When do the Benefits of using Geostatistics for Coal Resource Estimation outweigh the Costs ?

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Statistical Truisms

- Garbage In / Garbage Out
- There is no such thing as a free lunch
- Statistical analysis of data, rarely if ever, discovers anything that an experienced data collector and analyst is not already aware
- Statistical analysis of data, can provide the analyst with numbers to substantiate their case

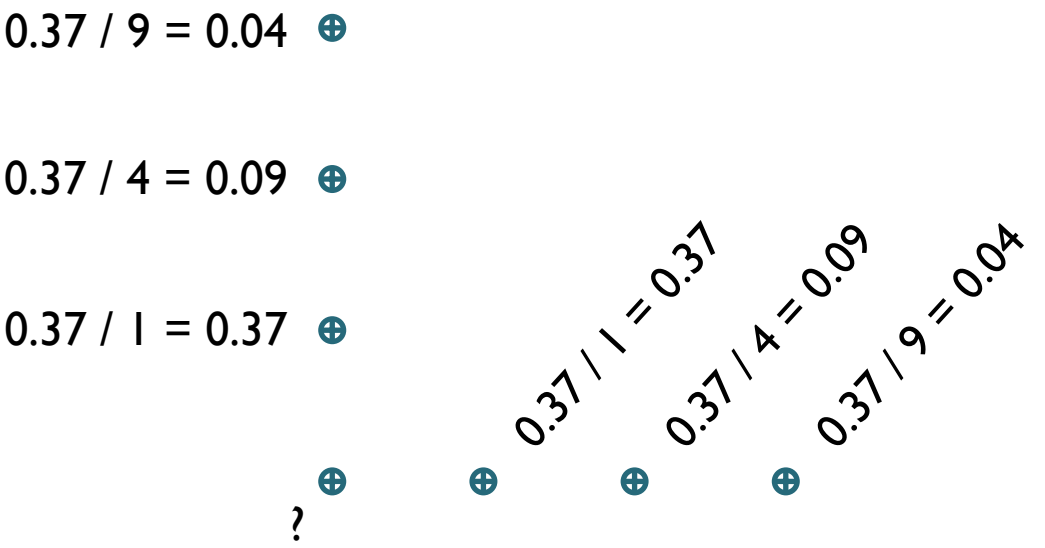
Potential uses of Geostatistics in Coal Resource Estimation

There are four areas that analyst consider using Geostatistics in Coal Resource Estimation:

- Estimation of coal and overburden volumes and coal quality parameters (kriging)
- Confidence limits on the above estimations
- Determining where to site additional drill holes
- Determining the minimum drill hole spacing for classification of resources as measured, indicated or inferred

Estimation of coal volumes, quality and overburden

Traditionally, these are estimated using "inverse distance squared" weightings such as:



