

EOS Remediation

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Accelerated Site Cleanup Using a
Sulfate-Enhanced *In Situ*
Remediation Strategy

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YOUR NATURAL SOLUTIONS

Patented Methods for *In Situ* Bioremediation

Soil & Groundwater Bioremediation Products

Category	Product Name	Target Contaminants
Biostimulation (Anaerobic)	AquaBupH® EOS® EVO™ EQR™ <i>(under development)</i> VOS™ <i>(under development)</i>	Chlorinated Solvents Perchlorate Chromate Explosives Radionuclides Acid Mine Drainage
	EAS™	Petroleum Hydrocarbons
Biostimulation (Aerobic)	EOx™	Petroleum Hydrocarbons
Bioaugmentation	BAC-9™	Chlorinated Solvents
	ENV-TCA20™	Chlorinated Alkanes
	PJKS-1™	Chlorinated Solvents

Presentation Overview

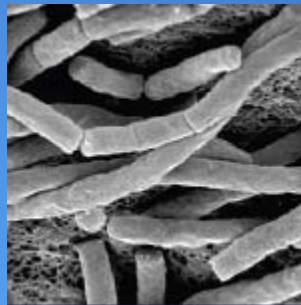
- Introduction to Bioremediation
- What is EAS™?
- Why add sulfate?
- What contaminants can be addressed?
- Case Study
- Conclusion

In Situ Bioremediation

In Situ
↓
In Place

Bio
↓
Microbial

Remediation
↓
Method to Fix

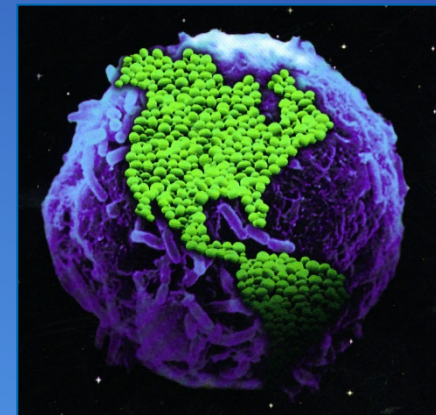


Microorganisms are used to Clean up Pollution
in the Environment

Microbial World: The unseen majority

- ~20,000 strains/species of bacteria in 1g topsoil
- Bacteria in 5g topsoil = ~total human population of Earth
- Total bacterial population of Earth = $\sim 5 \times 10^{30}$ cells
- **>90% of bacteria are in the subsurface below 30 feet**

Ref : Whitman et al. (1998) Proc. Nat Acad. Sci. USA 95: 6578-6583



How Does It Work?

- How does *in situ* bioremediation clean up pollution?
 - Soil microbes are remarkably versatile!
 - They eat (electron donor) and breathe (electron acceptor) many types of organic and inorganic chemicals to generate energy to live.
 - (Gasoline, oil, chromium, iron, solvents, perchlorate, nitrate, ammonia, MTBE, etc)
- They live in complex communities capable of degrading contaminants by “bucket brigade”.

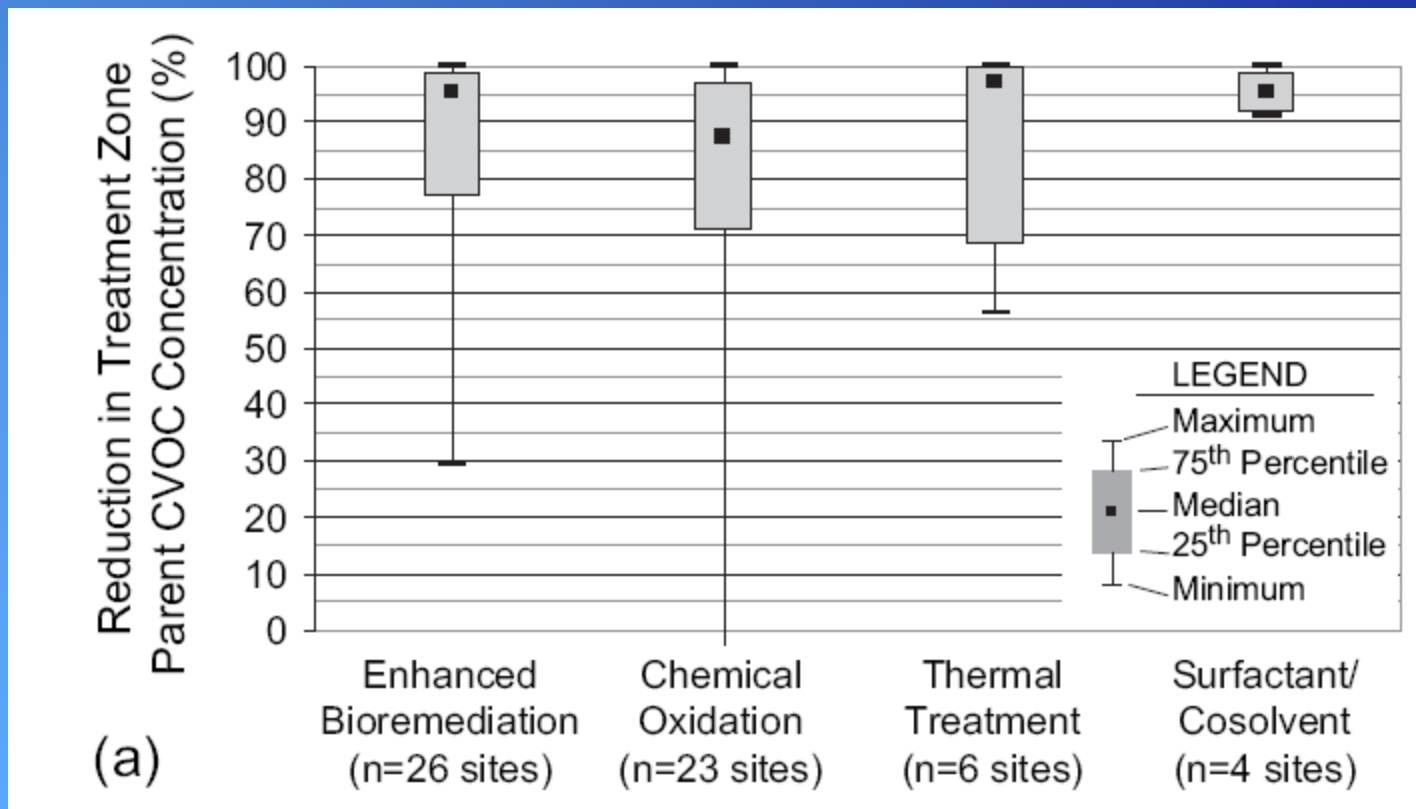


Applying *In Situ* Bioremediation

- Natural Attenuation – biotransformation occurs naturally: indigenous microbes present, substrates & nutrients present (can be MNA)
- Biostimulation - indigenous microbes present, substrates &/or nutrients must be added
- Bioaugmentation – indigenous microbes not present, organisms are added

Why Bioremediation?

