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Review

Efficient Use of Water in Tailings Management: New Technologies and Environmental Strategies for the Future of Mining

Carlos Cacciuttolo [1,*] and Fernando Valenzuela [2]

[1] Civil Works and Geology Department, Catholic University of Temuco, Temuco 4780000, Chile
[2] Unit Operations Laboratory, Faculty of Chemical and Pharmaceutical Sciences, Universidad de Chile, Santiago 8320000, Chile; fvalenzu@uchile.cl
* Correspondence: carlos.cacciuttolo@gmail.com or ccacciuttolo@uct.cl

Abstract: Nowadays, many major copper mining projects in desert areas with extremely dry climates, as in northern Chile and the southern coast of Peru, process sulfide ores at high production rates; in some cases over 100,000 metric tonnes per day (mtpd), generating large amounts of tailings, that are commonly managed and transported to tailings storage facilities (TSF) hydraulically using fresh water. Considering the extremely dry climate, water scarcity, community demands, and environmental constraints in these desert areas, the efficient use of water in mining is being strongly enforced. For this reason, water supply is recognized as one of the limiting factors for the development of new mining projects and for the expansion of the existing ones in these areas. New water supply alternatives, such as sea water desalinization, direct use of sea water, or water recovery from tailings, represent the strategy developed by the mining industry to deal with this growing scarcity. The focus of this paper is the possibility of applying different water supply technologies or a combination of these, implementing improved water management strategies that consider: environmental issues, technical issues, stringent regulatory frameworks, community requests and cost-effective strategies, that result in a reduction of freshwater make-up water requirements for mining (m^3 per metric tonnes of treated ore).

Keywords: fresh water; sea water use; dewatered tailings; water recovery; make-up requirement; sustainable water use; water supply strategies

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1. Introduction

Tailings are usually a very fine mud or powder, left over after ore is crushed and valuable minerals are extracted. Tailings production is immense, since only ounces or pounds of metal are extracted for every tonne of processed ore. Tailings may also contain chemicals used in metallurgical processes as well as other metals and sulphides contained in ore, which need to be considered for safe tailings management. For this reason, most tailings are not inert from a geochemical point of view and must be disposed of with control to care for the environment.

The transport and storage of tailings require relevant environmental management. This residue is generally managed and transported hydraulically using fresh water to tailings storage facilities (TSF), this alternative being cheaper than bulk transportation by conveyor belts, trains or trucks. It is relevant to mention that most of the water used for tailings transportation needs to be recovered for reuse in the metallurgical process [1].

Metal production of copper, silver, gold, lead, zinc, among others, is growing quickly, and part of the increasing water demand can be explained by the expansion of existing mines and new projects being developed. In addition, there is an important increase in copper extraction/production caused by declining copper grades at existing mines. As copper grades decline, more ore needs to be processed in order to produce the same amount of copper metal. The use of water is proportional to the amount of ore that is processed, so it follows that more water is needed to produce the same amount of copper when grades decline. The exploitation of large ore deposits with decreasing grades has led to the use of efficient large equipment for the milling and processing of ore, which enables higher production rates, that, in turn, implies an increase in water demand for the metallurgical process [2].

2. Efficient Water Management in Latin American Mining

In general, ore deposits located in Latin America, where countries with dry climates such as Chile, Peru, Mexico, Argentina, Bolivia have the following characteristics: (i) very low precipitation rates (annual precipitation of 10 mm/year or less), and (ii) high evaporation rates (monthly evaporation rates up to 10 mm/day); resulting in annual average evaporation rates over 2000 mm/year, as in the Atacama desert, where water supply becomes a major challenge [3]. These issues have raised the necessity of an efficient water management plan to transport and manage tailings during the mine lifetime. Other sites in Latin America with mining operations that lie in dry and water scarcity, where the themes of this paper can be applied, are the following areas:

- Northern Chile—Atacama Desert (Region of Arica, Region of Tarapaca, Region of Antofagasta, and Region of Atacama).
- Southern Peru—Atacama Desert (Tacna Department, Moquegua Department, Ica Department, and Arequipa Department).
- Northern Peru—Sechura Desert (Piura Department, and Lambayeque Department).
- Southern Bolivia—Atacama Desert (Potosí Department, and Oruro Department).
- Central and Northern Argentine—Sierra y Pampa (Province of Catamarca, Province of La Rioja, Province of San Juan, and Province of Mendoza).
- Central and Northern México (Chihuahua State, Sonora State, Zacatecas State, Durango State, and Baja California State).

Due to water scarcity in desert areas, the supply of fresh water (make-up) is not available from groundwater and surface courses, then it is necessary to use sea water. In addition, increasing water demand of communities, agriculture and other productive sectors has led to a vulnerability of freshwater resources, resulting in a conflict of needs for water between different water users. Water resources are increasingly affected by a combination of factors such as climate change, which results in the progressive decline of water supply, recharge and infiltration flows in these basins. Also, the productivity of watersheds has been affected dramatically as a result of dry hydrological conditions.

As a consequence, stakeholders have been affected and, in some cases, drinking water resources have been dramatically compromised, resulting in increasing social pressure. Figures 1 and 2 show, as an example, the amount of water consumption in two northern Chile regions registered in 2007 and the consumption projected for the year 2017.

