Open Environmental Restoration Resource (OER2) Webinar

Recent Developments in Petroleum Site Management

Presented by:
NAVFAC Environmental Restoration Program

Logistics

- Submit all questions via chat box throughout the presentation
- Presentation is being recorded
- Complete the webinar survey (main feedback mechanism)

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OER2 Webinar Series

- **Why Attend?**
  - **Obtain and hear about the latest DOD and DON's policies/guidance, tools, technologies and practices to improve the ERP's efficiency**
  - **Promote innovation and share lessons learned**
  - **FEEDBACK to the ERP Leadership**
- **Who Should Attend?**
  - **ERP Community Members: RPMs, RTMs, Contractors, and other remediation practitioners who support and execute the ERP**
  - **Voluntary participation**
- **Schedule and Registration:**
  - **Every other month, 4th Wed (can be rescheduled due to holidays)**
  - **Registration link for each topic (announced via ER T2 email)**
- **Topics and Presenters:**
  - **ERP community members to submit topics (non-marketing and DON ERP-relevant) to POCs (Gunarti Coghlan – gunarti.coghlan@navy.mil or Tara Meyers - tara.meyers@navy.mil)**
  - **Selected topic will be assigned Champion to work with presenter**

Speaker Introduction

Chuck Newell (Presenter)

- Vice President of GSI Environmental Inc.
- Specializes in:
  - Site characterization
  - groundwater and surface water quality modeling
  - risk assessments
  - natural attenuation
  - LNAPL/DNAPL problems
  - Bioremediation
  - Long Term Monitoring

- B.S. Chemical Engineering (Rice)
- M.S. Environmental Engineering (Rice)
- Ph.D. Environmental Engineering (Rice)

cjnewell@gsi-net.com

Michael Singletary (Presenter)

- Senior Engineer at NAVFAC SE
- Specializes in:
  - groundwater hydrology
  - fate and transport of contaminants
  - bioremediation technologies
  - strategic planning and optimization of site investigation and remediation approaches.

- B.S. Civil Engineering (George Tech)
- M.S. Environmental Engineering (Georgia Tech)

michael.a.singletary@navy.mil

Recent Developments in Petroleum Site Management

Mike Singletary, NAVFAC
Charles Newell, GSI Environmental

OER2 Webinar Series - October 2016

Roadmap to Closure for LNAPL Sites - 2010

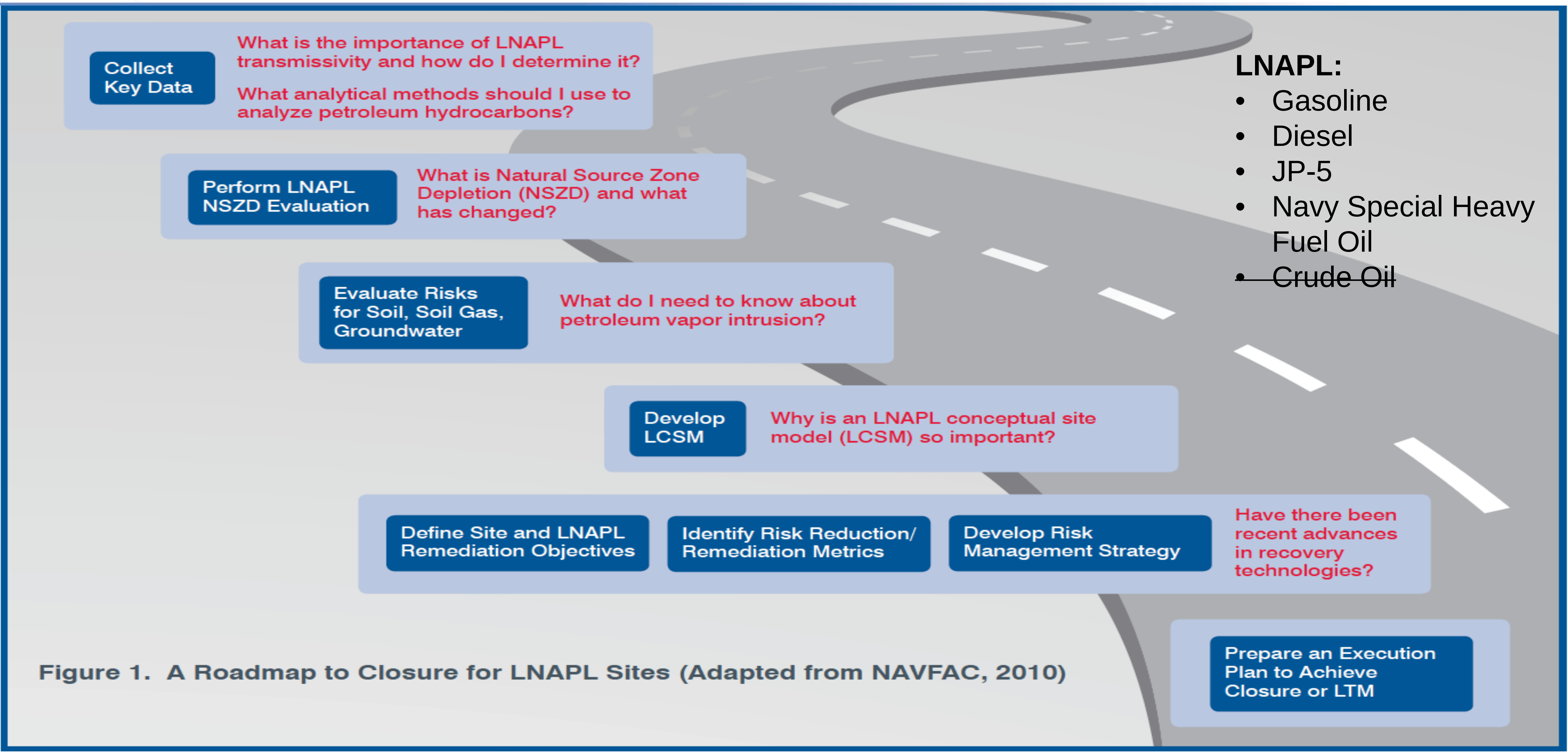
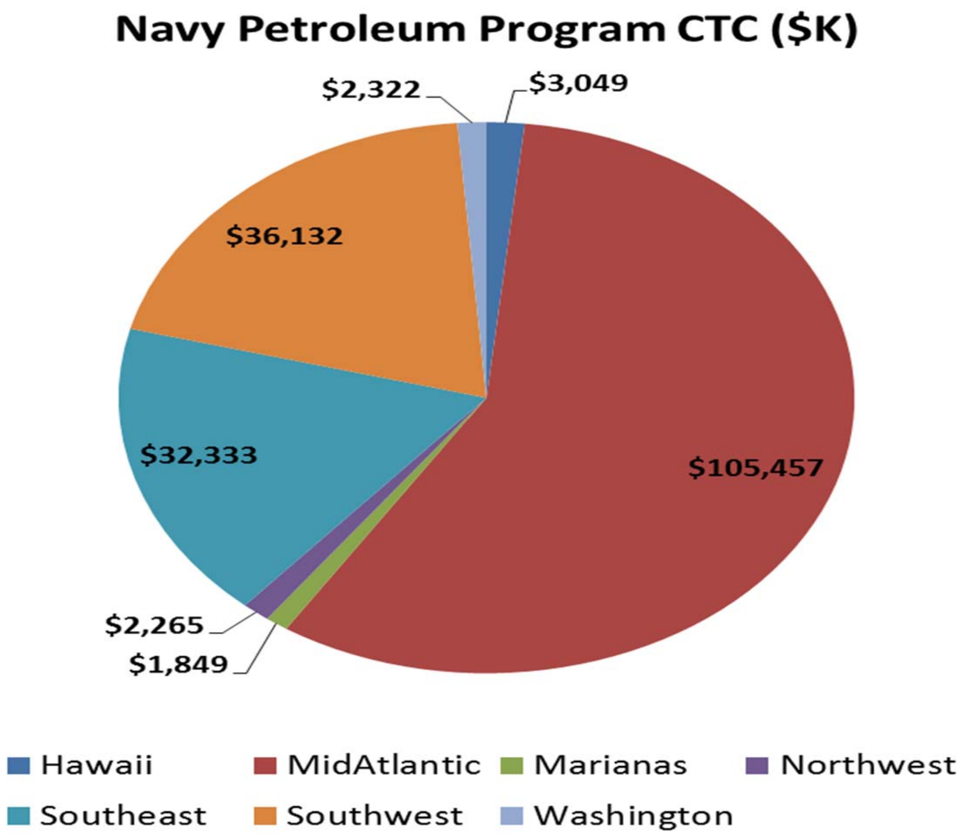


Figure 1. A Roadmap to Closure for LNAPL Sites (Adapted from NAVFAC, 2010)

Wait, there's more….

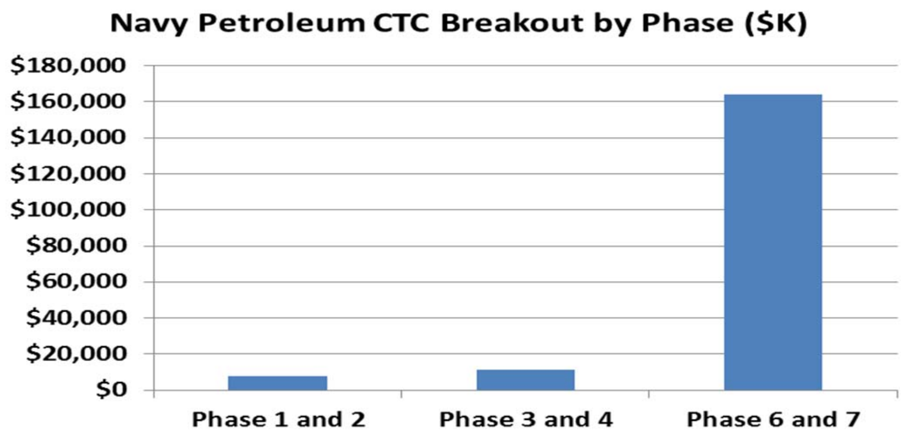
- Status of Navy petroleum site cleanup efforts
- Key regulatory issues related to Navy petroleum sites
- Key tools for evaluating the practicability of LNAPL recovery
- New issues regarding Total Petroleum Hydrocarbons (TPH) and petroleum metabolites (fractionation)
- Measuring and applying Natural Source Zone Depletion (NSZD)
- Emerging methods to enhance NSZD

Status of Navy Petroleum Site Cleanup Efforts



CTC = $183.4M

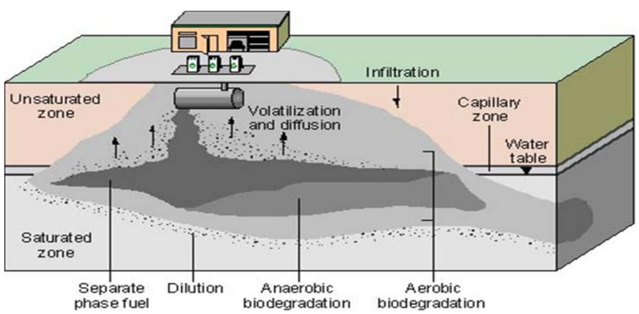
- Navy Petroleum CTC $183M
- Approximately 90% CTC in Phase 6 and 7
- Long-term costs for petroleum program likely underestimated
- Improved LNAPL conceptual site models needed to evaluate risk exposure and remedial options
- Optimization efforts needed to accelerate RC through risk-based closure options

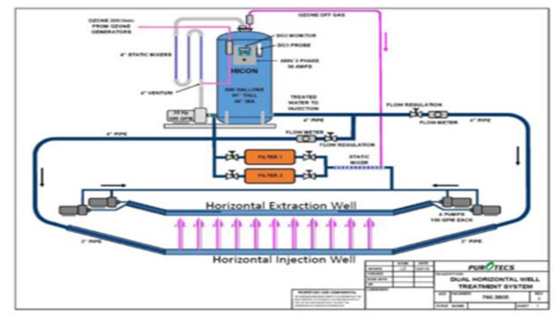


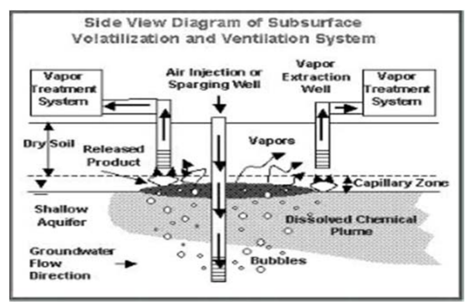
Two Ends of the Spectrum

Typical UST Cleanup
- *Excavate contaminated soils*
- *Extract free product for a while*
- *MNA for plume*

Difficult UST Cleanup
- *In-situ treatment of source*
- *Complicated groundwater remedy*
- *Pump and treat*







Webinar Outline

- Status of Navy petroleum site cleanup efforts
- **Key regulatory issues related to Navy petroleum sites**
  - **Discharge to Surface Water**
  - **Vapor Intrusion**
  - **LNAPL Recovery Limits**
- Key tools for evaluating the practicability of LNAPL recovery
- New issues regarding Total Petroleum Hydrocarbons (TPH) and petroleum metabolites (fractionation)
- Measuring and applying Natural Source Zone Depletion (NSZD)
- Emerging methods to enhance NSZD

Discharge to Surface Water

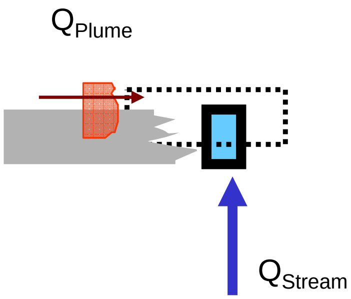
- **Discharge to Surface Water is Important Case:**
  - **Alternate Concentration Limits (ACLs)**

