Mining Scenario Analysis and Mine Variable Value

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ABSTRACT

Following a review of life-of-asset work at MMG's Rosebery mine in which a proposal to increase production from 0.8 Mt/a to 1.2 Mt/a was mooted, questions were raised as to the seemingly arbitrary reasoning for the production increase. They included: Did the proposal actually add value? Was the production rate from the mine sustainable? Was it the best identifiable value-adding configuration?

A multiple scenario analysis study commenced to model how various cut-off grade values against mill throughput, along with associated capital expenditure, would impact on the potential value of the operation. This was carried out utilising the 'hill of value' approach promoted by AMC Consultants.

The traditional approach to these studies uses a constant cut-off value (NSR – net smelter return) for the whole mine analysis. This was thought to potentially introduce a large amount of variability to the model as different ore types were thought to have different processing costs and different underground lenses were thought to have different mining costs. With the aim of developing a consistent value measure that would be comparable between the lenses, an alternative measure was suggested for all ore block values in this model, irrespective of lens location.

The new measure used was a mine variable value (MVV). This allowed for the variable factors of final metal concentrate production to be removed from the ore value. From a mining point this was the haulage distance from ore source to run-of-mine (ROM). For the mill it was the amount of reagents required, varying based on grade together with the amount of power required for crushing, grinding and tailings handling.

From the initial run of the model, preliminary results lead to a conclusion of increased value being gained by either increasing cut-off grade or increased mill throughput rate. The validity of the result was tested using alternative price scenarios, which although changed the absolute value achieved did not significantly change the identified value-adding strategies. The realisation of these value increases identified are however contingent on higher sustainable development rates being able to be achieved mine-wide, higher backfilling rates being able to be achieved and overcoming recognised ventilation constraints. Further detailed studies are being put in place to identify the practicality of overcoming these recognised constraints and achieving the higher-value strategies identified.

The ongoing objective of the hill of value model built is to keep the model alive as a life-of-asset planning tool and to continue refining the foundation data, such that various mining strategies can be analysed with increased confidence.

INTRODUCTION

The Rosebery mine is a polymetallic mine located on the west coast of Tasmania, Australia, producing zinc, lead, copper silver and gold. Following the discovery of mineralisation in the area in 1893 limited mining activity occurred through to the early 1920s. In 1936 the current mill was commissioned and the site has operated continuously since (Easterbrook, 1962). MMG took ownership of the mine in 2009.

Through 2012, 856 958 tonnes of ore were extracted from the underground workings and treated for the production of 70 410 tonnes of zinc, 20 146 tonnes of lead, 1587 tonnes of copper, 29 084 oz of gold and 2.32 Moz of silver. Over the life of the mine a range of ore lenses have been mined and the current focus is on K, N, P and W Lens, as shown in Figure 1. Currently the average haulage distance from working areas to surface is 11 km with deeper planned areas in the range of 12.3 km. Future production is planned for X and Y Lens.

In late 2011 work for life-of-asset documentation confirmed that as the mine extended both to the north and deeper the grades of the base metals, especially zinc, were decreasing but are offset in value by an increase in precious metals content.

