Starting Soon: Geospatial Analysis for Optimization at Environmental Sites

- Geospatial Analysis for Optimization at Environmental Sites (GRO-1) Guidance Document at http://www.itrcweb.org/gro-1
- Download PowerPoint file
  - Clu-in training page at www.clu-in.org/conf/itrc/gro/
  - Under “Download Training Materials”
- Using Adobe Connect
  - Full Screen button near top of page
  - Related Links (on right)
    - Select name of link
    - Click “Browse To”
  - Submit questions in the lower right

No associated notes.
**Training Course Overview:** Optimization activities can improve performance, increase monitoring efficiency, and support contaminated site decisions. Project managers can use geospatial analysis for evaluation of optimization opportunities. Unlike traditional statistical analysis, geospatial methods incorporate the spatial and temporal dependence between nearby data points, which is an important feature of almost all data collected as part of an environmental investigation. The results of geospatial analyses add additional lines of evidence to decision making in optimization opportunities in environmental sites across all project life cycle stages (release detection, site characterization, remediation, monitoring and closure) in soil, groundwater or sediment remediation projects for different sizes and types of sites.

The purpose of ITRC's Geospatial Analysis for Optimization at Environmental Sites (GRO-1) guidance document and this associated training is to explain, educate, and train state regulators and other practitioners in understanding and using geospatial analyses to evaluate optimization opportunities at environmental sites. With the ITRC GRO-1 web-based guidance document and this associated training class, project managers will be able to:

- Evaluate available data and site needs to determine if geospatial analyses are appropriate for a given site
- For a project and specific lifecycle stage, identify optimization questions where geospatial methods can contribute to better decision making
- For a project and optimization question(s), select appropriate geospatial method(s) and software using the geospatial analysis workflow, tables and flow charts in the guidance document
- With geospatial analyses results (note: some geospatial analyses may be performed by the project manager, but many geospatial analyses will be performed by technical experts), explain what the results mean and appropriately apply in decision making
- Use the project managers' tool box, interactive flow charts for choosing geospatial methods and review checklist to use geospatial analyses confidently in decision making

ITRC (Interstate Technology and Regulatory Council) [www.itrcweb.org](http://www.itrcweb.org)
Training Co-Sponsored by: US EPA Technology Innovation and Field Services Division (TIFSD) [www.clu-in.org](http://www.clu-in.org)
ITRC Training Program: training@itrcweb.org; Phone: 402-201-2419
Although I’m sure that some of you are familiar with these rules from previous CLU-IN events, let’s run through them quickly for our new participants.

We have started the seminar with all phone lines muted to prevent background noise. Please keep your phone lines muted during the seminar to minimize disruption and background noise. During the question and answer break, press #6 to unmute your lines to ask a question (note: *6 to mute again). Also, please do NOT put this call on hold as this may bring unwanted background music over the lines and interrupt the seminar.

Use the “Q&A” box to ask questions, make comments, or report technical problems any time. For questions and comments provided out loud, please hold until the designated Q&A breaks.

Everyone – please complete the feedback form before you leave the training website. Link to feedback form is available on last slide.
The Interstate Technology and Regulatory Council (ITRC) is a state-led coalition of regulators, industry experts, citizen stakeholders, academia and federal partners that work to achieve regulatory acceptance of environmental technologies and innovative approaches. ITRC consists of all 50 states (and Puerto Rico and the District of Columbia) that work to break down barriers and reduce compliance costs, making it easier to use new technologies and helping states maximize resources. ITRC brings together a diverse mix of environmental experts and stakeholders from both the public and private sectors to broaden and deepen technical knowledge and advance the regulatory acceptance of environmental technologies. Together, we’re building the environmental community’s ability to expedite quality decision making while protecting human health and the environment. With our network of organizations and individuals throughout the environmental community, ITRC is a unique catalyst for dialogue between regulators and the regulated community.

For a state to be a member of ITRC their environmental agency must designate a State Point of Contact. To find out who your State POC is check out the “contacts” section at www.itrcweb.org. Also, click on “membership” to learn how you can become a member of an ITRC Technical Team.

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Dave Becker is a geologist with the Environmental and Munitions Center of Expertise (EM CX) of the US Army Corps of Engineers (USACE) in Omaha, Nebraska. Since coming to the EM CX in 1991, Dave has been involved in providing technical consultation, teaching, review of environmental restoration-related documents, and preparation of guidance relevant to field studies and in-situ remediation. He has strong interests in optimization of remediation systems and long-term monitoring programs, site characterization techniques, and in-situ remediation technologies. Before coming to the EM CX in 1991, Dave was Chief, Geology Section at the USACE Omaha District between March 1989 and December 1990. For five years prior to becoming a supervisor, Dave was a project geologist in Omaha District actively involved in many environmental restoration projects. Dave is an active member of the ITRC Geostatistics for Remediation Optimization team and previously worked on the Remediation Risk Management and Remediation Process Optimization teams and has taught numerous Internet and live seminars for ITRC, USACE, and EPA. He is a member of the Geological Society of America, the American Geophysical Union, the American Association of Petroleum Geologists, and the Nebraska Geological Society. Dave is also an adjunct professor of geology at the University of Nebraska at Omaha where he teaches hydrogeology, geophysics, and environmental geology. Dave earned a bachelor's degree in geology from the University of Nebraska at Omaha in 1981 and a master's degree in geophysics from Southern Methodist University in Dallas, Texas in 1985. He is a registered professional geologist in Nebraska.

