Mine Water Balances – A New Proposed Approach

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Abstract

The industry has developed a dogmatic acceptance of one method for managing this uncertainty and risk -- using probabilistic water balance models. The currently accepted modeling standard in the mining industry leaves the client vulnerable to a different kind of risk – over engineering. This leads to high and unnecessary project costs. This paper encourages a different approach, succinctly stated in *Harvard Business Review*, "instead of trying to anticipate low-probability, high-impact events, we should reduce our vulnerability to them." This can be effectively done with a hybrid deterministic water balance.

This paper is not advocating for the abandonment of probabilistic water balance models, but is rather a cautionary warning towards the pitfalls of probabilistic water balances. It is a call to action for mine water experts to reframe their frame of thought process while designing and documenting water balances. It is insufficient to look at a model simply in terms probability and degree of certainty. The modeler must take a step further and understand the model's dynamics, including when and where the project is most vulnerable to extreme events, and why the vulnerability exists. A thorough documentation of vulnerabilities and recommendations for managing each identified vulnerability, as well as other unforeseen vulnerabilities should be provided to the client as part of a deliverable.

Key words: Mine water, modeling, water balance

Introduction

Effective and accurate management of water resources in a mine water balance model is crucial to the design, development, and operation of a mine. Moreover, the management of uncertainty in a water balance model is an essential element in the water balance design. The industry has developed a dogmatic acceptance of one method for managing this uncertainty and risk -- using probabilistic water balance models. In fact, the cyanide code now requires some probabilistic modeling for water balances. However, probability-based water balances carry a high risk of mismanagement and misapplication. The misuse of probabilistic models is widespread, and the ramifications vary from overly conservative water management design to catastrophic mine water related failures. This paper presents common pitfalls for probabilistic water balance models and presents a case study of a more holistic, hybrid water balance model that was prepared for a Pre-Feasibility Study (PFS) of a gold mine in Brazil.

The currently accepted modeling standard in the mining industry leaves the client vulnerable to a different kind of risk – over engineering. This leads to high and unnecessary project costs. This paper encourages a different approach, succinctly stated in *Harvard Business Review*, "instead of trying to anticipate low-probability, high-impact events, we should reduce our vulnerability to them." This can be effectively done with a hybrid deterministic water balance.

Misuse of Compounding Events

It is important to note that the Monte Carlo analysis can be both a powerful and a very dangerous tool in water balance modeling. Monte Carlo analysis is powerful because it can evaluate the net impact of combined probabilities. This can create robust models that accurately quantify risk. However, Monte Carlo analysis also has the potential to "run away with itself" and combine several low probability events together in a scenario with a very low probability of occurrence that is not within the range of probable events in the field. Figure 1 shows how this can occur.

