OPTIMIZATION OF MULTIPLE MINERAL DEPOSITS USING WHITTLE 4D

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INTRODUCTION

The Whittle 4D system is very flexible and can be used to find optimum open pit limits for most mineral deposits, with some skill and cunning. One type of deposit that can give a number of problems is the multiple product deposit. For instance, an orebody that may produce copper, gold and silver each with their own price and recovery structure. This type of deposit does not easily conform to the 4D system of optimization. The typical approach is to calculate block value and use Whittle 3D. This paper will attempt to show that there is no need to move away from 4D and lose the benefits of analysing the sensitivity of reserve size and grade to change in product price within one run, which 4D provides.

The main problem in using 4D to handle multiple minerals or even single minerals that produce different product streams is that although 4D handles multiple ore types it can only handle a single product with a simple pricing structure. The main trick in using 4D then is to convince it that it is only dealing with a single product. Two systems for doing this are discussed, these are the equivalent grade calculation and total potential revenue methods.

EQUIVALENT GRADE METHOD

The equivalent grade method aims to convert all the grades / metal contents of the different products in a block into a single product grade / metal content. A simple example of the equivalent grade calculation for a block containing copper, gold and silver is given in Table 1.

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Table 1 Equivalent Grade Calculation for a Block

Product	Grade	Price	Ore Value $/t
Copper	1%	$2200 /t	22
Gold	0.5 g/t	$16 /g	8
Silver	5 g/t	$0.20 /g	1
Total	**1.41% Cu Eq**		**31**

So this sample block has a equivalent grade of 1.41% Cu. All the blocks in an input model can be converted to an equivalent grade. The usual 4D options and methods can be used. However, there are a number of limitations to this approach that need to be considered.

LIMITATIONS TO EQUIVALENT GRADE METHOD

The various problems and limitations using the equivalent grade method will be highlighted using a copper deposit as an example. Many of the problems stem from the fact that the multiple products are reduced to a single product.

The first problem is that any price change for the equivalent product becomes a price change for all products. That is, a 10% change in copper price automatically means a change in gold and silver prices. The relationship between prices of the products is set when the equivalent grade is calculated. This is not a big problem but must be appreciated when carrying out sensitivity analysis.

The next problem is the way results are reported by 4D. The optimization will display grade as equivalents and therefore gives no indication of the individual mineral grades. That is, 4D may report 70,000t of ore at 1.65% Cu but will give no details of the mix of copper, gold and silver that makes up that equivalent grade. Sometimes it may be possible to estimate the mix of minerals such as in the case of gold and copper where there is a relationship between the grades of the individual components. This could be accurate for large tonnages but may not be suitable for smaller scale scheduling.

The effect of equivalent grades on the cut-off position must be carefully studied. First a cutoff grade of say 1.4% determined by the Whittle program may only represent an actual 1% copper grade. In addition, material that does not meet the copper cut off grade may be dragged to the plant because of gold or silver content. The plant may not be designed to handle these minerals as well.

In the example given, the calculation was fairly simple. However, usually the process and pricing routes for the products are far more complex. Usually the different products have different recoveries. The effects of this must be included in the calculation of the equivalent grades. So for the example previously presented, if copper recovery is 85% while the gold recovery is 75% and silver is 70%, corrections to the equivalent grade need to be made as shown below in Table 2.

Table 2 Equivalent Grade Calculation for a Block with Differential Recovery

Product	Grade	Price	Recovery	Differential Recovery	Ore Value $/t
Copper	1%	$2200 /t	85%	1	22
Gold	0.5 g/t	$16 /g	75%	.88	7
Silver	5 g/t	$0.20 /g	70%	.82	0.8
Total	**1.35% Cu Eq**				**29.8**

The calculation of equivalent grade can become messy and confusing if there are many potential products each with different prices, recoveries and costs. This can be particularly so if the product stream is broken up and the material follows different process routes. Mineral Sands are a case in point where there may be up to 6 products with different recoveries, pricing structure and decision possibilities. In cases like these the potential revenue method may be more appropriate.

