

Optimisation of metallurgical plant sampling procedures at the Macraes gold mine

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Abstract

History of mineral processing at Macraes shows a consistent trend of decreasing grade and increasing mineral complexity. Since the plant was commissioned, significant changes to the metallurgical process have occurred. However, the sampling systems and approach have not significantly changed over the same time period. As a result the once ‘fit for purpose’ sampling strategy was suspected to no longer be appropriate in many cases.

Accurate and precise sampling of product streams is critical for good metal accounting and reconciliations. Having confidence in the information on the grade of a process stream is critical for process control and optimisation in the metallurgical plant.

At Macraes, the evaluation of sampling and measuring stations through an assessment of sampling tools, procedures, accuracy and precision allowed the detailed mapping of points where improvements can be made. Cost-benefit analyses for each improvement give management a strong set of tools to methodically tackle the issues and improve the reconciliation and metal accounting, one step at a time.

Detailed assessments have revealed a list of issues that affect accuracy of sampling stations. At some sampling and measuring points a bias was able to be identified. The measurement of tonnes is an example and addressing these issues has made a notable impact on reconciliation and metal accounting.

Chronostatistics have been useful in determining sources of variance and have allowed a systematic approach to map out the tenor of variance across the entire processing plant. This revealed several sampling stations where the variance was out of control and the sampling tool was not giving fit-for-purpose results. Improvements identified and implemented include more stringent operating procedures and equipment upgrades. The result has been an increase in the accuracy and precision of the measurement being taken for gold accounting and allocation to the separate business units.

Keywords: plant sampling, chronostatistics, Macraes, gold, accuracy, precision.

Introduction

The Macraes processing plant treats various ore sources from underground and open pits within the Macraes gold mine, as well as concentrate from the Reefton gold mine on the West Coast of NZ. It is important to determine the economic viability and performance for each business unit against the resource by correctly allocating gold through metallurgical accounting. Macraes currently takes 98 samples from various points in the process streams with the objective to provide grade and tonnage information for process control, metal accounting and reconciliation purposes.

Using sampling data for which neither the precision nor accuracy is understood carries significant risks for the metal accounting, and ultimately affects the bottom line of the entire

business. Through much of the mine's operating history, for many important sample points the default assumption has been that they perform well enough for their intended purpose.

This paper shows how Macraes has established the representivity of sample and measuring points in the plant, in order to determine for each point whether it is 'fit for purpose'. Where issues were identified, a path of improvement was implemented. In this paper two examples are used to illustrate this process, the first is the mill feed tonnes (MFT) and the second is the gold grade determination of the final float tail (FFT).

This methodology of continuous data point management has led and will continue to lead to a higher confidence in the metallurgical accounting and performance of the process plant.

History of Macraes process operation

Decreasing gold grade

In 1992 Macraes commenced sulphide flotation, floating pyrite and arsenopyrite as the majority of the gold was hosted in these minerals. The ore was finely ground and leached using the Carbon in Leach (CIL) process. The feed grade in these early days was approximately 2 g/t, however, in 2014 the feed grade is half that (Fig. 1). The FFT grade follows a similar pattern moving from 0.2 g/t in 1992 to less than 0.13 g/t in 2014 as shown in Fig. 1.

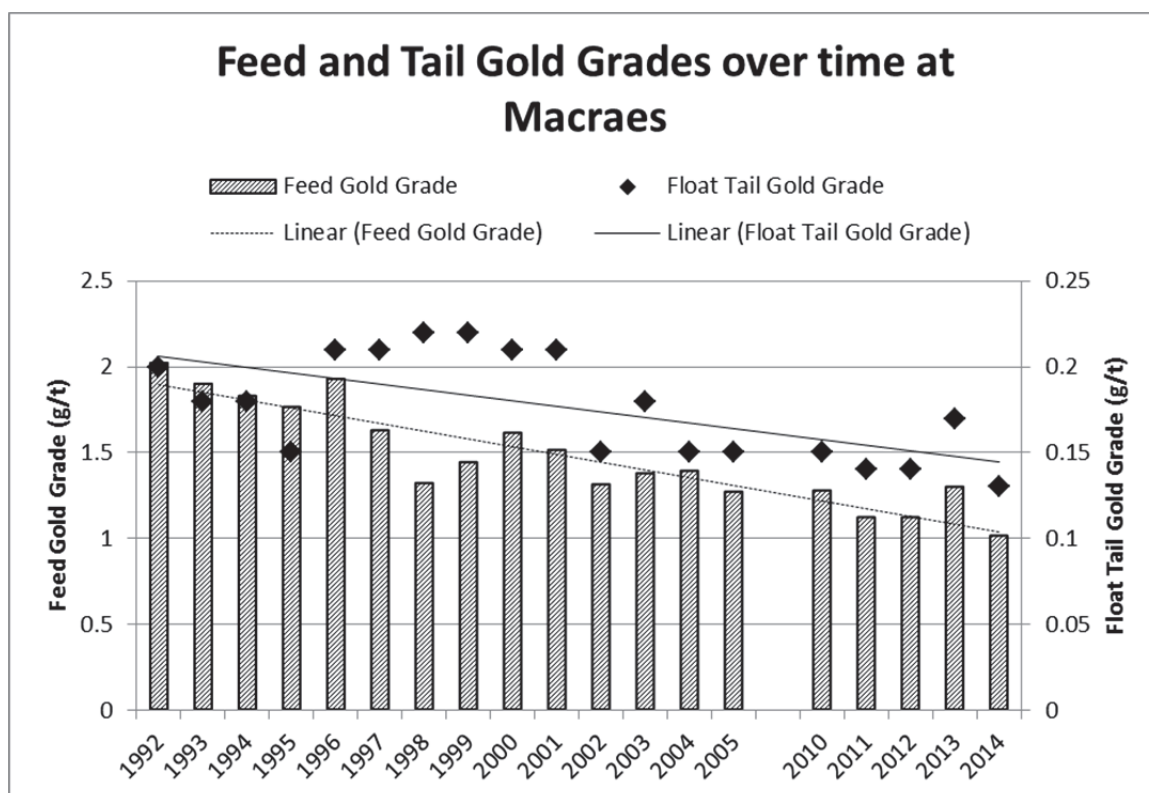


Figure 1. Feed and Tail gold grades from 1992 – 2014 Macraes Processing Plant.

