



How Effective is Thermal Remediation of Source Zones in Reducing Groundwater Concentrations?

Gorm Heron, CTO
TerraTherm/Cascade

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Some say “not very”

WATER RESOURCES RESEARCH, VOL. 41, W12411, doi:10.1029/2005WR004224, 2005

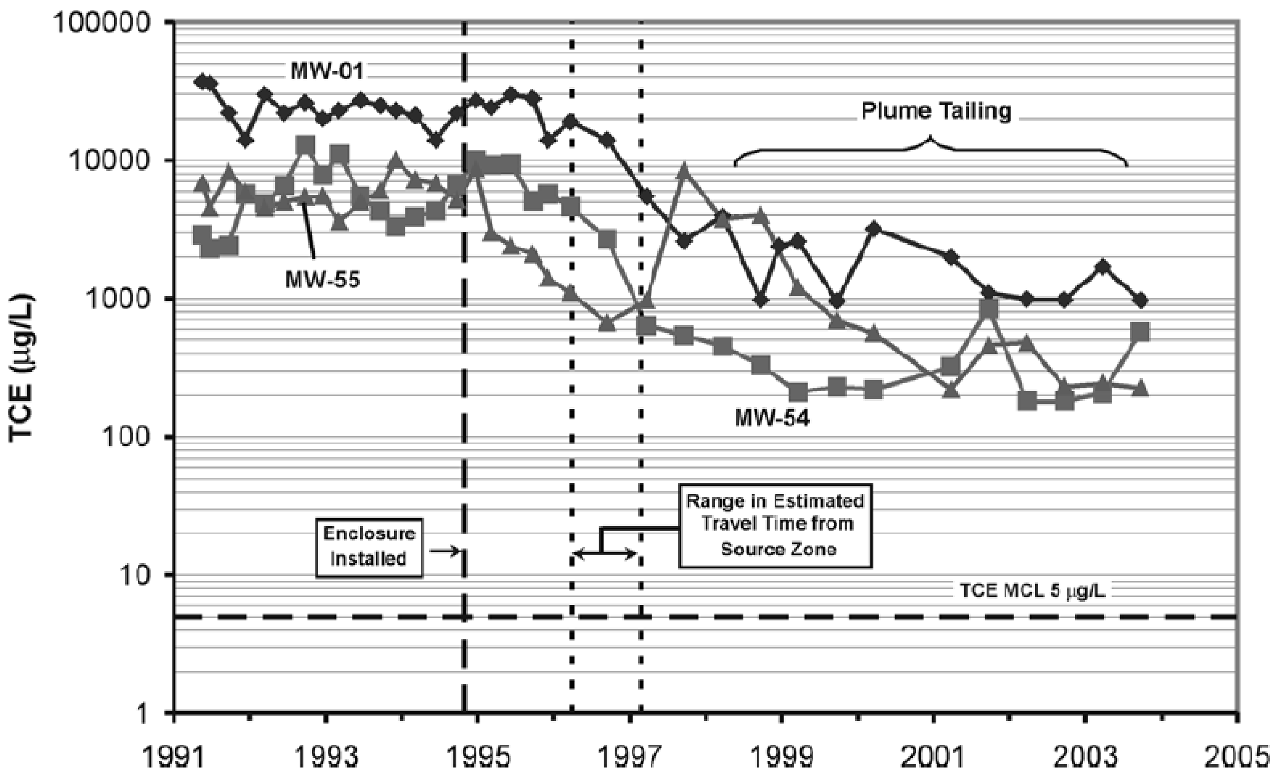
Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation

Steven W. Chapman and Beth L. Parker
Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada

Received 28 April 2005; revised 18 July 2005; accepted 4 August 2005; published 6 December 2005.

[1] At an industrial site on a sand aquifer overlying a clayey silt aquitard in Connecticut,
a zone of trichloroethylene dense
was isolated in late 1994 by inst
to this DNAPL isolation, three a
downgradient exhibited strong T
trichloroethylene (TCE) concentr
off between 200 and 2000 μg/L.
the aquitard below the plume an
aquifer sampled in 2000 were re
back diffusion from the aquitard
transverse dispersion account for
TCE will remain much above th

Citation: Chapman, S. W., and B. L.
phase liquid source removal or isolatio



Back diffusion – mass discharge

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Relative contribution of DNAl
long-term persistence of chlo

Mir Ahmad Seyedabbasi [a,*], Charles J.

[a] GSI Environmental Inc., 2211 Norfolk St., Suite 1000, Houston,
[b] Department of Civil & Environmental Engineering, Colorado St

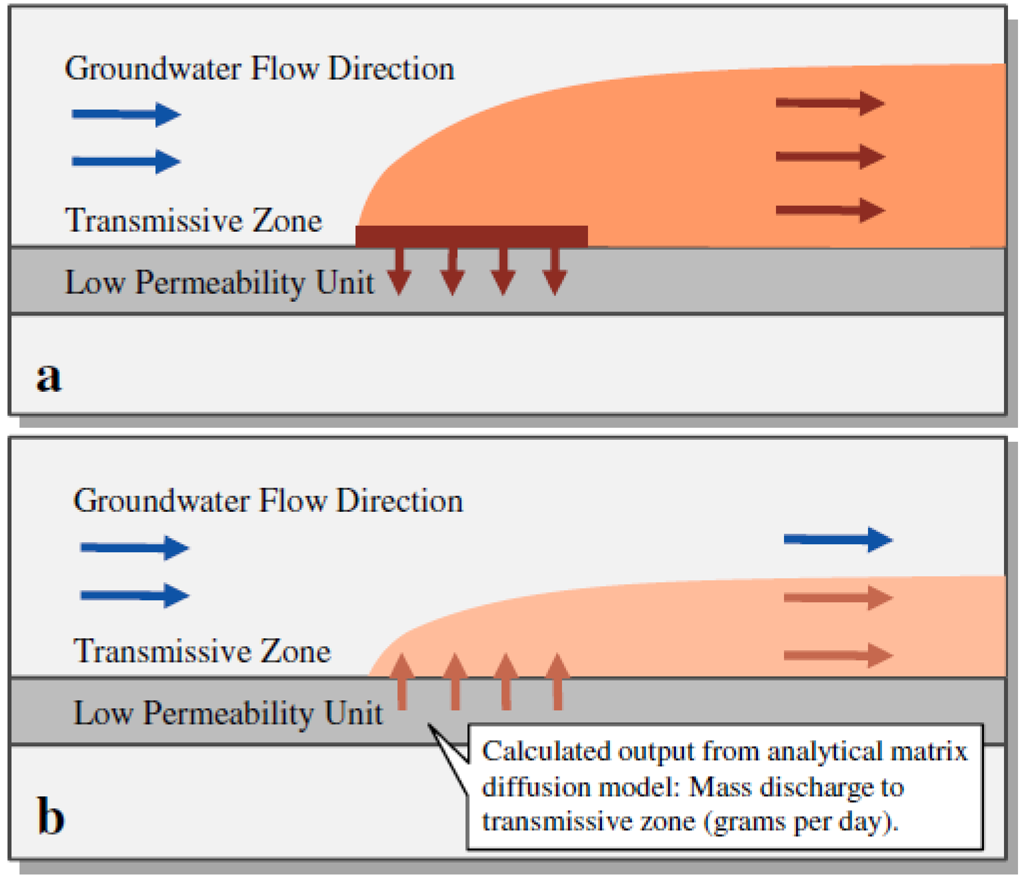


Fig. 1. Conceptual model for the combination of DNAPL dissolution and matrix diffusion for (a) charging period, and (b) after DNAPL pool was dissolved or removed. Analytical matrix diffusion model assumes zero concentration in the transmissive zone during back diffusion phase.

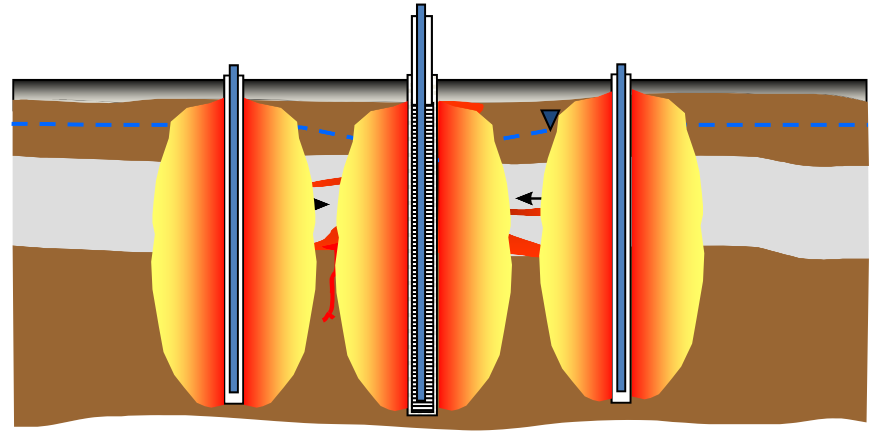
Typical Redevelopment Site

Cleanup Standard (mg/kg)
PCE < 5.60
TCE < 2.80
VC < 0.80
t-1,2-DCE < 1.20
TVOC <10.40
ALL ACHIEVED