Adam Janzen is an environmental engineer with Barr Engineering Company in Minneapolis, Minnesota. His primary area of expertise is in groundwater flow modeling with typical applications of wellhead protection, mine dewatering, water supply, and contaminant fate and transport. He has used geostatistical methods to evaluate and optimize sampling networks and presented a paper describing an automated optimization approach at the MODFLOW and More 2013 conference. At Barr he has taught an internal geostatistics training course. Prior to joining Barr in 2011, Adam developed multi-phase flow models to simulate injection and geologic storage of carbon dioxide for a start-up company. Adam earned a bachelor's degree in civil and environmental engineering from the University of Illinois at Urbana-Champaign in 2008 and a master's degree in civil and environmental engineering from Princeton University in 2010. He is a licensed professional engineer in Minnesota.

Chris Stubbs is a senior manager with Ramboll in Emeryville, California. Since 2000, he has worked in environmental science and engineering, with special emphasis on groundwater hydrology and chemical fate and transport in the environment. Specific areas of expertise include groundwater modeling, statistical analysis, risk-based site assessment and remediation, exposure analysis and human health risk assessment. He has prepared evaluations of the risk from vapor intrusion into indoor air at numerous sites, including preparing expert reports and giving deposition testimony as an expert witness. He has developed regional groundwater flow and transport models to evaluate remedial alternatives and to estimate cleanup times. Chris is a member of the ITRC Groundwater Statistics and Monitoring Compliance project team. Chris earned a bachelor’s degree in 1988 in physics from the University of California at Berkeley, CA. He earned a master’s degree in 1996 in environmental engineering, and a PhD in 2000 in hydrology and water resource engineering all from the Massachusetts Institute of Technology in Cambridge, MA. He is a professional civil engineer in California.

Ali Furmall is the Rural and Small Communities Specialist for the Brownfields Program at the Washington Department of Ecology in Spokane, WA. In this newly created position, she is working to build a program focused on promoting brownfields redevelopment to small communities in central and eastern Washington. She previously managed the Remediation Oversight Section in the Ground Water Quality Bureau at the New Mexico Environment Department in Santa Fe, New Mexico. The programs in her section, the Voluntary Remediation Program and State Cleanup Program, provide regulatory and technical oversight for environmental investigation and remediation at complex sites throughout New Mexico. In addition to reviewing the technical sufficiency of proposals submitted to her program, Ali ensures that staff are provided the training and support necessary to excel in their positions. Ali routinely presents at Brownfields conferences and is coordinating bi-monthly training sessions for technical staff in the Ground Water Quality Bureau. Ali has been active in ITRC since 2014 as a member of the Geospatial Analysis for Optimization at Environmental Sites team. Ali earned a bachelor's degree in geology from the University of South Florida in Tampa, Florida in 2007 and a master's in geology from the University of Oregon in Eugene, Oregon in 2010.
Presentation Overview

- Introduction
- Opportunities to Apply Geospatial Analyses
- Fundamentals of Geospatial Methods
- How to Apply and Application Examples
- Putting GRO into Practice
**Geospatial Analysis** for Optimization at Environmental Sites (GRO-1)

- If you use/view computer-generated contour maps, you’ve used geospatial methods!
- Computer-based tools to contour data are spatial tools
  - Groundwater contours
  - Concentration contours/plume maps
  - Surface elevations (including elevation of geologic features)
Geospatial Analysis for **Optimization** at Environmental Sites (GRO-1)

- We are being asked to do more with less
- Agencies/Department of Defense have policies requiring optimization
  - Some focus on post construction
  - Others promote optimization throughout life cycle
- ITRC Remediation Process Optimization guidance documents and fact sheets
- Other tools
  - Federal Remediation Technology Roundtable (FRTR)
  - EPA Clu-in web sites have references, case studies
  - US Air Force tools

ITRC GRO-1, History of Remedial Process Optimization
Why This Matters: Geospatial Tools Optimize Our Work

- Geospatial methods **helpful to optimize** activities
  - Optimization = effort (at any clean-up phase) to identify & implement actions that improve effectiveness & cost-efficiency of that phase

- Example: Geospatial analysis help optimize monitoring networks
  - Eliminating < 30 wells has small impact on map error
  - Greater reductions = more error
  - Compare plume maps with & without the eliminated wells

ITRC GRO-1, Figure 52, Example 1: Sampling Redundancy Analysis in Visual Sample Plan (VSP)
Why This Matters: Geospatial Methods Help You…

- Achieve cost saving for the total project life cycle
  - Improved planning
  - Optimization of scope for characterization and monitoring
  - Demonstration of attainment of goals

- Conduct enhanced data evaluation/interpretation
  - Improved quality of data
  - Identification of trends and patterns in data
  - More accurate estimates of important quantities (average concentrations, volumes)
  - Better decision making

- Effectively communicate (with your peers, the public)
  - Data visualizations

Dave Becker, USACE
Why This Matters: Geospatial Tools Aid Interpretation

- Geospatial analysis helps understand relationships between observed contamination and sources
- Example: The figures show relationship between metal contamination and a river that periodically floods
Why This Matters: Geospatial Methods Help Communication

- Visualization tools depend on geospatial methods to generate 2-D & 3-D information to present graphically.
- Example: Material identified for excavation at a site.

