

# Pit Lake Water Balance Modelling – Detail Matters

Pierre Rousseau<sup>1</sup>, Ignacio Vernengo Lezica<sup>2</sup>, Zip Boniecki<sup>1</sup>,  
Steven Murton<sup>2</sup>, Marilena Stimpfl<sup>3</sup>

<sup>1</sup>SRK Consulting (Australasia), Level 3, 18 - 32 Parliament Place, West Perth, 6002, Western Australia,  
prousseau@srk.com.au, ORCID 0009-0006-4651-3356, zboniecki@srk.com.au

<sup>2</sup>SRK Consulting (Australasia), Level 5, 200 Mary Street, Brisbane, Queensland, 4000, Australia,  
ivernengo@srk.com.au, smurton@srk.com.au

<sup>3</sup>BHP Limited, Level 30 125 St Georges Terrace, Perth, Western Australia, 6000, Western Australia,  
marilena.stimpfl@bhp.com

## Abstract

The influence of in-pit tailings deposition, long term salinisation and potential wind sheltering were assessed for a pit lake water balance.

Tailings slurry water content had a major influence. At 42% water content it was similar to surface water and groundwater inflow rates but at 80% water content it was about 5 times higher.

For scenarios with and without salinity and wind sheltering corrections, pit lake water levels varied by 3m to 22.5m, depending on pit morphology. Steeper slopes result in greater variability.

The work shows that operational, morphological, geotechnical and geochemical factors can have a substantial effect on outcomes.

**Keywords:** IMWA 2026, pit lake salinity, pit lake water balance, pit lake modelling

## Introduction

SRK Consulting (Australasia) Pty Ltd was appointed to review an existing closure model for a mine pit lake, constructed in GoldSim™ software, and to construct a revised version that included in-pit tailings deposition. Additionally, an operational water balance was to be constructed, to assess the effect of in-pit tailings deposition on the operational water balance. The objective of the models was to evaluate the probability of discharge from the pit to the surrounding environment, including groundwater, if the water balance simulated water levels to exceed the pit lake flow-through level, which was obtained from the MODFLOW groundwater model for the site.

During the review process it was identified that the evaporation rate used in the original closure water balance was excessive. This was based on the use of an A-pan correction factor of 0.8 (typically a factor of 0.7 is used for fresh water). It was also identified that local groundwater was saline (>10,000 mg/L TDS), which was

expected to result in a highly saline pit lake over time, due to evaporative concentration in an environment with high net evaporation. It was considered that this would result in suppression of evaporation, known to occur at high salinity concentrations (Salhotra *et al.* 2007, McJannet *et al.* 2019).

Several factors are known to influence evaporation rates in mine pit lakes, including solar shading, wind sheltering and salinity effects (McJannet *et al.* 2017, McJannet *et al.* 2019). These effects can vary widely between different mines due to pit morphology, surrounding topography, their location (latitude) and the local water balance and groundwater quality.

## Methods

### *Salinity corrections*

The existing GoldSim™ closure mine water balance model for the operation was used as a basis for constructing both an updated closure model, as well as for a separate operational model that required major modifications.



Both models were updated to include a module to calculate evaporation suppression based on salinity, specified as TDS in mg/L. This was done using the equation of Panin and Brezgunov (2007), in accordance with McJannet, *et al.* (2019). The equation was checked against other publications to evaluate its accuracy and it was found to agree satisfactorily (Salhotra *et al.*, 1987). Although evaporation suppression is affected by the ionic composition of salinity (Abdelrady, 2013), it was found that the equation was adequate to assess the effect of salinity on evaporation compared with other publications.

$$E_s = E_0 (0.75 + 0.25 \times e^{-0.655S}) \quad (1)$$

where  $E_s$  is the evaporation rate from a saline water surface,  $E_0$  is the evaporation rate from a freshwater surface,  $e$  is the constant 2.718 and  $S$  is the salinity in percent.

