Shooting Range Remediation

Using kriging to delineate the extent of lead contamination in soil from an uneven sample pattern

MONTROSE ENVIRONMENTAL

PennState College of Earth and Mineral Sciences

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Study Area

- Pennsylvania sporting clay shooting range and immediate surrounding areas
  - About 275 acres
- Shot – hundreds of tiny lead balls
- Client privacy – exact site location must be kept anonymous

Background

- Lead levels in soil have been increasing
- Adverse health effects
- Shooting ranges contribute to this increase in soil
- Lead management is necessary
- Environmental site characterization and remediation

Goals and Objectives

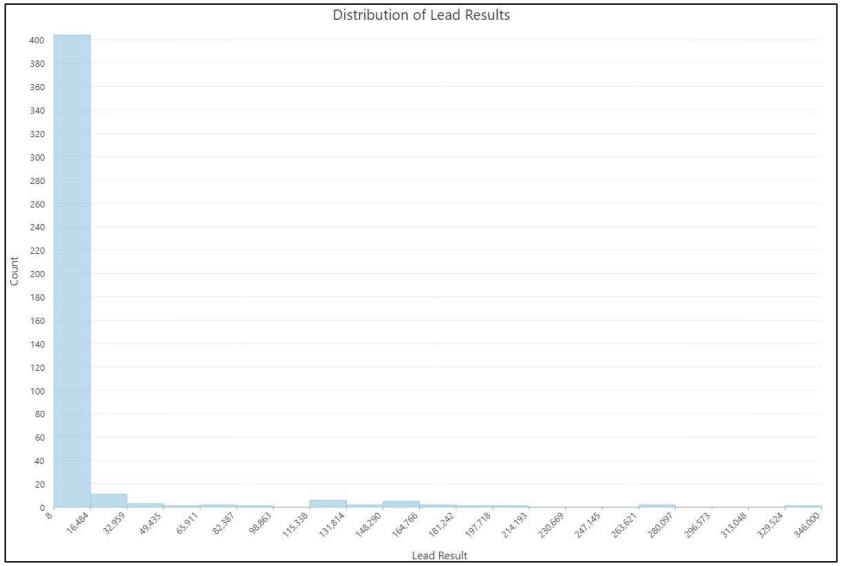
- Define the extent of lead contamination
  - 450 mg/kg – PA DEP Statewide Health Standard
- Assess which kriging method is best for the data

Data

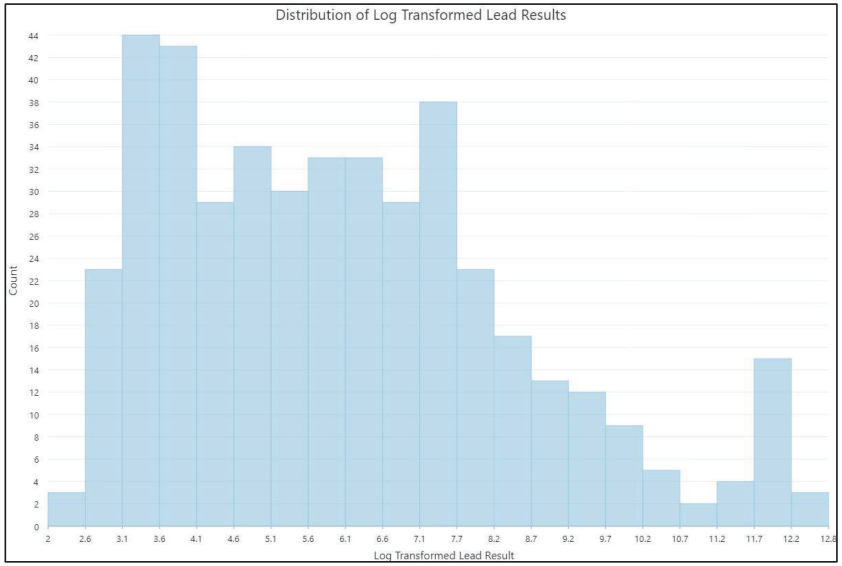
- 442 points
  - Uneven sampling distribution
  - Samples not taken at the same time
  - Sampling was independent of analysis

