COMPARISON OF MEDIAN AND FULL INDICATOR KRIGING IN THE ANALYSIS OF A GOLD MINERALISATION

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Abstract

This paper presents a comparison of median indicator kriging and full indicator kriging in the analysis of gold mineralisation data from the Goodall gold mine in the Northern Territory of Australia. The sample data used in this study consist of exploration drilling data, suitably composited, taken from the 540mRL bench of the main open cut. The data set is sparse, irregularly spaced and has a highly skewed distribution. An enlarged data set, used for the variography, was obtained by including exploration data from 20m above and 20m below the bench. In addition, the blast hole data from the chosen bench were considered as a model of reality. Careful choice of the common semivariogram model for median indicator kriging was necessary. Grade tonnage curves from median indicator kriging and full indicator kriging were compared with one another and with the grade tonnage curve of the blast hole data. There was little difference in the grade tonnage curves for the two indicator kriging methods. In both cases the grade tonnage curves fell below that obtained from the blast hole data.

Key Words*: indicator kriging, median indicator kriging, gold mineralisation, grade tonnage curve.*

Introduction

In this study we compare median indicator kriging (mIK) and full indicator kriging (fIK) in the analysis of gold mineralisation data. mIK is sometimes chosen in preference to fIK merely because it is less time consuming since the same semivariogram model is used at all cut offs, even when the assumptions for mIK are only approximately satisfied . The question then arises as to how much, if any, detail is lost by this choice, particularly in the case of sparse, irregularly spaced and highly skewed data. The data used in this comparison come from the Goodall gold mine which is located in the Northern Territory of Australia, approximately 150km from

Darwin. It falls within the Pine Creek 1:250 000 map sheet, at 8 525 000 mN: 750 000 mE. The mine produced 4.095 million tonnes of ore at a head grade of 1.99 g/t Au during openpit operations. Mining was completed in 1992 (Quick, 1994).

For the Goodall mine both the exploration drilling data and the mining-stage blast hole data are available. Assuming the close-spaced blast holes approximate "reality", predicted grade tonnages can be compared with "actual" grade tonnages to assess the performance of the two indicator kriging methods.

Data sets

The data used in this study are from the A-pod orebody of the main open pit. The first set comprises gold analyses from 21 inclined diamond and reverse circulation (RC) holes drilled during the exploration stage (see Figure 1).

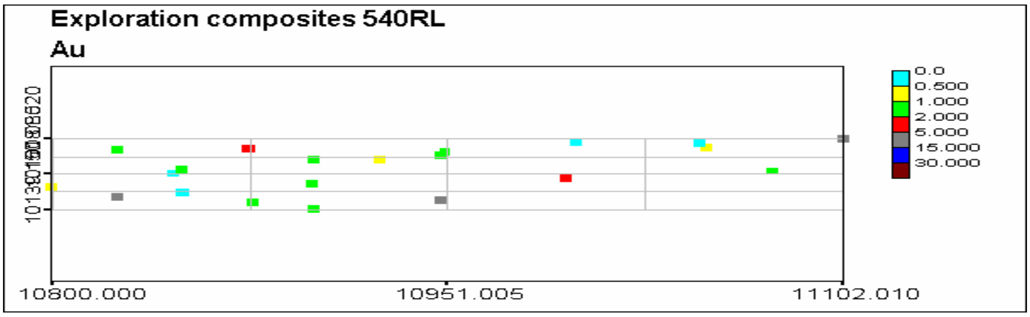


*Figure **1**: Exploration data composites from within the bench.*

The summary showed no substantial difference between the samples obtained from these two drilling types. We will refer to this data set as the exploration data set. The second set consists of gold analyses from 2.5m long blast holes drilled into the 540m RL bench. Both data sets were composited in such a way that samples represent 2.5 m vertical thickness at the same RL (Kentwell, 1997). The composited data were divided into mineralised and non-mineralised populations with a cut off of 0.5 g/t Au used to define the orebody. The part of the A-pod orebody analysed is located between mine co-ordinates 10 800 – 11 100N and 10 130 – 10 210E (see Figure 4 in Quick(1994)). Because of the small size of the exploration data set, an enlarged subset, referred to as the variography data set, containing additional drilling samples from up to 20m above and 20m below the 540m RL bench was used for variography. The total size of this set is 638 samples (see Figure 2).

The location of the data set for IK in relation to the variography data set is shown in Figure 3.