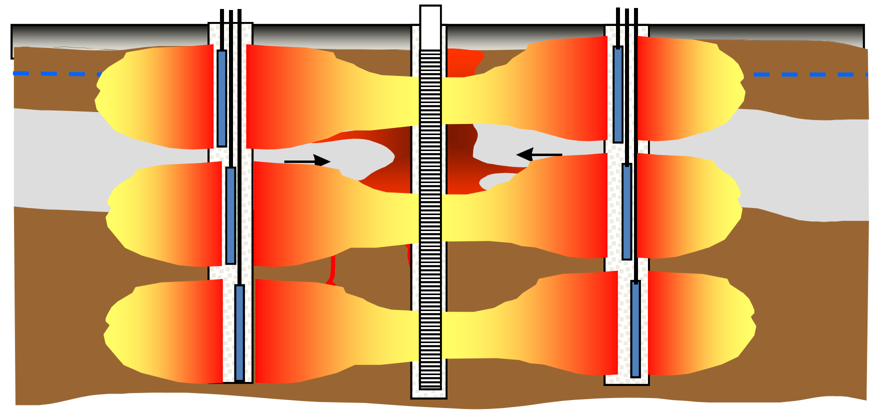
Both photos are from the actual site

Heating Methods

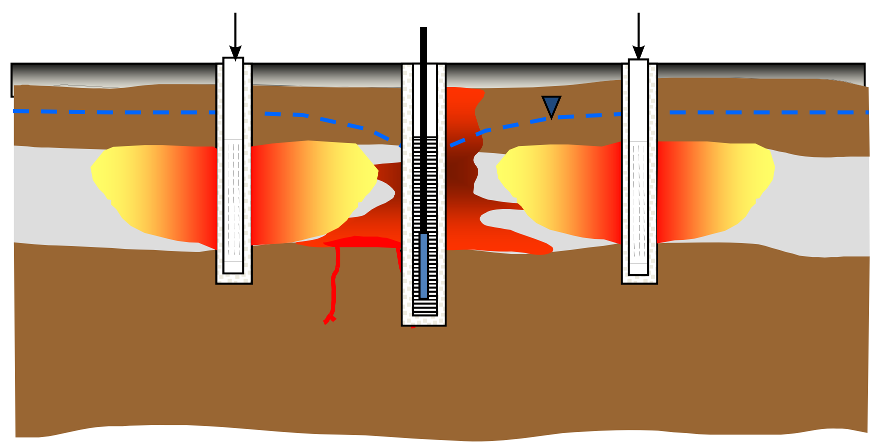
TCH/ISTD - Heating governed by **thermal conductivity**

