Perchlorate Remediation
Technology Options and the Challenges Ahead

DTSC / USEPA / GRA
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Geosyntec consultants
Perchlorate Remediation – A Decade of Progress

- It has been 10 years since perchlorate emerged as a chemical of concern
- Since then, a range of technologies have been developed to remediate perchlorate in soil, groundwater and drinking water supplies
- DoD has funded much of this technology development, either directly or indirectly
  - SERDP & ESTCP Research/Validation Programs
  - Remediation at DoD and related contractor sites
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<th>Soil Remediation</th>
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</thead>
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<td>Shaw Environmental</td>
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<td>Parsons</td>
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<td>GeoSyntec / U.C. Berkeley</td>
<td>IES Solutions</td>
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<td>NC State / IES Solutions</td>
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<td>Shaw Environmental</td>
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<td>IES Solutions</td>
<td></td>
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</table>

www.estcp.org www.serdp.org
Drinking Water Treatment Technology Development Projects

**Drinking Water Treatment**

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Description</th>
<th>Sponsor</th>
</tr>
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<tbody>
<tr>
<td>ESTCP-0540</td>
<td>Destruction by UV Catalysis</td>
<td>San Diego State</td>
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<tr>
<td>ESTCP-0541</td>
<td>Membrane Biofilm Reduction and Membrane Filtration</td>
<td>CDM / ASU</td>
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<tr>
<td>ESTCP-0542</td>
<td>Highly Selective IX Resin Coupled with Single Vessel Design</td>
<td>Rohm &amp; Haas</td>
</tr>
<tr>
<td>ESTCP-0543</td>
<td>Fluidized Bed Bioreactor Demonstration</td>
<td>Shaw Environmental</td>
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<td>ESTCP-0544</td>
<td>Fixed-Bed Bioreactor Demonstration</td>
<td>Carollo Engineers</td>
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<td>ESTCP-0545</td>
<td>Integrated IX Regeneration Process</td>
<td>Arcadis / ORNL</td>
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<tr>
<td>ESTCP-0546</td>
<td>Tailored Granular Activated Carbon Demonstration</td>
<td>Arcadis / PSU</td>
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</tbody>
</table>

www.estcp.org

www.serdp.org
Do Challenges Still Remain?

- How low can we / do we need to treat?
  - New analytical techniques can detect ClO$_4$ to low ppt levels
  - Cleanup to background (e.g., CA Resolution No. 92-49)
  - What is background?

- Treatment of contaminant mixtures

- Public & regulatory perception – biological reduction

- Control of biofouling for bioremediation applications

- Water quality impacts (dissolved Mn, Fe, H$_2$S)
Let’s Talk About

- Groundwater Remediation Techniques
- Case Studies
  - Perchlorate & TCE – California
  - Perchlorate & TCA – Maryland
- Soil Remediation Techniques
- Case Studies
  - Excavation & Ex Situ Treatment
  - In Situ Treatment
Groundwater Remediation Techniques

**Ex Situ (Pump & Treat)**

- Ion Exchange (regenerable, disposable, bi-functional resins)
- Granular activated carbon (GAC) & tailored GAC
- Fluidized-bed and fixed-film bioreactors

**In Situ**

- Metal-Catalyzed Reduction (Permeable Reactive Barriers)
- Bioremediation
Ion Exchange

**Advantages**
- High volume throughput (1000s Lpm)
- Approved for drinking water use
- Excellent for perchlorate

**Disadvantages**
- Large footprint, high capital and O&M cost
- Groundwater chemistry (nitrate) can affect resin usage and cost
- Does not treat chlorinated solvents

**Technology Status**
- First application ~1999
- Proven approach with at least 30 commercial applications for perchlorate
Granular Activated Carbon (GAC)

**Advantages**
- High volume throughput (1000s Lpm)
- Approved for drinking water use
- Good for chlorinated solvents, RDX

**Disadvantages**
- Can have high O&M cost – depends on GAC changeout frequency & GAC handling
- Does not sorb perchlorate – requires tailored GAC (limited to low concentrations)