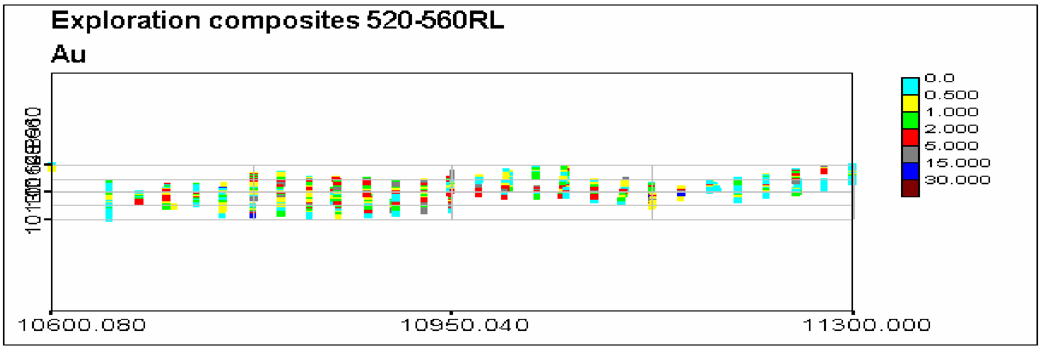


Figure2. Exploration data composites from up to 20m above and 20m below the bench.

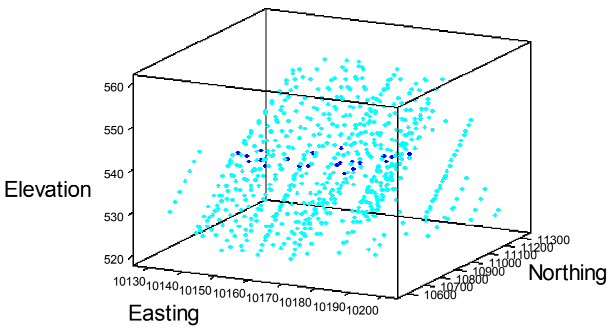


Figure 2. Exploration data composites – data from the bench of interest shown in dark.

Blast holes were drilled on a four metre by two metre grid. The size of the data set was reduced to represent 720 points on a four metre by four metre grid. The spatial distribution of grades is shown in Figure 4. Since only a single bench was used, this set was treated as two-dimensional (Kentwell, Bloom & Comber, 1997).

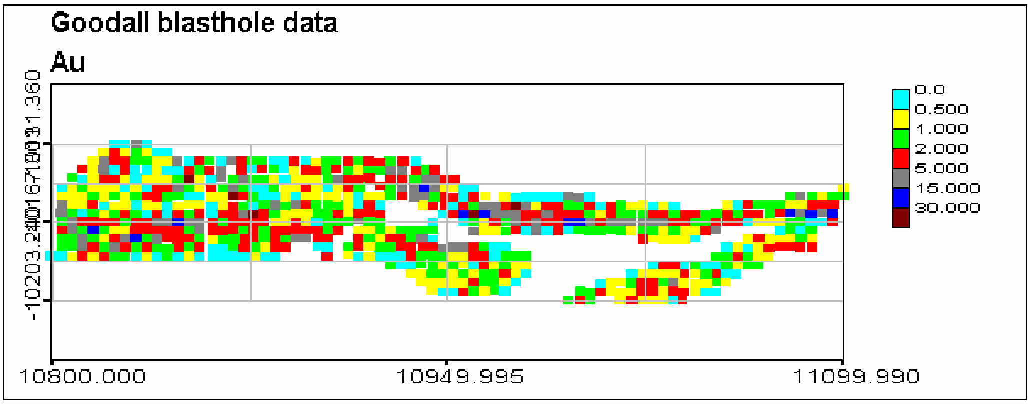


Figure 4. Blast hole data from within the bench.

Summary statistics for the three data sets (see Table 1) exhibit the highly skewed nature of the distribution. There appears to be some difference between the distribution of the blast hole data and the variography data, which is not unexpected considering the different spatial extent and sample density of the two data sets.

Table 1: Summary statistics for the grades (g/t) of the exploration, variography and blast hole data.

Data set	N	mean	median	standard deviation	minimum	maximum	skewness
Blast hole	720	2.766	1.425	4.620	0.010	49.300	4.800
Exploration	21	2.274	1.250	2.920	0.050	12.680	2.566
Variography	638	1.736	0.885	2.526	0.000	25.880	4.003

Variography

For the purposes of modelling the spatial structure and estimation all data will be treated as point data. Since the exploration data set is from a single bench the vertical bandwidth for calculating the experimental indicator semivariograms from the variography set was set to one. The parameters used in the calculation of each semivariogram are given in Table 2.

Table 2: Experimental semivariogram parameters

Lag spacing	10m
Lag tolerance	5m
Number of lags	10

Vertical bandwidth	1m
Angular tolerance	30°

The semivariogram value for a lag was discarded if the number of pairs contributing to the semivariogram was less than 15 for that lag. Due to the long narrow shape of the mineralised zone, the experimental semivariograms in the East-West direction were only reliable for the first two to three lags. More emphasis was therefore placed on fitting a model for the North-South direction. Most semivariograms had a similar overall sill for both directions, so it was decided to fit models with purely geometric anisotropy at all cut offs.

Indicator semivariograms were modelled for twelve cut offs, the deciles and the 95th, 97.5th and 99th percentiles. Semivariograms were standardised by dividing each semivariogram by the total sill, as suggested in Goovaerts (1997). Because of the sparseness of the exploration data set only five of these cut offs were used for indicator kriging (see Figure 5).

