Support Effects When Optimising with Whittle Four-D, Wirralie Gold Deposit, Nth Queensland

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Introduction

Ore body models and the estimation of recoverable resources/reserves are a critical part of feasibility and pit optimisation studies. Several modeling techniques may be used to estimate grade distributions for each block of the ore body being modelled at a given level of mining selectivity (David, 1988). Support effects is a term describing the effect of mining selectivity and dilution on ore reserves and metal recovery. Indicator kriging (Journel, 1983) is a popular technique for ore body modelling and recoverable reserve estimation and is used in this study. The implementation of the technique may critically influence key indices in optimisation studies, including project NPV, ounces recovered, cost per ounce (Whittle, 1998). This influence is demonstrated with an optimisation study using Whittle Four-D at the Wirralie Gold Deposit, North Queensland.

The Wirralie gold deposit is 210km south-south-east of Townsville, and 40km north of Mount Coolon, in north Queensland, (Figure 1). Wirralie is a low sulphidation

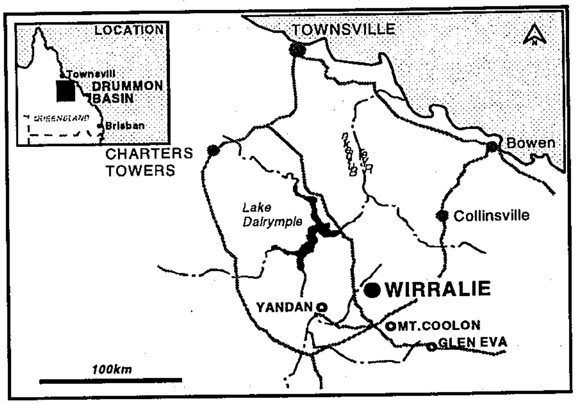


Figure 1: Location of the Wirralie Gold Deposit

quartz-adularia epithermal vein and replacement type deposit hosted by volcanic rocks and sediments of Late Devonian age. Australian Consolidated Minerals Pty Ltd (ACM) discovered the Wirralie deposit in 1986 as part of a regional stream sediment sampling program. ACM commenced development of the Wirralie mine in November 1987.

Production between March 1988 and July 1993 was 4.84 mt of ore at a grade of 2.45 g/t Au gold, above a cut-off grade of 1.00 g/t Au.

In the following sections, the geology of the Wirralie deposit and its geostatistical characteristics are outlined. The preferred implementation of indicator kriging (IK) with a support adjustment for the desired mining selectivity is presented, together with a simulation based support correction method. The optimisation study and related results are then given, based on the utilisation of the complete grade distribution for each estimated block of the ore body. Next, the results from the IK implementation are compared to three alternative IK block models. These three models are the: 'average' or estimated block grade from IK, 'uncorrected' or estimated average block grade from IK prior to support corrections, and 'small blocks' model or estimated average block grade from IK implemented on small size blocks. Discussion of the results concludes that IK with support corrections and full accounting of the block grade distributions generates substantially better results in the Wirralie pit optimisation study. The 'small blocks' model shows the adverse effects of over-smoothing on the project.

Geology

The Wirralie deposit is in the north-east portion of the Drummond Basin, a large north-north-west trending intracratonic basin which developed between the Late Devonian and Early Carboniferous. Host rocks comprise a hanging wall sequence of Bimurra Volcanics and a footwall sequence of Mount Wyatt Formation. Locally, Bimurra Volcanics consist of three distinct lithic and crystal-lithic rhyolitic tuffs (designated the Upper, Middle, and Lower tuff), each separated by volcanoclastic sediments. Hanging wall and footwall sequences are separated by a low angle fault called the Moderate Angle Shear (MAS). To the west, the hanging wall Bimurra Volcanics are offset by a series of parallel north-west striking faults. The change in strike of the MAS coincides with a later north-east trending structure, the Juggler fault, which forms a barren zone separating Pit A and Pit B ore bodies, Figures 2 and 3.