Changing process design

The Macraes processing plant is primarily a sulphide treatment plant. The ore is ground to liberate the sulphide minerals of pyrite and arsenopyrite and once liberated these minerals are recovered using selective froth flotation. The majority of the gold is closely associated with these minerals and is recovered alongside the pyrite and arsenopyrite. The gold typically occurs as micrometre scale particles of gold wedged into the sulphide minerals (Petrie et al., 2005).

The geology and mineralogy changes along strike of the Hyde-Macraes Shear Zone, as well as down-dip, which has an effect on how the gold is most effectively recovered. To maximise the gold recovery, the metallurgical process has changed since the commissioning of the plant in 1990. For instance, during the period 1992 to 1995, economical proportions of gravity recoverable gold were present and hence gravity extraction was part of the process. During this same period it was identified that significant losses were occurring due to unselective grinding resulting in the generation of fine ($<10\text{ }\mu\text{m}$) sulphides. To resolve this issue, a process called flash flotation was implemented. In this process, coarse cyclone underflow material is fed to the flash flotation before it heads back to the grinding mills for further grinding. This had a significantly positive impact on recovery, however, made determining mill feed grade more complicated and involving more sampling and calculations.

Over the period 1995 to 1998 the gold distributed in the sulphides increased in fineness, and the gravity recoverable proportion diminished. As a result, the proportion of the gold not being liberated sufficiently to be recovered with cyanide leaching increased (approximately 30%). Fine grinding of the flotation concentrate was introduced (90% passing $15\text{ }\mu\text{m}$), but even at these comminution levels the recovery became increasingly uneconomic at lower gold prices. Pressure Oxidation (POX) was added to the process in 1998. Pressure oxidation oxidises the sulphide minerals breaking the crystal structures of the pyrite and arsenopyrite enabling cyanide to access the fine gold. The result was significant, improvements in gold recoveries in the cyanide leaching circuit increasing from $75\% \pm 2\%$ to a respectable $97\% \pm 2\%$.

In 2007, Reefion concentrate was included in the Macraes process and this is treated on a campaign of four days followed by three days of Macraes ore. Gold from both streams are recovered in the same CIL circuit.

In 2009, the Frasers underground (FRUG) mining operation was commissioned and this mine focuses on the high grade contact zone. Due to the presence of tramp steel from ground support in the ore this material poses a higher risk of conveyor belt impact damage, and therefore the crushing and primary grinding of this material is performed through a separate process line.

Currently, the Macraes process is treating approximately 150 t/h of high grade quartz-rich material from FRUG, and 550 t/h of low grade, hydrothermally altered schist containing gold in pyrite and arsenopyrite from the open pit operations. These two process streams are blended together pre-flotation and the material is then treated as a homogeneous stream. The existing mineral processing circuit at Macraes is summarised in Fig. 2.

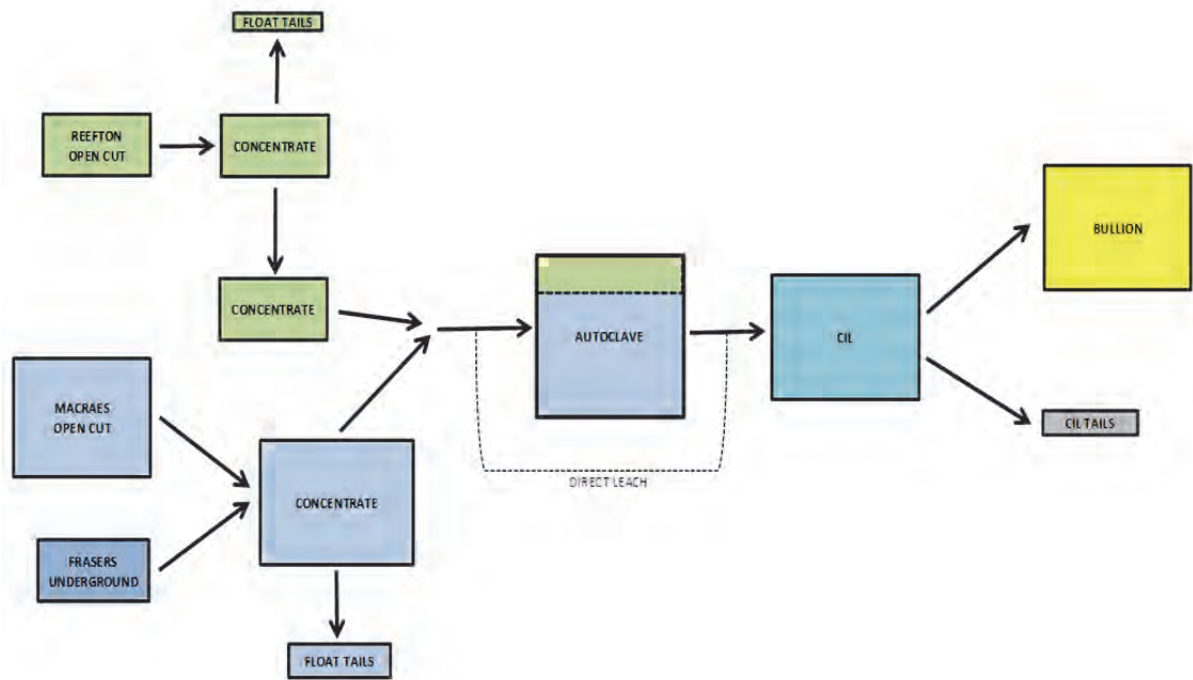


Figure 2. Macraes Process Plant Block Diagram.

