HARDNESS MODEL AND RECONCILIATION OF THROUGHPUT MODELS TO PLANT RESULTS AT MINERA ESCONDIDA LTDA., CHILE

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ABSTRACT

Minera Escondida operates two open pits on a porphyry copper district, southeast of Antofagasta, Chile. During 2005, ore will be delivered exclusively from one pit to two concentrators, while from 2006 both pits will provide ore to these plants. Annual testing programmes on drillhole samples, have allowed for the construction of hardness block models since 2000. These models have delivered two main hardness descriptors, the Bond work index and the SAG power index. These parameters and plant operational specifications have been used as input information to forecast, the expected throughput and ball mill product size (P80) for each block of ore. Two forecasting techniques have been used, an in house model, strongly dependant of bond work index and MinnovEx´s CEET2, dependant of Bond work index and Sag power index and other parameters. Model performance has been evaluated from reconciliating on a monthly basis, the forecasted throughputs against a recalculated plant throughput which accounts for losses in tonnage not caused by ore hardness but instead by unscheduled plant operation problems. The model performance for 2003 was ± 2% yearly and ± 5% quarterly, well within the expected ± 3% and ± 10%.

INTRODUCTION

The Escondida porphyry copper district is located 140 km SE of Antofagasta, Chile at 3150 m.a.s.l, at 24°16’ South latitude and 69°04’ West longitude (figure 1).

Detailed geological work dates back to 1981. The discovery of the supergene enriched deposit dates from March of that year. Following intense drilling campaigns, the feasibility study focused on mining the higher grade supergene enriched portion of the deposit, at a production rate of 35,000 metric tonnes of ore per day. Once in production in 1990, further drilling provided increased definition for detailed production planning purposes. The progressive increase in production capacity to 130,000 metric tonnes per day by 2000, was achieved by a series of expansion projects that were preceded by additional drilling campaigns. Several drilling campaigns have also been carried out at the Escondida Norte Deposit, also discovered in 1981 (MEL, 2000[A]).

Up until 1997, projections of ore hardness (and % Cu recovery and Cu concentrate

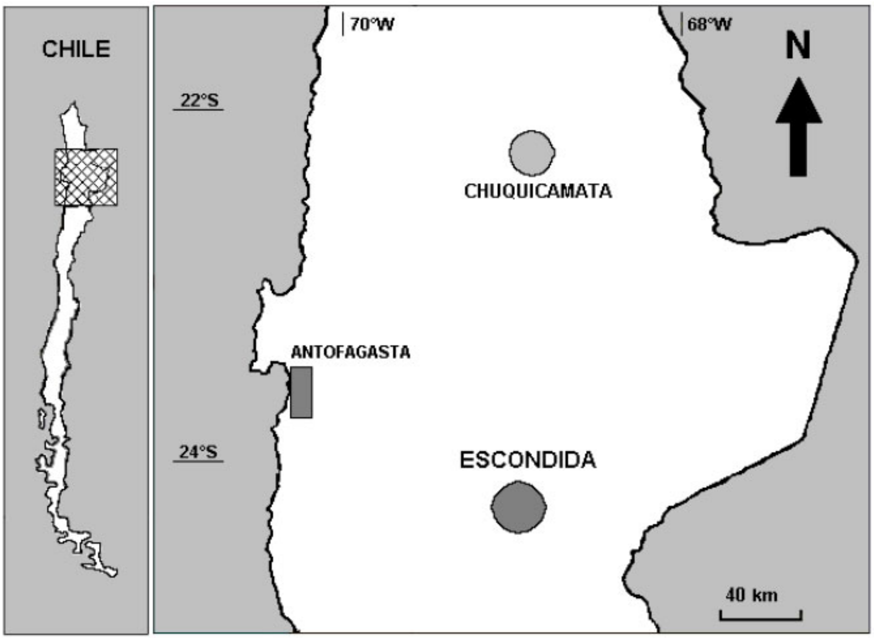

Figure 1: General location of the Escondida deposit in Chile

grade) were made from operating experience in the flotation plant. During this time, most ore treated was a fairly homogeneous porphyry with chalcocite pyrite mineralization and phyllic alteration. As the mine expanded, harder ore was encountered with more difficult metallurgy. This led to the recognition of the need for metallurgical ore definition. A study was initiated in 1998 in which metallurgical ore types were defined based on lithology, mineral zone and clay content. The results of the test work were fed back into the deposit´s block model by assigning average values per block according to its ore type, including Bond work index, % Cu recovery, Cu concentrate grade and % sulphides (MEL, 2000[A]).

Yearly sampling programs provided annual updates to the metallurgical parameters for the ore types defined in 1998. In October 2002, the Laguna Seca Concentrator plant initiated its operations, processing an additional 110,000 metric tonnes per day, based on the Feasibility Report and its Addendum, for the Phase IV Expansion, dated April and July 2000 respectively. This expansion, the increase in the amount of samples with available metallurgical data and the expected increase in complexity of the ore to be processed, motivated Escondida to focus on refining the Geometallurgical models from 2000.

In addition to the Bond Work index test (BWi), the SAG Power Index (SPI), was developed by MinnovEX Technologies Inc. to estimate power requirements of a SAG or AG mill (MinnovEX, 2000[D]). The resulting data was to be used for forecasting throughput in the existing milling operation at the time. The initial programs developed in 1999 (MinnovEX, 1999[A]) and 2000 (MinnovEX, 2000[A]) at Escondida, included BWi and SPI grinding tests on samples from the whole deposit. Subsequent sampling programs aimed to deliver sampling coverage within domains that reflected the ore to be processed in the next yearly periods according to the current mine plans (Flores, 2002[A], 2002[B], 2002[C]).

Several interpolation methods have been tested for the distribution of SPI and BWi data from samples into the block model including nearest neighbour, inverse distance squared, ordinary kriging, multiple indicator kriging and conditional simulation (Systèmes Géostat International, 2001; Preece, 2002[A]). Ordinary kriging was chosen as the method that was easiest to implement, yet provide a reasonably accurate result for monthly mining volumes.

The resulting hardness block models have then been used as inputs to forecast throughput following MinovEx´s CEET - CEET2 model (MinnovEX 2000B, MinnovEX 2001B; Preece, 2001[A]) and Escondida´s MEL BWi model (OrozA, A., 2001; Aguirre, 2002[A]; Bennett, 2002[A]; Contreras, 2002[A]; Oroz, A., 2002; Preece, 2002 , 2002[B] and 2002[C]; Flores and Soto 2003). Although both models may deliver circuit throughput estimates, they present relevant differences in their approach, as the input data and the plant information used as model constraints differ.

Due to sample coverage the Throughput model is designed to forecast on a yearly basis. However, Escondida has performed frequent reconciliation of the model´s performance on a monthly basis. This has been done by the evaluation of the monthly mined out volumes, filtered by a fixed total copper cut off. Escondida´s current practice considers the quarterly evaluation of the model´s performance against plant results, following the same approach as that of the total copper long term model and considering as key performance indicators, values agreed during Escondida´s Geometallurgical Workshop, May 2003 (MEL, 2003[A]).

