Spatial Analysis and Decision Assistance (SADA) Version 4 Geospatial Overview

EPA Cluin SADA Web Training Series

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Spatial Analysis and Decision Assistance (SADA) Version 4 Basic Spatial Analysis (Short Version)

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Basic Spatial Analysis Tools

"All models are wrong; some models are useful."
George Box, Professor Emeritus, University of Wisconsin

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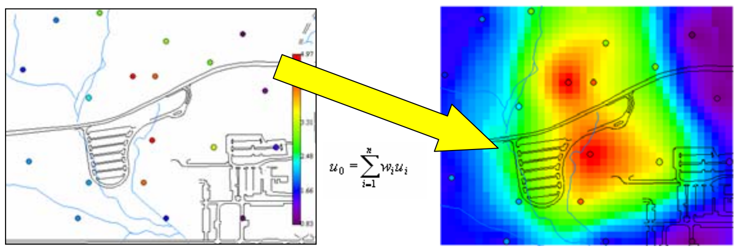
Basic Spatial Analysis Tools

Spatial interpolation is used to predict values between sampled locations.



The methods discussed throughout this text estimate the unsampled location as a weighted linear combination:

$$u_0 = \sum_{i=1}^{n} w_i u_i$$

Where u_0 is the estimate, u_i are the sampled data and w_i are the weights assigned to the data values.

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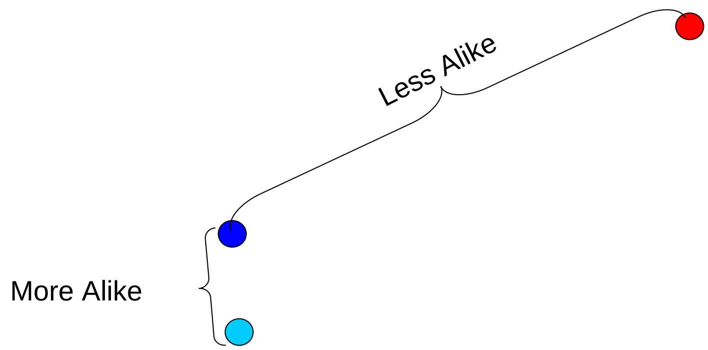
Determining Weights

All of the methods presented here generally work on the principle that data points closer are more alike than data points farther away. This plays a key role in all of the approaches to weighting sample values.



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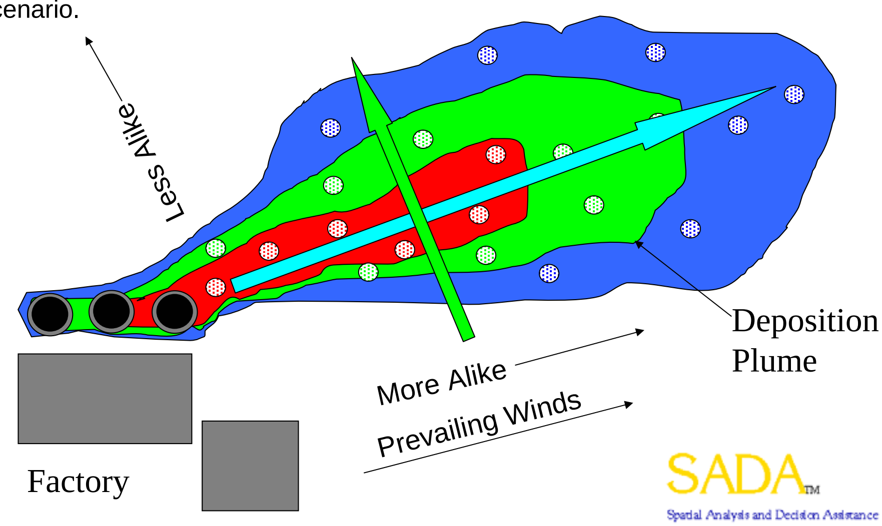
Spatial Anisotropy

One example of spatial correlation would occur with a plume or deposition scenario.



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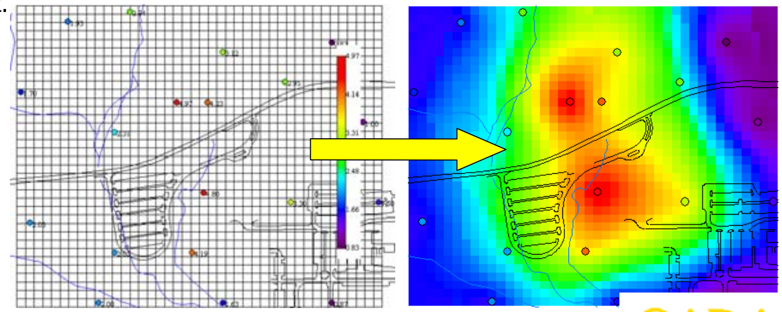
Grid Definition

Rather than estimate values at only a single point, we wish to estimate them at a number of points in order to fill in the picture of contamination. All spatial interpolators in SADA depend on a grid definition to function. A grid definition simply describes the number, size, and location of a uniform set of blocks. These blocks will be the focus of the interpolation schemes. SADA's interpolation schemes will estimate the concentration value at the center of each block. From the interview list choose **Interpolate My Data.** Select **Set Grid Specs** from the **Steps Window** to define the grid. Press **Show Grid** to see your result.



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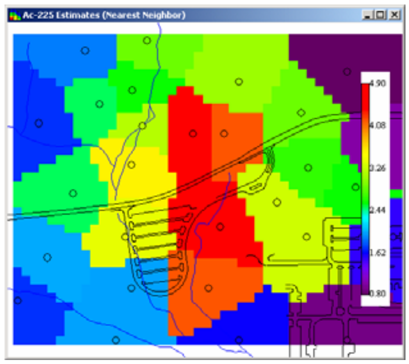
Nearest Neighbor

This is the simplest of all interpolants in SADA. Any unsampled point is simply equal to the data point closest to it. In our previous notation we would describe Nearest Neighbor as

$$u_0 = \sum_{i=1}^{n} w_i u_i \quad \textit{where } w_i = 1 \textit{ if } u_i \textit{ is the nearest value and } 0 \textit{ otherwise.}$$

- Choose **Interpolation methods** and then select Nearest Neighbor from the list of available interpolants.
- Press **Show The Results** to see the map.



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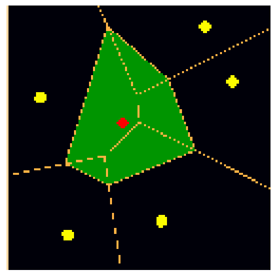
Natural Neighbor

In natural neighbor we allow more than the nearest neighbor to influence the estimation. When data points are distributed in space they are inherently representing a certain area around them. Sample points in sparsely sampled regions must represent a higher region than those in more densely sampled areas. These regions are called *area of* influence and it is possible to draw simple geometries that bound them.

