GETTING THE WATER BALANCE RIGHT

14.1 INTRODUCTION

The importance of water in an arid country like Australia is a theme that is constantly and validly highlighted. A number of mines across Australia were in dire straits during the recent droughts in the eastern states and many found it necessary to cut back on production due to water supply shortages. As a consequence of these recent experiences there has been a renewed focus on strategic water management by mining companies, regulators and interested and affected parties. This is further reinforced by the latest predictions by the weather bureau that summer temperatures will be hotter and rainfall lower all over Australia over the next few years.

Water management on a mining operation begins with an understanding of where the water comes from and where it goes. At the most basic level this entails recording the water intake and tracking this to form a measure of water use trends. One level up from this is tracking of outflows and using the difference between inflows and outflows to estimate losses. At this level it is possible to point to a water account which is balanced because the inflows equal the sum of the outflows and losses. But is it right/accurate? More importantly, is it enough information from which to build a water management strategy?

This paper attempts to review these two questions in the context of a typical mining operation that imports water either from a bore field or a water supply pipeline and discharges a portion of this water from the mine property. It begins by identifying types of water balances and their usefulness and presents a number of guiding principles on how to ensure that the mine has a reliable and appropriate water balance.

14.2 TYPES OF WATER BALANCES AND THEIR USEFULNESS

Generally water balances on a particular mining operation evolve in terms of scope or complexity, representativeness and accuracy. Most balances, even for greenfields operations, begin with a basic water accounting system so that contracts or arrangements for water supply can be secured. They usually are developed in response to the question “how much water do we need?” Soon, however, as mine production increases, or processing operations are found to be less water efficient than anticipated, or the available resource proves less reliable or extensive, the question becomes “how can we improve water use efficiency in the interests of reducing risk and cost”. To address these questions one needs a water balance that is accurate, reliable and can accommodate scenario assessment. The key issue, however, when it comes to water balances is not only “getting the water balance right” but also “getting the right water balance” for the needs of the mining company.
14.2.1 Water Data

All mining operations measure and record flows that are reportable in terms of license conditions. Flows are usually recorded on a monthly basis and, most commonly, are stored within a spreadsheet. By storing the data within a spreadsheet it is a simple task to produce trend graphs and compare trends against supply limitations, operating targets, guidelines or self imposed standards and so the spreadsheet becomes the source of data for environmental reporting and water supply planning. A typical data set is indicated in Figure 1.

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Figure 1: Typical Water Data and Graphing

However, to evaluate opportunities to improve water management and water use efficiency it is necessary to also have reliable information on water losses and discharges. Unfortunately flow records are seldom maintained in respect of these, and often for good reason. A typical example is seepage which can be so dispersed that it is impossible to bring it to a single measuring point. Another example is an intermittent spillage. To enable the evaluation of opportunities to improve water management, therefore, it is necessary to develop a closed water balance that accounts for all inflows, discharges and losses.

14.2.2 Basic Balances

The basic water balance usually comprises a spreadsheet in which the number of columns in the water record spreadsheet is increased so as to enable the deduction of flows to and from specific operating units within the mine water circuit. This is effected by accounting for all inflows, outflows and losses across the unit and calculating the unknown flow as the balancing flow. By balancing across operating units it is possible to deduce unmeasured flows and thereby increase the value of information in the balance. This process is illustrated in Figure 2 below:
Balancing across each operating unit within the water circuit ultimately leads to an overall water balance where the final unknown that closes the balance is calculated and is usually an un-measurable loss. The accuracy of the balance is a function of the accuracy of the flow measurements.

The basic water balance does not provide a means to check flow measurements and identify disparities other than by observing sudden changes in trends. However, the basic balance is useful in determining where the main water users and losers are in the mining circuit – an important step in the management improvement process. In addition, as measured flow data accumulates it is possible to use the balance to deduce variations in water flows on the basis of which the nature of potential management improvements can be identified.

Frequently, to improve water management, it is necessary to introduce controls. For example level sensors to open and close valves, or start and stop pumps. Or the introduction of supplementary storage capacity. All of these will result in changes to the balance with upstream and downstream effects that, until flow measurements are gathered, will remain unverified and possibly even un-quantifiable. To get around this a different balance is required often referred to as a predictive water balance.

14.2.3 Predictive Balances

The essential element in predictive balances is the incorporation of control logic into the balance. For example, spillage may be reduced if level sensors are used to close valves to a storage reservoir within the water circuit. When the valves are closed a different set of conditions will prevail through the balance than when the valves are open. Alternatively spillage could be routed to a new supplementary reservoir and re-drawn into the system under specific operating conditions thereby offsetting supply. Each of these arrangements will require control logic to operate and this control logic needs to be incorporated into the water balance.

