Darwinian Remediation – The Evolution of Remedial Technologies and the Survival of the Fittest

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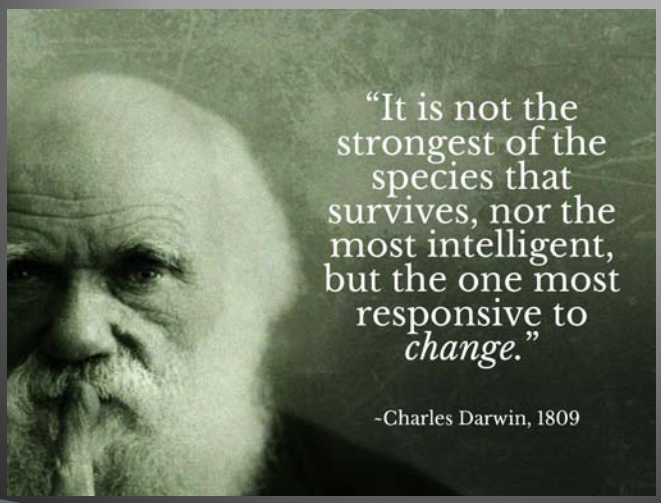
PATRIOT ENGINEERING and Environmental, Inc.
Engineering Value for Project Success

INDIANA CHAMBER

1

Adapt or Die



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In the Beginning…..

- Environmental rules & regulations initially developed in the 1970s (Clean Water Act, Clean Air Act, etc.)
- Many hazardous sites identified that required cleanup
- Engineers/Scientists assigned the task

3

The Simplest Solution

- Soil Excavation
- Still a viable option in source areas
- Problem – does not eliminate contamination, only risk

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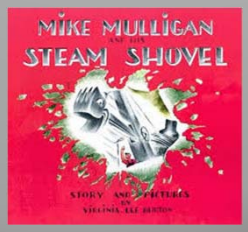
Soil Excavation – Moderation is the Key

Only excavate those soils that are significantly impacted and continuing to act as a source for impacting groundwater and/or vapor intrusion.



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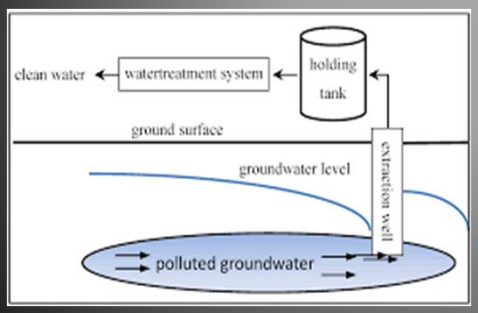
"But We Have All This Impacted Groundwater!"



- Pump-and-treat (P&T) – install pumping wells, remove the impacted groundwater, treat it to remove the chemicals, and discharge it.
- Clean water will replace the impacted water and the site will be cleaned up – right?

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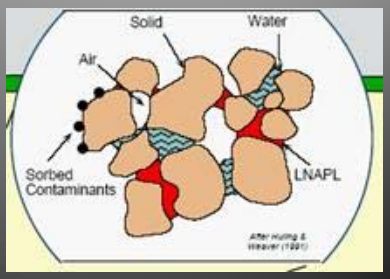
Groundwater Pump-and-Treat

Seemed like a simple, straightforward solution, but……

P&T <u>always</u> becomes "diffusion limited"



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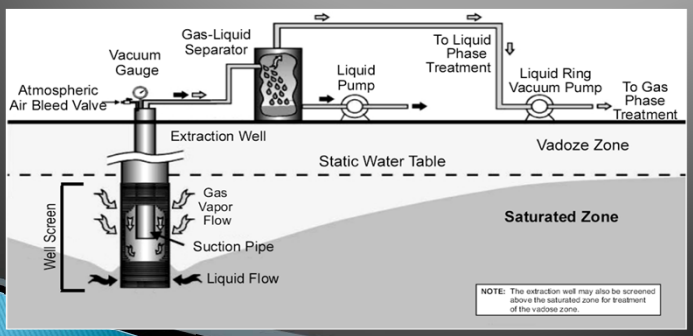
"So We're Pumping All This Water and the Site Isn't Cleaning Up – Now What?"