    If groundwater discharges to surface water

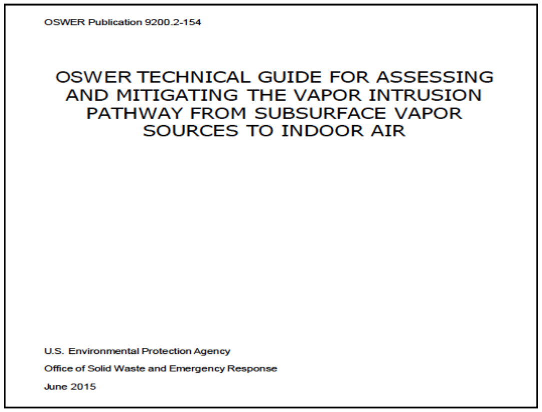
    + no increase of constituents in surface water

    + no human exposure = Possible ACL

    - Calculation based on GW models + mixing zones
  - **Transition zone (i.e., GW/SW interface)**
    - Key element in site characterization
    - Need **cross-media data** (GW, SW, sediment) to verify model results
    - Useful Navy technologies: Trident Probe, UltraSeep.
  - **Mixing zone rules**
    - State-specific from NPDES programs
    - Two criteria: Acute, lethal criteria "within short distance" & Chronic criteria at edge of mixing zone

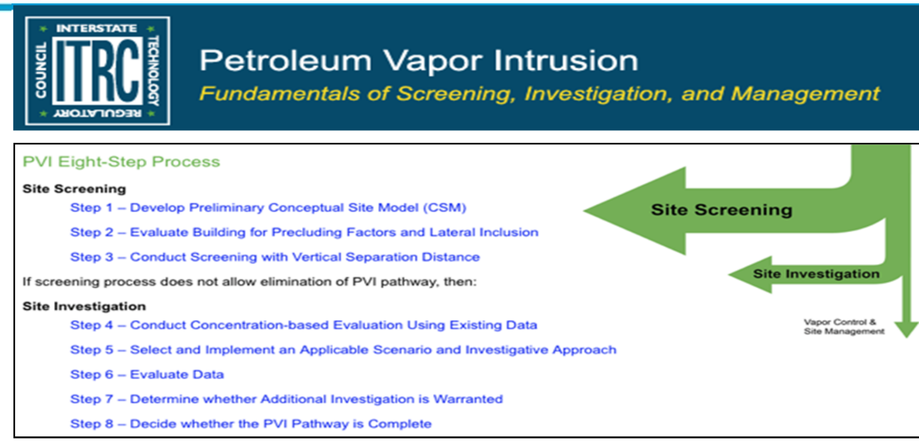


Vapor Intrusion at Petroleum Sites


OSWER Publication 9200.2-154

OSWER TECHNICAL GUIDE FOR ASSESSING AND MITIGATING THE VAPOR INTRUSION PATHWAY FROM SUBSURFACE VAPOR SOURCES TO INDOOR AIR

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
June 2015


INTERSTATE TECHNOLOGY REGULATORY COUNCIL ITRC

Petroleum Vapor Intrusion
Fundamentals of Screening, Investigation, and Management

PVI Eight-Step Process

Site Screening

- Step 1 – Develop Preliminary Conceptual Site Model (CSM)
- Step 2 – Evaluate Building for Precluding Factors and Lateral Inclusion
- Step 3 – Conduct Screening with Vertical Separation Distance

If screening process does not allow elimination of PVI pathway, then:

Site Investigation

- Step 4 – Conduct Concentration-based Evaluation Using Existing Data
- Step 5 – Select and Implement an Applicable Scenario and Investigative Approach
- Step 6 – Evaluate Data
- Step 7 – Determine whether Additional Investigation is Warranted
- Step 8 – Decide whether the PVI Pathway is Complete

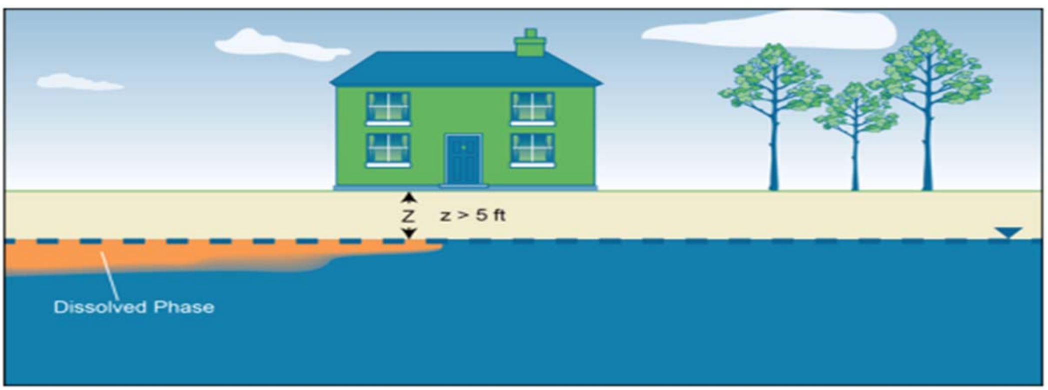


Figure 3-6. Vertical screening distances for dissolved-phase source.

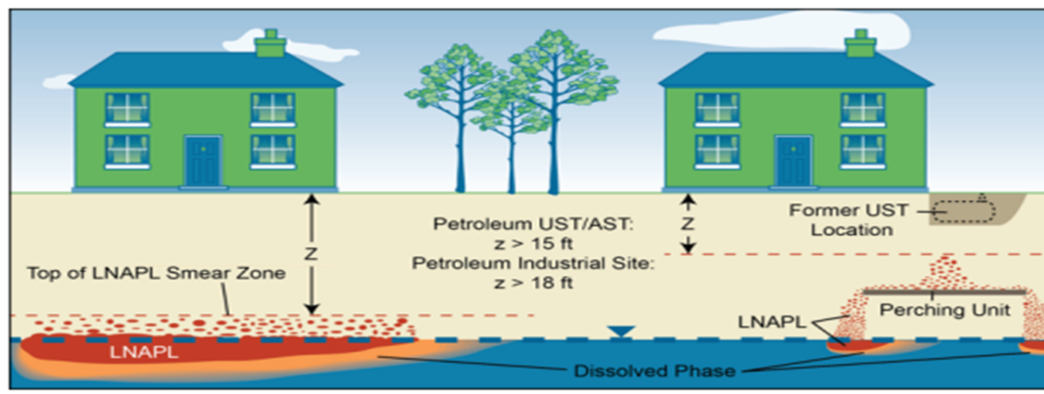


Figure 3-5. Vertical screening distances for LNAPL source.

LNAPL Recovery Limits

Old Conceptual Model

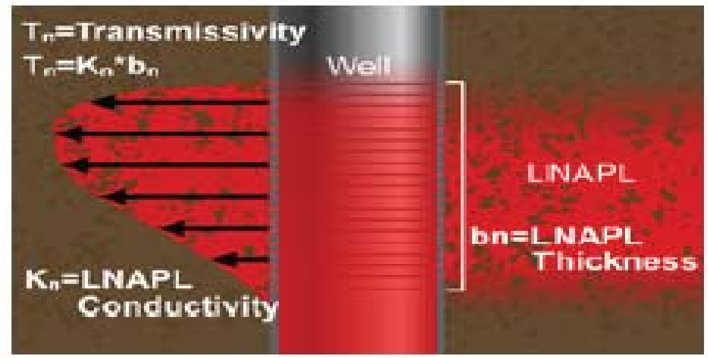
State	Measurable Level that Permits Closure	Closed Sites with LNAPL Greater Than Measurable Level? If So, Additional Criteria Used?	Source
CA	*Removed to extent practicable*	Yes. *"LUST sites can be closed if the required level of water quality will be attained within a reasonable period of time. California has closed several sites with LNAPL."*	Menatti, 2010; NEIWPCC, 2006; Lund et al., 2014
FL	*0.01 ft*	Yes. *"A site with residual soil contamination or groundwater contamination above cleanup target levels can only receive No Further Action if there are institutional controls (deed restrictions) on the property."*	NEIWPCC, 2006

		contamination above cleanup target levels can only receive No Further Action if there are institutional controls (deed restrictions) on the property."	

HI		Yes. *"Only if BTEX and PAHs are ND or well below action levels and no other receptors."*	NEIWPCC, 2006
IA	*<0.01 ft*	Yes. *"Following NAPL recovery activities, a site may be closed if product does not return in a monitoring well in excess of 0.02 ft for a period of one year."*	NEIWPCC, 2006
IL		Yes. *Obtained closures in Illinois with notable NAPL thicknesses. Site-specific basis, essentially along the same lines as Massachusetts.*	Payne, 2016
MA		Yes. *"Non-Stable NAPL is not present under current site conditions and for the foreseeable future, and all NAPL with Micro-Scale Mobility is removed if and to the extent feasible based upon consideration of CSM principles."(*)*	Marra, 2014
MI		Yes. *"Recovery of all LNAPL with a transmissivity greater than 0.5 ft²/day and that*	Lund et al., 2014

		can be recovered in a cost-effective and efficient manner."	
MO	*Maximum extent practicable*	Yes. "Site-specific criteria."	NEIWPCC, 2006
NC	*< 0.01 ft*	No. *"No receptors and removal is technically and economically infeasible."*	NEIWPCC, 2006; Lund et al., 2014
NV	*0.5 inch*	Yes. *"If a risk-based analysis was performed showing no vulnerable receptors and a fate and transport analysis performed showing that there was little potential for migration."*	NEIWPCC, 2006
RI		No	Lund et al., 2014
TX	*Unrecoverable or impractical*	Yes *"Closure can be granted when recoverable NAPL is still present if there are no receptors and the plume is stable."*	NEIWPCC, 2006
UT	*1/8-inch*	Yes. "RBCA-based approach considered on site-specific basis."	Menatti, 2010
VA	*<0.01 ft*	Yes. *"The data should support the claim that the technologies used and/or evaluated are no longer effective and that additional recovery is not practicable. If >0.01 ft exists also have to show: a) Remaining LNAPL and dissolved-phase constituents are not a risk to human health or the environment, and b). NSZD of the LNAPL body and natural attenuation of the dissolved-phase plume are documented as occurring at the site and are expected to further mitigate risk from the release, and c). The areal extent of the free phase plume at the site is shown to be stable or decreasing"*	NEIWPCC, 2006; Steers, J., 2012; Lund et al., 2014
WA	*<0.01 ft*	No. *"Ecology won't close*	NEIWPCC,

New Conceptual Model



CALCULATION TOOLS

The American Petroleum Institute (API) provides a useful tool for calculating LNAPL transmissivity from baildown test data (API, 2012).

The American Society for Testing and Materials (ASTM) has developed standardized guidance (E2856-13) for estimating LNAPL transmissivity at a site (ASTM, 2013). The ASTM method provides procedures for estimating transmissivity by performing baildown tests, skimmer pump tests, performing continuous recovery with a treatment system, and by performing tracer tests.

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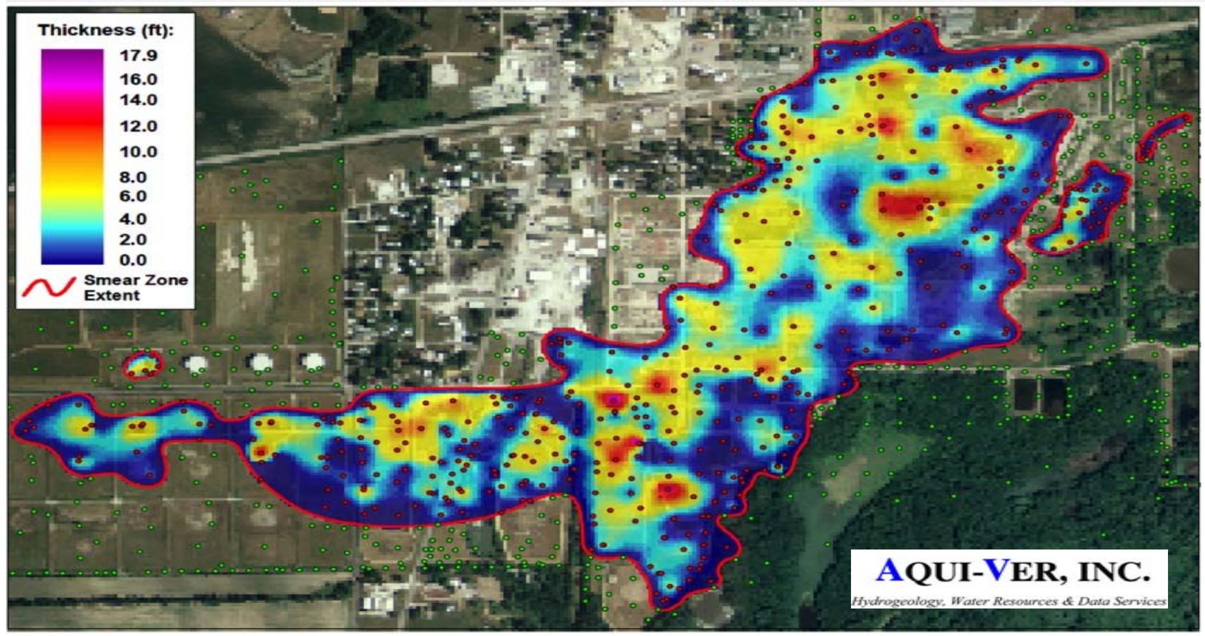
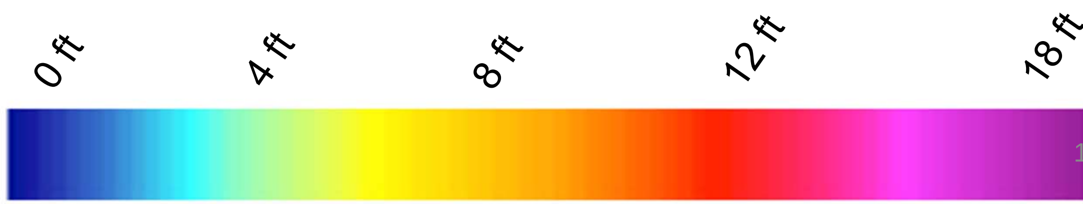
Former Midwestern Refinery LCSM Development

