Towards minimum impact copper concentrator – The link between water and tailings

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Abstract The paper is based on a simulated (HSC-SIM) study that investigated the link between environmental aspects and tailings management during a 15-year mine life. The findings evolve around water balance of a concentrator for different tailings management options and investigates their impact on water use, make-up and seepages from the tailings facilities, as well as changes on recycled water, evaporation, tailings lock-up and rainfall. Filtered tailings method can reduce the fresh water input index in a temperate climate by up to 80% and in arid up to 90% i.e. from 26.7 to 5.8 and from 67.3 to 6.5 kg blue water/kg concentrate produced respectively.

Key words water management, water balance, tailings management, seepage, TSF, HSC-SIM, Outotec

Introduction

Concentrators

Minerals processing concentrators are facing growing challenges with the fresh water availability and quality, which at worst case leads to serious reduction in the recovery of metals within the flotation process. Furthermore, environmental limitations for tailings management and related conventional tailings storage facilities, as well as water consumption and discharge volumes and quality arise a need for more sustainable operations. The continuing trend of lower grades in mineral deposits leads to further water consumption and expanding tailings storage facilities. Climate change in turn in having an impact on the available water supply (IPCC, 2014).

Water Management in Mineral Processing

Water is a commodity that has had an impact on mineral processing for decades. Often used frivolously, modern economic and social pressures are forcing a change to reduce water usage while improving the quality of water and effluents. Some studies Water management and recycling in mineral processing industry has been studied earlier (Joe et al. 1974-1984), as have the energy and water savings in tailings handling (Sellgren 1984). Franks et al, 2011 studied sustainable disposal of mining waste. Studies with full process including tailings and water management and their impact on the operational risk, economics and water savings has been discussed by Jansson et al. 2014 and Kotiranta et al. 2015. Holistic tailings management solutions with related water considerations were outlined by Suvio et al. 2016.

Hoekstra developed the water footprinting concept in 2002 and has been at the forefront of the related research. He acts as a member of the supervisory council of the Water Footprint Network (www.waterfootprintnetwork.org), which has since 2008 provided a leadership in the water footprinting numerous societal activities. This website provides information on footprint and how to calculate it for various different activities. The website also provides information on the impact of human activities on the use of different types of water in the activities ranging from food production to the impact of energy carriers and gives information on how virtual water affects the footprint of different activities (Hoekstra et al. 2011, Mekonnen and Hoekstra 2012, Dallemand JF and Gerbens-Leenes, PW, 2013).

Several studies exist on the analysis of economics, energy and environmental matters relating to different aspects of water, such as the economics and environmental considerations of portable water systems (Fagan et al. 2011, Loubet, et al. 2014, Nair, 2014), but a very a limited number of studies that link waste or material and water or water quality. Some do exist however, like the study carried out by Van Schaik et al. 2010, who applied a very large system optimization model that linked industry and farming wastewater to an industrial water treatment plant, combined with metallurgical processing of residues to maximize resource efficiency.

The study to which this paper is based on follows a similar approach as Van Schaik et al. (2010) in that simulation basis was used to map compounds and total flows with the objective to perform an environmental analysis in order to determine the optimal economic solution, but also considering the environmental impact (Reuter et al, 2015). A comprehensive sustainability indicator framework has been recently developed that combines numerous impacts into one simple result, while comparing it to a benchmark (Rönnlund et al. 2015). This allows combining and evaluation water, energy and materials simultaneously. This paper develops further the concepts presented by Jansson et al. (2014) and Kotiranta et al. (2015).

Water and Tailings Management

Water is used in many processes within mineral processing, but most of the water losses occur within the tailings processing and disposal area. New technologies that can increase the recovery of water are actively being developed, but the key to improving the efficiency of water use and reducing risks lies in closing water loops and increasing the slurry density in the tailings processing. With this shift from conventional tailings technologies towards paste and dry stacking, water efficiency is vastly improved, but it might in turn lead to process water challenges with impurities, reagents and fines being recycled and accumulated within the production processes and needs to be taken into account as a part of the holistic water and tailings management.

In conventional tailings systems, the process waters originate from natural sources and/ or include mine dewatering waters and the amount needed is directly related to the environmental conditions and filterability of the tailings dam, which indicates how much water is lost in this process stage. With these kinds of process conditions it is estimated that a Cu refinery process located in a temperate zone uses between 0.6–0.9 m³ of water per ton of ore (Jansson et al. 2014; Kotiranta T. et al. 2015).