Each of the ore sources may contain different geological domains and mineralogies. This material, if not blended well can introduce cyclic variations throughout the processing plant impacting on sampling precision, recoveries and production rate due to different hardness and mineralogical characteristics.

Feed tonnage determination

The objective of mass measurement for metal accounting is to establish the mass of the particular material present at a specific time, or the mass flow of that component over a defined time period, to a defined accuracy suitable for mass and metal balancing (Morrison et al., 2008). Tonnage is used in the Macraes mining/processing operation as a daily material movement key performance indicator and is used to back-calculate plant feed grade and overall metal recoveries on a daily basis.

At Macraes tonnage is recorded using four fixed weightometers listed below.

- CV-01 records tonnes off main stockpile to the main SAG mill (Span 0 to 690 tph)
- CV-02 records tonnes and SAG scats to SAG mill (Span 0 to 690 tph)
- CV-03 records scats from main SAG back to CV-02 (Span 0 to 80 tph)
- CV-500 records FRUG tonnage (Span 0- 210 tph)

Tonnes are also determined as they are mined, for FRUG using a combination of scanned volume and truck-mounted load cells (referred to as FRUG in the figures) and for the open pit using dump truck load cells (referred to as Minestar in the figures). As part of the quality improvement process, fixed Transcale weigh scales were installed to verify truck tonnes.

The data collected during a review in August 2014 shows that the measured or estimated tonnes at key nodes in a generalised reconciliation process overview varied significantly for the same isolated batch of ore (Fig. 3). Assuming that grade does not change, this would

result in incorrect allocation of ounces for the daily and monthly metal accounting. Such variance makes evaluation of performance and economics of the orebody difficult.

Because of the critical role tonnage plays in reconciliation, a site based team was established consisting of a representative from each operational department (Open Pit/FRUG/Processing). The team initially worked on understanding the variation in tonnage measurement from resource estimate to milled tonnes.

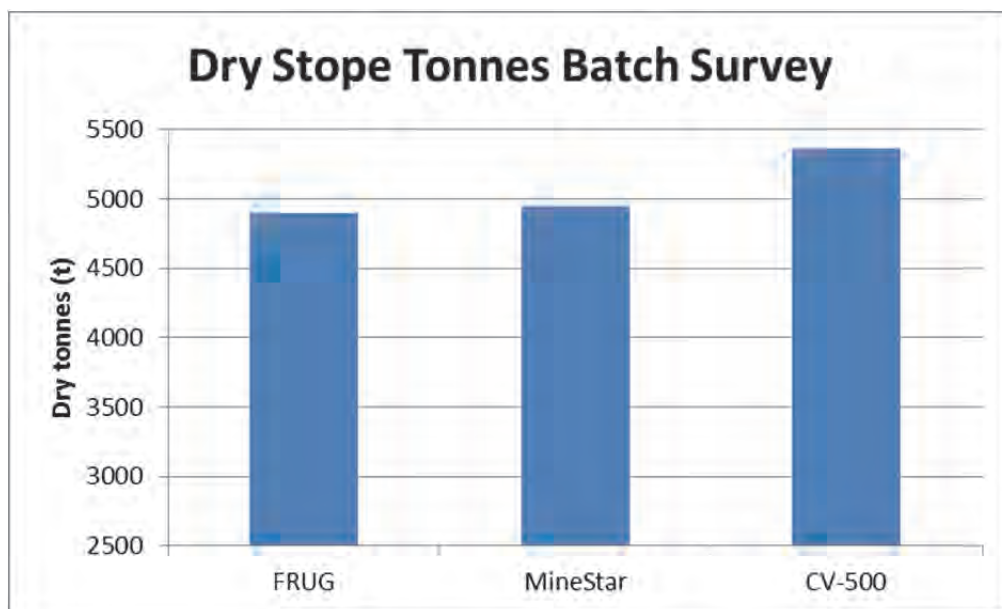


Figure 3. Tonnage measurements and estimations at various transfer points for an isolated batch of ore.

The team identified a number of issues that affected the precision and accuracy on this important metric. These improvements can be generally separated into improvements to the measuring system, quality assurance (QA) and quality control (QC) improvements. This paper covers the review of the improvements for three key tonnage measuring points: trucked tonnes, CV-500 tonnes and CV-01 tonnes.

Engineering improvements

Conveyor 500

The CV-500 weightometer records the higher grade FRUG tonnage delivered to the mill. Because the grade of this material is usually higher than the average feed grade, errors on this weightometer can have a notable impact on gold allocation and reconciliation. When it was originally installed, its capacity was based on treatment of an average of 60 t/h of oxide material, however, the belt currently operates at an average of 200 t/h. The original weightometer design was poor, with insufficient clearance between the weightometer frame and conveyor structure.