All stages are summarized in figure 2, from hardness data acquisition, grouping and spatial distribution, process information capture, modeling, and iterative stages of reconciliation, setting of constraints and Throughput ouptpus. It is worth to note the while the reconciliation process and stetting of constraints may sometimes direct iteration towards reviewing the hardness model, it is expected that benefit would normally come from iterations on the Throughput modeling.

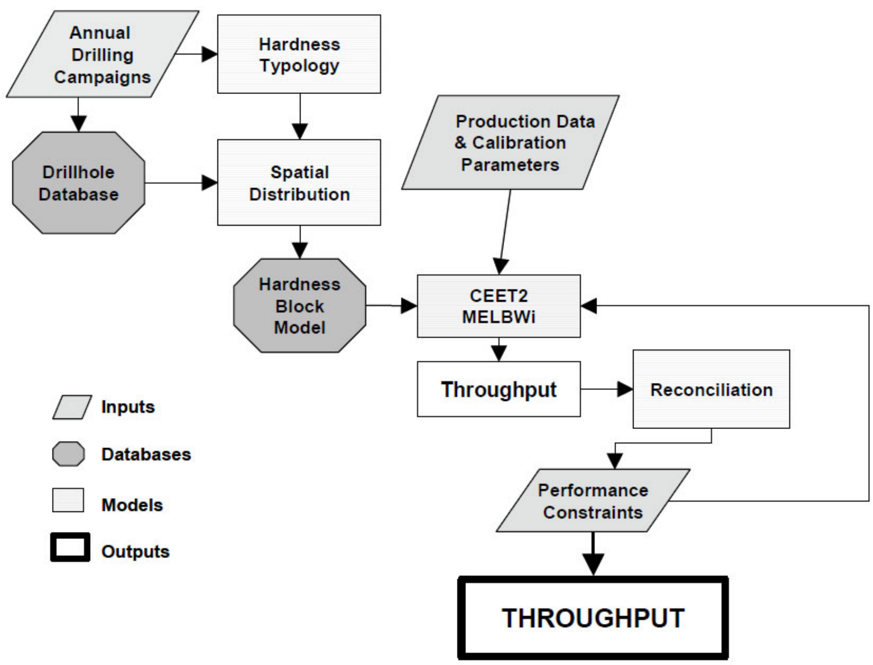

Figure 2: Flowsheet for the updating of the hardness and throughput models

ESCONDIDA´S GEOLOGY

LITHOLOGY

The mineralizing Oligocene porphyritic intrusive (felspar porphyry), the largest contributor of mineralized tonnage in the deposit, exhibits mainly monzonitic to granodioritic composition with a late quartz porphyry of rhyolitic composition, all hosted by andesites. Although not significant in terms of tonnage and ore content, hydrothermal and igneous breccias can be found through the entire deposit, with different grades of mineralization (MEL, 2004[A]). Lithology projected on a shell of the pit and a schematic cross section of the deposit, looking north, are presented in figure 3 below (units are metres).

MINERAL ZONING

The Escondida deposit is a supergene enriched deposit, in which two major stages of sulphide and one stage of oxide mineralization contributed to the formation of the copper ore body. The main copper-bearing minerals are chalcocite (Cu_2S), chalcopyrite ($CuFeS_2$), covellite (CuS), bornite (Cu_5FeS_4) and brochantite/antlerite ($Cu_34(SO_4)[OH]_6$). Chalcopyrite and bornite are typical of hypogene copper mineralization. While bornite is found normally at deeper levels, chalcopyrite is present at shallower levels associated with pyrite and in the lowest portion of the enrichment blanket. The supergene enrichment blanket at Escondida is defined by the presence of chalcocite and minor covellite, with remnant chalcopyrite and pyrite. It has a sub-horizontal shape with marked topography changes at a local scale due mainly to post enrichment faulting and also variable leaching-enrichment. This blanket locally reaches several hundred meters in thickness at Escondida (MEL, 2004[A]).

ALTERATION

The following alteration assemblages have been described as the main ones at Escondida: potassic, biotitic, quartz-sericite, propilitic. Additionally, chloritic, argillic, advanced argillic and siliceous are either late stages, which are overprinted on the main ones, or transitional.

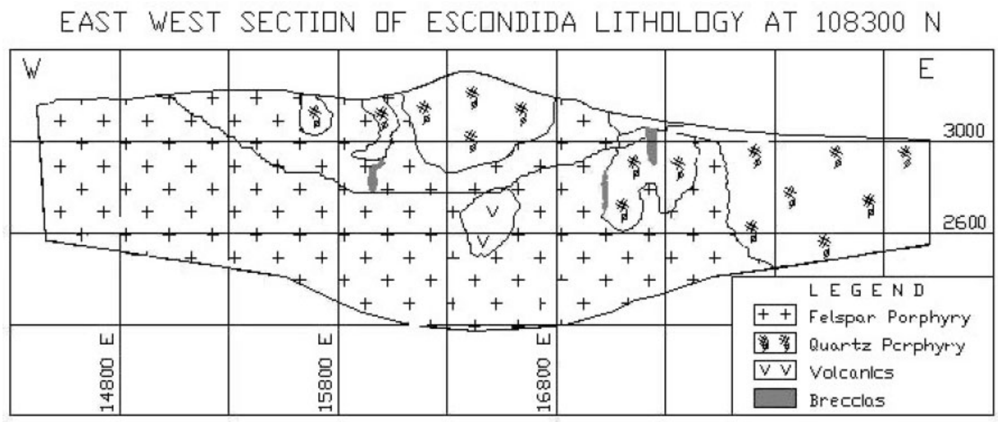

Figure 3: Lithology of Escondida

Potassic alteration represents the earliest stage in the hydrothermal process and preserves the rock texture, introduces K feldspar and quartz and is related to the occurrence of bornite in the deepest zones of the deposit. Biotite alteration is characterized by a change to biotite of the iron and magnesium silicates, especially amphiboles and is best developed in andesite wallrock.
The Sericite-Chlorite-Clay alteration is spatially related to a transition zone between the Biotite and Quartz-Sericite zones. Chloritization of biotite stands as its main feature. The presence of this assemblage is coincident with a drop in copper grade. The Quartz-Sericite alteration is related to the main event of alteration and mineralization in the pophyry system. It may obliterate the rock´s texture completely, appearing as an aggregate of quartz and sericite and it is commonly associated with the best copper grades in the deposit. The Advanced Argillic alteration is related to a later epithermal event, that overprints the porphyritic system and is typically associated with large quartz-sulphide veins. It is spatially related to the higher elevations of the deposit, mainly observed at the northwest portion and secondarily on the eastern zones (MEL, 2002[A]).

HARDNESS TESTS AND SAMPLING COVERAGE

Since the prediction of throughput represents the most critical driver for the current mine planning process, a reliable hardness model is required as input. Routine yearly programmes of drillhole sampling for hardness tests aim to cover the future mining areas. The hardness laboratory tests performed on drill core bench scale composites include Bond Work index (BWi), SAG power index (SPI, a descriptor of power for SAG mills) and Crusher index (a descriptor used to model SAG feed size distribution).

