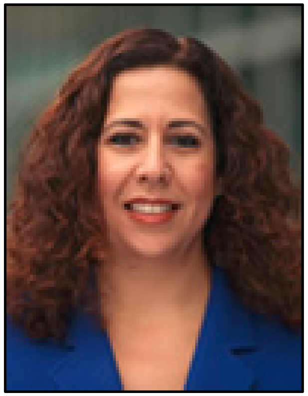
Quantitative Framework and Management Expectation Tool for the Selection of Bioremediation Approaches at Chlorinated Solvent Sites

March 19, 2015

SERDP DOD • EPA • DOE | ESTCP

Welcome and Introductions

Rula Deeb, Ph.D.
Webinar Coordinator



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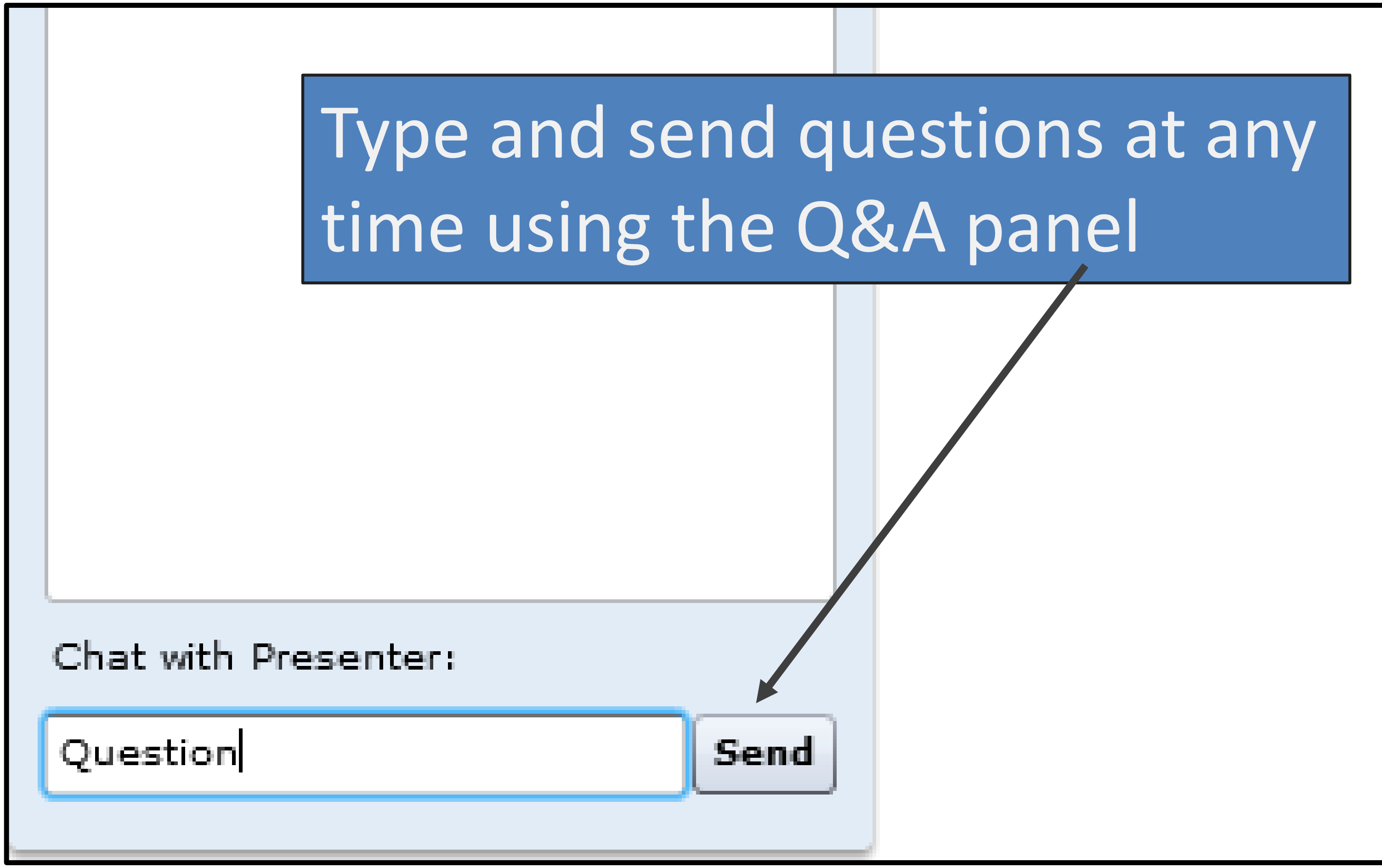
Webinar Agenda

- Webinar Overview and ReadyTalk Instructions
  Dr. Rula Deeb, Geosyntec (5 minutes)
- Overview of SERDP and ESTCP
  Dr. Andrea Leeson, SERDP and ESTCP (5 minutes)
- Quantitative Framework and Management Expectation Tool for the Selection of Bioremediation Approaches at Chlorinated Solvent Sites
  Ms. Carmen Lebrón, Independent Consultant (20 minutes + Q&A)
  Dr. John Wilson, Scissortail Environmental (40 minutes + Q&A)
- Final Q&A session

How to Ask Questions



SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
Environmental Restoration Program Manager

SERDP
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ESTCP

SERDP

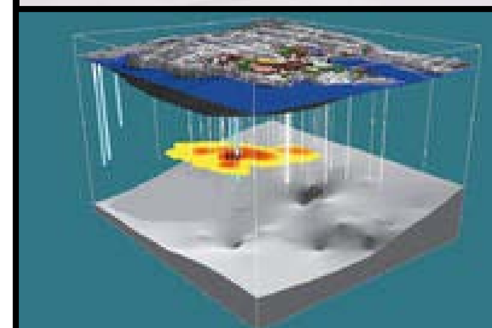
- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management

ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance

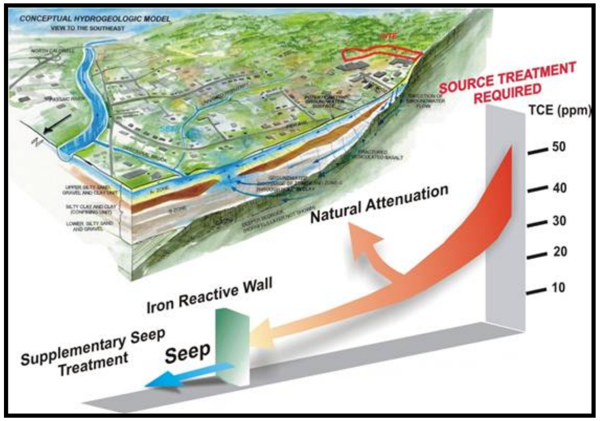
Program Areas

1. Energy and Water
2. Environmental Restoration
3. Munitions Response
4. Resource Conservation and Climate Change
5. Weapons Systems and Platforms


Environmental Restoration

- Major focus areas
  - Contaminated groundwater
  - Contaminants on ranges
  - Contaminated sediments
  - Wastewater treatment
  - Risk assessment



SERDP and ESTCP Webinar Series

DATE	WEBINARS AND PRESENTERS
March 26, 2015	**Innovative Tools for Species Inventory, Monitoring, and Management** • Dr. Caren Goldberg, Washington State University • Dr. Lisette Waits, University of Idaho
April 16, 2015	**Blast Noise Measurements and Community Response** • Mr. Jeffrey Allanach (Applied Physical Sciences Corp.) • Dr. Edward Nykaza (U.S. Army Engineer Research and Development Center)
May 7, 2015	**Munitions Mobility**
May 28, 2015	**Managing Munition Constituents on Training Ranges** • Dr. Paul Hatzinger (CB&I Federal Services) • Dr. Thomas Jenkins (Thomas Jenkins Environmental Consulting)

Quantitative Framework and Management Expectation Tool for the Selection of Bioremediation Approaches at Chlorinated Solvent Sites

ESTCP Project ER-201129
Carmen Lebrón, Independent Consultant
Dr. John T. Wilson, Scissortail Environmental Solutions, LLC

Project Objectives and Technical Approach

Carmen Lebrón
Independent Consultant

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Presentation Outline

- Background
  - Project objectives and goals
  - Technical approach (Tasks)
- Framework application
  - Review of regulator requirements
  - Intended application of the framework
  - Decision logic in a decision support tool
  - Case studies
    - Extracting rate constants for degradation
    - Dhc density to explain the rate of degradation
    - Magnetic susceptibility to explain the rate of degradation

Other Team Members

- Todd Wiedemeier, Wiedemeier and Associates
- Dr. Frank Löffler, University of Tennessee
- Yi Yang, University of Tennessee
- Mike Singletary, NAVFAC SE
- Dr. Rob Hinchee, Integrated Science and Technology, Inc.





Technical Goals

- Incorporate new science (tools, methods and findings) into a decision making framework addressing EPA's OSWER Directive 9200.4-17P
  - Monitored Natural Attenuation (MNA)
- Integrate the decision-making framework into an easy to use application
  - Excel spreadsheet
- Guide users in the selection of MNA, biostimulation and bioaugmentation

EPA/600/R-98/128
September 1998

Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water

Technical Approach

1. Parameter ID → 2. Parameter Down-select → 3. Determine Parameter Impact
Parameter Association Plots
Relate Rate to Parameter

3. ⇅ 4. Develop Decision Framework Logic → 5. Develop Screening Tool (BioPIC)

4. Develop Decision Framework Logic →
- Flow Charts and Decision Framework Matrices
- Explanations on Instrumentation, Sampling, Methods

Rate:
The overall degradation rate, bulk rate, or rate of attenuation

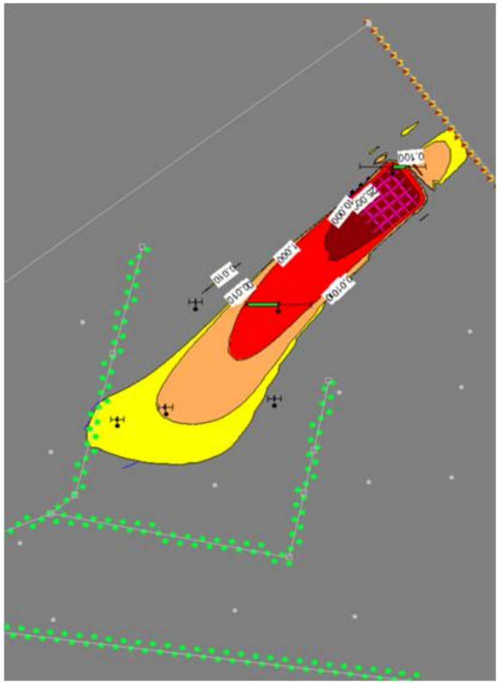
- **The sum rate of all abiotic, biotic and BMAD processes that contribute to contaminant detoxification**
- **Consistent with EPA's definition of Rate**

Pathways Addressed in Framework

Groundwater sample

Soil Sample

Degradation Pathways
Complete Anaerobic Reductive Dechlorination (RD) *(groundwater parameter)*
Partial Reductive Dechlorination *(groundwater parameter)*
Aerobic Biological Oxidation *(groundwater parameter)*
Abiotic Degradation *(soil parameter)*



EPA 1998 Protocol dealt only with reductive dechlorination

Task 1. Parameters' Identification

- Began with the EPA 1998 parameters
- Classified parameters based on:
  - Parameter important in determining a degradation pathway
  - Confidence in the analytical results

Parameters from EPA, '98 Protocol			
Oxygen	pH	VFAs	DCA
Nitrate	TOC	BTEX	Carbon Tet
Iron II	Temperature	PCE	Chloroethane
Sulfate	Carbon Dioxide	TCE	Ethene/Ethane
Sulfide	Alkalinity	DCE (all 3)	Chloroform
Methane	Chloride	VC	Dichloromethane
ORP	Hydrogen	1,1,1-TCA	

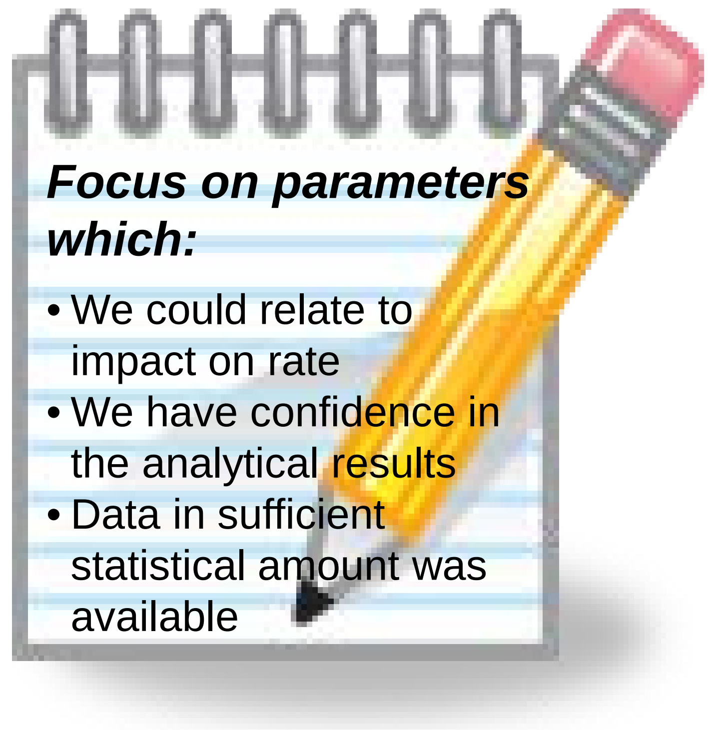
Parameters Specific to Pathways

Parameters of Interest	***Pathway Applicable To***
Concentrations of PCE, TCE, DCEs and VC	**All Pathways**
Dissolved Oxygen (DO)	**All Pathways**
pH	**All Pathways**
Fe(II)	**RD, Partial RD, Abiotic**
H_2S/HS^-	**RD, Partial RD, Abiotic**
Ethene	**All Pathways**
***Dhc* density (Ratio of *Dhc* to Total Bacteria)**	**RD, Partial RD**
Ratio of *bvcA* and *vcrA* to *Dhc*	**RD, Partial RD**
Bioavailable Organic Carbon (BOC)	**RD, Partial RD**
Magnetic Susceptibility	**Abiotic**
Acid Volatile Sulfide	**Abiotic**

Task 2: Down-Select Parameters

Parameters of interest
Concentrations of PCE, TCE, DCEs and VC
Dissolved Oxygen (DO)
pH
Fe(II)
H_2S/HS^-
Ethene
Ratio of *Dhc* to Total Bacteria (Dhc density)
Ratio of *bvcA* + *vcrA* to *Dhc*
Bioavailable Organic Carbon (BOC)
Magnetic Susceptibility (abiotic only)
Acid Volatile Sulfide (abiotic only)

■ (green)	From EPA, 1998
□ (white)	New Parameters



Focus on parameters which:

- We could relate to impact on rate
- We have confidence in the analytical results
- Data in sufficient statistical amount was available

Task 3: Estimate Parameter Impact on Rate

- Performance objective: To establish association (impact) using at least 10 data points (wells/transects/sites) for each parameter
  - How do different values for each parameter affect the rate constant?
- Well-known published sites were used as Poster-Child sites

Destruction Pathway	Poster Child Site
Complete Anaerobic Reductive Dechlorination	NAS North Island, Site 5
Partial Reductive Dechlorination	Kings Bay NAS Whiting Field
Aerobic Biological Oxidation	Little Creek Tooele Army Depot, UT Hill OU2
Abiotic Degradtion	Twin Cities AAP (*Ferrey & Wilson*) Hopewell Superfund Site (*Wilson*) Massachusetts Military Reservation Former AFB Plattsburgh Oscoda

BIOCHLOR Database / C. Newell *93 sites*
ER0518 Database / E. Petrovskis *4 sites*
ER2131 database /R. Borden *40 ERD sites, >800 wells*
Moffett Field / SWFEC and CB&I *1 site 26 locations*
Microbial Insights (MI) data used to correlate qPCR data for *Dhc* abundances with VOC concentration and other biogeochemical datasets with rates

Task 3: Estimate Parameter Impact on Rate

WATER RESEARCH 40 (2006) 3131–3140

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journal homepage: www.elsevier.com/locate/watres

WATER RESEARCH

Relationship between *Dehalococcoides* DNA in ground water and rates of reductive dechlorination at field scale

Xiaoxia Lu[a,*], *John T. Wilson*[b], *Donald H. Kampbell*[b]

[a]*National Research Council, Tenable at US Environmental Protection Agency, 919 Kerr Research Drive, Ada, OK 74820, USA*

[b]*US Environmental Protection Agency, 919 Kerr Research Drive, Ada, OK 74820, USA*

a r t i c l e i n f o

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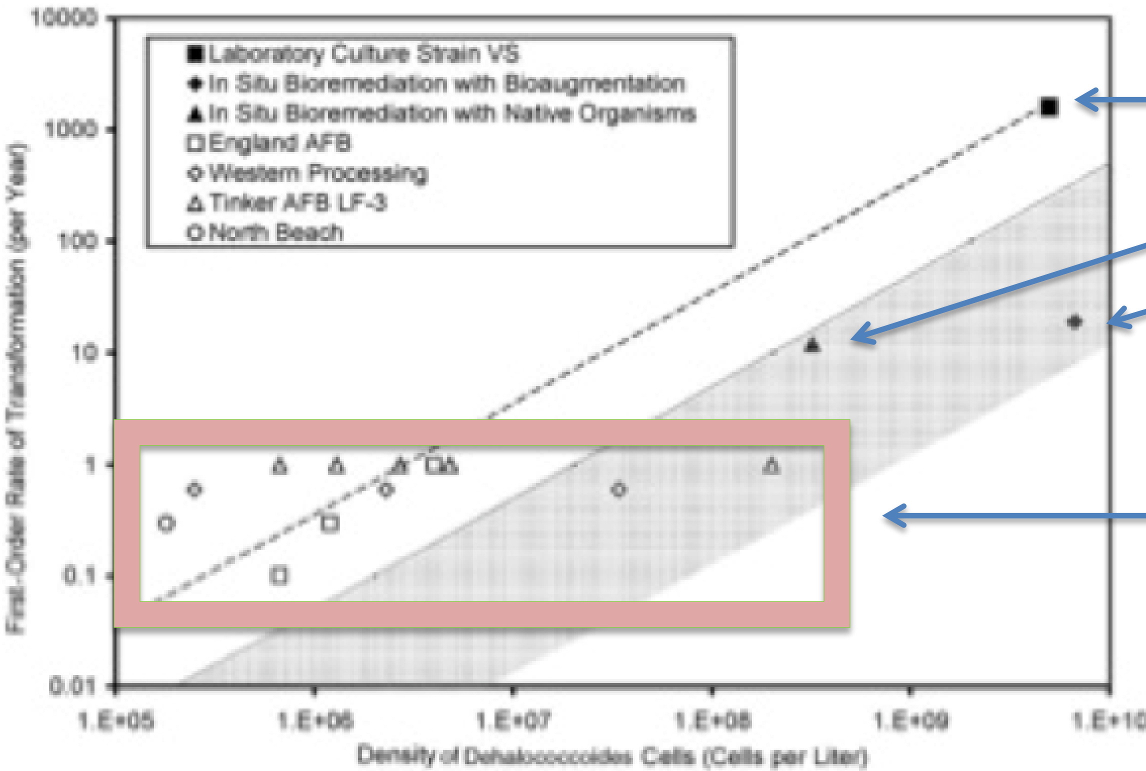
Keywords:
Ground water Chlorinated ethylenes
Dehalococcoides DNA Rate constants
Reductive dechlorination Natural attenuation

Certain strains of *Dehalococcoides* bacteria can dechlorinate chlorinated ethylenes to harmless products. This study was conducted to determ … ntitative real time polymerase chain reaction (q-PCR) with DNA primer set specific for *Dehalococcoides* organisms. Dechlorination rate constants were extracted from field data using the BIOCHLOR software. Of the six conventional plumes surveyed, ''generally useful'' rates of dechlorination (greater than or equal to 0.3 per year) of *cis*-dichloroethylene (*cis*-DCE) and vinyl chloride (VC) along the flow path were observed at three sites where *Dehalococcoides* DNA was detected, and little attenuation of *cis*-DCE and VC occurred at two sites where *Dehalococcoides* DNA was not detected. At the two sites where there was no net direction of ground water flow, the relationship between the density of *Dehalococcoides* DNA in ground water and the trend in concentrations of chlorinated ethylenes over time in monitoring wells was not so consistent as that observed for the conventional plumes. A comparison of our study to a field study performed by Lendvay and his coworker indicated that monitoring wells did not efficiently sample the *Dehalococcoides* organisms in the aquifer.

