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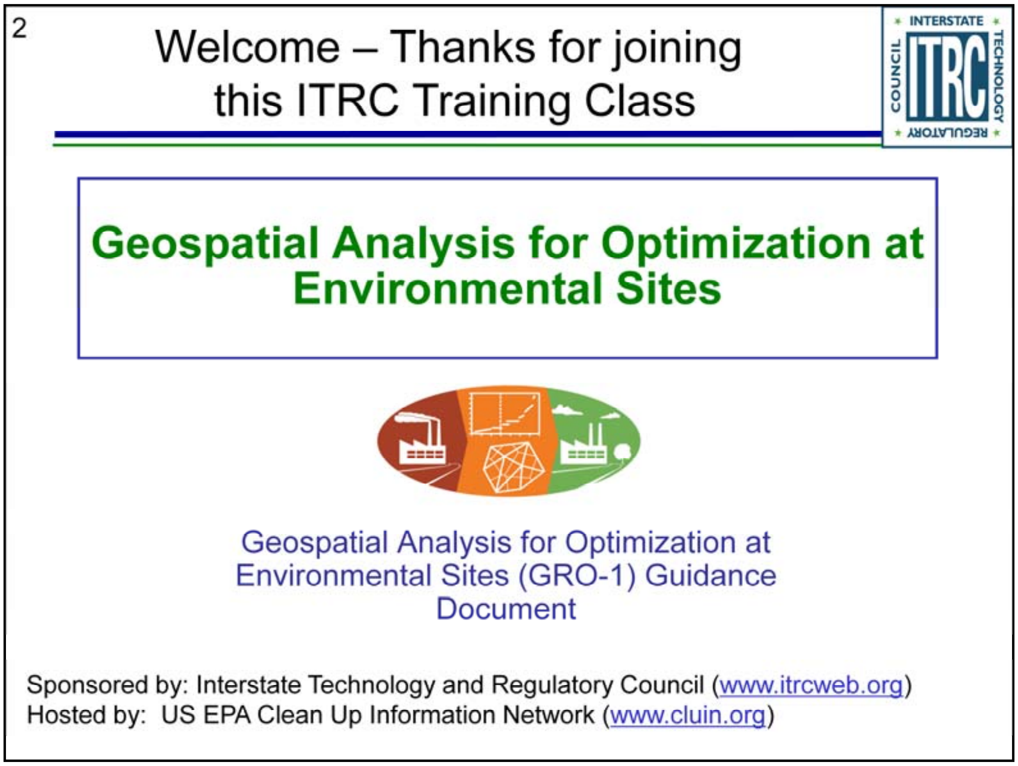
Starting Soon: Geospatial Analysis for Optimization at Environmental Sites

Poll Question

- 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

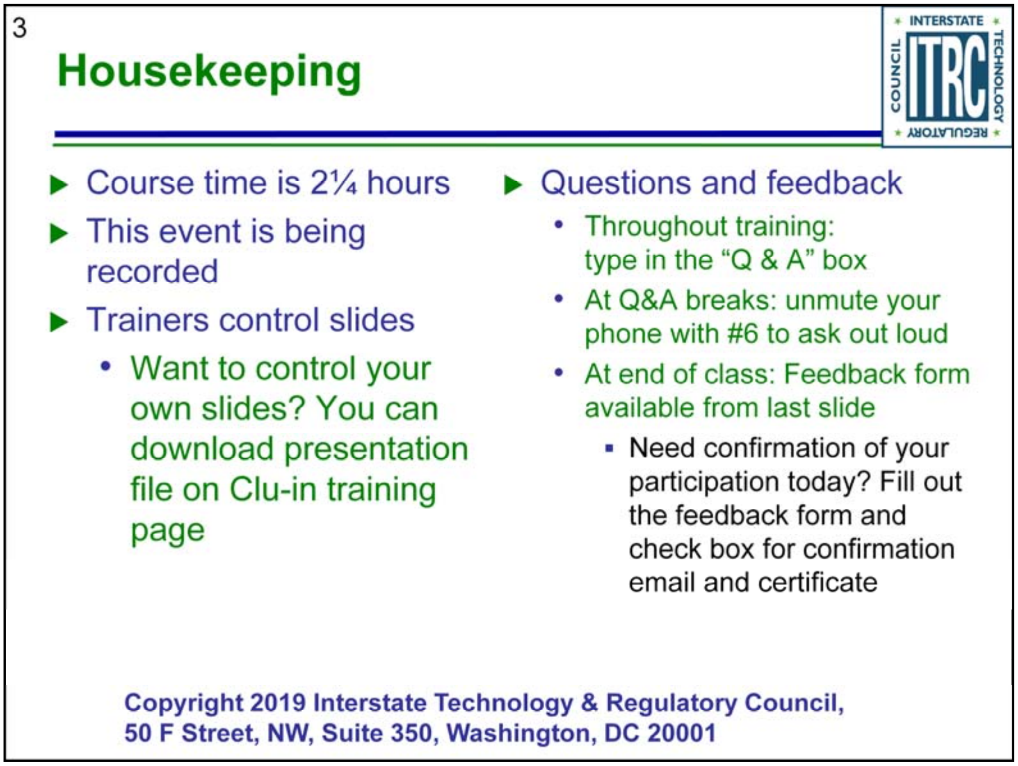
•For a project and specific lifecycle stage, identify optimization questions where geospatial methods can contribution to better decision making

•For a project and optimization question(s), select appropriate geospatial method(s) and software using the geospatial analysis work flow, 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
Training Co-Sponsored by: US EPA Technology Innovation and Field Services Division (TIFSD) (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.

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ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance

- Host organization
- Network
  - State regulators
    - All 50 states, PR, DC
  - Federal partners

    DOE DOD EPA
  - ITRC Industry Affiliates Program

    IAP
  - Academia
  - Community stakeholders
- Follow ITRC
- Disclaimer
  - Full version in "Notes" section
  - Partially funded by the U.S. government
    - ITRC nor US government warranty material
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- ITRC materials available for your use – see usage policy
- Available from www.itrcweb.org
  - Technical and regulatory guidance documents
  - Online and classroom training schedule
  - More…

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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Meet the ITRC Trainers

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Read trainer bios at https://clu-in.org/conf/itrc/GRO/

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 with 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 EMCX 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 technology and policy, 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.

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Presentation Overview

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

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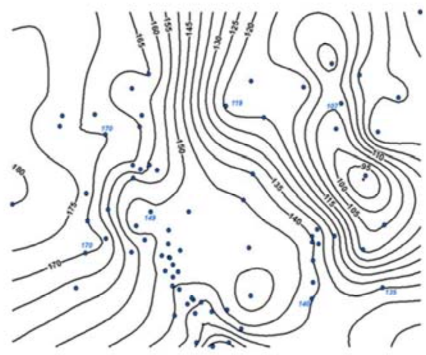
Geospatial Analysis for Optimization at Environmental Sites (GRO-1)

- 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)



ITRC GRO-1, Figure 19

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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

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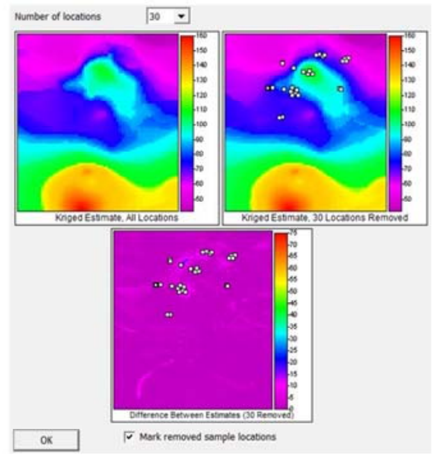
Why This Matters: Geospatial Tools Optimize Our Work

- 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)

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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

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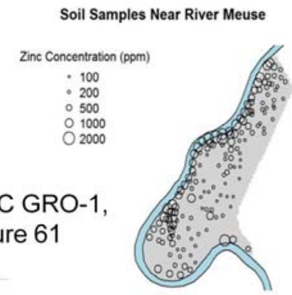
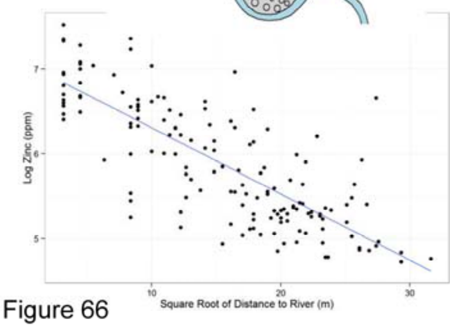
Why This Matters: Geospatial Tools Aid Interpretation

- Geospatial analysis helps understand relationships between observed contamination and sources
- Example: The figures show relationship between metal contamination and a river that periodically floods



ITRC GRO-1, Figure 61



ITRC GRO-1, Figure 66

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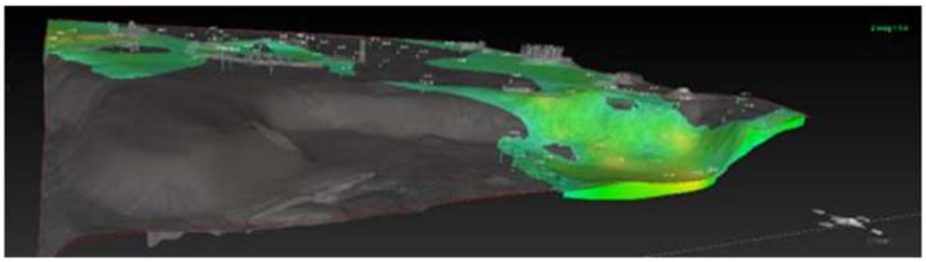
Why This Matters: Geospatial Methods Help Communication

- 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).

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Poll Question

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

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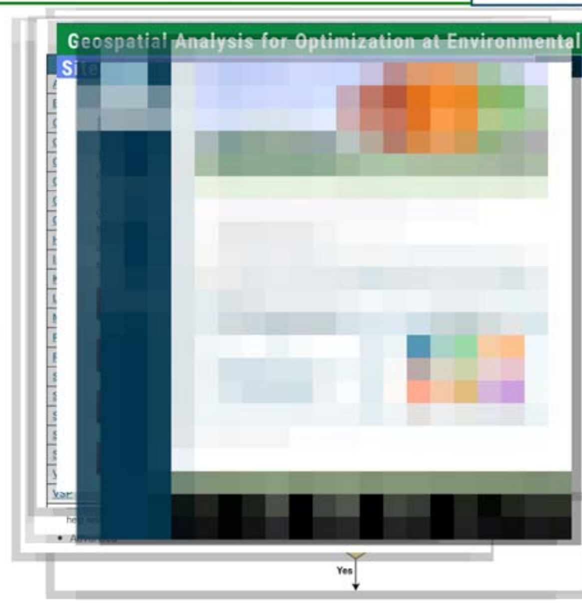
ITRC GRO Guidance is an Interactive Resource for Various Users and Includes…

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



http://www.itrcweb.org/gro-1

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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.