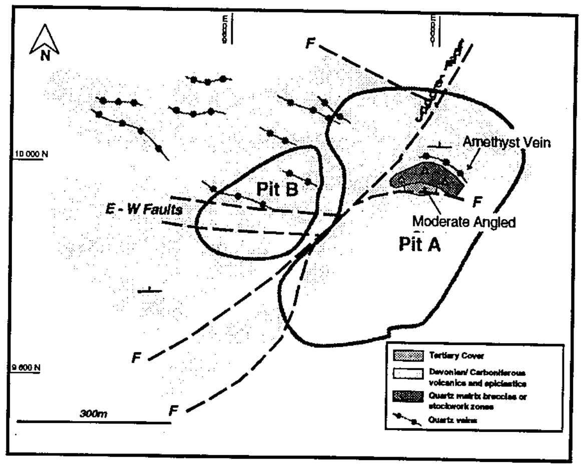


Figure 2: Local Geology Plan

Ross Mining NL is currently preparing to mine free milling ore, and is investigating the feasibility of mining the refractory phase of the Wirralie ore body. The oxidised phase of the ore body occurs in three distinct areas. These are: (a) remaining within the existing Pit A; (b) within and adjacent to the existing Pit B; and (c) within a 'deep lead' down slope from Pit A.

Gold mineralisation within the Pit A and B areas occurs as a tabular body that strikes east-west, dips north at 25° - 35° and is crudely conformable to bedding. Low grade material, ranging from >0.20 to 1.50 g/t Au, is disseminated over a large area, with economic mineralisation covering an area 1,200m east-west and 800m north-south. The topography, drill hole locations and location of planned open pits are shown in Figure 4. High grade mineralisation occurs within the amethyst zone; a localised quartz breccia zone in Pit A, which is conformable with the MAS, dipping from 25° - 35° to the north. Higher grades in the remaining oxide mineralisation tend to be scattered, with little continuity between drill hole cross sections. Mining to date has been restricted to oxidised ore in two pits, Pit A and Pit B.

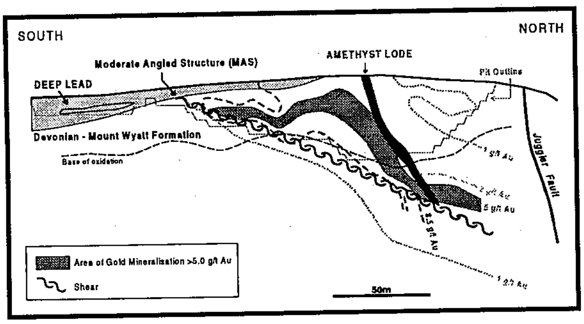


Figure 3: **Geological Section Through the Wirralie Gold Deposit**

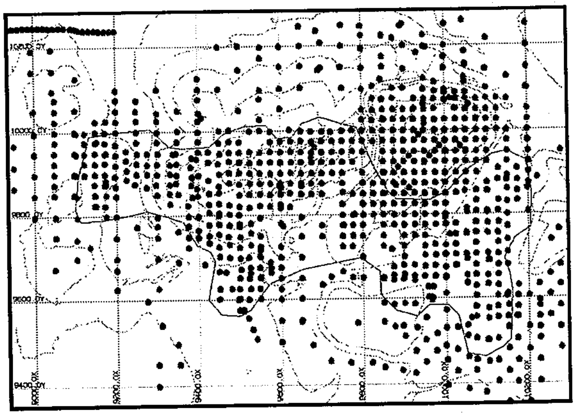


Figure 4: **Plan View of Wirralie Mine Showing Existing Topography, Drill-hole Locations and Outline of Proposed Pit**

Data Analysis and Variography

Available Data

The drill hole database comprises 913 reverse circulation drill holes, and 105 diamond drill holes. Assay data were composited over 2 metre intervals and were coded according to weathering to identify 'oxide' material. The deep lead was not included in this study. An envelope constraining the mineralisation was digitised from cross sections based upon a cut-off grade of 0.15 g/t Au, and on geological interpretation. All 15,948 composites falling within this 3-D solid were extracted for variography and grade modelling. General descriptive statistics for the mineralisation envelope composites and the data histogram are shown in Figure 5.

