# THE MIN-TRAP™ SAMPLER

## A New Monitoring Well-Based Sampling Tool for Documenting In Situ Mineral Formation

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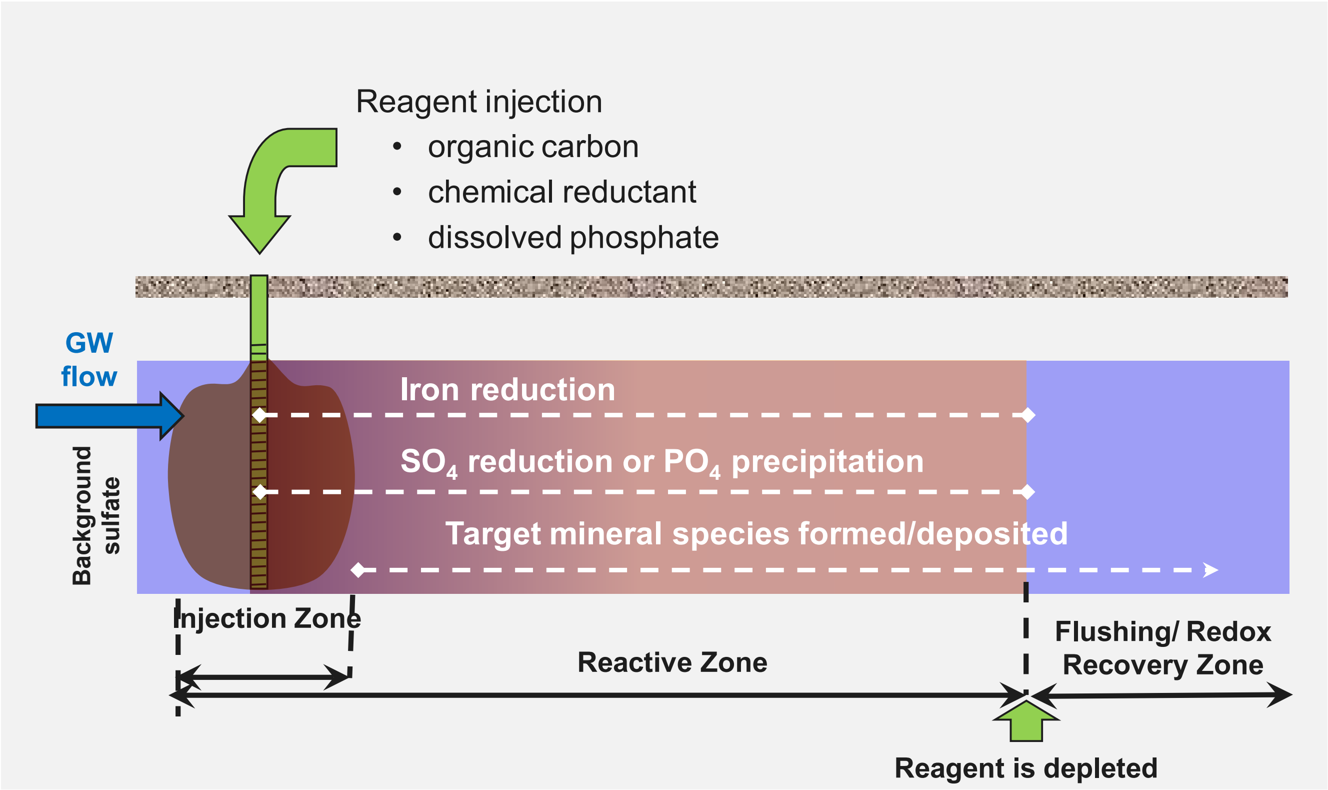
# In Situ Treatment and Mineral Precipitation

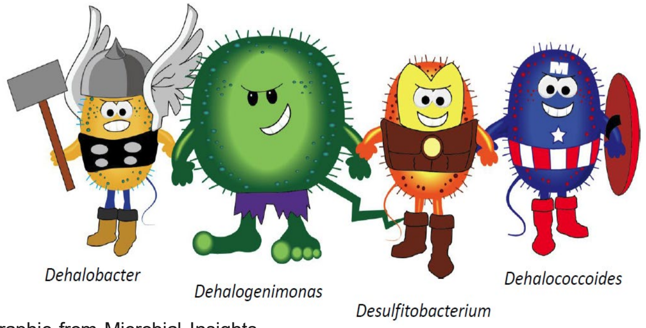
Examples:

1. Metal sulfides or phosphates for in situ sequestration (NiS, U-$PO_4$ compounds, etc.)
2. Reactive reduced iron minerals to abiotically degrade chlorinated solvents



## Anaerobic Biodegradation

Fermentable organic carbon provides electrons that drive the sequential reduction process

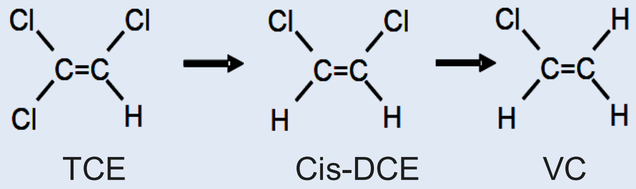



Graphic from Microbial Insights

**Biological Reductive Dechlorination**

Sequential Reductive Dechlorination

also called Hydrogenolysis

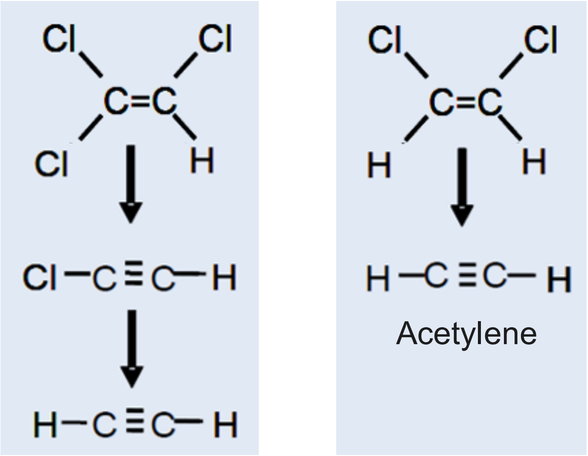



Adapted from Wilson 2014

## Abiotic Degradation

- ➔ Fermentable organic carbon provides electrons which drive microbial reduction of Fe and $SO_4^{2-}$
- ➔ $Fe^{2+}$ and $HS^-$ are generated and FeS (mackinawite) and $FeS_2$ (pyrite) can then form
- ➔ Reductive elimination results in degradation products not easily measured