The design also allowed spillage to build up on the framework regularly, resulting in distorted readings. This became more clear when the load increased beyond the capacity and the physical characteristics between oxide and sulphide material changed. After several tonnage reconciliation trials it was determined that this was resulting in tonnage being over-reported. Figure 4 shows that at the start of the review process the weightometer was recording more

tonnage than actually had passed over belt. As improvements were made through the installation of new equipment, introduction of better housekeeping and more frequent calibrations, this discrepancy decreased. The weightometer accuracy improved after instrument upgrades from 3% to 0.5%. On completion of CV-500 upgrades, both CV-500 and CV-01 showed similar bias of 7% to 12% to truck tonnes.

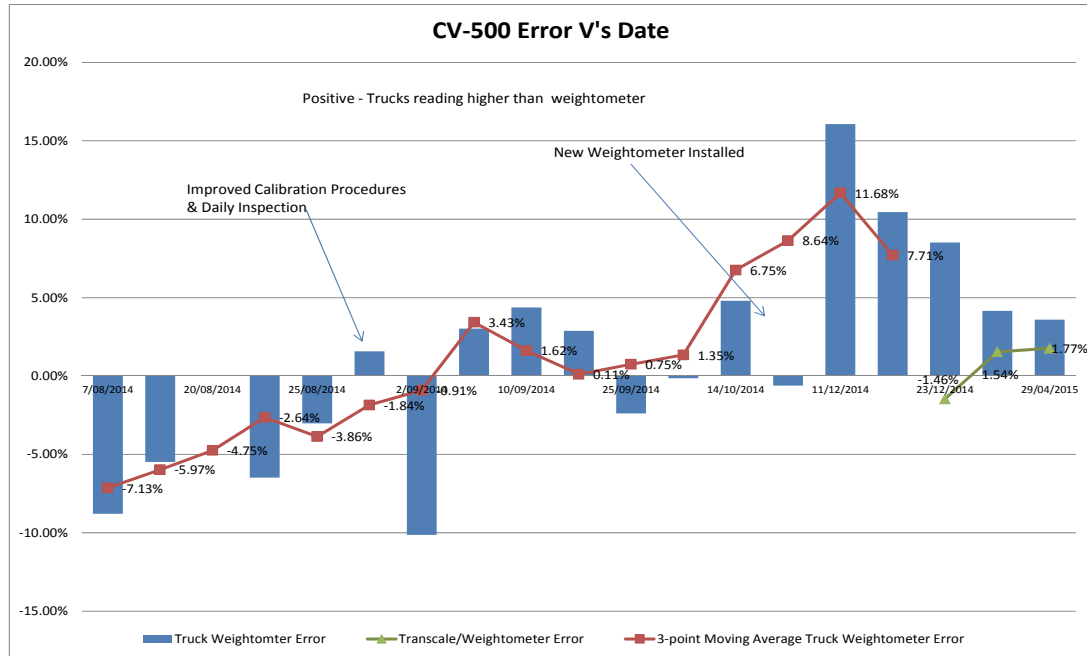


Figure 4. CV-500 calculated bias between truck load cells and weightometer.

Conveyor 1

A review of CV-01 identified that a more effective speed sensor was required. This improved the accuracy of the weightometer from 3% to 1.5%. Figure 5 shows that the mining truck load cells had been overestimating tonnes by approximately 7%. This compares well with current data from CV-500.

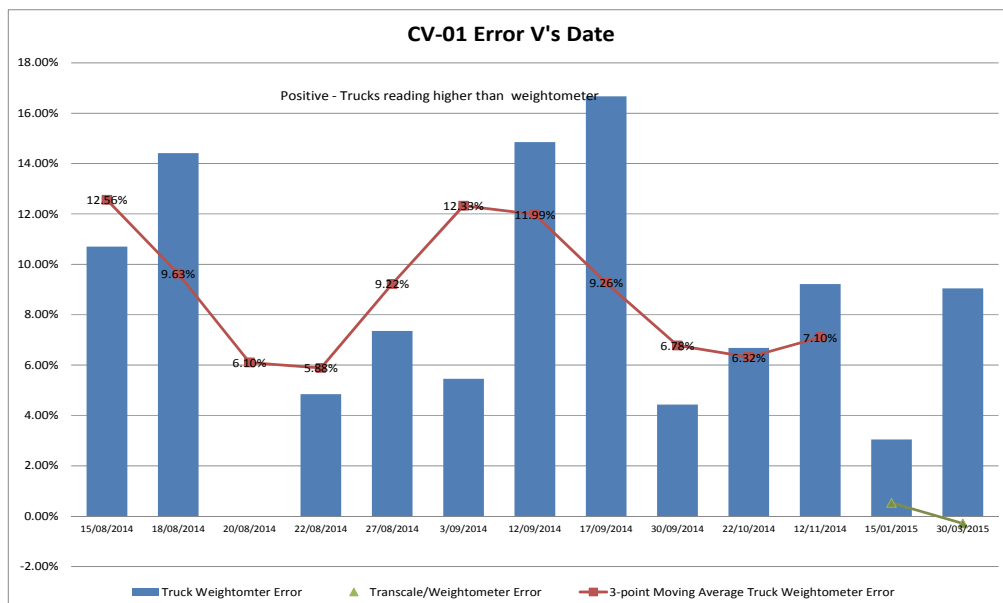


Figure 5. Conveyor one calculated error between truck and weightometer.

Truck tonnes

As part of the measuring improvement process, the mining department installed fixed Transcale weigh scales. Such fixed weighing devices are considered most accurate for determination of trucked tonnes. Hence, these were used to verify trial tonnages delivered to the run of mine (ROM) pad, check truck load cells and weightometer tonnes. The data collected after all the weightometer improvements confirmed that the weightometer data was measuring accurately and that the trucks load cell measurements were reading high by approximately 7% to 12%. Figure 6 shows a data set with the Transcale measurement against CV-500.

