Water Balances and their Role in Operational Mine Water Management

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Abstract Water balances are an important tool in mine water management yet there are a number of common pitfalls that can reduce the usefulness and value of a model. Water balances may 1) be too complicated to be of use or too simple to represent real conditions; 2) not be used due to an inability to see or understand the logic in the model; 3) not provide the answers that the user requires; 4) not be updated or calibrated; 5) not include all site water; and, 6) not be seen as valuable and therefore not used.

Keywords mine water management, water balance, useful models, update, calibration

Introduction

Efficient and effective water management at mine sites is critical to ensuring successful and sustainable operations. Mine water management at operating mines can be a complex problem given the various components that contribute or remove water from the overall system. A water balance is an important tool in mine water management that in its simplest form, tracks inflow and outflow from the mine water system. Water balance models vary from simple spreadsheets that track annual or monthly flows between major mine facilities to complex simulations that include numerous components and estimate flows on a daily basis from probabilistic and actual mine (*e.g.* ore production) input.

While water balances play an important role in mine water management, they are often incomplete or misunderstood. Water balances may be too complicated to be used in a practical sense, or too simple to represent operational conditions. With the exception of climate, water balances are often created assuming static conditions such as constant watershed size, constant mining rate and mill throughput, and constant groundwater inflow, but actual conditions at mines are much more dynamic. The dynamic nature of inflows and outflows can have a significant impact on the water balance, and on overall water management strategy. For most projects, the water balance is developed prior to the mine being constructed as part of the mine study to quantify water use. However, these models are often not updated after the mine has been put into production. Depending on conditions, this can lead to models that no longer reflect the actual mining situation, and produce results that are no longer meaningful. A robust water balance must be adaptable to the ever changing mining environment so that it can be calibrated with measured data and updated with actual conditions throughout operation to be a useful component of the mine water management system.

This paper discusses a number of common pitfalls that can reduce the value and usefulness of water balance models. Examples are included to demonstrate how useful and adaptable water balance models can be developed and utilized in the mining environment.

Common Water Balance Pitfalls

Some of the more common pitfalls with water balances are listed below and described in more detail in the following sections:

- Incorrect level of complexity – models may be too complicated to be of use or too

simple to represent actual conditions;
- Nontransparent or incomprehensible – models may not be used due to an inability on behalf of the user to see or understand the logic employed in the model;
- Irrelevant results – models may not provide the answers that the user requires;
- Static – models may not be updated or calibrated to account for dynamic conditions and therefore not provide useful results;
- Not integrated – models may not include all site water inflows and outflows; and,
- Not valued – models may not be seen as valuable operational tools by mine staff and management.

Incorrect Level of Complexity

The level of complexity for a water balance should reflect the system that it represents, and the data from which it is built. If very little information is available (*i.e.* early stage study), the water balance may be relatively simple. However, in advance stage studies or operations, the water balance complexity should reflect the actual site conditions within reason. A water balance should be detailed enough to provide results that account for the site conditions, but simple enough to be understood and efficiently used by site personnel. A water balance that is too complicated or overly detailed to be updated regularly has little value. On the other hand, a model that is too simple will not provide results that allow for good design and operation decisions to be made. As a project progresses through the development cycle and into operation, the water balance model should become more descriptive, which generally requires more complexity, but the model developer should continually try to maintain a balance between complexity and over simplification.

For example, the selection of the time step (*e.g.* yearly, quarterly, monthly, daily) used in the model should be based on trying to balance the level of resolution required and the time required to develop, run, and update the model. Fig. 1 shows an example for the volume of water in a water treatment plant surge pond for a given year. If the model user wants to determine the order of magnitude of the maximum volume in the pond, the quarterly or monthly time step model may suffice. However, if the model user wants to determine the maximum volume in the pond for design calculations, a daily time step would be preferable so that the design can match the level of risk. A yearly time step is clearly too simple for this case as it does not give any indication of the need for a surge pond, because the volume in the surge pond at the start and end of the year is zero.