WATER RESEARCH 40 (2006) 3131 – 3140

- Purpose of the study was to determine if there was a valid correlation between Dhc density and observed reductive dechlorination rate at 6 sites
- Spearman correlation used to analyze relationship between Dhc densities and reductive dechlorination rates
- Useful rates (> 0.3 per year) of cis- DCE and VC observed where Dhc was present
  - Very little degradation observed where Dhc was not detected
- An argument can be made for MNA if Dhc >10E7

Lu, Wilson and Kampbell, 2006



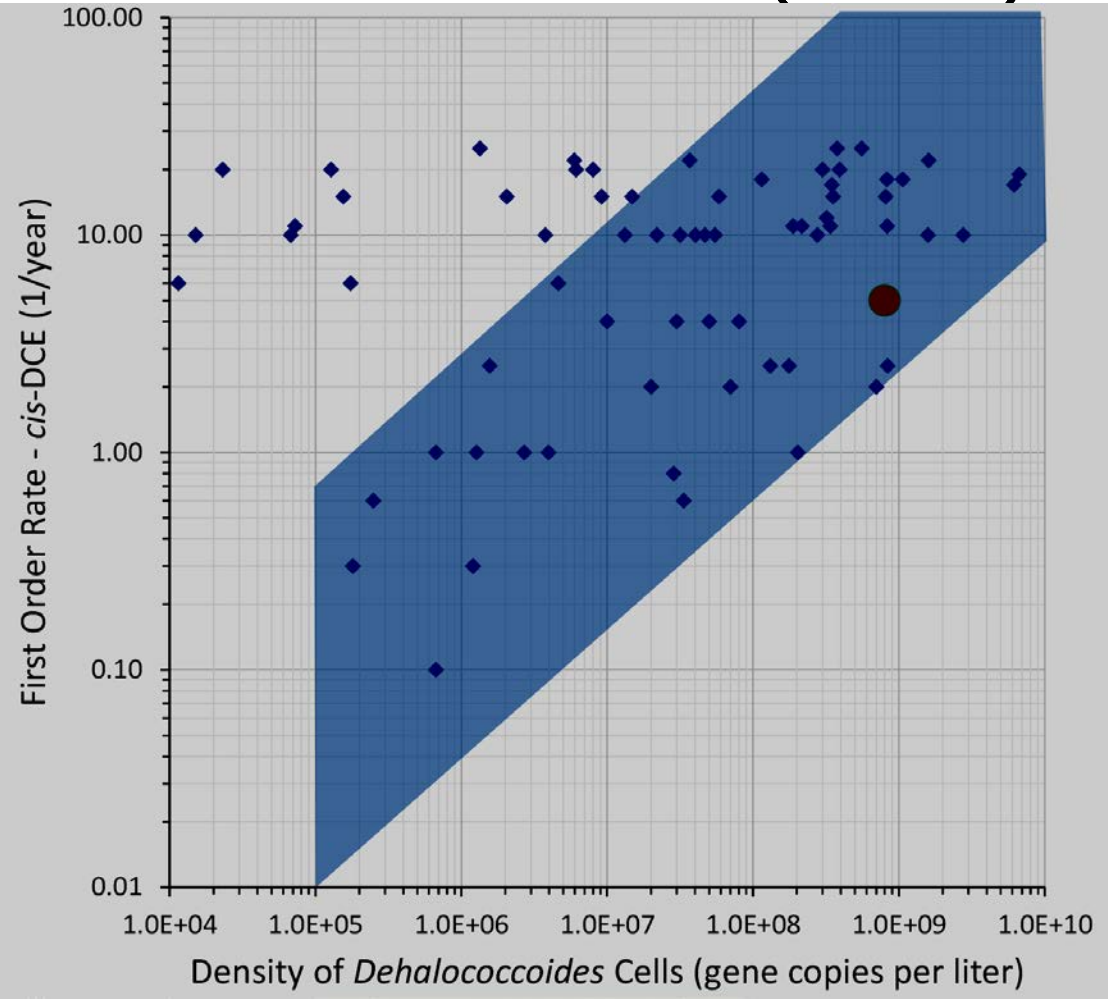
Laboratory study

Samples from a biological reductive dechlorination site

Samples collected at MNA sites

*Fig. 2 – Relationship between the **density of Dehalococcoides cells**) and **the first-order rate of attenuation of cis-DCE in ground water**. The data points with **an open symbol** are from ground water **samples collected at natural attenuation sites**. The data points with a solid diamond symbol or a solid triangle symbol are from sediment samples from a site where biological reductive dechlorination was used to clean up a PCE spill (Lendvay et al., 2003). The data point with a solid square symbol is from a laboratory study of cis-DCE transformation by Dhc strain VS growing under optimum conditions (Cupples et al., 2004).*

Distribution Plot: *cis*-DCE vs. Dhc (2015)



- Example: Can the attenuation rate be explained by Dhc?
- In which cases can the rate constant be attributed to the cell densities?
  - Draw line from 1.0E+05 to 1.0E+10
  - Draw another line (same slope) encompassing attained rates
  - Upper boundary explains the rate

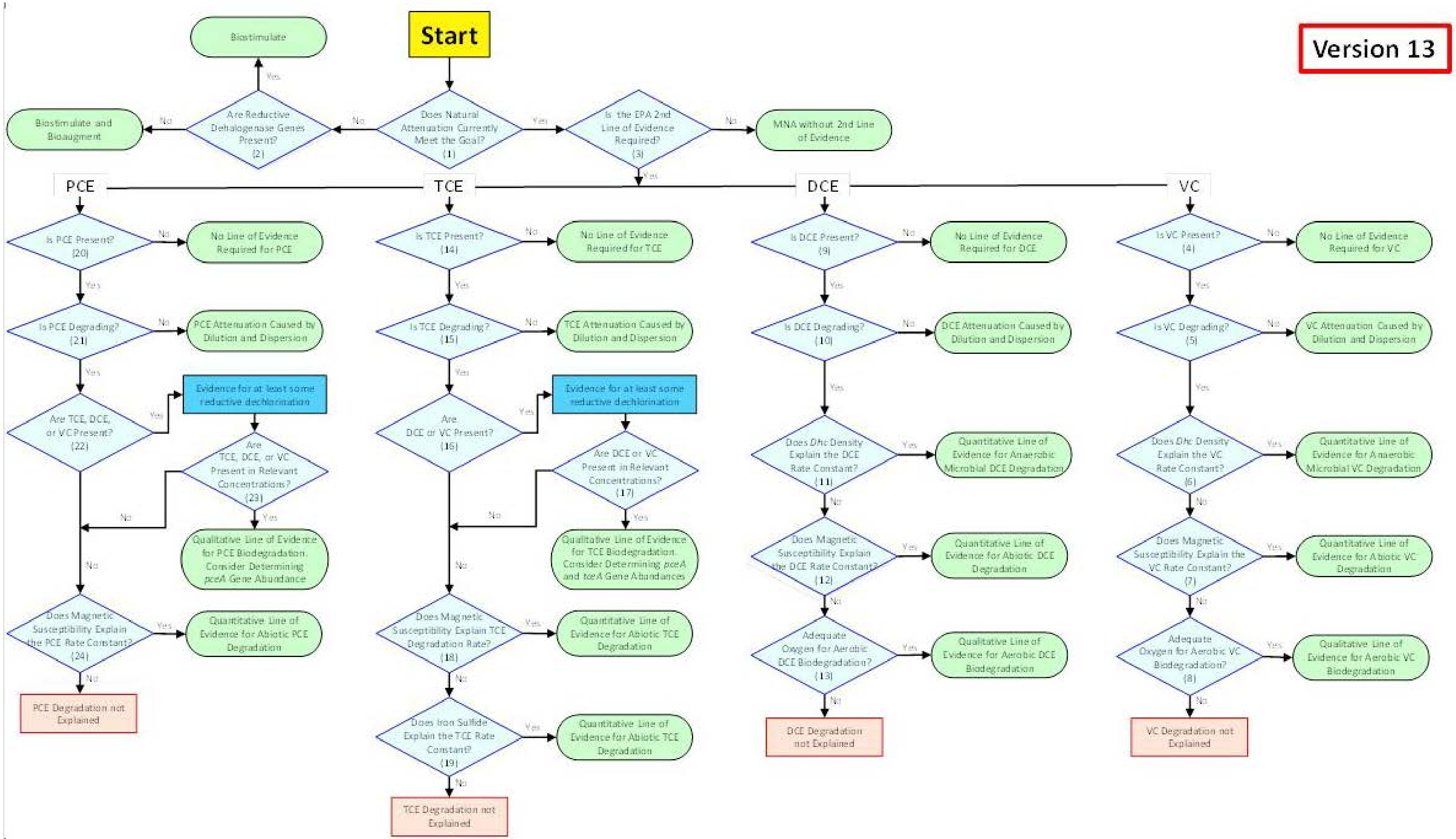
Related rates of PCE, TCE, *cis*-DCE and VC attenuation to these parameters:

- Dhc
- Dhc/Total Bacteria
- Rdases
- Rdases/Dhc
- DO
- ORP
- Magnetic susceptibility
- Fe(II)
- Mn(II)
- CH_4
- Ethene
- TOC (in H_2O)
- VC concentration
- Rdases vs. VC concentration

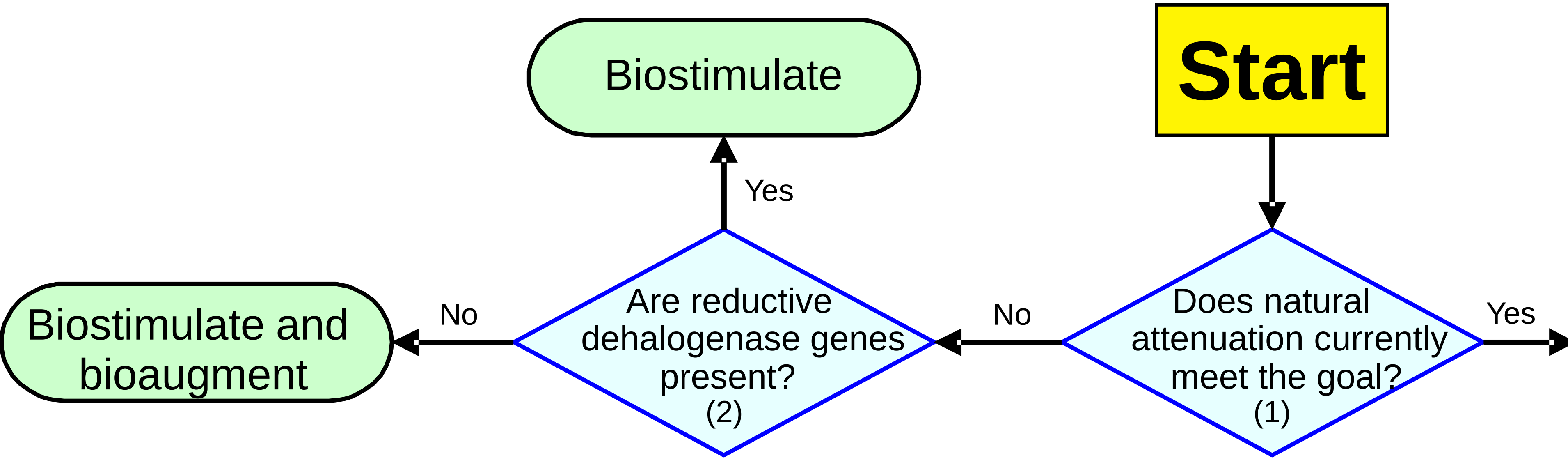
Task 4: Framework Development

- Parameters found to have a direct correlation on attenuation rate:
  - Dhc density (for TCE, cDCE, and VC only)
  - Magnetic susceptibility
  - FeS
  - CH_4
  - Fe(II)
- Used these parameters to develop decision framework logic

Task 4: Framework Logic



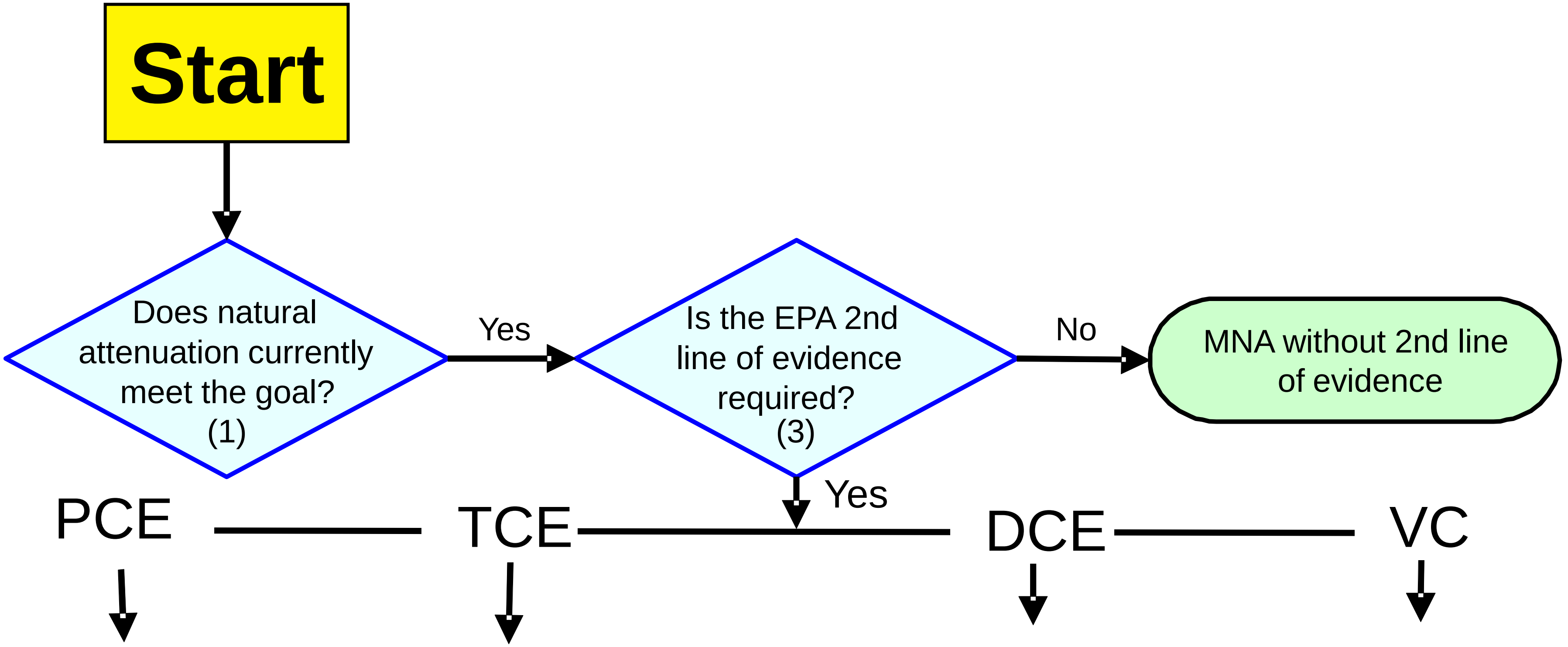
Task 4: Framework Logic



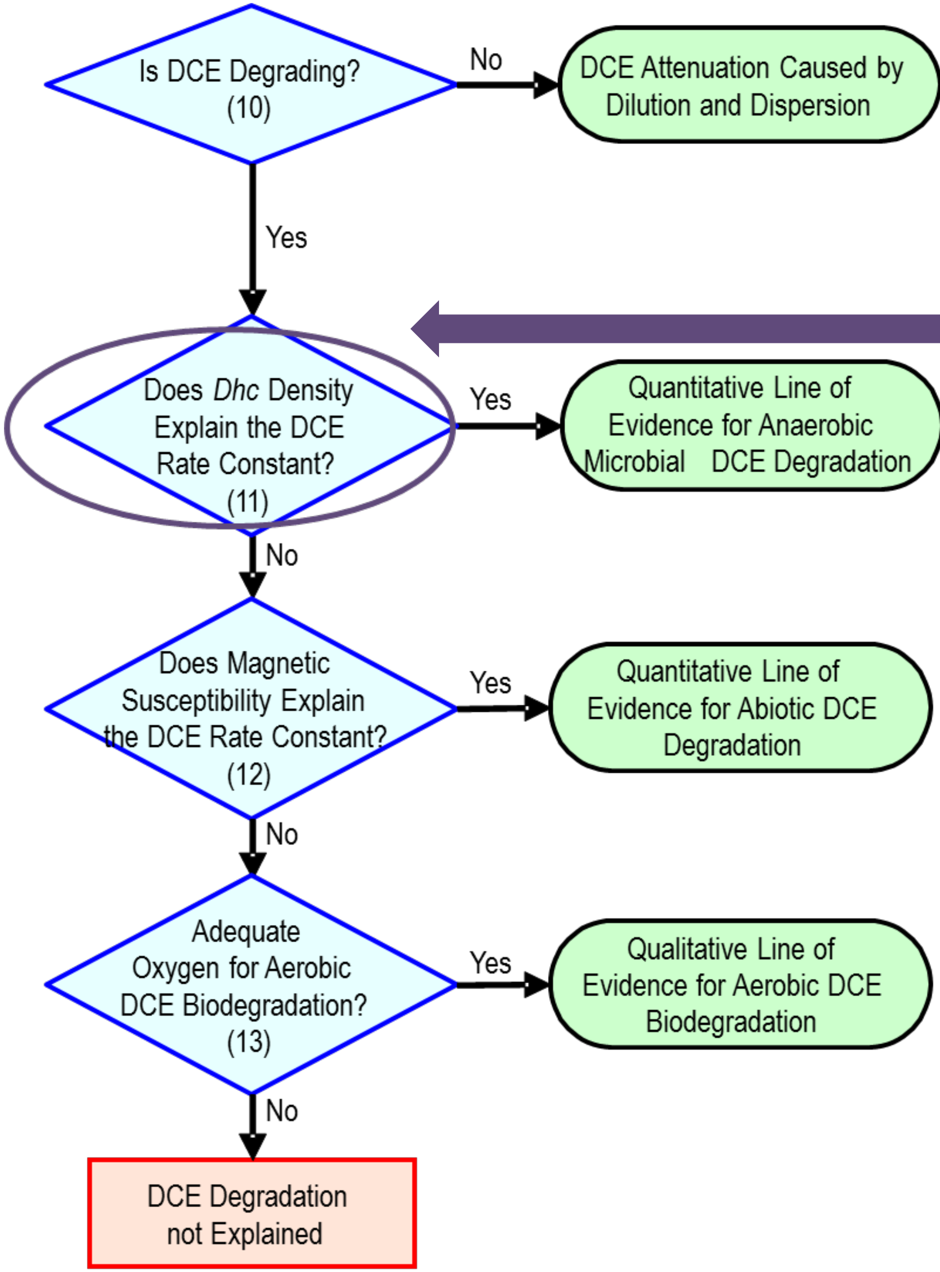
Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Directive 9200.4-17P