Additionally, an allowance of up to a 20% reduction in the evaporation rate, due to wind (and solar) sheltering, was also included, which was considered sufficiently conservative in the absence of a detailed wind and solar sheltering model.

### *Tailings deposition*

The inclusion of in-pit tailings deposition for the closure water balance was limited to revising the pit lake stage-storage curve from the pit shell to the modelled tailings deposition surface (and closure pit shell above the tailings surface). This update was required in order to correctly account for the change in available water storage capacity of the pit and the change in pit lake surface area associated with the sloped tailings surface. The model was run on a daily time-step to align with daily weather data. Weather data incorporated CMIP5 Access1-0Q RCP4.5 and RCP 8.5 climate change scenarios that were carried over from the existing pit lake water quality model.

For the operational water balance, the change in water and solid volume in the pit was modelled on a daily time-step. This was required to assess the influence on the pit water storage volume and the associated pit lake water level, as well as to align with daily weather data. Weather data was updated to

CMIP6 SSP 2.6, SSP 4.5 and SSP7.0 corrected daily data. Pump dewatering, at the specified pumping capacity of the dewatering system, was also included as an option. This element was used to check the duty cycle of the pumping system and to determine its capacity and the required pumping duration to remove excess water after large rainfall events.

## **Discussion**

### *Salinity corrections and wind sheltering*

The inclusion of detailed tracking of salinity evolution and the tailings water and solids balance provided useful insight into their influence on the water balance.

It was found that inclusion of wind sheltering and salinity in the evaporation calculation resulted in an effective A-pan correction factor to between 0.50 and 0.58 for the base case (no in-pit tailings deposition). This assessment was based on an initial correction for an open water body of between 0.7 and 0.8, maximum salinity correction of 0.9 (over the modelled period to 2400) and a wind sheltering correction of 0.8 (an assumed conservative value). With in-pit tailings deposition, salinity increases much quicker due to a lower in-pit water volume, reaching a salinity of >250,000 mg/L by 2400 and an evaporation reduction factor of 21%. Over the modelled period, average salinity changes from around 10,000 mg/L to >250,000 mg/L for this case, through evaporative concentration (Fig. 1). Over the very long term, salinity would be expected to continue increasing at the study site, due to relatively high magnesium concentrations in local groundwater. Magnesium salts are known to be highly soluble relative to NaCl salinity, thereby resulting in higher salinity than solutions where salinity is controlled by salt precipitation, e.g.  $\text{Na}^+$  and  $\text{Cl}^-$  forms halite. The evaporation rates ( $E_s$ ) may be reduced by more than 20% relative to fresh water if salinity exceeds about 250,000 mg/L, potentially resulting in a pan correction factor of as low as about 0.45 (assuming a 0.2 wind sheltering factor). Evaporation reduction over the modelled period is shown in Fig. 2. The salinity correction factor as modelled is shown in Fig. 3 and versus salinity according to Panin & Brezgunov (2007) in Fig. 4.

