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In-Situ Microcosm Array, A New Tool for In Situ Remediation Tests

Sponsored by: U.S. EPA Office of Superfund Remediation and Technology Innovation

Delivered: August 15, 2012, 2:00 PM - 4:00 PM, EDT (18:00-20:00 GMT)

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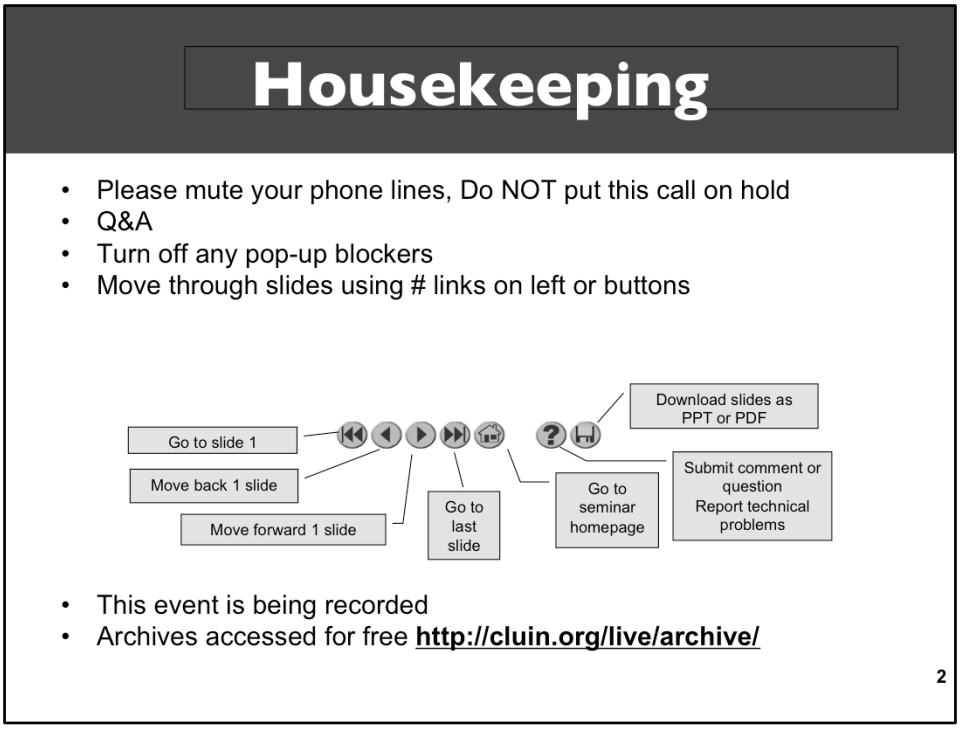

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You should note that throughout the seminar, we will ask for your feedback. You do not need to wait for Q&A breaks to ask questions or provide comments. To submit comments/questions and report technical problems, please use the ? Icon at the top of your screen. You can move forward/ backward in the slides by using the single arrow buttons (left moves back 1 slide, right moves advances 1 slide). The double arrowed buttons will take you to 1st and last slides respectively. You may also advance to any slide using the numbered links that appear on the left side of your screen. The button with a house icon will take you back to main seminar page which displays our agenda, speaker information, links to the slides and additional resources. Lastly, the button with a computer disc can be used to download and save today's presentation materials.

With that, please move to slide 3.

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In Situ Microcosm Array –
A New Tool for *In Situ* Remediation Tests

Presented by: Rolf U. Halden
Kristin McClellan and
Tomasz Kalinowski

August 15, 2012

www.biodesign.asu.edu

Outline

- Background & Rationale
- Technology Overview
- Results from Lab and Field Demonstrations
- Application Range & Requirements
- Summary & Conclusion

Background & Rationale

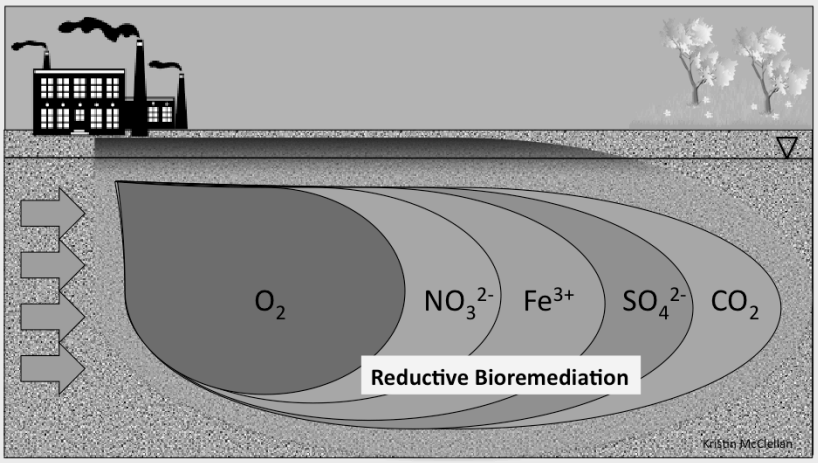
- *In situ* remediation is a rapidly growing market
- Field testing of *in situ* remediation strategies is essential but expensive using conventional means
- Innovation barrier exists: promising but unproven innovative technologies are rarely evaluated *in situ*

Objective

Development of a remedial design tool enabling parallel *in situ* testing of multiple candidate technologies without posing risk to aquifer during testing

Background

The Problem: How to test for *in situ* remediation potential?