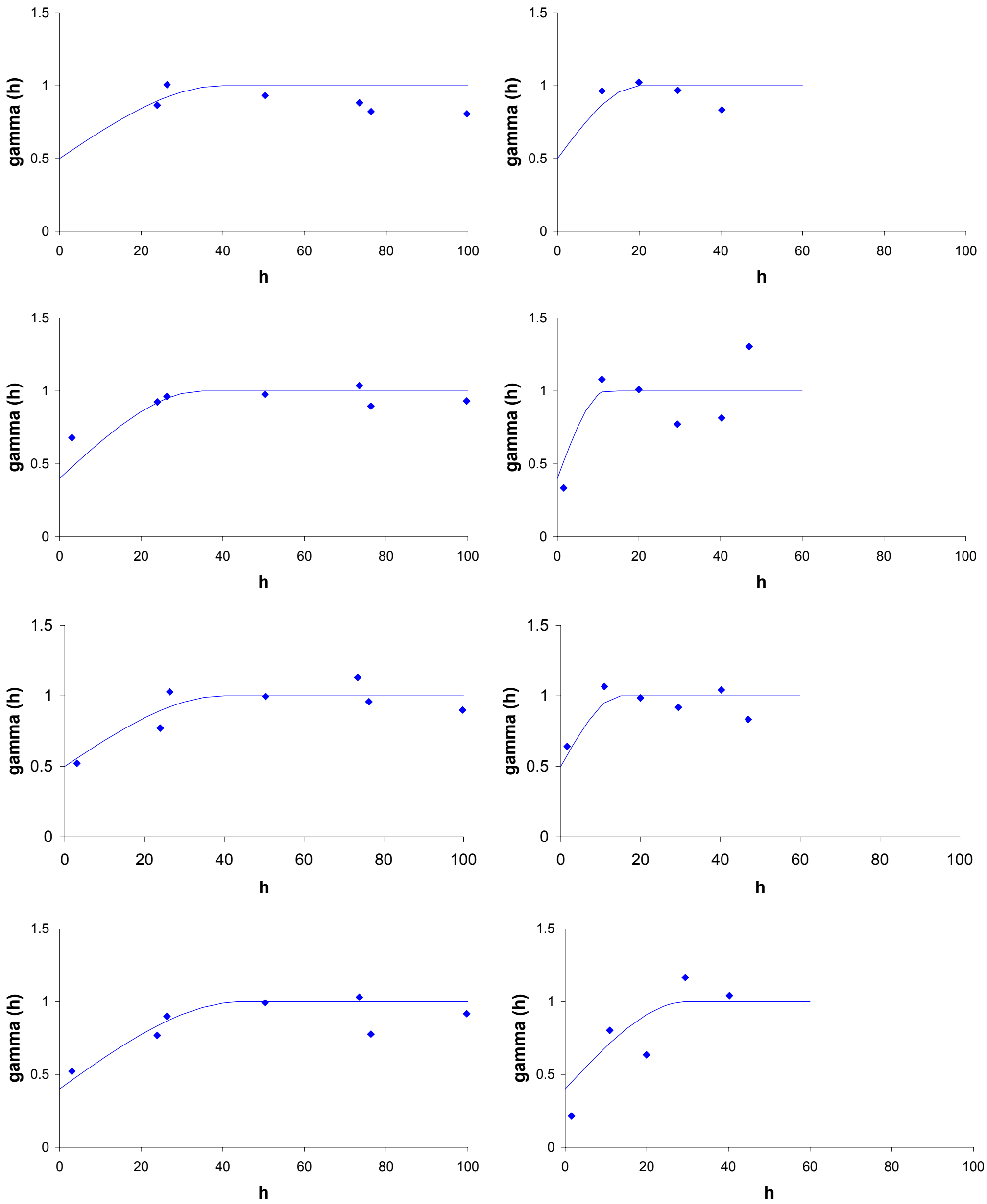
A single spherical structure plus nugget was fitted in each case. Table 3 shows the standardised semivariogram model parameters for the five cut offs used and the 50% cut off.

Table 3: Standardised semivariogram model parameters.

Cut offs		Semivariogram parameters – spherical model plus nugget			
Percentage	Grade	Nugget	Partial sill	Maximum range	Anisotropy factor
20	0.30	0.50	0.50	40	0.500
40	0.66	0.40	0.60	35	0.343
50	0.88	0.25	0.75	35	0.286
60	1.23	0.50	0.50	40	0.375
80	2.39	0.40	0.60	45	0.667
95	6.05	0.25	0.75	45	0.667