ITRC GRO-1, Figure 100. Oblique view of the site highlighting material identified for excavation (vertical exaggeration 5x horizontal).
Poll Question

- What role would you likely play in application of geospatial analysis?
  - Project manager overseeing team members who conduct the analysis
  - Technical reviewer of geospatial analysis
  - Technical practitioner applying the methods
  - Stakeholder interested in understanding basis and meaning of the results of geospatial analyses
  - Others
ITRC GRO Guidance is an Interactive Resource for Various Users and Includes...

- Fact sheets
- Summary and comparison information on software
- Project manager’s tool box
- Review checklist
- Flow charts

http://www.itrcweb.org/gro-1
Training and Guidance Objectives:

Learning objectives: With the ITRC Geospatial Analysis for Optimization guidance document and this associated training, project managers/technical staff will be able to:

- **Determine if appropriate** - based on available data & site needs, determine if geospatial analyses are appropriate for site
- **Identify questions** - for project and specific lifecycle stage, identify optimization questions to ask
- **Select method(s)** - select appropriate geospatial method(s) and software to answer questions
- **Explain and apply results** - explain what the results mean and appropriately apply in decision making

*NOTE! Training is meant primarily to give you a taste of the critical concepts and provide overview of the guidance.*
Presentation Overview

- Introduction
- Opportunities to Apply Geospatial Analyses
- Fundamentals of Geospatial Methods
- How to Apply and Application Examples
- Putting GRO into Practice

Optimization Questions  Methods  Software
PM's Tool Box  Work Flow  Choosing Methods
Geospatial Analysis Work Flow

- Review conceptual site model (CSM) and project goals
- Perform exploratory data analysis
- Choose geospatial method
- Build model / check model
- Generate results (predictions and uncertainty)

See Flow Charts

See Review Checklist

ITRC, GRO-1, Work Flow
Applications of Geospatial Methods

- What are the data requirements?
- Regulatory barriers and concerns – Fact Sheet 1
- What are the common misapplications?
- Using geospatial methods to support optimization
  - Optimization questions one may ask at various project phases for which geospatial methods can be used
What are the Data Requirements?

What are the minimum requirements of data sets for geospatial analyses?

- **Information needed:**
  - Spatial definition of data and study area
    - Horizontal, vertical
  - Cleanup goals
  - Site data such as
    - Hydrogeology, moisture, organic carbon
  - Chemical concentrations
- **Amount of data**
  - Depends on method, objectives

ITRC GRO-1, Figure 1
Prospective Barriers and Concerns

- Many state and federal agencies have accepted approaches for optimization
- Guidelines vary by agency – user should identify before proceeding
- Modification of project life-cycle activities can be difficult from a regulatory perspective
- Hesitance to use or accept new geospatial analysis

**POLL QUESTION:** Have you experienced resistance to using geospatial methods for a project?
What are the Common Misapplications?

- Common Misapplications include a list of common misapplications & recommendations to avoid them. Examples:
  - Inadequate amount of data
  - Extrapolation of data
  - Geospatial models inadequately addressing heterogeneity
  - Ignoring impact of censored data
  - Not accounting for data uncertainty
- Common misapplications – more info to come in subsequent slides
Optimization Questions – Examples for Different Project Phases

- Release Detection:
  - Do the detected concentrations represent an actual plume?
  - Note there is often only spatially sparse data at this phase

- Site Characterization:
  - What is appropriate sample spacing, considering spatial correlation?

- Remediation:
  - What are the estimated average concentrations (for treatment design)?

- Monitoring:
  - How can geospatial methods help optimize a monitoring program?

- Closure:
  - Can geospatial methods help determine if the monitoring program is adequate for closure?
  - Note that spatial data are often sparse near closure

ITRC GRO-1, Optimization Questions

Dave Becker, USACE
Example of Life-Cycle Optimization
Question & Geospatial Methods to Apply

- Site characterization phase – “What is appropriate sample spacing, considering spatial correlation?”
  - Planning for cost-effective sampling: choosing sampling spacing to characterize soil contamination
  - Use geospatial analyses to estimate sample spacing to avoid duplication of information (spatial correlation)
  - Construct variogram (will be discussed in more detail), determine geostatistical range, use as basis for sample spacing with independent data
  - Software to do this can be located using guidance

ITRC GRO-1. Site Characterization
Where to Next? Answering the Questions

- Geospatial methods are identified that may answer these questions and are generally categorized into:
  - Simple
  - More complex
  - Advanced

