Paste 2008 — A.B. Fourie, R.J.Jewell, A. Paterson, P. Slatter (eds)
©2008 Australian Centre for Geomechanics, Perth, ISBN 978-0-9804185-4-5

Alternatives to Paste Disposal with Lower Water Consumption

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Abstract

The assumption that water consumption is reduced by implementing better tailings dewatering technology in the plant is not always correct. This paper presents a simple relationship for comparing water losses for "paste" disposal to "slurry" disposal over a range of tailings, rates of rise and climatic conditions. The objective is to demonstrate and explain the mechanism whereby high rates of rise reduce water losses within the limits of assumptions that are valid for a wide range of practical conditions. The relationship can be used for preliminary and conceptual estimates of water consumption, but requires validation from more detailed water balances and testwork to satisfy feasibility studies.

The paper presents the preliminary results of an application of the method in an evaluation of possible water losses at a new valley disposal facility in South America where there is a large variation in rate of rise over the life of the facility. These results were compared to a detailed water balance and found to agree reasonably well for high rates of rise, but becomes inaccurate for low rates of rise. It has been shown that high rate of rise slurry deposition tailings facilities can yield similar or better water consumption rates than paste facilities.

1 Introduction

There is an increasing tendency in the mining industry to consider tailings paste disposal as a means of saving water. Water scarcity and other sustainable development considerations are the prime drivers. Unfortunately in some cases "paste" has been adopted as the solution because it is the latest technology, and the cost and environmental benefits have not always been properly evaluated in the decision making process.

There is a widely held view in the industry that water consumption is reduced by implementing better tailings dewatering technology in the plant. Automatically regarding thickening of tailings as being synonymous with water savings is sometimes a fundamental flaw and provides a background in which interested vendor parties are able to market thickening equipment without proper scrutiny.

Thickeners themselves do not directly "save" water. In order to save water it is necessary to reduce the actual water losses that need to be offset by make-up water. This cannot be done in isolation in the plant. In reality, savings can only be effected when water balances for the entire system including the dewatering plant, tailings disposal facility and return water facilities are considered as a whole, including an economic comparison with energy balances of the possible solutions.

For slurry disposal, excess water must be recovered and returned to the plant for re-use to minimise water losses at the tailings disposal facility. For paste, the recovery of water from the facility is minimal during normal operation, and often inefficient following precipitation, with the system relying heavily on recovery in the plant to minimise water consumption. Under certain circumstances, when slurry is deposited on a facility at a high rate of rise a large proportion of the basin remains effectively saturated all the time, and newly deposited slurry does not rewet the beach, instead releasing all excess pore water to the pool as it settles and consolidates. By virtue of the comparatively small dry beach area in such facilities water recovery is enhanced by capturing and returning the excess water runoff to the plant for re-use, and the water consumption may be lower than for a paste system. The cost of thickening together with the often costly disposal facilities required for paste disposal, can tip the scales against paste before the breakeven point in consumption is reached. It may be necessary to include some thickening in the plant to reduce the volumes of slurry and water pumped to and from the tailings disposal facility. This will be made evident from the inclusion of energy balances and costs in the trade-off comparisons.

This paper presents a simple mathematical relationship comparing water losses for paste disposal to those for slurry disposal over a range of tailings, rates of rise and climatic conditions. It also presents the preliminary results of an application of the method in an evaluation of possible water losses at a new valley disposal facility in an arid location in South America where there is a large variation in rate of rise over the life of the facility. One of the key but conservative assumptions is that the entire beach is wet, which is typically only valid for high rates of rise, and can only be achieved under certain operating conditions.

It will be shown in what follows that high rate of rise slurry deposition tailings facilities can yield similar or lesser water consumption rates than paste facilities, and that the simple relationship can provide results which agree reasonably well with more rigorous water balances.

2 Simple relationship between water losses and rate of rise

2.1 Primary water losses

The primary losses in tailings disposal are:

- Water locked up in the tailings voids.
- Evaporation.
- Unrecoverable seepage.