**Technology Status**
- Widely used for chlorinated solvents, not yet for perchlorate
**Metal-Catalyzed Reduction - PRBs**

**Advantages**
- No above-ground infrastructure
- Low O&M cost (no moving parts)
- Good for chlorinated solvents

**Disadvantages**
- Perchlorate not degraded abiotically
- Iron longevity affected by elevated nitrate

**Technology Status**
- Widely used for chlorinated solvents
- Not specifically used for perchlorate
- **BUT**, data from several recent applications show perchlorate degraded (biological?) within ZVI PRB
- Possible future use?
Fluidized Bed / Fixed Film Bioreactors

**Advantages**
- High throughput (~15,000 Lpm at Aerojet)
- Effectively treats perchlorate, nitrate, RDX
- Has potential to treat chlorinated solvents

**Disadvantages**
- Large footprint, high capital and O&M cost
- Significant biosolids handling required

**Technology Status**
- First major application ~1998 (Aerojet)
- Proven approach with at least 5 large commercial applications
- Conditional acceptance for treatment of water for public use
In Situ Bioremediation

Advantages
- Minimal above-ground infrastructure
- Lower capital cost than FBR or IX
- Can jointly treat chlorinated solvents, perchlorate, nitrate, RDX

Disadvantages
- Biofouling of electron donor delivery wells
- Potential impacts to secondary water quality

Technology Status
- First application 2000 (Geosyntec)
- Proven approach with at least 30 commercial applications
Technology Applicability

<table>
<thead>
<tr>
<th>Technology</th>
<th>Perchlorate</th>
<th>Solvents</th>
<th>Nitrate</th>
<th>RDX</th>
</tr>
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<tbody>
<tr>
<td>Air Stripping</td>
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<tr>
<td>Granular Activated Carbon T-GAC</td>
<td>✓</td>
<td>✓</td>
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<td>Ion Exchange</td>
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<td></td>
<td>✓</td>
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</tr>
<tr>
<td>Metal Cataylzed Reduction ?</td>
<td>?</td>
<td>✓</td>
<td></td>
<td>✓</td>
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<td>Ex Situ Biological Reduction</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

- Selection will depend on:
  - Chemicals present
  - Groundwater use – drinking water?
  - Treatment trains vs single technology
Case Study #1 - Active In Situ BiobARRIER

- Aerojet Superfund Site, Rancho Cordova, CA
- Alluvial aquifer, interbedded silts, sands and gravel
- Aquifer depth 100 ft bgs, watertable 30 ft bgs
- ClO$_4^-$ = 8 mg/L; Nitrate = 24 mg/L; Sulfate = 10 mg/L
- TCE = 2 mg/L
- Dissolved Oxygen = 4 mg/L; Redox = +200 mV
- Ethanol added as electron donor
- BiobARRIER bioaugmented with KB-1 to dechlorinate TCE to ethene
Perchlorate Biodegradation

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Jet Propulsion Lab</th>
<th>Rocky Mountain</th>
<th>Indian Head (Blg 1770)</th>
<th>Indian Head (Hogout)</th>
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<tr>
<td>Hydrogen</td>
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<td>NA</td>
<td>NA</td>
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</tr>
<tr>
<td>Propane</td>
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<tr>
<td>Ethanol</td>
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<td>Molasses</td>
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<td>NA</td>
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<tr>
<td>YE/Ethanol</td>
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<td>NA</td>
<td>NA</td>
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<td>Sucrose</td>
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<td>NA</td>
<td>NA</td>
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</tr>
<tr>
<td>FBR2-Culture</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>No Biodegradation</td>
</tr>
</tbody>
</table>

- **Rapid Biodegradation** (≤ 14 Days)
- **Slow Biodegradation** (≥ 14 Days)
- **No Biodegradation**

Dechlorosporillum sp.
Perchlorate-reducing microorganisms isolated from contaminated sites

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2GeoSyntec Consultants, Inc., 130 Research Lane, Suite 2, Guelph, Ontario, N1G 5G3, Canada.