TCE | cDCE




Acetylene

# How do we know what's really happening under the surface?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Groundwater samples

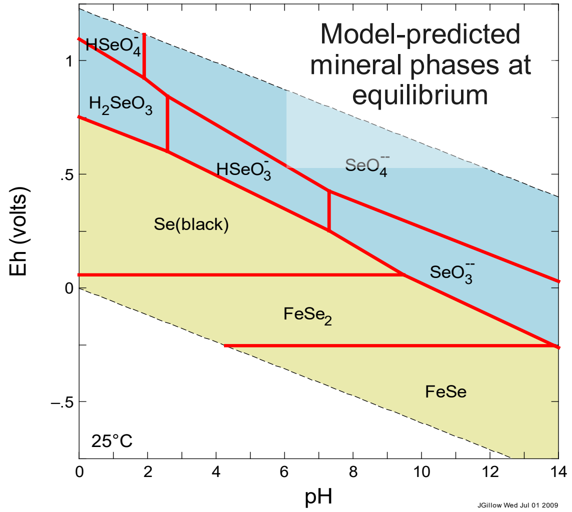
- Must extrapolate data to solid-phase processes
- Loss of reactive species such as $HS^-$ or $Fe^{2+}$
- Snapshots in time

Geochemical modeling

- All models have simplifying assumptions
- Predicts equilibrium conditions (kinetics not considered)

Soil samples from drill cores

- Costly, often a one-shot opportunity
- Obtaining representative samples can be difficult
- Samples may have significant background "noise"




Soil sample with heterogenous mineral distribution

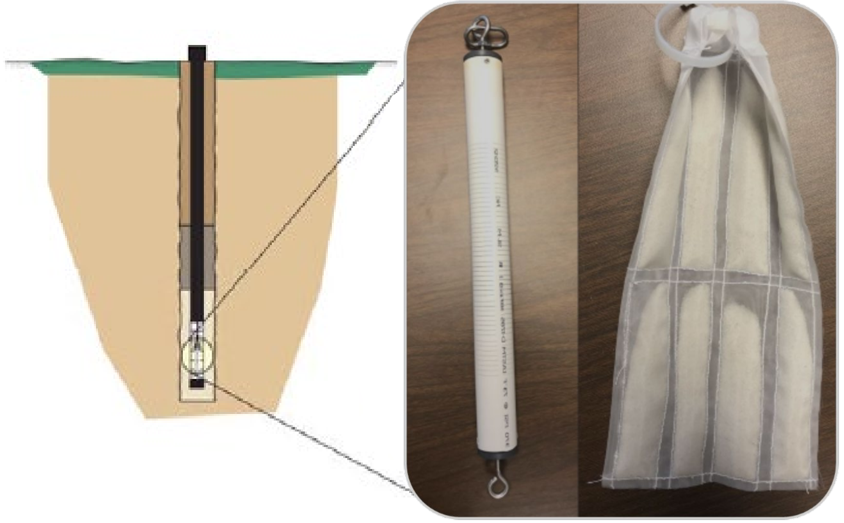
Soil core with heterogenous mineral distribution

***There is a clear need to improve our ability to assess mineralogical changes at remediation sites***

# Something New: The Min-Trap

- ➔ A 15-inch long PVC slot-screen housing containing multiple porous media pillows that collects minerals forming at site using existing monitoring well network
- ➔ Customizable porous medium inside mesh pillows acts as a matrix for precipitating minerals
- ➔ Analytical packages are tailored based on technical objectives
- ➔ Representative of conditions in higher-flux zones
- ➔ Inexpensive, easily repeated
- ➔ No significant background "noise" in samples
- ➔ Patent pending, manufactured and sold by Microbial Insights

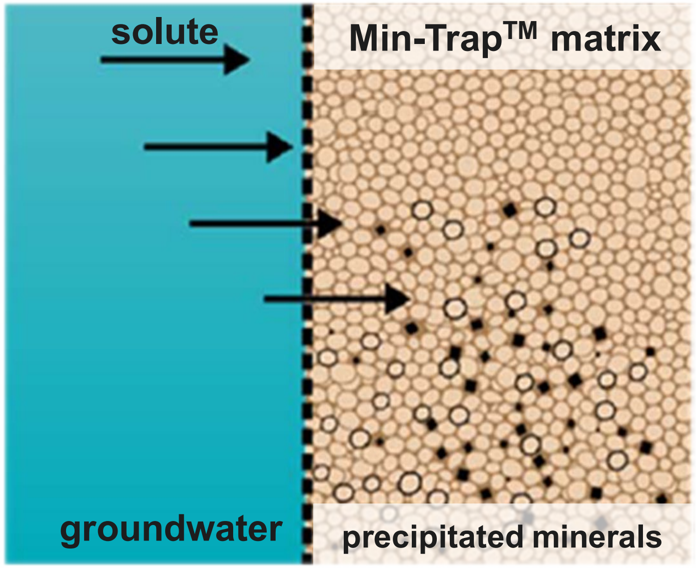
www.microbe.com



Deployed in standard 2"+ monitoring well

Slotted PVC casing

Porous medium in permeable mesh




***Min-Traps can conclusively document the formation of specific minerals; therefore, they can be used to verify important geochemical and remedial processes that usually are only inferred***

# Potentially Applicable Analyses

| Category | Analyses | Information |
|---|---|---|
| Chemical | • Metals and inorganics<br>• Weak and strong acid soluble iron (WAS, SAS)<br>• Acid-volatile sulfide (AVS), Chromium-extractable sulfide (CrES) | • Precipitated metals & element ratios<br>• Biogenic (pseudocrystalline) vs. crystalline minerals<br>• Sulfur forms: FeS vs. FeS2 and $S^0$ |
| Microscopy | • Light/petrographic<br>• Scanning Electron Microscopy (SEM)<br>• Transmission Electron Microscopy (TEM) | • Mineral grain size, shape, distribution |
| Spectroscopy | • Energy Dispersive X-ray Spectroscopy (EDS)<br>• X-ray Absorption Spectroscopy (XAS) | • Elemental composition<br>• Elemental coordination |
| General | • Magnetic susceptibility (magnetite) | • Mineralogy<br>• Magnetic mineral content |
| Molecular biology | • QuantArray | • Microbial community |