Indicator Kriging

The nugget to sill ratios for the semivariograms at the various cut offs are sufficiently similar to make the use of mIK an attractive option in this case. The initial estimation for mIK was performed with the 50% semivariogram. The range of the median semivariogram is only 35m in the direction of maximum continuity and 10m in the direction of minimum continuity, compared with 40m and 15m respectively for the 60% semivariogram. Because of the sparseness and irregular spacing of the exploration data set, for approximately 24% of all locations the distance between the closest sample datum and the point to be estimated was greater than the semivariogram range of the 50% semivariogram. At these locations all kriging weights were zero and the global cumulative distribution function was reproduced as the estimate. The slightly longer semivariogram range of the 60% semivariogram halved the number of locations at which this occurred. For this reason the 60% semivariogram was chosen as the common semivariogram model for mIK. Full indicator kriging of the exploration data set was performed for the cut offs at 20%, 40%, 60%, 80% and 95%. Non-estimation was less of a problem with fIK where ranges of the individual semivariograms varied from 35 m to 45 m (see Table 3).



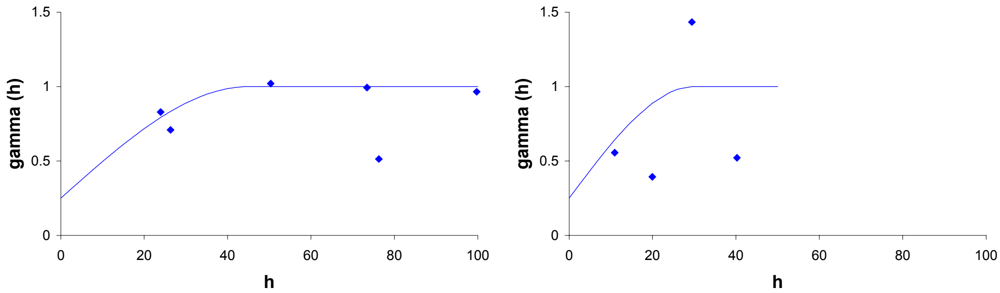


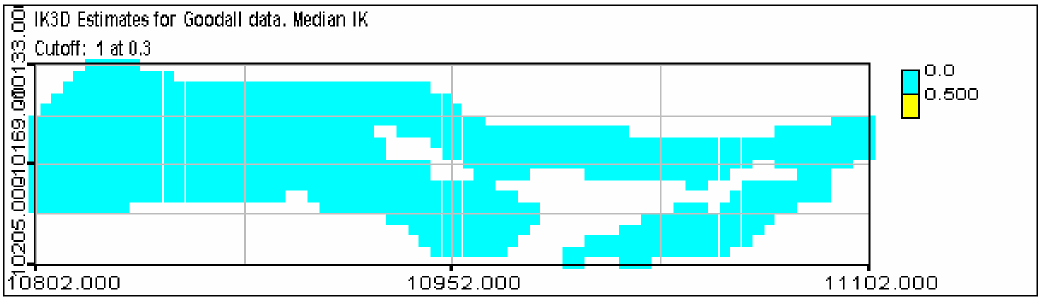
Figure 5: Experimental and model semivariograms (top to bottom) for 20%, 40%, 60%, 80% and 95% cut offs, in North-South (left) and East-West (right) directions for exploration data.

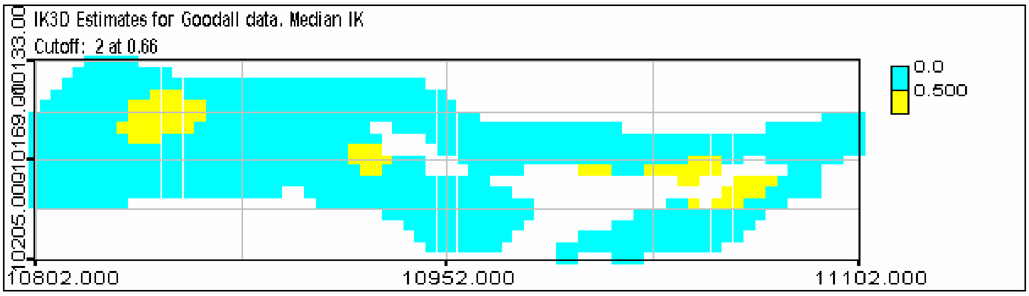
Order relation deviations

Very few order relation deviations were encountered. There were 0.87% with an average magnitude of 0.0113 for fIK and none for mIK. These were corrected by averaging the cdf derived from an upward correction and the cdf derived from a downward correction as described in the GSLIB User's Guide (Deutsch and Journel, 1992). It was noted that slight changes to the semivariogram model affected both the amount and average magnitude of order relation deviations. For example, removing the nugget from the model at the 95th percentile caused a rise in the number of deviations to 3.06% with an average magnitude of 0.0451.

Results

Figures 6 and 7 show probability maps produced by mIK and fIK respectively. The smoothing nature of kriging is apparent, with neither method producing any probability estimates greater than 0.5 for the 20% cut off. Also fIK produced only one small region with probabilities lower than 0.5 at the 95% cut off, while mIK did not produce any. Hence there appears to be little difference between mIK and fIK, particularly at the lower cut offs. At the two upper cut offs mIK underestimates high grades slightly more than fIK does. Overall the location of regions of high and low probabilities matches the blast hole data in Figure 8.


