

Thinking Outside the Boxcar: Combined Remedies using Single Application of Multi-Functional Amendments



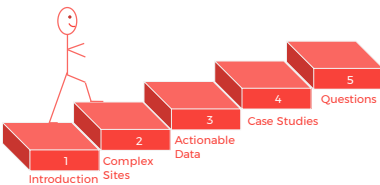
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Outline



1 Introduction Sites
 2 Complex Sites
 3 Actionable Data
 4 Case Studies
 5 Questions

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Complex Sites

Complex Sites

Asked: What is the percentage of remediation projects that are complex?

Response: More than half of the respondents thought less than 25% of all sites are complex. (brown, darker blue, and purple)




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Complex Sites

Complex Sites

Asked: Do you work on complex sites?

Response: About half of respondents have worked on 6 or more complex sites and half have been working on complex sites for 15+ years

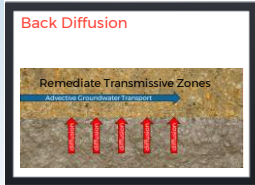


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Complex Sites

Complex Sites

Back Diffusion

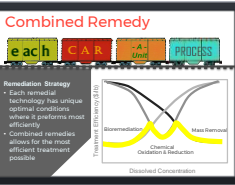


Combined Remedy

each CAR A Good PROCESS

Remediation Strategy

- Each remedial technology has unique optimal conditions where it performs most efficiently.
- Combined remedies allows for the most efficient treatment possible.



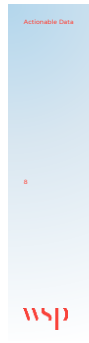
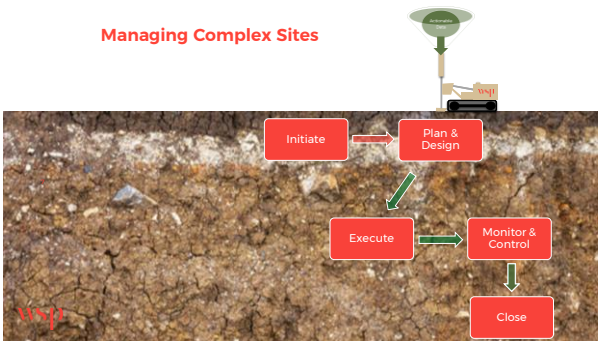
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Managing Complex Sites

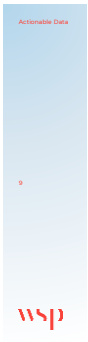
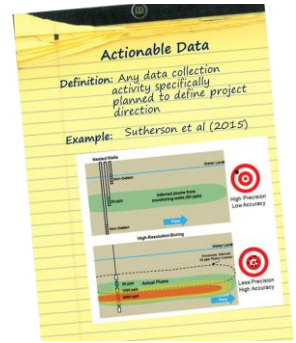


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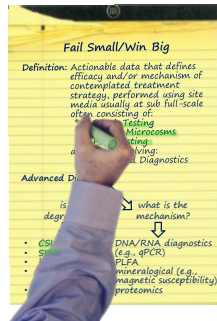
Managing Complex Sites



Actionable Data

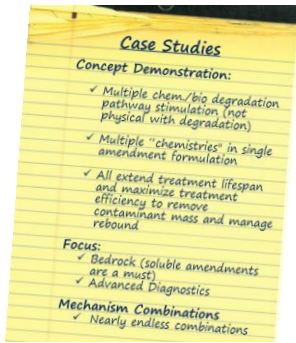
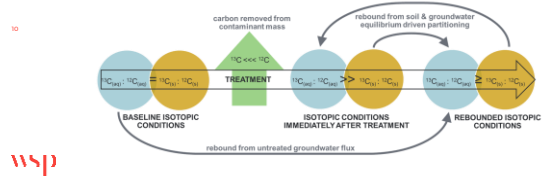