# Bench Testing

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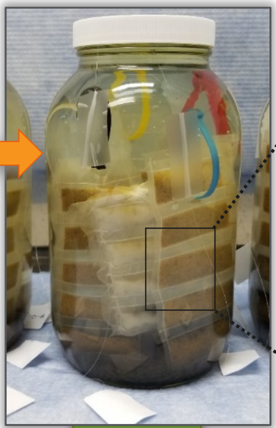
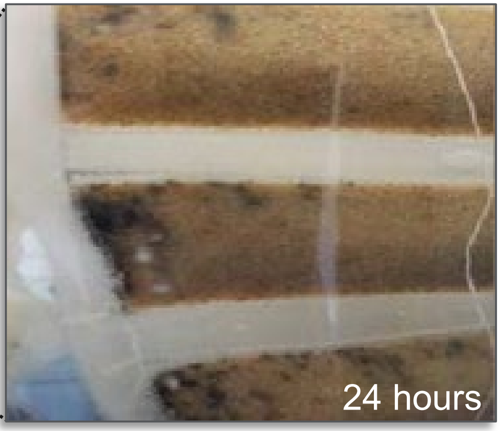
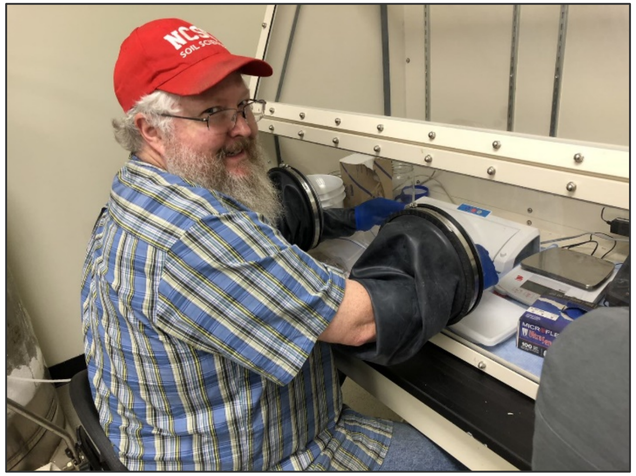
Incubation solution creates enhanced reductive dechlorination conditions