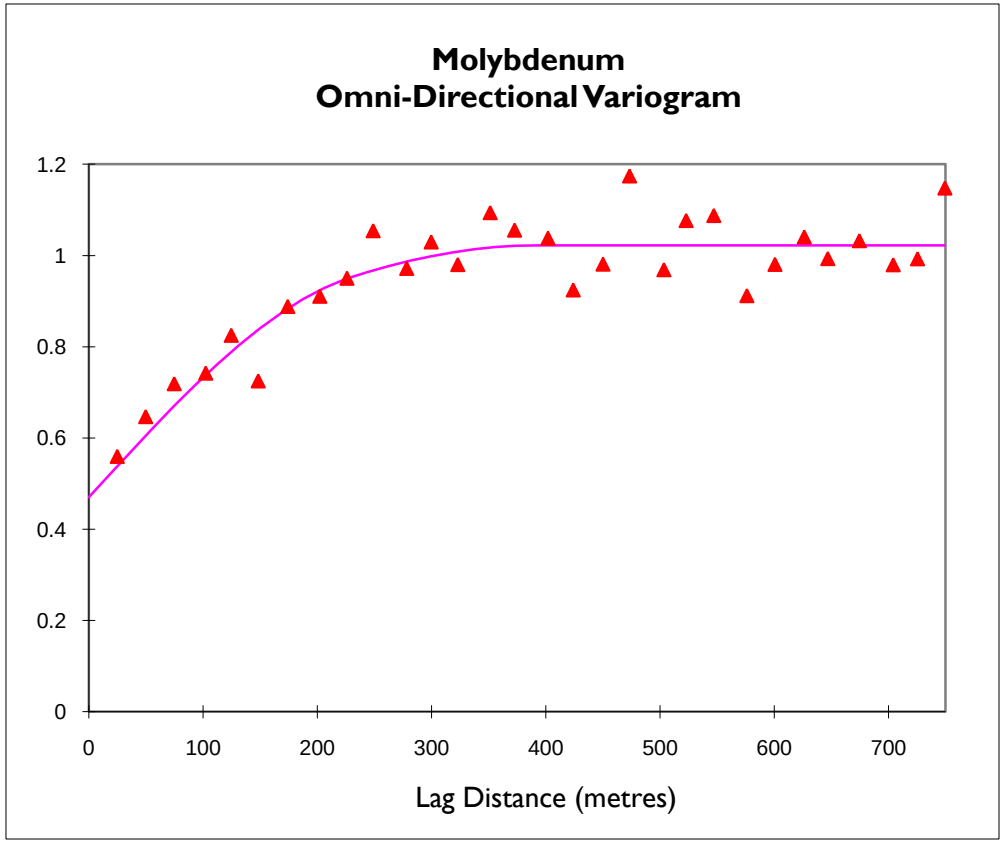
0.04 + 0.09 + 0.37 + 0.04 + 0.09 + 0.37 = 1

The main disadvantage of inverse distance squared is that it assumes a uniform spatial variability for:

- low, medium and high values
- all variables
- all directions
- all seams
- all areas
- all deposits

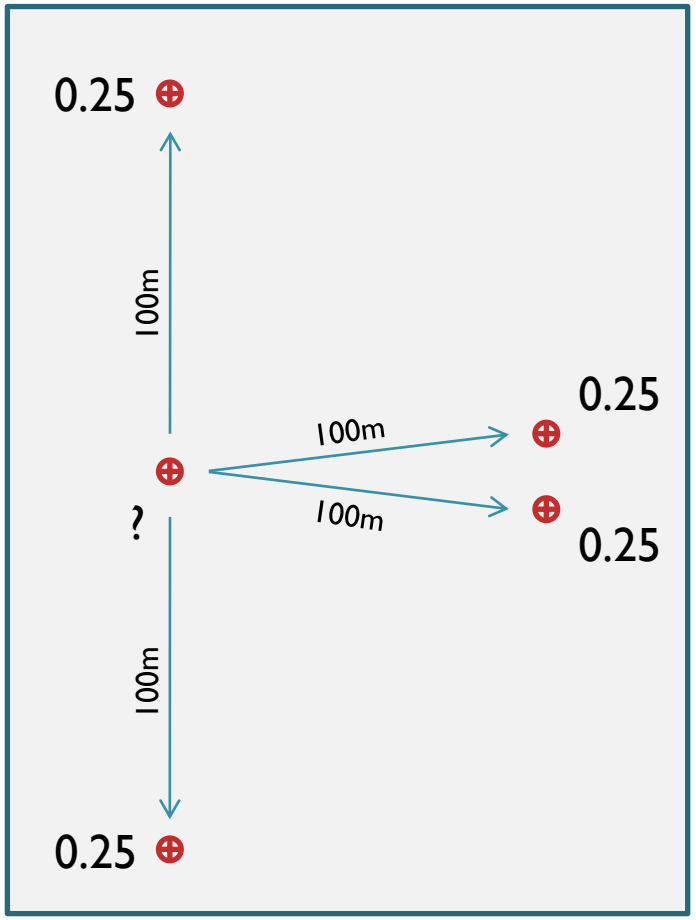
The "all directions" can, however, be overcome by performing a transform on the data coordinates but it still leaves the other issues.

