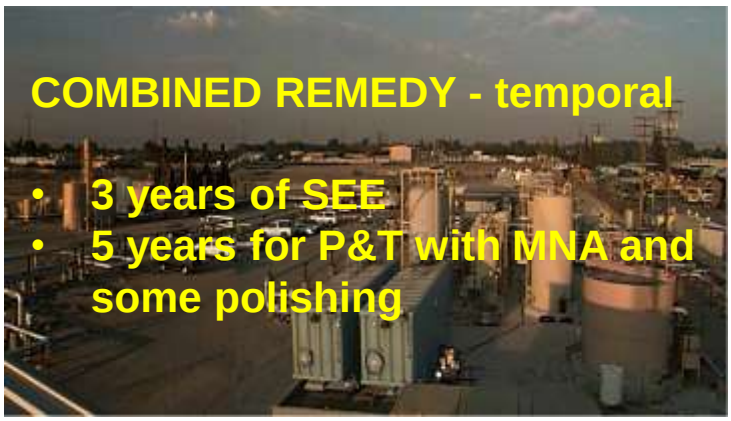
Combining Thermal with Complimentary Technologies

Gorm Heron
CTO
TerraTherm/Cascade Technical Services

Visalia Pole Yard, CA – 1998



Creosote DNAPL to +140 ft depth
Alluvial sands and gravels with clays
Both LNAPL and DNAPL

160,000 gallons removed from subsurface
Superfund Site delisted (GW goals met)
UC Berkeley – LLNL - SCE

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Pioneer, 2006 (Syracuse, NY)

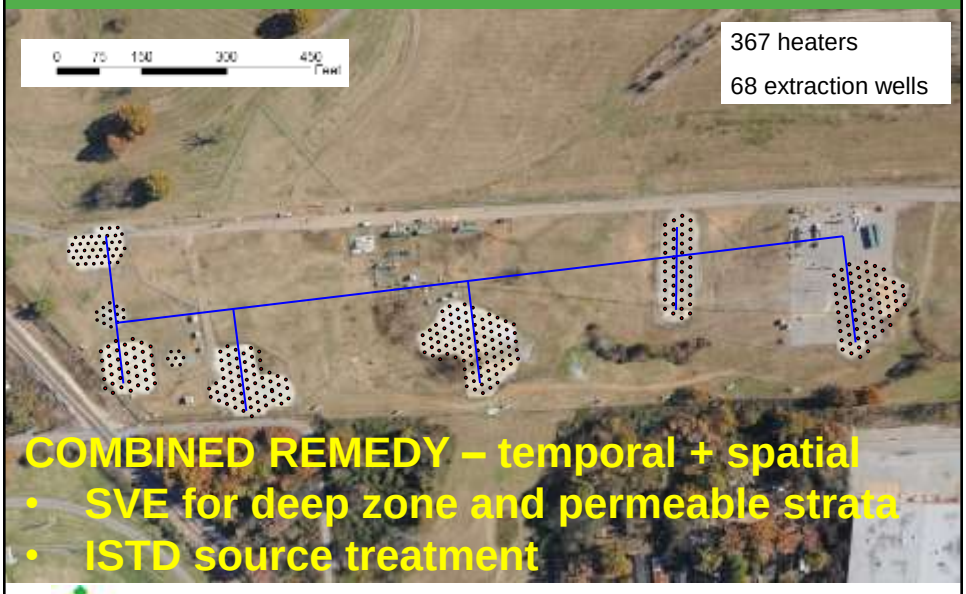
TERRATHERM
a Calgoade Company

Both photos are from the actual 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

TERRATHERM
a Calgoade Company

Memphis Depot, TN



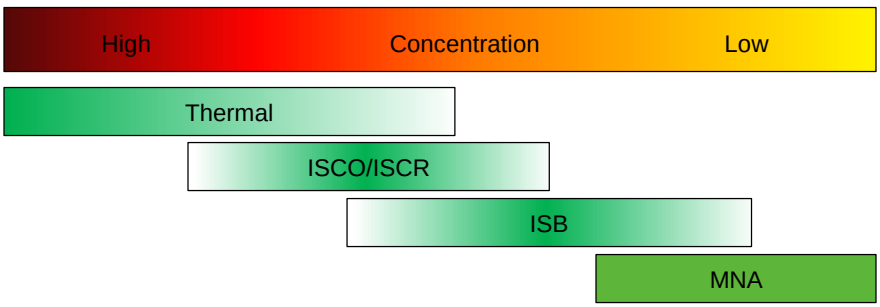
COMBINED REMEDY – temporal + spatial

- **SVE for deep zone and permeable strata**
- **ISTD source treatment**

TERRATHERM a Calgoda Company

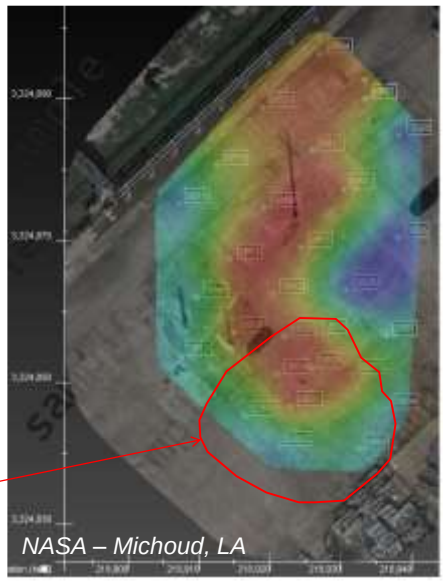
ADVISE | DESIGN | BUILD | OPERATE

Technology fit versus mass/concentrations



Site Characterization

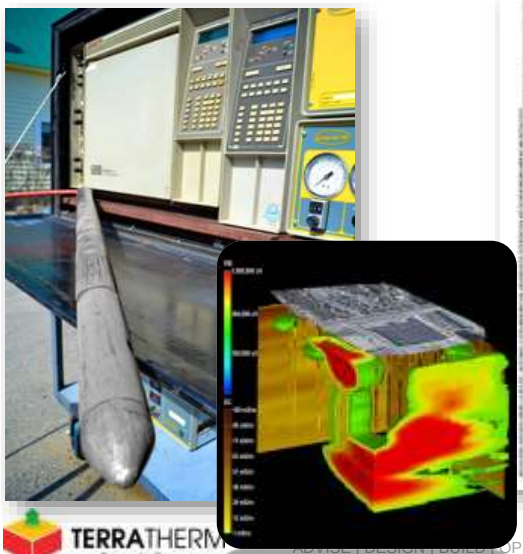
- Nail the Conceptual Site Model
- Define treatment volume
- Understand hydrogeology