In natural neighbor, the areas of influence are calculated first. Then the area of influence for the point we wish to estimate is overlaid creating regions of overlapping areas of influence. For any given sample point, the portion of the overlap becomes the weight assigned to that sample point.

$$u_0 = \sum_{i=1}^{n} \frac{a_i}{A} u_i$$



Where A is the area of influence for u_0 and a_i is the area of overlap between u_0 and u_i.

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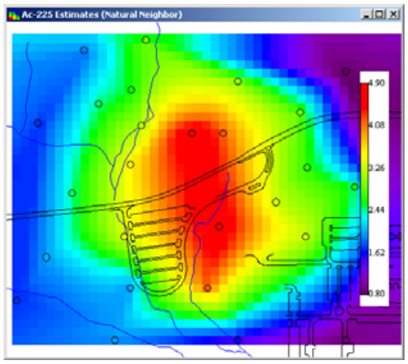
Natural Neighbor

- Press **Interpolation methods** and then select Natural Neighbor from the list of available interpolants.
- Press **Show The Results** to see the map.



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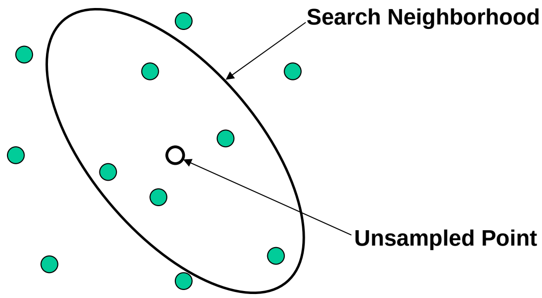
Inverse Distance

The estimated value V_o at an unsampled location is estimated as the weighted average of nearby values.

$$V_0 = \sum_{i=1}^{N} w_i V_i$$



Inverse Distance

$$w_i = \frac{1}{d_i^p \sum_{j=1}^{N} d_j^{-p}}$$

w_i is the weight for the ith neighbor
d_i is the distance of the ith neighbor
p is the power
N is the number of neighbors within the search neighborhood

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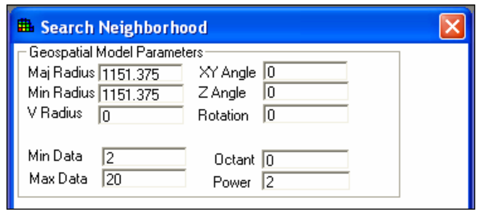
Search Neighborhoods

Inverse distance requires a neighborhood definition for estimating concentration values at a point. A neighborhood is defined as an area around the point in which data values will be used to estimate the concentration value. Data values outside the neighborhood will be excluded.

The neighborhood is always defined by a search ellipse that can be manipulated in shape and size to include or exclude various data. The parameters which control the shape and size of the search ellipse are entered on the **Parameters Window** when **Search Neighborhood** is selected from the **Steps Window**.



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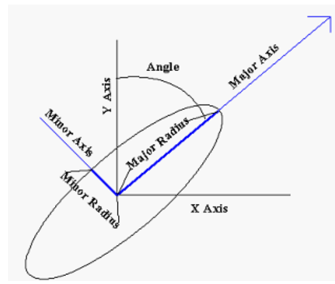
Search Neighborhoods

The parameters Major Radius, Minor Radius, and XY Angle control the size and shape of the search ellipse.

Major Radius
The long radius of the ellipse.

Minor Radius
The short radius of the ellipse.

XY Angle
The angle or direction the long radius points. This angle is measured clockwise from the positive Y axis (0 deg is North). The minor elliptical axis is perpendicular to the major axis.



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Search Neighborhoods

For three-dimensional data, the ellipse becomes an ellipsoid. The following parameters, in addition to those listed above, describe the search ellipsoid in 3D space.

Z Angle

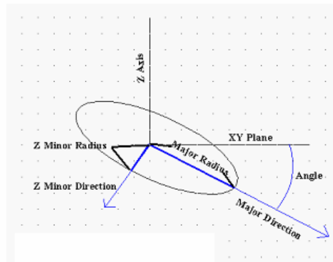
The angle or dip below the XY plane at the point of estimation. This angle is measured as negative degrees below the plane.

V Radius

Also referred to as Z minor radius, it is the radius of the ellipse in the vertical direction.

Rotation

The parameters described to this point fully form the body of the ellipsoid in 3D space. The rotation parameter then rotates this ellipsoid about the major axis the specified number of degrees.



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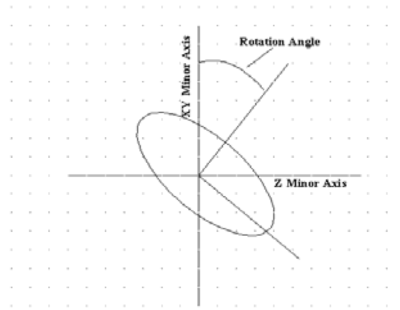
Search Neighborhoods

The following view shows the effect of the rotation parameter on the ellipsoid body. This view is along the major elliptical axis. The rotation angle rotates two orthogonal directions clockwise relative to the major elliptical axis when looking toward the origin. The following parameters define the search criteria within the search ellipse.

Min Data
The minimum number of data required before estimating the concentration. If the minimum is not met, SADA returns an unestimated value. These values become empty spaces in the plot.

Max Data
The maximum number of data to use in estimating a point.

Octant
The ellipsoid is divided into quadrants, four if two- dimensional, eight if three-dimensional. If the Octant value is greater than zero and there are fewer data points than the octant value in each quadrant, then the point will not be
15 estimated.



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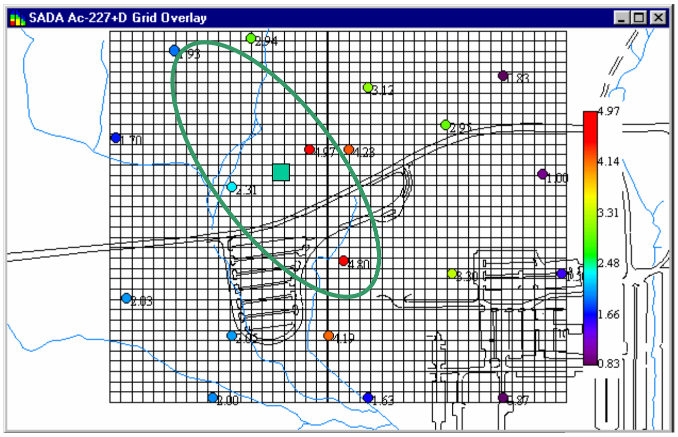
Search Neighborhoods

Neighborhoods allow the user to search for a single unsampled point.



