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

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From this…

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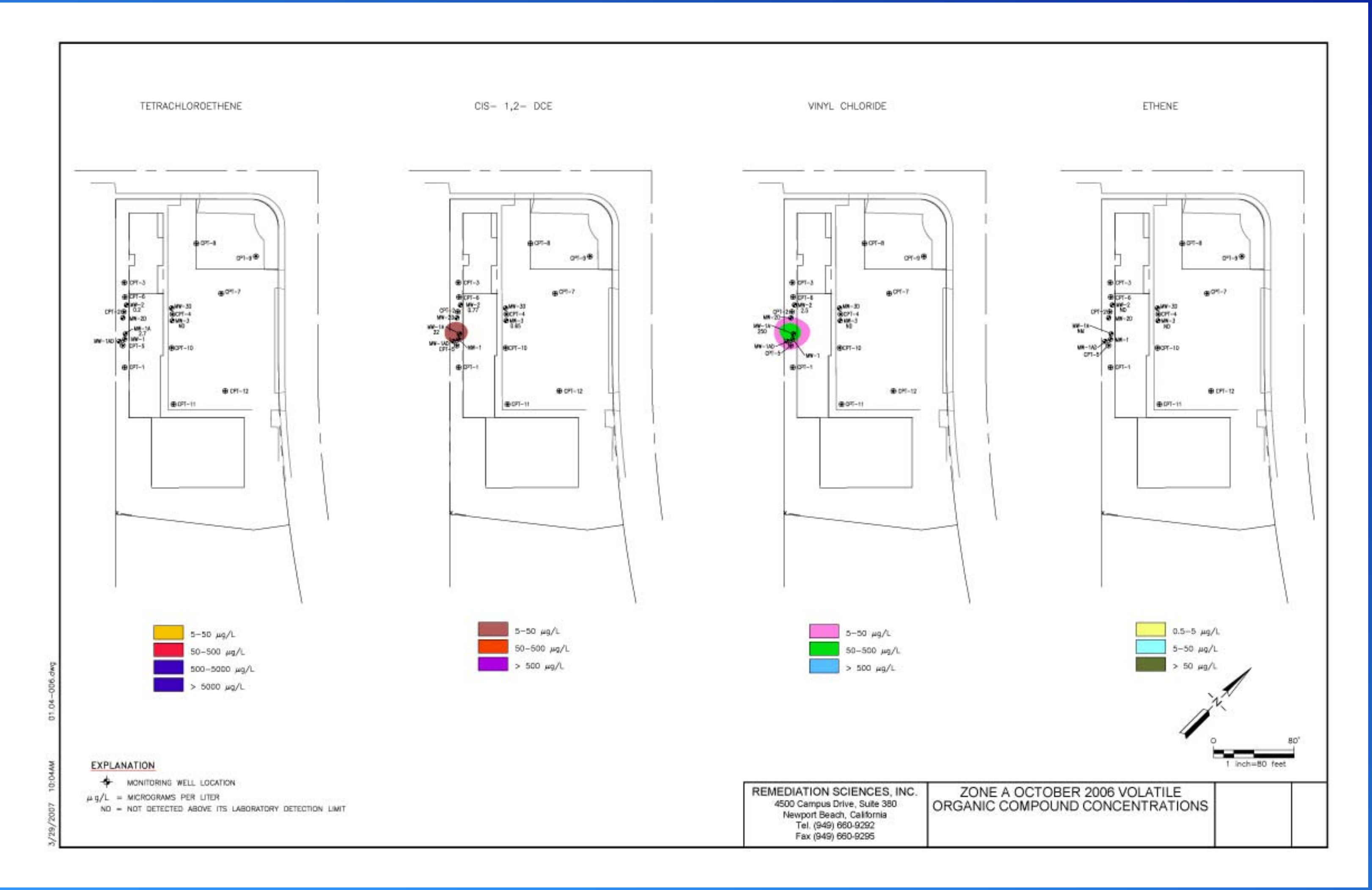
...to this in 18 months!



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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?

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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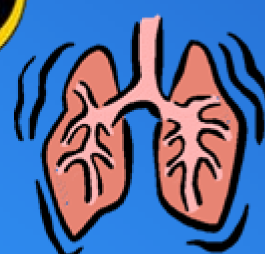
How Does Anaerobic Bio Work?

- **Growth-Promoting Biological Reduction**

Electron Donor (Food)

+



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

→

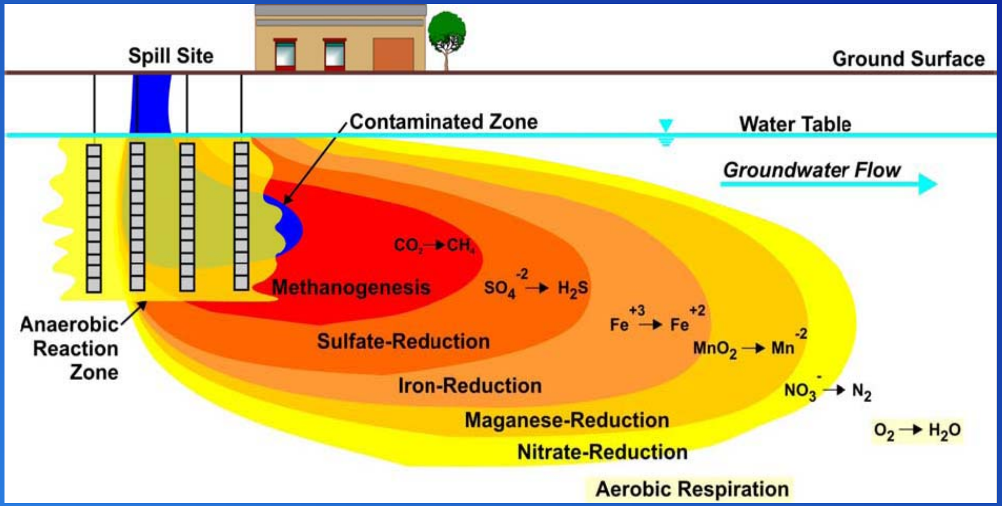
Waste Products [CO_2, N_2, FeS_2, Cl^-]

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:

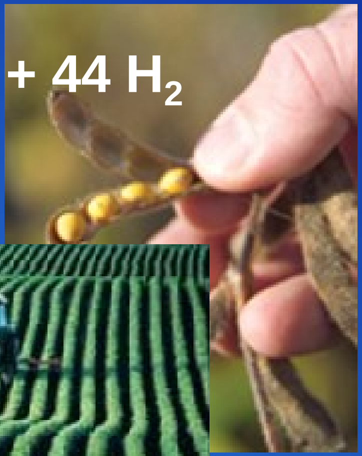
What quickly ferments to hydro?