- Bright idea – removing the water and passing air through the dewatered soil to remove adsorbed material – dual-phase extraction (DPE)



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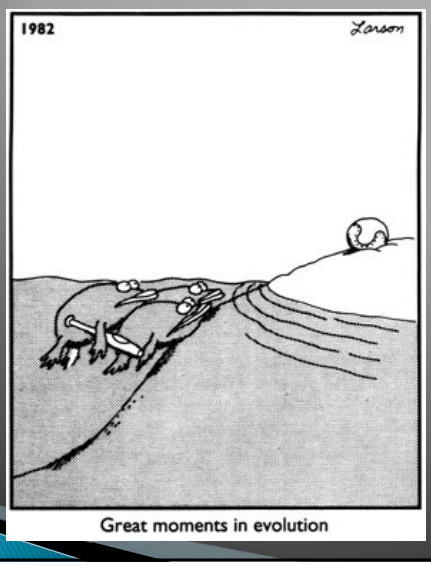
We Still Have a Lot of Water to Deal With – There Must Be a Better Way



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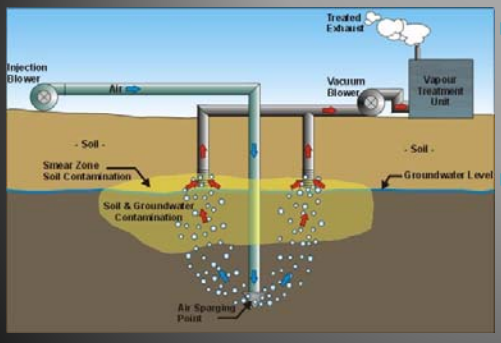
Air Sparging/Soil Vapor Extraction (AS/SVE)



- Air Sparging – introducing air below the water table to volatilize contaminants
- Soil Vapor Extraction (SVE) – removing the sparged vapors and treating them before discharging to the atmosphere

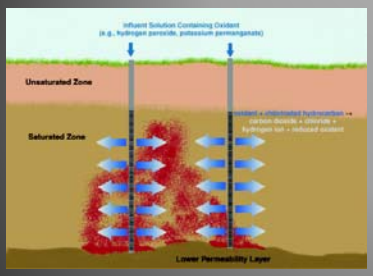
Does anyone still see a potential issue?

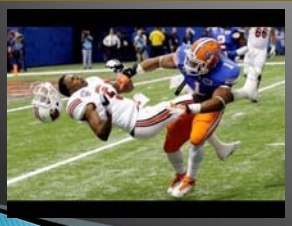
10

MECHANICAL SYSTEMS WILL ALWAYS BECOME DIFFUSION-LIMITED!!!

11

What If We Invade and Attack Them in Their Homes?





"It's a contact sport"

- In-Situ Chemical Oxidation (ISCO)
- Injection of aggressive chemicals to promote oxidation of contaminants
- Contact-based approach – injection materials must physically contact contaminants

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"Curse That Diffusion!"

- ISCO only feasible in high-permeability soils
- Prone to "channeling" which still creates a diffusion-limited situation

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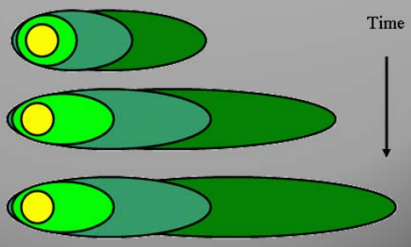
And Then Someone Noticed…….

- Groundwater modeling at a number of sites did not match the actual dimensions of the plumes
- What could be causing this phenomenon?



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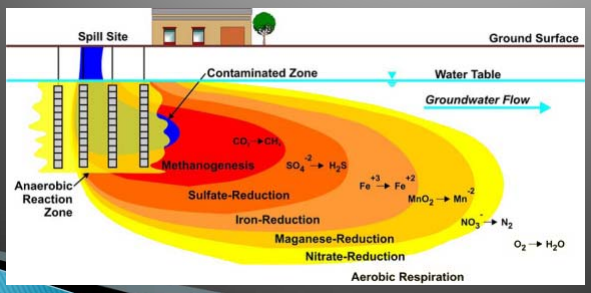
Biodegradation

Naturally occurring in most, if not all, petroleum sites

Eventually, migration = degradation and plume is stable

Remove source and plume will eventually remediate itself



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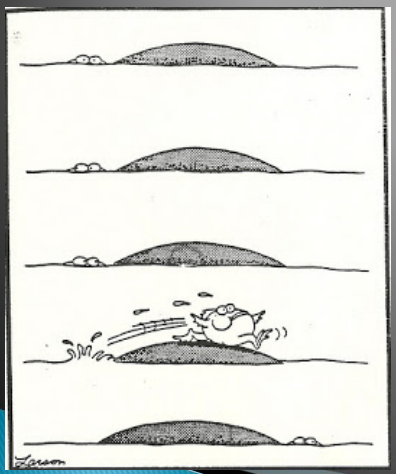
"But It Takes Too Long for Natural Attenuation to Work – I Don't Have That Kind of Time"



"In the long history of humankind, those who learned to collaborate and improvise most efficiently have prevailed" – Charles Darwin

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Enhanced Bioremediation (Injectables)