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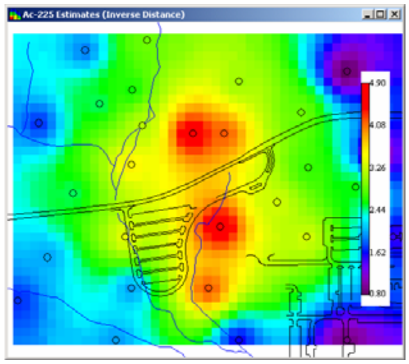
Inverse Distance in SADA

After understanding "Search Neighborhoods"; the procedure to produce an Inverse Distance map in SADA is simple:

- Select Inverse Distance from the list under **Interpolation methods**.
- Setup an appropriate search neighborhood and specify the power parameters after selecting **Search Neighborhood**.
- Press **Show The Results** to see the map.

Inverse Distance Estimates Map



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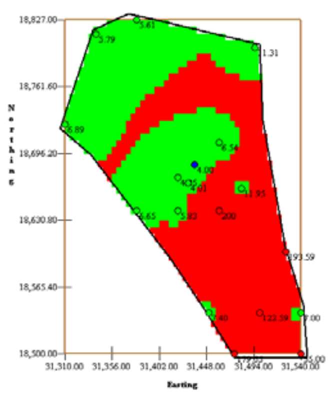
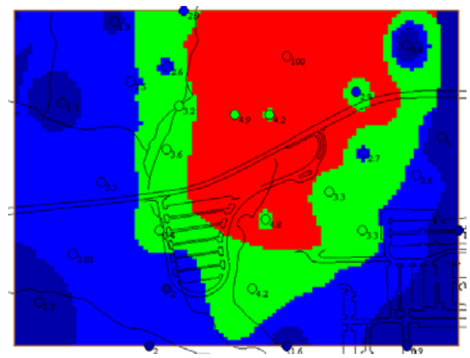
Extreme Value Effects

Interpolations can be “smeared” by extreme valued points causing an inaccurate elevation of interpolated values for great distances.





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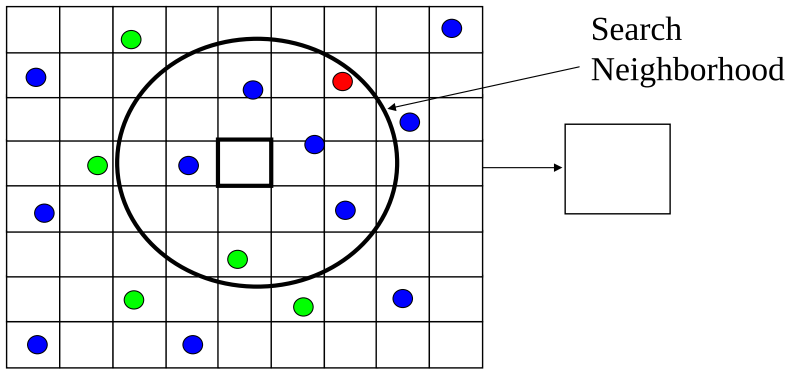
Extreme Value Effects

Extreme values can have unwanted effects on the interpolation model particularly for those that use search neighborhoods. These extreme values can cause high value "smears" or other artifacts in the result.



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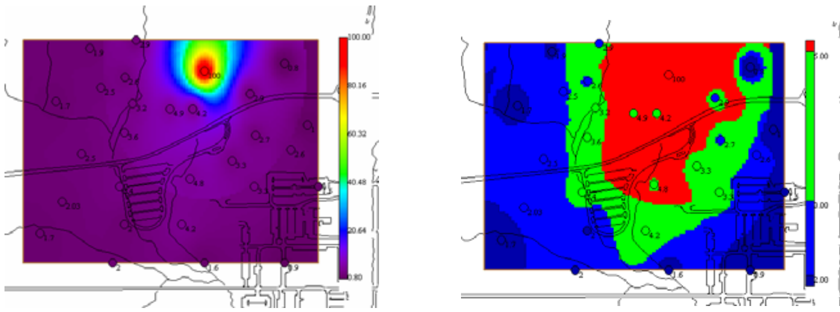
Extreme Value Effects

Sometimes smearing can go unnoticed because of the designation of the legend. Linear continuous legends tend to mask smearing. Categorical legends often better reveal smearing effects.



Here we have exactly the same interpolation results displayed in two different ways: with a smooth linear legend and a categorical legend. Notice how the smearing is highlighted in the later plot.

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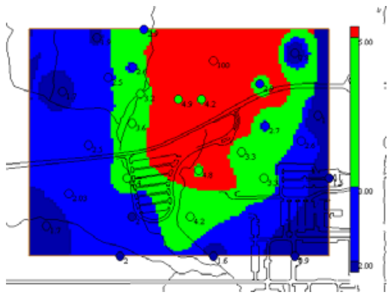
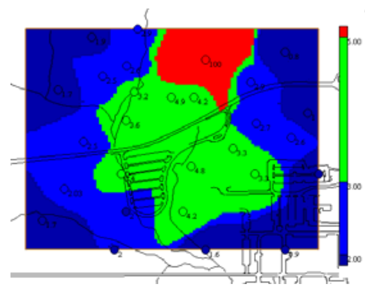
Addressing Extreme Value Effects

Smearing effects can be dealt with in various ways. In inverse distance, the power value (p) may be increased. By increasing the value of p, data points have very small influences over even short distances. Other methods include decreasing the search radius.



Power = 2



Power = 7

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Cross Validation

- Cross validation is the process of determining how well our modeling is reflecting reality.
- The truth is that we will almost never know how well it is performing since we will likely never have samples at every point we estimate. If we did we could simply compare them and evaluate the model performance.
- As an approximation to this approach, we can cross validate by removing one at a time each sample that we do have and allow the model to predict its value based on the remaining data
- We can then compare this estimate with the real value and make comparative statements between the different models.
- It is important to remember that cross validation provides evidence (rather than proof) of how a model is performing since in each estimation we have N-1 samples rather than N.

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Cross Validation in SADA

- Once you understand what information cross validation provides, generating error plots in SADA is simple:
- Clicking on **Cross validation** and choosing a method will allow you to:
  - Plot Error (Simple subtraction of estimated and real values),
  - Plot Absolute Error (Absolute value of the difference in real and estimated values) and/or,
  - Plot Percentage Error (Absolute difference/Real value *100)

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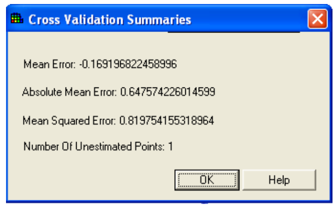
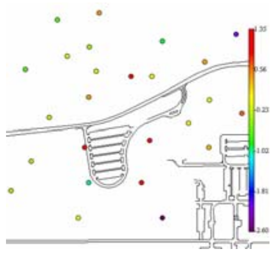
Cross Validation in SADA

- SADA produces a summary of the model's performance. This can be compared across models as form of performance assessment.
  - Mean of errors
  - Absolute mean error
  - Mean squared error
  - Number of unestimated points



- Pressing Ok SADA will show the graphical result. These results can understanding about model performances in regions of the site.