- 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.

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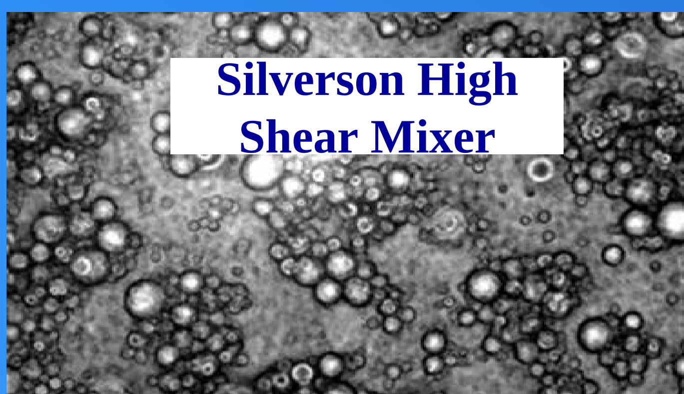
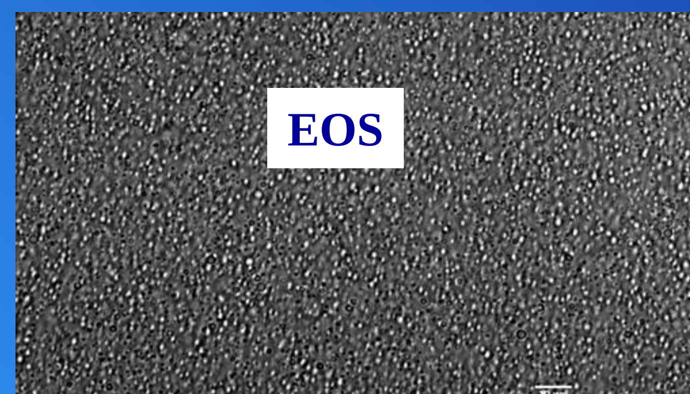
How Many Electrons Can We Pump into the Ground?

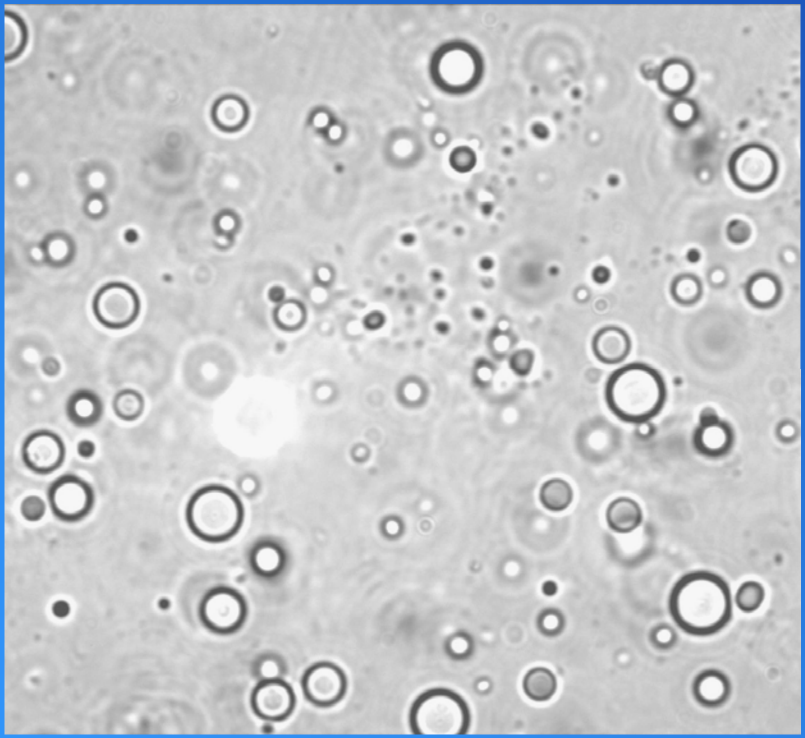
	e^- Released	
	per mole	per lb
Acetate	8	0.13
Lactate	**12**	**0.13**
Glucose	24	0.13
Soybean Oil	**313**	**0.36**
Canola Oil	319	0.36
Lard	311	0.36

Soy/Lactate Emulsions

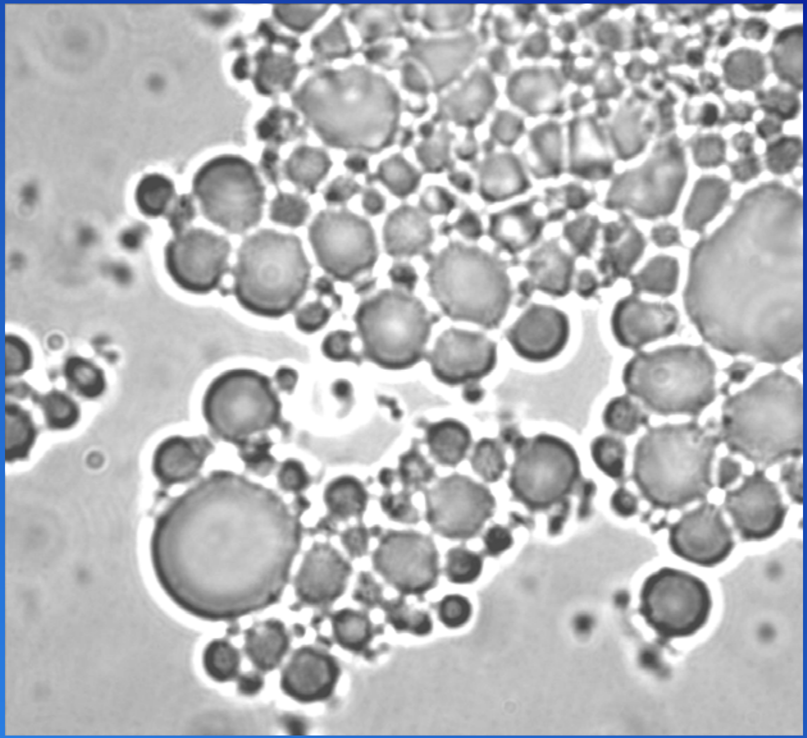




The Secret of Good Oil Distribution “Emulsions that do NOT Flocculate”