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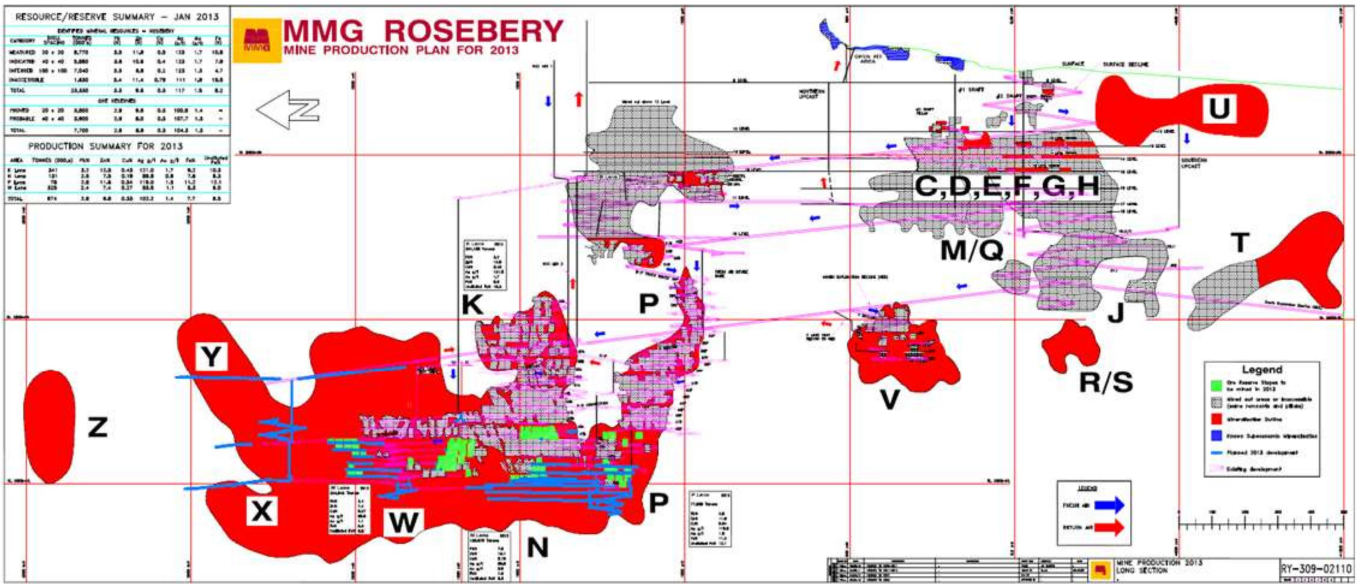

FIG 1 – Long section of the Rosebery mine.

At the time Rosebery was perceived as a zinc mine and with these decreasing grades the reduced amount of produced zinc metal would have an impact on site economics.

For the 2012 life-of-asset documentation two schedules were constructed looking at potential scenarios and values for the mine. The difference between these scenarios was the source of material being used. The base case used the current Rosebery Ore Reserves while an upside case included Inferred Mineral Resource material believed to have a reasonable chance of being economically extracted along with a range of sources external to the main Rosebery mine.

The key operating parameter that was built into these schedules was a ramp up from the then current mill production rate of 800 000 t/a to 1.2 Mt/a. The main basis of this increase was that as the zinc grade decreased there would need to be additional material processed to maintain a site goal of producing 80 000 t of zinc metal per annum.

Following completion and review of the life-of-asset work for 2012 it was recognised that the selection of 1.2 Mt/a throughput in order to maintain 80 000 t of zinc metal per year did not answer the fundamental question of what processing rate or indeed overall mining strategy was required to optimise the value inherent in Rosebery.

Discussions within Group Technical Services led to the decision to commence an optimisation study for the Rosebery mine. This was to be a 'hill of value' (HoV) study based on work and method developed by Brian Hall of AMC Consultants.

HILL OF VALUE BACKGROUND

For the review of increasing the production rate at Rosebery the defining value used for comparison was net present value (NPV). While Lane (1988) presents an analytical technique directed solely at maximising NPV, the application of this method to underground mines is limited due to understanding of the complexity involved. Lane's method is also limiting in that it is aimed at maximising NPV but not any other corporate goals.

As outlined in Hall (2005):

> *… to overcome many of these problems, the author has been using a technique that has been termed the 'hill of value'. In its simplest form, the methodology simply makes use of the advanced modelling and three-dimensional charting capability of Microsoft Excel™ to derive value surfaces showing the overall relationship between value and two independent variables, which will typically be cutoff and another key value driver, such as production rate target. Figure 2 is a hill of value from a real study demonstrating the concepts.*

For the study at Rosebery the main areas that were the focus for maximising value were as above the production rate and cut-off value. It should however be noted that the technique permits simultaneous flexing of more than two 'decision' or 'scenario' parameters. For the production rate the current base rate was used along with the planned mill upgrade throughput.

For the cut-off grade the existing mine cut-off value, $175 net smelter return after royalty (NSRAR), was used as a base value with a range of different cut-off values at $25 NSRAR increments. These increments covered a range from one step below the base value to three steps above. (The 'after royalty' suffix was added within MMG to distinguish the calculation from the NSR calculations undertaken by the company's commercial department that did not include royalty – similar to the original described NSR calculations by Goldie and Tredger (1991).)