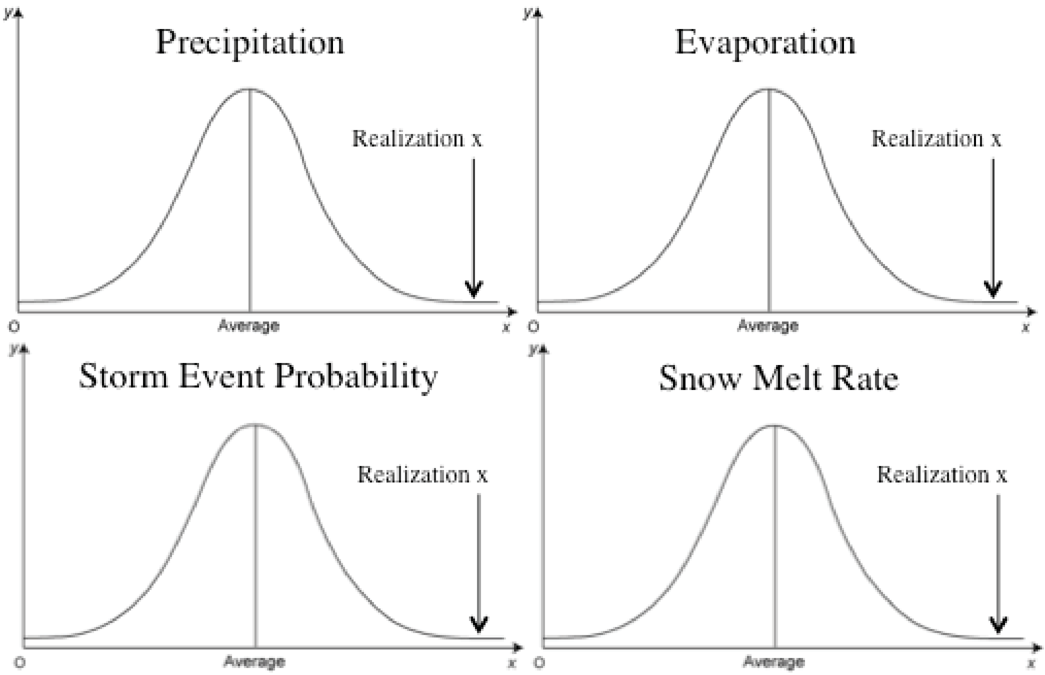

Figure 1 *Example of Monte Carlo Overprediction*

By selecting a realization (the word used for Monte Carlo iteration) with several low probability, high flow events (ex. Realization x, shown on the right of the distribution curves shown in Figure 1), one can select a scenario that has an insignificant probability of existing. If the engineers are trying to take a conservative approach, selecting Realization x seems reasonable – it is the realization that provides the largest ponds, and the least likelihood of a discharge of Mine Impacted Water (MIW) to the environment. However, this logic must be double-checked. Sizing a pond to satisfy 95^{th} percentile conditions for six parameters results in a design that is sized for an event that has a 0.000000016% chance of occurring. One must confirm that Realization x is possible within the range of conditions in the field.

For a recent mining project (confidential) located in a mountainous and snowy region, a probabilistic water balance was performed. The realization selected as the design criteria was the 95% percentile flow in the model. This realization included:

- No consideration of sublimation (up to 30% of annual precipitation);
- 70% runoff from a Waste Rock Dump (WRD) during operations (likely impossible, but at the least, requiring an exceptionally short intense storm event;
- Exceptionally heavy rainfall and snowfall; and
- Exceptionally rapid snowmelt.

The probability of all of these events occurring simultaneously was insignificant – far lower than the 1 in 100 threshold in the design criteria. The end result as an Acid Rock Drainage treatment plant designed to treat 150% of the total annual precipitation on the basin. This clear case of over-engineering severely damaged project economics.

"10,000 Iterations" Fallacy

Probabilistic models also lull the user into a false sense of confidence in the results. For example, a GRE staff member participated as an expert witness in a court case regarding estimates of required mine closure costs (Breckenridge, 2008). During the proceedings, GRE witnessed a mine closure expert, defending his probabilistic model of anticipated mine closure costs, he stated in his testimony, "We ran 10,000 realizations and as a result, have a high confidence level in the results." Indeed, a model with 10,000 iterations does sound like a robust model. However, if the initial assumptions are not correct, additional realizations do not improve the accuracy or confidence of the result. In the aforementioned example, the model used input distributions that were neither realistic nor accurate. Therefore 10,000 realizations based on flawed distributions creates 10,000 incorrect results, rather than one robust and correct result.

Furthermore, the user in a stochastic model programs in distributions for key factors, such as rainfall, storm intensity, etc (see Figure 1). Because the result of an individual realization is generated at random, the modeler does not have control over the placement of extreme stress events, such as a 100-year storm, within each realization. In 10,000 realizations, the 100-year storm event is present in 100 of the realizations, but the timing of that event is at random As a result, it is possible that a model with 10,000 realizations will never evaluate the effect of a 100-year storm during the worst possible conditions. This may be catastrophic if the storm occurs at a vulnerable point in a mine's timeline, such as when the mine water containment system lags behind mine footprint expansion.

GRE endeavoured to avoid these pitfalls by creating a hybrid water balance that incorporated uncertainty, yet retained transparency, user control, and helped clients improve project economics.

Holistic, Hybrid Water Balance Model, and Alternative Approach to Probabilistic Modeling

The Aurizona mine, owned by Luna Gold, is located in Maranhão State, Brazil, as displayed in Figure 2. The project sits on a peninsula that extends into the Atlantic Ocean, and tidally-influenced water exists less than 5km to the east and west of the mine. The Aurizona mine is an open-pit mine with conventional wet tailings disposal in a location that receives, on average, 2,760 mm of precipitation annually, with nearly all precipitation occurring in a pronounced 6-month long wet season. The Aurizona mine produced from 2006 to 2015 and is currently in a retooling period to allow for a mine expansion and changes in the process circuit.

Figure 2 *Aurizona Mine location in Maranhão State, Brazil*

Background Information and Conceptual Model

The objective of the Site Wide Water Balance (SWWB) is to provide an integrated approach to managing the project water resources and determine if the mine has excess water (that must be discharged to the environment) or a water deficit. This is done by balancing the water sources, water storage, and water losses site-wide to create a comprehensive picture of Project water use and supply. The model must consider climate, runoff conditions, and any other factors that affect the availability of water. The end result is a comprehensive picture of water flows around the site for each month of the year and each year of mining operations. The final objective is to resolve the water supply and/or the water discharge conditions so that the operation can adequately operate and so that environmental regulations can be met. The water balance also supplies a plan on how and when the Tailings Storage Facilities (TSF) must be raised.