Task 4: Framework Logic



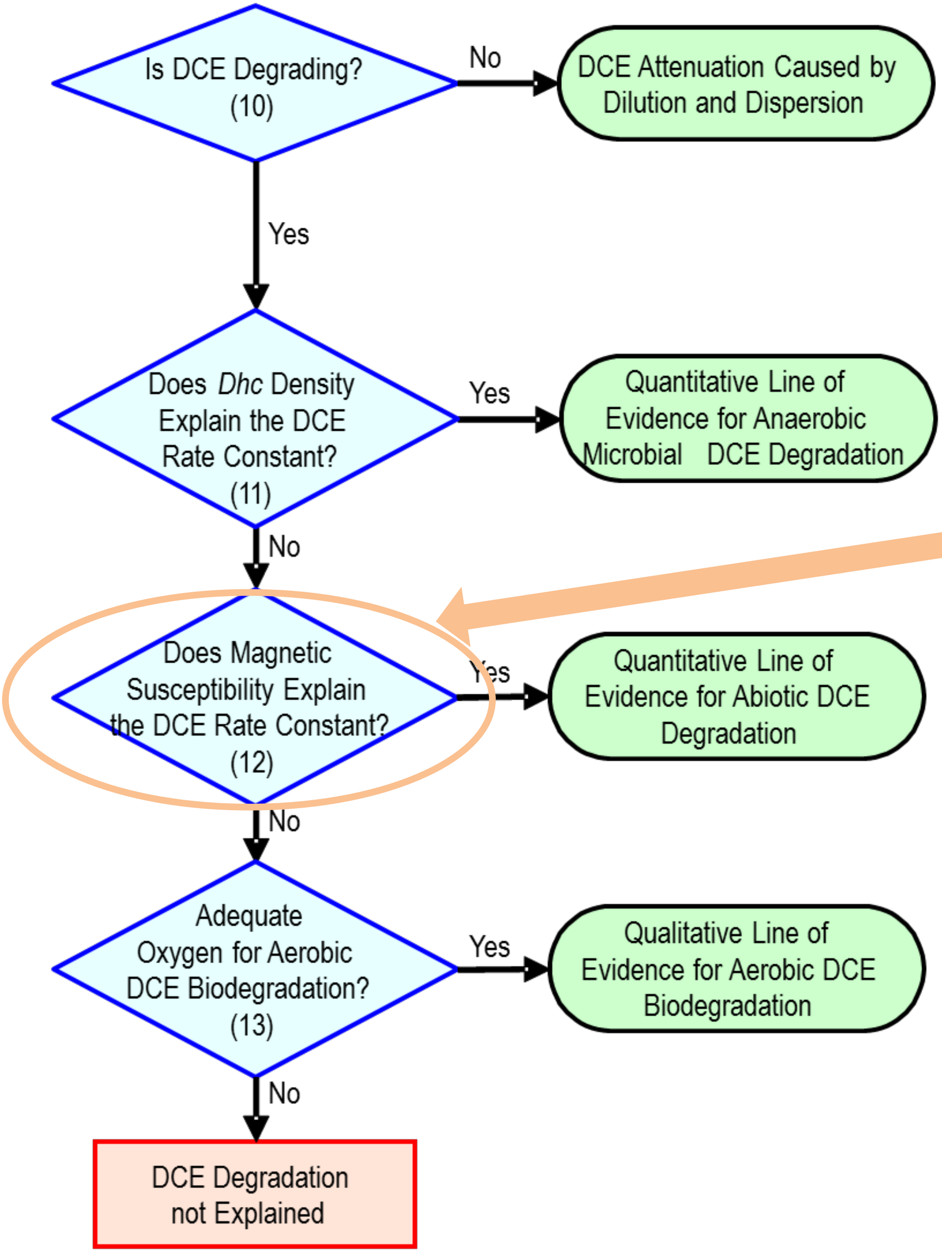
Framework Logic



Compare the rate of degradation and the density of Dehalococcoides bacteria at the site to the rate of degradation and the density of Dehalococcoides at benchmark sites

Use the spreadsheet Dhc explains rates.xlsx

Framework Logic



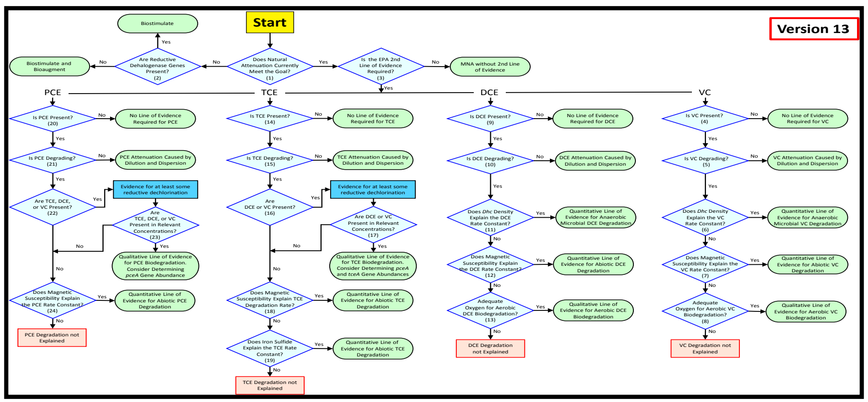
Compare the magnetic susceptibility and rate of abiotic degradation at the site to the magnetic susceptibility and rate of abiotic degradation of *cis*-DCE at benchmark sites

Use the spreadsheet *Magnetic Susceptibility explains rates.xlsx*

Task 5: Bio Pathway Identification Criteria (BioPIC)

BioPIC: Pathway Identification Criteria

A Decision Guide to Achieve Efficient Remediation of Chlorinated Ethenes



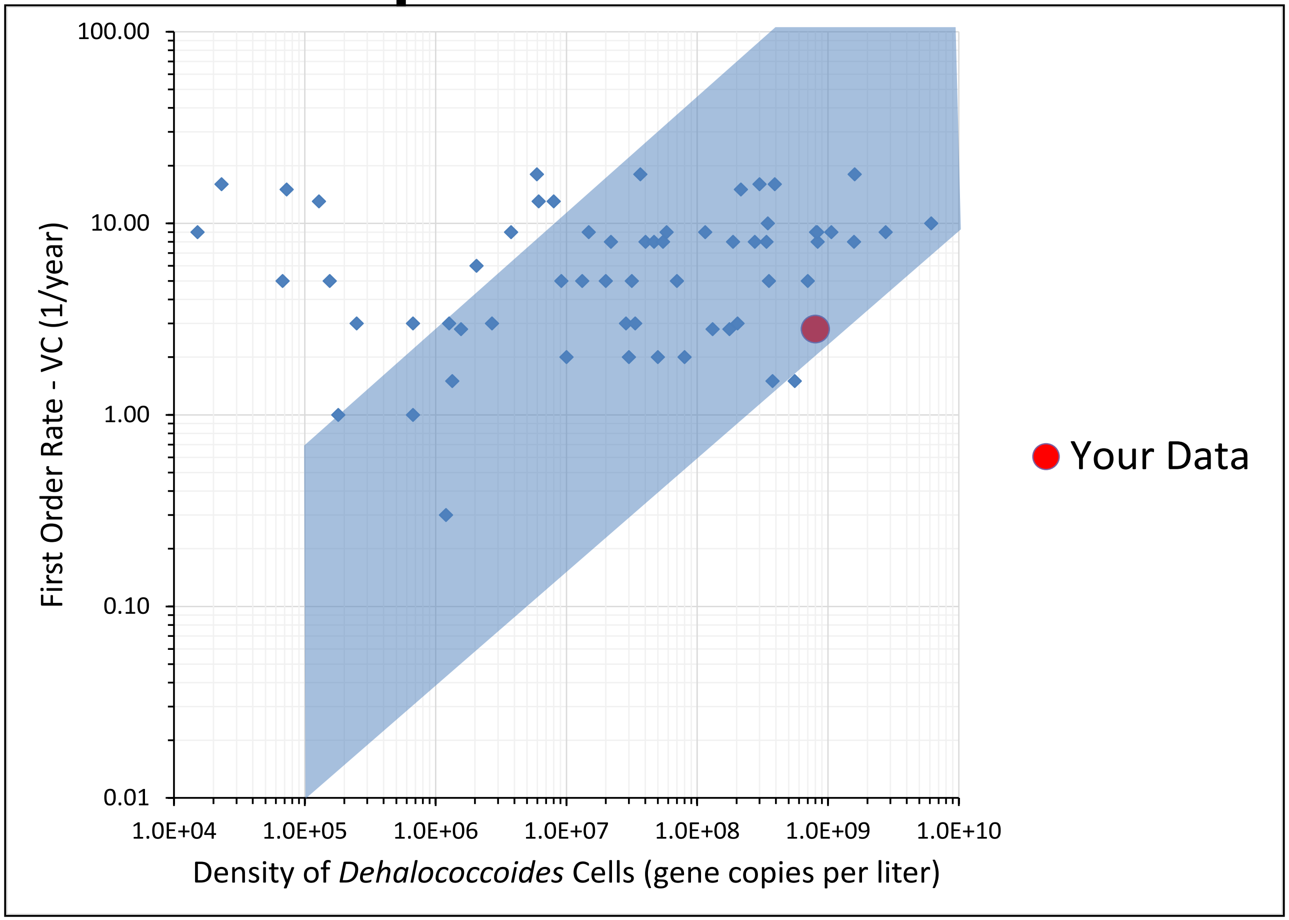
1	Does Natural Attenuation Meet the goal?	YES	NO	Decision Criteria	Help
3	Is the EPA 2nd Line of Evidence Required?	YES	NO	Decision Criteria	Help
		PCE	TCE	DCE	VC
4	Is VC present?	YES	NO	Decision Criteria	Help
5	Is VC degrading?	YES	NO	Decision Criteria	Help

Can biotic degradation by *Dehalococcoides* bacteria explain the field scale rate constant for degradation?

	Overwrite Input Cells with Data Specific to Your Site				
	Input				
	First order rate constant for degradation per year			pCR Assay Gene Copies per Liter	
TCE			*Dehaloccoides* 16sRNA	8.00E+08	
cis-DCE	2.5				
Vinyl Chloride	2.8				

Excel Spreadsheet ***Dhc explains rates.xlsx***

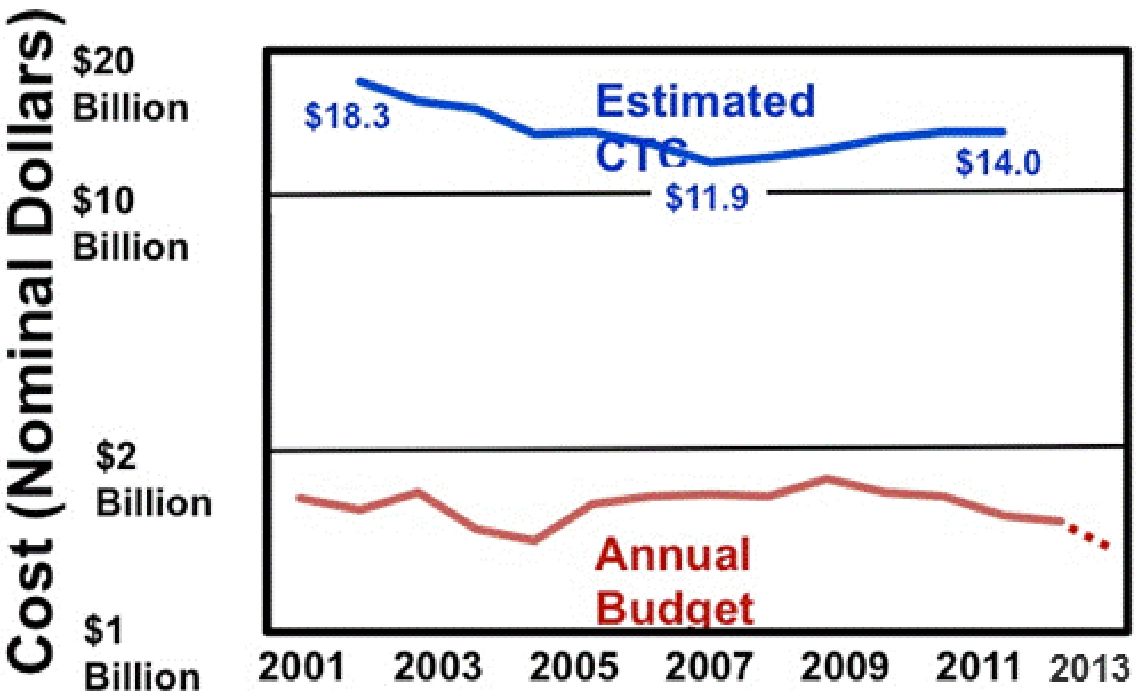
Impact to Users



If your data falls within the blue shape defined by the benchmark Poster Child sites, then the density of Dhc can explain your rate constant

Benefits to DoD

- Framework enables more focused site characterization tailored to the predominant detoxification pathways
- Follows EPA's MNA guidance
- Guides users in the most appropriate bioremediation approach



Defense Environmental Restoration Program Annual Reports to Congress http://www.denix.osd.mil/arc/

Q&A Session 1

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Project Results and Conclusions

Dr. John T. Wilson
Scissortail Environmental Solutions, LLC

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ESTCP

USEPA Primary Guidance Document for MNA

Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action and Underground Storage Tank Sites

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response Directive 9200.4-17P

USEPA Primary Guidance Document for MNA (Cont'd)

- *"Once site characterization data have been collected and a conceptual model developed, the next step is to evaluate the potential efficacy of MNA as a remedial alternative"*
- *"This involves collection of site-specific data sufficient to estimate with an acceptable level of confidence both the **rate of attenuation processes** and the **anticipated time required** to achieve remediation objectives"*

USEPA Primary Guidance Document for MNA (Cont'd)

A Tiered Approach

1. …Historical groundwater … data that demonstrate a clear and meaningful trend of decreasing contaminant … concentration over time at appropriate monitoring or sampling points
2. Hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site, and the **rate** at which such processes will reduce contaminant concentrations to required levels

Proposed Framework

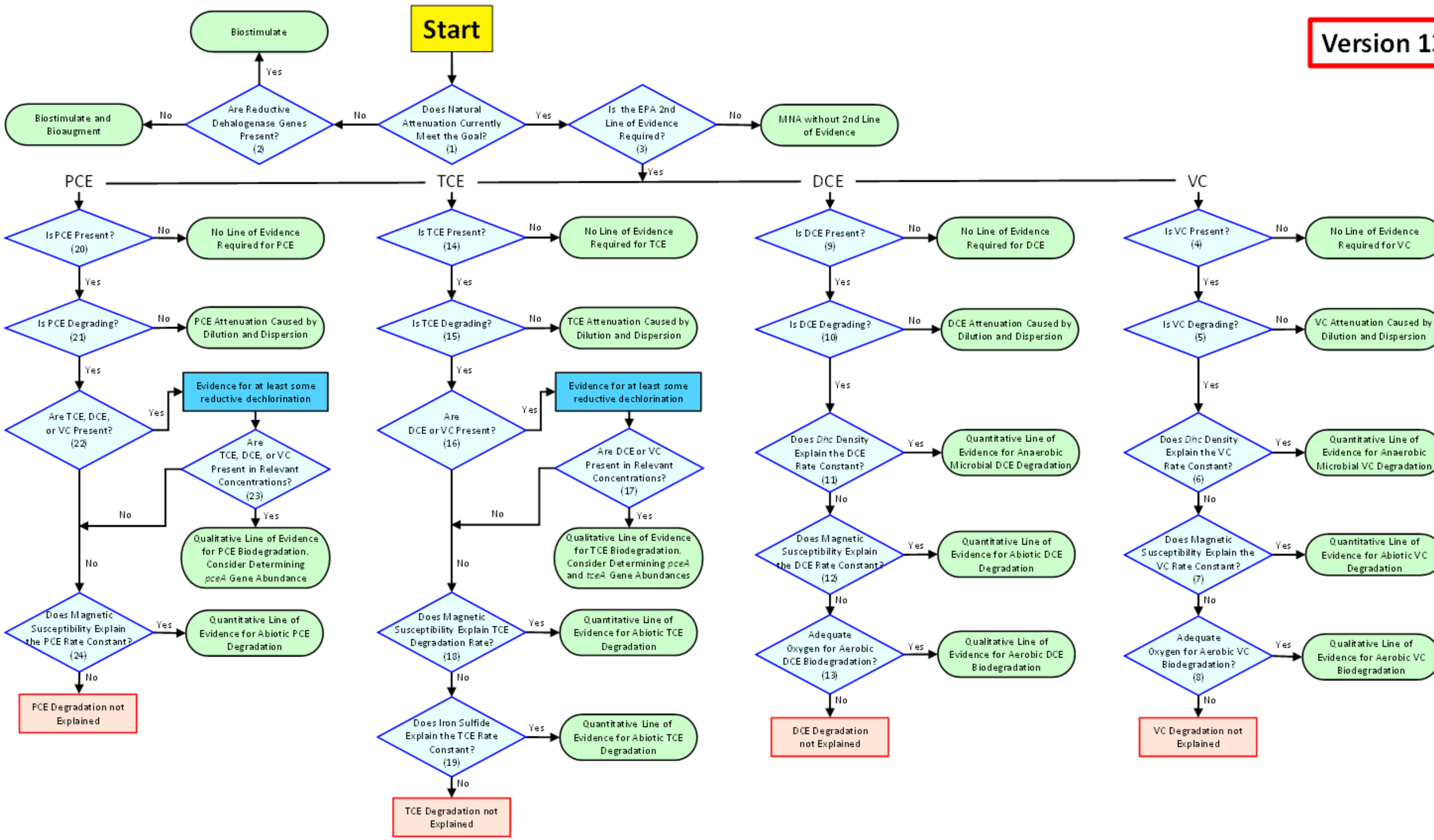
- The framework is intended to answer the following question: “Will a plume impact a receptor?”
  - Will the rate of attenuation bring the highest concentrations in groundwater to acceptable concentrations before the groundwater reaches the receptor of the sentry well?
  - Evaluated by extracting a rate constant from field data for the rate of degradation necessary to meet the goal

The Framework and BioPIC are not useful to answer this question

- Is the entire plume required to meet the goal?
  - The performance depends on the success of source treatment and the kinetics of natural attenuation of the source
  - These processes can not be evaluated or understood based on the rate of degradation of contaminants in groundwater

Decision Logic

Version 13



BioPIC Example

1	Does Natural Attenuation Meet the goal?	YES	NO	Decision Criteria	Help
3	Is the EPA 2nd Line of Evidence Required?	YES	NO	Decision Criteria	Help
		PCE	TCE	DCE	VC
4	Is VC present?	YES	NO	Decision Criteria	Help
5	Is VC degrading?	YES	NO	Decision Criteria	Help

CASE STUDY
EXTRACTING THE RATE CONSTANTS

Installation Restoration Site 5-Unit 2 (Golf Course Disposal Area)
North Island Naval Air Station, San Diego, California