At each of these cut-off values an indicative mining inventory was created. The work to create the mining inventory values

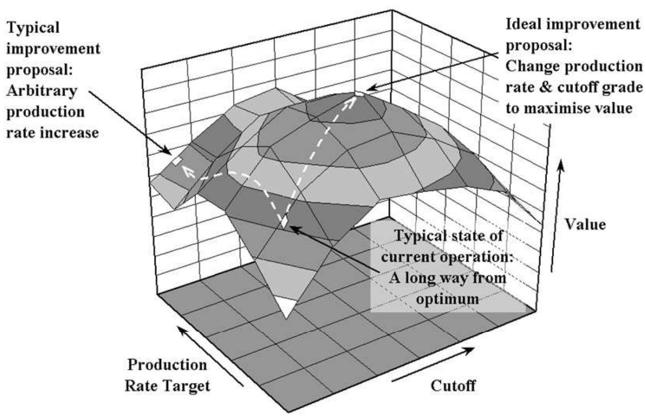

FIG 2 – Adjusted Rosebery hill of value outcome.

followed the intent used for official Ore Reserve work but not to the final detail. Once each amount was totalled these were broken down into smaller mining blocks. Table 1 outlines each of the blocks created detailing their Level and Northing limits. For each block, along with contained ore[4] information, further information was added in relation to the amount of development required, broken down into capital and operating waste and ore, along with backfill requirements.

TABLE 1
Mining block definition.

Block	Level from	Level to	Northing limits
K1	51	56	1280 mN – 1505 mN
K2	47	50	1310 mN – 1665 mN
N1	59	61	1450 mN – 1605 mN
N2	54	58	1450 mN – 1605 mN
N3	56	60	1170 mN – 1450 mN
N4	50	55	1170 mN – 1450 mN
P1	57	63	1160 mN – 1365 mN
P2	50	56	1080 mN – 1280 mN
W1	60	62	1600 mN – 2020 mN
W2	55	59	1600 mN – 2020 mN
W3	49	54	1600 mN – 2085 mN
W4	41	45	1700 mN – 2140 mN
W5	35	40	1850 mN – 2140 mN
X1	60	65	2020 mN – 2465 mN
X2	55	59	2020 mN – 2140 mN
Y1	41	50	2120 mN – 2440 mN
Y2	35	40	2300 mN – 2500 mN

The range of further information placed in the model covers the following areas:

- capital costs covering mill upgrades, mine expansion and tailings storage facilities (TSF) upgrades and new locations
- scheduling relationships between mining blocks
- price assumptions
- operating site costs – mine, mill and general costs
- TSF capacities.

MINE VARIABLE VALUE

During the initial stages of the mining inventory generation consideration was given to the application of variable cut-off grades for each lens. This was based on a review carried out for Rosebery in early 2012 that applied a range of break-even cut-off grades to each lens. The range of break-even grades ranged from a situation where no development had been carried out to broken ore in the stope available to be bogged.

Following a review of initial mining inventory data that was being created using the variable cut-off values it was perceived that these variable values for each lens would lead to debatable results. While this was perceived to potentially add doubt to the results the variability of ore location and characteristics was deemed to be important to consider.

This variability of the ore prompted the creation of a mine variable value (MVV), which takes into account the variability in costs based on the ore location or characteristics. In an ideal situation the analysis would be undertaken using concepts such a 'cash flow grades' proposed by King (1999), however the development of the knowledge base to undertake such an analysis is still a considerable distance in the future. The MVV was felt to be an achievable step in the right direction.

From a mining aspect the cost of development, drilling and blasting, loading and backfill operations were perceived at this stage to not significantly vary with a block's geographical location while haulage costs however do increase as depth increases. This was the only area of variability allocated to the mining area of the operation.

For each of the mining blocks as defined in Table 1 the haulage distance from each level to the Portal was calculated. Initial information was taken from a distance spreadsheet maintained at the mine while additional levels were calculated based on mine designs. From the base Ore Reserves the tonnage from each level was used to gain a total tonne kilometre (tkm) value. Over the total block each level was combined and weighted to gain an average haulage distance for the block. This is outlined below in Table 2. The haulage cost was based on a cost of $1.63/tkm.

In the mill area the main variability comes from the grade and the impact of this upon the amount of reagents or consumables required for treatment along with the power required due to ore hardness and throughput.

