In Situ Chemical Oxidation for Groundwater Remediation

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Site Specific Engineering & Technology Application

ISCO CD Introduction and User's Information

ESTCP Project ER-0623

SERDP


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Background

- Project was sponsored by ESTCP to enable predictable, cost-effective application of ISCO at DoD sites
  - Title: In Situ Chemical Oxidation of Groundwater Remediation – Technology Practices Manual ~ ER-0623
  - Goal: To assemble a comprehensive Technology Practices Manual (TPM), provided on this CD, comprised of protocols and tools to enable site-specific engineering of ISCO to clean up contaminant source zones and groundwater plumes
  - Team: Composed of Colorado School of Mines, Clarkson University and CH2MHILL in collaboration with the Navy

- Principal contributors to Project ER-0623
  - Bob Siegrist – Colorado School of Mines
  - Michelle Crimi – Clarkson University
  - Tom Simpkin – CH2MHILL, Inc.
  - Jeff Heiderscheidt – U.S. Air Force Academy*
  - Tissa Illangasekare – Colorado School of Mines
  - Fritz Krembs – Aquifer Solutions, Inc.*
  - Junko Munakata-Marr – Colorado School of Mines
  - Gene Ng – CH2MHILL, Inc.
  - Tom Palaia – CH2MHILL, Inc.
  - Benjamin Petri – Colorado School of Mines
  - Mike Singletary – NAVFAC South

* Formerly with Colorado School of Mines

- Acknowledgements
  - Bob Borden, North Carolina State University
  - Ky young Cha, North Carolina State University
  - Kathryn Lowe, Colorado School of Mines
  - Megan Smith, Colorado School of Mines
  - John McCray, Colorado School of Mines
  - Participants in the ISCO Technology Practices Workshop
  - Reviewers of draft documents and tools
  - Andrea Leeson, SERDP/ESTCP
  - Nancy Ruiz, Navy Facilities Engineering Services Center
  - Marvin Unger, HydroGeoLogic, Inc.

Development of an ISCO TPM

Literature Review | **Case History Analysis** | **Technology Practices Workshop** | **SERDP / ESTCP Projects**

