# Beyond Reconciliation — A Proactive Approach to Using Mining Data

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## ABSTRACT

Anyone who has driven backwards using only their rear view mirrors knows how difficult it is to avoid spinning the steering wheel the wrong way. So why run your mine that way? Traditionally *Reconciliation* has focused on the past performance of the mine. In this paper we make a case for *Prognostication* – the act of forecasting or predicting something in the future from present indications or signs.

Reconciliation is a common activity carried out at most mines around the world. Countless geologists and engineers spend hours poised in front of spreadsheets diligently comparing how their resource/reserve model, grade control, and survey pick ups compare to what was actually produced. The result is usually a group of factors, which are applied to future estimates in an attempt to better predict how the operation may perform. Unfortunately, if the road ahead isn't the same as what you have just been down, you'll be 'off-roading' in no time!

An alternative is to constantly collect and analyse key measurements that are used to calibrate critical estimates in an iterative process. When variations occur, they are analysed and corrective action is taken to ensure the estimates and measurements realign. In this way the estimates become forecasts and can then form the basis for decision making to ensure that what does happen in the future will match the plan or schedule.

By automating this process, some mines have been able to be proactive on a daily basis in order to improve the overall performance of the operation. This paper outlines the key estimates and measurements used for reconciliation, details the characteristics of an automated web based information management system to facilitate the process and provides some insights about how mining operations might move beyond reconciliation.


## INTRODUCTION

Many mines complete reconciliation using a complex system of spreadsheets and data exports from various mining packages and other databases or information sources. Typically the results are used to calculate annual 'factors' that can be applied to resource estimates or grade control data to more accurately define what may be produced by the processing plant (for example Elliott *et al*, 1997; Pevely, 2001; Bischoff and Morley, 1993).

In this paper the author examines ways to go beyond using annual reconciliation 'factors'. The focus is on analysing key parameters so that critical estimates can be reconciled in an ongoing and iterative process. Significant results can be achieved at most operations within one year of putting a system in place (Pitard, 2001). This is the case for *Prognostication* – the act of forecasting or predicting something in the future from present indications or signs – in order to improve the process.

## RECONCILIATION AND THE ART OF FACTORING

In a mining industry context Reconciliation equates to the comparison of an *estimate* (a Mineral Resource model, a Mineral or Ore Reserve model, or grade control information) with a *measurement* (survey information or the official production, usually from the processing or treatment plant) (Glacken and Morley, 2003; Schofield, 2001). The basic aims of reconciliation are to (after Glacken and Morley, 2003):

- measure performance of the operation against targets;
- ensure valuation of mineral assets is accurate;
- confirm grade and tonnage estimation efficiency; and
- provide key performance indicators – in particular for grade control predictions.

This is illustrated schematically in Figure 1 which presents a summary of a typical reconciliation process from resource through to metal and highlights key questions that should be addressed at various junctions throughout the process.

The outcome of these comparisons are often 'factors' which give an indication of how accurate an estimate turned out to be (for example resource and reserve factors, truck or volume factors, mine call factors). These factors which are generally calculated over a long period of time (in excess of a year and typically over the history of the mine) are often then applied to resource and reserve estimates and grade control predictions to provide some approximation of the metal that could reasonably be expected to be produced by the plant. For example, if historically the plant has produced ten per cent more gold than predicted by the resource estimate, common practice is to apply a mine call factor of 110 per cent to the ounces predicted by the resource model when estimating what the total metal production might be.

This calculation of factors therefore provides an operation with an indication of performance. In a perfect scenario there would be no factors – the estimate of metal in a slice through a resource model would balance with the amount of metal produced by the plant plus what remained in the tails. Of course the two numbers will rarely match due to the many variables involved in the process. Table 1 presents some common examples of variables that effect reconciliation results.