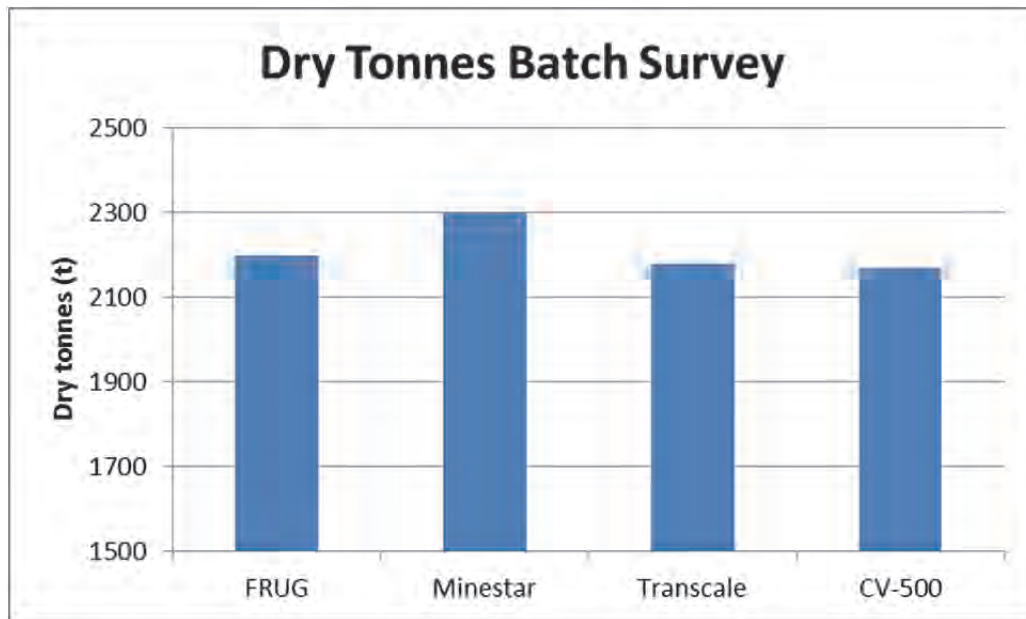


Figure 6. Tonnage measurements and estimations at various transfer points for an isolated batch of ore.

Other administrative controls

In addition to the improvements to the measuring equipment, several procedures were put in place to improve the QA/QC of the process (i.e. prevent and monitor for errors). All weightometers are now audited on a yearly basis by an independent qualified person. Routine maintenance tasks have been set up in the maintenance system to calibrate and check weightometers each fortnight. A data reporting system has been developed which is distributed internally to all relevant parties, and these reports identify span and zero errors using conditional formatting. The Pi database recording system now calculates the live bias by comparing different weightometers and calculates the relative errors (Fig. 7). Regular tonnage trials are conducted, comparing Transcale tonnes with weightometer tonnes. Weightometers are regularly inspected and cleaned.

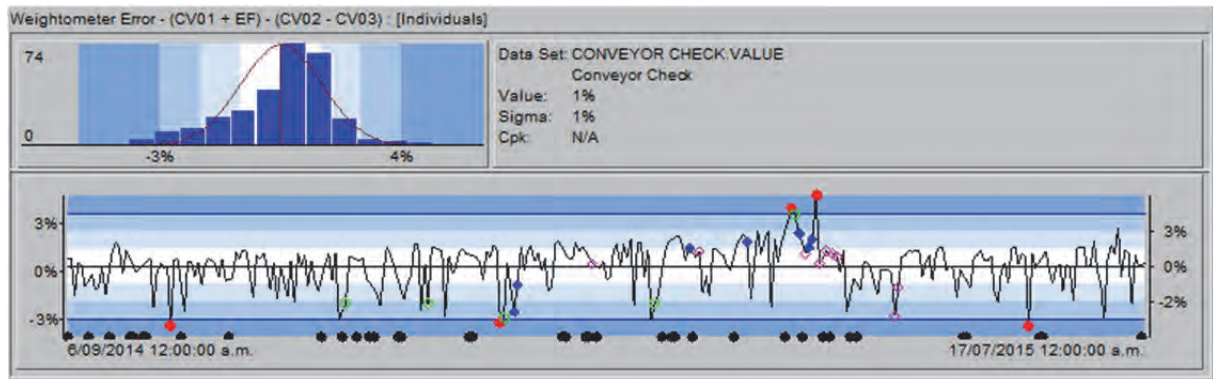


Figure 7. Process Control chart set up to monitor error.

Final float tailings grade

Importance of good sampling

The sampling process must provide information that allows decisions to be made that optimise the profit of the operation. Assuming a 5 Mt/y operation at an average grade of 1.5 g/t of gold, a 1% change in recovery has a direct revenue impact of NZ\$3.6M dollars (assuming a NZ\$1500/oz value). This is an equivalent change of 0.015 g/t in the FFT stream. It is therefore easy to justify suitable efforts and expenditure to make sure that the FFT grade is accurate and precise. Without it, optimisation is not possible and money is being lost.

The sample

The final tail sampler is a combination of two streams (Scavenger Tail and Cleaner-Scavenger Tails). The whole stream passes into an Outotec MSA2/80 metallurgical sampler which splits the stream by four primary vertical cutters with a 25 mm gap expanding to 50 mm. The process stream first enters into a box where the process flow speed is partly stopped by beams causing mixing. The reduction of flow speed raises the level of slurry in the box causing a head that forces the flow out under a gate. When the flow exits the box it hits a set of cutters with almost horizontal bottoms, which allow the sample to flow forward in the same near-horizontal direction as the primary flow. The primary flow drops between the cutters to a lower level where a sump or a launder receives it.