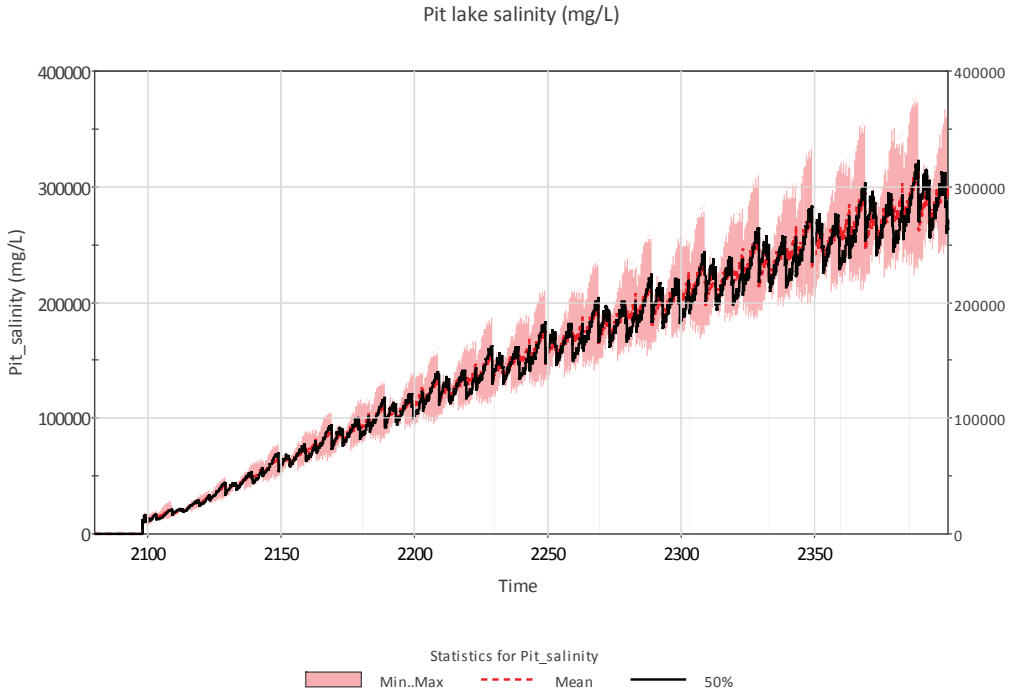


Figure 1 Pit lake salinity evolution over the modelled period to year 2399.

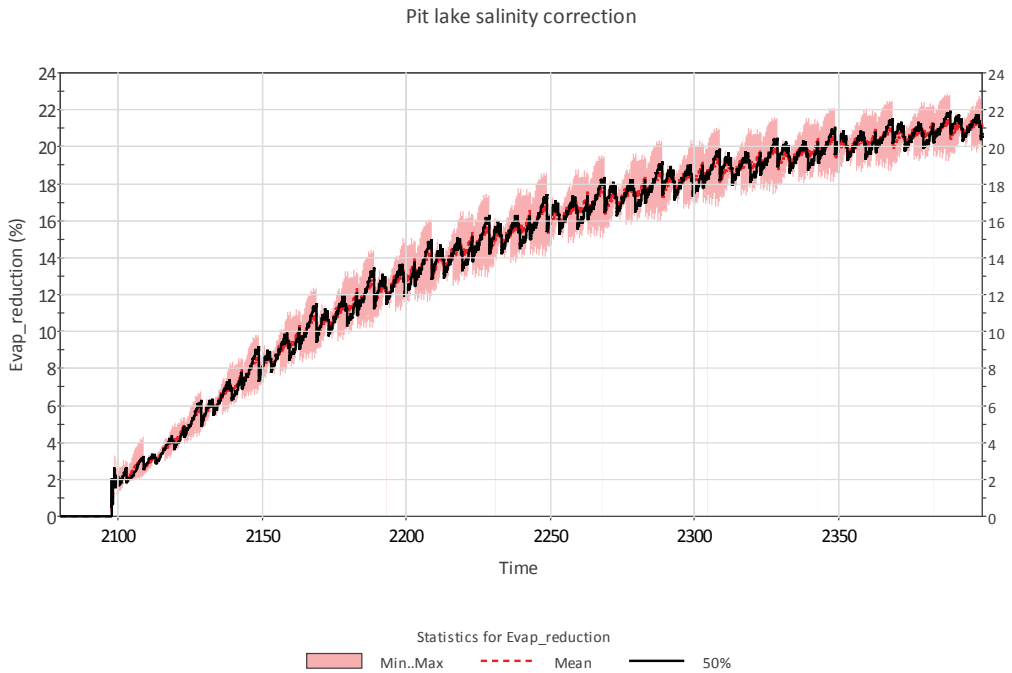


Figure 2 Reduction in the evaporation rate with increasing salinity, as a fraction relative to fresh water by year.