**TABLE 1**

*Examples of variables that affect reconciliation (after Pitard, 2001).*

| Geological model causes | Mining causes |
|---|---|
| • True *in situ* nugget effect<br>• Sampling and subsampling errors<br>• Analytical errors<br>• Estimation errors<br>• Excessive rejection of outliers<br>• Estimation methodology issues<br>• Ore density assumptions<br>• Definition of ore boundaries | • Mining model parallel to cross mineralisation in open pit<br>• Displacement of mineralisation boundaries upon blasting<br>• Survey inaccuracies<br>• Truck dispatch inaccuracies<br>• Loss of fines<br>• Estimation of tonnes<br>• Dilution |
| **Grade control causes** | **Mill and flotation plant causes** |
| • *In situ* nugget effect<br>• Sampling and subsampling errors<br>• Analytical errors<br>• Blast holes parallel to mineralisation<br>• Averaging or kriging methodology issues<br>• Ore grade contouring<br>• Survey inaccuracies | • Retention of metal within the<br>• Mill Analytical inaccuracy<br>• Process cycles either unknown or misunderstood<br>• Calibration of weightometers and flowmeters<br>• Poor laboratory subsampling<br>• Reconciliation calculated over too short a timeframe |

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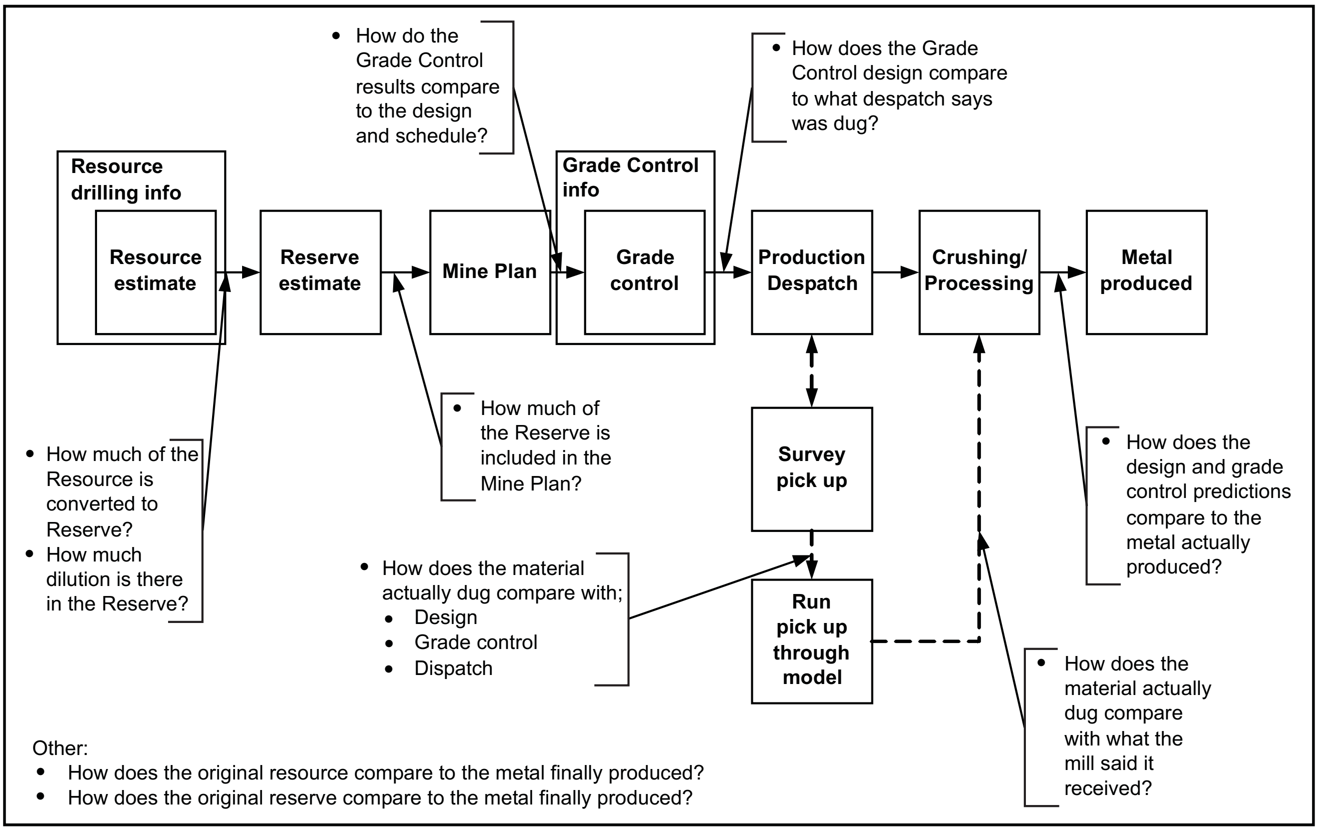