- Adding oxygen (aerobic) or chemicals/bacteria (anaerobic) to accelerate degradation
- Not diffusion limited because bacteria are mobile

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Natural (Unenhanced) Petroleum Biodegradation is Typically Anaerobic – Much Slower for Petroleum than Aerobic

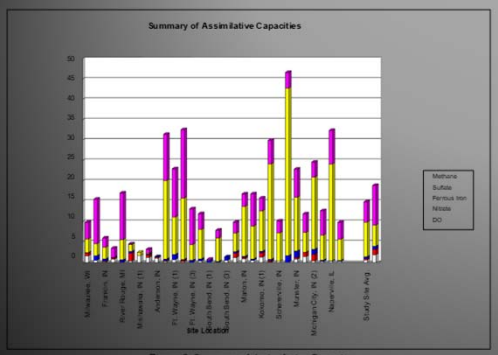

Figure 2. Summary of Assimilative Capacity

- Most of natural attenuation is methane (purple) & sulfate (yellow) reduction

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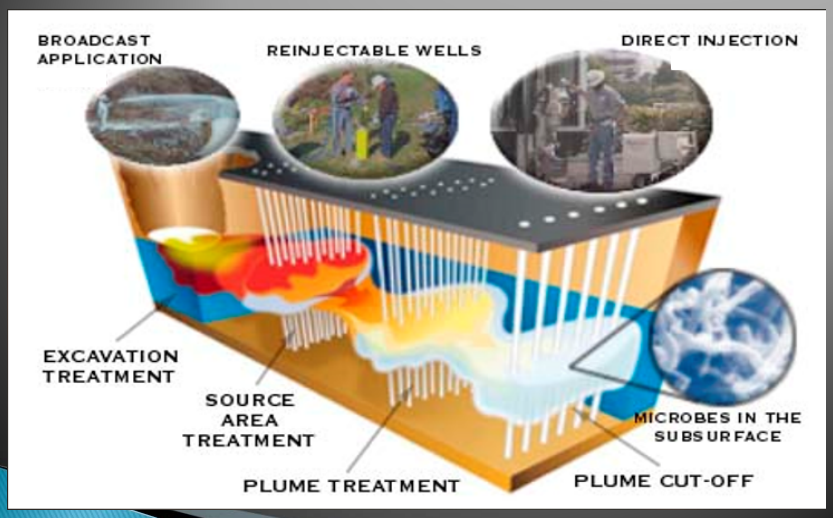
In-Situ Enhanced Bioremediation Application Options



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Aerobic Biodegradation (Oxygen Addition)

Primarily applicable to Petroleum Hydrocarbons
Can also be effective for Vinyl Chloride

Case History O-9

ORC OXYGEN RELEASE COMPOUND

REGENESIS
Advanced Technologies for Groundwater Resources

Surgical Site Closure –
30 Sites in Indiana Receive Closure using ORC®

CASE SUMMARY

Surgical Site Closure

"Surgical Site Closure" is an innovative remedial strategy designed to intelligently integrate natural attenuation, risk-based cleanup goals and focused source removal/treatment to cost-effectively remediate contaminated areas. This approach is best applied at sites where released materials are amenable to biodegradation and where long-term, natural attenuation-type strategies are not suitable for reasons of property transfer or potential off-site liability. This strategy was performed at 30 sites in Indiana for a major oil company.

Service Stations/Bulk Storage Terminals – Indiana

From 1998-2008, a total of 30 service station/bulk storage terminal sites were targeted for Surgical Site Closure in Indiana. The subsurface matrix consisted of unconsolidated sediments ranging from low-permeability silty clays with sand stringers to sand and

Figure 1. Site Closures in IN

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Aerobic Bio Case History Summary

- 30 Sites (1998 – 2008)
- 30 of 30 (100%) rec'd NFA (last one 4/08)
- Average time to closure: 3 years
- Average cost to closure: $70,000

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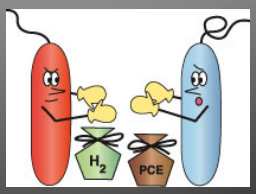
Chlorinated Hydrocarbon Degradation

- Occurs under anaerobic conditions
- Most Midwestern sites have aerobic conditions



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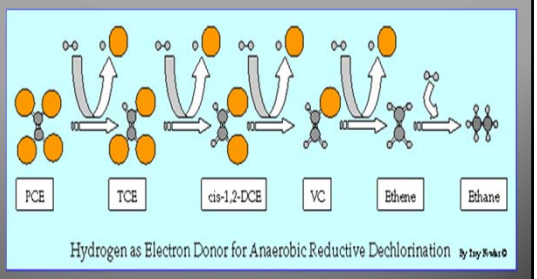
Anaerobic Biodegradation (also known as Enhanced Reductive Dechlorination, or ERD

