Anaerobic Bioremediation of Chlorinated Solvents in Groundwater Using Edible Oil Substrate EOS®

- *Matt Sedor, M.S.*, Yonathon Yoseph, P.G., C.H.G. (Remediation Sciences, Inc.)
- Jeff Baker (Vironex, Inc.),
- John Sankey, P.Eng. (True Blue Technologies Inc.).

Given by
John Sankey, P.Eng.,
True Blue Technologies

From this…

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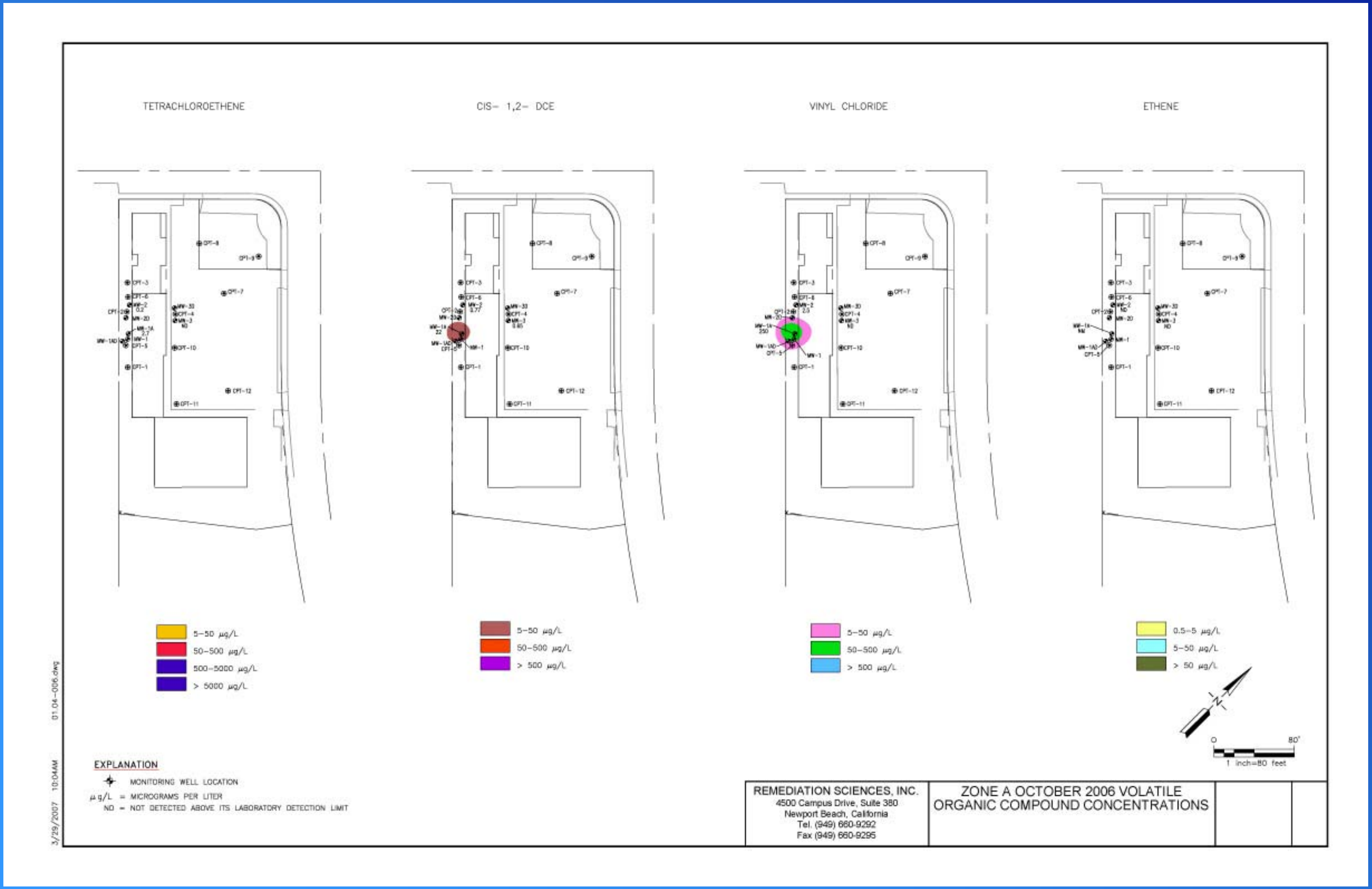
...to this in 18 months!



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Anaerobic Bioremediation of Chlorinated Solvents in Groundwater Using Edible Oil Substrate EOS®

Site Intro

Anaerobic Bioremediation– Few slides

Options: What ferments to hydrogen?

Designing the Project

Preparing and Injecting Substrate

Results

Ground Water Characterization--What to Monitor?

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Site Intro: Dry Cleaners Site Located in San Jose, California

Highest PCE and TCE concentrations in the January 2005 were 8,500 µg/L.

After evaluating several alternatives, *in situ* bioremediation was selected.

The goal was to find a substrate that was long lasting and easily distributed into the saturated soils.

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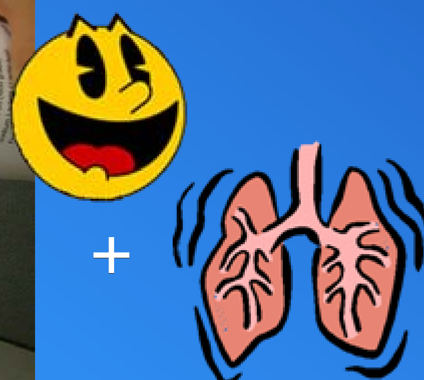
How Does Anaerobic Bio Work?

- **Growth-Promoting Biological Reduction**

Electron Donor
(Food)

+



Electron Acceptor
(something to breathe)
[O_2, NO_3, SO_4, TCE, etc.]

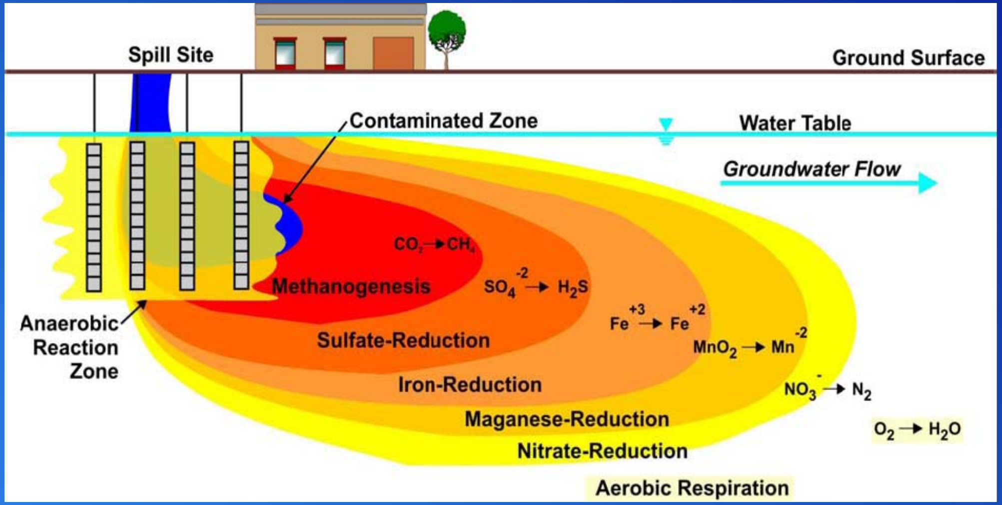
Waste Products
[CO_2, N_2, FeS_2, Cl^-]

Energy

(Drawing Modified from AFCEE and Wiedemeier)

What is Needed for Effective Anaerobic Bioremediation?