FIG 1 - Schematic illustration of the reconciliation process and key issues for analysis.

**TABLE 2**

*An example of the data to prediction process.*

| Data | Information | Knowledge | Prediction |
|---|---|---|---|
| Collect material type data and crusher throughput data. | For each material type, correlate corresponding average crusher throughput rates. | Analysis shows that one particular material type has an average throughput rate that is half the optimum rate. | Throughput will fall if that material type is fed to the crusher. Throughput will not fall if this material is blended into the crusher. |

To further complicate the process the application of a Factor will often disguise the causes of the error responsible for the discrepancy. It is the author's opinion that the use of generic factors that are applied across differing time scales and material types is not industry best practice. Mine site personnel can only identify the root causes of any given variance by analysing the information behind any variance and then making changes to methodologies and processes. Action can then be taken to address these issues – hopefully with the effect of reducing the variance to an acceptable level. This is an iterative process resulting in constant recalibration of the inputs and the calculations, leading to proactive reconciliation or prognostication.

## INTRODUCING PROGNOSTICATION

Moving from traditional reconciliation practices to prognostication at a mining operation requires commitment to the collection of data, ongoing analysis of the information and the identification of trends. *Data* gives rise to *Information* which in turn provides *Knowledge* which in turn allows *Prediction* of future events. Table 2 provides a common practical example of this process.

This is the essence of prognostication – analysis of the data available through the reconciliation process provides an understanding of the impact of various decisions made in the mining operation on the processing plant and ultimately the metal produced. This understanding can be used to ensure that the variance between original estimates and actual results stay within acceptable ranges.

Some observations relating to the main elements of the process are presented below.

## DATA – WHERE IT ALL STARTS

Without quality data you might as well save yourself the effort and time associated with analysis and just make some guesses. After all, reconciliation and prognostication is all about the analysis and comparison of data from many different sources, and so any inconsistencies will have a significant effect on the results. This section provides a summary of the key sources of data as well as notes on data capture and storage.

## Key data sources

Typically data can be sourced from:

- Resource and Reserve models;
- mine plans;
- grade control designs;
- survey pickups of the actual mining activities;
- dispatch systems or records;
- plant feed sources such as weightometers;
- plant performance indicators such as crusher power consumption, cyclone throughput, etc;
- plant calculations such as head grade; and
- plant actuals such as metal produced and tailings assays.

The availability of these different sources of data will obviously vary from site to site.

## Data capture

Best practice is seeing more and more sites move towards automating the capture of data sets wherever possible (Glacken and Morley, 2003). For example using data captured from 'programmable logic controllers' (PLCs) via plant systems or computer-based Dispatch systems. The data should be interrogated and validated as close to the point of capture as possible using documented business rules. Data validation is critical to the process. It is not only important to collect valid and accurate data, but also to collect and flag inaccurate data that is being reported out of various systems so that the problems with this data can be identified, analysed and then fixed.

It is also desirable to capture data frequently – for example capture grade control dig blocks when they are created, or dispatch information at the end of each shift. This means that the data is being built up incrementally over time rather than leaving it all to one massive labour intensive end of month processing effort where transposition and human errors can creep in.

It is important to reconcile ore blocks *as they are mined*, and not as they are laid out, since these two situations may differ for many reasons (for instance if there is significant visual control on the digging) as shown in Figure 2. This will result in some data requiring processing after it has been captured to ensure it accurately reflects what was actually mined. Base data should always be stored along with the processed data and an audit trail of what processing has been carried out. This ensures that processed data can be 'rolled back' at a later date and re-processed if necessary.