- Software tools are identified to apply the proposed methods
Poll Question

- Based on what we’ve presented in this section, do you work on sites that could benefit from geospatial analysis?
  - Yes
  - No, not enough data
  - No, we don’t need geospatial analysis
  - Don’t know yet
Presentation Overview

- Introduction
- Opportunities to Apply Geospatial Analyses
- **Fundamentals of Geospatial Methods**
- How to Apply and Application Examples
- Putting GRO into Practice
After Fundamentals Section, You Can…

► Explain how geospatial methods work
  • Classification and components
  • Variograms – key concept for geospatial analysis
► Avoid misapplications
Basic Premise of Geospatial Methods

- Tobler’s First Law of Geography (Tobler 1970):
  “Everything is related to everything else, but near things are more related than distant things.”
- Sample observations collected close together in space or time are more related than sample observations collected farther apart.
- This is the basic premise of geospatial methods

ITRC GRO-1. Fundamental Concepts

Spatial Correlation Illustrated

Classical Statistics Realm

Geospatial Method Realm

No Spatial Correlation

Systematic Variation (Trend)

Bounded Spatially-Correlated Variation (Autocorrelation)

ITRC GRO-1, Figures 8, 9 and 10
Trend and Autocorrelation Together

- Trend: Blue line
- Autocorrelation: Deviation from trend
Geospatial Model Components

Geospatial Model = Trend + Error + Autocorrelation

- Trend: Large-scale variation (e.g., regional)
  - All methods (simple, more complex, advanced)
- Error: Measurement error and micro-scale variation
  - More complex and advanced methods
- Autocorrelation: Small-scale variation around the trend
  - Advanced methods only

ITRC GRO-1, Categories of Geospatial Interpolation Methods
Geospatial Method Classification

► Simple (trend)
  • Inverse distance weighting, natural neighbor, Voronoi
    Diagrams/Thiessen Polygons, Delaunay Triangulation

► More complex (trend + error)
  • Regression-type methods, splines
  • Focus on modeling the trend component with
    secondary data (predictor variables)

► Advanced (trend + autocorrelation + error)
  • Kriging or geostatistical-type methods
  • Trend component is usually simple
  • Focus on modeling the autocorrelation component
Simple methods focus on making good maps
  • “Good” is typically evaluated visually
  • Map should be consistent with CSM

Many optimization tasks require more than just mapping.
  • More complex and advanced methods are based on statistical modeling
  • They produce more accurate predictions with estimates of uncertainty

More complex and advanced methods can also be “simple” methods when using default parameters. This is acceptable for mapping ONLY.
Why Is Spatial Correlation Important?

- **Good news:** spatial correlation allows mapping between samples!
  - Used by all methods to interpolate between sample locations
- **Bad news:** correlated samples reduce uncertainty less than independent samples
  - Need to understand correlation scale to optimize sampling
  - Sample spacing $<<$ correlation scale do not provide much additional information
Quantifying Spatial Correlation with Variograms

- The variogram (or semivariogram) quantifies spatial correlation
- The variogram is a plot of the squared differences between measured values as a function of distance between sampling locations
- Kriging requires a variogram (autocorrelation model)
- Variogram is also useful by itself to identify the scale of spatial correlation
Variogram Terminology

- Directionality is important when constructing the variogram
  - 2D vs 3D problems
The Three General Variogram Cases

No Spatial Correlation | Trend | Autocorrelation

ITRC GRO-1, Figures 8, 9 and 10
Variogram Pop Quiz

What are the range and sill of this variogram?

A) Range = 60, Sill = 10
B) Range = 9, Sill = 24
C) Range = 24, Sill = 9
D) Sill = 60, Range = 10
And the answer is…

- C) Range = 24, Sill = 9

- Sill is theoretically the variance of the data
- Range is the scale of spatial correlation; has implications for sample spacing
65% Reduction in Total Number of Samples for Comparable Delineation – Case Study

- More information in GRO-1 Case Study: Optimization of Sediment Sampling at a Tidally Influenced Site
- Delineate area of sediment with PCB concentrations above a risk-based threshold
- Retrospective geospatial analysis used variography and kriging to optimize the sampling approach

<table>
<thead>
<tr>
<th></th>
<th># sediment samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial sampling 2001-2002</td>
<td>240</td>
</tr>
<tr>
<td>Actual, additional samples collected from 2003-2008</td>
<td>509</td>
</tr>
<tr>
<td>If choice of 2003-2008 sample locations had been guided by the range of the 2001-2002 variogram</td>
<td>24</td>
</tr>
</tbody>
</table>

Orange: S simple methods
Green: MC more complex methods
Blue: A advanced methods
Search Neighborhood Radius Impacts Map Smoothness

- Kriging and inverse distance weighting estimate values at unsampled locations using a weighted sum of nearby data points.
- Value of search neighborhood radius affects smoothness of final map.

ITRC GRO-1, Figure 18
Exact vs. Inexact Interpolation Affects Perceived Map Accuracy

- Exact interpolation: predictions exactly match measured values at measurement locations
- Most simple methods are exact interpolators
- Kriging can be an inexact interpolator – incorporates error
  - Locational error
  - Lab and field sample error
  - Duplicate samples?