Data

- Range: 7.7 – 346,000 mg/kg
- Mean: 10,443.45
- Median: 374.5

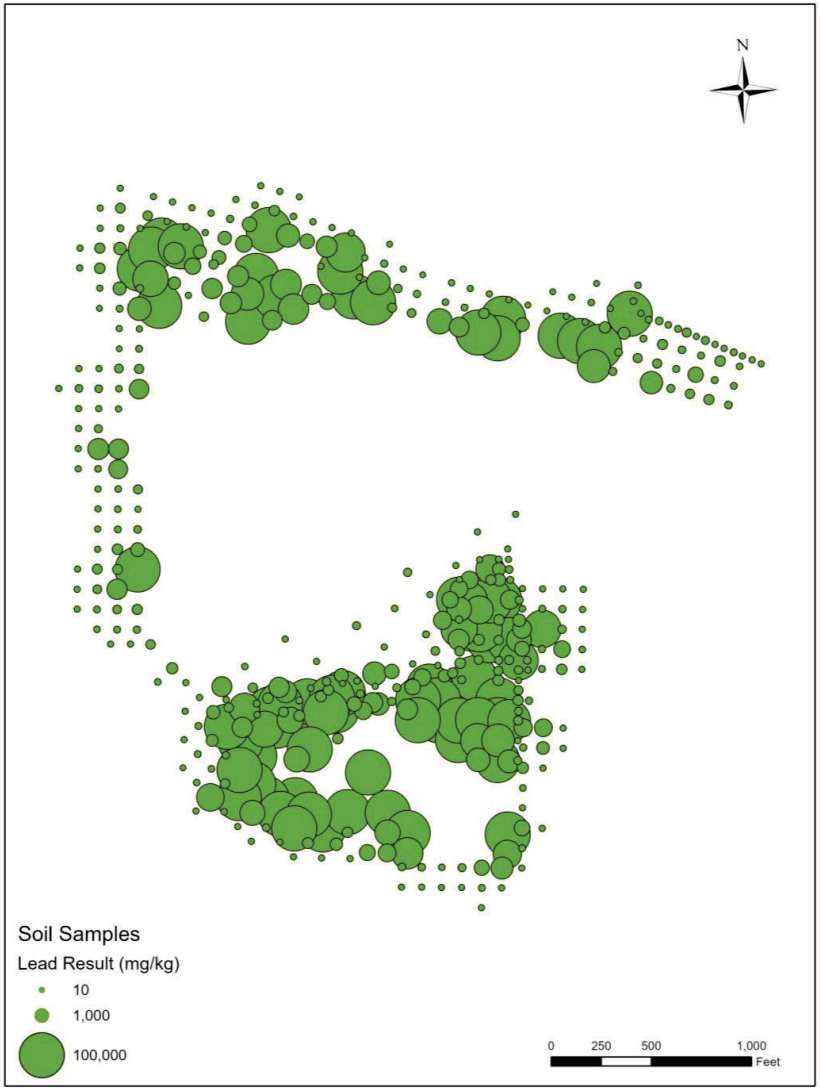


- Natural log transformation



Spatial variability

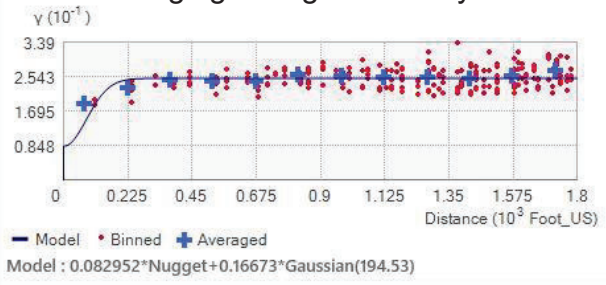
- Lead levels varied across site
- To determine viability of kriging, Moran's I was calculated
- Moran's I value for lead levels = **0.147343**
  p ≈ 0



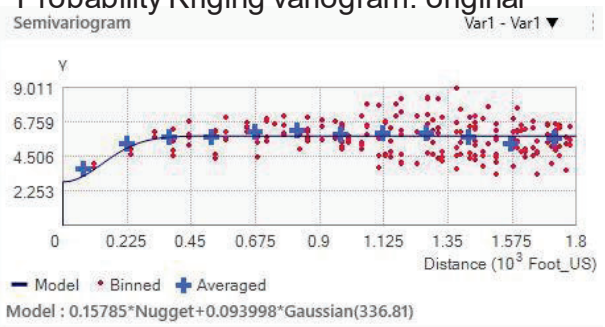
Indicator and Probability Kriging

- Both nonparametric kriging approaches
  - Helps to prevent interference due to large variations or skewed distributions
- Indicator Kriging uses binary data created using threshold
  - Threshold = 450 mg/kg
  - Challenge: loss of information
- Probability Kriging is form of co-kriging where primary variable is indicator variable and secondary variable is original lead variable
  - Challenge: more complicated model
- Kriging was done using all samples & using sampling stratified into sections