## Data storage

Data storage is also a critical aspect to effectively managing the quality information that you are going to build up over time. A serious commercial database package is the only place to store these volumes of data. High performance hardware should be used to house the system to get the performance, reliability and security required (Burgess *et al*, 2000).

*A spreadsheet is not a database*. Studies have found that any spreadsheet greater than 1MB in size has between an 80 per cent and 90 per cent chance of having errors that significantly effect the conclusions drawn from the results (Panko, 2000). Spreadsheets are ideal tools for ad-hoc data analysis and charting – but not to form the basis of a corporate reconciliation system.

Microsoft Access is a widely-used database – but its limited data capacity, functionality and ability to service multiple users will result in most medium to large scale mining operations finding it inadequate. The author suggests that only commercial grade products such as Microsoft SQL Server, MSDE, Oracle, DB2, etc will provide the security, functionality, flexibility and features that a corporate grade reconciliation package should offer.

Multiple databases containing the same or similar information also present a problem. To ensure consistency in the results presented by various users only one central set of data should be maintained so that all users are presented with the same data. If multiple databases are required then links (such as ODBC connections) should be used to ensure that data remains consistent across the operation.

Avoid reinventing the wheel by developing a system designed to provide all functionality. It is a more efficient and cost effective to integrate third party applications allowing you to access data directly (Burgess *et al*, 2000). Figure 3 presents a schematic illustrating this approach to data storage for reconciliation.

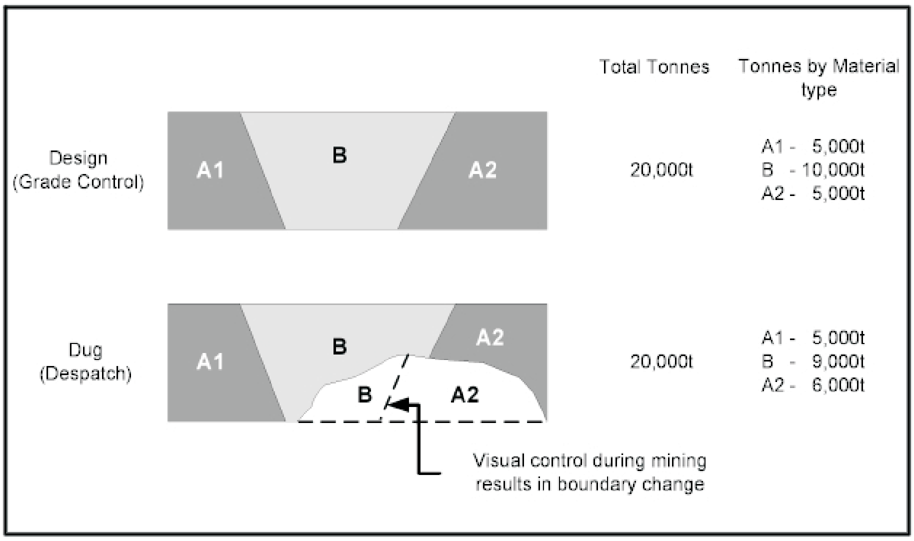


FIG 2 - Schematic representations showing a comparison between grade control design and what is actually dug.