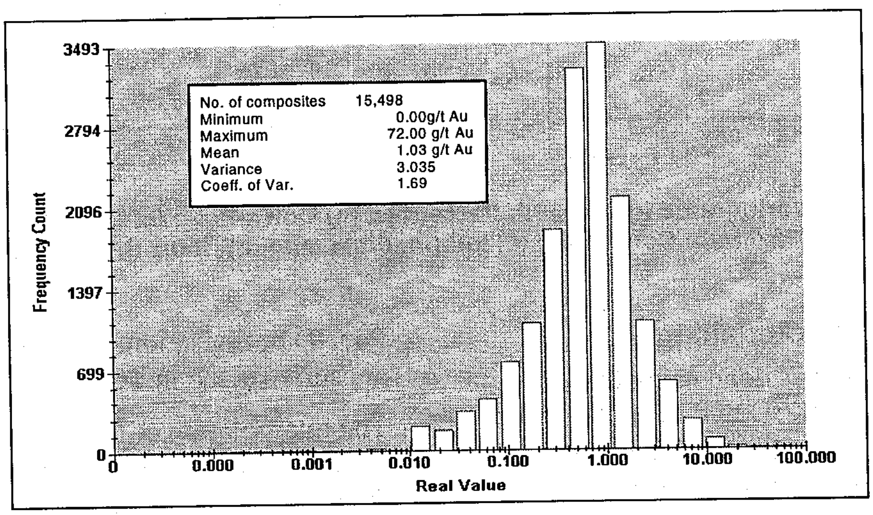


Figure 5: **Log Histogram of 2m Composites Within the Interpreted Mineralised Envelope**

Indicator Variograms

The cut-offs selected for this study include the deciles and 95th, 97.5th and 99th percentiles. The 99th percentile cut-off was 7.49 g/t Au, with 144 composites between 7.49 and 20.00 g/t Au. Variograms were calculated for several cut-offs and modelled using known geological parameters. The existing open pits provide good geological exposure and the general trends of the mineralisation are well understood, allowing the geological validation of variograms. Variograms for the higher cut-offs were experimentally adjusted using the method described by Dimitrakopoulos (1998). The experimental and model variograms for the 50% cut-off are shown in Figure 6.