Pit lake salinity correction

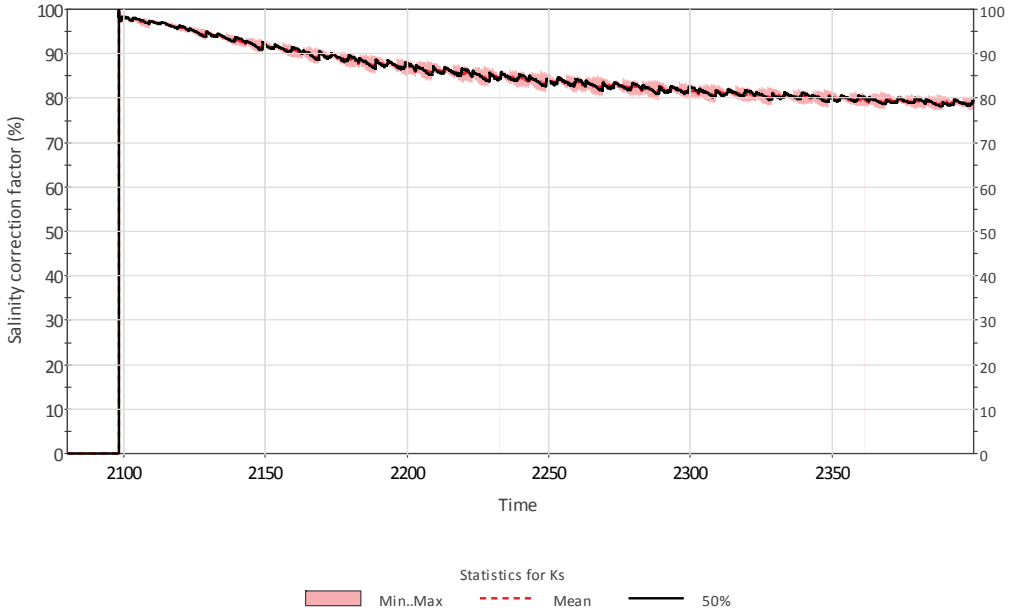


Figure 3 Evaporation rate relative to fresh water, as a result of salinity correction, over the modelled period.

Modelled evaporation suppression based on Panin & Brezgunov equation

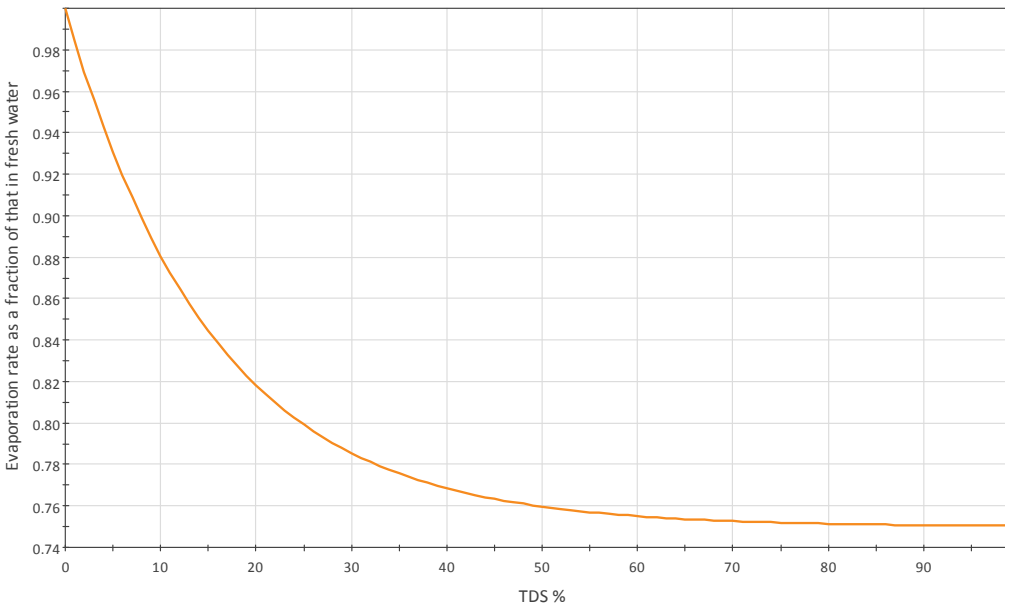


Figure 4 Correction factor vs salinity based on Panin & Brezgunov (2007), as a function of total dissolved solids, in weight %.