Introduction
Perchlorate salts are used in the manufacture of propellants, explosives and pyrotechnic devices by the chemical, aerospace and defence industries (Renner, 1998; 2003; Urbansky, 1998). The main source of perchlorate contamination in groundwater is the past unregulated discharge of ammonium perchlorate, a major component of solid rocket fuels (Urbansky, 1998). Perchlorate contamination in soil and groundwater is prevalent in the south-western United States. Perchlorate has been detected frequently in drinking water reservoirs in many states (Renner, 1998; Urbansky, 1999; Hogue, 2003), more recently in crops such as lettuce (Hogue, 2003) and even in milk (Kirk et al., 2003), and has therefore become a major public health concern. Perchlorate exerts its major physiological effects on the thyroid gland. It blocks iodide uptake by the thyroid, thus inhibiting the synthesis of thyroid stimulating hor...
**Reductive Dechlorination**

Can accumulate if requisite bacteria are absent

- PCE → TCE → cis-1,2-DCE → VC → Ethene

- **Dehalobacter**
- **Dehalospirillum**
- **Desulfitobacterium**
- **Desulfuromonas**
- **Dehalococcoides**

*some strains of Dehalococcoides (Dhc)*
Dehalococcoides (Dhc)

- Unique, very small organisms
- Can be added to sites where absent to promote dechlorination (e.g., KB-1 culture)
- KB-1 sold by SiREM, injected at > 100 sites
Electron Donor & KB-1 Injections
Design Concept – Active BiobARRIER

Groundwater Flow Direction

Extraction Wells and Capture Zones

Electron Donor Addition

Injection Wells and Electron Donor Mixing Zones

Perchlorate Degradation Zone

Compliance Boundary
Active BiobARRIER Layout

- Extraction Well 3619
- Extraction Well 3620
- Bioaugmentation Zone

- groundwater flow

- 200'

- electron donor addition

- 50'

- 4385
- 3617
- 3601
- 3600
- 100
- 3618

- black circle: extraction well
- filled circle: electron donor delivery well
- hollow circle: performance monitoring well
Active Biobarrier Hydraulics
Perchlorate Biodegradation Results

Performance monitoring wells

- Concentration (mg/L)
- Time (days)

- Influent (4385)
- 3600
- 3617
- 100

Electron donor addition at time 8 days.

Day 0 = Nov 20, 2001
Day 60 = Jan 19, 2002
Nitrate Biodegradation Results

Performance monitoring wells

- Influent (4385)
- 3600
- 3617
- 100

day 0 = Nov 20, 2001
day 60 = Jan 19, 2002
TCE Dechlorination to Ethene

Day -1 (19-Nov-01)
- Increasing distance downgradient
- Transgradient

Day 44 (3-Jan-02)
- Increasing distance downgradient
- Transgradient

Moles/L
TCE Dechlorination to Ethene
1,1-DCE Biodegradation Results

Electron donor addition

Time (days)

Concentration (μg/L)

Influent (4385)

3600

3617

100
Carbon Tetrachloride Biodegradation Results

- Influent (4385)
- 3600
- 3617
- 100

Electron donor addition at time 0 days.
Chloroform Biodegradation Results

![Graph showing chloroform biodegradation results with different concentration trends over time.]

- Influent (4385)
- 3600
- 3617
- 100

Electron donor addition at time 0 days.
## Detection of *Dehalococccoides* in Groundwater

### Monitoring Wells

<table>
<thead>
<tr>
<th>Test</th>
<th>Day</th>
<th>3601 (15 ft)</th>
<th>3600 (35 ft)</th>
<th>100 (65 feet)</th>
<th>3618 (100 feet)</th>
<th>3617 (50 feet)</th>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>nt</td>
<td>nt</td>
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<tr>
<td>157</td>
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<td>Bioaeration with KB-1 (via well 3601)</td>
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<tr>
<td>163</td>
<td></td>
<td>+++</td>
<td>--</td>
<td>--</td>
<td>nt</td>
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<td>232</td>
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<td>+++</td>
<td>+++</td>
<td>++</td>
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### System Re-Start

<table>
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<th>Test</th>
<th>Day</th>
<th>3601 (15 ft)</th>
<th>3600 (35 ft)</th>
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<tr>
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<td>System Re-Start</td>
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<td></td>
</tr>
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<td>72</td>
<td></td>
<td>nt</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
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</table>