Introduction of substrates/bacteria into the water-bearing zone to create an anaerobic environment and provide electron donors (hydrogen)



Beware of Dog

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Case History – Manufacturing Facility – Northern Indiana

<u>Problem</u>

- Dissolved Plume emanating from former AST area
- ISCO approach proposed initially – difficult to inject and more costly

<u>Solution</u>

- IDEM-mandated ERD pilot test followed by full scale injection of electron donor and bioaugmentation substrate

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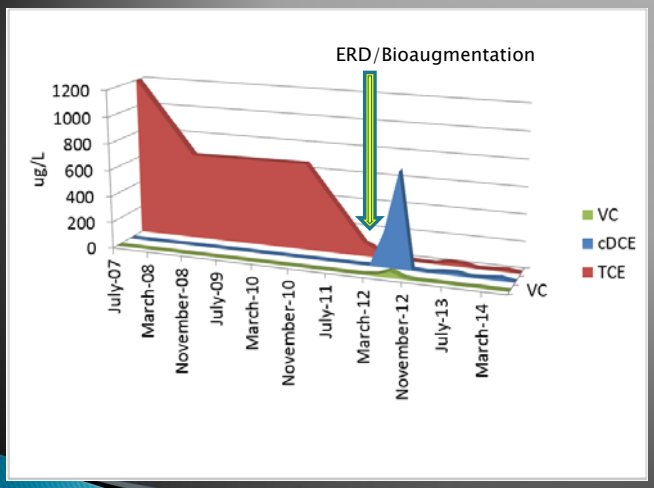
Case History – Manufacturing Facility – Northern Indiana

MW-4 (Source Area Well) – Pilot



Site Details

- 13,000 square foot injection area
- TCE 40-600 ppb
- Geology: Fine-medium sand; DTW 15-20' bgs
- Products: 3DMe, BDI-Plus

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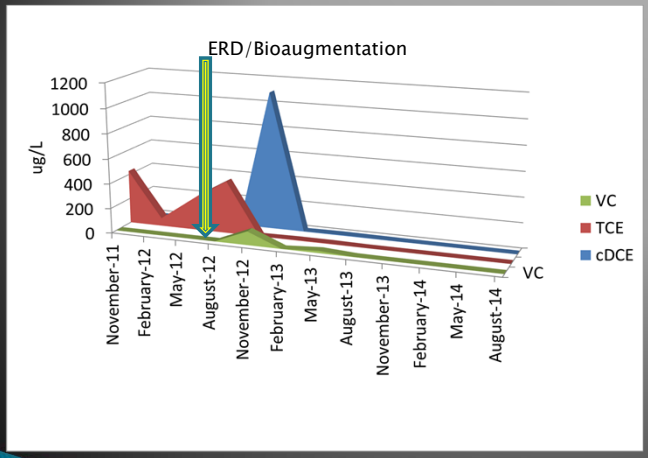
Case History – Manufacturing Facility – Northern Indiana

MW-16



Site Details

- 13,000 square foot injection area
- TCE 40-600 ppb
- Geology: Fine-medium sand; DTW 15-20' bgs
- Products: 3DMe, BDI-Plus

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Manufacturing Facility – Northern Indiana

Results

- Pilot study demonstrated to regulatory agency that ERD would work quickly and effectively
- Full-scale injection resulted in dramatic reductions within 6 months of the ERD treatment. Continued reductions with time
- After 3 years of monitoring, all wells achieved target cleanup levels
- Closure received Feb. 2016 (3 ¼ years after full-scale injection)

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Success!

INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

CERTIFICATE OF COMPLETION

ISSUED TO: WPI Holding Company

FOR: The successful completion of the Voluntary Remediation Work Plan for the Whitley Products, Inc. site, IDEM #6090801, located at 1403 Stanley Drive, Plymouth, (Marshall County), Indiana, as more specifically described in the attached Exhibits1-3, which are incorporated herein by reference. The issuance of a Certificate of Completion under IC 13-25-5 is a final agency action for purposes of IC 4-21.5.