EQUIVALENT GRADE METHOD CASE STUDY

This case study involves the use of the equivalent grade method for a large Mineral Sands deposit in Africa. The deposit contained over 100 Mt of resource covering an area 11 km long by 1 km wide. The aim was for a scoping study to highlight optimum areas for future mining and to calculate the reserves within these areas.

A geological model was developed in a standard mine planning package. The block size was 100 m x 100m x 2m high. This size was set by the dimensions of the deposit, drillhole data spacing and topographic information plus the relatively shallow depth of the deposit.

GRADE INTERPOLATION

The deposit contained three minerals, rutile, ilmenite and zircon. As rutile was to be the major product, an equivalent rutile grade (ERG) was calculated for each block using the following formula:

$$\text{ERG} = \text{Rutile Grade} + \text{Ilmenite Grade} \times \frac{\text{IP}}{\text{RP}} + \text{Zircon} \times \frac{\text{ZP}}{\text{RP}}$$

Where:

ERG = Equivalent Rutile Grade (%)
RP = Rutile Price ($/t)
IP = Ilmenite Price ($/t)
ZP = Zircon price ($/t)

For the base prices and sample grades below:

RP	= $600 /t	Rutile Grade	= 0.2%
IP	= $800 /t	Ilmenite Grade	= 0.02%
ZP	= $350 /t	Zircon Grade	= 0.03%

then ERG = 0.2 + 0.02 x 800/600 + 0.03 x 350/600
= 0.2 + 0.027 + 0.018
= <u>0.245%</u>

The 4D input model was then created using the ERG grades.

A series of cases were run for rutile prices ranging from $200 /t to $800 /t. This was done by the normal method of varying mcostm. The ERGs did not require recalculation. A typical set of results are shown in figures 1 and 2. As for a single product optimization, Figure 1 graphically shows how reserves change with price, while Figure 2 shows the change in average grade by rutile price.

Using these results, the areas of the deposit with low 4D pit numbers were selected for more detailed planning and evaluation. Figure 3 shows the areas of the deposit