Direct comparisons between thickened and unthickened tailings systems are impossible to find because the two systems have never been used side by side. However, in order to quantify and gain an understanding of these losses as they are affected by the rate of rise in disposal facilities, a simple model relating water losses within a tailings deposit to its beach rate of rise has been developed.

2.2 Assumptions

The following assumptions have been made for “slurry” and “paste” disposal facilities.

For slurry (applies to unthickened and thickened tailings):

- The deposition rate is such that the entire beach surface remains wet.
- The extensive wet beach acts as a horizontal gravitational thickener with supernatant water runoff.
- Consolidation water reporting to the beach after the initial bleedwater runs off is ignored (conservative), i.e. the initial beach void ratio determines the volume of water locked up in the tailings voids. However consolidation water would in reality be recoverable.
- The full evaporation rate is applied over the entire beach area (conservative).
- Return water dam losses, if relevant, have been ignored in the comparison.

And for paste:

- No return water is recovered from the tailings deposit, i.e. the total water loss equates to the water contained in the paste as delivered to the deposit (worst case).

In both cases, a worst case or conservative approach is taken. Unrecoverable seepage has been assumed to be similar for “paste” and “slurry” systems formed on similar soil strata (ignoring differences in area and hydraulic gradient). Consolidation water for both systems arising from compression under increasing overburden has been ignored, although in all probability it would be recoverable from the slurry facility, but evaporated from the paste facility. Some supernatant and storm water run-off would be recovered from a paste facility.

2.3 Relationship between water losses and rate of rise

On the basis described above, a simple relationship between water losses and rate of rise can be determined. The rate of rise is inversely proportional to the beach area. For slurry the water loss is the sum of locked up water and evaporation losses determined on the basis of the full evaporation rate applied over the full beach area. For paste it is independent of rate of rise.

2.3.1 Water losses for slurry deposition

It can readily be shown that:

Dry density = $G / (1 + e_b)$ tonnes of ore/m^3 on the beach. (1)

Water lost in evaporation = $1000\,(E - P)\,(1 + e_b) / (G * \alpha)$ L/t ore milled (2)

Where E = evaporation rate in m/year.

P = precipitation rate in m/year.

e_b = void ratio on the beach after runoff of bleed water.

G = particle density in tonne/m^3.

α = net beach rate of rise in m/year.

Water lost in voids = $1000\, e_b / G$ L/t ore milled. (3)

The total make-up water is the sum of Equations 2 and 3. Based on the entire beach being wet, seasonal variations or monthly rainfall and evaporation differences do not need to be taken into consideration.

2.3.2 Water losses for paste deposition

Assuming no return water is recovered from the tailings deposit:

Total water lost = $1000\, e_p / G$ L/t ore milled. (4)

Where

$e_p = (G - \gamma_t) / (\gamma_t - 1)$

γ_t = total relative bulk density of the paste (thickener underflow).

2.3.3 Graphical representation

Based on the above relationships, the following graph has been prepared using typical properties that may be expected for Witwatersrand gold tailings. The results for a range of beach void ratios and paste densities are given in Figure 1 to indicate the envelope of tailings behaviour and thickener performance, based on the following assumed input values.

- Particle density = 2.65 t/m^3.
- Paste relative bulk density = 1.70 t/m^3. Target value (lower bound 1.65; upper bound 1.75).
- Void ratio on beach after bleed water runoff = 1.0 (lower bound 1.2; upper bound 0.8).
- Precipitation = 0.7 m/yr.
- Evaporation = 1.4 m/yr.