LOMA
Cabrillo Memorial Dr

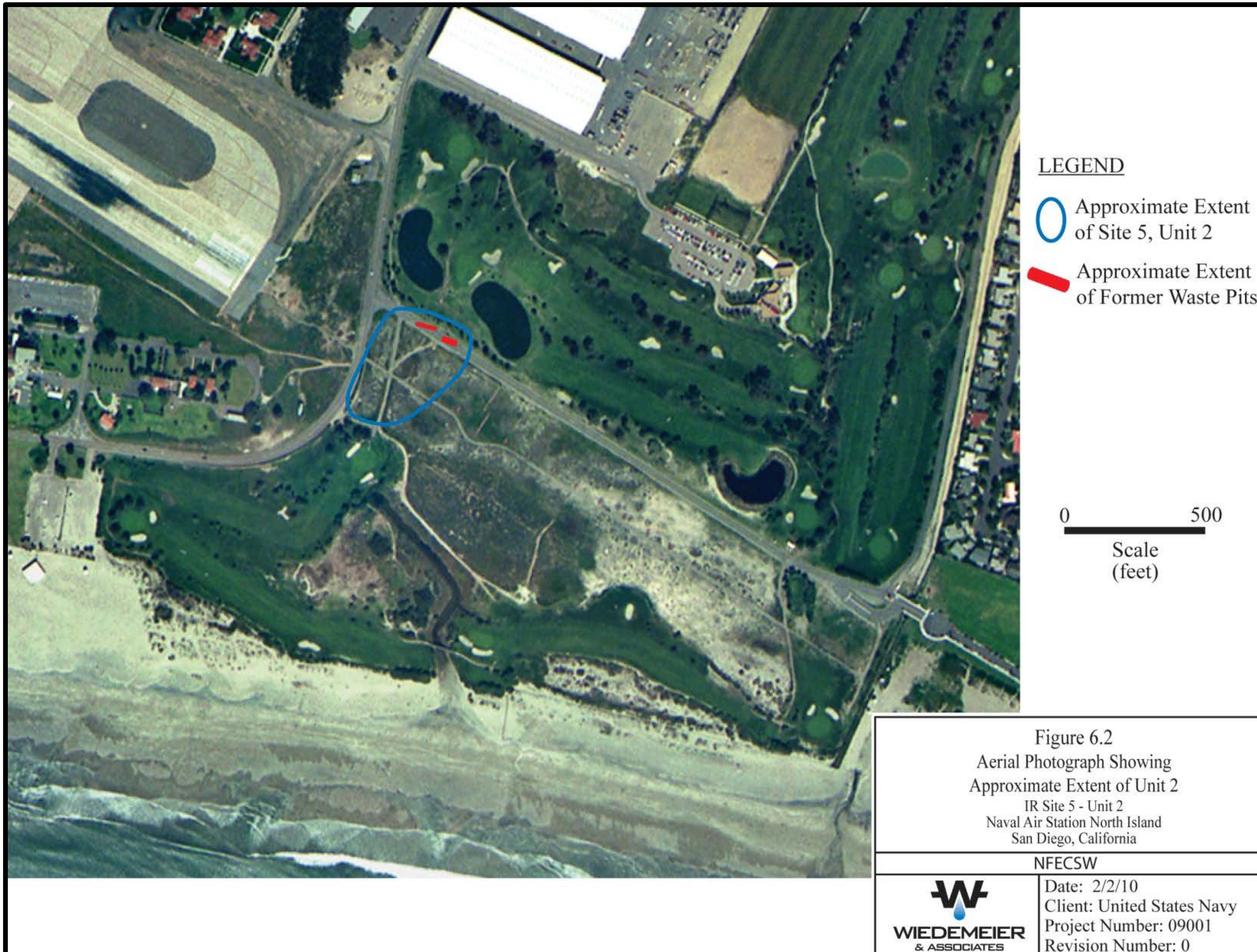
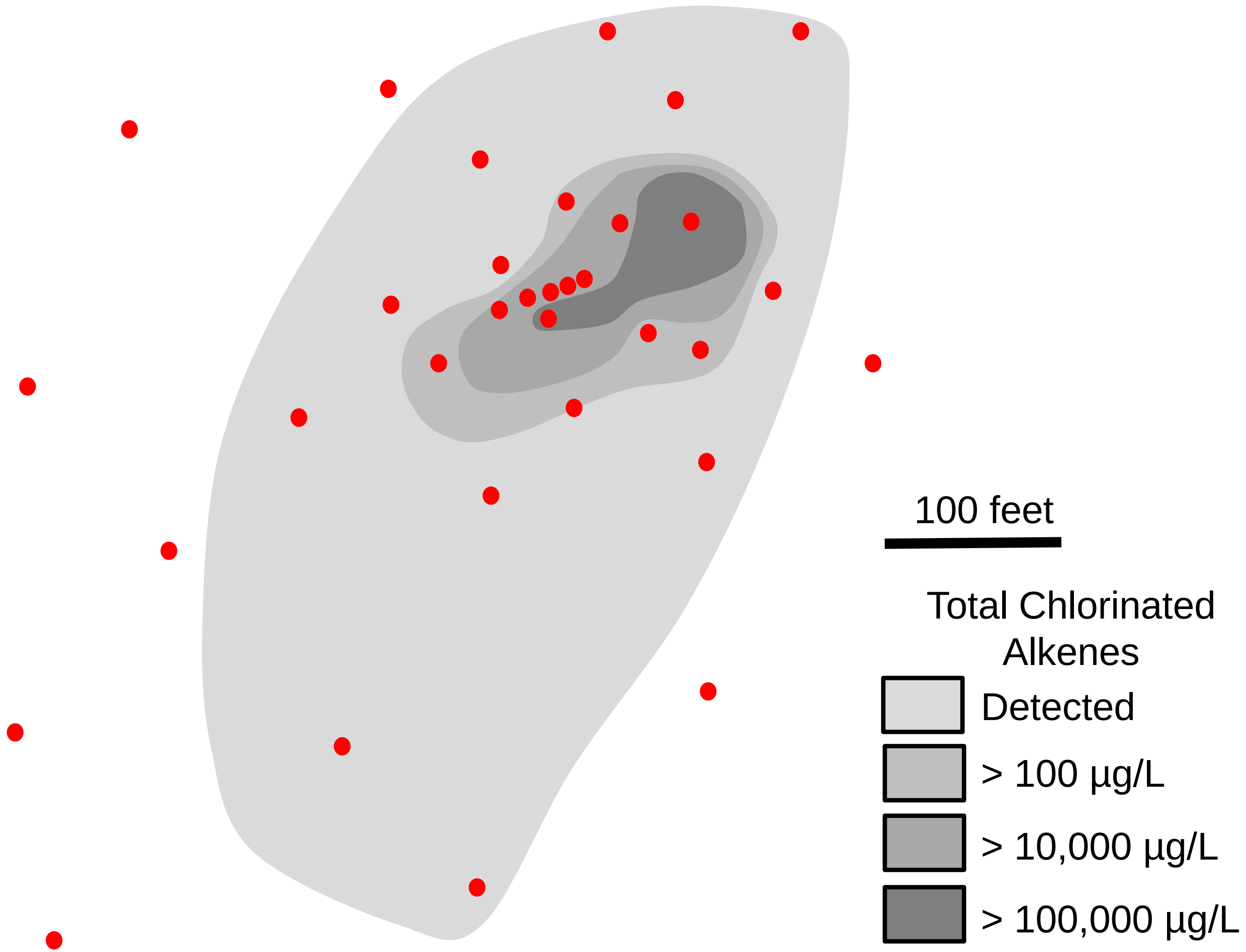


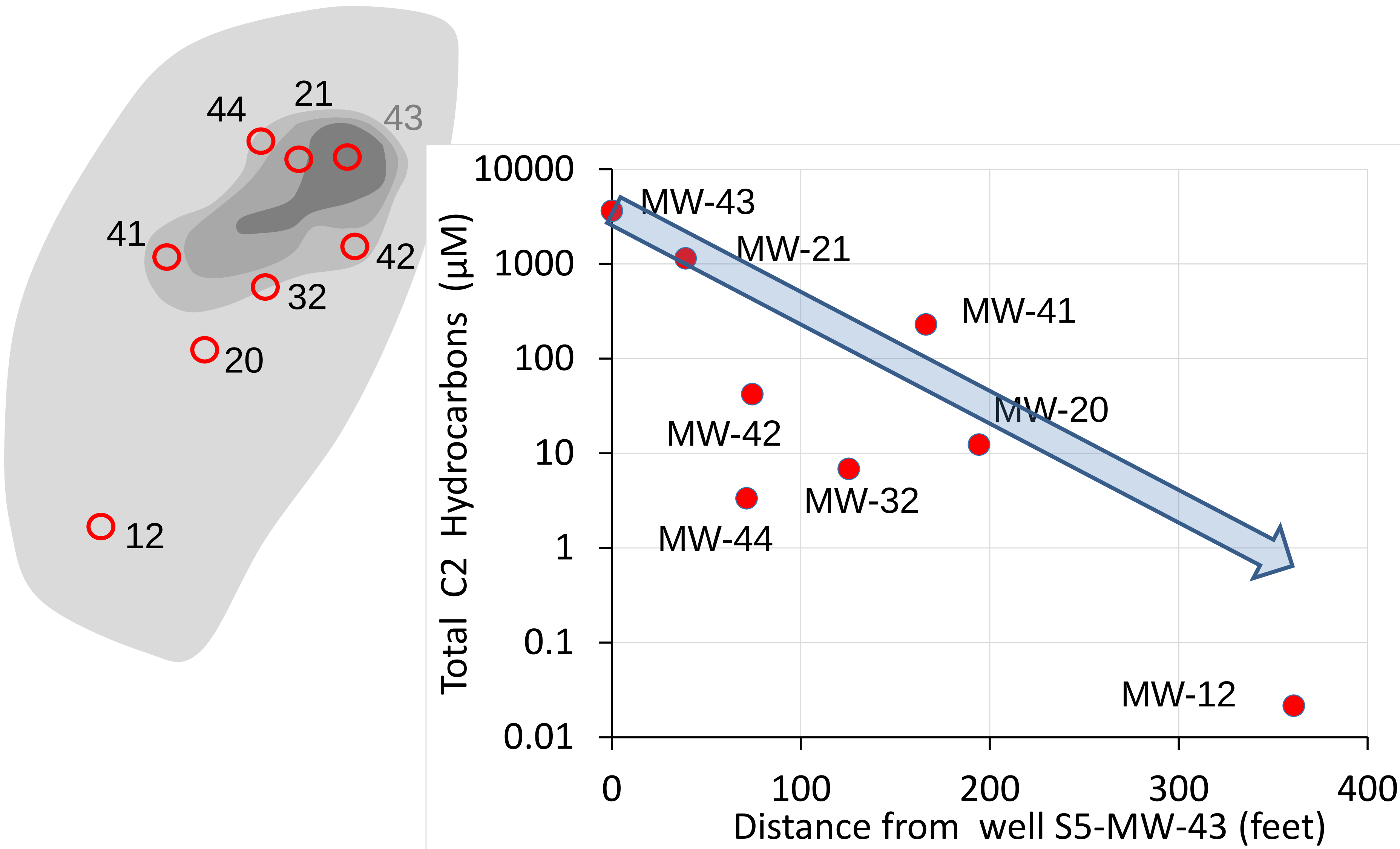
Figure 6.2
Aerial Photograph Showing
Approximate Extent of Unit 2
IR Site 5 - Unit 2
Naval Air Station North Island
San Diego, California

Regulatory Boundary

- For purposes of illustration, assume the receptor is the high tide line, which defines the waters of the State of California
- In the absence of biodegradation, would TCE, DCE and Vinyl Chloride reach the receptor at concentrations in excess of the MCL?

500 feet


100 feet
Total Chlorinated Alkenes
Detected
> 100 µg/L
> 10,000 µg/L
> 100,000 µg/L


44
21
43
41
42
32
20
12
Total C2 Hydrocarbons (µM)
10000
1000
100
10
1
0.1
0.01
MW-43
MW-21
MW-41
MW-42
MW-20
MW-32
MW-44
MW-12
0
100
200
300
400
Distance from well S5-MW-43 (feet)

BIOCHLOR Natural Attenuation Decision Support System

Version 2.2

Excel 2000

NAS North Island
Site 5 - Unit 2
Run Name

Data Input Instructions:

115 → 1. Enter value directly....or
or 2. Calculate by filling in gray
0.02 cells. Press Enter, then C
(To restore formulas, hit "Restore Formulas" button)
Variable* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

TYPE OF CHLORINATED SOLVENT: Ethenes (selected) / Ethanes

1. ADVECTION C

Seepage Velocity*	Vs	163.9	(ft/yr)
or			
Hydraulic Conductivity	K	9.9E-03	(cm/sec)
Hydraulic Gradient	i	0.004	(ft/ft)
Effective Porosity	n	0.25	(-)

2. DISPERSION

Alpha x*	29.447	(ft)
(Alpha y) / (Alpha x)*	0.1	(-)
(Alpha z) / (Alpha x)*	1.E-99	(-)

Calc. Alpha x

3. ADSORPTION C

Retardation Factor* → R

or

Soil Bulk Density, rho	1.4	(kg/L)
FractionOrganicCarbon, foc	5.0E-3	(-)

Partition Coefficient	Koc		R	
PCE	300	(L/kg)	9.40	(-)
TCE	100	(L/kg)	3.80	(-)
DCE	50	(L/kg)	2.40	(-)
VC	3	(L/kg)	1.08	(-)
ETH	1	(L/kg)	1.03	(-)

Common R (used in model)* = 2.40

4. BIOTRANSFORMATION **-1st Order Decay Coefficient*** C

Zone 1	λ (1/yr)	half-life (yrs)	Yield
PCE → TCE	0.000		0.79
TCE → DCE	0.000		0.74
DCE → VC	0.000		0.64
VC → ETH	0.000		0.45

Zone 2	λ (1/yr)	half-life (yrs)
PCE → TCE	0.000	
TCE → DCE	0.000	
DCE → VC	0.000	
VC → ETH	0.000	

λ HELP

5. GENERAL C

Simulation Time*	33	(yr)
Modeled Area Width*	500	(ft)
Modeled Area Length*	1500	(ft)
Zone 1 Length*	1500	(ft)
Zone 2 Length*	0	(ft)

L W

Zone 2= L - Zone 1

6. SOURCE DATA TYPE: Continuous Single Planar

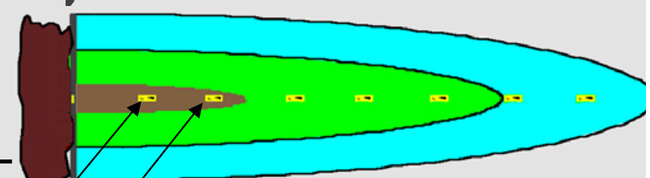
Source Options

Source Thickness in Sat. Zone* 80 (ft)

Width* (ft) Y1: 50

Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE		0
DCE	500.0	0
VC	87.0	0
ETH	0.72	0

Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations



View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)											
TCE Conc. (mg/L)											
DCE Conc. (mg/L)	500.0	17.0	16.0	.046							
VC Conc. (mg/L)	87.0	25.0	71.0	.88							
ETH Conc. (mg/L)	0.7	48.0	72.0	178.0							
Distance from Source (ft)	0	48	72	178							

Date Data Collected 20005 July

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE | RUN ARRAY | Help | Restore | RESET | SEE OUTPUT | Paste | Unprotect

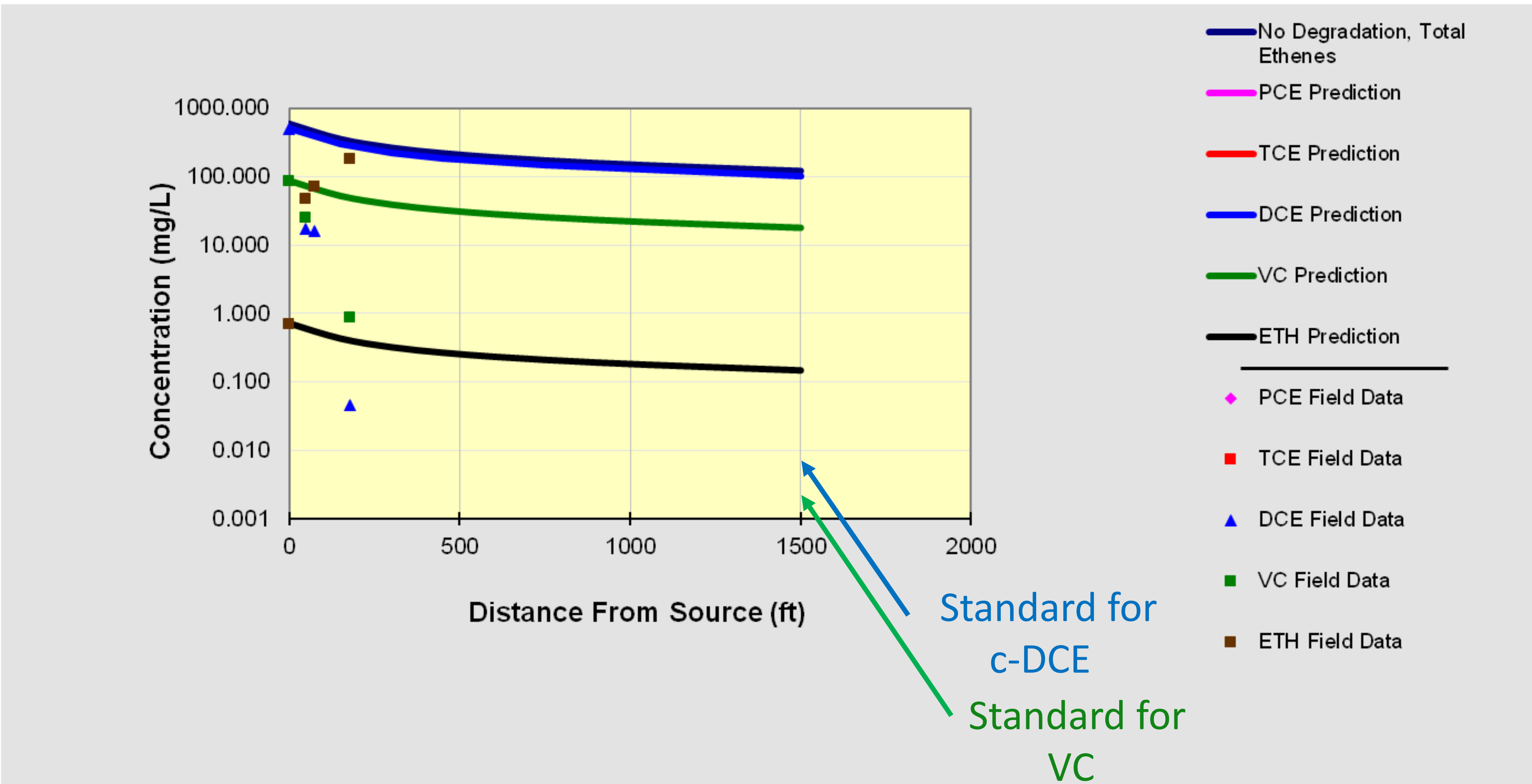
Set rate constants for degradation of DCE to VC and VC to ETH to zero

4. BIOTRANSFORMATION **-1st Order Decay Coefficient*** C

			λ (1/yr)		half-life (yrs)	Yield
Zone 1						
PCE	→	TCE	0.000	←		0.79
TCE	→	DCE	0.000	←		0.74
DCE	→	VC	0.000	←		0.64
VC	→	ETH	0.000	←		0.45
Zone 2			λ (1/yr)		half-life (yrs)	
PCE	→	TCE	0.000	←		
TCE	→	DCE	0.000	←		
DCE	→	VC	0.000	←		
VC	→	ETH	0.000	←		

