Thank you for signing in early

The webinar will begin promptly at 12:00 pm ET, 9:00 am PT
SERDP and ESTCP Webinar Series

The webinar will begin promptly at 12:00 pm ET, 9:00 am PT

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“Geophysics 101: Realistic Expectations for Geophysics When Used for Site Characterization and Remediation Monitoring”

Part 2

July 28, 2016
Welcome and Introductions

Jennifer Nyman, Ph.D., P.E.
Webinar Facilitator
Agenda

- Webinar Logistics (5 minutes)
  Dr. Jennifer Nyman, Geosyntec Consultants
- Overview of SERDP and ESTCP (5 minutes)
  Dr. Andrea Leeson, SERDP and ESTCP
- Geophysical Characterization and Monitoring Studies: Hydrogeologic Framework and Processes (30 minutes)
  Dr. Frederick Day-Lewis, United States Geological Survey
- Borehole Geophysical Logging (20 minutes)
  Ms. Carole Johnson, United States Geological Survey
- Final Q&A session
How to Ask Questions

Type and send questions at any time using the Q&A panel.
In Case of Technical Difficulties

- Delays in the broadcast audio
  - Click the mute/connect button
  - Wait 3-5 seconds
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    - Required conference ID: 6102000

- Submit a question using the chat box
SERDP and ESTCP Overview

Andrea Leeson, Ph.D.
SERDP and ESTCP
SERDP

- Strategic Environmental Research and Development Program
- Established by Congress in FY 1991
  - DoD, DOE and EPA partnership
- SERDP is a requirements driven program which identifies high-priority environmental science and technology investment opportunities that address DoD requirements
  - Advanced technology development to address near term needs
  - Fundamental research to impact real world environmental management
ESTCP

- Environmental Security Technology Certification Program
- Demonstrate innovative cost-effective environmental and energy technologies
  - Capitalize on past investments
  - Transition technology out of the lab
- Promote implementation
  - Facilitate regulatory acceptance
Program Areas

1. Energy and water
2. Environmental restoration
3. Munitions response
4. Resource conservation and climate change
5. Weapons systems and platforms
Environmental Restoration

- Major focus areas
  - Contaminated groundwater
  - Contaminants on ranges
  - Contaminated sediments
  - Wastewater treatment
  - Risk assessment
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<td>An Environmentally Acceptable Alternative for Fast Cook-off Testing, Demonstration, Validation and Implementation Efforts</td>
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<td>September 8, 2016</td>
<td>Assessment of Redox-Based Groundwater Remediation Technologies</td>
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<td>October 6, 2016</td>
<td>Cyber Security Requirements and Impacts on Installation Energy Systems</td>
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<td>Resource Conservation and Climate Change</td>
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Geophysical Characterization and Monitoring Studies: Hydrogeologic Framework and Processes

Frederick Day-Lewis, Ph.D.
United States Geological Survey
Agenda

- Challenges
  - Understanding hydrogeologic framework
  - Tracking changes in aquifer properties, water quality, contaminants
- Hydrogeophysical characterization
  - Geophysical opportunities
  - Case studies
    - Hill AFB
    - Hanford, WA
- Hydrogeophysical monitoring
  - Geophysical opportunities
  - Case studies
    - Brandywine, MD
    - Naval Air Warfare Center, West Trenton, NJ
- Avoiding being oversold on geophysics

Key Message

When used appropriately, geophysical imaging technologies [1] can help resolve the hydrogeologic framework controlling fluid flow, [2] may provide indirect information on contaminant plume distribution, and [3] can sense changes related to injections or biological activity.
Understanding Hydrogeologic Framework: Challenges

Borehole data

- Expensive
- Spatial interpolation required
- Small sampling volume of cores

- Subsurface heterogeneity
- Drilling creates unwanted hydraulic pathways/exposure to contaminants
Contaminant Delineation: Challenges

Borehole data
- Expensive
- Spatial interpolation required
- Small sampling volume of cores

- Subsurface heterogeneity/anisotropy
- Contaminant transport not easily inferred from hydraulic gradients
- Contaminants diffuse into the immobile pore domain that cannot be sampled from a well
Tracking Aquifer Changes: Challenges

Borehole data

- Expensive
- Spatial interpolation required
- Gaps between sampling events

Subsurface heterogeneity/anisotropy
- Expense of sampling events and chemical analyses
- Trends may not be fully captured in quarterly or annual sampling