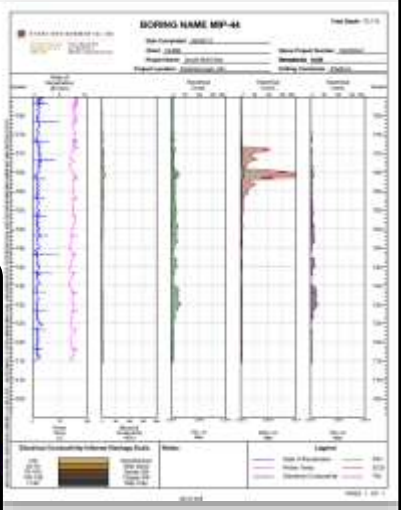


TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

MIP: High Resolution Rapid Screening





TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

UVOST

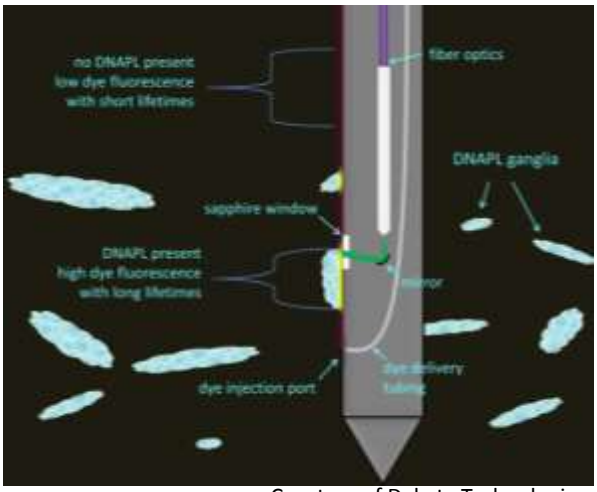
Ultra Violet Optical Screening Tool (UVOST)

- Fuel NAPL
- Best for use where presence of NAPL is driver for investigation
- Detects PAH
- Provides identification of fuel type
- **Cannot see dissolved phase PAHs**

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Dye LIF- Direct Detection of Cl Solvent DNAPLs



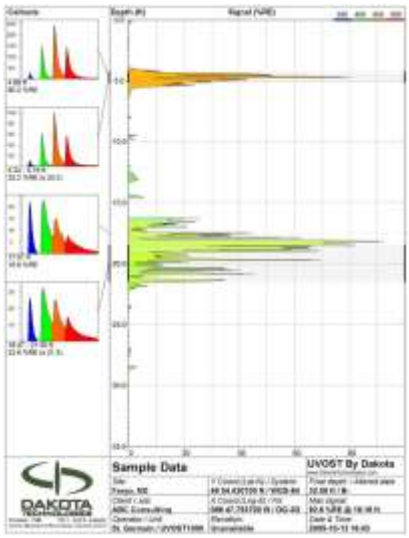
Courtesy of Dakota Technologies

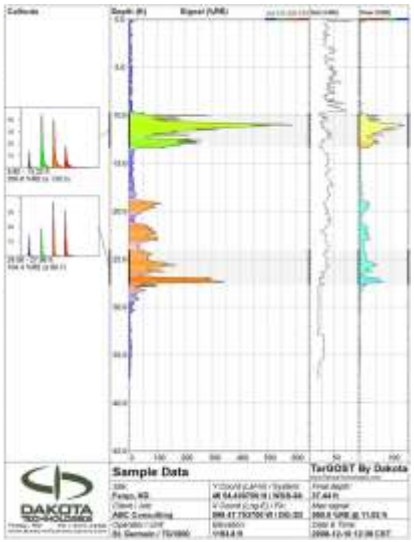
Laser Induced Fluorescence with hydrophobic dye injection

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

UVOST TarGOST

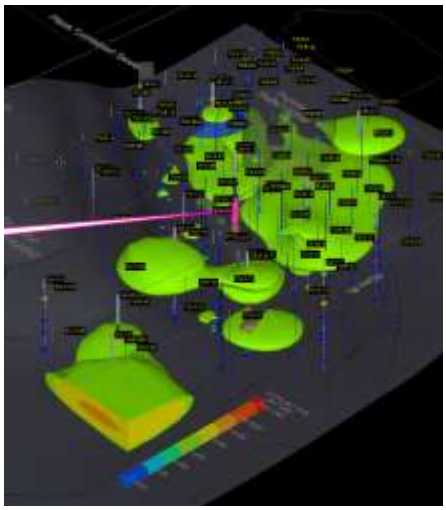


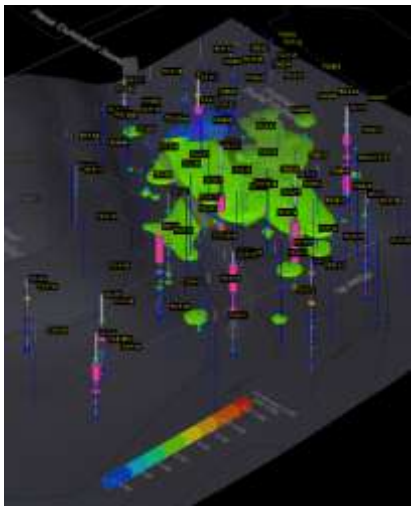


TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

HRSC and Thermal (Alton, IL)





TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

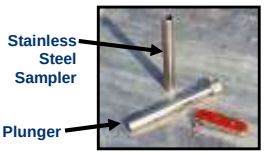
Norco, CA (100 ft deep granite rock)

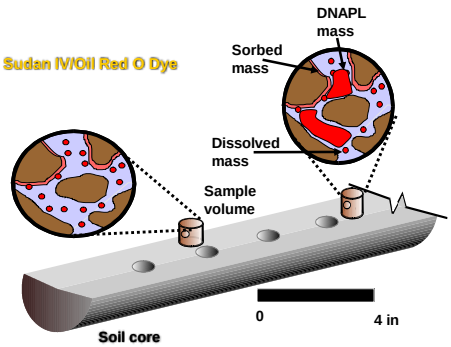
TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Essential Information from Cores

- Geologic/hydrogeologic features
- Physical, chemical & microbial properties
- Contaminant mass distributions
  Contaminant phase distributions
  (detection of DNAPL)
- Concentration gradients/diffusive fluxes
- Effectiveness of remedial technologies