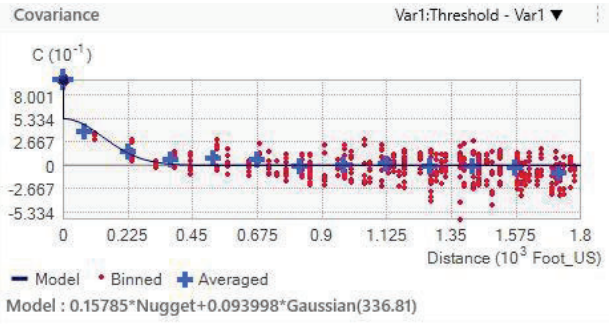
Indicator Kriging variogram: binary



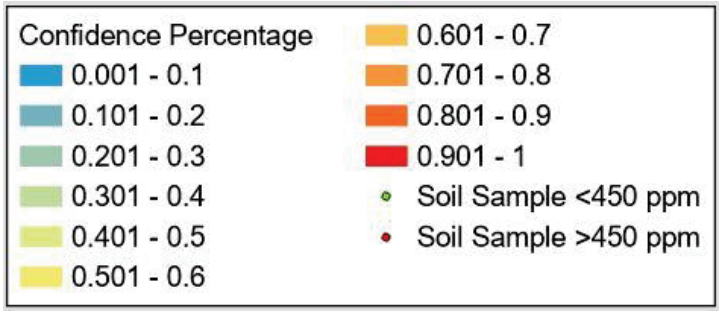
Probability Kriging variogram: original

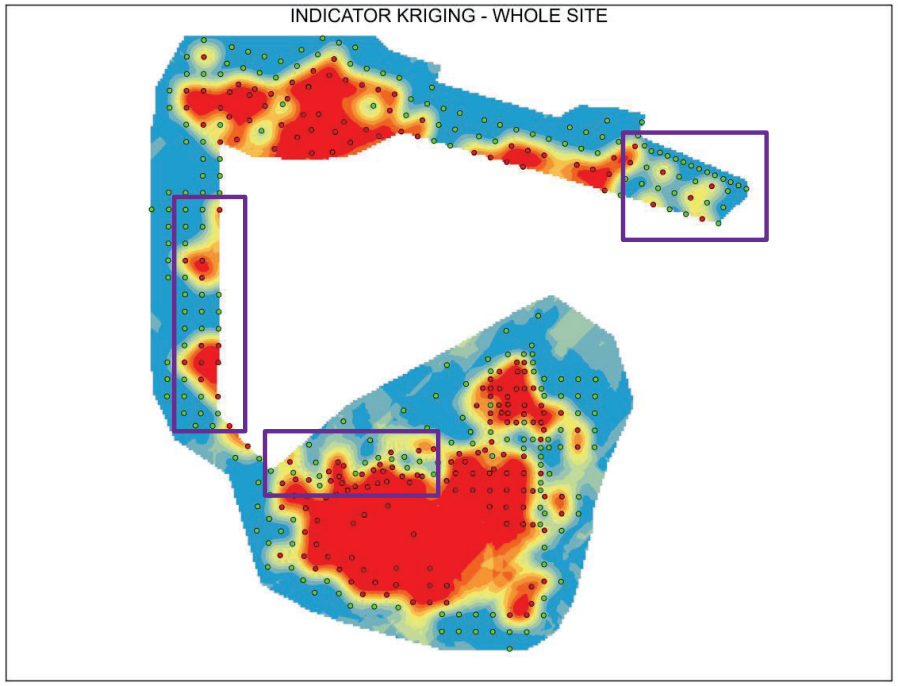


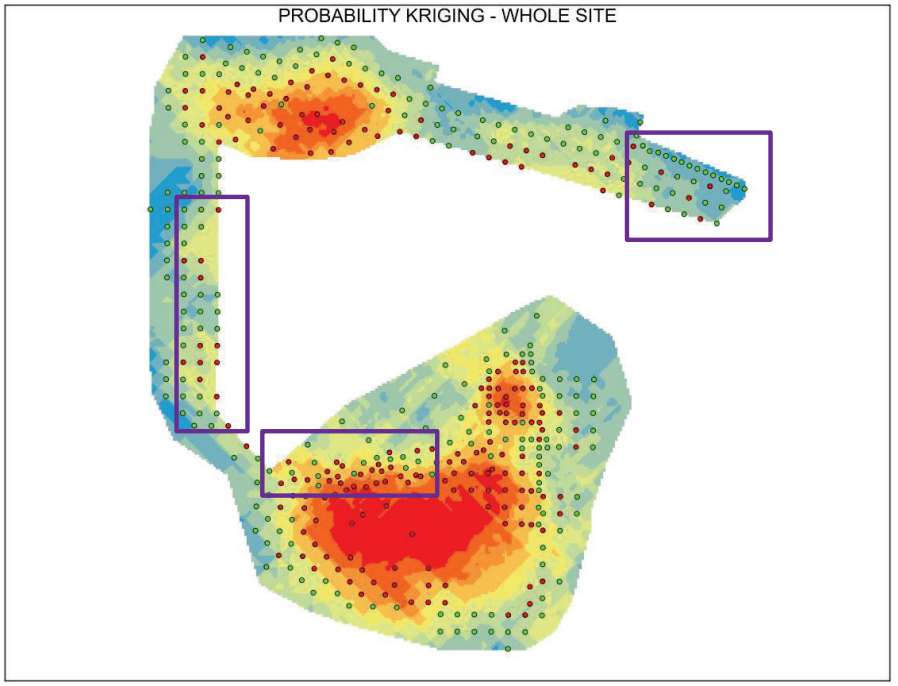
Probability Kriging variogram: cross correlation