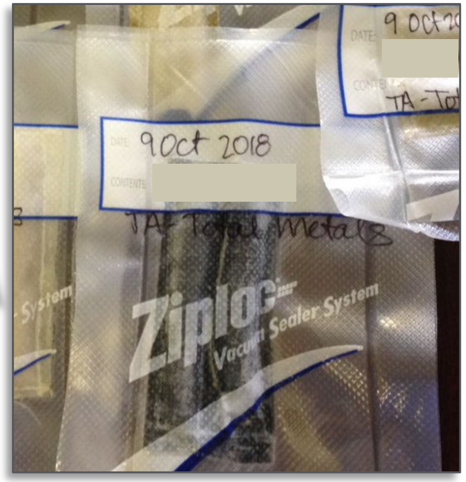


Two weeks

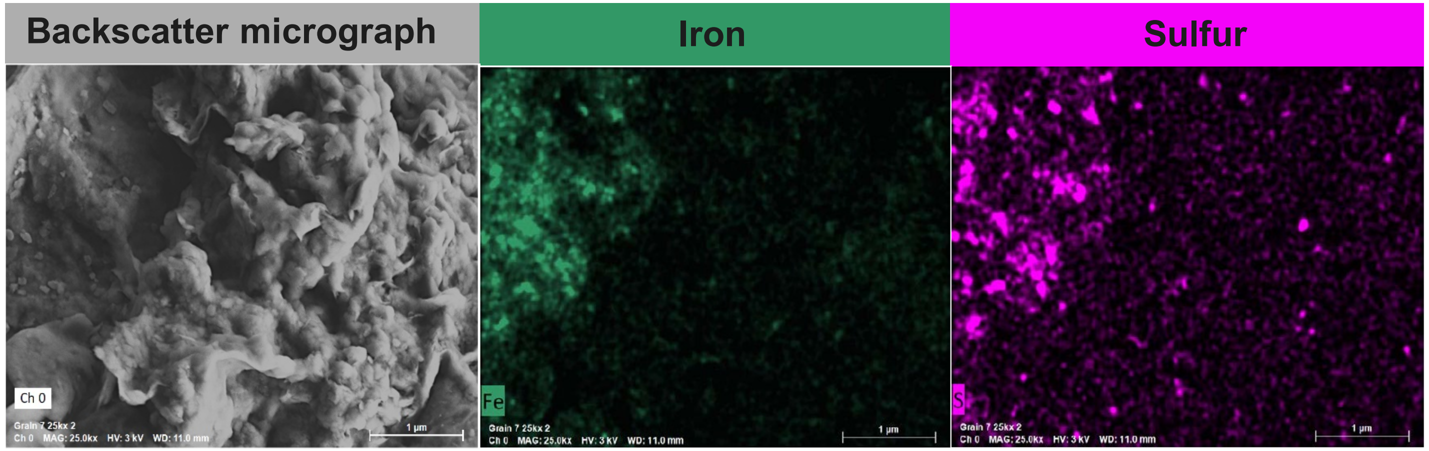
Harvest

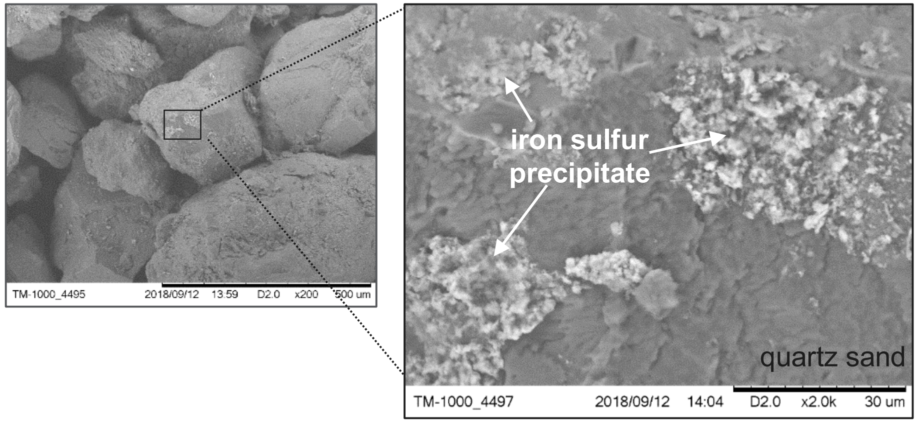
Subsample & analyze

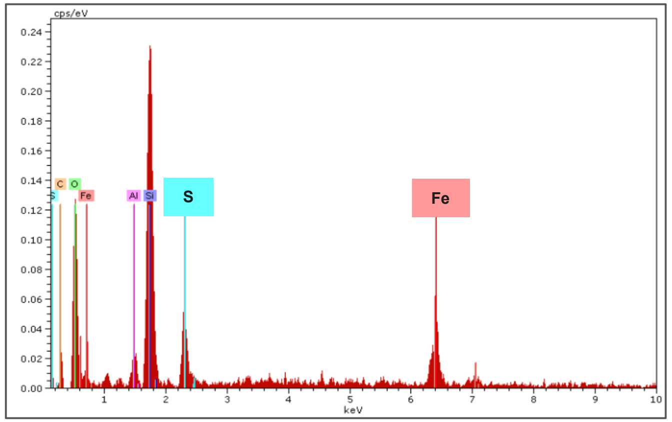


WAS/SAS iron: >95% ferrous iron

AVS/CrES: 80% FeS , CrES ~20% $FeS_2$ or $S^0$



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# Field Testing


Chloromethanes up to ~20 mg/L

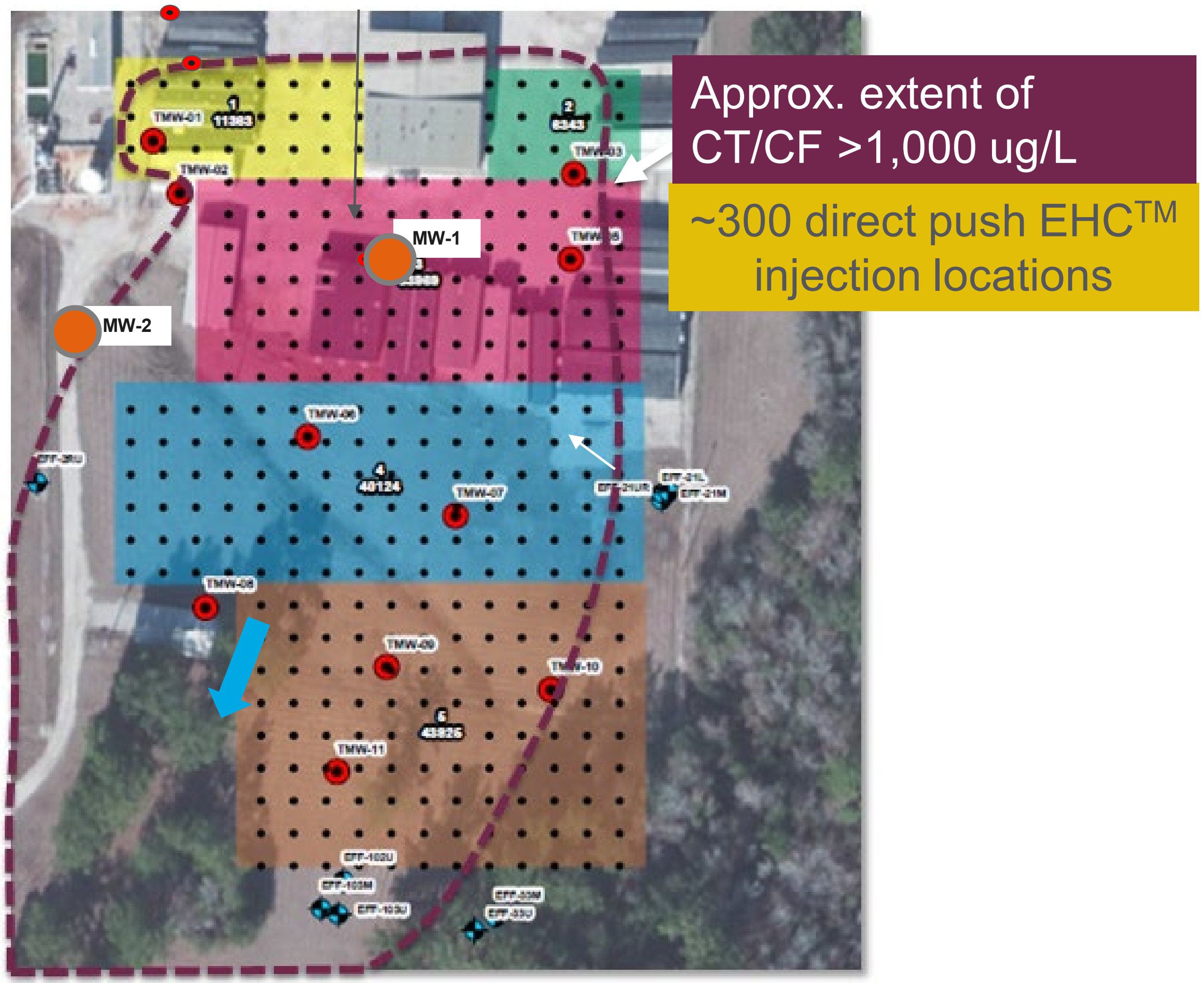
Co-disposed S-containing compounds

Naturally high iron

EHC™ treatment June-August 2018

Min-Traps deployed Aug 2018

Retrieval and analysis October 2018 April 2019, respectively



# Field Testing

Documentation of FeS, $FeS_2$ in Min-Traps would confirm:

✓Formation of reactive minerals in the aquifer

✓Presence of multiple CVOC degradation pathways

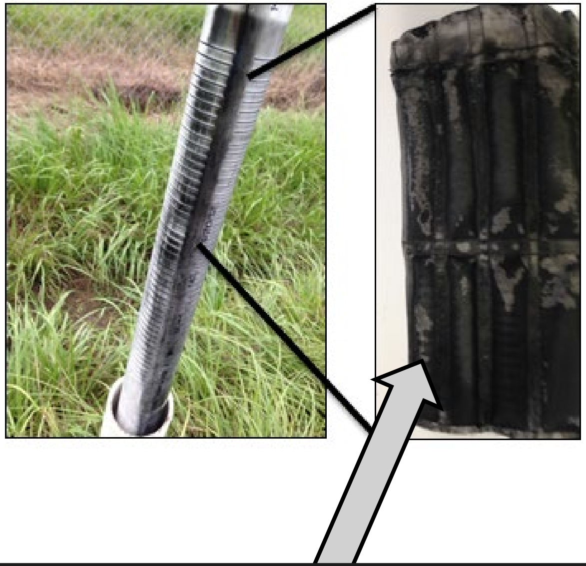
✓Migration and re-precipitation of dissolved constituents ($Fe^{2+}$) from EHC™ injection site (***increased ROI***)

✓Expanded treatment capacity beyond EHC™'s direct reduction by ZVI/biological ERD by increasing the treatment zone size and longevity

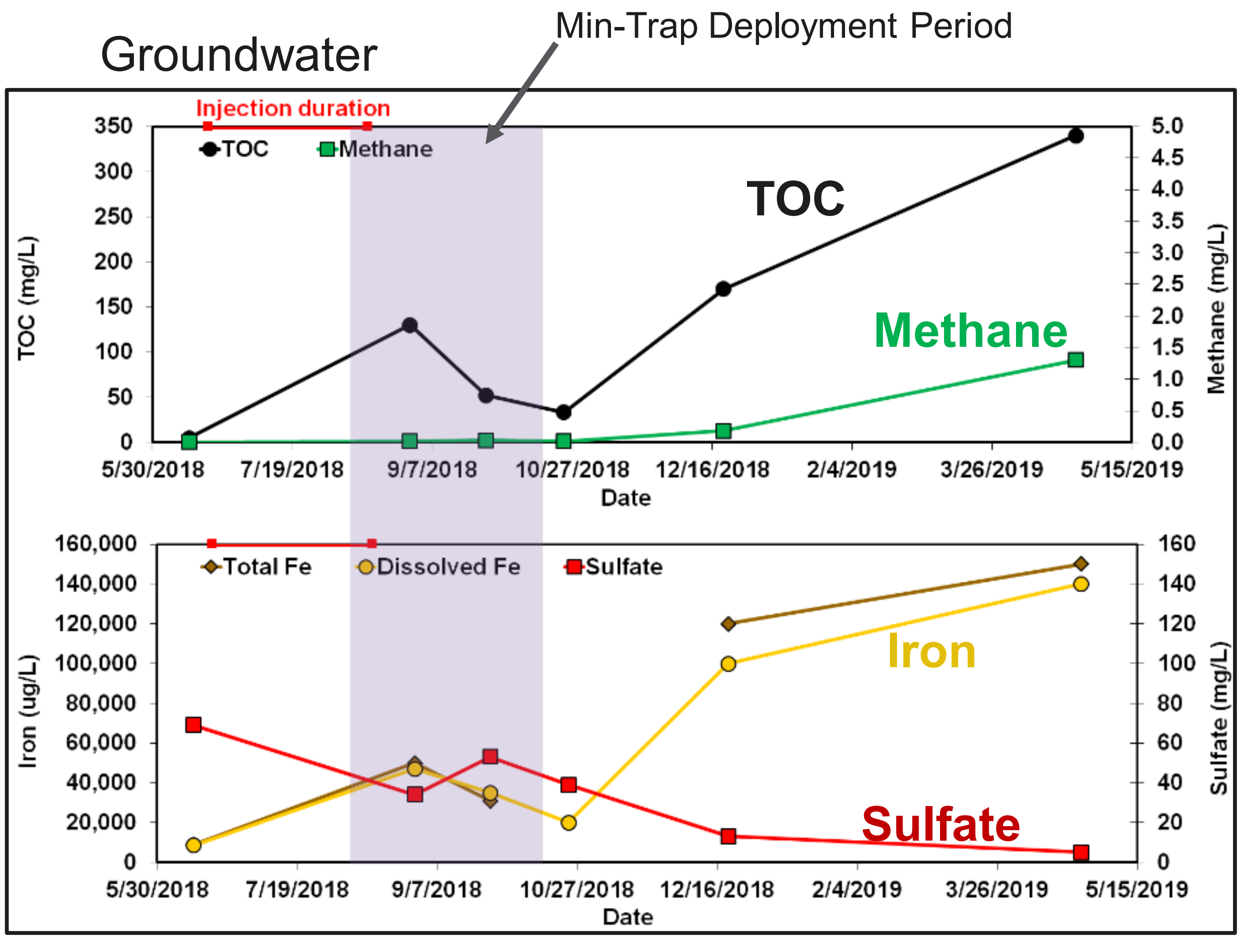
***Min-Trap data can help optimize remedial strategies to maximize formation of reactive mineral species.***

# Field Testing

MW-2: located at downgradient edge of EHC™ injection area



Groundwater




| WAS Iron (mg/kg) | SAS Iron (mg/kg) | AVSulfide (mg/kg) | CrESulfide (mg/kg) |
|---|---|---|---|
| $Fe^{2+}$ = 330<br>$Fe^{3+}$ = 0 | $Fe^{2+}$ = 300<br>$Fe^{3+}$ = 30 | 240 | 120 |