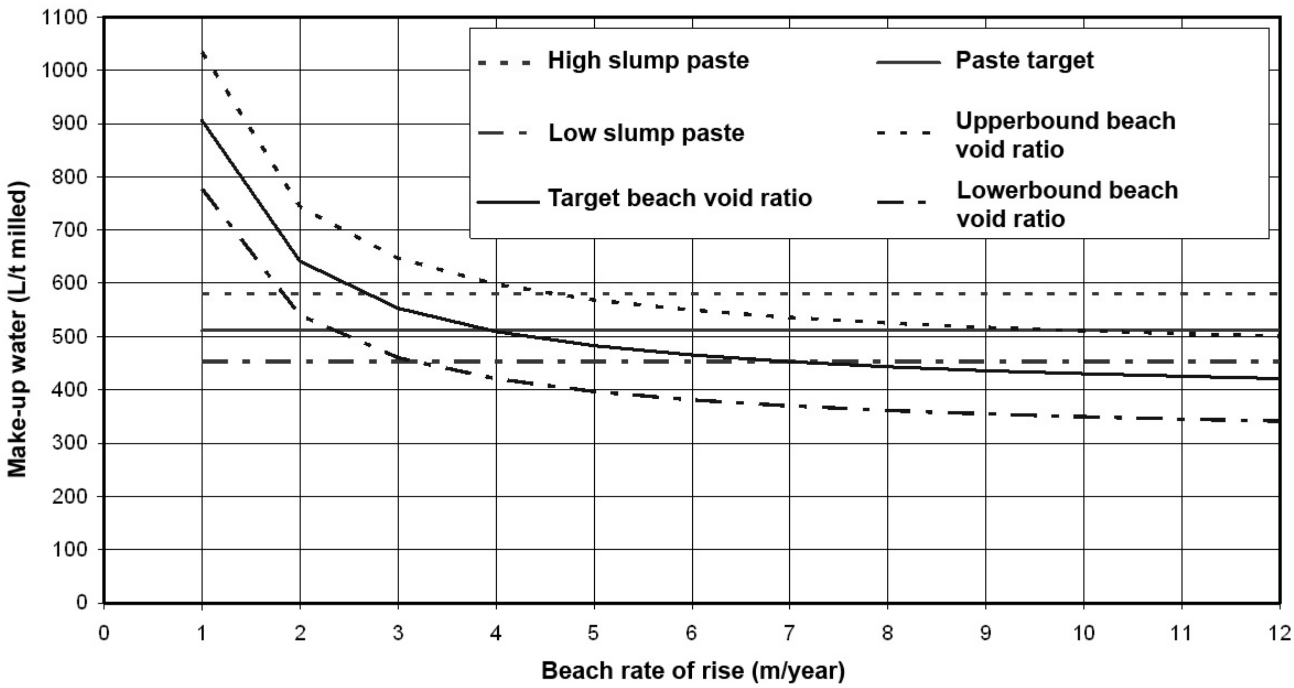

Figure 1 Relationship between make-up water and beach rate of rise for Witwatersrand gold slimes under normal weather conditions

Figure 1 shows that for rates of rise higher than 4 m/yr with slurry deposition (low density or high density), better water recoveries can be expected than for a paste based on the target consumption value of 510 L/t milled. Such rates of rise are easily attainable for cycloned tailings dams, and for impoundment dams with preconstructed walls. Under these circumstances, when a slurry is deposited on a high rate of rise facility, the basin remains effectively saturated all the time and hence water recovery is high.

A high rate of rise is defined as a rate exceeding the evaporation rate such that the basin of the facility remains effectively saturated all the time. This results in minimal rewetting by fresh deposition of tailings and maximises run-off from rainfall events. In reality, for high rate of rise facilities, it is unlikely in most cases that 100% of the beach will be wet at all times, and hence the relationship derived may be conservative unless significant re-wetting offsets this. Underdrain flow will also be recovered but has been ignored in the calculation (for both systems). Consolidation water can be accounted for by the difference between the target void ratio and the lower bound void ratio. The difference in costs of transporting and distributing slurry or paste from the plant to the tailings facility would need to be accounted for in the economic comparison.