A shift towards more advanced tailings processing options, such as filtered tailings, not only changes the set-up of the water flows, but also the water quality, when moving away from a conventional tailings dam with a 30–60-day water retention time and bio/chemical reactions taking place, to a dry stack/high density process, where the water is in contact with the solids for only a few hours with the tailings and water being separated in the thickener. The changes on water quality taking place at the conventional dam may be harmful, especially for polymetallic mineral processes. In some cases, metal recovery or selectivity may be negatively impacted without suitable process water treatment.

In the dry stacking model, where the water can be much more effectively captured and reused back in the process, the amount of process make-up water is strongly reduced. The estimated water usage drops to 0.15–0.2 m³ of water per ton of ore in a Cu refinery plant located in a temperate zone (Jansson et al. 2014; Kotiranta T. et al. 2015), equaling up to 80% savings in comparison to conventional tailings processing. The final rate of water savings is dependent on the final layout of the tailings management solution and on the climate zone, in which the mine and the process are located.

Methodology

Study Scope

The calculation outlined in this paper are based on an imaginary 20Mt/a capacity copper concentrator (porphyry Cu) with an estimated 15 year life time of the mine. The process set-up used for the concentrator plant includes 1 SAG mill, 2x Ball mills, 2 lines with 8 flotation cells each, 1 regrinding HIG mill, one concentrate thickener as well as 2 PF concentrate filters with a storage system. Water calculations were carried out for two different climate scenarios of a temperate and semiarid/arid location. In both cases fresh water intake was determined to be about 10 km away from the concentrator with a 25 m static head. The tailings area was also located 10 km away from the concentrator with 25 m static head. No considerations were given to mine water, freezing conditions, dust control (wind), acid mine drainage (AMD) generated water or earth quakes were taken into account. Project scope includes considerations for 4 different tailings processing methods of conventional, thickened, paste and filtered tailings

Approach

The basic water and material balances were calculated for four different tailings processing approaches, including: Case 1: Conventional tailings management, Case 2: Thickened tailings management, Case 3: Paste tailings management and Case 4: Filtered tailings management based on the approach discussed by Reuter et al. (2015). In all mass balance calculation the focus was on fresh water intake in order to estimate blue water footprint in line with the water footprint concept. Furthermore, estimates were carried out for effluent volumes from different tailings processing approaches.

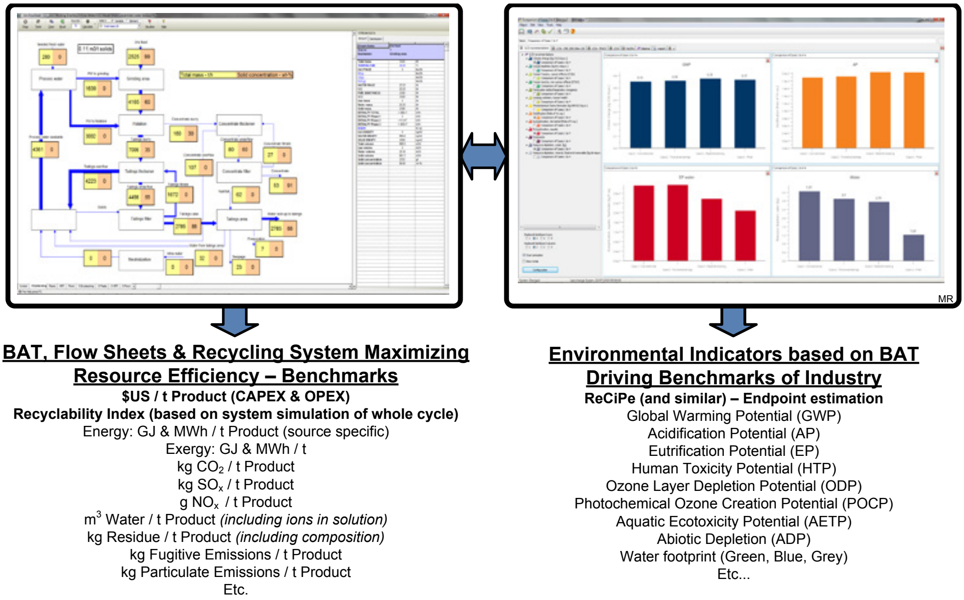

Figure 1 *Summary of the methodology: Left the HSC Simulation (www.outotec.com) of the water system for the four cases and right the environmental footprint calculation produced from the simulation results by life cycle assessment tool GaBi (www.thinkstep.com) (Reuter et al, 2015).*