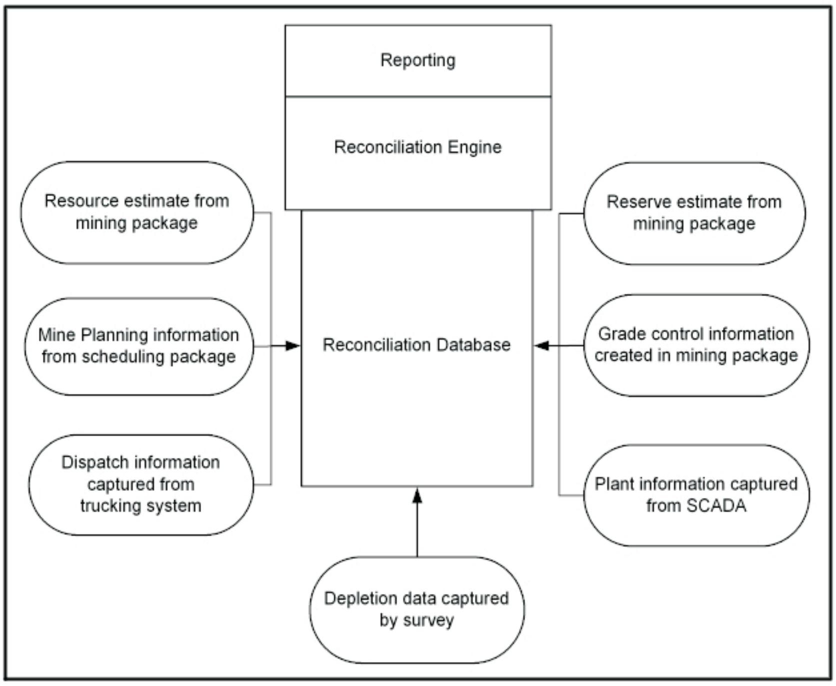


FIG 3 - Schematic illustration of a reconciliation system.

The database in this model is sourcing information from multiple commercial packages and data stores and then facilitating the reconciliation process by allowing analysis and reporting to occur from single source. Such a system has been implemented at Cadia Hill Gold Mine, Lihir Gold Mine and Sishen Iron Ore Mine. The system, known as 'Reconcilor', utilises a Microsoft SQL Server database which links to each sites grade control, dispatch and plant systems, as well as importing information from Resource/Reserve estimates and Mine Planning software. A case study of the 'Reconcilor' system is presented below.

## ANALYSIS – THE CREATION OF KNOWLEDGE

The key to the analysis of large data sets is the ability to identify anomalies and patterns in the data. This is where commercial grade database products provide strong benefits via tools which facilitate pattern recognition (Datamining) and the flexibility to summarise large quantities of data into meaningful tables and charts (using tools such as OLAP Cubes). Rules and business logic can be built into the database, triggering exception reports when the rules are broken. When an anomaly or pattern is identified the user can then drill down to the individual source record in an effort to determine the root cause of the anomaly.

The types of questions that should be answered during analysis are summarised below (and are also shown on Figure 1):

- how much of the Resource is converted to Reserve?
- how much dilution is there in the Reserve?
- how do the grade control results compare to the design/schedule?
- how much of the Reserve is included in the mine plan?
- how does the material reported by survey as being mined compare with:
  - design,
  - grade control,
  - dispatch, and
  - mine plan
- how does the grade control design compare to what dispatch says was dug?
- how do the design and grade control predictions of what would be sent to the plant compare to the metal actually produced?
- how does the material actually dug compare with what the mill said it received?
- how does the original resource compare to the metal finally produced?
- how does the original reserve compare to the metal finally produced?
- how does the calculated head grade compare to the grade control prediction?

Unfavourable results from any of these questions should result in further analysis, which drills down into the variance to identify the root cause thus allowing personnel to carry out actions that might correct the causes.

The practice of routinely collecting quality data and storing it in a manner that makes it accessible for analysis will enable site personnel to quickly identify areas where assumptions or estimates can be refined. For example, consistent undercalling of a resource model compared to the metal actually produced might indicate that top cutting practices need reassessing or that the grade estimation method is inappropriate. Having identified the root cause, personnel can modify the process or procedure and then monitor the result – the objective being to 'fix' the variance.

## PREDICTION – THE HOLY GRAIL

As discussed above, when variations occur they can be analysed and corrective action taken to ensure that the estimates and measurements realign. The downside to this approach is that the damage has already been done. The objective is to build on the information and to analyse trends so that estimates can become forecasts and may then form the basis for day to day decision making to ensure that future results will match the plan or schedule. Three examples are presented below.