Geostatistical estimation, instead uses a variogram to describe the spatial variability:

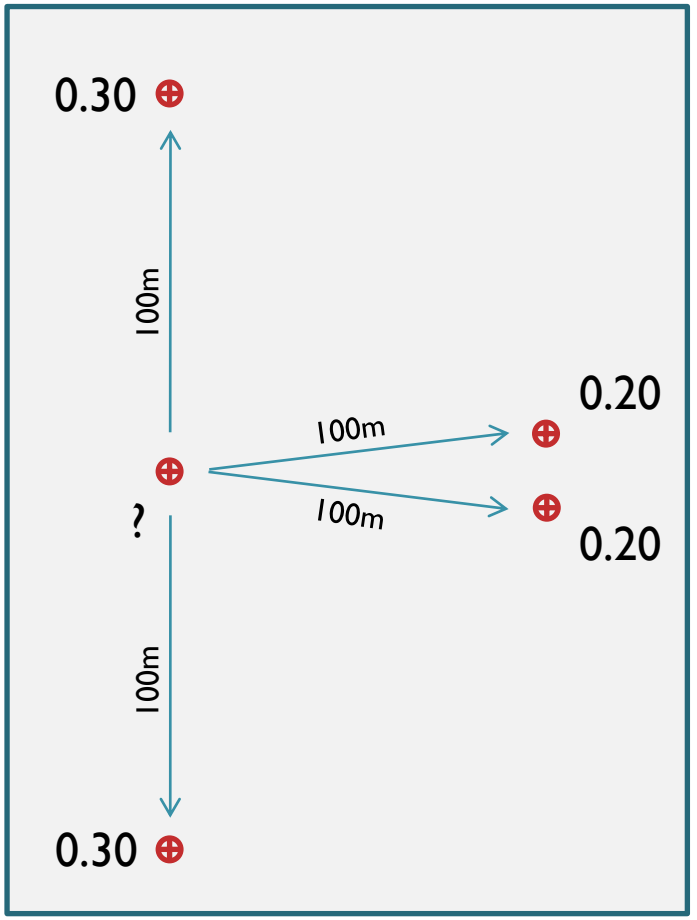


Geostatistical estimation provides more effective declustering as shown in the weightings below.

Inverse Distance^2



Kriging

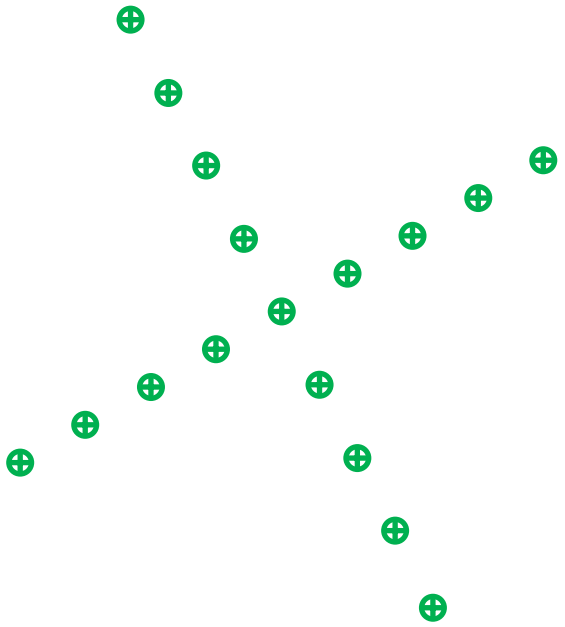


Benefits

- Ability to have different degrees of spatial inference for different deposits, areas of a deposit or seams
- Ability to have different degrees of spatial inference for different variables
- Ability to have different degrees of spatial inference for low, medium and high values
- Ability to have different degrees of spatial inference for different directions (??)
- More effective declustering of clustered data

Costs

- Time and skill to determine the different spatial variabilities for different deposits, areas, seams, variables and value ranges
- Additional closely spaced data in a typical area of each deposit to determine short range spatial variability, preferably in a "geostatistical cross" running parallel and perpendicular to strike



If a 500m spacing being used for measured, probably require the cross to have at most a 125m spacing between drill holes

WARNING !!!

