Source Longevity:

Data Mining and Models

C. J. Newell, T. M. McGuire, I. C. Cowie,
J. M. McDade, and D. T. Adamson
Groundwater Services, Inc.

Tom Sale
Colorado State University

Walt McNab, Jr.
Lawrence Livermore National Lab

Groundwater Services, Inc.

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

This Talk…..

1. Longevity Data Mining Studies - SERDP Project

- ***Performance & Cost Database***
- ***Untreated Site Database***

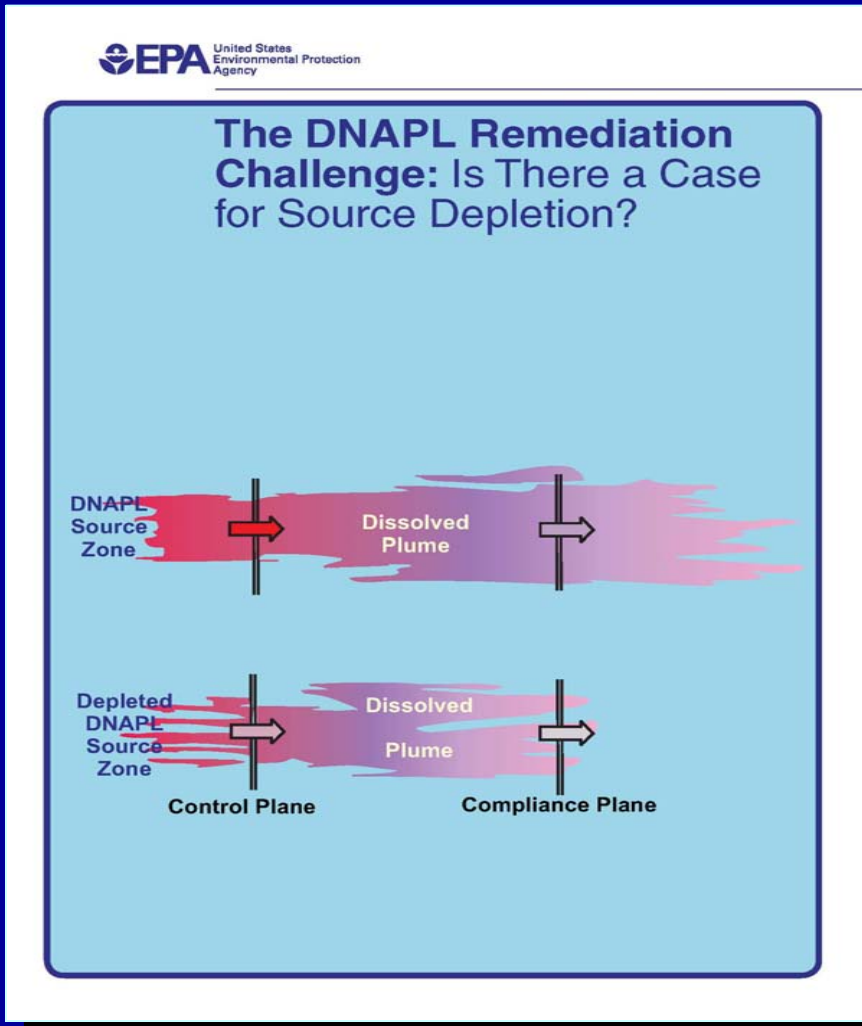
2. Simple Longevity Models

- ***SourceDK***
- ***SERDP Equations***

3. Qualitative Decision Chart from

"DNAPL Remediation Challenge"

Motivation…



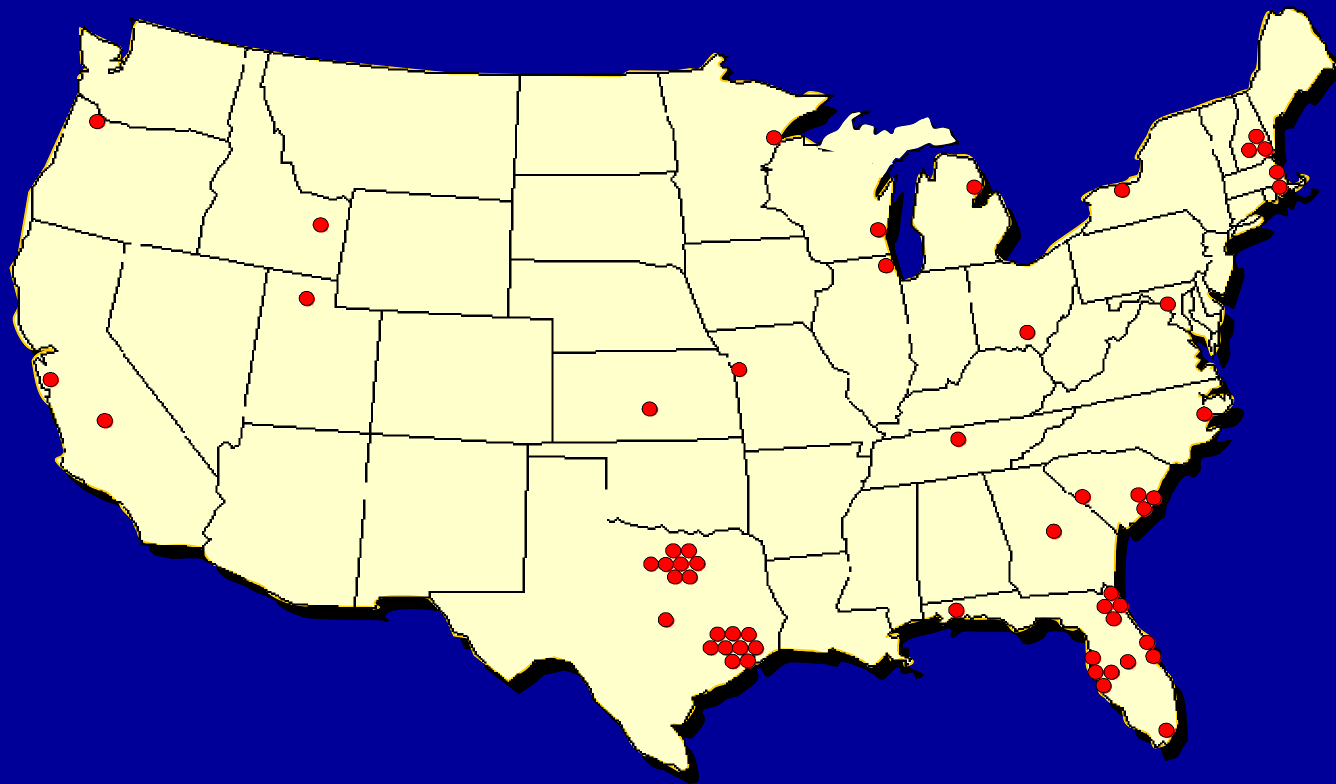
Primary Research Need:

"…a thorough and independent review of a selected number of DNAPL sites where sufficient documentation is available to assess the performance of source depletion…"

TEMPORAL CONCENTRATION DATA FROM 59 CHLORINATED SOLVENT SITES

FOUR SOURCE DEPLETION TECHNOLOGIES:

- ***Enhanced Biodeg.***
- ***Chem. Oxidation***
- ***Surfactants/Cosolv.***
- ***Thermal Treatment***



- ***Median Treatment Volume = 3,800 yd³***
- ***~70% Full-Scale Projects***

Source: McGuire et al., 2006, Ground Water Monitoring and Remediation

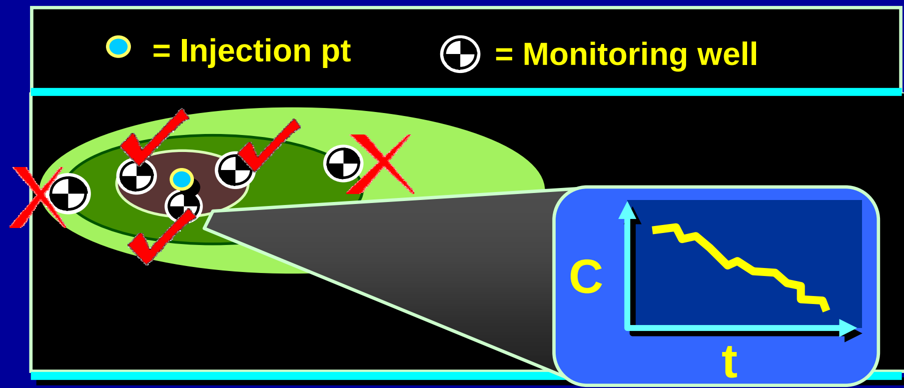
DATA ANALYSIS METHODS

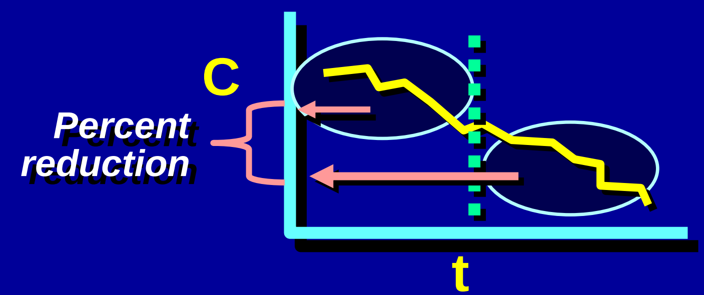
PERFORMANCE:

- Compiled conc. vs. time data (before and after treatment) for up to 4 wells within treatment zone

- Calculated geometric mean conc. of before treatment data and after treatment data;
- Then calculated percent reduction for each well

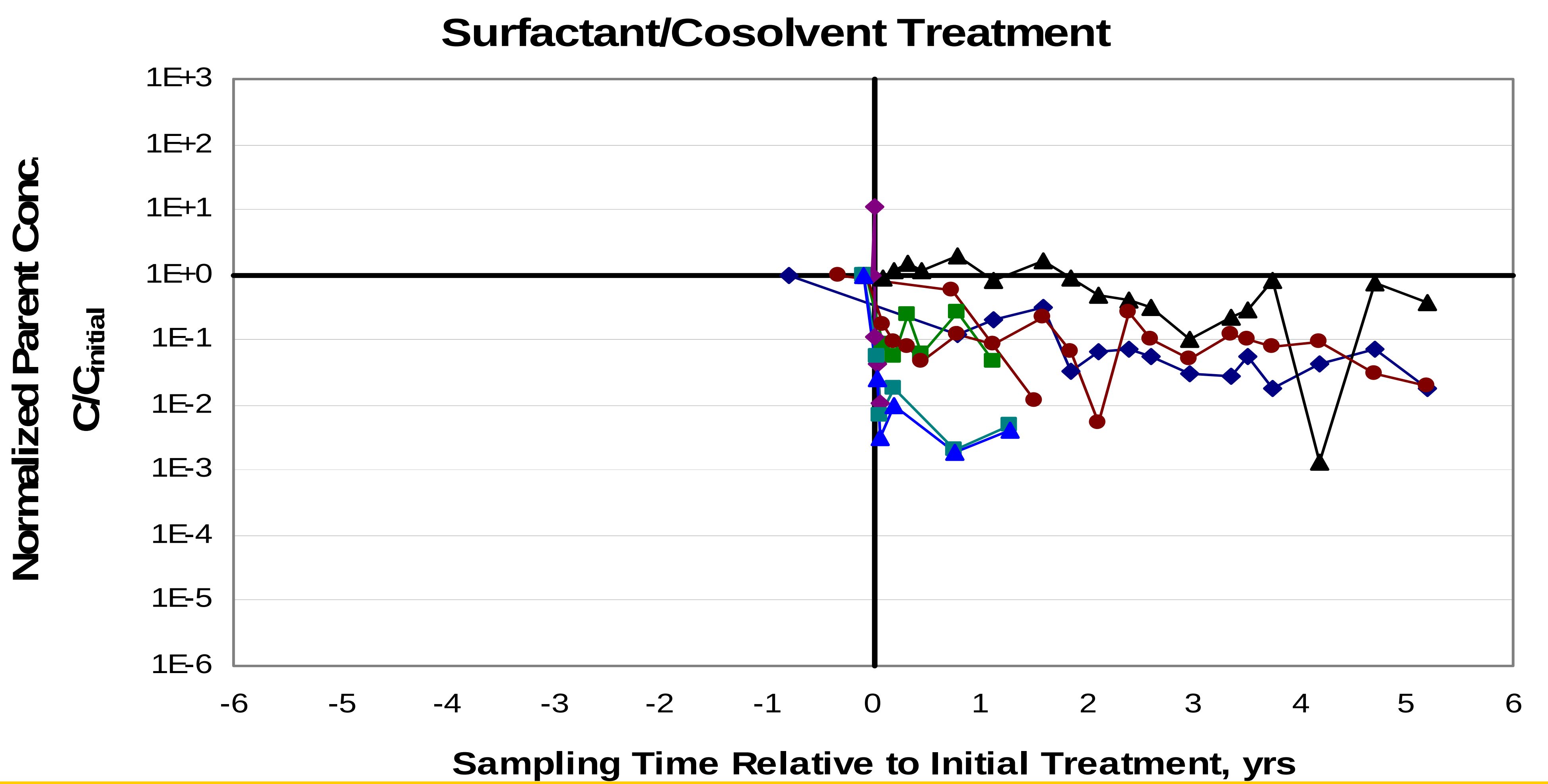
- Median percent reduction of all treatment zone wells as final performance metric





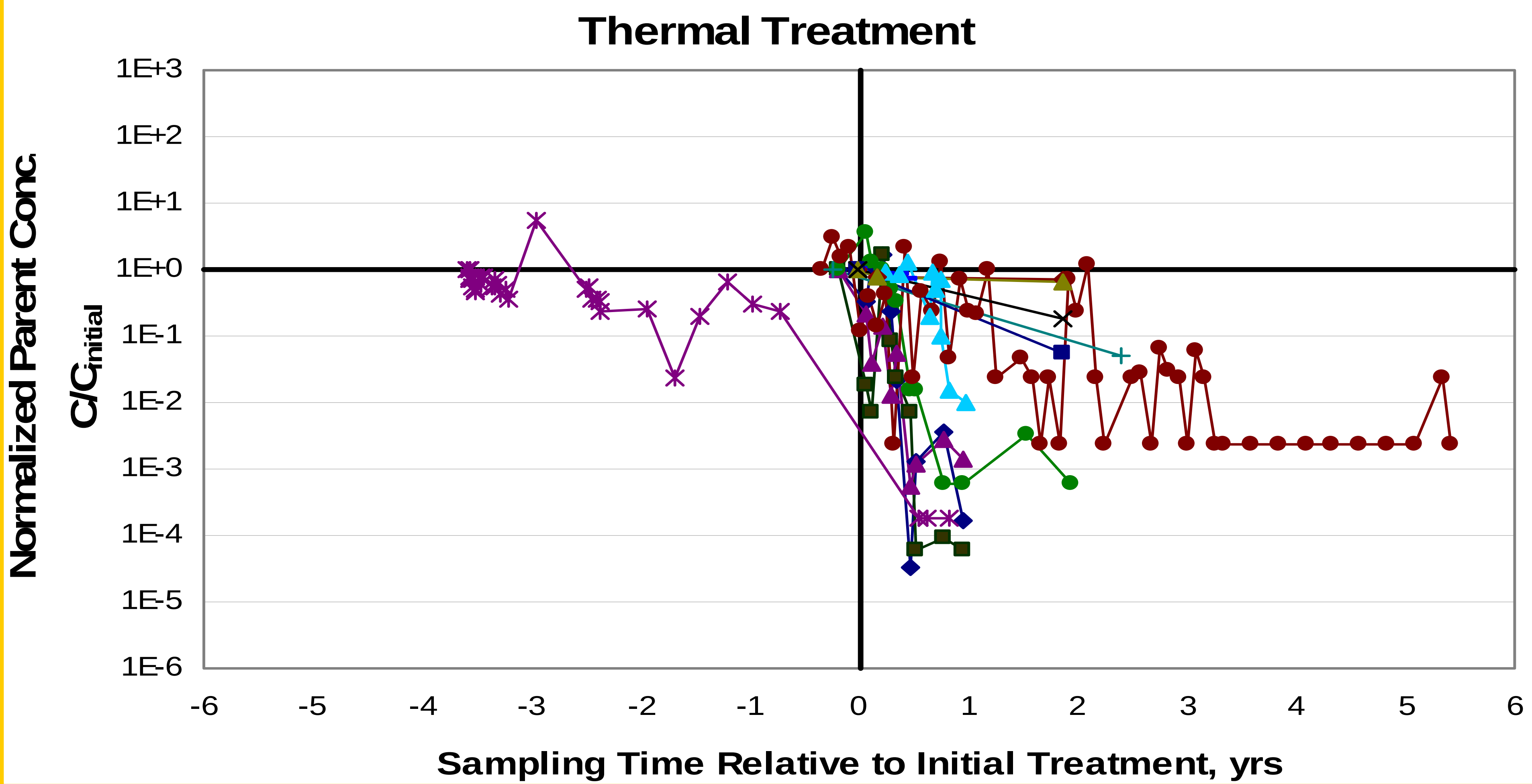
	% Red'n	*Site % Red'n*
Well # 1	*99.9*	*90.0*
Well # 2	*91.0*	
Well # 3	*89.0*	
Well # 4	*+ 10.0*	