The Vené TSF (See Figure 3) is currently used as the primary water storage facility for plant operations, and a pool is accumulated during the rainy season to ensure dry season operations. This requirement brings a series of disadvantages including increased TSF seepage; slow tailings consolidation rates, the need for accelerated raises in order to ensure safe operations, and decreased operational flexibility. In the future, the mine will use the Boa Esperança pit as a water storage reservoir. Under this proposed scenario, reclaim water from the TSF would be pumped back to the plant as quickly as possible, while fresh water makeup would be pumped from the Boa Esperança Reservoir (Reservoir). Excess water would be discharged tested for quality, and discharged into a nearby river from the Reservoir.

The model was designed in two conceptual blocks: a water balance for the TSF and a water balance for the Reservoir. Water inflows and outflows into the TSF include: runoff from precipitation (+), tailings slurry water inflows (+), evaporation (-), tailings entrainment (-), plant return water (-), TSF seepage to groundwater (-), and Reservoir excess water (-). Water flows into the Reservoir from most sources of mine influenced water (MIW) on the site. Water inflows and outflows into the Reservoir include: TSF excess water (+), runoff from the WRD (+), runoff from plant (+), runoff from interior catchments (+), direct precipitation the Reservoir surface (+), Piaba pit dewatering (+), groundwater seepage into the Reservoir (+), evaporation (-), return water to plant (-), and discharge to environment (-). Figure 3 displays the project's facilities.

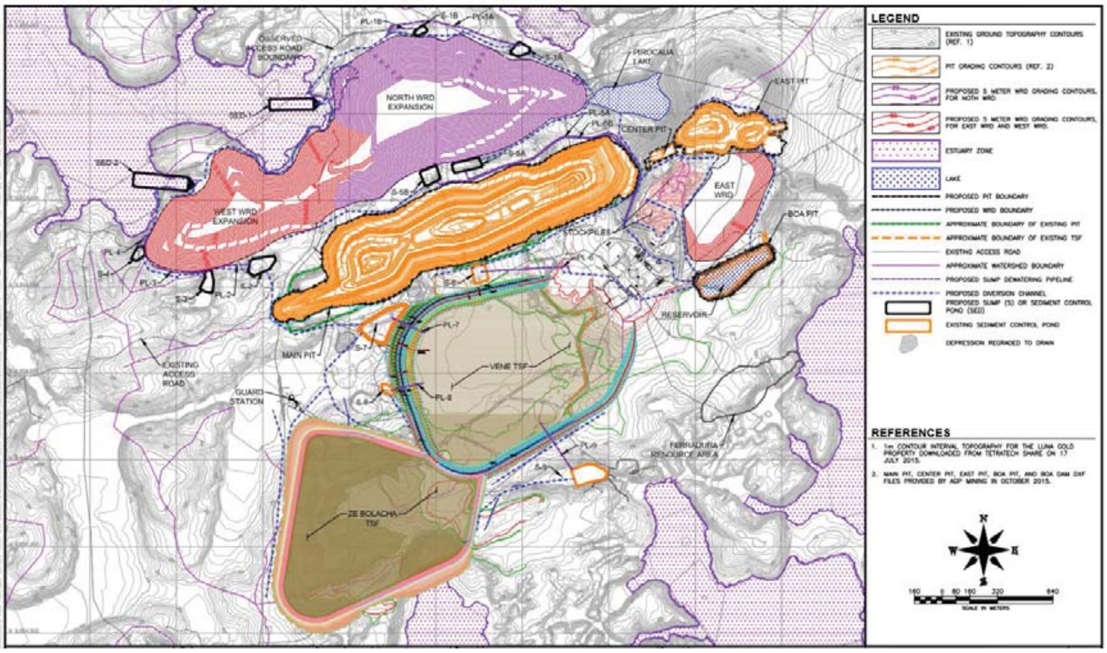

***Figure 3** Aurizona Mine General Facilities Arrangement*

Water Balance Model Parameters

The primary information the client gleaned from the SWWB included:

1. Scheduling TSF dam raises;
2. Determining excess water discharged to environment;
3. Determining freshwater makeup water requirements;
4. Determining the site wide flow of water and pumping requirements; and
5. Determining the number and location of discharge points back to the natural drainages for environmental permit compliance.