TPM Building Blocks

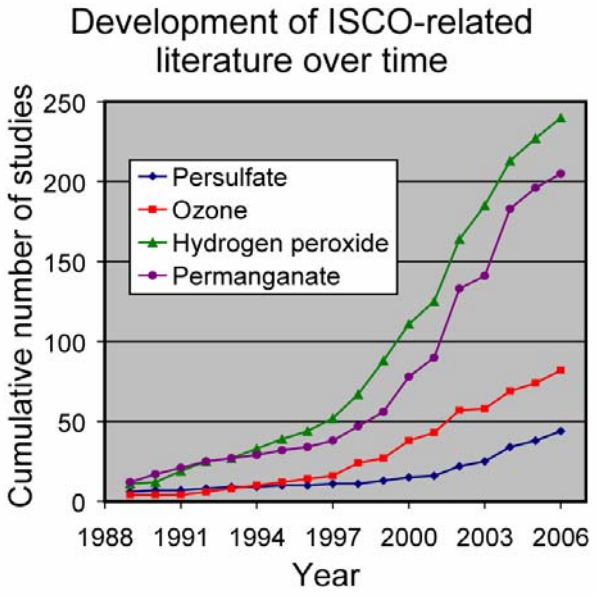
TPM = This CD

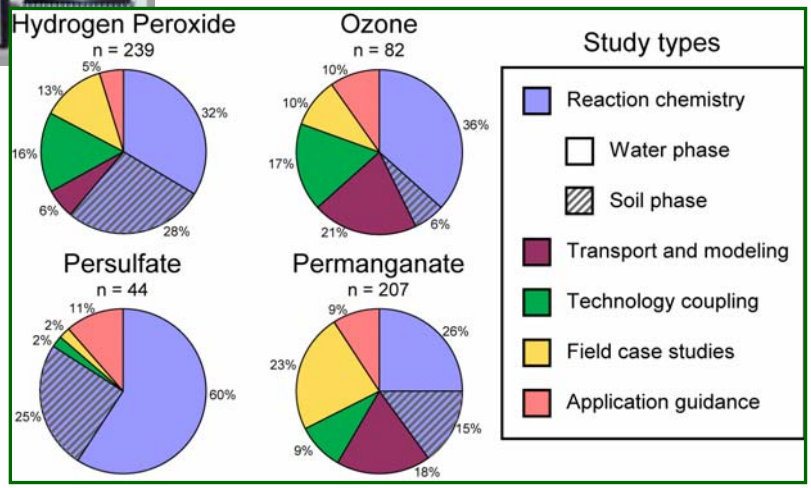
- **Frequently Asked Questions Guide**
- **E-Protocol**
- **Case History Analysis & Database (DISCO)**
- **Supplemental Information & Tools**
  - Annotated Literature Review
  - CORT3D Numerical Model
  - Technology Practices Workshop

TPM Components

TPM Building Blocks

- Literature Review
  - ~ 600 ISCO-relevant publications
  - Search limited to common oxidants
    - Permanganate
    - Persulfate
    - Hydrogen Peroxide
    - Ozone
  - Sources characterized, classified, and thoroughly reviewed for key findings
  - The Annotated Literature Review is also a component of this CD

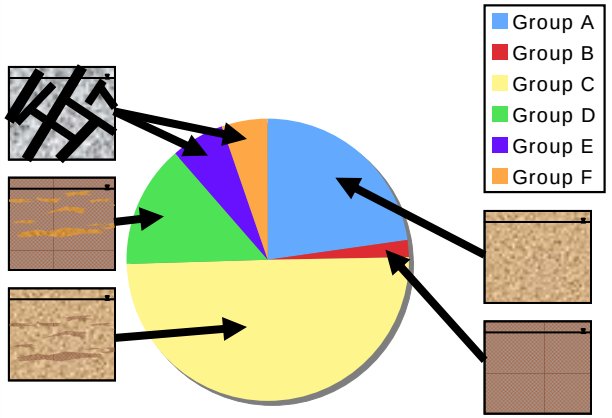




TPM Building Blocks

- Case History Analysis
  - Design and populate the ISCO-DB1 database
  - Analyze case study information
    - 242 ISCO projects (42 states, 7 nations)
    - ISCO design *vs.* site conditions *vs.* cost and performance…
  - ISCO-DB1 is also a component ("DISCO") with this CD

ISCO applications
to different site conditions
(n=149)



A - Permeable and Homogeneous;
B - Impermeable and Homogeneous;
C - Permeable and Heterogeneous;
D - Impermeable and Heterogeneous;
E - Fractured Rock w/ low matrix porosity;
F - Fractured Rock w/ high matrix porosity
Permeable $K>10^{-5}cm/s = 0.028ft/d$
Homogeneous $K_{max}/K_{min} < 1000$

TPM Building Blocks

- Technology Practices Workshop
  - 2-day workshop convened at CSM included 43 participants representing chemical companies, technology vendors, environmental consultants, academics, and RPMs
    - Presentations, panel sessions, and breakout sessions
    - Exercise where 6 scenarios were used to obtain views regarding ISCO design and performance
    - Views and consensus were developed including
      - Wide range of situations appropriate for ISCO
      - Basic reasons why treatment goals are not met
      - Circumstances were performance deficiencies were viewed as *more likely* to occur…
  - The Technology Practices Workshop Proceedings are also a component of this CD

TPM Building Blocks

- SERDP/ESTCP Project Findings
  - SERDP/ESTCP initiative ongoing for several years to:
    - Advance the understanding of ISCO,
    - Develop improved ISCO technical practices, and
    - Increase successful ISCO application
  - Wide range of R&D focus
    - Reaction chemistry, site characterization, treatability tests, biogeochemical effects, modeling, performance monitoring
    - Oxidant delivery/mobility control; reaction control / manipulation (e.g., MnO_2 formation); improved contact with contaminant
    - For more information see Project #'s: ER-1288, ER-1289, ER-1290, ER-0116, ER-1489, ER-1490, ER-0626, and ER-0632
  - Findings were incorporated into this CD through the literature review, e-protocols, and decision tools

