In-Situ Thermal Remediation of Soil Contaminated with Organic Chemicals

Ralph S. Baker, Ph.D.

TerraTherm, Inc.

Fitchburg, Massachusetts USA

NATO/CCMS Pilot Study

Prevention and Remediation in Selected Industrial Sectors: Small Sites in Urban Areas

Athens, Greece

7 June 2006

TERRATHERM®

Overview

- Introduction to In Situ Thermal Remediation (ISTD)
  - Steam-Enhanced Extraction
  - Electrical Resistance Heating
  - Thermal Conduction Heating
- Representative Field Projects and Results
  - SEE – Aalborg, Denmark
  - TCH – Richmond, California, USA
- Conclusion
- Supplemental Data

Changes in Physical Properties with Heating (to 120°C)

Component property	**Oil based LNAPL**	**Chlorinated solvents**	**Creosote**	**Coal tar**	**PCB**	**Comment**
Vapor pressure increase factor	20 **20-80**	**20-100**	**20-300**	**20-300**	**2000**	Abundance of data in literature
Solubility increase factor	2-100?	1.5-3	10-1000	10-1000	10-1000	Chlorinated solvent less affected than larger hydrocarbons
Henry's constant increase factors		10-20	0-10	0-10	0-10	Data absent for most compounds, some decrease?
Viscosity reduction factor	2 to 100+	1.3-3	5-10	20-100+	3-100	The higher initial viscosity, the more reduction
Interfacial tension reduction factor	<2	<2	2-5	1-5	<5	Typically not dramatic effect (less than factor 2)
Density reduction (%)	10-20	10-20	10-20	10-20	10-20	Note that DNAPL may become LNAPL
K_d (reduction factor)	?	1-10	5-100	5-100	NA	Estimates based on limited data

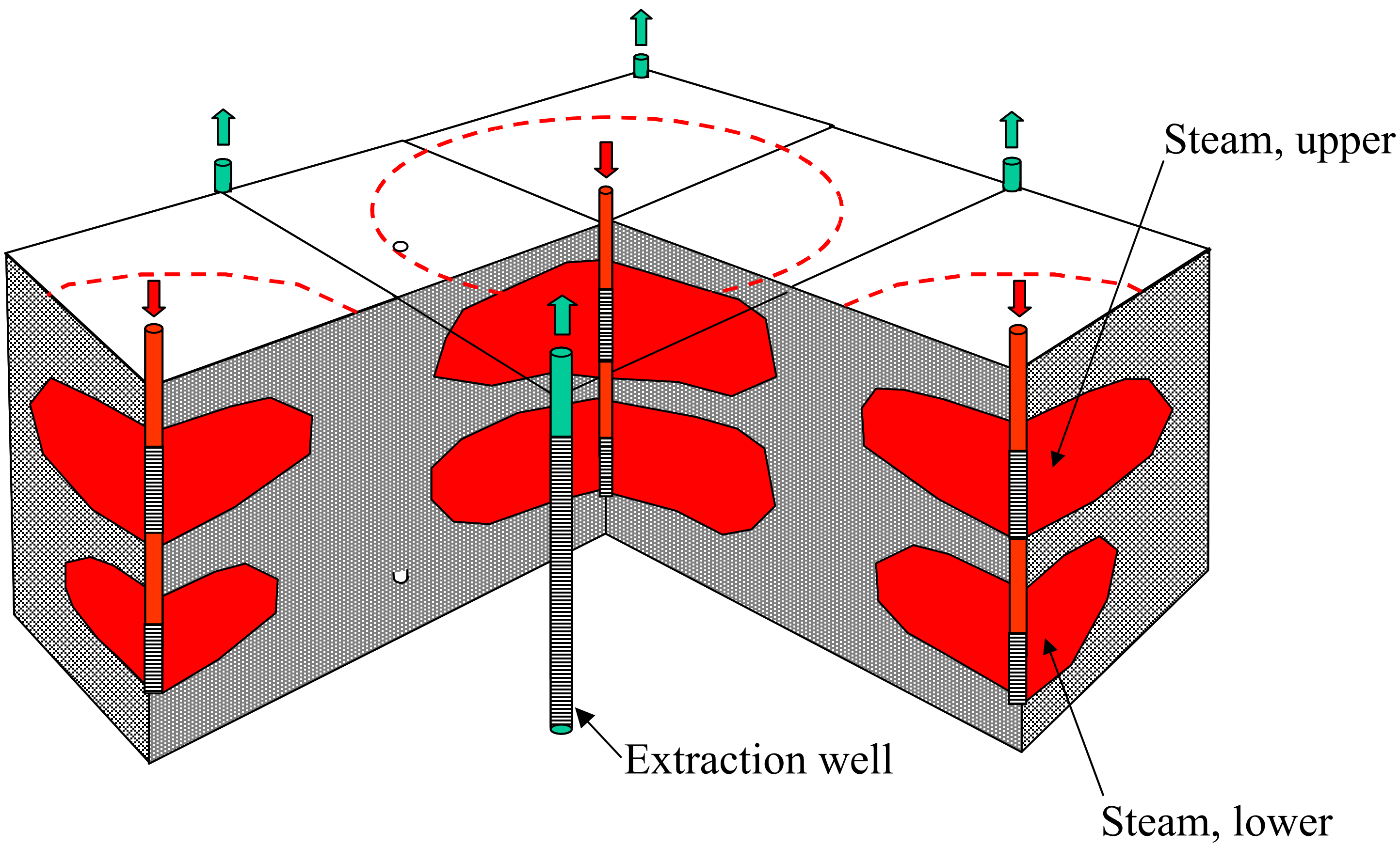
Udell (1989, 1991, 1993, 1996)
Davis (1997, 1999)
Imhoff et al. (1997)
Sleep and Ma (1997)
Heron et al. (1998, 2000)
Stegemeier and Vinegar (2001)

Note: Abiotic and biological reactions not listed

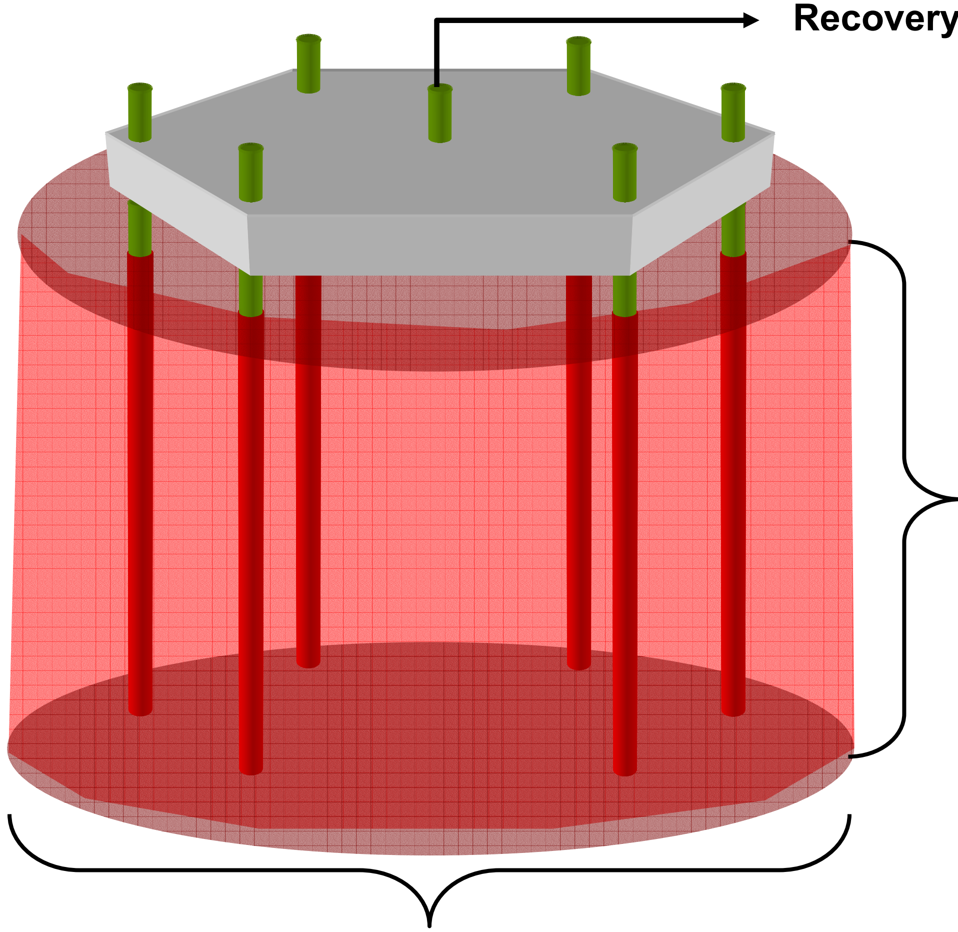
Consider In-Situ Thermal Remediation (ISTR):

- For Source Remediation of Organic Contaminants (e.g., DNAPL)
- To Facilitate a Brownfields Cleanup
- To Achieve Rapid Site Closure
- As part of overall optimization of an existing system, especially where additional source control/removal would significantly shorten the duration of a long-term pump and treat, SVE, or Multi-Phase Extraction system.