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Spatial Analysis and Decision Assistance (SADA) Version 4 Advanced Spatial Tools (Short Version)

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Advanced Spatial Tools
(Geostatistics)

"Most researchers use statistics the way a drunkard uses a lamppost – more for support than illumination."
Winifred Castle

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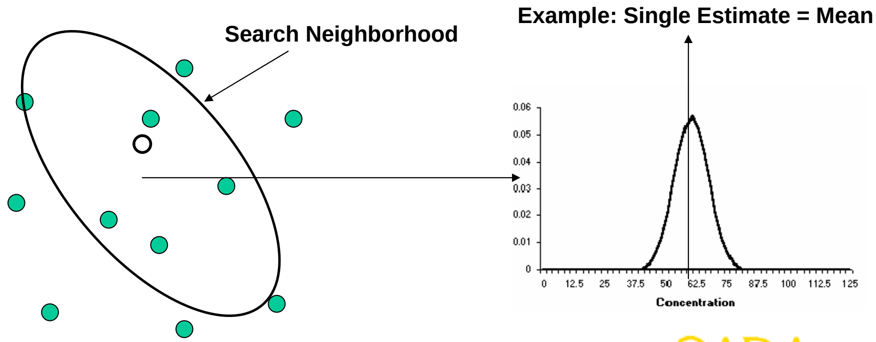
Advanced Spatial Tools (Geostatistics)

With basic spatial analysis tools, each interpolant produced a single estimate for each unsampled point. With a geostatistical approach, a distribution of possible values is constructed and used as a model for the actual unsampled value. Both an estimate and a model of uncertainty can be now obtained. From this distribution of points, a central moment, such as the mean or media, is chosen as a single estimate for contouring purposes.



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Geostatistics

SADA provides two kriging (geostatistical) models: Ordinary and Indicator kriging. Ordinary kriging assumes a normal or lognormal distribution for the data. Indicator kriging is a non parametric approach that does not assume any distribution.

Like the methods discussed in Basic Spatial Analysis Tools, both methods are based on a weighted combination of nearby samples. However, the development and expression of these weights is quite complex and beyond the scope of this training guide.

It may be helpful to think of kriging as an advanced form of the inverse distance method. Recall that the inverse distance method weights sampled values by their distance from the unsampled location.

Kriging approaches the problem in much the same way. However, rather than distance (d), the weights are based on the amount *of spatial correlation* or *spatial covariance* that samples exhibit at varying distances C(d).

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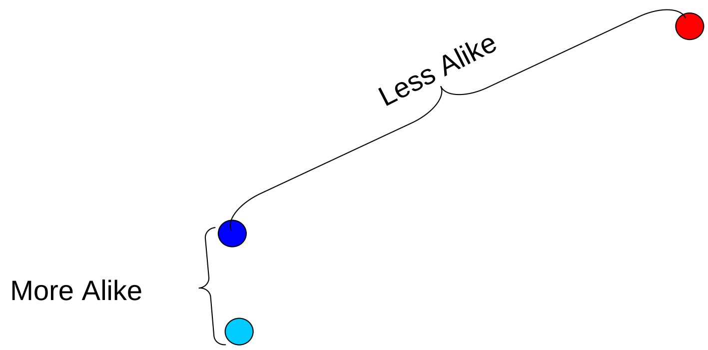
Spatial Correlation

If data are spatially correlated, then on average, sample points that are close to each other are more alike than sample points further away. (More complex spatial correlations exist but this type is the most common).



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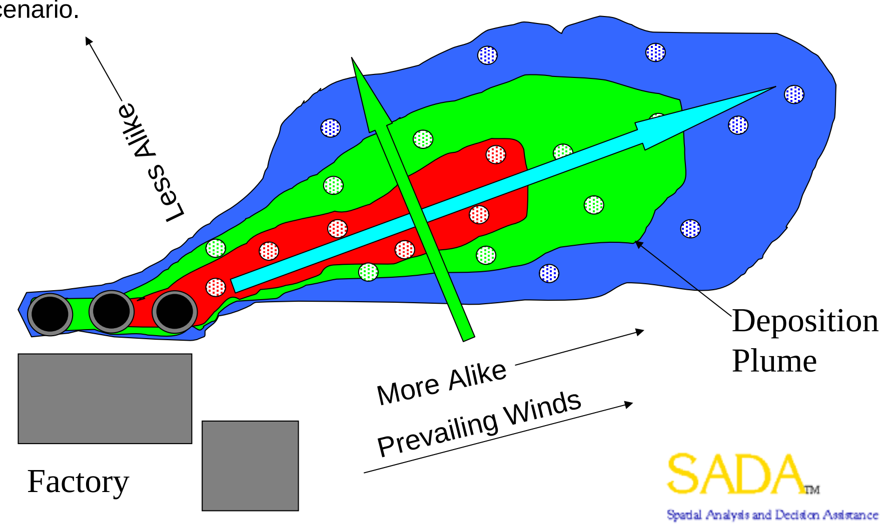
Spatial Anisotropy

One example of spatial correlation would occur with a plume or deposition scenario.



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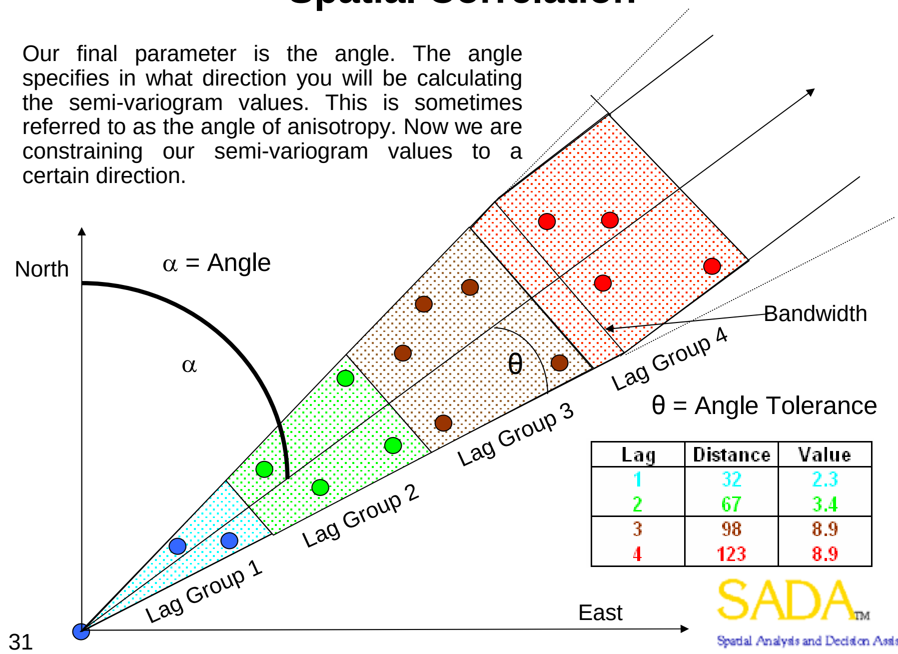
Spatial Correlation

Our final parameter is the angle. The angle specifies in what direction you will be calculating the semi-variogram values. This is sometimes referred to as the angle of anisotropy. Now we are constraining our semi-variogram values to a certain direction.