Nontransparent or Incomprehensible

A water balance model should be clearly understood by the users of the model. Therefore,

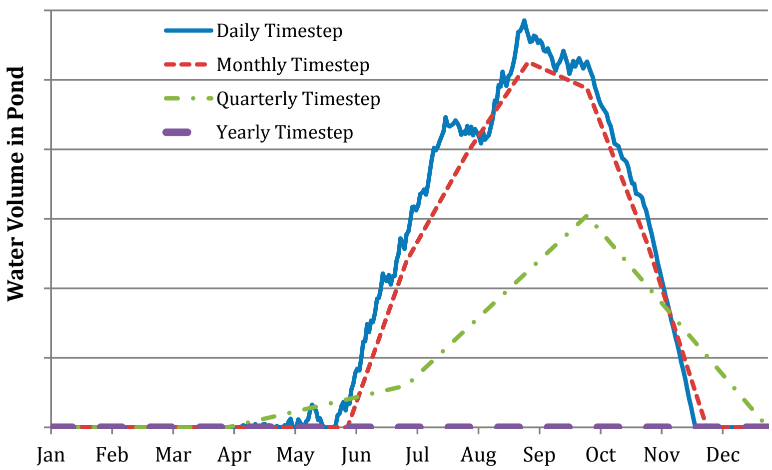

Fig. 1 *Example of time step impact for a water treatment plant surge pond volume.*

the model should be developed for the intended audience to allow users to view and understand the logic and calculations that the model performs. If site staff are unable to view or to understand the water balance calculations, there will be much less support for using the results of the water balance at an operation. While it may be necessary to have an external party develop and update the water balance due to lack of time or proficiency of the site staff, the model should be developed using a program that allows mine operators to view the calculations and results, and at least make minor modifications relatively easily. It is important that the water balance users clearly understand the intent of the water balance. Water balances are developed for a number of reasons (*e.g.* permitting, water treatment, make-up water estimation), but the intent of the water balances is sometimes not clearly conveyed to the users. This can lead to applications of the models outside of their original intention, resulting in poor performance or predictive capabilities.

A water balance should be developed and presented in a manner that allows users to understand the calculations that are being performed. Explanations of the model should be included within the model program, where possible, and documented in a user manual. Site users should be trained in the use of the model, as required.

Irrelevant Results

A water balance should provide results that enable site staff to make good operating and risk decisions. A water balance that provides numerous detailed results but does not answer the questions required to operate the water management systems at the mine is of little value.

The results of the water balance should be presented in a way that allows users to clearly understand their meaning. For example, if a water balance model presents probabilistic results from numerous model runs, the model developer should ensure that there is clear documentation to explain the significance of the results. Fig. 2 shows probabilistic results for a sump that collects runoff from rainfall in an open pit prior to pumping the water to a water treatment facility. The 95th percentile daily sump volume represents the volume below which 95 % of the model runs are found for a given day. The 95th percentile annual maximum sump volume represents the volume below which 95 % of the model runs are found for the highest volume in the sump during the year. If the water balance model shows only the 95th percentile daily sump volumes, the mine operators may size the sump to the highest value shown for the year and then incorrectly assume that the probability of the sump overtopping and mine operations being negatively impacted is 5 % for the year.

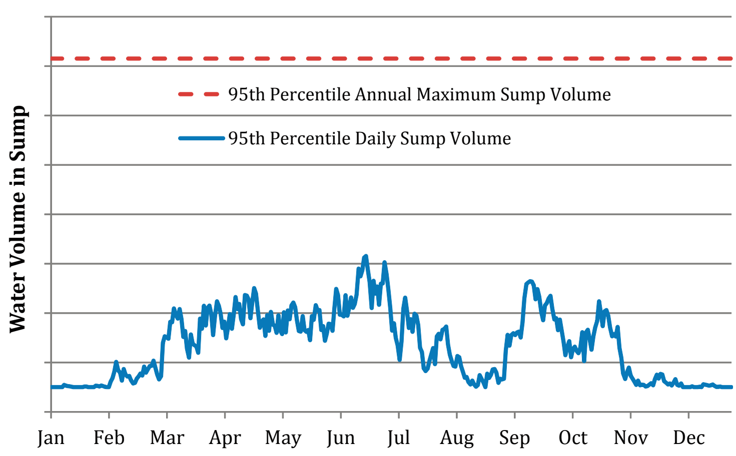

***Fig. 2** Example of probabilistic results for a sump.*

As shown by the 95th percentile annual maximum sump volume, the sump would be required to be significantly larger than the highest 95th percentile daily sump volume to actually have a 5 % probability of overtopping in the year.

