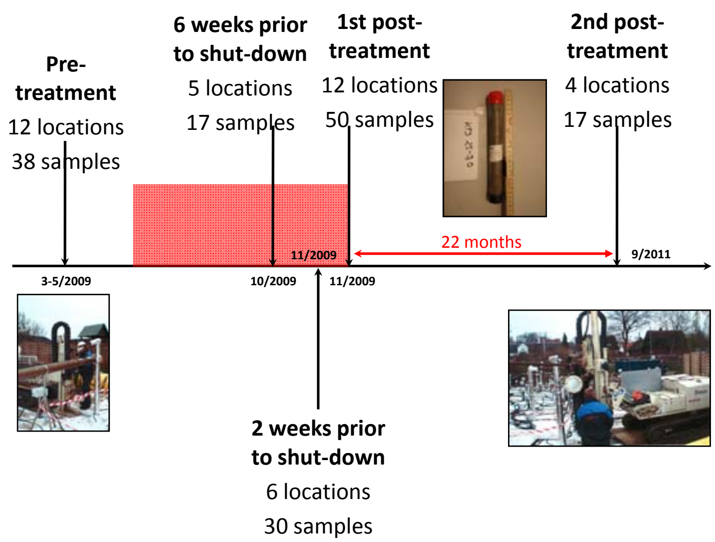
- Area: 1,300 m^2
- Volume: 11,500 m^3
- Days of operation:169 days
- CVOC mass removed: 2,300 -2,500 kg PCE (>97% of mass was PCE)