Steam Enhanced Extraction (SEE)



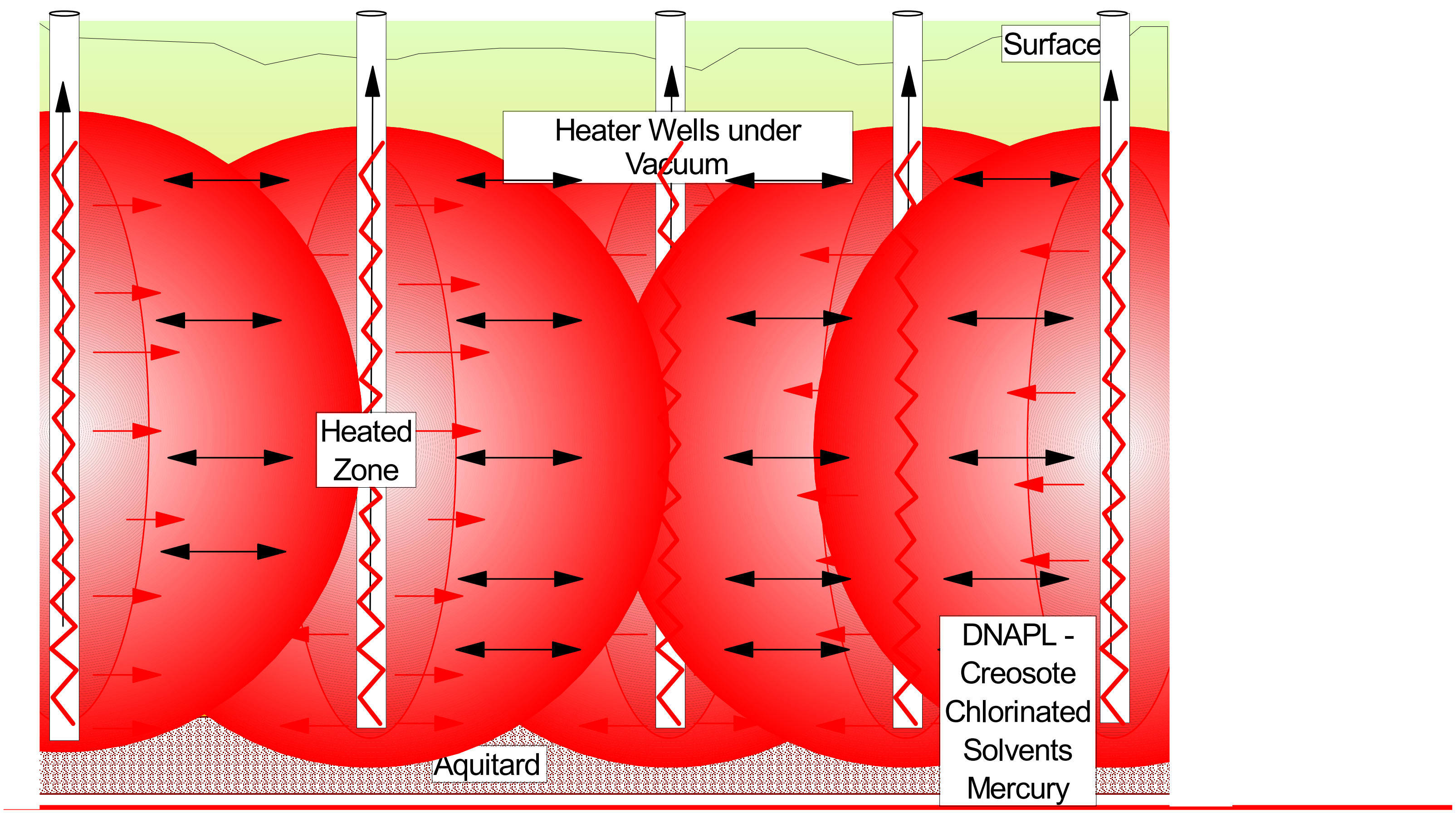
Electrical Resistance Heating (ERH)



Courtesy of CES

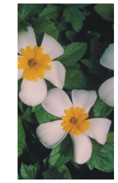
- Six-Phase Heating: Electrical current moves between the 6 electrodes on the outside diameter and the central neutral.
- Three-Phase heating is another option

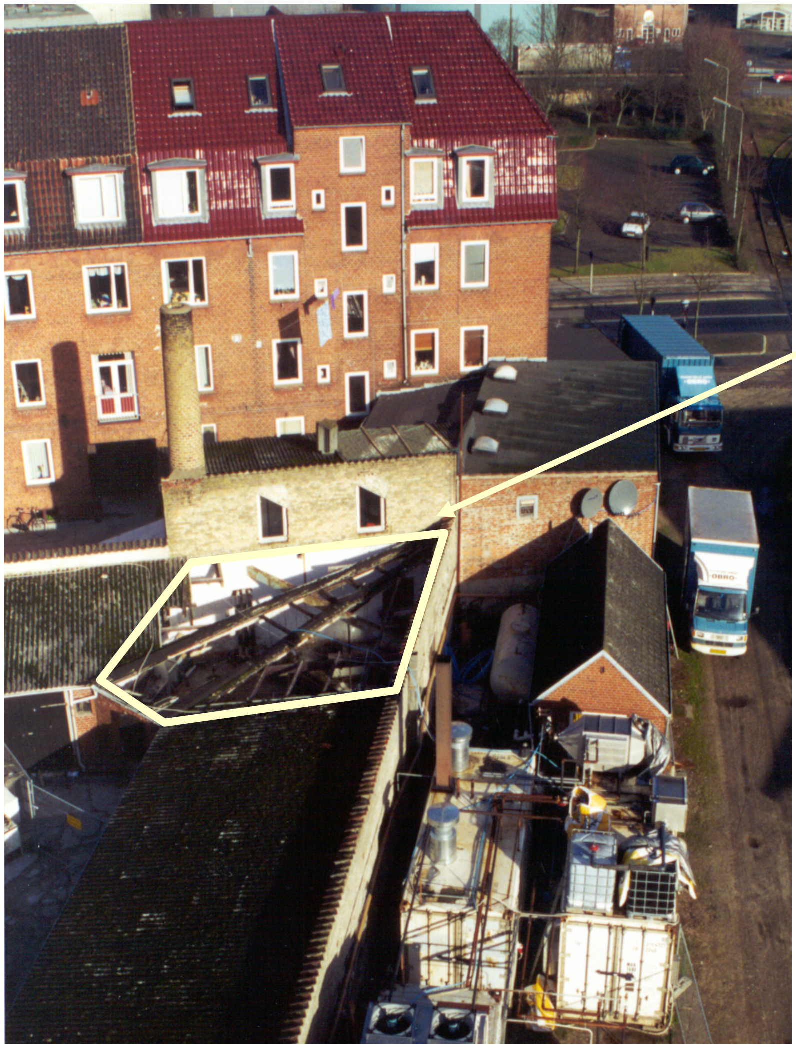
Thermal Conduction Heating (TCH) Combined with Vacuum: In-Situ Thermal Desorption (ISTD)



TERRATHERM

NIRÁS SEE Project, Aalborg, Denmark



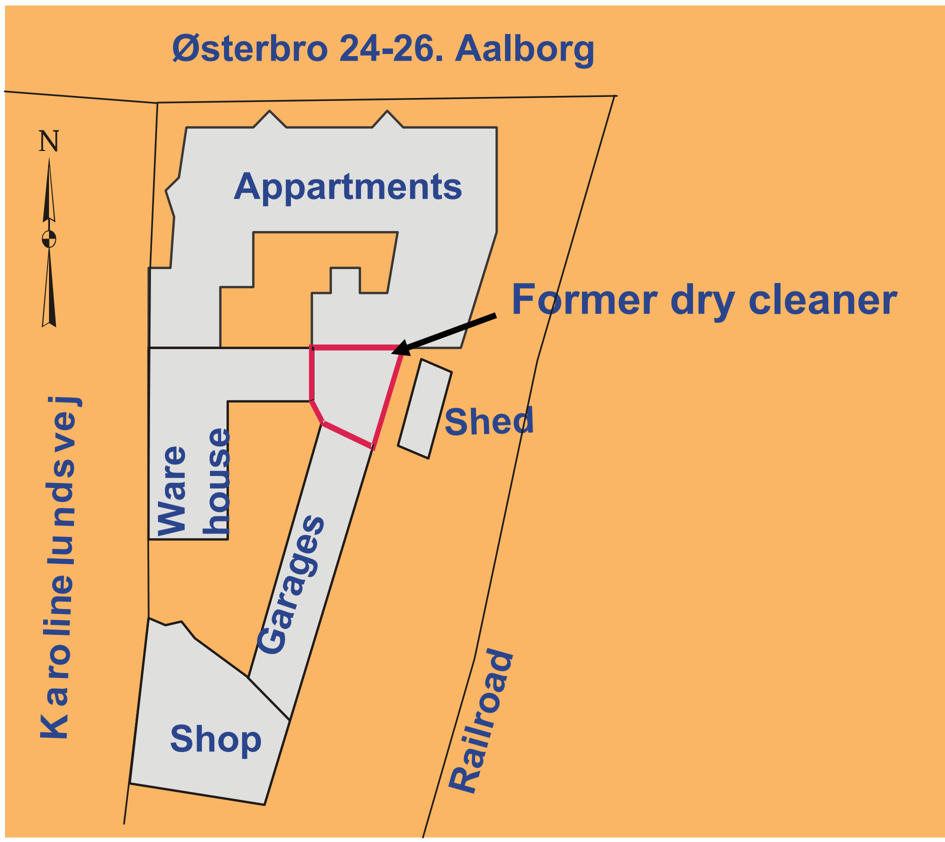


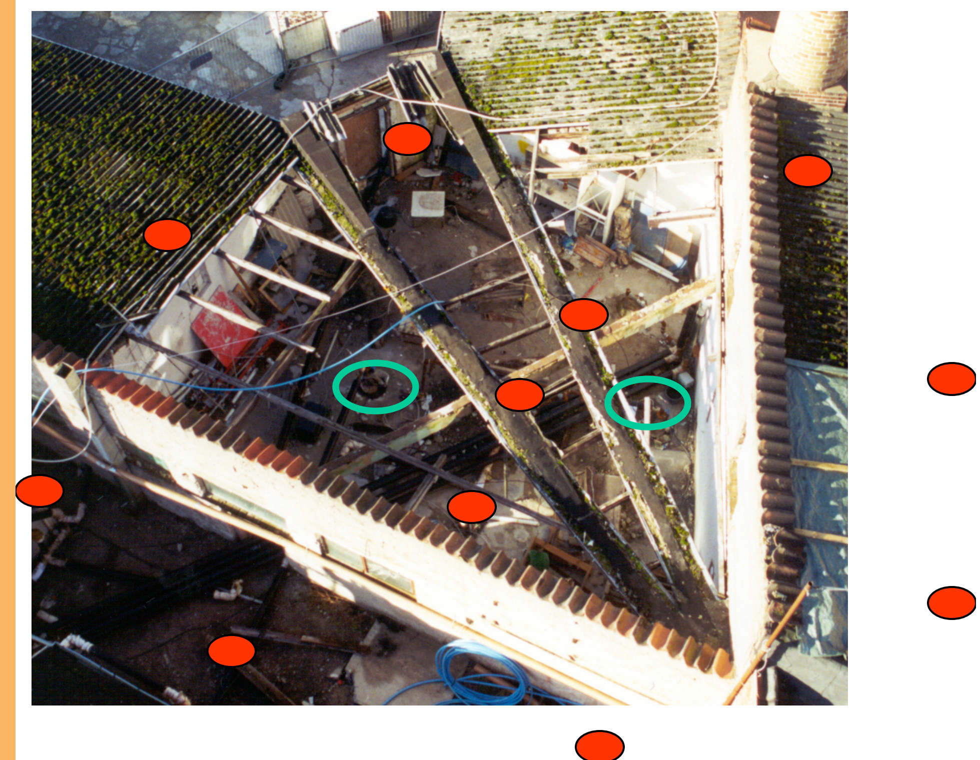
Former dry cleaning facility

- **50 years of dry cleaning activity (~ 1936-1985)**
- **Perchloroethylene (PCE) and turpentine (stoddard solvent) as cleaning fluid**