Information for the mill data was collected from site in early January 2013. The initial information that was collected during the site visit covered the tonnes and grades (Zn, Pb and Cu) that were treated for 2011 and 2012. Information in relation to the amount of reagents used was supplied for the two year

TABLE 2
Lens level information for haulage distances.

Mining block	Average haul distance (km)	Haulage cost for block ($/t)
K1	10.06	$16.40
K2	9.08	$14.80
N1	10.67	$17.39
N2	10.12	$16.49
N3	10.24	$16.69
N4	9.86	$16.08
P1	11.20	$18.26
P2	10.04	$16.37
W1	11.07	$18.05
W2	10.31	$16.80
W3	9.65	$15.73
W4	9.83	$16.02
W5	10.64	$17.34
X1	11.66	$19.01
X2	10.99	$17.91
Y1	10.09	$16.44
Y2	10.63	$17.32

4. The words 'ore', 'orebody' and 'reserve' are used in this paper in a colloquial sense and not according to the strict definitions of the JORC Code. To determine the optimum cut-off, it is necessary, for internal planning processes, to derive a number of different potential 'reserves' at different cut-offs, one of which may eventually form the basis of a publicly reported Ore Reserve that is consistent with the JORC Code.

period along with the mill run times. All of the information is based on a monthly time period to avoid daily fluctuations.

Each stage of the mill process there was a review to check if any change in the ore characteristic would impact on the operation and drive a cost change. The crushing and milling area considered the throughput rate, which anecdotally the mill personnel assessed as increasing with higher grade (in general as the grade decreases as measured by metal sulfide content, the higher the siliceous gangue content and consequently the harder the ore and the lower the expected throughput rate).

In the flotation area the amount of reagents required was found to vary based on the grade. Each of the flotation products; being separate concentrates for zinc, lead and copper, were reviewed for the usage of each reagent. The amount required for a given grade and the cost of this usage was estimated.

While relationships between grade and reagent usage and power consumption were found, a relationship between grade and throughput was not identified. This may have been more due to the coarse nature of the data available and other variables at work (for a period of the data collected a mobile crusher was being used to precrush some of the lower grade ore to increase throughput – this was a difficult effect to isolate).

The final form of the MVV equation is outlined below:

$$MVV = NSR - royalty - product\ costs\,(mill) - (differential)\, variable\ ore\ costs\,(mine/mill)$$

Following the generation of the relationships of each of the mill and mine aspects that feed into the MVV calculation a macro script was generated to run over the block model and generate the value for an MVV field. This was carried out following a test of the script on a small section of the block model for validation of the process.

Once the script was validated it was run over the full model. An investigation was carried out to determine the relationship between NSRAR and MVV and to determine an equivalent average MVV value comparable to the NSRAR break-even cut-off value for 2013 at $175. From the relationship between the two this was found to be a value of $160. A mining inventory value for each mining block was generated at this value along with additional mining inventories at three $25 increments above this value and one below it.

The original premise of using the MVV rather the NSRAR was that the MVV would be a better representation of the potential profit margin than the NSRAR would be. An examination of the range of NSRAR values for a small range of MVV values is shown in Figure 3.

HILL OF VALUE ANALYSIS

Following the creation of the mining inventory data by running a mineable shape optimiser (MSO) operation over the modified block model using the new MVV field as the optimisation parameter all supporting data was placed into the HoV model. During the process there was a large amount of cross checking and review of the information.

At the early stage of the analysis of the model it was clearly noted that this was a holistic approach that covered the whole operation from the mine to the tailings placement and that it would indicate what direction further detailed study should take. It was also important for the site to understand that the

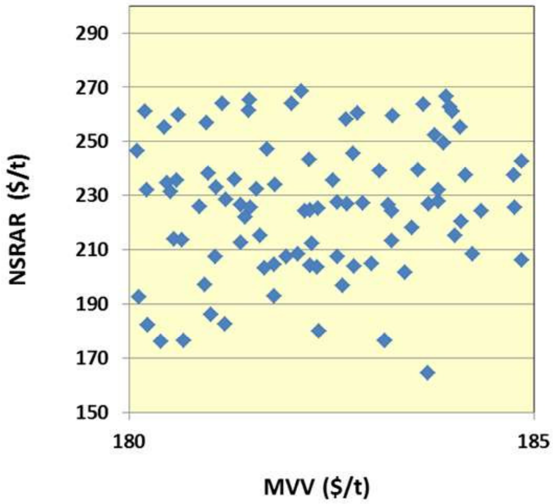

FIG 3 – Range of net smelter return after royalty (NSRAR) variation for a small mine variable value (MVV) variation.

value was optimised using the MVV and not NSR that the site was accustomed to. At this early stage two initial points were identified for further follow up: mining dilution and costs.