In essence, the beach acts as a horizontal gravitational thickener in which thickening occurs by gravitational settlement. Thickening occurs with no thickening plant or flocculant, and gravitation comes free.

On a paste facility some water recovery may be possible through collection of bleed water and rainfall run-off. The geometry of the paste facility may result in inefficient and uneconomic recovery, and therefore has been ignored for the simple case. A more rigorous water balance would have to account for this, taking into account the site specific aspects of the facility.

3 Validation of the simple relationship in a practical case

An assessment of the water losses for a proposed mine in Peru has recently been undertaken by Anglo Technical Division. The proposed tailings dam is a valley-type facility with a cycloned cross-valley main wall. This assessment provided an opportunity to check the validity and applicability of the simplistic approach in a practical example as described in Section 3.1. In order to check this simple validation, a detailed water balance comparison was made, as described in Section 3.2.

3.1 Estimation of water consumption using the simple relationship

Estimated results have been obtained and are to be confirmed through testwork. Figure 2 shows the results, based on certain assumptions described below.

The following assumptions were made:

- The dam basin is fully saturated at all times (this would not be true at low rates of rise but the rewetting losses could be similar to the evaporative losses from a wet beach).
- A high rate of rise for this example was considered to be the annual evaporation rate plus 1.0 m/yr (in this case 1.7 + 1.0 m/yr = 2.7 m/yr) to ensure that an extensive wet beach is achieved and evaporative losses are capped.
- A run-off factor of 1.0 applies across the whole beach area.
- An evaporation factor of 1.0 (standard A-pan) applies across the whole area (beach and pond).
- No water is recovered or returned to the plant in the case of paste (in reality some water could be recovered, especially at high rates of rise).
- Unrecoverable seepage losses are ignored, and all collected underdrain flows are pumped back to the cyclone plant for dilution of the feed and hence are not lost.
- No seasonal effects are included – only annual rainfall (50 mm/yr) and evaporation values are considered.
- The changes in surface area of the facility are taken into account by the rate of rise.
- No rainfall run-off from the catchment was included.
- Paste disposal would take place on the same valley site behind an impoundment wall.

3.1.1 Base case (design case with normal weather conditions)

The base case assumed a target beach void ratio of 0.95 and normal weather conditions. The results are given in Figure 2.

The water consumption for a paste would average 0.53 m^3/tonne of tailings deposited, and lie within a range of 0.49 and 0.60 m^3/t. This represents the new water or volume of make-up water needed to maintain production.

Figure 2 shows that at a rate of rise exceeding 7 m/yr, deposition of a slurry would result in the same or lower water consumption than for paste deposition. At a rate of rise between 5 and 7 m/year, the water consumption rate drops from 0.53 to 0.60 m^3/t (around the limit for high slump paste). At lower rates of rise, paste disposal would achieve lower water consumption. Many paste thickeners are only able to consistently produce a high slump or dilute paste, in which case a water consumption of 0.60 m^3/t applies. By considering the lower bound void ratio, consolidation water recovery from a slurry can be included. For the proposed valley tailings facility this implies that for a period somewhere between 10 and 15 years of operation, conventional disposal would achieve the same or better water consumption rate than for paste.

While a high rate of rise of 2.7 m/yr was ‘defined’ for this case, in the dry climate in which this tailings facility is located, a rate of rise >5 m/yr is required to compete with paste disposal in terms of water consumption. The comparison ignores the situation where the surface area of the high rate of rise “slurry” operation would be much less than that of the “paste” operation on a flatter site for a given annual tonnage, in which case (E-P) over the respective surface area will be much reduced in the case of the “slurry” operation.