The incorporation of control logic into the water balance requires:
An understanding of the control branches. Control branches are the alternate conditions that arise for each control setting. All mining operations will have these within operating units. A simple example could be the pit dewatering pumps. Under dry conditions the pumps may pump to a reservoir. Under rainfall conditions a second, larger pump may start that can either pump to the reservoir and overflow to the process water pond or be pumped directly to a separate water storage dam. Each of these situations needs to be identified in conjunction with the operators and then set up in the water balance as control branches regulated by “if”, “if and” and “then” statements.

Continual tracking of both flow and storage. The control logic is based on supply, storage and demand in the operating units. There are limitations on flow rate dictated by pump and pipe capacities but also by storage state. For example there may be a demand for water at an operating unit and sufficient flow capacity to allow transfer of the water from a storage unit but insufficient storage available within the storage unit to accommodate the demand making it necessary to open an alternate source of water that is only used in this particular set of circumstances. At other locations there may be water available in storage but insufficient pipe capacity to allow transfer of the water.

A calibration process to verify the logic is operating correctly. Calibration is vital for the development of a reliable water balance model and is effected by ensuring that there are more flow measurement points than are actually required to derive all flows within the balance. In this situation it is possible to estimate flows at selected metering points and then compare the calculated flows to the measured flows. If this is done for a range of operating conditions that cover all of the control states, modifications can be made to the calculation process and the control logic until a reasonable correlation between prediction and measurement is obtained.

The water balance has now progressed from a basic balance to a water balance model within which it is possible to incorporate potential management changes together with associated control logic modifications or additions and simulate the potential effectiveness of the modifications. The basis of each simulation is the fact that within each step the water balance needs to balance so that all water is accounted for.

14.2.4 Probabilistic Predictive Balances

Probabilistic predictive balances enable us to incorporate variability and uncertainty into the water balance model.

Variability occurs as a result of random events or sporadic operating conditions. Causes of variability in a mine water balance model include:

- Rainfall events
- Evaporation area, specifically the pond on the tailings storage facility (TSF)
- Evaporation rate
• Production rate
• Ore type
• Equipment failures
• Maintenance schedules

Uncertainty arises from the accuracy with which parameters in the water balance can be estimated. Commonly uncertainty in a mine water balance arises from:

• Rainfall runoff coefficients
• Seepage from the TSF
• Lock-up water volumes in the TSF
• Evaporation rates from wet/damp beaches on the TSF.

Probabilistic modeling enables the incorporation of variability and uncertainty into the water balance model and, in a spreadsheet environment, this is commonly done by:

• Incorporating probability distributions into the spreadsheet model using a spreadsheet add-in package such as @RISK or Crystal Ball.
• Incorporating random counters into the control logic to simulate the randomness of sporadic nature of the variable elements.
• Incorporating historical records such as rainfall records as seed data in the simulations.

Calibration of the probabilistic water balance is no different to the predictive balance (usually referred to as the deterministic predictive water balance). This time, however, instead of comparing single data points one compares a histogram of data points. This enables a check that the variability of the calibrating flow as a result of all of the variabilities and uncertainties inherent in the system is being representatively simulated. This is determined by using the spreadsheet to calculate the correlation coefficient of the output data, or, if calibration data has gaps, by comparing histograms of the calculated and measured flows. This is in addition to a comparison of the mean flow which calibrates the overall magnitude of the simulated flow. These are illustrated in Figure 3.
The output flows from a probabilistic water balance model are usually expressed together with a statistical measure of the confidence in the result. For example “the flow will be 300l/s plus or minus 50l/s with 95% confidence.” @RISK and Crystal Ball enable this directly from the output results.