Remedial Performance and Cost



\$29/yd³

\$125/yd³

\$88/yd³

\$385/yd³



From:

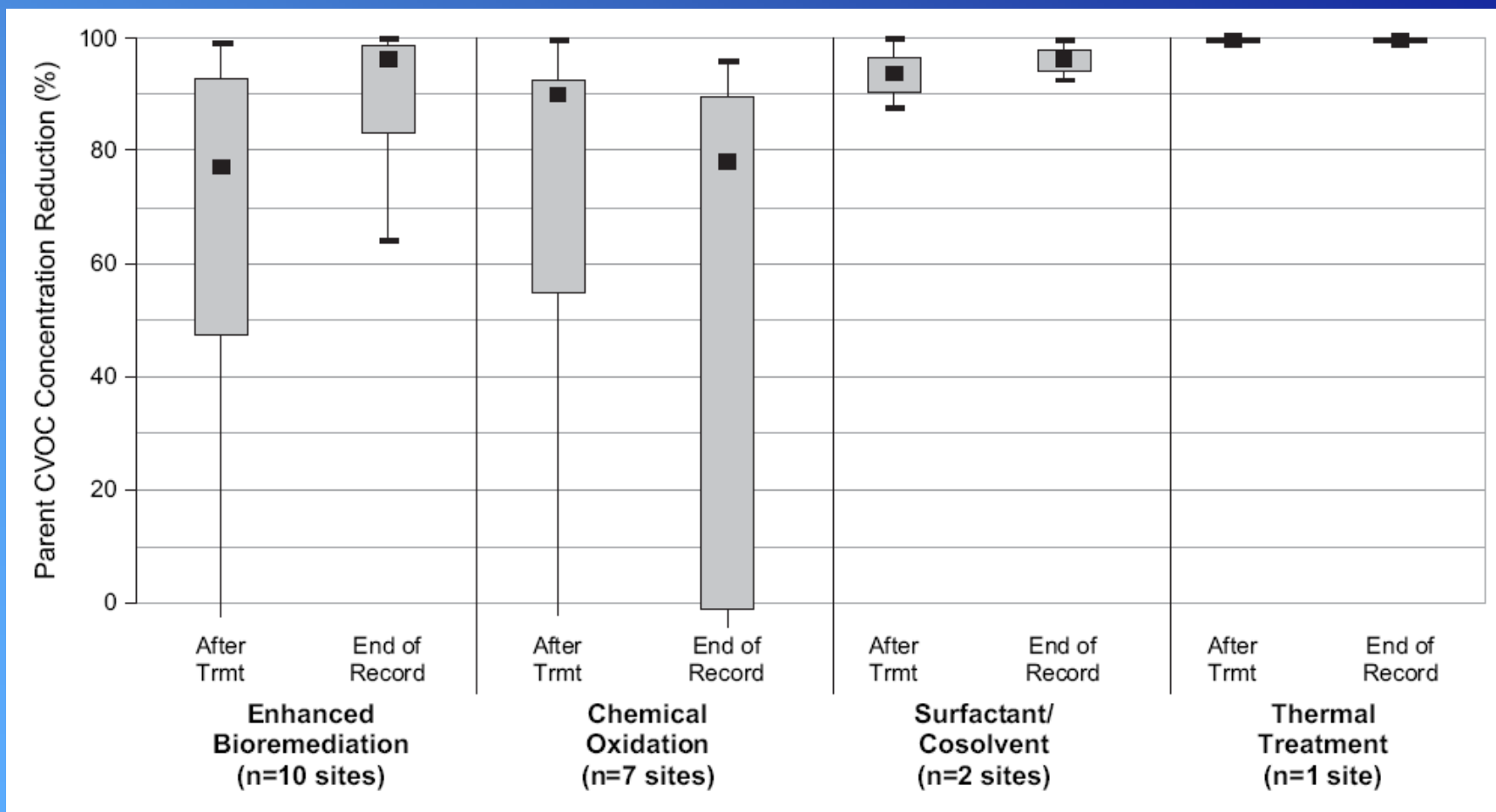
McDade et al, *Remediation Journal* 15, 9-18, 2005.

McGuire et al, *Ground Water Monitoring and Remediation* 26, 73-84, 2006.

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Contaminant Rebound



From: McGuire et al, Ground Water Monitoring and Remediation 26, 73–84, 2006.

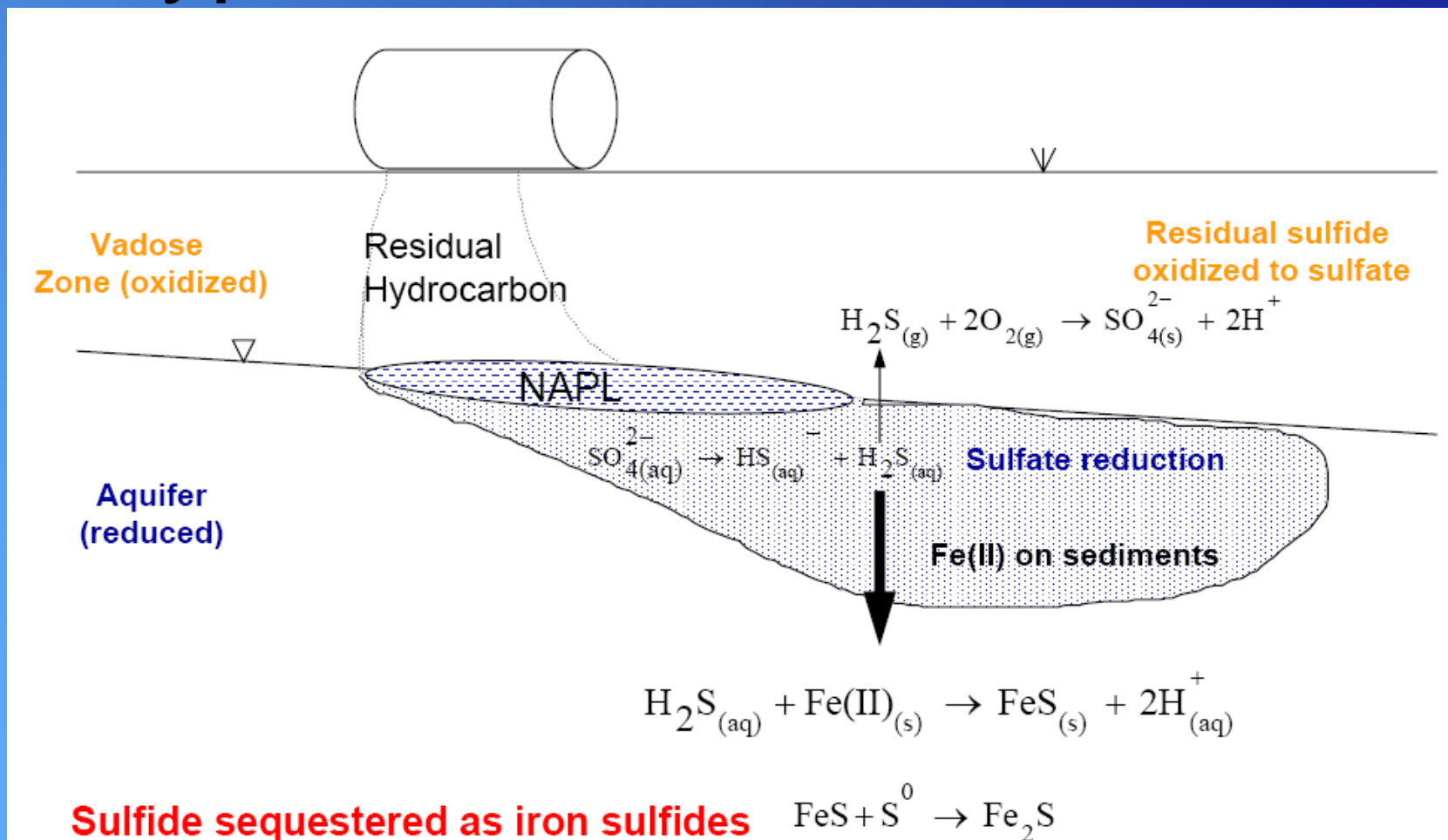
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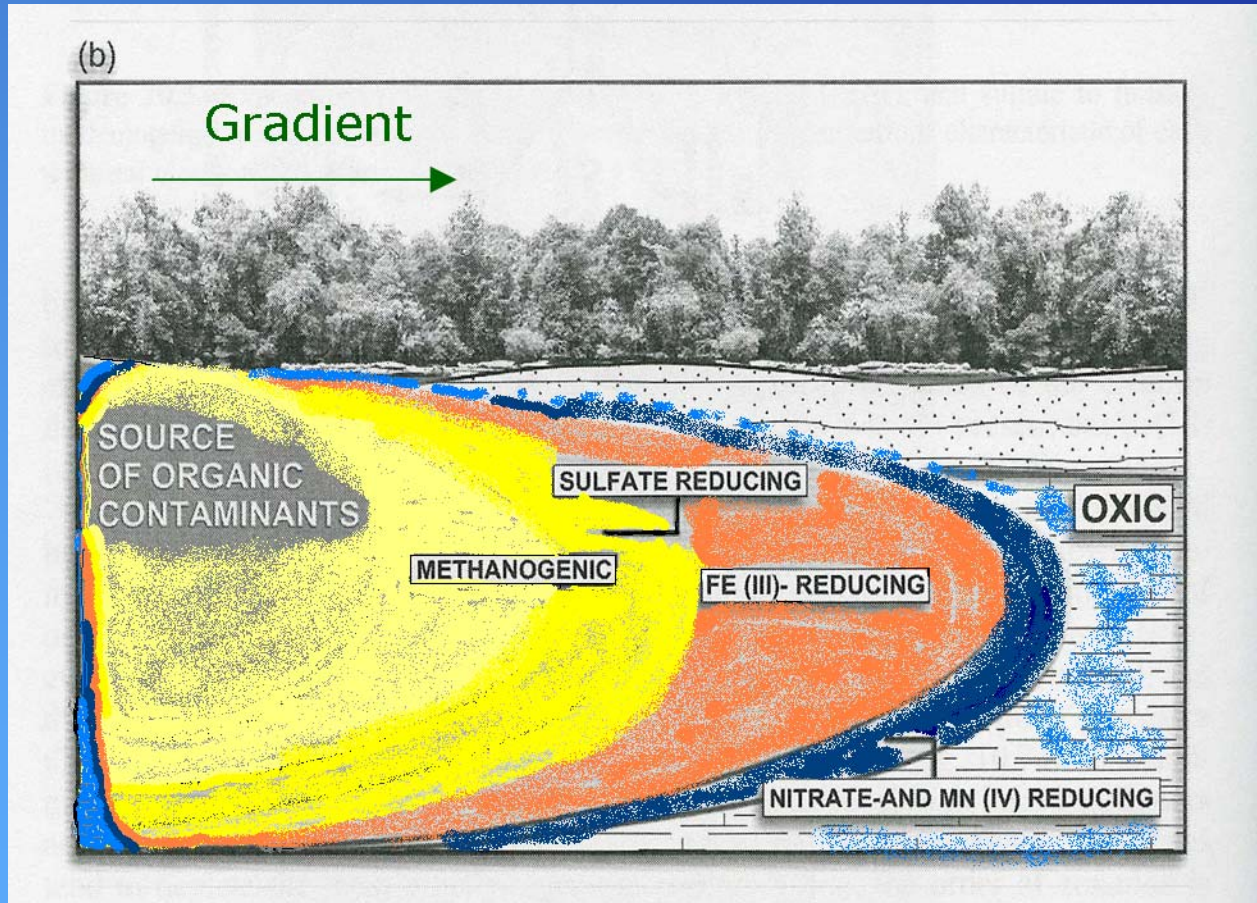
What is EAS?