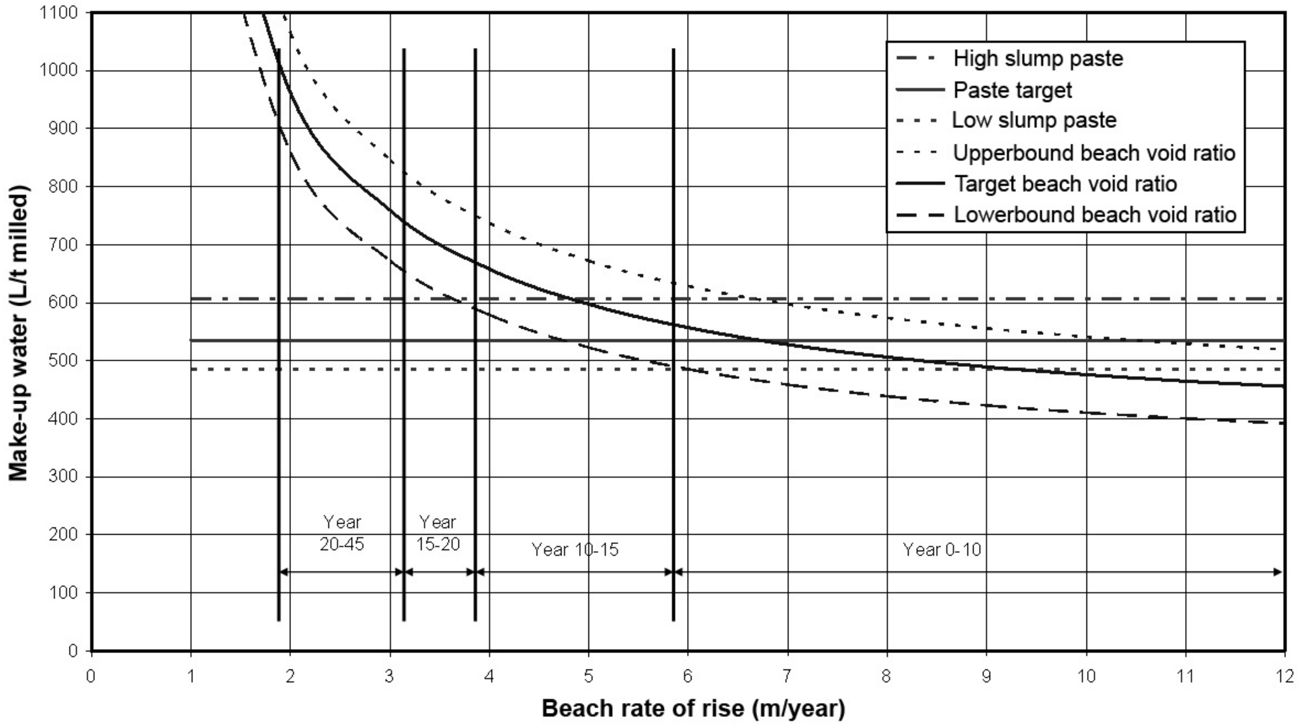

Figure 2 Relationship between make-up water and beach rate of rise for a proposed mine in Peru under normal weather conditions

3.1.2 Abnormally dry condition (high evaporation rate and no rain)

The exercise was repeated for abnormally dry conditions. For these conditions a minimum rate of rise of 6 m/yr is required to achieve the same water consumption as a paste, and the water consumption break even point reduces from between 10 and 15 years for the base case, to at most 10 years.

3.1.3 Low beach void ratio (beach void ratio of 0.85 with normal weather conditions)

In the previous cases, the void ratio used was 0.95. For this low void ratio case, a value of 0.85 was used. A lower void ratio is considered feasible due to the coarse grading of the tailings which allows time for consolidation to take place despite the high rate of rise and saturated conditions.

The effect of reducing the void ratio means that the same water consumption as paste can be achieved up to a rate of rise of 5 m/yr, and the water consumption break even point increases from between 10 and 15 years for the base case, to at least 15 years.