<table>
<thead>
<tr>
<th>Test</th>
<th>Day</th>
<th>3601 (15 ft)</th>
<th>3600 (35 ft)</th>
<th>100 (65 feet)</th>
<th>3618 (100 feet)</th>
<th>3617 (50 feet)</th>
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</thead>
<tbody>
<tr>
<td>Post</td>
<td>455</td>
<td></td>
<td></td>
<td></td>
<td>+++</td>
<td>+</td>
</tr>
</tbody>
</table>

### Notes:

- **DHE** - *Dehalococcoides* ethenogenes
- **--** DHE not detected
- **++** DHE detected
- **nt** - Not Tested
Conclusions – Aerojet

- Perchlorate & nitrate readily degraded
- Bioaugmentation (KB-1) stimulated rapid and complete dechlorination of TCE to ethene
- Effective biobarrier – 600 ft wide x 100 ft deep
- Ethanol was very efficient electron donor
- Very low methanogenesis (<100 ppb) observed
Case Study #2 - Passive In Situ Biobarrier

- DOD-ESTCP Project - Bob Borden at UNC/IES Solutions
- Active rocket manufacturing facility, Maryland
- Shallow aquifer ~10-20 ft bgs over silty clay
- Water table at 5 to 10 ft bgs
- Groundwater flow velocity ~ 100 ft/yr
- 1,1,1-TCA = 5 to 20 mg/L; TCE = 0.1 to 0.3 mg/L
- Perchlorate = 5 to 150 mg/L
- Emulsified Oil Substrate (EOS®) added as electron donor
Injection & Monitoring Layout

• EOS® Barrier
  – EOS® injected through temporary wells
  – No above ground equipment
  – Used only food-grade materials
  – Inject and monitor only
Field Implementation

• Injection
  – 55 gal/well of diluted EOS®
  – 165 gal/well of chase water
  – Completed by two people in 2 days
Results - Perchlorate

![Perchlorate Graph]

- **Perchlorate (µg/L)**
- **Days Since EOS Injection**
- **25 feet Upgradient (Avg 3 wells)**
- **Injection Wells (Avg 5 wells)**
- **10 feet Downgradient**
- **20 feet Downgradient (Avg 3 wells)**

The graph shows the concentration of perchlorate over time at various locations relative to the EOS injection points. The perchlorate levels are measured in parts per million (µg/L) and are plotted against the days since the EOS injection.
Results – 1,1,1-Trichloroethane

20 ft Downgradient of Barrier

Days Since Injection

Concentration (µg/L)

1,1,1-TCA
1,1-DCA
1,1-DCE
CA
Conclusions – Maryland

- Perchlorate readily degraded
- 1,1,1-TCA dechlorinated via 1,1-DCA to chloroethane, which also attenuated (mechanism unclear)
- EOS had reasonable longevity, provided effective biobarrier
- Elevated dissolved iron and manganese, methane levels downgradient of biobarrier
Soil Remediation Techniques

Ex Situ Treatment
- Composting
- Slurry Bioremediation
- Soil Washing Coupled to Water Treatment

In Situ Treatment
- Surface Infiltration of Electron Donors
- Direct Injection of Liquid Electron Donors
- Direct Injection of Gas Phase Electron Donors
Ex Situ Anaerobic Composting

**Advantages**
- Facilitates electron donor mixing with soil
- Short duration & relatively low cost

**Disadvantages**
- Depth-limited (excavation capabilities/costs)
- Can require large treatment footprint & significant materials handling
- Loss of volatiles during soil handling

**Technology Status**
- Proven approach with many commercial applications for perchlorate, TNT, RDX
Ex Situ Anaerobic Slurry Bioremediation

**Advantages**
- Facilitate electron donor mixing
- Provides optimal conditions for biodegradation

**Disadvantages**
- Requires larger treatment footprint & more infrastructure (lined cell)
- Requires soil de-watering after treatment and extra materials handling
- Loss of volatiles during soil handling