- Organic substrates that ferment to:
  - Acetate
  - Hydrogen (H_2)
- Strongly reducing conditions (Sulfate Reducing or Methanogenic)
- Right halorespiring bacteria (*Dehalococcoides* for DCE / VC)
- Nutrients
  - Vitamins and trace minerals to stimulate *Dehalococcoides* growth



Source: AFCEE, Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents, August 2004

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OPTIONS:

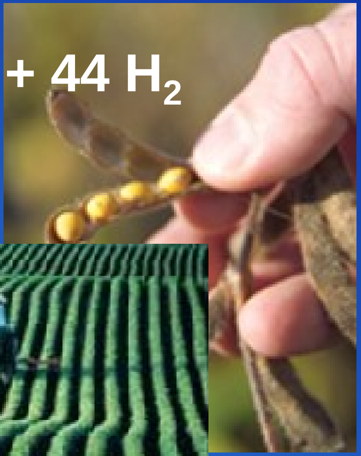
What quickly ferments to hydro  ?

- Soluble substrates (e.g., lactate, butyrate, propionate, acetate, molasses, and sugars).
- Solid substrates (e.g., bark mulch, compost, chitin and peat).
- Slow release substrates such as vegetable oil.

What lasts longer in-situ?

- **Soybean oil**
  - **$C_{56}H_{100}O_6$ *(soybean oil[1])* + 50 H_2O -*B*->**

    -*B*-> 28 CH_3COOH *(acetic acid)* + 44 H_2

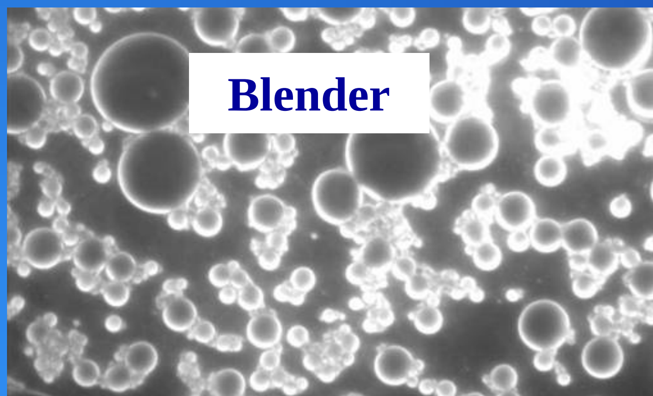


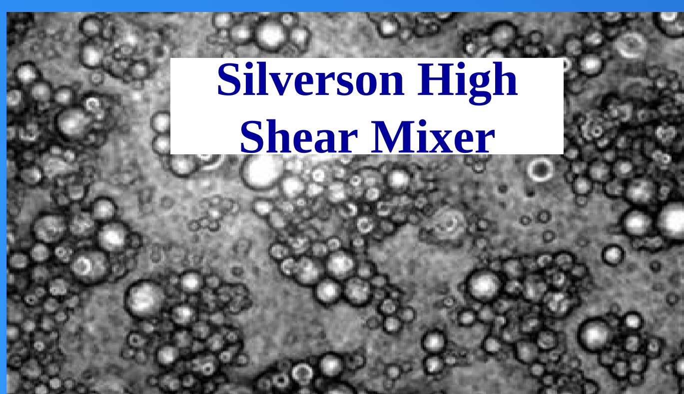
[1]Represents weighted average of constituent fatty acids and glycerol.

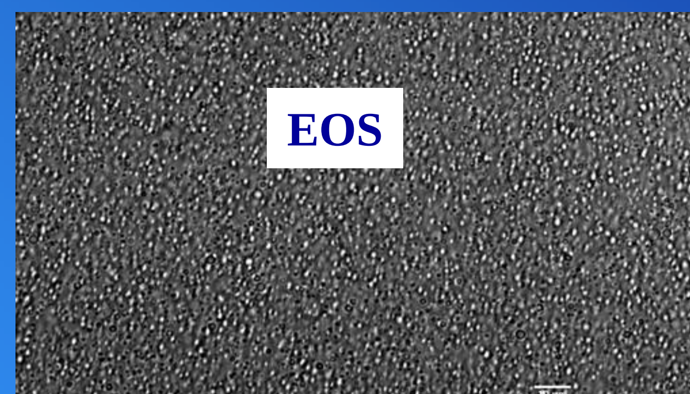
How Many Electrons Can We Pump into the Ground?

	e^- Released	
	per mole	per lb
Acetate	8	0.13
Lactate	**12**	**0.13**
Glucose	24	0.13
Soybean Oil	**313**	**0.36**
Canola Oil	319	0.36
Lard	311	0.36

Soy/Lactate Emulsions







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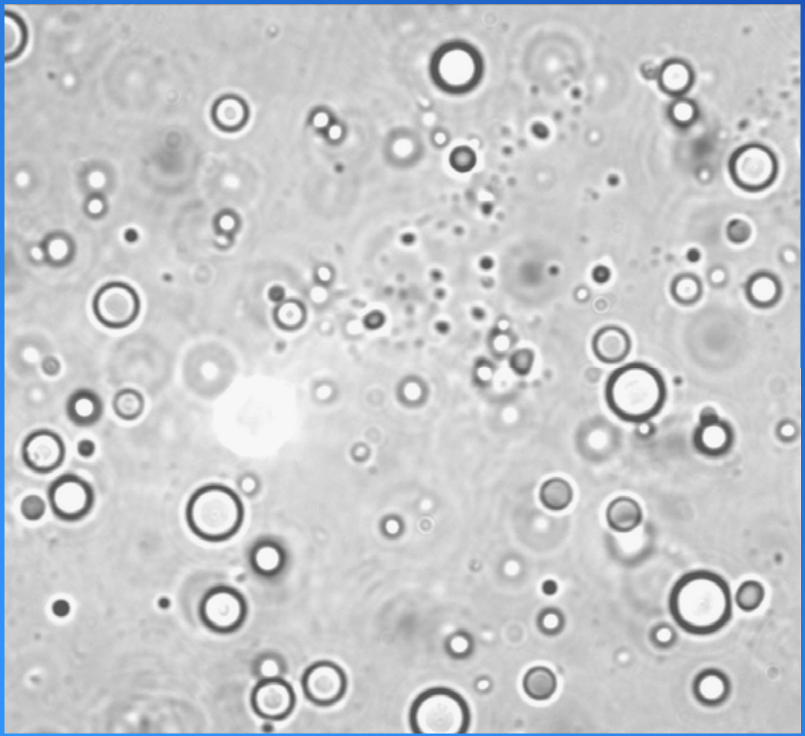
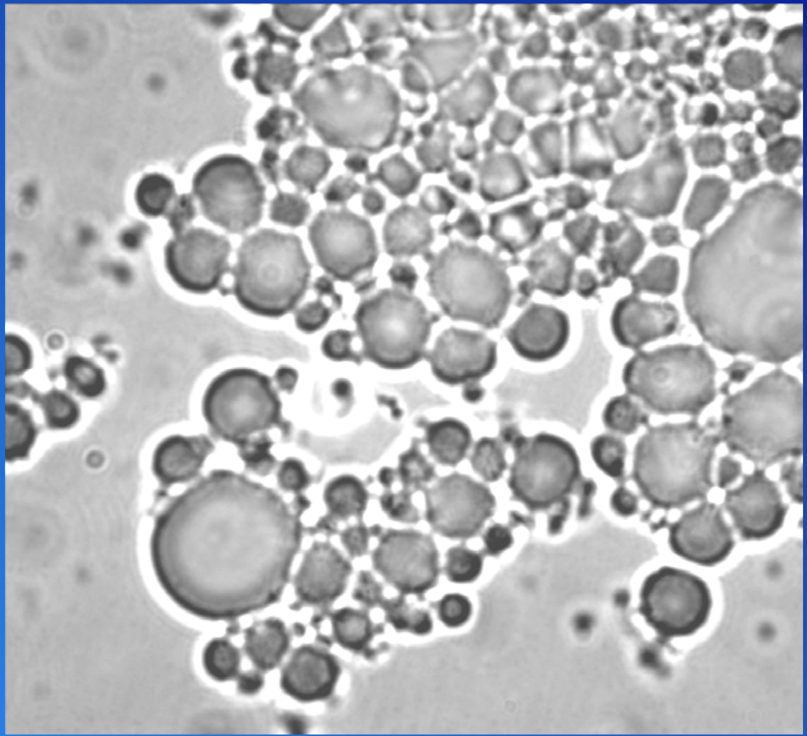
The Secret of Good Oil Distribution "Emulsions that do NOT Flocculate"