Temporal Records for Surfactant/Cosolvent Wells (4 Sites, 8 Wells)



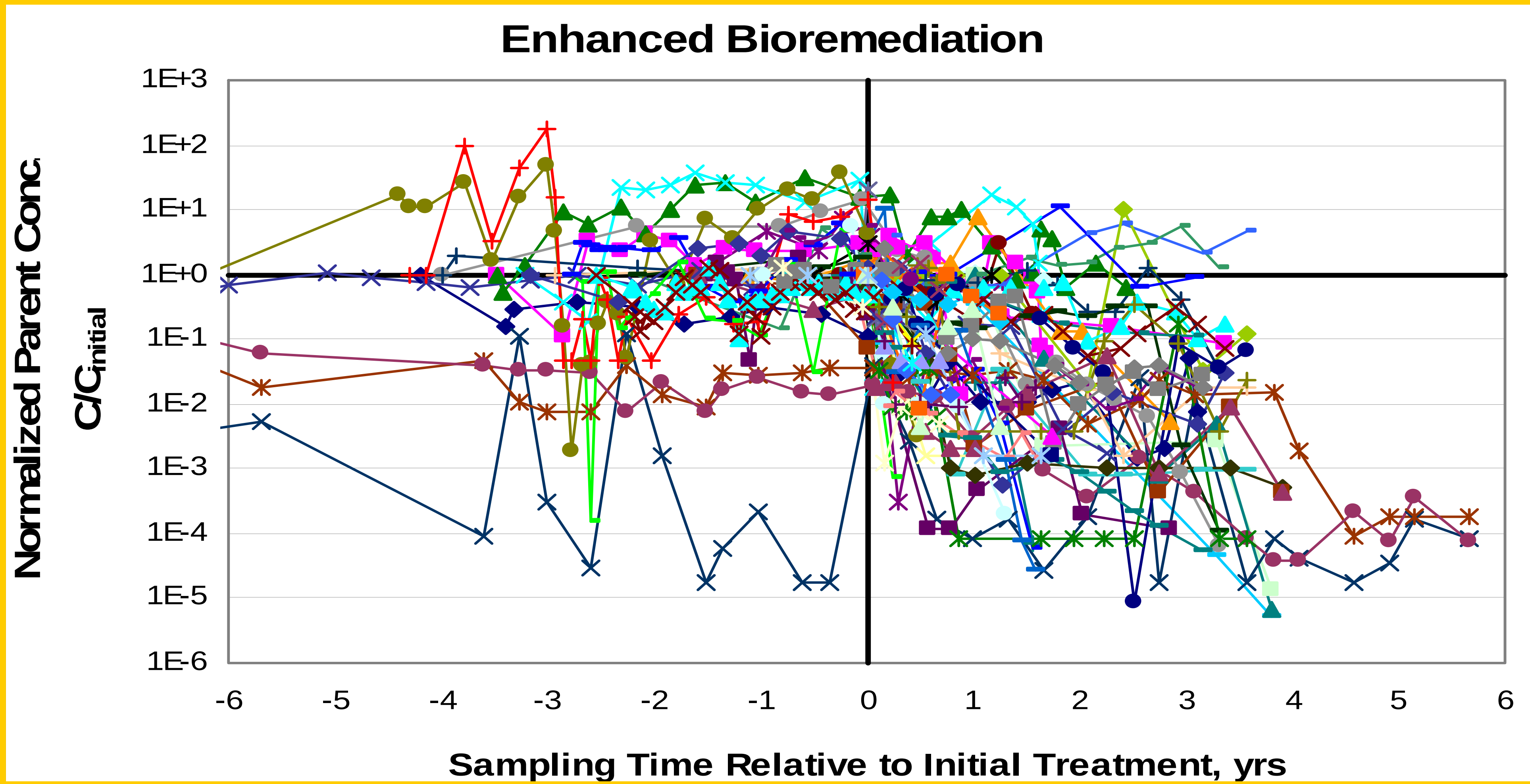
Any site achieve MCLs everywhere? No

Temporal Records for Thermal Treatment Wells
(6 Sites, 13 Wells)



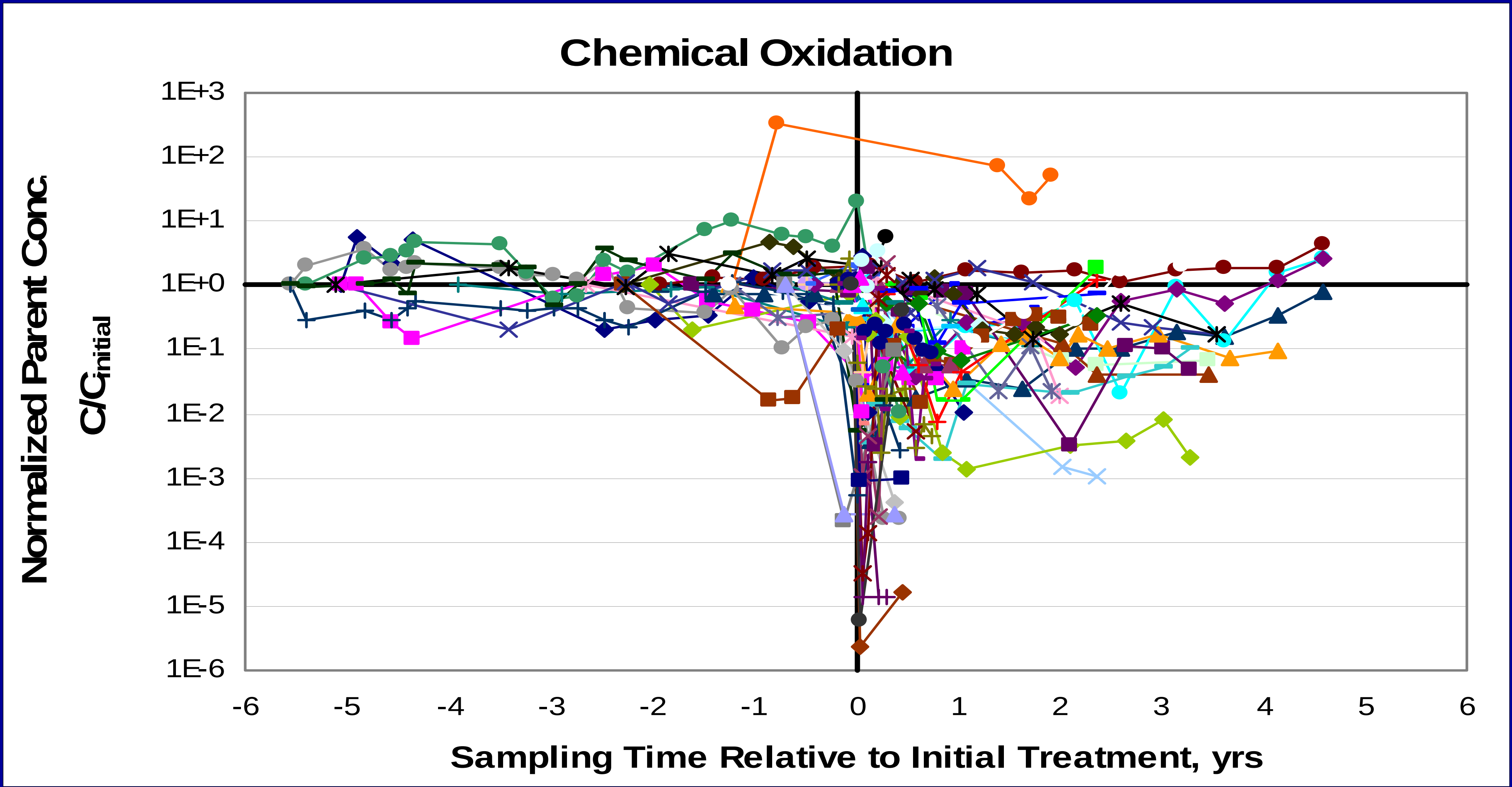
Any site achieve MCLs everywhere? No

Temporal Records for Enhanced Biodegradation (26 Sites, 68 Wells)



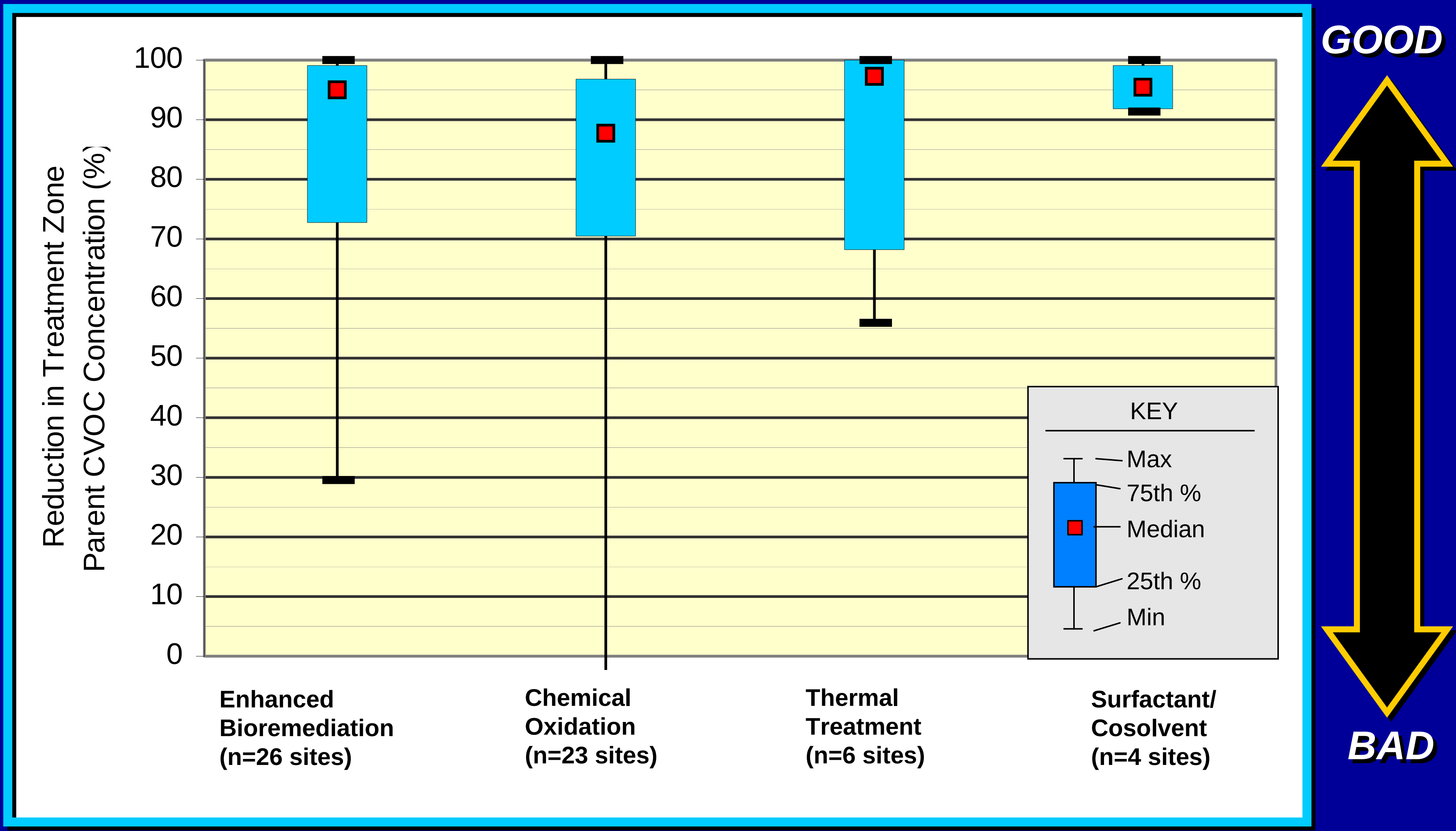
Any site achieve MCLs everywhere? No

Temporal Records for Chemical Oxidation (23 Sites, 58 Wells)