TPM Components

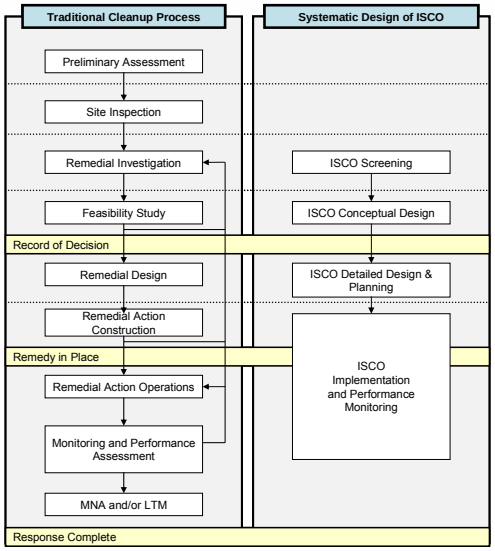
- Frequently Asked Questions Guide
  - Concise overview of ISCO applicability, design, implementation, and performance for groundwater remediation in the form of “Frequently Asked Questions”
  - 25 commonly asked questions by remedial project managers (RPMs) and similar constituencies
  - The FAQ Guide component is provided on this CD

What are the potential advantages and disadvantages of lab and field testing?

	Advantages	Disadvantages
Laboratory batch	• Initial assessment of ISCO applicability • Comparison of reaction chemistries • Ability to evaluate wide range of conditions economically • Extensive data collected efficiently and cost-effectively	• Managing issues of scale up and extrapolation of results from bench top to in situ
Laboratory flow-through	• Extensive data collected with moderate efficiency and cost-effectiveness •Transport/deliverability factors can be evaluated	• Managing issues of scale up and extrapolation of results from bench top to in situ
Field pilot	• Ability to collect data at the field scale • Ability to evaluate oxidant deliverability • Greater certainty in full-scale performance and cost	• Greater cost and time associated with field scale data collection

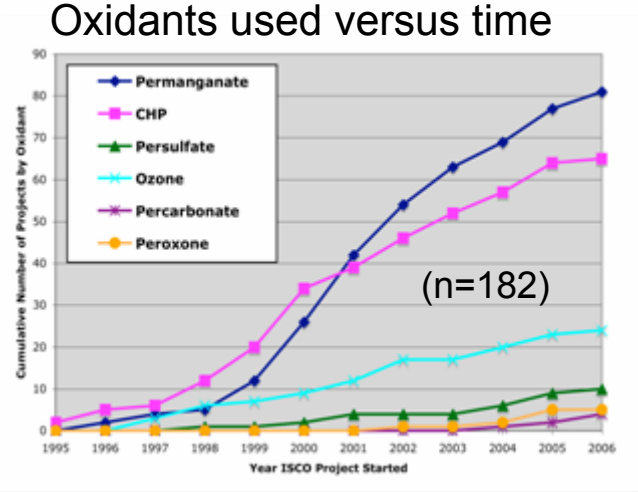
TPM Components

- E-Protocol
  - Text guide to assist remediation professionals making decisions about the implementation of ISCO to remediate groundwater
    - Series of processes
      - Information is gathered or analyzed
      - Decision points where a course of action is decided
  - Flow diagrams illustrating typical procedures
    - Screening to conceptual design to detailed design to implementation
  - Tools for key process and decision points
    - Look-up tables, spreadsheet calculators, modeling tools
  - The E-Protocol component is provided on this CD



TPM Components

- DISCO
  - Interactive tool that provides case study details from field-scale ISCO projects
    - Enables queries from selection of subsets of data within DISCO
    - Provides results as narrative discussion and summary tables and graphs
  - The DISCO component is provided on this CD



Performance Results
(for query of heterogeneous, permeable geology & chloroethene COCs without DNAPL)

Quantitative Measures of Success

	Q1	Median	Q3	n
% reduction in maximum total chloroethene concentration	47	59	64	10
% of sites w/ rebound at one or more locations in TTZ		60		10
at sites where rebound occurred, % of wells w/ rebound				
total cost (1000s US $)				
unit cost ($ / cubic yd treated)				

Attainment of Site Closure

	%	n
percent attaining site closure	20	10

Notes: **n** is the sample size (number of sites that match the query and had data for that parameter). **na** is not applicable.