Holistic, Hybrid Water Balance Model

Water balance results and associated risk should be defined not only in terms of probability, but also in terms of vulnerability.

Instead of Monte-Carlo style probabilistic analysis as the method to resolve model sensitivity to extreme wet or dry conditions, GRE applied a deterministic approach to climate variation and model response. GRE evaluated the probabilistic climate data as one would do for a probabilistic approach, and selected specific conditions:

- Typical year conditions (50^{th} percentile);
- Extreme wet year (85^{th} percentile);
- Extreme dry year (15^{th} percentile); and
- 100-year storm event.

These conditions were programmed into the spreadsheet using date toggles permitting the application of extreme wet or dry conditions, or an extreme storm, at monthly time steps within the project development. This allowed for the placement of extreme events at vulnerable times in the mine life.

Extreme wet and extreme dry conditions were applied to the entire mine life to simulate the project under extreme stress at both ends of the spectrum to identify project pinch points. Prolonged, multi-year droughts raise concern as to whether sufficient makeup water is available to supply the plant demand without drawing below the minimum TSF Pond volume of 150,000 m^3 (a required minimum to control dust). Conversely, extreme wet conditions put the greatest stress on the storage capacity of the Project and pose the threat of exceeding the maximum permitted discharge of 2,000 m^3/hour (555 L/s) from the Reservoir.

Analysis of Makeup Water Results

Plant demand is preferentially met through water from the TSF; however, additional water is required from the Reservoir in some months to offset shortages from the TSF Pond and to prevent the TSF Pond volume from dropping below 150,000 m^3. During typical precipitation conditions, the water balance is designed to draw 100% of the plant makeup water from the TSF Pond in January through May. During the driest months of September through November, the plant demand is met with 50% from the TSF and 50% from the Reservoir. In the remaining months, June through September and December 75% reports from the TSF and 25% reports from the Reservoir. In general, if the TSF lacks sufficient available water to meet the designed discharge schedule, the remaining plant demand is satisfied with water from the Reservoir.

However, extreme dry conditions require an adjustment in ratio of TSF water to Reservoir water that is pumped to the plant. The water balance is designed to draw 100% of the plant makeup water from the TSF Pond in January through May. In the remaining months, June through December, the plant demand is met with 50% from the TSF and 50% from the Reservoir. In general, if the TSF lacks sufficient available water to meet the designed discharge schedule, the remaining plant demand is satisfied with water from the Reservoir. Figure 4 displays side-by-side comparison of the plant water source during typical conditions (top) versus extreme dry conditions (bottom).