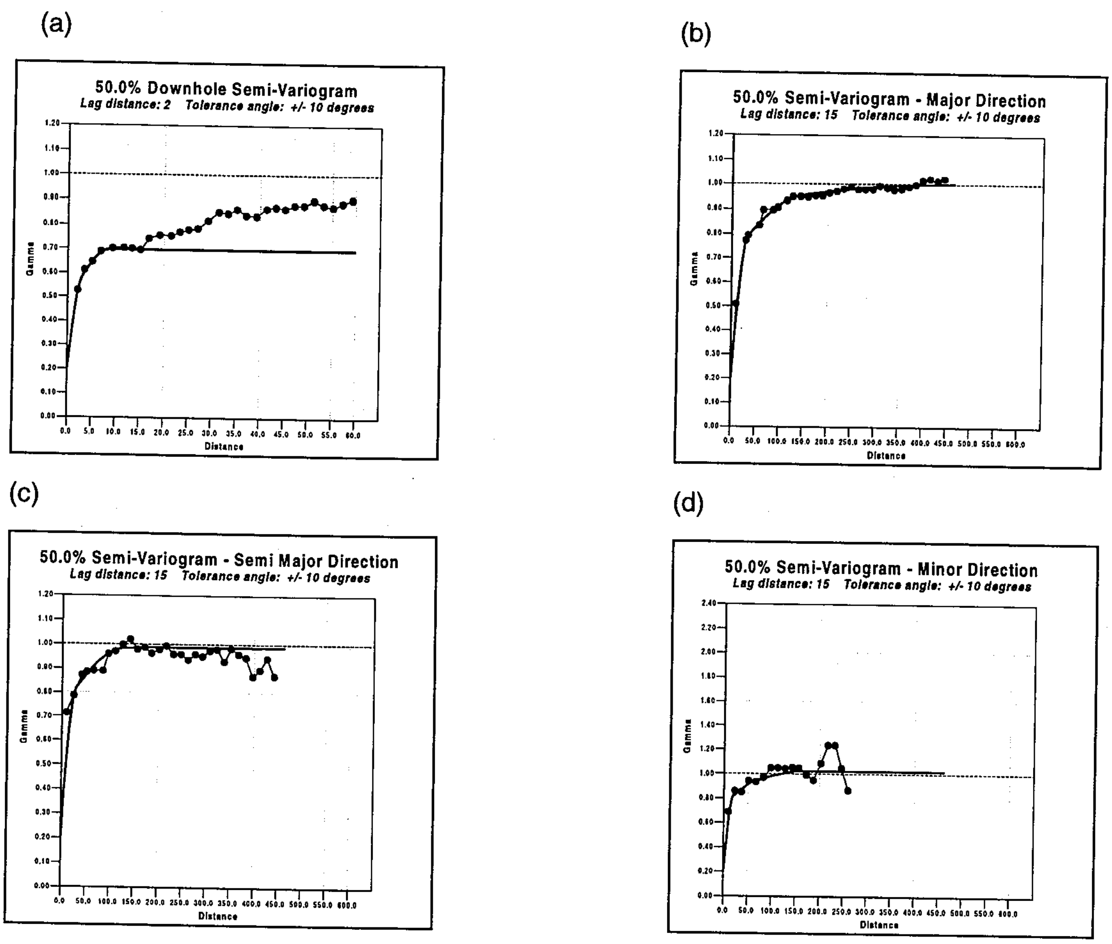


Figure 6: Variograms for the 50th Percentile. (a) Down-hole; (b) Direction of Maximum Continuity; (c) Intermediate, and (d) Short Range Continuity

Ore body Block Modelling

Block modelling was done using the GSLIB programs IK3D and POSTIK (Deutsch & Journel, 1998). The Gemcom mining software was used to display the resulting grade models for validation against drill hole data, to report the resource estimates and to output the data for Whittle Four-D optimisation. The model specifics are summarised in Table 1.

The interpolation of the Wirralie resource models used only those 2m composites from within the mineralised envelope. Three kriging runs were made, using successively larger search ellipse radii. These models were designated 'Measured', 'Indicated', and 'Inferred' respectively, and were combined after interpolation. For the indicated model the minimum data required for kriging a block was also relaxed to 8 samples. The outcome from the full indicator kriging process was a file containing the distribution of grade within each block. This data file was processed through the GSLIB POSTIK program to generate a file of probabilities (proportions) and grades for each block.

Block Model Specifics	
Block Size – X, Y, Z	25, 20, 5m
Search Ellipse Azimuth & Dip	060°/-07°
Measured Search Ellipse	(60,50,10,)m
Indicated Search Ellipse	(80,70,20)m
Inferred Search Ellipse	(100,85,25)m
Min/Max Samples for Kriging a Block	18 (8 for Inferred) / 25

Table 1: Block Model Origin & Dimensions

Support Corrections

Ore body models derived from indicator kriging were constructed at the 'composite or point' support. To represent the proportions of ore grade ranges or categories within the estimated blocks, the 'point support' histogram IK generated for each block of the ore body is corrected to the histogram of grades representative of the selectivity of the mining operation. Several methods for change of support correction are available for a given selective mining unit, or SMU (David, 1988). The indirect log-normal support correction was used in this study, and assumes that both the point support and SMU support grade distributions are log-normal. The quantiles of the corrected distribution are generated from the quantiles of the point-support distribution in the estimated block, the data mean and coefficient of variation, as well as the variance reduction factor f (Isaaks & Srivastava, 1989, page 474). f is the ratio of the SMU to sample variances and, in this study, f was calculated experimentally from a small scale conditional simulation study (using the sequential Gaussian algorithm; e.g. Dimitrakopoulos, 1997). This included the following steps: (a) Conditional simulation on a very dense grid; (b) re-blocking at the SMU size of interest; (c) calculation of the corresponding variances and variance correction factors; (d) repeat for several realisations to check sensitivity; and, (e) repeat the study in various parts of the deposit to evaluate the local spatial changes in f.

Table 2 shows the variance correction factors for two SMU sizes and the corresponding variance correction factors. The global f factor is shown to be insensitive to various simulation runs and for the purpose of support corrections. However, f is found to vary locally within the deposit as the comparison of the eastern to the western part of the ore body indicates. The difference was not found to effect the resource reporting while effects on optimisation were beyond the scope of the present study.