Dispersed Oil Droplets



Flocculated Oil Droplets

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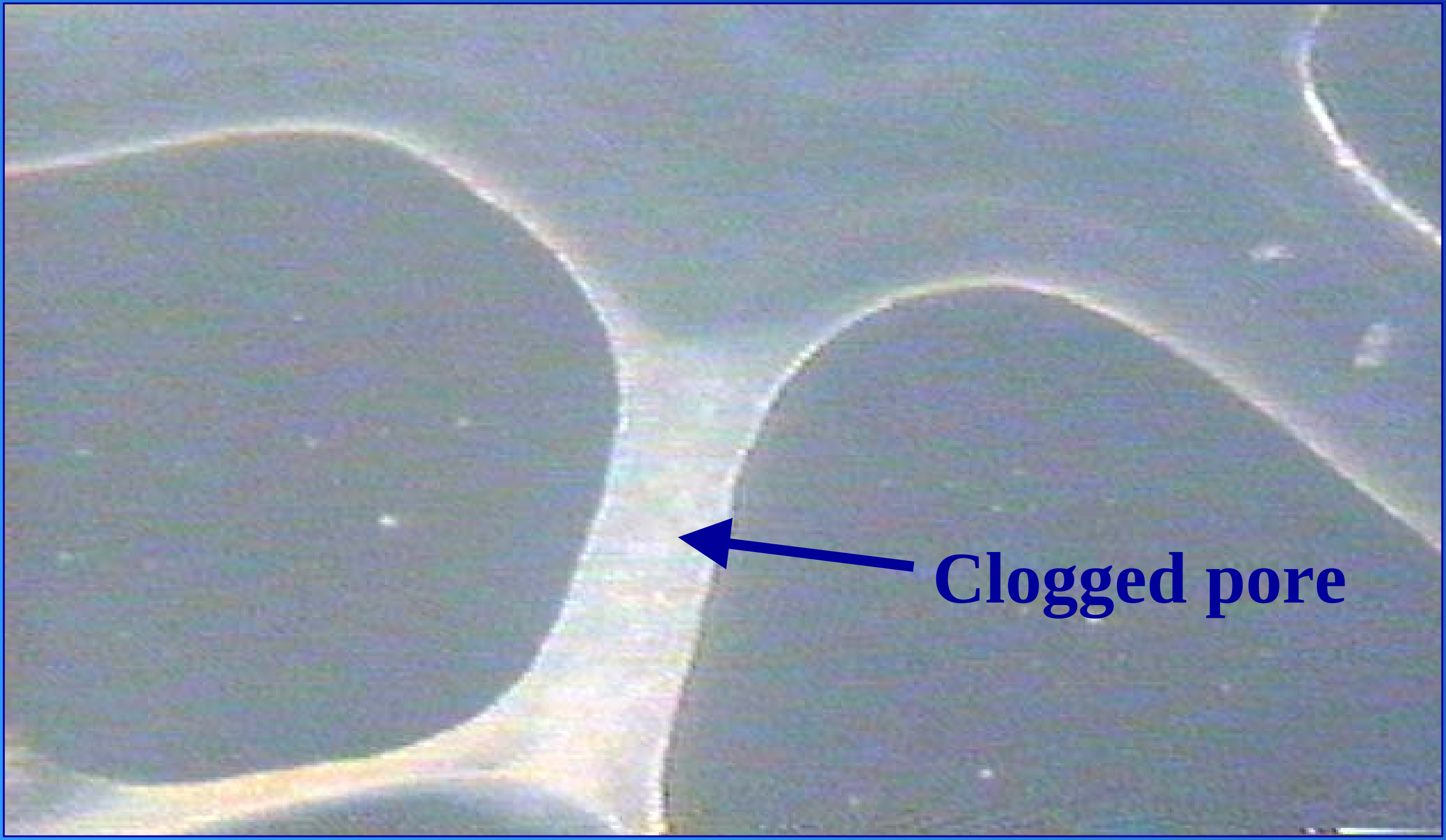
Secrets of Good Emulsion Distribution "Use Emulsions that do NOT Flocculate"



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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

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Designing the Injection at The Dry Cleaner Site

“You need to make contact…with the contaminant

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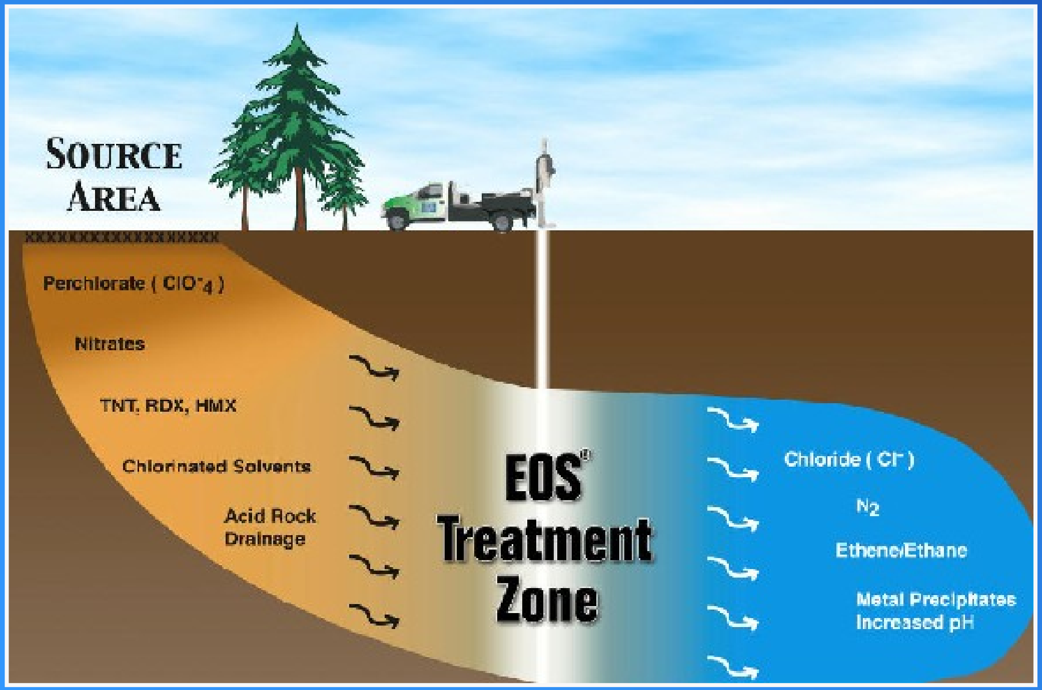
Radius of Influence?