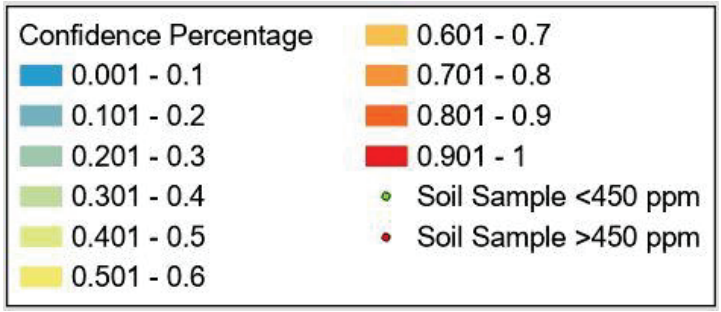
Probability Surfaces: Whole Site

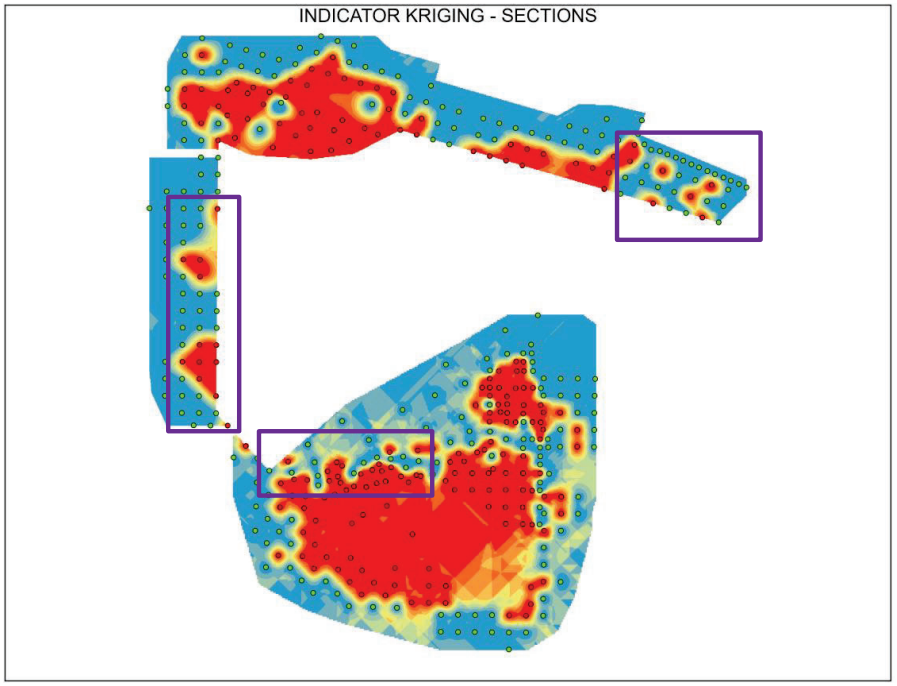


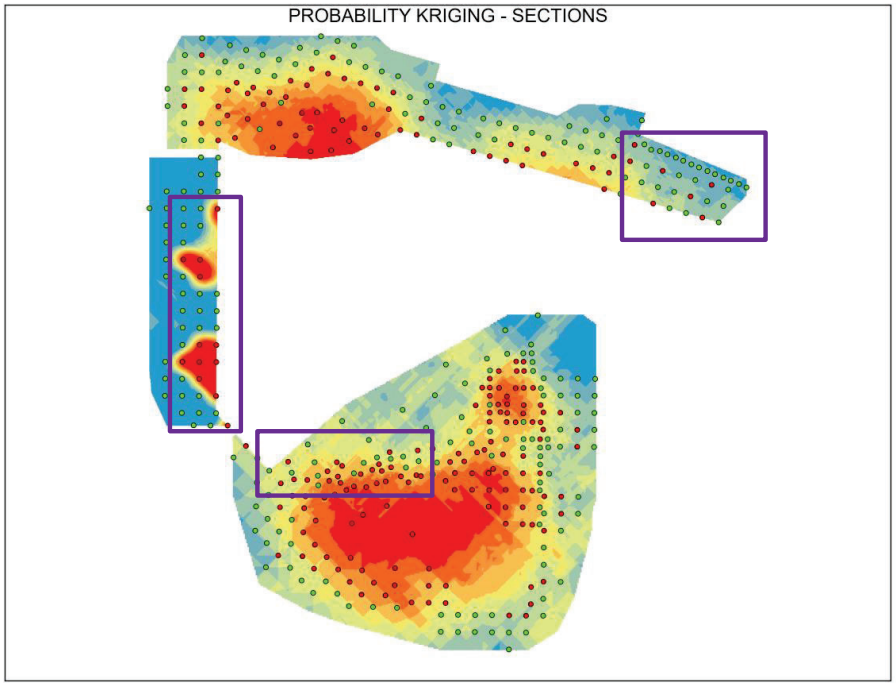