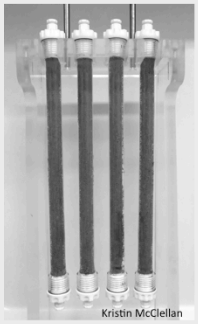


Background

Current strategies of testing for *in situ* remediation potential:

Batch microcosm

Flow-through microcosm



Field

Advantages of Lab Treatability Studies

- Possible to compare multiple technologies
- Replicates give statistical significance to results
- Nothing is released into the environment
- Batch bottles are relatively simple to conduct
- Column studies using flow-through conditions are the gold standard, as they more accurately simulate mass transfer conditions in aquifer

How to test for *in situ* remediation potential?

1. Batch studies

- Groundwater and sediment from contaminated site
- Monitoring of contaminant reduction over time
- Closed system
- Sediment slurry

How to test for *in situ* remediation potential?

1. Batch studies - Anoxic/anaerobic bioremediation

- Groundwater and sediment from contaminated site
- Monitoring of contaminant reduction over time
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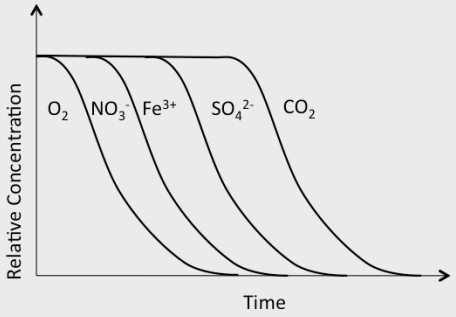
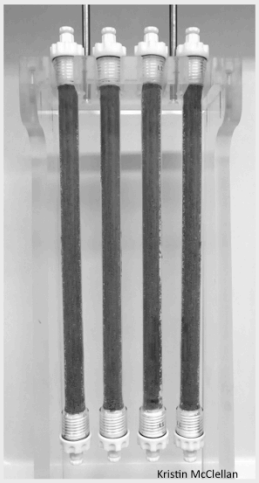


Kristin McClellan

How to test for *in situ* remediation potential?

2. Column study

- Sediment from site in columns
- Groundwater is pumped through
- Flow-through system
- Sediment dominated



How to test for *in situ* remediation potential?

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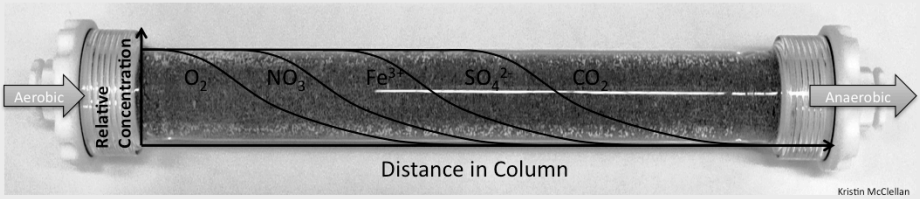


Kristin McClellan

Ex Situ Limitations

- Chemical changes
- Microbial changes
  - O_2 intrusion
  - Grazing
- Temperature differences
- Rates not truly predictive

Arguments for Conducting Field Studies

- A process observed in the field typically can be replicated in the laboratory but not all processes observed in the laboratory (e.g., batch microcosm) can be replicated in the field
- Lab ≠ Field => For example, mixing ingredients in a bottle is easy but creating under field conditions proximity between pollutants, degradative agents (e.g., oxidants, bacteria) and initiators (e.g., catalysts, nutrients) is a supreme challenge in subsurface remediation

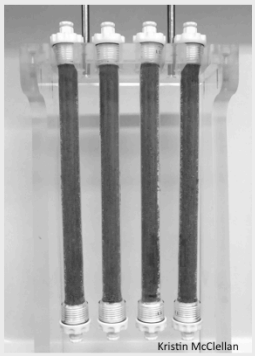
3. Field Pilot Trials

In situ results are the most valuable

Challenges of Field Pilot Trials

- Compounds released into the well
- Limited to safe / approved technologies
- Risk of damaging well
- Only single trial per well
- Can be difficult to discern between remediation and dilution
- Expensive

A New Alternative:
The *In Situ* Microcosm Array (ISMA)



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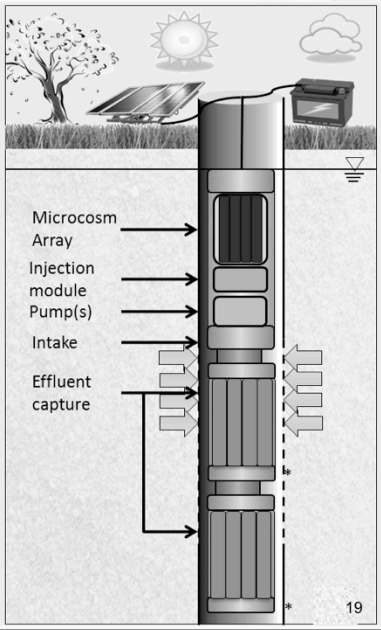
In Situ Microcosm Array