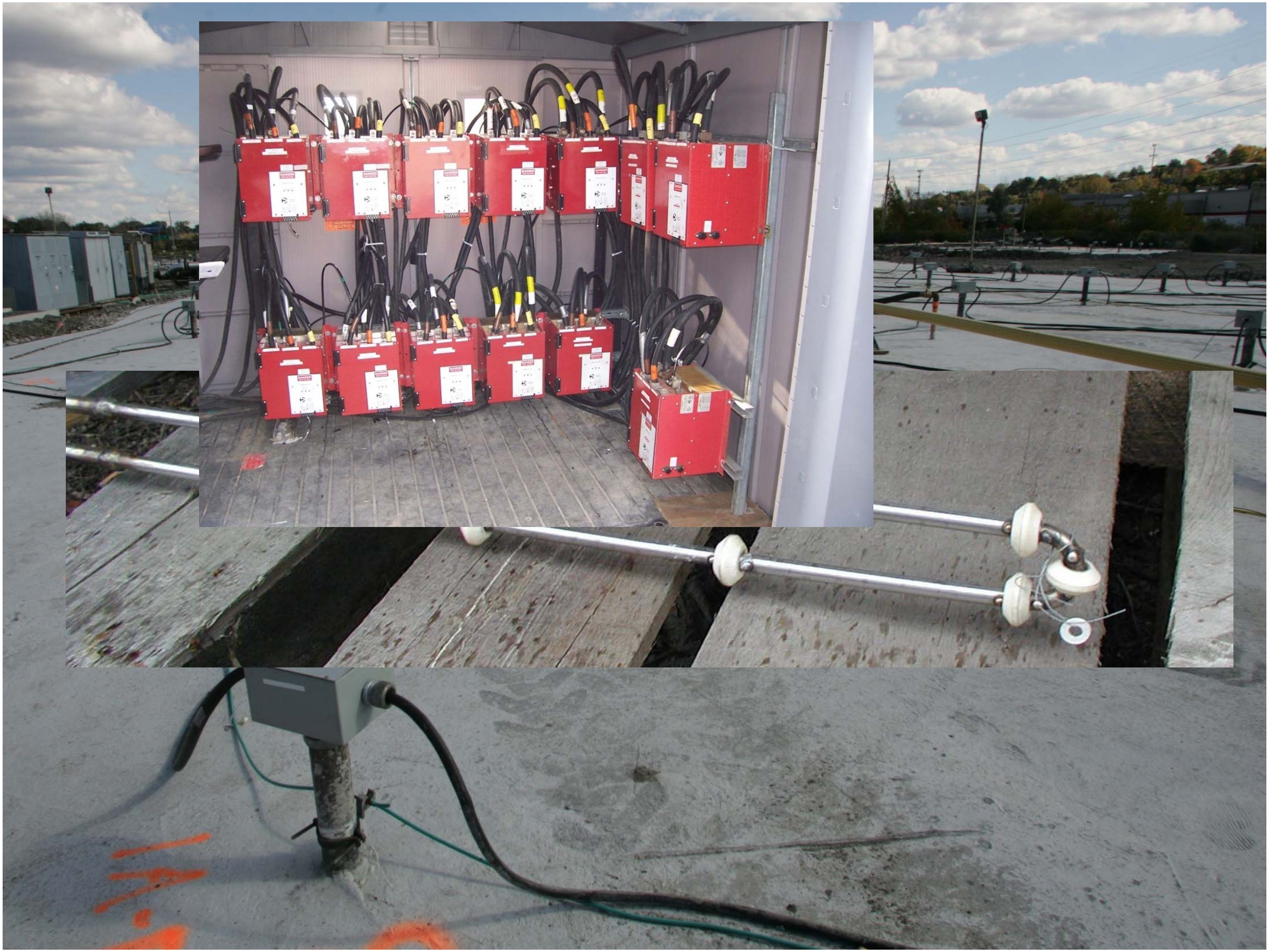


ET-DSP/ERH - Heating governed by **electrical conductivity**

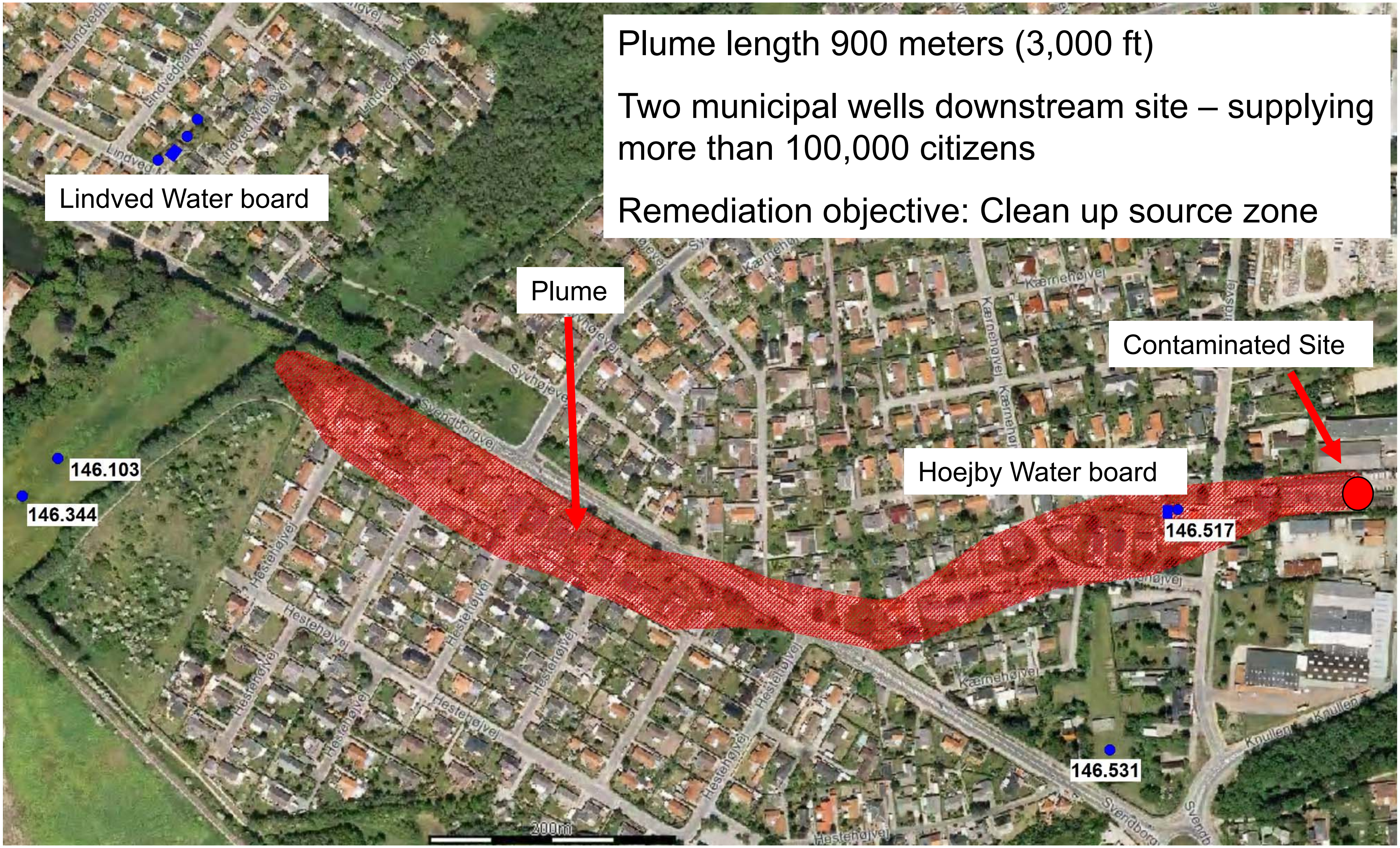


SEE - Heating governed by **hydraulic conductivity**

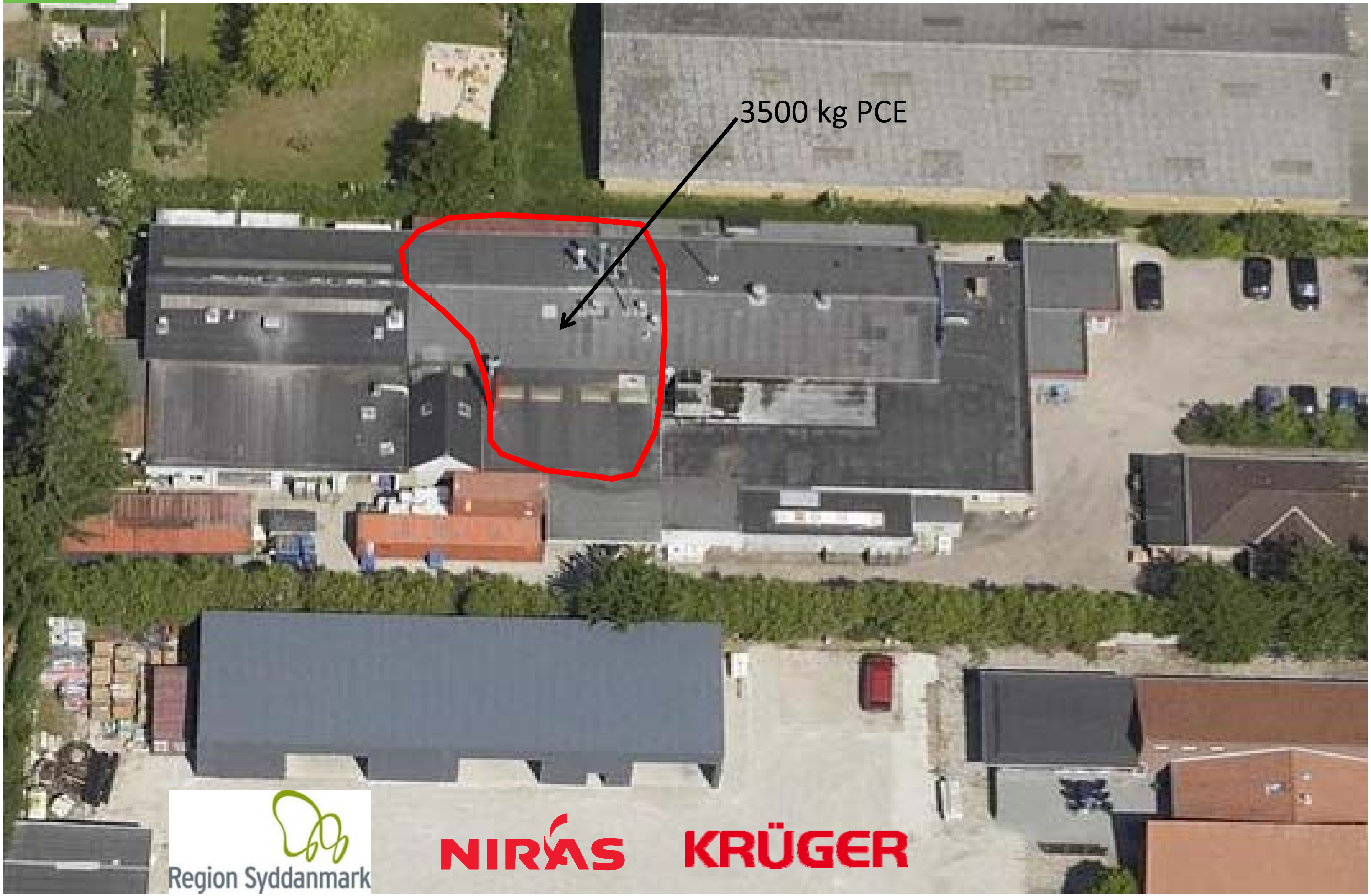




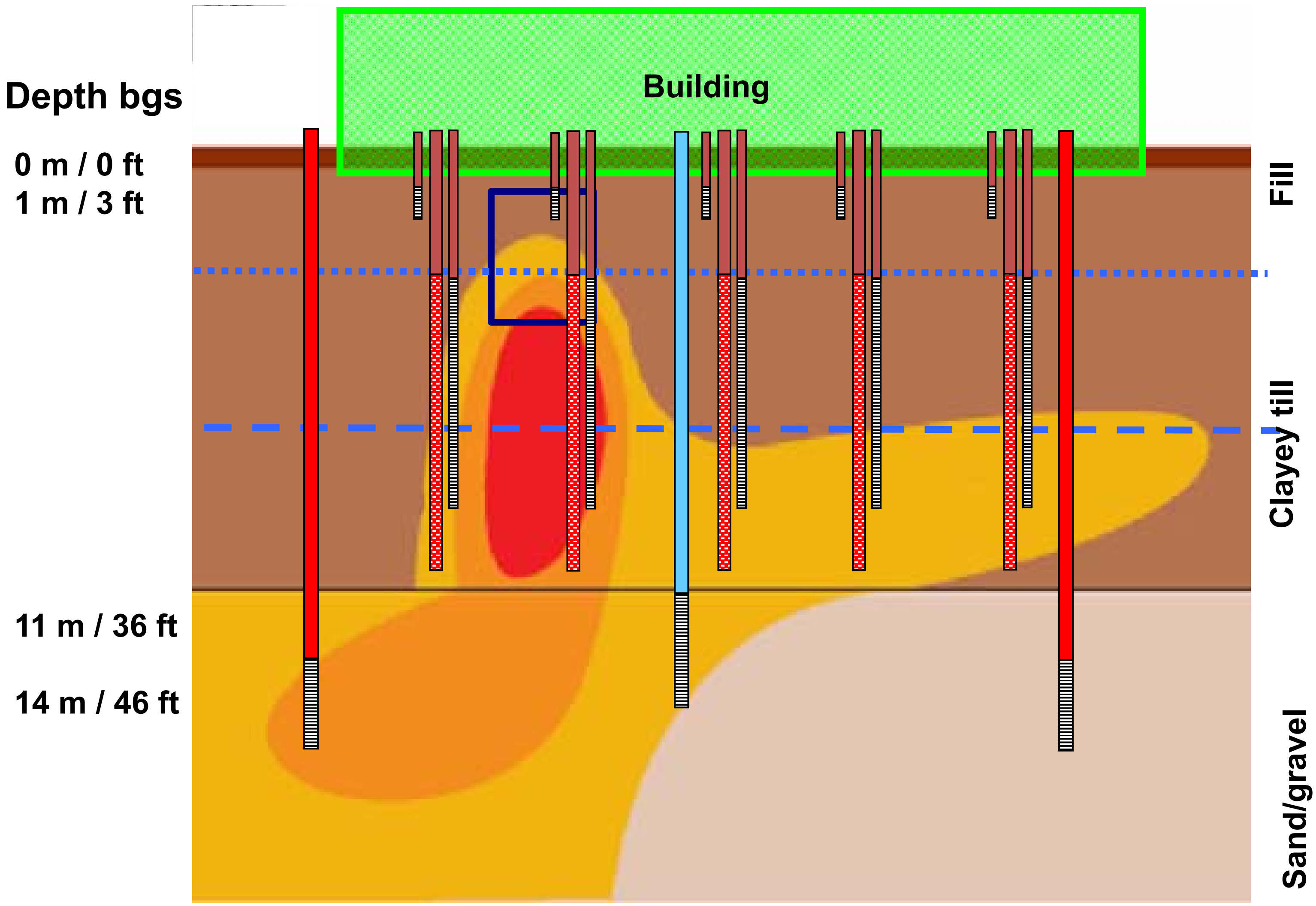
Knullen, Denmark

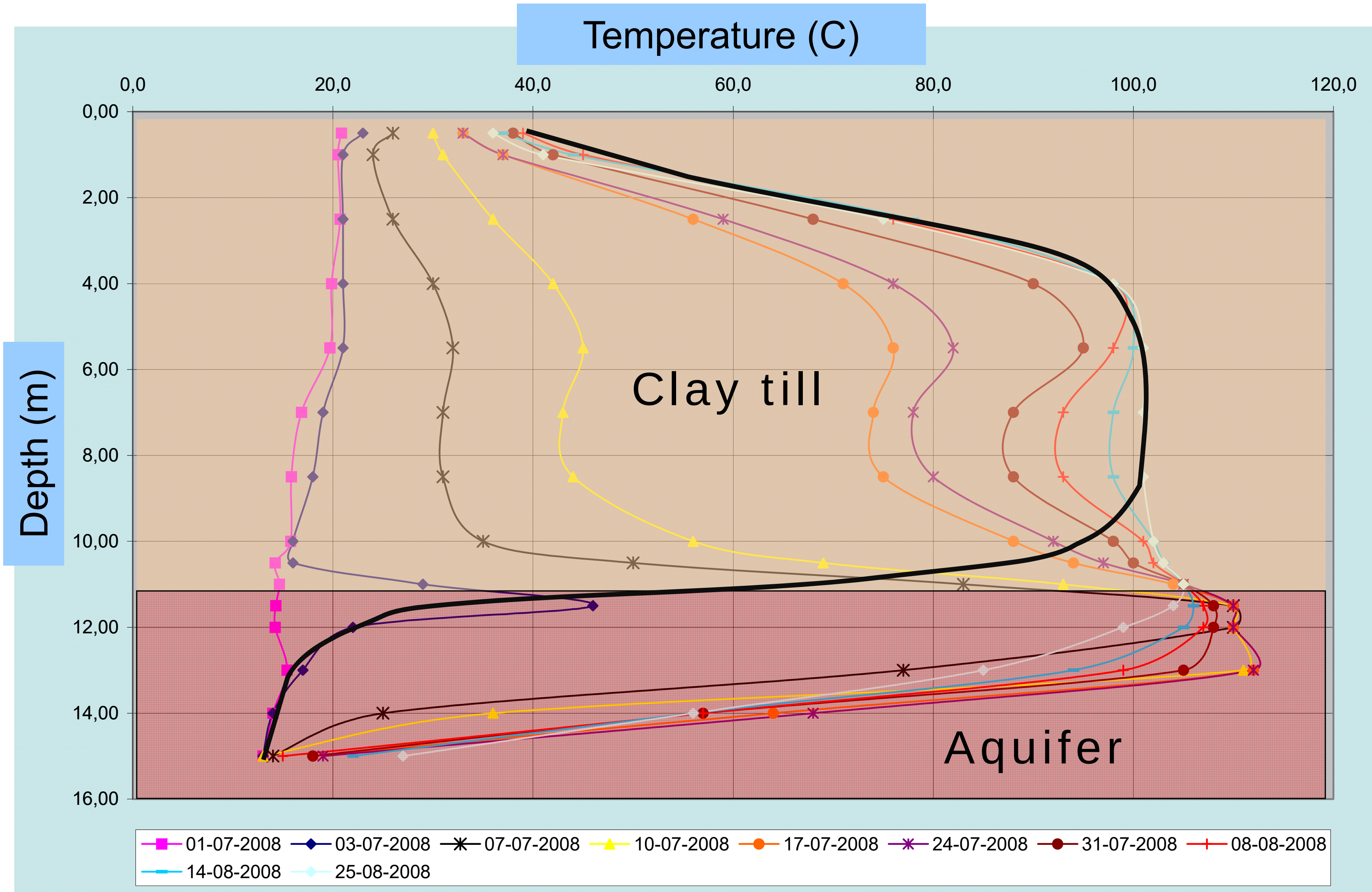


Knullen:Dry cleaner in operation

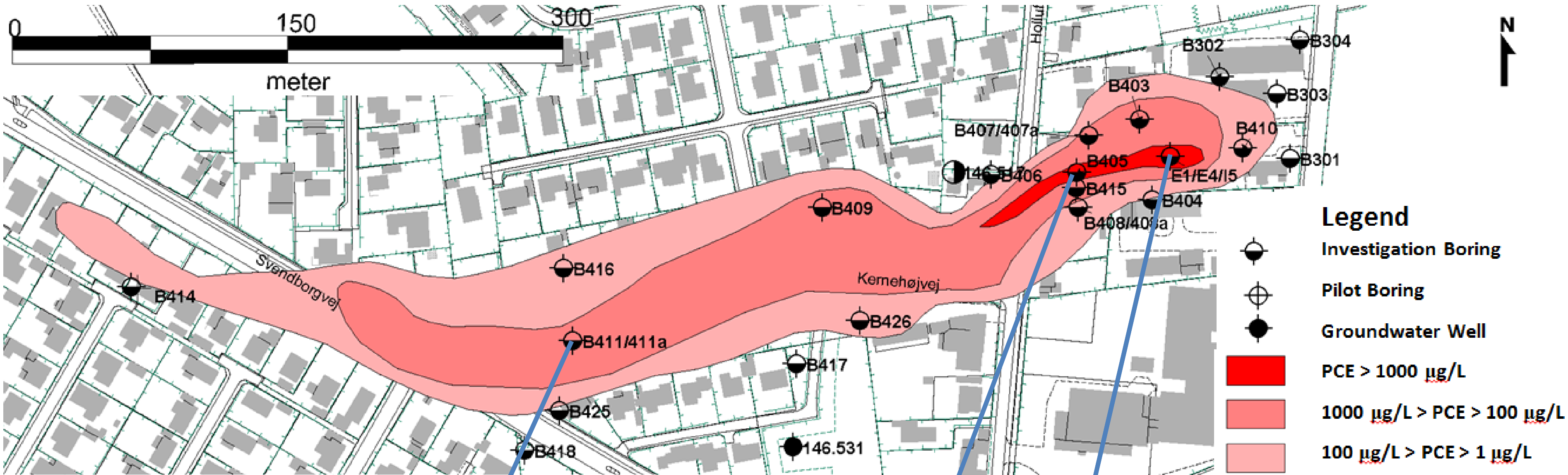