- Smear zone delineation (X, Y, Z)
- Review of historic conventional data
  - Wells with LNAPL
  - Dissolved phase indicators
  - Soil sample and PID indicators from soil borings
- Approximately 200 acre footprint smear zone of varying thickness and impact

Smear Zone extent





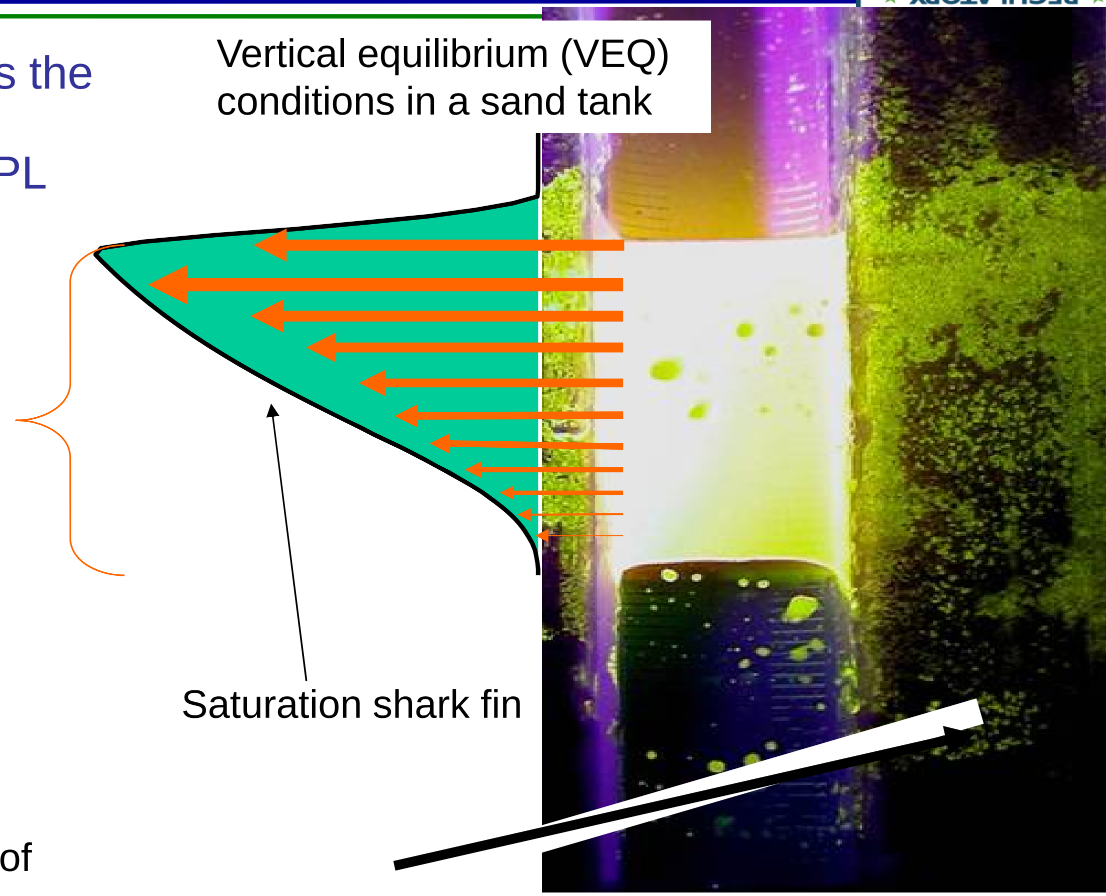
LNAPL Saturation / Transmissivity

- The zone of highest LNAPL saturation has the highest LNAPL conductivity
- Low LNAPL saturation results in low LNAPL conductivity

LNAPL Transmissivity = Sum

$$T_o = K_o \cdot b_o$$

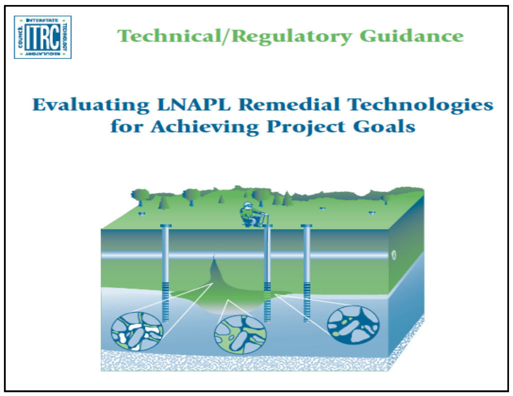
- Hydraulic recovery rate is proportional to transmissivity for a given technology
- Well thickness does not dictate relative recoverability



More information: ASTM Standard Guide for Estimation of LNAPL Transmissivity at http://www.astm.org/Standards/E2856.htm

How To Use LNAPL Transmissivity

Transmissivity as a Performance Metric:


Technical/Regulatory Guidance

Evaluating LNAPL Remedial Technologies for Achieving Project Goals

Difficult to recovery LNAPL hydraulically if T < 0.1- 0.8 ft^2/day

Four Methods To Get T_{LNAPL}

Designation: E2856 – 13

Standard Guide for
Estimation of LNAPL Transmissivity[1]

This standard is issued under the fixed designation E2856; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Manual Skimming Methods
2. Long-Term Recovery Based Methods
3. *Short-Term Baildown Tests*
4. *Tracer Based Method*

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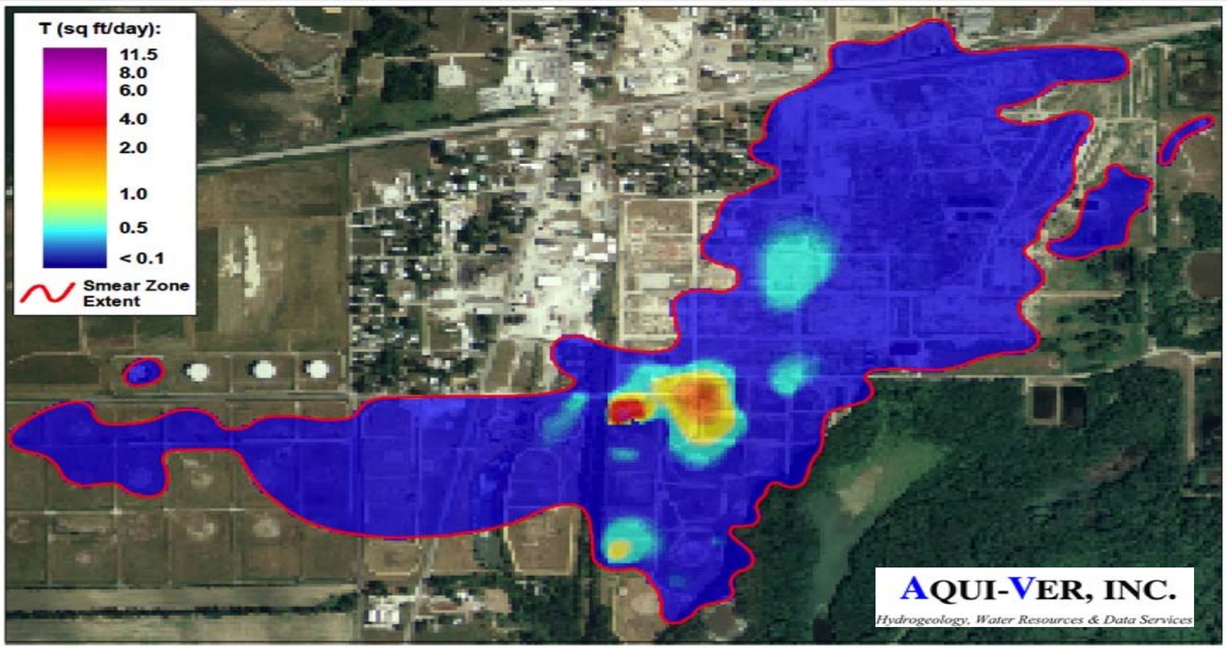
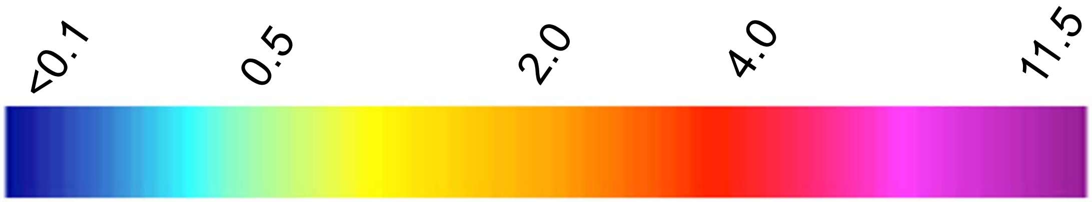
Smear Zone Transmissivity (Property of Fluid, Aquifer Material, and LNAPL Formation Thickness)

- LNAPL baildown tests conducted in all wells with LNAPL
- Transmissivity was used to focus remedial efforts where LNAPL mass recovery had a high likelihood of success
- Area of transmissivity over 1 ft^2/day is 20 acres (of 200 acre smear zone)



Ft^2/Day



METHOD 3: LNAPL Baildown Tests

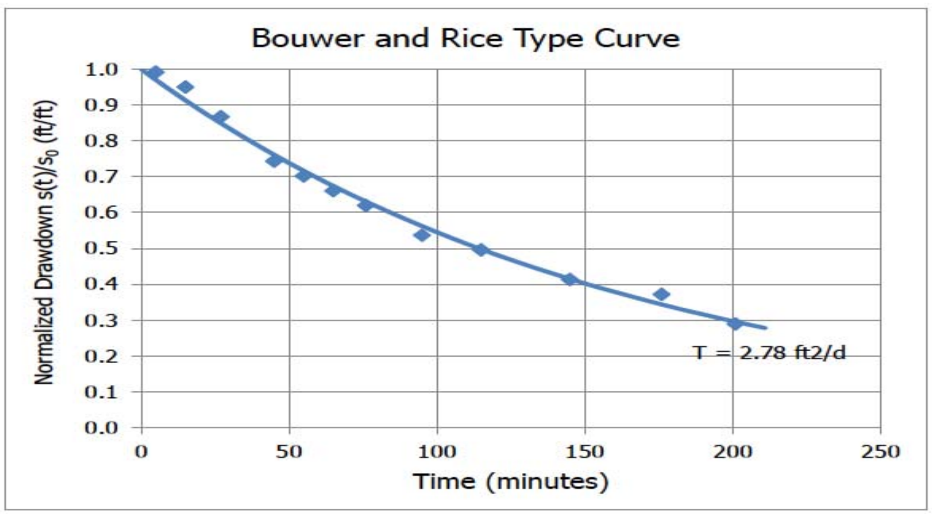
User Guide for the

API LNAPL Transmissivity Workbook: A Tool for Baildown Test Analysis

API Regulatory and Scientific Affairs Department

API Publication 46xx (pre-publication draft)
SEPTEMBER 2012

NOTE: This is a 'pre-publication' version of the API LNAPL Transmissivity Workbook that is provided to allow early access to this report. Minor formatting changes may occur prior to its formal publication.



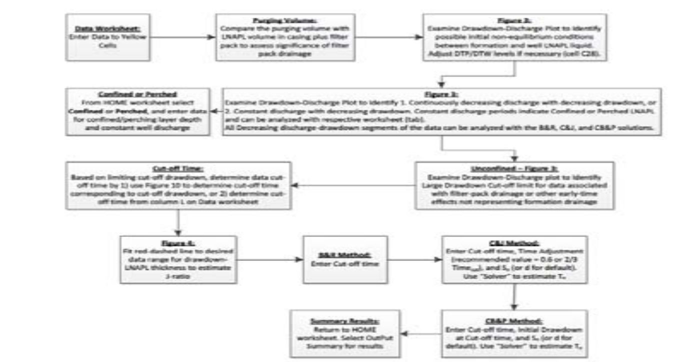


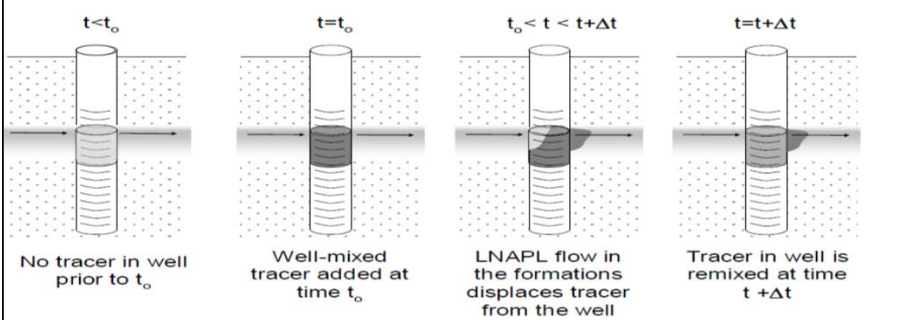
Figure 6.3. Flowchart outlining steps in LNAPL baildown test analysis

Well Designation:	YYY	Beckett and Lyverse (2002)		
Date:	date			
Ground Surface Elev (ft msl)	0.0	Enter These Data		Drawdown Adjustment
Top of Casing Elev (ft msl)	0.0			
Well Casing Radius, r_c (ft):	0.170	r_{e1}		(ft)
Well Radius, r_w (ft):	0.500			0.08
LNAPL Specific Yield, S_y:	0.175			
LNAPL Density Ratio, ρ_r:	0.780			
Top of Screen (ft bgs):	0.0			
Bottom of Screen (ft bgs):	0.0			
LNAPL Baildown Vol. (gal.):				
Effective Radius, r_{e3} (ft):	0.260	Calculated Parameters		
Effective Radius, r_{e2} (ft):	0.245			
Initial Casing LNAPL Vol. (gal.):	2.10			
Initial Filter LNAPL Vol. (gal.):	2.81			