GIVEN UNDER MY HAND IN THE CITY OF INDIANAPOLIS
THIS 12th DAY OF February, 2016

CAROL S. COMER, COMMISSIONER
Department of Environmental Management

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ERD Performance Review – 8 Sites

Details

- 8 Sites (4 Industrial, 4 Dry Cleaners)
  - Reviewed Total of 36 Performance Monitoring Wells Within Treatment Areas
- Chlorinated Solvent Average Starting Concentrations of Performance Wells
  - PCE Avg. = 2.7 mg/L
  - TCE Avg. = ~0.6 mg/L
  - Cis-DCE Avg. = 0.9 mg/L
  - VC Avg. = 0.2 mg/L
- Variable Geology (Sand – 4 sites; Sand Lenses – 4 sites)
- Risk-Based Closure Goals (Com/Ind)

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ERD Performance Review – 8 Sites

Details

- Grid arrays – ranging from 10 ft spacing to 20' x 50'
- Projects with >1 year of Data
- Injection Areas: 1,000 to 66,000 sq. ft.
- 3DMe Injected: 1,300 to 48,000 gallons-solution 10% -25%.
- BDI Plus Injected: 18 to 170 Liters
- Focused Supplemental Injections
  - Average 30% of initial injection

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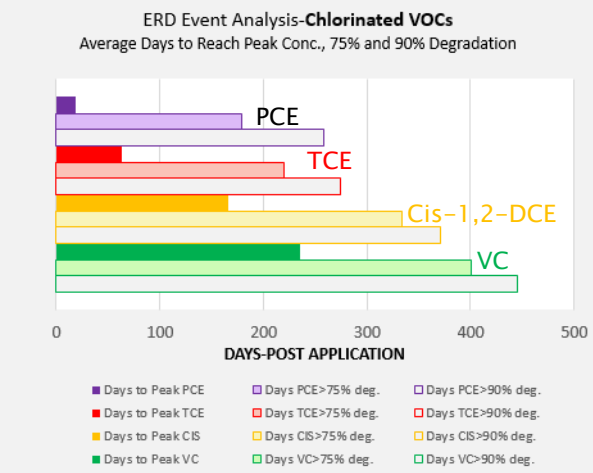
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



Explanation of Parameters

- Peak PCE/TCE/CIS/VC = Days after application when maximum (peak) concentration was detected
- 75% Reduction = days after application when 75% concentration reduction metric was reached (from maximum)
- 90% Reduction = days when 90% reduction metric was reached (from maximum)

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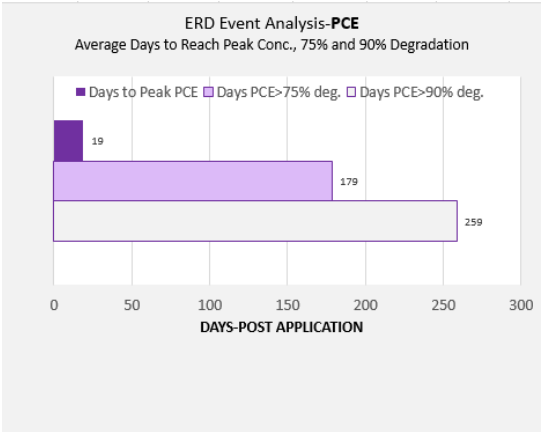
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



PCE

- PCE Elimination 180 to 260 days on average
- 160 to 240 days from peak

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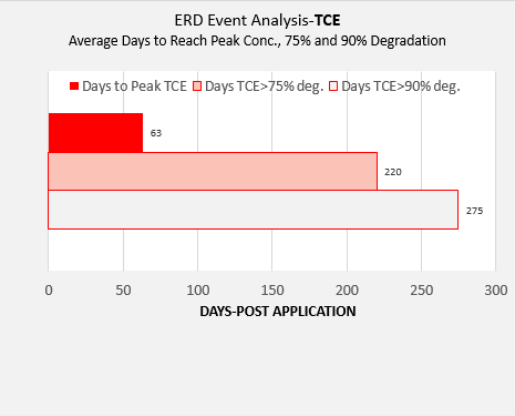
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



TCE

- TCE Elimination 220 to 275 days on average
- 160 to 210 days after peak (max. conc.)

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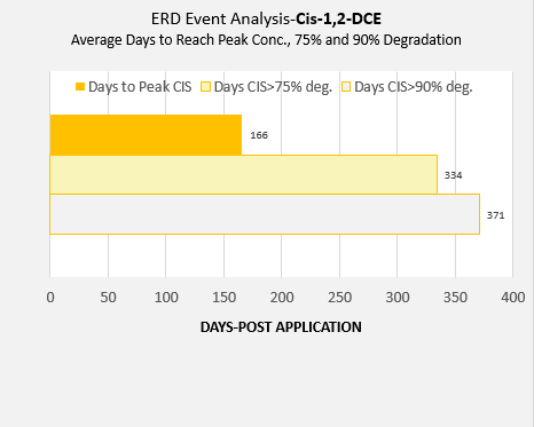
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



Cis-DCE

- Cis-DCE Elimination 330 to 370 days on average
- 170 to 200 days after peak

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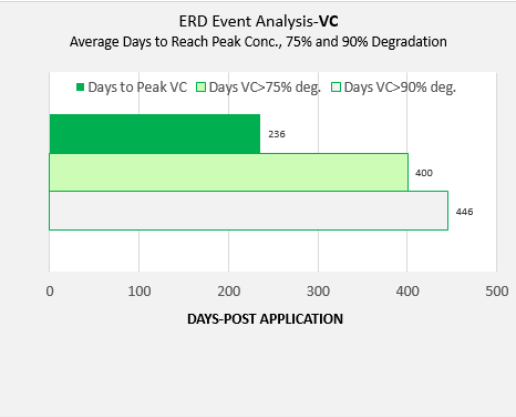
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



VC

- VC Elimination 400 to 405 days on average
- 170 to 210 days after peak
- Complete ERD – Once you've eliminated VC you are done!!