SAMPLING PROGRAMMES

The initial Escondida programmes aimed to cover most of the deposit and included BWi and SPI grinding tests for core. These were named Phase 1 and 2. Subsequent sampling programmes aimed to deliver sampling coverage within domains that reflected the ore to be processed in the next yearly periods according to the current mine plans at the time (Flores, 2002[A], 2002[B], 2002[C]). Programmes were named FY or CY depending on the mine planning period they sample, being this July to June for the former and January to December for the latter. During 2004, 239 samples were selected for CY2006 (Flores et al, 2004). Irregardless of the programme, drillholes are not neccesarily drilled in the same year as the samples were collected for hardness tests. A limit of five years constrains how old a drillhole may be in order to be used in hardness tests. Table 1 summarizes all samples obtained and used in the construction of the 2004(Mar) Hardness Model.

Table 1: Hardness Sampling Programmes at Escondida.

PROGRAMME	REFERENCE REPORT	SAMPLING YEAR	TOTAL	CORE USED	RC USED	TOTAL USED
Phase 1	MinnovEx, 1999[A]	1999	274	262	-	262
Phase 2	MinnovEX, 2000[A]	2000	578	509	-	509
Phase 3	MinnovEX, 2001[A]	2001	210	101	91	192
CY04.5 (4.1)	Flores, 2002A; MinnovRX, 2002[A]	2001	65	65	-	65
Fy03-04 (4.2)	Flores, 2002C; MinnovRX, 2002[B]	2001	56	55	-	55
CY04	Flores, 2002B; MinnovRX, 2002[C]	2002	57	55	90	145
CY05	Flores, 2002A; MinnovRX, 2002[A]	2003	200	200	-	200
Total			1440	1247	181	1428

Figure 4 shows a planview with a projection of Escondida pit as of June 2004 with the sample distribution for all programmes. The main sampling is within the northwestern, central and southeastern areas of the pit, where the sulphide ore has historically been mined out for grinding.

It is Escondida´s common practice, since Septmeber 2001, to ideally sample only core drillholes for hardness tests to be used in long term forecasting. Consequently the majority of the samples used to updated the latest hardness models are from core. Prior to these programs, in 1999, a modified Bond test similar to the MinnovEX modified Bond Work index test was developed and used at Escondida and CIMM laboratories in Chile (Oroz, 2001). It was found that modified full Bond Work index determined by Escondida and CIMM were systematically biased when compared to the modified full Bond Work index measured by MinnovEX. Methods to adjust for this bias have been developed and used (Preece, 2002[A]). For programmes FY2003 and CY2004, additional RC samples were taken for Bond Work index tests (Flores, L., 2002B, MinnovEX, 2001[A] and Preece, 2002[A]).

SAMPLING DENSITY

The actual hardness sampling density used for overall deposit is 100x100x30 metres, with a denser grid of 50x50x15 metres within annual volumes. The total number contained in the mine plan volume that represents the period between years 2004 to 2008 is 978 samples. All of these samples were used to construct the Nov 2003 hardness model for a total of 1.15 billion tonnes. An improved appreciation of the critical need for having this information available and the value it may deliver to the forecasting process has been achieved progressively in Escondida during the last four years. As a result of this, additional test will be undertaken in order to augment the yearly sampling coverage.

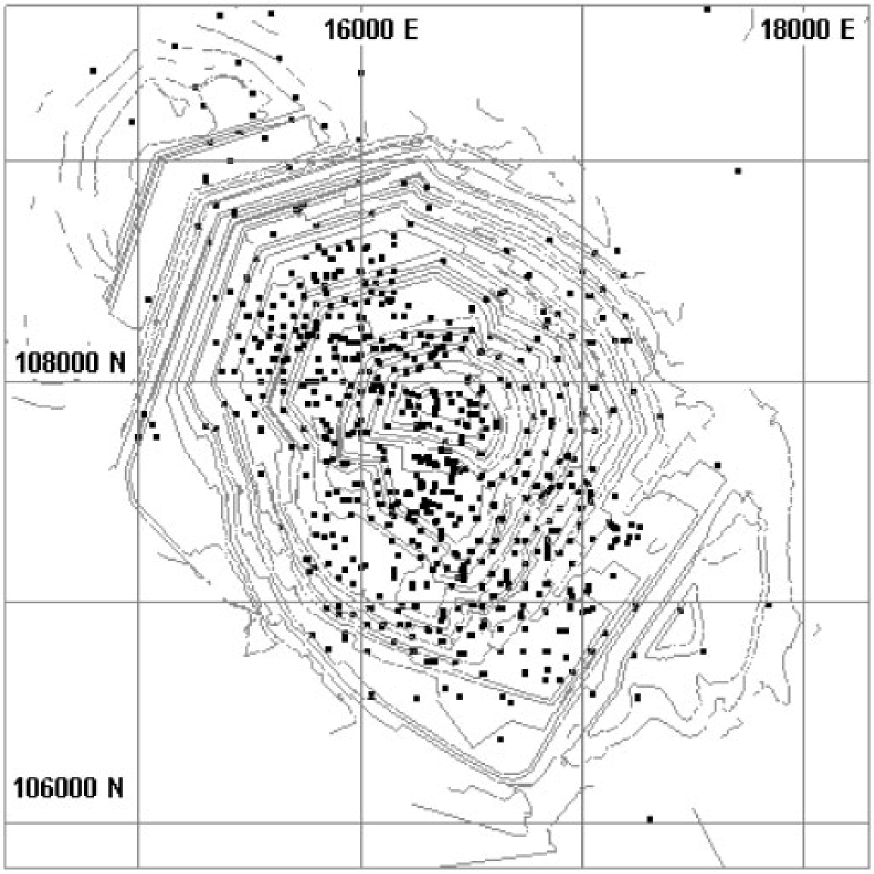

Figure 4: Hardness Samples distribution at Escondida

HARDNESS GROUPS, VARIOGRAPHY AND INTERPOLATION

The process of interpolating these hardness results into a block model requires an appropriate definition of hardness domains, which are likely to be driven by rock characteristics. The historical approach for this domain definition includes but is not limited to, identifying combinations of lithology, rock alteration, mineral zone, and structural domains. Currently, an alternative domain definition uses the PLT (Point Load Test) block model in order to control local variability for BWi and SPI. Interpolation into space of these two hardness descriptors follows ordinary kriging, which yields values used for yearly and five year mine plans. Since the majority of the blocks outside the five-year plan volume, do not have interpolated values, average values for BWi and SPI are assigned. For the last three years, two independent approaches have been used to develop the Throughput (Tph) models used to forecast plant performance. One was developed in house and based on BWi (MEL BWi model) and the other using MinnovEX´s CEET2 software (CEET2 model).

SPI is not a linear function, in that the average of SPI vslues of 50 and 70, for a blended ore is not equal to 60 (Preece, 2002[A], Systèmes Géostat International, 2001). The non-linearity of SPI is well documented from studies on SAG milling of physical mixtures (MinnovEX, 2000[C]). However, a power function (mSPI) used in the SAG specific energy relationship has been shown to be linear in blending studies (Preece, 2002[A] after Dobby, G., 2001, Pers. Comm). Although it has not been demonstrated that the power function of SPI is also linear with respect to interpolation, the fact that CEET2 uses the power function of SPI, rather than SPI itself suggests that the distribution of raw data is better by interpolation of the transformed SPI (Preece, 2002[A]). From the above, averages have been derived and data analyses has been conducted on modified SPI, with SPI calculated from the inverse power function. Bond Work index has been treated as a linear function in analysis and estimation (Preece, 2002[A], Flores and Soto, 2003).