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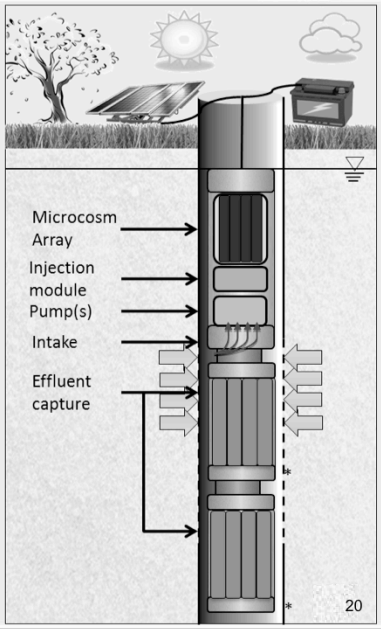
In Situ Microcosm Array

- Groundwater drawn directly from screened portion of well by *intake unit*
- Filtered for particulate matter
- Split into 12 lines by the manifold



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In Situ Microcosm Array

- Groundwater drawn directly from screened portion of well by *intake unit*
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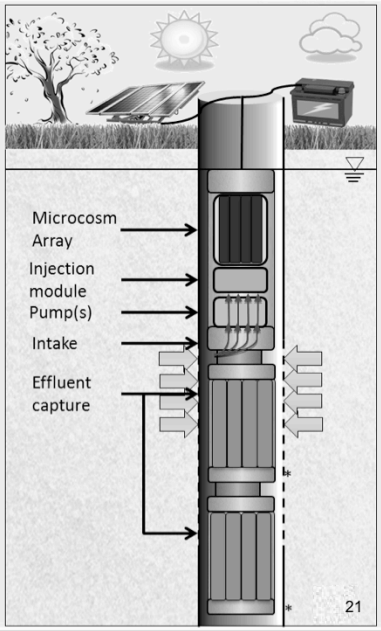
- *Peristaltic pump* regulates flow rate



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In Situ Microcosm Array

- Groundwater drawn directly from screened portion of well by *intake unit*
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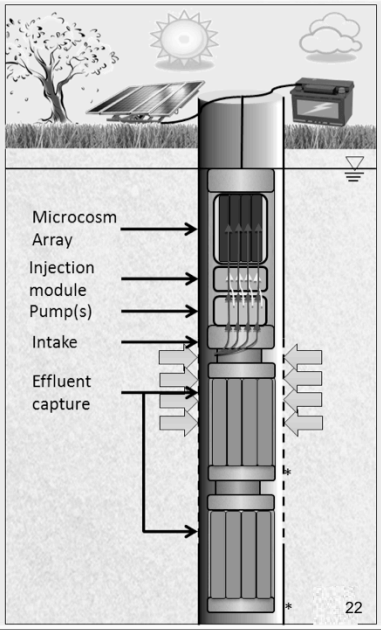
- Split into 12 lines by the manifold
- *Peristaltic pump* regulates flow rate
- *Injection module* delivers remediation agents (biological or chemical)



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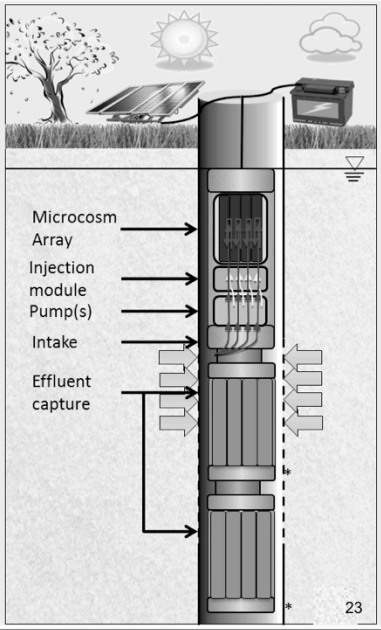
- Sediment *microcosm array* packed with site-materials



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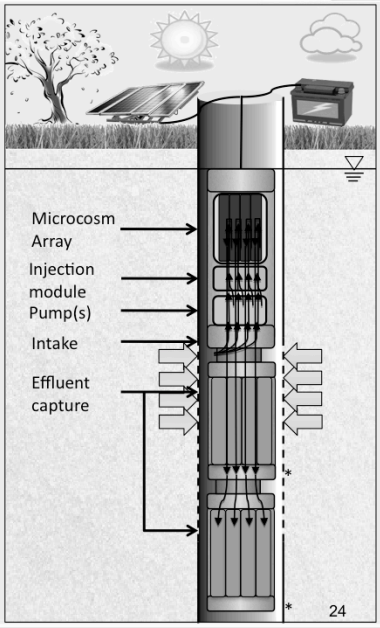
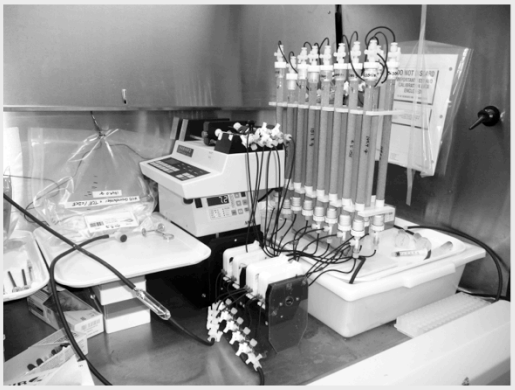
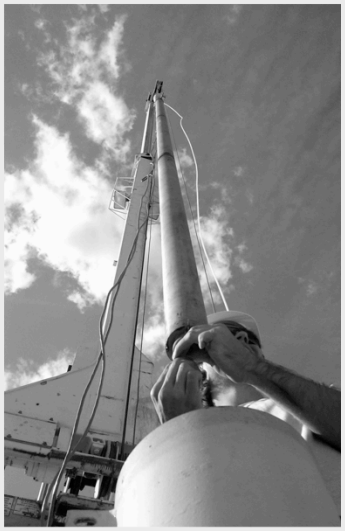
In Situ Microcosm Array