(Courtesy Tom Heron, NIRÁS)

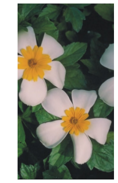
Site layout and treatment wells



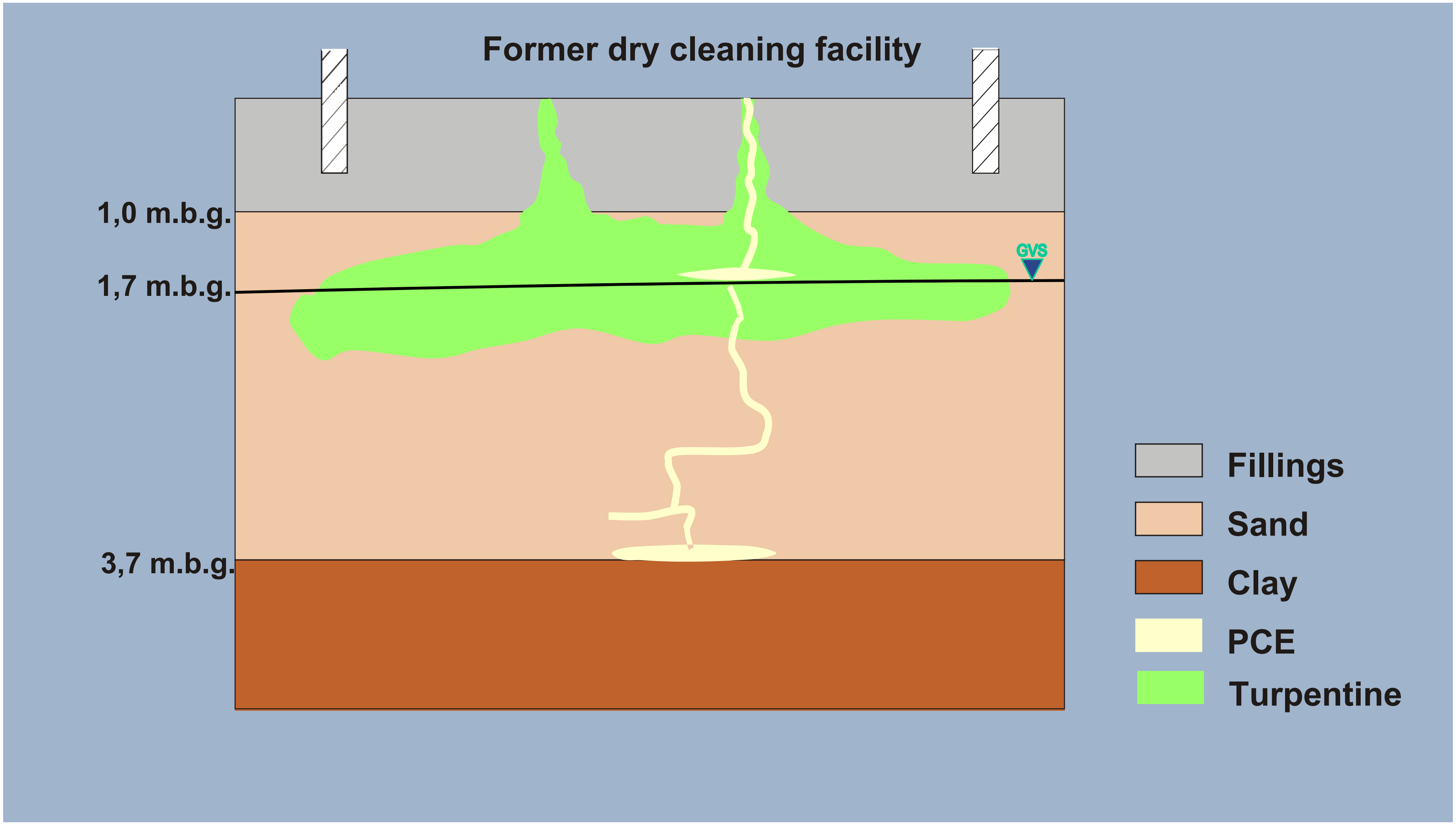


Extraction well

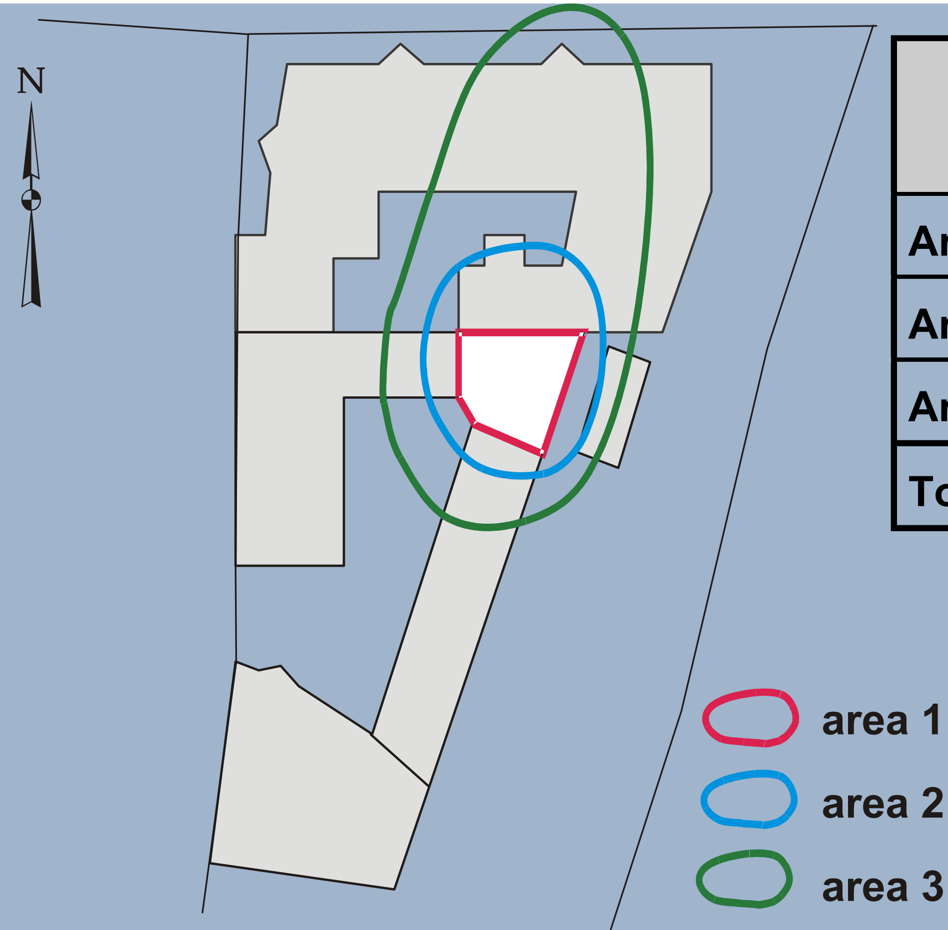
Steam Injection well



Contaminant distribution

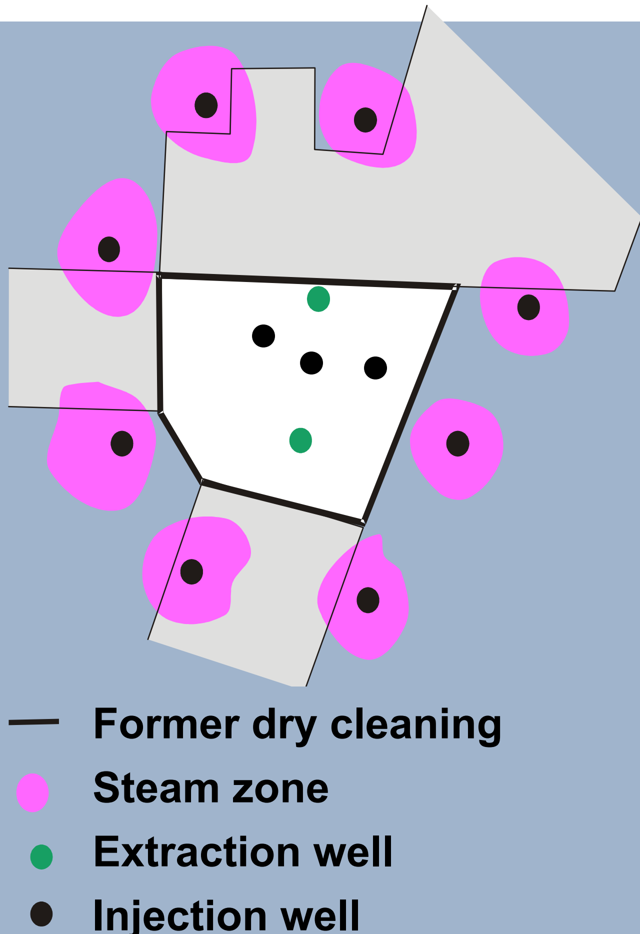


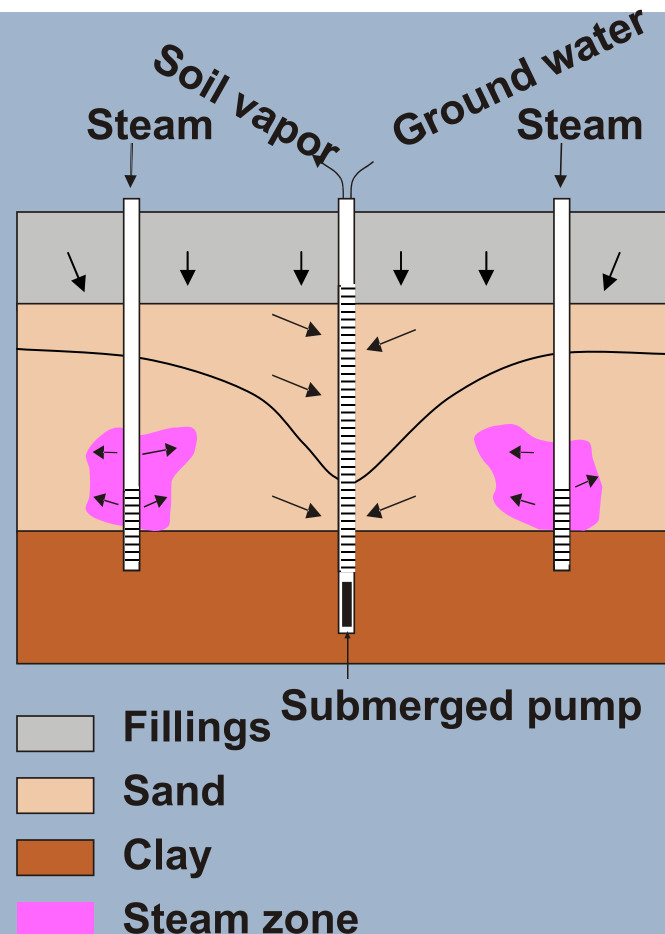
Source zone & estimated mass



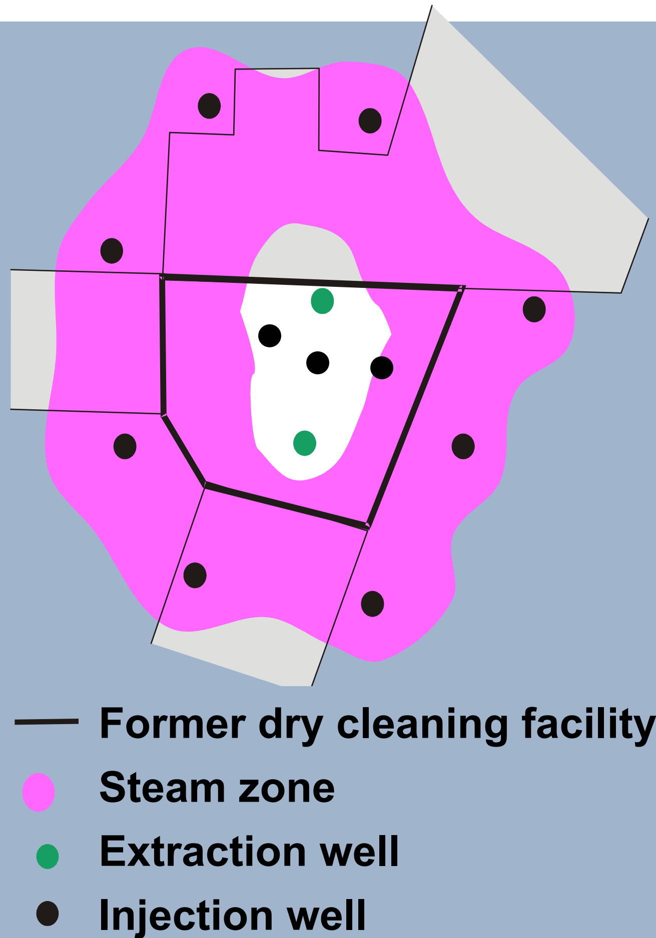
	Turpentine kg	PCE kg	%
Area 1	2.800	70	86
Area 2	400	5	13
Area 3	25	1	1
Total	3.225	106	100

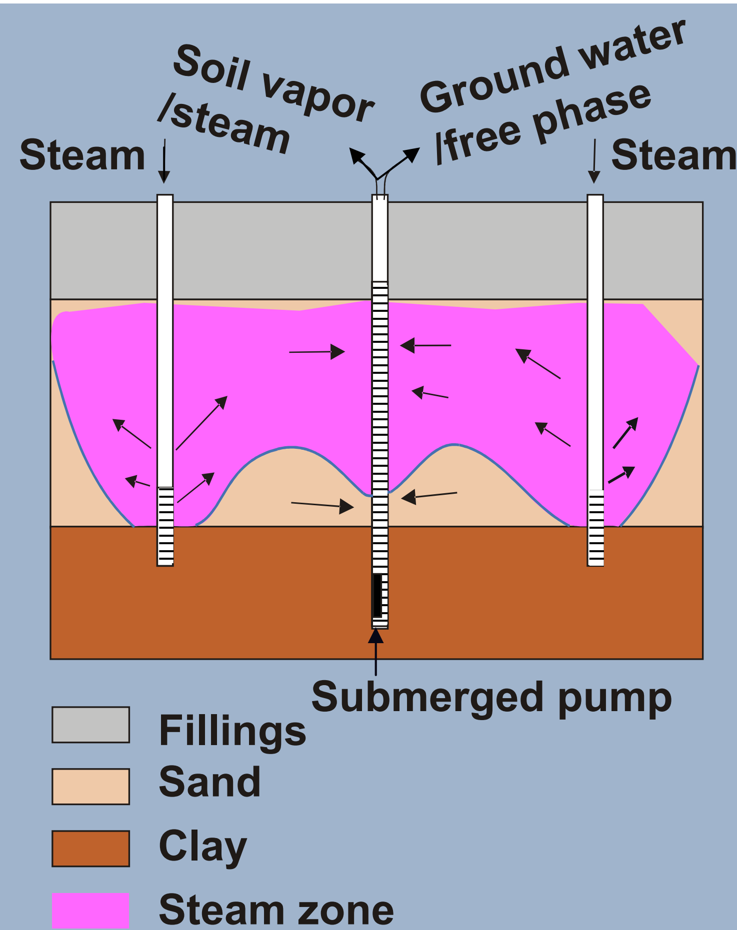