	Enter Data Here						Water Table Depth (ft)	LNAPL Drawdown s_n (ft)		Average Time (min)	LNAPL Discharge Q_n (ft³/d)	s_n (ft)	b_n (ft)	r_e (ft)
	Time (min)	DTP (ft btoc)	DTW (ft btoc)	DTP (ft bgs)	DTW (ft bgs)									
Initial Fluid Levels:	0	22.29	25.38	22.29	25.38		22.97						3.09	
Enter Test Data:	1.0	22.80	23.30	22.80	23.30		22.91	0.43					0.50	
	1.5	22.79	23.38	22.79	23.38		22.92	0.42		1.3	55.041	0.43	0.59	0.260
	2.0	22.74	23.41	22.74	23.41		22.89	0.37		1.8	48.925	0.40	0.67	0.260
	3.0	22.73	23.50	22.73	23.50		22.90	0.36		2.5	30.578	0.37	0.77	0.260
	4.0	22.72	23.54	22.72	23.54		22.90	0.35		3.5	15.289	0.36	0.82	0.260
	5.0	22.72	23.59	22.72	23.59		22.91	0.35		4.5	15.289	0.35	0.87	0.260
	7.5	22.69	23.66	22.69	23.66		22.90	0.32		6.3	12.231	0.34	0.97	0.260
	12.0	22.67	23.89	22.67	23.89		22.94	0.30		9.8	16.988	0.31	1.22	0.260
	15.0	22.67	23.90	22.67	23.90		22.94	0.30		13.5	1.019	0.30	1.23	0.260
	20.0	22.64	23.98	22.64	23.98		22.93	0.27		17.5	6.727	0.29	1.34	0.260
	25.0	22.62	24.04	22.62	24.04		22.93	0.25		22.5	4.893	0.26	1.42	0.260
	30.0	22.61	24.07	22.61	24.07		22.93	0.24		27.5	2.446	0.25	1.46	0.260
	40.0	22.6	24.15	22.60	24.15		22.94	0.23		35.0	2.752	0.24	1.55	0.260
	52.0	22.58	24.22	22.58	24.22		22.94	0.21		46.0	2.293	0.22	1.64	0.260
	70.0	22.55	24.31	22.55	24.31		22.94	0.18		61.0	2.039	0.20	1.76	0.260
	80.0	22.54	24.36	22.54	24.36		22.94	0.17		75.0	1.835	0.18	1.82	0.260
	90.0	22.53	24.39	22.53	24.39		22.94	0.16		85.0	1.223	0.17	1.86	0.260
	101.0	22.52	24.44	22.52	24.44		22.94	0.15		95.5	1.668	0.16	1.92	0.260
	120.0	22.5	24.50	22.50	24.50		22.94	0.13		110.5	1.288	0.14	2.00	0.260
	140.0	22.49	24.57	22.49	24.57		22.95	0.12		130.0	1.223	0.13	2.08	0.260
	170.0	22.47	24.65	22.47	24.65		22.95	0.10		155.0	1.019	0.11	2.18	0.260
	201.0	22.46	24.74	22.46	24.74		22.96	0.09		185.5	0.986	0.10	2.28	0.260
	226.0	22.44	24.79	22.44	24.79		22.96	0.07		213.5	0.856	0.08	2.35	0.260

Google: API Baildown Test LNAPL

Method 4: Calculating LNAPL Transmissivity From Tracer Tests



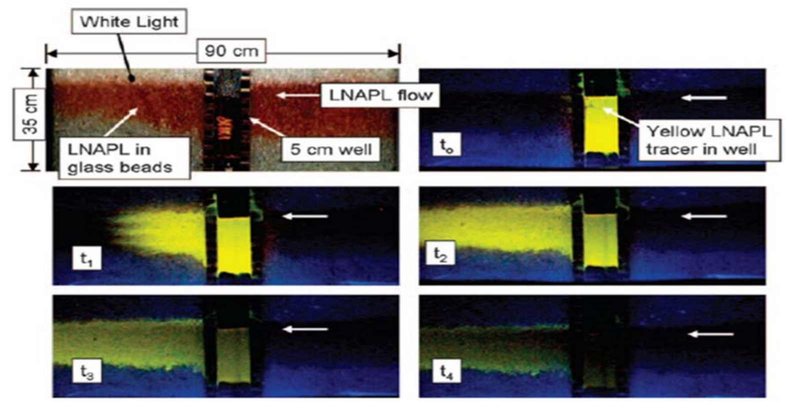


Figure 4. A 15-cm ID well equipped with pipes for (C_0 and C_{100}) standards and a cap for access to LNAPL in the well C_{well}.

One 1” pipe before adding tracer (control)

Second 1” pipe after adding tracer (100%)

Third pipe for measurements

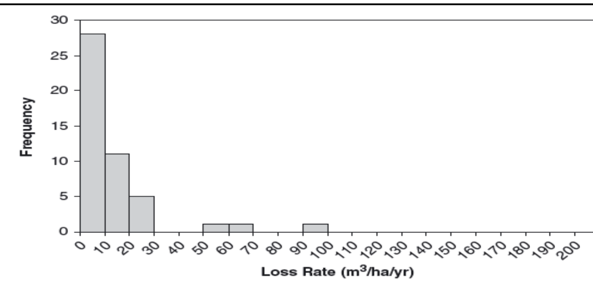
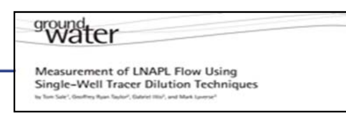


Figure 9. Histogram showing the distribution of calculated loss rates of the LNAPL bodies, assuming the bodies are stable.


ground water

Measurement of LNAPL Flow Using Single-Well Tracer Dilution Techniques


ground water

Use of Single-Well Tracer Dilution Tests to Evaluate LNAPL Flux at Seven Field Sites

CSU: LNAPL Can be Moving Inside LNAPL Zone Without Increasing the LNAPL Footprint!

ground water

A Mass Balance Approach to Resolving LNAPL Stability

by Nicholas Mahler[1], Tom Sale[2], and Mark Lyverse[3]

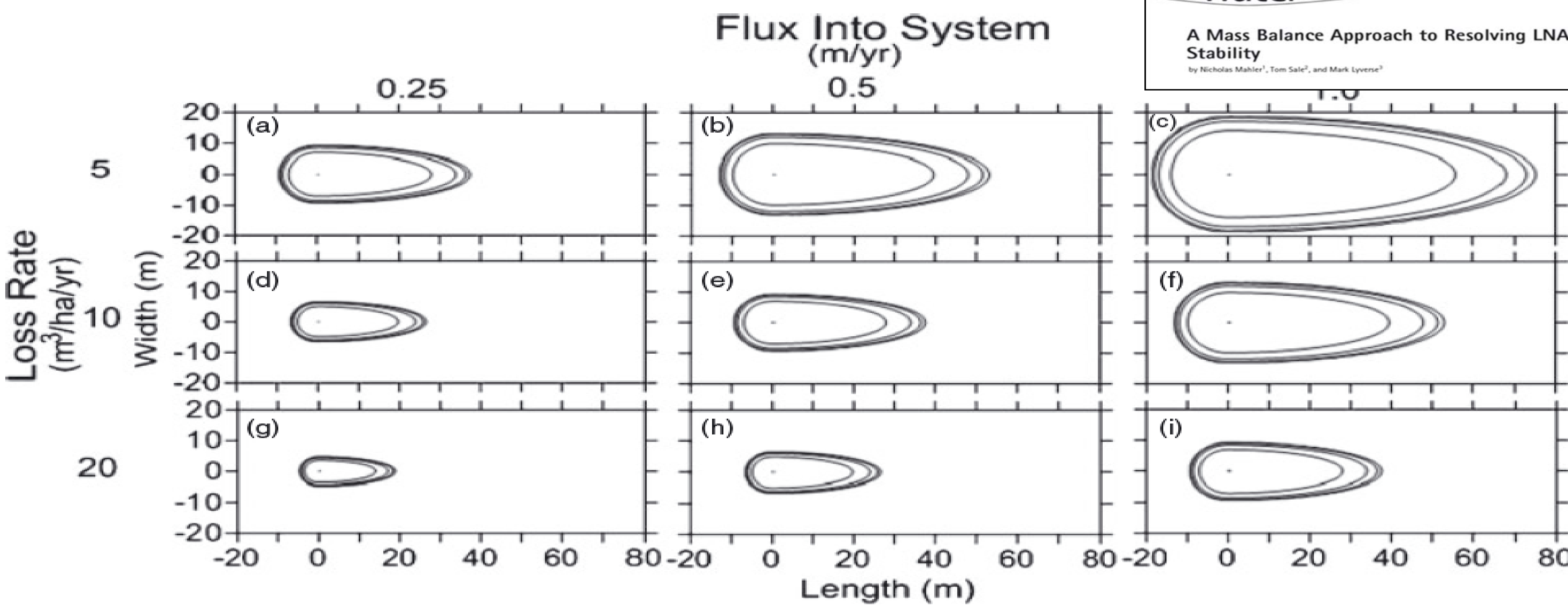


Figure 9. Comparison of the effects of inflow rate and loss rates on the extent over time of an oblong LNAPL body. The contours are given in years. The contour time increments are 40 years for panels (a), (b), and (c), 20 years for panels (d), (e), and (f), and 10 years for panels (g), (h), and (i).

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- Key tools for evaluating the practicability of LNAPL recovery
- **New issues regarding Total Petroleum Hydrocarbons and petroleum metabolites (fractionation)**
- Measuring and applying Natural Source Zone Depletion (NSZD)
- Emerging methods to enhance NSZD

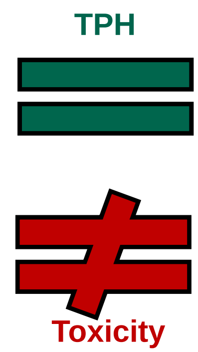
What is TPH?

- **TPH measures the Total Petroleum Hydrocarbons without quantifying concentrations of individual petroleum constituents**

- **Total TPH alone do not indicate risk to human health or the environment**

Soil impacted by different products might have the same TPH but very different toxicities

Baby Oil



TPH Fraction Method

- TPH fractions are separated into different classes by compound type and by carbon number
- Conservative toxicity and fate and transport characteristics are applied to estimate health and environmental risk

Step 1:

Analyze Soil or GW Samples with:

Step 2:

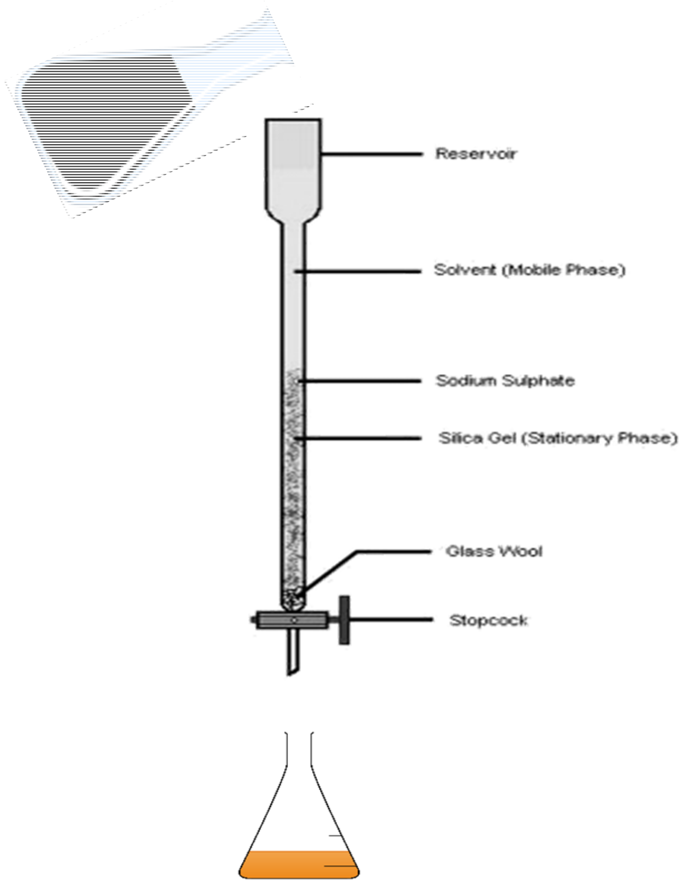
Apply Risk Calculations

TPH Considerations

- TPH can report false positives and register natural organics and petroleum degradation products

- Background sources of non-hydrocarbons should be considered by reviewing chromatograms

- Silica Gel Cleanup was designed to remove these polar compounds



Polar Metabolites at Hydrocarbon Sites

- But silica gel cleanup may be removing hydrocarbon metabolites

- "Polars" comprised of organic acids, alcohols and ketones, with few phenols

- At one crude oil site:
  - Polars concentrations about 2-3 times TPH-D concentration
  - Polar plume still expanding

- Two different perspectives in these two papers

Groundwater

Crude Oil Metabolites in Groundwater at Two Spill Sites

by Barbara A. Bekins[1], Isabelle M. Cozzarelli[2], Melinda L. Erickson[3], Ross A. Steenson[4], and Kevin A. Thorn[5]

Groundwater Monitoring&Remediation

Nature and Estimated Human Toxicity of Polar Metabolite Mixtures in Groundwater Quantified as TPHd/DRO at Biodegrading Fuel Release Sites

by Dawn A. Zemo, Kirk T. O'Reilly, Rachel E. Mohler, Asheesh K. Tiwary, Renae I. Magaw, and Karen A. Synowiec

Webinar Outline

- Status of Navy petroleum site cleanup efforts
- Key regulatory issues related to Navy petroleum sites
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- New issues regarding Total Petroleum Hydrocarbons and petroleum metabolites (fractionation)
- **Measuring and applying Natural Source Zone Depletion (NSZD)**
- Emerging methods to enhance NSZD

Original Conceptual Model for Natural Source Zone Depletion: *Groundwater Mass Flux*

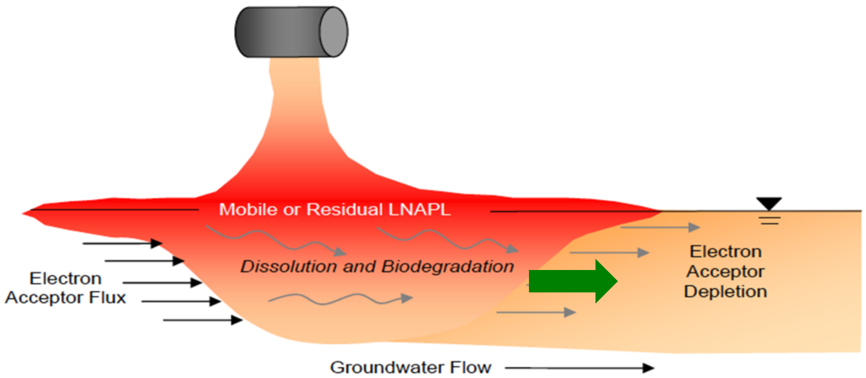


Figure 2-1. Groundwater transport–related NSZD processes.