3.2 Validation of relationship using a detailed water balance

A detailed water balance was compiled to estimate the losses for the proposed tailings dam to improve on the accuracy of the simple method described above. The water balance includes aspects such as seepage, infiltration, cycloning, run-off from the dam catchment area, changes in evaporation factors over the dam life. It also takes into account differences between different dewatering systems over the full operational life, and includes the effect of cycloning.

Assumptions which can be made are:

- The same site to be used for paste disposal and for cycloned wall impoundment. For paste disposal it was assumed that a waste rock wall would be constructed.
- The coarse cycloned beach zone is small relative to the total basin area.

- The pool size was estimated to occupy 20% of the total dam basin area (storage capacity to maintain production if water supply interrupted), except in the case of paste disposal where this reduced to 2% of the area.
- Runoff and evaporation factors were varied to suit the different rates of rise over the dam's life.
- Seepage collected from the under drains (wall and basin) is recovered and pumped back for cyclone dilution.
- Infiltration to the ground is treated as a loss. Inflow from ground water is ignored as it is expected that the head of inflows from infiltration will counteract any recharge from groundwater. Such inflows would contribute towards the saturation of the under-lying soils as the basin area expands.
- All excess water reports to the pond and can be recovered.
- The sand wall remains saturated, and that all rainfall gains and evaporation losses from the surface of the wall are ignored.

Water balances were undertaken for various dewatering scenarios (conventional thickening, high density and paste). A graph of the results is shown in Figure 3, and assumes that the paste thickener consistently produces a high slump paste. If the paste thickener can perform at its target density, then the water consumption would reduce accordingly.