- Groundwater drawn directly from screened portion of well by *intake unit*
- Filtered for particulate matter
- Split into 12 lines by the manifold
- *Peristaltic pump* regulates flow rate
- *Injection module* delivers remediation agents (biological or chemical)
- Sediment *microcosm array* packed with site-materials
- *Effluent capture* compartments store all samples during deployment



The Challenge

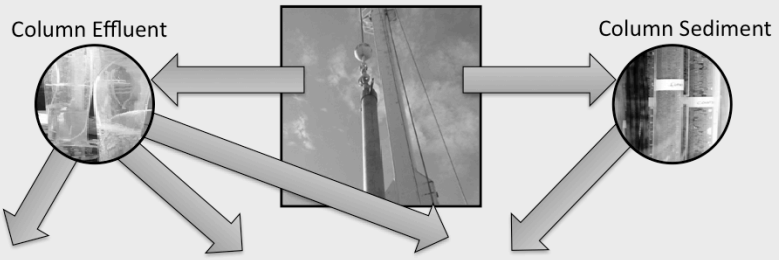




The Hardware

In the Field

Post-Deployment Analyses



Chemical

- Contaminant reduction
- Secondary contaminants

Protein

- Biomass

DNA

- PCR
- qPCR
- Pyrosequencing
- …

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Case Study I - Perchlorate

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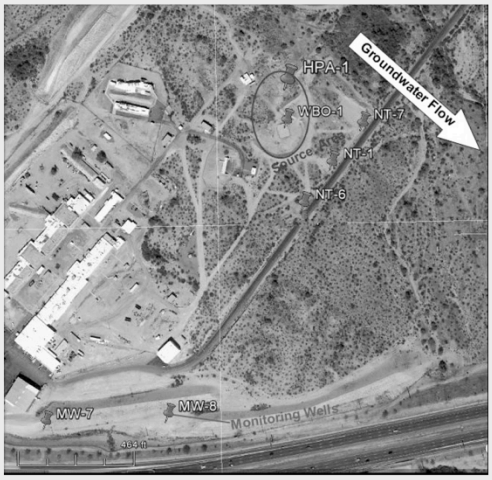
Tomasz Kalinowski, PhD Cand.
Rosa Krajmalnik-Brown, PhD
Thomas Bruton
Isaac Roll
Sam Supowit
Heping Zhao, PhD

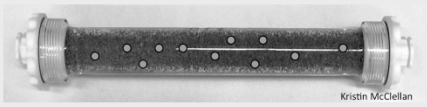
Perchlorate Case Study

- Small ammunitions manufacturing plant in Phoenix Metropolitan Area
- Perchlorate in vadose zone (ppm) and aquifer (ppb)
- Rising water table is mobilizing high perchlorate mass present in soil



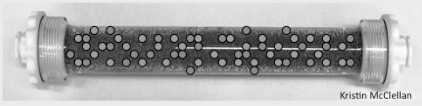
Column Test Design – *In Situ* Perchlorate Reduction

1. Monitored natural attenuation (MNA)



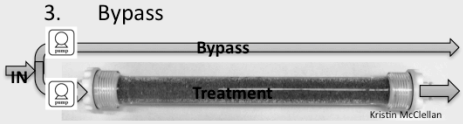
- Site sediment used as solid matrix
- Site groundwater containing live bacteria is pumped through sediment columns
- Naturally occurring bacteria settle in sediment column and grow

2. Biostimulation/Bioaugmentation



- Same setup as #1 (MNA)
- Sodium lactate added as carbon source / electron donor for biostimulation
- Perchlorate reducing seed culture added for bioaugmentation

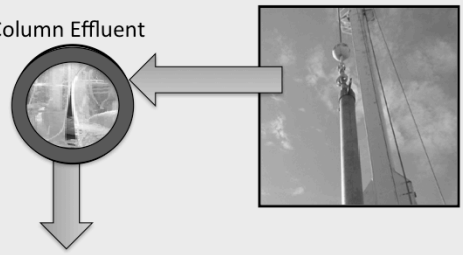
3. Bypass



- Site groundwater is collected throughout experiment to determine starting perchlorate concentration