- Electron Aceptor Solution
- A soluble product for anaerobic biodegradation of petroleum hydrocarbon
- Stimulates microbial growth
- Patented Process (US Patent No. 7,138,060)

Typical Petroleum Release

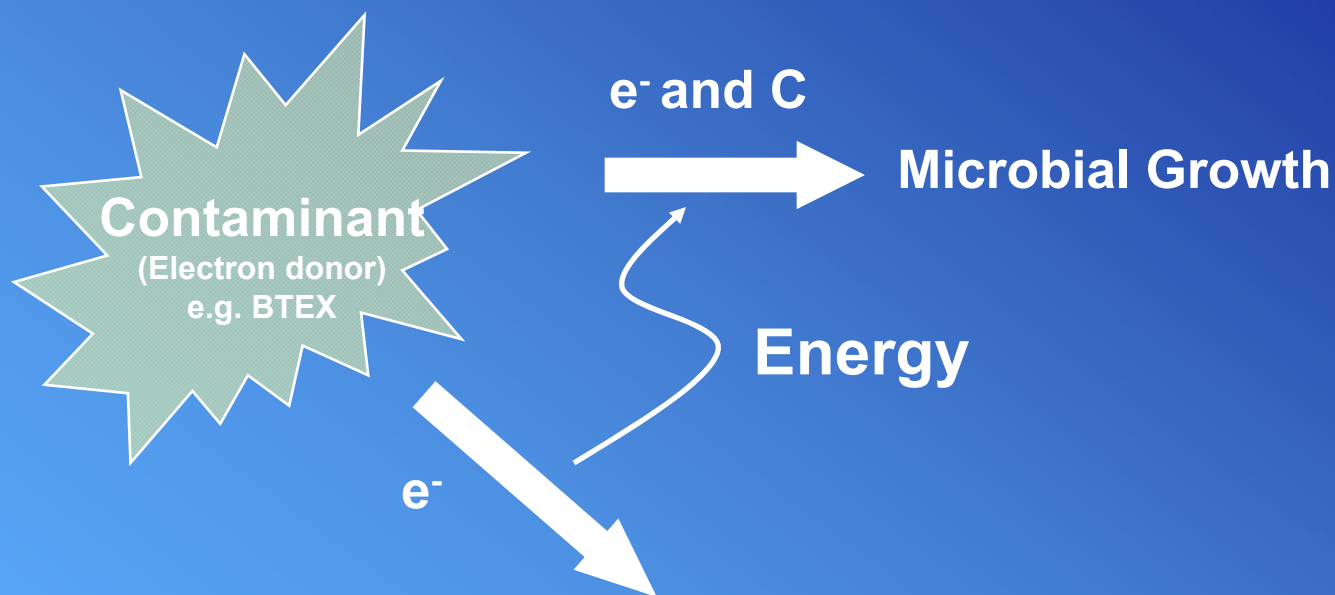


Hydrocarbon Impacted Aquifers



After Chapelle (2001)

Hydrocarbon Biodegradation



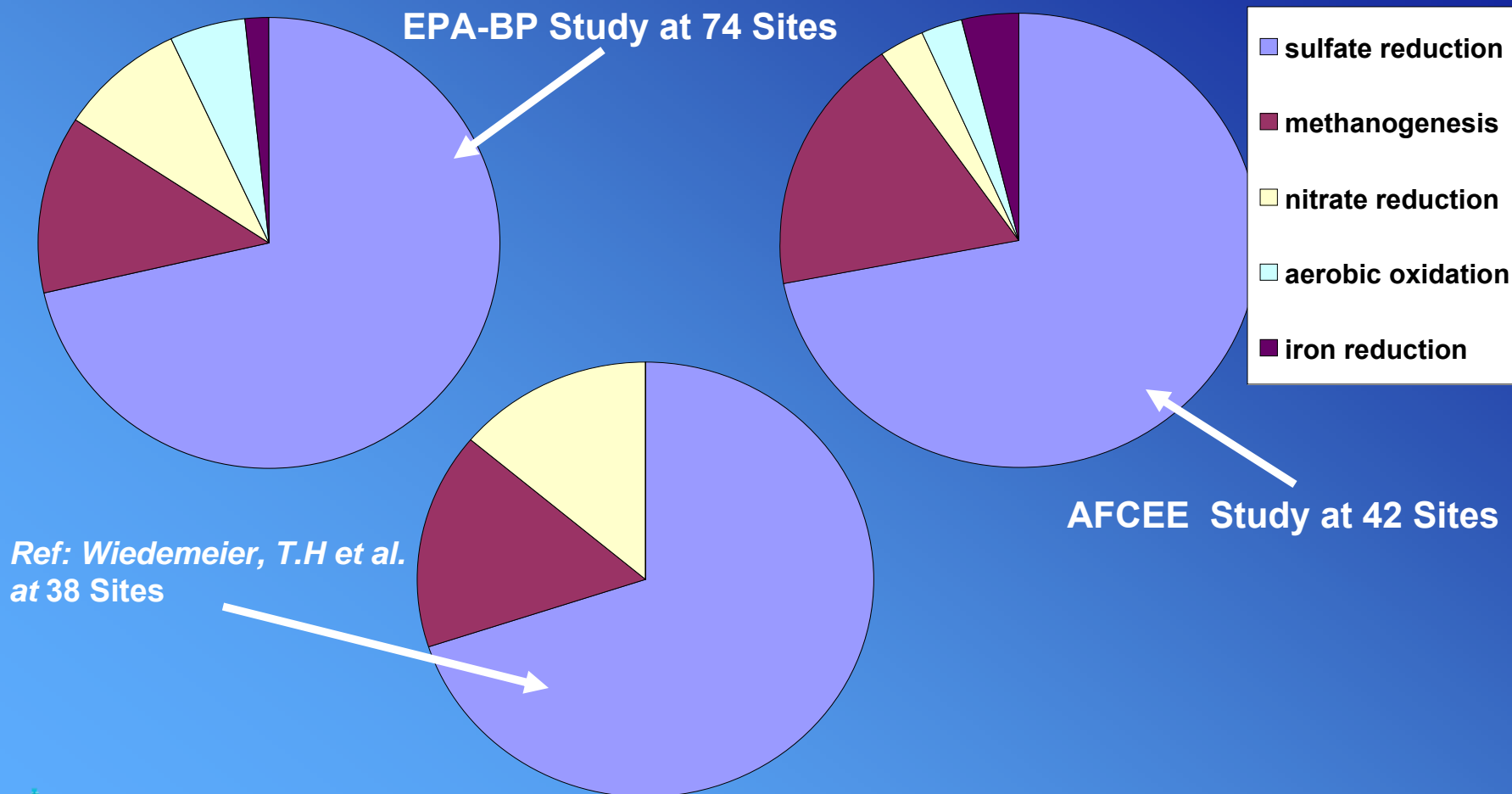
Modified from Kolhatkar, R and Taggart, D, 2004