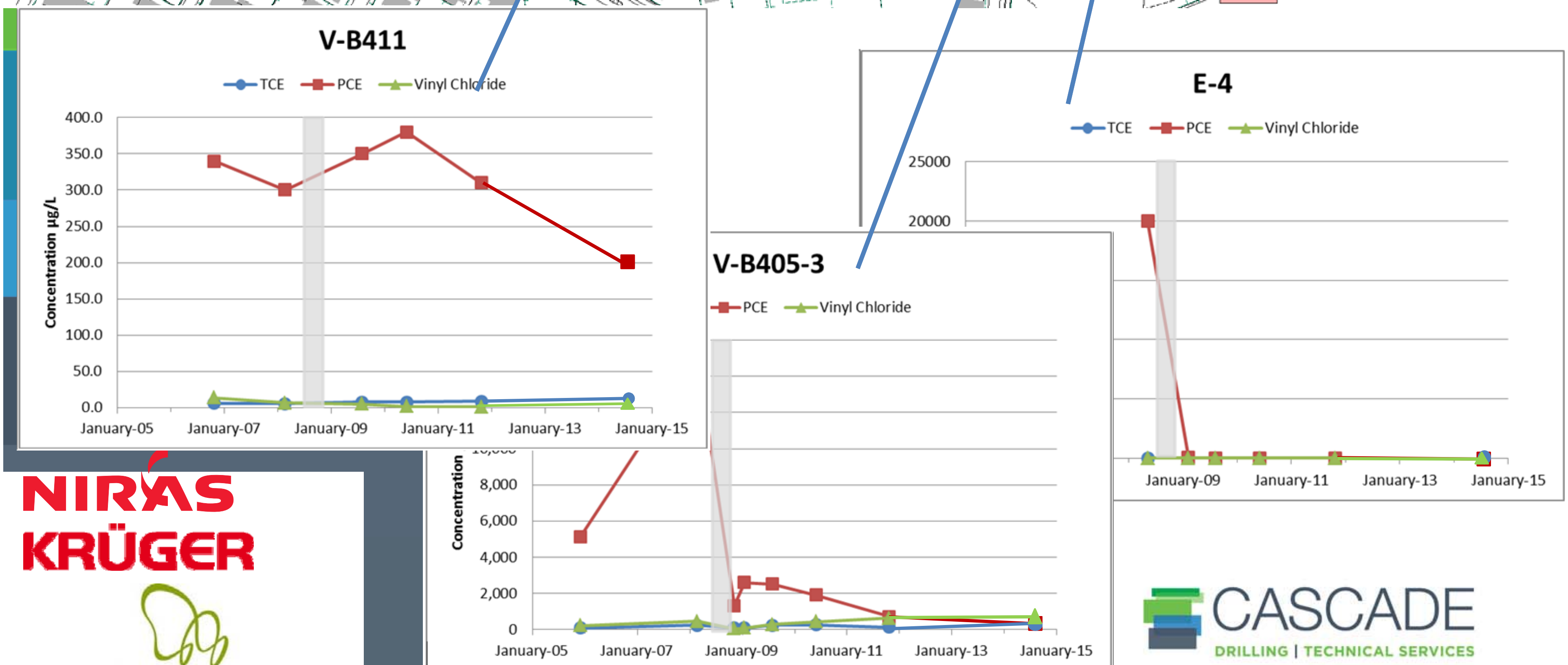
Knullen site, Denmark





Temperature (C)
0,0
20,0
40,0
60,0
80,0
100,0
120,0
Depth (m)
0,00
2,00
4,00
6,00
8,00
10,00
12,00
14,00
16,00
Clay till
Aquifer
01-07-2008
03-07-2008
07-07-2008
10-07-2008
17-07-2008
24-07-2008
31-07-2008
08-08-2008
14-08-2008
25-08-2008





NIRAS

KRÜGER

Region Syddanmark

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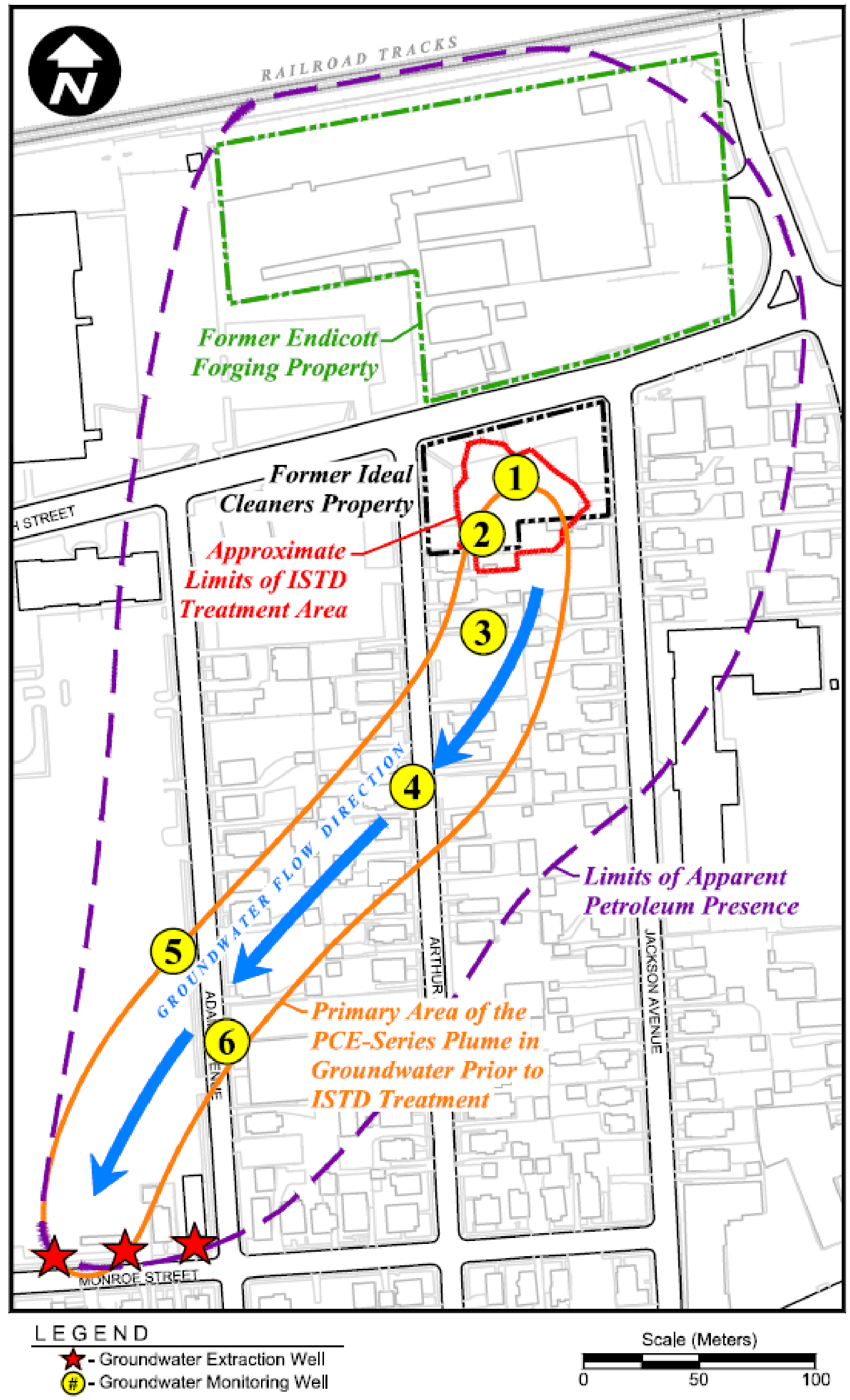
Endicott, NY, USA