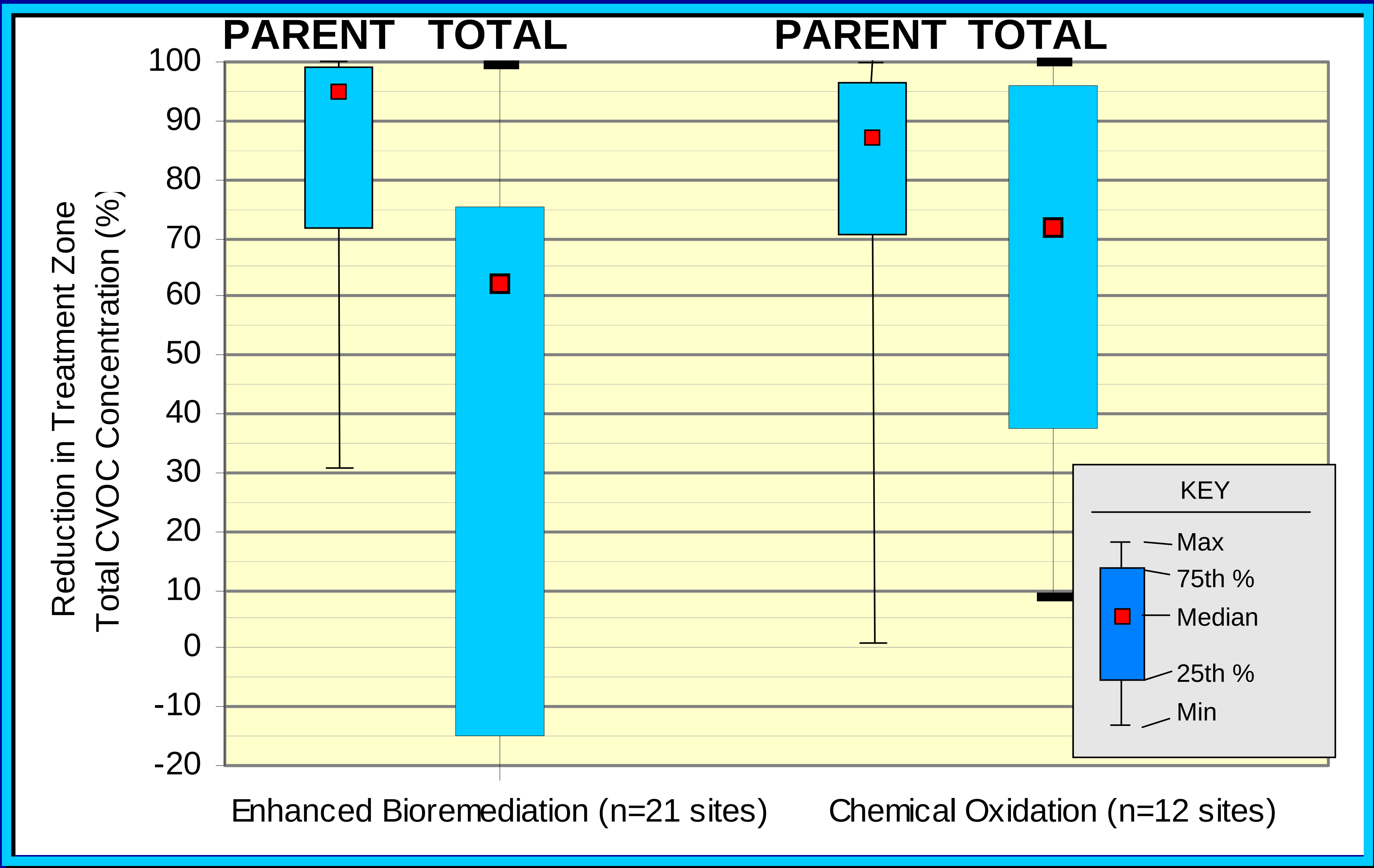


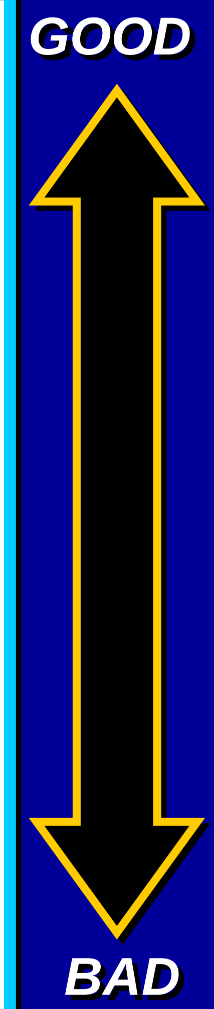
Any site achieve MCLs everywhere? No

% REDUCTION IN ***PARENT*** *DUE TO SOURCE DEPLETION*

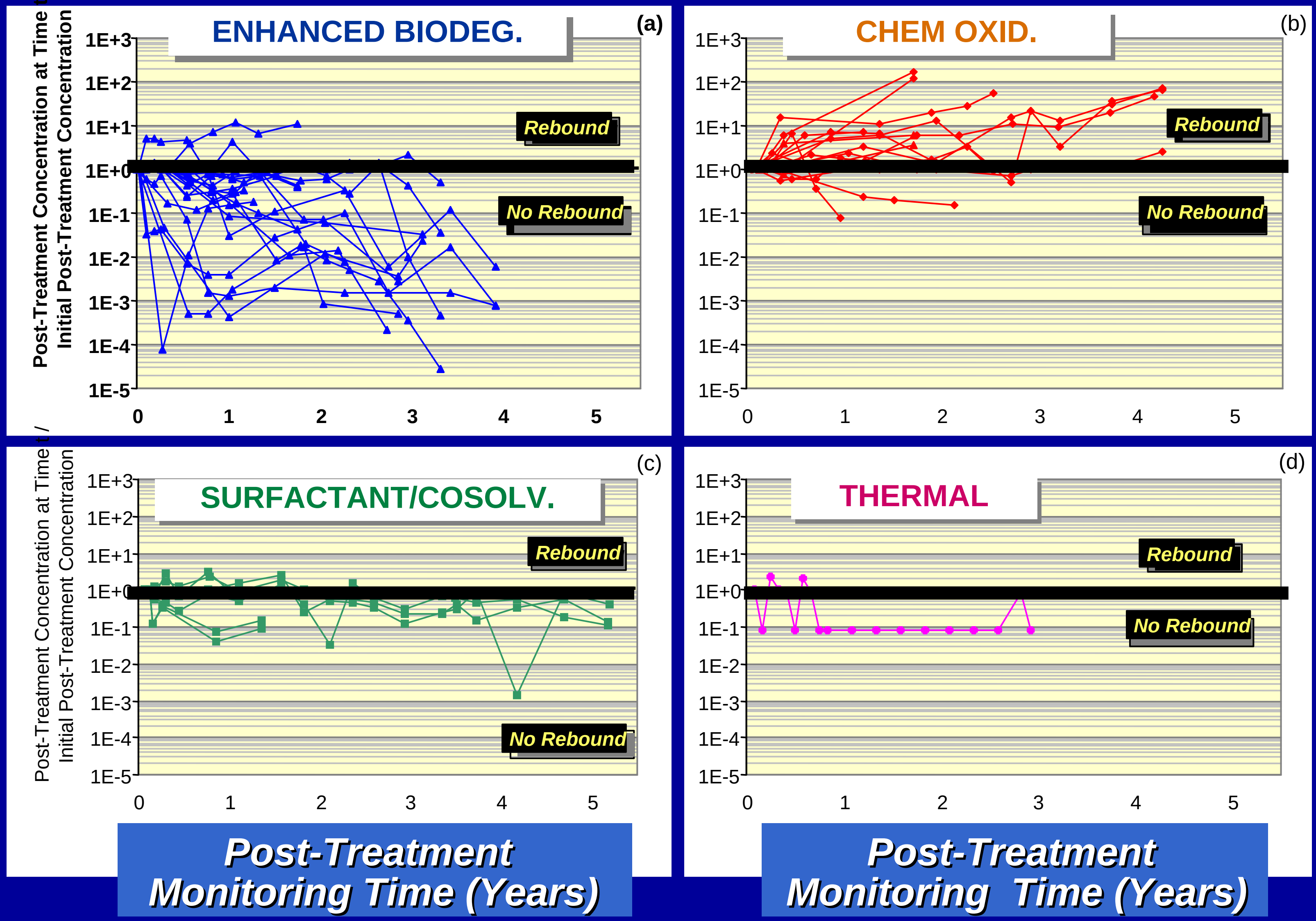


% REDUCTION IN ***PARENT vs. TOTAL CVOC*** ***CONCENTRATION***

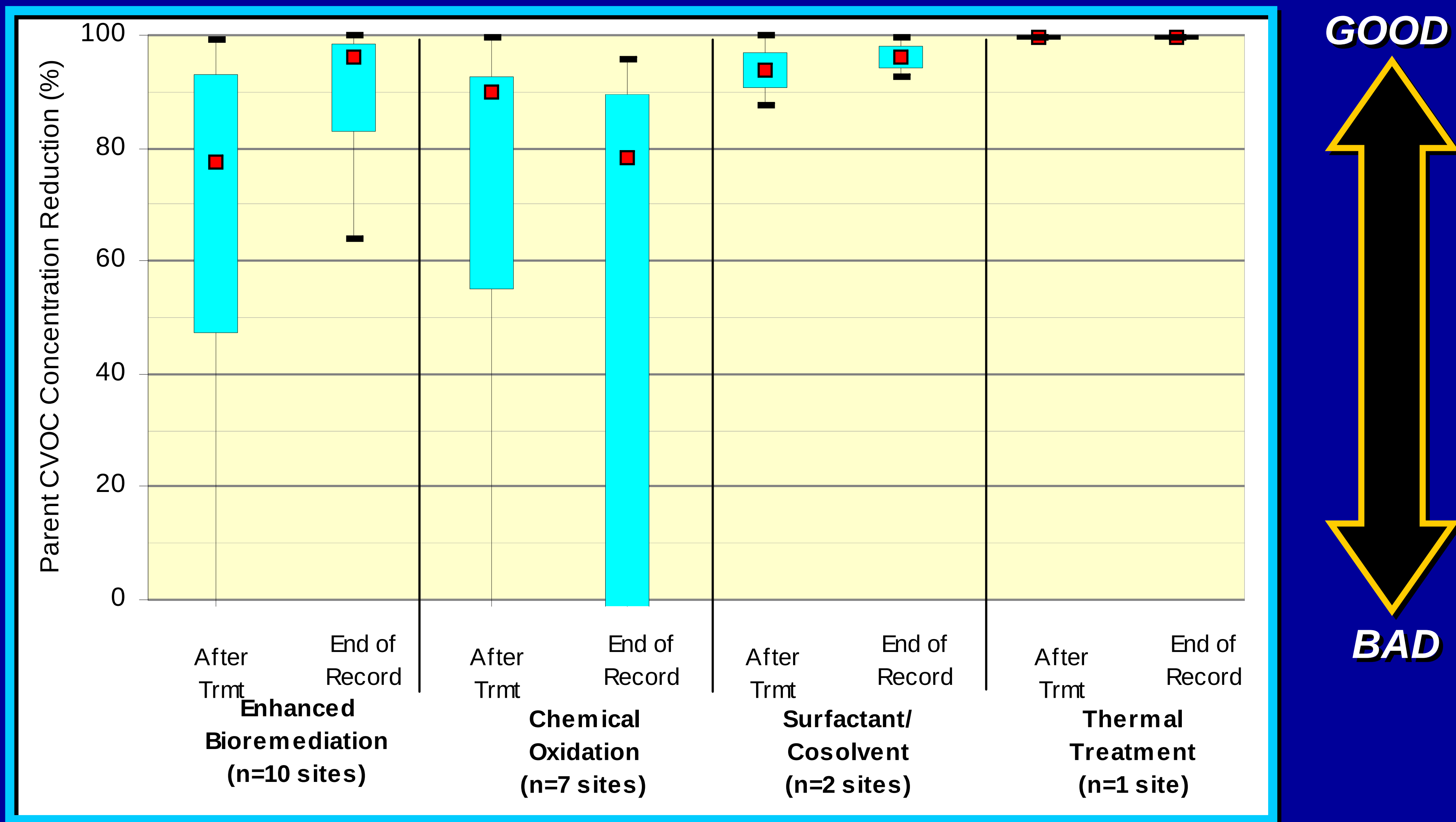




WHAT ABOUT *REBOUND?* (Parent Compounds)



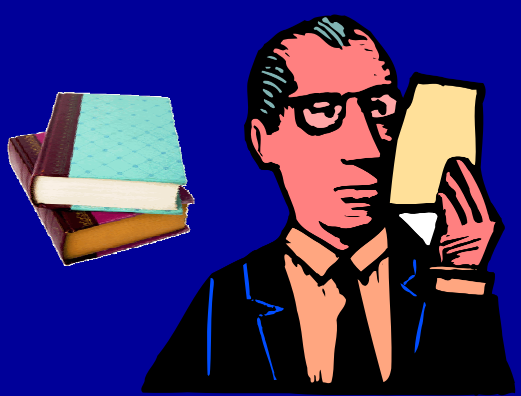
WHAT ABOUT *REBOUND?*
(PERCENT REDUCTION)



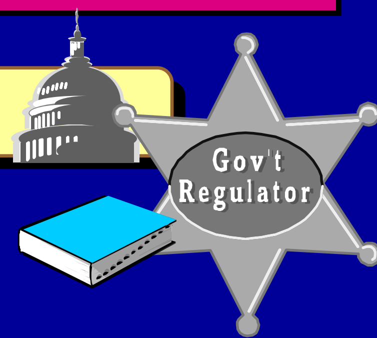
Cost Study: Data Sources

Peer-Reviewed Literature

- *ES&T*
- *Groundwater*
- *Groundwater Mon. & Rem.*
- *J of Contaminant Hydrology*
- *Surfactants and Cosolvents for NAPL Remediation*
- Battelle Conf. Proceedings



Agencies



- FRTR
- Florida DEP
- ITRC
- Lawrence Livermore
- TCEQ
- U.S. EPA
- U.S. DOD
- U.S. DOE

Survey/Web Sites

- SERDP Survey
- CLU-IN Website; www.clu-in.org

Source: McDade et al. 2005. Remediation

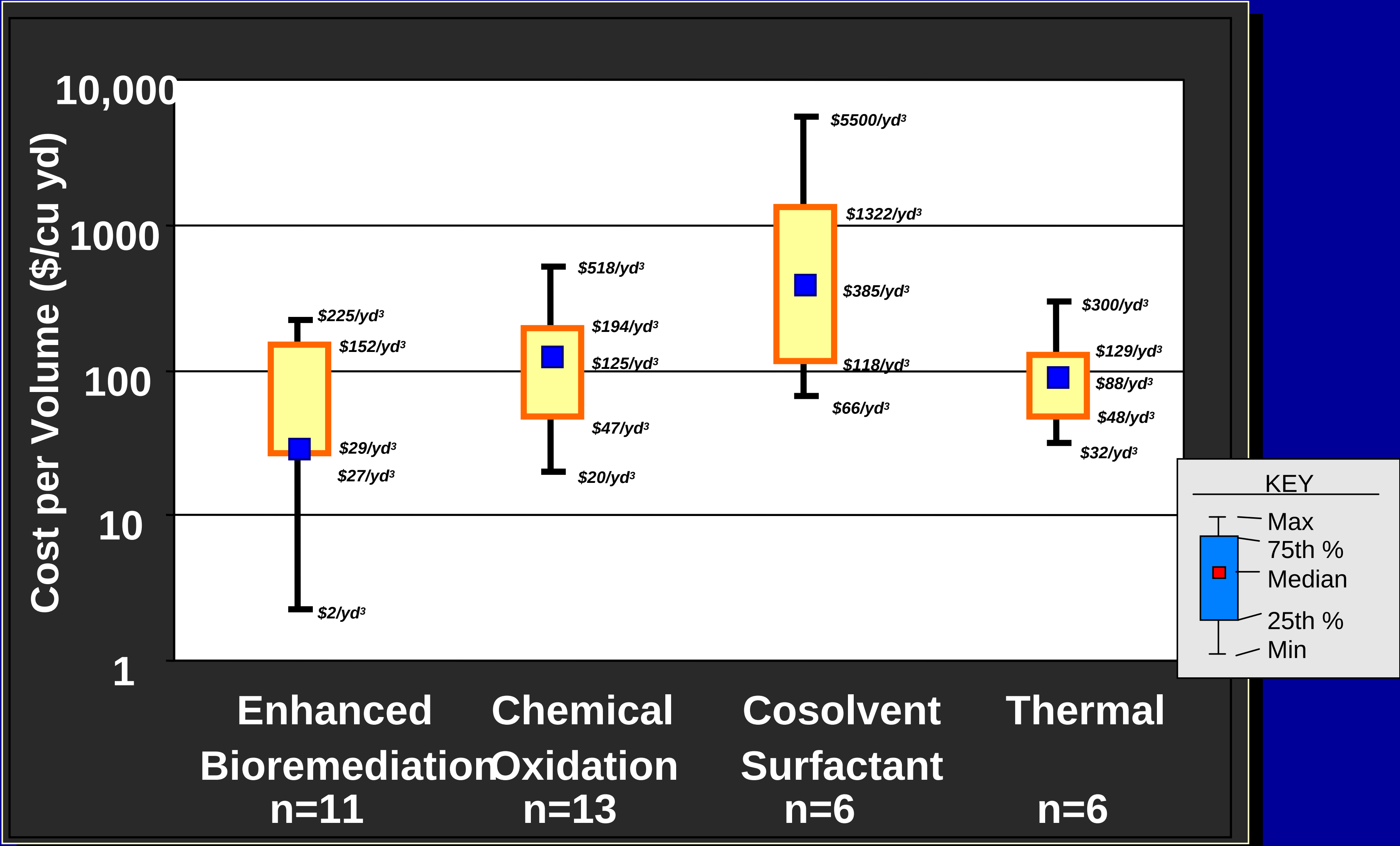
Cost Evaluation – Total Project Costs

Groundwater Services, Inc.