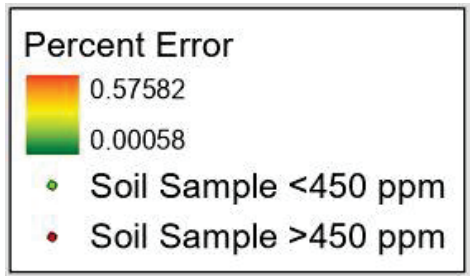
Probability Surfaces: Sections

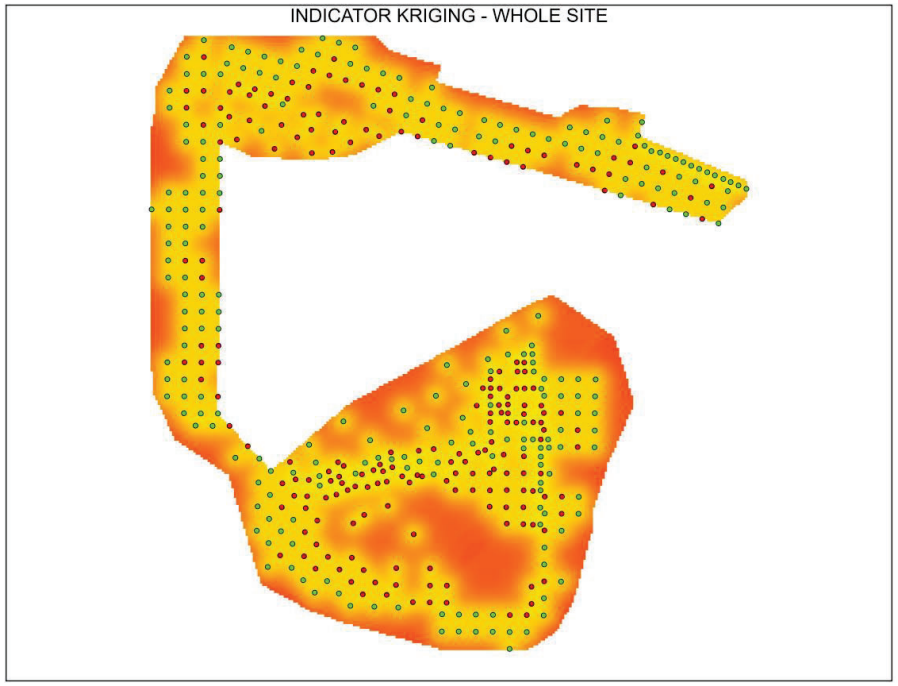


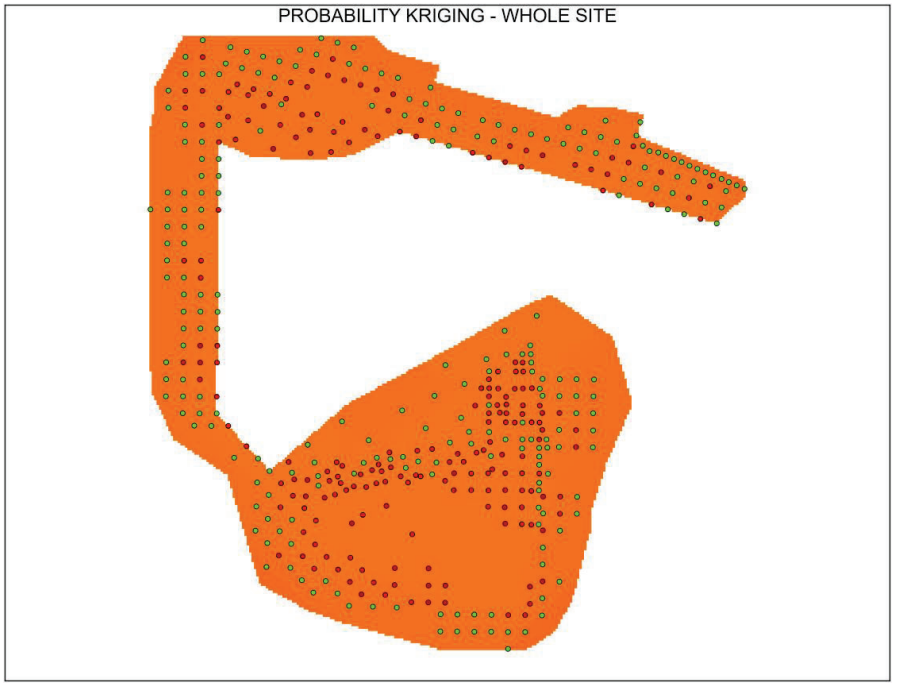




Error Surfaces: Whole Site