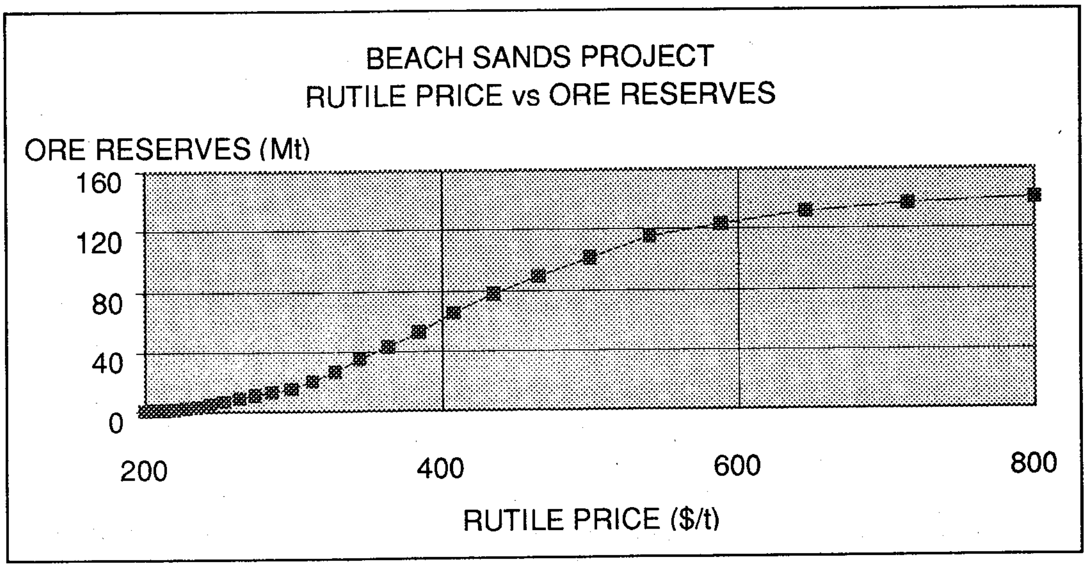


Figure 1

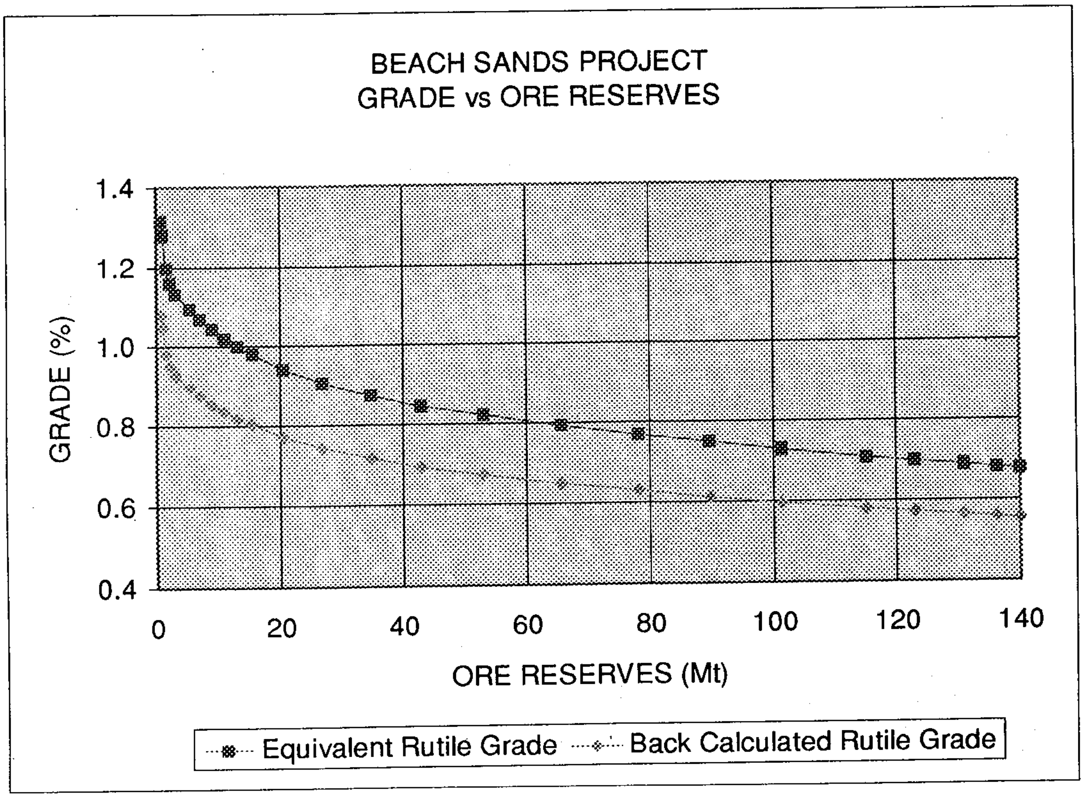


Figure 2

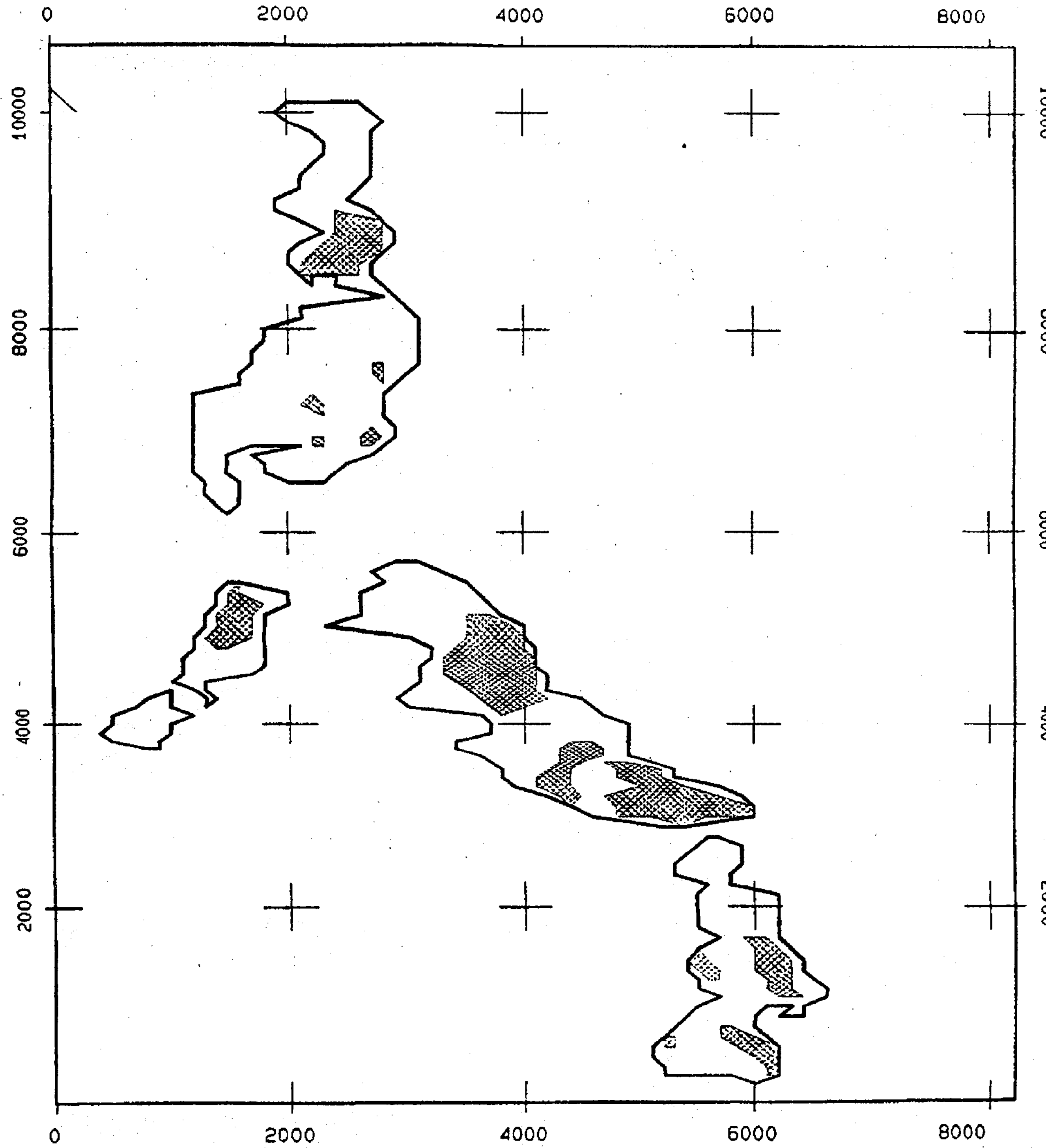


Figure 3 Beach Sands Deposit - Areas of Interest

The equivalent grade method was very useful in this case as it gave tonnages and grades for the optimized pits. It was possible to back calculate an "actual" rutile grade from the equivalent grades. This allowed some very rough scheduling to be carried out and to highlight the areas of interest within the deposit very quickly. A series of 26 different pits were created. To have done this using 3D would have been much slower and the tonnages and grades would have had to be calculated separately by comparison with the resource model.

It may not always possible to use the equivalent grade method for multiple products. Sometimes the number of products may be large, the pricing structure or recovery structure very complex or a combination of these. The potential revenue method has some advantages in these situations.