- Lowest Median <u>Total Costs</u> = **Chemical Oxidation**
- Highest Median <u>Total Costs</u> = **Thermal**
- Highest Total <u>Cost Variation</u> = **Enhanced Bioremediation**

Technology	Total Project Costs		
	Minimum	Median	Maximum
Enhanced Bioremediation	$20,000	$354,000	$35,410,000
Chemical Oxidation	$73,000	$230,000	$1,270,000
Surfactant/ Cosolvent	$222,000	$500,000	$2,662,000
Thermal	$138,000	$1,065,322	$20,000,000
Total	$20,000	$440,000	$35,410,000

Cost Evaluation – Cost per Volume Breakdown



Groundwater Services, Inc.

Source: McDade et al. 2005. Remediation

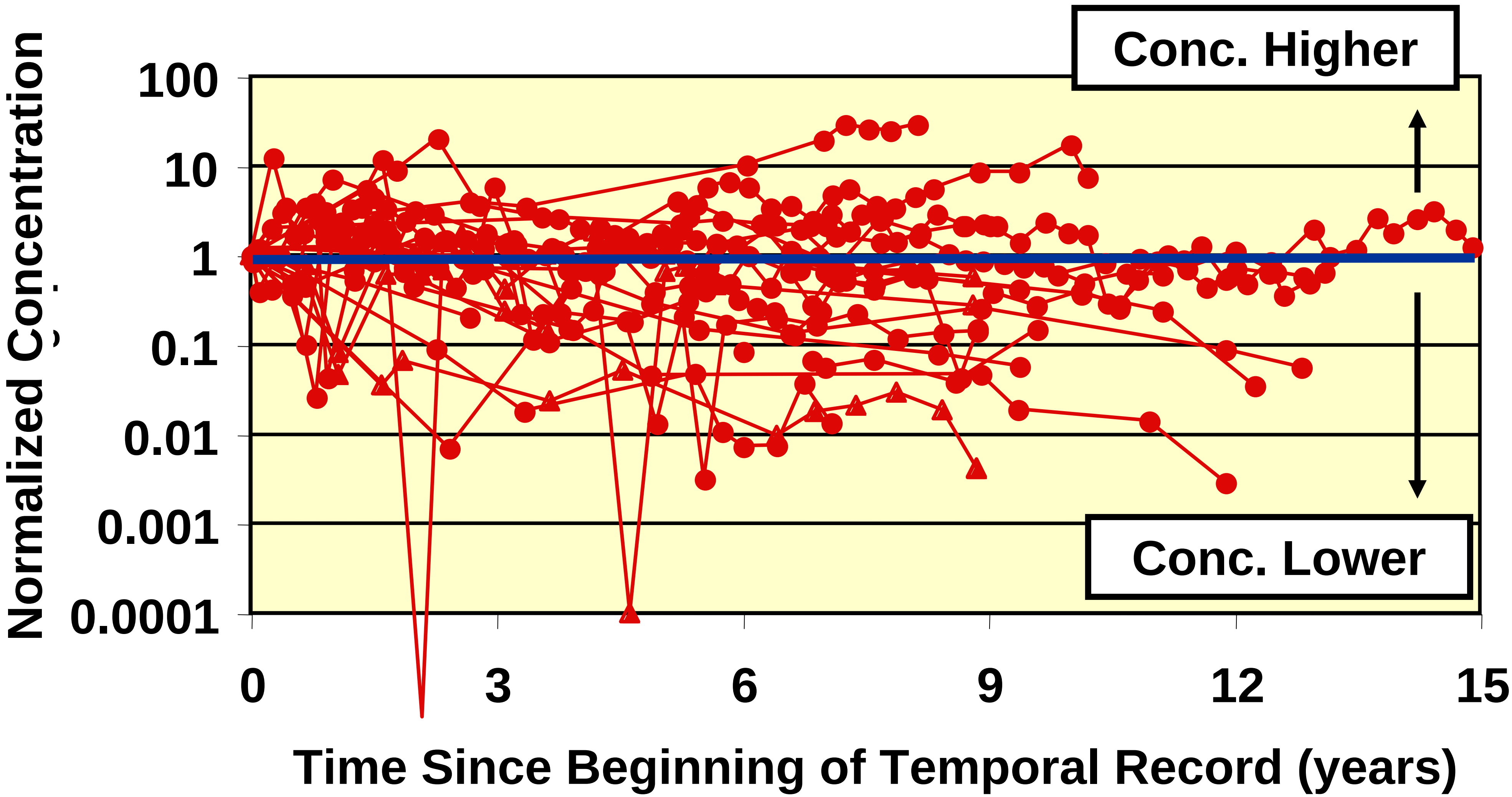
This Talk…..

1. *Longevity Data Mining Studies - SERDP Project*
   - *Performance & Cost Database*
   - *Untreated Site Database*

2. *Simple Longevity Models*
   - **SourceDK**
   - **SERDP Equations**

3. *Qualitative Decision Chart from "DNAPL Remediation Challenge"*

TCE



Conc. Higher
Conc. Lower
Normalized Concentration
100
10
1
0.1
0.01
0.001
0.0001
0
3
6
9
12
15
Time Since Beginning of Temporal Record (years)

Change in TCE Over Time

Number:* *13 sites, 21 wells

Median Duration:* *10 years

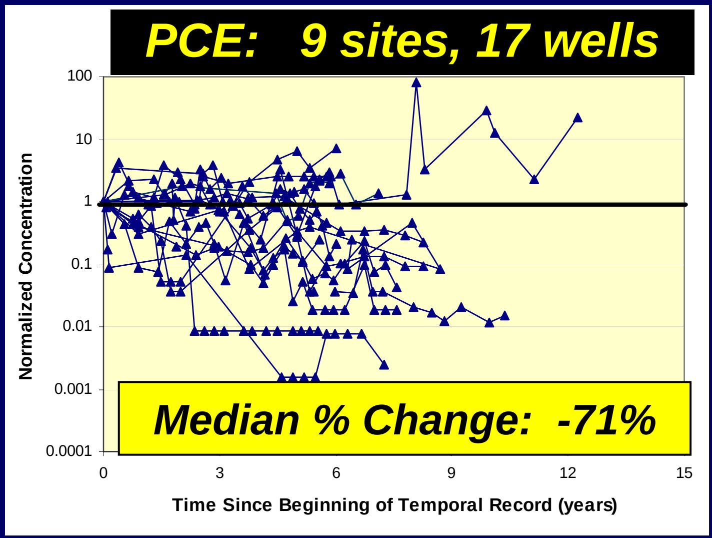
Median % Change:* *- 81%

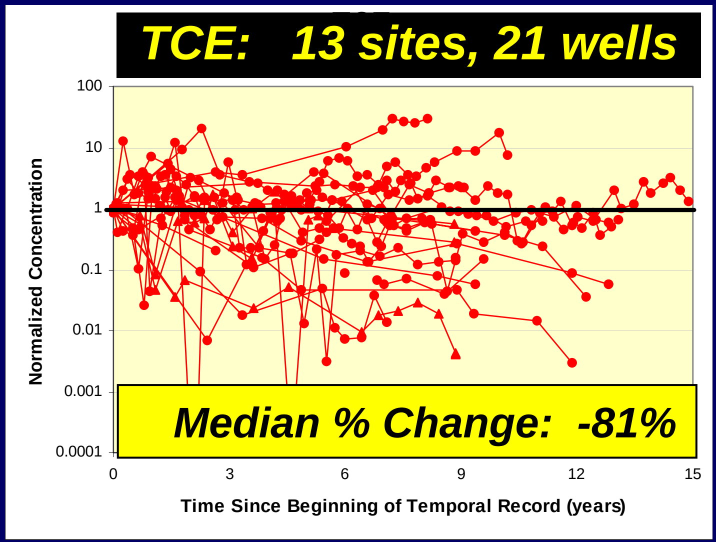
Concentration Trend (MAROS Software)

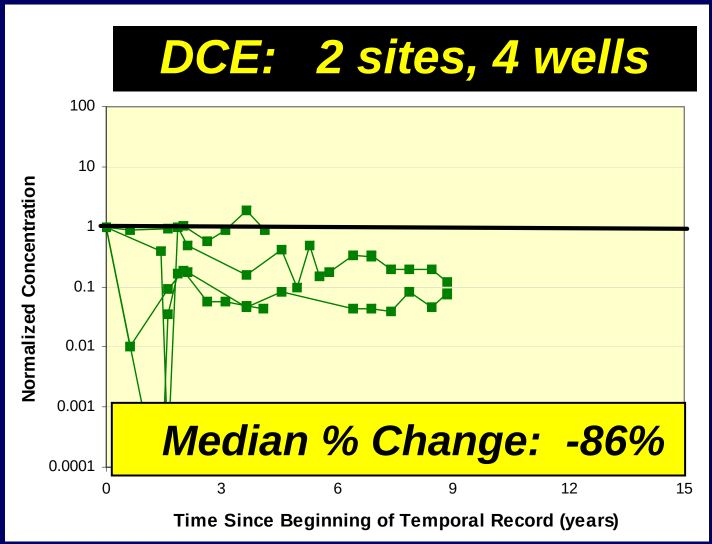
- **Increasing: 3 sites**
- **Stable: 3 sites**
- **Decreasing: 7 sites**

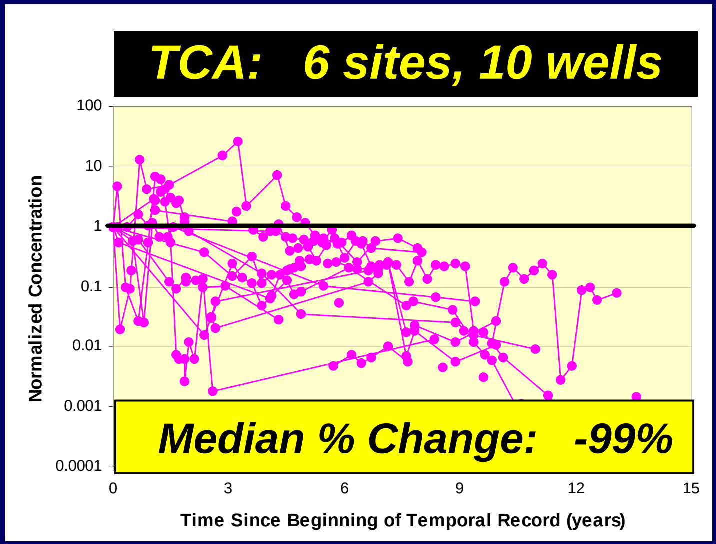
TCE

TEMPORAL TRENDS IN UNTREATED PLUME SOURCE ZONES





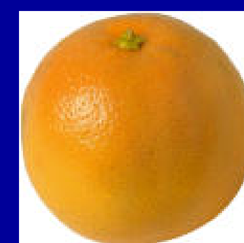




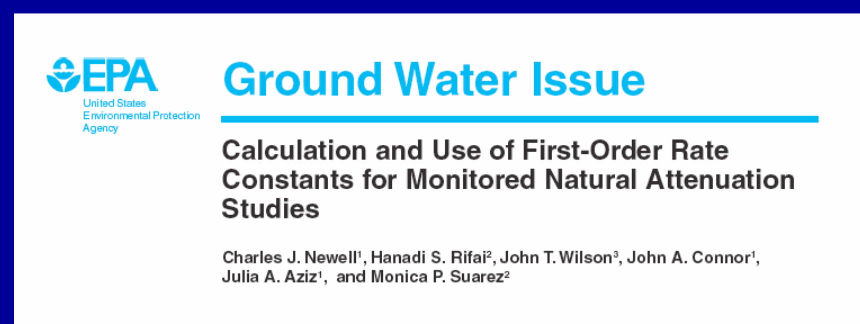
Two Different Types of Rate Constants

Lambda **represents how quickly dissolved organics are biodegraded (half-life months or years)**

$k_{point\ or}$ k_s represents how quickly <u>source</u> is being dissolved (half-life in years)



Reference:
EPA 540/S-02/500
Nov. 2002

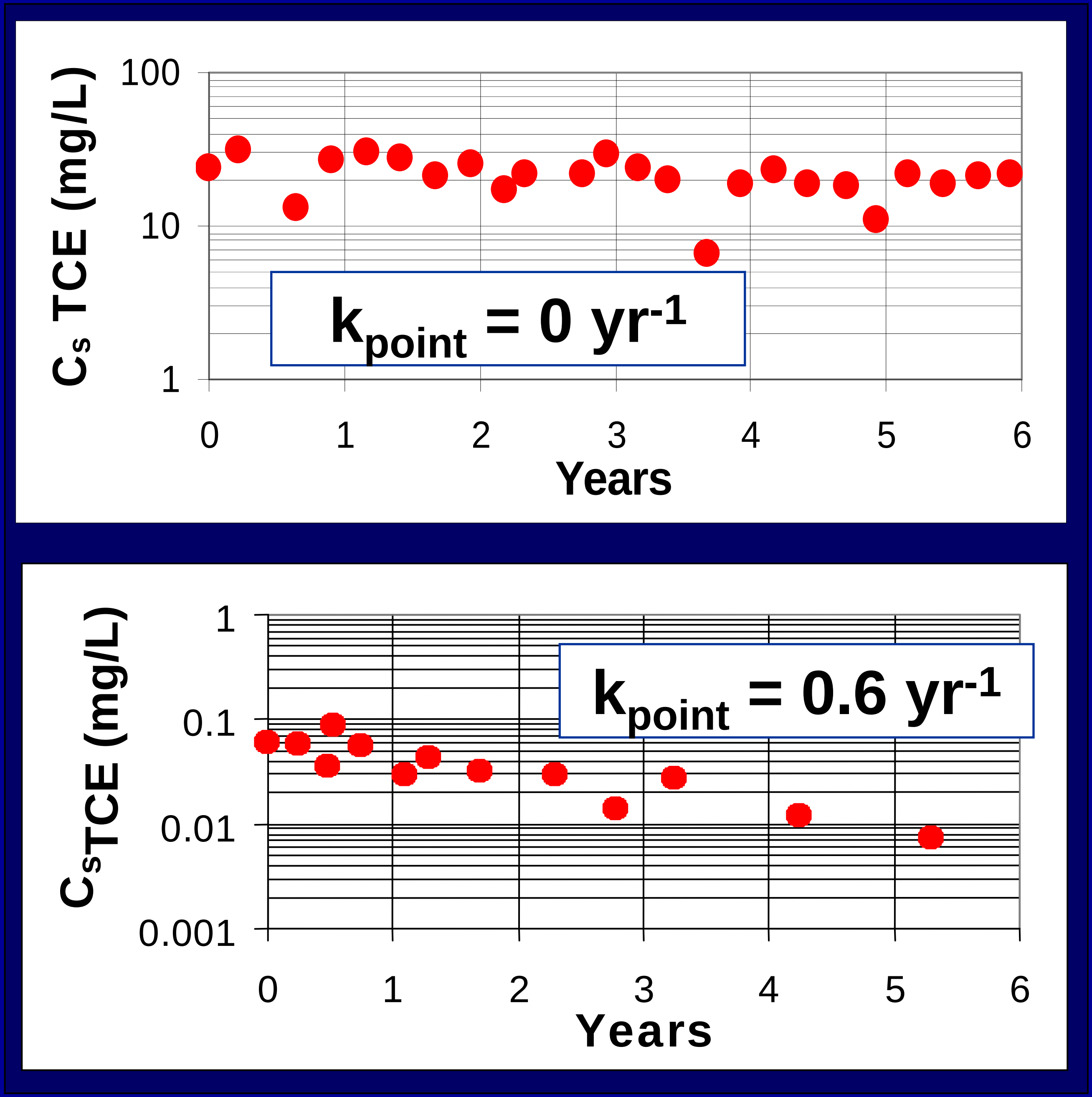

EPA
United States Environmental Protection Agency

Ground Water Issue

Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies

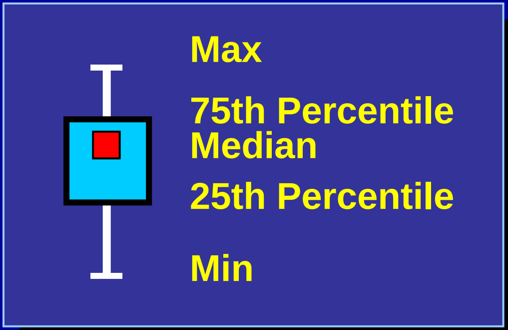
Charles J. Newell[1], Hanadi S. Rifai[2], John T. Wilson[3], John A. Connor[1], Julia A. Aziz[1], and Monica P. Suarez[2]