Conventional Wisdom

➤ Add Oxygen

High Energy Yield Low	Fast Kinetics (Lab Experiments) Slow	Electron Acceptors		Products	Aerobic
		1. Oxygen	>>>	Water, CO ₂	<hr/>
		2. Nitrate	>>>	Nitrogen, CO ₂	
		3. Fe(III)	>>>	Fe(II), CO ₂	Anaerobic
		4. Mn(IV)	>>>	Mn(II), CO ₂	
		5. Sulfate	>>>	Sulfide, CO ₂	
6. CO ₂ or fermentation	>>>	Methane			

Sulfate-Utilizing Microbes Dominate Process



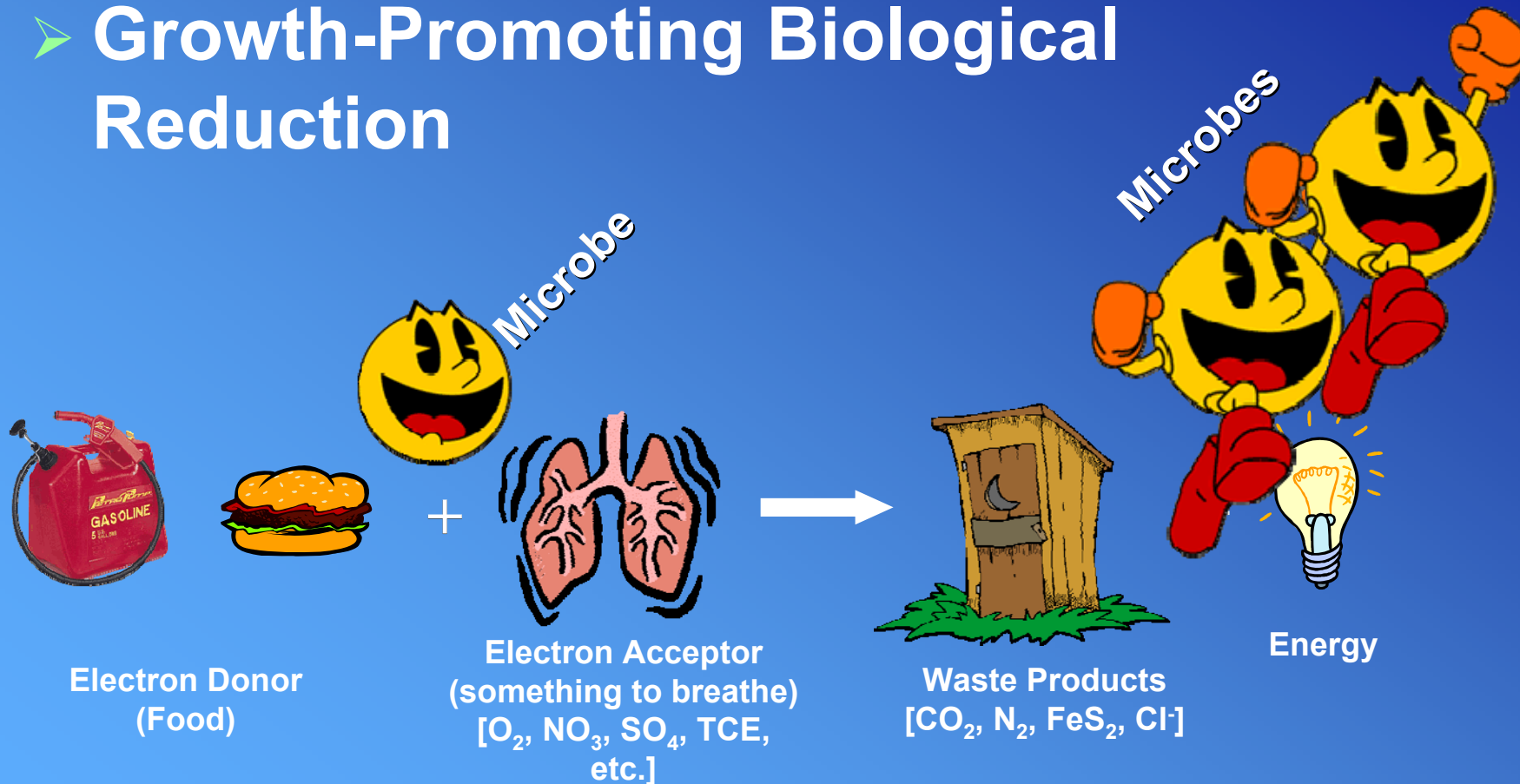
Why EAST™?

Electron Acceptor (EA)	Maximum Concentration (mg/L)	Potential Benzene Degraded (mg/L)	Issues
Oxygen (in air)	9 – 10	3.0 – 3.3	<ul style="list-style-type: none"> Limited solubility Numerous oxygen sinks Potential aquifer clogging Biofouling near injection point
Pure Oxygen	60 – 70	19.8 – 23.1	
Sulfate	100 – 250*	22.0 – 55.0	<ul style="list-style-type: none"> Hydrogen sulfide; never documented as an issue in the field Secondary MCL for sulfate - 250 mg/L*
EAS™	>1,000	>220	

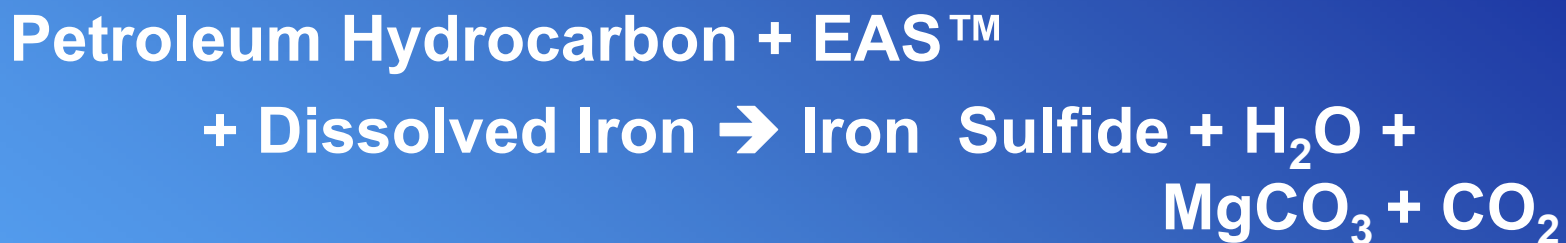
Mass of Benzene Degraded per Unit Mass of EA: Oxygen = 0.33; Sulfate = 0.22

How Does EAS™ Work?