POTENTIAL REVENUE METHOD

In Whittle 4D there are many ways that allow complex costs to be assessed, such as the use of CAFs and selling costs. Unfortunately the ways of handing complex pricing or multiple minerals can be limited. The equivalent grade method can be used to handle a simple multiple mineral case as above. This section will demonstrate how a slightly more complex case can be optimized using the potential revenue method.

In the potential revenue method, the mine planning software is used to calculate the potential revenue for each block. This is then inserted into the 4D input model as contained metal. The other inputs such as Costp, Costm and recovery are calculated and input as usual. If Costm is set to 1, this can make mcostm somewhat more transparent than usual. The base price is 1, so with Costm set at 1 and considering the usual formula for Mcostm given below, the base value for Mcostm will be 1.

$$\text{Mcostm} = \frac{\text{CostM}}{\text{Price}}$$

So a range of Mcostm from say, 0.8 to 1.2 directly shows the ratio between price and costs. The disadvantage of course is that you are no longer dealing with grades.

The advantage over 3D is that you can run a series of pits in one run and still obtain tonnages. The reported grades are in fact an average value per unit. So you get many of the advantages of 4D with only a little extra pain.

IRON ORE DEPOSIT CASE STUDY

In this study the potential revenue method was used to optimize a typical WA iron ore deposit. This case offers a couple of interesting insights.

1) In iron ore mining the cut-off grade is not usually an economic decision. Rather it is based on the need to create a product or products acceptable to the market. For a typical operation the theoretical economic cut-off might be of the order of 40% Fe but a cut-off between 55% and 60% Fe might have to be applied to make a saleable product. Because of this, the ore used in the Whittle model must already have had a cut-off criteria applied. For this study two cases were considered:

a) Ore cut-off at 60% Fe

b) Ore cut-off at 58% Fe

2) The revenue was calculated as a variable for each block. This was then used as a substitute for contained metal, the usual 4D input. This was done as the calculation of price was complex being dependent on lump/fines split and the Fe, Al_2O_3, SiO_2 and P grade of each product.

OPERATING COST AND 4D PARAMETERS

Regression analysis was used to determine mining cost/ t rock by elevation. These costs were then used to calculate the cost adjustment factors (CAFs). By setting the Costm to 1.0 the mining costs could be used directly as CAFs.

Recovery was assumed to be 100% with ore material fed to the crusher becoming product. The cost of processing was calculated as normal. The Cratio became Costp.

Because the revenue has been calculated outside 4D and fed in as contained metal the price will be 1. A series of nine pits were calculated for each case using the mcostm values given below in table 3.

Table 3 Pit Number by Price and Cost

Pit #	Mcostm	Price Factor	Cost Factor
1	1.20	0.83	1.20
2	1.15	0.87	1.15
3	1.10	0.91	1.10
4	1.05	0.95	1.05
5	1.00	1.00	1.00
6	0.95	1.05	0.95
7	0.90	1.11	0.90
8	0.85	1.18	0.85
9	0.80	1.25	0.80

As Mcostm is the ratio of Costm/ Price the base pit is shell 5 with Mcostm of 1. Because Mcostm equals 1, the relationship between price and cost can be seen more clearly than usual. The optimum pit for each change in price or cost is shown by the columns price factor and cost factor. Thus pit 1 is the optimum pit where either the price of ore is only 83% of base price or costs are 20% more than base costs.

REVENUE CALCULATIONS

As discussed, revenue is used as a pseudo contained metal. The revenue for each block is calculated using a set of rules such as those in Table 4. This table demonstrates how the revenue is calculated for a sample block.