Issue: People Like Contours with Exact Interpolation

ITRC GRO-1, Figure 19
Boundary Omission Leads to Misapplication

- Surface water features, concentration source zones, impermeable boundaries (slurry walls), faults
- Rely on conceptual site model
- Failure to incorporate can result in misapplication

Make sure all necessary data are included in the analysis.

ITRC GRO-1, Figure 21
Fundamentals Section Wrap Up

- Data must show spatial correlation in order to use geospatial methods
- Geospatial model = Trend + Error + Autocorrelation
- Variograms quantify spatial correlation and are a key concept in geospatial analysis
- Choose a geospatial method consistent with your CSM
Question & Answer Break
Presentation Overview

- Introduction
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- Optimization Questions
- Methods
- Software
- PM's Tool Box
- Work Flow
- Choosing Methods
How to Apply and Application Examples -- Outline

► Modeling the data for optimization
  • Geospatial analysis work flow
  • Quantifying uncertainty
► How to apply more complex methods
  • Exploratory data analysis (EDA)
  • Nonparametric regression
► How to apply advanced methods
  • Kriging
  • Model evaluation
  • Conditional simulation
  • Cokriging
Modeling the Data for Optimization

- Quantitative predictions for optimization require *modeling* the data with more complex or advanced methods
  - Predictions are more accurate
  - Uncertainty in predictions can be quantified
  - Sampling can be better optimized
- Modeling goes beyond mapping the data
  - Fit statistical model to the data
  - Assess accuracy of predictions

ITRC GRO-1, More Complex Methods, Advanced Methods
Follow the Geospatial Work Flow

» Practitioners
  • Conduct the geospatial analysis
  • Follow the work flow to model the data
  • Document each step of work flow

» Reviewers
  • Review the geospatial analysis
  • Follow the work flow to check that model is appropriate
  • Verify that documentation includes each step of work flow
Geospatial Analysis Work Flow

- Review CSM and project goals
  - Identify key site features and questions
- Perform exploratory data analysis
  - Evaluate distribution, outliers, trend, spatial correlation, auxiliary data
- Choose geospatial method
  - Simple, more complex, advanced
- Build model / check model
  - Cross-validation and CSM consistency
- Generate results (predictions and uncertainty)

ITRC GRO-1, Work Flow Overview
Measures of Uncertainty

- Standard error and variance
  - Output of more complex and advanced methods
- Confidence/prediction interval
  - Can be calculated from predictions and standard error or variance
- Exceedance probability
  - Probability of exceeding a threshold

ITRC GRO-1, Evaluate Accuracy, Generate Results
Measures of Uncertainty

Data

![Data plot showing a scatter of points with a trend line.](image-url)
Measures of Uncertainty

Data + Model

![Graph showing the relationship between Result and Location]
Measures of Uncertainty

Data + Model + Standard Error
Measures of Uncertainty

Data + Model + 95% Confidence Interval
More Complex Methods Example

Soil Samples Near River Meuse

Zinc Concentration (ppm)
- 100
- 200
- 500
- 1000
- 2000

CSM: Flooding of River Meuse causes elevated zinc in floodplain

ITRC GRO-1, Figure 61
What are Optimization Questions?

- Optimization questions
  - What is 95% upper confidence level (UCL) of mean zinc concentration?
  - How can secondary (proxy) data be used to improve predictions of mean zinc concentration?

ITRC GRO-1, Table 2
EDA: Normalize Zinc Distribution

Zinc Concentrations

Log-Zinc Concentrations

ITRC GRO-1, Figure 62
EDA: Zinc Autocorrelation

Vargogram

Log Zinc Semivariance

Distance (m)

ITRC GRO-1, Figure 64
EDA: Zinc vs. Distance to River

ITRC GRO-1, Figure 65
EDA: Zinc vs. Soil Type

ITRC GRO-1, Figures 67, 68

*Categorical variables can only take one of a fixed number of values*
When to Use More Complex Methods

- Description
  - Regression methods with no spatial correlation model
  - Very flexible (e.g. can incorporate features such as faults)
  - Works best when other predictor variables are available
  - Assumes regression residuals are spatially uncorrelated and normally distributed (after transformation)
  - Provides prediction standard error or variance

- Methods
  - Parametric regression
  - Splines and kernel smoothing
  - Nonparametric regression

ITRC GRO-1. More Complex Methods
Nonparametric Regression Can Model Complex Data

ITRC GRO-1, Figure 29

ITRC GRO-1, Figure 27
Select Method (More Complex)

- Nonparametric regression selected due to availability of secondary data
- Final model based on:
  - Distance to river
  - Soil type
  - Flood frequency
  - Smooth fit (thin-plate spline) of trend
- Best predictors selected using model evaluation techniques (cross validation)
Predictions and Standard Error

Predicted Log Zinc Concentrations

Prediction Standard Error

ITRC GRO-1, Figures 73, 74
Check Residuals for Autocorrelation

Variogram of Residuals

Regression assumes no autocorrelation of residuals
Use Model for Optimization

- Calculate average concentration with confidence limits to compare to remediation target concentration
- Optimize sampling/remediation
  - Locate additional samples at locations with highest uncertainty
  - Select subareas to target for remediation in order to reduce upper confidence limit below remediation target

ITRC GRO-1, Using Results
Advanced Methods Example

Soil Samples Near River Meuse

Zinc Concentration (ppm)
- 100
- 200
- 500
- 1000
- 2000

CSM: Flooding of River Meuse causes elevated zinc in floodplain
ITRC GRO-1, Figure 61
Advanced Methods Example

- Same CSM and zinc data as Example 1, but no secondary data available
- Optimization questions
  - What is the area requiring remediation?
  - Where should additional samples be located?