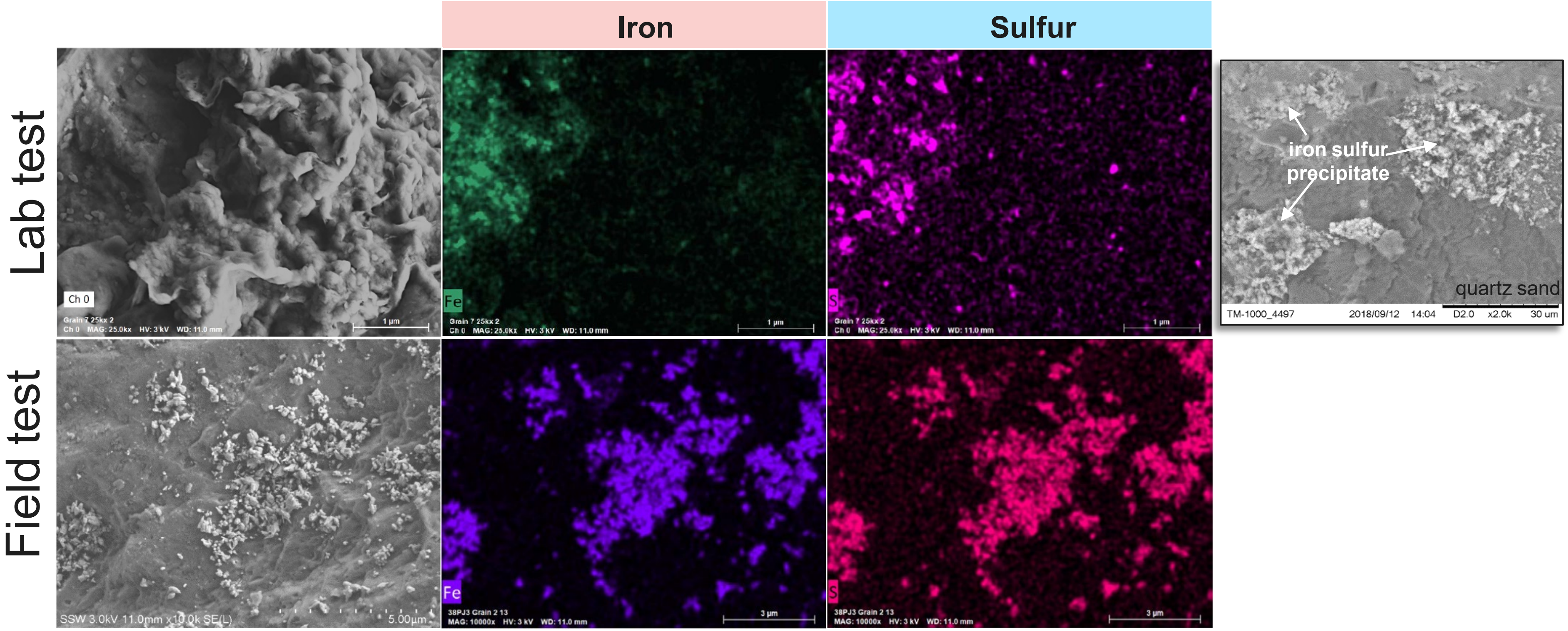
WAS/SAS iron: 90% ferrous iron, biogenic

AVS/CrES: Mostly FeS, some $FeS_2$ and/or co-disposed S

# Min-Trap Analysis



MW-2 Results – SEM with Energy Dispersive X-Ray Spectroscopy (EDS)



# Field Testing

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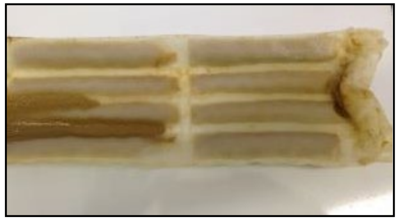
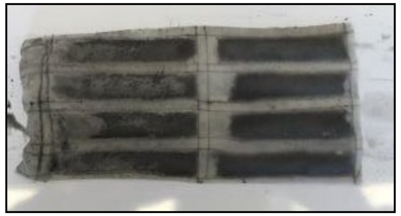
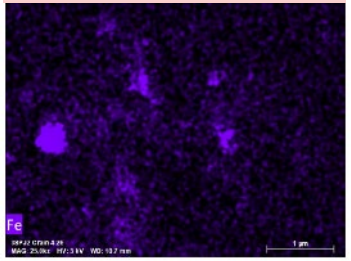
## MW-1: Original source area, within injection area

| Collected on 10/9/18 (~2 months after deployment) | Collected 4/26/19 (~6 months after deployment) |
| --- | --- |