Geostatistical estimation (kriging) has considerably more "knobs and dials" for controlling the estimate than traditional inverse distance squared approaches.

If the analyst understands what they are doing they can produce a more accurate estimate but if they don't they can turn the "knobs and dials" the wrong way and produce a considerably less accurate estimate than using the traditional approach.

Estimate of Potential Ranges of "Actual" Values

Quantitative answers to problems such as:

- Confidence limits on estimations
- Determining where to site additional drill holes
- Determining the minimum drill hole spacing for classification of resources as measured, indicated or inferred

require estimates of what the potential range of "actual" values are at various locations.

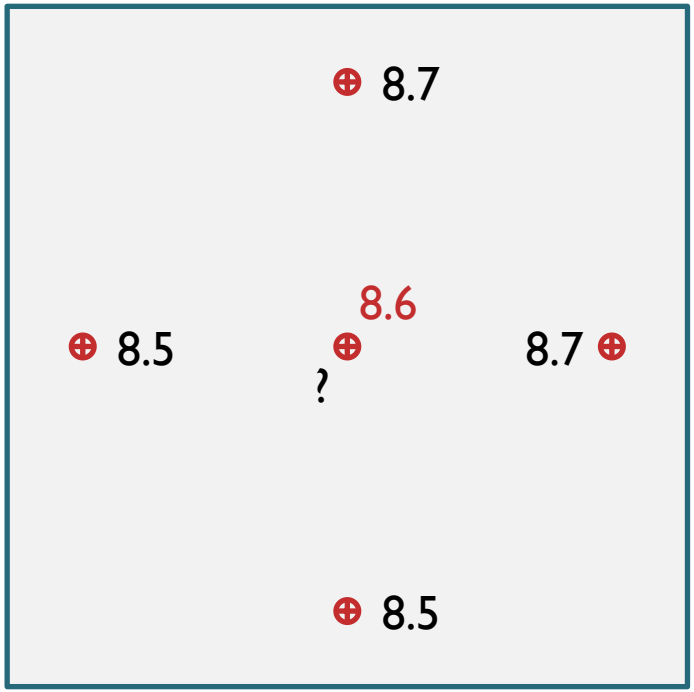
This can not be done quantitatively with traditional estimation methods, therefore geostatistics is required for quantitative answer to these questions.

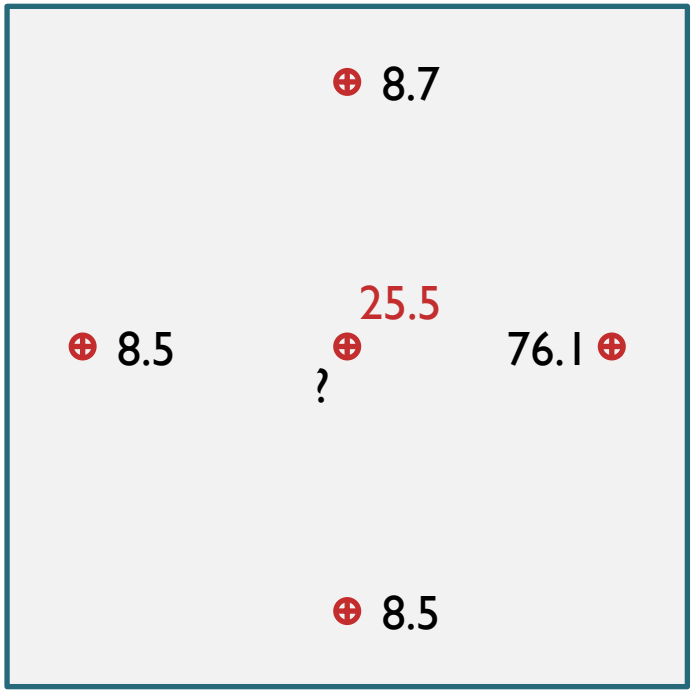
Geostatistics offers two different methods for determining estimates of the potential range of "actual" values at various locations.