11 ft

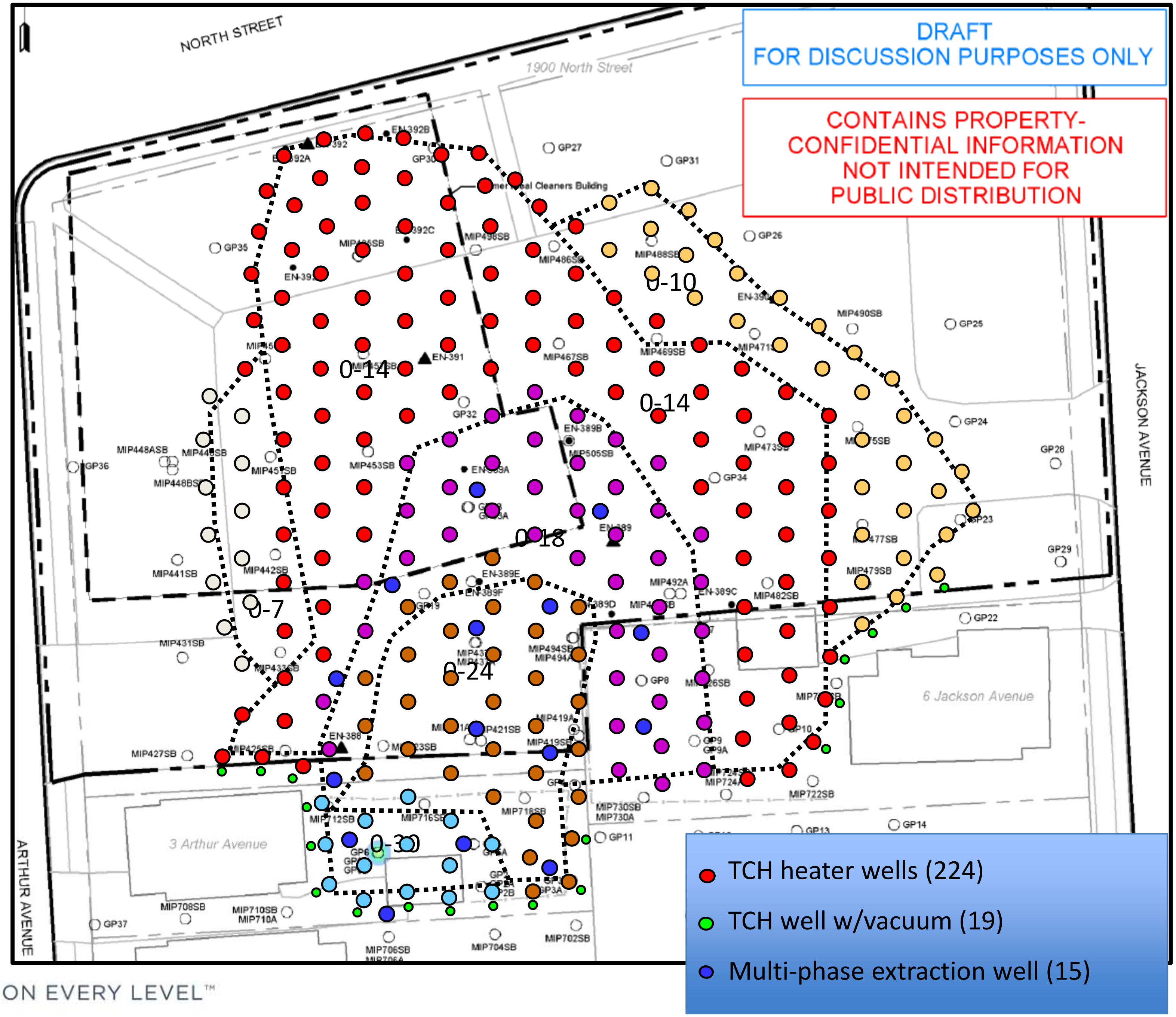
14 ft

18 ft

22 ft

28 ft

34 ft



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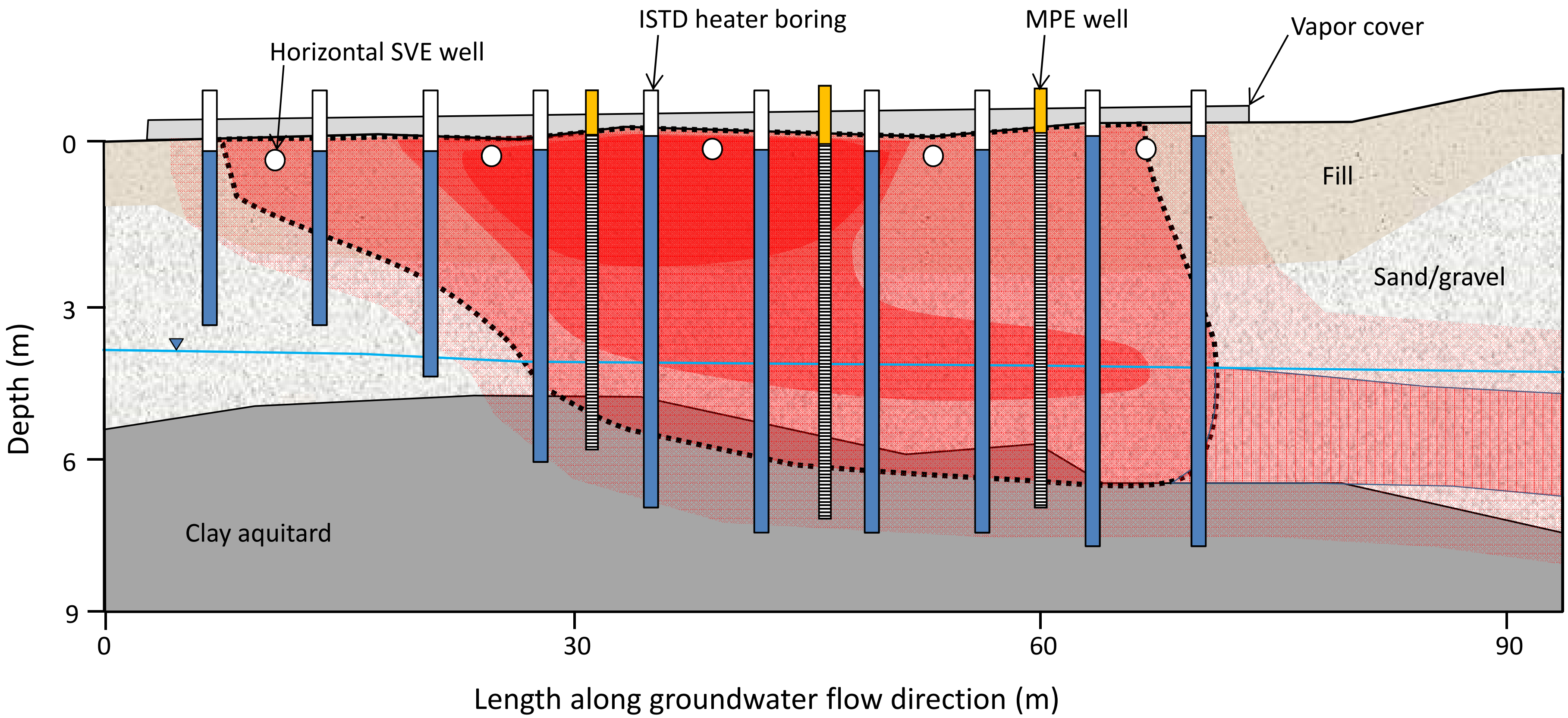
Horizontal SVE well
ISTD heater boring
MPE well
Vapor cover
Fill
Sand/gravel
Clay aquitard
Depth (m)
0
3
6
9
0
30
60
90
Length along groundwater flow direction (m)