Sampling events (triangles)
Geophysical proxy data (dots)
The Geophysical Toolbox

- Diverse methods for application in different settings and for different goals
- Studies presented here include electrical imaging
  - 4-electrode, direct-current measurements
  - Electrodes are in boreholes and/or installed at ground surface
  - Thousands of measurements to construct an image
  - Produces images of electrical conductivity (or resistivity)

See “Part 1”
The Geophysical Toolbox (Cont’d)

- Studies presented here also include **seismic refraction**
  - Uses seismic waves, generated from hammer strikes, weight drop, seis gun, or explosives
  - Measurements involve recording waveforms and picking arrival times
  - Produces images of seismic velocity (or slowness)

See “Part 1”
Geophysical Characterization Opportunities

- Geophysical data
  - Inexpensive
  - Spatially continuous
  - Minimally-invasive
  - Multi-scale

Electrical geophysical characterization of the hydrogeological framework of a fractured mudstone sequence at the Naval Air Warfare Center (ER-201118)
3D SEISMIC REFRACTION TRAVELTIME TOMOGRAPHY AT A GROUNDWATER CONTAMINATION SITE

Zelt et al., 2006. Geophysics
Seismic Refraction Tomography
Characterization of the Hydrogeologic Framework at Hill Air Force Base

Depth to clay from well data with geometry of seismic acquisition superimposed
Geophysical Concepts Employed

Non-invasive geophysical data acquisition

Interrogating the subsurface from surface observations

Model calibration

Final model

Imaging

Travel time residual (ms)

Offset (m)

Z (m)

Y (m)

Z (m)

y=5 m

y=23 m

Velocity (m/s)
Seismic Imaging of Paleochannels

Preferred model

Geophysical models are uncertain

Demonstrates how geophysics can be used to image hydrogeological structures controlling contaminant transport at a DoD site.
Mwakanyamale et al., 2012. Geophysics

2D ELECTRICAL IMAGING AT THE US DOE HANFORD 300 AREA
Hanford 300 Area

- **Contamination legacy:** 241 metric tons of copper, 117 metric tons of fluorine, 2060 metric tons of nitrate and between 33 and 59 metric tons of uranium
- **Environmental concern:** Contaminated groundwater is discharging into the Columbia River. Resolving hydrogeological framework is critical
Direct Characterization

- Drilling is extremely expensive
- Lack of information between facilities and the river

Hanford 300 Area showing boreholes
Simplified Geological Cross-Section at Hanford 300 Area

Hanford-Ringold contact is a critical boundary directing flow towards the river

Paleochannels incised into the Ringold unit suspected to channel flow towards the river
2D Resistivity Imaging

2D ERT Lines

Surface resistivity survey line

SERDP and ESTCP Webinar Series (#38)
Geophysical Reconstruction of Controls on Groundwater Flow

- Elevation of Hanford-Ringold contact compared to temperature anomalies (from distributed temperature sensing [DTS]) showing [1] groundwater-surface water exchange locations, and [2] contours of uranium concentrations (mg/L) in aquifer from boreholes.
Contamination

What Can Geophysics Really See?

Cannot see

- Concentrations of specific contaminants
- Chlorinated solvents (directly)

Potentially can see

- Proxies of contaminant extent
  - e.g., elevated groundwater TDS, strong redox gradients
- Biogeochemical transformations associated with mature contaminants
  - e.g., solid metal mineral phases

Mineral precipitation formed during contaminant treatment results in a geophysical target.
Geophysical Proxies of Contamination

Electrical imaging of distribution of contaminants leaking from tank farm and crib waste disposal sites at US DOE Hanford site

Johnson et al., 2014. Treatise on Geophysics
Geophysical Monitoring Opportunities

Geophysical monitoring
- Can be automated
- Can be autonomous
- Is easier than detection
- Complements sampling → fills gaps in space and time
TIME-LAPSE ELECTRICAL GEOPHYSICAL MONITORING OF AMENDMENT-BASED BIOSTIMULATION

Johnson et al., 2015. Groundwater
ER 200717: Brandywine, MD

- **Primary Objective**: Demonstrate the capability to autonomously image 3D bio-amendment distribution with time.