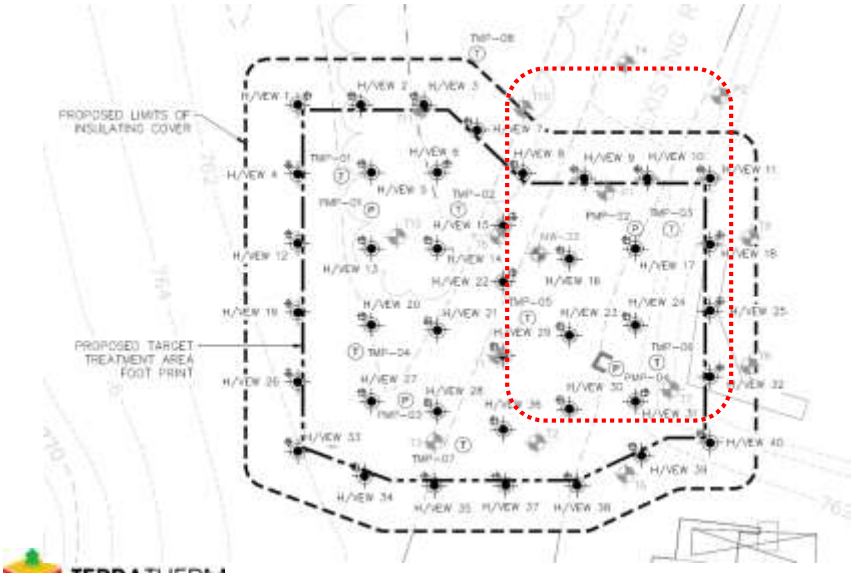


Courtesy of Beth Parker

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

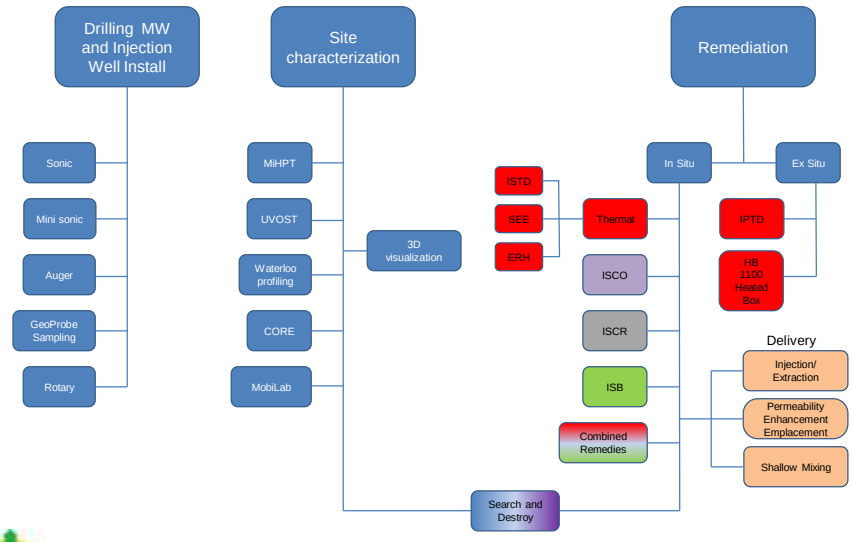
Layout (final)



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Cascade and TerraTherm

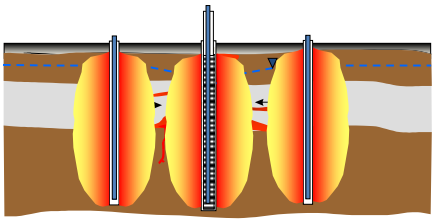


TERRATHERM a Cascade Company

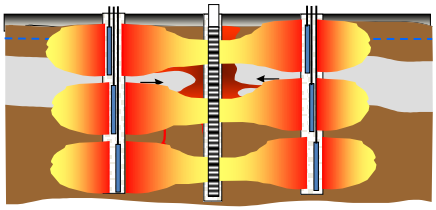
ADVISE | DESIGN | BUILD | OPERATE

Heating Methods

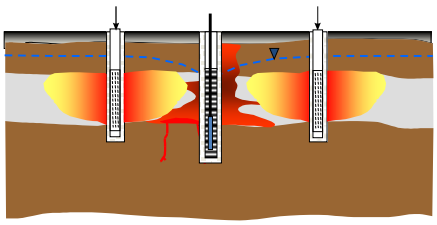
TCH/ISTD - Heating governed by **thermal conductivity**



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



SEE - Heating governed by **hydraulic conductivity**



TERRATHERM
a Cascade Company

ISTR adopted from Oil Field


Kent Udell
UC Berkeley


Robin Newmark
LLNL


Roger Aines
LLNL


Hank Sowers
Steamtech


Craig Eaker
Southern Cal Edison


Kern River oil field


Modern ISTR site


Thermally enhanced oil field equipment


ISTR treatment equipment

TERRATHERM
a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Why Combine Thermal with X?

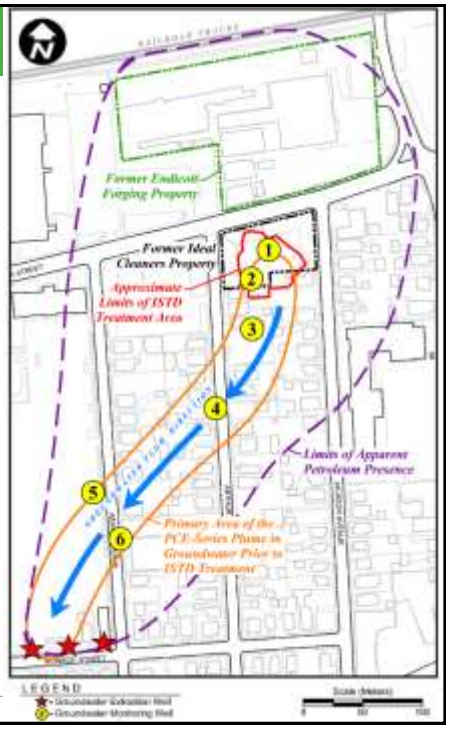
- Thermal can handle the mass
- Everything speeds up
  - SVE, P&T, NAPL removal
  - Abiotic reactions (ISCO, ISCR, Hydrolysis)
  - Biological reactions (doubling for each 10 C)
    - Aerobic (!)
    - Anaerobic (!!!)
  - The water
- Heat can be moved around
  - Steam
  - Warm water
  - Air
- Spatial and temporal combinations ready

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Endicott, NY, USA

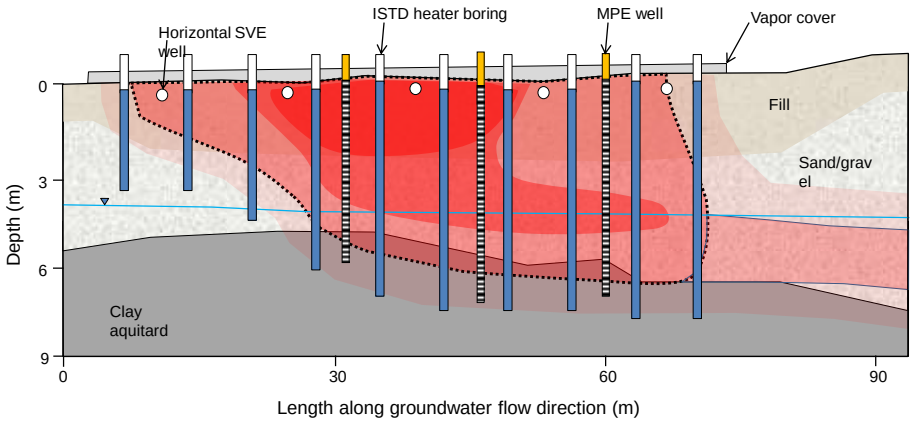
ISTR + MNA



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUIL

Thermal Treatment of source (ISTD)