Full Scale Wellfield

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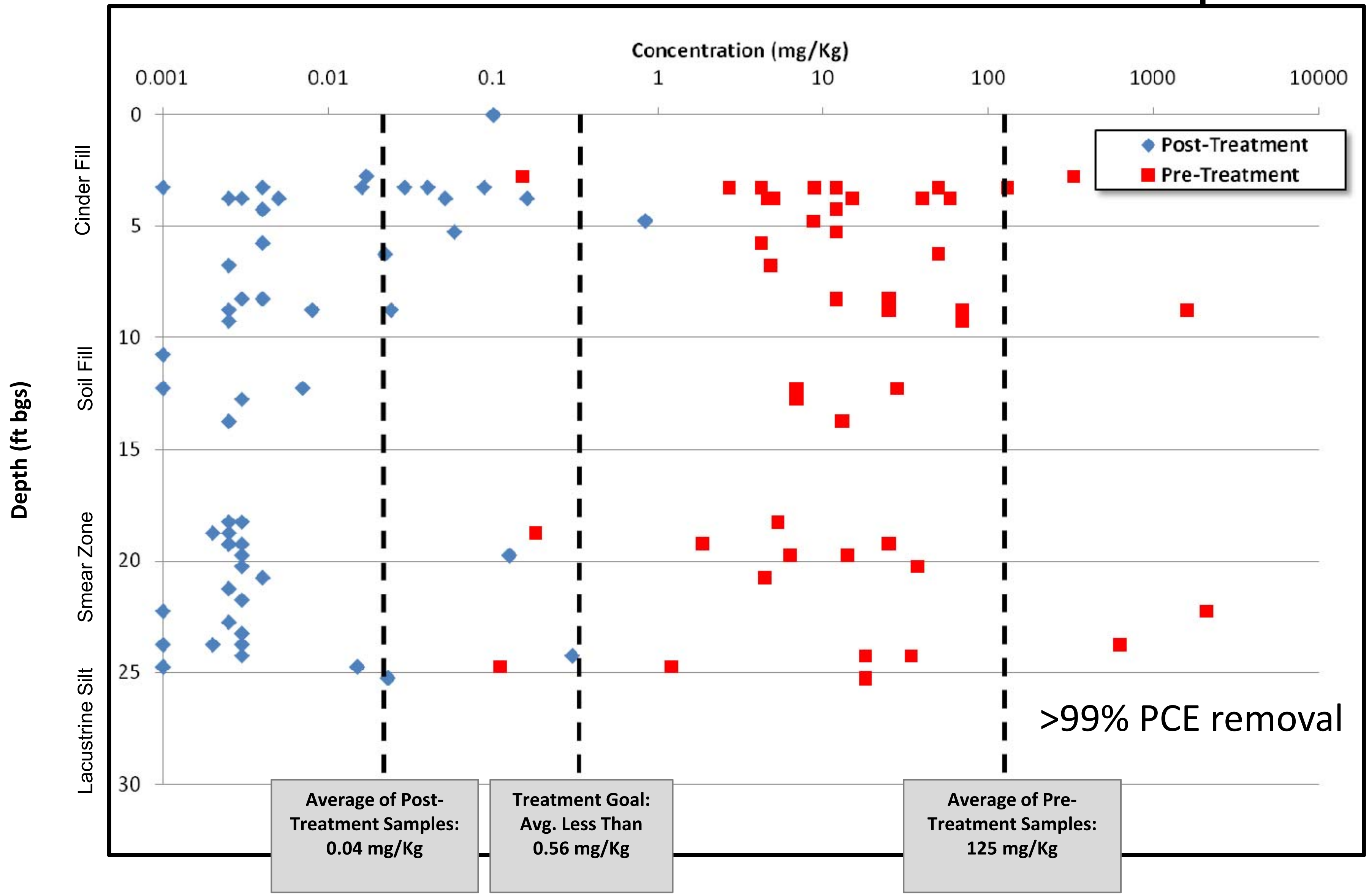
Post-Thermal Treatment

gheron@terratherm.com

Pre- and Post-Treatment Soil Samples



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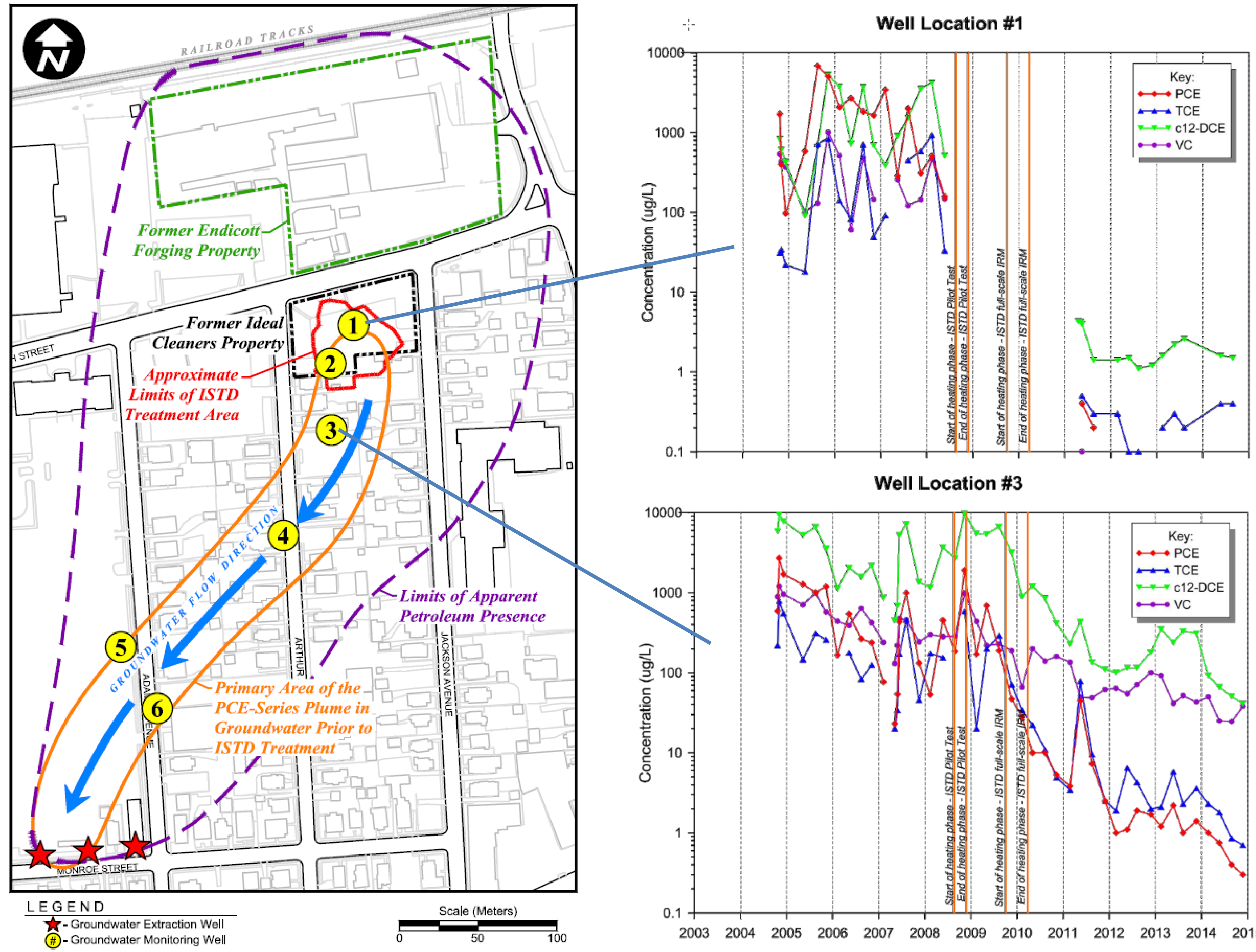
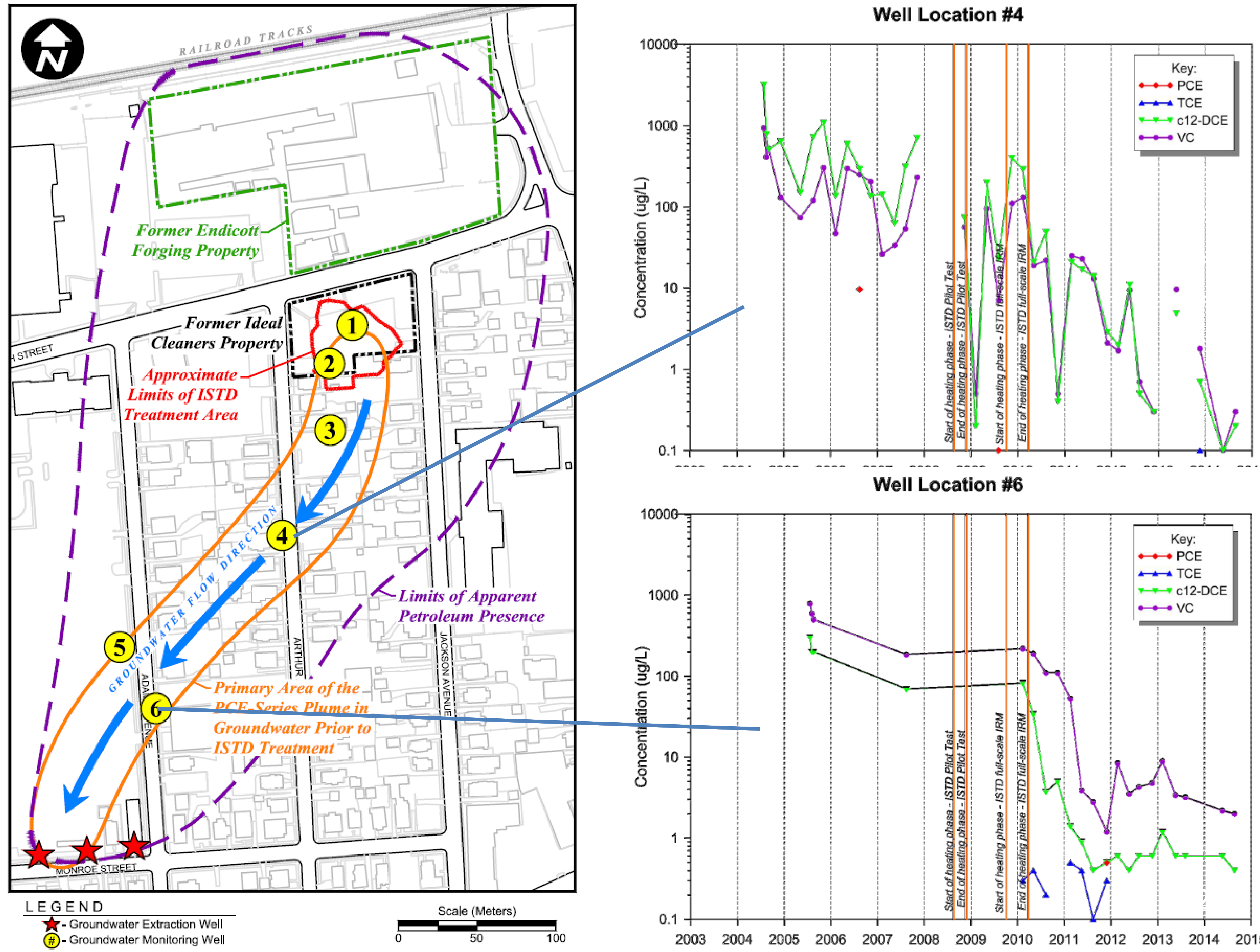
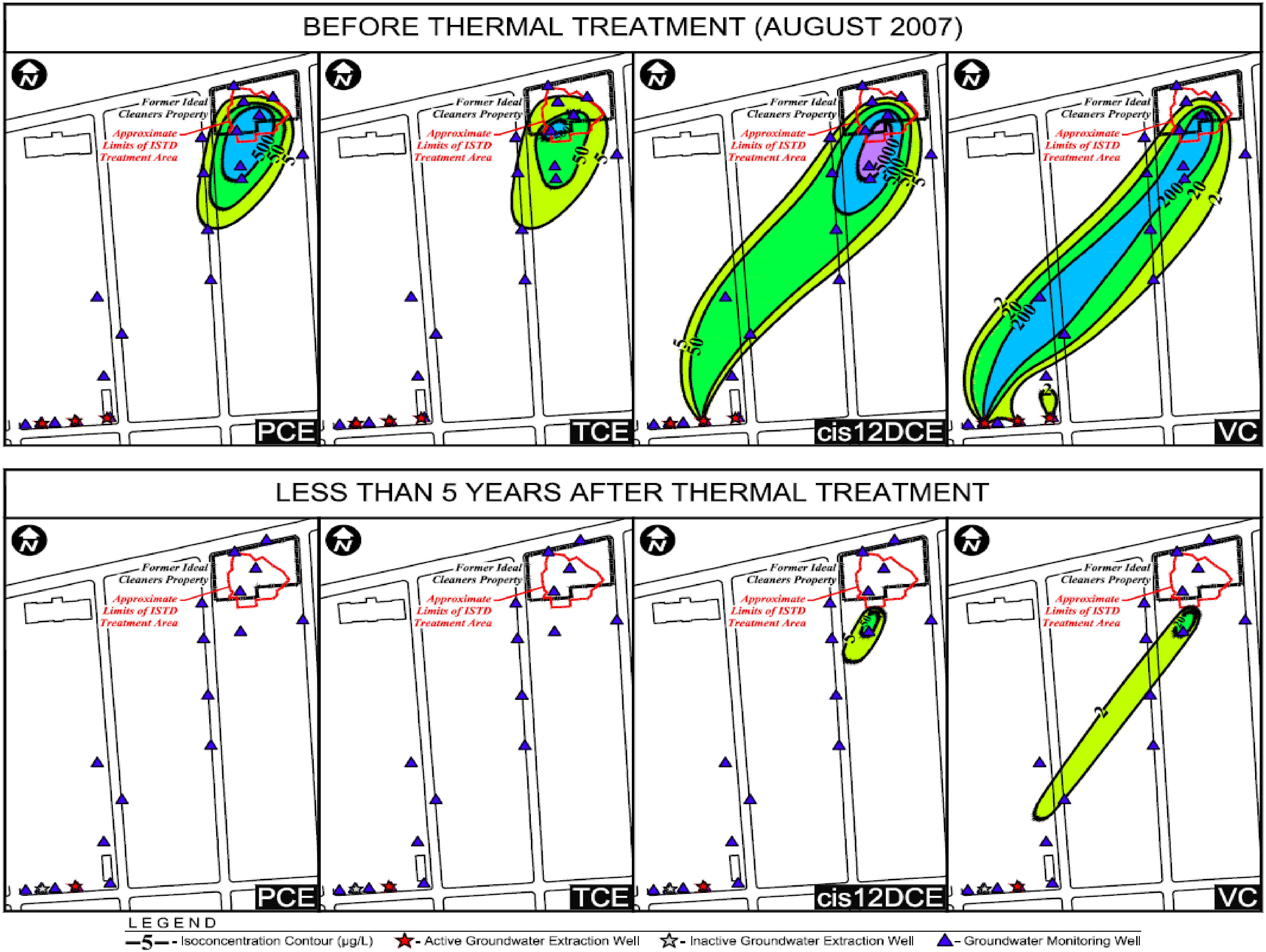