Treatment Goals and Success

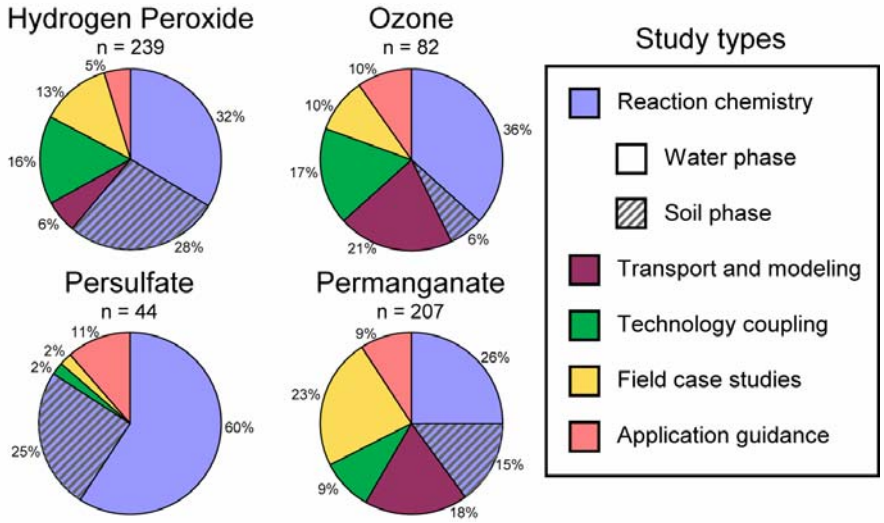
Goal Attempted	% Meeting Goal	n
meet MCLs	0	7
meet ACLs	50	2
reduce concentration / mass	100	4
evaluate effectiveness	100	6

(Continued on following page)

Project ER-0623

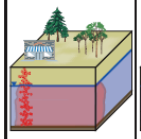
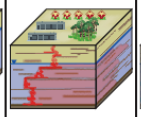
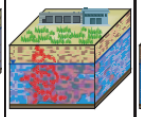
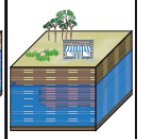
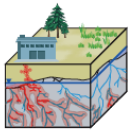
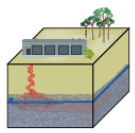
TPM Components

- Supplemental Information & Tools
  - Literature Review
    - Gather technical information necessary to develop the e-protocol contained on this CD
    - Summarize the present state of scientific knowledge
    - Provide summary information about each study identified