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Geospatial Analysis Work Flow

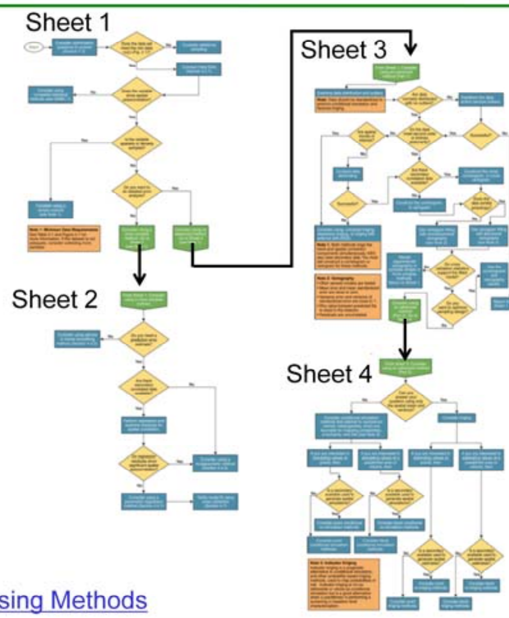
- Review conceptual site model (CSM) and project goals
- Perform exploratory data analysis
- Choose geospatial method
- Build model / check model
- Generate results (predictions and uncertainty)

See Flow Charts

See Review Checklist

ITRC, GRO-1, Work Flow

ITRC GRO-1 Flow Charts



ITRC GRO-1, Choosing Methods

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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

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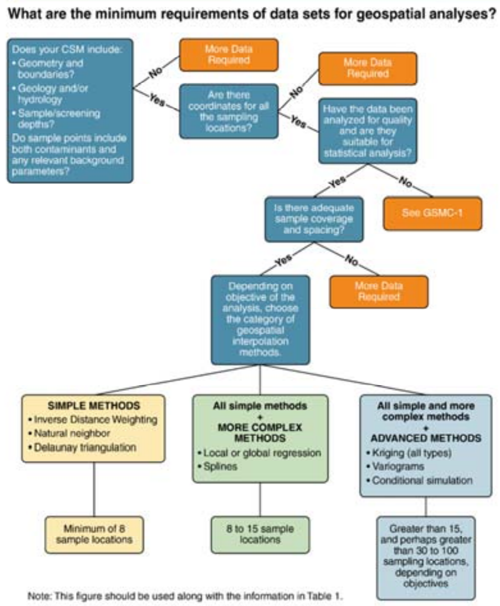
What are the Data Requirements?



- 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

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Regulatory Barriers and Concerns

Poll Question

- 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?***

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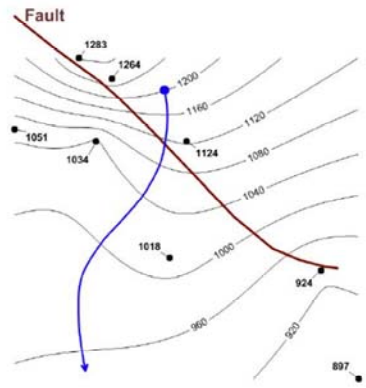
What are the Common Misapplications?

- 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*



ITRC GRO-1, Figure 22
Water levels near a fault

ITRC GRO-1, Common Misapplications

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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

Dave Becker, USACE

ITRC GRO-1, Optimization Questions

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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

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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

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After Fundamentals Section, You Can…

- Explain how geospatial methods work
  - Classification and components
  - Variograms – key concept for geospatial analysis
- Avoid misapplications

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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

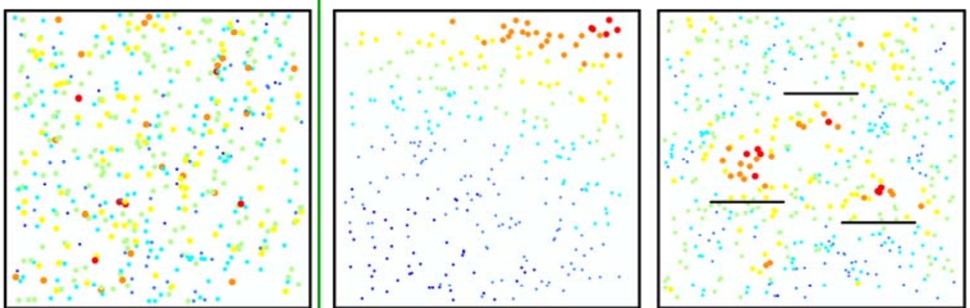
ITRC GRO-1, Fundamental Concepts

Tobler, W. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." Economic Geography 46 (2):234-240.

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

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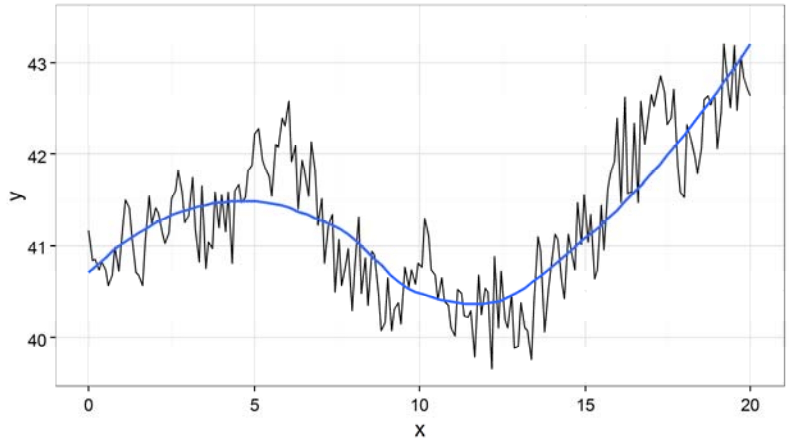
Trend and Autocorrelation Together



- 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

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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

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Simple Methods for Maps, More Complex or Advanced for Optimization

- 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

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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

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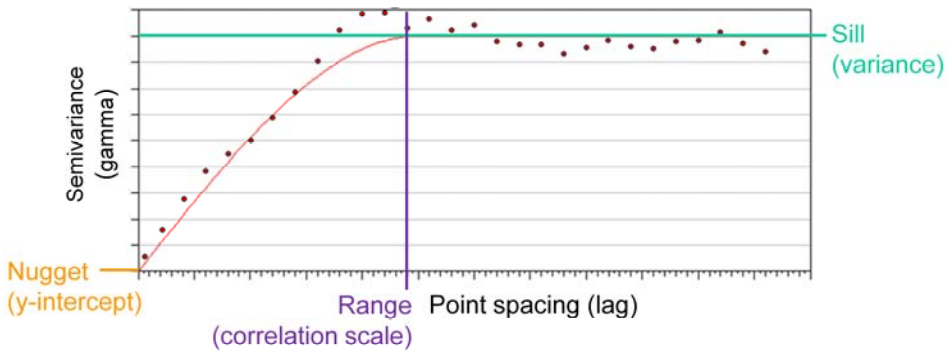
Variogram Terminology



- Directionality is important when constructing the variogram
  - 2D vs 3D problems

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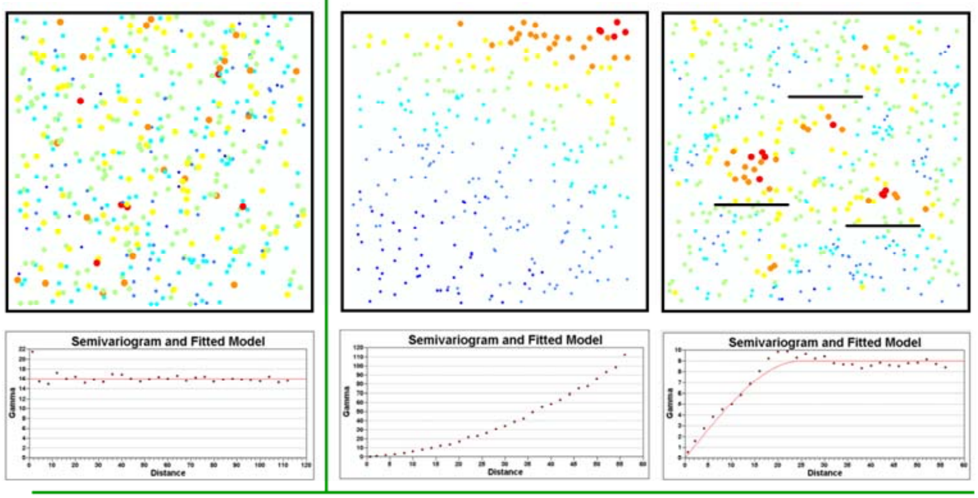
The Three General Variogram Cases

No Spatial Correlation | Trend | Autocorrelation



ITRC GRO-1, Figures 8, 9 and 10

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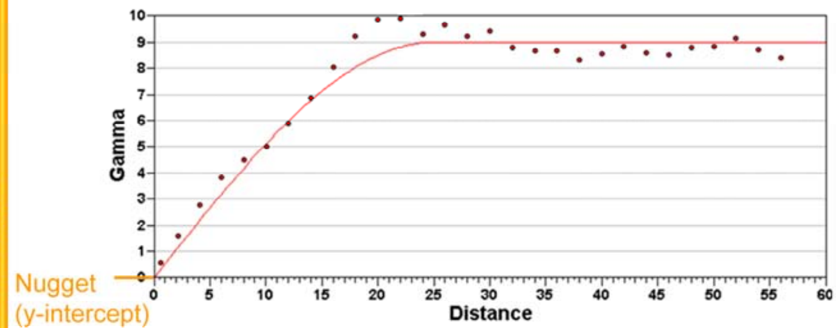
Variogram Pop Quiz

Poll Question

- What are the range and sill of this variogram?



A) Range = 60, Sill = 10

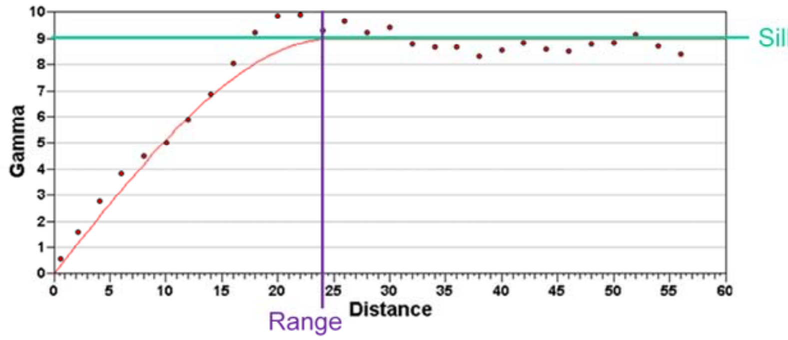
B) Range = 9, Sill = 24

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

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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

	# sediment samples
Initial sampling 2001-2002	**240**
Actual, additional samples collected from 2003-2008	**509**
If choice of 2003-2008 sample locations had been guided by the range of the 2001-2002 variogram	**24**