In this example, this significant difference is due to the sumps filling up quickly following rainfall events and then emptying relatively quickly after the event by pumping. In the individual model runs, rainfall events occur intermittently during the wet season, with most days having no rainfall. Therefore, on any given day, most of the model runs have very little water in the sump, but almost all model runs have at least one day with significant rainfall during the wet season and therefore, significant water volume in the sump. Therefore, it is critical that the model users clearly understand what the results represent and how the results can be applied to the mine water management system.

Static Models *vs.* Dynamic Models

To be of any practical use at an operating mine, a water balance must be regularly calibrated and updated in order to reflect actual conditions. Therefore, the water balance should be developed to be adaptable and allow for the user to calibrate the model based on actual measurements and update key inputs as they change through the mine life.

Key inputs to the model, such as precipitation and runoff parameters, can be calibrated based on site measurements. Precipitation is often the key input to determine the amount of water entering the mine water management system and therefore, should be regularly updated as additional site precipitation data become available. Most water balance models include a calculation to determine the amount of runoff from a catchment as a result of precipitation. This runoff calculation can be calibrated by comparing actual measurements of precipitation and stream flow, where available. If stream flow measurements are not available, it may be possible to calibrate the runoff calculation based on measurements of reservoir water levels that receive flow from upstream catchments.

The water balance model will include a number of inputs related to the mine plan such as footprint areas for mine facilities (*e.g.* pits, waste rock, heap leach, tailings), volumes of materials (*e.g.* waste rock, ore, tailings), mining rate, mill throughput, leaching rates, make-up water, and domestic water use. Since these inputs will determine the amount of water entering and exiting the mine water management systems, they should be regularly updated to reflect the latest mine plan. The water balance model will also include a number of operations flows such as dewatering flows from the open pit or underground mine, and flows within the process system. The water balance model should be regularly updated to include actual flows from, and capacities of these systems.

A dynamic, adaptable model will allow the model user to update key inputs and determine how these changes may impact the mine operations and water management risk. Like a bank account, a water balance can move relatively quickly from a positive balance to a negative balance based on relatively minor changes to inflows and outflows. For example, Fig. 3 shows the water volume in a tailings pond. It can be seen that the water volume remains below the spillway level throughout the year and therefore the pond does not discharge. Make-up water is required for the process during much of the year. Fig. 4 shows the water volume in the tailings pond with less water losses due to a decrease in mill throughput. In this case, the water balance model estimates that the tailings pond would overtop. Regular updates to water balance models potentially allow mine operators to foresee these changes in operating conditions and take required steps to prepare for these changes, such as obtaining discharge permits and constructing water treatment plants for the discharge flow.

Not Integrated

A water balance model should include all relevant water inflows, outflows, and processes, which again highlights the importance of understanding and communicating the intent of the model. While it may be necessary to have more detailed water balance models for specific areas such as a heap leach facility or process plant, the site should have an overall, integrated, site-wide water balance model that allows staff to fully understand the water interaction between the different mine facilities. This integrated model should allow for evaluations of how changes in water management in one area of the site may impact other areas, such that water management risks that are critical to operations can be identified.

An integrated, site-wide model may also allow mine operators to identify and implement more efficient water use methodologies. For example, the base case presented in Fig. 3 shows a requirement for make-up water during a significant portion of the year. Fig. 5 shows this make-up flow and assumes that the same mine site treats water from the pit and waste rock facilities and discharges this treated water to the environment. An integrated, site-wide water balance model would allow the operators to evaluate the impact of using the treatment discharge to reduce the amount of make-up water required, as shown in the modified case in Fig. 5.