Dispersed Oil Droplets



Flocculated Oil Droplets

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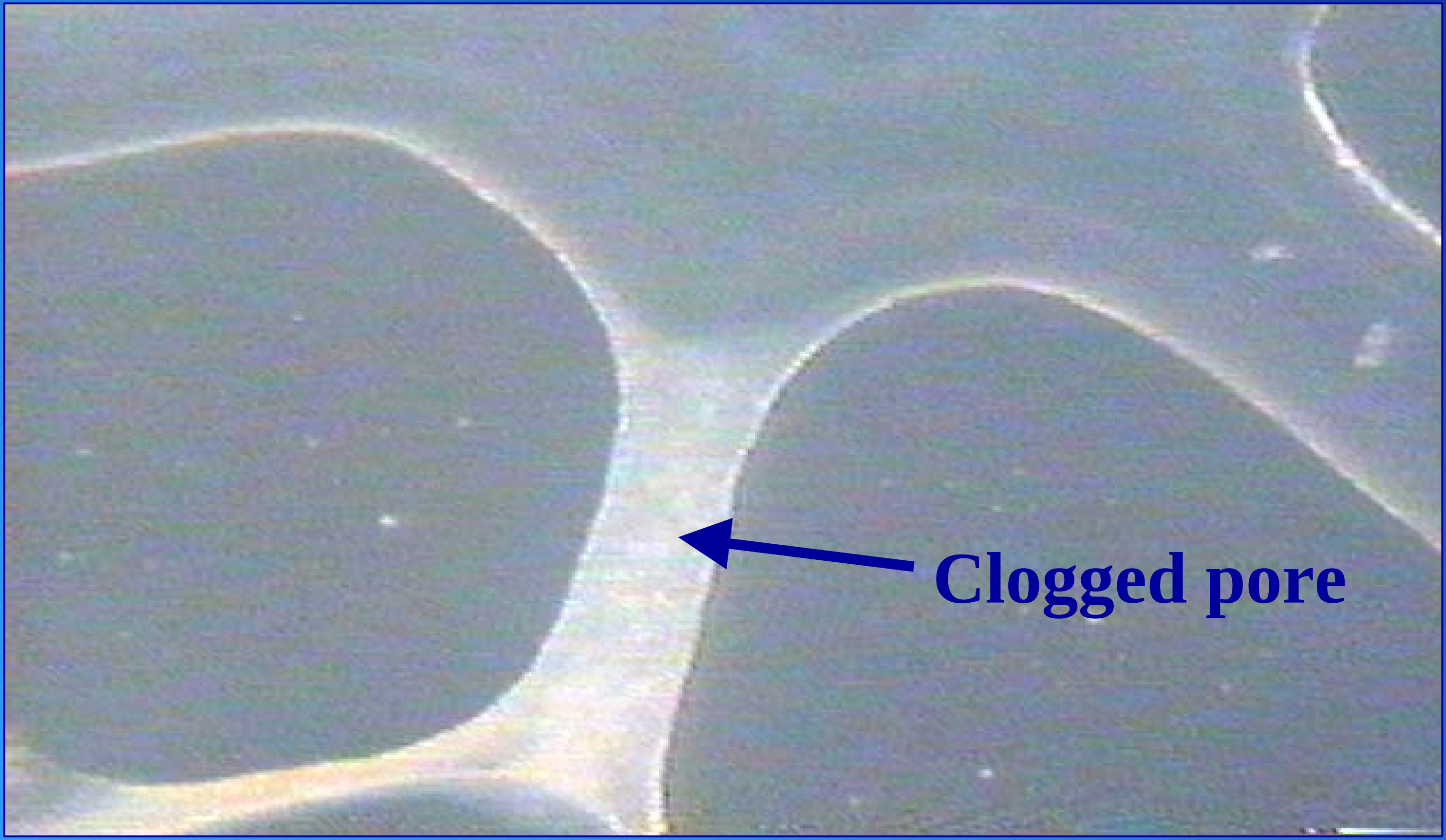
Secrets of Good Emulsion Distribution "Use Emulsions that do NOT Flocculate"



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Technology Choice--EOS®

Why?

- Slow release substrate
  - Emulsified soybean oil (GRAS)
  - Small, uniform droplets
  - Negative surface charge
- Easily biodegradable substrate
  - Lactate
- Micronutrients
  - Amino acids, Trace nutrients, Vitamins
- Easy to inject and distributed throughout treatment area
- Solid reputation
- Cost

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Technology Choice—Proposed Cost

EOS598 B42 Cost-6600 lbs

- $19,000

Drilling 12 points, injected 4,400 gallons of EOS mix and 22,700 gallons of flush water over a period of 6 days.

- $30,000

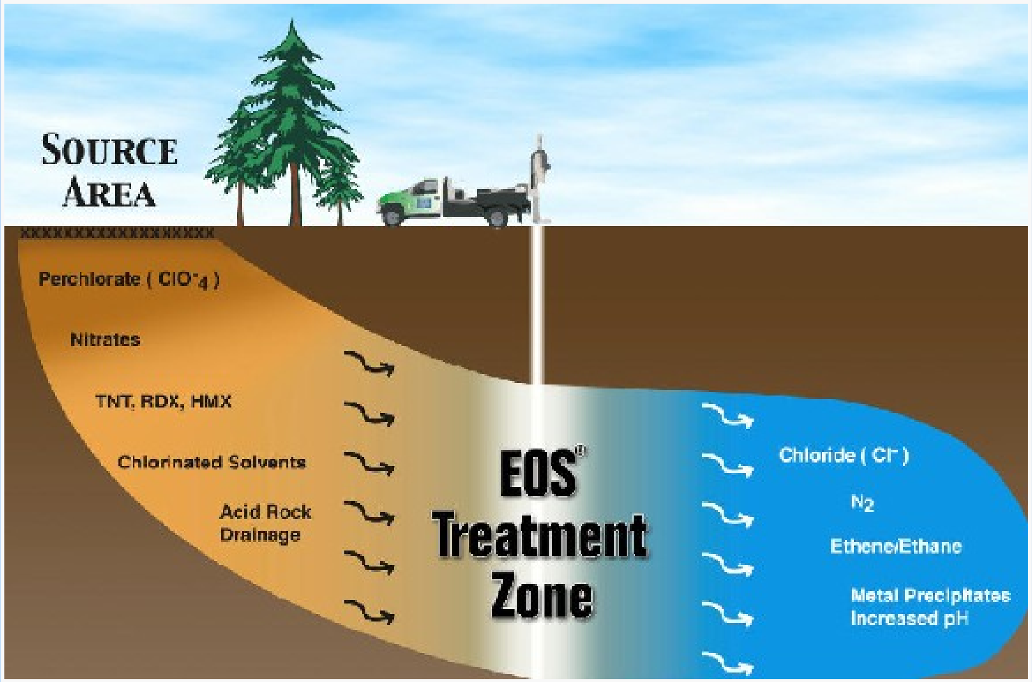
Plus monitoring and engineering

Designing the Injection at The Dry Cleaner Site

"You need to make contact…with the contaminant

Radius of Influence?