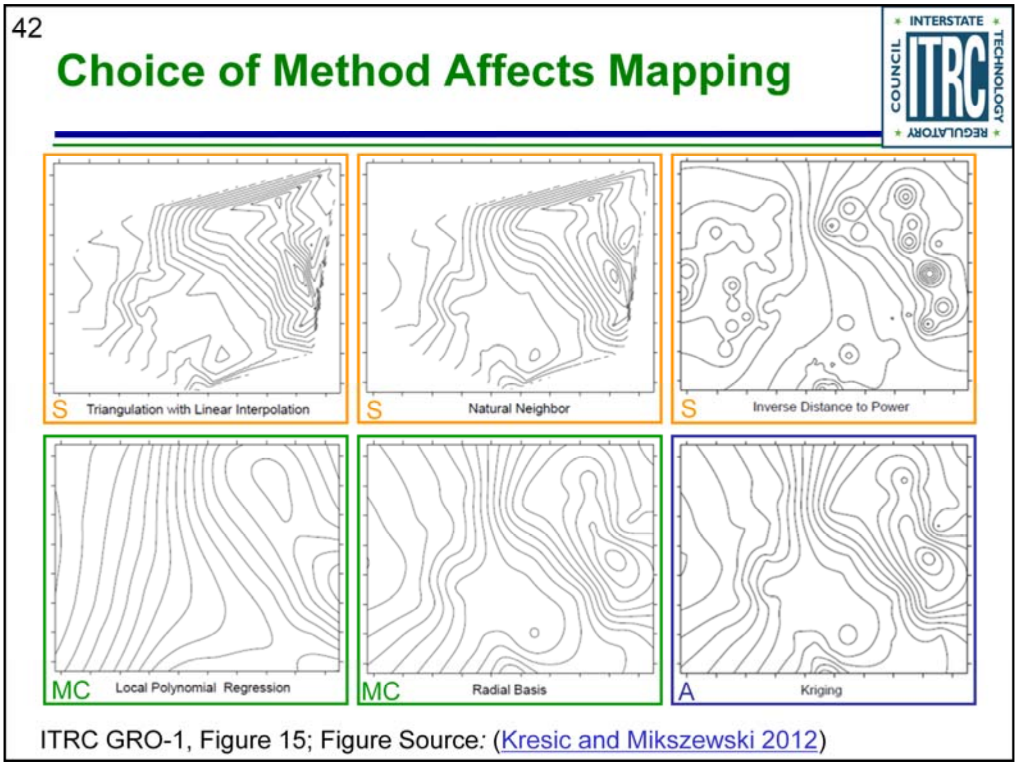

Figure Source: Kresic, N., and A. Mikszewski. 2012. Hydrogeological Conceptual Site Models: Data Analysis and Visualization. Boca Raton, FL: CRC Press. https://www.crcpress.com/Hydrogeological-Conceptual-Site-Models-Data-Analysis-and-Visualization/Kresic-Mikszewski/p/book/9781439852224

Orange: S simple methods

Green: MC more complex methods

Blue: A advanced methods

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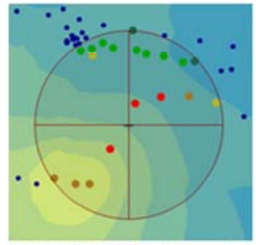
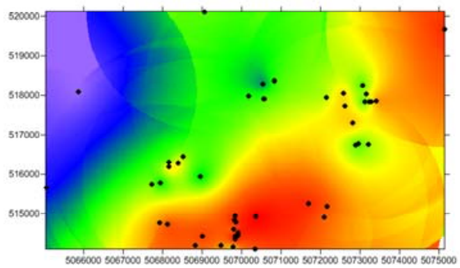
Search Neighborhood Radius Impacts Map Smoothness

- 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:

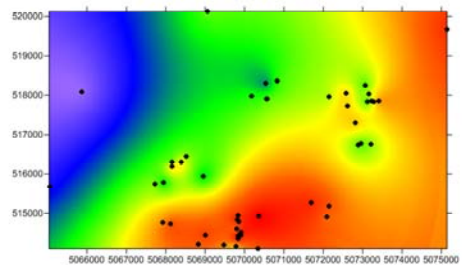


ITRC GRO-1, Figure 18

Radius = 3000 m



Radius = 6000 m



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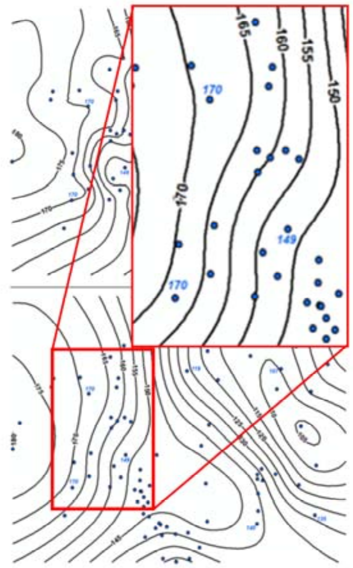
Exact vs. Inexact Interpolation Affects Perceived Map Accuracy

- 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

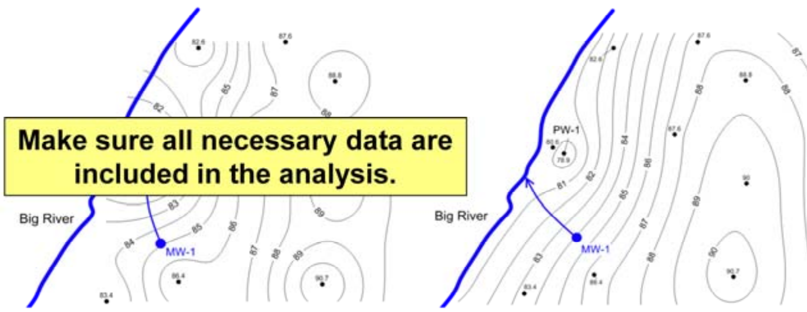


ITRC GRO-1, Figure 19

45

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



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

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Question & Answer Break

Poll Question

Presentation Overview

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

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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

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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

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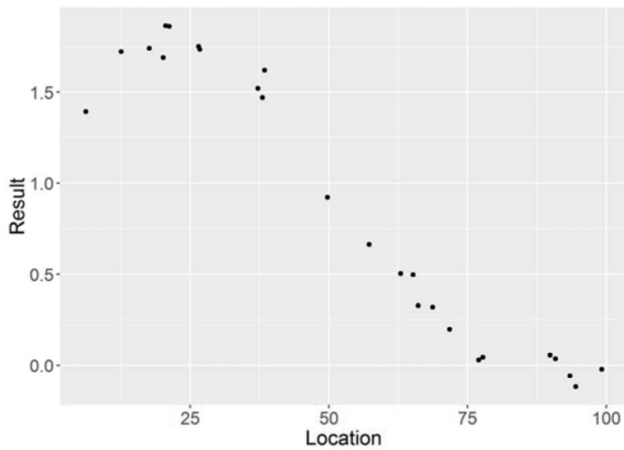
Measures of Uncertainty

- 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



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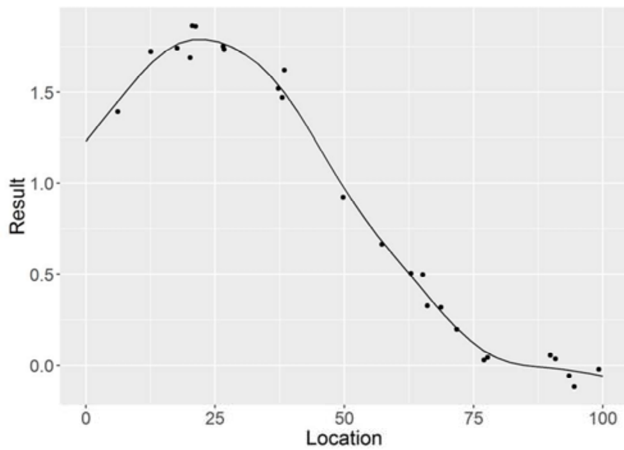
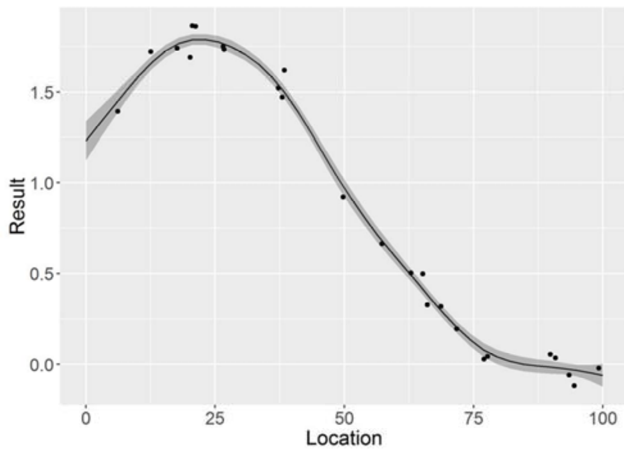
Measures of Uncertainty

Data + Model



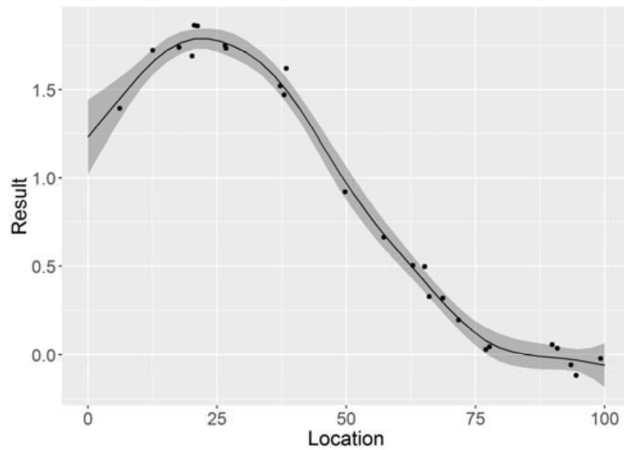
Measures of Uncertainty

Data + Model + Standard Error

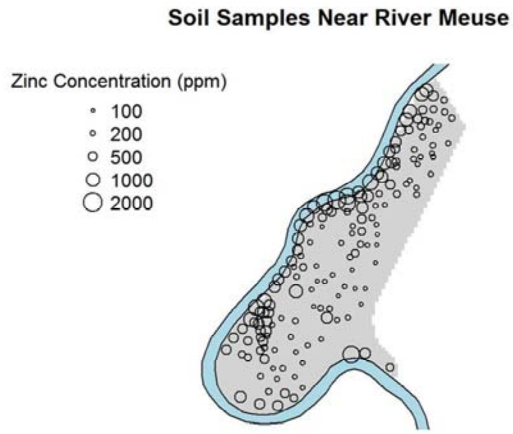


Measures of Uncertainty

Data + Model + 95% Confidence Interval



More Complex Methods Example



CSM: Flooding of River Meuse causes elevated zinc in floodplain

ITRC GRO-1, Figure 61

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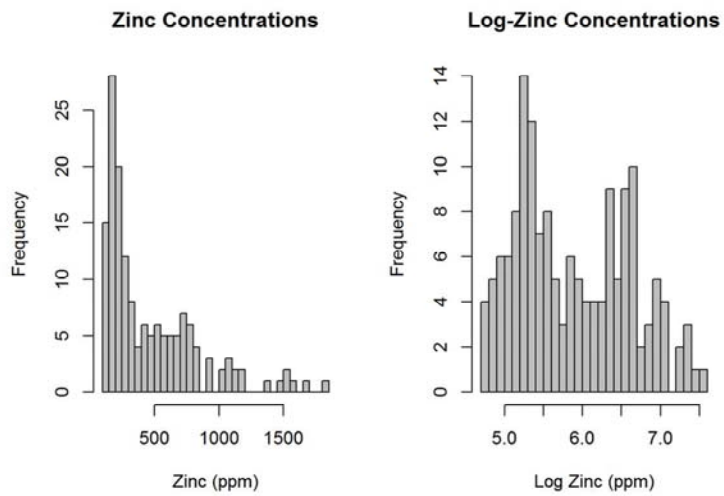
What are Optimization Questions?