➤ Growth-Promoting Biological Reduction



Sulfate-Reducing Bacteria (SRB) Reaction



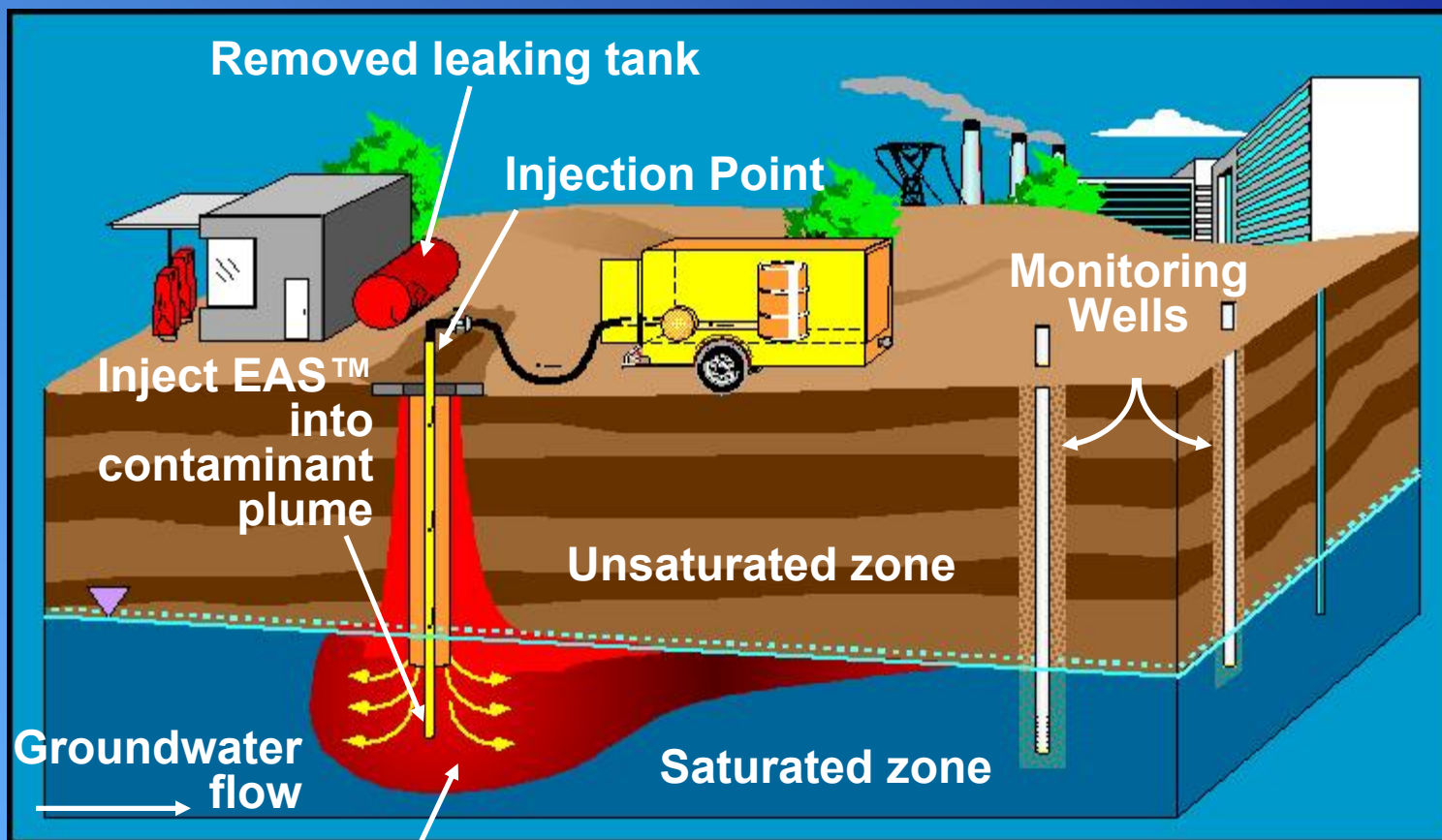
Iron Sulfide and Magnesium Carbonate are insoluble and immobile.

Why EAS™ Enhancement?

- Accelerates site cleanup
- *In Situ*
 - Minimal Disruption & O&M
- Cost effective
- “Green Technology”
- Proven



Typical EAS™ Project



(Drawing Modified from ITRC and Koenigsberg 2007)



Plume of dissolved contaminants

Contaminants that can be Treated with EAS™

- Petroleum Hydrocarbons
 - Aromatic Hydrocarbons
 - Total Petroleum Hydrocarbons (TPH)
 - Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)
 - Methyl tert-butyl ether (MTBE)
 - tert-Butyl Alcohol (TBA)

How Much EAS™ is Required?

- Generally 3-4 EAS™ applications
- ~ 4.6 pounds of sulfate per 1 pound of hydrocarbon — Wiedemeier et al (1994)

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Case Studies

Courtesy of James F. Cuthbertson, Senior Consultant
Delta Consultants, an Oranjewoud N.V. Company

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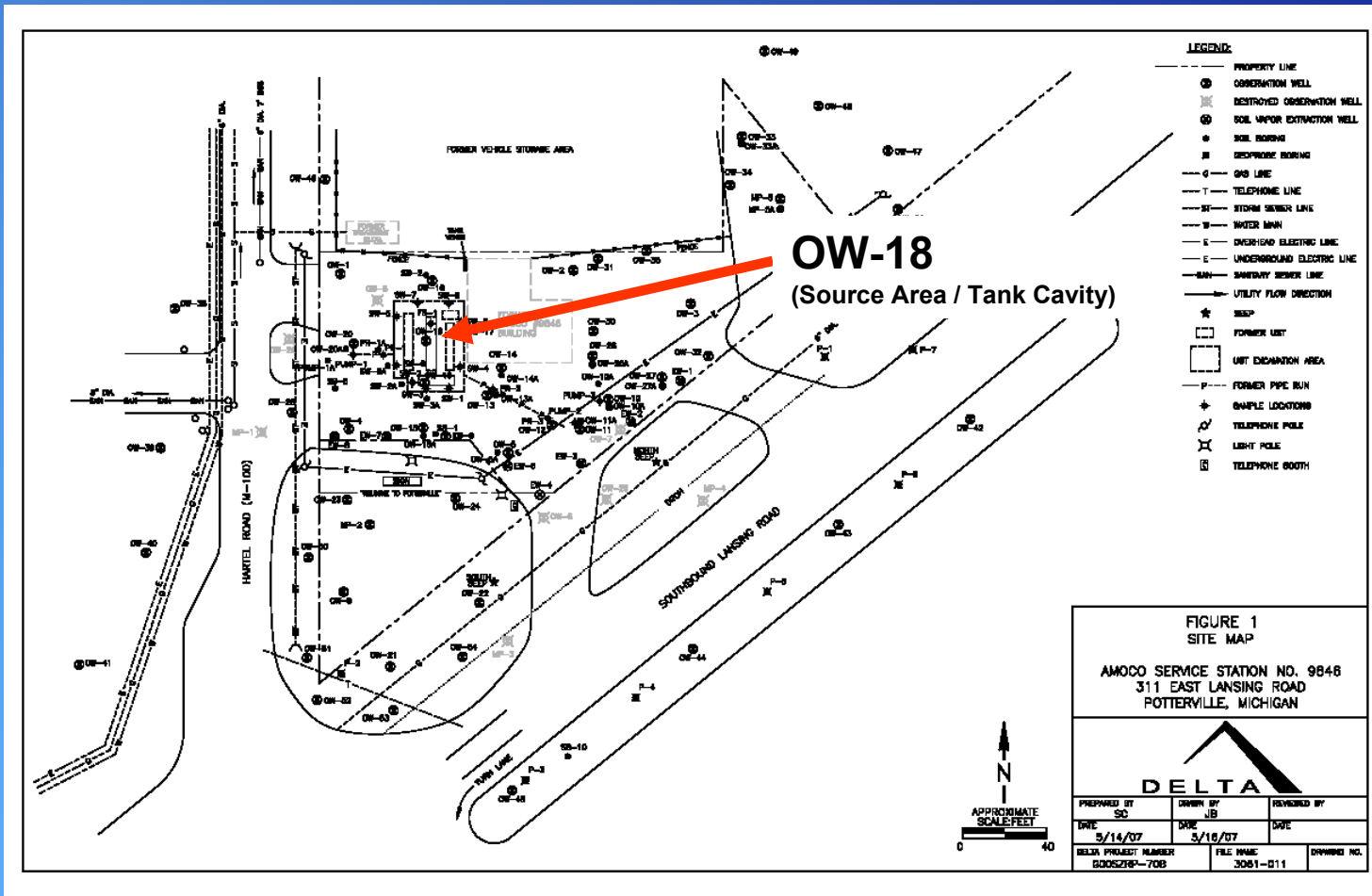
Patented Methods for *In Situ* Bioremediation