Table 4

SAMPLE REVENUE CALCULATION FOR IRON ORE CASE BLOCK

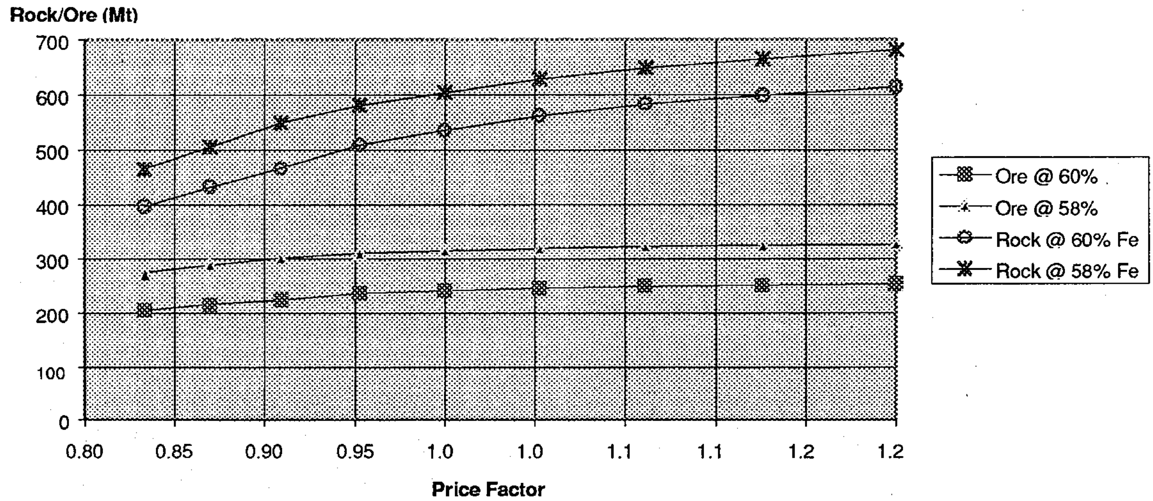
Rule 1 - Cut-off - If ROM Fe% less than 60% then material is rock and revenue is zero.
Rule 2 - Lump is paid at A$0.4435 / Fe unit / dry metric tonne
Rule 3 - Fines are paid at A$0.3295 /Fe unit /dry metric tonne
Rule 4 - Penalty of A$0.13 / t if SiO2% greater than 5% for lump and 7% for fines
Rule 5 - Penalty of A$0.67 / t if Al2O3% greater than 2% for lump and 3% for fines
Rule 6 - Penalty of A$0.27 / t if P% greater than 0.06% for lump and 0.07% for fines

Quality		ROM	Lump	Fines	
Proportion		1.00	0.40	0.60	
Fe %		61.00	61.5	60.67	
SiO2 %		6.00	5.80	6.13	
Al2O3 %		3.00	2.85	3.10	
P %		0.060	0.055	0.063	
Block Tonnage		22500	9000	13500	
Fe content price			0.4435	0.3295	
	$/DMT		27.28	19.99	
less penalties for					
SiO2	$/DMT		0.13	0	
Al2O3	$/DMT		0.67	0.67	
P	$/DMT		0.00	0.00	
Net Price	$/DMT		26.48	19.32	
Revenue			238277	260816	
Total Block Revenue	$	499093			
Average Price	$/DMT	22.18			

RESULTS

The graph in figure 4 shows how the ore reserves and pit sizes vary with price factor.

Figure 4
Pit Size and Reserves by Price Factor



When using the potential revenue method, a few points must be remembered. Firstly the grade reported will actually be the average price. Proper grades will have to be obtained from the mine planning package. Secondly the system is very flexible. In this case the costs were calculated and input into 4D in the standard manner. But instead of using revenue as contained metal, net block value could also be used. That is revenue less mining and processing costs. This may be useful where the cost calculations are very complex or vary with revenue. In this case 4D is running like 3D and Costm, Costp and price would all become 1.

CONCLUSIONS

Optimization using 4D for deposits where multiple products are produced, or where product quality determines price, requires alternative approaches to be considered for input values of ore quality. The cases presented show how either an equivalent grade or potential revenue can be used as ore grades in the 4D input model. The outstanding benefit of using 4D is the ability to analyse the sensitivity of reserve size and grade to change in product price. Where multiple products, complex pricing or costing are an issue this can still be carried out. However, additional steps may be required to calculate the actual reserve tonnages and grades in each pit shell.

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