Lag	Distance	Value
1	32	2.3
2	67	3.4
3	98	8.9
4	123	8.9

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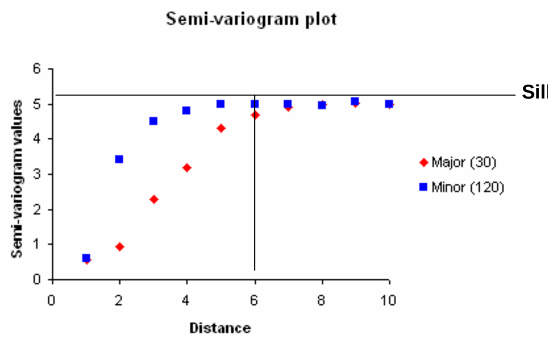
Spatial Correlation

Theoretically, the semi-variogram values will continue to rise until they reach the *sill* value. The sill is the point at which the data are now far enough apart to be independent. The sill value should be roughly equivalent to the variance of the data set. A *semi-variogram plot* is useful in detecting the sill value and location.

Lag	Major (30)	Minor (120)
1	0.56	0.6
2	0.95	3.4
3	2.3	4.5
4	3.2	4.8
5	4.3	5
6	4.7	5
7	4.9	5
8	5	4.95
9	5.01	5.05
10	4.99	5



In the above example, we see a major direction at 30 degrees and the corresponding minor direction at 120 degrees. A sill value of approximately 5 is detected around 6 feet of separation.

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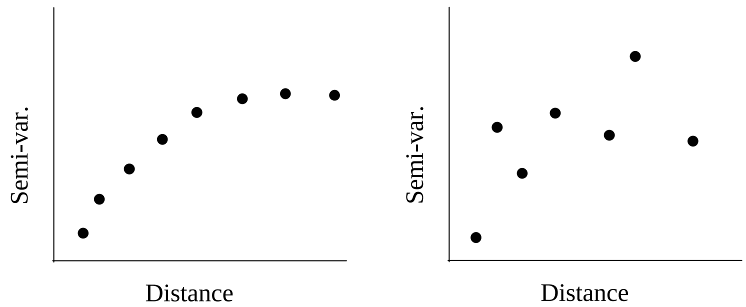
Semi-variogram Behaviors

- Semi-variograms often do not conform to the well behaved monotonic increasing variogram structures seen in text book examples.



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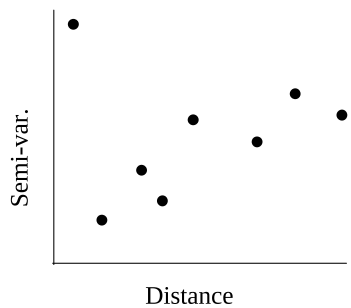
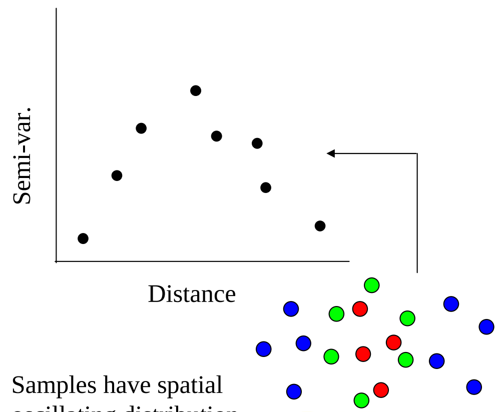
Semi-variogram Behaviors

- Semi-variograms often do not conform to the well behaved monotonic increasing variogram structures seen in text book examples.



A high sample occurs close to a small value.



Samples have spatial oscillating distribution.

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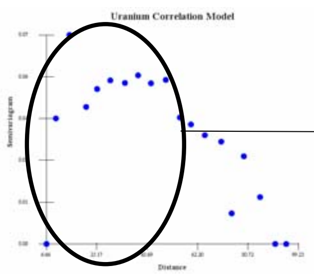
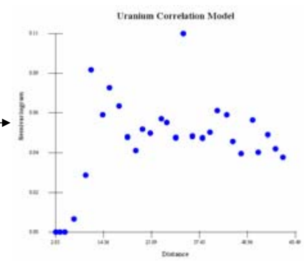
Semi-variogram Behaviors

- Sometimes the variability is really short range and you have your lags set too large. This blurs the true spatial structure and can result in bizarre cases especially as the cone distance increases. In the case of indicator kriging below we can see this effect.





Lag Dist = 5

Lag Dist = 2

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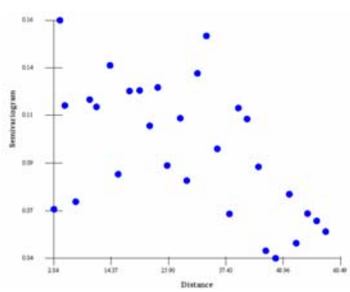
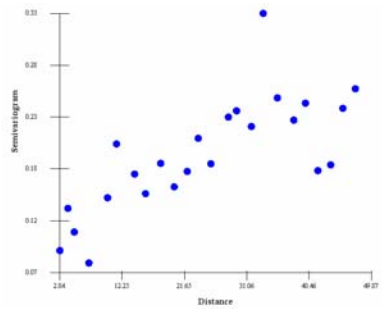
Semi-variogram Behaviors

- In 3d dimensional applications DIP can be very important.



Dip = 0



Lag Dist = 2

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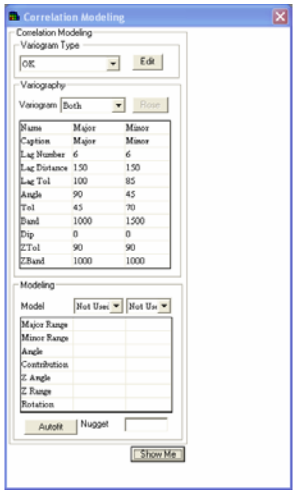
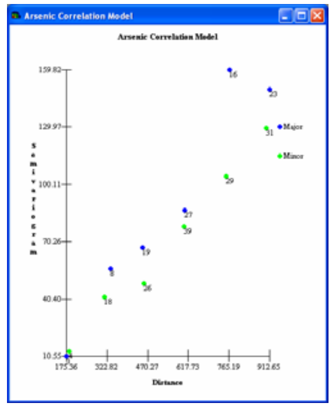
Setting Variography Model

To calculate semivariogram values, select **Correlation Modeling** from the **Steps Window** and enter the appropriate information on the **Parameters Window**. The results of two separate cones are viewed at once to provide visual comparison and check for anisotropic correlation. Press **Show Me**.