- 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



ITRC GRO-1, Figure 62

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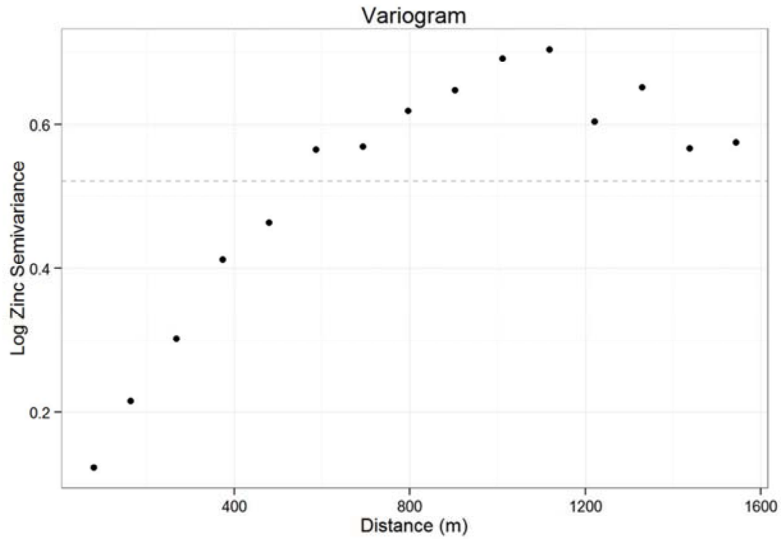
EDA: Zinc Autocorrelation



ITRC GRO-1, Figure 64

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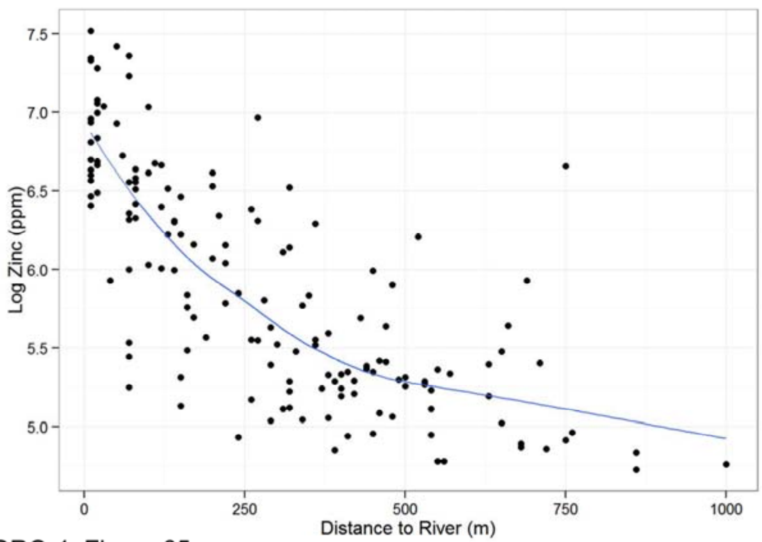
EDA: Zinc vs. Distance to River



ITRC GRO-1, Figure 65

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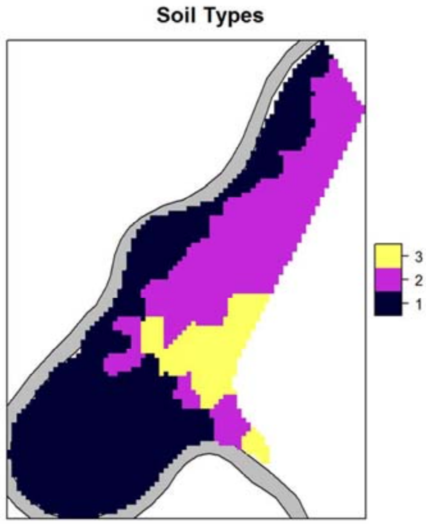
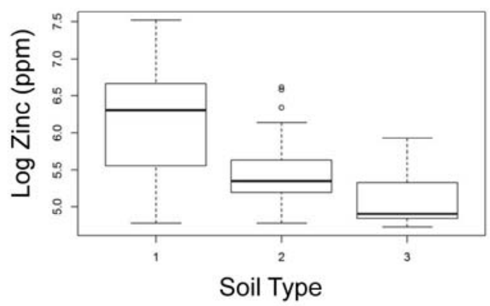
EDA: Zinc vs. Soil Type





Categorical variables can only take one of a fixed number of values

ITRC GRO-1, Figures 67, 68

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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

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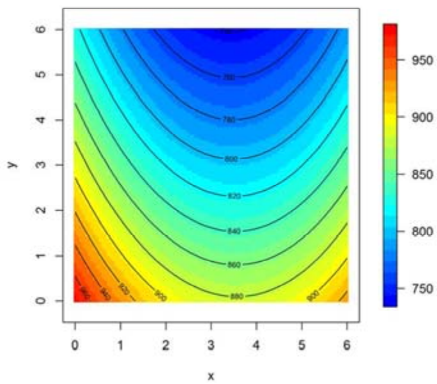
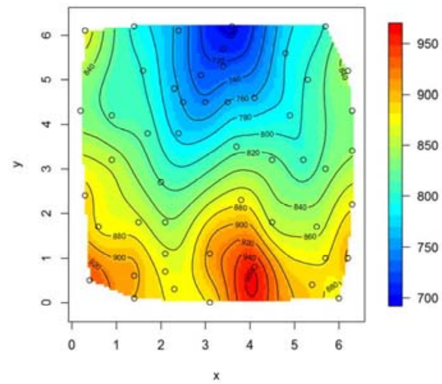
Nonparametric Regression Can Model Complex Data

Parametric



ITRC GRO-1, Figure 29

Nonparametric



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)

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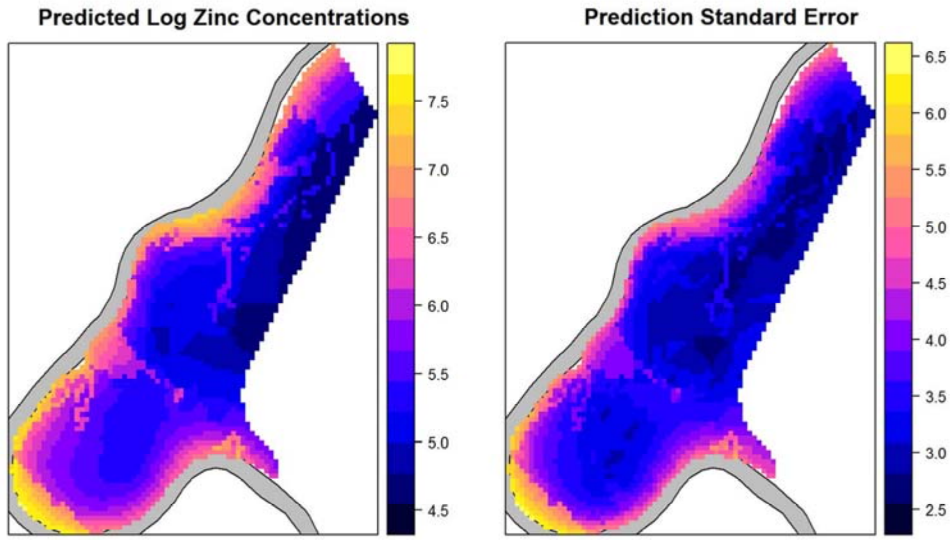
Predictions and Standard Error



ITRC GRO-1, Figures 73, 74

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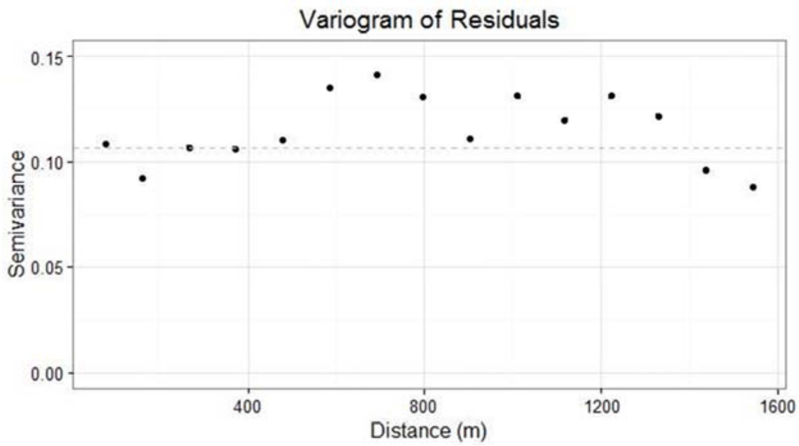
Check Residuals for Autocorrelation



Regression assumes no autocorrelation of residuals

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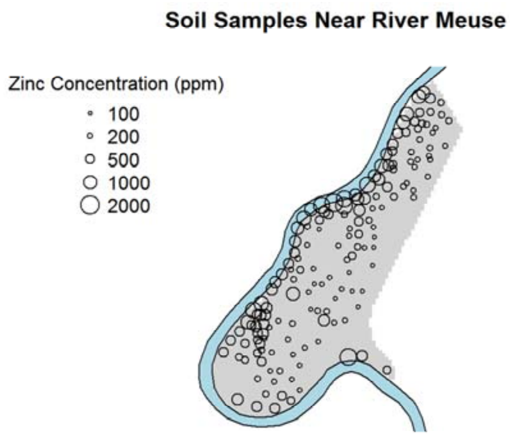
Use Model for Optimization

- 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



CSM: Flooding of River Meuse causes elevated zinc in floodplain

ITRC GRO-1, Figure 61

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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

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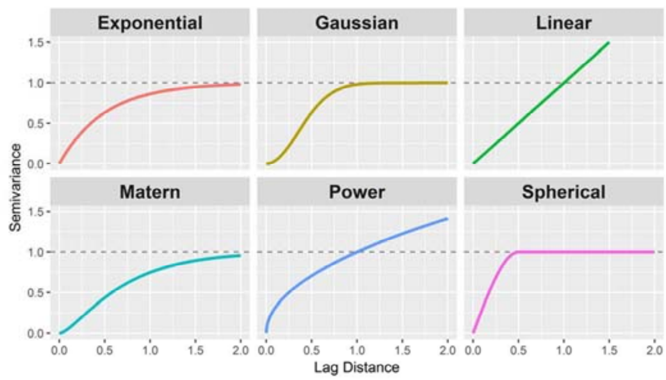
Advanced Methods Require Variography