HARDNESS GROUPS AND GLOBAL ASSIGNMENTS

Escondida´s historical approach followed the exploratory data analysis considering combinations of geological features and a reasonbale degree of subgrouping that would preserve geological coherence. A total of 16 hardness groups were distinguished in the exercise, determined by having similar paired means of SPI and BWi (Preece, 2002[A]; Flores and Soto, 2003). Most groups contain a small number of samples, thus segmenting the data too much for use in variography and interpolation. Instead, these hardness groups of global averages, were used for assignments to assure that long-term mine planning exercises would have complete throughput models (Preece, 2002[A]).

In the current approach, the hardness group definition is based upon similar domaining, although a calculation of a declustering factor was introduced in order to obtain global averages that would honour more appropriately the local sample density. Closely spaced sampling of certain areas, particularly those located at the centre of the deposit, has occurred at Escondida. Thus, the characterization of the different groups includes declustering of the drill hole composite data set in order to obtain a set of unbiased statistics from the current drilling pattern (MEL, 2004[A]). These averages are presented in table 2 below for the main 12 groups (out of 16 in total). BWi is presented in Kilowatt-hour per metric tonne and SPI is in minutes.

Table 2: Hardness Groups in the Hardness Model Update at Escondida

MARCH 2004 DECLUSTERED AVERAGES			
HARDNESS GROUP	# SAMPLES	AVERAGE Bwi	AVERAGE Spi
1	19	9.8	35.1
2	33	10.9	42.9
3	21	14.2	76.3
4	205	11.3	35.6
5	132	12.4	38.6
6	390	13.2	45.3
7	214	13	48.5
8	16	12.1	54.3
9	81	14.6	72.3
10	59	13.2	67.2
12	18	12.7	42
14	21	15	71.3

In groups 1 to 8 and 12, the deculstered averages are within 10% of clustered averages used in the previous exercise. In groups 9, 10 and 14 however, the declustered averages are higher for SPI only or for both SPI and BWi. While the current sampling programmes aims to avoid clusters of oversampling, especially within the upcoming year periods, these clusters may still be observed when a comparison of sampling density is performed on the next year, five years and life of mine periods. This sample density condition corresponds to a compromise between expenditure and the best sampling representation possible in the immediate upcoming years and a wider spaced grid for the years beyond the mid-term five year period.

VARIOGRAM MODELS AND ESTIMATION DOMAINS

The increasing quantity of data provided by each year´s sampling programme has allowed the development of variograms for the hardness descriptor, in particular BWi and the power function of SPI, mSPI. The variogram is a measure of the continuity of spatial phenomena expressed as an average squared difference between measured quantities at different locations (Bailey and and Gatrell, 1995). It may be understood as a quantitative descriptive statistic that can be graphically represented in a manner which characterizes the spatial continuity of the data set (Warden, 2003). The main challenge for the hardness variogram construction is the irregular sampling density available depending on which zone of the deposit is to be characterized. Two variogram models were explored in the 2001 model (Preece, 2002[A]). However, since 2002 only the Escondida in house model has been used, which is actually a correlogram model instead. The correlogram transform was used to estimate mSPI and BWi variography, which corrects for changing means and variances at variance lag distances. Correlograms were checked against normal variograms, and were found to show nearly identical features but were a little easier to interpret (Preece, 2002[A], Flores and Soto, 2003).

In Models 2001(Feb 2002), 2002(Oct), 2003(Nov) and 2004(Mar), data was subdivided into structural zones 1 + 4 and 2 + 3 to determine if local domains were significantly different from the global variograms. Structural zones 1 + 4 consist largely of granodiorite porphyry altered to QS, while zones 2 + 3 contain much of the andesite and nearly all of the SCC alteration. While the low number of samples contained in zones 2 + 3 has made it difficult to obtain a variogram, it appears that the variograms in the zones are different enough to warrant separate variograms (Preece, 2004[A], 2004[B] and 2002[A], Flores and Soto, 2003).

In models 2001(Feb 2002) and 2002(Oct) structural zones 1 + 4 combined into a single kriging unit, while those from zones 2 + 3 combined into a second kriging unit (Preece, 2002[A]). In models 2003(Nov) and 2004(Mar) a different approach was followed in order to improve the previous models and expecting to better characterize the estimation domains. While potassically altered lithologies have long been established as "hard", classic qualitative designations in lithology, alteration, and mineral type have not been successful in subdividing softer material (Preece, 2004[B]). A geotechnical block model based the Oct 02 geological model was constructed in July 2003 by the Escondida geotechnical and resource estimation staff. Geotechnical parameters include material hardness estimated by drill core Point Load Tests (PLT), and uniaxial compressive strength tests (UCS) (Preece, 2003[A], Soto and Elgueta, 2003). From discussions with the engineers and geologists responsible for the PLT model and being the first one ever built in Escondida, some challenges existed about its coherence, integrity and robustness (Soto, Luis, pers. Comm.). Nevertheless, the model appears to provide a satisfactory prediction of material properties for purposes of production blasting. This suggested that PLT/UCS modelling might provide Aquantitative definitions of hardness domains useful in predicting SPI and BWi (Preece, 2003).

This PLT model allowed for the definition of four hardness domains that were assigned to the Nov 03 geometallurgical

Table 3: Kriging Plan for March 2003 Hardness Model Update at Escondida.

		PRIMARY SEARCH (METRES)						KRIGING MODELS
		LIMITING PRISM			MAX. DISTANCES			
HARDNESS DOMAINS		X	Y	Z	MAX DISTANCE FROM BLOCK CENTRE	MAX DISTANCE FROM CLOSEST COMPOSITE	MAX DISTANCE TO CLOSEST	
1	PLT in [0, 20] percentile	200	200	60	200	150	50	1
2	PLT in [20, 80] percentile	200	200	60	200	150	50	2
3	PLT in [80, 100] percentile	200	200	60	200	150	50	3
4	Potasic in Porphyry or Andesite	200	200	60	200	150	50	4

		VARIOGRAM PARAMETERS (FEET AND DEGREES)							
		MODEL TYPE	C_0	FIRST STRUCTURE			SECOND STRUCTURE		
KRIGING MODELS				C_1	$0_1/0_2/0_3$	$Y^1/X^1/Z^1$	C_2	$0_1/0_2/0_3$	$Y^1/X^1/Z^1$
1	Str Domain 1 + 4: Bwi	SPH	0.28	0.377	-142/14/15	19/13/70	0.343	13/-9/3	283/1463/72
2	Str Domain 1 + 4: mSPI	SPH	0.39	0.401	17/-31/-47	40/76/22	0.209	51/-15/11	600/728/52
3	Str Domain 2 + 3: Bwi	SPH	0.255	0.509	18/-62/-30	35/112/27	0.236	-7/-32/-2	69/130/67
4	Str Domain 2 + 3: mSPI	SPH	0.25	0.496	42/-27/-38	15/22/59	0.254	-1/-17/0	120/90/60

Search ellipse comprises a secondary search volume within the primary search prism defined by:
Rotation angles 1: clockwise around Z looking down; 2: clockwise around X' ; and 3: clockwise around Y'

model using the June 03 point load test block model and Oct 03 lithology/alteration model.