Not Valued

A water balance model must be seen as a valuable operations tool by users and manage-

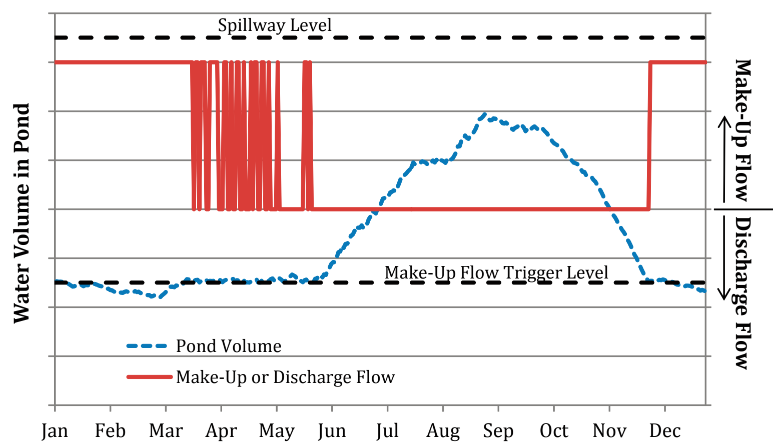

Fig. 3 *Example of base case tailings pond volume.*

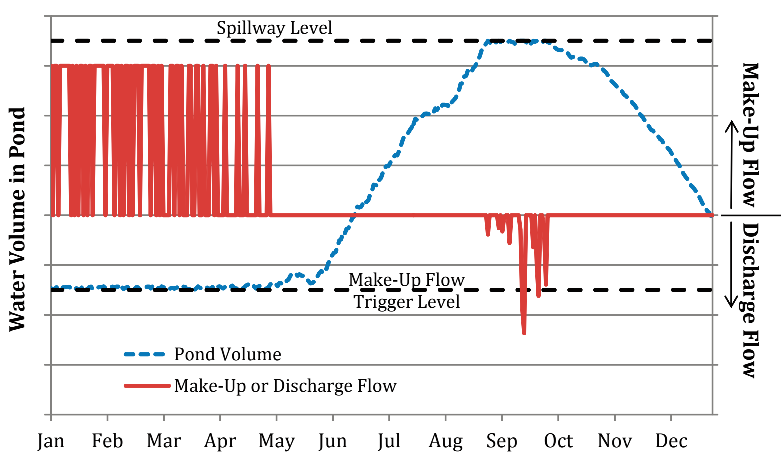

Fig. 4 *Example of a reduction in water losses causing spillway discharge.*

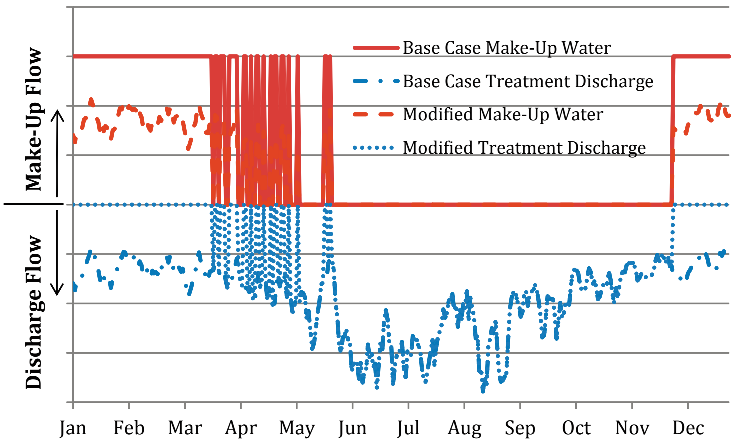

***Fig. 5** Example of an integrated model resulting in more efficient water use.*

ment. Often a water balance is under-valued and not considered as an important component. However, water use and efficient water management are critical for sustainable mining operations. Developing, calibrating, updating, and using a water balance model can involve significant effort, and if the results are not valued, the resources required to maintain the model will not be included in the operating budget for the mine. Model developers and users can ensure that key stakeholders appreciate the importance of the model by avoiding the pitfalls mentioned above and by effectively communicating the results and advantages of the model.

Conclusions

A water balance is an important tool in mine water management. For a water balance to be useful and of value to mine operations, it should 1) be detailed enough to provide results with sufficient accuracy but simple enough to be understood and efficiently used by site personnel; 2) be transparent and understood by the users of the model; 3) provide results that enable site staff to make good operating decisions; 4) be regularly calibrated and updated to reflect actual conditions at the mine site; 5) include all relevant water inflows, outflows, and processes at site; and, 6) be seen as a valuable operations tool by users and management so that it is used. A water balance model that achieves these goals will support efficient and effective water management practices at operating mine sites.