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

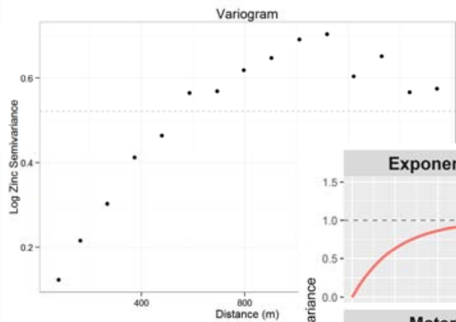


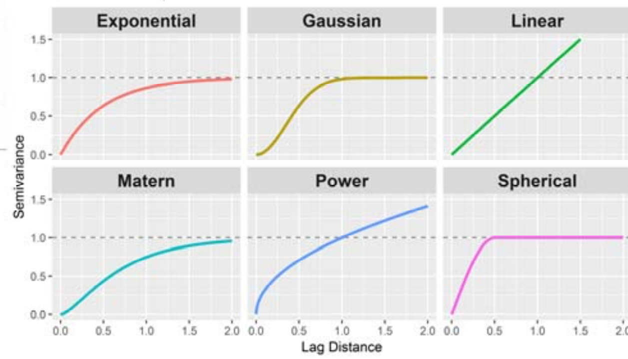
ITRC GRO-1, Figure 79

Quiz: Selecting Variogram Model

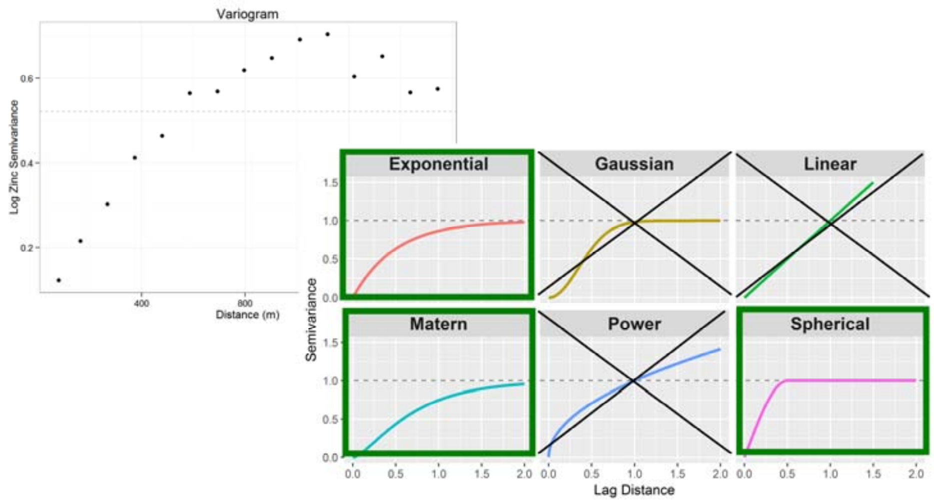
Poll Question

- What variogram function(s) could be used?



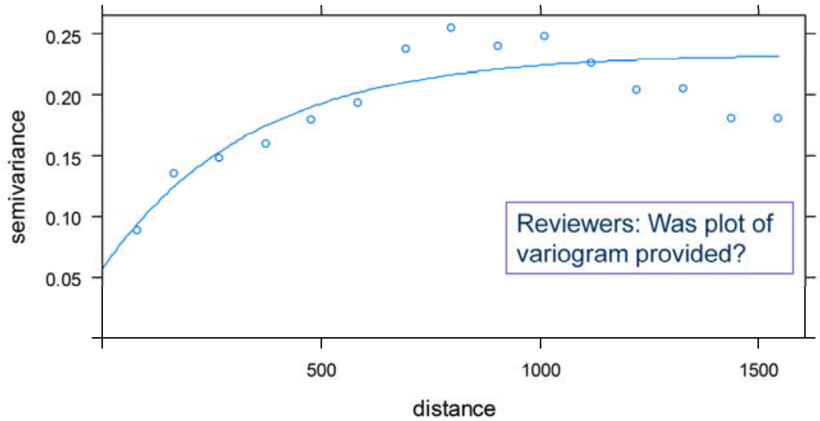


Answer: Selecting Variogram Model



Variography of Meuse Data

- Fit variogram using exponential model



ITRC GRO-1, Figure 44

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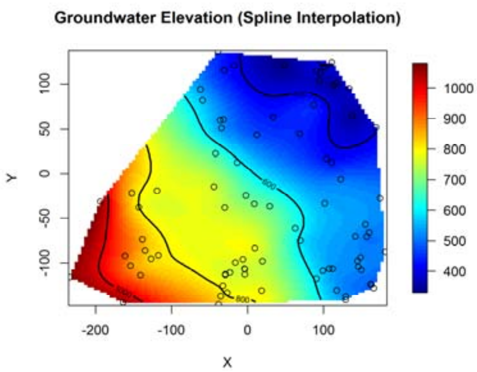
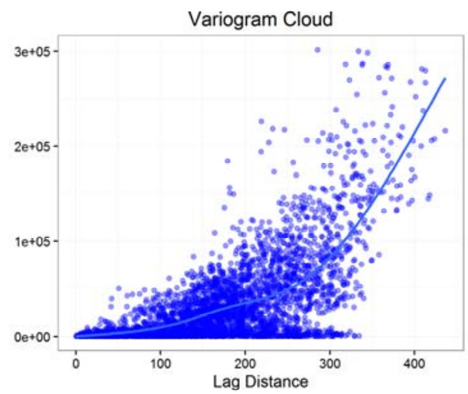
Remove Trend When Variogram Unbounded





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

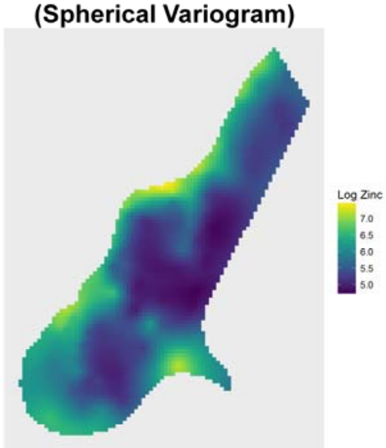
Name	Trend Model
Simple Kriging	Constant (known, usually zero)
Ordinary Kriging	Constant (unknown)
Universal Kriging	Polynomial function of coordinates
Kriging with External Drift	Regression on secondary data (simultaneous)
Regression Kriging	Regression on secondary data (sequential)

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

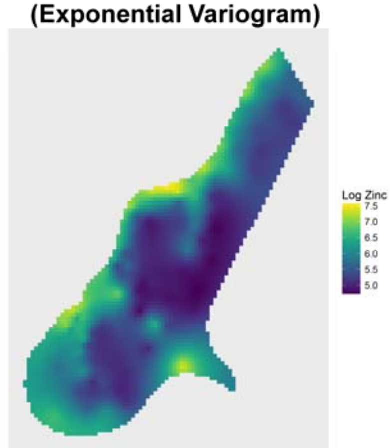
ITRC GRO-1, Kriging

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

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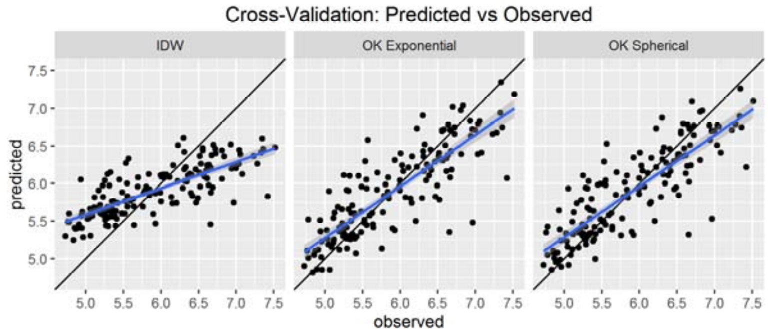
Compare Models Using Cross-Validation



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

ITRC GRO-1, Figure 47

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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)

Method	Cross Validation Statistics				
	Variogram	Mean Error	Root Mean Square Error	Mean Standardized Error	Root Mean Square Standardized Error
Inverse Distance Weighting	NA	-0.0128	0.514	NA	NA
Ordinary Kriging	Exponential	0.00213	0.393	0.00301	0.93
Ordinary Kriging	Spherical	-2.06E-05	0.392	0.00017	0.90

ITRC GRO-1, Table 4

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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)

Reviewers: Was summary of cross-validation provided?

Method	Cross Validation Statistics				
	Variogram	Mean Error	Root Mean Square Error	Mean Standardized Error	Root Mean Square Standardized Error
Inverse Distance Weighting	NA	-0.0128	0.514	NA	NA
Ordinary Kriging	Exponential	0.00213	0.393	0.00301	0.93
Ordinary Kriging	Spherical	-2.06E-05	0.392	0.00017	0.90

ITRC GRO-1, Table 4

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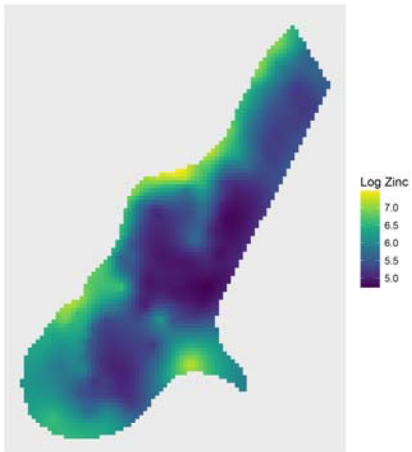
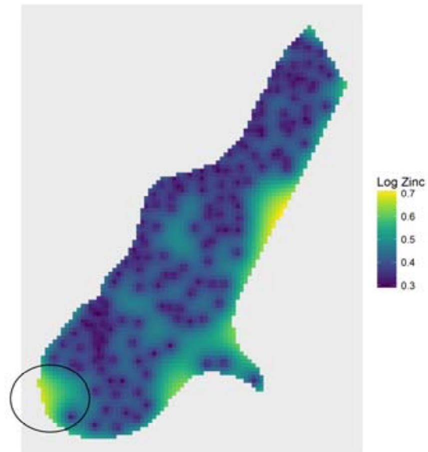
Log Zinc Point Kriging Results

Predictions



Prediction Standard Error



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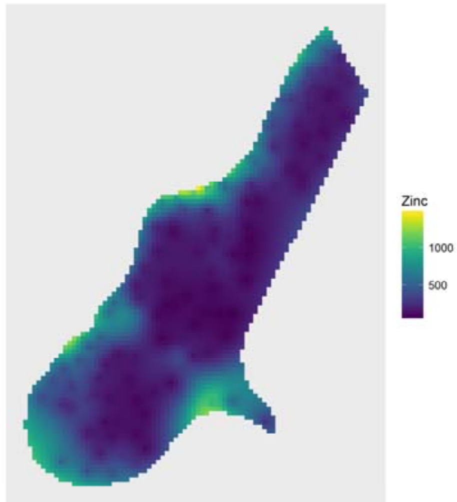
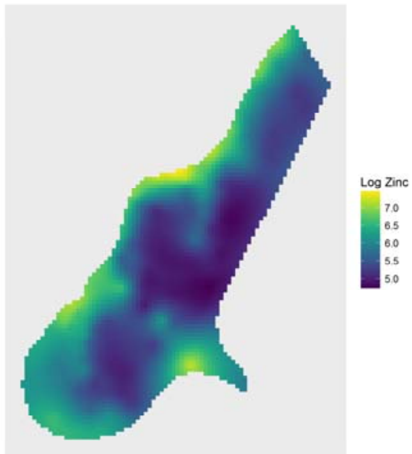
95% Upper Confidence Limit