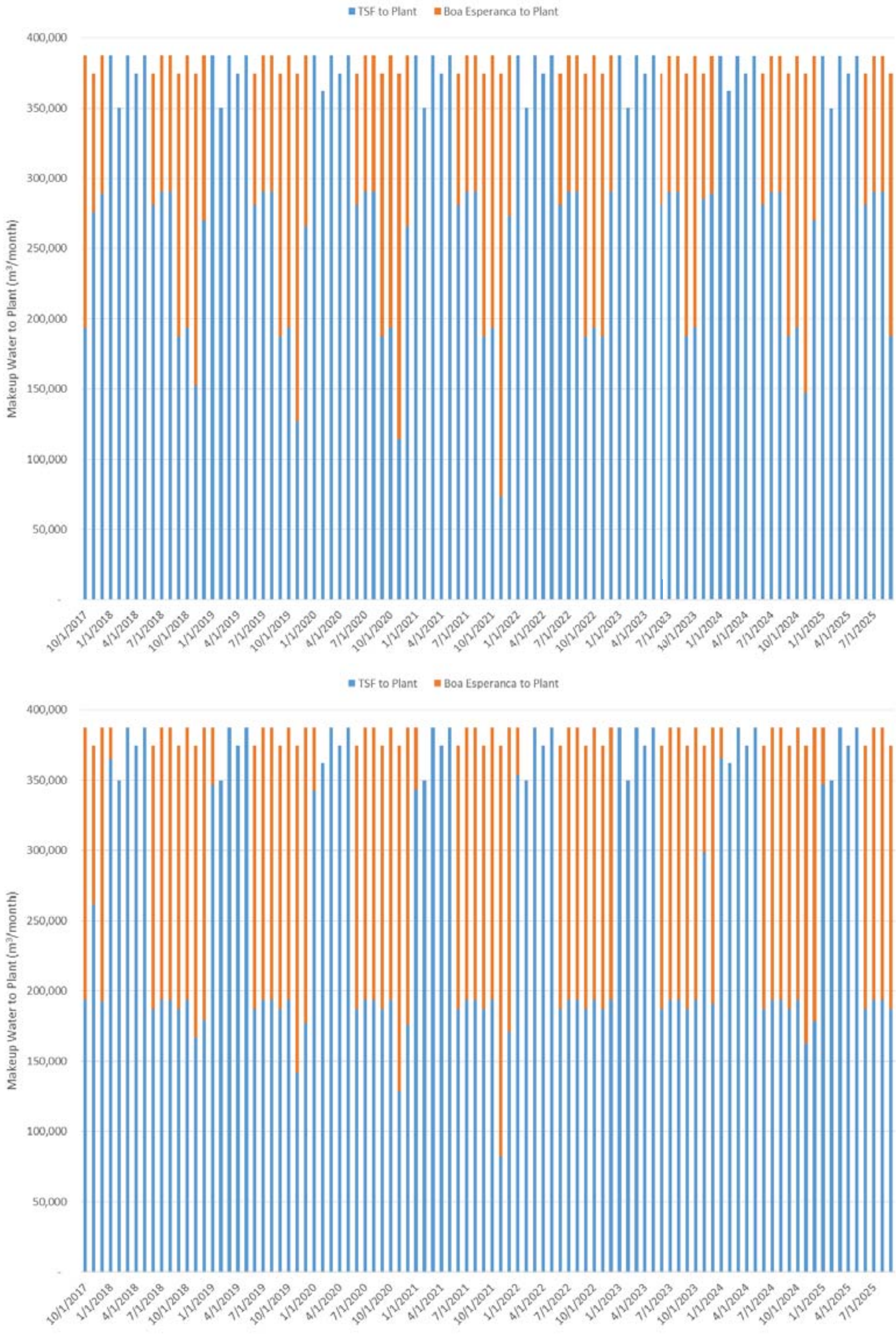

Figure 4 *Plant Water Source*

The water balance demonstrates that sufficient water is available within the system to supply the processing plant, even during an extreme multi-year drought. However, the system requires active monitoring of vulnerabilities and the appropriate response to mitigate the vulnerability in order to be successful. For example, if the Environmental Manager on site observes that the Project area is currently in a drought but fails to appropriately adjust the TSF/Reservoir pumping ratio to the plant, the plant may run out of water. If this example were to occur, the mine would have to endure the costly expense of pumping makeup water from an external source like a nearby river to be able to continue processing at full capacity, or they would have to drastically scale back processing until precipitation sufficiently replenishes the TSF and Reservoir. Both options result in a loss of revenue.

Conclusion

This paper is not advocating for the abandonment of probabilistic water balance models, but is rather a cautionary warning towards the pitfalls of probabilistic water balances. It is a call to action for mine water experts to reframe their frame of thought process while designing and documenting water balances. It is insufficient to look at a model simply in terms probability and degree of certainty. High-quality commercially-available packages create a dangerous "black box" methodology where mine water engineers fail to confirm and evaluate the results of the model against common-sense and hydrologic standards. This risk is compounded by the lack of transparency present in these models. Frequently, neither the engineers nor their clients are able to comprehensively analyze and track the reason why a particular result has been calculated.

The modeler must take a step further and understand the model's dynamics, including when and where the project is most vulnerable to extreme events, and why the vulnerability exists. A thorough documentation of vulnerabilities and recommendations for managing each identified vulnerability, as well as other unforeseen vulnerabilities should be provided to the client as part of a deliverable. It is of tremendous value to tell a client, for example: "Your containment of MIW is most vulnerable during the construction of the third phase HLF expansion. Under these circumstances, if you are to receive a 100-year storm, you may overtop a pond." This answer is far more specific and more useful than: "you have a 95% probability of overtopping a pond." This is exactly the kind of thinking advocated by the *Harvard Business Review*. In the example of the HLF expansion risk, the mine can include a design for temporary diversion berms, re-schedule the construction during a drier time of year, or evacuate available pond capacity in anticipation of the period of greatest risk. These methods are far less expensive than simply building the biggest pond produced by the probabilistic model. The hybrid approach allows the mine to reduce the vulnerability to low probability events, a requirement of all mine water design, but do to it more intelligently.

References

Breckenridge, Larry (2008), Personal Notes taken during the Groupo Mexico Expert Witness Testimony concerning the Sacaton Mine (Arizona) Closure Cost Estimate, Asarco Bankruptcy Trial, March 2008, Corpus Christi, Texas.

Taleb, Nassim, et. al. (2009), The Six Mistakes Executives Make in Risk Management, *Harvard Business Review,* October 2009.

Wilton, Michael and John Lupo (2013), Water Balances and Their Role in Operational Mine Water Management, IMWA 2013, pp. 223-228.