Remediation strategy ~ day 1-2





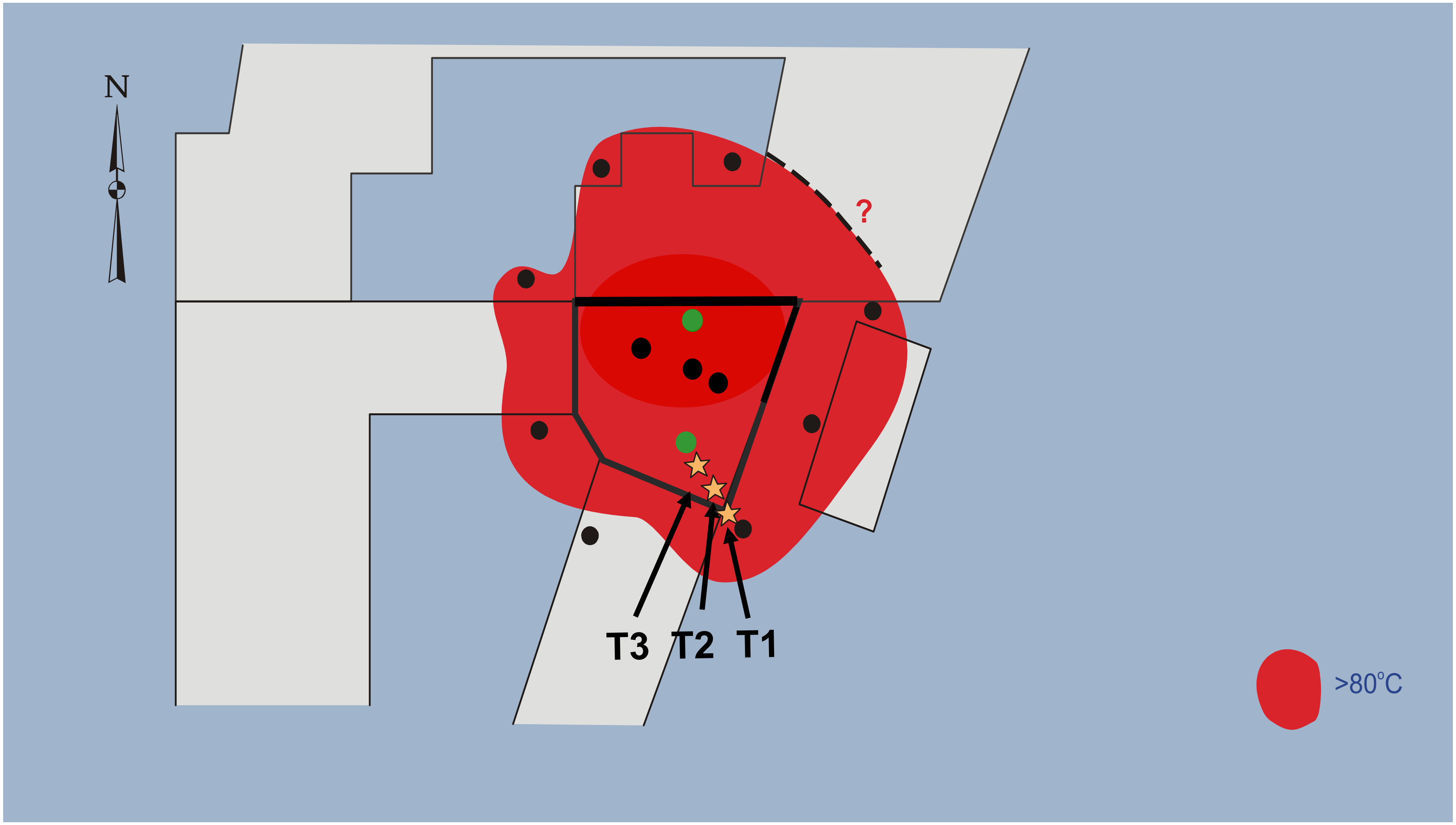
Remediation strategy ~ day 15





Continous operation

Temperature distribution 3,0 m.b.g. after 41 days



Clean up results

- Removed ~ 900 - 1.000 kg of PCE/turpentine
- Remaining contamination in cold spots: ~ 5 - 8 kg
  - PCE in soil: 0,04 - 37 mg/kg
  - PCE in air: 1,2 - 600 mg/m^3
  - PCE in water 0,57 - 62 µg/l
- Efficiency: 98-99 %
- Remediation goal achieved: Threat to in- and outdoor air quality significantly reduced