10ft to 100ft with EOS



From This

…..To This

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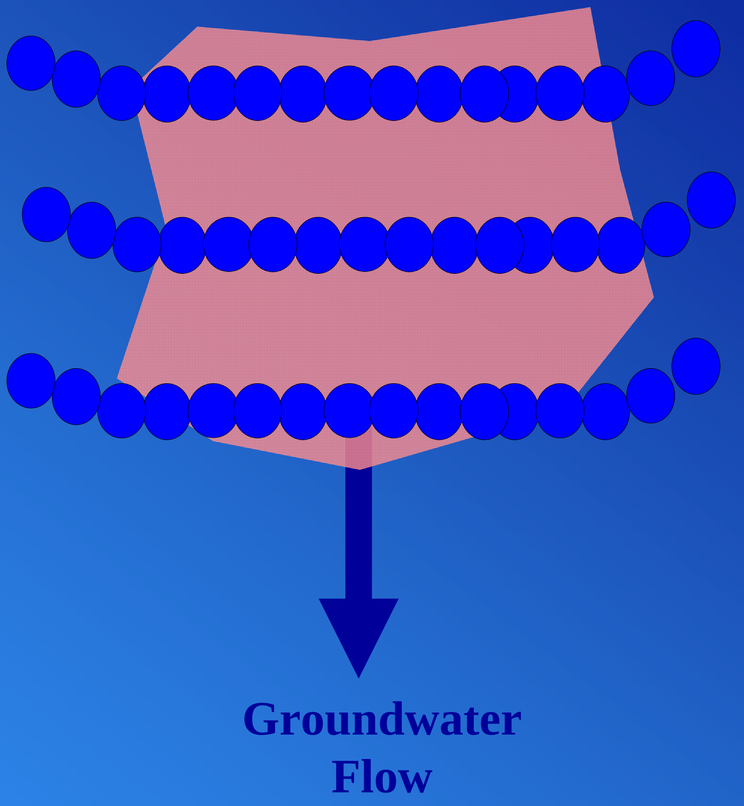
Source Treatment with Barriers

- 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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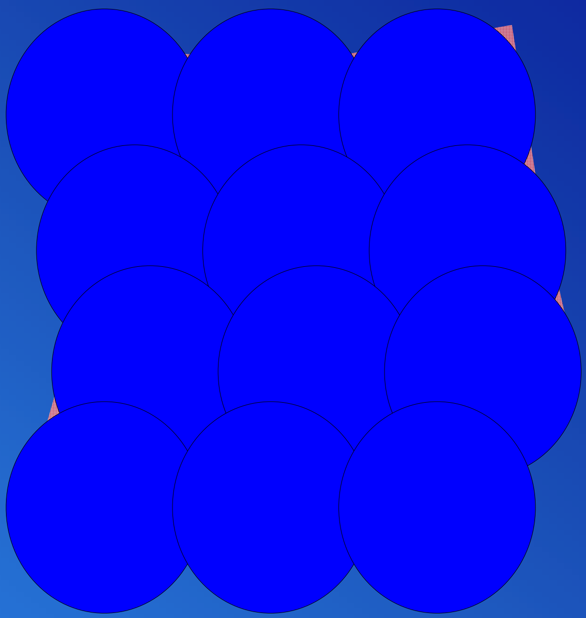
Source Area Treatment