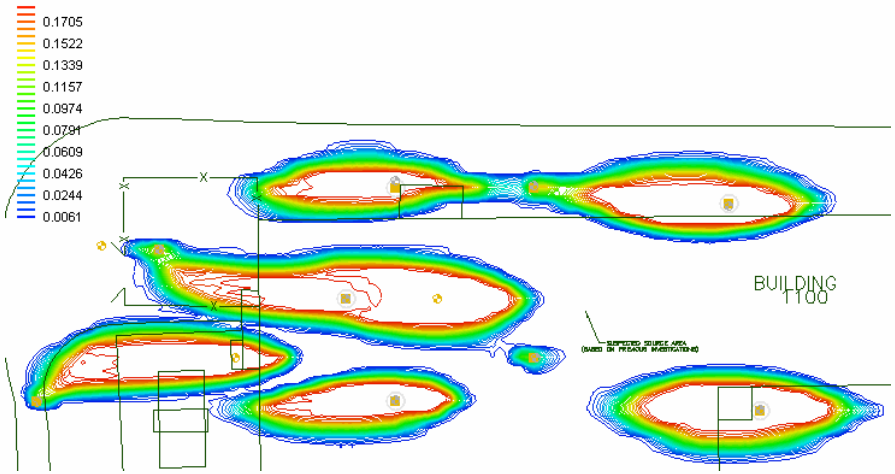
TPM Components

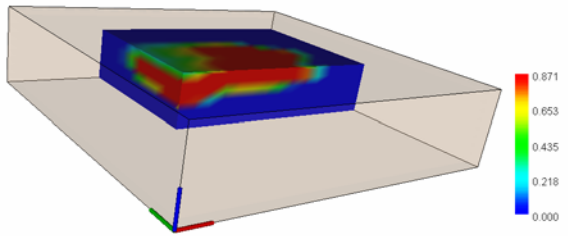
- Supplemental Information & Tools
  - Technology Practices Workshop
    - Provide a forum to share insights and perspectives gained on the application of ISCO for groundwater remediation
    - Refined frequently asked question, identified inherent ISCO limitations, and provided insight into best practices to ensure success

Scenario parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Site conceptual model						
Hydrogeology						
Morphology	Unconsolidated homogeneous	Unconsolidated heterogenous	Unconsolidated heterogeneous	Unconsolidated homogeneous	Fractured igneous rock	Fractured sedimentary rock
Permeability	Permeable	Permeable	Impermeable	Impermeable	Low matrix porosity	High matrix porosity
Velocity (m/day)	1.5	0.1	0.01	0.01	0.01	0.2
Geochemistry						
foc	0.0095	0.003	0.005	0.03	0.0005	0.005
pH	6.5	7.0	7.5	6.5	6.0	8.0
Eh (mV)	150	100	-150	-100	-200	-100
Contaminant conditions						
Primary COCs (phase)	Chloroethene (DNAPL)	Chloroethene (DNAPL)	Chloroethane (DNAPL)	Chloroethene (aqueous)	Chloroethene (DNAPL)	BTEX and MTBE (LNAPL)
Approximate age of spill	2 years	15 years	20 years	15 years	20 years	5 years
Source zone area (m^2)	400	8000	1000	n/a	2000	150
Plume area (m^2)	20000	80000	3000	500	13000	7000
Depth of COCs (m bgs)	7	50	15	6	30	12

TPM Components

- Supplemental Information & Tools
  - CORT3D
    - Provides simulation of three-dimensional reactive transport of ISCO using permanganate
    - Enables evaluation and optimization of various oxidant delivery options
    - The CORT3D model program and User's Manual is provided on this CD (install CORT3D)





2D and 3D representations of oxidant distribution

CD Purpose

- Disseminate TPM components developed through ESTCP Project ER-0623
  - Frequently Asked Questions Guide
  - E-Protocols and decision-support tools
  - Case History Database (DISCO)
  - Supplemental Information
- Serve as final deliverable for Project ER-0623

CD Contents

- Introduction (this set of slides)
- Frequently Asked Questions concerning ISCO
- E-Protocol for Site-Specific Engineering and Application
  - Introduction and User's Guide (Protocol Index)
  - ISCO Screening
  - Conceptual Design
  - Detailed Design and Planning
  - Implementation and Performance Monitoring
- Supplemental Information
  - Annotated Review of the ISCO Literature
  - Critical Review of Field Applications and Experiences (Krembs, 2008)
  - DISCO – Database of Field Applications and Experiences
  - ISCO Technology Practices Workshop Proceedings
  - CORT3D Numerical Model for Permanganate ISCO (install CORT3D)

Path to Completion of ER-0623

- Documents and tools prepared by ER-0623 team members and affiliated contributors
  - Disseminated during project period of 2006 to 2008
  - Subjected to series of internal and external reviews including:
    - CSM faculty, staff and students
    - CH2MHILL project managers and engineers
    - SERDP/ESTCP Program staff
    - DoD site personnel
    - Independent external reviewers
- Companion component
  - In Situ Chemical Oxidation for the Remediation of Groundwater volume of the SERDP / ESTCP Remediation Technology Monograph Series
  - Slated for publication by Springer Science+Business Media, LLC in 2011