### Lihir Gold Mining Company – Lihir, Papua New Guinea

Lihir have automated the capture and storage of their key reconciliation data in a central database. The information is processed incrementally throughout the month significantly reducing the time required to complete month-end processing. Lihir carries out fortnightly and sometimes weekly surveys of the mining activity enabling them to process a smaller volume of survey/dispatch/grade control comparisons at any given time. This increased frequency allows the mine geologists to calibrate data over shorter time frames and be more proactive in the operation and their grade control activities. This constant calibration has resulted in a significant improvement in the daily truck dispatch information – enabling grade control geologists to now rely on this data when building the ROM fingers that are used to blend ore into the plant.

### WMC Resources Limited – Mount Keith, Western Australia

Mount Keith reconcile on a bench by bench basis rather than over a fixed time period. A lot of effort is made to ensure a comparison is made of the relevant slice of the resource model with the relevant grade control and plant results. A key initiative is the sampling and modelling of contaminants at the resource estimation stage and the reconciling of these contaminants with grade control and plant information. The contaminants have a significant impact on plant recoveries and reconciliation is assisting in improving their prediction and thus management.

### Newmont – Batu Hijau, Indonesia

A database system has been implemented at the Batu Hijau mine that allows the tracking of over 200 variables from blasting, mining and milling (Pontin and Setiawa, 2002). This information is then associated spatially in the geological model. This data is analysed against mill feed statistics and the performance of the SAG mill to allow optimisation of the SAG mill performance. Because the information is linked to the geological model it can be reconciled with grade control information, greatly enhancing the ability to predict how material to be mined will behave when it is delivered to the mill.

## CASE STUDY – 'RECONCILOR' – CHARACTERISTICS OF AN INTEGRATED SYSTEM

Snowden initially worked with Cadia Hill Gold Mine to develop a browser based reconciliation system that meets the requirements outlined in the discussion above. Similar systems have now been implemented at Lihir Gold Mine and Sishen Iron Ore Mine.

The key characteristics of the systems are:

- use of a single central commercial database that stores each sites data;
- automated capture of data from other independent systems such as grade control, dispatch and the plant;
- validation of all data against established business rules;
- facilities to upload and store resource, mine plan and survey data;
- use of a web browser interface allowing all users across a site quick and easy access (see Figure 4);