Analysis Approach

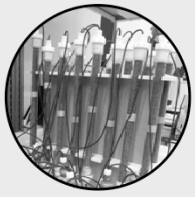
Column Effluent



Chemical

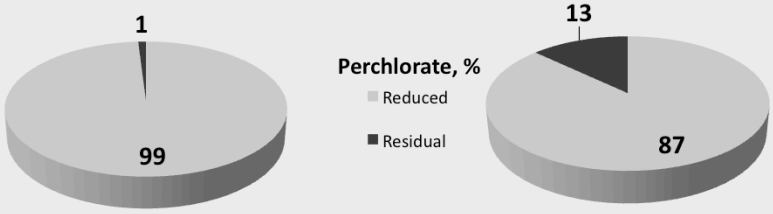
- Contaminant reduction
- Secondary contaminants

Column Tests – Biostimulation/Bioaugmentation



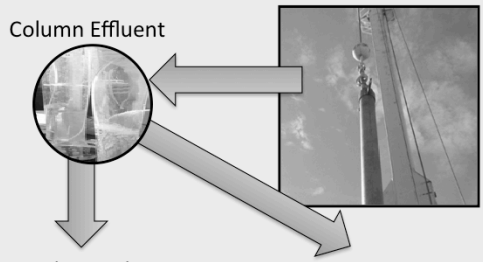
Lab Column Study

Field Column Study



(Based on analysis of column effluent)

Post-Deployment Analysis



- Contaminant reduction
- Secondary contaminants

- PCR
- qPCR
- Pyrosequencing
- …

DNA Copy Numbers in Column Effluent

Lab

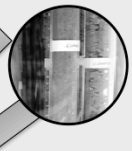
- General bacteria increased 2 orders of magnitude during Bioaug/Biostim
- Perchlorate reducers increased 2.5 orders of magnitude during Bioaug/Biostim
- No change for Natural Attenuation

Field

- General bacteria increased 2 orders of magnitude during Bioaug/Biostim
- Perchlorate reducers increased 3 orders of magnitude during Bioaug/Biostim
- No change for Natural Attenuation

Post-Deployment Analysis

Column Sediment



DNA

- PCR
- qPCR
- Pyrosequencing
- …

DNA Copy Numbers in Sediment

Lab

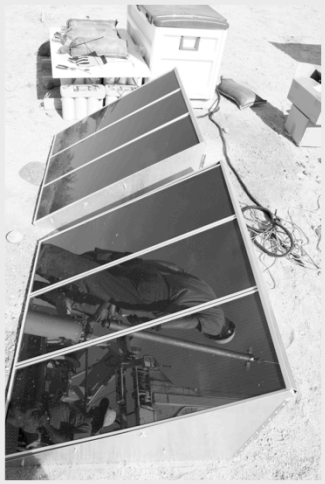
- General bacteria increased 2.5 orders of magnitude during Bioaug/Biostim
- Perchlorate reducers increased 3.5 orders of magnitude during Bioaug/Biostim

Field

- General bacteria increased 2.5 orders of magnitude during Bioaug/ Biostim
- Perchlorate reducers increased 3 orders of magnitude during Bioaug/ Biostim

Case Study Summary

- Evaluated biostimulation, bioaugmentation, MNA *in situ* in a single well without releasing any bacteria or chemicals
- Demonstrated that suitable conditions can be created *in situ* at this site enabling anoxic bioreduction of perchlorate in this presently aerobic aquifer
- Obtained quadruplicate measurements for two mutually exclusive candidate cleanup strategies in the field in a single well & deployment



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Case Study II – Chlorinated Solvents, Chromium (VI)

Authors and Contributors: Rolf Halden, PhD, PE
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Kristin McClellan, PhD Cand.
Thomas Bruton
Isaac Roll
Rosa Krajmalnik-Brown, PhD
Michal Ziv-El, PhD

Objective: Demonstrate the possibility of measuring potential rates of reductive dechlorination in a presently aerobic aquifer using ISMA

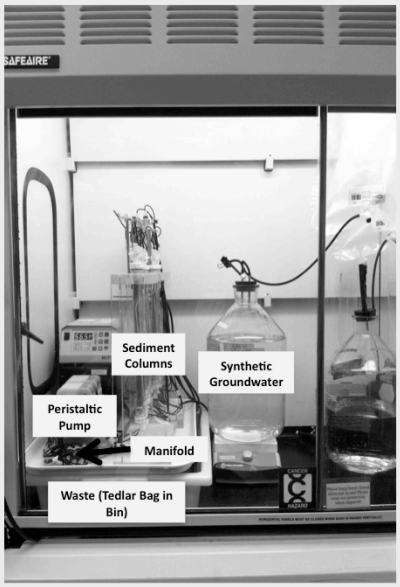
- Selected well has contaminant mixture:
  - Trichloroethene (15 mg/L)
  - Hexavalent chromium (25 mg/L)
- Can *in situ* bioremediation work?
  - Chromium toxicity / inhibition concerns

Experimental Design – Lab Study

Name	Column Media	Inoculum	Injection Module	Replicates
MNA	Site Sediment	-	-	3
Biostimulation	Site Sediment	-	Sodium Lactate	3
Bioaugmentation	Site Sediment	KB-1	Sodium Lactate	3