Dilution has a significant effect on value and variation in dilution can easily overwhelm the other cost effects being modelled in the MVV. Mining inventories were input into the HoV model without dilution and loss and in the HoV model dilution and loss were accounted for with a single overall fixed value per lens (varying from 11 per cent to 22 per cent). In future development of the model, we would like to determine the panel tonnes and grades in an already diluted form – allowing for variation of geotechnical conditions within a lens.

Costs need further follow up, not only for accuracy of costs being used, but also to check and possibly for the effects of differences of fixed costs such as a slot raise over significantly varying stope tonnages.

As can be seen in Figure 4 the outcome of the analysis did not look like the typical hill shown in Figure 2. With the assumptions modelled, the optimum cut-off and production rate are higher than the highest values evaluated: the peak of the hill is 'off-the-scale', though there is an indication that the optimum cut-off, generating the maximum NPV, has been reached at the highest production rate used. The red star indicates the current operating configuration at Rosebery of 800 000 t/a at a cut-off value equivalent of $160 MVV. There is a small dip in the surface at 900 000 t/a, resulting from

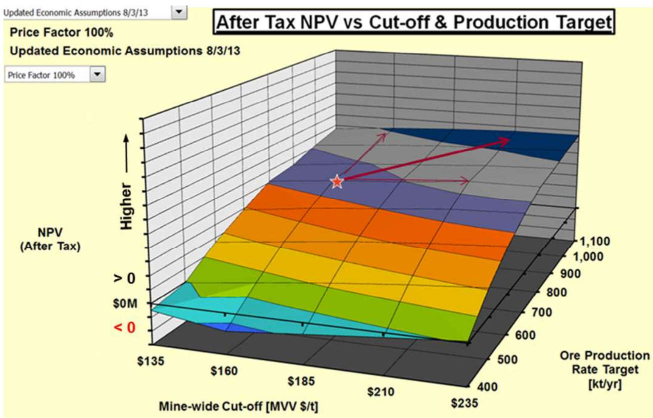

FIG 4 – Rosebery hill of value outcome.

the estimated capital expenditure required to achieve this production rate. Major capital expenditure, which is as yet undetermined but will significantly reduce the value, will be required to produce more than 1.1 Mt/a.

What can be seen from Figure 4 is that a significant value increase in the asset could be achieved by just increasing the cut-off value. An increase in cut-off value of $50/t MVV would achieve the same value increase as a 200 kt/a increase in mill throughput. Increasing only the mill throughput leaves significant value still 'on the table' and the best additional strategy would be to increase both cut-off value and mill throughput. This option obviously, however, will put significant pressure on the mine's capacity to produce and a substantially detailed study is required into the mine's capacity to deliver both a higher tonnage and higher grade solution.

The strategy outcome was tested by changing the economic assumptions from the prevailing long-term corporate assumptions to the prevailing prices in March 2013. This changed the surface to the chart shown in Figure 5. The immediate point of comparison between the two charts is that while the values have decreased in the second chart the relative shape of the surface is similar. The strategy from the first economic scenario of increasing mill throughput and cut-off value still holds in the adjusted economic environment. It is also clear that the current operating strategy is a highly

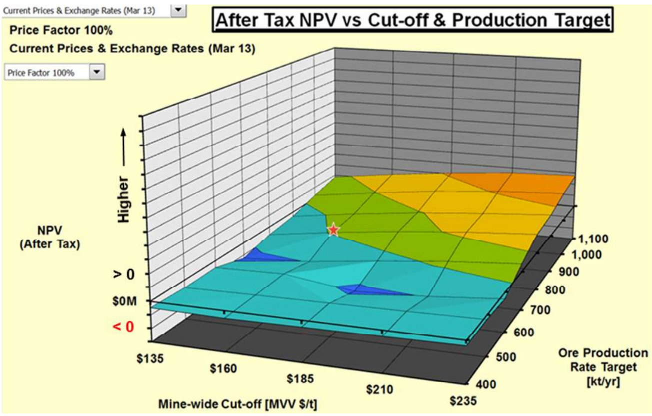

FIG 5 – Adjusted Rosebery hill of value outcome.

vulnerable one should prices drop further. Increasing the cut-off value and/or production rate is essential to ensure the economic viability of the operation for a range of economic scenarios.