Reerslev (Capital Region of Denmark) - ISTD

Wellfield Layout

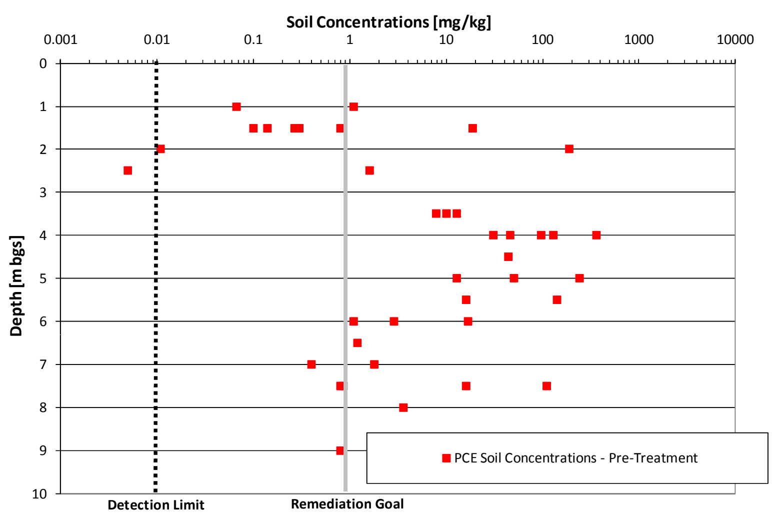


Sample Collection

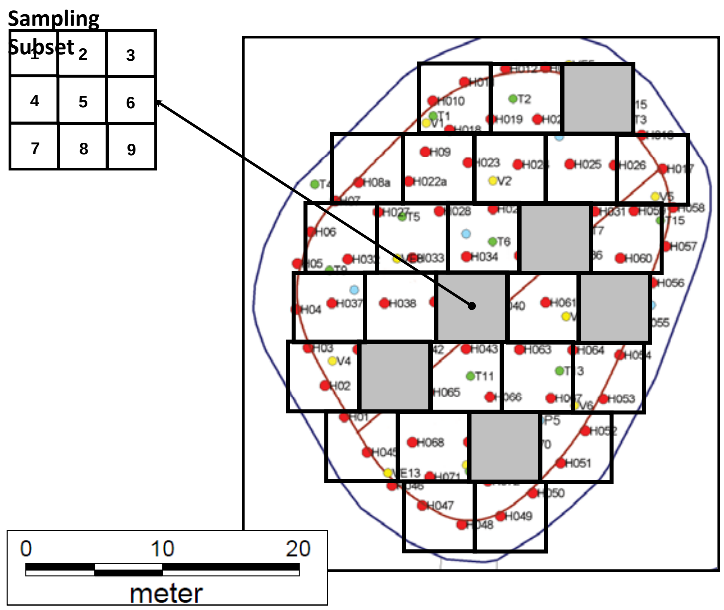


Pre-Treatment PCE Soil Concentrations

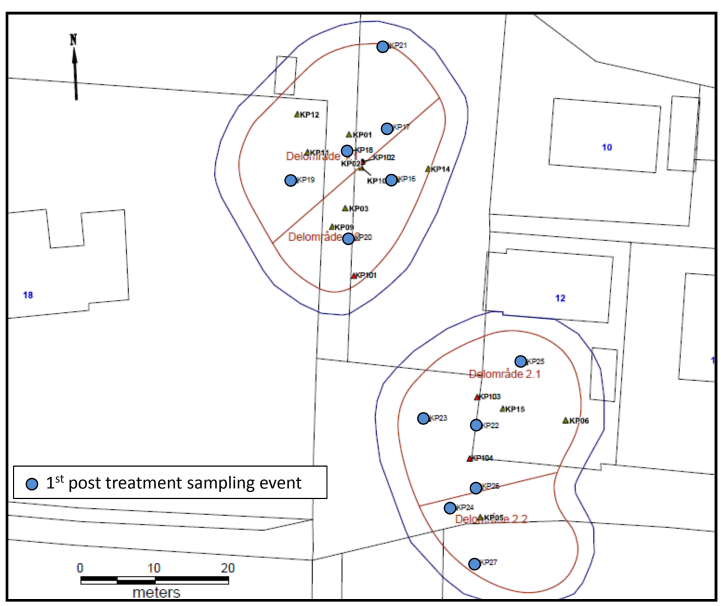
Pre-Treatment
38 samples
Max: 360.4 mg/kg
Avg: 41.3 mg/kg