14.3 THE BIGGEST USER, THE MOST VARIABILITY, THE HIGHEST UNCERTAINTY

Regardless of the level of sophistication of the water balance it is vital in setting up the balance to take careful note of the operating units that have the most variability and uncertainty. This, as it turns out, is seldom the pit or the processing plant but rather the TSF and associated water management infrastructure such as reclaim pond, plant storm water control pit, etc. This is because of the list of factors that cause variability and uncertainty on a mining operation, most are associated strongly with the TSF. The water balance around a TSF is particularly sensitive to:

- Rainfall and rainfall runoff coefficients
- Evaporation (rate, area, coefficients)
- Foundation seepage

Commonly 80% of the water in circulation on a mining operation is associated with the tailings facility and the largest losses from the water circuit occur in the course of tailings storage operations. Therefore, getting the water balance right must focus on getting the TSF balance right.
14.4 TSF WATER BALANCE TIPS

Since this presentation is aimed at providing hints on getting the water balance right it is appropriate to provide a number of tips for ensuring that the largest user (and abuser) of water on the mine is appropriately catered for. Figure 4 shows a plan layout of a typical TSF. Features of this plan are:

- The beach and the pond area and decant inlet
- Current, recent and previously deposited areas on the beach of the TSF

Figure 5 shows a typical cross section through the TSF and indicates:

- Seepage from the pond through the tails into the foundation and also into underdrains
- Infiltration into the beach area during and immediately following deposition
- Exfiltration from the drying beach

![Typical Plan of a TSF](image)

**Figure 4: Typical Plan of a TSF**

![Typical Section through the TSF](image)

**Figure 5: Typical Section through the TSF**
The following tips developed from experience with TSF water balances are presented:

1. Remember that the TSF is not a bath tub. The catchment area for rainfall is larger than the pond area by a factor of 3 to 5 (or higher for valley impoundments).

2. Runoff on the tails is low for low rainfall events as the infiltration often exceeds the precipitation rate. Over a month of rainfall it is common to assume a runoff factor of 50% to 65% for rainfall over the dry tails and the beach area outside of the pond. This is a reasonable averaging factor. The runoff factor on the pond is 100%, naturally.

3. Beach angles are frequently shallow and small changes in pool elevation can result in large changes in pond area. Moreover, these changes can take place over a matter of days. Choose a pond area that is representative of the actual operation. If no information exists use 10% to 30% of the beach area depending on the steepness of the beach.

4. Evaporation on the pond is usually taken as the full evaporation rate but with a lake correction factor of 0.8 during the summer months and 1 during the winter months.

5. Evaporation on the beach depends on how wet the beach area is. Wet beaches will evaporate at a rate of 0.6 to 0.8 of the pond evaporation rate. Damp beaches will evaporate at a rate of 0.4 to 0.6 of the pond evaporation rate. Dry beaches will be 0 to 0.2 depending on the rate of rise of the TSF. It is important to estimate the areas of wet, damp and dry beach in calculating the evaporation.

6. Be sure to build in the appropriate control logic for decanting. This will be different for a gravity decant compared with a pumped decant. It will be best to incorporate the hydraulics of the decant facility into the calculations regulated by the control logic.

7. Seepage rates are determined by the permeability of the tailings or the foundation, whichever is lower. Estimate the pond seepage rate by incorporating a representative pond depth.

8. Allow for infiltration down the beach during deposition on the following basis
   - Determine the rate of rise of the TSF in m/year
   - Estimate the moisture content of the newly placed tailings mass as between 30 and 50% (mass of water/dry mass of solids).
   - Subtract an allowance for interstitial water of approximately 15% (mass of water/dry mass of solids). Note that this will reduce with time as a result of desiccation but that this does not influence seepage.
   - Assume approximately half of the remaining water content change is due to evaporation and half is due to seepage. Note that during long dry summers
water exfiltrates from the dam so the proportion of seepage that reaches the base would be reduced by a further 50%.

9. It is common for underdrainage and decant water to be 30% to 50% of the water pumped onto the dam even allowing for rainfall.

14.5 MODELING WATER QUALITY

Having prepared a water balance it is worth noting that this is a significant step in the journey to modeling water quality. Changes in water management can, frequently, involve changes in water quality particularly if the management strategy is to increase re-circulation of water through the processing plant. Increased re-circulation usually implies less clean water make up, and lower dilution. Unless evaporation rates also change it is highly likely that contaminants such as salts will accumulate in the system until they reach new, higher, equilibrium concentration levels concomitant with the lower clean water dilution. New equilibrium concentrations may impact on processing plant efficiency and/or may impact on the quality of water discharging from the mine site. Water quality simulation can be carried out at two levels depending on the reactivity of the contaminant.

14.5.1 Mass Balance Basis

Contaminants such as chloride and sulfate can be incorporated into a water balance using a simple mass balance basis. In this case the concentration of contaminant in the water leaving a unit is the total mass of contaminant entering the unit divided by the flow rate. To determine the mass of contaminant entering the unit the flow rate for each stream is multiplied by the concentration of the contaminant in the stream and the result cumulated across all inflowing streams.