- Estimation variance
- Conditional simulation

Estimation variance was the initial method developed by geostatisticians for determining these ranges. It is simpler but has a number of limitations compared to conditional simulation.

The chief limitation is that "Estimation Variance" at a point is a function of the location of the data values and the variogram not of the actual data values. So what ???





These two estimated points would have the same Estimation Variance !!!

The second limitation is that a normal distribution is generaaly used to turn the estimation variance into a range of potential "actual values".

To overcome these issues conditional simulation was developed by geostatisticians. This not only uses the variogram and location of data values but also incorporates the values at data locations.

Why is it called conditional ?

Because it is constrained by the data point values, that is all realizations honour the data.

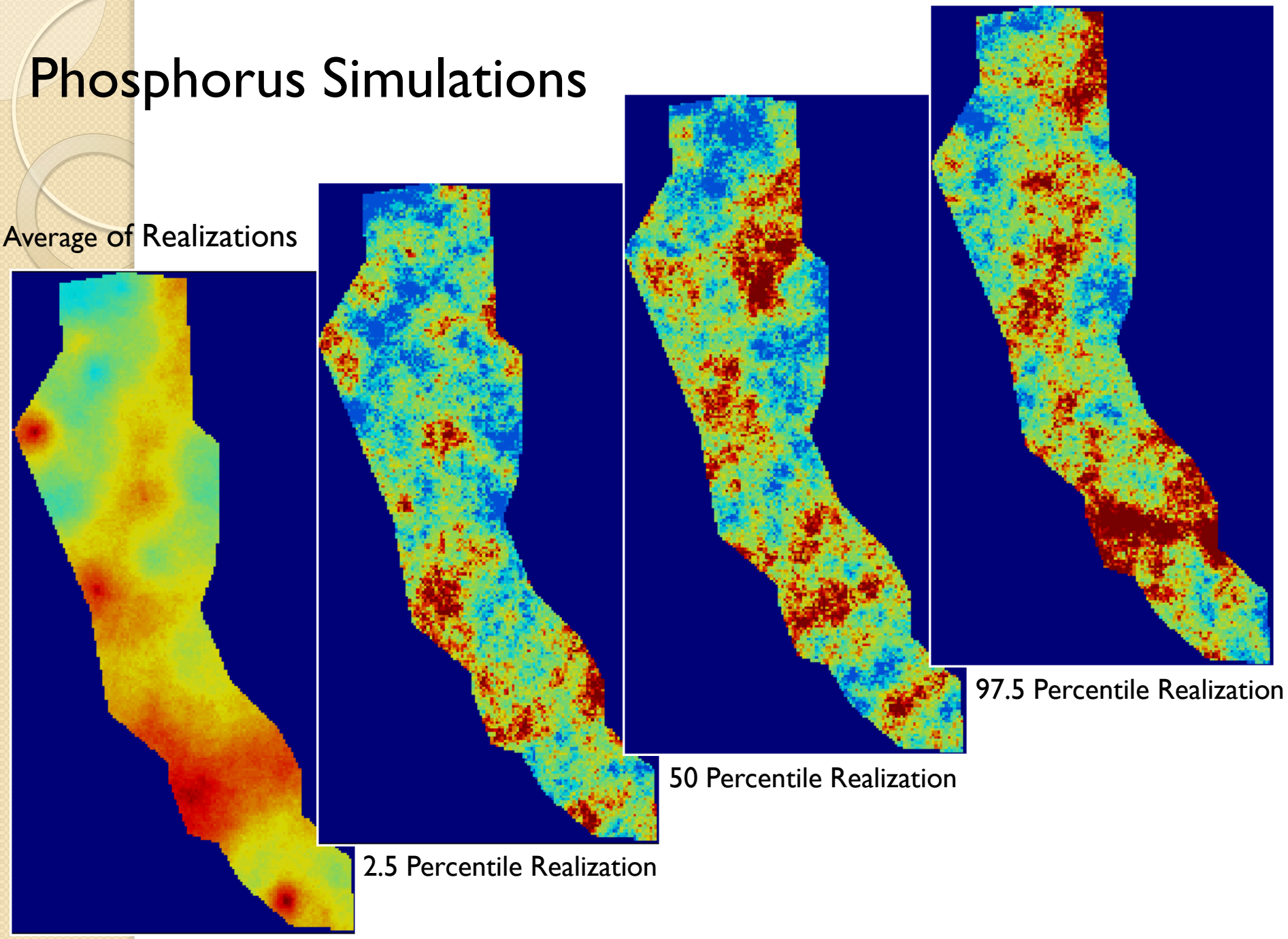
What do we mean by realization ?