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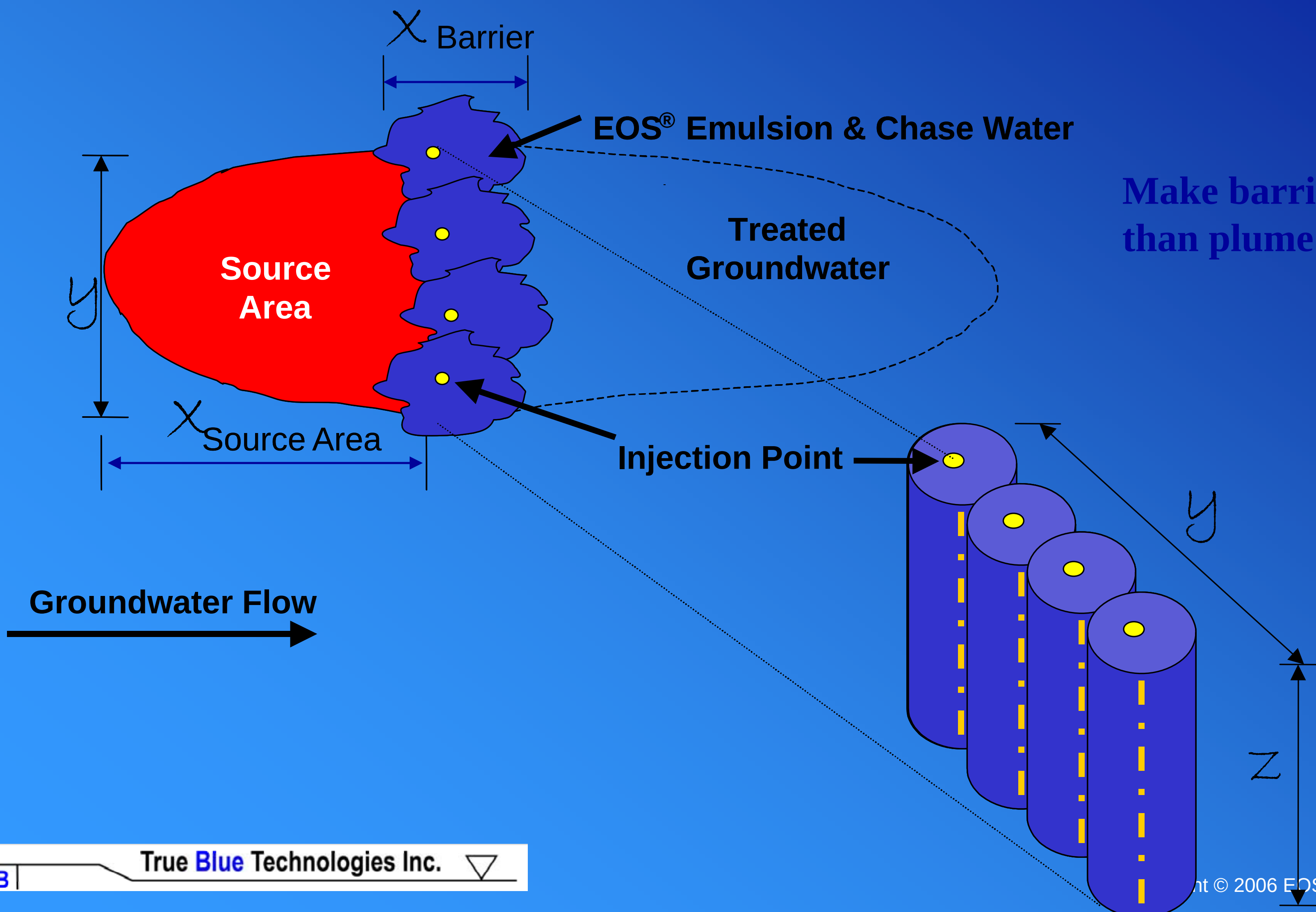
- *How much do we inject?*

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

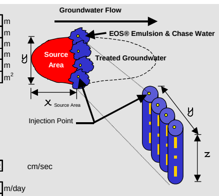
EOS Remediation, Inc.

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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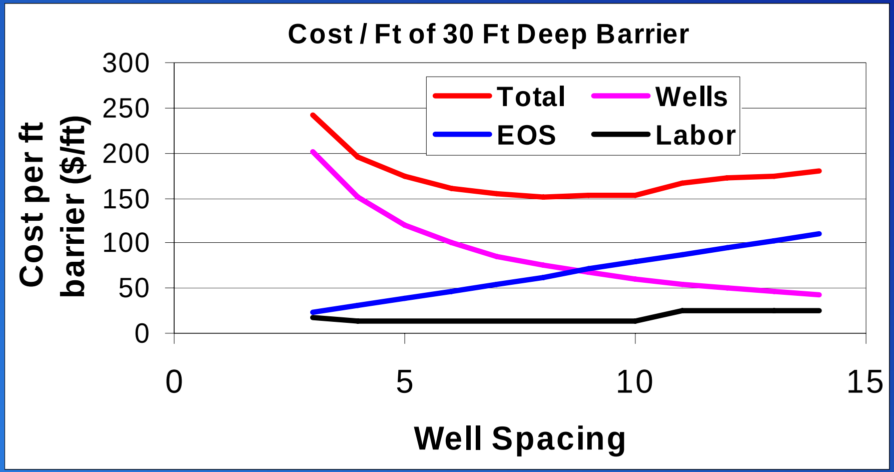
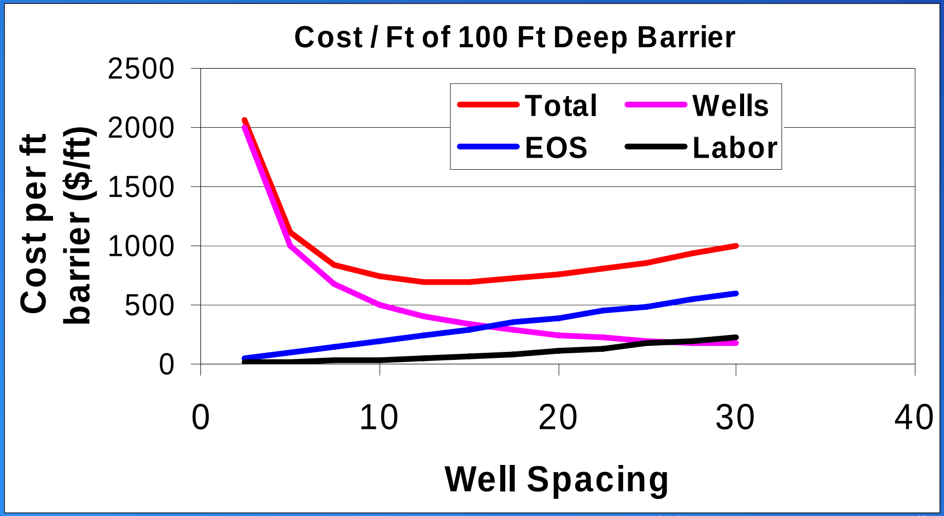
Determining Injection Well Spacing