Selective Mining Unit (m)	Variance Correction Factor (& Sensitivity)	West Part	East Part
5 x 5 x 2.5	0.43 (0.43, 0.41, 0.44, 0.45, 0.43)	0.35	0.48
10 x 10 x 2.5	0.26 (0.23, 0.28, 0.28, 0.26, 0.27)	0.22	0.30

Table 2: Variance Correction Factors Derived Through a Conditional Simulation Study

The '10 Parcel' Block Model

By applying the indirect log normal correction (f=0.43, for the selected 5 x 5 x 2.5m SMU size) at a series of cut-off grades above and below the expected economic cut-off grade for each of the blocks in the model, the support corrected IK model was generated. Each corrected distribution within each block represents the proportion above each grade cut-off. This generated a single model with up to 10 parcels per block. The cut-off grades defining the parcels were selected to cover the expected economic cut-off grade as follows: 0, 0.2, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 2.0, and 3.0 g/t Au. The results were used as an input to Whittle Four-D. The global oxide resource estimate based upon the 'parcelled' resource model was reported using Whittle Four-D's FDUT program above a 0.60 g/t Au cut-off as shown in Table 3.

0 Parcel Block Model >0.60 g/t Au	Tonnes	g/t Au	Ounces Au
Measured Resource	5,829,415	1.21	226,778
Indicated Resource	1,604,407	1.12	38,328
Inferred Resource	531,566	1.08	18,457
Total Resource	7,425,388	1.19	284,090

Table 3: 10 Parcel Resource Estimate Above 0.60 g/t Au.

Support Corrected 'Average' Grade Block Model

For comparison, the average grade for each block was generated from the support adjusted IK distributions in each block of the block model. The 'average' support corrected model estimated the global oxide resource above 0.60 g/t Au as shown in Table 4. Differences from Table 3 are largely due to not accounting for selectivity at the time of mining.

Support corrected block model > 0.60 g/t Au	Tonnes	G/t Au	Ounces Au
Measured Resource	6,311,000	0.98	198,642
Indicated Resource	1,012,000	0.89	29,088
Inferred Resource	462,000	0.83	12,321
Total Resource	7,785,000	0.96	240,131

Table 4: Support Corrected 'Average' Grade Model Estimate > 0.60 g/t.

'Uncorrected' Average Grade Block Model

The average grade model from IK was used without any support corrections for mining selectivity. The average grade model is probably the most easily used model, having no distribution details within each block. The average grade block model estimated the total oxide resource above 0.60 g/t Au as shown in Table 5 and, as expected, generates almost identical results to the previous model.

Average Grade Block Model >0.60 g/t Au	Tonnes	g/t Au	Ounces Au
Measured Resource	6,311,000	0.98	198,845
Indicated Resource	1,012,000	0.89	28,968
Inferred Resource	462,500	0.83	12,318
Total Resource	7,785,500	0.96	240,306

Table 5: 'Uncorrected' Average Grade Block Model Resource Estimate Above 0.60 g/t Au.

'Small Block' Model

The large blocks used in the previous block models represent 2,500m^3 of material, or 5,500 tonnes of material. At Wirralie, this would be approximately one day's milling for the proposed plant. Such a large block causes some difficulties in accurately calculating volumes of rock where the surface relief is steep. It may be tempting to model such a deposit using much smaller blocks. To illustrate the effects of using a smaller block size (over-smoothing), a model was developed using all the same kriging parameters as for the previous IK models, but with a block size of 10 x 7.5 x 5m. Each of the small blocks represents 825 tonnes of oxide material. This is an average grade model without any support correction. The small block model estimated the total oxide resource above 0.60 g/t Au as shown in Table 6. The small block model returns a very similar global estimate to the average grade models. The difference between these two global estimates is only 637 ounces, which is less than 0.30%.

'Small block' model >0.60 g/t Au	Tonnes	g/t Au	Ounces Au
Measured Resource	6,443,250	0.97	200,940
Indicated Resource	1,013,100	0.91	29,640
Inferred Resource	317,625	0.89	9,088
Total Resource	7,773,975	0.96	239,669

Table 6: 'Small Block' Model Estimates Above 0.60 g/t Au.