Key factors for groundwater biodegradation mass balance:

- *Delta dissolved oxygen*
- *Delta dissolved nitrate*
- *Delta dissolved sulfate*
- *Delta dissolved ferrous iron*
- *Delta dissoved methane*

BIOSCREEN model

NSZD: Groundwater Mass Flux vs. Vapor Phase Mass Flux

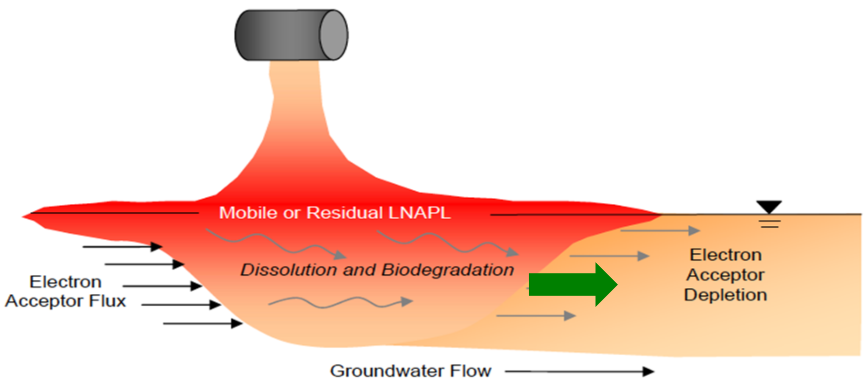


Figure 2-1. Groundwater transport–related NSZD processes.

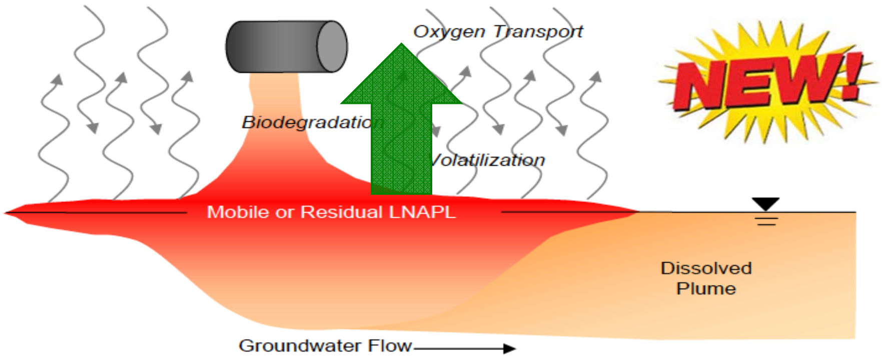


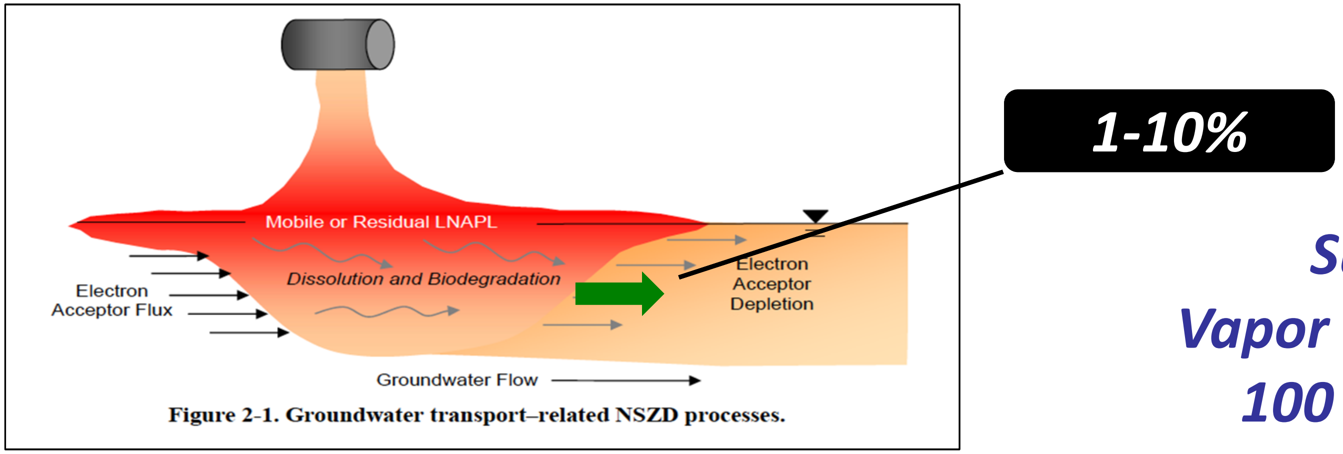
Figure 2-2. Vapor transport–related NSZD processes.

BIOSCREEN model

Key factors for vadose zone biodegradation mass balance:

- *Oxygen gradient from surface into vadose zone*
- *Methane generation*
- *Carbon dioxide at surface*

New NSZD Conceptual Model: Vapor Phase Mass Flux is Much More Important



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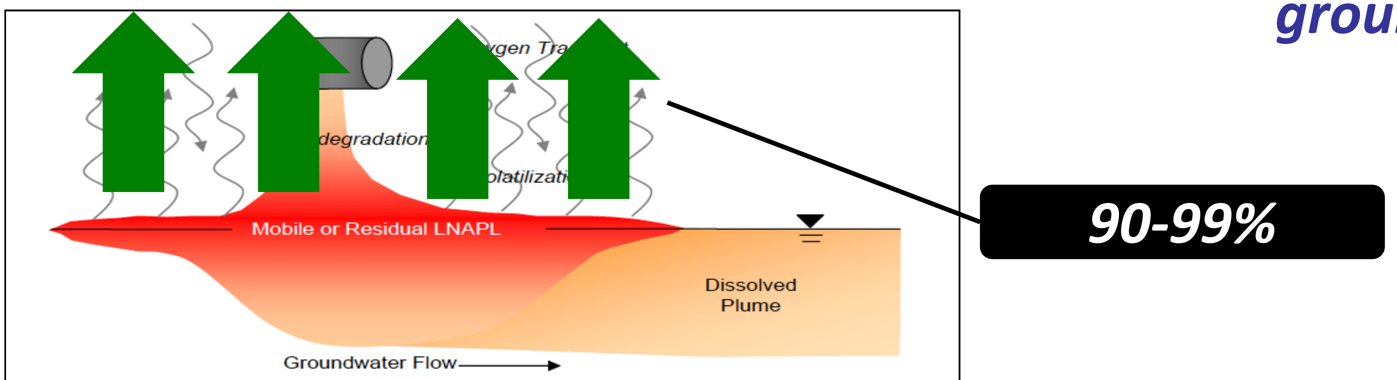
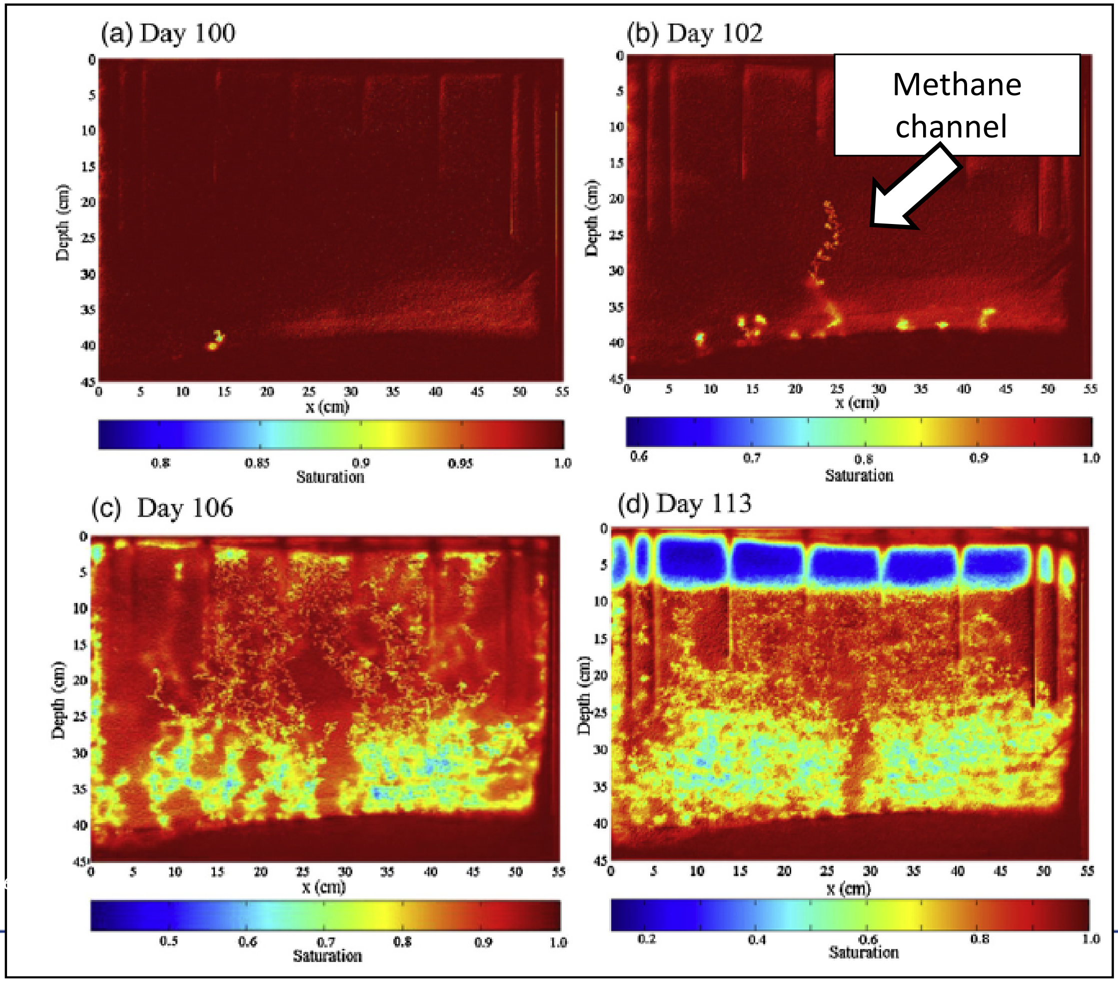


Figure 2-2. Vapor transport–related NSZD processes.

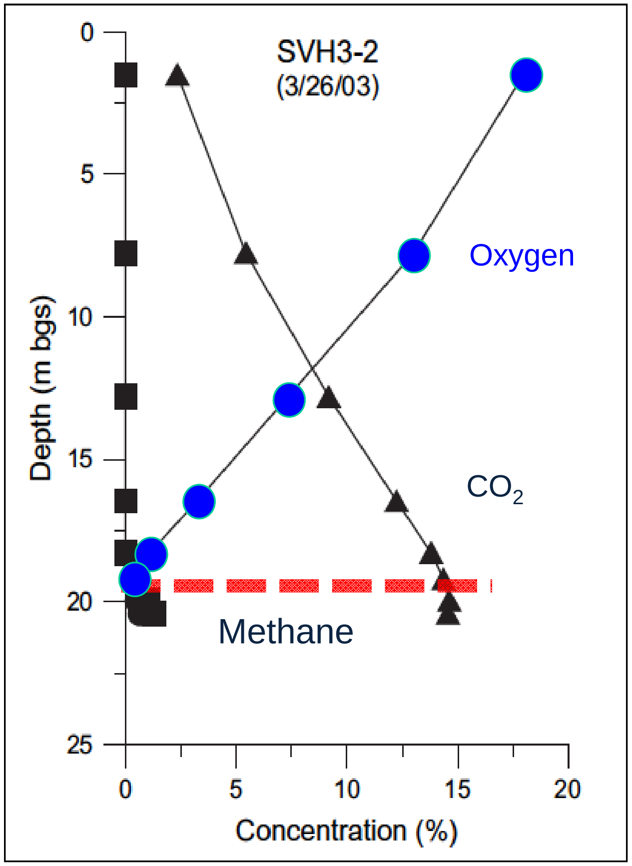
Surprising Result:
Vapor transport fluxes 10 to 100 times greater than groundwater fluxes!