This process of mass transfer is carried through the entire balance and the concentration in each flow stream is determined. It is important to remember that while the TSF concentrates contaminant as a result of evaporation, it also acts as a sink for contaminant by virtue of the interstitial water that is held in the tailings. This water will lock up part of the contaminant mass.

14.5.2 Incorporating Chemical Equilibrium and Kinetics

For reactive contaminant species it is necessary to enter the realms of chemical equilibrium modeling incorporating reaction and residence/contact times (kinetics). This is a highly specialized field but there have been significant advances in the past 10 years in terms of models and reaction databases. A number of sound models are now available.

Usually this form of modeling would be required on, for example, gold processing plants where cyanide consumption by metals other than gold eg copper, nickel, etc is an issue and where increased re-circulation could result in an increase in concentrations of the competing metals.
14.6 OWNERSHIP ISSUES

Getting the water balance right is not simply a matter of having a balance that meets the needs of the mining operation. There needs to be a water balance “owner” or custodian on each mining operation. The skills of the owner need to be matched to the water balance if the mining operation is to maximize the benefit of the water balance.

Water data maintenance in a spreadsheet is well within the capabilities of environmental officers who are also usually responsible for regulatory reporting and are most adept at wheedling the information out of those people responsible for recording specific water meter readings. The maintenance and use of a basic water balance also falls well within this skill level. Most importantly, in today’s era of mobile workforces, ownership is easily transferred and picked up.

Progression up to predictive balances requires skill levels that would include an element of database programming or, in the least, setting up of conditional logic cells in the spreadsheet. More experienced environmental personnel would in most cases be capable of using and maintaining a predictive water balance. Owners with an engineering qualification would easily be capable not only of using the predictive water balance model but also of modifying it to evaluate alternative water management strategies. The issue of transfer of ownership with personnel changes will be a problem unless there is a significant period of overlap. Sadly, once a new owner loses confidence in being able to understand and use the water balance model, or has no particular interest in the model, ownership will lapse and the model will fall into disuse. At that stage there is usually regression back to the water data spreadsheet and a large element of ducking and weaving when reference is made to the predictive balance.

The leap into probabilistic modeling requires the owner to be comfortable with statistics and probability. Probabilistic predictive models will make use of probability density functions to specify uncertainty and variability and the interpretation of output data requires the owner to be comfortable with histograms and confidence limits. Most often these skills are available on mining operations but the problem of ownership and transfer of this ownership increases exponentially relative to even the predictive balance. Mining operations know this all too well and most often the “fit for purpose” debate is opened up to ensure that there is not more complication than it is worth.

In addressing this question, as this presentation has sought to highlight, it is important to bear in mind that the biggest water user on a mining operation, the TSF and associated water management structures, usually also has the most variability and uncertainty. As a consequence the only practical way to simulate water balance effects representatively is using a probabilistic water balance model. Rarely is a mining operation suitably resourced with personnel who are willing, capable and have sufficient time to develop a probabilistic model from scratch. It is therefore most common for probabilistic predictive water balance models to be set up by external specialists who are tasked with ensuring that actual use and application of the model is simplified as far as possible. Moreover, since the control logic
programmed into the model is often complex, and will usually change significantly when operating units make changes to water management, it is common to retain these specialists to make the relevant changes to the model, compile an evaluation report and hand the updated model back to the water balance “owner” once water management changes have been set.

Similarly, with regard to water balance model calibration, it is common to assemble the calibration data and pass this on to specialists who understand the range of appropriate changes that can be made to the uncertain and variable parameters to re-calibrate the water balance model.

14.7 CONCLUDING REMARKS

This presentation has shown that there are a number of tiers of water balance that could be appropriate for a mining operation ranging from simple spreadsheet data records to complex probabilistic water balance models. Where a mining operation positions itself in regard to water balances complexity is directly related to the consequences of excessive spillage, on the one hand, or vulnerability to water shortages, on the other. Getting the water balance right, therefore:

• Begins with an assessment of the primary driver that generates the need for the water balance in the first place;
• Moves through an assessment of the levels of accuracy and reliability required;
• Considers the need for being able to simulate water volume changes that could result from potential water management changes; and
• Homes in on the appropriate water balance owner with more than just a passing thought being given to succession planning to ensure that the water balance lives on through more than one generation of owner.

Finally, don’t forget the chemistry. Many mines have implemented water savings strategies based purely on consideration of water volume only to find that the resulting water quality changes have created mineral processing issues that were not considered.