The appearance of the surface, while not looking like a typical hill as seen in Figure 2, could be viewed as being a corner of the hill. Additional increments of the cut-off grade might flesh out the surface further to form more of a hill surface; however, other detailed mining practicalities that have not been explicitly modelled to date at higher cut-offs or production rate targets may need to be identified and brought into the analysis to further refine the shape of the hill.

Further analysis of the outcome indicated a number of areas for further study with the three main ones being:

1. waste handling/backfill
2. tailings
3. development.

Figure 6 shows the modelled waste and fill material movement over the life of the project at an increased cut-off value of $185/t MVV and at an increased production rate of 1.1 Mt/a. During the first six quarters there is a small excess amount of waste rock generated that will be needed to be transported to surface. Following that time the amount of rock fill required will significantly outstrip the amount of waste generated from development. This will lead to material currently held on the surface being returned back underground or the need for alternative fill methods such as paste fill.

The application of paste fill to alleviate the above issue of fill material would also have a beneficial impact on the current TSF storage limitation. In Figure 7, the sources of ore from the different lenses are shown along with the limitation of the current Bobadil TSF as the black line. (Note that the chart includes placeholders for other lenses not included in the case illustrated.) There are plans for alternative TSF sites and this is a further highlight of work needing to be progressed for a final location decision leading to required permitting.

The final main point that was found in the analysis is in relation to the required rate of development. Figure 8 outlines the total development required per quarter. The initial rate through the first couple of years is in the range of 600 m per

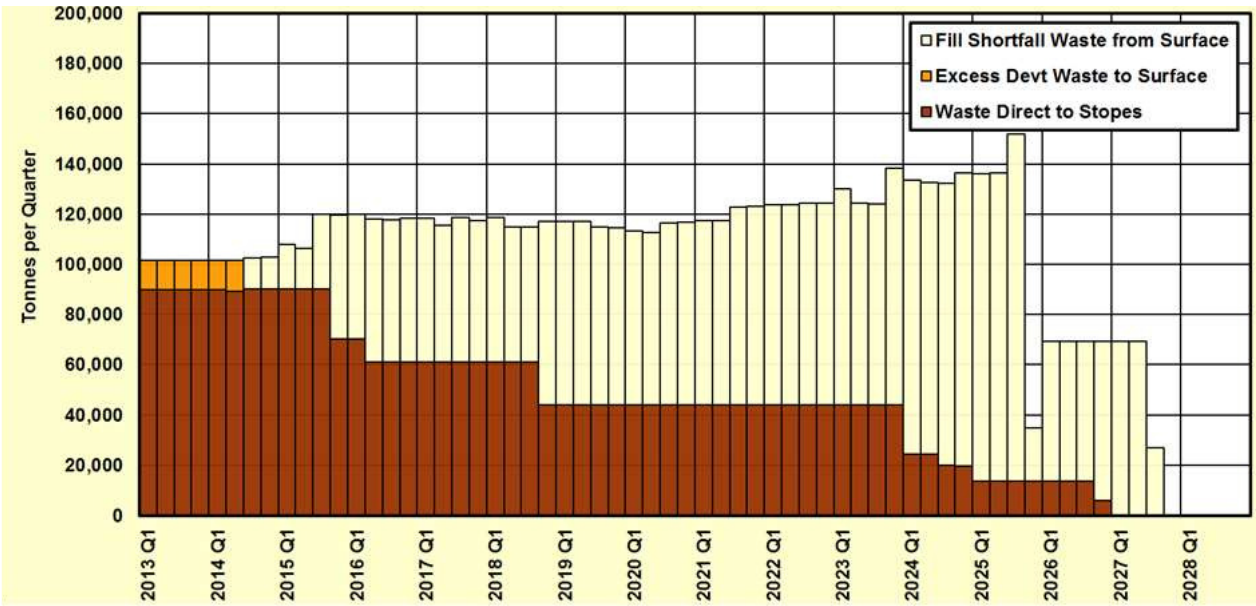

FIG 6 – Waste and rock fill movement.