1st Event – Random Sampling

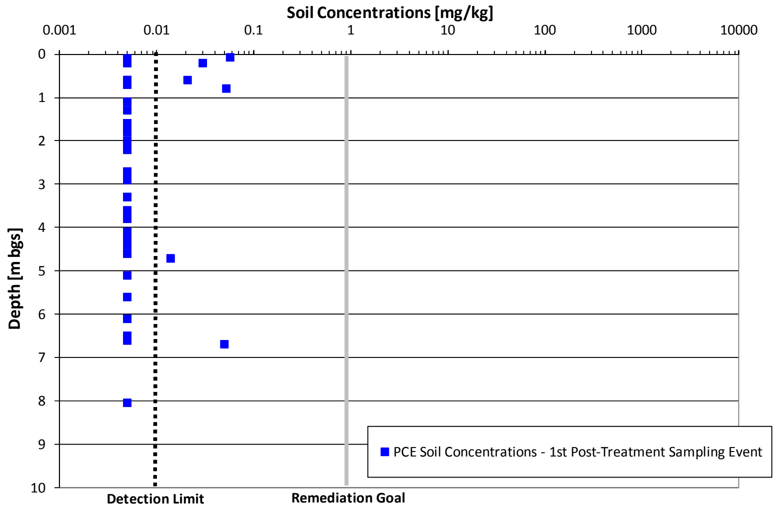


Sample Locations



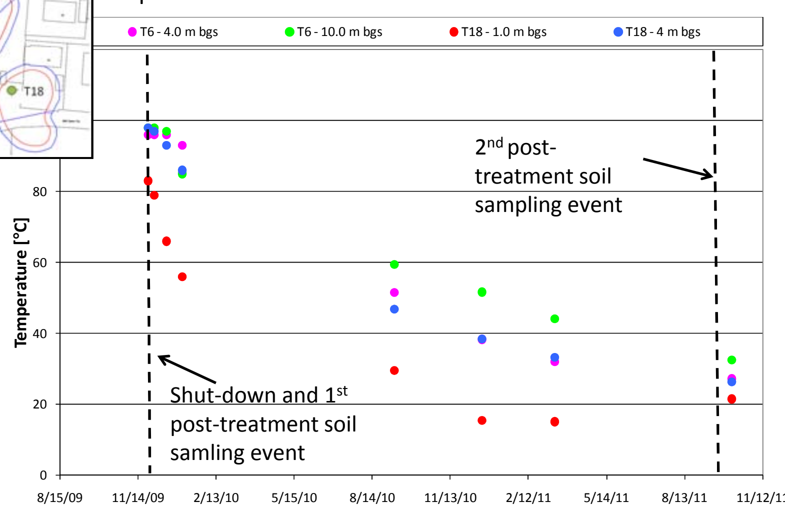
1st Post-Treatment Soil Sampling Event

1st Post-Treatment
50 samples
Max: 0.057 mg/kg
Avg: 0.014 mg/kg

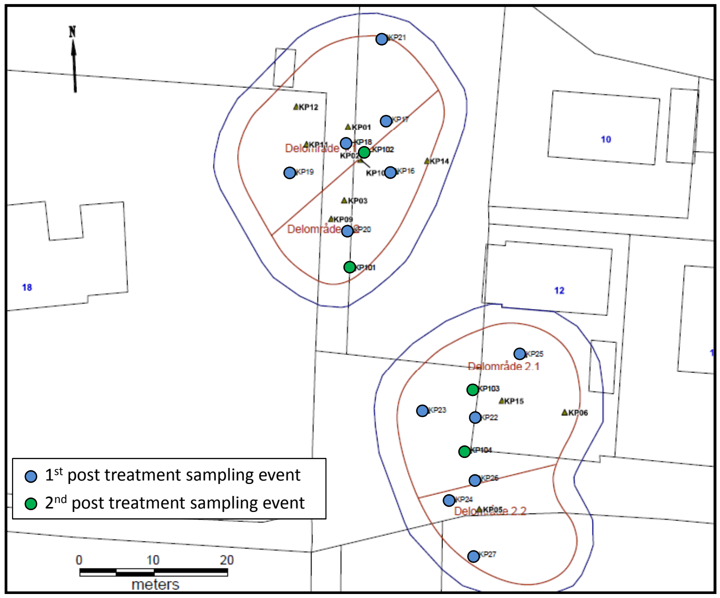


Post-Treatment Temperature Monitoring

- Temperatures monitored at 2 locations post-treatment
- Eight temperature monitoring rounds over a 22 month period