The stream is cut through four 50 mm vertical cutters that move back and forward every 12 seconds. The cut slurry flows by gravity into a sample collection launder and then into a surge box. The surge box is installed to regulate the flow of the slurry better and to prevent airlocks in pumps. The slurry is then pumped from an outlet at the bottom of the surge box to a Courier 30 On-Stream Analyser (OSA). The OSA is set up to taking one cut every 10 minutes. The composite sample bucket is being collected at the end of day shifts and night shifts. These samples are combined in the laboratory where the sample is dewatered using a pressure filter. This filtered sample is then dried in an oven at 95 degrees Celsius for approximately 16 hours. The dried sample is bottle rolled to break up agglomerates before being fed through a rotary splitter and a sub sample of approximately 250 g is collected and retained for assay. The 250 g sample is pulverised and placed in a paper sample bag. A subsample is scooped from the bag and used to determine gold content using the 'gold by fire assay, AAS, nominal weight 30g' standard procedure by SGS laboratory, SGS (2013). Approximately two grams of sample is drawn through the AAS to determine the grade of

approximately 15,000 t of FFT material. The process of sampling, subsampling and gold determination is illustrated in Fig. 8.

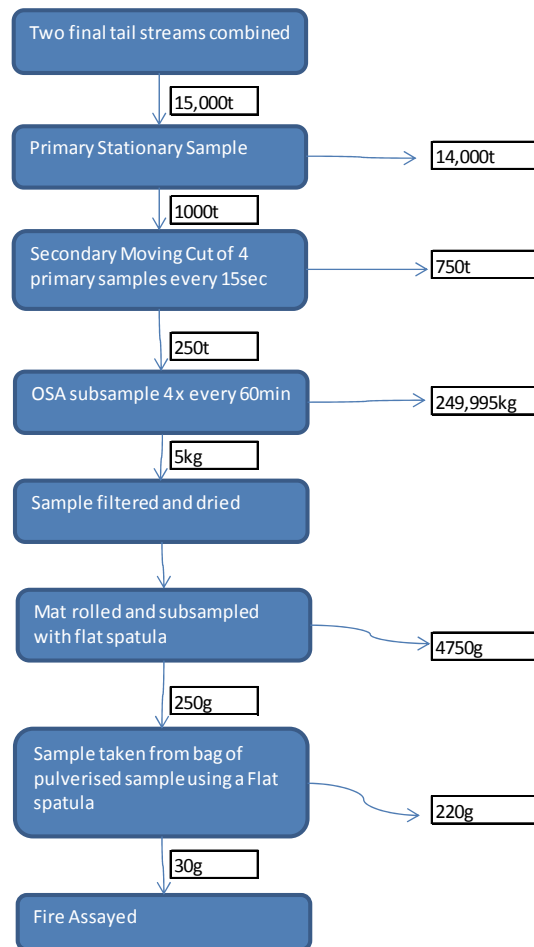


Figure 8. Final float tail subsampling process for 1 day.

Accuracy and precision

Central to the optimisation of a sampling point is the determination of whether it is representative. A representative sample is accurate and its precision is fit-for-purpose.

The *accuracy* of this sampling station cannot be quantified since there are no "known" sampling points to compare the data with. However, a detailed review of the sampling station revealed a number of issues that affect the accuracy of the sampling. Because in theory the sampling equipment should produce an unbiased sample, all these were determined to be caused by modifications to the process and the way it was operated.

For such an important sampling station, the *precision* should be very good in order for it to be fit-for-purpose. To determine the precision of this sample, chronostatistics (Pitard, 2006) were used on:

- 217 daily *composite* samples, each of these samples consisting of 144 increments, with one increment collected every 10 minutes,

- 160 samples collected every half-hour, covering a three day and eight hour period, and
- 105 samples collected every two minutes, covering a three and a half hour period.

Two laboratory replicates were consistently used to assess laboratory precision in this investigation. The analysis of the one-day composite data is explained below.

The detrended data (Fig. 9) shows only two outliers of greater than 0.20 g/t Au, which were capped for further statistical data analysis. To establish limits that can demonstrate fit-for-purpose, the metallurgical team determined the data quality objectives (DQO's) as shown by the red lines in Fig. 10. Next, the various components of variance are presented separately on the same plot. These include:

- variability from sampling, subsampling, and measurement that does not exist in the process;
- long-range variance, which usually is non-random, continuous and an inherent property of the feed heading through the plant, for example the slowly changing grade of the crushed ore; and
- a periodic variance, which is continuous, tied to ways people work or to ways some process machineries work