N
RAILROAD TRACKS
Former Endicott Forging Property
Former Ideal Cleaners Property
Approximate Limits of ISTD Treatment Area
GROUNDWATER FLOW DIRECTION
Limits of Apparent Petroleum Presence
Primary Area of the PCE-Series Plume in Groundwater Prior to ISTD Treatment
ARTHUR
JACKSON AVENUE
MONROE STREET
1
2
3
4
5
6
LEGEND
- Groundwater Extraction Well
- Groundwater Monitoring Well
Scale (Meters)
0
50
100
Well Location #1
Well Location #3
Concentration (ug/L)
10000
1000
100
10
1
0.1
Key:
PCE
TCE
c12-DCE
VC
Start of heating phase - ISTD Pilot Test
End of heating phase - ISTD Pilot Test
Start of heating phase - ISTD full-scale IRM
End of heating phase - ISTD full-scale IRM
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

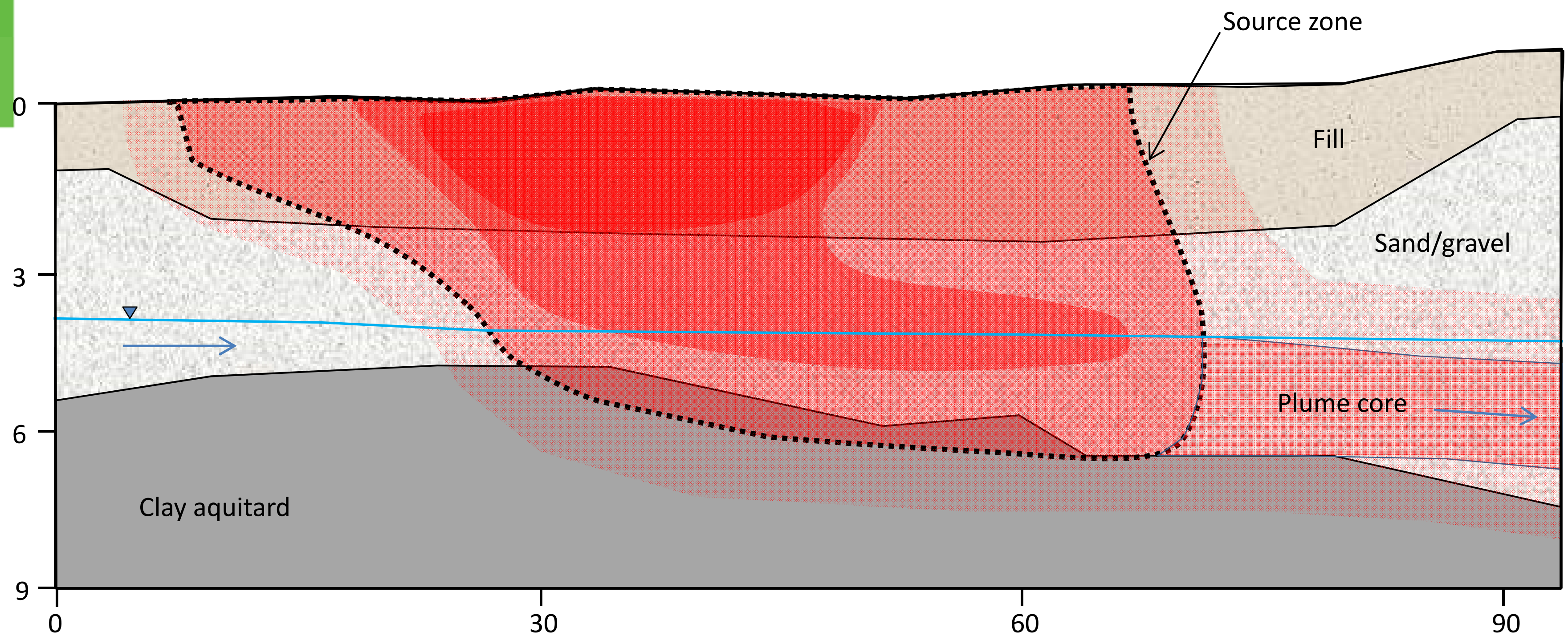


RAILROAD TRACKS
N
Former Endicott Forging Property
Former Ideal Cleaners Property
Approximate Limits of ISTD Treatment Area
GROUNDWATER FLOW DIRECTION
Limits of Apparent Petroleum Presence
Primary Area of the PCE-Series Plume in Groundwater Prior to ISTD Treatment
ARTHUR
JACKSON AVENUE
MONROE STREET
1
2
3
4
5
6
LEGEND
- Groundwater Extraction Well
- Groundwater Monitoring Well
Scale (Meters)
0
50
100
Well Location #4
Well Location #6
Concentration (ug/L)
10000
1000
100
10
1
0.1
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Key:
PCE
TCE
c12-DCE
VC
Start of heating phase - ISTD Pilot Test
End of heating phase - ISTD Pilot Test
Start of heating phase - ISTD full-scale IRM
End of heating phase - ISTD full-scale IRM



BEFORE THERMAL TREATMENT (AUGUST 2007)
LESS THAN 5 YEARS AFTER THERMAL TREATMENT
Former Ideal Cleaners Property
Approximate Limits of ISTD Treatment Area
PCE
TCE
cis12DCE
VC
LEGEND
5 - Isoconcentration Contour (µg/L)
- Active Groundwater Extraction Well
- Inactive Groundwater Extraction Well
- Groundwater Monitoring Well