Former Gasoline Service Station Potterville, MI

- Confirmed releases in 1992 and 2001
- Prior remedies:
 - High vacuum total fluids extraction, oxygen bio-sparging, bioaugmentation & MNA
- Geology:
 - Silty clay with granular fill material
 - Perched groundwater 1 to 2 feet bgs
- Liquid phase hydrocarbon (LPH) was last encountered in March 2003
- Sulfate enhancement was pursued as the lowest cost alternative to accelerate remediation and respond to a potential sensitive receptor (wetland area)

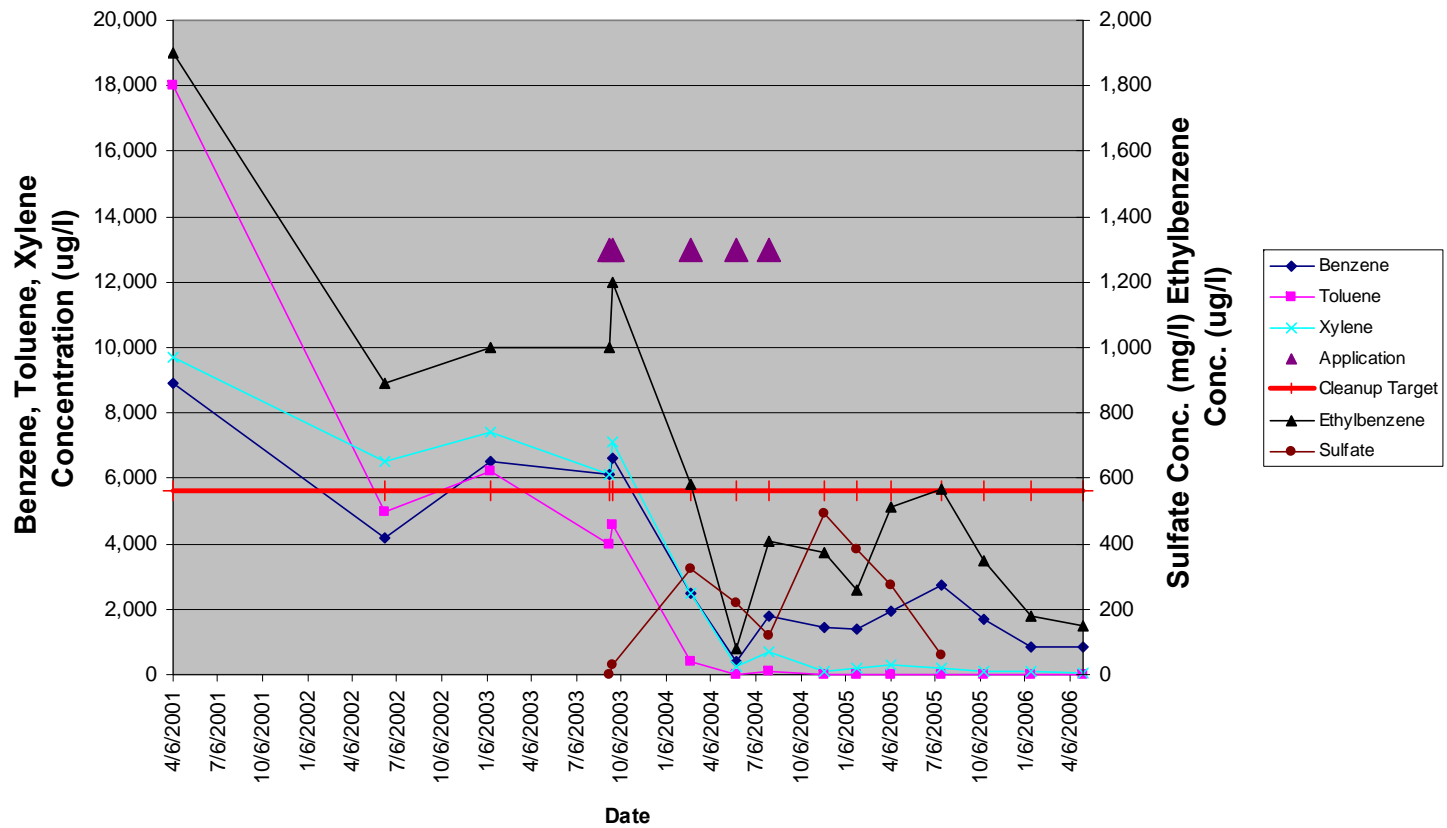


Potterville, MI Site Map



Results

Potterville, MI Source Area/Tank Cavity B,T,E,X vs. Sulfate

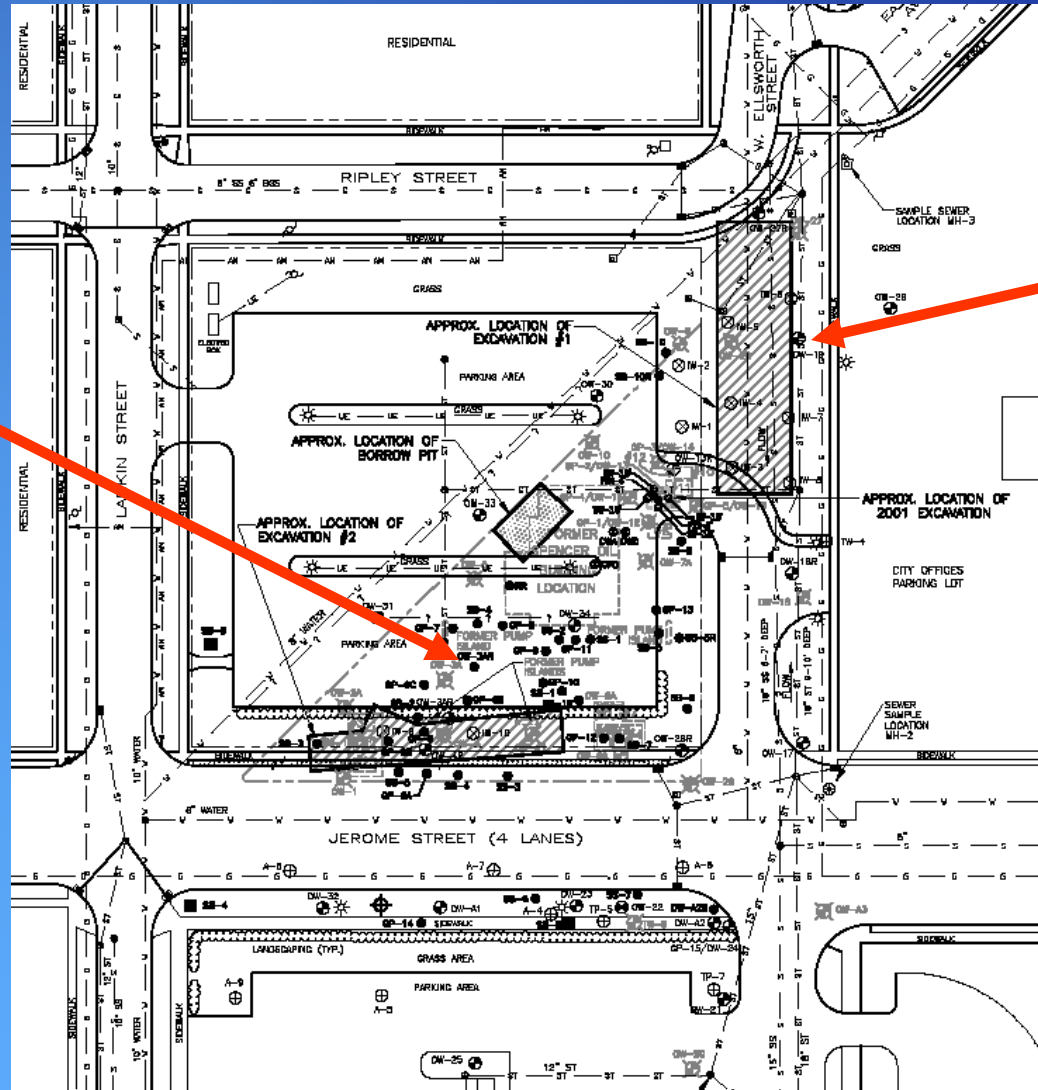


Midland, MI Case Study

- Confirmed releases in 1988 and 2000
- Primarily Sands with granular fill material to 8 feet bgs with clay to maximum explored depth
- Groundwater approximately 6 to 8 feet bgs