ITRC GRO-1, Table 2
When to Apply Advanced Methods

Description
- Extension of regression methods including a spatial correlation model
- Works best when sufficient data to estimate correlation model are available
- Assumes residuals after trend removal are stationary and normally distributed (after transformation)
- Provides prediction standard error or variance

Methods
- Kriging/Cokriging (point and block)
- Conditional simulation

ITRC GRO-1. Advanced Methods
Advanced Methods Require Variography

- A variogram model is fit to model autocorrelation. Most common choices:

ITRC GRO-1, Figure 79
Quiz: Selecting Variogram Model

- What variogram function(s) could be used?
Answer: Selecting Variogram Model
Variography of Meuse Data

- Fit variogram using exponential model

Reviewers: Was plot of variogram provided?

ITRC GRO-1, Figure 14
Remove Trend When Variogram Unbounded

When data has trend (non-stationary), variogram is unbounded.
→ Remove trend and use variogram of residuals

ITRC GRO-1, Figure 32, 34
## Selecting Method: Kriging Types

<table>
<thead>
<tr>
<th>Name</th>
<th>Trend Model</th>
</tr>
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<tbody>
<tr>
<td>Simple Kriging</td>
<td>Constant (known, usually zero)</td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>Constant (unknown)</td>
</tr>
<tr>
<td>Universal Kriging</td>
<td>Polynomial function of coordinates</td>
</tr>
<tr>
<td>Kriging with External Drift</td>
<td>Regression on secondary data (simultaneous)</td>
</tr>
<tr>
<td>Regression Kriging</td>
<td>Regression on secondary data (sequential)</td>
</tr>
</tbody>
</table>

Use ordinary kriging unless there is a strong trend in the data with a physical basis

ITRC GRO-1, [Kriging](#)
Kriging of Zinc Concentration

Ordinary Kriging (Spherical Variogram)

Ordinary Kriging (Exponential Variogram)
Model Evaluation

- Evaluate consistency of predictions with CSM
- Verify assumptions of method
- Use cross-validation to quantitatively evaluate model quality
  - Can be used with any method
  - Take one out cross validation is most common
  - Look at accuracy of predictions and accuracy of prediction standard errors

ITRC GRO-1, Evaluate Accuracy
Compare Models Using Cross-Validation

- Inverse distance weighting (IDW) added for comparison to ordinary kriging (OK)
- All methods smooth the data

ITRC GRO-1, Figure 47
Use Cross-Validation to Check Model Accuracy

- Evaluate prediction accuracy using:
  - Mean Error: average of cross-validation errors (should be close to 0)
  - Root Mean Square (RMS) Error: square root of the average squared cross-validation errors (should be close to 0)

<table>
<thead>
<tr>
<th>Method</th>
<th>Variogram</th>
<th>Mean Error</th>
<th>Root Mean Square Error</th>
<th>Mean Standardized Error</th>
<th>Root Mean Square Standardized Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverse Distance Weighting</td>
<td>NA</td>
<td>-0.0128</td>
<td>0.514</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>Exponential</td>
<td>0.00213</td>
<td>0.503</td>
<td>0.00301</td>
<td>0.03</td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>Spherical</td>
<td>-2.06E-05</td>
<td>0.392</td>
<td>0.00017</td>
<td>0.00</td>
</tr>
</tbody>
</table>

ITRC GRO 1, Table 4
Use Cross-Validation to Check Model Accuracy

- Evaluate accuracy of prediction uncertainty with:
  - Mean Standardized Error: mean error divided by standard error (should be close to 0)
  - RMS Standardized Error: RMS error divided by standard error (should be close to 1)

<table>
<thead>
<tr>
<th>Method</th>
<th>Variogram</th>
<th>Mean Error</th>
<th>Root Mean Square Error</th>
<th>Mean Standardized Error</th>
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<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>Exponential</td>
<td>0.00213</td>
<td>0.303</td>
<td>0.00301</td>
<td>0.03</td>
</tr>
<tr>
<td>Ordinary Kriging</td>
<td>Spherical</td>
<td>-2.06E-05</td>
<td>0.392</td>
<td>0.00017</td>
<td>0.00</td>
</tr>
</tbody>
</table>

ITRC GRO 1, Table 4
Log Zinc Point Kriging Results

Predictions

Prediction Standard Error
95% Upper Confidence Limit
Log Zinc Block Kriging Results