**Test Site Configuration**

- Injection Well B6 (3/7/08)
- Sample Well
- Injection Well B7 (3/10/08)
- ERT/IP Well
- Electrodes
- Sample Ports

**Baseline ERT Image**

- Injection points
- Electrodes
- Aquifer
- Lower confining unit
- Log10 conductivity (S/m)
Brandywine DRMO

- 3D Electrical tomograms show amendment emplacement, movement

- Strong correlation between total organic acids and electrical conductivity from geophysical imaging → proxy data

- Secondary increase in conductivity indicative of mineral precipitation and/or biological activity
IMAGING PATHWAYS IN FRACTURED ROCK USING THREE-DIMENSIONAL ELECTRICAL RESISTIVITY TOMOGRAPHY

Robinson et al., 2015. Groundwater
Naval Air Warfare Center (NAWC), West Trenton, NJ

CONTAMINANT TRANSPORT PRIMARILY IN FRACTURE ZONES
NAWC Well Arrangement

84BR  86BR  87BR  88BR  89BR

**Diagram Notes:**
- Borehole wall
- Sch 40 PVC surface casing
- Length varies
- Corehole
- 4"
- 6"
- 10"
- NOT TO SCALE

**Legend:**
- Cement Grout
- Bentonite

**Context:**
- SERDP and ESTCP Webinar Series (#38)
Electrode Array Design

- Designed, constructed and implemented borehole instrumentation for geophysical imaging with packers and water sampling capability

Major technology development aspect of project
Background Image: 87BR-83BR-85BR

- Cond (S/m)
  - 0.1000
  - 0.0178
  - 0.0032
  - 0.0056
  - 0.0001

- Black: Fracture intersection depths
- White: Packers
- Dashed line: Strike-dip 3D orientation

Borehole cross section shown
Tracer Injection

- Conductivity contrasts associated with tracer injection highlight tracer transport via preferred flow paths
- **An effective** tracer injection strategy

\[ \text{Inj} = \text{Injection} \quad \text{Ext} = \text{Extraction} \]
Amendment Injection

- Conductivity contrasts associated with amendment injection highlight amendment transport via preferred flow paths.
- Amendment transport differs from tracer due to [1] different injection strategy; [2] different physical properties?
- Captures heterogeneous, channelized flow in the fracture zone.

Inj = Injection
Conclusions

**Take-away messages**

- **Geophysical site characterization**
  - Geophysical methods can help define hydrogeological framework and structures controlling groundwater flow and transport
- **Geophysics** can detect proxies of contaminants and transformations
- **Geophysics cannot** visualize contaminant concentration (e.g. DNAPL) directly
- Monitoring for changes is an easier problem than detection
Relevance


Recommendations

- Geophysical investigations prior to drilling
- Use tech transfer tools (e.g., FRGT) developed for selection of appropriate methodologies
- Avoid being oversold on geophysics
Benefits

- **Time and cost reductions**
  - Reduce drilling costs needed to characterize site hydrogeologic framework and contamination

- **Expanded spatiotemporal information**
  - Fill gaps in space that plague direct data (interpolation)
  - Fill gaps in time between sampling events with proxy data
  - Minimally invasive sampling
  - Reduce likelihood of cross-contamination and human exposure associated with drilling

- **Scale**
  - Scale-appropriate information for parameterizing flow and transport models
Acknowledgments

- Lee Slater (Rutgers University Newark)
- Judith Robinson (Rutgers University Newark)
- Carole Johnson (USGS)
- Timothy Johnson (PNNL)
SERDP & ESTCP Webinar Series

For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201118

Speaker Contact Information
daylewis@usgs.gov; 860-487-7402
Q&A Session 1
Borehole Geophysical Logging

Carole D. Johnson, P.G.
United States Geological Survey
Agenda

- What is borehole geophysical logging?
- Tool selection
- Objectives for logging
- Logging results used for survey design
- Benefit to DoD sites
- Summary
Borehole Geophysical Logging

- Depth dependent measurements of geohydrologic properties
  - Potentially critical for
    - Site characterization
    - Planning well completion
    - Design of sampling, monitoring and remediation strategies
    - Performance monitoring
  - Tool selection based on property of interest
Borehole Geophysical Tool Selection

- Fractured Rock Geophysical Toolbox (FTG)
Objectives for Logging

- Characterization
  - Well construction and integrity
  - Geology
  - Structure
  - Fluids (in formation and borehole)
  - Hydraulics and hydrogeology