- 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*

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**

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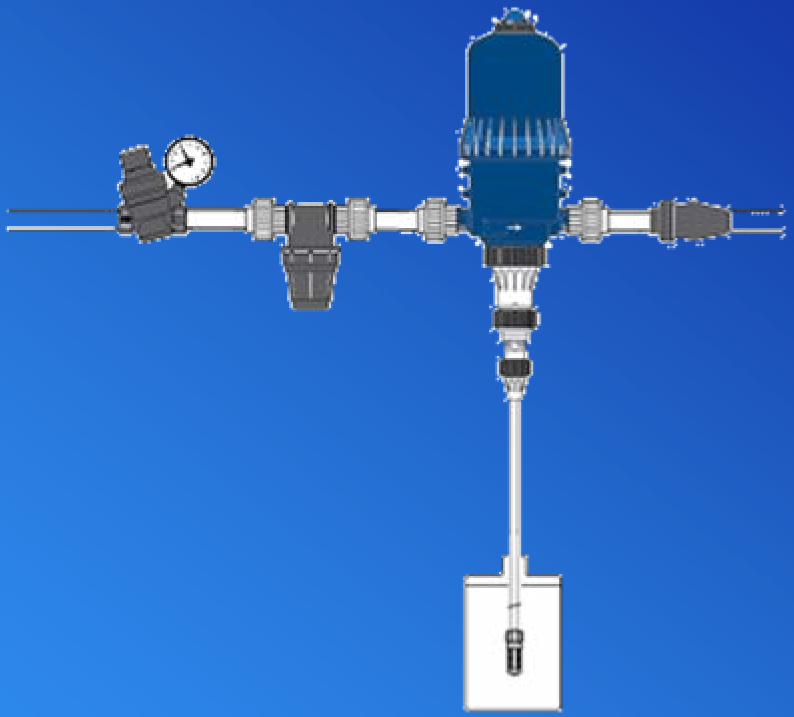
Emulsion Dilution

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

Continuous Metering System



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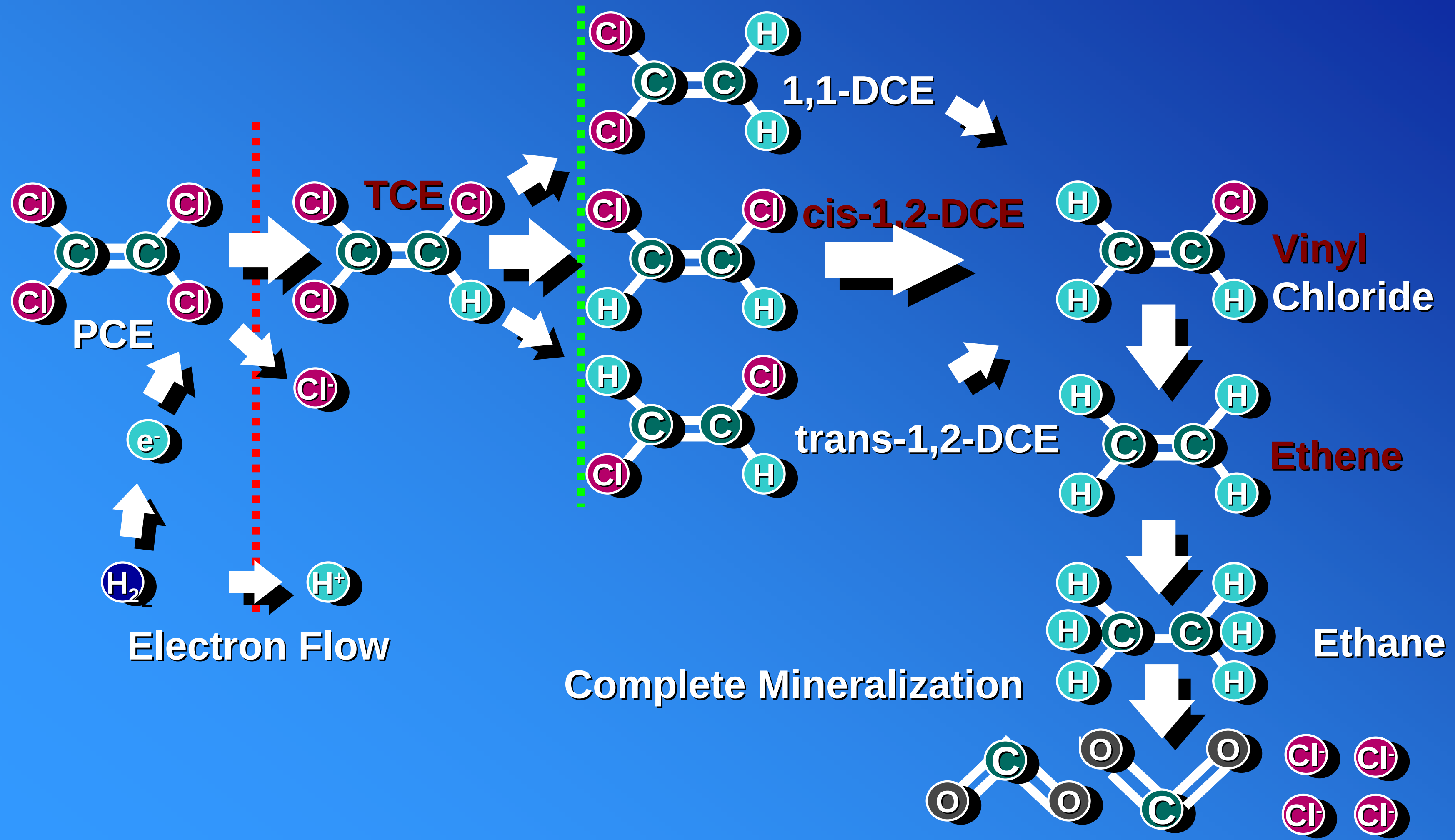
Ground Water Characterization
What to Monitor