In order to carry out the simulation and obtain the average water flows (Figure 1), data for climate conditions and soil seepage capacity were inputted into the Outotec thermodynamic HSC simulation tool, which is steady state simulator, where all the data inputted into the process also exit the process and it is able to carry out calculations to provide a snapshot of a specific situation. HSC-SIM is not able to take into account the normal process variations. The climate conditions for the selected site were gathered from www.WorldClimateGuide.co.uk, whereas the soil seepage capacity was estimated from data collected from mines nearby the imaginary location for this minerals processing site. The results for the flows were used as a basis of the cost calculations discussed by Jansson et al. 2014 and Kotiranta 2015 and also to produce the data used in the environmental footprint software GaBi (www.thinkstep.com) (see Reuter et al. 2015) for details).

Study Outcome

The original idea of the study was to investigate possibilities to decrease the whole operational costs of the minerals processing during the 15-year mine life. The considerations included both CAPEX and OPEX costs together with indirect costs including legal and other official procedures and unpredictable costs such as operational risks (e.g. production losses due to water shortage), regulation/environmental/rehabilitation, reputation and financial risks. It was found out that the combined costs of CAPEX and OPEX with the four studied cases were fairly close to each other.

Further to financial considerations, the study provided several results for different tailings processing options, including water footprint, operational risks, risks related to dam wall and its construction, water requirements, global warming potential (CO2 impact), environmental impact analysis and considerations for their relation. Following the estimation of the operational risks related to different tailings processing options, a simple risk matrix, with *risk value* in € versus potential *risk level* was set up with the basic operational risks. Figure 2 depicts various scenarios for three solution types of conventional tailings management (black), paste (green) and filtered tailings (blue).

As seen from this evaluation, the highest operational risks are allocated to conventional tailings management, and lowest to the filtered tailings. It can be concluded that switching from conventional tailings to dry stacking technology, it is possible to reduce the operational risks.

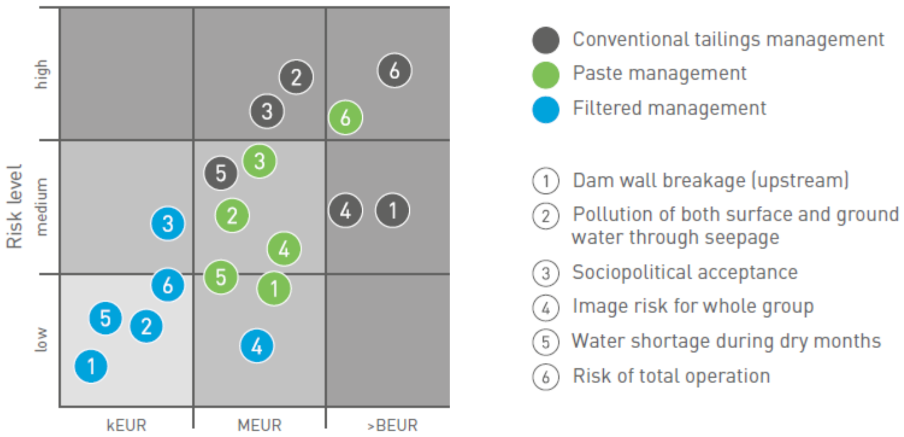

Figure 2 *Risk matrix for the assessment of operational risks associated with different tailings management processes*

The results of this paper discuss especially the risks related to the water and its relation to tailings processing. Some of the most important considerations here include risks related to the climate conditions and seepages from tailings facilities, which have been considered a water consumer. As previously mentioned, the water related calculations were carried out for two different location scenarios, where the first was located in the temperate zone, where summers are relatively hot and dry and autumns and springs are wet with lots of rain. The average rainfall was 52 mm/month and evaporation is 45 mm/month (from 0 to 144). The second scenario is located in a semiarid to arid zone with average rainfall of 20 mm/month and evaporation 238mm/month (from 84 to 415). For both cases the area for total water collection area is 725 ha.