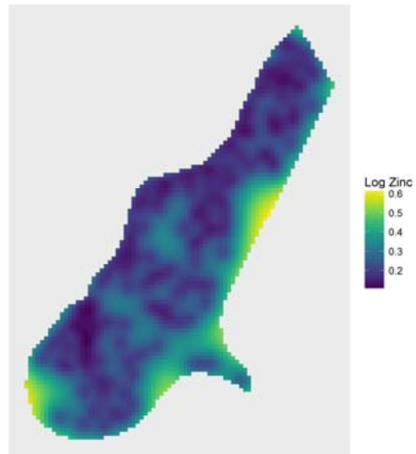


Log Zinc Block Kriging Results

Predictions



Prediction Standard Error



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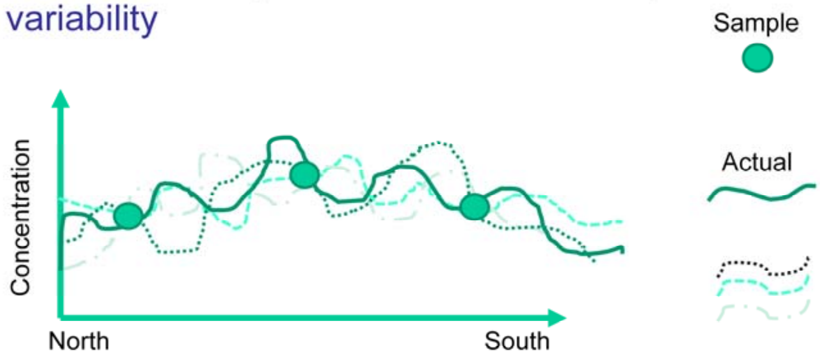
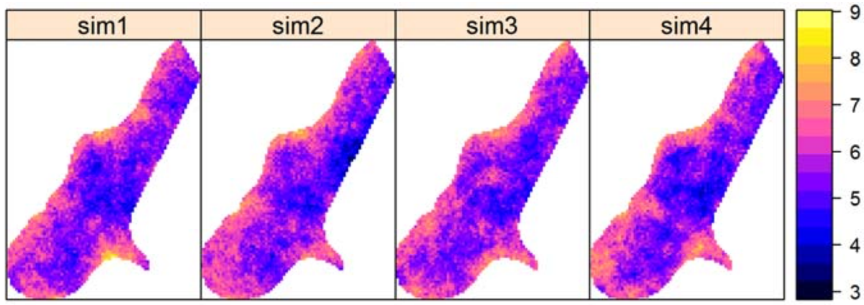
Prediction vs Simulation

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



Simulation of Log Zinc

Each simulation is consistent with data and variogram



Repeat ~1,000 times

ITRC GRO-1, Conditional Simulation

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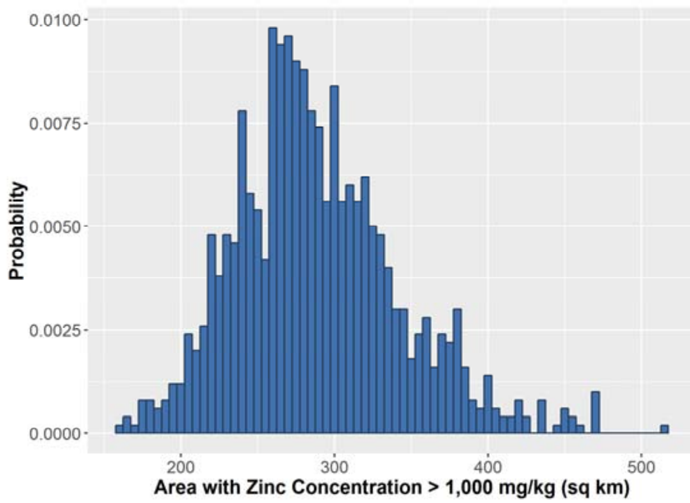
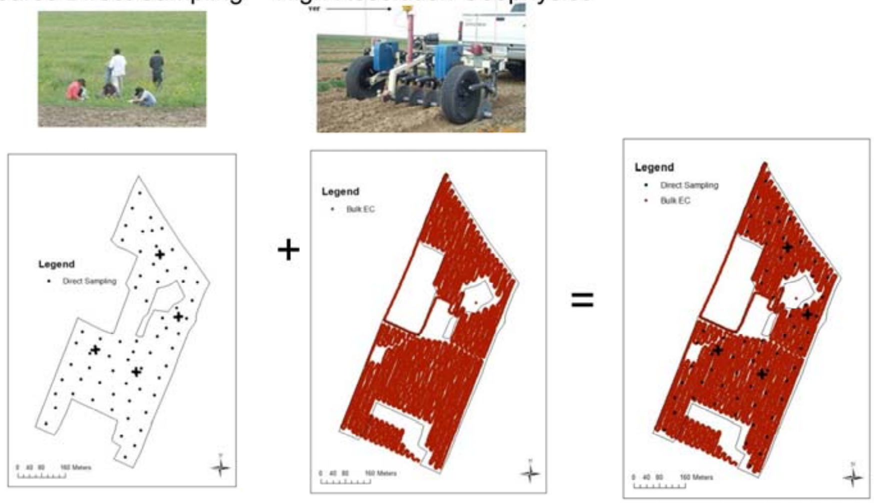
Uncertainty in Area Above Cleanup Level (1,000 mg/kg)



Cokriging Application

Coarse Direct Sampling High Resolution Geophysics



ITRC GRO-1, Example 3, Figure source: Landrum 2013

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).

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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**

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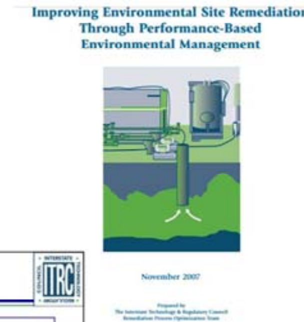
Companion Guidance

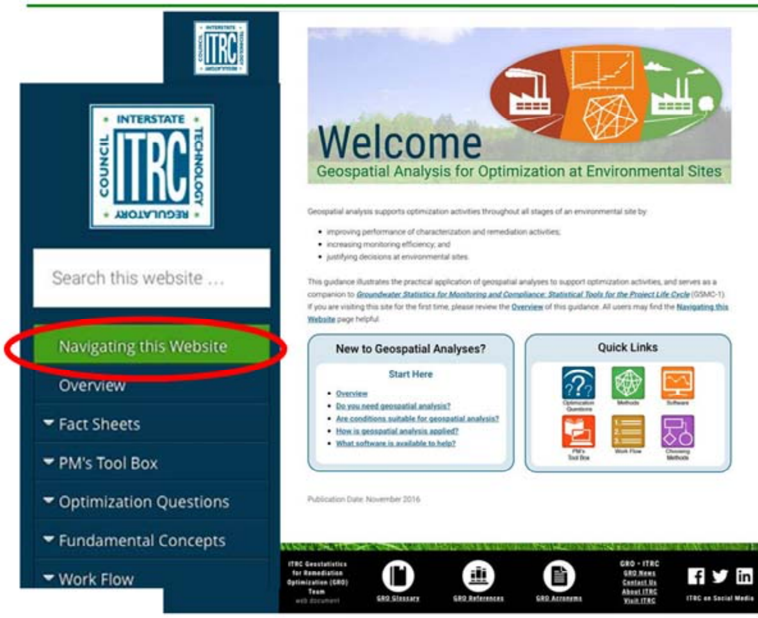
ITRC GSMC-1



ITRC RPO-7

ITRC GSMC-1 Training

Navigating ITRC's GRO Guidance



ITRC GRO-1

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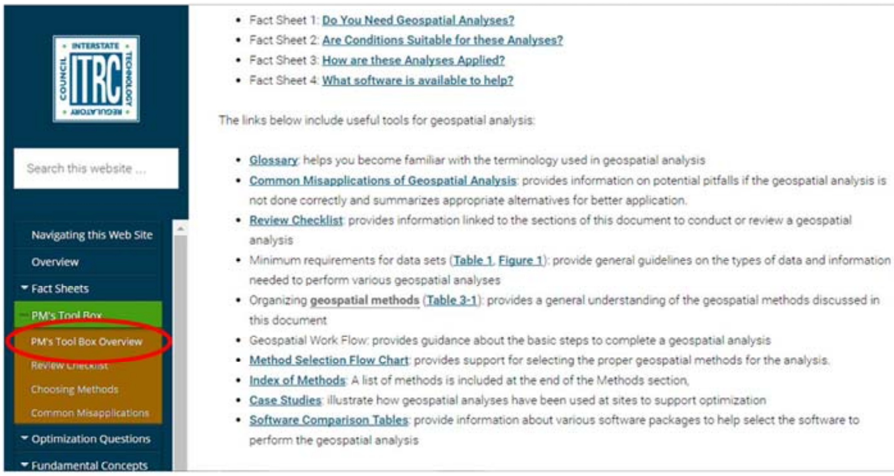
Fact Sheets – How to Use the Guidance

Fact sheets are available as web pages and as PDFs

Fact Sheet 1

Geospatial Analysis for Optimization at Environmental Sites
HOME
Search this website ...
Navigating this Web Site
Overview
Fact Sheets
Fact Sheets Overview
Fact Sheet 1 Do you need geospatial analyses?
Fact Sheet 2 Are conditions suitable for these analyses?
Fact Sheet 3 How are these analyses applied?
Fact Sheet 4 What software is available to help?
PM's Tool Box
Fact Sheet 1: Do You Need Geospatial Analysis?
This is the first of four fact sheets developed by ITRC to go along with the new ITRC guidance (GRO-1). It introduces the value and use of geospatial analysis to support optimization activities to project managers, program or financial managers, and stakeholders. The GRO-1 defines geospatial analysis as the process of compiling and analyzing data that are related in time or space.
How Geospatial Methods Support Optimization Activities During Environmental Project Life Cycle Stages?
The guidance defines optimization and identifies the questions to be answered, as well as determining whether site conditions are suitable to use geospatial analysis (See Fact Sheet #2). Depending on site-specific conditions and the regulatory framework, geospatial analysis can support optimization activities in any stage of the project life cycle. The minimum data for a viable geospatial analysis are different and usually more stringent than those for other data analyses. If the site data meets minimum data criteria (see Section 2.1 Preliminary Requirements for Geospatial Analysis), then appropriate geospatial methods can be selected. Numerous software packages are available to aid in applying these methods.
What is Optimization?
USEPA has published the National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion (USEPA 2012a), which describes how regulators can develop and track remedial optimization programs. In this document, USEPA defines optimization as
efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the

Project Manager's Tool Box

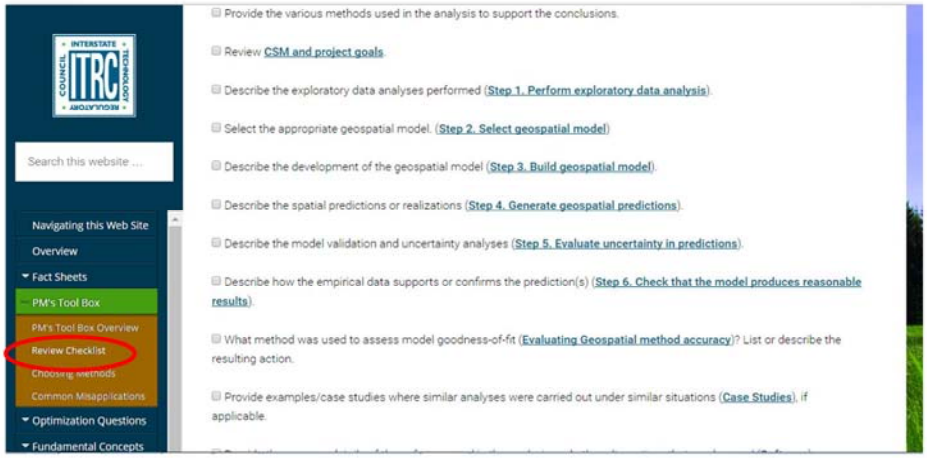


- Fact Sheet 1: **Do You Need Geospatial Analyses?**
- Fact Sheet 2: **Are Conditions Suitable for these Analyses?**
- Fact Sheet 3: **How are these Analyses Applied?**
- Fact Sheet 4: **What software is available to help?**