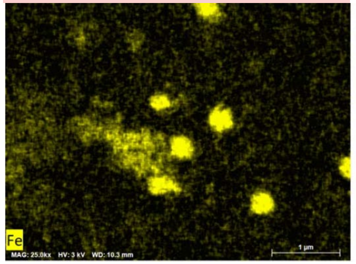




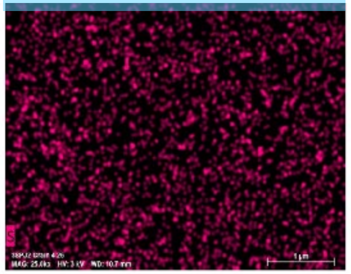
Iron



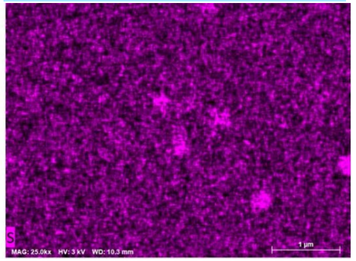

Iron




Sulfur



Sulfur

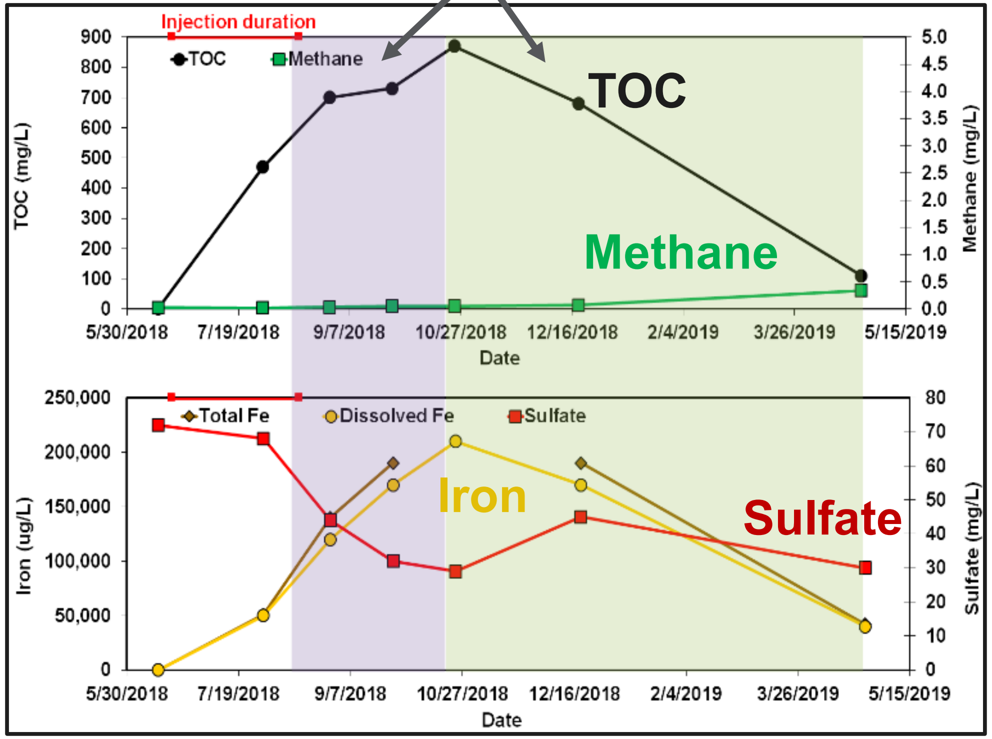


No apparent co-location of Fe and S

Some apparent co-location of Fe and S

## Groundwater

Min-Trap Deployment Periods

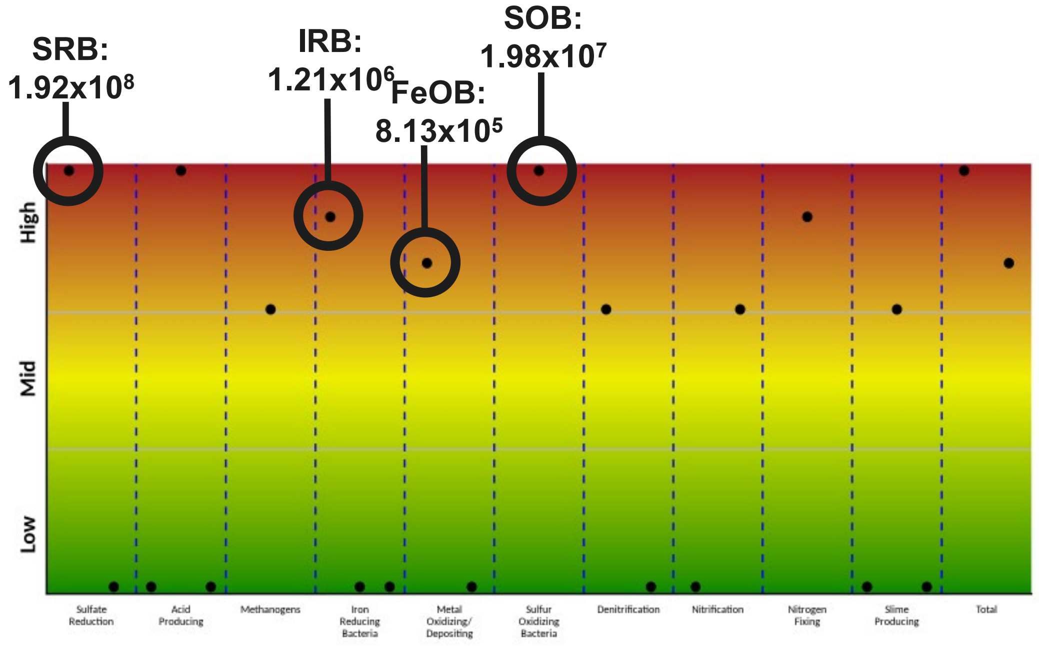



WAS/SAS iron: Low iron, both $Fe^{2+}$ and $Fe^{3+}$ present, biogenic

AVS/CrES: Some FeS forming in later sample; likely co-disposed S

# Min-Trap Analysis: Microbial

| Sample Name<br>Sample Date | MW-2<br>10/09/2018 |
|---|---|
| *Microbial Induced Corrosion* | cells/g |
| Total Bacteria (EBAC) | 7.74E+08 |
| Total Archaea (ARC) | 3.58E+05 |
| Sulfate Reducing Bacteria (APS) | 1.92E+08 |
| Sulfate Reducing Archaea (SRA) | <1.00E+04 |
| Methanogens (MGN) | 1.69E+04 |
| Acetogens (AGN) | <1.00E+04 |
| Fermenters (FER) | 3.11E+08 |
| Iron Reducing Bacteria - Other (IRB) | 1.21E+06 |
| IRB *Geobacter* (IRG) | <1.00E+04 |
| IRB *Shewanella* (IRS) | <1.00E+04 |
| Iron Reducing Archaea (IRA) | <1.00E+04 |
| Iron Oxidizers (FeOB) | 8.13E+05 |
| Manganese Oxidizing Bacteria (MnOB) | <1.00E+04 |
| Sulfur Oxidizing Bacteria (SOB) | 1.98E+07 |
| Denitrifying Bacteria (nirK) | 1.02E+04 |
| Denitrifying Bacteria (nirS) | <1.00E+04 |
| Ammonia Oxidizing Bacteria (AMO) | <1.00E+04 |
| Nitrite Oxidizing Bacteria (NOR) | 8.37E+04 |
| Nitrogen Fixers (NIF) | 5.57E+06 |
| *Burkholderia cepacian* Exopolysaccharide (BCE) | <1.00E+04 |
| *Deinococcus* spp. (DCS) | 5.35E+04 |
| *Meiothermus* spp. (MTS) | <1.00E+04 |
| *Cladosporium* spp. CLAD | <1.00E+04 |