IK3D Estimates for Goodall data. Median IK
Cutoff: 1 at 0.3
0.0
0.500
10802.000
10952.000
11102.000
10205.000
10169.000
10133.000


IK3D Estimates for Goodall data. Median IK
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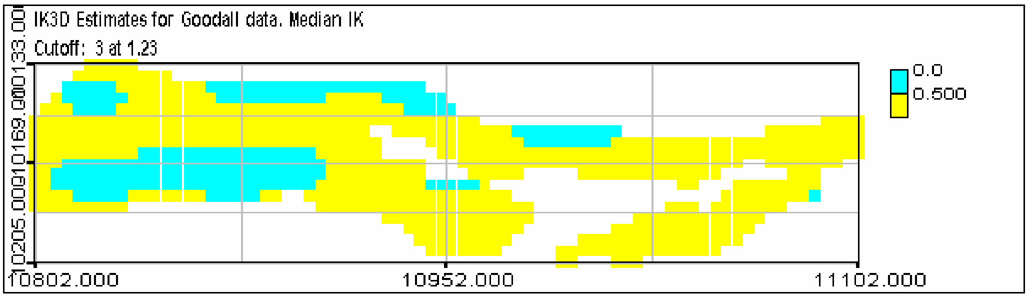
10952.000
11102.000
10205.000
10169.000
10133.000


IK3D Estimates for Goodall data. Median IK
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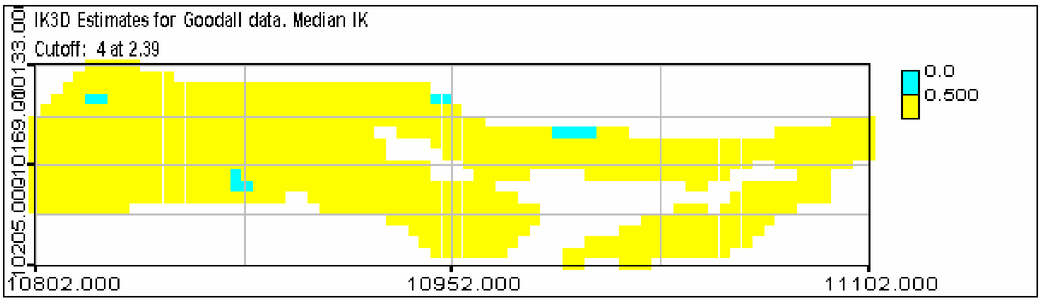
11102.000
10205.000
10169.000
10133.000


IK3D Estimates for Goodall data. Median IK
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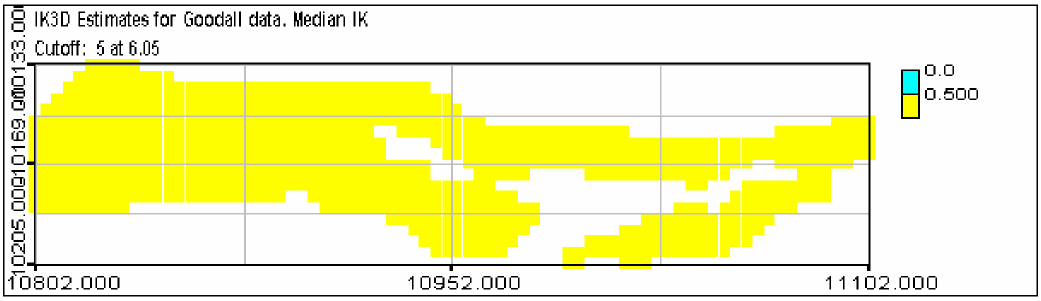
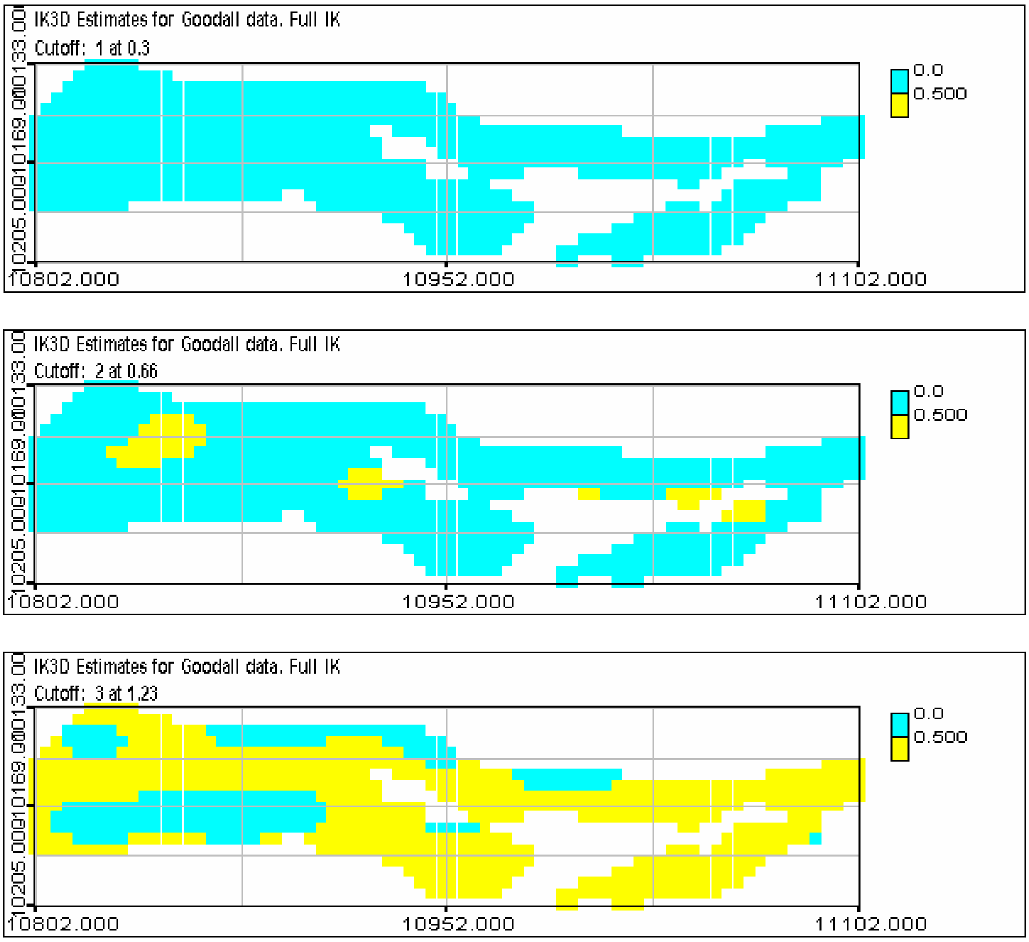