Predictions

Prediction Standard Error

Log Zinc
70
65
60
55
50

Log Zinc
5.5
5.4
5.3
5.2
Prediction vs Simulation

- Predictions from regression and kriging are smoothed estimates of reality (expected values)
- Simulation can provide more realistic depiction of variability

![Graph showing concentration changes in North and South directions with sample and actual data points.](image)
Simulation of Log Zinc

Each simulation is consistent with data and variogram

Repeat ~1,000 times

ITRC GRO-1, Conditional Simulation
Uncertainty in Area Above Cleanup Level (1,000 mg/kg)
Landrum, C. 2013. “Mapping and decomposing scale-dependent soil moisture variability within an inner bluegrass landscape.”, Theses and Dissertations, Plant and Soil Science, University of Kentucky (Paper 34).
More Complex/Advanced Methods: Questions for Reviewers

► Is the method selected clearly described, along with a description of how it was implemented?
► Why was this method selected over alternative methods? Are the assumptions of the method met?
► How were the method parameters fit, and how was goodness-of-fit evaluated?
► Was prediction uncertainty described and quantified using cross-validation?
► Are the results consistent with the CSM?

ITRC GRO-1, Review Checklist
Presentation Overview

- Introduction
- Opportunities to Apply Geospatial Analyses
- Fundamentals of Geospatial Methods
- How to Apply and Application Examples
- Putting GRO into Practice

![Diagrams for Optimization Questions, Methods, Software, PM's Tool Box, Work Flow, Choosing Methods]
Companion Guidance

ITRC GSMC-1

ITRC RPO-7

ITRC GSMC-1 Training
Navigating ITRC’s GRO Guidance

Welcome
Geospatial Analysis for Optimization at Environmental Sites

How to Use Geospatial Analysis?

Geospatial analysis supports optimization activities through all stages of an environmental site by:
- measuring performance of remediation and remediation activities,
- verifying/remediation success,
- identifying remediation activities.

The guidance illustrates the practical application of geospatial analysis to support optimization activities, and serves as a 'how-to' guide for geospatial analysis to support optimization at environmental sites.

Publication Date: November 2019

ITRC GRO-1
Fact sheets are available as web pages and as PDFs
Review Checklist is available as a web page and as a PDF
Choosing Geospatial Methods

Choosing Methods

This guidance provides information about selecting a geospatial method. The following flowcharts provide more detailed information about choosing a geospatial method. Follow the steps below to choose the geospatial methods that may be appropriate to conduct the geospatial analysis.

Step 1: What questions are you trying to answer for each phase in the project life cycle? See Geospatial Methods for Optimization Questions in the Project Life Cycle Stages.

Step 2: Do you have the minimum data required in order to use geospatial methods? See Table 1 and Figure 1.

Step 3: Perform exploratory data analysis.

Step 4: Use the flow charts below to determine if simple, more complex, or advanced methods are suitable for the geospatial analysis.

Sheet 1 of 4 — Selecting a Geospatial Method
Common Misapplications of Geospatial Analysis

Mistakes in geospatial modeling frequently appear in professional practice. Listed below are common misapplications of these methods and appropriate alternatives to the erroneous practices. These problems and errors below can occur during all lifecycle phases and are grouped by four general topic areas: CSM, EDA, model use, and model assumptions.

- CSM: Read more
- EDA: Read more
- Model Use: Read more
- Model Assumptions: Read more

Print this page
Data Requirements and Method Selection

What are the minimum requirements of data sets for geospatial analyses?

- Minimum of 8 sample locations
- 6 to 15 sample locations
- Greater than 15 sample locations

Note: This figure should be used along with the information in Table 1.
Geospatial Methods for Optimization Questions in the Project Life Cycle Stages

<table>
<thead>
<tr>
<th>Site Characterisation</th>
<th>Geospatial Methods for Optimization Questions in the Project Life Cycle Stages</th>
<th>Release Detection</th>
<th>Data Requirements</th>
<th>Methods for Optimization</th>
<th>General Considerations</th>
</tr>
</thead>
</table>

**Geocharacterization**

- How can background concentrations be estimated when working with spatially correlated data?
- What methods are used to estimate this question?
- How can background concentrations be estimated when working with spatially non-correlated data?
- What methods are used to estimate this question?

**Estimating Average Concentrations**

- What is an estimate of the average concentration of a contaminant for any area?
- How can this be improved?
- What methods are used to answer this question?

**Estimating Concentrations Based on Proxy Data**

- How can a large amount of transparent data be used to improve interpretation of other data?
- What methods are used to answer this question?

**Estimating Quantities**

- How can an estimate of quantities (e.g., mass or volume of media) be developed?
- What methods are used to answer this question?

**Background Estimation**

- How can background concentrations be estimated when working with spatially correlated data?
- What methods are used to estimate this question?
- How can background concentrations be estimated when working with spatially non-correlated data?
- What methods are used to estimate this question?
Software Selection

Software Comparison Tables

Three tables (Tables 7 through 9) are available as a downloadable Excel workbook. These tables provide information about the individual software packages in a spreadsheet format for ease of comparison. These tables can help to identify appropriate software based on a series of screening criteria, such as optimization questions, products (outputs), operating system, costs, and operational methods.