Mass discharge



$$dm/dt = Q \times A \times C_w$$

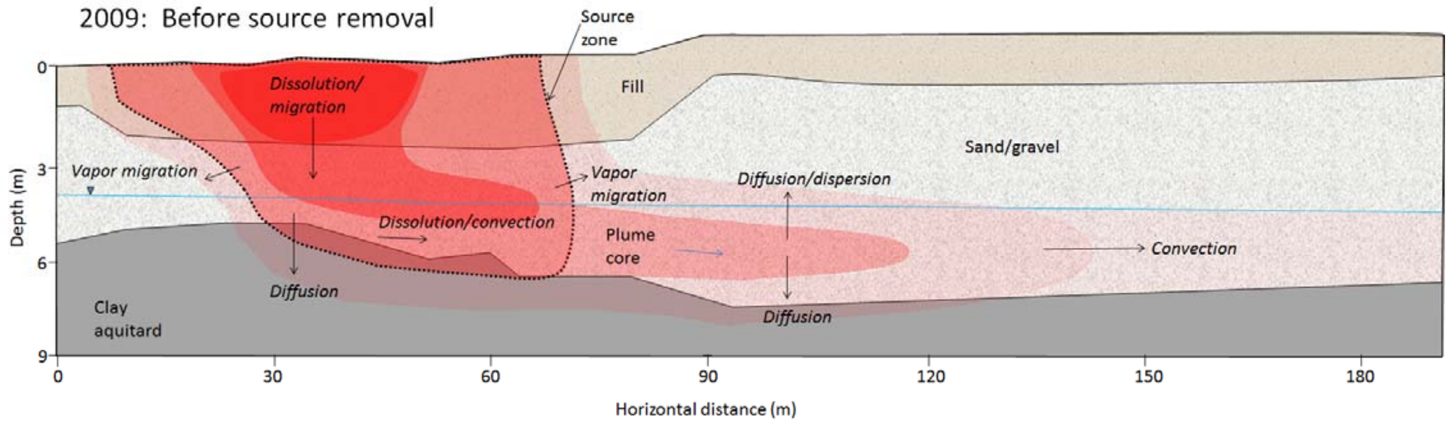
Mass discharge

Sample	Depth (ft bgs)	PCE soil concentration (mg/kg) Before treatment	After treatment	
PST27M2#	24.5 to 25	0.11	0.001	
PST28L4#	23.5 to 24	630	0.001	
CS5K4	21.5 to 22	2100	0.003	
CS11L1	22 to 22.5	2100	0.001	
CS14K1	20 to 20.5	37	0.003	
CS15J4	19.5 to 20	14	0.125	
CS17J4	19.5 to 20	6.3	0.003	
CS19K2	20.5 to 21	4.4	0.004	
CS22J3	19 to 19.5	1.85	0.0025	
CS27J2	18.5 to 19	0.18	0.0025	
CS29J3	19 to 19.5	25	0.0025	
CS35J1	18 to 18.5	5.3	0.003	
CS43J1	18 to 18.5	not sampled	0.0025	
CS44J2	18.5 to 19	not sampled	0.002	
CS46J3	19 to 19.5	not sampled	0.003	
Average		410.3	0.0106	mg/kg
Percent reduction			99.9974	%

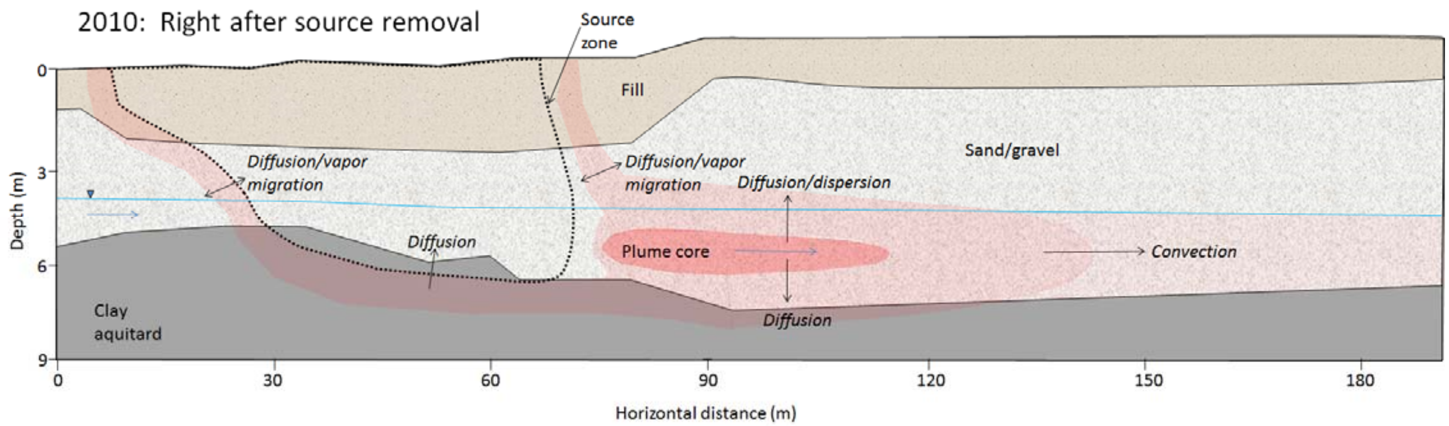
$$dm/dt = Q \times A \times C_w$$

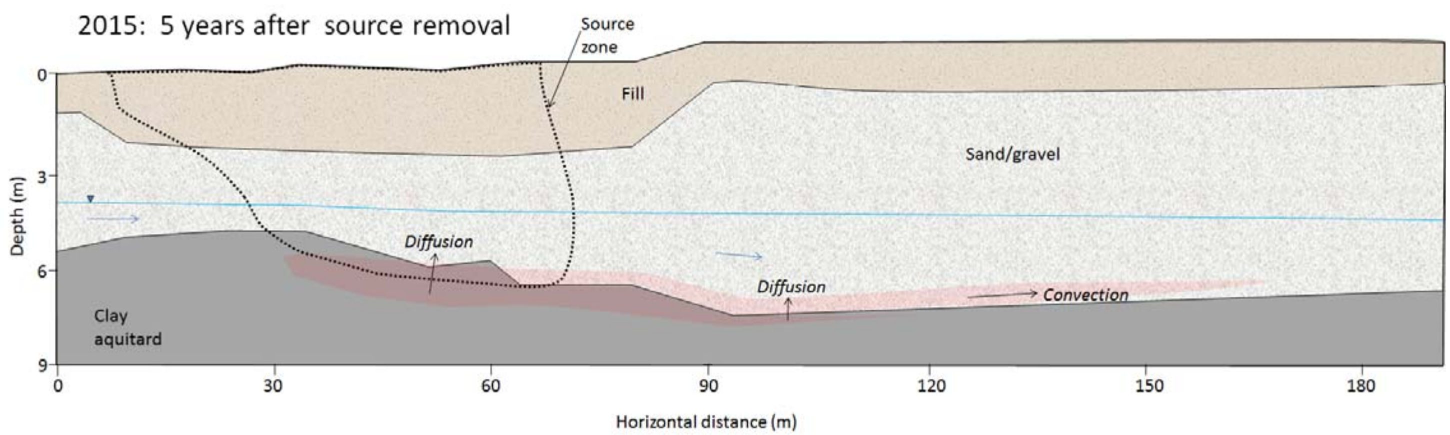
Mass discharge estimates	Before treatment	After treatment	
Plume width	50		m
Plume depth	2		m
Seepage velocity	1.5		m/day
Porosity	35		%
Groundwater volume flow	52.5		m^3/day
PCE concentration	3	0.0036	mg/L
PCE mass discharge	157.5	0.19	g/day
PCE mass discharge	57	0.069	kg/yr

57 kg/yr



0.07 kg/yr





Results – for IBM

Saved >$2 million compared to excavation

Source removal complete

Plume attenuated

Turned off pump and treat system in 2015

Discontinued soil slab ventilation under houses

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Summary

Source reductions by 99% or more

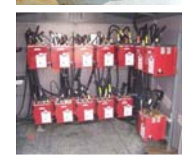
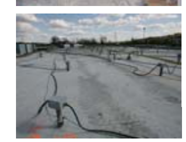
Mass discharge strongly reduced

Natural attenuation versus back diffusion

Plume life determined by groundwater flow and site-specific conditions

Yes – source removal does matter



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Groundwater Monitoring&Remediation

Thermal DNAPL Source Zone Treatment Impact on a CVOC Plume

by Gorm Heron, John Bierschenk, Robin Swift, Robert Watson, and Michael Kominek

Abstract

The tetrachloroethene (PCE) source zone at a site in Endicott, New York had caused a dissolved PCE plume. This plume was commingled with a petroleum hydrocarbon plume from an upgradient source of fuel oil. The plume required a system for hydraulic containment, using extraction wells located about 360 m downgradient of the source. The source area was remediated using in situ thermal desorption (ISTD). Approximately 1406 kilograms (kg) of PCE was removed in addition to 4082 kg of commingled petroleum-related compounds. The ISTD treatment reduced the PCE mass discharge into the plume from an estimated 57 kg/year to 0.07 kg/year, essentially removing the source term. In the 5 years following the completion of the thermal treatment in early 2010, the PCE plume has collapsed, and the concentration of degradation products in the PCE-series plume area has declined by two to three orders of magnitude. Anaerobic dechlorination is the suspected dominant mechanism, assisted by the presence of a fuel oil smear zone and a petroleum hydrocarbon plume from a separate source area upgradient of the PCE source. Based on the post-thermal treatment groundwater monitoring data, the hydraulic containment system was reduced in 2014 and discontinued in early 2015.

Introduction

Dense nonaqueous phase liquids (DNAPL) have created significant environmental concerns. Soil and groundwater contaminated with DNAPL are relatively slow to remediate naturally, with typical plume life expected to be hundreds of years. The longevity of source zones is primarily caused by the environmental stability of the DNAPL, its immobility in the subsurface, low dissolution rate into moving groundwater, and its low vaporization rate when located below the groundwater table at typical ambient temperatures (Hunt et al. 1988; Mercer and Cohen 1990; Pankow and Cherry 1996). As such, DNAPL source zones release contaminants for decades or centuries and can sustain long dissolved objectives (Davis 1997; BERC 2000; EarthTech and SteamTech 2003; McGee 2003; LaChance et al. 2004; Heron et al. 2005, 2013, 2014; Johnson et al. 2009). Typical mass removal percentages exceed 99% (equal to two orders of magnitude) and in some instances, more than 99.9%, equal to three orders of magnitude (Heron et al. 2005, 2013).

However, the reduction of source zone concentrations of the contaminants of concern (COC) to below target levels does not directly translate into site closure when a dissolved plume is present downgradient of the source, often due to back-diffusion from low-permeability zones (Liu and Ball 2002; Kavanaugh and Rao 2003; Chapman and Parker 2005; Parker et al. 2008; Seyedabbasi et al. 2012).

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