- Design well completions or other surveys
- Monitoring transient processes
Borehole Conditions

- Characterize depth, diameter, casing materials and integrity
  - e.g., steel casing limits tool selection
  - e.g., caliper diameter to optimize packer location

- Deviation (x,y,z position)
  - Structure log correction
  - Hole-to-hole geophysics/tomography
Geologic Framework

- Identify stratigraphy or lithology
  - Methods: nuclear, electrical, seismic, imaging logs
  - e.g., gamma and imaging logs
  - e.g., identify structurally controlled water-bearing zones

- Revise conceptual site model (CSM)
Correlation Across Wells and Site

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Gamma

Optical and Acoustic Imaging

0 50 FT
Structure

- Identify orientation of fractures and contacts
  - Methods: acoustic (ATV), optical (OTV), electrical imaging tools
  - e.g., characterize fracture networks – potential preferential pathways
- Consider deviation, declination and bias
- Characterize/refine CSM

Williams and Johnson, 2004
Characterize Fluids

- **Fluids in formation**
  - Bulk electrical measurements outside of the borehole

- **Fluids in borehole column**
  - Infer zones of different chemistry and vertical flow zones
  - Before and after pumping: identify inflow zones
Characterize Fluids with NMR

- Nuclear Magnetic Resonance to measure water content, estimate pore size distribution and hydraulic conductivity
- Designed to measure beyond disturbed zone
- Water content results match neutron
- No active sources

Modified from Walsh et al., 2013
Characterize Hydraulics

- Monitor change in response to stress – identify inflow zones
- Fluid differencing logs
- Flowmeter
  - Heat pulse, electromagnetic, spinner – appropriate for borehole
  - Point or continuous
- High-resolution temperature
- Dye tracer and dilution methods

e.g., Ambient flow regime and fluid dilution test

Korb et al., 2005
Characterize Hydraulics

- Flow profiles can be modeled
- Qualitative vs. qualitative analysis
- Estimate discrete zone
  - Transmissivity
  - Head
- e.g., Flow-Log Analysis of Single Holes (FLASH) Model

Day-Lewis et al., 2011
Borehole Logging Results Used for Design of Additional Site Work

- Well completions – packer locations, liners, conventional multilayer wells
- Designing other tests
  - Single-hole packer tests
  - Hydraulic tomography
  - Electrical imaging tomography
  - Identify injection/sampling zones
  - Long term monitoring

Tiedeman et al., 2015
Potential Benefits of Logging Program

- Identify sources of water to wells
- Design sampling/monitoring systems with consideration of flow regime
- Prevent cross-contamination
- Collect meaningful samples
  - Reduce costs by targeting sample zones
  - Avoid samples that represent a mixture of zones
Example: Open Hole and Point Sampling

- **High head**: Contaminated
- **Low head**: Uncontaminated
- **Dilution and Cross contamination**

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Example: Vertical Flow in Open Hole and Significance for Sampling
Example: Sampling Design Based on Flow Logs

- **High head**
  - Contaminated
  - Inflatable packer

- **Low head**
  - Uncontaminated

- **Borehole**
- **No flow through borehole**

- **Concentration (ppb)**
- **Flow (gpm)**

- Depth

- Depth

- Depth

- Concentration (ppb)
- Flow (gpm)
Summary Geophysical Logging

- Characterize hydrogeology of site – improve CSM
- Plan other surveys
  - e.g., flowmeter/packer tests
  - e.g., hole-to-hole (electrical/hydraulic) tests
- Design well completions
- Design sampling, monitoring, remediation programs
- Corroborate interpretations and/or constrain other geophysical or hydraulic models

Johnson et al., 2005
Conclusions

- Tool selection based on project goals, objectives, site conditions
- No single tool can “do it all”
- Multiple tools used together to enhance interpretation – and minimize/avoid non unique interpretations
- Appropriately used borehole logging program can improve CSM, sampling strategies, remediation and monitoring programs at DoD sites
Acknowledgments

- Frederick Day-Lewis (USGS)
- Lee Slater (Rutgers University Newark)
- Judith Robinson (Rutgers University Newark)
For additional information, please visit https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201118

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Q&A Session 2
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“An Environmentally Acceptable Alternative for Fast Cook-off Testing, Demonstration, Validation and Implementation Efforts”
Survey Reminder

Please take a moment to complete the survey that will pop up on your screen when the webinar ends