**Technology Status**
- First application 1998-99 for perchlorate, Simplot Process for explosives
Surface Infiltration of Electron Donors

**Advantages**
- Relatively low cost
- High degree of control for donor delivery
- Follows standard agronomic practices

**Disadvantages**
- Electron donor distribution is affected by geologic heterogeneity/layering
- Typically not suitable for deep or low permeability sites

**Technology Status**
- First application 2003
- Proven approach with regulatory closure for perchlorate, fewer applications for solvents
Direct Injection of Liquid Electron Donors

**Advantages**
- Relatively low cost
- No permanent infrastructure required

**Disadvantages**
- Electron donor distribution is significantly affected by geologic heterogeneity
- Donor coverage and treatment can be spotty

**Technology Status**
- In use at multiple sites for perchlorate & solvents
- Data emerging from field applications
Gaseous Electron Donor Injection Technology

**Advantages**
- Delivery of donor to deep vadose zone
- Gaseous donor does not displace perchlorate like liquid injection does

**Disadvantages**
- Oxygen (up to 21%) in vadose zone may cause high electron donor demand
- Potential impacts to indoor air; some electron donors can be toxic/hazardous
- Injection can displace VOCs

**Technology Status**
- Promising but experimental; ESTCP demonstration in progress

*Courtesy of Patrick Evans, CDM*
### Comparison of Approaches

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Gaseous Donor</th>
<th>Liquid Flushing</th>
<th>Excavation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment of contaminant in soil at very shallow depths (0-5 m)</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Treatment of contaminant in soil at greater depths</td>
<td>++</td>
<td>+</td>
<td>—</td>
</tr>
<tr>
<td>Distribution of electron donors in heterogeneous media</td>
<td>+</td>
<td>—</td>
<td>++</td>
</tr>
<tr>
<td>Compatible with soil vapor extraction and chemical oxidation using ozone</td>
<td>++</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Minimal risk of secondary groundwater impacts</td>
<td>++</td>
<td>—</td>
<td>++</td>
</tr>
<tr>
<td>Potential application to ClO₄, TNT, RDX, HMX and VOCs</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

++ Very Favorable    + Favorable    — Less Favorable

Courtesy of Patrick Evans, CDM
Soil Remediation Case Study

- Former road flare manufacturing site
- More than 650 soil samples to delineate on-site soil impacts
- No soil above commercial PRG (maximum perchlorate ~ 14 mg/kg)
- ~1000 yd$^3$ soil above residential PRG
- Estimate 40,000 yd$^3$ soil above Site Specific Cleanup Level of 50 ppb (to protect groundwater)
- Target Soil Treatment Area = 65,000 ft$^2$ x 16 ft depth
Site Remedy

♦ On-site groundwater containment & treatment by ion exchange (started February 2004)

♦ Soil - Two Stage remediation process

  1. Excavation & ex situ composting of soil with perchlorate exceeding 7,800 μg/kg EPA residential remediation goal
  2. In situ bioremediation of remaining impacted soils to meet SSL of 50 μg/kg

♦ Ex situ composting successfully completed in April 2005

♦ In situ bio successfully completed in May 2006
Ex Situ Bioremediation Design

- ~1,000 m$^3$ of soil excavated
- Ex situ pile dimensions – 30 m x 30 m x 1.5 m
- Starting average perchlorate concentration in pile ~7,000 μg/kg (August 2004)
- Electron donors: 1,000 kg of calcium magnesium acetate (CMA) road-deicing salt and 450 kg of citric acid

Target Soil Treatment Area

Ex Situ Soil Excavation Limits

10-MIL VISQUINE PLASTIC TARP

EXISTING GROUND

SANDBAGS

SOIL AMENDED WITH DONOR

2'  4'  90'  2'
Ex Situ Soil Pile Construction

Construction of pile in 15 cm lifts

CMA being applied to the top of a construction lift

Drip-tape for water application to soil pile
**Ex Situ Bioremediation Results**

- Average start ClO$_4$ = 7,000 µg/kg
- Average final ClO$_4$ = 11 µg/kg
- CMA & citric acid performed well and did not impact detection limits
- Pile drying is problematic – need to maintain pile moisture or ClO$_4$ salts out at surface
- Duration affected by temperature impact on degradation rate
- Success gained regulatory approval
In Situ Bioremediation Design

