Monitoring of In-Situ Chemical Oxidation (ISCO) with Time Series Geophysical Surveys

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Review of Time Series Geophysical Surveys for ISCO

- Repeated geophysical surveys to identify temporal change in bulk (formation and fluid) “electrical” properties at discrete depths
  - Includes background or pre-injection survey
- Effective with electrically conductive injectate, i.e. permanganate
- Allows for a more complete picture of treatment
- Provides enhanced mapping capability when coupled with conventional monitoring
Application of Time Series Geophysical Surveys for ISCO

- Signal to noise ratio and signal strength
  - Electrical signal > Measurement resolution
- Site infrastructure considerations
  - Interferences
- Well construction (tool specific)
- Selection of the correct method/tool
Geophysical Survey Methods

- Surface (e.g. Electromagnetic (EM), Direct Current (DC) resistivity)
- Borehole Logging (e.g. EM, **Gamma, **Neutron, **ATV)
- Cross hole (e.g. Radar, Radio frequency, Electrical (ERT))
- Surface to Borehole (e.g. Electrical, Heat, Radar, etc.)

**Geologic characterization
Method 1: Borehole Electromagnetic (EM) Log

- Works in open holes, pvc wells, 2 inches or greater
- Induces current and measures formation bulk electrical properties (including water conductivity) beyond solid wall pvc casing or screen
  - Does not require direct fluid or formation contact
Method 1: Borehole EM Log

A. No detection in water sample

UNIT A

UNIT B

B. Detection with Borehole EM

Sample zone of monitoring well screen

UNIT A

UNIT B

Survey zone of Borehole EM Log

Injection well

Monitoring well

Well screen

Well screen

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Animation of injection/EM logging
Method 2: Surface Direct Current (DC) Resistivity
Method 2: Surface Direct Current (DC) Resistivity

- Resistive unsaturated washed cobbles
- Conductive groundwater near water table
- Conductive groundwater on bedrock
- Sand and Gravel
- Bedrock
- Ground
Permanganate Injection, OU1, Savage Superfund Site, Milford, NH

- PCE contaminant plume in a sand and gravel aquifer
- OU1 treatment system contains barrier wall, and pump-n-treat system (since 1999)
- Outside barrier, PCE declines to below 10 ppb in many areas
- Inside barrier, declines slow
- ISCO Treatment initiated several times with permanganate
Permanganate-DC Resistivity/Conductivity Lab Testing

- Calibrate field results to geology
- Measure differences in bulk electrical conductivity with the addition of permanganate (and changes to pore fluid conductivity)
DC Resistivity Lab Testing Results

"Bulk measurement of formation and pore fluid"
Location of injection wells, 2008

Barrier Wall
(low permeability)

Area of detail in next slide

EXPLANATION
- River
- Barrier wall
- Extraction wells
- Monitoring wells

Injection wells (2008)

<table>
<thead>
<tr>
<th>Depth in feet</th>
<th>Radius (Volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>185-195</td>
<td>2.0 - 2.5</td>
</tr>
<tr>
<td>195-205</td>
<td>2.5 - 12.5</td>
</tr>
<tr>
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<tr>
<td>fully penetrating (205-255)</td>
<td>...</td>
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Stratigraphy

Injections (from Nov. 13-18, 08)

Injections

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Groundwater flow

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PW-6R EM time series

Background

Nov 3, 08
Nov 5, 08
Nov 7, 08
Nov 12, 08
Nov 19, 08

U.S. Department of the Interior
U.S. Geological Survey

Injections (from Nov 10 - 17, 08)
Injections (from Nov. 5-12, 08)
Injections (from Oct. 31 to Nov. 03, 08)

Logged well: PW6R

Permanganate flow

0 20 40 60 80 100 120 140 EM conductivity, mS/m

Dec 3, 08
Apr 16, 09

Borehole EM detects permanganate

bedrock = 96 FT, TIC, FT OR 183 FT ELEVATION

Logged well: PW6R

No permanganate

STATE PLANAR FEET, NAD88

EM conductivity, mS/m

0 20 40 60 80 100 120 140
Temporal PCE

PCE Concentrations, Pre-, Post (6 months) ISCO

- PW-6S No permanganate
- PW-6M No permanganate
- PW-6MB No permanganate
- PW-6D Permanganate
- PW-6R No permanganate

PCE concentration, µg/L

- Pre: PCE-Pre ISCO
- Post: PCE-Post ISCO
Location of injection wells, 2008

Barrier Wall
(low permeability)

Area of detail in next slide
Stratigraphy

- Soil
- Cobble 1
- Upper sand
- Cobble 2
- Middle sand 1
- Interbedded sand
- Middle sand 2
- Basal sand
- Till

Likely metal from bit during drilling

EM conductivity, mS/m

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Location of DC Resistivity Survey

Area affected by injection

Area affected by injection

EXPLANATION

River
Barrier wall
Barrier wells
Extraction wells
Monitoring wells

Injection wells (2008)

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Background DC Resistivity Survey

30 Sept 2008

A

Barrier

PW-6D

IP-5

IP-9-11

IP-2

Barrier

A'

40

400

4,000

High Conductivity

Resistivity, ohm-m

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Temporal Surveys

PRE-INJECTION, SEPT. 08

POST-INJECTION, Nov. 19, 08

POST-INJECTION, SEPT. 09

Permanganate

Permanganate decrease

Permanganate increase
Summary- Time series geophysical surveys

- Provided enhanced mapping capabilities
- Effectively tracked spread of permanganate
- Established framework to interpret post-PCE trends
- Identified data gaps
- Identified density induced transport control
- Aided in formulation of alternate injection strategies
Acknowledgments

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