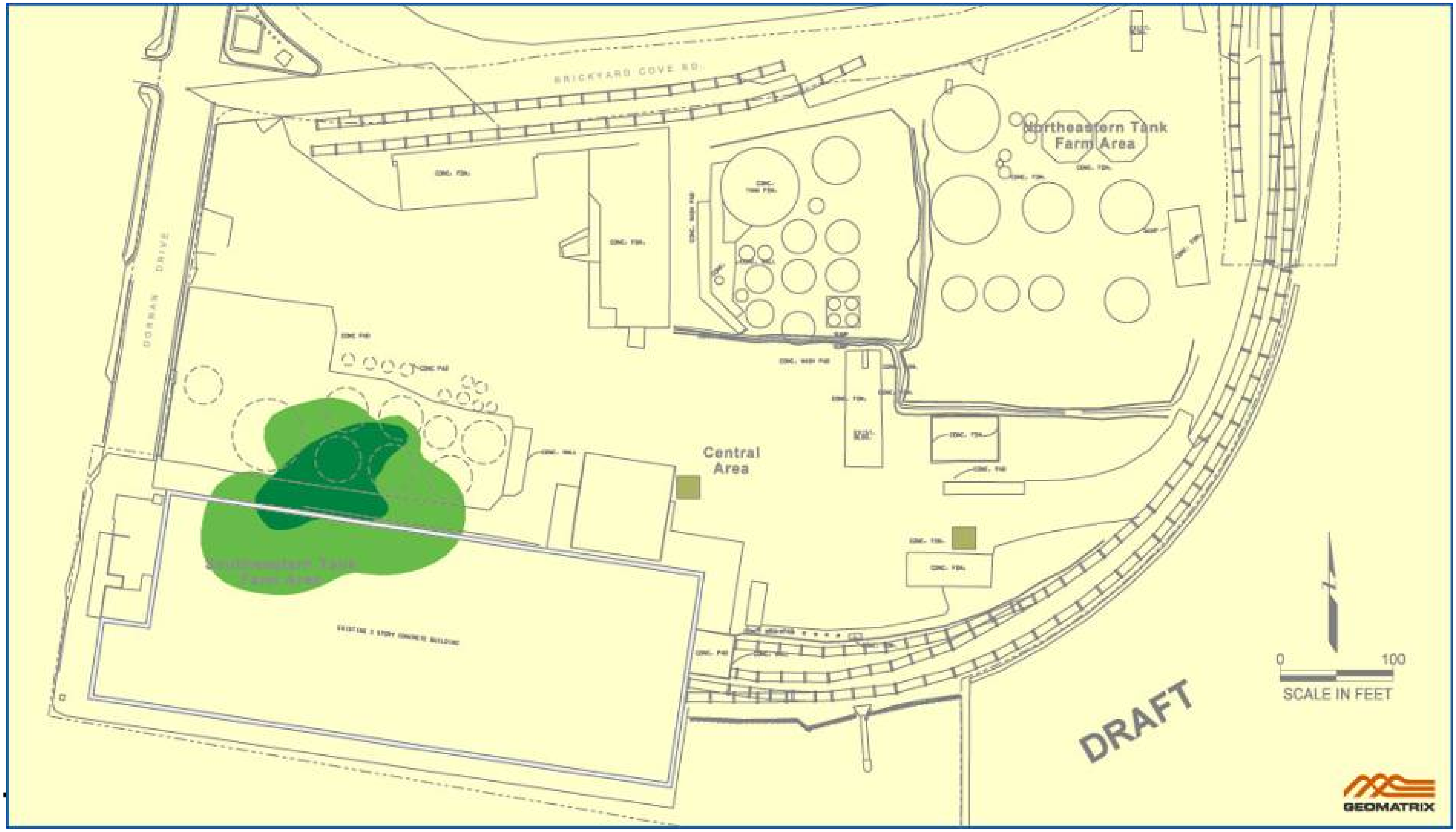
Terminal One Project, San Francisco Bay Area, California

TERRATHERM®


SeaCliff Estates Site
Brickyard Landing
Brickyard Cove
Nichol Nob
Terminal One Site
Ferry Point
Target
Treatment
Zone