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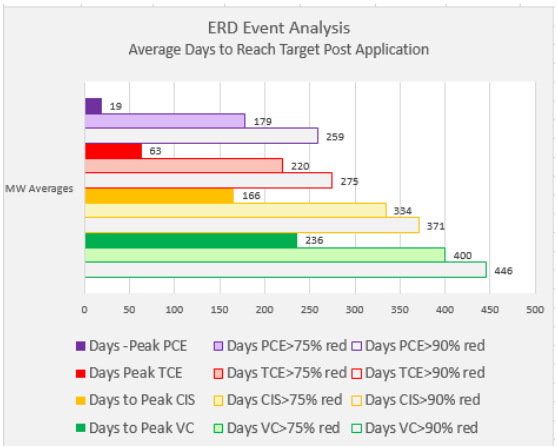
Question #1 – How Long Does ERD Take? ERD Performance Review – 8 Sites



Summary of Observations

- Each constituent degraded approximately 6 months after peak – strikingly consistent on average
- Looking at PCE timeframes will give you early indication of likelihood for success
- Use Proactive Monitoring. Spot any "dogs" early, then respond quickly!!

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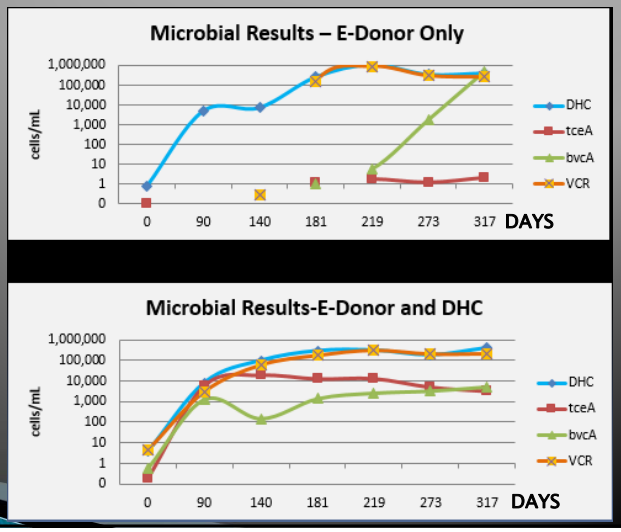
Key to Success: Co-application of Donor and DHC at Outset-Why?

Pilot test-two areas-NW IN Site:
1-E-Donor Only
1-E-Donor + DHC

- DHC populations is similar for two cells over time
- Functional genes tceA, bvcA and VCR populations much more robust early on
- Note >6 month lag time for these in E-Donor only cell!



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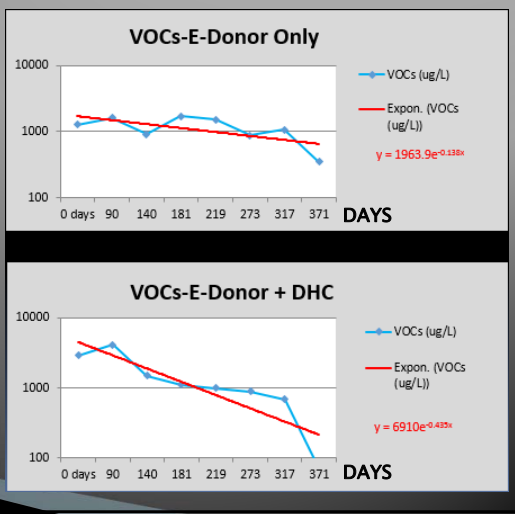
Co-application of Donor and DHC at Outset-Why?

Answer = Results!

- Faster Degradation Rates
- ~3X VOC degradation rate increase over 1 year



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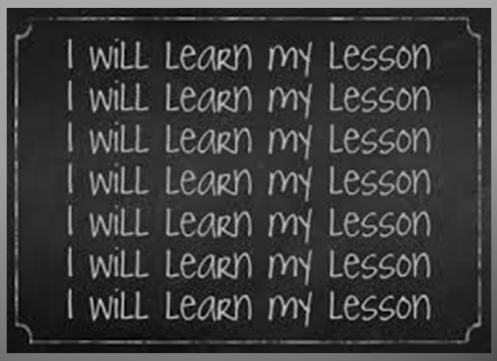
Lessons Learned

- Well Defined CSM is KEY
- Good Data = Good Design = Good Application
- Bioaugmentation is almost always beneficial
- ERD happens **quickly**
- Be **aggressive** with supplemental injections. If needed go early.