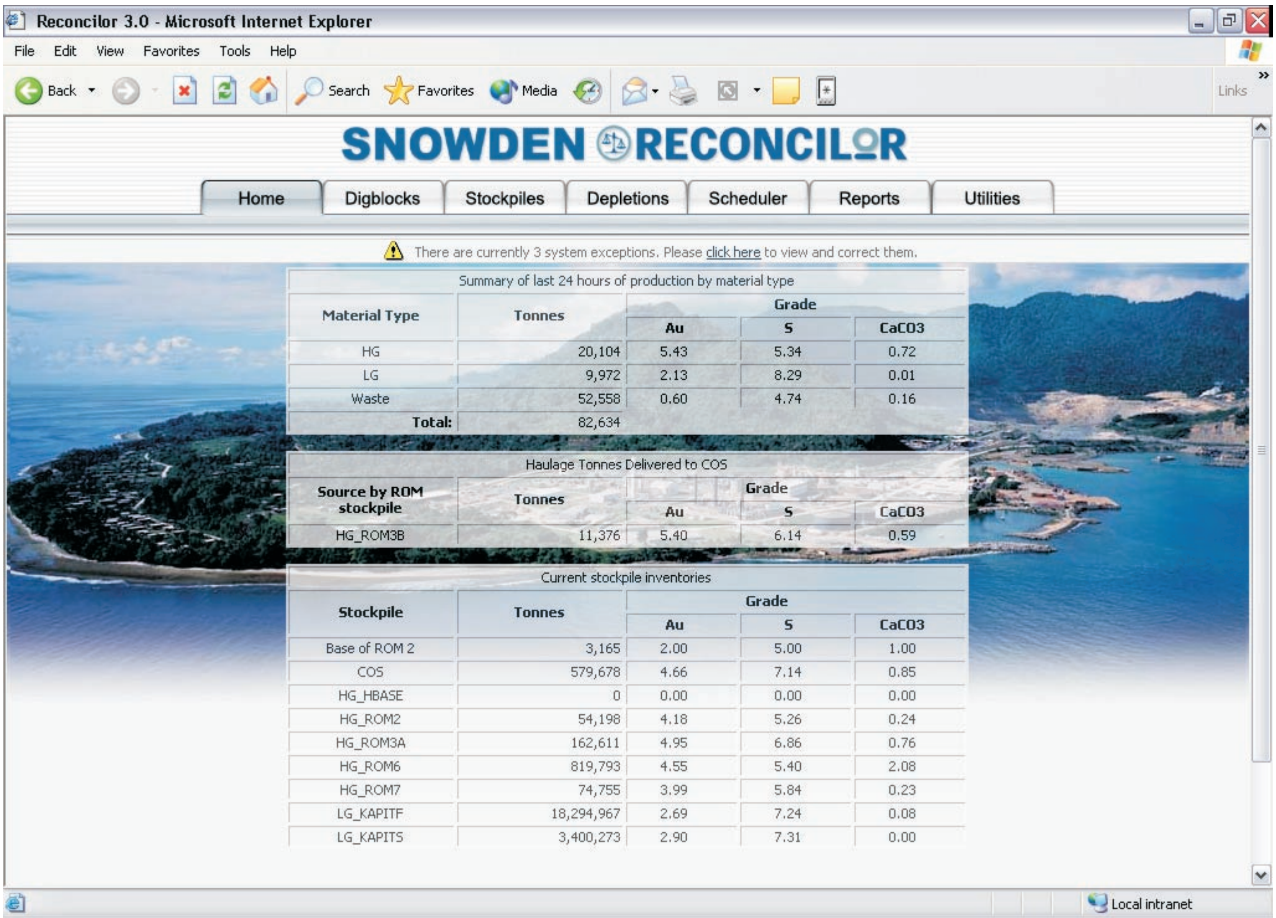


FIG 4 - Browser based system that integrates key data to facilitate reconciliation (image courtesy of Lihir Gold Ltd).

- automation of key analysis functions to reduce processing time and greatly enhance users ability to forecast;
- exception reporting based on business rules built into the database and interface;
- the ability to produce a wide range of reports, charts and outputs (see Figure 5); and
- the incorporation of datamining technology to facilitate detailed analysis and drill down of the data.

The system architecture is schematically illustrated in Figure 3. The main benefits of the system are derived from the automated collection and validation of data, standardisation of terms and definitions across site, ease of access to the data and automation of reporting. This has led to reduced processing time, and improved decision making which in turn has led to better quality material being delivered to the plant, improved dispatch data quality, greater resource model accuracy and improved blast block design.

## CONCLUSIONS AND RECOMMENDATIONS

Experience at Cadia, Lihir and Sishen illustrates the significant benefits gained through the processes of reconciliation and prognostication. These benefits include:

- improved recoveries as a result of improved capability to predict the characteristics of material being fed to the plant;
- improved decision-making due to access to timely, validated data in an efficient manner;
- reduced processing time as there is constant incremental data capture and automation of many of the routine processing tasks;
- reduced mishandling of material due to constant calibration of information from dispatch, grade control, survey and the plant; and
- improved resource model accuracy as a result of regular comparison of actual results to modelled results.