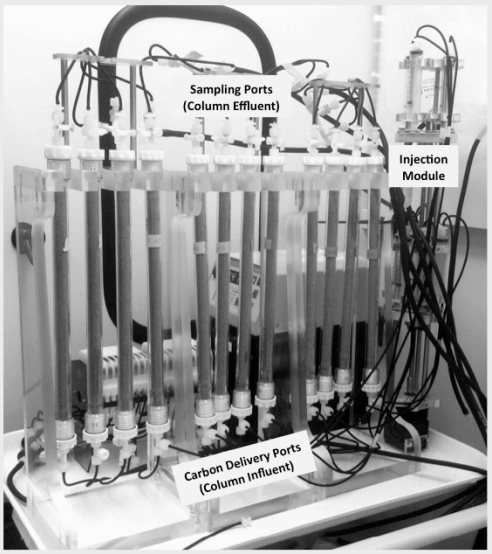
Lab configuration

- Entire assembly in fume hood
- Columns operated in up-flow mode
- Synthetic groundwater is completely aerobic
- Shares parts with the ISMA (only main peristaltic pump is modified to fit in the 3.5” shell)

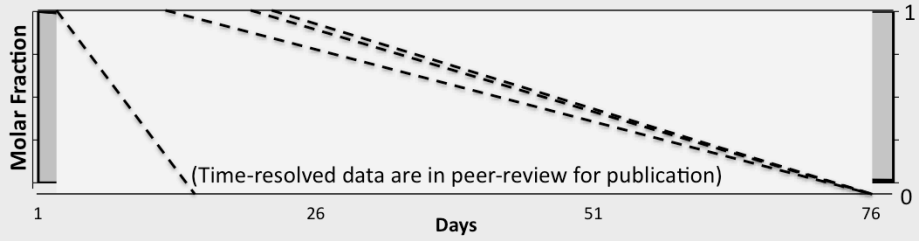


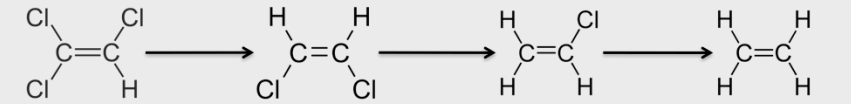
Lab configuration

- Injection Module delivers carbon source from 10 mL syringe
- Delivered into columns via 3-way port directly at column influent
- Carbon source ~1% of influent flow-rate

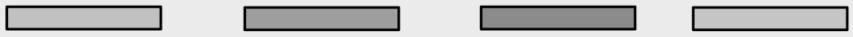


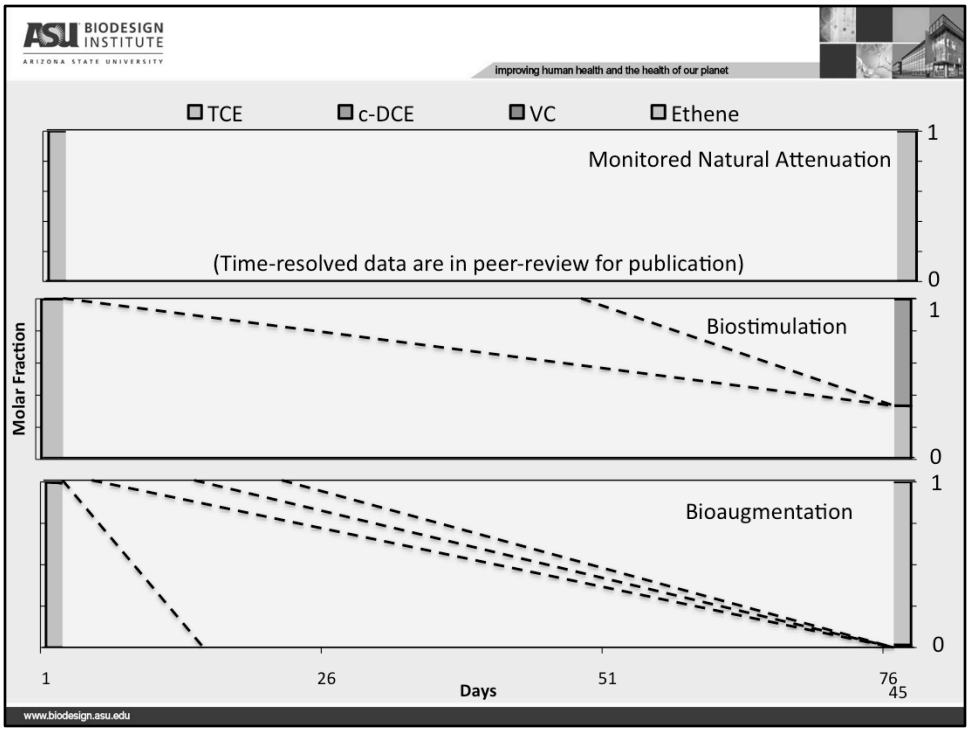
Mass Balance in Lab Study: Effluent of bioaugmented columns