When analysts estimate block values they accept that this is a smoothing process which gives them an average possible value for each block rather than an actual value.

Further, if you calculate the variogram of estimated block values it will not at all resemble the original variogram.

Conditional simulation uses a random number generator to produce equally likely sets of actual block values. Each of these are called a “realization” and each realization will honour the data values and the variogram.

Phosphorus Simulations



With enough realizations the average of the realizations should be equivalent to the kriged estimates.

Let us look at the questions we wanted the simulations to answer.

Confidence Intervals for Estimates

The average of the block values for the 2.5th and 97.5th percentile realization will give us a range for the deposit's average sulphur value with a 95 percent confidence.

Benefits

- It emphasises that the model is just that and not reality
- Mine planning and contractual arrangements can be made on worst and best case scenarios
- More drilling can be planned if it is felt that the range of potential values is too large
- It provides an explanation when the material is mined and values are considerably away from the model estimate

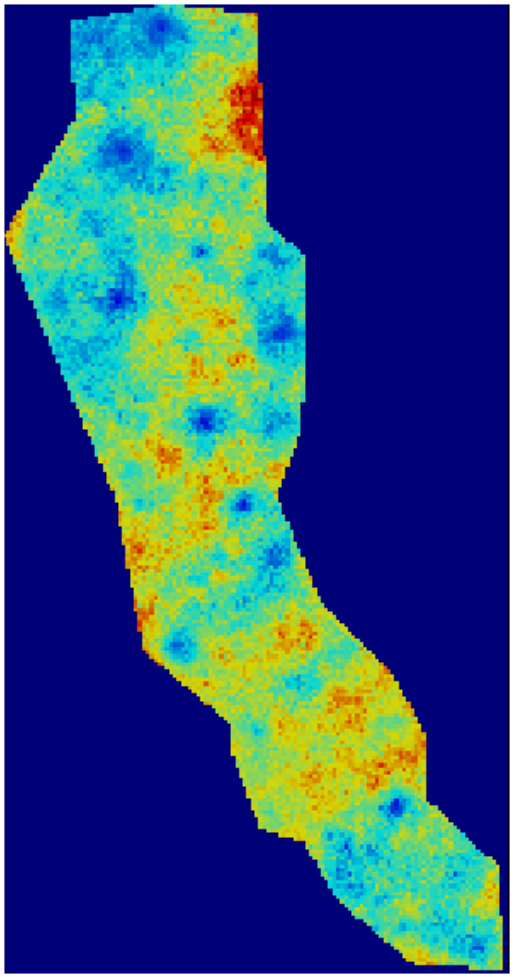
Costs

- All the costs mentioned in using geostatistics for estimation apply
- Realizations will only be realistic if the variograms clearly reflect the deposit, therefore it may be necessary to augment the drilling to obtain reliable variograms
- It requires even more skill to implement conditional simulations and ensure they are realistic than using geostatistics purely for estimation

Determining where to Site Additional Drill Holes

For each block in the simulation, we can calculate the variance of the values across all the realizations and then map the result.