The links below include useful tools for geospatial analysis:

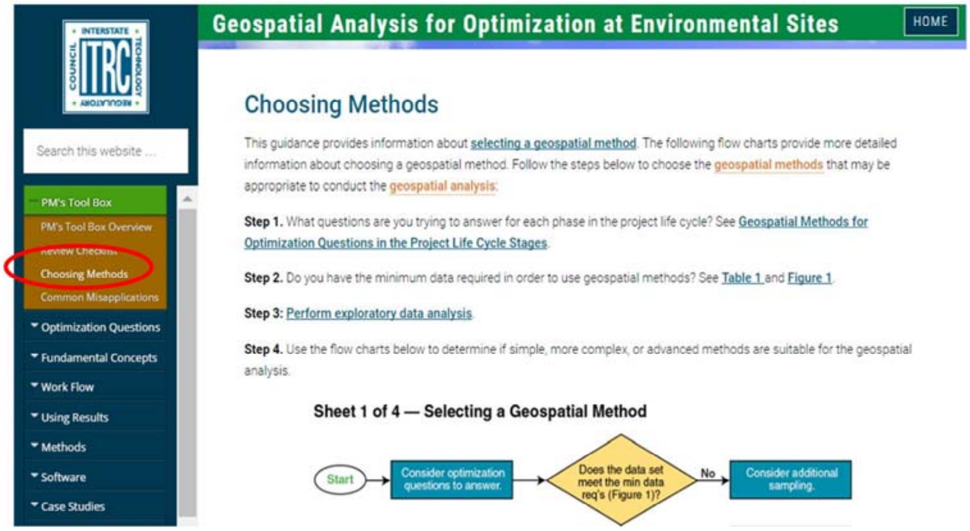
- **Glossary**: helps you become familiar with the terminology used in geospatial analysis
- **Common Misapplications of Geospatial Analysis**: provides information on potential pitfalls if the geospatial analysis is not done correctly and summarizes appropriate alternatives for better application.
- **Review Checklist**: provides information linked to the sections of this document to conduct or review a geospatial analysis
- Minimum requirements for data sets (**Table 1**, **Figure 1**): provide general guidelines on the types of data and information needed to perform various geospatial analyses
- Organizing **geospatial methods** (**Table 3-1**): provides a general understanding of the geospatial methods discussed in this document
- Geospatial Work Flow: provides guidance about the basic steps to complete a geospatial analysis
- **Method Selection Flow Chart**: provides support for selecting the proper geospatial methods for the analysis.
- **Index of Methods**: A list of methods is included at the end of the Methods section.
- **Case Studies**: illustrate how geospatial analyses have been used at sites to support optimization
- **Software Comparison Tables**: provide information about various software packages to help select the software to perform the geospatial analysis

Review Checklist

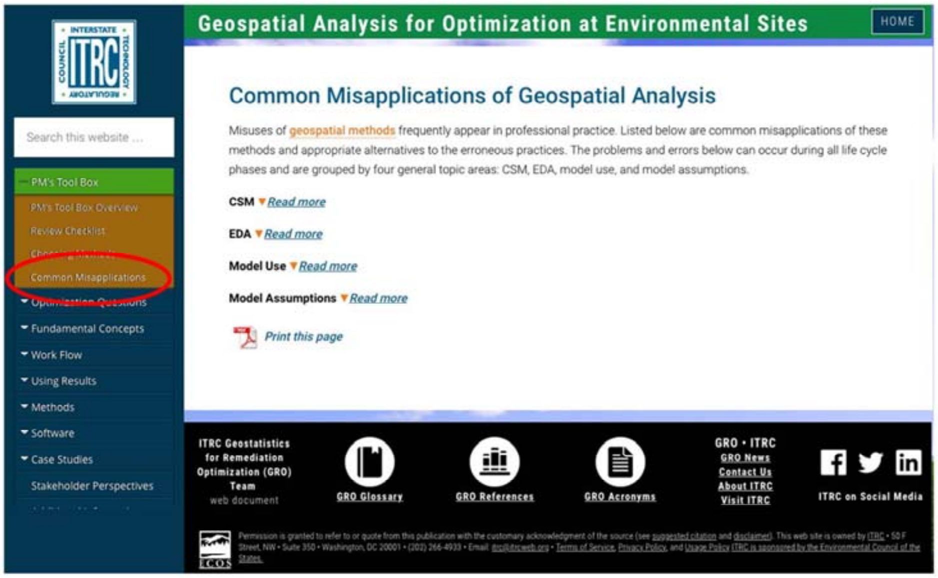


Review Checklist is available as a web page and as a PDF

Choosing Geospatial Methods



Common Misapplications



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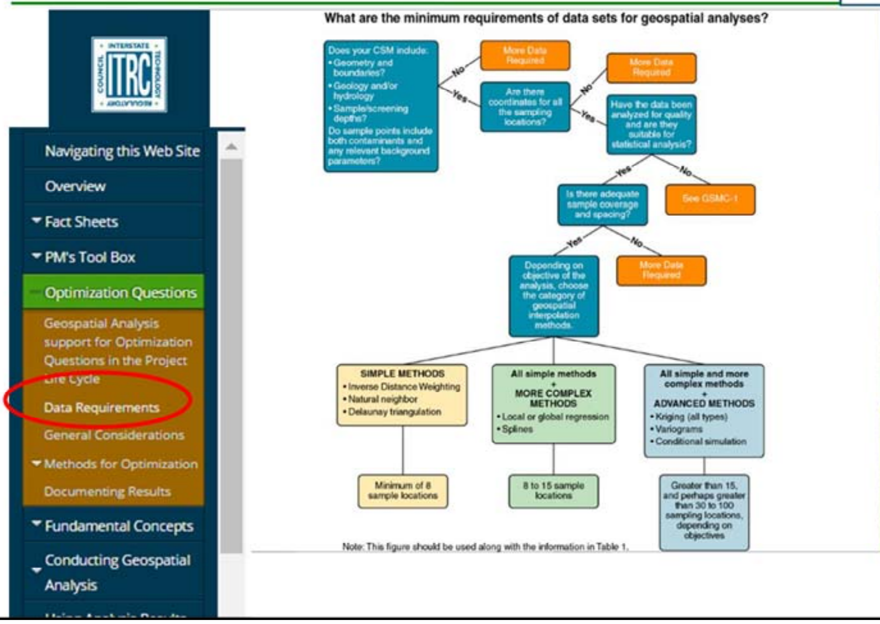
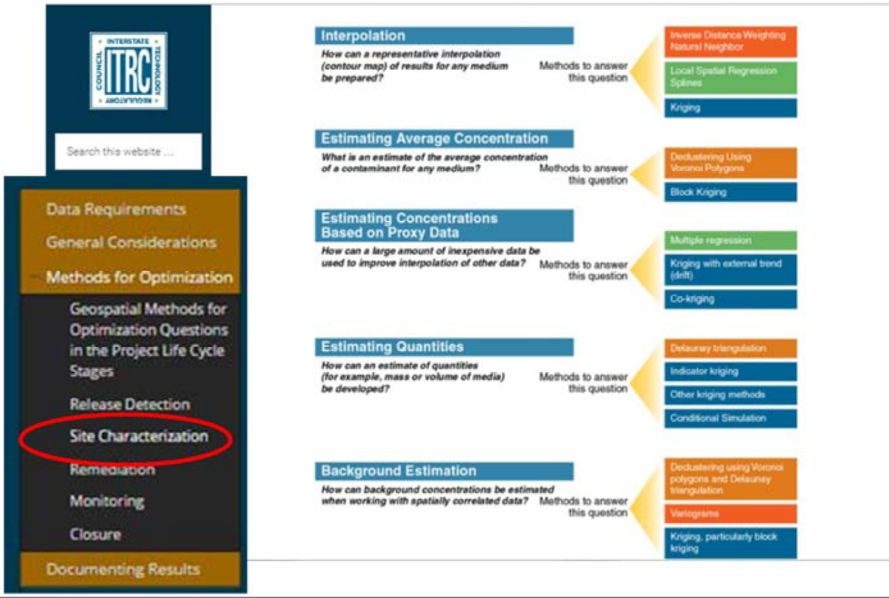
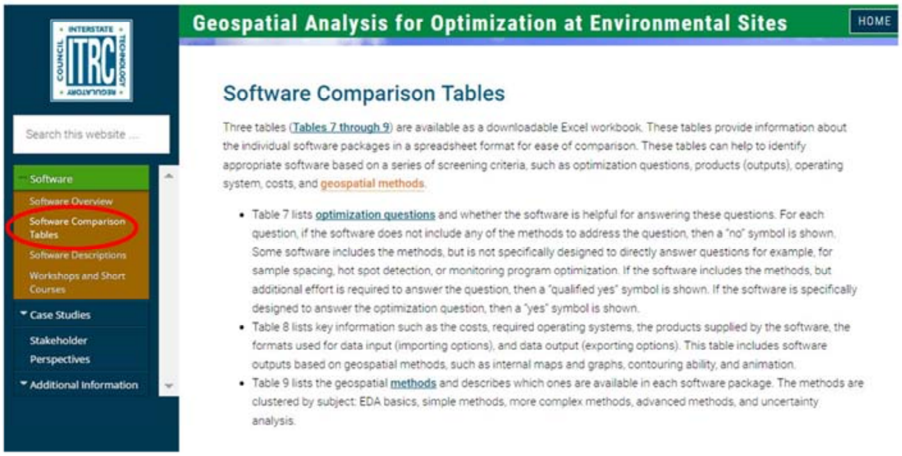
Data Requirements and Method Selection



Geospatial Methods for Optimization Questions in the Project Life Cycle Stages

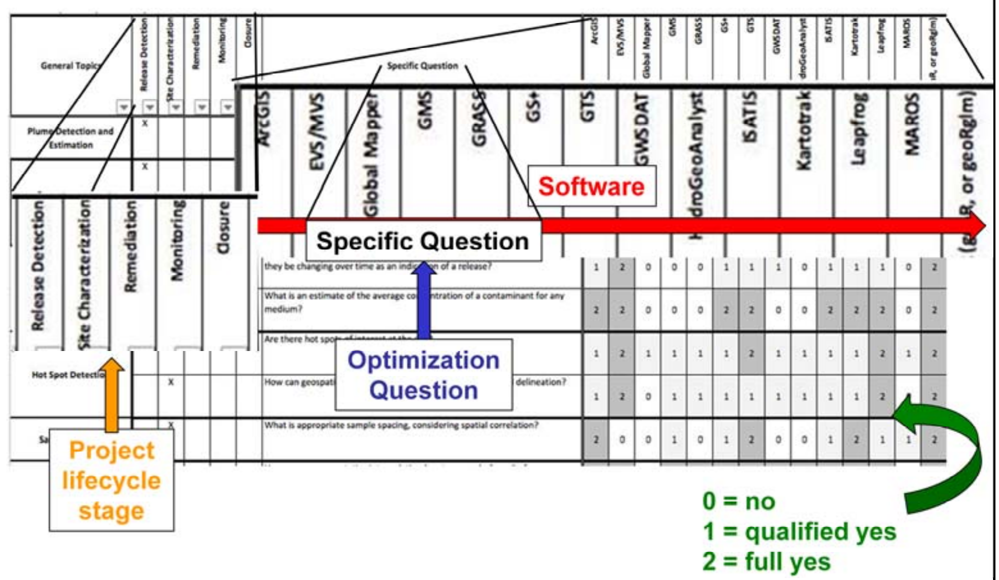


Software Selection



Tables 7 – 9 are available as a downloadable Excel workbook

Table 7 – Connection between optimization questions and software capabilities



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.