10ft to 100ft with EOS



From This

…..To This

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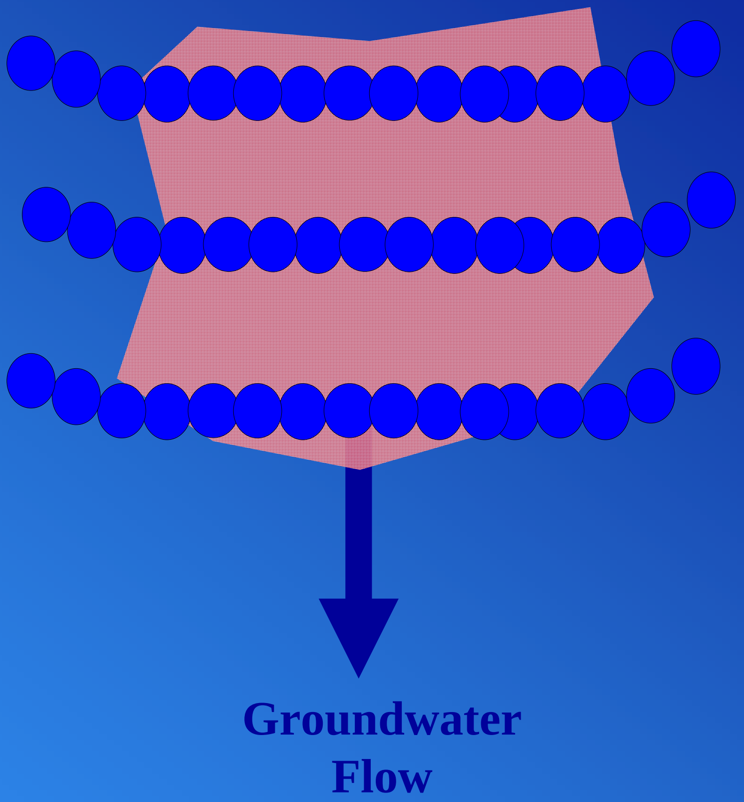
Source Treatment with Barriers

- Barriers 0.5 to 1 year apart
- Advantages
  - Low cost
    - Fewer injection points
    - Less oil and water
  - Release of TOC enhances downgradient biodegradation
  - Aquifer remains permeable
- Disadvantage
  - Longer clean-up time



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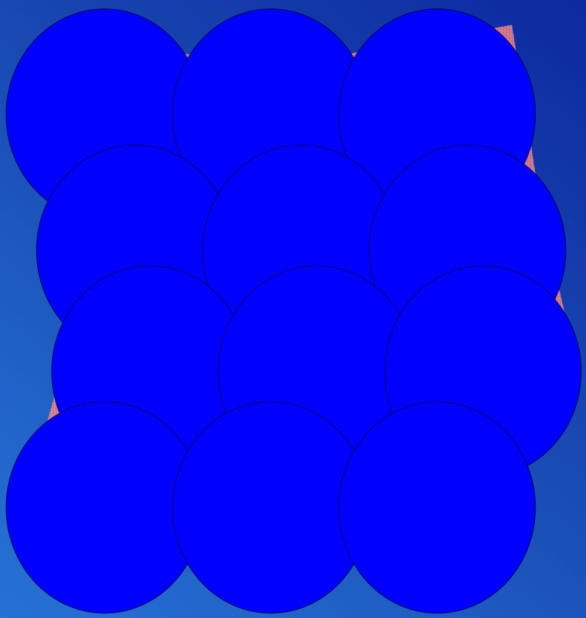
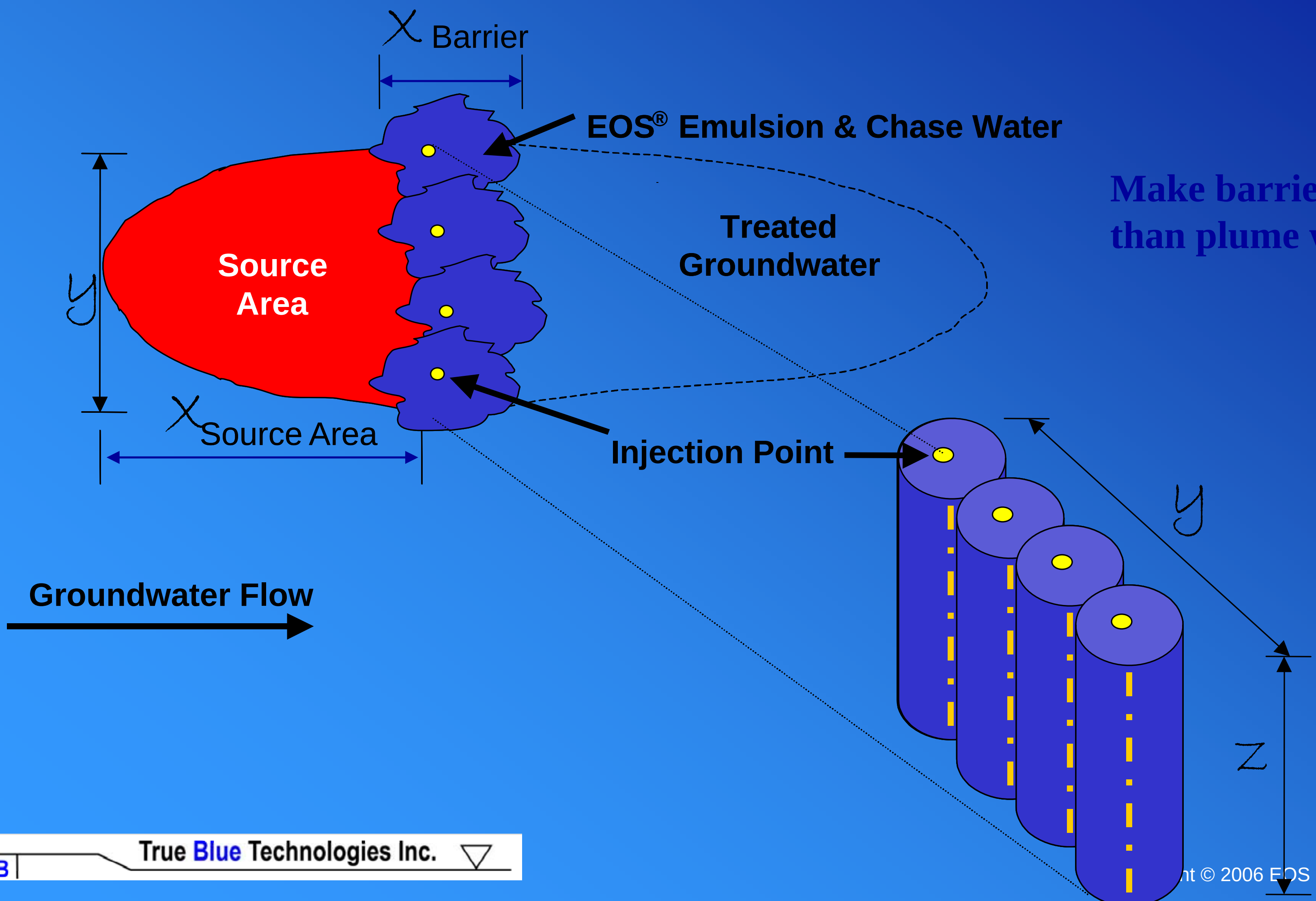
Source Area Treatment