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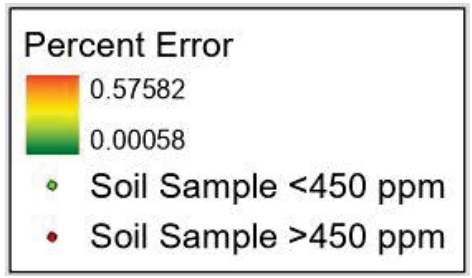
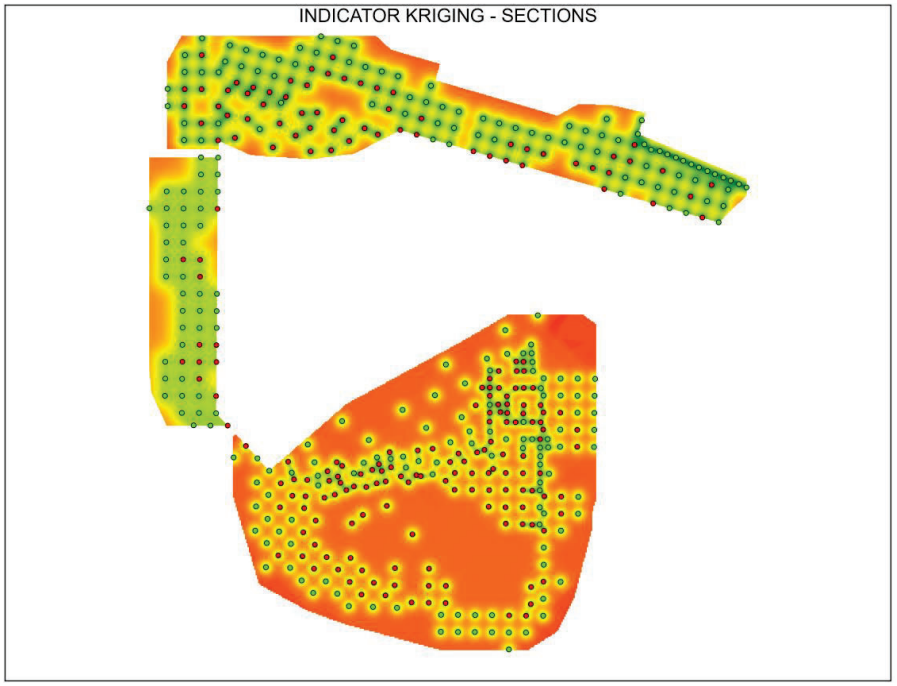
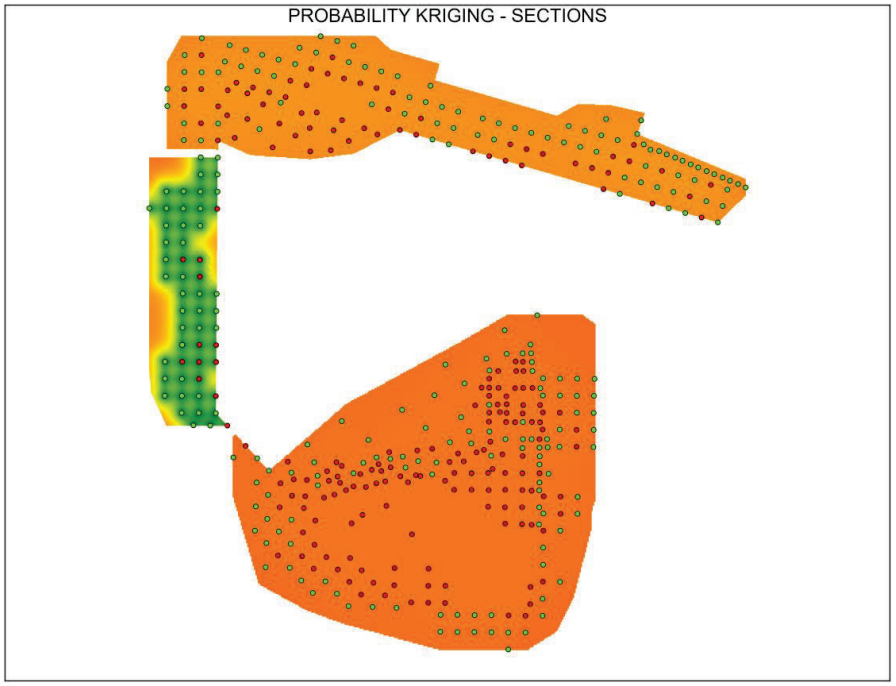