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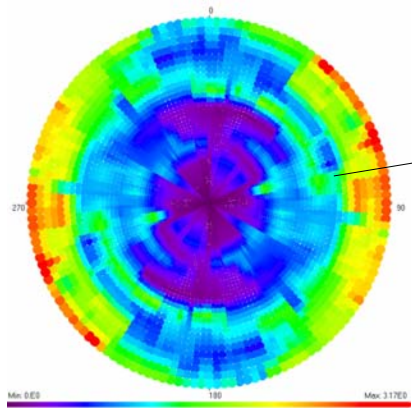
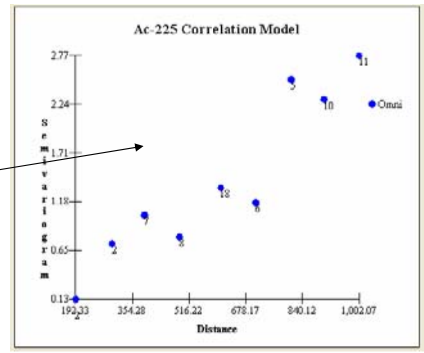
Rose Diagrams

Rather than viewing only on angle at a time, users can view semivariogram values in all directions at once. They can then choose an angle of interest by clicking on the rose diagram map. SADA will show the semivariogram values for that direction.





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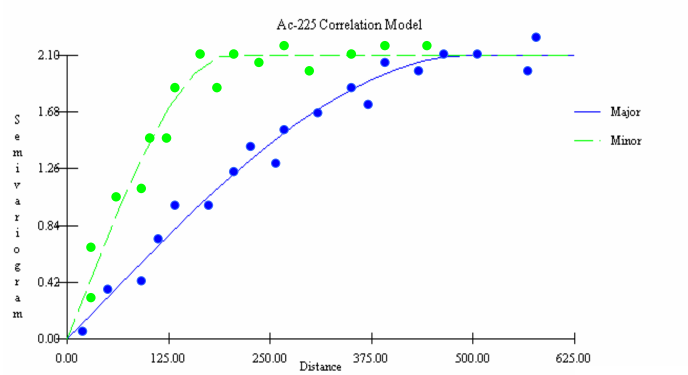
Spatial Covariance

When the kriging models are used, they will require that the semi-variogram values are known for any distance **h**. At this point, we only have these values for a few discrete distances. Therefore, we need to fit a model to the data so that a semi-variogram value is available for every distance.



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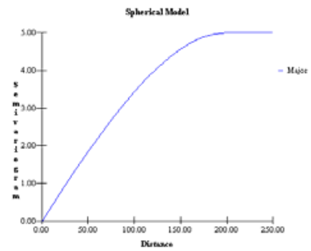
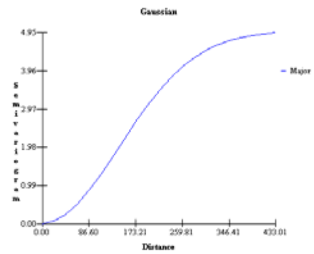
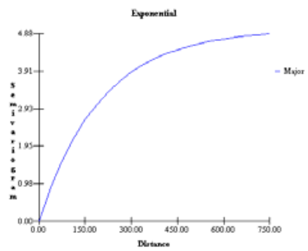
Spatial Covariance

SADA provides 3 standard correlation models that provide a great deal of flexibility in semi-variogram data: Spherical, Exponential, and Gaussian.







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Spatial Covariance

All three models require the same set of parameters. Most of these parameters were encountered while specifying a search neighborhood.

2D and 3D

- Major Range – distance to sill or *correlation length* along the major anisotropic axis.
- Minor Range – distance to sill or *correlation length* along the minor anisotropic axis.
- Angle – the angle of anisotropy

3D

- Z Angle – the angle of anisotropy in the Z plane (equal to the Dip parameter in experimental variography).
- Z Range – a value describing how anisotropy behaves in the z minor direction, relative to major axis.
- Rotation – how the anisotropic ellipsoid is rotated about its major axis.

- Contribution – The model's contribution to the sill (maximal model value)
- Nugget – where the model should cross the y axis (white noise)

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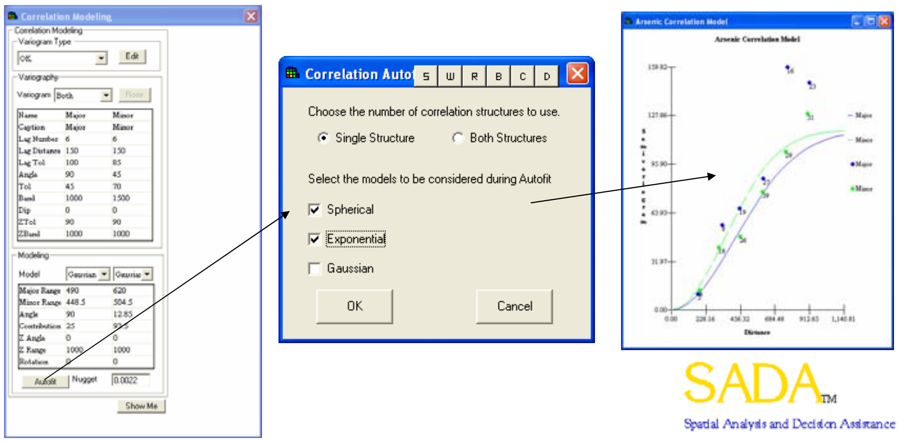
Estimating the Correlation Model

SADA can estimate the model and associated parameters to use for a given set of semi-variogram values. Press the **Autofit** button and select the models and whether a nested model is needed. Typically, users will only choose a single structure and choose from spherical or exponential. Estimation quality can vary from variogram set to variogram set and results should only be used as a basis for adjusting the correlation model parameters.



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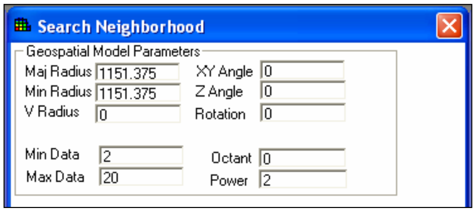
Search Neighborhoods

Inverse distance requires a neighborhood definition for estimating concentration values at a point. A neighborhood is defined as an area around the point in which data values will be used to estimate the concentration value. Data values outside the neighborhood will be excluded.

The neighborhood is always defined by a search ellipse that can be manipulated in shape and size to include or exclude various data. The parameters which control the shape and size of the search ellipse are entered on the **Parameters Window** when **Search Neighborhood** is selected from the **Steps Window**.