- *How much do we inject?*

Treatment Zone Dimensions



Make barrier wider than plume width

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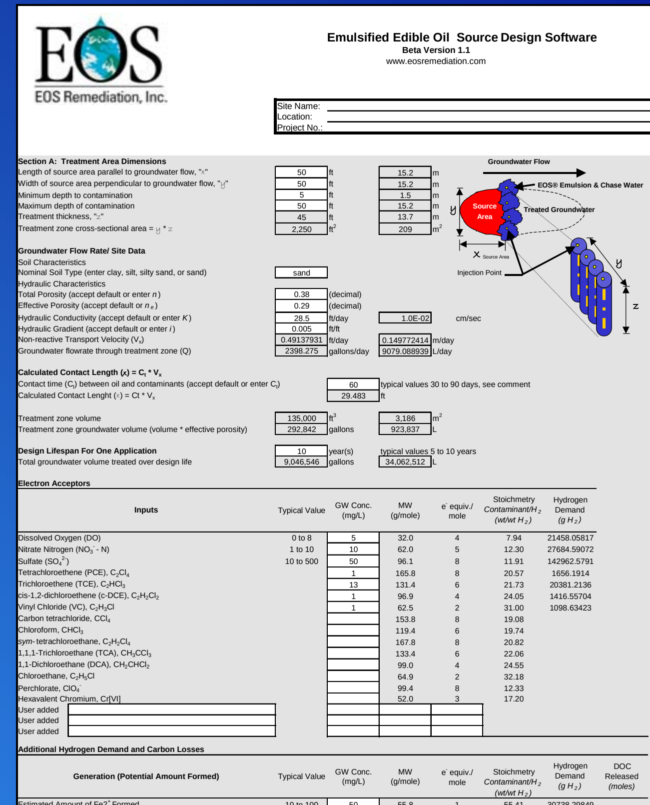
Design Tool Used

- Substrate needed for biodegradation
  - Flow rate through barrier
  - Pollutant concentrations
  - Competing electron acceptors (O_2, NO_3, SO_4)
  - Theoretical substrate life (5 to 10 years)
- Oil retention by aquifer
  - Higher retention with fine grained materials



EOS Remediation, Inc.

Emulsified Edible Oil Source Design Software
Beta Version 1.1
www.eosremediation.com

Site Name:
Location:
Project No.:

Section A: Treatment Area Dimensions

Length of source area parallel to groundwater flow, "x"	50	ft	15.2	m
Width of source area perpendicular to groundwater flow, "y"	50	ft	15.2	m
Minimum depth to contamination	5	ft	1.5	m
Maximum depth of contamination	50	ft	15.2	m
Treatment thickness, "z"	45	ft	13.7	m
Treatment zone cross-sectional area = y * z	2,250	ft^2	209	m^2

Groundwater Flow Rate/ Site Data
Soil Characteristics

Nominal Soil Type (enter clay, silt, silty sand, or sand)	sand			
Hydraulic Characteristics				
Total Porosity (accept default or enter *n*)	0.38	(decimal)		
Effective Porosity (accept default or n_e)	0.29	(decimal)		
Hydraulic Conductivity (accept default or enter *K*)	28.5	ft/day	1.0E-02	cm/sec
Hydraulic Gradient (accept default or enter *i*)	0.005	ft/ft		
Non-reactive Transport Velocity (V_x)	0.49137931	ft/day	0.149772414	m/day
Groundwater flowrate through treatment zone (Q)	2398.275	gallons/day	9079.088939	L/day

Calculated Contact Length (x) = C_t * V_x

Contact time (C_t) between oil and contaminants (accept default or enter C_t)	60	typical values 30 to 90 days, see comment	
Calculated Contact Lenght (x) = Ct * V_x	29.483	ft	

Treatment zone volume	135,000	ft^3	3,186	m^2
Treatment zone groundwater volume (volume * effective porosity)	292,842	gallons	923,837	L
Design Lifespan For One Application	10	year(s)	typical values 5 to 10 years	
Total groundwater volume treated over design life	9,046,546	gallons	34,062,512	L

Electron Acceptors

Inputs	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)	0 to 8	5	32.0	4	7.94	21458.05817
Nitrate Nitrogen (NO_3^- - N)	1 to 10	10	62.0	5	12.30	27684.59072
Sulfate (SO_4^{2-})	10 to 500	50	96.1	8	11.91	142962.5791
Tetrachloroethene (PCE), C_2Cl_4		1	165.8	8	20.57	1656.1914
Trichloroethene (TCE), C_2HCl_3		13	131.4	6	21.73	20381.2136
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		1	96.9	4	24.05	1416.55704
Vinyl Chloride (VC), C_2H_3Cl		1	62.5	2	31.00	1098.63423
Carbon tetrachloride, CCl_4			153.8	8	19.08	
Chloroform, $CHCl_3$			119.4	6	19.74	
sym-tetrachloroethane, $C_2H_2Cl_4$			167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3			133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2			99.0	4	24.55	
Chloroethane, C_2H_5Cl			64.9	2	32.18	
Perchlorate, ClO_4^-			99.4	8	12.33	
Hexavalent Chromium, Cr[VI]			52.0	3	17.20	
User added						
User added						
User added						

Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichmetry *Contaminant/H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	50	55.8	1	55.41	30738.29849	

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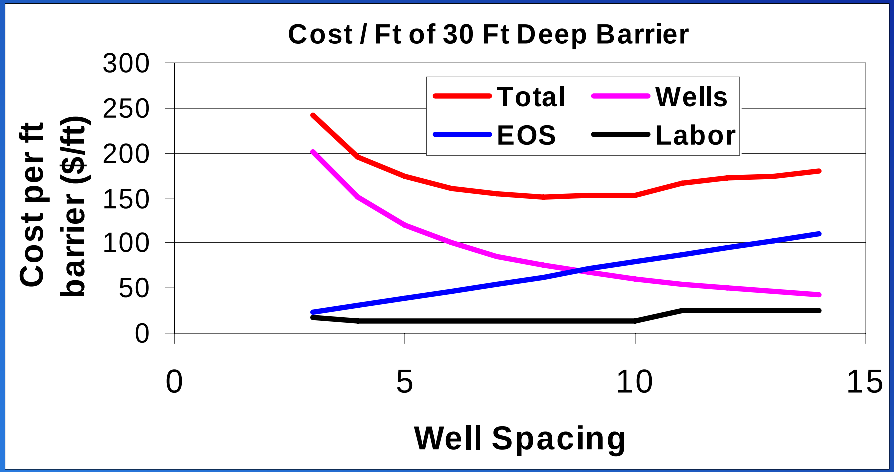
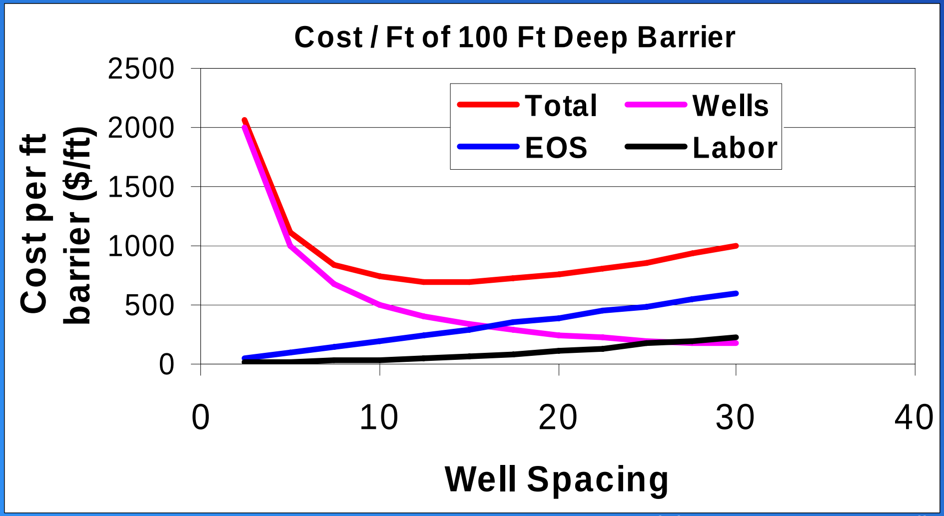
Determining Injection Well Spacing