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*

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

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

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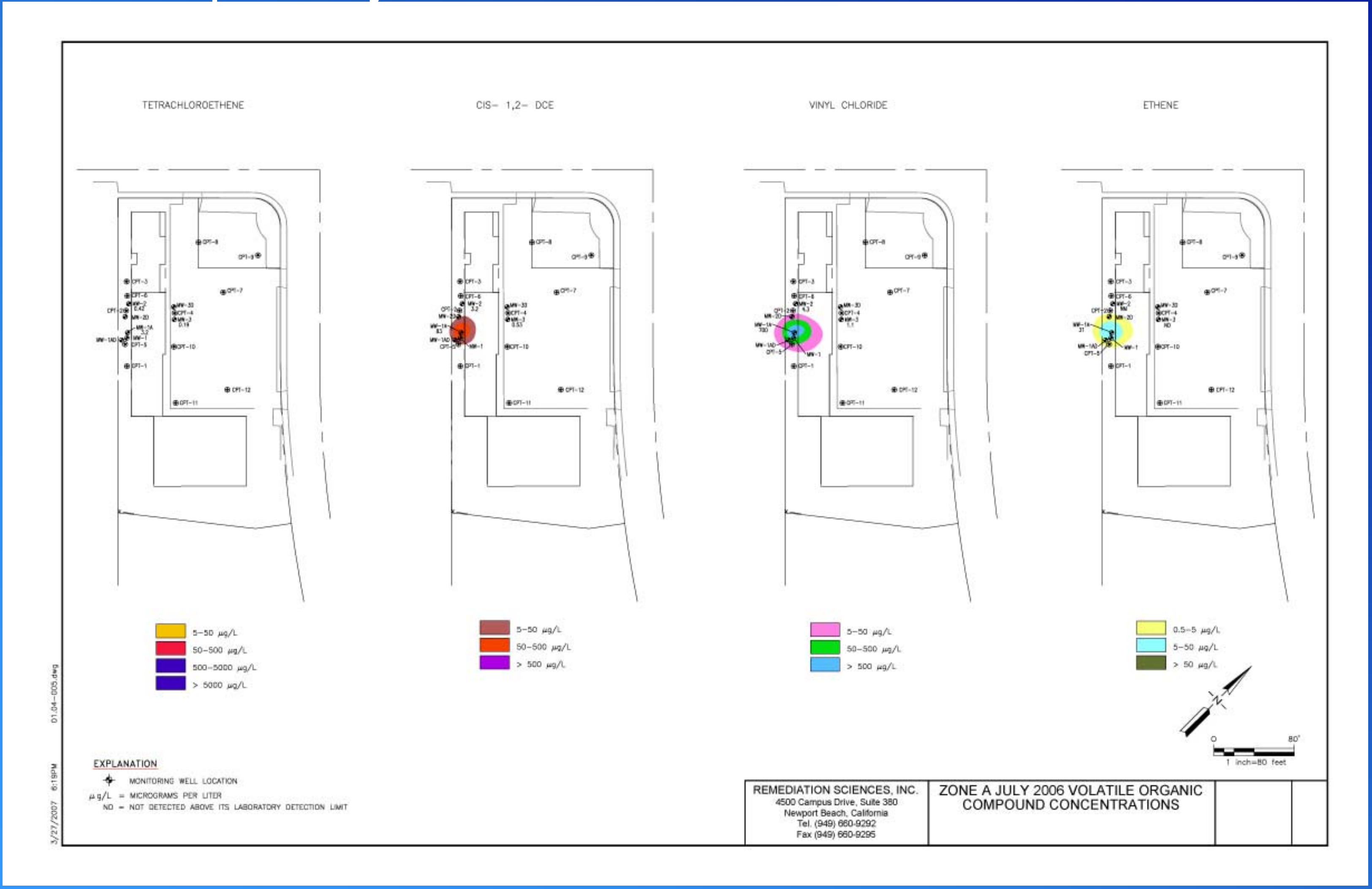
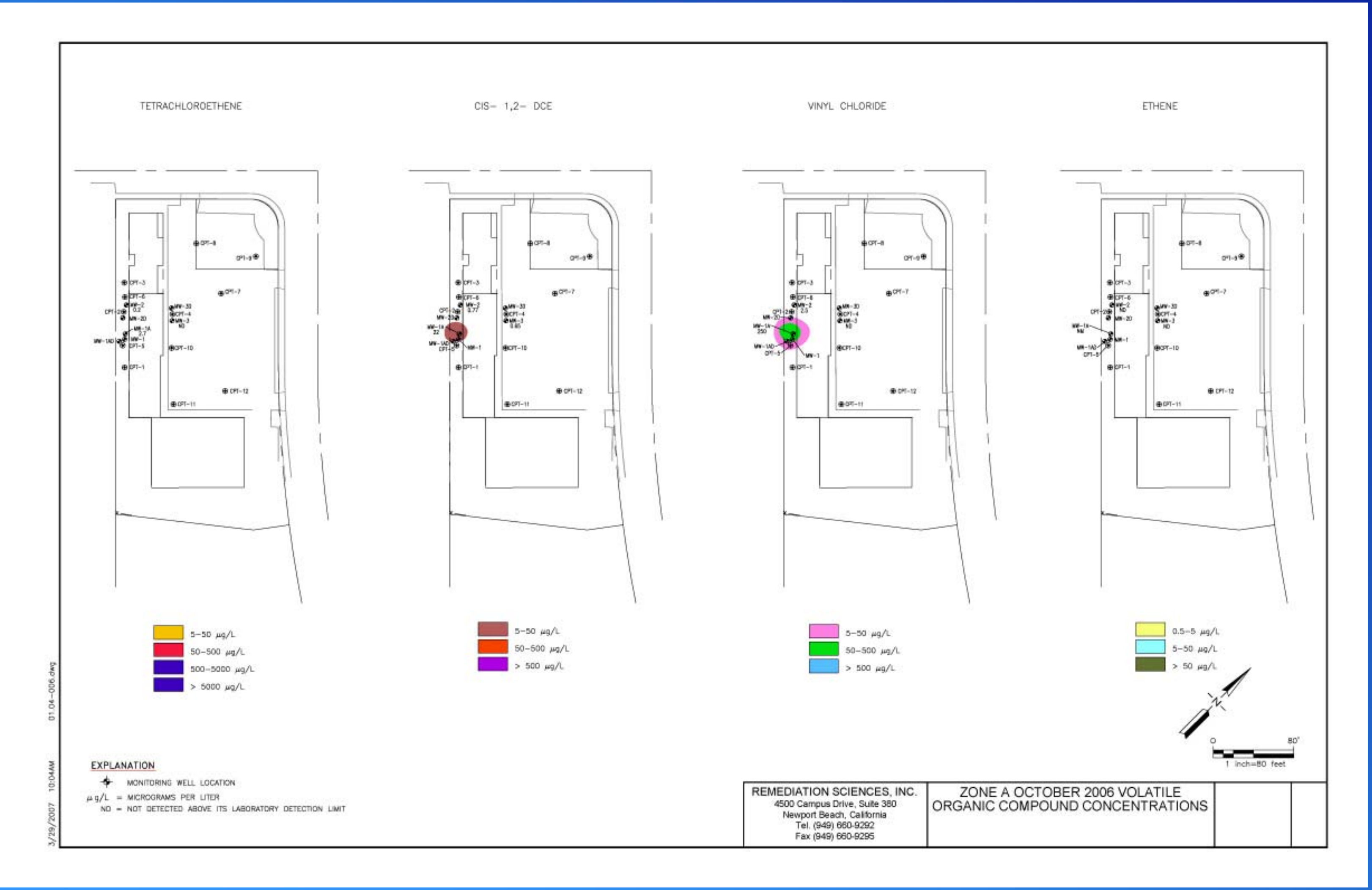
PLUME OF THE MAJOR CONTAMINANTS
15-months post-injection