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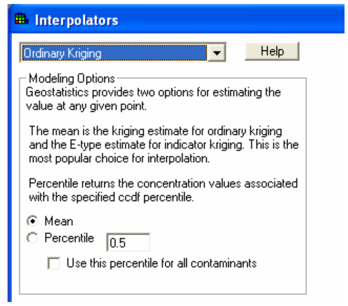
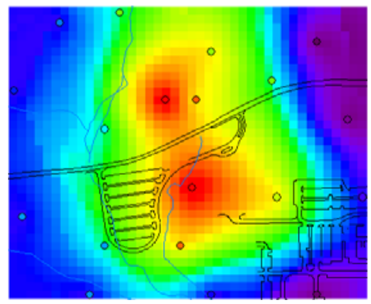
Ordinary Kriging in SADA

- Select the analysis, data type and data name of interest
- Select **Interpolate My Data** from the **Interview** list (or any other spatial model map)
- Define a grid by selecting **Set Grid Specs**.
- Press **Interpolation methods**, and then select Ordinary Kriging from the list of available interpolants.
- Select **Correlation Modeling** and set variography and correlation models.
- Setup an appropriate search neighborhood and specify the power parameters after selecting **Search Neighborhood**.
- Press **Show The Results** to see the map.





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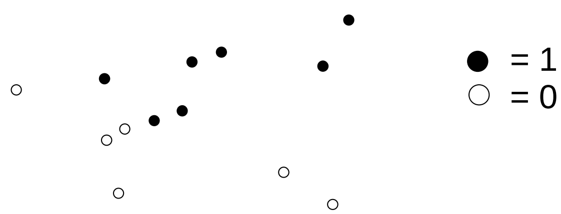
Indicator Variograms

To this point, all variograms we have calculated have been on the actual data points. This type of variography is necessary for ordinary kriging. Indicator kriging requires variography be calculated on the *indicator transformed* values. When performing an indicator transform, you need a threshold value **t**. All sample values greater than **t** become equal to 1, and all values less than **t** are 0. We can write the indicator transform of the data as follows

$$I(u_i) = \begin{cases} 0 \ if \ u_i > t \\ 1 \ if \ u_i \le t \end{cases} \quad for\ all\ i$$

If we plot the transformed data values, they would look something like this.



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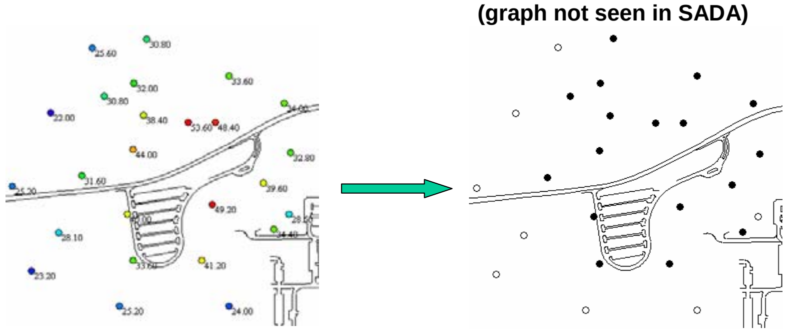
Indicator Variograms

The following example shows Arsenic data that has been indicator transformed at a threshold of 30 mg/kg.

Raw Data **Indicator Transformed (graph not seen in SADA)**



Calculations of the variogram of the indicator transformed data then proceed exactly as in the case of the untransformed data.

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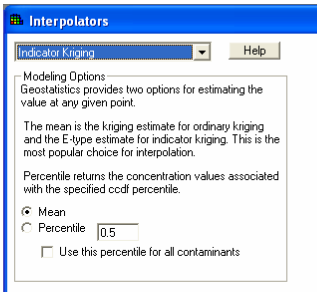
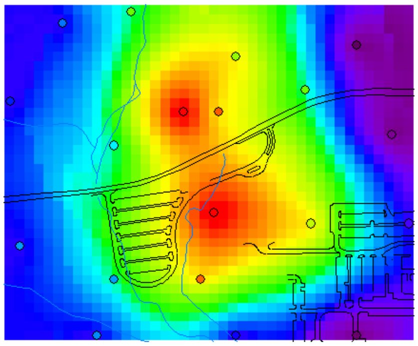
Indicator Kriging in SADA

- Select the analysis, data type and data name of interest
- Select **Interpolate My Data** from the **Interview** list (or any other spatial model map)
- Define a grid by selecting **Set Grid Specs**.
- Press **Interpolation methods** and then select Indicator Kriging from the list of available interpolants.
- Select **Correlation Modeling** and set variography and correlation models for a range of threshold values.
- Setup an appropriate search neighborhood and specify the power parameters after selecting **Search Neighborhood**.
- Press **Show The Results** to see the map.





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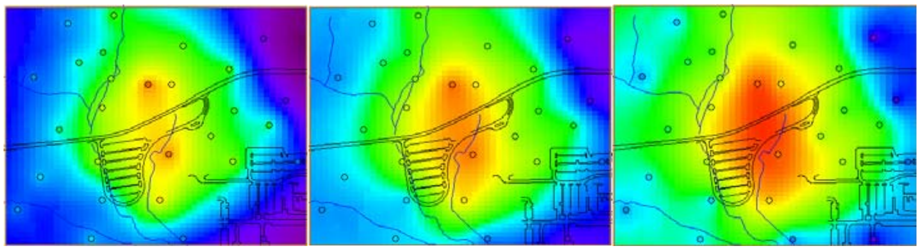
Plotting Percentile Maps

- Allows one to be conservative (e.g. percentiles > .5)
- Allows one to spatially ascertain the difference between an “optimistic, realistic, and pessimistic” (e.g. 25^{th}, 50^{th}, and 75^{th}) maps.
- Helps identify regions that could benefit from further sampling.



“optimistic” P=.25 | “realistic” P=.5 | “pessimistic” P=.75

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Geospatial References

- Applied Geostatistics, Isaaks and Srivastava
- Geostatistical Software Library (GSLIB), Deutsch and Journel
- Geostatistics for Natural Resources Evaluation, Pierre Goovaerts
- Geostatistics in Five Easy Lessons, Journel
- Spatial Data, Cressie

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Spatial Analysis and Decision Assistance (SADA) Version 4 Decision Analysis

(Short Version)

EPA Cluin SADA Web Training Series

Robert N. Stewart
University of Tennessee, Knoxville

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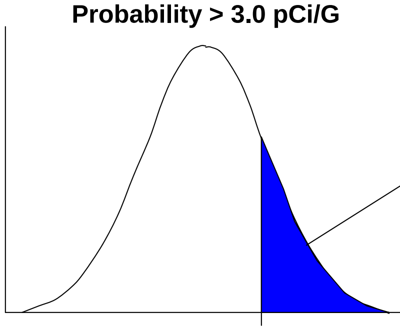
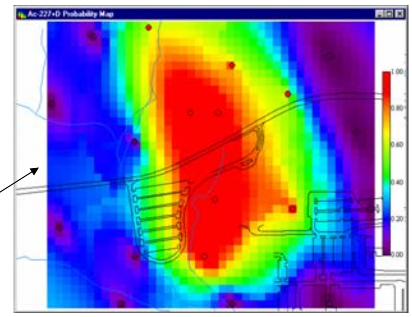
Probability Maps

- A probability map spatially delineates the probability of exceeding a specified threshold.
- The probability of the center of each block exceeding the threshold value is calculated.
- Probability maps can only be created with ordinary or indicator kriging.