Lundegard and Johnson, 2006; Suthersan 2015

Methane and "Ebullition"



Three Conventional Ways to Measure NSZD



Lundegard and Johnson, 2006

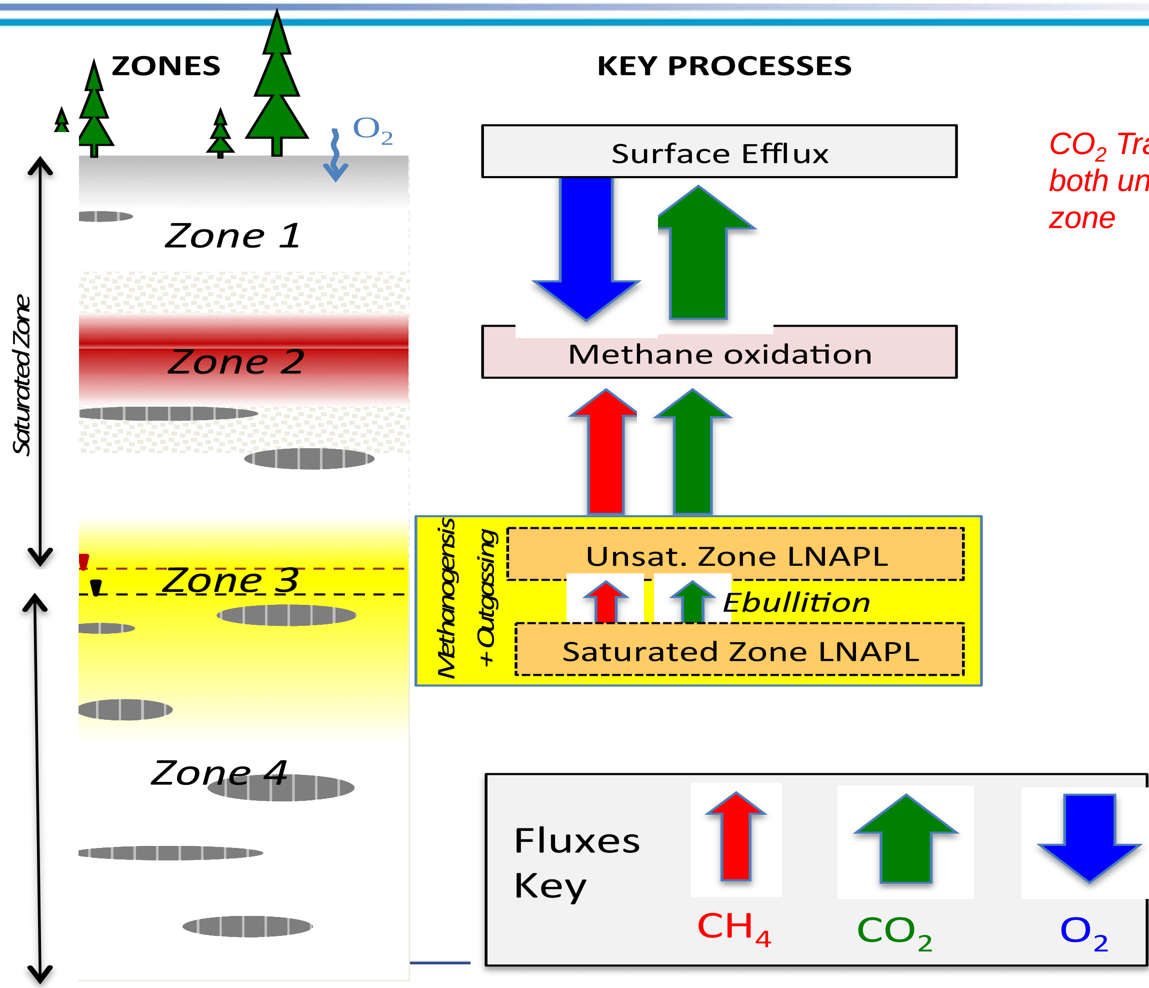
What NSZD Rates are Being Measured?

NSZD Study	Number of Sites	Site-Wide NSZD Rate (gallon per acre per year)	Reference
Refinery terminal sites	6	2,100 - 7,700	McCoy et al., 2012
1979 crude oil spill	1	1,600	Sihota et al., 2011
Refinery/terminal sites	2	1,100 - 1,700	LA LNAPL Wkgrp, 2015
Fuel/diesel/gasoline	5	300 - 3,100	Piontek, 2014
Diverse petroleum sites	11	300 - 5,600	Palaia, 2016

Key Point: Measured NSZD rates in 100s to 1000s of gallons of LNAPL biodegraded per acre per year.

Locations across U.S. where carbon traps have been used to measure NSZD rates (E-Flux, 2015)

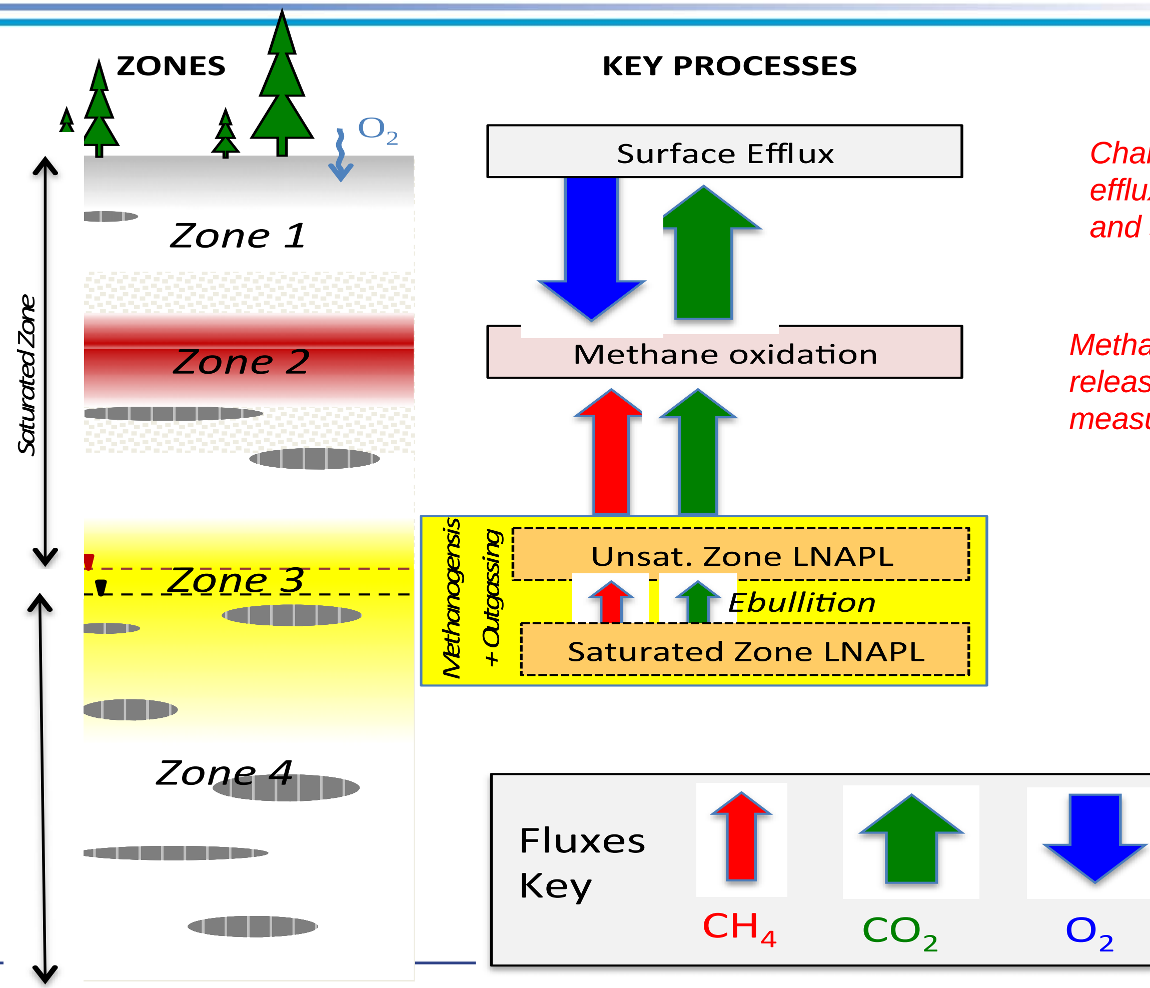
NSZD Conceptual Model



CO_2 Traps Measure efflux from both unsaturated and saturated zone

Source: Sale, 2016

NSZD Conceptual Model



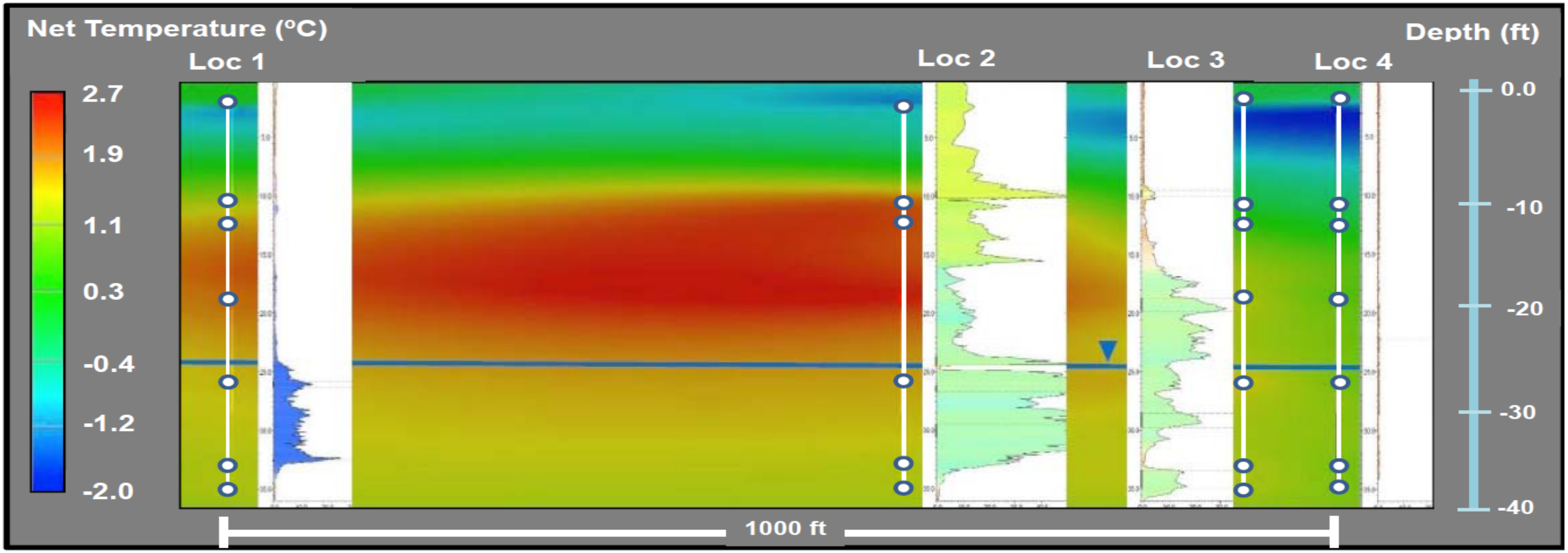
KEY POINTS

Chambers, traps measure CO_2 efflux from <u>both</u> unsaturated and saturated zone

Methane oxidation reaction releases heat that can be measured

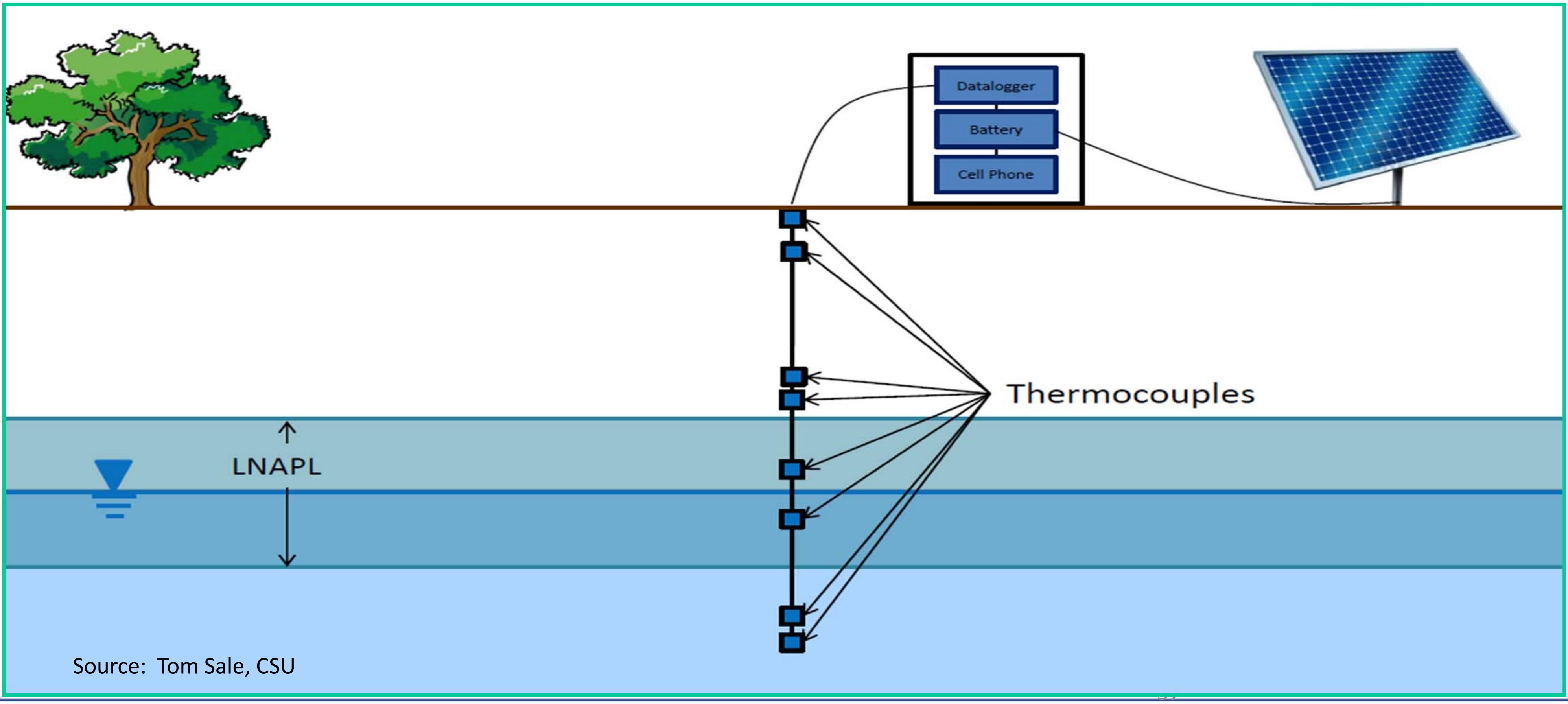
Source: Sale, 2016

Kansas Site:
Subsurface Temperatures



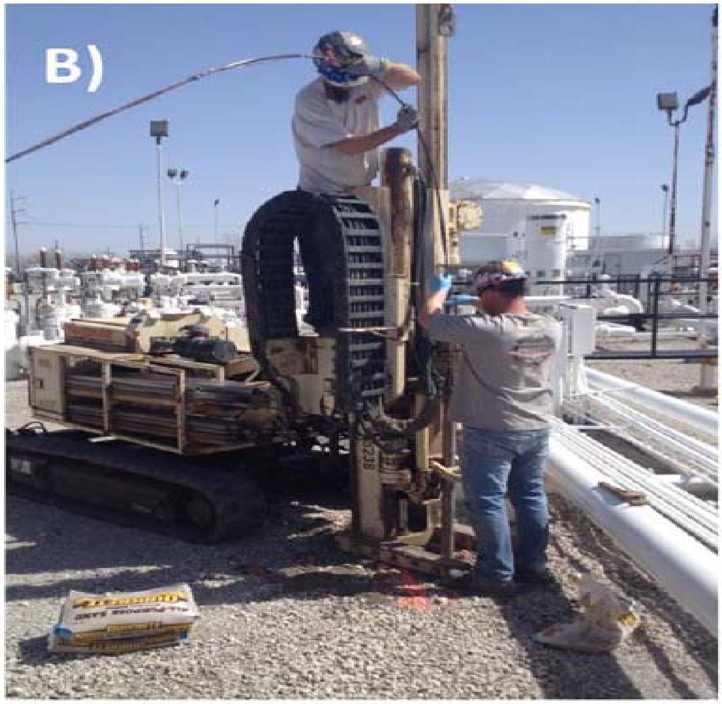
Source: Emily Stockwell, Tom Sale Colorado State University

Field Installation: Thermal Monitoring System



Field Installation: Thermal Monitoring System

Thermocouple on temperature monitoring "stick"



Installation of stick using direct push rig.