Actionable Data



Recorded Webinar: On Microbial Insights Website

Successful Advanced ISCO Analytical Practices



Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene



Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene



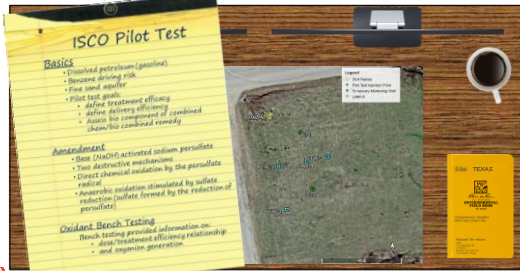
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Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene



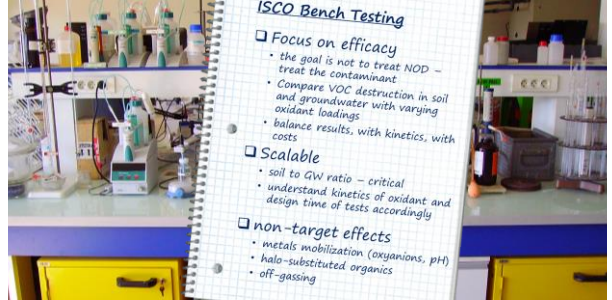
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Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene

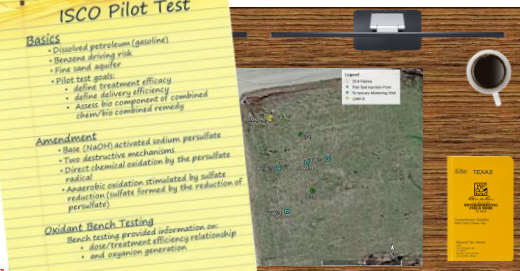


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Bench Testing

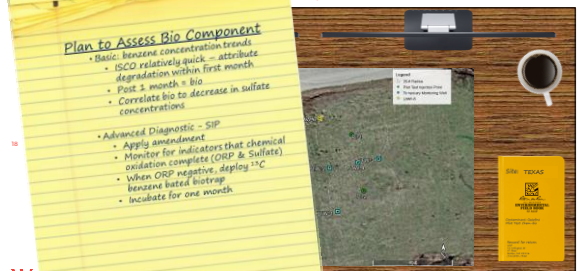


Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene



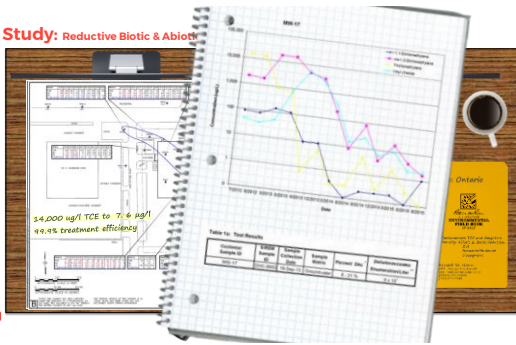
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Texas Case Study: Bio Contribution of a Chem/Bio Treatment Train of Benzene



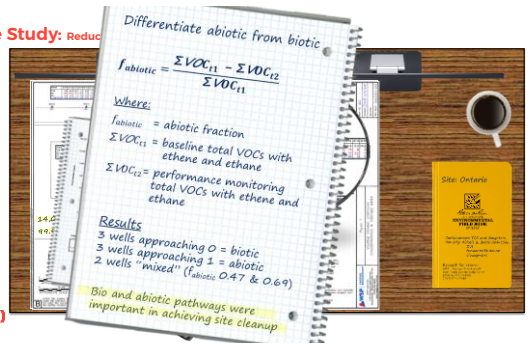
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Case Study: Reductive Biotic & Abiotic



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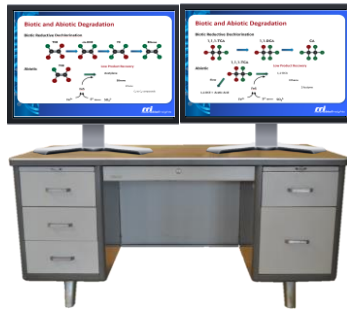
Case Study: Reductive Biotic & Abiotic