- 20th and 80th percentiles of PLT defined soft, medium, and hard domains in QSA and SCC alteration
- Potassic alteration in porphyry and andesite irregardless of estimated PLT defined the fourth domain (Preece, 2003[A]).

KRIGING PLANS AND INTERPOLATION

In the 2003(Nov) model mSPI and BWi were kriged in two passes using the Oct 2002 variograms and kriging plans (Preece, 2003[A]). For the 2004(Mar) model, while new variograms were developed in order to address the inclusion of additional hardness results from 200 samples, the same four hardness domains described above were used. Four runs were used for mSPI and four for BWi, within each of the four hardness domains and using the variogram models by structural zone. A requirement for interpolating a block was set at a minimum of one and a maximum of eight samples with up to two samples per drillhole. Table 3 below summarizes the overall krigging plan used in the 2004(Mar) model.

HARDNESS MODEL

A permanent challenge at Escondida has been to appropriately model the very hard ore zones, with the mentioned sample spacing as an important constraint. While it is expected that some smoothing will be produced by the interpolation, the main focus has been to preserve the local variability and honour especially the few samples that actually show very high SPI and or BWi values. The change in methodology (use of PLT Model) for the definition of the hardness domains for interpolation, had an important impact in the distribution of hardness values. Between models 2002 and 2003, there exists an offset towards higher values in the SPI and BWi distribution. It is quite relevant in the case of SPI since values of 55 minutes set a threshold for SAG limitations in Escondida and the change between the two models is pronounced at SPI values of 60 minutes and above. In the case of BWi, while the critical value

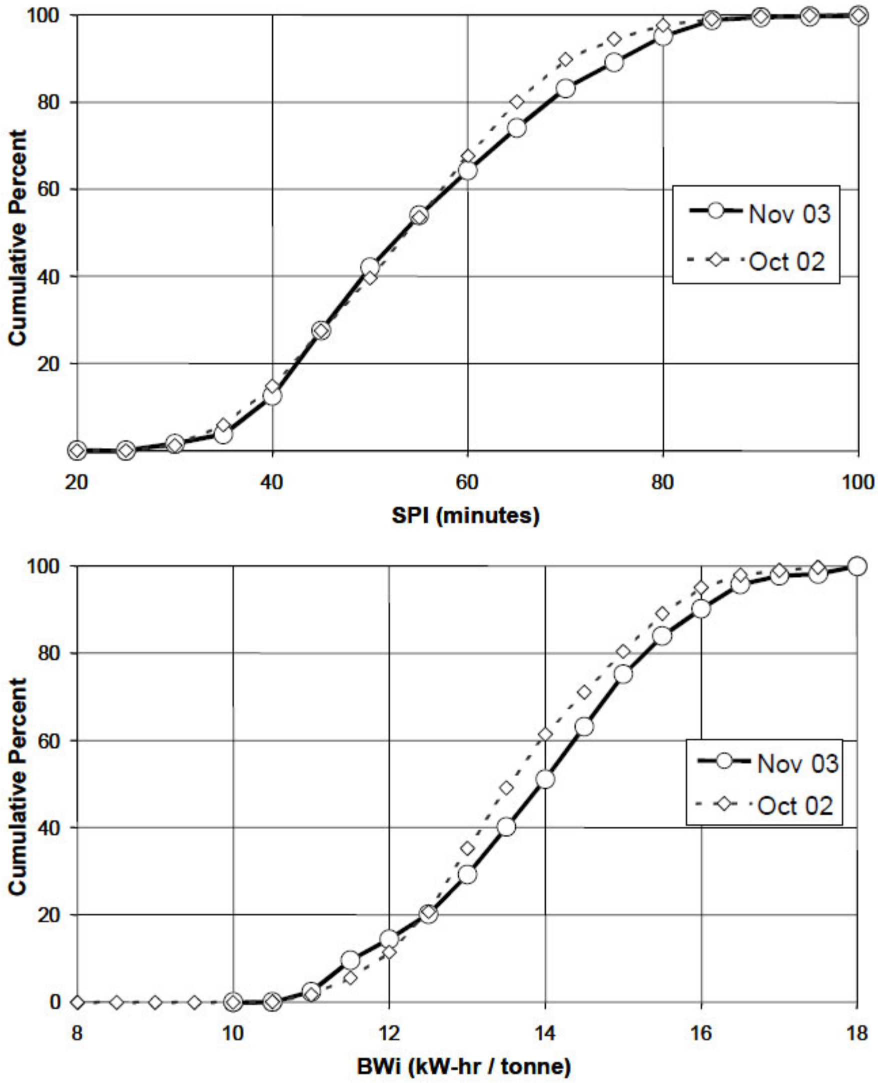

Figure 5: Distributions of SPI and BWi from 2002 and 2003 Hardness Models (after Preece, 2004[B])

is 14.0 Kw- hr/tonne, the difference in the distributions appears at 13.0 Kw-hr/tonne. See figure 5 below for a graphical representation.

Although originally conceived for long term strategic purposes, in the absence of a shorter term model, Escondida has chosen to have the hardness model also provide information for quarterly, and even monthly purposes. The new spatial definition of the model, showing more hard ore and producing less smoothing, as presented in the distributions above, will help maintain the operation informed of but not at the weekly level of detail, of possible bottleneck periods. From year 2000, it was observed that the model did predict hard ores within the original definition of one year. However, the expectation of performance at weekly or monthly periods is in fact, very demanding and unrealistic at the current sampling density.

CRUSHER INDEX (CI)

The development of a crusher index allowed for the direct estimation of the SAG feed size distribution for a given sample (Preece, 2001[A]). The development of this laboratory test followed that of SPI and thus the availability of Crusher Index data on Escondida samples was very limited. Since the 2001(Feb 2002) model, the requirement of maintaining the same systematic relationship between SPI and BWi also applied to Ci and SPI. This meant that if Ci was to be interpolated, only those samples with the Ci, SPI, BWi triplet were to be used for the interpolation (Preece, 2002[A]). This was not accepted since enough samples were in fact available for the interpolation of the duplet SPI-BWi. Instead, in models 2001(Feb 2002), 2002(Oct), 2003(Nov) the Crusher Index was derived from SPI.

Tests conducted by MinnovEX on a large number of samples from several deposits show that SPI and Ci are inversely related to each other (Preece, 2002[A] after G. Dobby, pers. comm.). It was suggested that a linear regression fAit on available Ci - mSPI pairs could be used to estimate missing crusher indices (Preece, 2002). While a unique regression was used in the 2001(Feb 2002) model, two regressions were used in 2002(Oct), 2003(Nov) models, one for porphyry and one for andesite. For the current 2004(Mar) model, enough Ci results were available in order to conduct an interpolation and refine the regression equations to be used in areas were interpolation was not granted by sample availability.