λ HELP

Dissolved Chlorinated Solvent Concentrations Along Plume Centerline



Optimum Rate Constants for Degradation of DCE to VC and VC to ETH

4. BIOTRANSFORMATION **-1st Order Decay Coefficient***

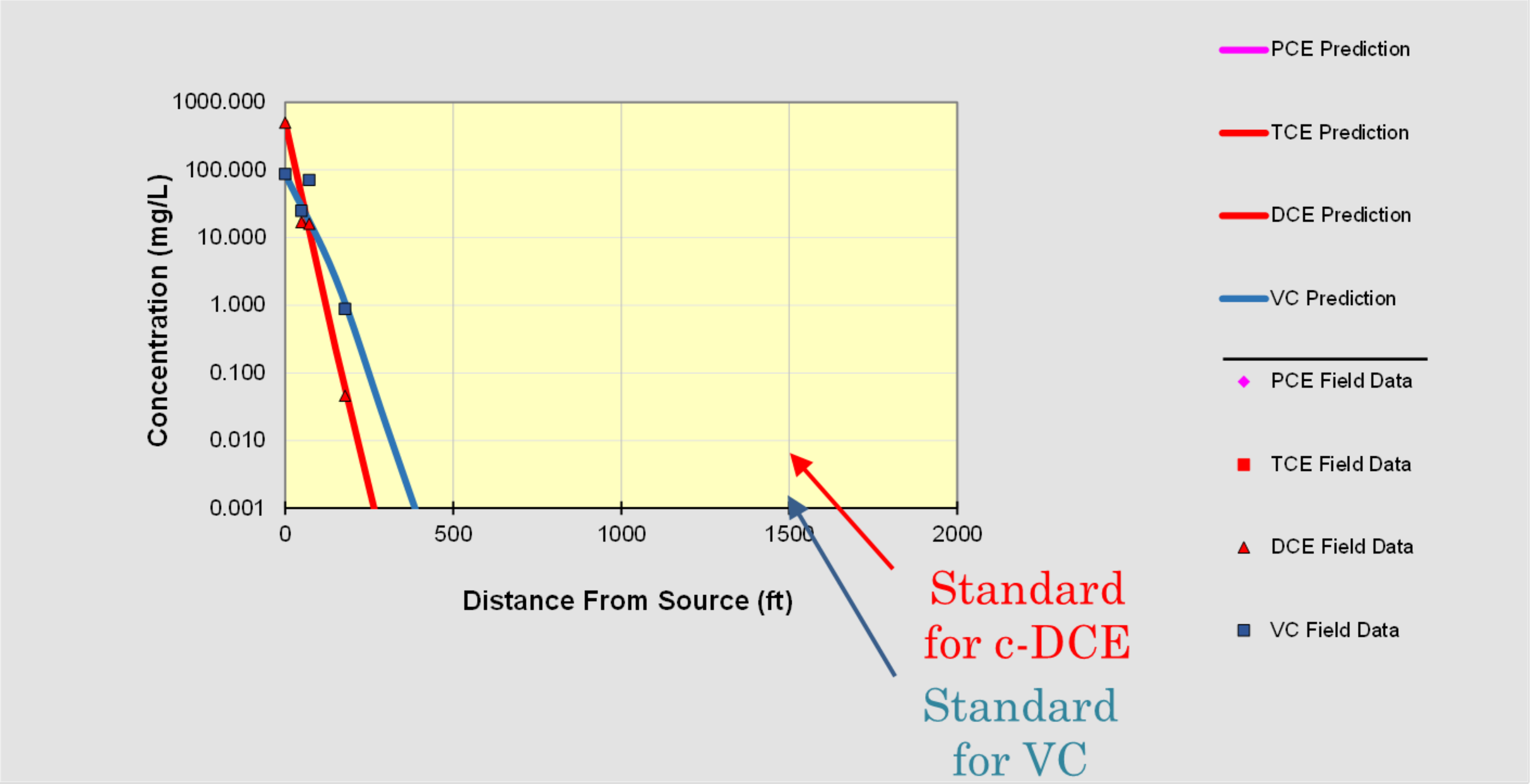
C

Zone 1			λ (1/yr)	half-life (yrs)	Yield
PCE	→	TCE	0.000		0.79
TCE	→	DCE	0.000		0.74
DCE	→	VC	17.000		0.64
VC	→	ETH	10.000		0.45

Zone 2			λ (1/yr)	half-life (yrs)
PCE	→	TCE	0.000	
TCE	→	DCE	0.000	
DCE	→	VC	0.000	
VC	→	ETH	0.000	

λ HELP

Dissolved Chlorinated Solvent Concentrations Along Plume Centerline



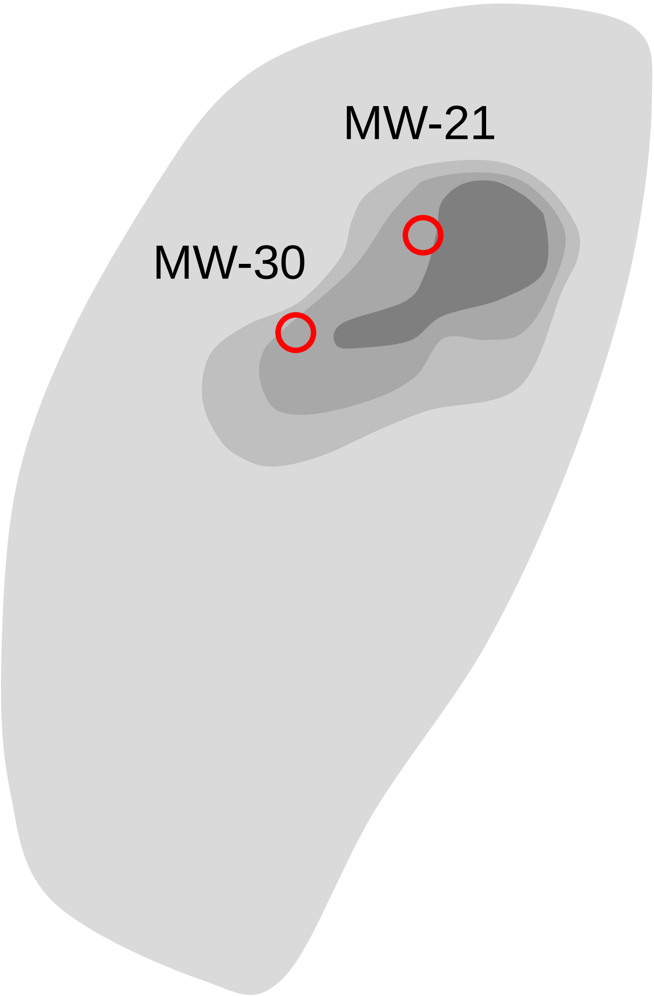
Is the Rate of Degradation of DCE and VC Adequate?

- Based on the monitoring data and geo-hydrological data as evaluated with BIOCHLOR, natural attenuation can be expected to keep the concentrations of DCE and VC below the regulatory standard at the receptor
- Can we explain the removals of DCE and VC?

CASE STUDY

USE OF QPCR FOR GENE COPIES OF *DEHALOCOCCOIDES* BACTERIA TO BOUND THE RATE OF BIOLOGICAL REDUCTIVE DECHLORINATION

Installation Restoration Site 5-Unit 2 (Golf Course Disposal Area), North Island Naval Air Station, San Diego, California



10-6-2005

Density of Dhc 16s ribosomal DNA
Gene Copies per Liter

MW-21 has 6.15E + 09

MW-30 has 3.47E + 08

WATER RESEARCH 40 (2006) 3131–3140

Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Relationship between *Dehalococcoides* DNA in ground water and rates of reductive dechlorination at field scale

Xiaoxia Lu[a,*], *John T. Wilson*[b], *Donald H. Kampbell*[b]

[a]*National Research Council, Tenable at US Environmental Protection Agency, 919 Kerr Research Drive, Ada, OK 74820, USA*
[b]*US Environmental Protection Agency, 919 Kerr Research Drive, Ada, OK 74820, USA*

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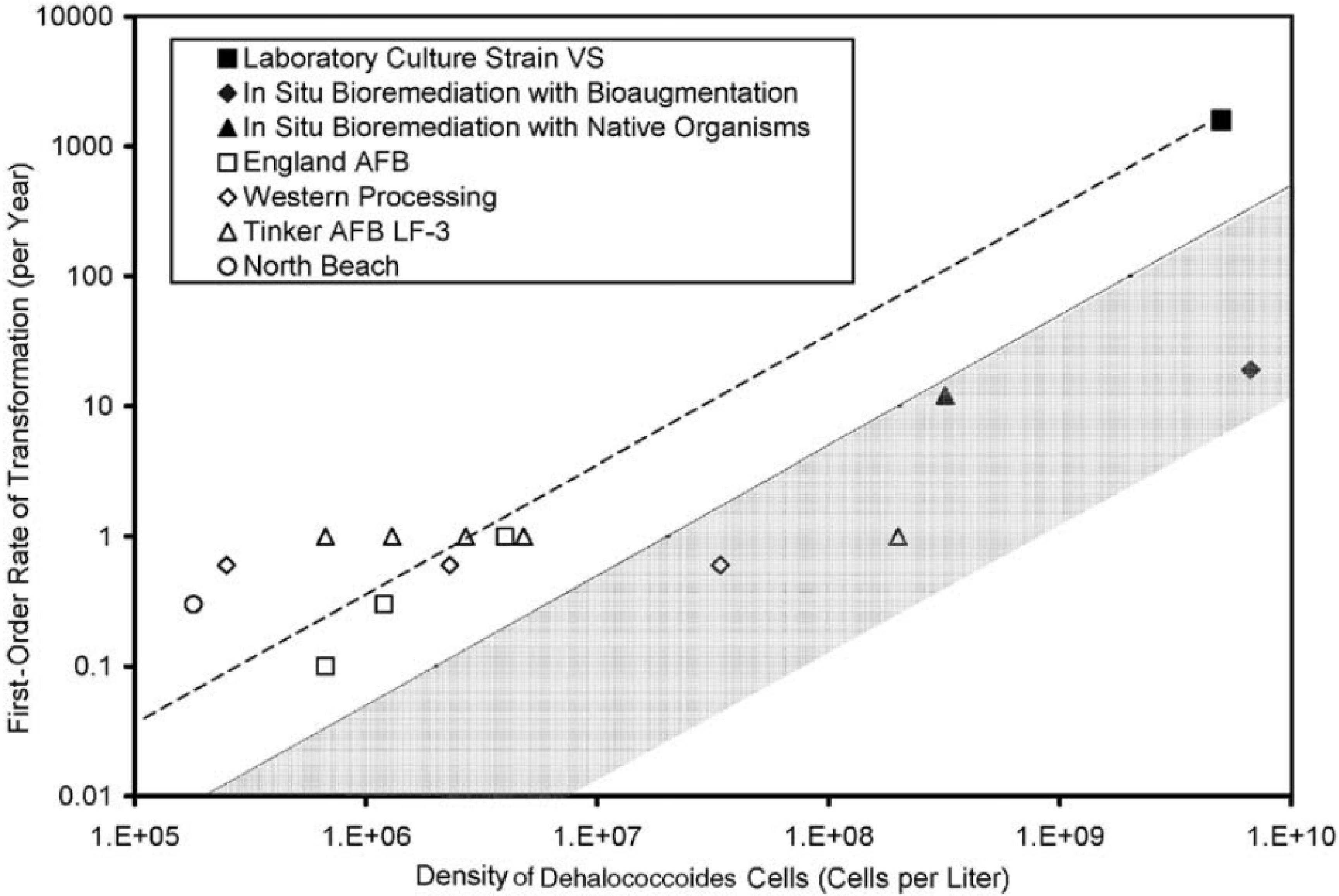
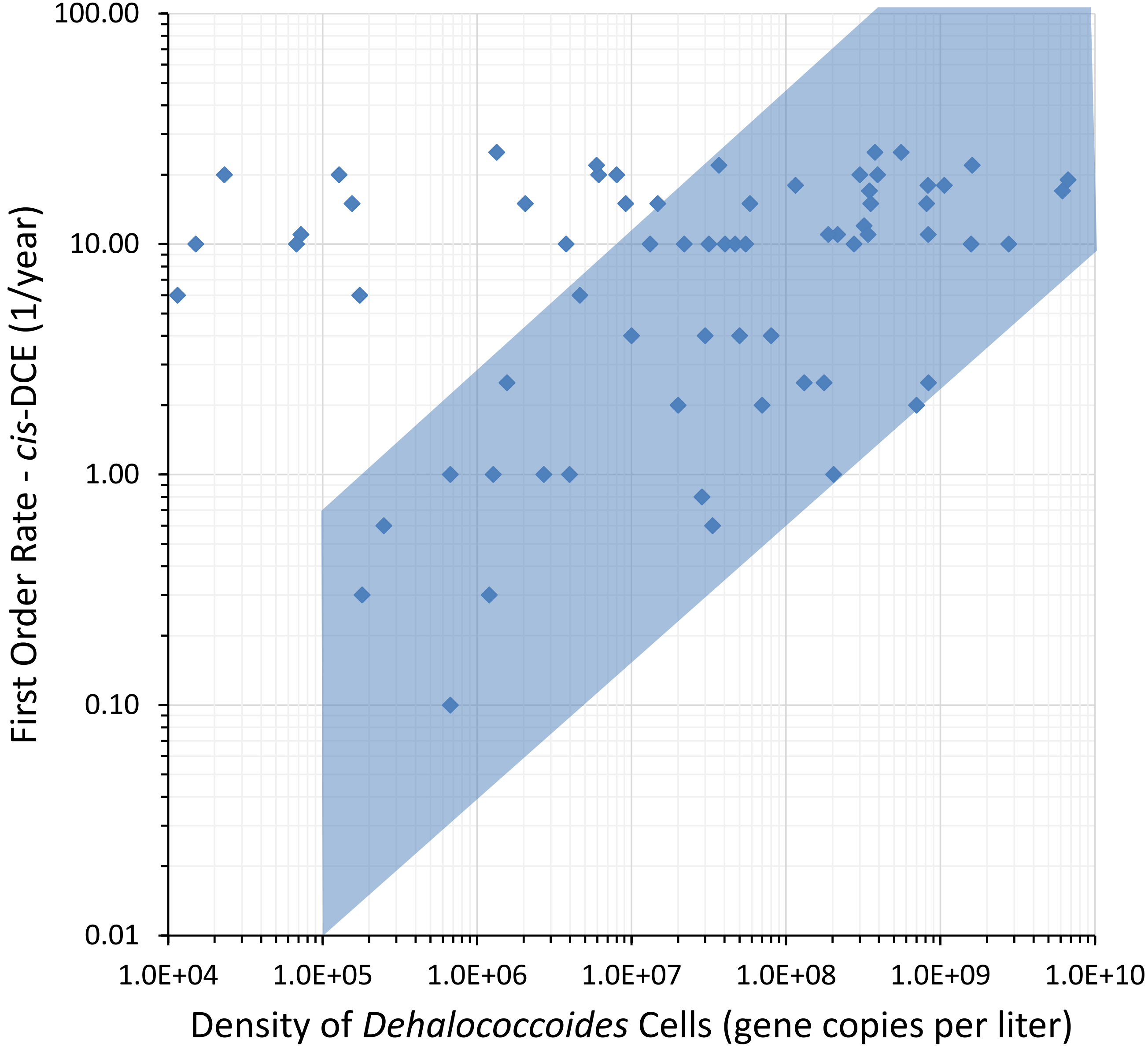
Reductive dechlorination
Natural attenuation

ABSTRACT

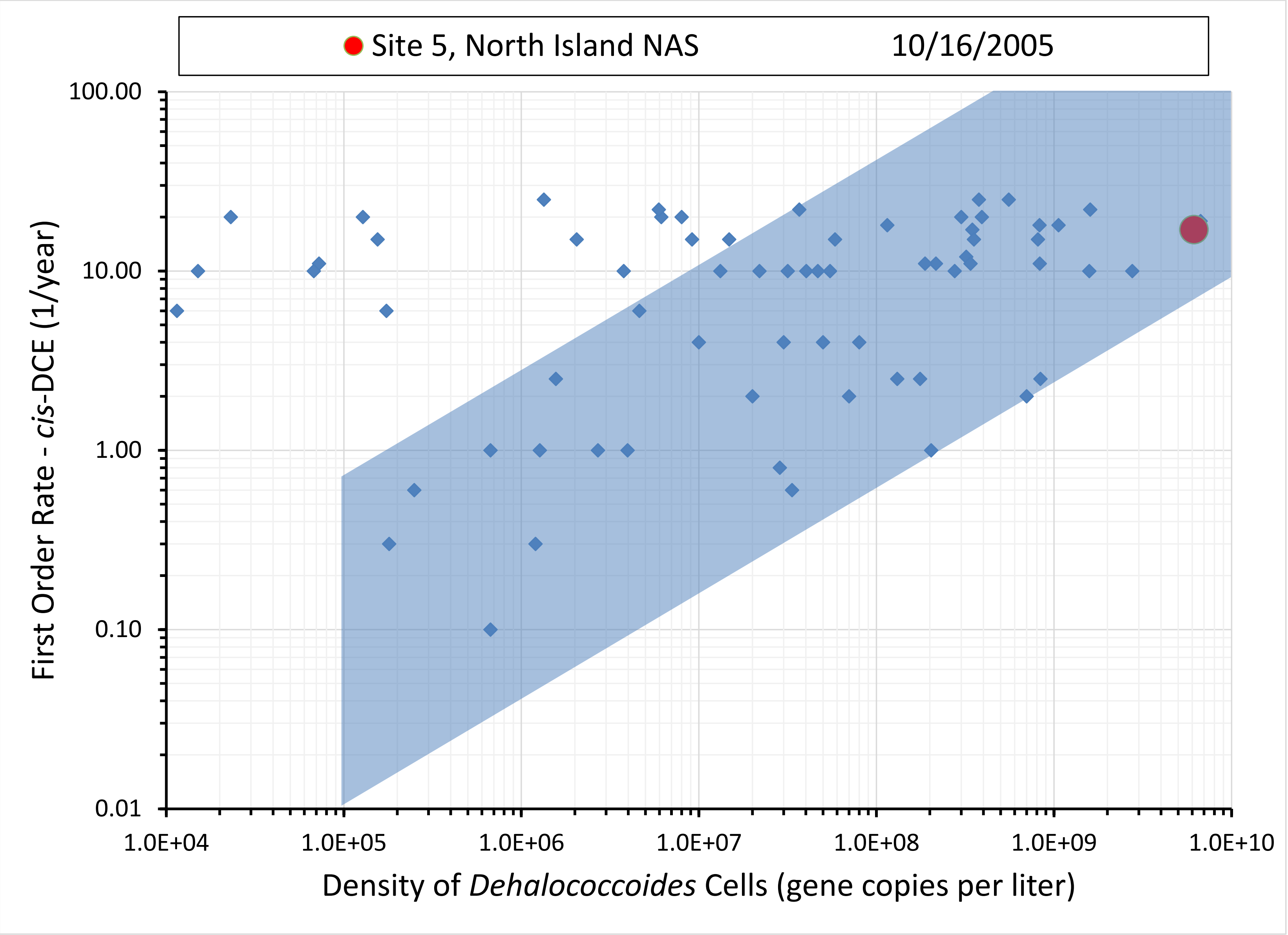
Certain strains of *Dehalococcoides* bacteria can dechlorinate chlorinated ethylenes to harmless products. This study was conducted to determine if there is a valid association between the density of *Dehalococcoides* DNA in ground water and the observed rates of reductive dechlorination at field scale. *Dehalococcoides* DNA in water from monitoring wells was determined using the quantitative real time polymerase chain reaction (q-PCR) with DNA primer set specific for *Dehalococcoides* organisms. Dechlorination rate constants were extracted from field data using the BIOCHLOR software. Of the six conventional plumes surveyed, "generally useful" rates of dechlorination (greater than or equal to 0.3 per year) of *cis*-dichloroethylene (*cis*-DCE) and vinyl chloride (VC) along the flow path were observed at three sites where *Dehalococcoides* DNA was detected, and little attenuation of *cis*-DCE and VC occurred at two sites where *Dehalococcoides* DNA was not detected. At the two sites where there was no net direction of ground water flow, the relationship between the density of *Dehalococcoides* DNA in ground water and the trend in concentrations of chlorinated ethylenes over time in monitoring wells was not so consistent as that observed for the conventional plumes. A comparison of our study to a field study performed by Lendvay and his coworker indicated that monitoring wells did not efficiently sample the *Dehalococcoides* organisms in the aquifer.