Solar power supply and weatherproof box with data logger and wireless communications system.

Source: CSU, TRC Consultants

ThermalNSZD

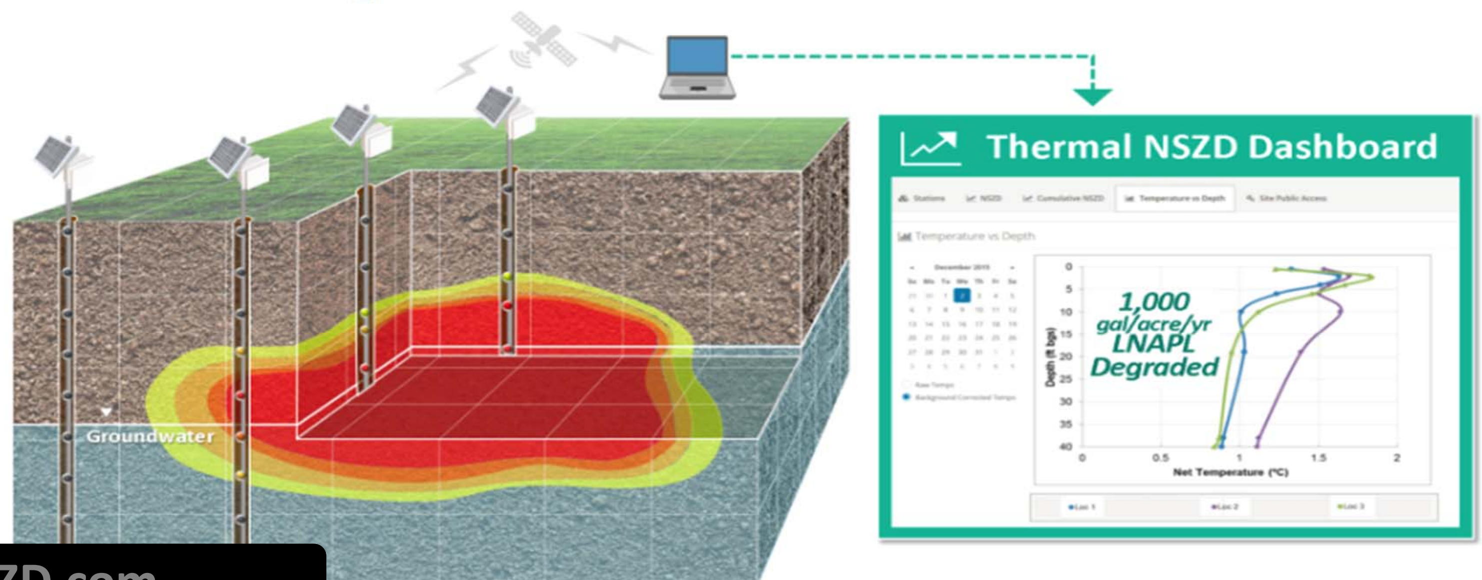
HOME TECHNOLOGY DEMO IMPLEMENT CONTACT CUSTOMER LOGIN

Thermal NSZD: Continuous Remote Monitoring of Natural Source Zone Depletion (NSZD)

The Thermal NSZD technology (patent pending) measures the rate at which natural biodegradation destroys free-phase product (LNAPL) in the subsurface by measuring the heat released by the microbial reactions.

Advantages of Thermal NSZD

- One-time field installation of remote monitoring system with minimal O&M, no site visits, no sampling and no lab.
- Daily temperature readings from vertical profiles of thermocouples.
- Secured, read only access to site data for regulators.



www.ThermalNSZD.com

Thermal NSZD

HOME TECHNOLOGY DEMO IMPLEMENT CONTACT CUSTOMER LOGIN

Demo GSI Demo Site

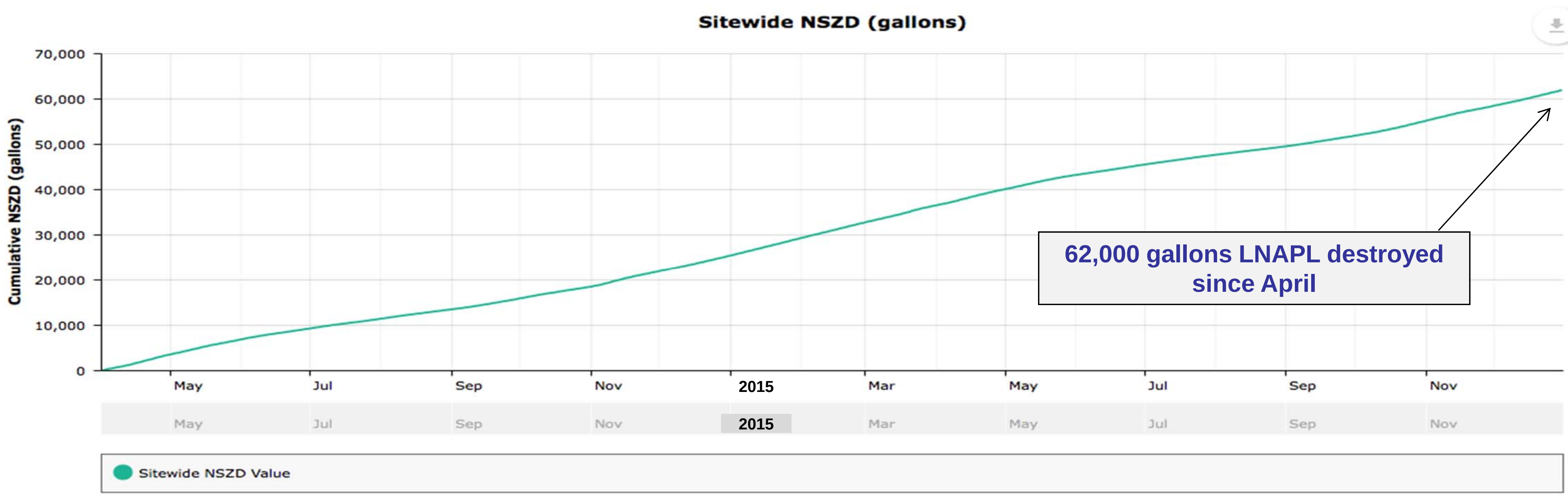
Sitewide NSZD Rates

Sitewide NSZD | Cumulative NSZD | NSZD | Temperature vs Time | Temperature vs Depth | Parameters

Sitewide NSZD

Amount of LNAPL Degraded Since NSZD Monitoring Began: 61,966 gallons LNAPL

Natural Source Zone Depletion Rate Over Past 30 Days: 497 gallons/acre/year



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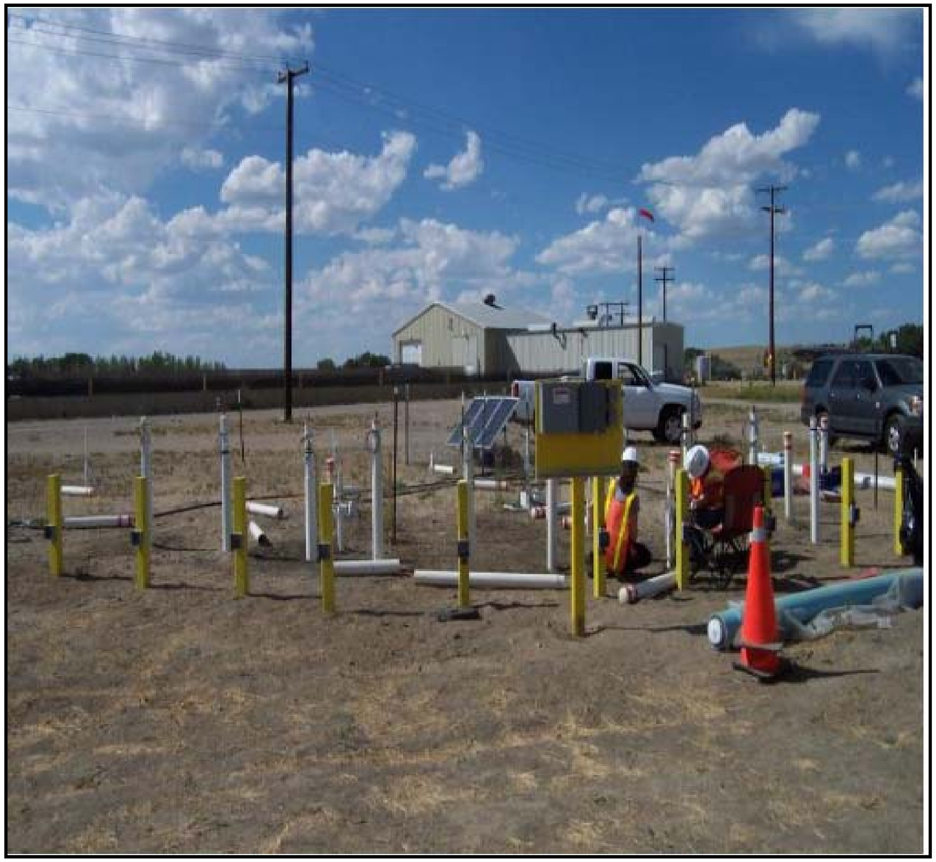
“The color is a symbol for calm, cleanliness, and purity, but it also serves to contrast the light of the city, which is predominantly amber or bright white”

Pilot Tests: Casper Wyoming

Low-Cost Heating Elements using Heat Tape

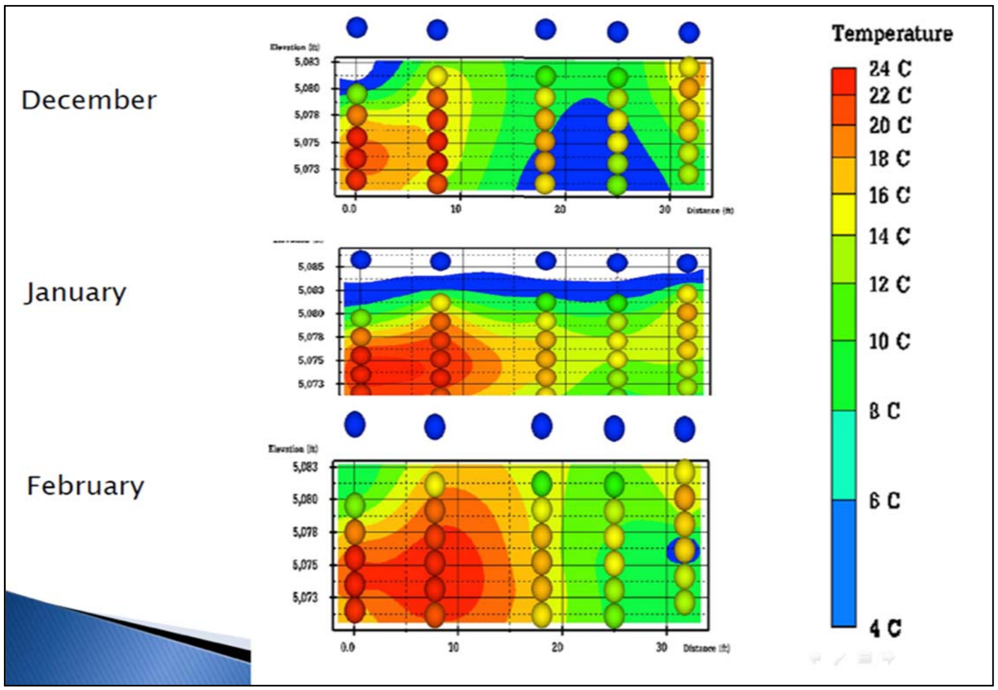


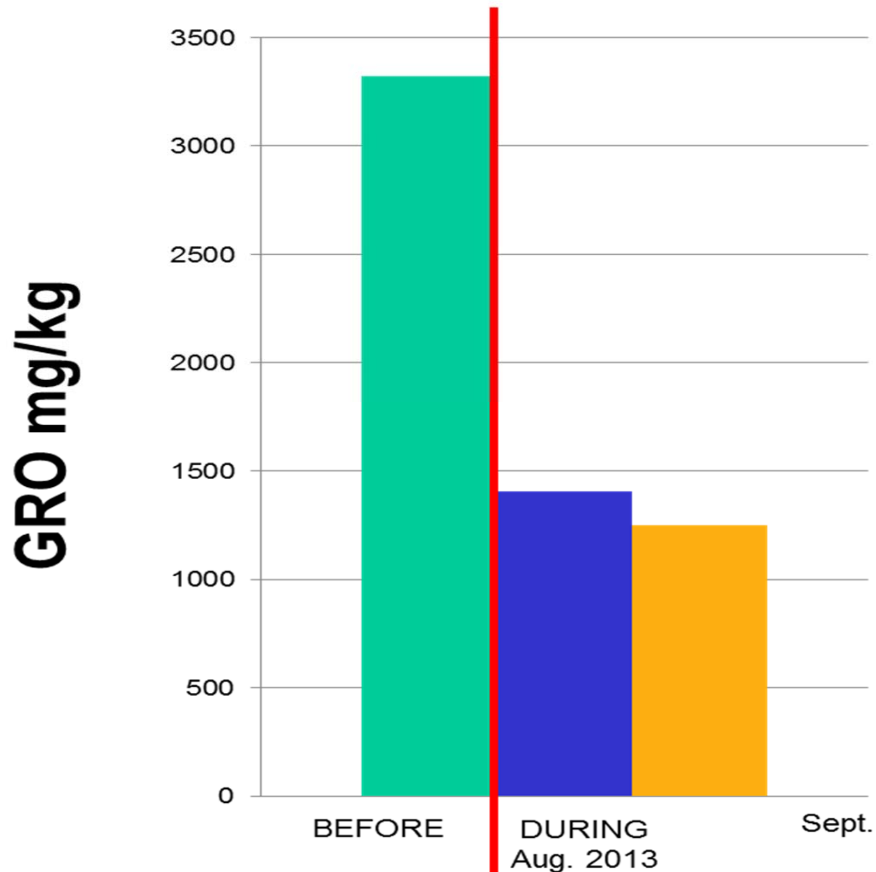
Key Point:

- **Increase in subsurface temperatures achieved**
- **Performance data analysis in progress**

Source: Dr. Tom Sale, CSU

STELA: Heating and Core Results

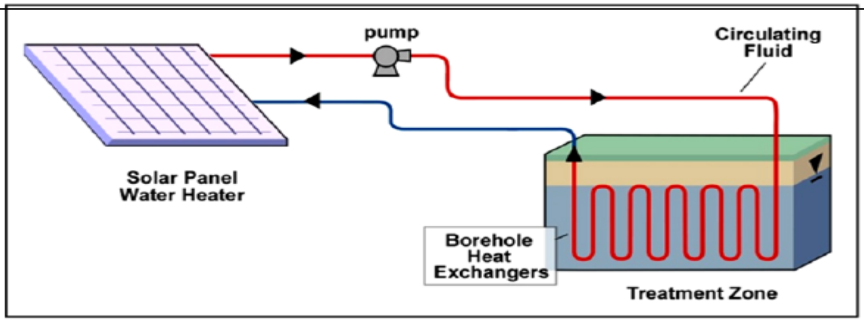




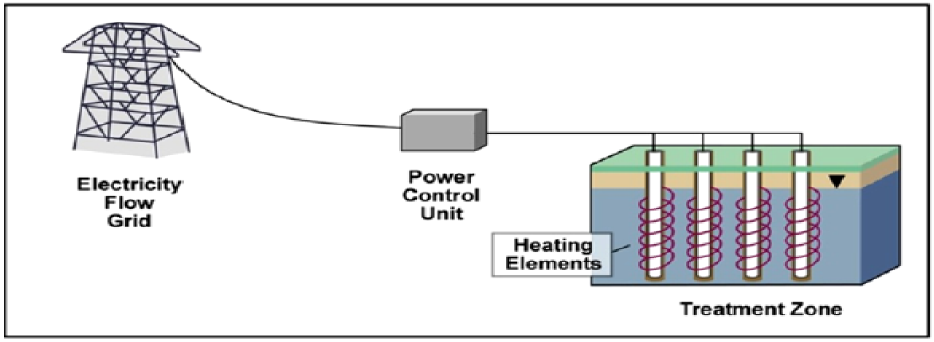
Source: Dr. Tom Sale, CSU

Preliminary Data

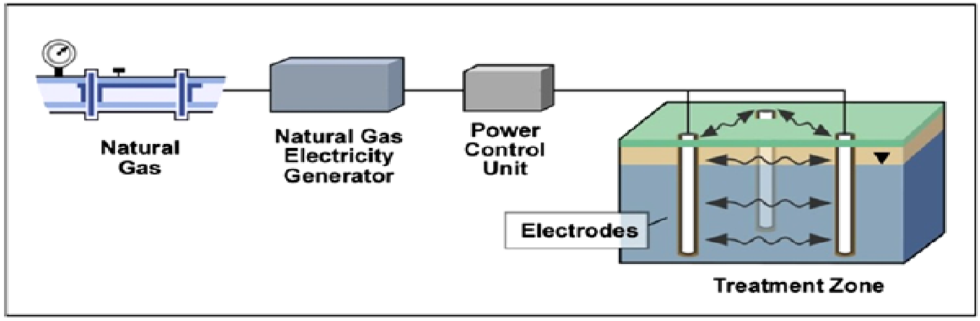
STELA Heat Delivery Methods



Borehole Heat Exchangers

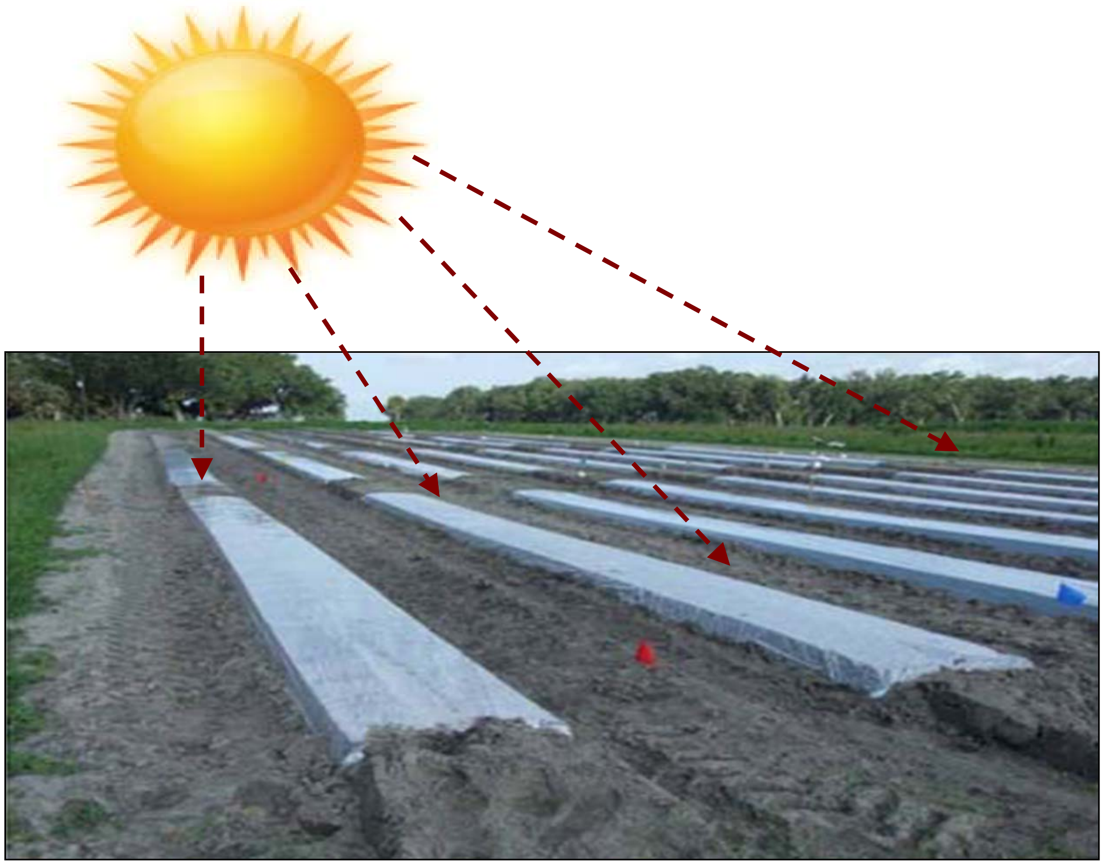


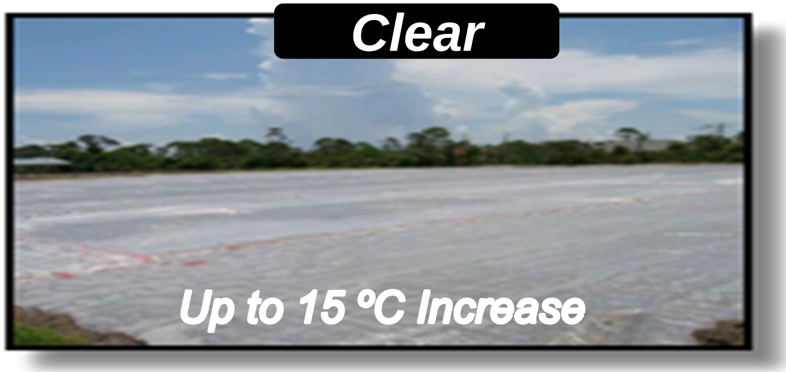
Thermal Conductance Heating



Electrical Resistance Heating

Soil Solarization: *Why Plastic?*

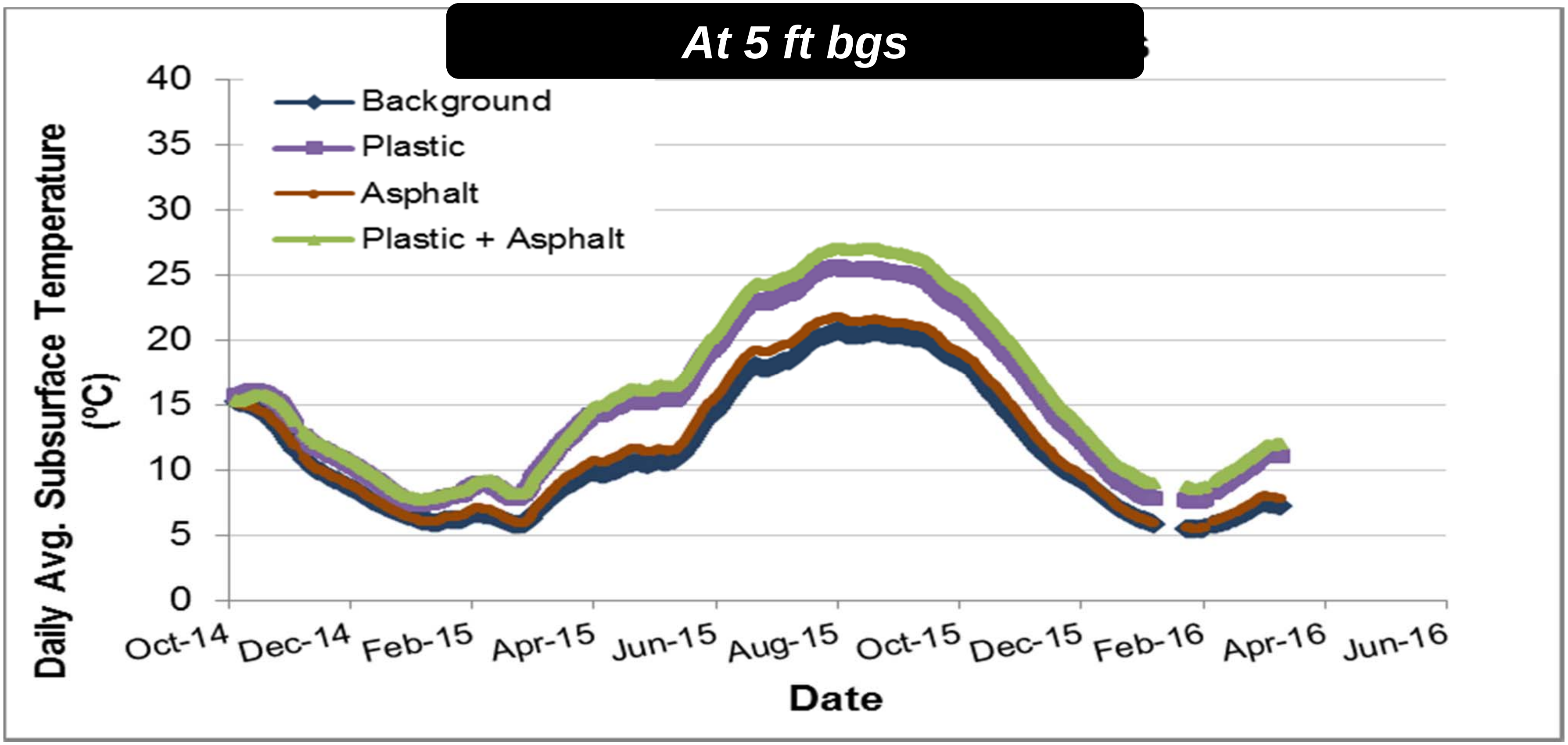





CSU STELA Test Plot. Source: Dr. Tom Sale, CSU


New Jersey STELA Site

Subsurface Heating Over Time



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Key Points: Soil Solarization Pilot Tests

- **Soil solarization using plastic is a potentially promising subsurface heating method**

- **Likely applicable for to enhance NSZD at LNAPL sites**

- **On-going work by CSU/GSI Understanding gas transport / venting options**

Tufflite IV
“The Greenhouse Film of the Future”

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?

Wrap Up

- Please complete the feedback questionnaire at the end of this webinar. We are counting on your feedback to make this webinar series relevant!

- Check the T2 email for upcoming OER2 Webinar Announcements!

- Thank you for participating!