- Table 7 lists optimization questions and whether the software is helpful for answering these questions. For each question, if the software does not include any of the methods to address the question, then a “no” symbol is shown. Where software includes the methods, but is not specifically designed to directly answer questions for example, for example designing, cost control, and monitoring optimization, if the software includes the methods, but in additional effort is required to answer the question, then a “qualified yes” symbol is shown. If the software is specifically designed to answer the optimization question, then a “yes” symbol is shown.

- Table 8 lists key information such as the class, required operating systems, the products supplied by the software, and the factors that are input (requiring options), and data outputs (producing options). This table includes software outputs based on geospatial methods, such as internal maps and graphs, contouring ability, and animation.

- Table 9 lists the geospatial methods and describes which ones are available in each software package. The methods are divided into subsets: ESRI basics, tool methods, more common methods, advanced methods, and uncertainty analysis.

Tables 7 – 9 are available as a downloadable Excel workbook.
For each question, if the software does not include any of the methods to address the question, then a “no” symbol is shown. Some software includes the methods, but is not specifically designed to directly answer questions for example, for sample spacing, hot spot detection, or monitoring program optimization. If the software includes the methods, but additional effort is required to answer the question, then a “qualified yes” symbol is shown. If the software is specifically designed to answer the optimization question, then a “yes” symbol is shown.
Using Analysis Results for Optimization

Geospatial Analysis for Optimization at Environmental Sites

Using Analysis Results for Optimization

Geospatial methods can be used to guide sampling plan design, determine the extent of a groundwater plume, understand trends, identify redundant sampling points, and aid in a number of other approaches to optimizing remediation efforts. This section includes descriptions of using geospatial results to support different optimization activities and also some examples. Several examples in this section, as well as other case studies elsewhere in this guide, illustrate how geospatial methods are used at various stages in the project life cycle. Often, more than one geospatial method is appropriate for a scenario, so an analysis might start with ESRI’s and simple methods, then progress to more complex or advanced methods. The method selection flow chart can be used to assist in determining applicable methods for a site.

Table 6 below summarizes the general hegemony that geospatial analysis can play in each stage of the project life cycle.

<table>
<thead>
<tr>
<th>Life Cycle Stage</th>
<th>General Topic</th>
<th>Sub-Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning/Conceptual</td>
<td>Release Detection, Site Characterization, Monitoring</td>
<td>Planning/Conceptual</td>
</tr>
<tr>
<td>Feasibility Assessment</td>
<td>Release Detection, Site Characterization</td>
<td>Feasibility Assessment</td>
</tr>
<tr>
<td>Feasibility Evaluation</td>
<td>Site Characterization</td>
<td>Feasibility Evaluation</td>
</tr>
<tr>
<td>Site Definition</td>
<td>Site Characterization, Closure</td>
<td>Site Definition</td>
</tr>
<tr>
<td>Site Characterization</td>
<td>Site Characterization, Closure</td>
<td>Site Characterization</td>
</tr>
<tr>
<td>Remedial Action Determination</td>
<td>Remediation</td>
<td>Remedial Action Determination</td>
</tr>
<tr>
<td>Site Closure</td>
<td>Site Closure</td>
<td>Site Closure</td>
</tr>
</tbody>
</table>

Three examples illustrate how geospatial analysis is performed for optimization.

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Plume Shrinkage Example

ITRC GRO-1, Figure 54. Plume shrinkage and mass reduction over time. Source: Courtesy of Ted Parks, Ameo Foster Wheeler. Example 2
Case Study Example

- Achieve cost saving for the total project life cycle
  - Improved planning
  - Optimization of scope for characterization and monitoring
  - Demonstration of attainment of goals

ITRC GRO-1 Lead Contamination in Soil Case Study
Wrap-Up: Geospatial Analyses

- Geospatial analyses optimize our work, facilitate interpretation/communication
- The guidance and training mean to encourage proper use of geospatial analyses
- Geospatial analyses help optimize actions throughout the project life cycle
- The data must exhibit spatial correlation in order to use geospatial methods
- All geospatial methods can be used to make maps, but only the more complex or advanced methods can provide estimates of uncertainty
Data Interpolation is Method Dependent!

ITRC GRO-1, Figure 15, Source: (Kresic and Mikszewski 2012)

Other Guidance Uses

- Estimating average concentrations
- Calculating contaminant mass
- Sample spacing
- Evaluating source strength and geometry
- Not just contaminant concentrations!
The benefits that ITRC offers to state regulators and technology developers, vendors, and consultants include:

- Helping regulators build their knowledge base and raise their confidence about new environmental technologies
- Helping regulators save time and money when evaluating environmental technologies
- Guiding technology developers in the collection of performance data to satisfy the requirements of multiple states
- Helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations
- Providing a reliable network among members of the environmental community to focus on innovative environmental technologies

How you can get involved with ITRC:

- Join an ITRC Team – with just 10% of your time you can have a positive impact on the regulatory process and acceptance of innovative technologies and approaches
- Sponsor ITRC’s technical team and other activities
- Use ITRC products and attend training courses
- Submit proposals for new technical teams and projects