Results

Fresh-water and seepages

Risks related to climate conditions and seepages create the biggest pressures for water within the concentrator environment as the water is lost with no ability to recover via these ways. For the first location scenario the average rainfall is 52 mm/month and the second 20 mm/month, the evaporation was 45mm/month and 238mm/months respectively. The concentrator of the first scenario is located in a temperate zone, whereas the second is located in an arid climate zone and even the average rainfall at the arid zone is approximately 40% of the rainfall in the temperate zone, the evaporation is more than 450% of the evaporation at the temperate zone.

Figures 3 and 4 show the estimated seepage amount (b) in the two different scenarios for the 4 different tailings management options. In both cases high seepage is related to conventional and thickened tailings management options, whereas with the paste and filtered tailings management options the water is locked inside the tailings by capillary forces and the only accountable and partly recoverable seepage would arise during heavy rain fall conditions. In the arid climate scenario, the seepage is almost non-existing at the paste and filtered tailings management option. What should be noted is that in an arid location fresh water need is dramatically lower for conventional tailings than thickened tailings management during the summer months.

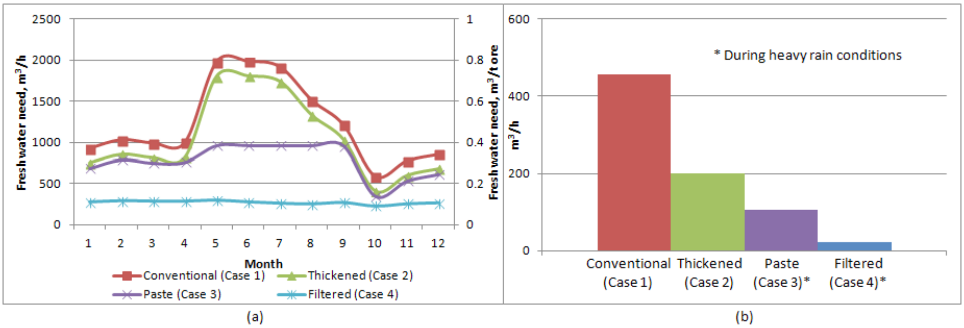

***Figure 3**: Risk related to seepages from tailings management facilities. Monthly fresh water make-up of the plant (a) and the estimated total seepage from the tailings facilities (b)*

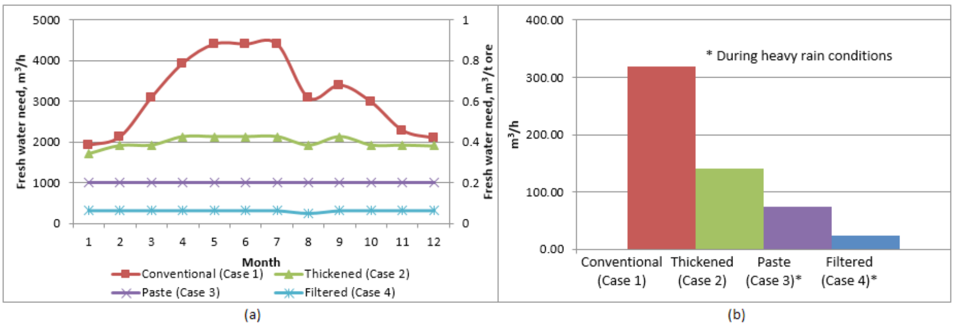

***Figure 4** Risk related to seepages from tailings management facilities at an arid region. Monthly fresh water make-up of the plant (a) and the estimated total seepage from the tailings facilities (b)*

The climate impact on average fresh water demand was estimated based on Figures 3 and 4. In both scenarios it can be seen that traditional and thickened tailings management processes have the highest water needs. It can also be seen that the filtered tailings management option squeezed the most water from the tailings and therefore has the highest capability from the water conservation and reuse point of view. This showed that the filtered option decreases the water footprint significantly i.e. at the first case from 26.7 to 5.8 kg blue water/kg concentrate produced (or 0.51 to 0.11 kg blue water/kg ore feed) and at the second case from 67.3 to 6.5 kg blue water/kg concentrate produced (or 1.29 to 0.12 kg blue water/kg ore feed. The advanced tailings management options also improved the water quality and toxicity indicators. What is important to note is that the fresh water need for the arid scenario is much higher for the conventional tailings management than for the other tailings management options, whereas for the temperate scenario, both conventional and paste tailings management option has high fresh water need. When drilling down deeper on the different tailings management methods at the arid location (Figure 5-8) and the investigating different water factors, including recycled water, evaporation, tailings lock-up, seepage and rainfall, it can be seen that there are clear differences between the different tailings management options.