When including the adjusted evaporation factors in model calculations, the morphology of the pit was found to be an important influence on the outcome. Pits with relatively flat slopes (about 15° on average) were not affected by dramatic changes in pit lake elevation, with a change of only 3m calculated for the closure model. In a pit with steep slopes (about 35° on average), a change of up to 22.5m in the pit lake elevation was calculated. This is attributed to flat slopes resulting in large changes in evaporative surface area with small changes in water elevation, whereas the opposite is true for steep slopes. Factors such as surface water catchments and groundwater inflow rates versus pit lake elevation must also be taken into account to calculate the pit lake water level, hence it is not possible to generalise the extent of these impacts.

#### *In-pit tailings disposal*

Modelling of in-pit tailings disposal showed that accurate representation of the elevation – volume stage curve can be an important factor in calculating the water balance, particularly post closure when dewatering has ceased.

In the case of the project under discussion, a single-point discharge was specified for tailings disposal. This would create a sloping tailings surface, with a sump (decant pond) on the opposite end of the pit from the discharge point. An initial calculation was done assuming a flat tailings surface at the approximate crest height of the tailings. It was found that spills (overtopping) would occur from the pit during large rainfall events, due to limited water storage capacity above the tailings. The model was adjusted to include the modelled tailings surface, as used in deposition modelling for estimation of total tailings storage. The model results indicated that the sloping tailings surface would create sufficient additional storage to hold a probable maximum precipitation event within the pit, without creating spill events. This was complemented by an evaporative surface that remained active below the tailings crest as the water receded. On a flat tailings surface evaporation would effectively cease, or would be much lower than from open water, once the pit lake water level intercepts it, as tailings would be exposed over the whole area.

For the operational phase, a flat tailings surface was modelled, but to a lower elevation to accommodate an equivalent quantity of tailings to the final tailings surface. This was done to estimate the effect of tailings deposition on the water balance, in particular the probability of creating spills from the pit and to evaluate pumping requirements. Simulations were run using 58% solids content (42% water content) and 20% to 40% (60% to 80% water content) for the tailings stream to be deposited. It was found that the change in solid content of the tailings made a major difference to the overall pit water balance. For the higher solid content, free water (defined as total water minus entrained water trapped in deposited tailings) was of a similar magnitude to groundwater and surface water inflows. For the lower solid content, free water generated was about 5 times higher on average. With the higher solid content, only 5% to 10% of maximum pumping capacity would be required, reducing to virtually zero at mine closure due to evaporative losses. For the low solid content scenario, pump utilisation was generally between 30% and 35% of maximum capacity, reducing to a mean of about 10% at closure (see Figs. 5 and 6).

#### **Conclusions**

The results of the GoldSim water balance model showed that oversimplification of the modelled scenario had major effects on the simulated results. Where groundwater inflowing to a pit lake is highly saline, there is the potential for significant reduction of the pit lake evaporation rate in the long term. This can result in an evaporative sink becoming a flow-through system due to reduced water losses. The potential for wind and solar sheltering to reduce the evaporation rate should also be considered in modelling, particularly for deep pits and those with north-south orientation, as these factors would also impact on evaporation rates.

Where in-pit tailings disposal is practiced, a sloped tailings surface may have an important influence on the long-term pit lake water balance, due to increased storage and evaporation relative to a flat surface.