- Tradeoff between
  - Well installation cost
  - Labor cost for injection
  - Material cost for emulsion





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Enhanced Anaerobic Bioremediation Using Emulsified Edible Oils

- *Preparing and Injecting Emulsions*

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Injection System Design Options

- **Direct-push technology**
  - **Using pressure**
- Injection wells
  - Gravity feed
  - Low pressure

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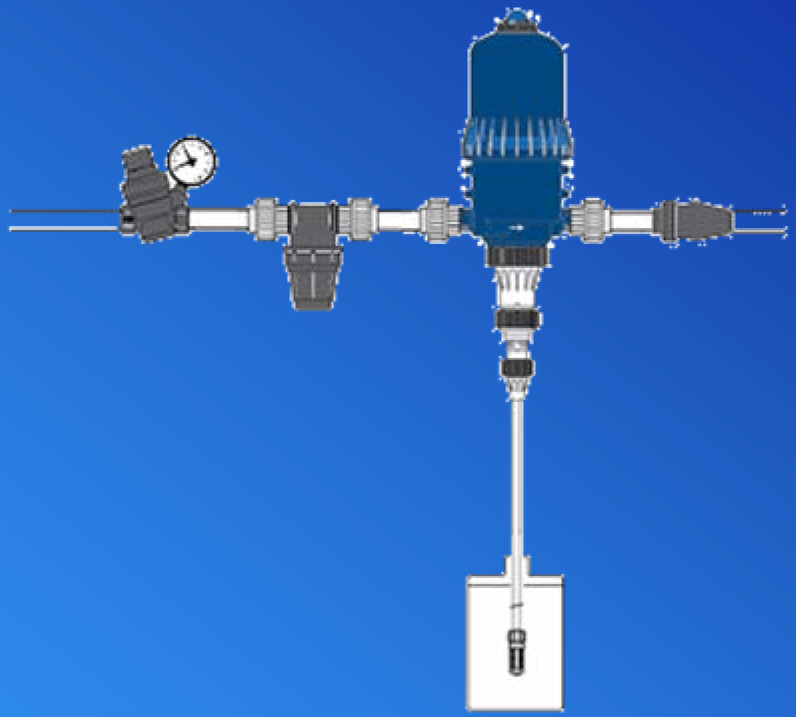
Emulsion Dilution Options

- Continuous injection of dilute emulsion without chase water
  - Dilution ratios range from 1:10 to 1:30
  - Depends on effective porosity
- **Injected 4,400 gallons of EOS mix and 22,700 gallons of chase water**
- **Chase water used to distribute emulsion out into the formation**

Emulsion Dilution

- In-line metering system
  - Eliminates labor and equipment for field blending
  - Adjustable dilution ratio

Continuous Metering System

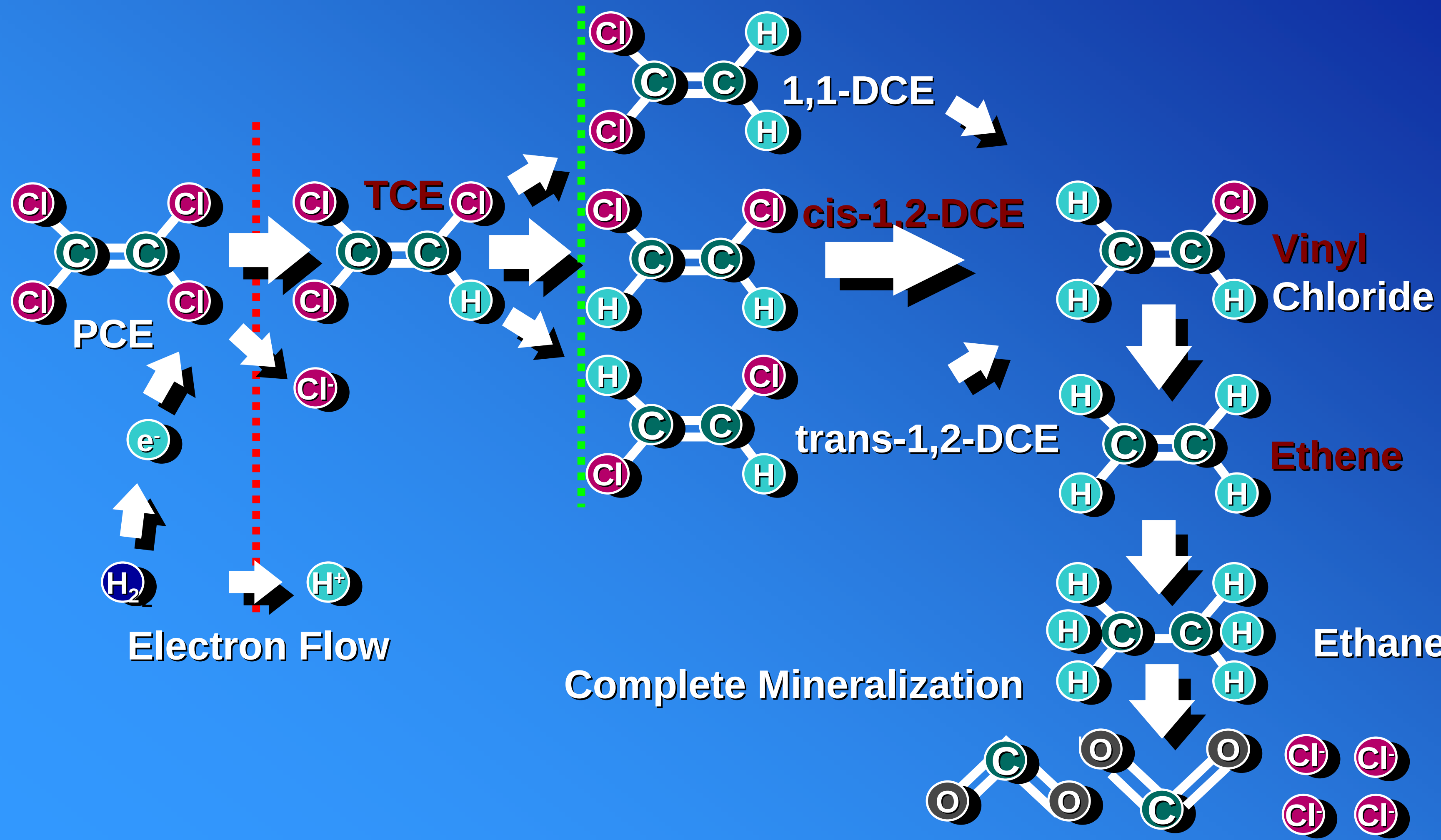


Ground Water Characterization
What to Monitor

Indicator Parameters

- Electron acceptors (O_2, NO_3, SO_4)
  - Low levels of O_2 are not a major problem
  - High levels of SO_4 increase substrate demand
- Electron donors (Mn, Fe, CH_4, TOC)
- ORP, PH
- Degradation products
- See EPA / AFCEE protocol for MNA of Chlorinated Solvents