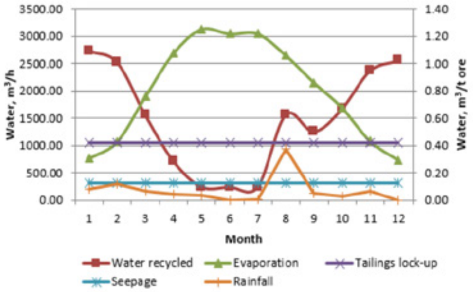

Figure 5 *Water in Conventional Tailings Management*

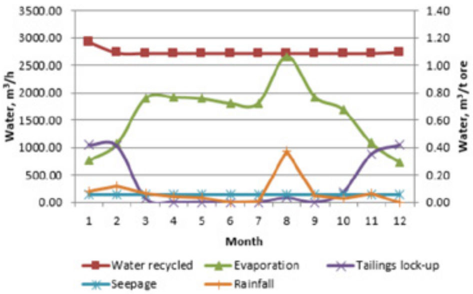

Figure 6 *Water in Thickener Tailings Management*

As seen in Figure 5 and 6, in the case of conventional and thickened tailings, water evaporation, especially in summer months reaches 2500-3000 m³/h, whereas with paste tailings it's below 2500 m³/h throughout, but generally around 1000 m³/h and with filtered tailings there isn't even enough water present to evaporate more than residual amounts. The amount of the recycled water is also impacted by the tailings management method and whereas for filter, paste and thickened tailings the numbers are fairly stable and approx. 4500, 3500 and 2750 m³/h respectively, for conventional tailings management, the amount of recycled water varies a lot from and in summer months dives under 500 m³/h.

Water Mass Balances

Furthermore, water balance calculations were carried out for all the different tailings management options and these can be seen in Figures 9-12. It should be noted that rainfall, evaporation and seepages are not shown in the water mass balances.

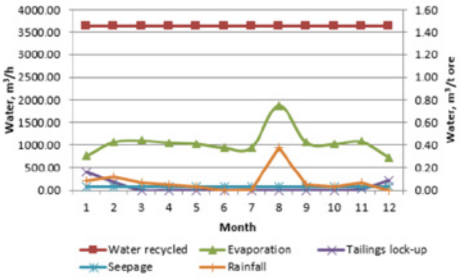

Figure 7 Water in Paste Tailings Management

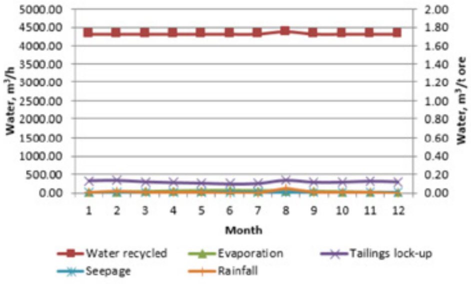

Figure 8 Water in Filtered Tailings Management

Case 1: The simulation results with Conventional tailings management effects on fresh water usage

Conventional option is shown in (**Virhe: Viitteen lähdettä ei löydya**). Using the simulation for sensitivity analysis one can estimate that the average fresh water need is around 1.3 m³/t-ore or 3700 m³/h with a typical 15% addition to the calculation due to process flow variations at the conventional tailings balance due to the tailings dam.

Case 2: The simulation results with thickened tailings management effects on fresh water usage

Figure 5b shows the impact of thickened tailings. In an arid climate the thickened tailings processing decreases the fresh water usage significantly to under 2000 m³/h. In the thickened tailings management part of the water is still circulated through tailings area and the rainfall and evaporation in the area will have effect on the plant water balance. This means an average fresh water usage still averages 0.77 m³/t ore.