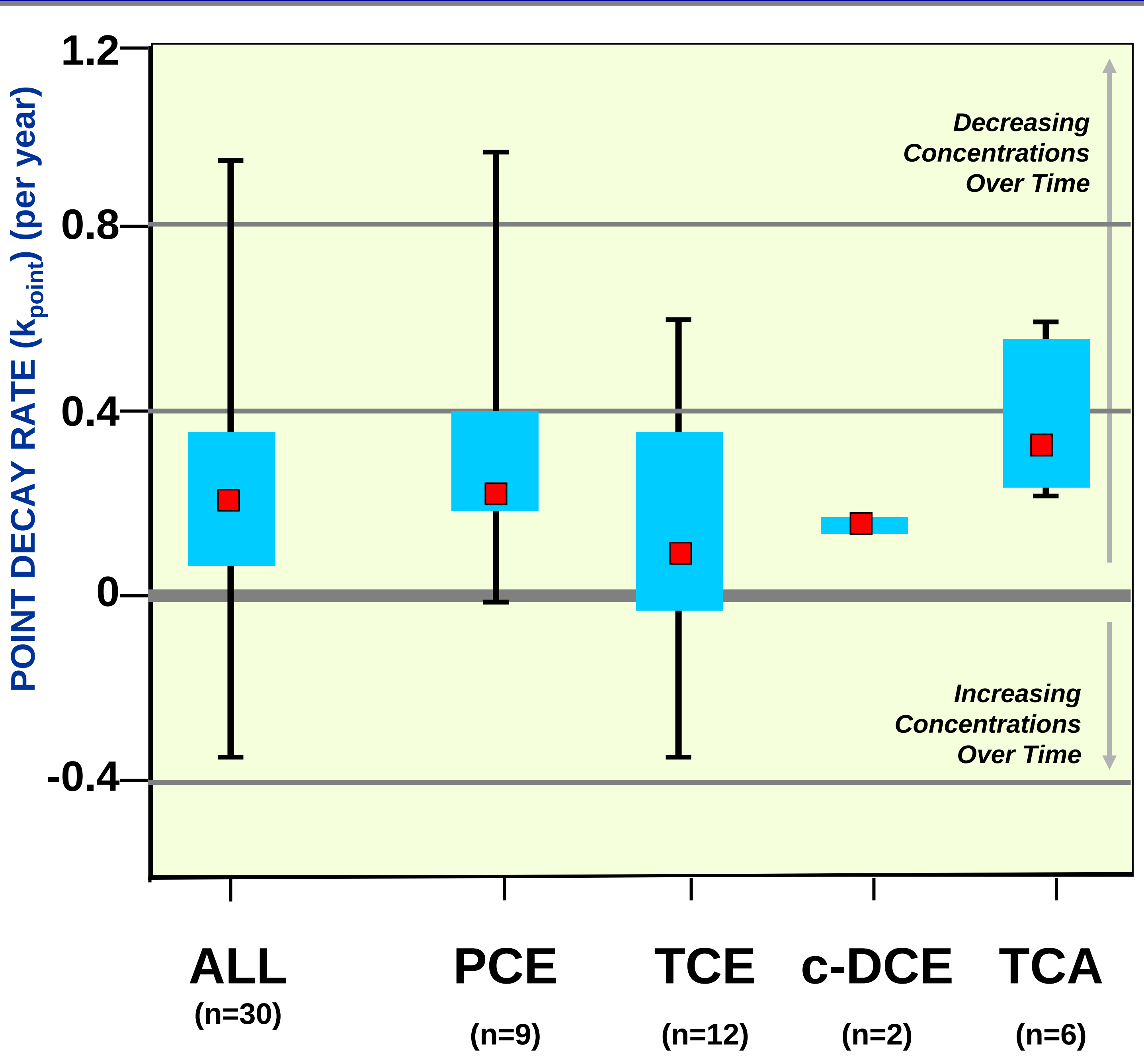
EXAMPLE C_{point} vs. Time Curves



k_{point} = source decay rate constant

POINT DECAY RATES FOR *CVOCS BY SITE*





Median Half-life

PCE: 3.0 years

TCE: 6.1 years

DCE: 4.3 years

TCA: 2.0 years

Implication

Benefits of partial source depletion is reduced if source is decaying naturally.

For example:

If source depletion gives 88% reduction in concentration….

That is equal to 3 source decay half-lives…..

These untreated source zones need < 20 years to achieve same result (?)

(median decay values from 23 site database)

This Talk…..

1. *Longevity Data Mining Studies - SERDP Project*
   - *Performance & Cost Database*
   - *Untreated Site Database*

2. *Simple Longevity Models*
   - **SourceDK**
   - **SERDP Equations**

3. *Qualitative Decision Chart from "DNAPL Remediation Challenge"*

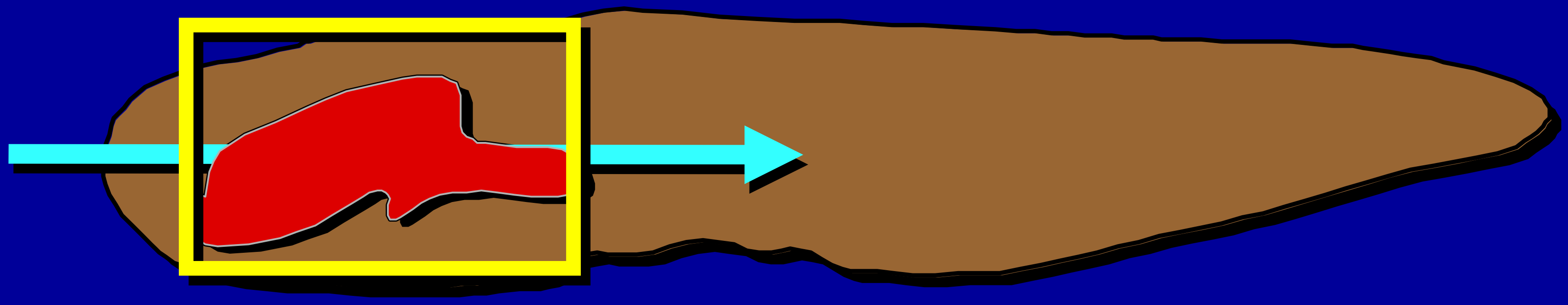
What Tools Do What

	HOW FAR DOES PLUME GO?	HOW LONG DOES MNA TAKE?
• BIOSCREEN	✓	✓
• BIOCHLOR	✓	✓
• MAROS		✓
• SourceDK		✓
• SERDP Eqns.		✓

SourceDK

How long will the source be there?

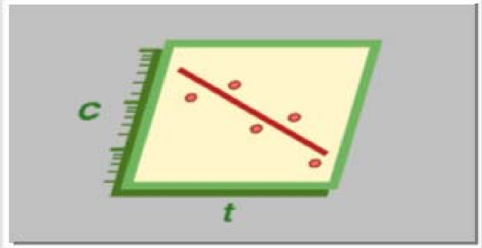
-Based on site data
-Based on simple model



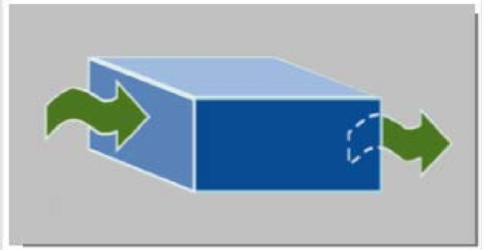
Air Force Center for
Environmental Excellence

SourceDK

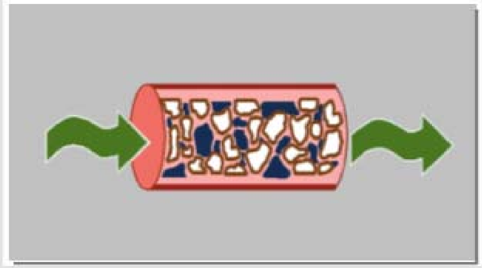
Remediation Timeframe Decision Support System



Use Empirical Data (Tier 1)



Use Box Model (Tier 2)



Use Process Models (Tier 3)

Version 1.0

Groundwater Services, Inc.

About | System Requirements

http://www.afcee.brooks.af.mil/products/techtrans/models.asp

SourceDK

Remediation Timeframe Decision Support System

Air Force Center for Environmental Excellence *Version 1.0 beta*

TIER 1 Empirical Data

Data Input Instructions:

10.80 → *Enter value directly.*

10.80 → *Value calculated by model. (Don't enter any data).*

Site Location and I.D.: LPST

Constituent of Interest: BTEX

1. ENTER CONSTITUENT NAME AND HISTORICAL DATA

	Date (mm/dd/yy)	Concentration (mg/L)			
		Constituent A	*Constituent B*	*Constituent C*	*Constituent D*
		Benzene	***Toluene***	***Ethylbenzene***	***Xylenes***
1	8/19/86	1.8	14	25	3.7
2	7/17/87	0.44	18	2.1	14
3	9/29/87	0.37	0.25	0.34	2.3
4	12/19/87	0.32	0.081	0.065	3
5	6/25/88	0.27	0.022	0.025	2.1
6	9/30/88	0.26	0.012	0.01	0.68
7	12/21/88	0.26	0.016	0.14	3.9
8	4/25/89	0.22		0.155	2.17
9	10/23/89	0.11		0.138	1.29
10	7/4/91	0.03			
11	11/20/91	0.018			
12					
13					
14					
15					

Print Historical Data

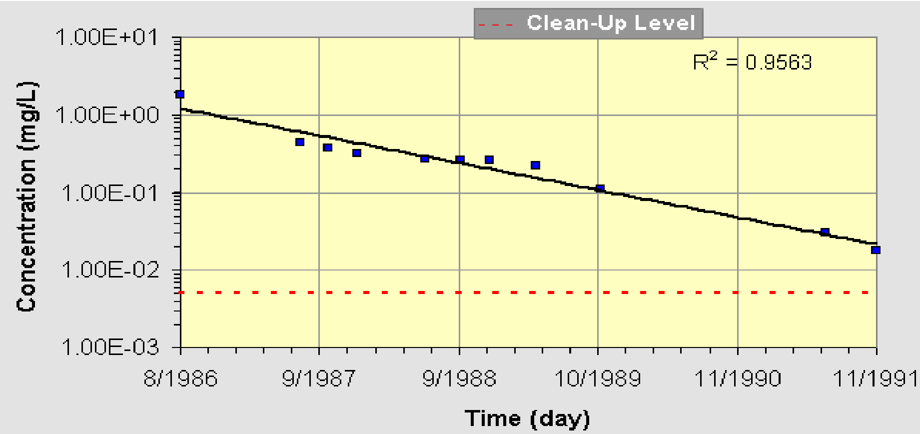
2. WHICH CONSTITUENT TO PLOT?

What is the cleanup level?

◉ **Benzene**	0.005	(mg/L)
○ Toluene	1	(mg/L)
○ Ethylbenzene	0.7	(mg/L)
○ Xylenes	10	(mg/L)

3. OUTPUT GRAPH

DISSOLVED BENZENE CONCENTRATION (mg/L)



Number of Years Over Which to Plot Graph (yr) Update Graph

4. RESULTS

Predicted Date to Achieve Cleanup: **1993**

Confidence Interval on Predicted Cleanup Date:
(at least 3 data points needed to calculate confidence intervals)

◉ 90 % Confidence Interval
○ 95 % Confidence Interval

1992 to **1995**

(Lower Limit on Confidence Interval) (Upper Limit on Confidence Interval)

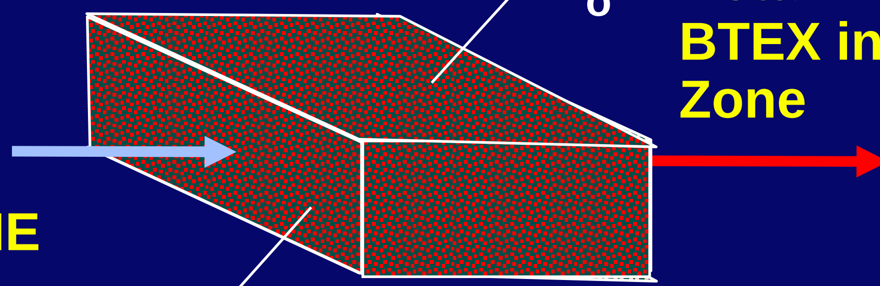
Return To Main Screen | ***New Site/Clear Screen*** | ***Paste Example Data Set*** | ***HELP***

Tier 2 Approach:
Assume Source Zone Is a Box

- **Simple Box Model**
- **Estimates source attenuation from:**
  - **source mass estimate**
  - **mass flux of contaminants leaving source**
  - **biodegradation processes in source zone**

Approach: *Assume Source Zone Is a Box*

Q = FLOW RATE THROUGH SOURCE ZONE



M_o = Total Mass of BTEX in Source Zone

C_o = Concentration in Source Zone at Time = 0

IF CONSTANT SOURCE CONCENTRATION:

C_o

t

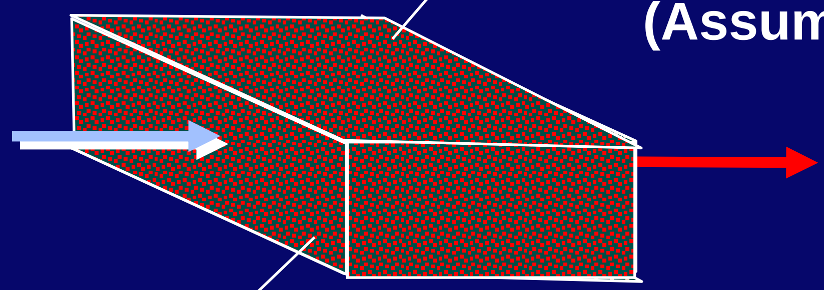
$$t = \frac{M_o}{Q \quad C_o}$$

Example Assuming Constant Source Conc.