Figure 6: mIK estimates for 20%, 40%, 60%, 80% and 95% cut offs.



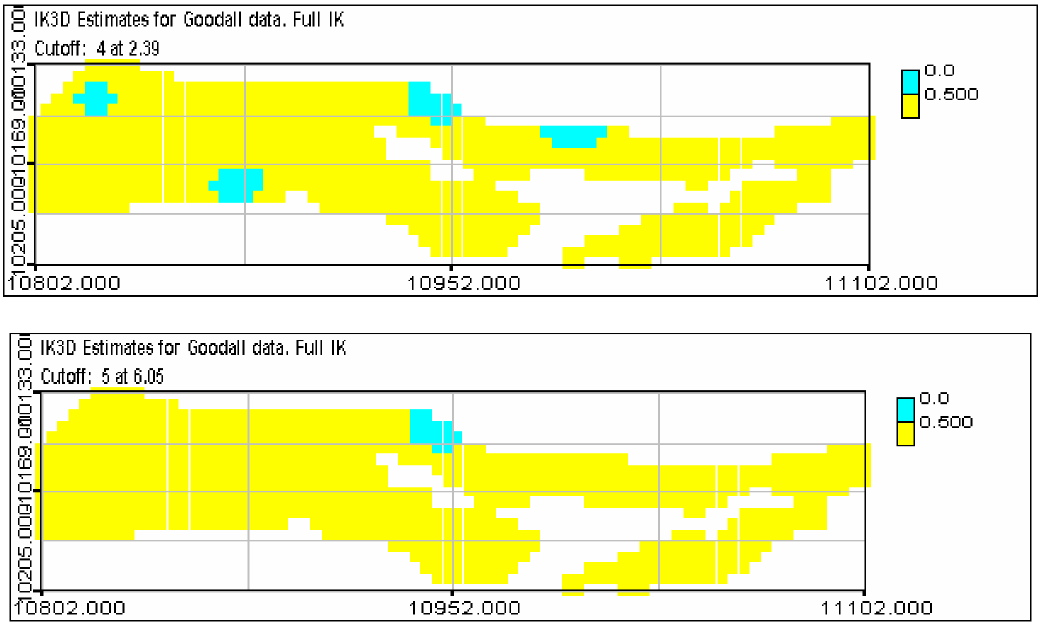
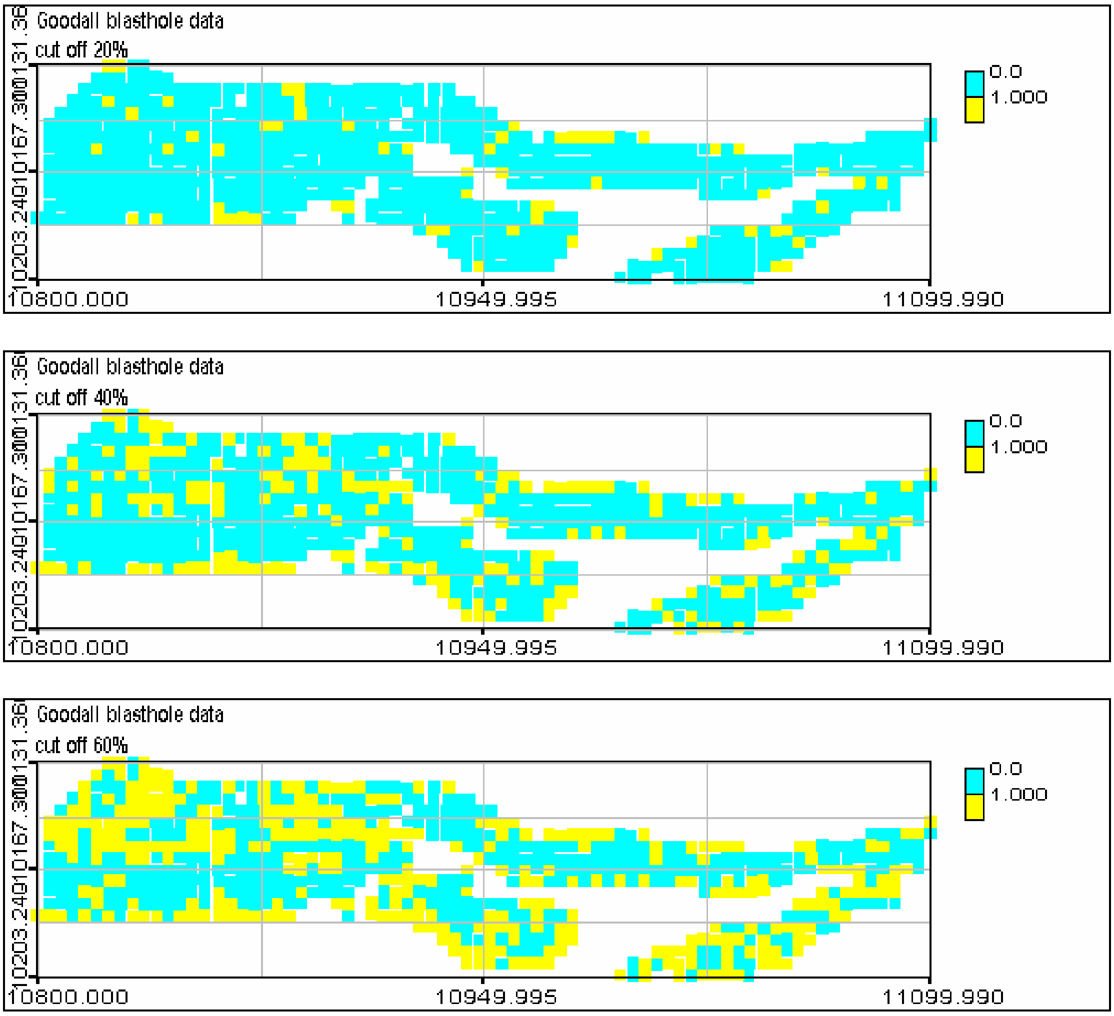