TERRATHERM®

Areas To Be Cleaned Up in Southwestern Tank Farm

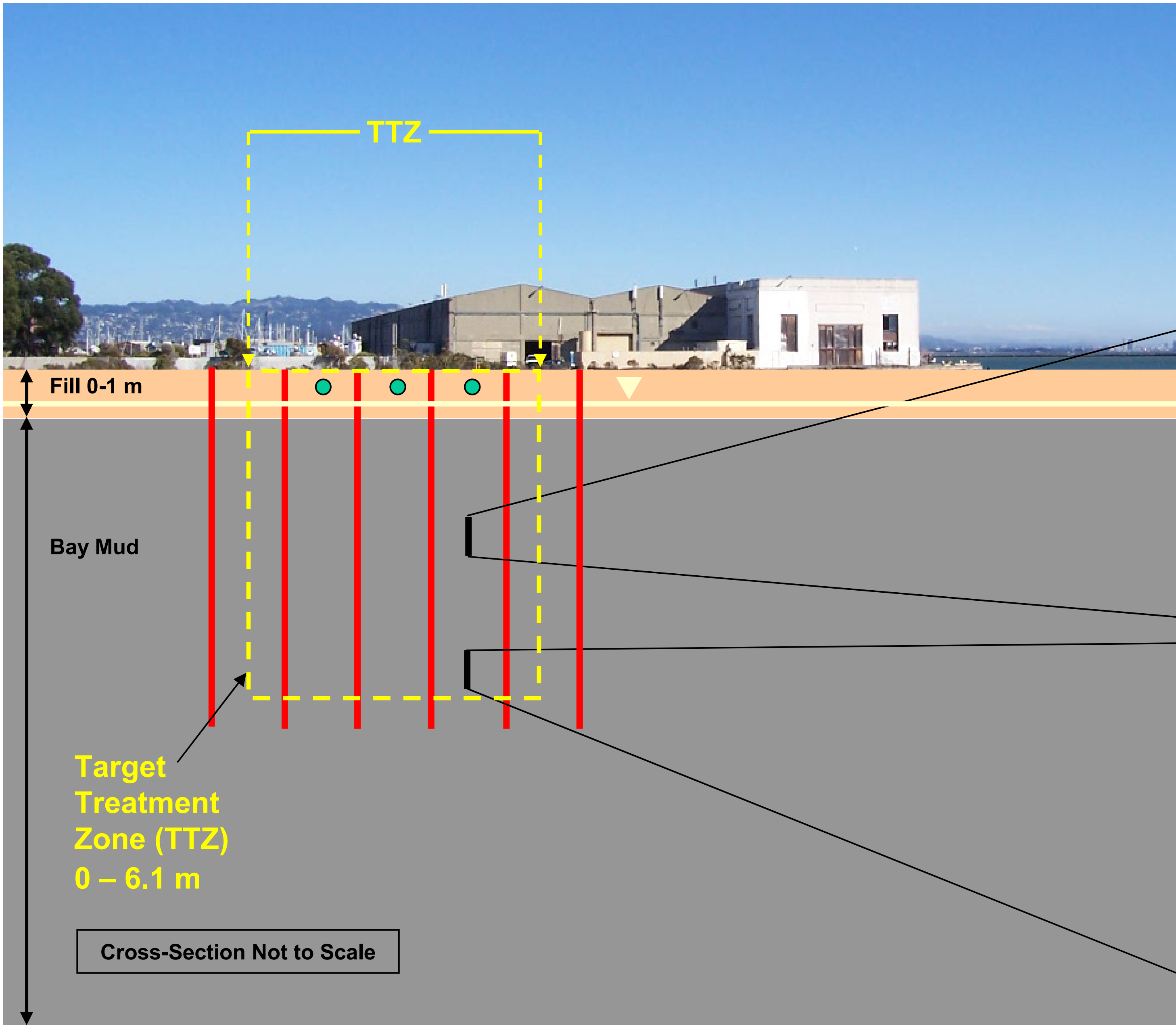


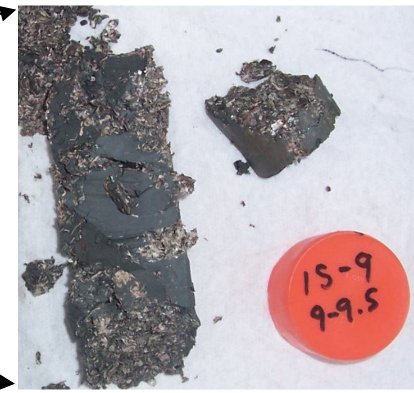
Richmond Site Cross-Section

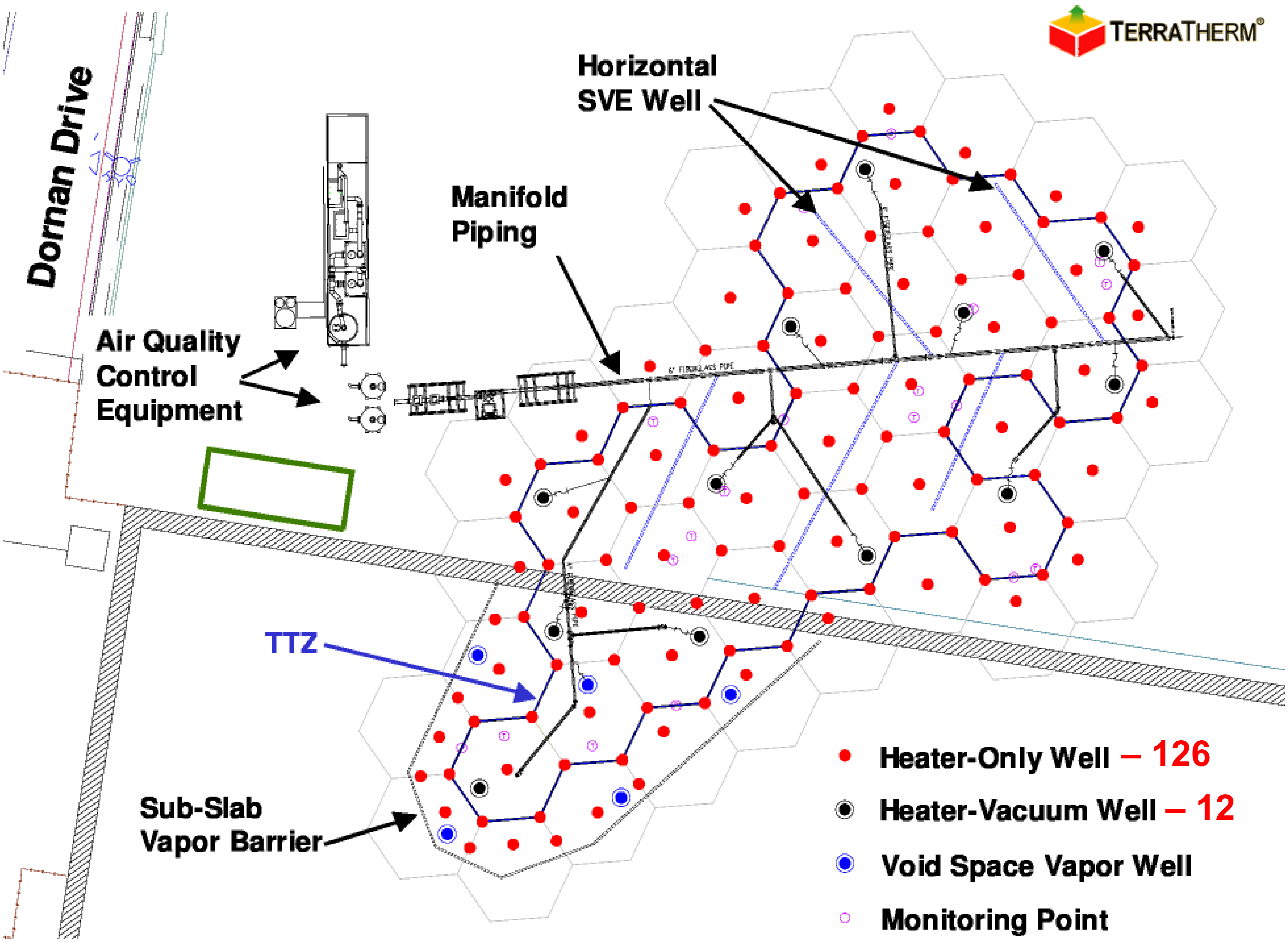
5400 m^3

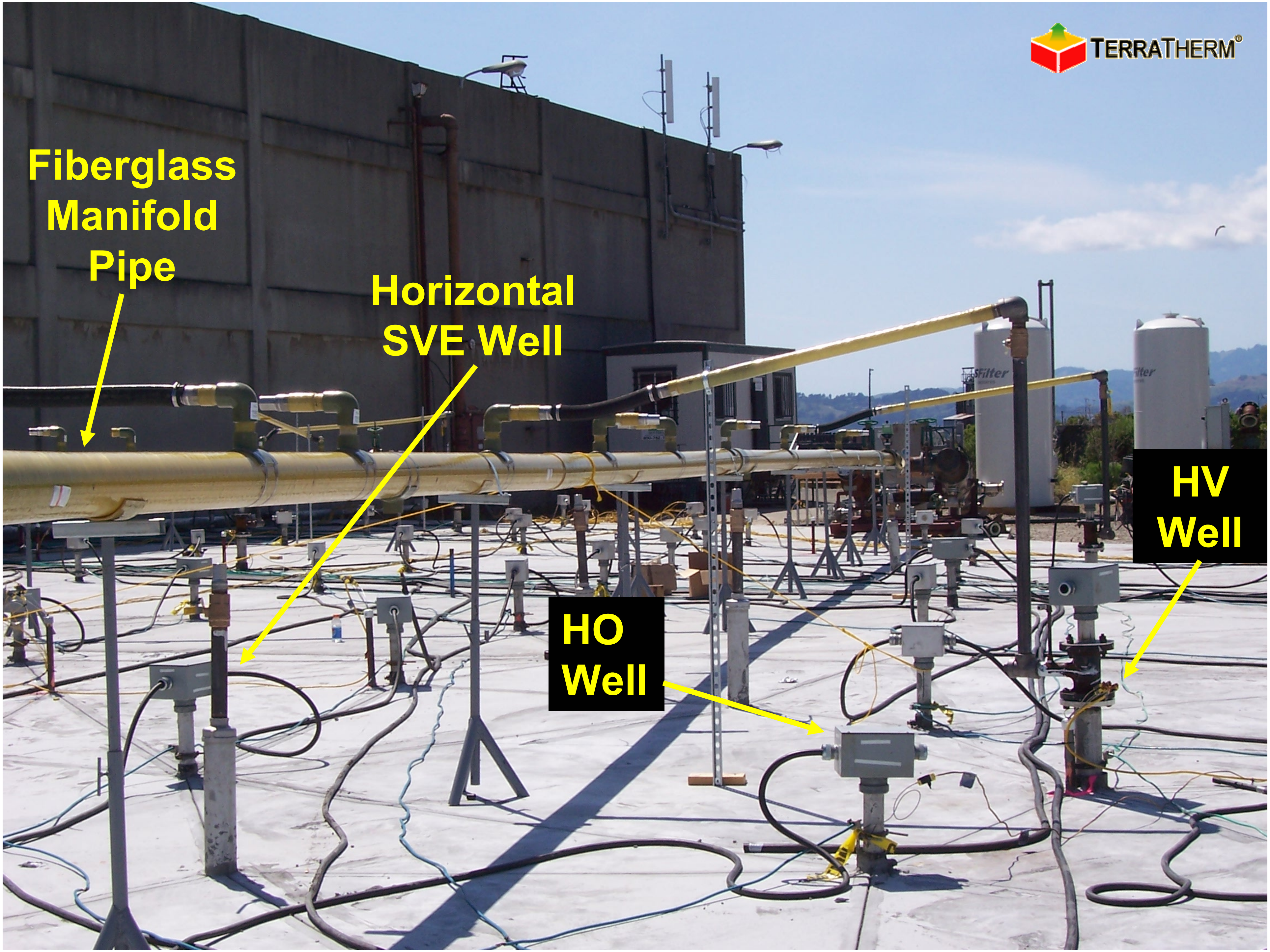
CVOCs:
PCE, TCE,
DCE, and VC

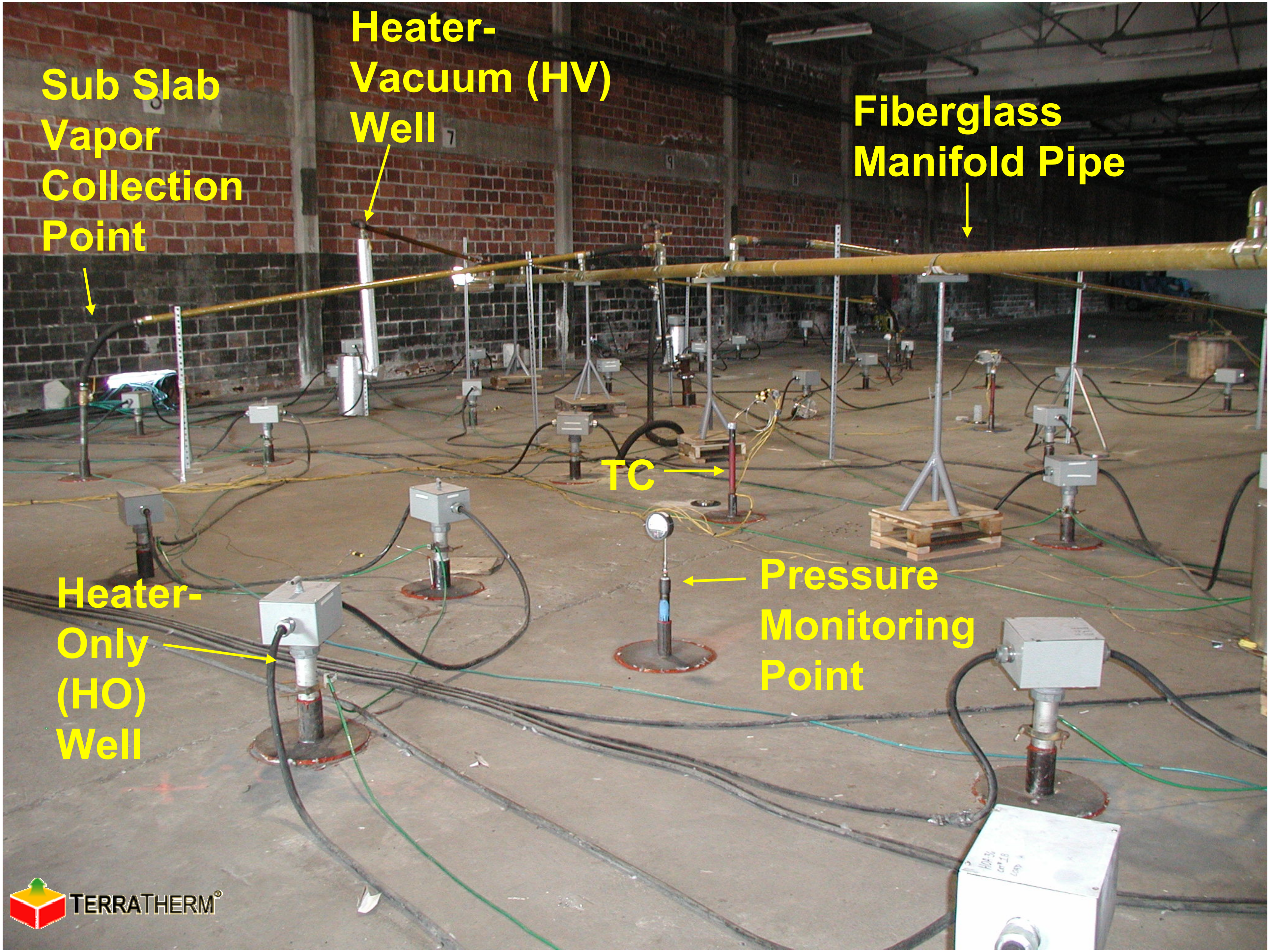
NAPL



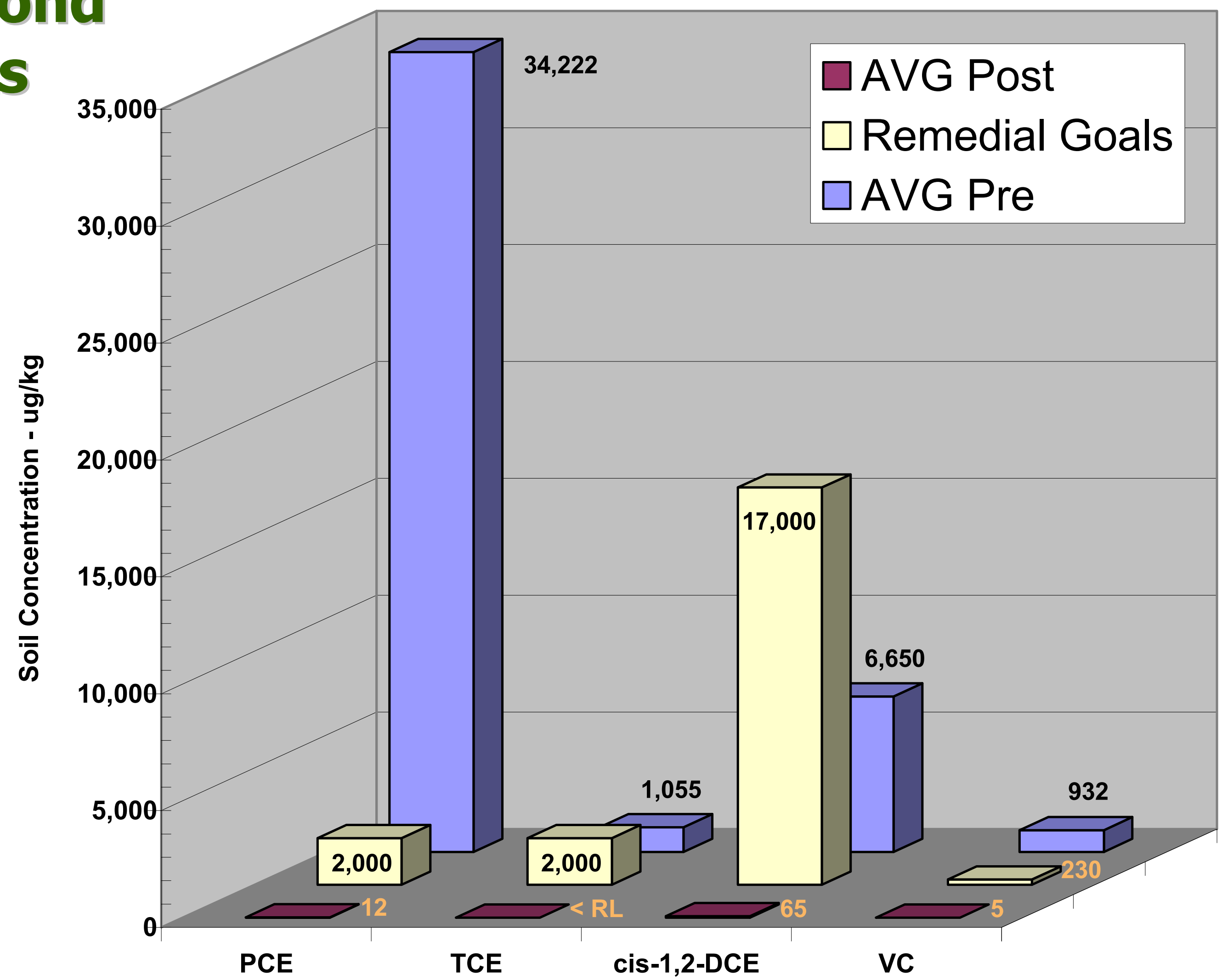



TERRATHERM®
Dornan Drive
Horizontal SVE Well
Manifold Piping
Air Quality Control Equipment
TTZ
Sub-Slab Vapor Barrier
Heater-Only Well – 126
Heater-Vacuum Well – 12
Void Space Vapor Well
Monitoring Point


TERRATHERM®
Fiberglass Manifold Pipe
Horizontal SVE Well
HO Well
HV Well


Sub Slab Vapor Collection Point
Heater-Vacuum (HV) Well