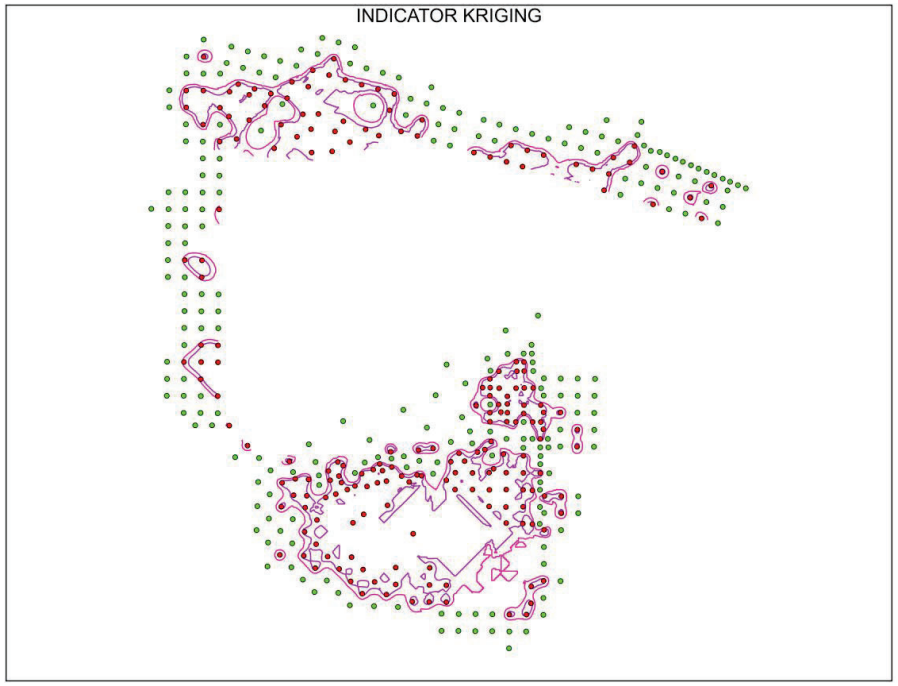


Error Ranges

Output	Probability - RMSE	Error - Min	Error - Max	Error - Mean
Indicator - whole site	0.42051	0.31992	0.55629	0.40820
Probability - whole site	0.43416	0.50965	0.52164	0.51150
Indicator - north	0.43044	0.00058	0.53857	0.25637
Probability - north	0.43498	0.46300	0.48823	0.46835
Indicator - west	0.38162	0.18185	0.51049	0.25601
Probability - west	0.40656	0.01956	0.51440	0.17617
Indicator - south	0.44083	0.00532	0.57582	0.41865
Probability - south	0.42702	0.50679	0.51872	0.50913