Figure 7: fIK estimates for 20%, 40%, 60%, 80% and 95% cut offs.



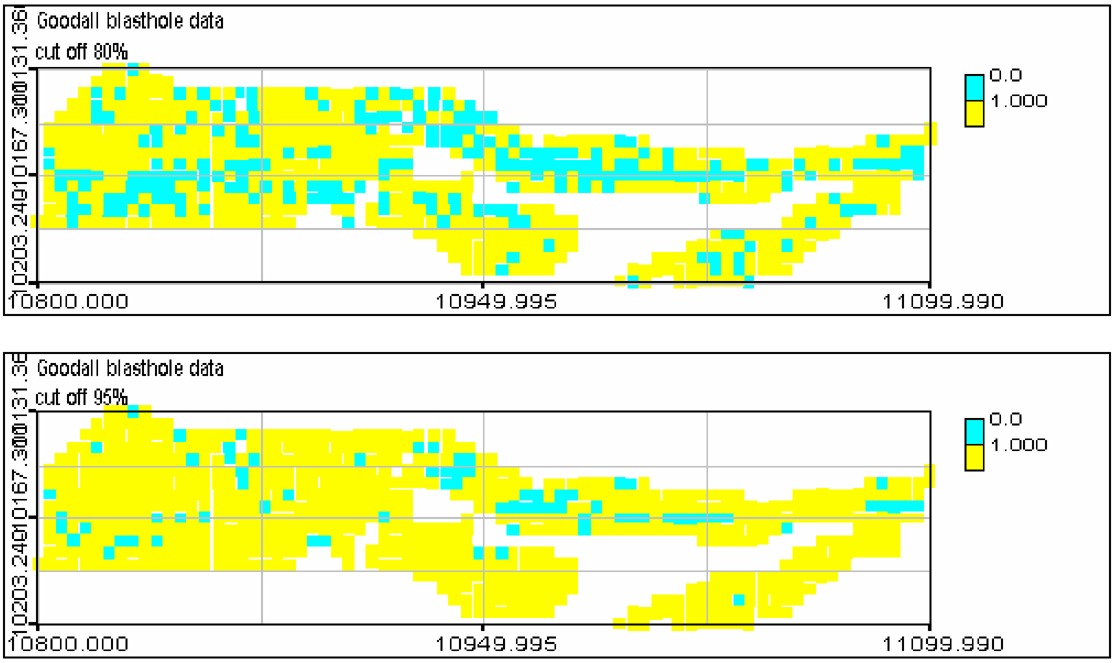


Figure 8: Blast hole data indicators for 20%, 40%, 60%, 80% and 95% cut offs.