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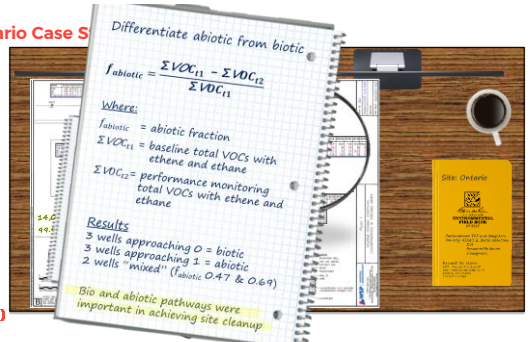
Complex Sites

Degradation Pathways



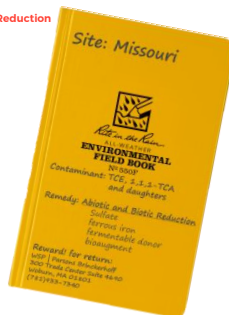
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Ontario Case Study



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Missouri Case Study: Bio + Biogeochemical Reduction



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Case Study Missouri

Biogeochemical Reduction

Biogeochemical Reductive Transformation
 a.k.a.

- biogeochemical transformation
- biogeochemical reductive dechlorination (BiRD)

Has been used to remediate chlorinated VOCs and other compounds for about 10 years

It involves abiotic reduction by reactive iron minerals – similar to ZVI. These ferrous iron-containing minerals include:

- Mackinawite
- Pyrite
- Magnetite
- Green rust

Can be a mechanism of MNA

Biogeochemical Reduc

Engineering Biogenic Iron Sulfide

- (1) Iron Reduction**
 $Fe^{2+} + \text{organic matter} \rightarrow Fe^{2+} + H_2O + CO_2$
- (2) Sulfate Reduction**
 $SO_4^{2-} + \text{organic matter} \rightarrow S^{2-} + H_2O + CO_2$
- (3) Iron Sulfide Precipitation**
 $HS^- + Fe^{2+} \rightarrow FeS + H^+$

Addition of sulfate to form FeS to treat chlorinated VOCs is a Patented Process:

- Kennedy - US Patent Off. #6,884,302 B3
- Contact Jim Studer of IntraSur
- jstuder@intrasur.com
- 505-858-5336

Synergies

Groundwater Monitoring & Remediation

More details including SEFA - in article

Biotic and Fe-based Abiotic Reductive Pathways are Compatible & Complementary

- Ferric iron inhibition disproven
 - Wei and Fineran Sci. Technol., 2013, 45 (17)
- Fe Reduces Dehalococoides (DHC) inhibition
 - Sulfide precipitates with Ferrous iron
 - Abiotic treatment of 1,1,1-trichloroethane
 - Iron reducers supply vitamin B12
- Some reduced minerals are not very reactive with dichloroethene - biodegradation can manage
- Generally, fermentable donors have a higher delivery efficiency than zero valent iron (ZVI) which results in a greater radius of influence (ROI)
- Lower redox potentials
- Minimize surface passivation
- Extend treatment longevity and manage rebound

Missouri Case Study: Bio + Biogeochemical Reduction

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Figure 1. Groundwater Total CVOC Degradation Trends

Missouri Case Study: Bio + Biogeochemical Reduction

Total CVOC Molar Conc. and $f_{abiotic}$ Trends

Recorded Webinar:
On Regenesi Website

Arkansas Site - Fractured Bedrock
Plume Stop + Bio
Biogeochemical + Bio

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REGENESI
Back Diffusion of VOCs from a Fractured Sandstone Aquifer Treated At Former Industrial Facility

Project Highlights

- 2014-2015: Initial site investigation of fractured VOC hot spot
- 2016-2017: Remediation design and implementation of bioremediation
- 2018-2019: Remediation design and implementation of bioremediation

Project Summary

Bioremediation is a natural process that uses microorganisms to break down and remove contaminants from the environment. It is a cost-effective and sustainable remediation technology that can be used to treat a wide range of contaminants, including VOCs, in fractured sandstone aquifers.