➔ Microbial analyses can be performed with Min-Trap samples

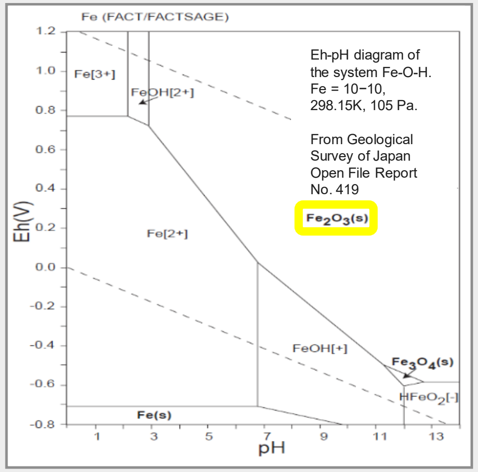
➔ Data provide insight on geochemical (redox) conditions and abundance of key microbial groups

➔ Data from Min-Trap samples are comparable to data from corresponding groundwater samples

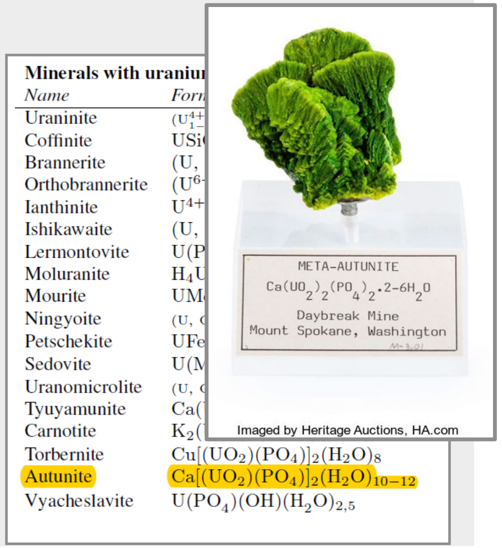
# Additional Min-Trap Applications

Laboratory Testing Completed

## Co-precipitation of As with Fe




## Precipitation of U with phosphate

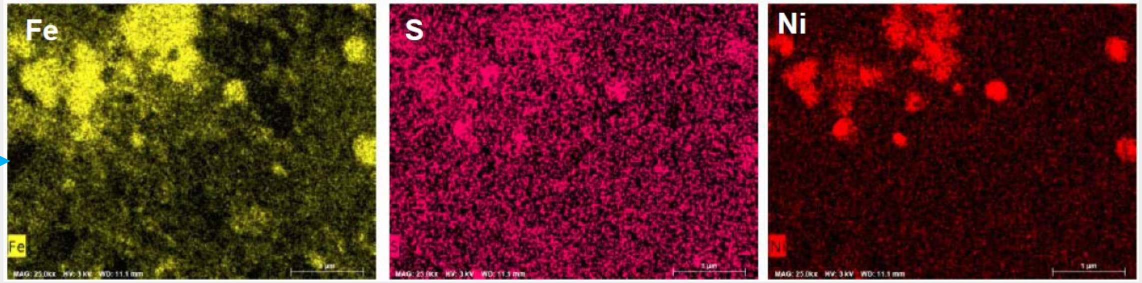



From Závodská et al. 2008. Environmental chemistry of uranium.

Testing Completed

## Precipitation of Ni under reducing conditions as NiS

Min-Trap @ ~2 months




- Apparent co-precipitation of Ni, Fe, and S.
- Leaching tests imply Ni is both sorbed to Fe (temporary) and incorporated into sulfide minerals (stable)
- Verified the process is working but it's more complex and harder to achieve consistent treatment than expected

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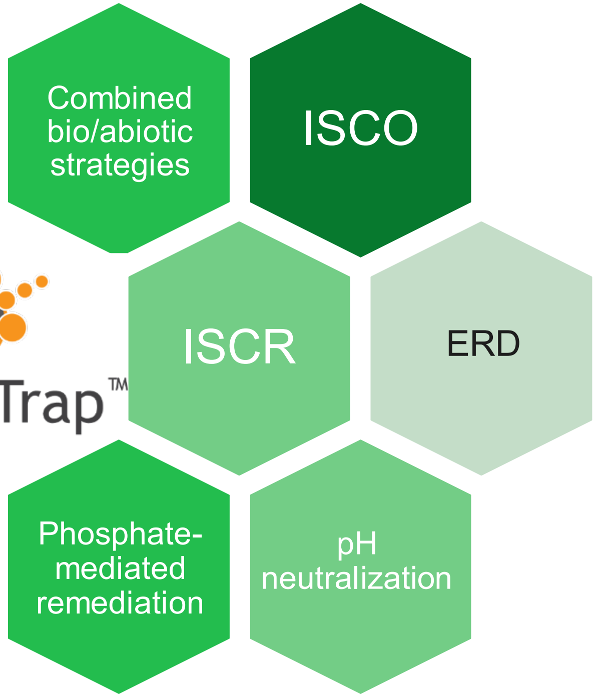
# Key Takeaways

- Min-Traps can fFill major data gap for metals and CVOC treatment performance evaluations
- Inexpensive and easy to use
- Can advise treatment program and expected treatment behavior, longevity, permanence
- Applicable anywhere you have active precipitation, dissolution, or transformation of minerals

Min-Trap™



# Questions

## Additional Information

https://serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Monitoring/ER19-5190

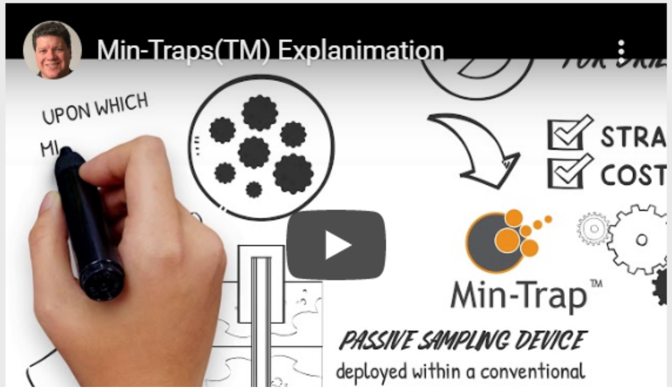
### Demonstration of Mineral Traps to Passively Evaluate and Monitor In Situ Reactive Minerals for Chlorinated Solvent Treatment

Dr. Craig Divine | Arcadis U.S., Inc.

ER19-5190

Objective | Technology | Benefits

Objective

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https://microbe.com/min-trap-sampler/