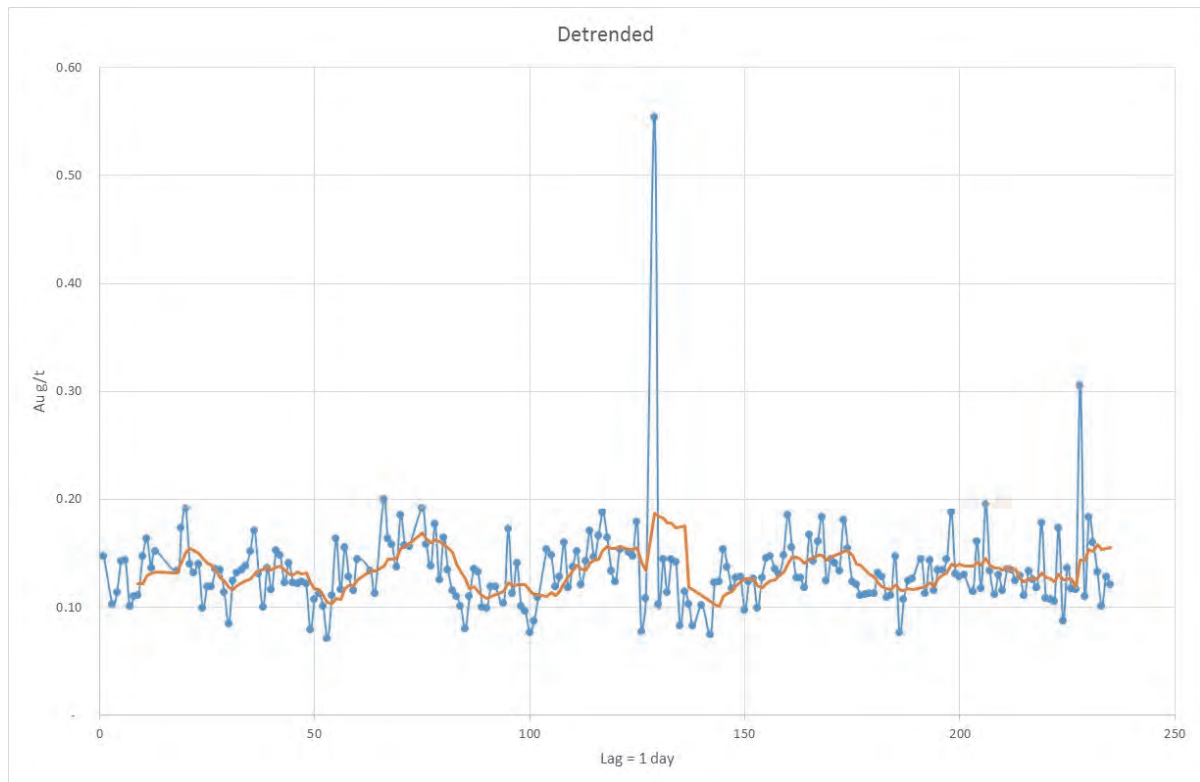


Figure 9. FFT gold grades plotted chronologically, orange line is 5-point moving average, red line is 6th order polynomial. Detrended using 6th order polynomial.

These components can all be determined from the variogram, with the x-axis showing the lag as units of time and the y-axis showing the variance (Fig. 11). By assessing each component of the variance it is possible to determine the best ways to improve the system and by representing the components in the same plot as the DQO lines it can be determined whether the precision is fit-for-purpose.

In the case for the daily composite samples, the variogram shows a very high value of $V(0)$, as determined by the extrapolated intersection of the variogram with the y-axis. This indicates an excessive variability caused by the sampling, subsampling, and measurement process. $V(1)$, represented by the first point of the variogram only adds a little bit of variance and therefore the combination of the 10 minute sample interval and daily composite can be considered adequate. The variogram also indicated a variance caused by a cyclical event, roughly every 6-8 days. This was supported by several other sampling points and may be due to how the ore is blended and fed to the process plant.

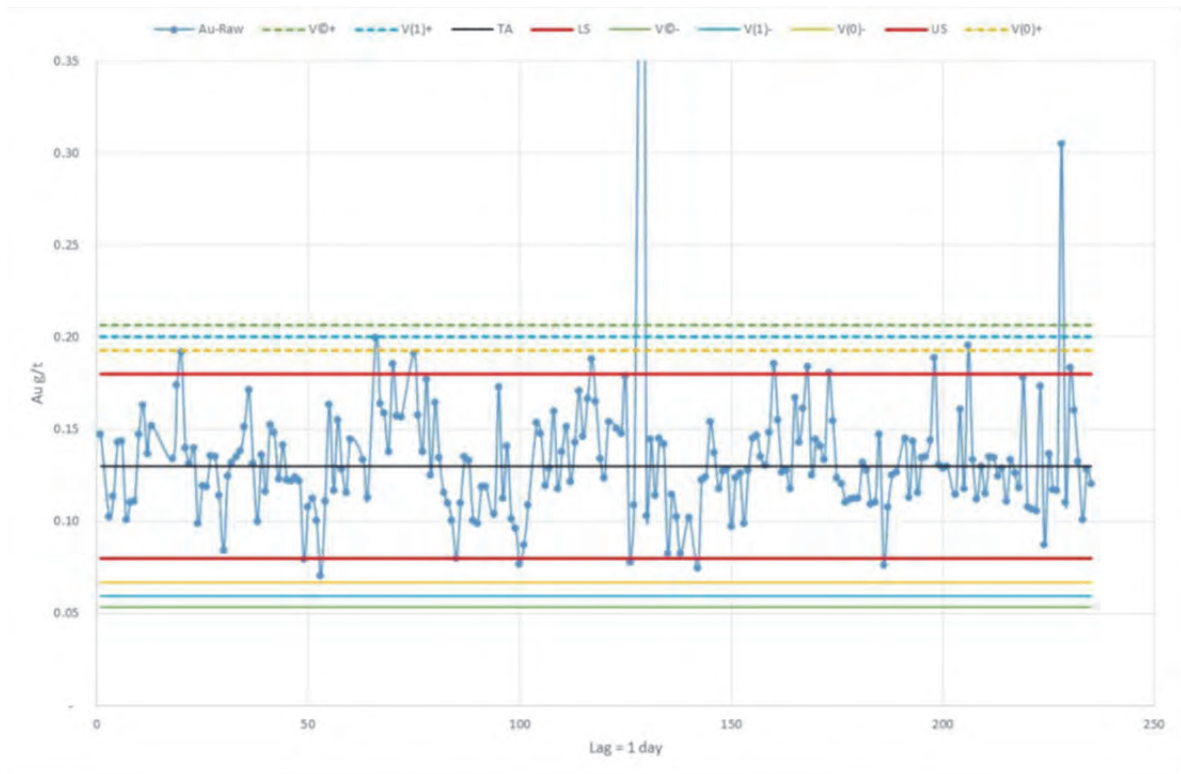


Figure 10. Control Chart for Final Float Tail, detrended.