Q = FLOW RATE THROUGH SOURCE ZONE

(Assume 500 L/Day)

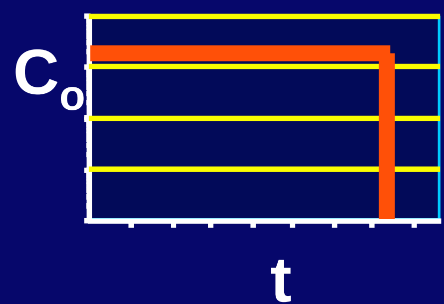
Mo = Total Mass of BTEX in Source Zone (Assume 10 kg)



(~ 30 gal gas)

C_o = Concentration in Source Zone at Time = 0 (Assume 2 mg/L)

IF CONSTANT SOURCE CONCENTRATION:

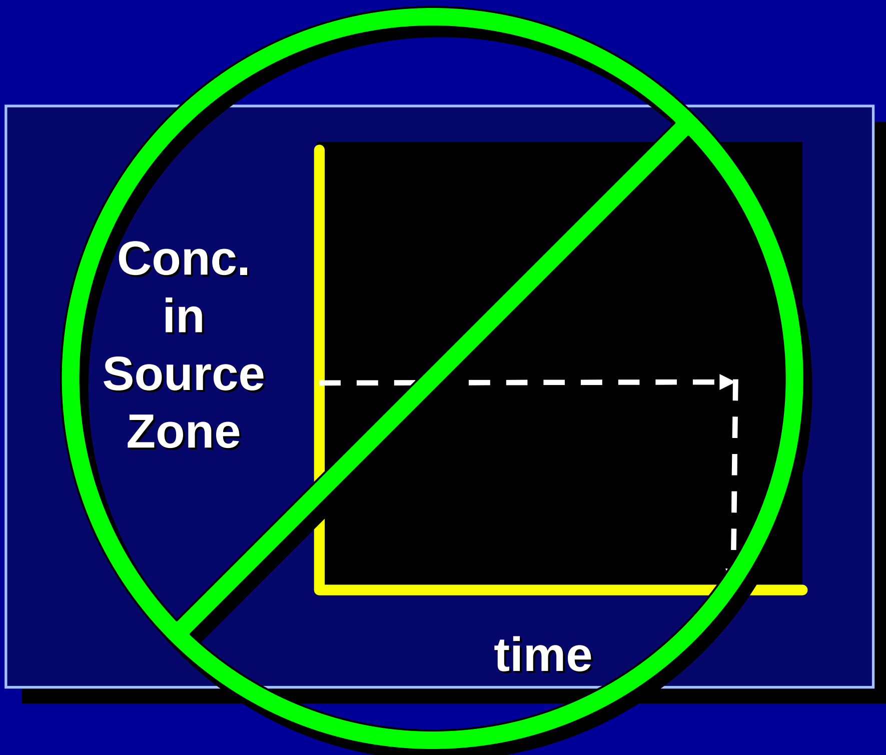


$$t = \frac{M_o}{Q\ C_o} = \frac{10{,}000{,}000}{(500)\ (2)}$$

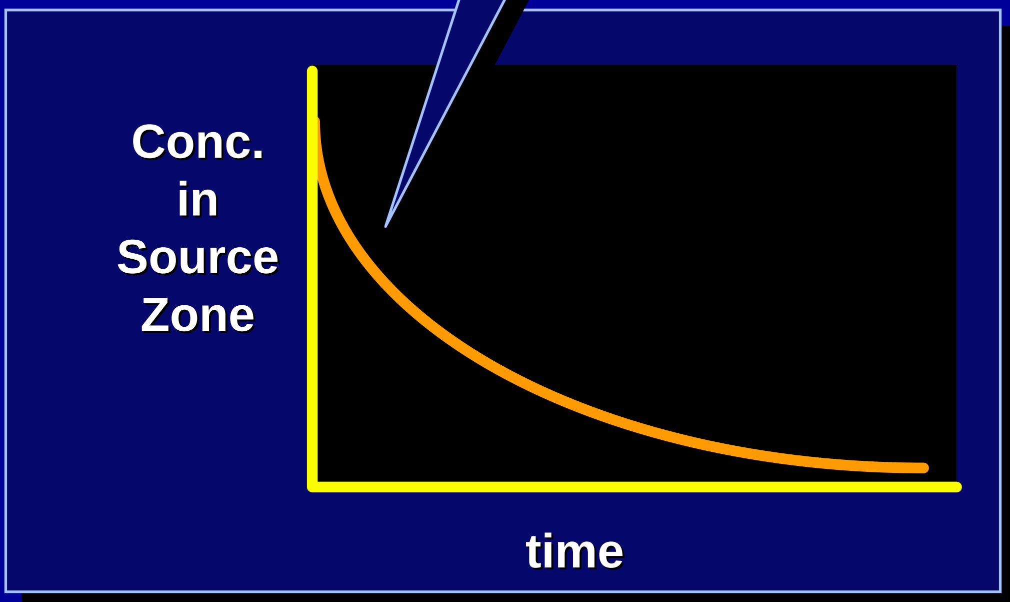
$$t = 10{,}000 \text{ days (27 yrs)}$$

Better Approximation: Conc. Declines With Tail

First Order Decay Model



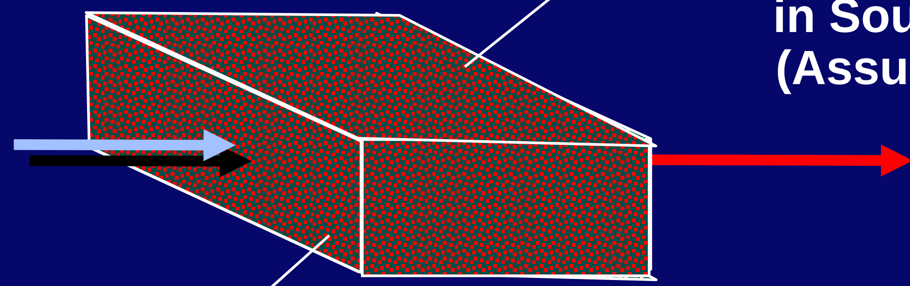
$$C_t = C_o \times e\,(-k_s t)$$



Example Assuming Declining Source Conc.

Q = FLOW RATE THROUGH SOURCE ZONE

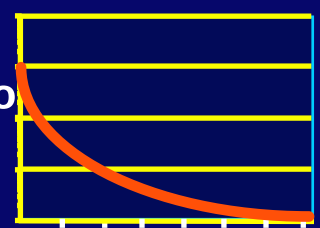
(Assume 500 L/Day)



M_o = Total Mass of BTEX in Source Zone (Assume 10 kg)

C_o = Concentration in Source Zone at Time = 0 (Assume 2 mg/L)

IF DECLINING SOURCE CONCENTRATION:



$$k_s = \frac{Q \quad C_o}{M_o} = \frac{(500) \quad (2)}{10{,}000{,}000} = 0.0001 \ \text{day}^{-1}$$

$$C_t = C_o \times e^{-0.0001\,t}$$

Example: Source Concentration vs. Time

Time (days)	Time (years)	Source Concentration (mg/L)
0	0	2.0
365	10	1.4
7,300	20	0.96
18,250	50	0.32
36,500	100	0.052
54,750	150	0.008
73,000	200	0.001

Rearrange eqn. to yield time:

$$C_t = C_o \; e^{-ks}$$

$$t = \frac{\ln (C_t / C_o)}{-k_s}$$

$$t = \frac{\ln (0.005 / 2)}{-0.0001}$$

t = 73,000 days (200 yrs)

SourceDK TIER 2 Box Model

Remediation Timeframe Decision Support System

Air Force Center for Environmental Excellence *Version 1.0 beta*

Data Input Instructions:

- 115 → 1. Enter value directly ... or
- 115 → 2. Calculate by filling in gray cells. Press Enter, then hit "Calculate" button.
- 115 → 3. Value calculated by model. (Do not enter any data.)

Site Location and I.D.: Texas
Constituent of Interest: BTEX

1. HYDROGEOLOGY

Darcy Velocity *Vd* 402.27 *(ft/yr)*
or
Hydraulic Conductivity *K* 8.1E-03 *(cm/sec)*
Hydraulic Gradient *i* 0.048 *(ft/ft)*

[Calculate Vd]

2. SOURCE CHARACTERISTICS

Key Assumption: Source Represented as Box Model

Average Source Groundwater Concentration at Time = 0 *Cgwo* 4.26 *(mg/L)*
Source Length *Sl* 38 *(ft)*
Source Width *Sw* 50 *(ft)*
Source Thickness *St* 10 *(ft)*

Enter Value for Specific Discharge or Press "Calculate Q" Button *Q* 2.0E+05 *(ft³/yr)*

[Calculate Q]

3. SOURCE DECAY CONSTANT

○ Enter Directly *ks* *(1/yr)*
or
● Calculate Source Decay Constant Using Sections 3A and 3B *ks* 0.93996 *(1/yr)*

3A. SOURCE MASS

Source Mass at Time = 0 *Mo* 2000 *(kg)*

Select Method for Calculating Source Mass

● **Method 1:** Enter Source Mass Directly 2000 *(kg)* ?
or
○ **Method 2:** Simple Volume X Concentration Calculation
or
○ **Method 3:** Detailed Volume X Concentration Calculation
or
○ **Method 4:** Estimated From NAPL Relationships

3B. SOURCE ZONE BIODEGRADATION

○ No Biodegradation

or

Assume Biodegradation Occurs in "Box" in Dissolved Phase Only

○ Select Method 1:
Biodegradation Rate Constant *lambda* *(per yr)*

or

● **Select Method 2:**
Biodegradation Rate Derived From Electron Acceptor By-Product Data.
(Applies Only to Petroleum Hydrocarbon Sites)

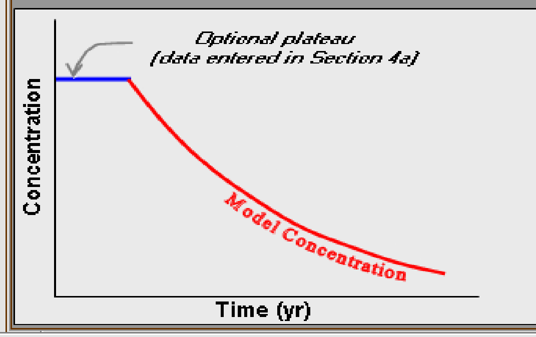
a) Biodegradation Capacity *BC* 320 *(mg/L)*
or
Delta Oxygen *DO* 5.78 *(mg/L)*
Delta Nitrate *NO3* 17 *(mg/L)*
Observed Ferrous Iron *Fe2+* 11.3 *(mg/L)*
Delta Sulfate *SO4* 100 *(mg/L)*
Observed Methane *CH4* 0.414 *(mg/L)*

[Calculate BC]

and

b) Percentage of Biodegradation Capacity Applied to This Constituent 100 *(%)*

SourceDK OUTPUT SHOWS THIS:



4. TIME FOR OUTPUT

a) Number of Years Over Which to Plot Data 10 *(yr)* (Required)
b) Time in Years at Which Decay Starts 1.5 *(yr)* (Optional)

5. UNCERTAINTY RANGE FOR MASS ESTIMATE

● ± Factor of 2 ○ ± Factor of 10 ○ ± Factor of 100

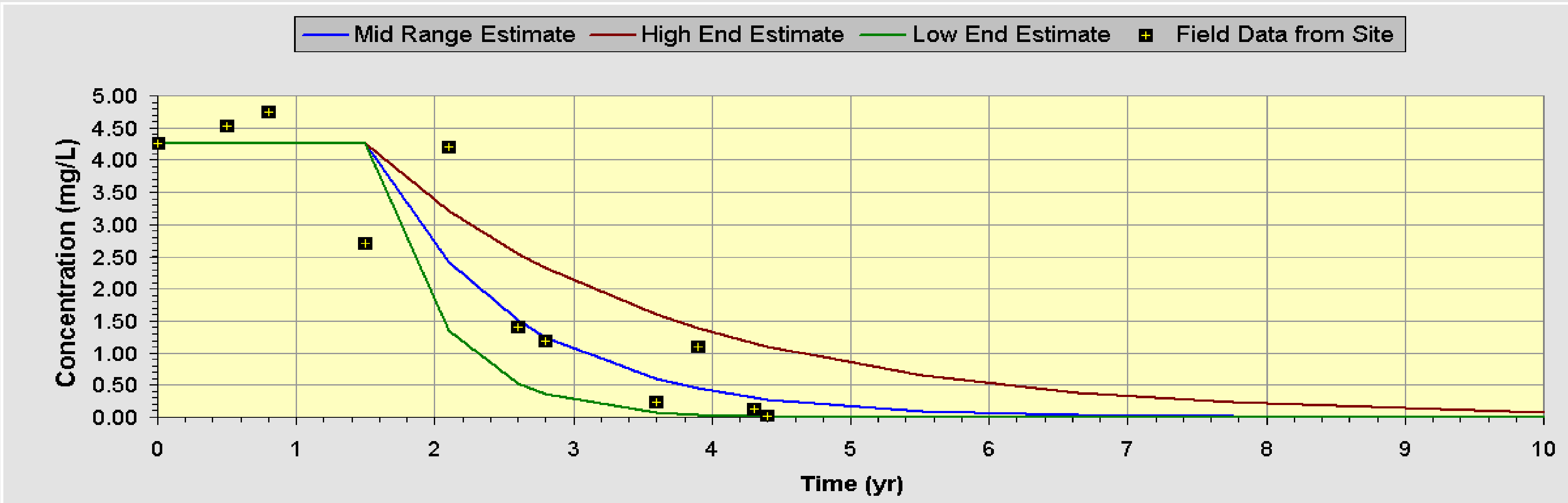
6. FIELD DATA FOR COMPARISON

Year From Time = 0 (yr)	0	0.5	0.8	1.5	2.1	2.6	2.8	3.6	3.9	4.3	4.4	
Concentration (mg/L)	4.26	4.54	4.74	2.7	4.2	1.4	1.2	0.23	1.1	0.12	0.025	

7. CHOOSE OUTPUT TO VIEW

[Show Graph] [Return to Main Screen] [New Site/Clear Screen] [Paste Example Data Set] [HELP]

	Time (yr)														
TYPE OF MODEL	0.00	0.50	0.80	1.50	2.10	2.60	2.80	3.60	3.90	4.30	4.40	5.52	6.64	7.76	10.00
Model Conc. (mg/L)	4.260	4.260	4.260	4.260	2.424	1.515	1.255	0.592	0.446	0.306	0.279	0.097	0.034	0.012	0.001
Actual Conc. (mg/L)	4.260	4.540	4.740	2.700	4.200	1.400	1.200	0.230	1.100	0.120	0.025				
Mass Discharge (kg/yr)	2.4E+01	2.4E+01	2.4E+01	2.4E+01	1.4E+01	8.6E+00	7.1E+00	3.4E+00	2.5E+00	1.7E+00	1.6E+00	5.5E-01	1.9E-01	6.7E-02	8.2E-03



1. **Display Concentration Vs. Time Chart**
or
Display Source Mass Vs. Time Chart