Fiberglass Manifold Pipe
TC
Pressure Monitoring Point
Heater-Only (HO) Well
TERRATHERM®

Richmond Results

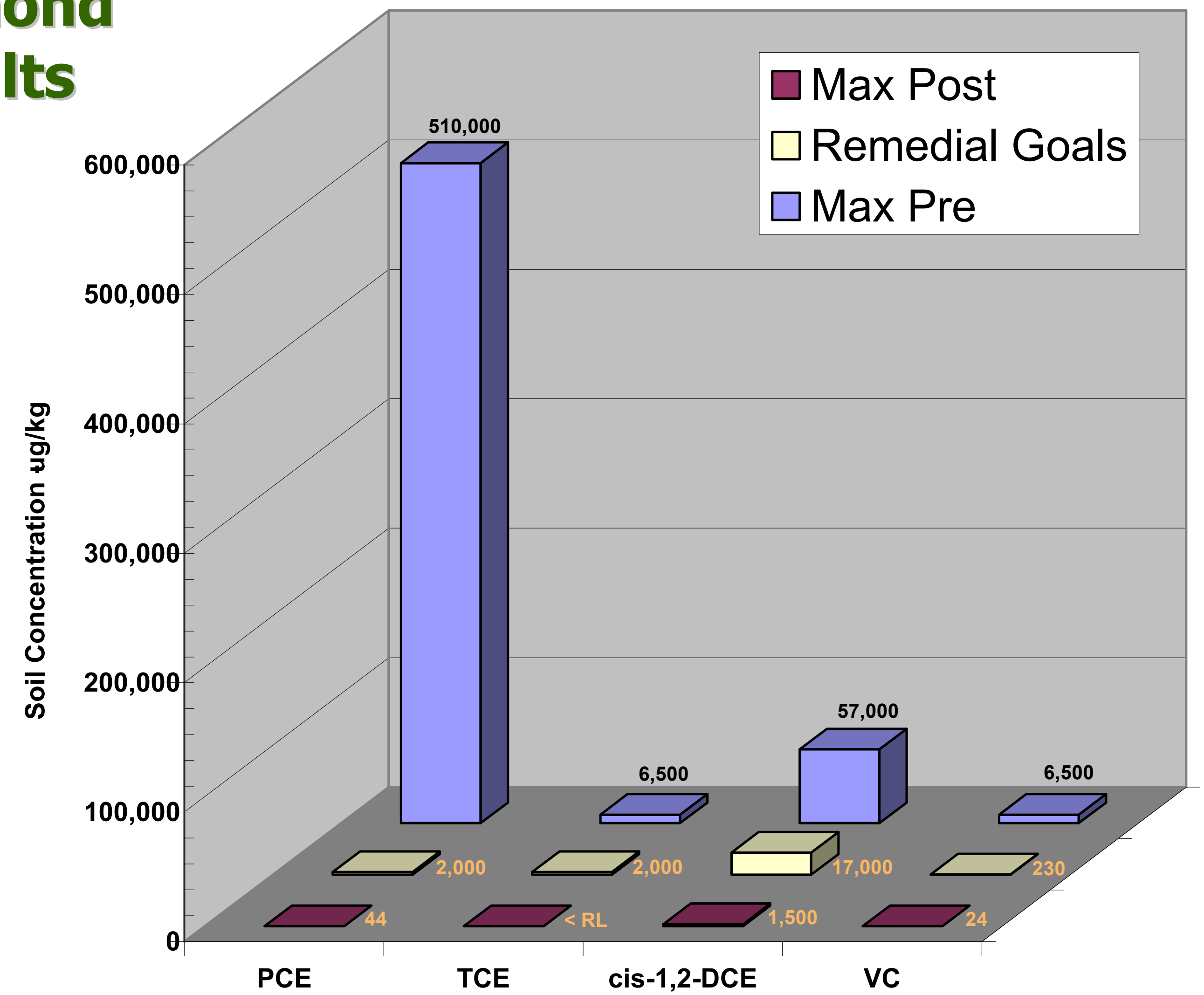


Reductions:	99.96%	99.63%	99.03%	99.49%

TERRATHERM®

Results are based on 17 pre-treatment samples and 64 post-treatment samples. Post-treatment samples were collected from centroids (i.e., coolest locations) at random and biased depths (15 or 23% were collected between 18 and 20 ft bgs).

Richmond Results



Reductions: 99.96% 99.63% 99.03% 99.49%

Richmond results are based on 17 pre-treatment samples and 64 post-treatment samples. Post-treatment samples were collected from centroids (i.e., coolest locations) at random and biased depths (15 or 23% were collected between 5.5 and 6.1 m bgs).