PLUME OF THE MAJOR CONTAMINANTS
18-months post-injection



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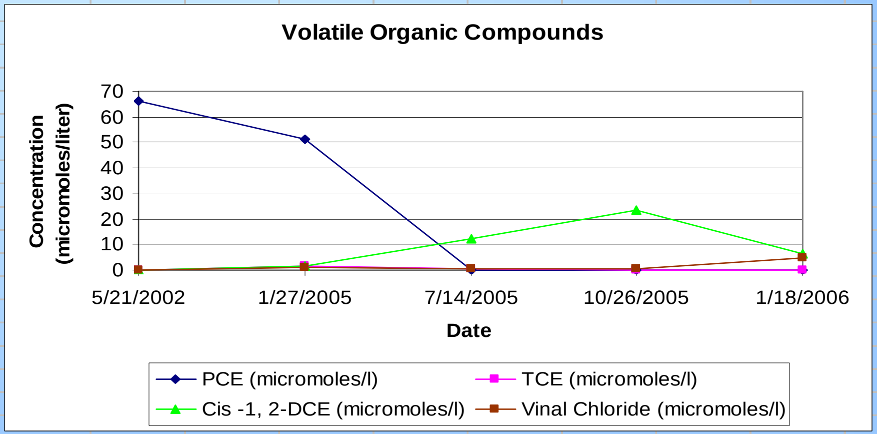
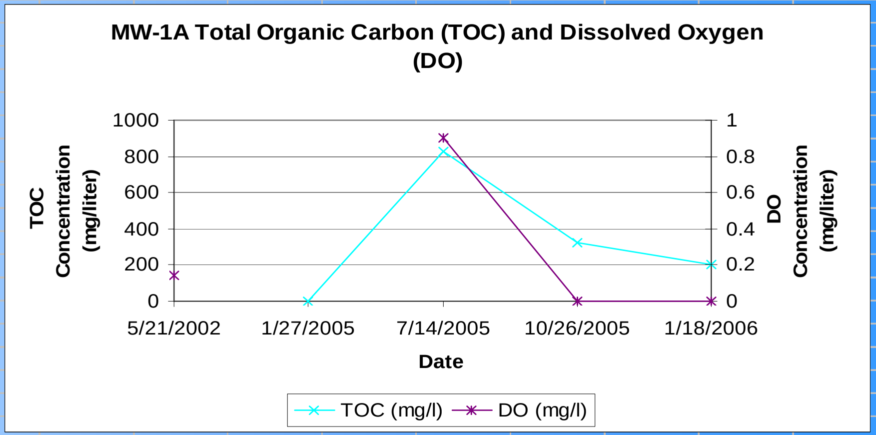
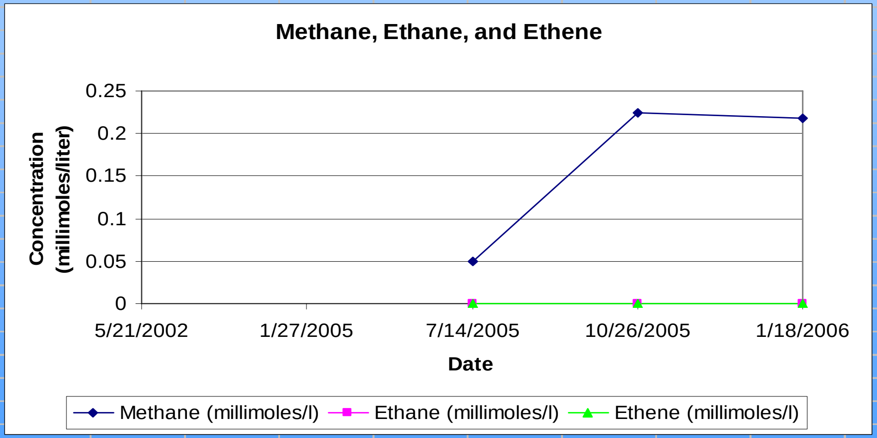
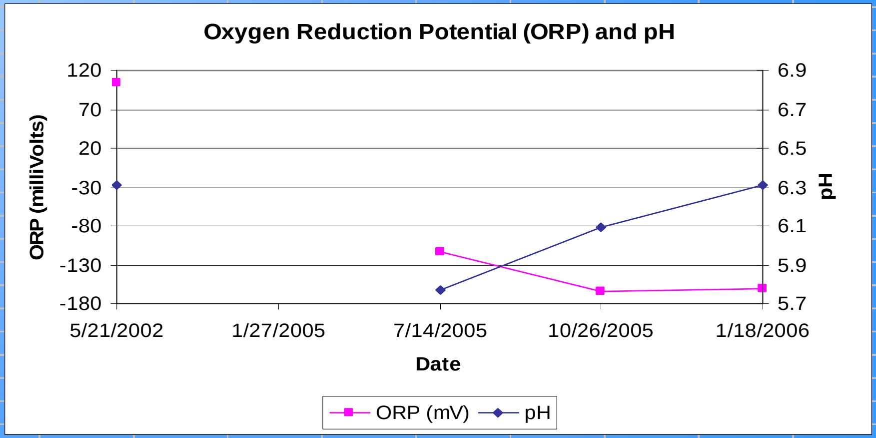
RESULTS: CHART 1: MW-1A ANALYTICAL RESULTS VERSES TIME









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

For More Information

Contact John Sankey, P.Eng

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

Visit www.eosremediation.com

- Design Tool, Case Studies
- Complete Product Line
  - **Chlorinated Solvent Site Remediation**
    - **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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