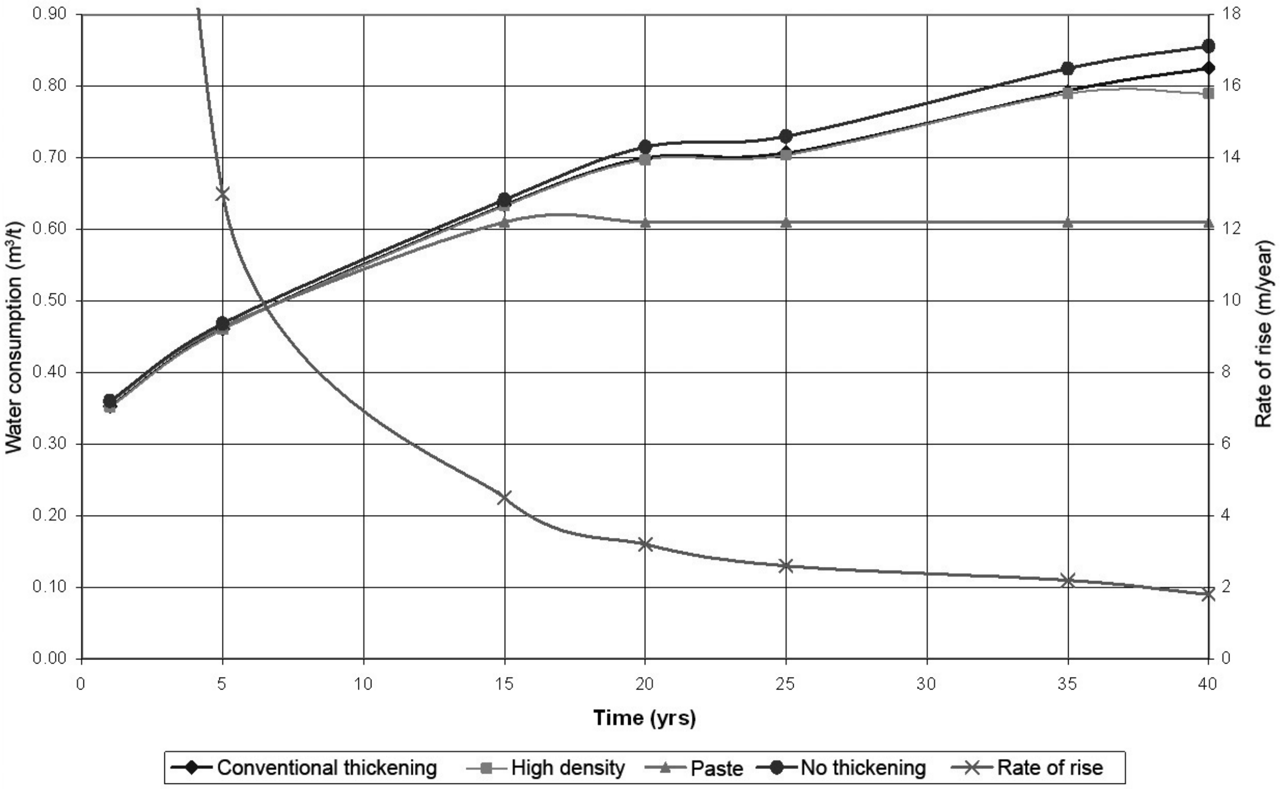

Figure 3 Relationship between water consumption and beach rate of rise for a proposed mine in Peru under normal weather conditions and high slump paste

While the rate of rise of the tailings facility is high (>7 m/yr for first 10 years), there is little to choose between the different dewatering options since the water consumption rates are similar, provided stability requirements can be met. Thereafter, the rate of rise drops and paste disposal maintains a lower consumption rate. For the first 15 years, in Figure 3, the paste water consumption line tracks the other slurry lines. This shows that in a paste facility that has a high rate of rise, and where all excess water can be recovered efficiently, the assumption used in Figures 1 and 2 of zero water recovery is not valid. In reality, it may not be economically feasible to recover all bleed and stormwater run-off from a paste facility, depending on geometry, and the detailed water balance would need to account for the losses.

It was confirmed that if the tailings consolidates to a lower void ratio (higher in situ density), then for the first 15 years there is no advantage in producing a high slump paste. The water balances provided better accuracy on water consumption rates at the lower rates of rise (<2.7 m/yr) than the simple model, but otherwise supports the results found of the simple relationship.

4 Limitations

The case study described above and the graph given in Figure 1 applies to typical hard rock mining tailings (copper, platinum and gold tailings) which have granular, frictional properties. Where a Kimberlite or soft ore is mined resulting in a significant clay content in the tailings, caution needs to be exercised in using the relationship, especially in the selection of the void ratio target value and range of upper and lower bound values. In such cases, very high rates of rise (>6 m/yr) may be required to achieve the same water consumption as a paste. Equally, such tailings are not easy to dewater or to maintain thickener performance.

In all cases testwork should be used to determine the void ratio and paste range values to fairly compare paste versus high rate of rise disposal.

5 Conclusions

Automatically regarding thickening of tailings as being synonymous with water savings is sometimes a fundamental flaw. In order to save water it is necessary to reduce the actual water losses from the entire system. This cannot be done in isolation in the plant.

In order to properly understand the mechanisms causing water losses, the water and energy balances for the entire system including plant, tailings disposal facility and return water facilities should be considered as a whole. Economics plays an important part in proper decision making. The cost of thickening together with the often costly disposal facilities required for paste disposal, can tip the scales against paste before the breakeven point in consumption is reached.

The simple relationship presented in the paper comparing water losses for paste disposal to that for slurry disposal, highlights the importance of evaporation. High rates of rise can significantly minimise these effects.

At high rates of rise, the beach acts as a horizontal gravitational thickener in which thickening occurs by gravitational settlement. Thickening occurs with no thickening plant and gravitation comes free.

The preliminary results of a practical application of the method have shown its usefulness as a quick and simple decision-making tool for conceptual studies. It has been shown in this paper that high rate of rise slurry deposition tailings facilities can yield similar or better water consumption rates than paste facilities, and that the simple relationship can provide results which agree reasonably well with more rigorous water balances. While this may favour slurry disposal, it does not negate the need to carry out comprehensive trade-off studies to determine the most cost-effective and water-efficient solution.