TERRATHERM®

Projected Post Redevelopment View

350 Condominium Residential Area and Waterfront Park Planned for Site

TERRATHERM®

TERRATHERM®

Project completed on time and on budget

- Performance guaranteed
- Remedial goals achieved

7 months for construction and treatment

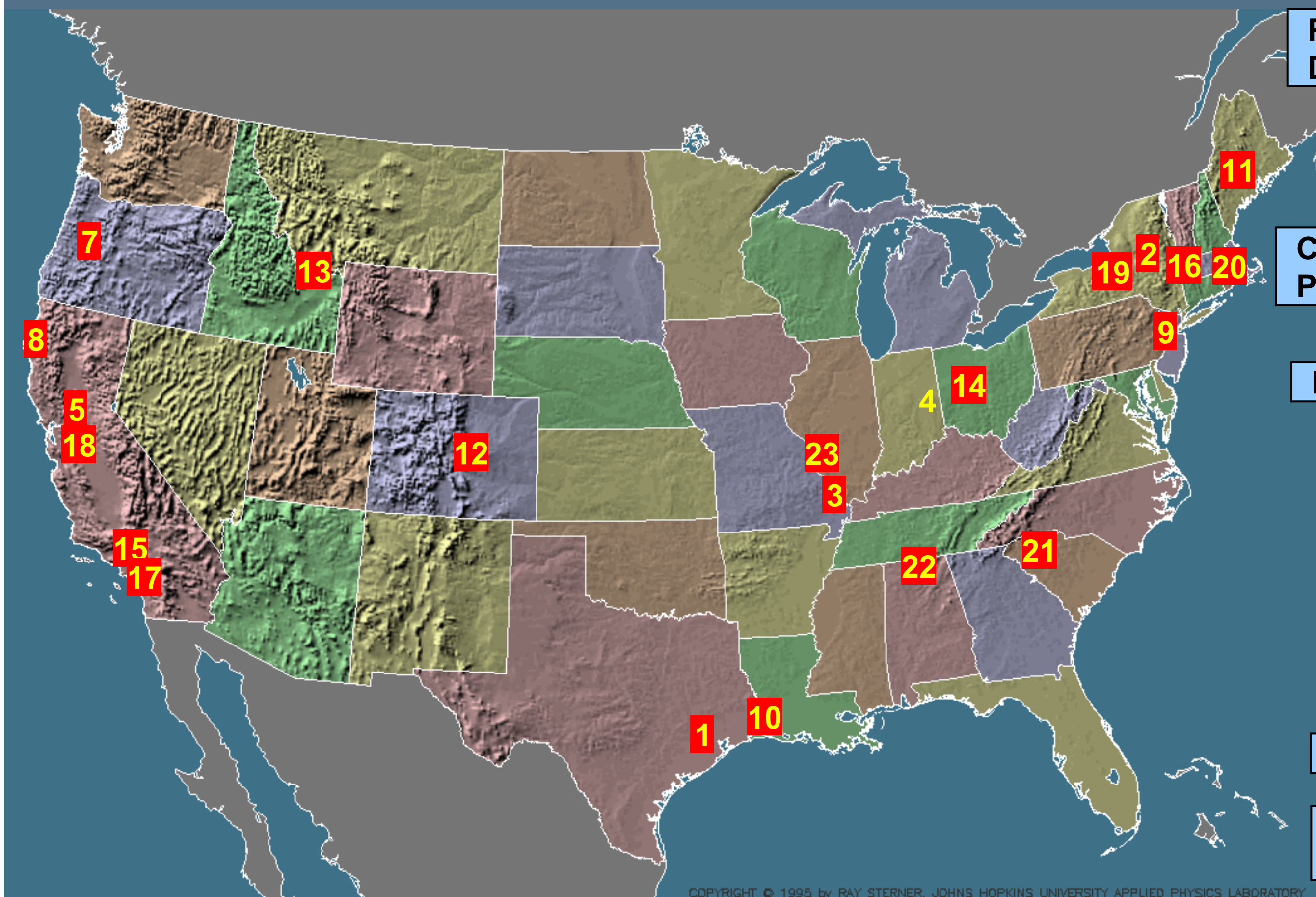
Total TT project cost: ~$1.7M

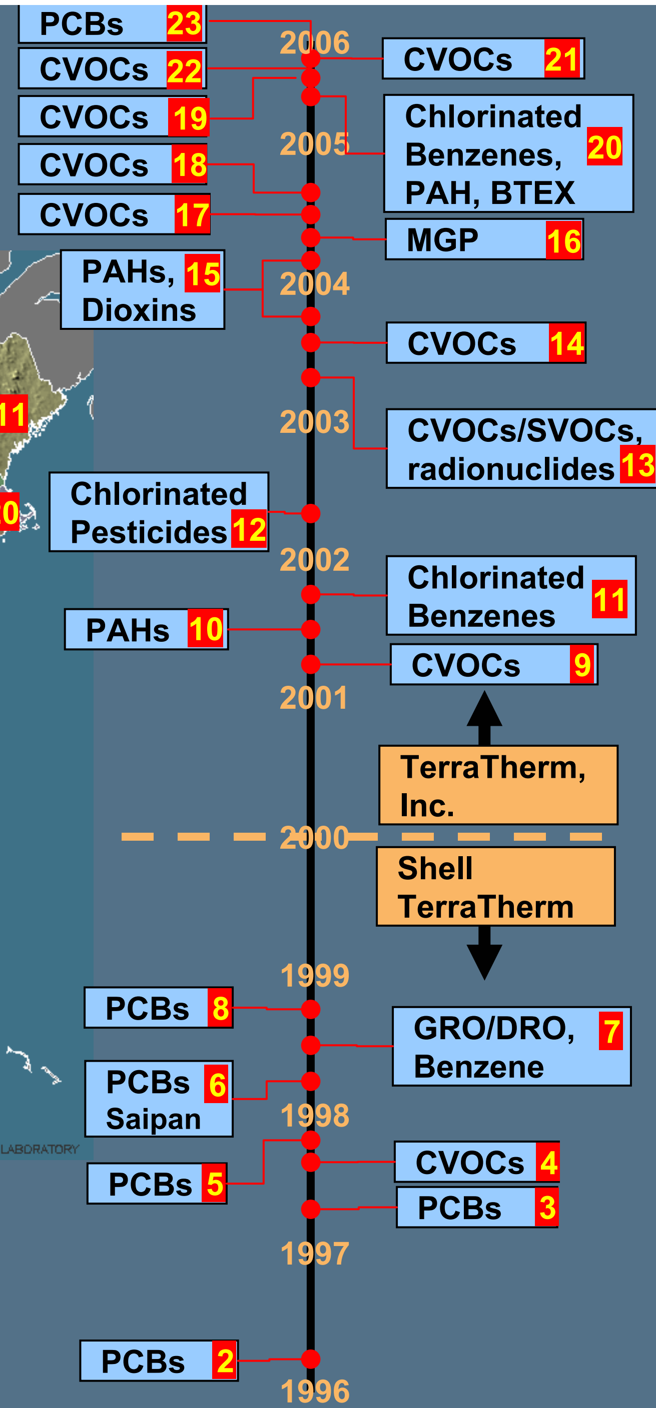
Cost of power: $250K

Post-development value: ~$300M

TERRATHERM®

ISTD Development and Deployment





Shell R&D 1
1980's through 2000's

SERDP
Strategic Environmental Research and Development Program

TCH Research (Ongoing)

TERRATHERM® | MK Tech Solutions | VEGAS

1D

2D

- **1D tests to select and characterize soils** for large-scale experiments
- **2D experiments on heat front propagation and DNAPL mobilization**

- **Large-scale (150 m³) 3-D container experiments of TCH treatment of DNAPL under saturated conditions**
- **Accompanying numerical simulations**

Reerslev, Denmark Municipal Well Field

Threatened by nearby DNAPL source area, which is currently being considerated for ISTD.

TERRATHERM®

Concluding Remarks

- ISTR can be Tailored to the Needs of the Remediation Project
- ISTR is Well-Suited to Small Urban Sites
- ISTR is Rapid, Certain and Thorough, without the Drawbacks of Excavation
  - Clean to Residential Standards if Desired
  - Low Impacts to Neighbors
  - Cost-Competitive
  - Guarantees Available
- Turn a Liability into an Asset!

About TerraTherm, Inc.

- Exclusive licensee of ISTD technology:
  - Within the U.S., from the Univ. of Texas at Austin. Protected by 24 U.S. patents.
  - Outside the U.S., from Shell Oil Co. Protected by 8 patents, and patents pending.
- Sublicensees in Denmark and Sweden (Krüger A/S); U.K. (AIG Engineering Group, Ltd.)
- International Partners in Denmark (NIRÁS); Germany (reconsite GmbH; *VEGAS*); and Japan (SheGoTec Japan, Inc.)
- For more information, please visit www.terratherm.com

TERRATHERM®

Supplemental Data

Documented Results of Representative SEE, ERH and TCH Projects

Representative Steam Enhanced Extraction (SEE) Results

Site Name	Contaminants	Depth (m)	Volume (m^3)	# wells	Starting contamination level	Post-treatment contaminant levels	Cost ($/m3)
Portsmouth Gaseous Diffusion Plant, OH	TCE	11	3,800	22	>500 mg/kg, ~ 500 kg	~90% reduction in soils, removed 1,100 lbs	NA
Alameda Point, CA	TCE+diesel+motor oil	4	2,300	13	>3,000 mg/kg, >10,000 µg/L	99.8 % TCE mass reduction (<5 mg/kg, <50 µg/L)	390
Beale AFB, Marysville, CA	TCE	12	300	1	1,000 µg/L	80-90% reduction in target zone	NA
Edwards AFB, CA	TCE+GRO+DRO	18	1,500	5	NAPL in fractures, >1,000 kg in source zone	ND above water table (<10 µg/kg TCE in rock chips), 50-90% dissolved TCE reduction below water table	260
Young-Rainey STAR Center Area A, FL	TCE,Toluene, $MeCl_2$, DCE, TPH	10	10,700	51	LNAPL and DNAPL, >500 mg/kg VOCs, >100,000 µg/L TCE	<0.03 mg/kg VOCs, <30 µg/l TCE	350
Visalia Pole Yard	Creosote	43	306,000	30	NAPL and >1,000 mg/kg	<MCL in compliance wells	85

(Courtesy of G. Heron)

Representative Electrical Resistance Heating (ERH) Results

Site	Major COC	Volume (m^3)/ depth (m)	Electrode Spacing (m)	Pre-treatment concentration	Remedial Goals	Post-treatment concentration	% Removal	$/m^3
AF Plant 4, Ft. Worth, TX	TCE	18300/ 11	5.8	32.2 mg/L	met	4.1 mg/L	97	170-180
IR Site 5, Alameda Pt., CA	1,1,1-TCA	13000/ 9	6.1		met		99	
Paducah, KY	TCE	4400/ 30			met		99	1570 (pilot)
Silresim, Lowell, MA	TCE	960/ 12	5		not met		96	1675 (pilot)
Dry Cleaner Chicago, IL	PCE	680/ 6	2.4 to 3.7	1,400 mg/kg	met	50 mg/kg	96	1020
ICN Pharmaceut. Portland, OR	TCE	/ 18		150 mg/L	met	8.1 mg/L	99.9	130

(Peacock et al. 2004; Cacciatore et al. 2004; Beyke et al. 2004; Hayes and Borochaner, 2004; Hoenig et al. 2004; Peterson et al. 2004)

Representative Thermal Conduction Heating (TCH) Results

Site	Major COCs	Depth (m)	Volume (m^3)	Initial Max. Concentration (mg/kg)	Final Concentration (mg/kg)*	Cost ($/$m^3$)
Confidential Mfg Site, OH	TCE	4.6	8800	4,130	< 0.07	180
Terminal One, Richmond, CA	PCE	6.1	5350	610	0.012	350
Shell Fuel Terminal, Eugene, OR	Benzene Gasoline/ Diesel	3.7	13800	3.3 < 2.4 m free product	< 0.044 free product removed	260
Naval Facility Centerville Beach, Ferndale, CA	PCB	4.6	1180	800	< 0.17	550
National Grid, N. Adams, MA	Naphthalene B[a]P	5.5	780	679 20	5.7 0.33	1090
Southern California Edison, Alhambra, CA	PAH (B[a]P Eq.) Dioxins (TEQ)	30	12400	30.6 0.018	0.059 0.00011	570

(**Stegemeier and Vinegar 2001; LaChance et al. 2004, 2006; Bierschenk et al. 2004**)

***All remedial goals met**