TERRATHERM a Cascade Company

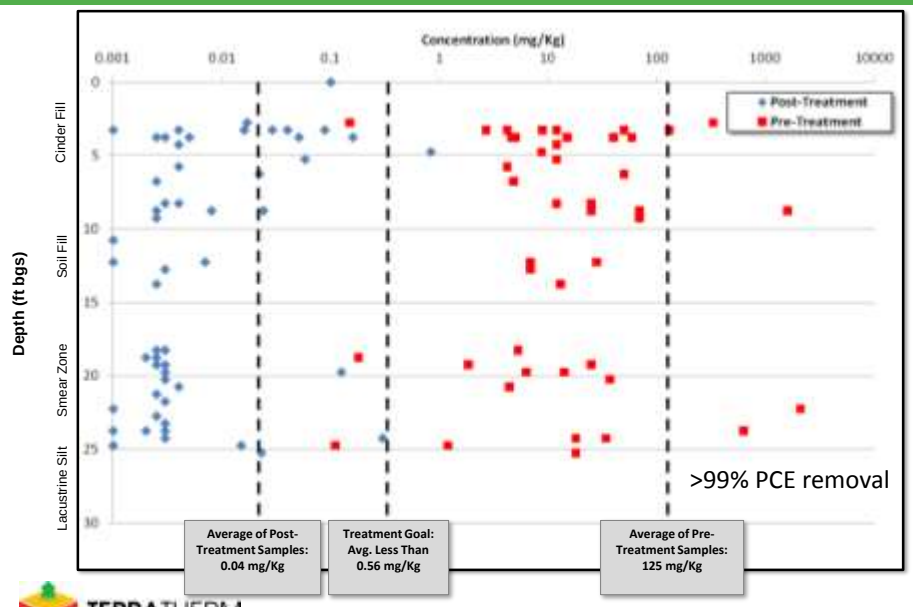
ADVISE | DESIGN | BUILD | OPERATE

Full Scale Wellfield

TERRATHERM a Cascade Company

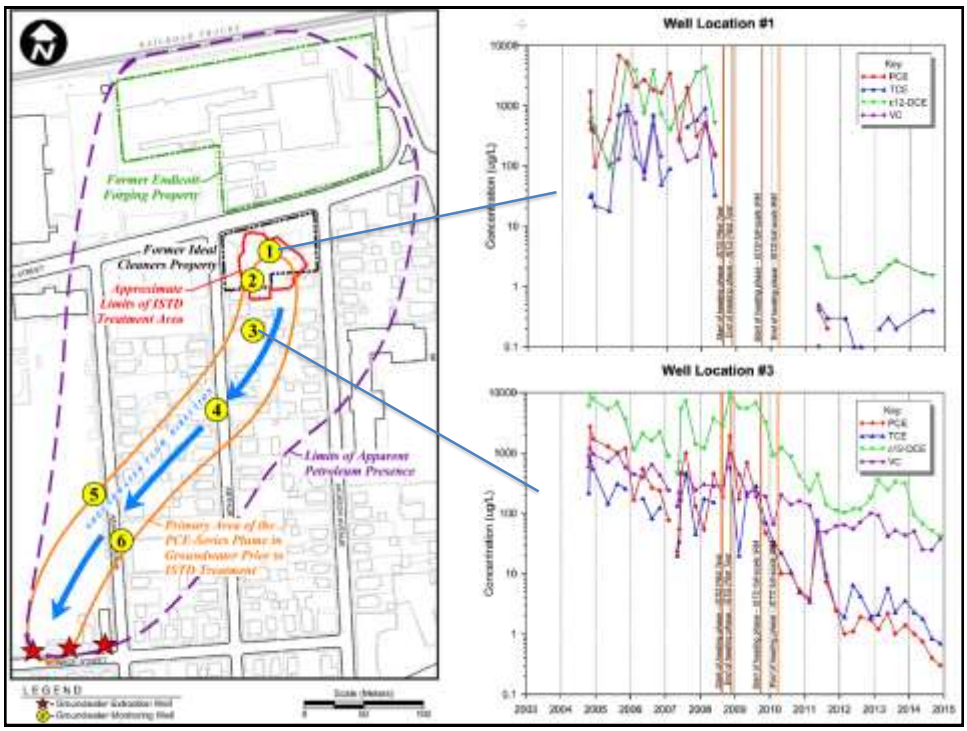
ADVISE | DESIGN | BUILD | OPERATE

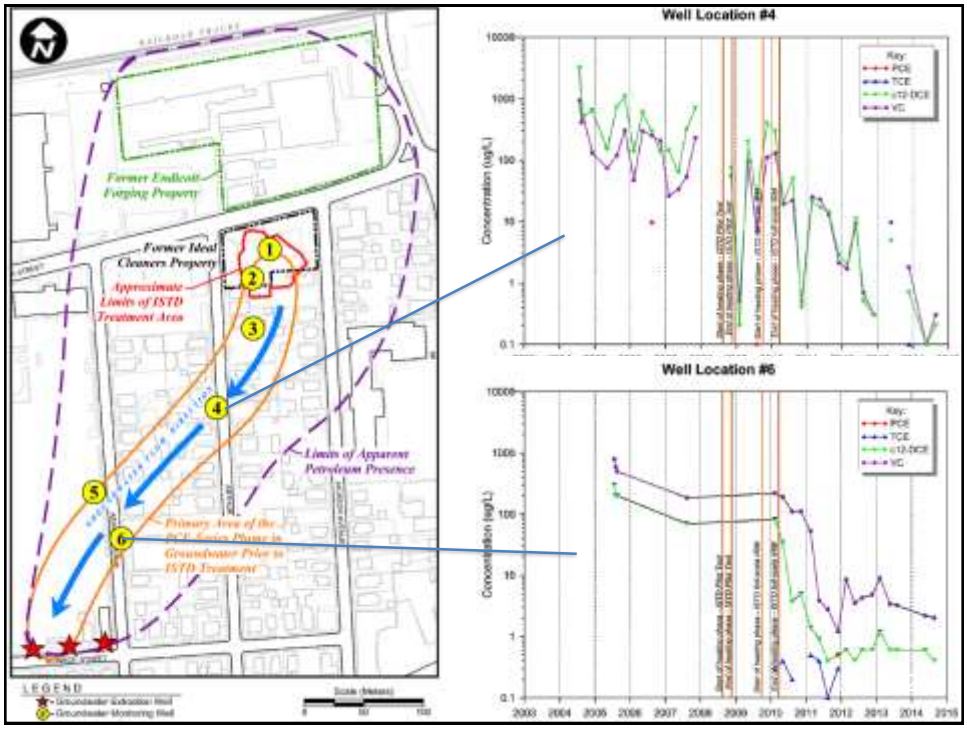
Pre- and Post-Treatment Soil Samples

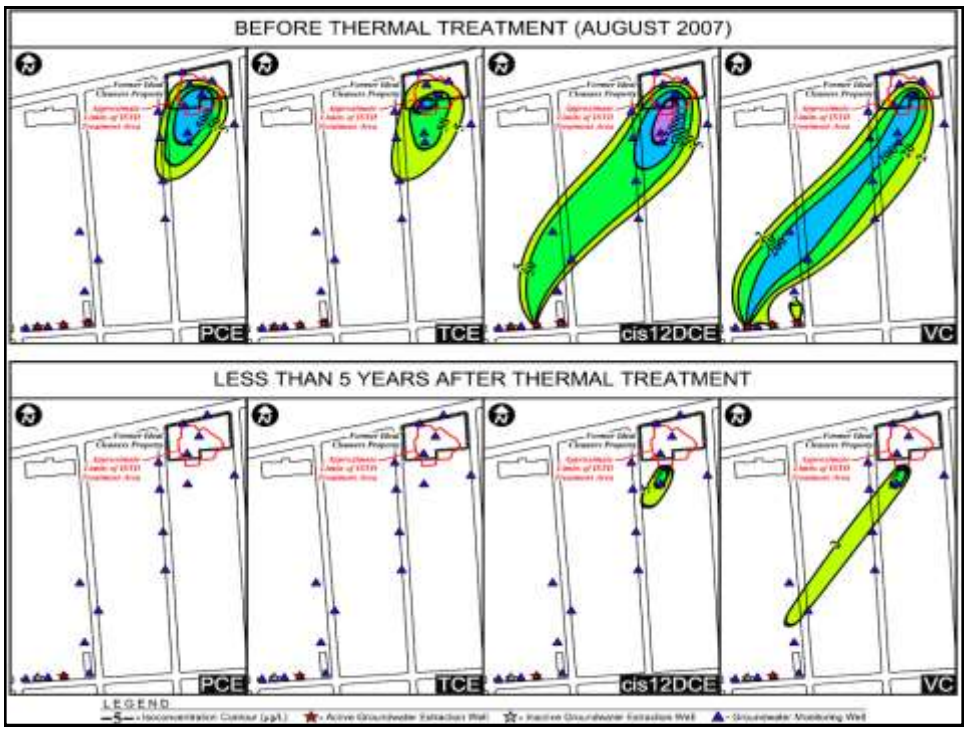


TERRATHERM
a Calscale Company

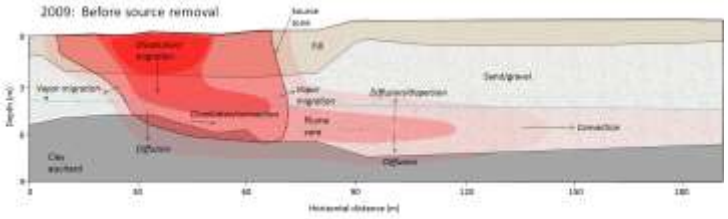
ADVISE | DESIGN | BUILD | OPERATE



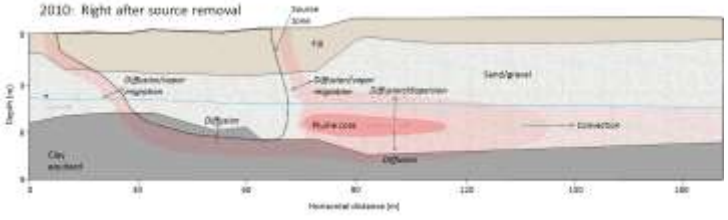

Former Endicott Forging Property
Former Ideal Cleaners Property
Approximate Limits of ISTD Treatment Area
Limits of Apparent Petroleum Presence
Primary Area of the PCE Source Plume in Groundwater Prior to ISTD Treatment
1
2
3
4
5
6
LEGEND
Well Location #4
Well Location #6
Concentration (ug/L)
Key:
PCE
TCE
c12-DCE
VC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015

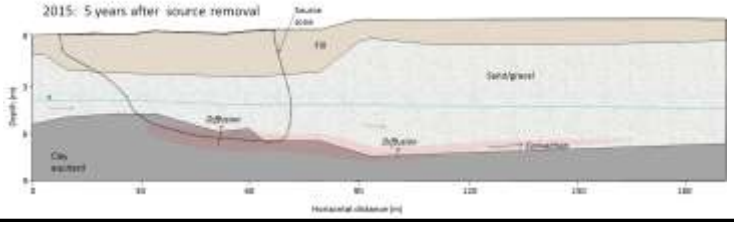

BEFORE THERMAL TREATMENT (AUGUST 2007)
PCE
TCE
cis12DCE
VC
LESS THAN 5 YEARS AFTER THERMAL TREATMENT
PCE
TCE
cis12DCE
VC
LEGEND