Laboratory Culture Strain VS
In Situ Bioremediation with Bioaugmentation
In Situ Bioremediation with Native Organisms
England AFB
Western Processing
Tinker AFB LF-3
North Beach
First-Order Rate of Transformation (per Year)
10000
1000
100
10
1
0.1
0.01
1.E+05
1.E+06
1.E+07
1.E+08
1.E+09
1.E+10
Density of Dehalococcoides Cells (Cells per Liter)

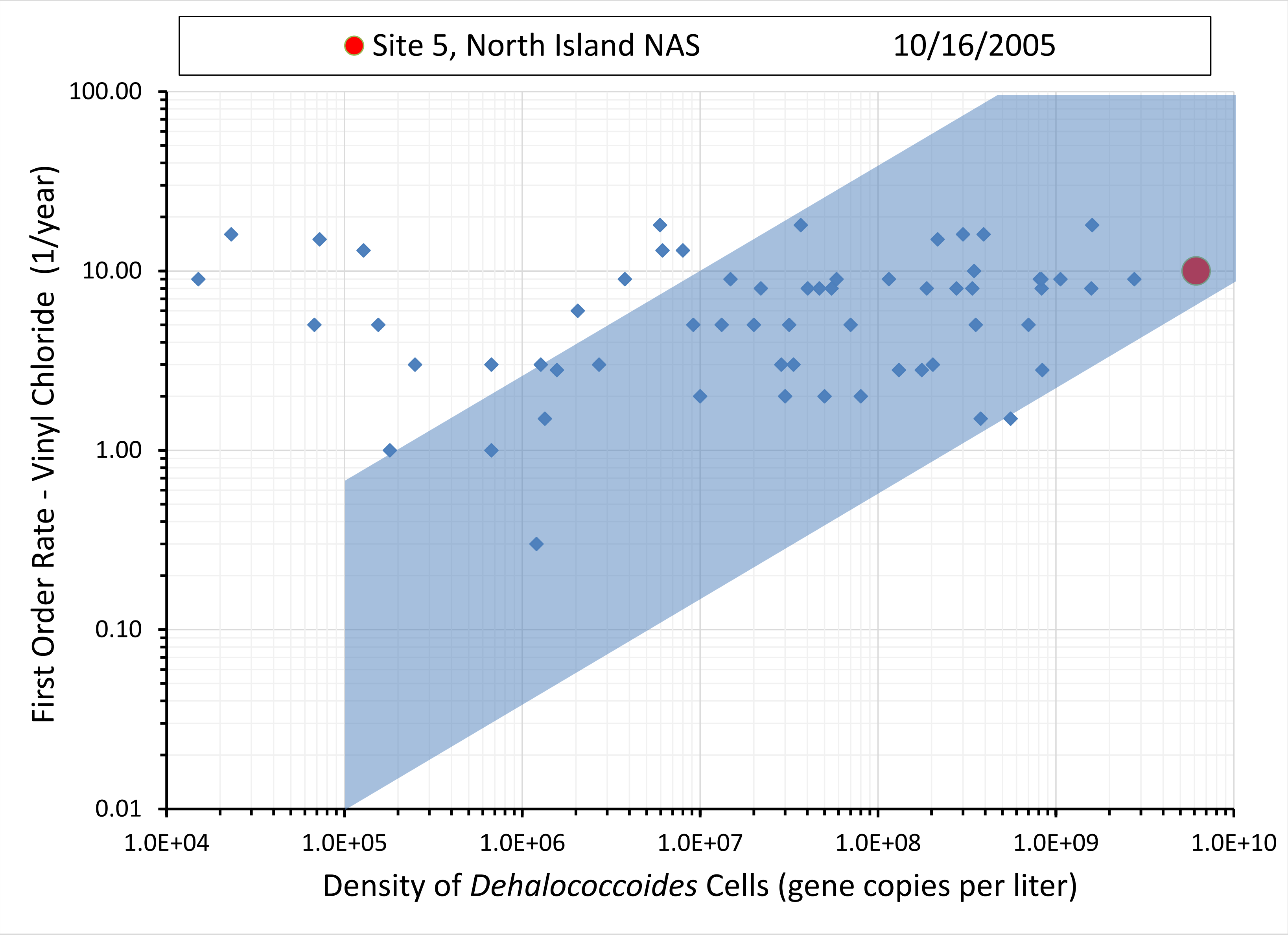


100.00
10.00
1.00
0.10
0.01
First Order Rate - *cis*-DCE (1/year)
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Density of *Dehalococcoides* Cells (gene copies per liter)

	Overwrite input cells with data specific to your site	The BASELINE rate constant is the slowest rate constant that is plausibly associated with *Dehalococcoides* DNA (*Dhc*)
	Input	
	First order rate constant for degradation per year	Fraction of rate constants in the benchmark data set that exceed the BASELINE to a extent than this rate constant
cis-DCE	17	>80%
Vinyl Chloride	10	>80%
	qPCR assay Gene copies per liter	
Dehalococcoides 16s rRNA	6.15E+09	
Location and Site	Site 5, North Island NAS	
Date	10/16/2005	

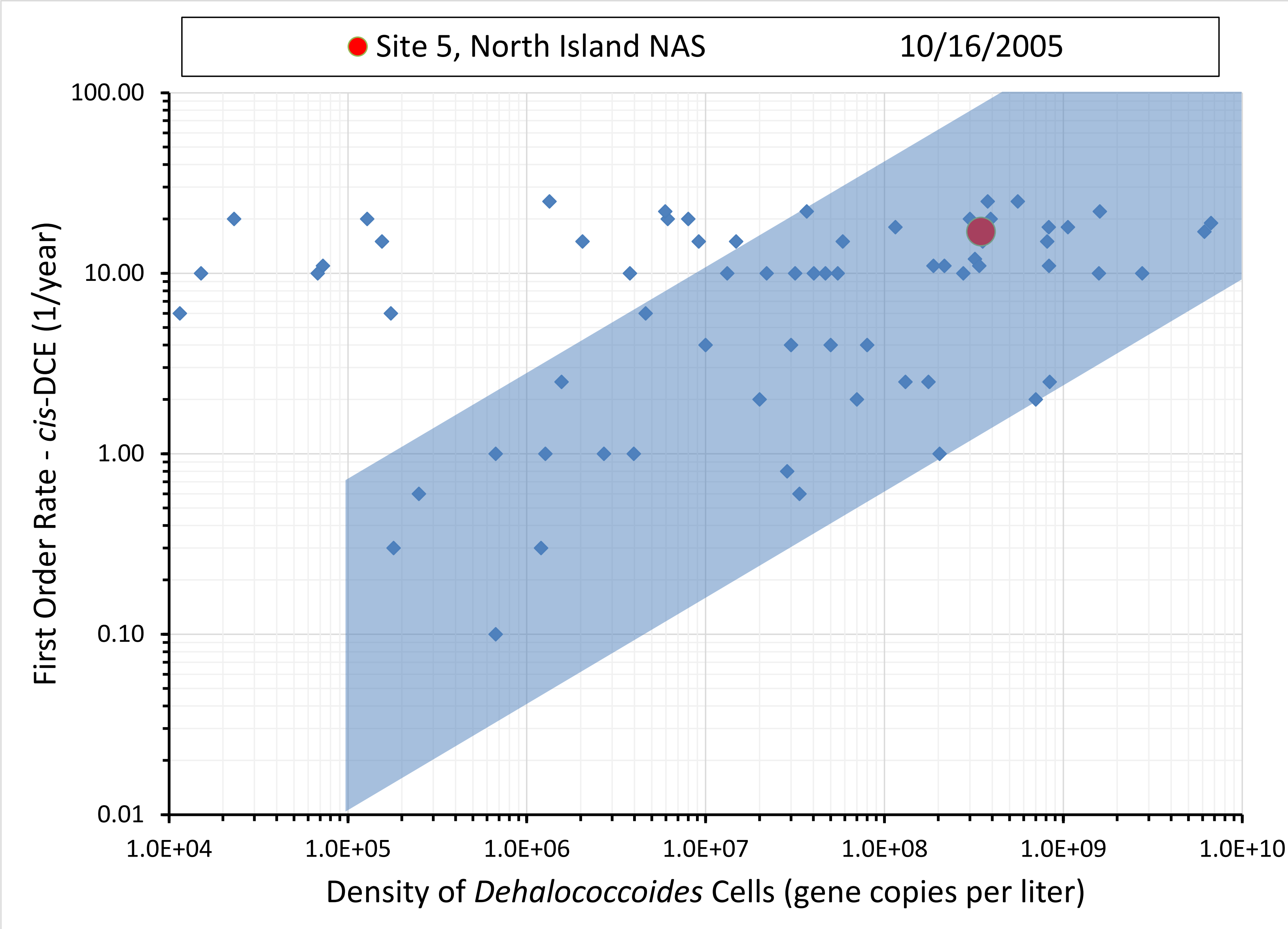


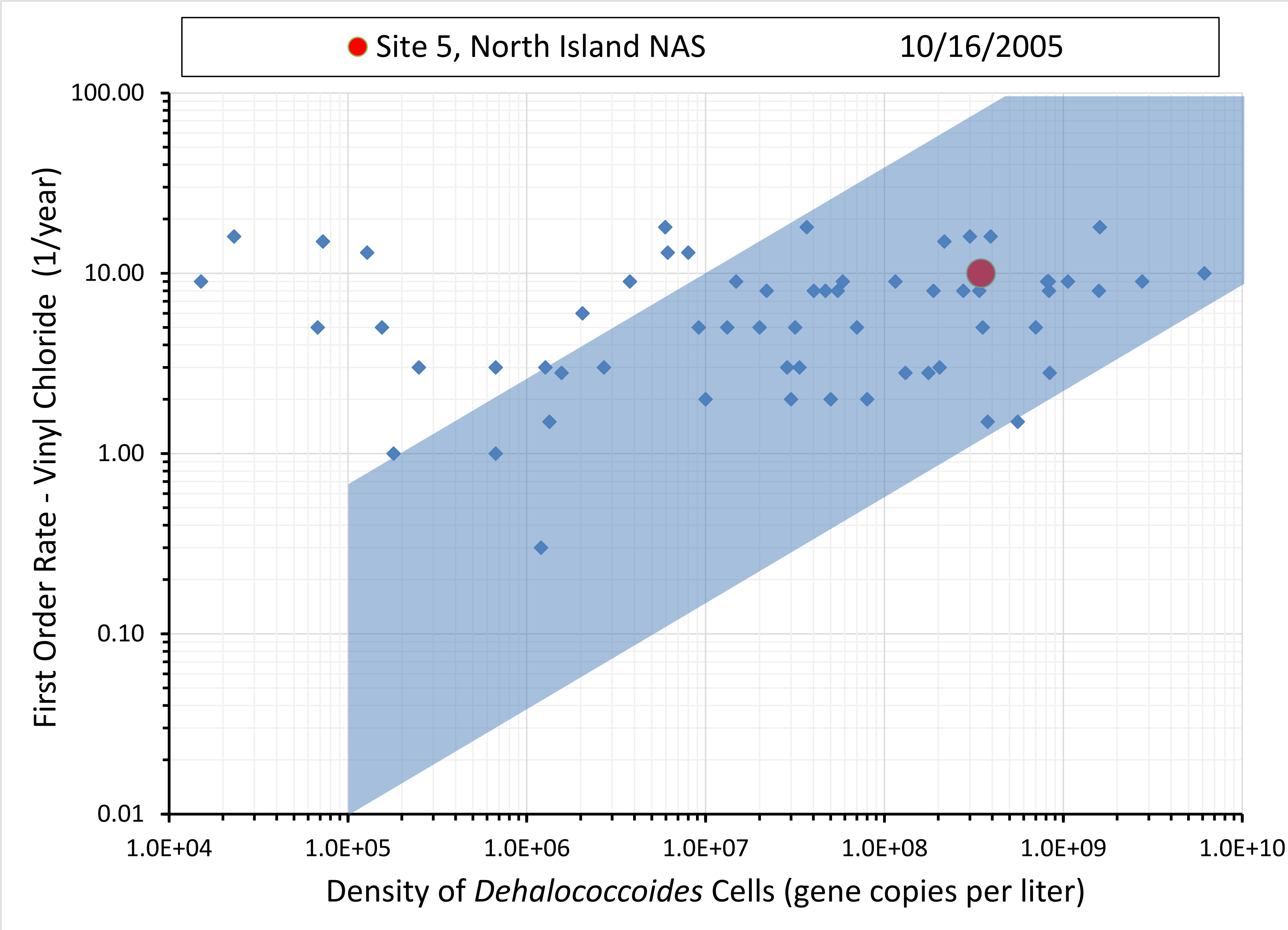
Site 5, North Island NAS
10/16/2005
100.00
10.00
1.00
0.10
0.01
First Order Rate - cis-DCE (1/year)
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Density of Dehalococcoides Cells (gene copies per liter)



Site 5, North Island NAS
10/16/2005
100.00
10.00
1.00
0.10
0.01
First Order Rate - Vinyl Chloride (1/year)
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Density of *Dehalococcoides* Cells (gene copies per liter)

	Overwrite input cells with data specific to your site	The BASELINE rate constant is the slowest rate constant that is plausibly associated
	Input	with *Dehalococcoides* DNA (*Dhc*)
	First order rate constant for degradation per year	Fraction of rate constants in the benchmark data set that exceed the BASELINE to a extent than this rate constant
cis-DCE	17	>40%
Vinyl Chloride	10	>40%
	qPCR assay Gene copies per liter	
Dehalococcoides 16s rRNA	3.47E+08	
Location and Site	Site 5, North Island NAS	
Date	10/16/2005	


Site 5, North Island NAS
10/16/2005
First Order Rate - *cis*-DCE (1/year)
100.00
10.00
1.00
0.10
0.01
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Density of *Dehalococcoides* Cells (gene copies per liter)



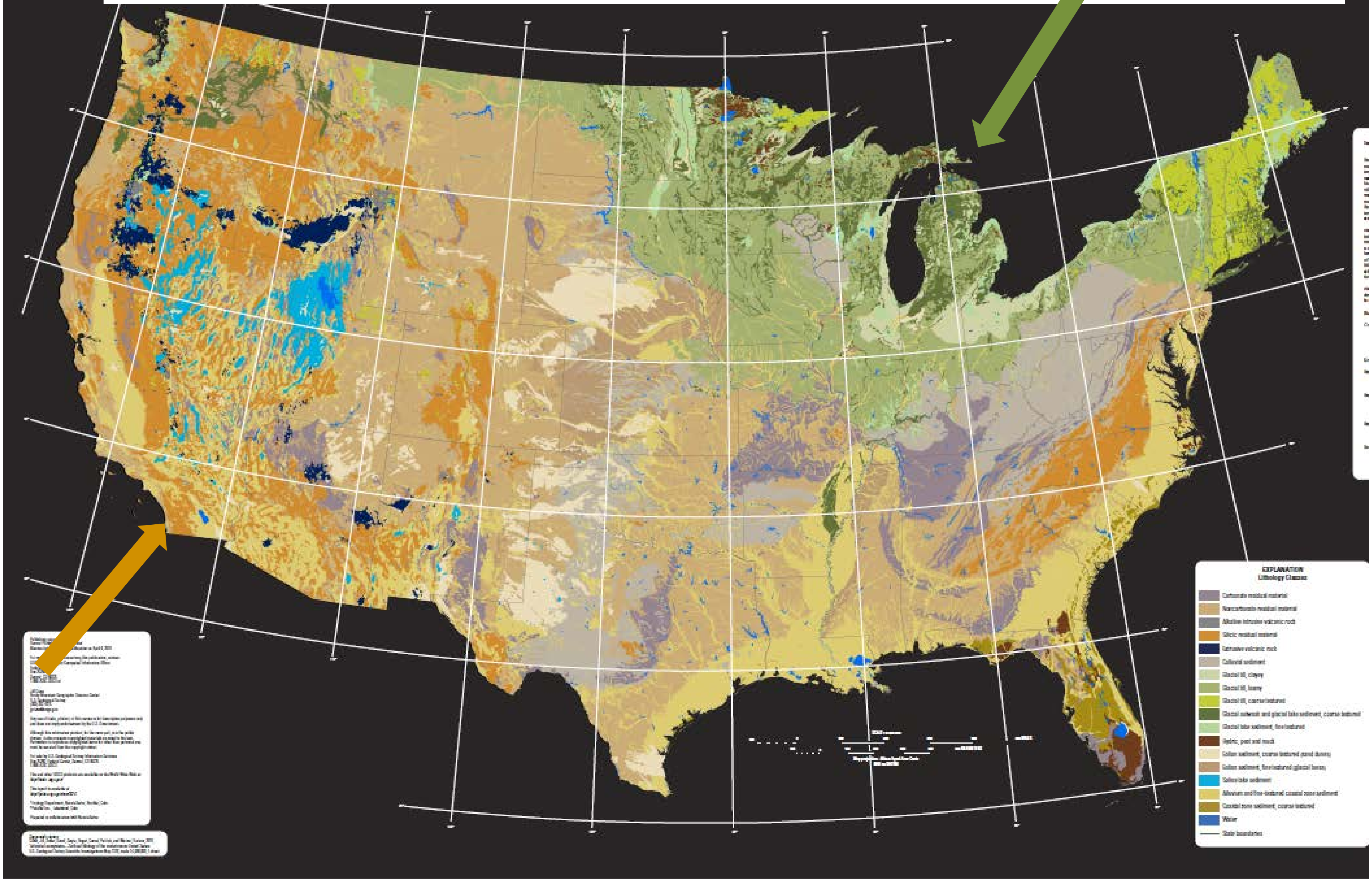
Site 5, North Island NAS
10/16/2005
100.00
10.00
1.00
0.10
0.01
First Order Rate - Vinyl Chloride (1/year)
1.0E+04
1.0E+05
1.0E+06
1.0E+07
1.0E+08
1.0E+09
1.0E+10
Density of *Dehalococcoides* Cells (gene copies per liter)

Contribution of Magnetite to Abiotic Degradation

- Magnetite ($FeO.Fe_2O_3$) often occurs naturally in sediments formed by weathering of igneous or metamorphic rock
- Magnetite can also be produced in situ by iron-reducing bacteria
- Magnetite can degrade TCE or *cis*-DCE or Vinyl Chloride to oxidized products under either aerobic or anaerobic conditions
- If the TCE or *cis*-DCE is degraded by magnetite, there is no production of Vinyl Chloride