Optimisation Results and Discussion

To demonstrate the support effects on optimisation studies, the results of the optimisation of each of the previous four models is presented here. Note that the four studies use the same optimisation parameters. The optimisation parameters reflect the expected costs of mining at Wirralie and the planned plant throughput rate.

The '10 parcel' IK model was optimised first. This model is the preferred one as it accounts for the desired selectivity during mining. The results of the '10 parcel' model are summarised in Table 7 together with the results of all the optimisation runs. The support corrected 'average' IK block model was optimised as a single parcel per block. Not withstanding that a variance correction was made, Four-D may still only 'mine' or 'not mine' an entire block. As a result, Whittle Four-D does not account for mining selectivity and achieves similar results as the 'uncorrected' average grade model, as shown in Table 7. The small block model based on the average grade of a block was also optimised. The results show the substantial drop of the project NPV as a consequence of over-smoothing with small blocks.

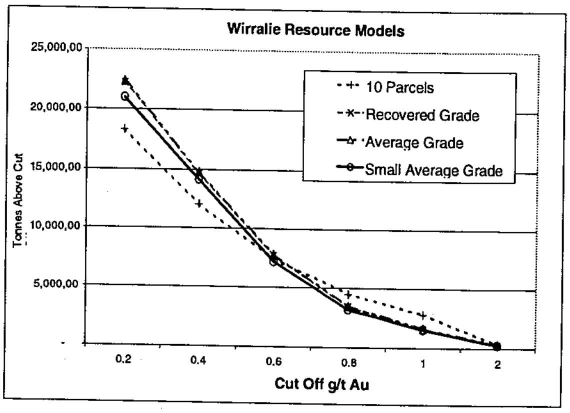
	'10 Parcel' IK Model	Support Corrected 'Average' IK Model	'Uncorrected' Average Grade IK Model	'Small block' Average Grade IK Model
Tonnes	2,522,380	2,154,220	2,222,525 t	1,276,728
Grade Input (g/t)	1.78	1.50	1.50	1.67
Ounces Recovered	119,739	86,217	88,904	56,706
Cost Per Ounce	$287.13	$286.05	$292.45	$301.11
NPV(10%)	$24,717,000	$17,965,600	$17,970,795	$10,867,624
Strip Ratio	1.29	0.22	0.22	0.26

Table 7: Optimisation Results From the '10 Parcel' IK Model, 'Average', 'Uncorrected' and 'Small Blocks' Ore Body Models

The outcomes from the Whittle Four-D optimisations may, in addition, be summarised graphically. All resource models estimate a similar global resource above a 0.60 g/t Au cut-off as shown in Figure 7. However, the consequences to mine planning from each type of model are quite different. The ore tonnes and contained gold ounces planned for extraction from each model are summarised in Figure 8 (left). Clearly, the optimisation based on the 10 parcel model mines the most ore and produces the largest quantity of gold. Concerns with the effects of sensitivity to the support correction may be addressed by applying local variance reduction factors, as well as by repeating the study for different SMU sizes and analysing the results. In comparison, the small block model returns less than half the ore tonnage of the 10 parcel model and recovers substantially less gold, which is theoretically expected. The predicted by Four-D cost of mining for each model is shown in Figure 8 (right) which shows the adverse effects of mine planning based on the small block model. The high cost per ounce combined with the shorter mine life and lower gold return may lead to the project being shelved.

The support corrected 'average' model recovers about the same quantity of gold as the average 'uncorrected' block model, but at a reduced cost per ounce of gold. The 10 parcel grade model accounts, and is valid for the given selectivity during mining. The optimisation results may be further explored with different SMU sizes, as already mentioned. The increase in selectivity yields the highest quantity of gold and has only a small increase in cost over the recovered grade model as a result of the higher strip ratio.

The decisions arising from optimisation and mine planning of the 'small blocks' model would undoubtedly be quite different from those using the 10 parcel model or any of the other block models considered. Obviously, optimisation of an inappropriate block model cannot produce an optimum answer.