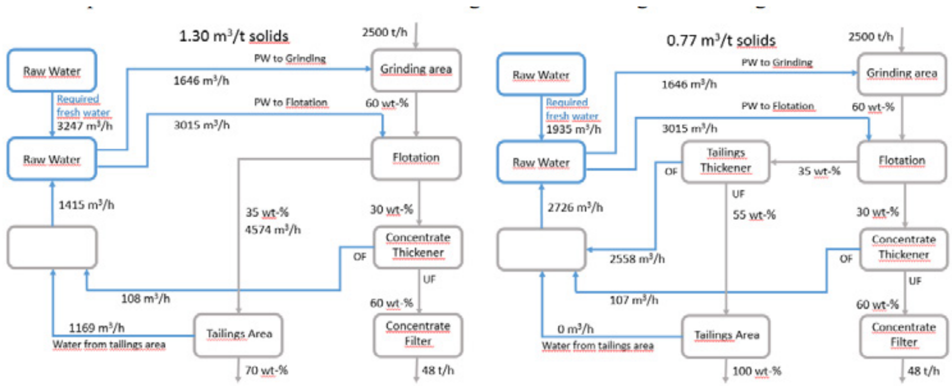

Figure 5 Simplified water balance calculations for conventional tailings (a, on the left) and for thickened tailings management (b, on the right)

Case 3: The simulation results with paste tailings management effects on fresh water usage

As the paste thickener underflow is estimated to be near 70% and the sand lock-in-capability to 30% then a very small or no effluent treatment is needed. The fresh water usage is still in the range of 0.4 m^3/h, and the average need around 1000m^3/h. If paste backfill options is applied, most of the operational risks are reduced, but water related management considerations remain important.

Case 4: The simulation results with filtered tailings management effects on fresh water usage

This filtered tailings mass balance shows that the big opportunity for lowering the required fresh water amount comes from the removal of wet tailings. In addition this approach also minimize seepage issues and risk through contaminating ground water, evaporation losses are minimized. Furthermore, the rainfall does not impact the dry stacking option in a same ways as in the previous three cases. Under optimal conditions the fresh water usage is estimated to be around 0.13 m^3/t ore and the fresh water flow around 310m^3/h.

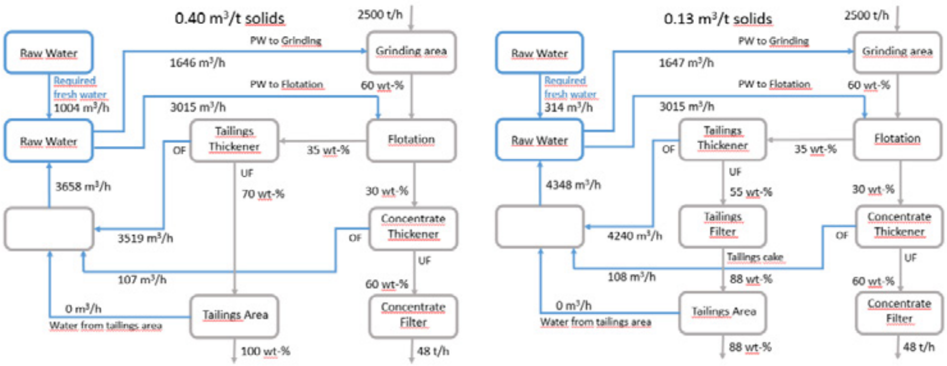

Figure 6 *Simplified water balance calculations for paste thickening (a, on the left) and for filtered tailings management (b, on the right)*

The above described results represent the situation with the ores that are currently being processes. However, in the future lower grade deposits will increase the capacity of the processing plants and therefore the fresh water requirements, therefore placing extra pressure on the water related considerations and will stress the need for tailings and water related considerations at the concentrator environment.

Conclusions

Water related challenges have ever increasing impact on concentrator operations. Risk related to poor fresh water quality and scarcity, wet tailings dam and new effluent limitations are growing. The choice of tailings management option has a strong impact on the water balances and especially fresh water requirements, water recycling possibilities, seepage from the TSF and evaporation.

The finding of this study include:

- The future of water management includes more closed water loops and smaller consumption volumes to overcome increasing operational risks
- Paste thickening is a very good alternative with low operational risks, especially if a backfill option does exist, but it does not solve the water management issues
- Filtered tailings have the most neutral water balance out of the tailings management options studied with required fresh water input of 0.13m3/ton of ore
- The above described results represent the situation with the ores that are currently being generally processes. However, in the future lower grade deposits will increase the capacity of the processing plants and will increase the fresh water requirements, therefore placing extra pressure on the water related considerations and will stress the need for tailings and water related considerations at the concentrator environment

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