2. Number of Years Over Which to Plot Graph 10 *(yr)*
(Press "Calculate Current Sheet" button after changing value.)

Log **Linear**

Concentration/Time Mini-Calculator

4 *(yr)*
Time

1.330 *(mg/L)*
High End Conc Estimate

0.406 *(mg/L)*
Mid Range Conc Estimate

0.035 *(mg/L)*
Low End Conc Estimate

0.005 *(mg/L)*
Concentration

16 *(yr)*
High End Time Estimate

9 *(yr)*
Mid Range Time Estimate

5 *(yr)*
Low End Time Estimate

Return To Input

Calculate Current Sheet

HELP

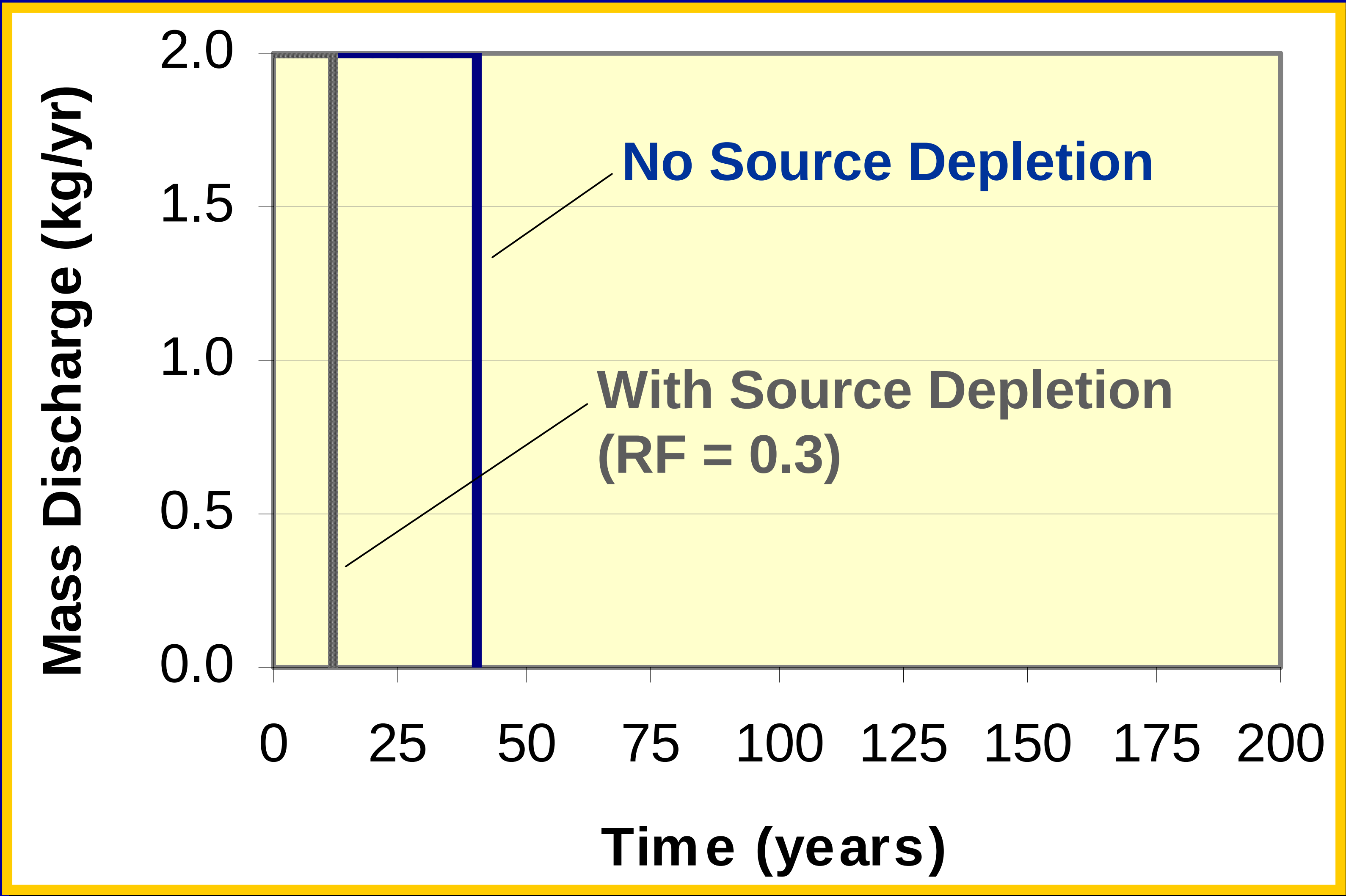
This Talk…..

1. *Longevity Data Mining Studies - SERDP Project*
   - *Performance & Cost Database*
   - *Untreated Site Database*

2. *Simple Longevity Models*
   - **SourceDK**
   - **SERDP Equations**

3. *Qualitative Decision Chart from "DNAPL Remediation Challenge"*

STEP FUNCTION MODEL - WITH AND WITHOUT *SOURCE DEPLETION*



RF: Remaining Fraction

REMEDIATION TIMEFRAME EQUATIONS - STEP FUNCTION

$$\frac{RTF_{SD}}{RTF_{MNA}} = RF$$

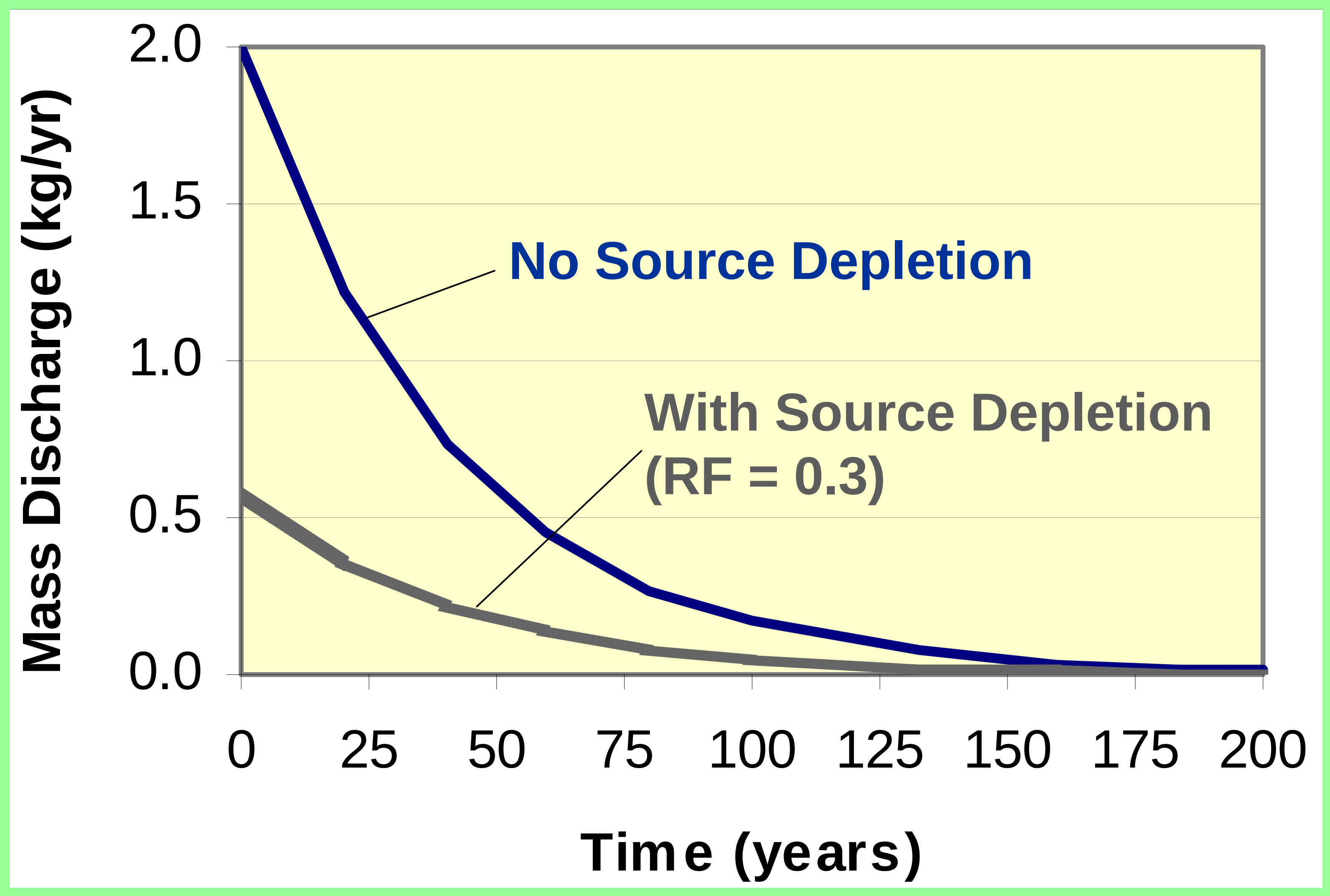
TERMS

RTF_{MNA}: ***Remediation Timeframe MNA (Untreated Source Zone)***

RTF_{SD}: ***Remediation Timeframe with Source Depletion***

RF: ***Remaining Fraction of Source Mass After Source Depletion***

FIRST ORDER DECAY MODEL - WITH AND WITHOUT *SOURCE DEPLETION*



Assume C_t proportional to M_t

RF: Remaining Fraction

REMEDIATION TIMEFRAME EQUATIONS – FIRST ORDER DECAY

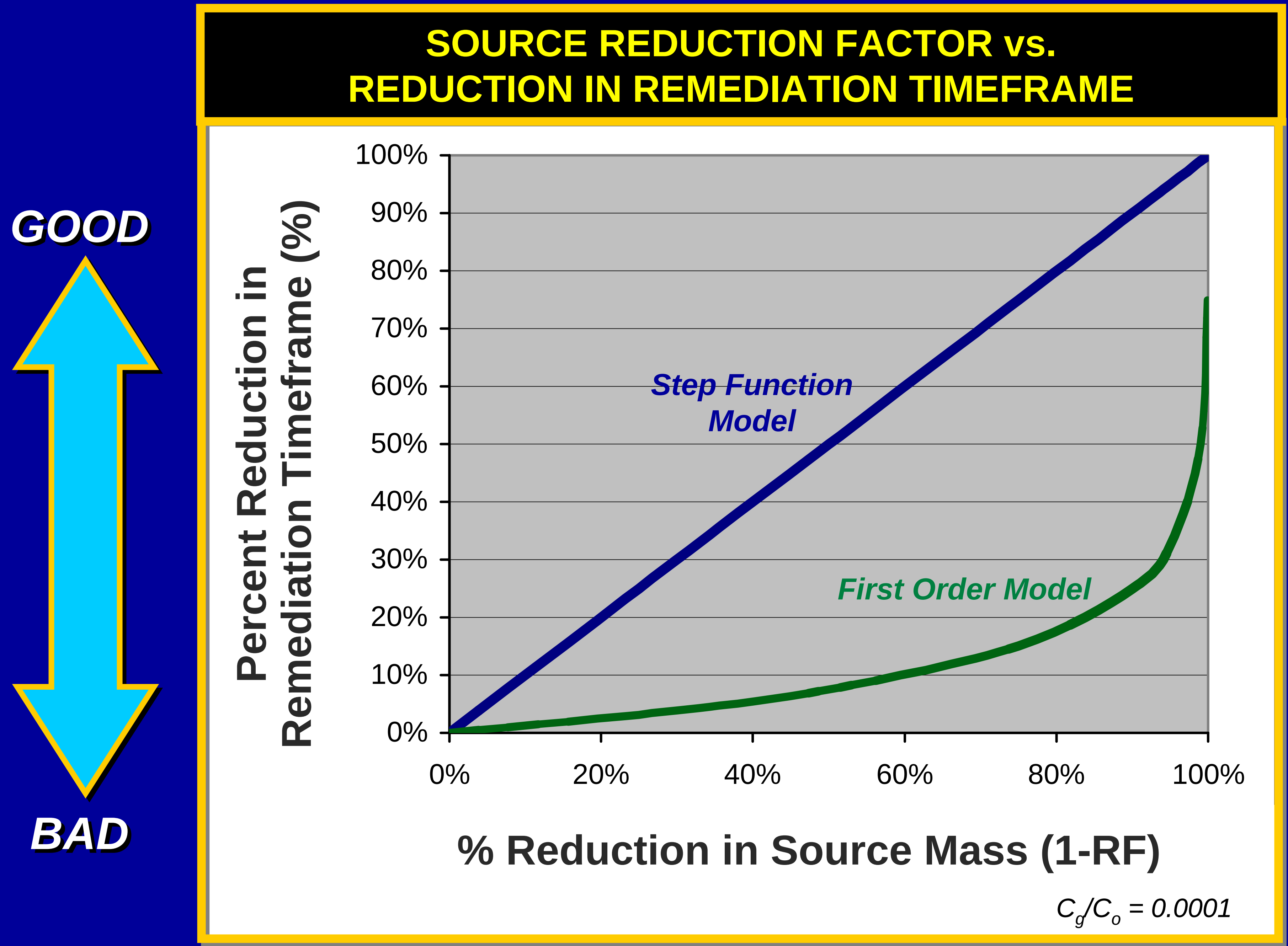
$$\frac{RTF_{SD}}{RTF_{MNA}} = \frac{\ln\left(\dfrac{C_g}{C_0 RF}\right)}{\ln\left(\dfrac{C_g}{C_0}\right)}$$

TERMS

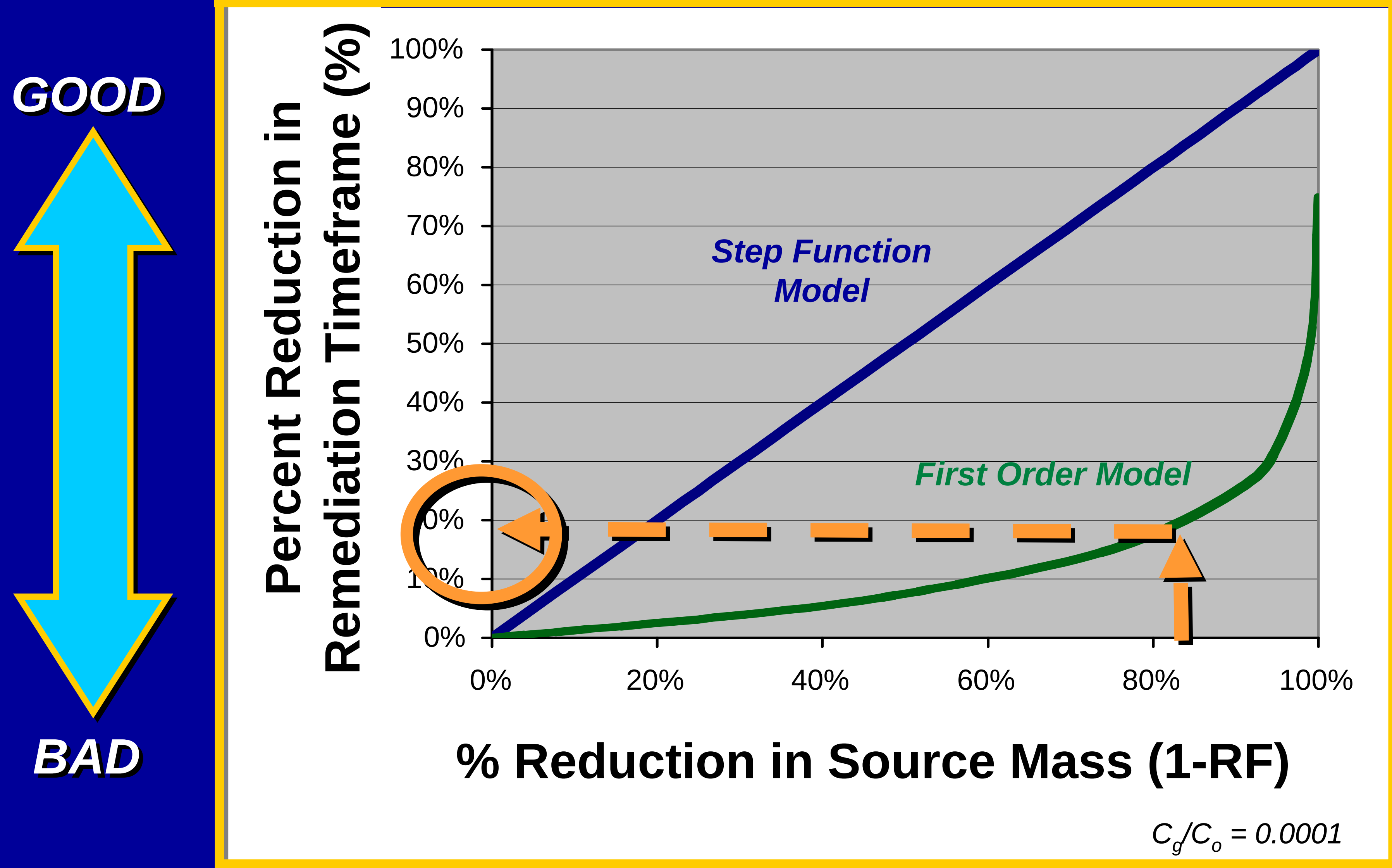
Newell and Adamson, 2005

C_g = Concentration Goal (such as MCL)
C_0 = Original Source Concentration

RF: Remaining Fraction of Source Mass After Source Depletion


SOURCE REDUCTION FACTOR vs.
REDUCTION IN REMEDIATION TIMEFRAME
GOOD
BAD
Percent Reduction in Remediation Timeframe (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Step Function Model
First Order Model
0%
20%
40%
60%
80%
100%
% Reduction in Source Mass (1-RF)
$C_g/C_o = 0.0001$

FIRST ORDER DECAY MODEL:
REMOVE *80%* SOURCE MASS
REDUCE RTF BY *17%*



This Talk…..