57 kg/yr

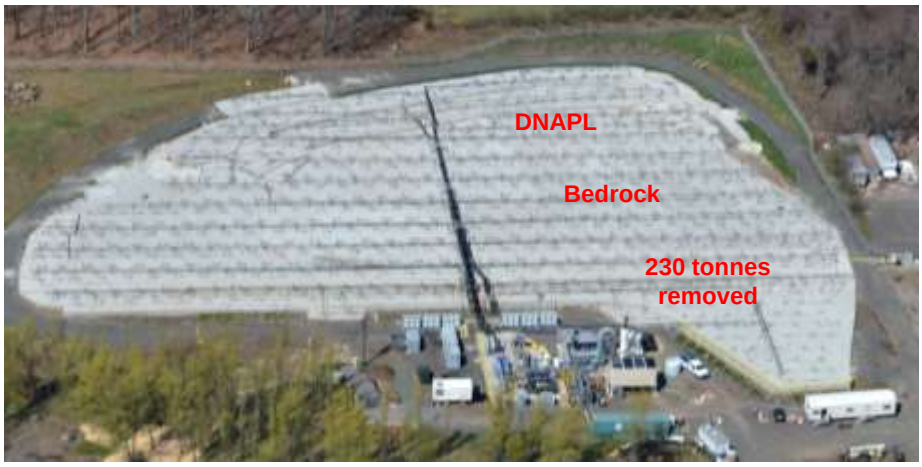


0.07 kg/yr





SRSNE - DNAPL in overburden



TERRATHERM a Cascade Company

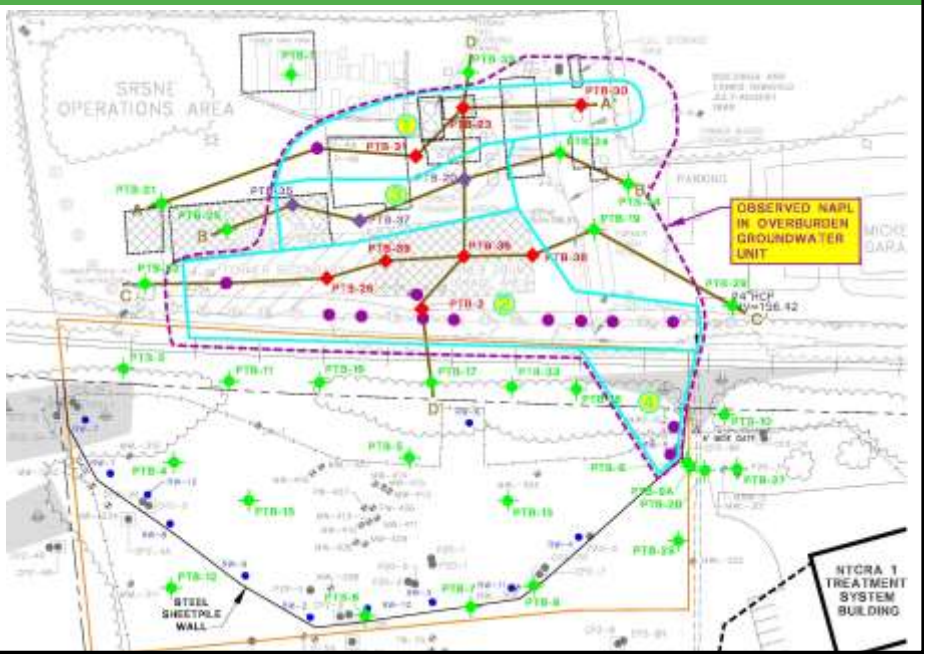
ADVISE | DESIGN | BUILD | OPERATE

Thermal Conduction Heating

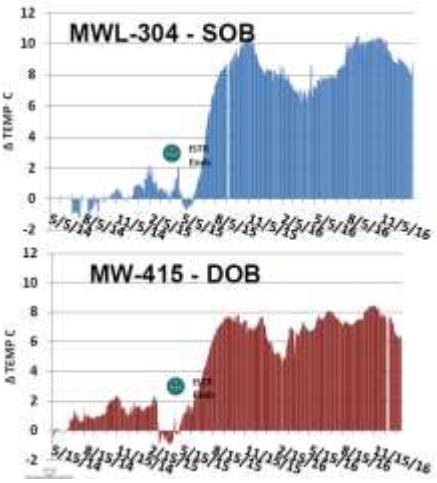
TERRATHERM a Calgoide Company

ADVISE | DESIGN | BUILD | OPERATE

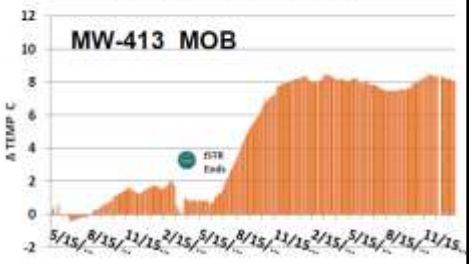
ISTR Target Zone



SRSNE – groundwater temperature



Monitoring wells ~115' downgradient of ISTR Zone

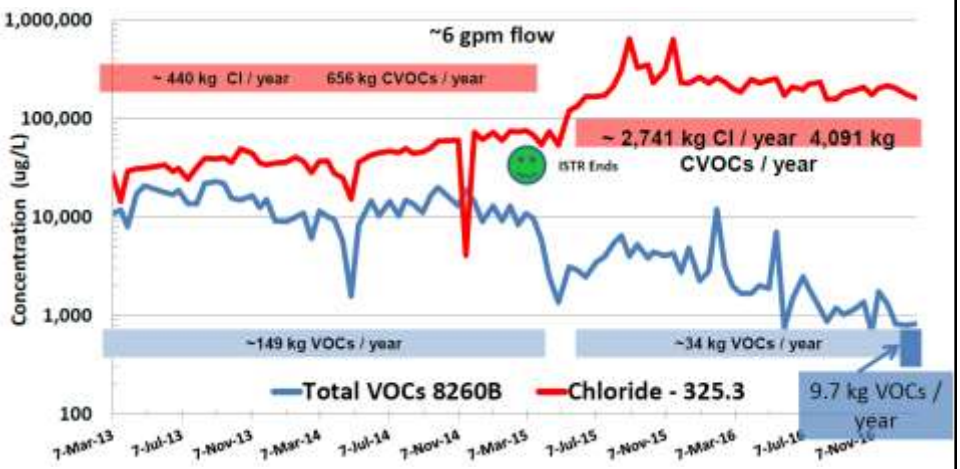


Figures thanks to Rowan Thompson BS/MS - RIT '17

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

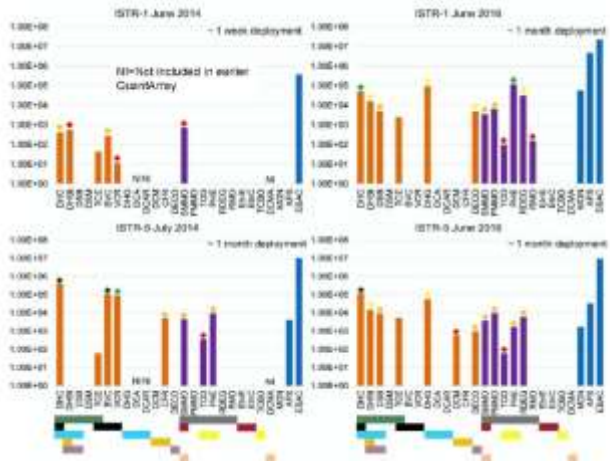
SRSNE – treatment system influent



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

SRSNE – qPCR data



GW Temperatures		
ISTR-1	Apr-14	Jun-16
Depth	°C	
Top	29.8	31.3
Middle	33.9	33
Bottom	35.4	34

Abundance
- Low
- Medium-Low
- Medium
- Medium-High
- High

- Anaerobic Reductive Dechlorination
- Aerobic Cometabolism
- Methanogens, sulfate reducers, total Bacteria

ISTR-5	Apr-14	Jun-16
Depth	°C	
Top	29.3	32.9
Middle	32	36
Bottom	34.4	36.5

Anaerobic Degradation
- Parent Chlorinated Ethenes
- Daughter Chlorinated Ethenes
- Chlorinated Ethanes
- Chlorinated Methanes
- Chlorinated Benzenes

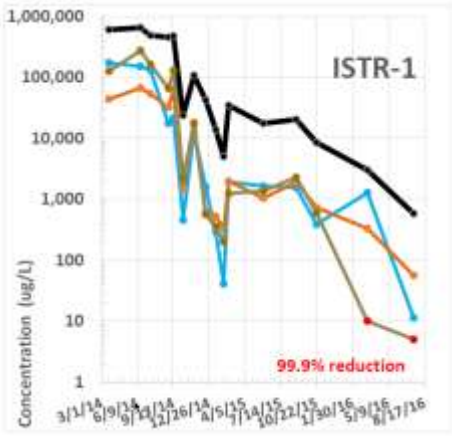
Aerobic Degradation
- Chlorinated Ethenes
- Vinyl Chloride
- Chlorinated Benzenes
- Chlorinated Methanes

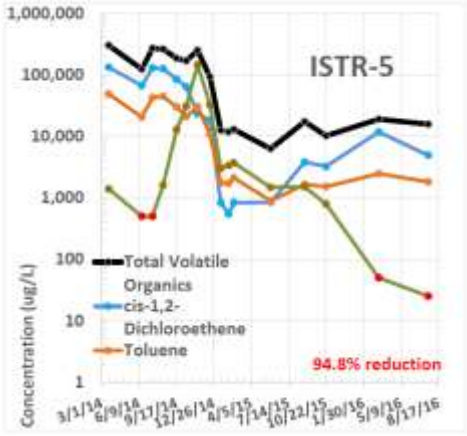
Annual Compliance Report (February 2017)

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

SRSNE – VOCs in groundwater





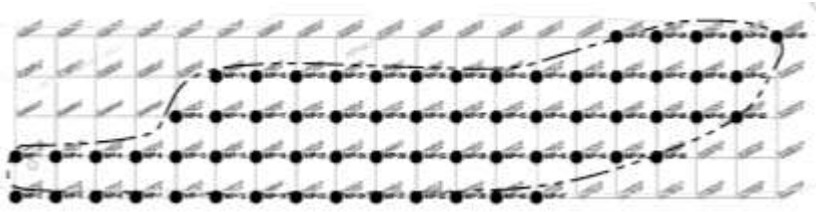
TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