Probability > 3.0 pCi/G



Probability > 3.0 pCi/G



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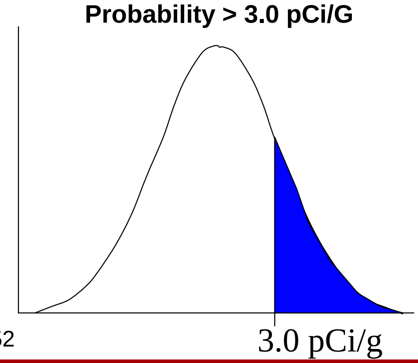
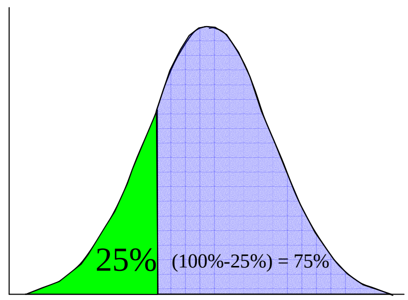
Percentile Maps vs Probablity Maps

- In a percentile, we fix the probability and determine what concentration is associated with that probability in each block. So you get a map of concentrations.
- In a probability map, we fix the concentration and calculate the probability associated with that concentration.

Probability > 3.0 pCi/G





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Area of Concern Maps

- Draws the area of concern based on the modeled values, a threshold value, and a decision framework.
- Can be drawn with any of the five available interpolants.
- Threshold values can come from user-defined concentrations, human health risk, ecological risk, or custom analysis.
- Three decision frameworks are available
  - *Block Scale* (Nearest Neighbor, Natural Neighbor, Inverse Distance)
    The decision criteria is applied to individual blocks.
  - *Confidence Based Block Scale* (Ordinary and Indicator Kriging)
    The decision criteria, which now includes a remedial confidence parameter, is applied to individual blocks.
  - *Site Scale* (All Five Interpolants)
    The decision criteria is applied to the site. Individual blocks are "remediated" until the site-wide model average satisfies the specified threshold.
- Density and Post Remediation Parameters

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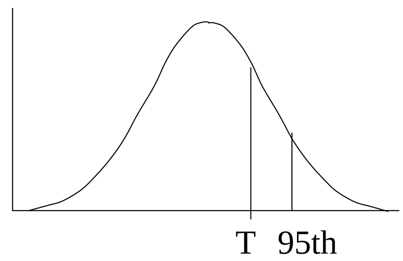
Decision Scales

- Block Scale (Average Map)
  - If the estimated block value is above the threshold value, it must be remediated. For ordinary and indicator kriging, set the confidence parameter equal to .5.

- Block Scale (Percentile Maps)
  - Given a threshold value, if the specified percentile (e.g. 90^{th}) is greater than the threshold value, then remediation is required. Otherwise, there is at least for example a 90% chance the true value falls below the threshold.
- Site Scale
  - If the site-wide model average is above the threshold value, “remediate” the individual blocks from worst to least contaminated until the average, including post remedial concentrations, drops below the threshold value.



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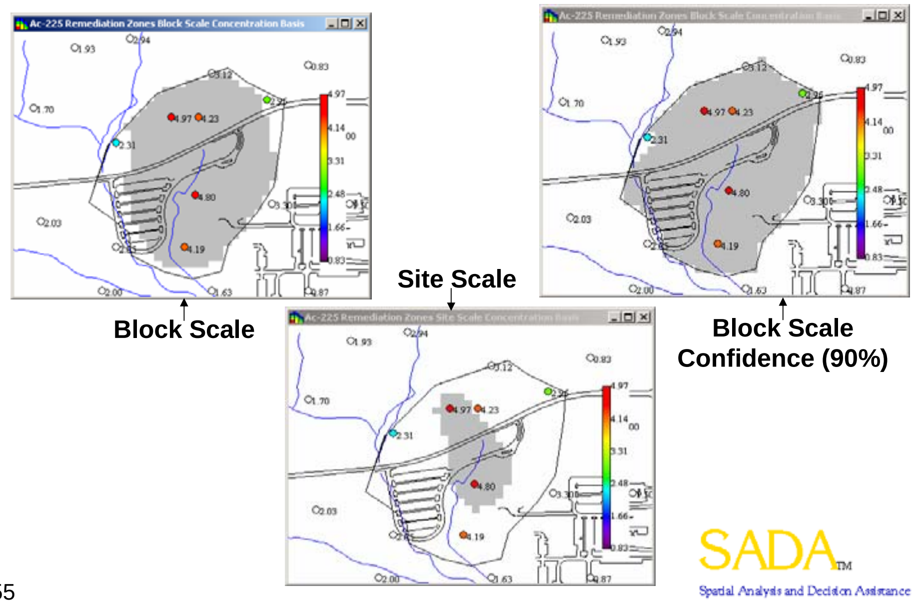
Decision Framework Results



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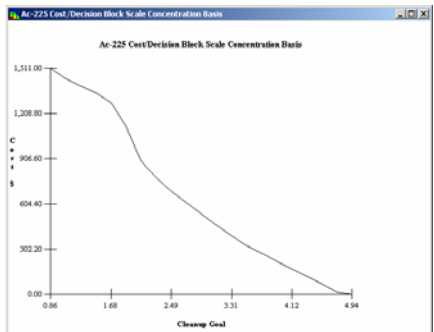
Cost Benefit Analysis

- The decision framework (block, block confidence, site) determines the associated cost for a range of cleanup goals.
- Cost is calculated by determining the area of concern (or volume for 3d) for a threshold value, then multiplying the number of blocks in this area by the remedial cost per block.
- After the threshold value range is calculated, cost is calculated for each incremental value in this range.



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Additional SADA Training

"Environmental Assessment Methods Using SADA:"
April 25-27, 2007 in Knoxville, TN (USA)

Includes a more extended discussion, and hands-on training with SADA.

For information and registration:

http://www.tiem.utk.edu/~sada/training_Knoxville_Apr07.html

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Thank You

After viewing the links to additional resources, please complete our online feedback form.

Thank You

Links to Additional Resources

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