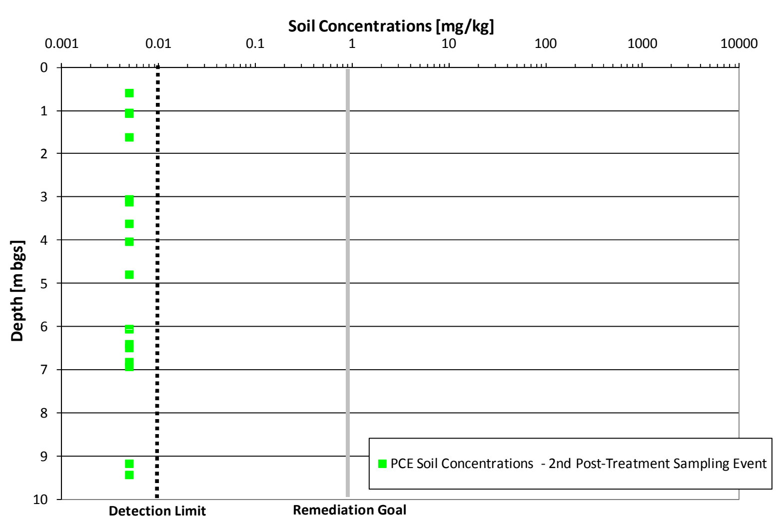


Sample Locations



2nd Post Treatment Soil Sampling Event

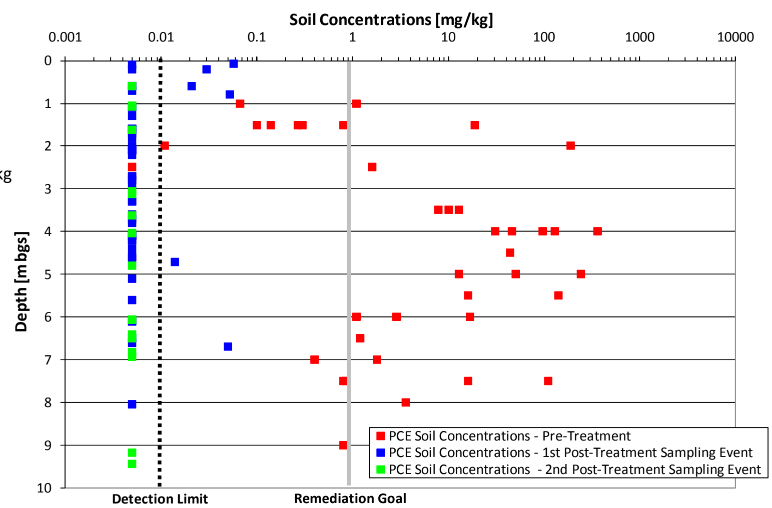
2nd Post Treatment
17 samples
Max: <0.01 mg/kg
Avg: <0.01 mg/kg



Comparison of Pre- and Post-Treatment Soil Concentrations

Pre-Treatment
38 samples
Max: 360.4 mg/kg
Avg: 41.3 mg/kg

Post-Treatment
67 samples
Max: 0.057 mg/kg
Avg: ND-0.014 mg/kg
DRE: 99.9-100%



Lessons Learned

- How can one sample hot soil for reliable CVOCs concentration data?

  Use proper hot soil sampling procedures.

- Will the thermally treated site experience rebound during the cooling period?

  No, data collected in this study documents that no rebound occurs following cooling when the flux of contaminants back into the TTZ is limited.

- Will it be necessary to repeat soil sampling once the site cools?

  No, data collected in this study documents that CVOC concentrations actually decreased after 22 months of cooling due to biological polishing at the Reerslev site.

References

Capital Region of Denmark. 2008a. MW Gjøes Vej, Reerslev. Forklassificerings-undersøgelse. NIRAS. May 2008 (in Danish).

Capital Region of Denmark. 2008b. MW Gjøes Vej, Reerslev. Supplerende Undersøgelser – Supplerende Forklassificering, Risikovurdering og Ventilationstest. NIRAS, August 2008 (in Danish).

Capital Region of Denmark. 2011. ISTD Entreprise, Entreprise 1, MW Gjøes Vej, Reerslev. Slutdokumentation. NIRAS. February 2011 (in Danish).
Capital Region of Denmark. 2012. ISTD Oprensning, MW Gjøes Vej, Reerslev. Jordprøvetagning i Afkølet Område. NIRAS. January 2012 (in Danish).

Gaberell, M., A. Gavaskar, E. Drescher, J. Sminchak, L. Cumming, W.-S. Yoon, and S. De Silva. 2002. "Soil Core Characterization Strategy at DNAPL Sites Subjected to Strong Thermal or Chemical Remediation." in: A.R. Gavaskar and A.S.C. Chen (Eds.), Remediation of Chlorinated and Recalcitrant Compounds—2002. Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2002). ISBN 1-57477-132-9. Battelle Press, Columbus, OH.

TerraTherm. 2011. Standard Operating Procedure. Hot Soil Sampling for Chlorinated Volatile Organic Compounds. TerraTherm. December 2009.