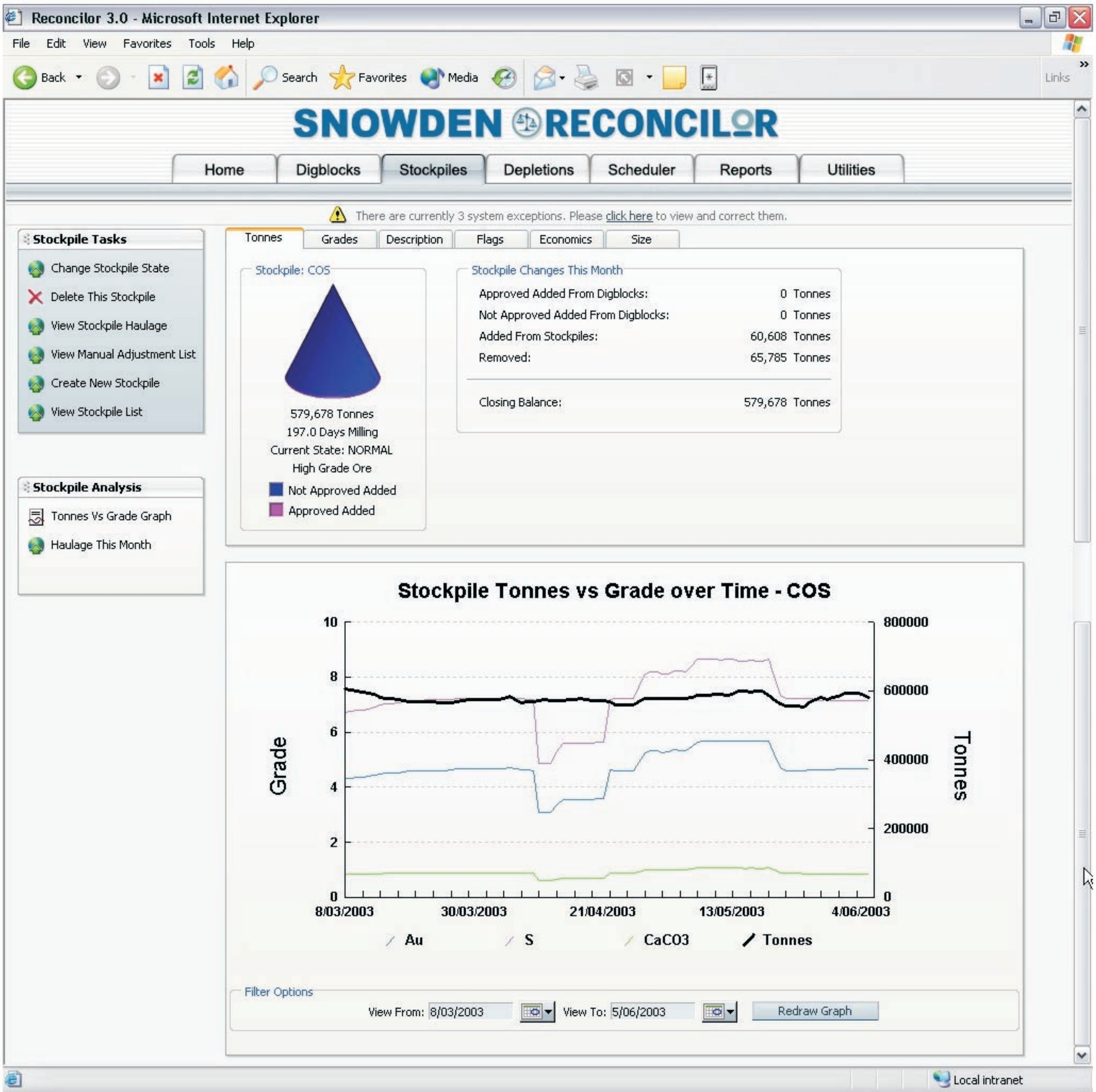


FIG 5 - Examples of the system outputs, charts and diagrams (image courtesy of Lihir Gold Ltd).

For any operation to move beyond reconciliation to prognostication that author recommends the following ten steps:

1. identify key sources of data;
2. automate the capture of this data;
3. establish business rules for the validation of the data;
4. store the data in one central commercial quality database;
5. establish an interface that enables efficient analysis of the data;
6. research trends and patterns in the data;
7. drill down into these trends/patterns for causes and effects;
8. use this information to establish and test hypothesis;
9. develop a knowledge base that enables you to predict the future plant performance; and
10. constantly modify your knowledge base though ongoing analysis.

The main objective of any reconciliation system should not be to generate a list of factors used to 'correct' estimates – but should be to allow personnel to adjust processes so that results align within acceptable tolerance ranges. This will result in significant benefits for the operation and provide a basis for ongoing improvement.

## ACKNOWLEDGEMENTS

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