The Formula: Donor + DHC + Distribution = Success!

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Liquid Activated Carbon (LAC) – A New Enhancement to Biodegradation

BOS 200 TOTAL TURNAROUND
FOR PETROLEUM HYDROCARBON CONTAMINATION

BOS 100 COMPLETE REMEDIATION
FOR CHLORINATED CONTAMINATION

PetroFIX
Remediation Fluid

40

LAC – A Promising New Approach

- Captures and biodegrades a wide range of contaminants
- Distributes widely under low injection pressures
- Stops contaminant migration
- Addresses back-diffusion
- Promotes long-term biodegradation as well as continued capture

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A Brief Case History

- Former petroleum bulk plant site in northern Indiana
- Historical releases from both ASTs and USTs
- Previous remedial attempts (2005-2009) using AS/SVE
- Widespread, high-level dissolved-phase impacts (10,000 – 50,000 ppb total petroleum VOCs)
- High-permeability aquifer

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Liquid AC Pilot Test

- Performed around 1 well with approx. 30,000 ppb total petroleum VOCs
- 2,000 lbs. PetroFix injected into 12 points
- Results:
  - 1 mo. – ND for VOCs
  - 3 mo./6 mo. – 99.99% removal maintained despite continued impact from upgradient
  - Microbial activity confirmed to be increasing

REGENESIS

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Remedial Plan

- Liquid AC (PetroFix, mfg. by Regenesis) barriers in multiple areas (6 total)
- 1,600 – 6,000 lbs. of PetroFix per area
- ISCO/Enhanced Bio in one area
- Injected uniformly from 17–25 feet
- Injection completed April 2019

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Preliminary Results (2 months post-injection)

Total VOC Concentration (ppb)

	Pre-Inj.	Post-Inj.
PMW-29	15,700	115
PMW-30	4,100	ND
PMW-31	2,000	300
PMW-32	5,700	ND
PMW-34	6,800	70
PMW-35	30,000	10
PMW-37*	41,400	20,100

*PersulfOx/ORC-A injection area

Only one PetroFix area (PMW-25) where no significant reductions occurred (yet)

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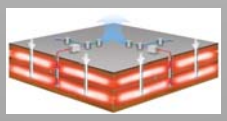
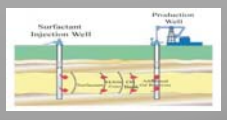
Other (Expensive) Technologies

- Steam-enhanced extraction

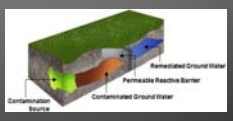


- Surfactant injection/Extraction



- Thermal Desorption

- Permeable Reactive Barriers ("containment only in most cases")



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Vapor Intrusion (VI) Issues

- Of primary concern for chlorinated solvents (or free-phase petroleum)
- VI has become the driver at many sites
- In general, vapor mitigation is **NOT** remediation

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Vapor Mitigation

Includes both passive and active systems

PASSIVE

- Sealing
- Vapor barriers (pre- and post-construction)
- Passive venting

ACTIVE

- Sub-slab depressurization
- Building overpressurization

Sub-slab depressurization system

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And On Top of All That…

"The Proverbial Dirt-Eating Kid"

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Protect Your Liability, But Don't Be a Victim of Pointless Remediation

"We are not here to clean up the environment, we are here to close sites"

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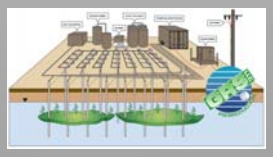
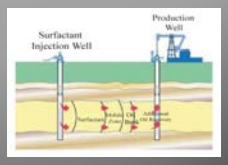
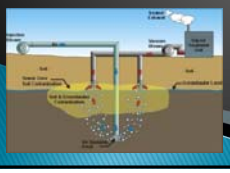
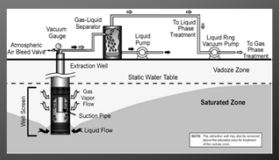
"So How Do I Know What's Best for My Site?"