- Infiltration unit – 245 ft wide x 425 ft long
- Acetate tilled into surface soils (top 3 feet)
- Water application rate 20-45 gpm
- Citric acid addition ~250 mg/L
- Start - August 2005
- End – May 2006
In Situ Soil Bioremediation

- Initial ripping of soil
- Electron donor delivery system
- Water/electron donor distribution system
- Constructed ISB Infiltration Unit
Groundwater Capture Zone, Target Soil Area, & Infiltration Unit Boundaries
Soil Sampling Program

• Pre-Remedial Soil Sampling Event (Baseline)
  May 2005:
  12 locations
  0-16 ft cores

• Annual Soil Verification Sampling Event
  May 2006:
  24 locations
  0-16 ft cores
## Baseline Soil Conditions:
**May 2005**

### Perchlorate Results
#### Riffle-Split Samples

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Result (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRS-001</td>
<td>210</td>
</tr>
<tr>
<td>PRS-002</td>
<td>60</td>
</tr>
<tr>
<td>PRS-003</td>
<td>27</td>
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<tr>
<td>PRS-004</td>
<td>1100</td>
</tr>
<tr>
<td>PRS-005</td>
<td>57</td>
</tr>
<tr>
<td>PRS-006</td>
<td>21</td>
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<tr>
<td>PRS-007</td>
<td>130</td>
</tr>
<tr>
<td>PRS-008</td>
<td>93</td>
</tr>
<tr>
<td>PRS-009</td>
<td>62</td>
</tr>
<tr>
<td>PRS-010</td>
<td>780</td>
</tr>
<tr>
<td>PRS-011</td>
<td>11</td>
</tr>
<tr>
<td>PRS-012</td>
<td>28</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>215</strong></td>
</tr>
</tbody>
</table>

### Perchlorate Results Depth-Discrete Samples

<table>
<thead>
<tr>
<th>Interval (ft)</th>
<th>PRS-007A (µg/kg)</th>
<th>PRS-008A (µg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>290</td>
<td>79</td>
</tr>
<tr>
<td>2-3</td>
<td>77</td>
<td>73</td>
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<tr>
<td>4-5</td>
<td>170</td>
<td>110</td>
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<tr>
<td>6-7</td>
<td>77</td>
<td>96</td>
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<tr>
<td>8-9</td>
<td>96</td>
<td>83</td>
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<tr>
<td>10-11</td>
<td>55</td>
<td>110</td>
</tr>
<tr>
<td>12-13</td>
<td>77</td>
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<td>14-15</td>
<td>10</td>
<td>110</td>
</tr>
<tr>
<td>16-17</td>
<td>10</td>
<td><strong>Not Analyzed</strong></td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>96</strong></td>
<td><strong>96</strong></td>
</tr>
<tr>
<td><strong>Core (0-16’)</strong></td>
<td><strong>130</strong></td>
<td><strong>93</strong></td>
</tr>
</tbody>
</table>

**95% UCL**

1020
In Situ Bioremediation
2006 Soil Verification
Sampling Results

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Perchlorate (µg/kg)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>May 2005</td>
</tr>
<tr>
<td>CBS-001</td>
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</tr>
<tr>
<td>PRS-001/CBS-002</td>
<td>210</td>
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<tr>
<td>CBS-003</td>
<td>--</td>
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<tr>
<td>CBS-004</td>
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<td>CBS-005</td>
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<tr>
<td>CBS-006</td>
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<tr>
<td>PRS-002/CBS-007</td>
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<tr>
<td>PRS-003/CBS-008</td>
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<tr>
<td>PRS-004/CBS-009</td>
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<td>PRS-005/CBS-010</td>
<td>57</td>
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<tr>
<td>PRS-006/CBS-011</td>
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<tr>
<td>CBS-012</td>
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</tr>
<tr>
<td>PRS-007/CBS-013</td>
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<tr>
<td>CBS-014</td>
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<td>CBS-015</td>
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<td>PRS-008/CBS-016</td>
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<td>PRS-009/CBS-017</td>
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<tr>
<td>PRS-010/CBS-018</td>
<td>780</td>
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<tr>
<td>CBS-019</td>
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</tr>
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<td>PRS-011/CBS-020</td>
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<tr>
<td>CBS-021</td>
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</tr>
<tr>
<td>CBS-022</td>
<td>--</td>
</tr>
<tr>
<td>PRS-012/CBS-023</td>
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<tr>
<td>CBS-024</td>
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<tr>
<td><strong>Average</strong></td>
<td>215</td>
</tr>
<tr>
<td><strong>UCL&lt;sub&gt;95&lt;/sub&gt;</strong></td>
<td>1020</td>
</tr>
</tbody>
</table>
2006 Soil Verification Results