The relationship between SPI and Ci that is seen in the drill hole data seems to be well reproduced in the block model. On a local basis, the crusher index doesn't seem to always honor the local data, but the worst areas are where there are missing Ci values in the drillhole data base (early programmes, Phases 1 and 2). It is suspected, that in those areas where poor spatial relationships of the Ci drillhole data and Ci in blocks exist, inaccurate SPI-Ci relationships will be present (Preece, 2004[C]).

THROUGHPUT MODELS

Two throughput models have been developed at Escondida since 2001(Preece, 2004C ; Flores and Soto, 2003; Bennett, 2002):

- CEET2 model developed by MinnovEX
- MEL BWi developed by Escondida

In terms of the hardness information used as input, the main difference between both models is that CEET2 uses SPI, BWi and Ci while the MEL model uses only BWi. CEET2 uses Ci and SPI to model the F80, feed size to SAG (Preece, 2001[A]) and MEL BWi calculates F80 as a function of rock type (Contreras and Flores 2003). For the 2003 (Nov) MEL BWi model, the grind circuit product size (P80), is derived from an equation that uses BWi from each block in the model, subsequently capped to a maximum value (Contreras and Flores 2003). Differently enough, in CEET2, several approaches have been used, including a)operating with a P80 average and a variable P80 maximum never exceeding an upper limit value and b) with a P80 maximum (Bennett, 2002). The major difference between the CEET2 and MEL BWi models in terms of output is that for the same hardness input data, the MEL model delivers only one throughput value while CEET2 may deliver different values subject to how the operation is conceived in terms of target product size.

The MEL model is an empirically derived model, which uses all plant settings in the calibration period, such as SAG grate and screen openings, pebble crusher products PC50 and PC80, primary crusher close side setting. However, while only the SAG and Ball Mill power draws and their drive efficiencies are specified, the rest of the settings are embeded into the scalar factors.

The CEET2 model does specify all considerations regarding plant operation such as described above and also, but not limited to the operation policy for P80, pebble crushers, the bond correction factor (MinnovEx, 2003) and the benchmark information used to tune CEET2 to actual plant operation at Escondida (MinnovEX, 2003c).

Calibration for the 2001(Feb02), 2002 (Oct) (Preece, 2004C ; Flores and Soto, 2003; Bennett, 2002) and 2003 (Nov) throughput models used model hardness and plant production data for 12, 6 and 16 months, respectively.

A summary of the information described above, required as input in both CEET2 and MEL throughput models is presented in table 4 below.

Table 4: Summary of the input information used in CEET2 and MEL throughout models

	PLANT OPERATION INPUTS											
	Grate size [mm]	Screen size [mm]	SAG Circuit max power [KW]	Sag Drive efficiency	Ball Circuit max power [KW]	Ball Drive efficiency	TpH max [tonne/hr]	Target for Aveg P80 [µ]	Pebble Crusher PC50 [mm]	Pebble Crusher PC80 [mm]	Primary Crusher CSS [mm]	Bond Correction Factor
CEET2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
MEL			Yes	Yes	Yes	Yes	Yes					

	Hardness Inputs				Copper Inputs	
	Spi [mm]	Bwi [Kw=hr/tonne]	Ci	Sg [tonne/m3]	Tcu [%tot copper]	Codmat [material code]
CEET2	Yes	Yes	Yes	Yes	Yes	Yes
MEL		Yes			Yes	Yes

The MEL BWi throughput model is run directly in the software that hosts the hardness block model in Escondida´s servers (Vulcan) with reconciliation as the final step in the process. The CEET2 model is run on MinnovEX´s server and requires an input file with hardness data from the Vulcan model, which is uploaded to MinnovEX´s server as excell or ascii. The CEET2 result, is downloaded as a throughput model to one of Escondida´s servers. Finally it is uploaded into the Vulcan block model for reconciliation. Although additional steps are required to run CEET2, the overall run time required to have a Vulcan block model ready for reconciliation is equivalent. This allows for a forecasting exercise with Escondida yearly mine plans and life of mine plan to be completed within one day, irregardless of using CEET2 or MEL BWi throughput models.

In order to understand the outcome of the throughput models, an evaluation by period was made (month, quarter, year) and subsequent to that a reconciliation against plant performance. Two outstanding constrains arised when analyzing Escondida´s throughput models. One is the dependency of the throughput model outcome when it is evaluated within the mine plan volumes and in addition to that, how reliable the plant operation information is. An exercise was done in order to compare distribution of values within Fiscal year 2003 using a single mine plan in order to understand the influence of the hardness model and plan operation only. Three configurations were used and actual plant production instead of recalculated throughput was used.

- The Oct02 Model and Oct02 Plant configuration (Forecast)
- The Nov03 Model and Oct02 Plant configuration (Forecast)
- The Nov03 Model and the actual FY03 Plant configuration (Actual)

In figure 6 (previous page), the Oct 2002 model shows a higher percent of values below 5,400 Tph than the Nov 2003 model. The large difference between plant and models comes from not using recalulated throughputs.

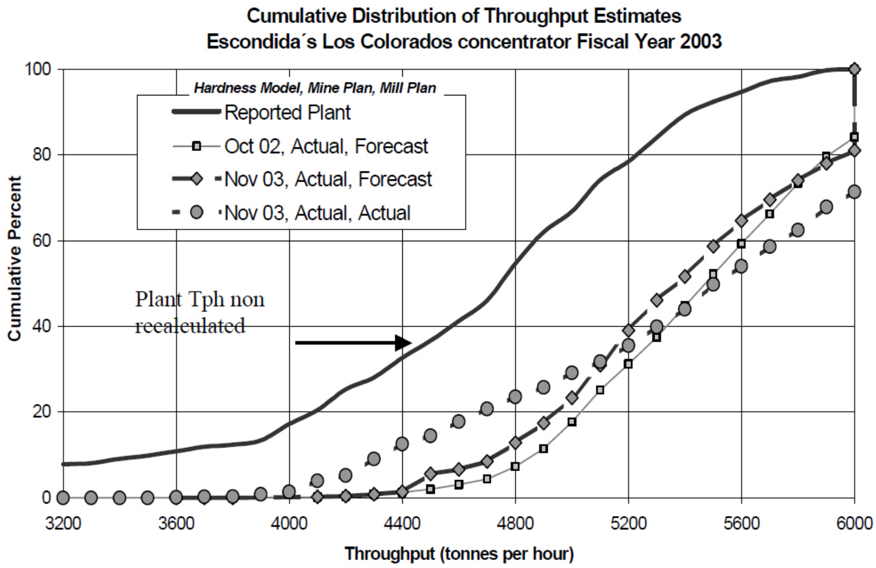

Figure 6: Tph Estimates for Escondida´s Los Colorados Concentrator FY2003 (after Preece, 2004 [c])

All of the throughput estimates used exactly the same hardness data, therefore investigates the effect of the interpolation model (Oct02 vs. Nov03) and actual versus planned operating conditions within the plant.