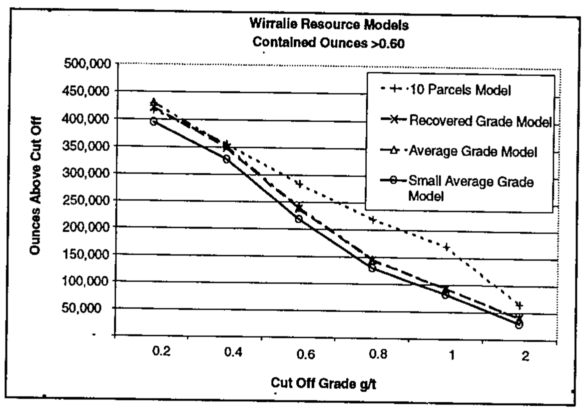
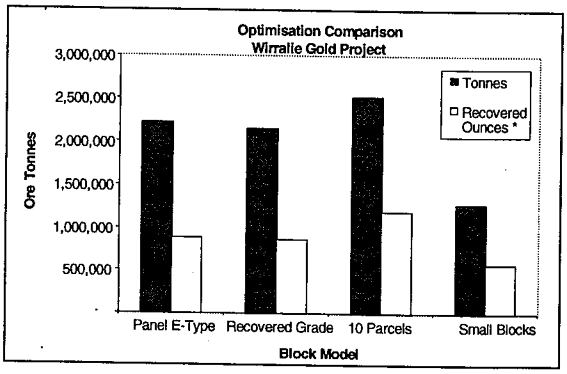


Figure 7: Comparison of Resource Model Tonnes Above 0.60 g/t Au (left) and Contained Resource Ounces Above 0.60 g/t Au (right)



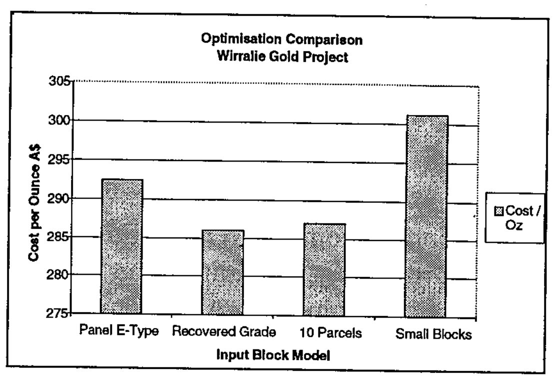


Figure 8: Comparison of Optimised Ore Tonnes for Each Model (left) and Cost Per Ounce for the Optimum Pit Shell From Each Resource Model (right)

Summary and Conclusions

Ore body models, support effects, and estimation of recoverable reserves are a key part of pit optimisation studies. The work on the Wirralie gold deposit presents an implementation of indicator kriging based on support corrections founded on a simulation approach. Subsequently, the input of the results to Four-D via a parcel input formulation is utilised to account for the grade proportions within a block for a given mining selectivity. To show the effects of different approaches, the optimisation study is repeated for three additional cases. The average block grade for each support corrected block grade distribution is first input to Whittle Four-D; then the average grade for each block is used from the uncorrected IK block grade distributions, and finally a small block size IK model is constructed and the average block grades are used in the optimisation study.

The comparisons of the optimisation results at the Wirralie gold deposit are as expected. Small blocks over-smooth and have adverse effects on the optimisation results. The average corrected or uncorrected for support effects ore body models have little effect on the results, particularly in reporting resources. The use of IK models adjusted for a given selectivity and the utilisation of grade proportions in each block for the optimisation study provide a presentation of the expected ore recovery for a predefined level of selectivity. In addition, the approach allows the study of the effects of different mining selectivity to the project.

In making strategic decisions regarding a company's commitment to a project such as the one at Wirralie, this type of approach to optimisation provides a clear indication of the likely up side and down side of the resource from a mining perspective. Decisions regarding plant throughput, mining fleet size and make up, and project financing are only a few areas directly using results from optimisation studies. The examples in this study stress that care must be taken to ensure that the technical characteristics of block models and their effects are well understood.

Acknowledgements

The permission of Ross Mining NL to use and publish data from the Wirralie Gold Project is gratefully acknowledged. The assistance of Tatjana Holtz for drafting, and Dr Greg Partington for review and critical comment is also gratefully acknowledged.

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