Site Details

The site is a former industrial facility located in Arkansas. It contains a fractured sandstone aquifer that has been contaminated with VOCs. The aquifer is fractured, which allows for the back diffusion of VOCs from the aquifer to the surface. The site is currently being remediated using bioremediation.

PLUME STOP

Michigan Case Study: Abiotic Reduction + Aerobic Bio

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Site: Michigan

ENVIRONMENTAL FIELD BOOK
No. 5507
Contaminant: trichlorobenzene and daughters
Remedy: Abiotic Reduction & Aerobic Bio
ZVI
fermentable donor

Reward: for return:
wsp | Parsons Brinckerhoff
500 Trade Center Suite 4440
Waltham, MA 02155
781.579-7540

Michigan Case Study: Abiotic Reduction + Aerobic Bio

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Small yellow field book on a wooden clipboard with a coffee cup.

Michigan Case Study: Abiotic Reduction + Aerobic Bio

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Site map with handwritten data:

- DO = 0.0 mg/l
- ORP: negative
- TCB ≈ 4,000 µg/l
- DCB ≈ 2.5 µg/l
- CB ≈ 10 µg/l
- B = 0.0 µg/l

Annotations on map: "Small area 2,000's permeable Aquifer", "Easy Delivery".

Michigan Case Study: Abiotic Reduction + Aerobic Bio

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Clipboard with site map and scientific paper titled "Anaerobic Oxidation of chlorobenzene (Michigan Site)".

Michigan Case Study: Abiotic Reduction + Aerobic Bio

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Clipboard with handwritten notes and scientific paper:

in situ microcosms - Study 2

Study 2 goal:
Assess the key step - anaerobic oxidation?
reduction to CB is known science

Study 2 tools:
bugs - qPCR
SIP-DNA 100% ¹³C chlorobenzene
DIC 10 to 20% ¹³C chlorobenzene
pre vs. post CB concentrations
idea about rate

Michigan Case Study: A

LAB REPORT

Site: Michigan Chlorobenzenes
Sample: M9-102
Procedure: SIP with 100% ^{13}C Chlorobenzenes with DOGE

Band	Similar Genus	Similarity Index
1.1	Bacteroides spp.	0.851
1.2	Clostracia spp.	0.811
1.3	Methanobrevibacter (family)	0.938
1.4	Acetivibrio spp.	0.896
1.5	Tribacterium spp.	0.912
1.6	Clostridia spp.	0.891
1.7	Tribacterium spp.	0.887
1.8	Bacteroides (order)	0.887
2.1	Acetivibrio spp.	0.888
2.2	Tribacterium spp.	0.866

Identified Genera:
 Acetivibrio
 Bacteroides
 Clostridia
 Methanobrevibacter
 Tribacterium

Similarity Index:
 > 0.8 = excellent
 0.7 - 0.8 = good
 < 0.6 = unique sequences

Additional Notes:
 Aerobic bacteria known to utilize aromatic compounds.
 Tribacterium: Aerotolerant/facultative fermentative bacteria.

Michigan Case Study: B

microaerophilic

Balozec et al. (2008) demonstrated in ex-situ microcosms that the extremely high oxygen affinities for chlorocatechol 1,2-dioxygenase support microaerophilic degradation chlorobenzenes.

In Gossett (2010), this phenomenon is tied to an "unexplained disappearance of vinyl chloride (VC) from what are thought to be anaerobic subsurface environments".

Michigan Case Study: Abiotic

microaerophilic

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Concurrent and Complete Anaerobic Reduction and Microaerophilic Degradation of Mono-, Di-, and Trichlorobenzenes

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Questions?

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