The 2 curves presented for Nov 2003 are significantly different both above and below 5,100 Tph. The "Actual, Actual" curve is the best representation of the control given by the current Hardness model in term of local variability, prevention or over-smoothing and a correct use of plant configuration that will not overestimate large tonnages with high throughput as may be observed for values below 5,100 Tph. For instance, at 20% it yields values of 4,700 Tph when the "Actual, Forecast" yields 5,000 Tph, approximately 5,500 tonne per day higher which is significant for a 110,000-120,000 tonne per day operation.

The major difference is created by the Plant Operation configuration. The approach for the model had been incorrect in Escondida until the Nov2003 model. Until then it was accepted the use of key performance indicators (KPI) or expected plant configuration parameters as input to CEET2 or any model. Outstanding progress was achieved for the Nov2003 Throughput model because the Plant Operation parameters provided by the concentrators were in fact their best estimation of how the plant would run during July04-June05.

The forecasting exercise needs to be kept updated, specially every time there is a configuration change in the plant with potential impact to Tph such as but not limited to those detailed in table 4 above. Otherwise it is likely that the forecasting process looses validity even for mid to long term planning.

PLANT LIMITATIONS AND THROUGHPUT RESTRICTIONS

Since both models use plant operational specifications, the choice of values such as grind size and mill power is critical since it may severely impact the models' outputs. Before 2003, the reconciliation of Tph compared the block model evaluation within monthly volumes, against actual plant performance. Detailed analysis of plant tonnage restrictions has shown that throughput is often limited by plant operational problems which are not necessarily related to ore hardness. In such cases a recalculated Tph is provided for reconciliation against the block model evaluation.

In November 2001, for the first time operational data was used for model tuning and considerable effort was needed to obtain "clean", and validate the neccesary data. This includes eliminating data affected by sensor malfunction, equipment downtime, converting to the appropriate unit, for instance shell power instead of meter power (Bennett, 2002A, MinnovEX, 2003B). Escondida´s practice since 2003 has been to account for any limitations in throughput that are not subject to ore hardness but instead, that respond to plant conditions such as, but not limited to, stockpile problems, SAG feed blockage, unscheduled Ball mill stops, pebble crushers and tailings thickeners problems. The first exercise covered three months and looked at limitations per day´s of operation, all of which added to a throughput value that is not likely to be forcasted by the model. This means that on any day, should a ball mill undergo an unschedulled stop which limited throughput in 1,000 tonne, that tonnage would be accounted for in order to reconcile the forecast with actual production. In that particular example, that tonnage would be added to the actual plant throughput. Figure 7 presents a summary of 80% of plant limitations at Escondida´s Los Colorados concentrator between July and September 2003. Note how stockpile and SAG blocking add up to one third of the limitations. The existance of unassigned events that limit throughput, suggest that room for improving operation control exists. Ball mill, pebble and thickener problems contribute to over 15%.

This analysis is kept updated monthly so that reconciliation is now done against Recalculated throughput values as oposed to actual plant throughput.

RECONCILIATION

The throughput model is conceived as a long term models and giving the sample availability, it is expected to perform on a yearly basis within ± 3%. Although demaning for a long term model, it has also been expected that thise model performs in quarterly periods to within ± 10%. The current model performance is within ± 2% and ± 5%, yearly and quarterly respectively.

Reconciliation for three models is discussed below, 2001(Feb 2002), 2002(Oct) and 2003(Nov). As discussed above, prior to 2003, the reconciliation compared the model forecast vesus the actual plant throughput, on a monthly basis. Additionally, parameters used as operational inputs to CEET2 and MEL BWi were both KPI. The results showed a dramatic overestimation on some specific months. Month to month divergence quite often exceeded 10% and the overall year results were not satisfactory. Until June 2003 there had been neither an agreement reached at Escondida with respect to the precision expectancy for the throughput model, nor did the organisation develop an understanding of what might be expected of a long term model such as the one available. Consequently, the throughput model performance was judged on a monthly or even, weekly and daily basis. This incorrect approach led to a loss of confidence in the model. Strong effort was invested from July 2003 in order to ensure greater team work between process engineers and geologists and significant progress was reached for the 2003(Nov) model. All operational information from the plant was corrected for the reconciliation stage and was the best estimation of how the plant was going to be operated in the mid term future. This, in addition to the development of the updated hardness model led to completing an improved an accepted Throughput model in November 2003. This effort received the support from MinnovEX for CEET2 and Escondida´s engineers and geologists finally developed a well informed opinion of what CEET2 was able to do in terms of forecasting, considering the available data. Furthermore, even though the throughput model´s performance is quite good on a monthly basis, it is accepted that while this model is intended to perform on a quarterly and yearly basis, its prediction must be considered only an indication of the throughput for shorter term planning.

Figure 8 below shows the evolution of the 2001(Feb) and 2002(Oct) models and their forecasting capabilities against actual plant throughput. The Oct01CEET2 model, when compared to actual plant throughput, was overestimating systematically with the exception of the period January to August 2001 however, the 2002 model exhibits an overall better fit. Neither model was able to perform well from September 2001, showing strong overestimations. The MEL BWi models also presented significant changes from one version to the following. While the Oct01 version performed well until august 2001, the 2002 version was systematically underestimating throughput. Similarly with CEET2, neither model predicted the very strong drop in throughput observed in the plant. In fact the MEL BWi 2002 model is insensitive and presents a very narrow band of monthly variability around 5,400 tonnes per hour.

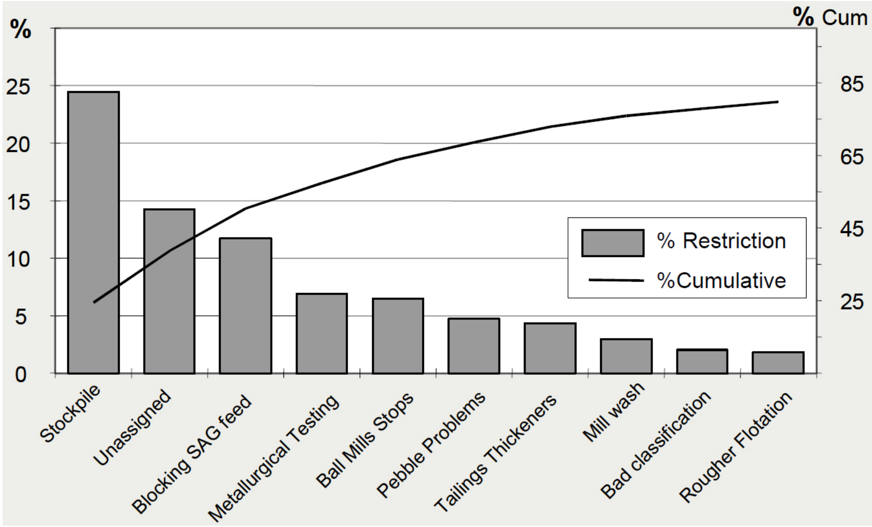

Figure 7: 80% of Los Colorados limitations not due to Ore hardness with impact Tph MEL Jul-Sep '03

The 2003(Nov) throughput model on the other hand, meets the required precision of ± 3% yearly and ± 10% quarterly. This model however is reconciled against recalculated plant throughputs.