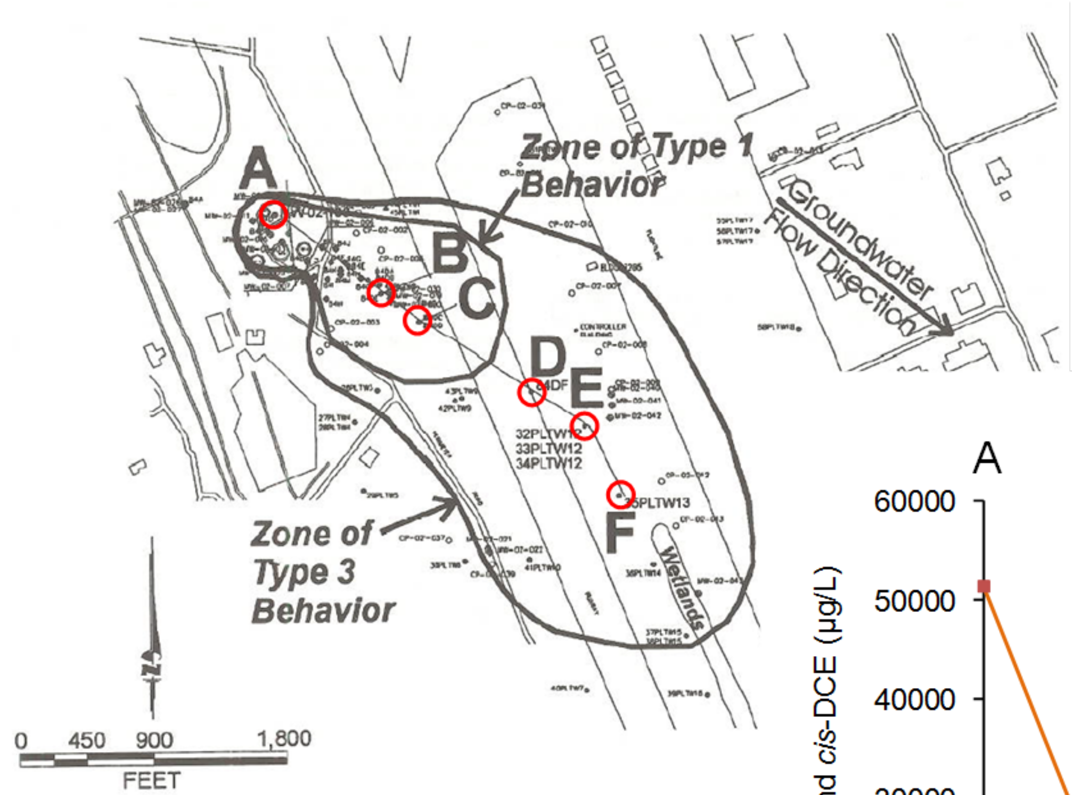
Sediment from Tooele Army Depot

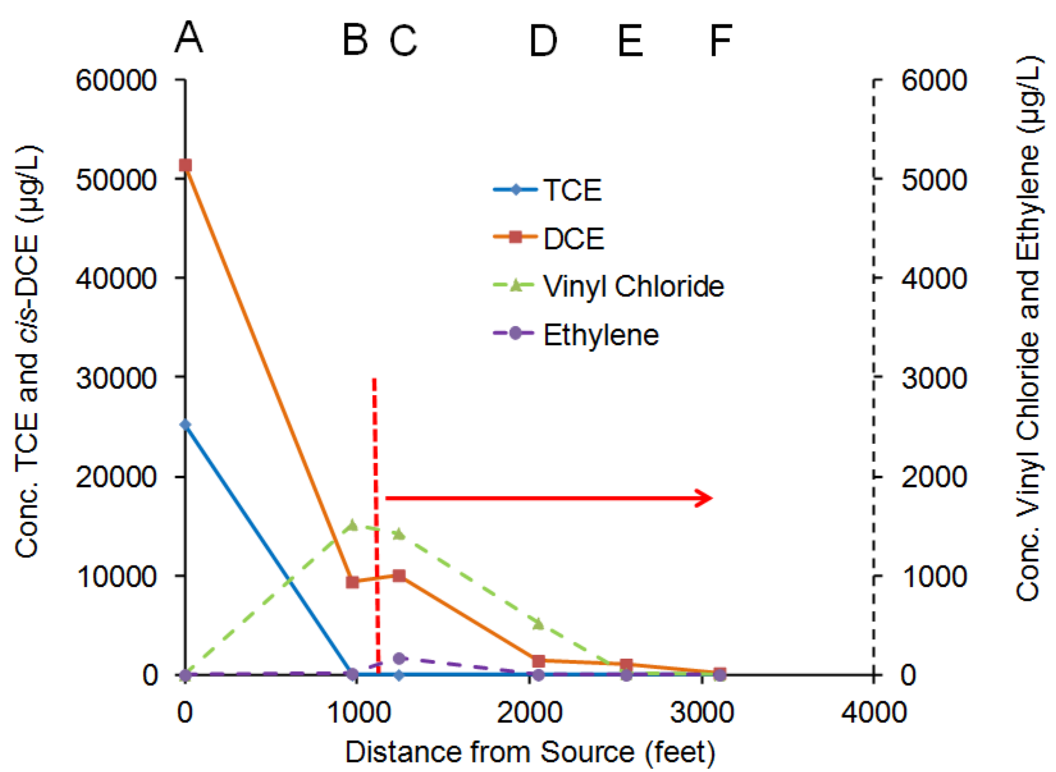
Terrestrial Ecosystems—Surficial Lithology of the Conterminous United States
http://pubs.usgs.gov/sim/3126/



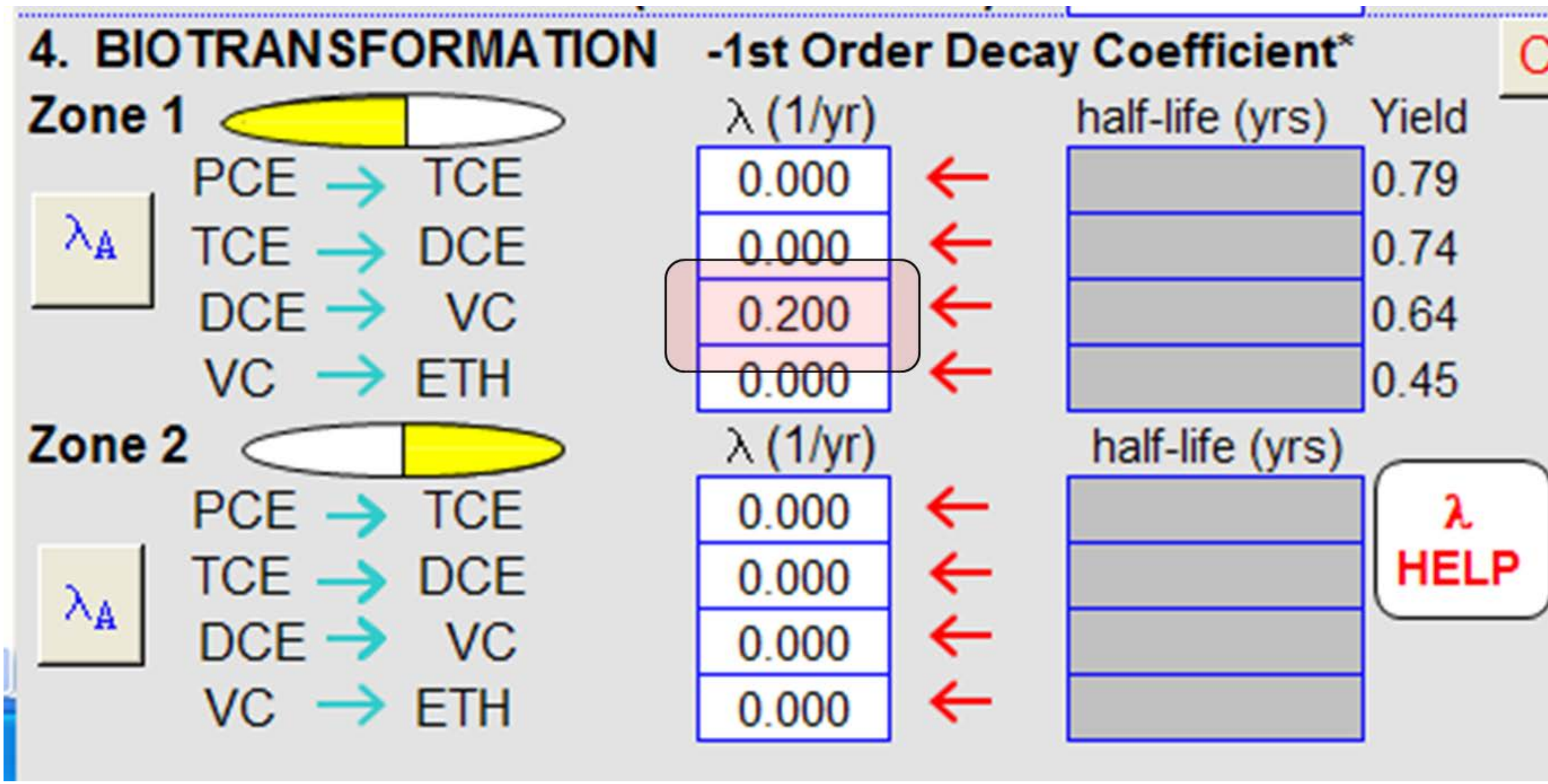
CASE STUDY
ABIOTIC DEGRADATION

Large plume originating at a fire protection training facility on the former Plattsburgh AFB, New York


A
B
C
D
E
F
Zone of Type 1 Behavior
Zone of Type 3 Behavior
Groundwater Flow Direction
Wetlands
0 450 900 1,800
FEET


A B C D E F
Conc. TCE and cis-DCE (µg/L)
Conc. Vinyl Chloride and Ethylene (µg/L)
TCE
DCE
Vinyl Chloride
Ethylene
Distance from Source (feet)
0
1000
2000
3000
4000
60000
50000
40000
30000
20000
10000
6000
5000
4000
3000
2000
1000

DCE set to 0.2 per year



Special Case for Abiotic Degradation

- BIOCHLOR models the degradation of TCE to produce DCE, and the degradation of DCE to produce Vinyl Chloride
- Magnetite does not degrade DCE to Vinyl Chloride
- To model the degradation of Vinyl Chloride, it is also necessary to ignore the concentrations of the DCE in the source well

DCE is not made available to the model to produce more Vinyl Chloride

6. SOURCE DATA

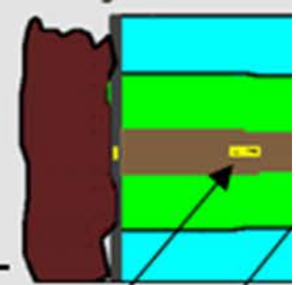
TYPE: Continuous Single Planar

Source Options

Source Thickness in Sat. Zone* 30 (ft)

	Y1
Width* (ft)	200

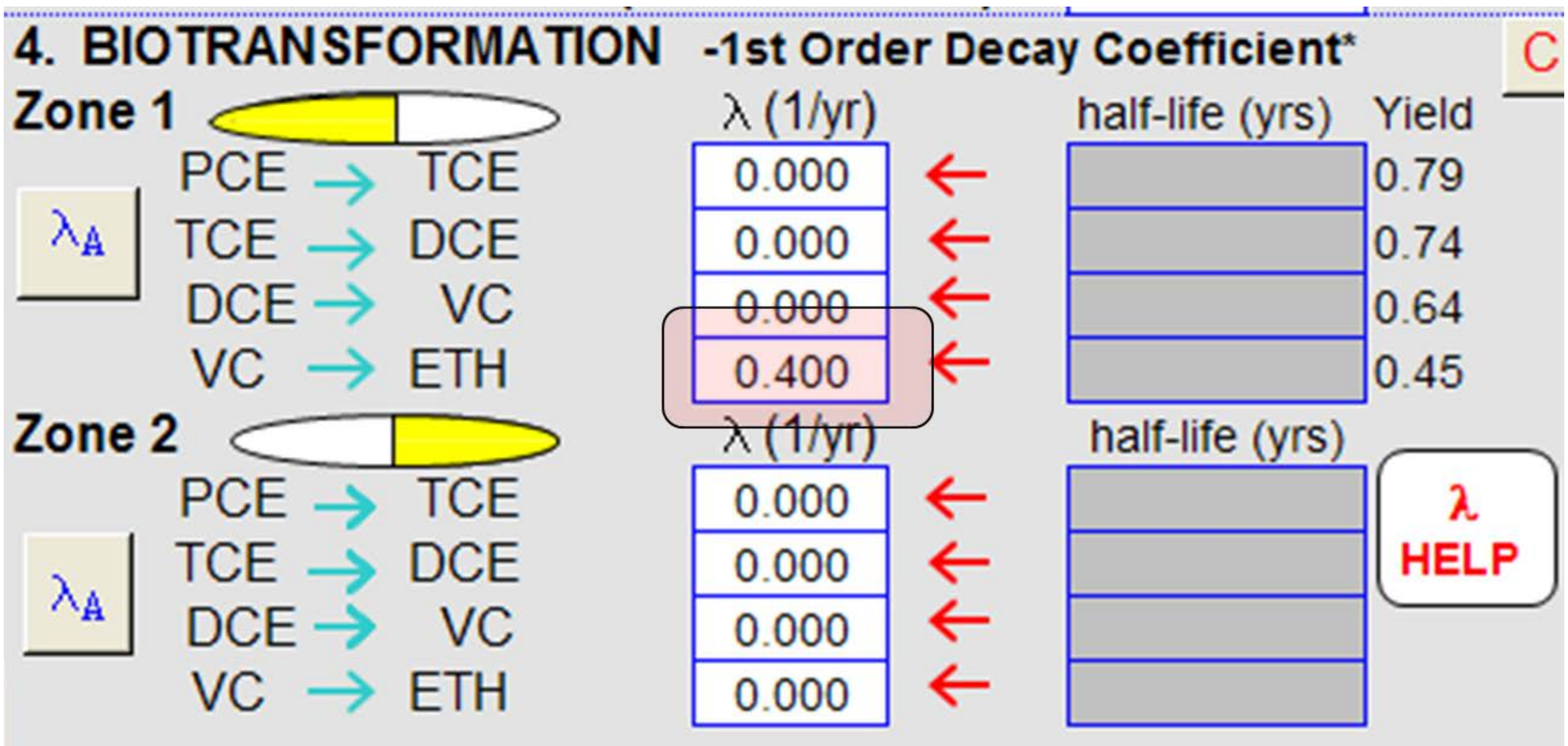
Conc. (mg/L)*	C1	k_s* (1/yr)
PCE		0
TCE		0
DCE		0
VC	1.05	0
ETH	0.17	0



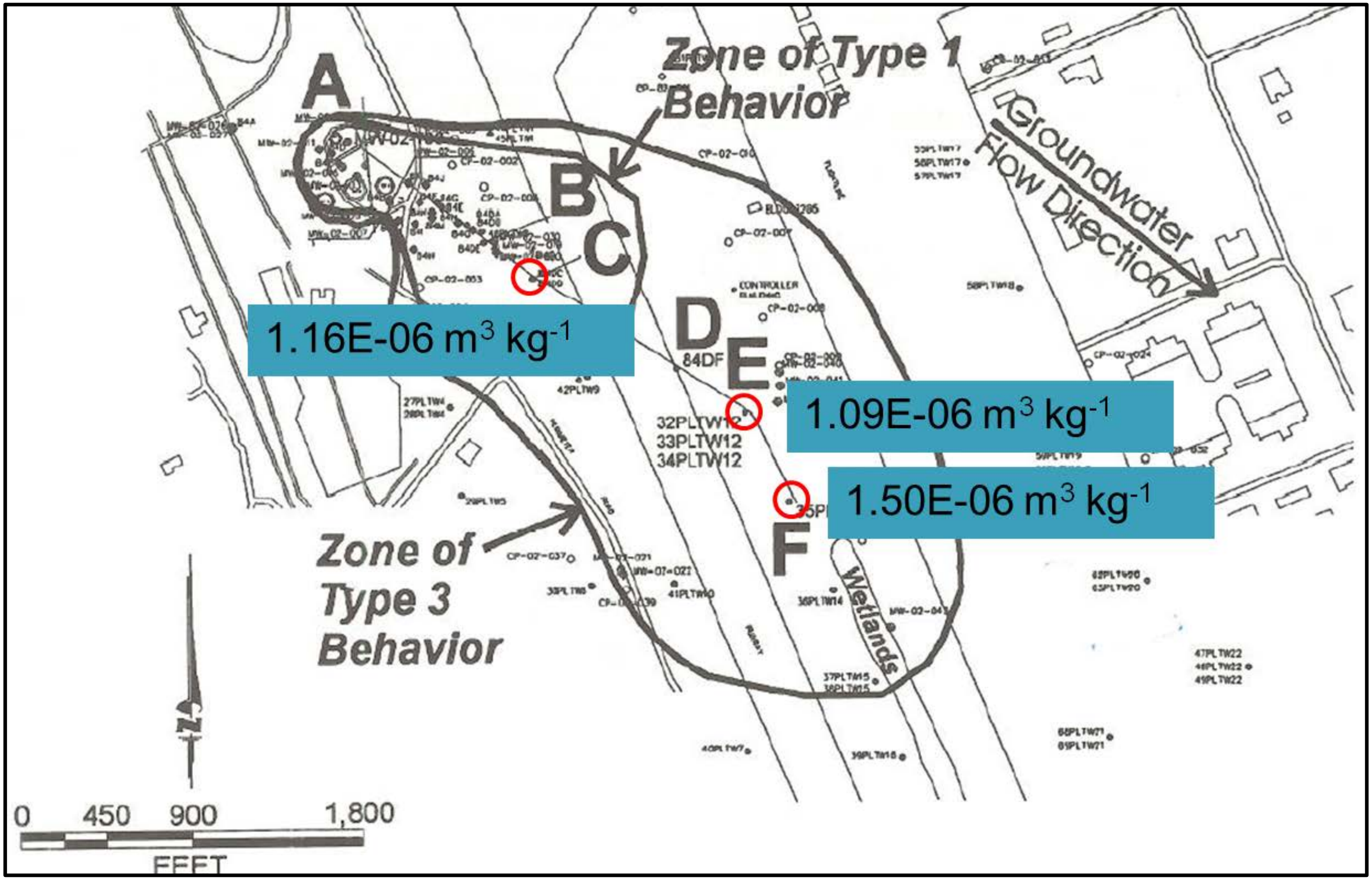
7. FIELD DATA FOR COMPARISON

PCE Conc. (mg/L)					
TCE Conc. (mg/L)					
DCE Conc. (mg/L)	10.32	1.42	1.05	.177	
VC Conc. (mg/L)	1.05	.524	.012	.004	
ETH Conc. (mg/L)	.17	.004	.001	.001	
Distance from Source (ft)	0	810	1320	1863	
Date Data Collected	1996				