Degradation products



(Drawing Modified from AFCEE, Technology Transfer Division)

Anaerobic Bioremediation of Chlorinated Solvents in Groundwater Using Edible Oil Substrate EOS®

- *Results*

PLUME OF THE MAJOR CONTAMINANTS
Pre-Injection (injection April 2005)

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PLUME OF THE MAJOR CONTAMINANTS
6-months post-injection

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PLUME OF THE MAJOR CONTAMINANTS
9-months post-injection

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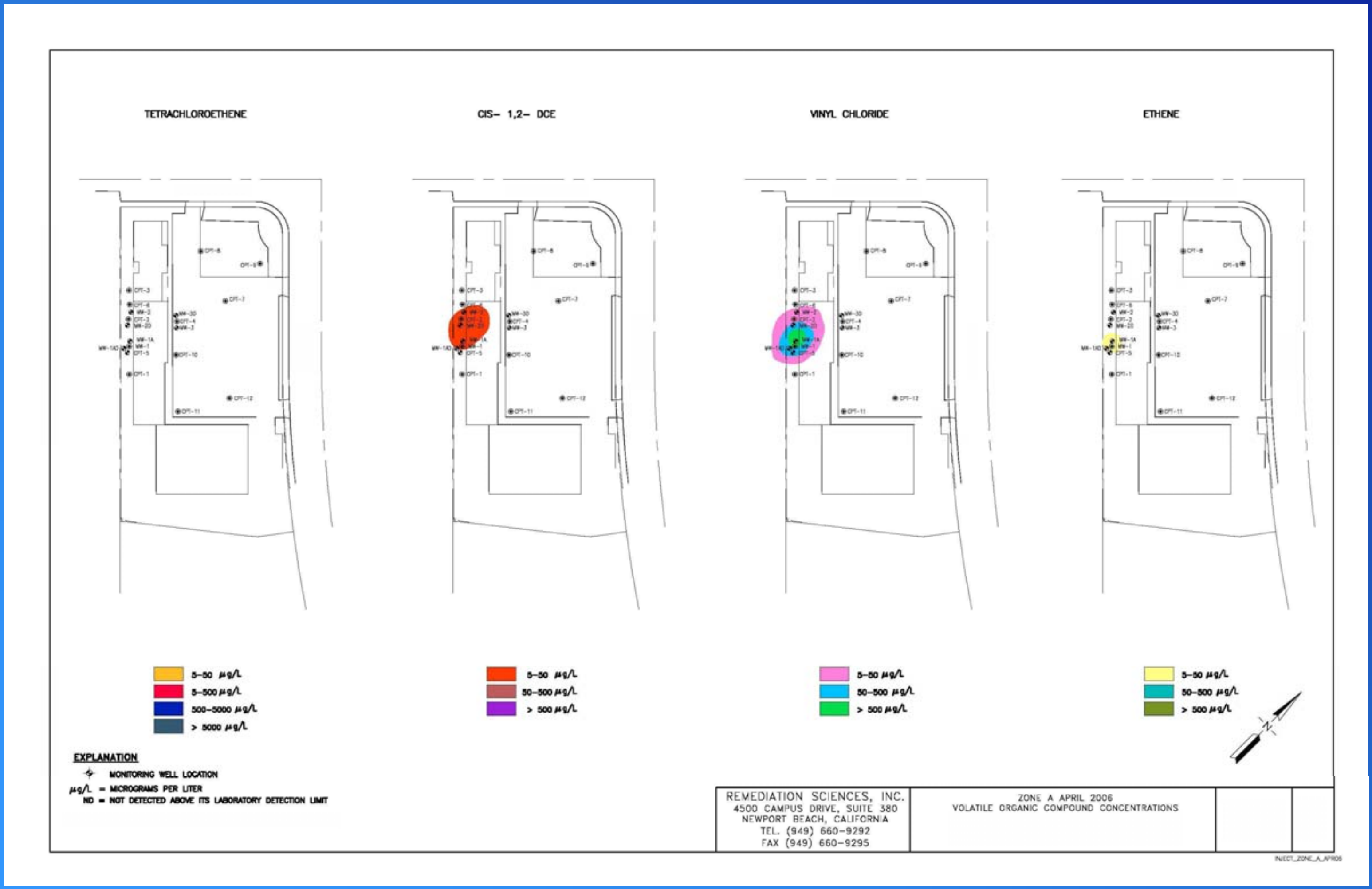
PLUME OF THE MAJOR CONTAMINANTS
12-months post-injection



PLUME OF THE MAJOR CONTAMINANTS
15-months post-injection

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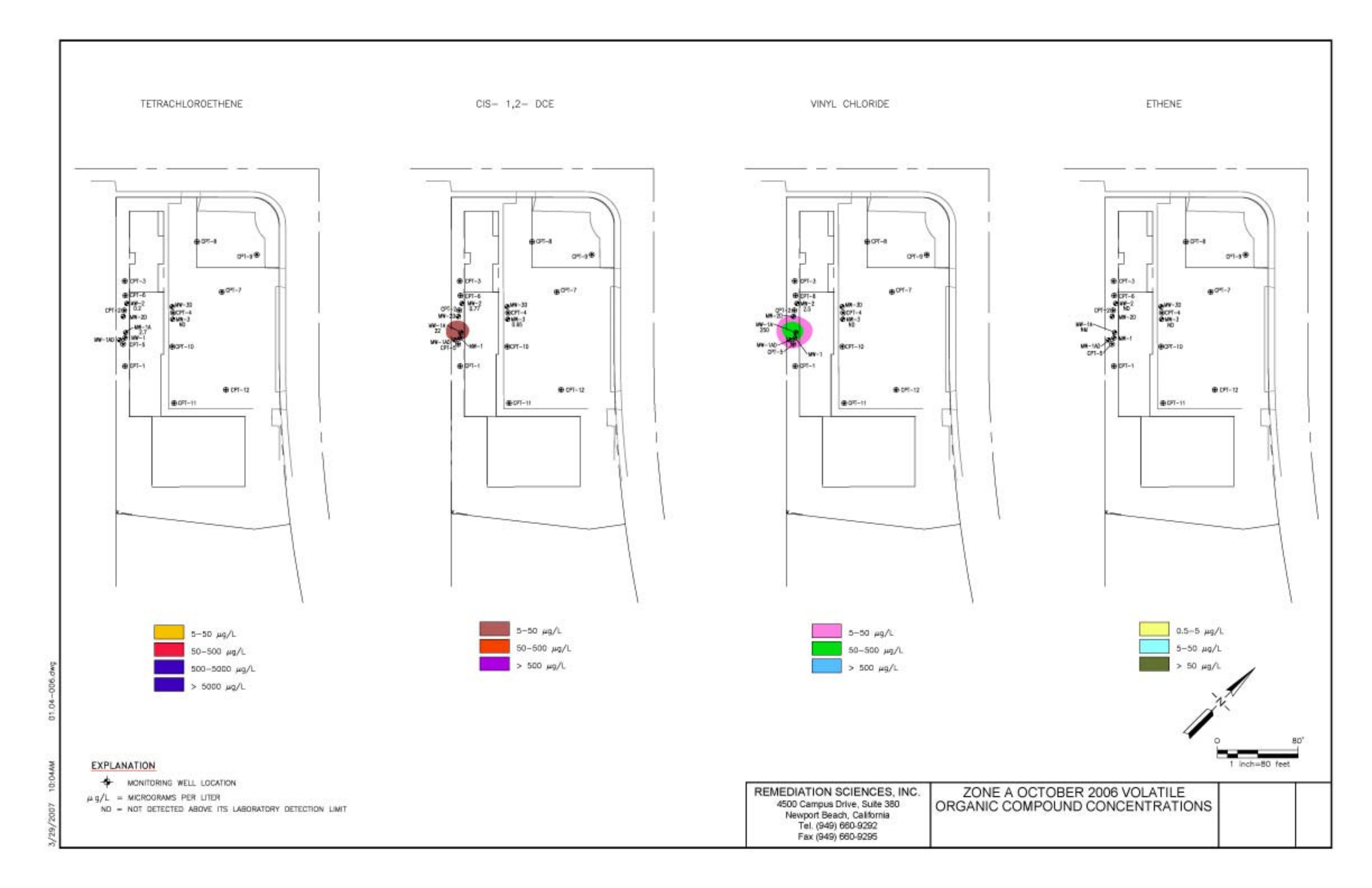
PLUME OF THE MAJOR CONTAMINANTS
18-months post-injection