Note specially that in November 2002 and during the period November 2003 to January 2004, there exists a significant difference between actual and recalculated throughputs, with the latter always higher (see figure 9). This means that for those months, the past approach for reconciliation would have shown strong overestimation. Today, this approach is indeed no longer followed, nevertheless, it misled Escondida´s team in seeking explanations for the poor forecasting capabilities of the throughput model in the wrong places.

Significant operational improvements have taken place in the Los Colorados concentator which came in evidence since November 2003, when throughput underwent a persistent increase for several months. This is remarkable given that the natural development of the Escondida pit exposes rocks that are likely to be as hard or even harder than those crushed and milled during the history of the operation. Figure 9 shows that the model starts underestimating systematically since Februay 2004. This again, is a very good example of the impact that an appropriate use from plant operational information will have on the outcome of the throughput model. The model presented in figure 9 has not been updated for February 2004, in order to show the described effect, largely related to pebble crusher operational improvements.

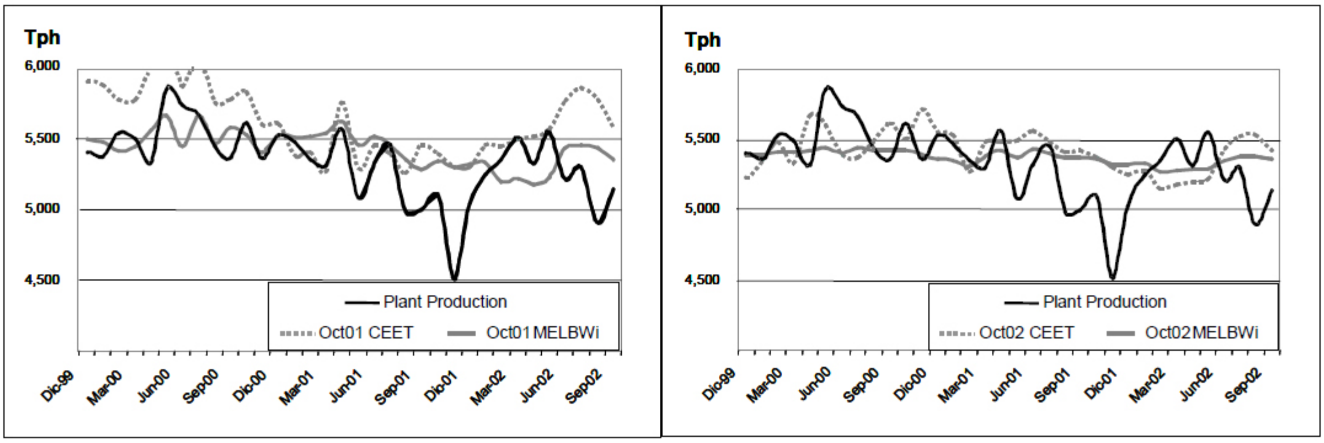

Figure 8: OCT 2001 and 2002 CEET and MEL BWi reconciliation against actual plant throughput

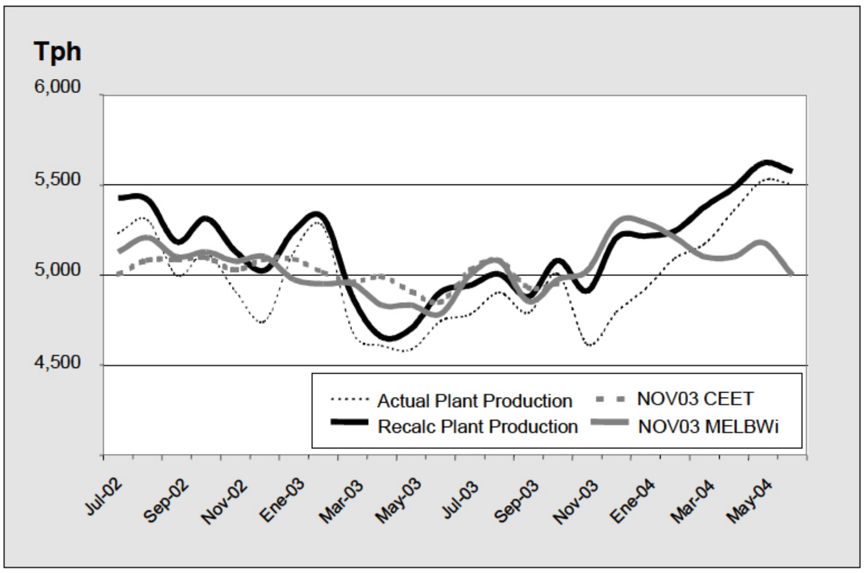

Figure 9: NOV 03 CEET and MEL BWi reconciliation against recalculated and actual plant tph

The precision of this model is presented in figure 10 below. The yearly moving average stays within the ± 3% band until May 2004, while the quarterly moving average stays within ± 10% although the model starts presenting a negative bias after March 2004.

FUTURE

The fine forecasting capability shown by the current throughput model during 2003, is a result of Escondida´s profound commitment to team work, operational excellence and innovative thinking.
The future scenario includes two pits delivering ore to five primary crushers; two concentrators, one acid leach and one sulphide leach plant. The operational complexity rising form this, demands the development of hardness and throughput models that are supportive of the short term planning for day-to-day operation, within acceptable performance limits.
In order to acomplish this, permanent efforts will be required to maintain good practices and search for creative and practical improvements. Concordantly, the development and maintainance of one or more throughput models, require a well informed understanding of the purpose for which they are conceived and their limitations, particularly they time frame they should be expected to perform in.

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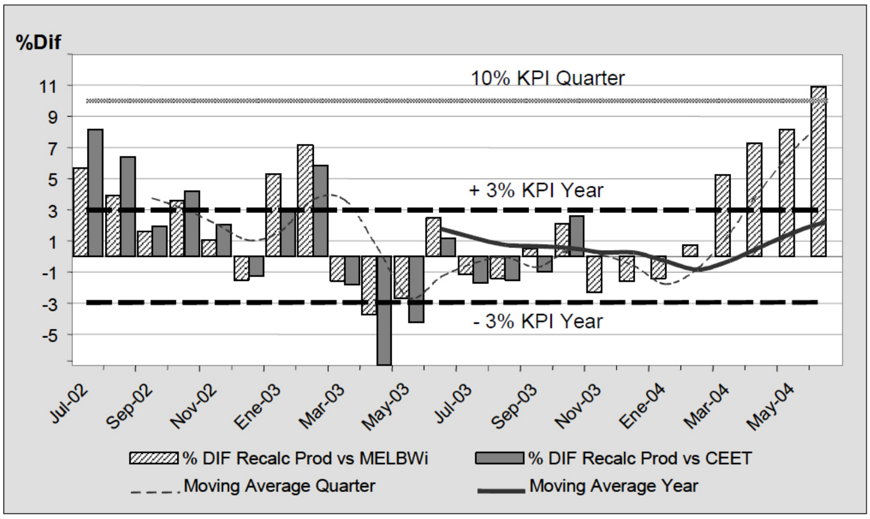

Figure 10: NOV 2003 CEET2 and MEL BWi model performance

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