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1. Identify Your True Risks and Manage Them Accordingly

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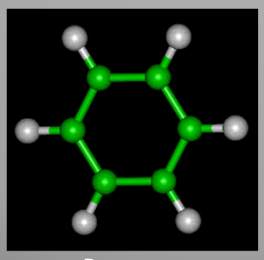
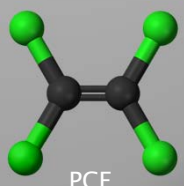
2. Understand the Physical Properties of the Chemical(s) to be Remediated

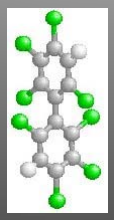
- VOCs (BTEX/MTBE; PCE; TCE, etc.) are volatile, mobile, and biodegradable
- Most PAHs are adsorptive, non-volatile, and relatively immobile
- Metals and PCBs are very highly adsorptive with very low mobility



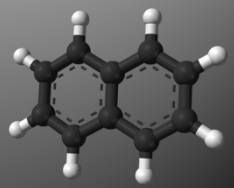
Benzene



PCE



PCB



Naphthalene

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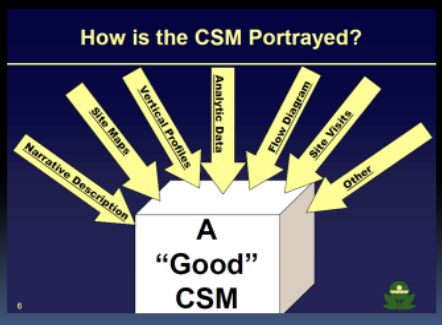
3. Develop an Accurate CSM

Key to Success – Designing to A Well Defined Conceptual Site Model

- Geology/Hydrogeology
- Nature & Extent of Soil/GW Impacts
- Limitations
  - Depth of impacts
  - Buildings/utilities
  - Operations
- Remedial Goals



*http://www.epa.gov/osw/hazard/correctiveaction/pdfs/workshop/csm_slides.pdf

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4. Know The Benefits & Limitations of Various Remedial Technologies

Soil Excavation – still good for focused source removal

P&T/DPE – only really useful for free product recovery or capture/containment

AS/SVE – only for volatile compounds in permeable formations and if plume too large for an injection approach

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Know The Benefits & Limitations of Remedial Technologies

ISCO – primarily for rapid mass removal in source areas

Enhanced Bio – often a viable option if applied properly

Liquid Activated Carbon/Enhanced Bio – a promising new approach

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Know The Benefits & Limitations of Remedial Technologies

Other Approaches
- Steam-enhanced extraction
- Surfactant-enhanced extraction
- Thermal desorption

Very costly – handle with care!!!

Permeable reactive barriers – containment only

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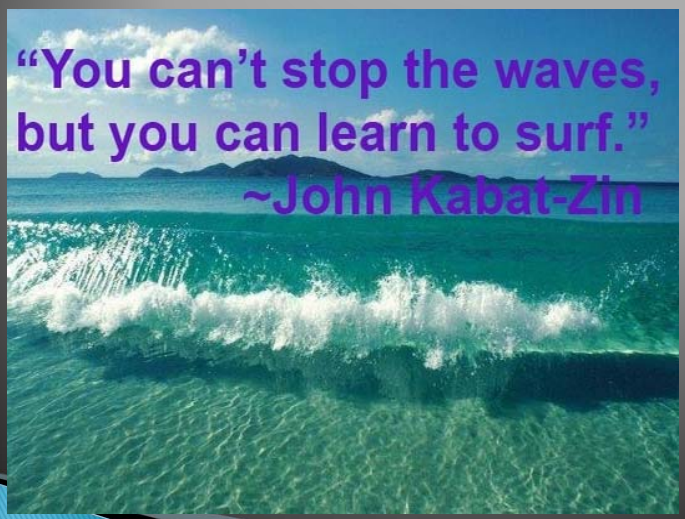
Contaminated Sites Will Happen – Deal With Them Cost-Effectively



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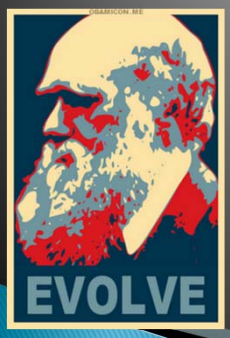
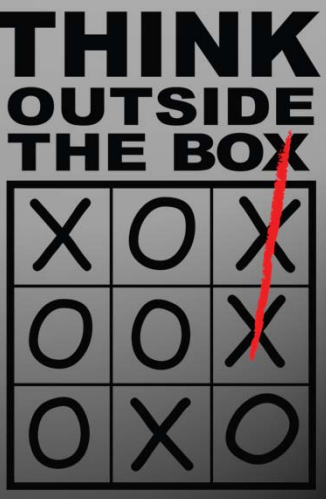
5. Always Choose a Trusted, Experienced Partner

PATRIOT ENGINEERING and Environmental, Inc.

Engineering Value for Project Success



"I am not apt to follow blindly the lead of other men" – Charles Darwin



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