The high zones on this map will be where further drilling is best sited.



Costs and Benefits

This is using a sledgehammer to crack a nut !

Any geologist who knows his trade and the deposit would come up with a very similar conclusion with much less effort.

Determining the Minimum Drill Hole Spacing for Classification of Resources

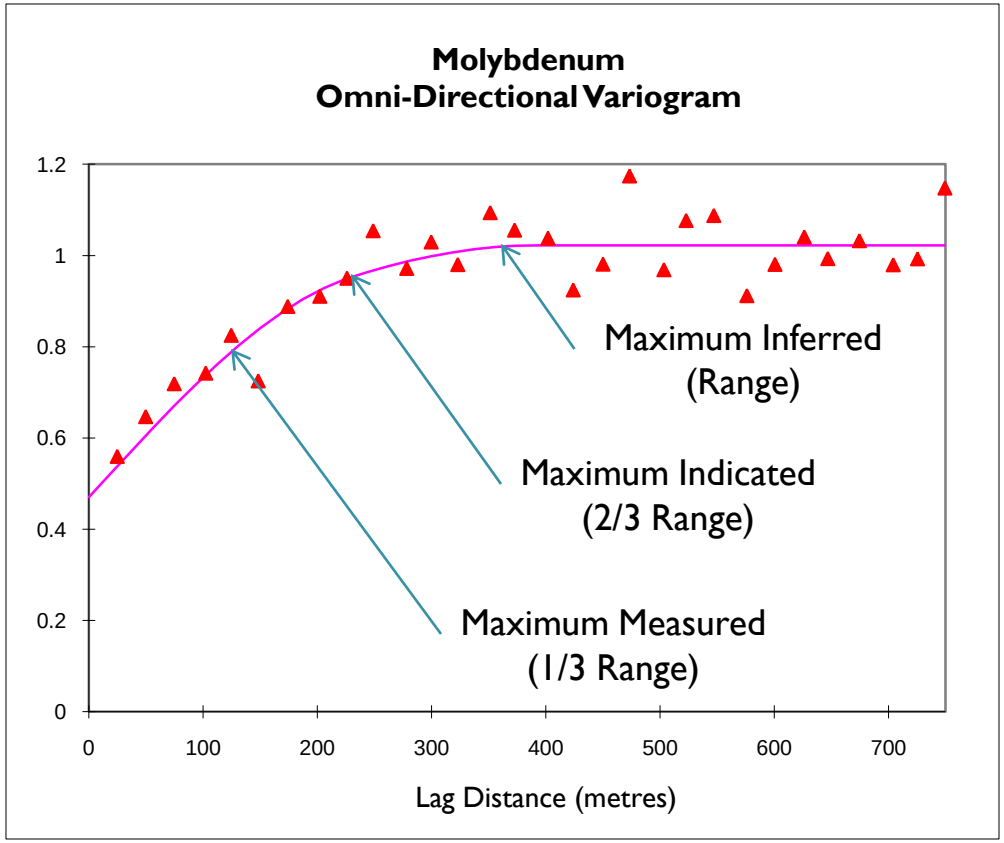
Geostatistics can be in two ways to classify resources as measured, indicated or inferred:

1) Reading the appropriate distances from the variograms

2) "Drilling" the realizations at different drill hole spacings and determining what the maximum "error" would be for each drill hole spacing and then using a maximum acceptable error for each category

However, for both methods there is no clear guideline on what values should be used as cutoffs between categories.