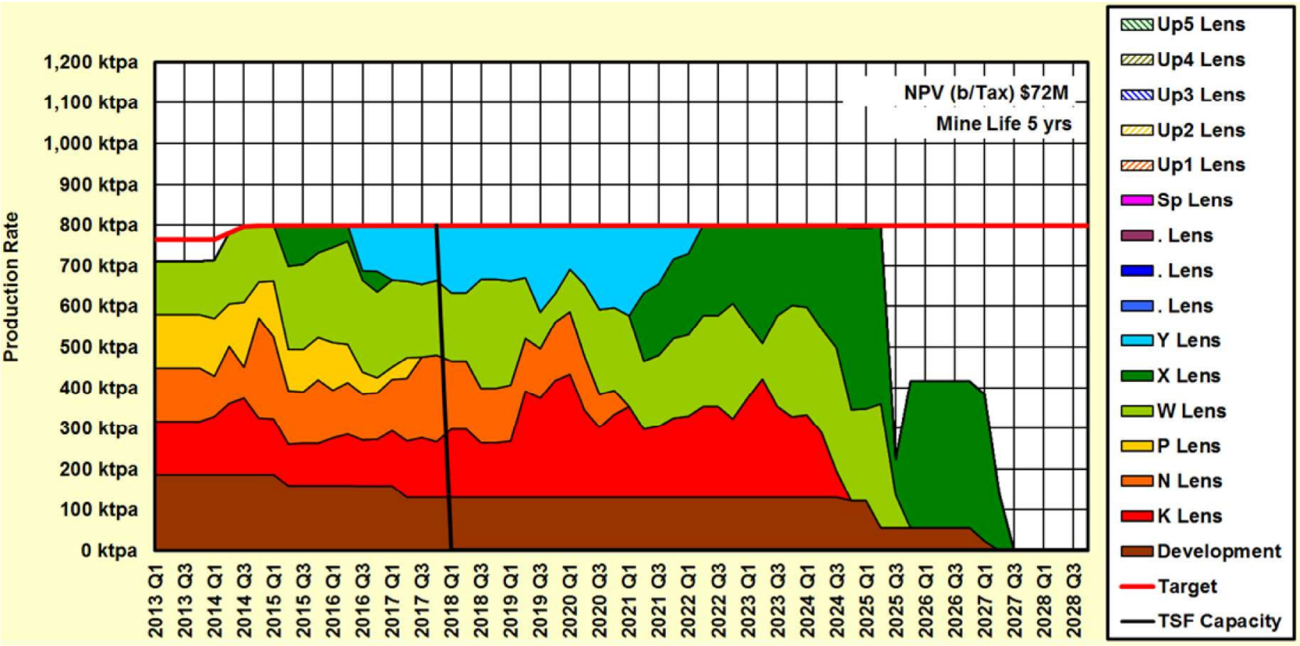

FIG 7 – Mined ore sources and tailings storage facilities (TSF) limitation.