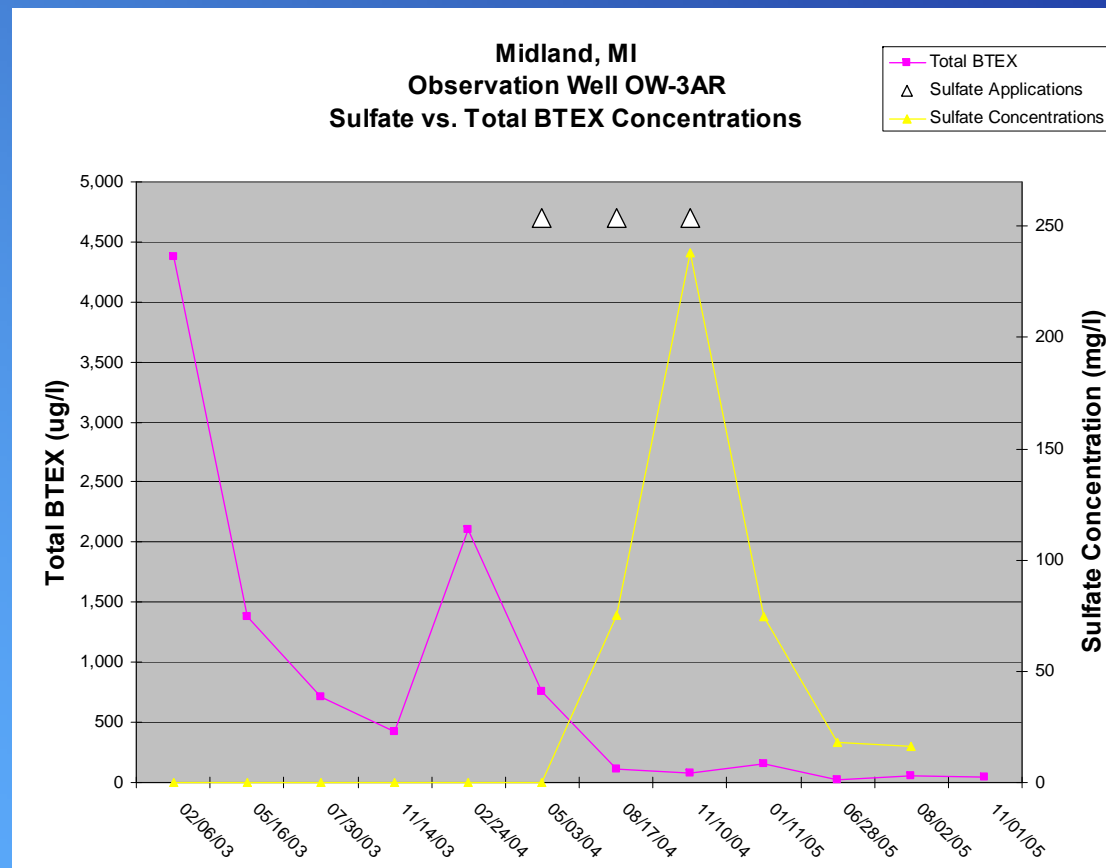
Midland, MI Site Map

OW-3AR
(Within Treatment Zone)

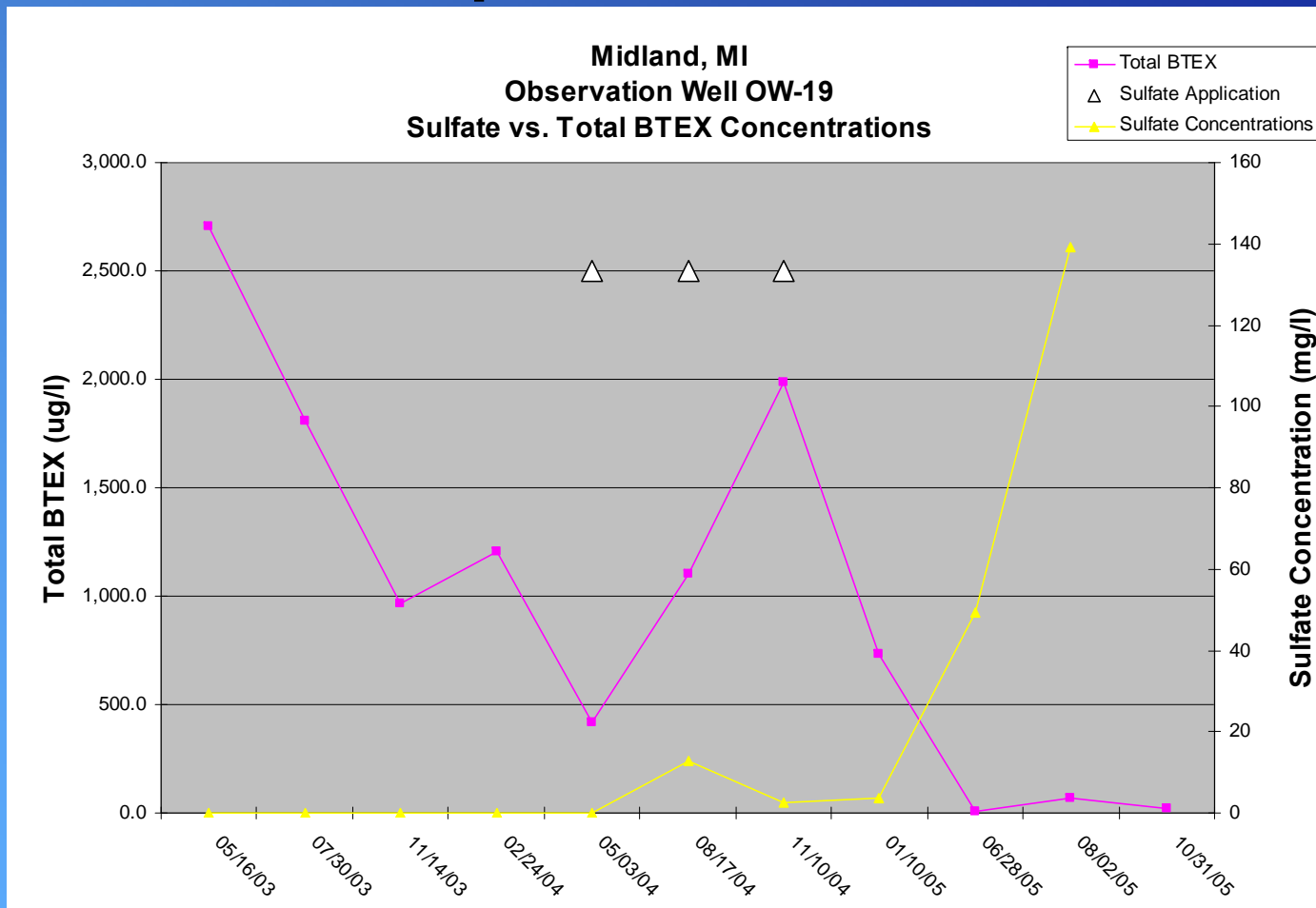


OW-19
(Compliance Well)