35

Schenectady: Waterloo^{APS} Profiling

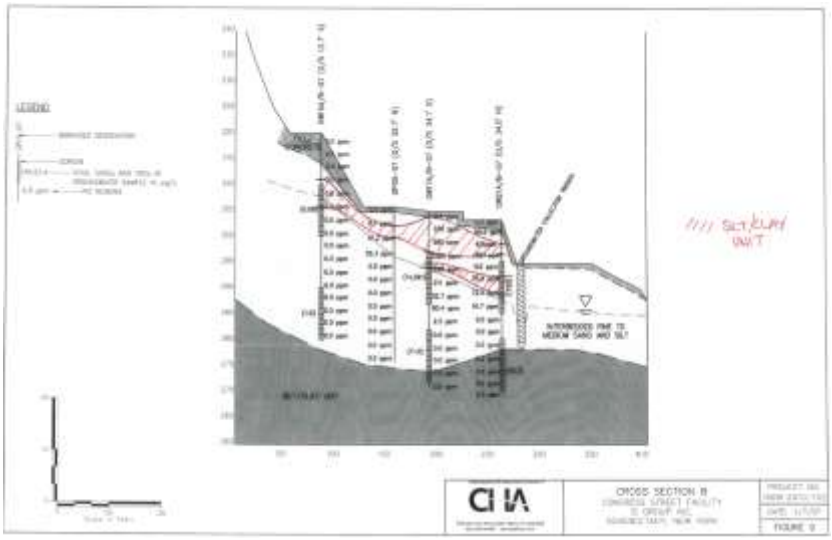
- 65 borings
- Sampled on a grid with uniform 25ft spacing
- All borings advanced to 15 ft bgs



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

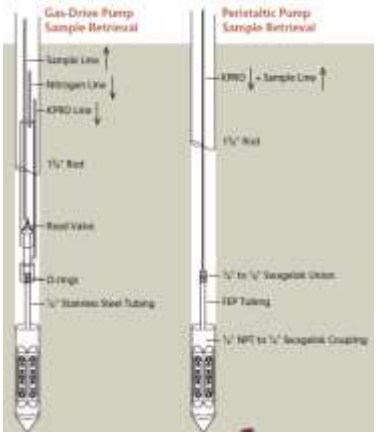
Conceptual Model: Cross Section B to B'



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

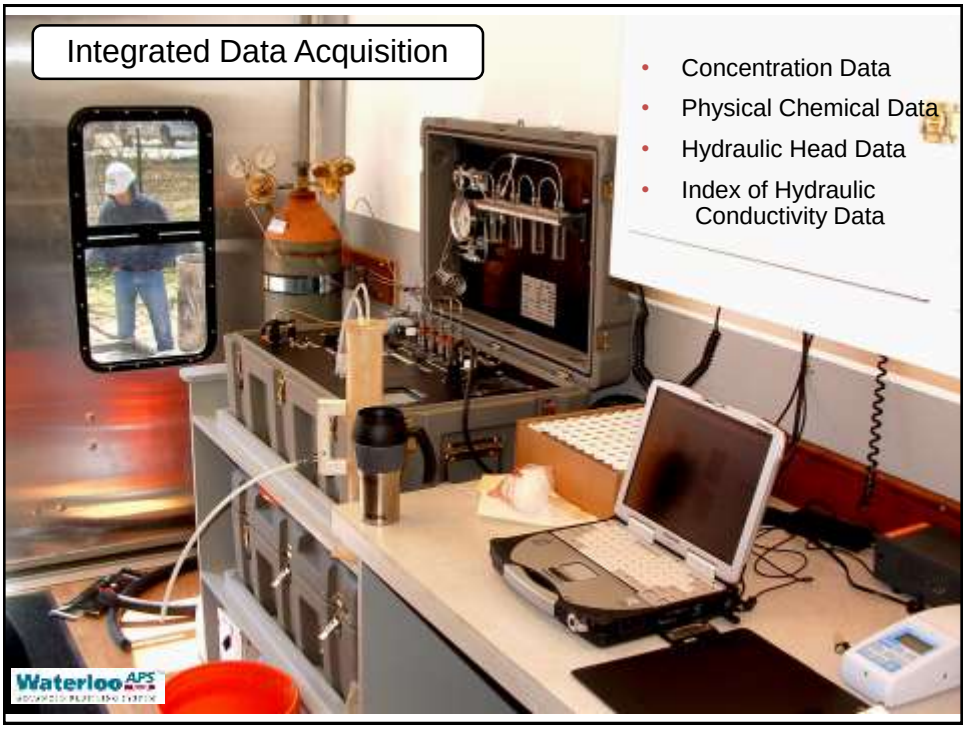
The Right Profiler for the Job



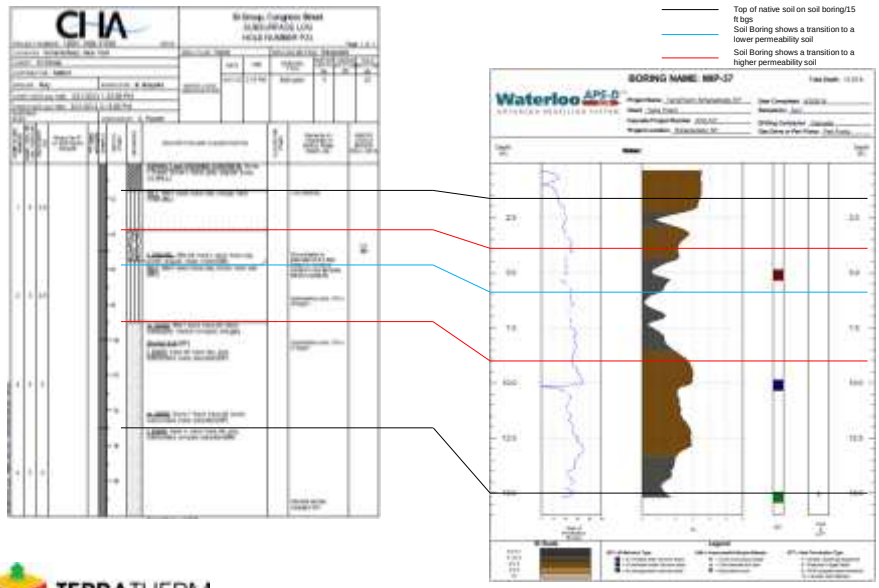
APS 225 APS 175 APS 150

Waterloo APS THERM

ADVISE | DESIGN | BUILD | OPERATE



PZ3, K ~ 2.37E-05 cm/s

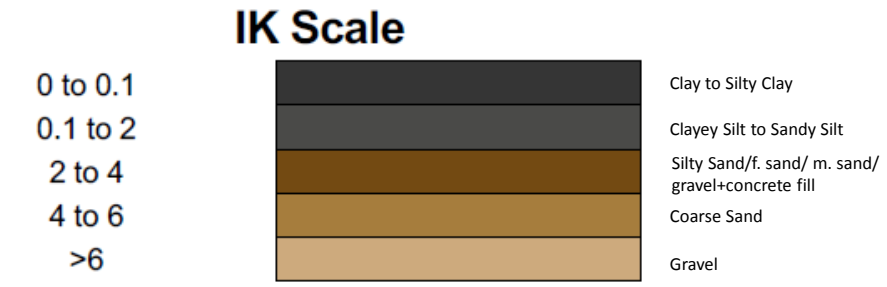


TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Waterloo^{APS} I_K Correlated to Soil Borings

Based on the analysis in previous slides the I_k scale generally corresponds to the lithology indicated on the right:

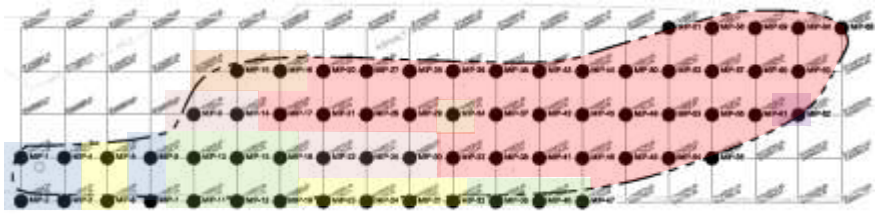


TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Interpolating Screen Locations from Waterloo^{APS} Boring Logs – Results

Bottom of Screened Interval and/or Boring over MIP Layout

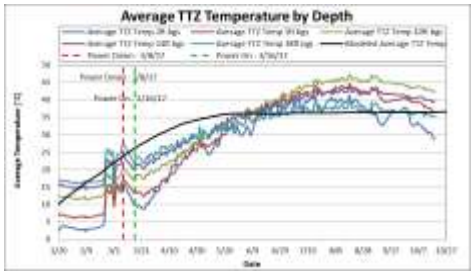


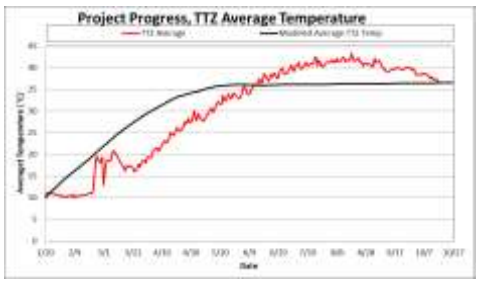
Key	Bottom of Boring [ft bgs]
	5.0
	5.5
	6.0
	6.5
	7.0
	7.5
	8.0

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Average TTZ Temperature



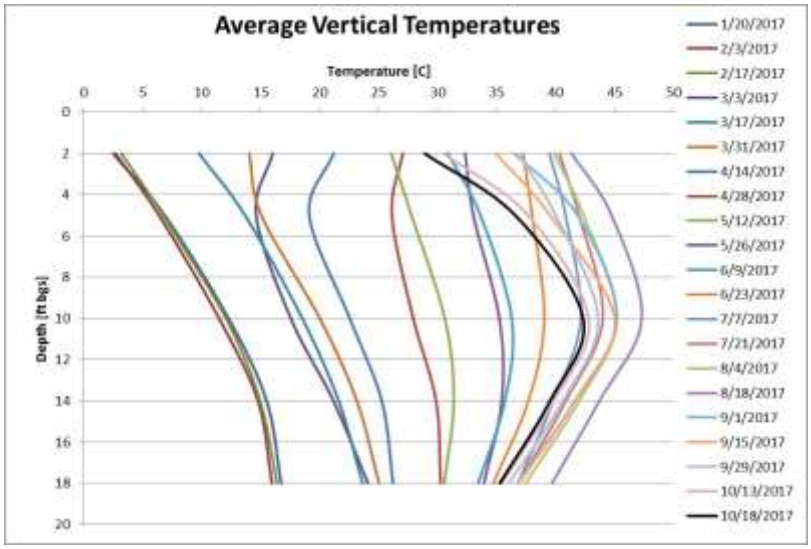


Average Temperature at Centroid Locations: 36.5°C (Last Week 38.5°C)

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

TTZ Vertical Temperature Profile



Most recent data is black line

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

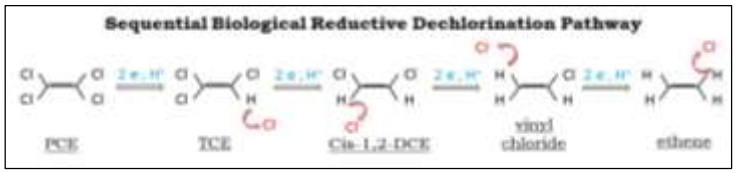
Chlorinated Solvent Biodegradation

Aerobic metabolism - COCs, **temperature**, pH, and salinity

Anaerobic - chlorinated compounds used to facilitate respiration via an electron transfer processes

Chlorinated compound degradation - reductive dechlorination

- H atoms substituted for a Cl atom
- VC resists reductive dechlorination - co-metabolism for breakdown of VC



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Combining ISTR with Bio

Bio-Polishing – Utilizing residual heat energy from completed ISTR to "polish" off source area contamination through enhanced biodegradation.

Low-Temp Heat Enhanced Bio Application – Deploy an ISTR system with the operational strategy of achieving 30 to 35 ^{0}C temperatures throughout subsurface, maximizing hydrolysis and biodegradation reaction rates while increasing free product extraction (if exists).

ISTR Source- Heat Enhanced Biodegradation Diffuse Downgradient Plume – Deploy an ISTR system with the operational strategy of achieving 100^{0}C temperatures in the source area, and allow warm water to move downgradient to aid in the biodegradation of dissolved phase diffuse plume area.

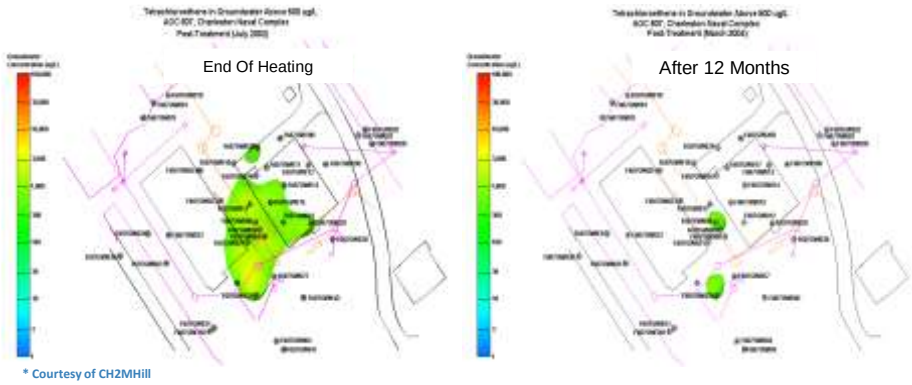
TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Advantages to Combined ISTR-Bio Approaches

Bio-Polishing

- Well defined treatment strategy
- $/lb COC removed increases as concentrations decrease
- Repurposes and reuses energy already input into subsurface – Sustainable and Efficient
- little additional stimulation/augmentation following ISTR treatment

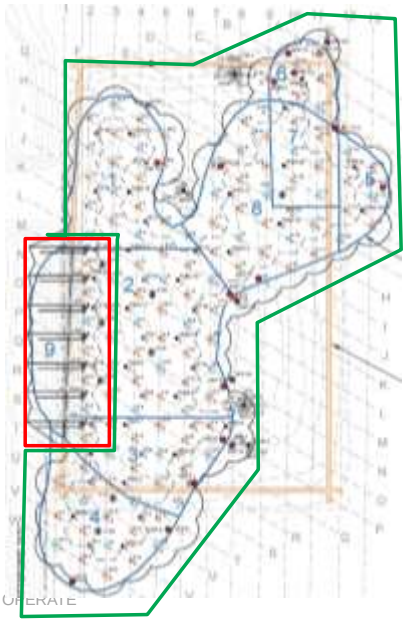


* Courtesy of CH2MHill

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Example ERH-TCH Site



TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Example ERH-TCH Site

TERRATHERM a Cascade Company

ADVISE | DESIGN | BUILD | OPERATE

Summary

- Thermal technologies are well suited for combined remedies
- Multiple options
- Experience gained over 20 years