Reading Maximum Resource Category Distances from Variograms



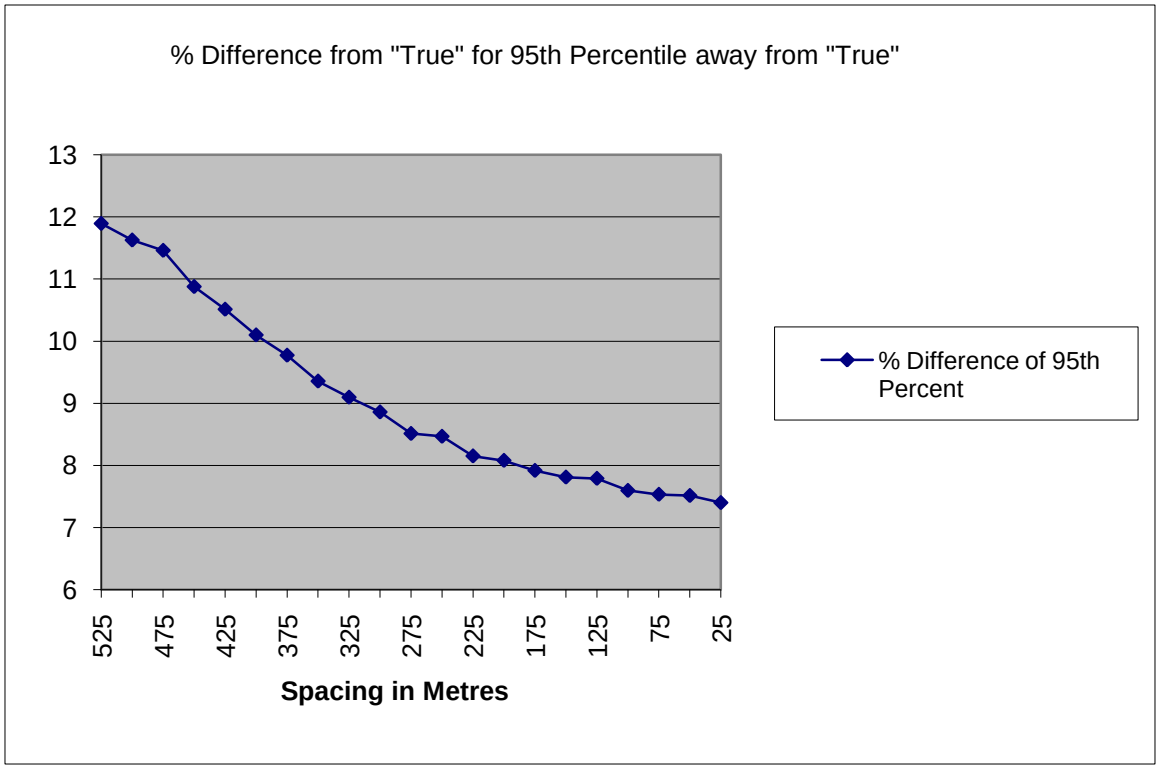
Benefits

This is a considerable improvement on blindly using 250m, 500m and 1000m for all variables, for all seams, for all areas across all deposits.

Costs

- There are no additional costs if you are already using geostatistics for estimation purposes.
- No specific percentages of the range have been agreed on as the appropriate cutoffs between categories.
- It is not clear how to apply this method where different variograms are used for low, medium and high values

“Drilling” the Realizations at Different Drill Hole Spacings



Maximum error obtained from “drilling” the realizations from the previously described phosphorus study

Benefits

- Possibility of decreasing drilling costs by using a wider drilling spacing
- Determine if necessary to increase drilling spacing
- Determine if increasing drilling spacing is going to provide substantial additional information

Costs

- As well as the costs in performing simulations additional manipulation of the results is required
- No specific percentage differences have been agreed on as the appropriate cutoffs between categories.

Conclusion

Geostatistics provides many benefits when calculating resource estimates. Each of these benefits comes at a cost.

For a typical coal resource calculation of just tonnages of coal and cubic metres of overburden the costs of using geostatistics probably outweigh any benefits.

The value of using geostatistics really only comes about where you are dealing with more complex variables such as contaminants and where one requires confidence intervals on one's results.