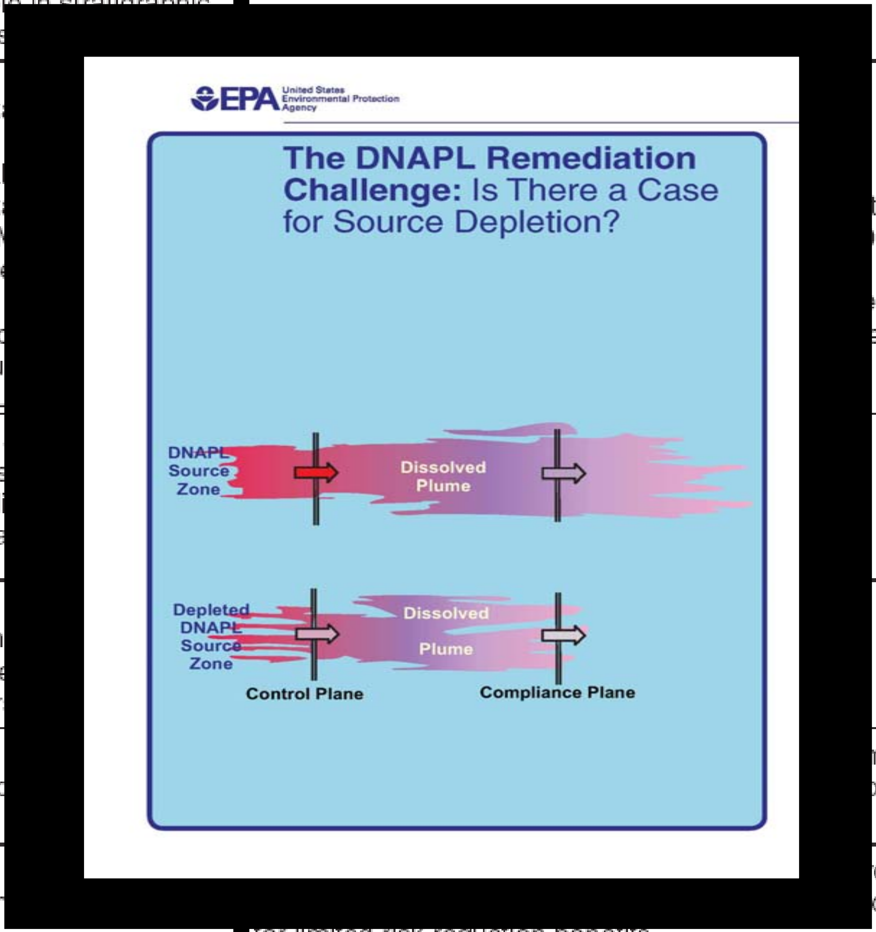
1. *Longevity Data Mining Studies - SERDP Project*
   - *Performance & Cost Database*
   - *Untreated Site Database*

2. *Simple Longevity Models*
   - **SourceDK**
   - **SERDP Equations**

3. *Qualitative Decision Chart from "DNAPL Remediation Challenge"*

"Benefits from Full-Scale Application of Source Depletion"

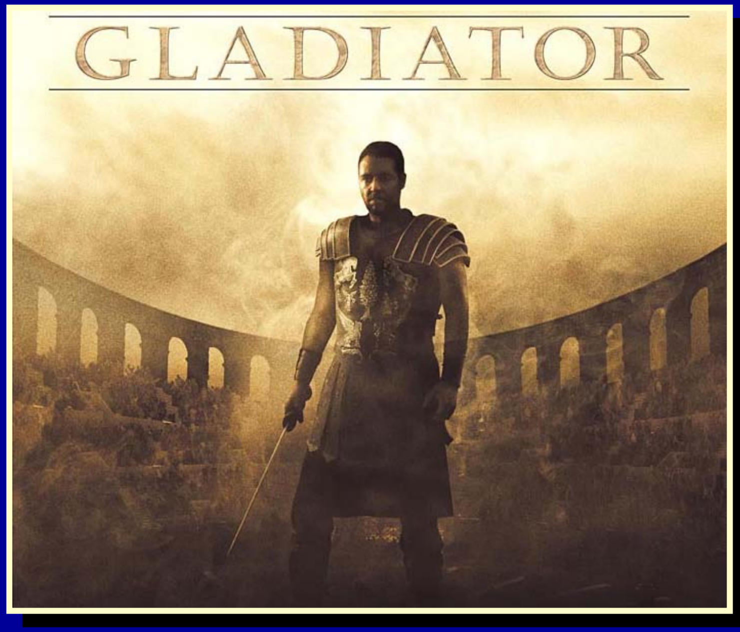
DESIRED REMEDIAL BENEFITS[1]	<u>MORE NEED</u> FOR SOURCE DEPLETION ←		<u>LESS NEED</u> FOR SOURCE DEPLETION →
Reduce potential for DNAPL migration as separate phase	1a. Expanding mobile DNAPL Zone (probably rare at chlorinated solvent sites)[2] *(<u>containment</u> addresses this problem too)*	1b. Free-Phase DNAPL present but stable in stratigraphic traps	1c. Immobile, residual DNAPL Zone
Reduce source longevity, and reduce long-term management requirements	2a. High life-cycle containment cost (for example, containment Net Present Value (NPV) >> cost of remediation) 3a. Low reliability of containment system 4a. High resource value that cannot be used due to DNAPL (for example, sole-source aquifer OR Well Yield > 144,000 gpd with TDS < 3000 mg/L)[3] 5a. High probability of a meaningful reduction in time to reach MCLs (for example, small sites with low complexity)	2b. cont 3b. relia cont 4b. M value 5b. ility c redu MCL	t ,000 to ex
Near-term enhanced natural attenuation due to reduced dissolved phase loading	6a. Expanding dissolved phase plume (source loading > assimilative capacity) *(<u>containment</u> addresses this problem too)*	6b. phas loadi capa	
Near-term reductions in dissolved phase loading to receptors (e.g., a well or a stream)	7a. Receptor impacted now or impacted soon (for example, < 2 years travel time)[5] *(<u>containment</u> addresses this problem too)*	7b. term (for e year	
Near-term attainment of MCLs	8a. Need for rapid cleanup (for example, impending property transfer)	8b. rapic	me osure
Intangibles	9a. Desire for active remedy; desire to test new technologies; desire to reduce stewardship burden on future generations	9b. intan	oven ces for limited risk reduction benefits



U.S. EPA, EPA/600-R-031/143, 2003. Page 39

Qualitative Decision Chart: Definition of Thumbs Up

If Thumbs Up, Apply Source Depletion



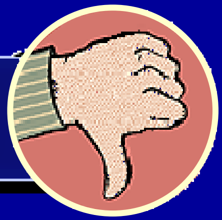
If Thumbs Down, Contain Source

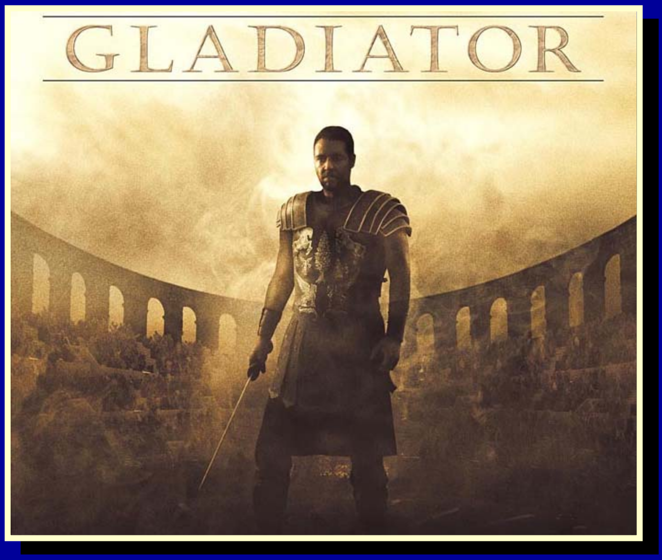
Reduce Potential for DNAPL Migration as Separate Phase

Status of NAPL Zone:

Expanding

Immobile, residual DNAPL





Reduce Source Longevity and Reduce Long-term Management Requirements

Life-cycle containment cost	High	Low
Reliability of containment system	Low	High
Resource value	High	Low
Probability that remediation timeframe can be signif. reduced?	High	Low

Other Categories

Plume Status
- Expanding Plume
- Shrinking Plume

Travel Time to Receptor
- < 2 years
- No risk

Need for Rapid Clean Up
- High need
- No need

Example: Less Likely to Benefit from Source Depletion

DESIRED REMEDIAL BENEFITS[1]	**MORE NEED** FOR SOURCE DEPLETION ←		**LESS NEED** FOR SOURCE DEPLETION →
Reduce potential for DNAPL migration as separate phase	1a. Expanding mobile DNAPL Zone (probably rare at chlorinated solvent sites)[2] *(containment addresses this problem too)*	1b. Free-Phase DNAPL present bu[illegible] stable in stratigraphic traps	1c. Immobi[illegible] APL Zone
Reduce source longevity, and reduce long-term management requirements	2a. High life-cycle containment cost (for exam[illegible], containment Net Present Value (NPV) >> cos[illegible] of remediation) 3a. Low reli[illegible] system 4a. High resour[illegible] cannot be used due to DNAPL (for e[illegible] urce aquifer OR Well Yield > 144[illegible] TDS < 3000 mg/L)[3] 5a. High probabili[illegible] aningful reduction in time to reach MCLs (for example, small sites with low complexity)	2b. Moderate life-cycle containment cost 3b. Moderate reliability of containment system 4b. Moderate resource value 5b. Moderate probab-ility of a meaning[illegible] reduction in time to MCLs	2c. Low life-cy[illegible] tainment cost (for example, containment [illegible] Value (NPV) << cost of remediation) 3c. High rel[illegible] ainment system 4c. Low reso[illegible] for example, resource not being used AN[illegible] Total Dissolved Solids > 10,000 mg/L or W[illegible] gpd) 5c. Low pro[illegible] aningful reduction in time to reach MCLs [illegible] large releases at complex sites)
Near-term enhanced natural attenuation due to reduced dissolved phase loading	6a. Expanding dissolved phase plume (source loading > assimilative capacity) *(containment addresses this problem too)*	6b. Stable dissolved phase plume (source loading ~ assimilative capacity)	6c. Shrinking dissolved phase plume (source loading < assimilative capacity)
Near-term reductions in dissolved phase loading to receptors (e.g., a well or a stream)	7a. Receptor impacted now or impacted soon (for example, < 2 years travel time)[5] *(containment addresses this problem too)*	7b. Potential longer term risk to receptor (for example, >2 years travel time)	7c. No risk [illegible] w or in the future
Near-term attainment of MCLs	8a. Need for rapid cleanup (for example, impending property transfer)	8b. Limited need for rapid cleanup	8c. No users [illegible] within expected [illegible] frame needed for [illegible] quifer and no other exposure pathways lik[illegible] r migration
Intangibles	9a. Desire for active remedy; desire to test new technologies; desire to reduce stewardship burden on future generations	9b. Neutral on intangible issues	9c. Desire for [illegible] remedy; desire to use proven technologies; desire to not expend financial resources for limited risk reduction benefits

Example: More Likely to Benefit from Source Depletion

DESIRED REMEDIAL BENEFITS[1]	**MORE NEED** FOR SOURCE DEPLETION		**LESS NEED** FOR SOURCE DEPLETION
Reduce potential for DNAPL migration as separate phase	1a. Expandin[illegible]L Zone (probably rare at chlorinated [illegible] *(containment a[illegible] problem too)*	1b. Free-Phase DNAPL present but stable in stratigraphic traps	1c. Immobile, residual DNAPL Zone
Reduce source longevity, and reduce long-term management requirements	2a. High life-cycle containment cost (for example, containment Net [illegible]alue (NPV) >> cost of remediation) 3a. Low reliab[illegible]ment system 4a. High reso[illegible] cannot be used due to DNAPL (for ex[illegible]le-source aquifer OR Well Yield [illegible] with TDS < 3000 mg/L)[3] 5a. High proba[illegible]aningful reduction in time to reach [illegible]ple, small sites with low complexity[illegible]	2b. Moderate life-cycle containment cost 3b. Moderate reliability of containment system 4b. Moderate resource value 5b. Moderate probability of a meaningful reduction in time to MCLs	2c. Low life-cycle containment cost (for example, containment Net Present Value (NPV) << cost of remediation) 3c. High reliability of [illegible]ent system 4c. Low resource v[illegible]mple, resource not being used AND ei[illegible]olved Solids > 10,000 mg/L or Well Yield [illegible] 5c. Low probability [illegible]l reduction in time to reach MCLs (for example, large releases at complex sites)
Near-term enhanced natural attenuation due to reduced dissolved phase loading	6a. Expanding dissolved phase plume (source loading > assimilative capacity) *(containment addresses this problem too)*	6b. Stable dissolved phase plume (source loading ~ assimilative capacity)	6c. Shrinking dissolved phase plume (source loading < assimilative capacity)
Near-term reductions in dissolved phase loading to receptors (e.g., a well or a stream)	7a. Receptor [illegible]or impacted soon (for example, < 2 y[illegible]e)[5] *(containment a[illegible] problem too)*	7b. Potential longer-term risk to receptor (for example, >2 years travel time)	7c. No risk to receptors now or in the future
Near-term attainment of MCLs	8a. Need for r[illegible](for example, impending pro[illegible]	8b. Limited need for rapid cleanup	8c. No users of resource within expected time frame needed for restoration of aquifer and no other exposure pathways likely, e.g., vapor migration
Intangibles	9a. Desire for act[illegible]edy; desire to test new technologies; desire to reduce stewardship burden on future generations	9b. Neutral on intangible issues.	9c. Desire for low-impact remedy; desire to use proven technologies; desire to not expend financial resources for limited risk reduction benefits

This Talk.....

1. *Longevity Data Mining Studies - SERDP Project*
   - *Performance & Cost Database*
   - *Untreated Site Database*

2. *Simple Longevity Models*
   - **SourceDK**
   - **SERDP Equations**

3. *Qualitative Decision Chart from "DNAPL Remediation Challenge"*

www.gsi-net.com

Groundwater
Services, Inc.