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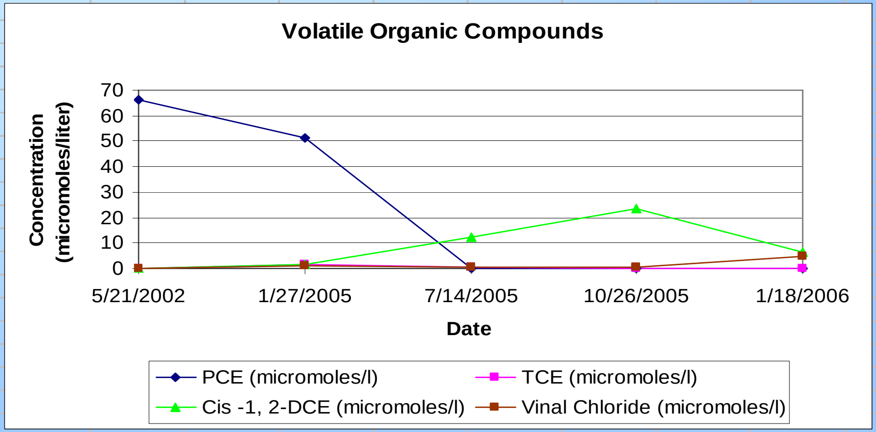
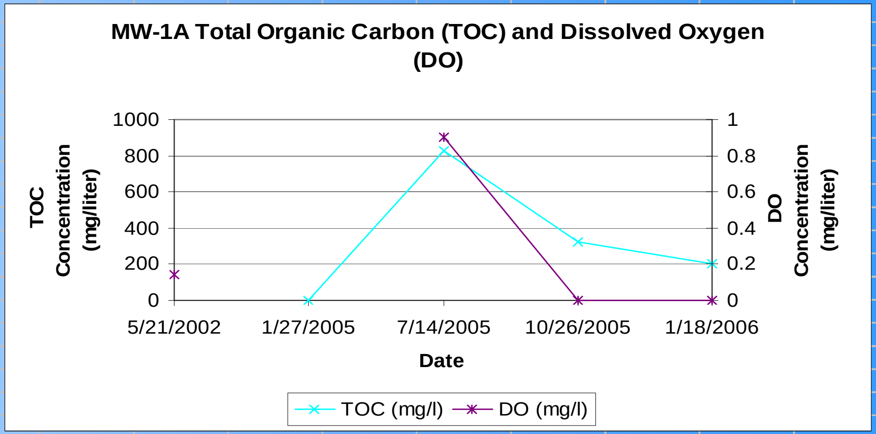
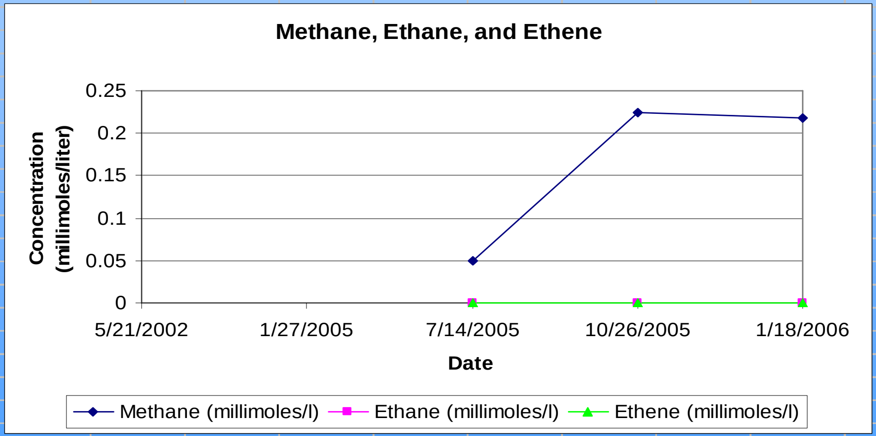
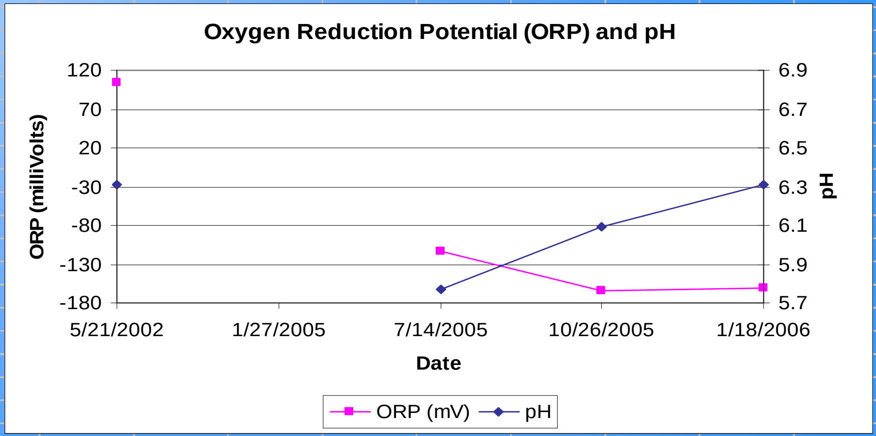
RESULTS: CHART 1: MW-1A ANALYTICAL RESULTS VERSES TIME









Project Conclusions

- EOS® effectively distributed throughout treatment area
- Quickly established favorable geochemistry for reductive dechlorination.
- Dramatic improvements in groundwater conditions compared to prior technologies
- Substantial reductions in TCE observed.
- Apply for decrease monitoring to every 6 months.
- Apply for closure this year.

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I would like to thank:

Matt Sedor, M.S., Yonathon Yoseph, P.G., C.H.G. (Remediation Sciences, Inc.)

Jeff Baker (Vironex, Inc.)

Robert C. Borden and Christie Zawtocki, Michael D. Lee, Erica S Becvar, Patrick E. Haas, Bruce M. Henry, AFCEE Protocol For Enhanced Anaerobic Bioremediation Using Edible Oils

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For More Information

Contact John Sankey, P.Eng

- **jsankey@telus.net or (604) 562-7836**

Visit www.eosremediation.com

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- Complete Product Line
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    - **EOS ®**, emulsified soybean oil, for enhanced in situ bioremediation
    - **BAC 9,** microbes for bioaugmentation
  - **Petroleum Site Cleanup Remediation**
    - **EOx™,** a calcium-based oxygen releasing substrate for aerobic bioremediation

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