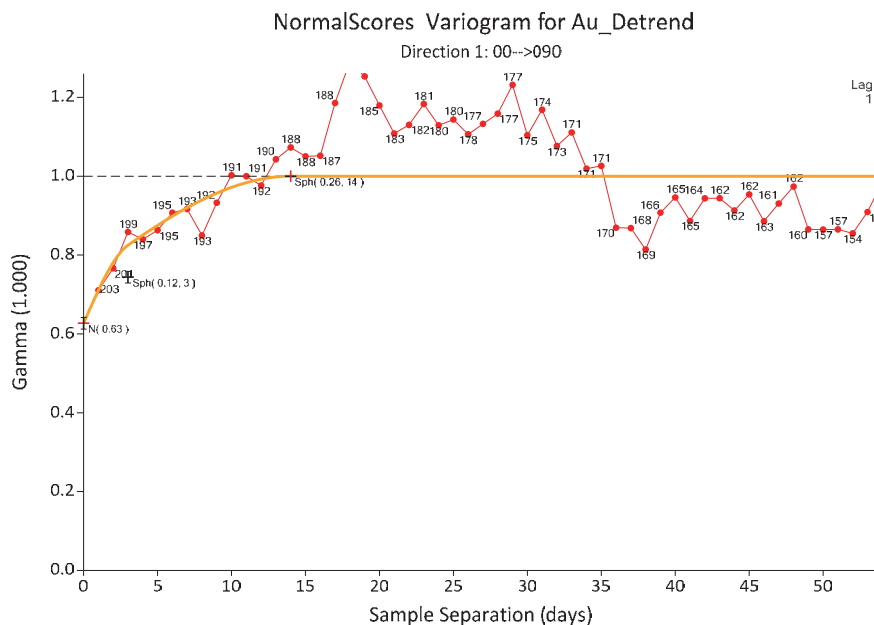


Figure 11. Variogram for Final Float tail with a lag of 1 day.

Combining all these components on a control plot (Fig. 10) indicates that the system was not performing well; the lines representing the various components of variance lie well away from the red DQO lines, indicating that the system was not performing as desired.

The value $V(0)$ obtained in this way is likely to contain non-random components taking place along this one-day period. When $V(1)$ is long (i.e. hours or days), then $V(1)$ includes the true random variability, the unknown non-random variability, and the unknown periodic variability. When $V(1)$ is short (i.e. seconds or a few minutes), then $V(1)$ probably includes only the random variability and extrapolation to $V(0)$ would therefore be giving a more realistic value.

Therefore, two shorter spaced sampling programmes were implemented to investigate the high value of $V(0)$ further.

Besides the relatively more significant contribution of analytical variance to the total sampling variance, the analysis shows that there is still some room for improvement on the actual sampling variance. This may include things such as sample tool engineering, maintenance, sample size, sample preparation, etc.

Importantly, the data shows that for both the ½-hour and two-minute sampling programmes the $V(0)$ is similar, suggesting that there are no significant non-random components to the variance taking place along the ½-hour period; e.g. $V(0)$ includes only the variability from sampling, subsampling, and measurement that does not exist in the process, and doesn't include additional variances due to cycles and other non-random sources of variance.

With $V(0)$ only showing the variability from sampling, subsampling, and measurement that does not exist in the process, casting judgment on $V(1)$ and the efficiency of the sampling interval can be more reliably assessed than before (i.e. because $V(0)$ does not seem to include any non-random components, the difference between $V(0)$ and $V(1)$ should only reflect the variance added by the sampling interval). In both cases this is around 30-40% of the total variance (depending on how the outliers for the two-minute programme are manipulated). This suggests that the typical and non-random process variability between two consecutive ½-hour and two-minute samples does not seem to be a significant problem and that further increasing the increment sampling frequency does not make a notable impact on precision. The current 10-minute sampling interval therefore is considered appropriate.

Conclusion

At Macraes, the evaluation of sampling and measuring stations through an assessment of sampling tools, procedures, accuracy and precision allowed the detailed mapping of points where improvements can be made. Cost-benefit analyses for each improvement give management a strong set of tools to methodically tackle the issues and improve the reconciliation and metal accounting, one step at a time.

Detailed assessments have revealed a list of issues that affect accuracy of sampling stations. At some sampling and measuring points a bias was able to be identified. The measurement of tonnes is an example and addressing these issues has made a notable impact on reconciliation and metal accounting.

Chronostatistics have been useful in determining sources of variance and have allowed a systematic approach to map out the tenor of variance across the entire processing plant. This revealed several sampling stations where the variance was out of control and the sampling tool was not giving fit-for-purpose results.

The review has resulted in the implementation of several improvements. Many of those involve a better assurance of quality through improvements and enhancements to existing equipment and stronger standard operating procedures, preventing errors to come into the system. Others involve a better control on quality by introduction of more checks and balances and better ways to get useful insights from such data.

The overall results of the study indicated that significantly skewed grade distributions and outliers propagated through the plant. These can cause many issues with sampling and compromise the metallurgists' abilities to make sound decisions on the data. Removing outliers or otherwise manually adjusting the numbers is a dangerous approach. One of the outcomes of the study was to address the nature of the ore feed across the various sources and determine the impact on the overall heterogeneity of the feed.

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