SSL = 50 µg/kg

Perchlorate Results
Depth-Discrete Samples
Board Closure for Site Soils

In addition to reviewing the subject report and to confirm the reported results, Water Board staff reviewed first and second quarter 2006 performance monitoring reports. We concur that the remedial objective for the ISB phase has been achieved.

We congratulate you on successful completion of on-site soil remediation activities. Olin may now decommission the soil ISB system at any time. If you have any questions, please contact Hector Hernandez at: (805) 542-4641 or via e-mail at: Hhernandez@waterboards.ca.gov, or Eric Gobler at (805) 549-3467.

Sincerely,

Roger W. Briggs
Executive Officer
Improvement of Groundwater Quality Following Soil Remediation

**EW-001A**

**S-05**

**O-05**

**N-05**

**D-05**

**J-06**

**F-06**

**M-06**

**A-06**

**M-06**

**J-06**

**J-06**

**A-06**

**S-06**

**O-06**

**N-06**

**D-06**

**DATE (M-Y)**

**PERCHLORATE CONCENTRATION (µg/L)**

**MW-016**

**S-05**

**O-05**

**N-05**

**D-05**

**J-06**

**F-06**

**M-06**

**A-06**

**M-06**

**J-06**

**J-06**

**A-06**

**S-06**

**O-06**

**N-06**

**D-06**

**DATE (M-Y)**

**PERCHLORATE CONCENTRATION (µg/L)**

**EW-002A**

**S-05**

**O-05**

**N-05**

**D-05**

**J-06**

**F-06**

**M-06**

**A-06**

**M-06**

**J-06**

**J-06**

**A-06**

**S-06**

**O-06**

**N-06**

**D-06**

**DATE (M-Y)**

**PERCHLORATE CONCENTRATION (µg/L)**

**EW-001A**

**S-05**

**O-05**

**N-05**

**D-05**

**J-06**

**F-06**

**M-06**

**A-06**

**M-06**

**J-06**

**J-06**

**A-06**

**S-06**

**O-06**

**N-06**

**D-06**

**DATE (M-Y)**

**PERCHLORATE CONCENTRATION (µg/L)**
Perchlorate – A Decade of Progress

- We now have many technologies to treat perchlorate in soil, groundwater and drinking water
- Technology selection (single vs treatment train) driven by:
  - Chemicals present
  - Groundwater use – drinking water?
- Groundwater remediation in progress at most sites
- Soil remediation likely new frontier to reduce long-term impacts to groundwater
Challenges Ahead for Perchlorate Treatment

- How low can we / do we need to treat?
  - New analytical techniques can detect ClO$_4$ to low ppt levels
  - Cleanup to background (e.g., CA Resolution No. 92-49)
  - What is background?

- Treatment of contaminant mixtures
- Deep vadose zone treatment
- Public & regulatory perception – biological reduction
- Control of biofouling and water quality impacts from bioremediation applications
Acknowledgements

- James Deitsch, Leslie Griffin, Robert Borch, Michaye McMaster, Carey Austrins - Geosyntec
- Rick McClure – Olin Corporation
- Scott Neville – Aerojet
- SERDP & ESTCP
- Bob Borden – NC State / IES Solutions
- Pat Evans – CDM
- Paul Hatzinger – Shaw Environmental
- SiREM Laboratory
Questions?