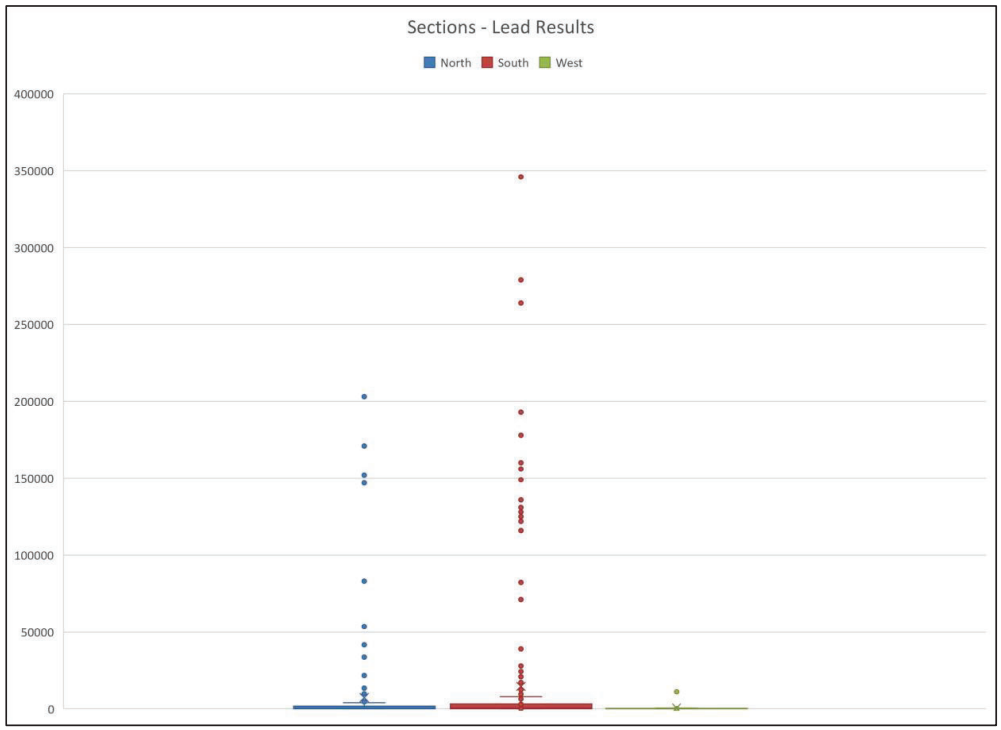
Thresholds

Soil Sample <450 ppm
Soil Sample >450 ppm
95 Percent Confidence Threshold
75 Percent Confidence Threshold



Considerations

- Probability kriging performs better overall compared to Indicator kriging in the areas with an even sampling distribution
- There is also a larger range of values in the north and south
- Juang and Lee study
  - Found probability better than indicator
  - Range of lead was 9.52 to 126.67

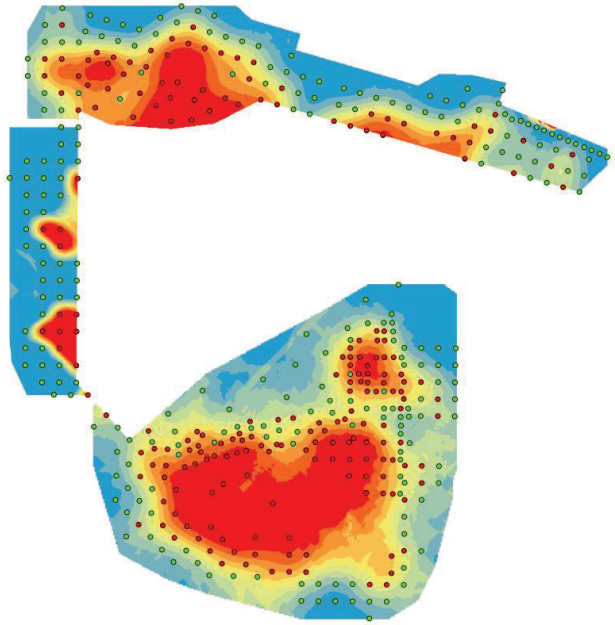


Key Takeaways

- Even sampling improves results
  - Sectioning for irregular sampling pattern
    - Greater control of parameters
- Interpolation results are only as good as the data
- Interpolation will never be perfect
  - Error is still high
  - Secondary variable?
- Probability and Indicator kriging are great tools for remediation areas
  - Flexibility

Thank you!
Questions?

PROBABILITY KRIGING - SECTIONS



PROBABILITY KRIGING - SECTIONS