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Using Analysis Results for Optimization

Geospatial Analysis for Optimization at Environmental Sites

HOME

Search this website ...

- Using Results
  - Using Analysis Results for Optimization
  - Plume Intensity and Extent
  - Trend Maps
  - Estimating Quantities
  - Hot Spot Detection
  - Sample Spacing
  - Estimating Concentrations Based on Proxy Data
  - Background Estimation
  - Quantifying Uncertainty
  - Remedial Action Optimization
  - Monitoring Program Optimization
- Examples

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 longer case studies elsewhere in this guidance) illustrate how geospatial methods are used at various stages in the project life cycle. Often, more than one geospatial method is appropriate; for example, an analysis might start with EDA and simple methods, then progress to more complex or advanced methods. The method selection flow charts can be used to assist in determining applicable methods for a site.

Table 5 below summarizes certain general topics that geospatial analysis can support in each stage of the project life cycle.

Table 5 Using Geospatial Results for Optimization

General Topic	Life Cycle Stage
Plume Intensity and Extent	Release Detection, Site Characterization, Monitoring
Trend Maps	Release Detection, Remediation, Monitoring, Closure
Estimating Quantities	All Stages
Hot Spot Detection	Release Detection, Site Characterization
Sample Spacing	Site Characterization
Estimating Concentrations Based on Proxy Data	Site Characterization
Background Estimation	Site Characterization
Quantifying Uncertainty	Site Characterization, Closure
Remedial Action Optimization	Remediation
Monitoring Program Optimization	Monitoring, Closure

The examples illustrate how geospatial analysis is performed for optimization.

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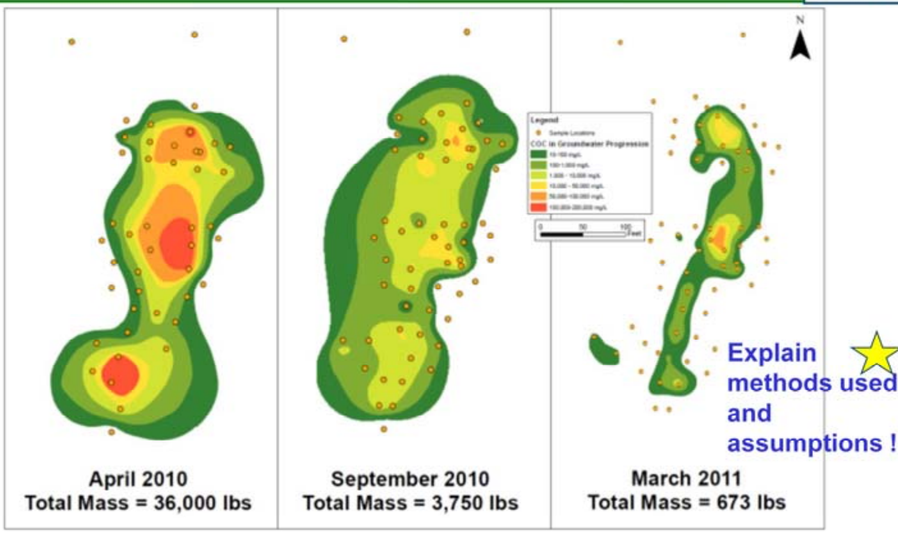
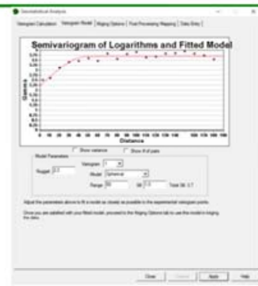
Plume Shrinkage Example



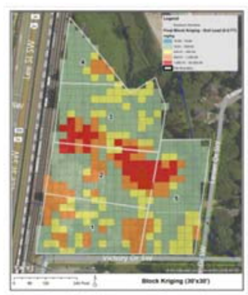
ITRC GRO-1, Figure 54. Plume shrinkage and mass reduction over time.
Source: Courtesy of Ted Parks, Amec Foster Wheeler. Example 2

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, Figure 122



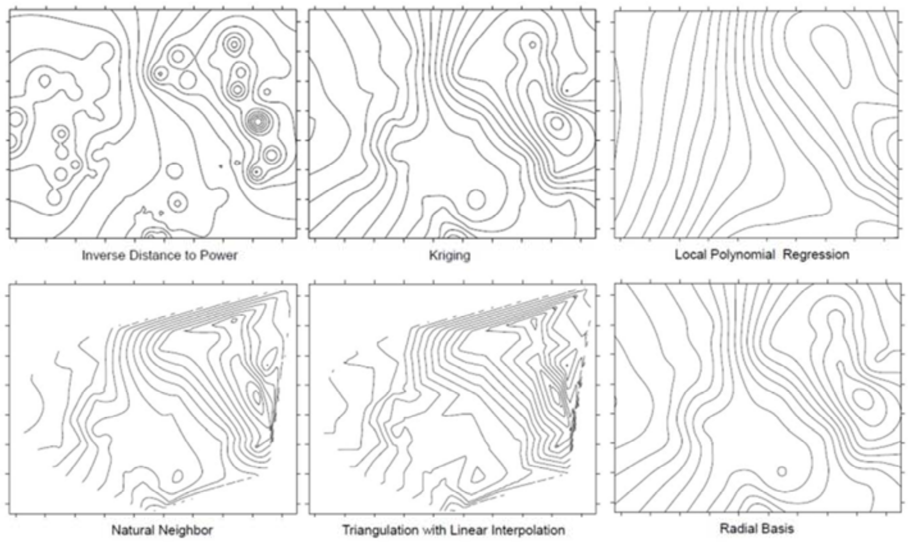
ITRC GRO-1, Figure 124

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

109 **Data Interpolation is Method Dependent!**

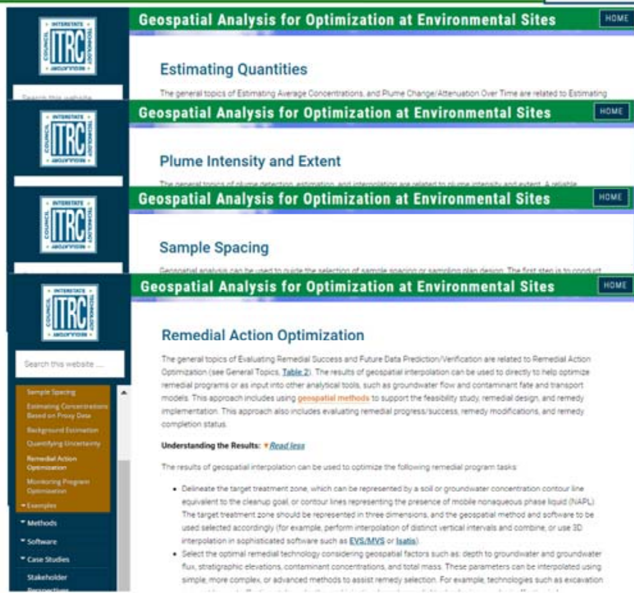


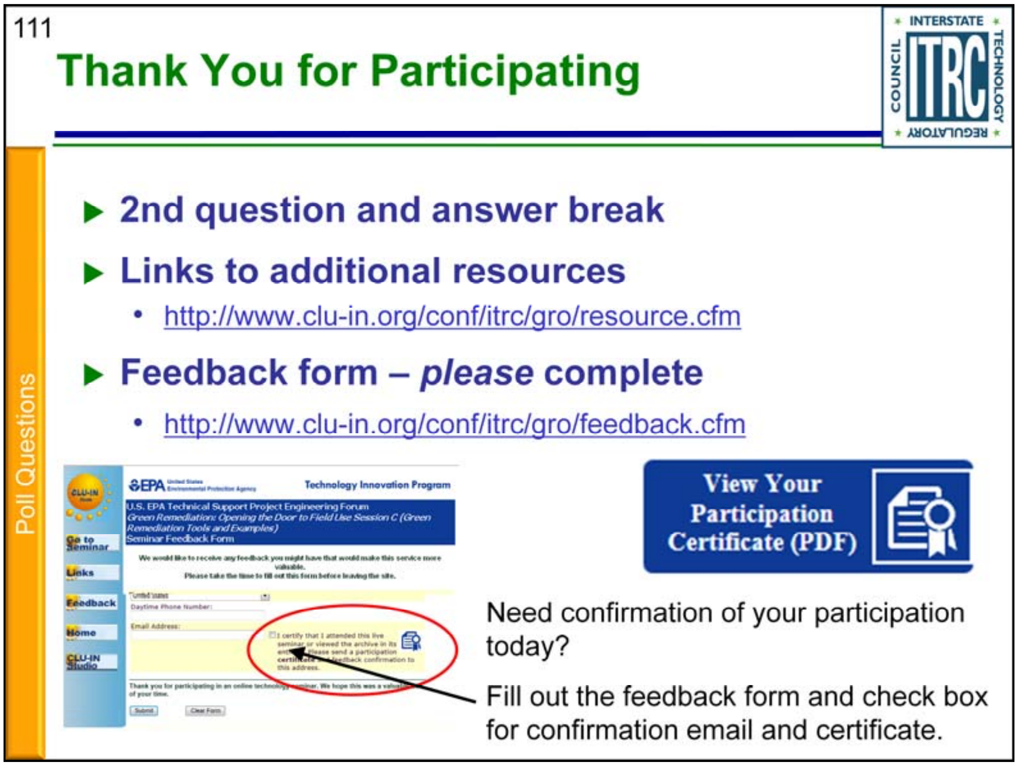
ITRC GRO-1, Figure 15, *Source:* (Kresic and Mikszewski 2012)

Figure Source: Kresic, N., and A. Mikszewski. 2012. Hydrogeological Conceptual Site Models: Data Analysis and Visualization. Boca Raton, FL: CRC Press. https://www.crcpress.com/Hydrogeological-Conceptual-Site-Models-Data-Analysis-and-Visualization/Kresic-Mikszewski/p/book/9781439852224

Other Guidance Uses

- Estimating average concentrations
- Calculating contaminant mass
- Sample spacing
- Evaluating source strength and geometry
- Not just contaminant concentrations!





Links to additional resources:
http://www.clu-in.org/conf/itrc/gro/resource.cfm

Your feedback is important – please fill out the form at:
http://www.clu-in.org/conf/itrc/gro/feedback.cfm

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