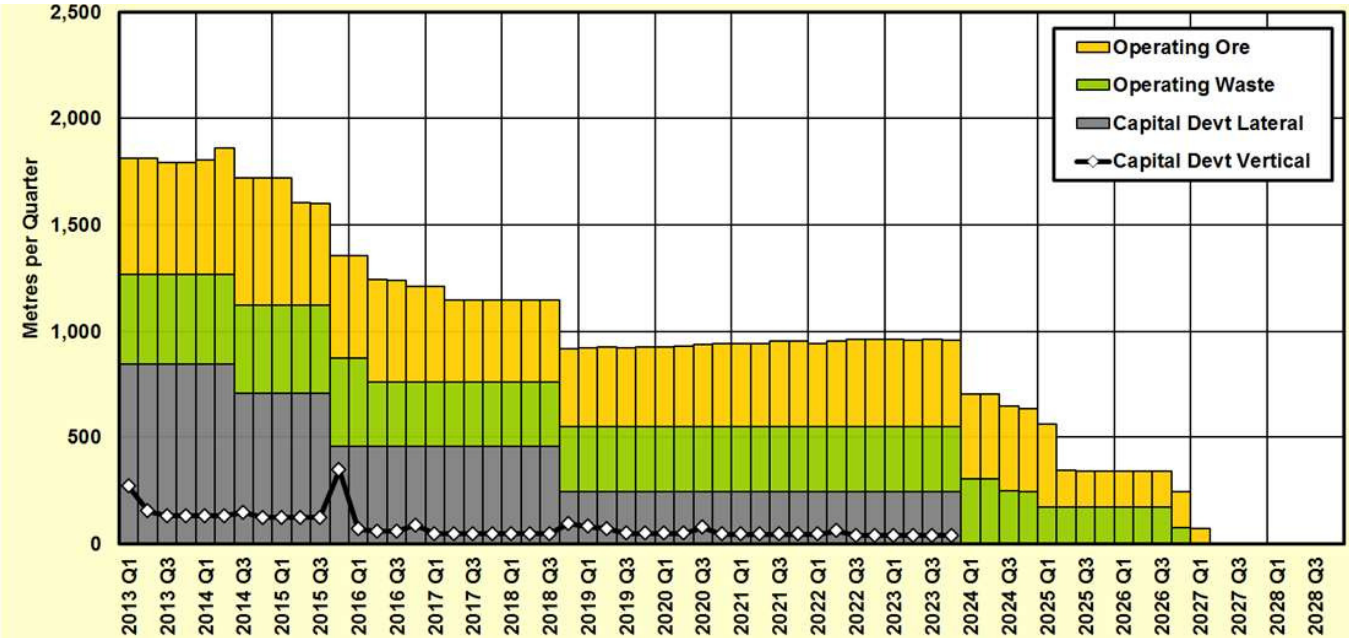

FIG 8 – Development requirements.

month (1800 m per quarter). At the time that the HoV work was being analysed the first quarter of 2013 was complete and the rate achieved was slightly less than 1500 m. The HoV model is constructed to allow the specification of when various mining blocks can start production and this in turn will change the development requirements.

WORK MOVING FORWARD

The immediate work moving forward from the HoV study is that further detailed investigation is required with respect to the mine's ability to achieve the higher rates of production (ideally at higher cut-offs values) and the feasibility of upgrading the mill throughput rates. For the mine there are numerous areas for study around the aspects of development rates (and associated ground support activities), production areas, ventilation requirements and stope fill methods.

During the mid-2013 life-of-asset process, a first pass at a development design layout and schedule was carried out. The initial results from this were encouraging in suggesting that with an increase in development rates a higher mine tonnage output allied with an increase to the cut-off value could be achieved. Initial studies have indicated an ability to increase required ventilation capacities, and filling strategy studies are still underway.

In relation to the mill the strategy for throughput increase, methods have been devised that require further study to advance through to a feasibility level.

There had been a previous HoV study carried out at Rosebery through 2008 to 2009. At the time of this study there were a number of documented issues with the study. However, there were results achieved that were applied to the site. Following those previous studies there was no further follow on work. From the work that has been carried out on this HoV study the intent is to keep the process alive as a key strategic in-house tool and to review and update values as new information is generated.

Keeping the process alive will maintain the ability to verify that the planned strategy moving forward is still generating positive value and also to compare it to new strategies and ideas.

From the new Ore Reserves generated in 2013 a new set of mining inventories can be generated across an increased range of cut-off values. These new inventories along with ongoing review of the cost and dilution details used in the model need to be the first areas to be updated.

Additional work around the MVV will also be undertaken to further understand the relationship between the NSRAR and MVV. The first stage is to review and strengthen the correlations between grade and mill parameters. Since the time the MVV was first calculated a review of the original NSRAR script has been carried out resolving some small errors and using updated economic assumptions.

Key to unlocking the value of using MVV rather than NSRAR will be the ability of the site to use MVV – a journey still to be undertaken

CONCLUSION

The use of a HoV study to optimise the value of a mine operation, be it maximising the NPV or any other measure, is a strong tool that can continue to provide direction through the ability to keep the process alive. For Rosebery, the process has allowed an open revelation of where value lies and the appropriate strategies to release that value, rather than an arbitrary strategy without economically backed justification.

Application of the investigation of the variability in block values based on geographical location and the differences in mill-related costs is a step up from the analysis by NSRAR and further work and understanding will make this a stronger measure.

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