Grade tonnage curves

All data were treated as point data in two dimensional space rather than block data. The grade tonnage curves were calculated on the assumption that each value of the blast hole data and each estimate is representative of a block of size 4m by 4m by 2.5m centred on the location of the datum. No block support correction was applied because point estimates were compared with point support grade control data. To calculate the average grade above each cut off it was necessary to extrapolate above the highest cut off. As the distribution is highly skewed and a maximum possible value is not known, a hyperbolic extrapolation was used as given in the GSLIB User's Guide (Deutsch and Journel, 1992). It is given by

$$\phi(z)_{Hyp.} = 1 - \frac{\lambda}{z^{\omega}} \qquad \forall z > z_K$$

where ω is a parameter greater than or equal to one, z_K is the grade of the maximum cut off and λ is a constant such that $\phi(z_K) = \phi^*(z_K)$, the sample cumulative frequency. Figure 9 shows the grade tonnage curves produced from the mIK and fIK estimates using parameters $\omega = 1.5$ and $\phi_{max} = 0.995$ together with the actual grade tonnage curve. .

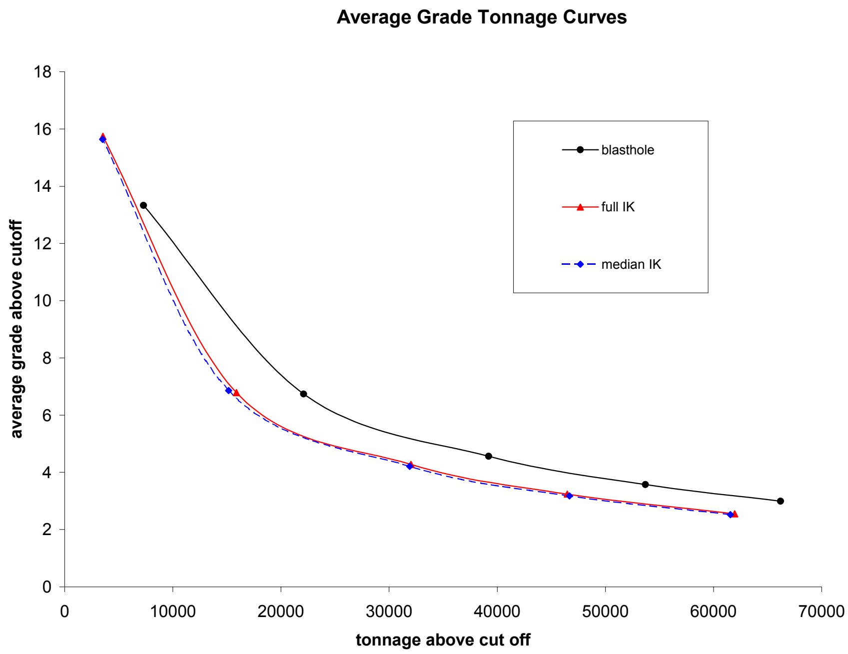


Figure 9: Average grade tonnage curves for mIK, fIK and blast hole data.

Both grade tonnage curves produce tonnage estimates which underestimate the actual value at the chosen cut off. For each cut off chosen the estimates derived from mIK and fIK are almost identical, with fIK producing slightly higher values. However, even though mIK and fIK underestimate the average grades at the lower cut offs, they overestimate the average grades at the two highest cut offs.

Conclusions

This study reinforces the theory that little is lost by using the more time-efficient mIK rather than the more involved fIK. This is true even here where we are dealing with a highly skewed, sparse data set. However, as indicated earlier, care must be taken in choosing the cut-off value for the common semivariogram to be used in the mIK approach. Even though only one semivariogram is needed it may be worthwhile to model the semivariogram at several cut offs close to the median in order to ensure a sufficiently large range is used in the kriging procedure. For large data sets this may not be important, but for sparse data sets such as the one we used, a judicious choice for the cut off can help to minimise the number of locations at which only the global cumulative distribution function is used.

Acknowledgements

The authors would like to thank WMC Resources for making available the raw data (exploration and blast hole) from the Goodall mine. Thanks go also to D. J. Kentwell (a former Edith Cowan University graduate student now at SRK Consulting) for allowing us to use his composited data for this study and for making available the code for the bounding polygon used to delimit this irregularly shaped region.

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