Monitoring Well Within Treatment Zone

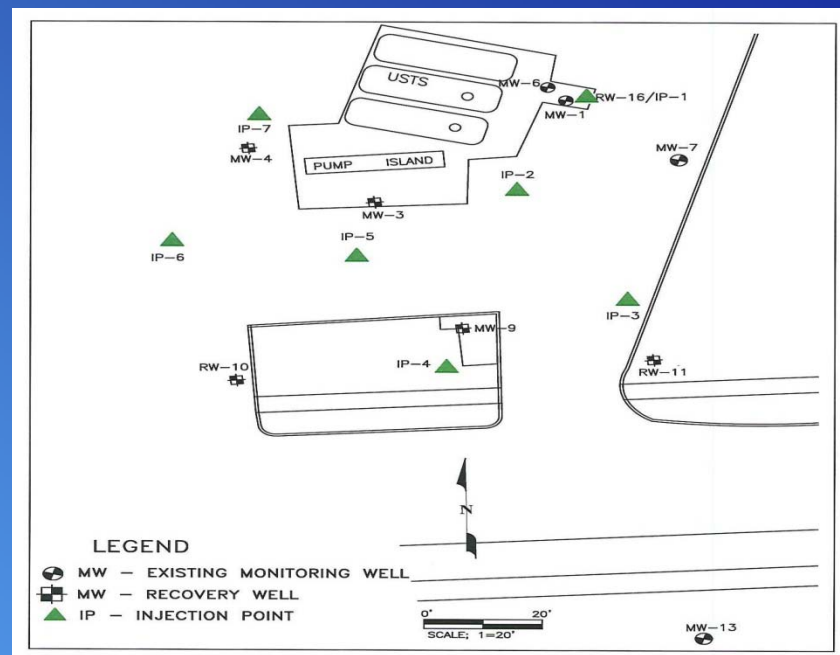


Compliance Well



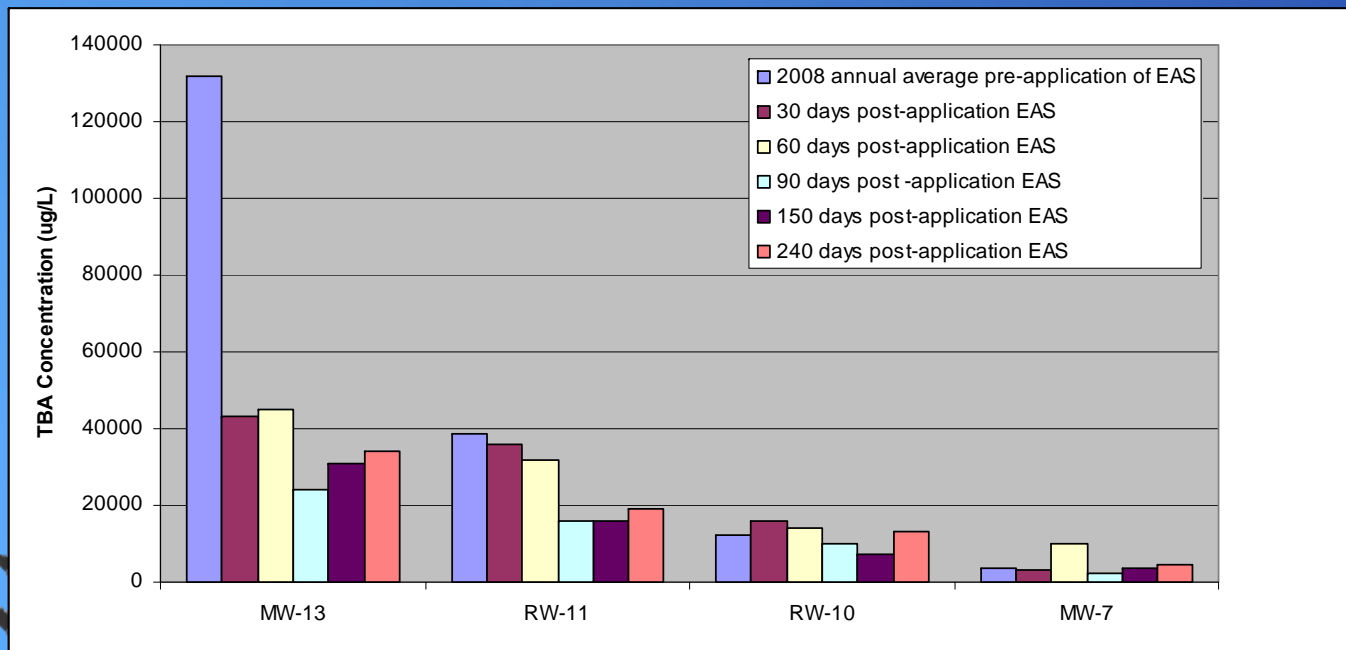
tert-Butyl Alcohol (TBA) Case Study – Silver Spring, MD (In Progress)

- Active retail petroleum facility
- Regulatory drivers
 - Elevated BTEX, MTBE & TBA
- Remediation target area is approximately 100 feet by 100 feet
- 175 gallons of EAS™ applied
 - 7 application points (IP-1 through IP-7).
- Observed Radius
 - 20 to 80 feet



TBA Results

- Post-application sampling events were conducted at 30 day intervals for 90 days. Sampling will be performed quarterly thereafter
- 90 day TBA concentrations have decreased an average of 50% in site wells that reported a detectable result of TBA in post-application analysis



Conclusions Silver Spring, MD

- Literature searches and field site data indicate that Sulfate Enhanced Biodegradation is a feasible technology for TBA remediation
- Material, Application and Oversight Costs approx. \$11,000
- Anticipate completing 2 additional applications to meet closure end points at this cost

Example Closure / NFA Projects

- Gas Station, GA – 1995 Release, Dissolved BTEX, EAS™ Application May 2008, NFA Granted October 2008
- Bulk Terminal, VA – 1993 Release, LPH Sheen, EAS™ Applications 2006 and 2007, Closure Granted October 2008
- Gas Station, Washington, D.C. – Dissolved BTEX and MTBE, EAS™ Application June 2008, NFA Granted July 2009 – cost savings of > 55%
- Gas Station, Washington, D.C. – Dissolved BTEX and MTBE, EAS™ Application June 2008, NFA Granted September 2009 – cost savings of > 50%



Application Overview

- After an EAS™ application, sulfate levels initially rise and then decrease in conjunction with the reduction of contamination levels
- If the contaminant is still present and sulfate is at background levels, another application may be needed

Application Experience



- Applied at over 200 sites
 - FL, CA, MI, IN, IL, WV, VA, IA, GA & NY

- Method of Injection & application
 - Infiltration trenches
 - Vertical wells
 - Surficial spreading
 - Former recovery wells
 - Former SVE wells
 - Temporary Geoprobe® points

- Variety of geological and hydrogeological settings

Benefits of EAS™

- Minimal site disruption
 - *In situ* approach with no ongoing O&M activities
- Cost effective



Benefits of EAS™

- Safe
- Green – Natural Process



Benefits of EAS™

- Accelerated cleanup
 - Information gained significantly strengthens advocacy position with regulatory agencies
 - Monitoring frequency showed no lag time for acclimation of native sulfate reducing bacteria



Overview of Patented Process

- US Patent No. 7,138,060
 - Issued November 21, 2006
- Patent issued for:
 - A process that enhances the environmental conditions existing within a contaminant plume by replenishing a natural groundwater compound required by bacteria to degrade the contaminants.
 - Sulfate solution in excess of 1,000 ppm
 - Covers all pollutants that can be degraded by sulfate-reducing microorganisms



Conclusion

- Enhancement of biodegradation with the addition of EAS™ is a viable technique to safely and aggressively remediate BTEX, MTBE and petroleum impacted groundwater
- Design, implement and monitoring is a relative easy process

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For more information, please visit:
www.EOSRemediation.com



Thank you for attending ...
Questions?

YOUR NATURAL SOLUTIONS
Patented Methods for *In Situ* Bioremediation

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