Trichloroethene | *cis*-1,2-Dichloroethene | Vinyl chloride | Ethene

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Biostimulation
Bioaugmentation
Molar Fraction
1
0
1
26
51
76
Days
45
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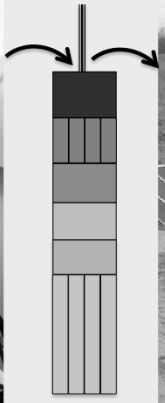
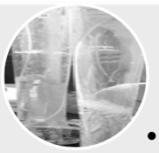
Deploy pre-conditioned columns *in situ*



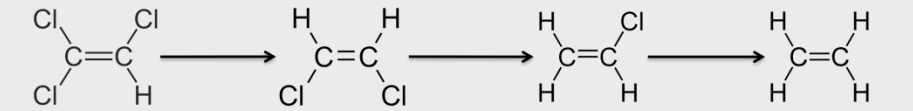
35 days



Chemical Analysis of Effluent from *In Situ* Columns

- Total chromium
  - MNA: no reduction
  - Biostimulation: 4 mg/L reduction
  - Bioaugmentation: 4 mg/L reduction
- Trichloroethene
  - MNA: 2 µM reduction
  - Biostimulation: 2 µM reduction
  - Bioaugmentation: 3.5 µM reduction
- Dechlorination byproducts (*c*DCE, VC, ethene)
  - Detected in bioaugmented columns

Can anaerobic *in situ* bioremediation work at this presently aerobic site?



Trichloroethene	*cis*-1,2-Dichloroethene	Vinyl Chloride	Ethene
Consumed	Produced	Produced	Produced
✔	✔	✔	✔

Case Study II: Summary

- Demonstrated the *in situ* use of small, pre-conditioned sediment columns that take in aerobic site groundwater and produce anaerobic effluent
- Successfully simulated *in situ* reductive dechlorination of TCE in aerobic aquifer in the presence of Cr^{VI}
- Demonstrated the feasibility of measuring three mutually exclusive treatment strategies *in situ* in a single well in triplicate experiments
- Nothing was released into the aquifer during ISMA test

Application Opportunities:
Biological & Chemical

ISMA – Examples of Chemical Applications

✓ ISCO	In Situ Chemical Oxidation
✓ ISCR	In Situ Chemical Reduction
✓ ZVI	Zero Valent Iron
✓ n-ZVI	Nano-ZVI

(Continued)
ISMA – Examples of Biological Applications

- ✓ MNA Monitored Natural Attenuation
- ✓ EOS Emulsified Oil Substrates
- ✓ **ISAB** **In Situ Anaerobic Bioremed.**
- ✓ ORC/HRC O_2/H_2-Release Compounds
- ✓ e-ZVI Emulsified ZVI
- ✓ IWR In-well Recirculation
- ✓ Bio-/Air-sparging Aerobic Biostimulation
- ✓ BA Bioaugmentation

What Does It Take to Conduct an ISMA Field Test?

- *In Situ* Microcosm Array is a reusable device
- Consumables include disposable tubing and effluent compartments (anything that comes into contact with groundwater)
- Deployable in about 2 hours by one site worker and a boom-truck operator
- Unattended *in situ* incubation takes days to multiple weeks
- Retrieval takes about 4 hours
- Sediment and water samples can be analyzed by certified contract lab

What Are the Requirements at the Field Site?

ESSENTIAL*

- Standard 4”-ID well or larger
- >10 feet borehole length
- >3 feet of saturated thickness
- Sufficient space for access of boom truck or crane

DESIRABLE

- Sediment/soil from field site (fresh, archived or from surface/outcrop)

NON-ESSENTIAL

- Grid power in lieu of solar power/battery operation

* Specifications apply to DoD/ESTCP-evaluated 4”-ID ISMA device

How Much Does an ISMA Deployment Cost? *It Depends!*

Configuration considerations:

- # of treatments simulated (typically 2-3; maximum 11 plus influent)
- # of replicates within the device (up to 6)
- Pre-conditioning of columns in lab can increase cost

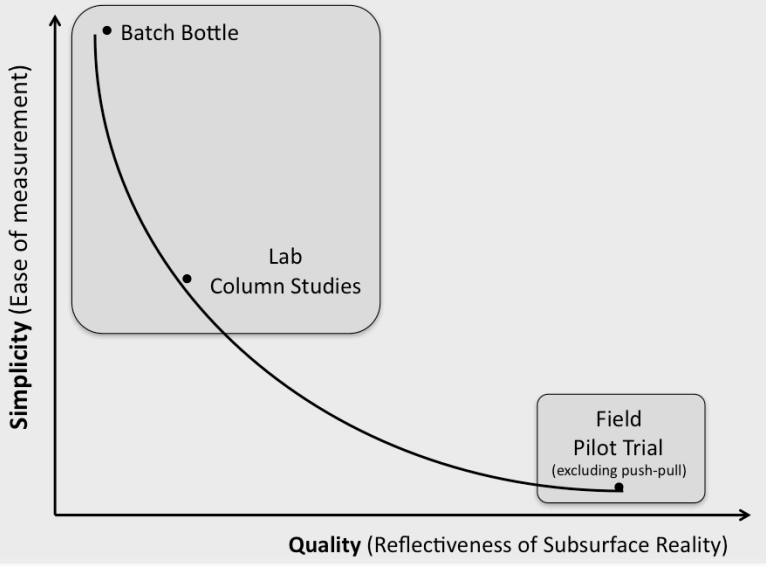
Analysis considerations:

- Water only or water & sediment
- Chemistry only or chemistry & microbiology

Placement of ISMA in cost continuum:

Lab microcosms ($) < ISMA deployment ($ to $$) << field pilot test ($$$)

Goal of ISMA: Quality ↑, Simplicity ↑ & Cost ↓



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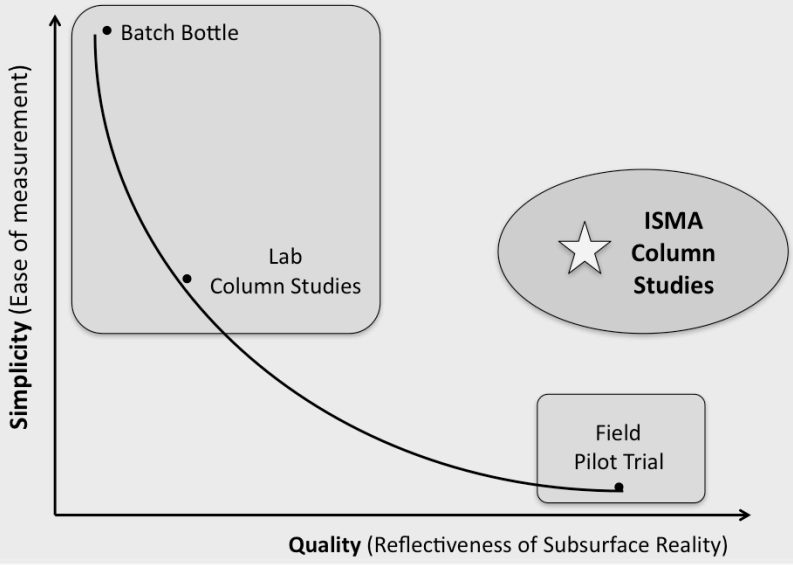
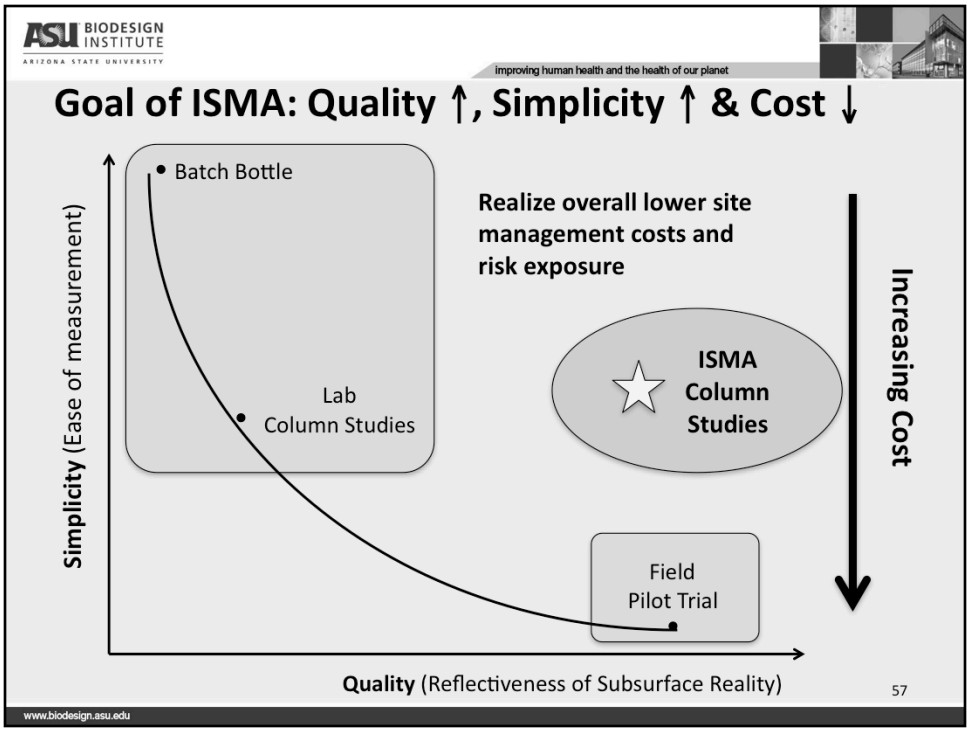
Goal of ISMA: Quality ↑, Simplicity ↑ & Cost ↓

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Goal of ISMA: Quality ↑, Simplicity ↑ & Cost ↓
Batch Bottle
Lab
Column Studies
Realize overall lower site management costs and risk exposure
ISMA
Column
Studies
Increasing Cost
Field
Pilot Trial
Simplicity (Ease of measurement)
Quality (Reflectiveness of Subsurface Reality)
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Take Home Message

- *In Situ* Microcosm Array (ISMA) is a new remedial design tool for evaluating *in situ* remediation technologies
- Performs multiple treatment tests simultaneously under *in situ* conditions
- Poses no risk to aquifer (nothing is released during *in situ* incubation)
- Can evaluate mutually exclusive chemical and biological treatments side-by-side *in situ*
- Yields field data at a fraction of the cost of a conventional field pilot test

The ISMA Team


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