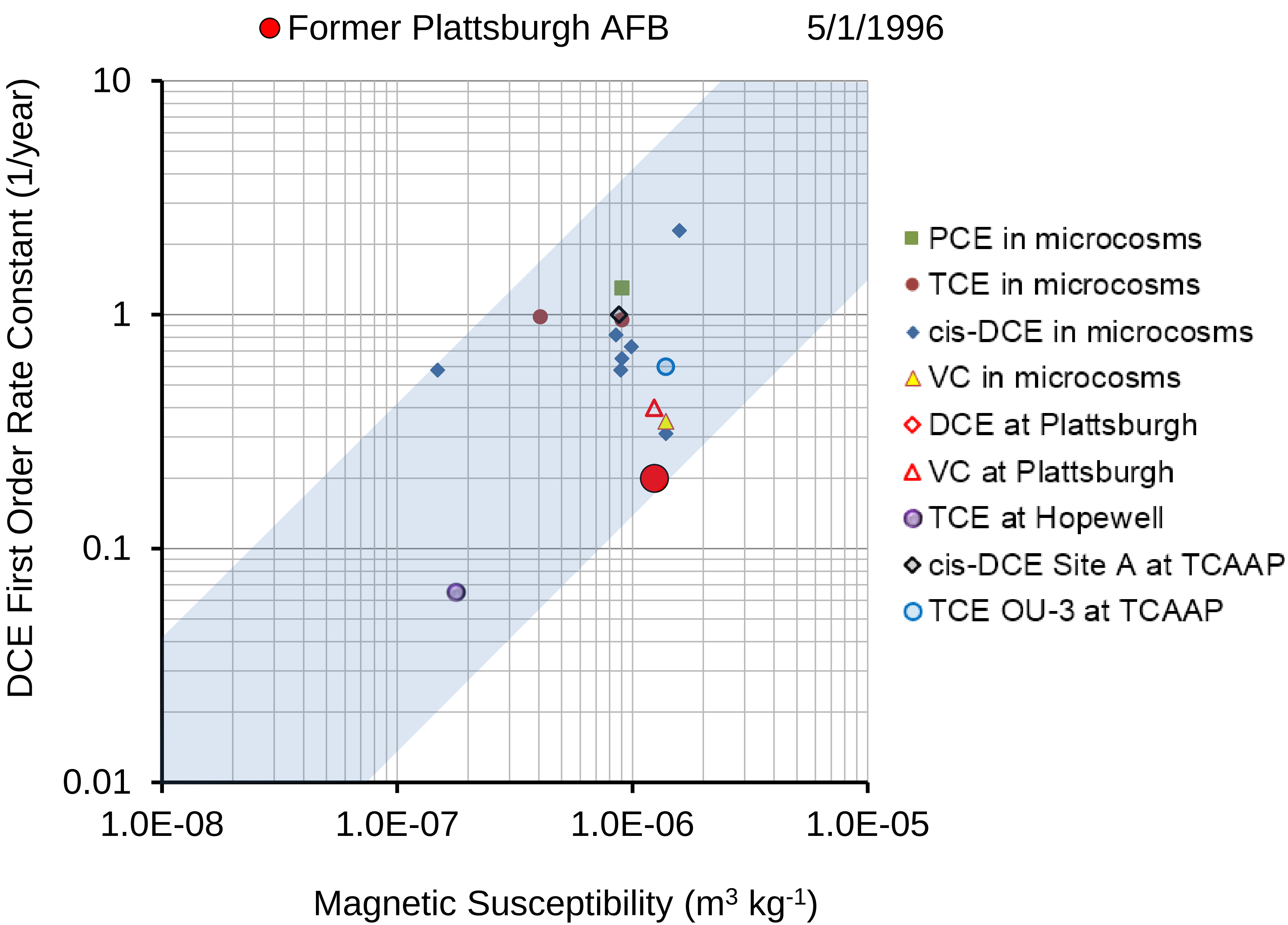
Vinyl Chloride rate constant set to 0.4 per year



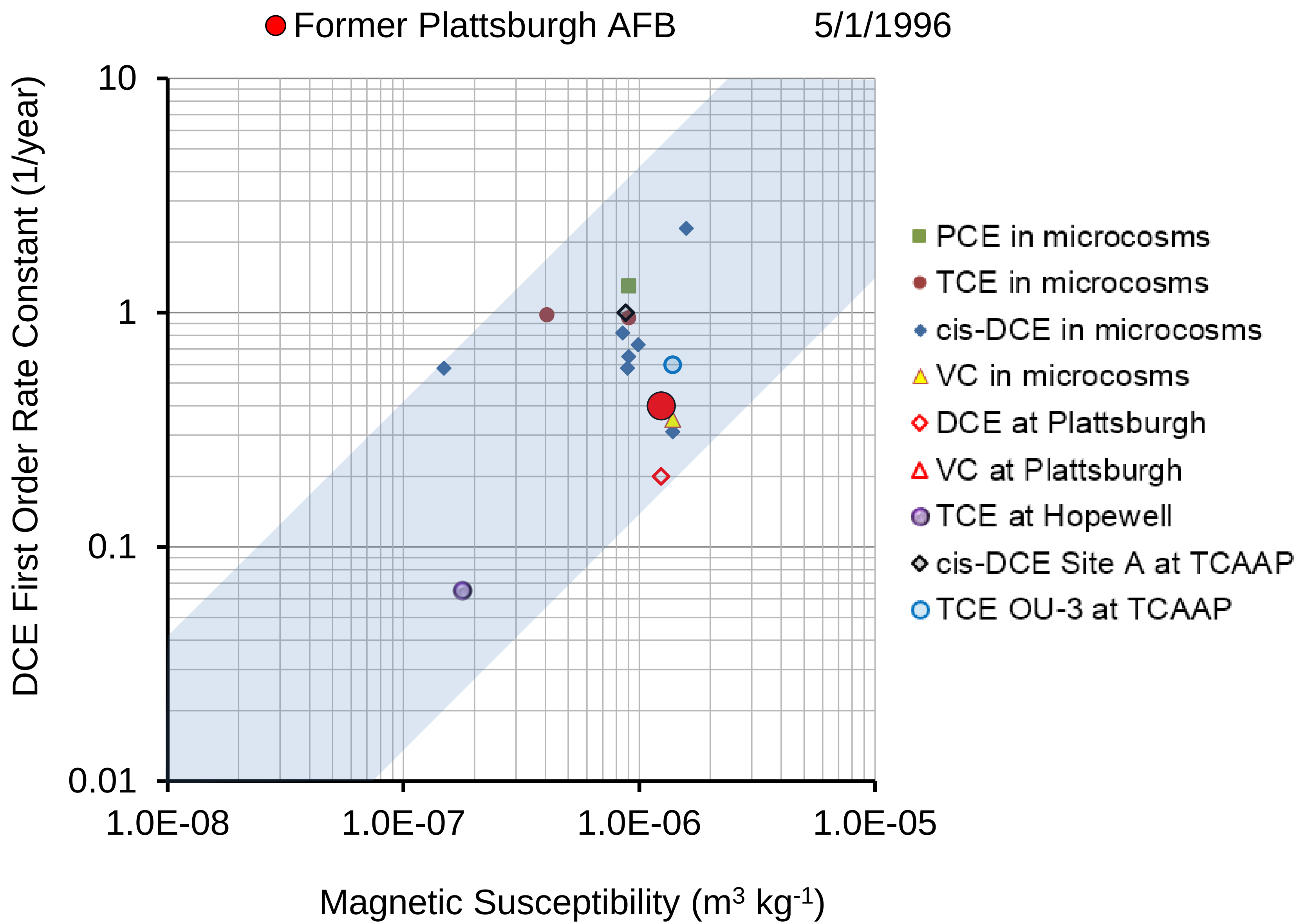
Average Magnetic Susceptibility of Sediment Samples



	Overwrite input cells	The BASELINE is the lower boundary
	with data	of the blue shape that encompases
	specific to your site	plausibe rate constants associated
		with degradation on magnetite
	Input	
		Fraction of rate constants in the
	First order rate constant	benchmark data set that
	for degradation	exceed the BASELINE to a greater
	per year	extent than this rate constant
PCE		rate slower than expected
TCE		rate slower than expected
cis-DCE	0.2	>80%
Vinyl Chloride	0.4	>60%
	Magnetic Suceptibility	
	SI Units (m^3kg^{-1})	
	1.25E-06	
Location and Site	Former Plattsburgh AFB	
Date	5/1/1996	

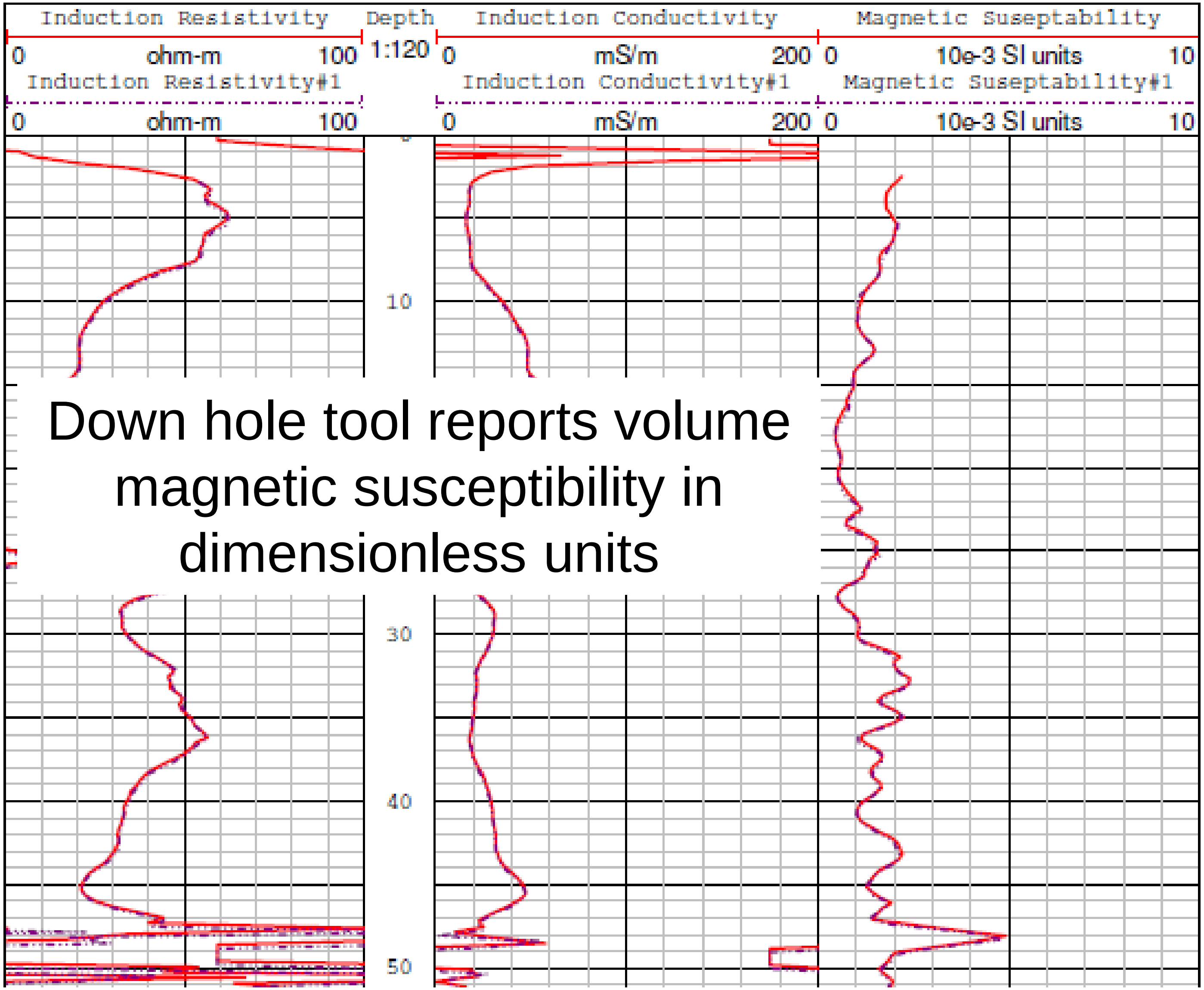


Former Plattsburgh AFB
5/1/1996
DCE First Order Rate Constant (1/year)
10
1
0.1
0.01
1.0E-08
1.0E-07
1.0E-06
1.0E-05
Magnetic Susceptibility (m3 kg-1)
PCE in microcosms
TCE in microcosms
cis-DCE in microcosms
VC in microcosms
DCE at Plattsburgh
VC at Plattsburgh
TCE at Hopewell
cis-DCE Site A at TCAAP
TCE OU-3 at TCAAP


Former Plattsburgh AFB
5/1/1996
DCE First Order Rate Constant (1/year)
10
1
0.1
0.01
1.0E-08
1.0E-07
1.0E-06
1.0E-05
Magnetic Susceptibility (m3 kg-1)
PCE in microcosms
TCE in microcosms
cis-DCE in microcosms
VC in microcosms
DCE at Plattsburgh
VC at Plattsburgh
TCE at Hopewell
cis-DCE Site A at TCAAP
TCE OU-3 at TCAAP

SECOND CASE STUDY
ABIOTIC DEGRADATION

Fruit Avenue Plume Superfund Site
A large plume of TCE in a water supply aquifer beneath downtown Albuquerque, NM



Down hole tool reports volume magnetic susceptibility in dimensionless units

Mass Magnetic Susceptibility

- To calculate Mass Magnetic Susceptibility, the Volume Magnetic Susceptibility is divided by the Bulk Density of the sediment
- At 30% porosity, the Bulk Density is approximately 0.7 * 2,560 kg/m^3 or 1,792 kg/m^3

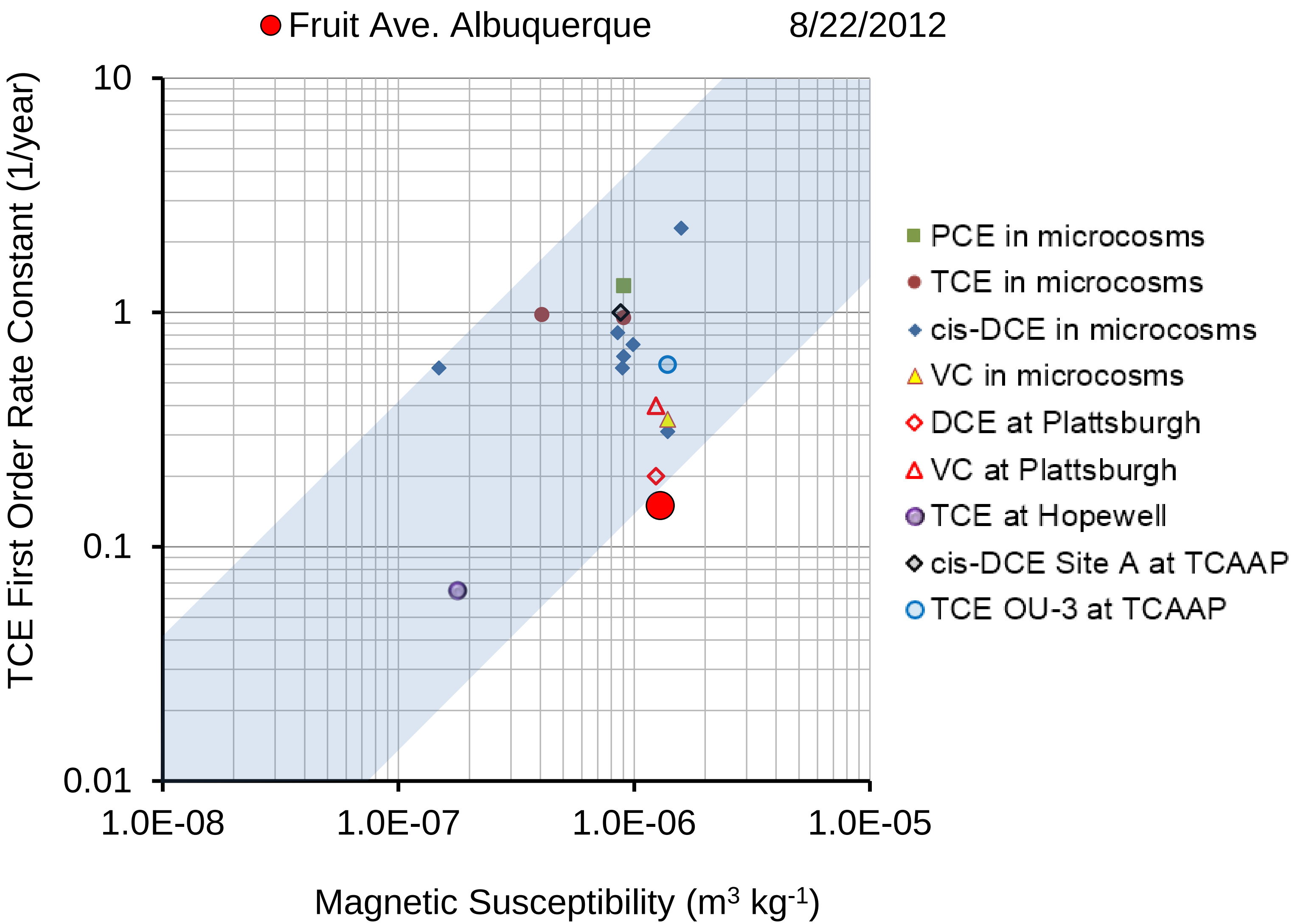
Magnetic Susceptibility in Sediments Harboring the Fruit Avenue Plume

Well ID	VMS SI Units x 10^{-3}	MMS m^3/kg
DM-13(D1)	$2.91 \pm 1.85 \times 10^{-3}$	
HSM-12-5	$1.93 \pm 0.91 \times 10^{-3}$	
MNW-5(D4)	$2.24 \pm 1.40 \times 10^{-3}$	
SFMW-44(D2)	$2.17 \pm 1.11 \times 10^{-3}$	
Average	2.3×10^{-3}	1.3×10^{-6}

Point Rate Constants for Attenuation in Wells in the Fruit Avenue Plume

Well ID	First Order Rate Constant (1/year)
Average of 16 wells in source	0.18
MNW-5-(D1)	0.10
SFMW-46-(D1/D2)	0.19
MNW-5-(D2)	0.14
Grand average	0.15

	Overwrite input cells with data specific to your site	The BASELINE is the lower boundary of the blue shape that encompases plausibe rate constants associated with degradation on magnetite
	Input	
	First order rate constant for degradation per year	Fraction of rate constants in the benchmark data set that exceed the BASELINE to a greater extent than this rate constant
PCE		rate slower than expected
TCE	0.15	rate slower than expected
cis-DCE		rate slower than expected
Vinyl Chloride		rate slower than expected
	Magnetic Suceptibility SI Units (m^3kg^{-1})	
	1.30E-06	
Location and Site	Fruit Ave. Albuquerque	
Date	8/22/2012	


Fruit Ave. Albuquerque
8/22/2012
TCE First Order Rate Constant (1/year)
10
1
0.1
0.01
1.0E-08
1.0E-07
1.0E-06
1.0E-05
Magnetic Susceptibility (m3 kg-1)
PCE in microcosms
TCE in microcosms
cis-DCE in microcosms
VC in microcosms
DCE at Plattsburgh
VC at Plattsburgh
TCE at Hopewell
cis-DCE Site A at TCAAP
TCE OU-3 at TCAAP

Conclusions

- Incorporate new science into a framework consistent with EPA's OSWER Directive
- Integrate the decision-making framework into an easy to use application called BioPIC
- Guide users in the selection of MNA, biostimulation and bioaugmentation

For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201129/ER-201129

Carmen Lebrón, lebron.carmen.a@gmail.com
John T. Wilson, john@scissortailenv.com

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The next webinar is on March 26

Innovative Tools for Species Inventory, Monitoring, and Management

http://www.serdp-estcp.org/Tools-and-Training/Webinar-Series/03-26-2015

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Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends

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