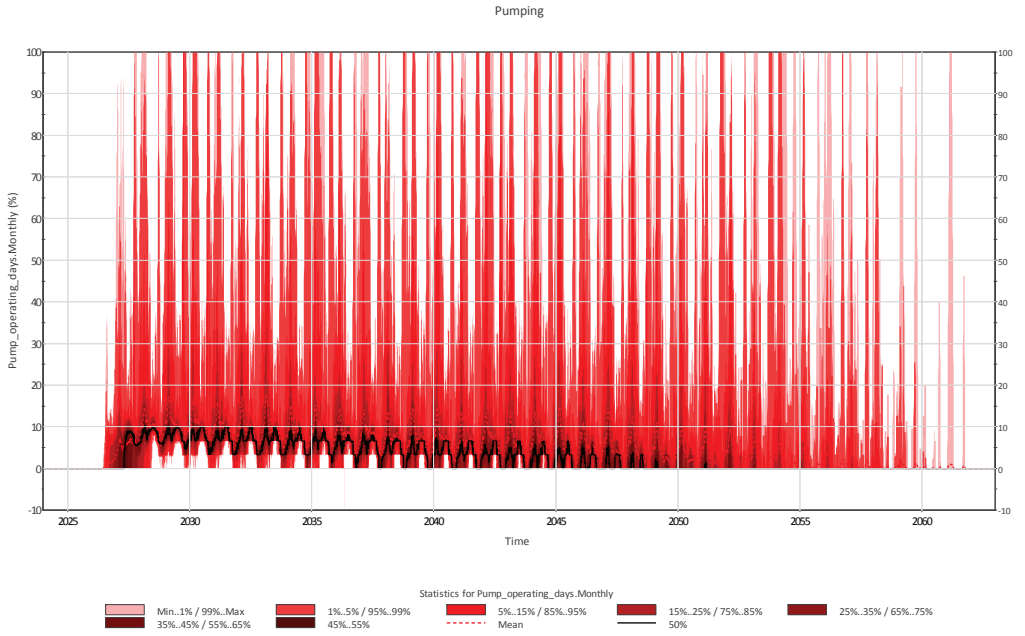


Figure 5 Modelled pumping requirements with 58% solids.

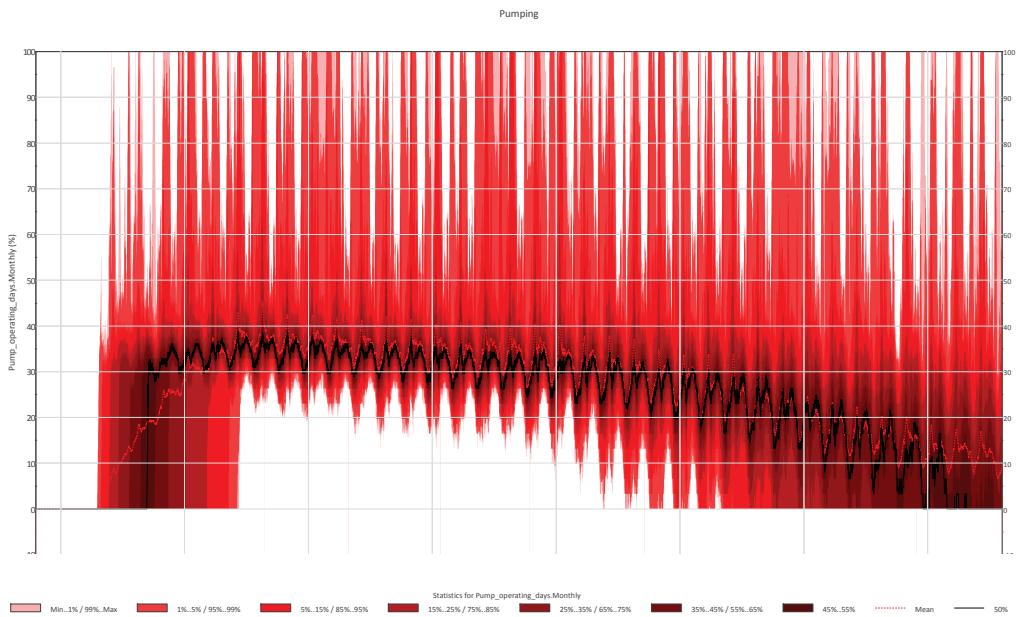


Figure 6 Modelled pumping requirements for 20% to 40% solids.



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