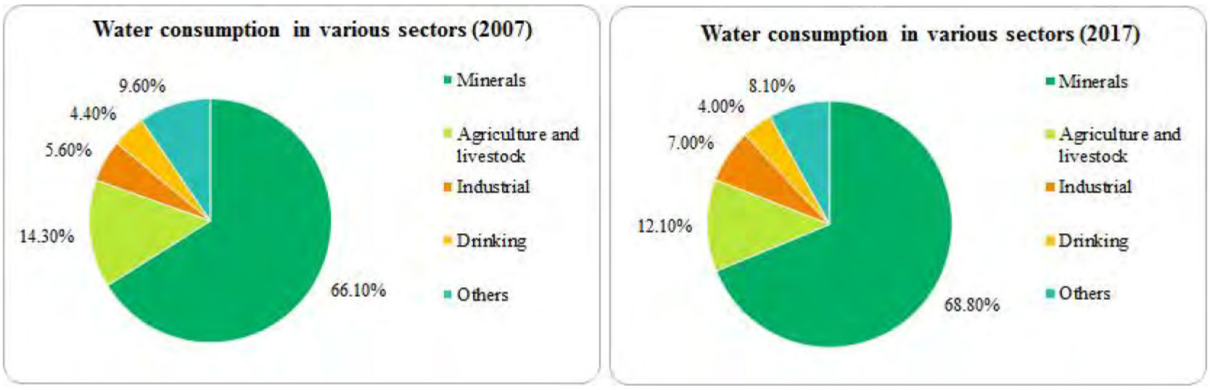


Figure 1. Water consumption in Antofagasta Region (Region II) of Chile [4].

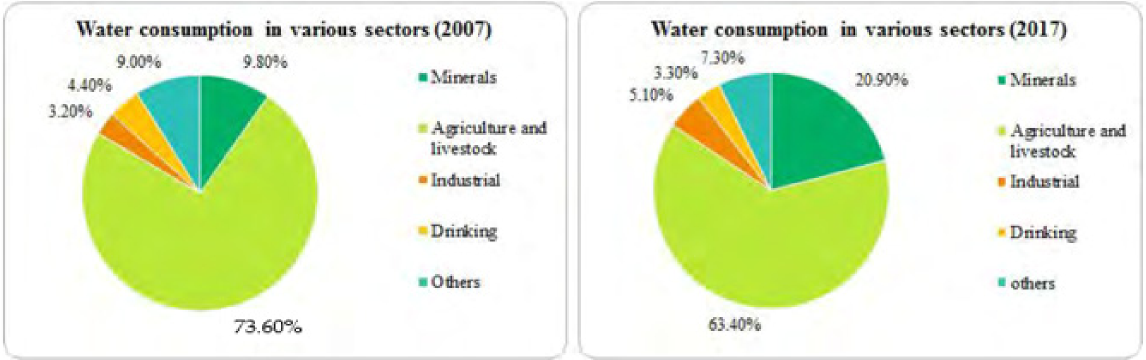


Figure 2. Water consumption in the Atacama Region (Region III) of Chile [4].

As shown in both figures, the proportion of water consumption in mining and industrial activities tends to increase, whereas in agriculture, livestock and drinking water, consumption rate tends to decrease in both regions.

These studies demonstrate a competition for water use; therefore, it is necessary to implement solutions and implement water management tools to meet the water demands of all stakeholders.

3. Tailings Management Methodologies Description

Engineers, scientists, mine operators, and authorities are working to improve the design and operation of tailings storage facilities (TSFs), focusing on the development of optimal solutions, which considers the following aspects: (i) reliable performance of technologies; (ii) a dynamic and robust TSF water balance (considering site-specific conditions); and (iii) efficient water management with the control of water losses (evaporation and infiltration). If these key issues are successfully implemented, a reduction of water make-up requirements, decrease of negative environmental impacts and an increase of natural water supply for the community will promote sustainable development [5]

Freshwater sources for mining activities must be carefully studied given the environmental impacts and costs for their implementation. Water supply during the operation must have the capacity to grow to provide the necessary supply of fresh water during the entire useful life of the project. Figures 3 and 4 show typical water flows in a mill and thickening plant and tailings disposal facility in a mining project.

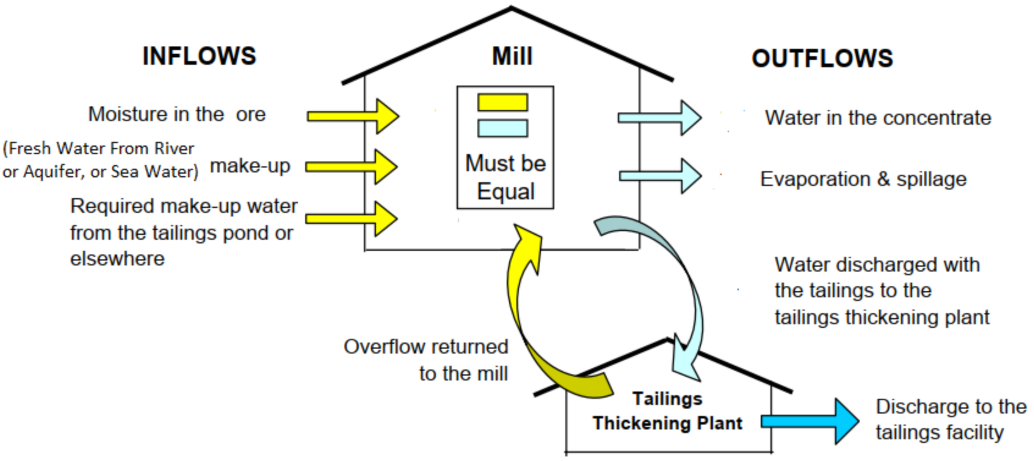


Figure 3. Typical flows into and out of a mill and thickening mining plant.

In the case of sea water, the different possible locations for the water intake plant at the coast, the requirement or not for desalination, the required pumping station, and the transport pipelines must be analyzed [6]. In the design phase of the desalination and pumping plant, it is important to consider the variability of the required water flow from the ocean. In general, water losses in tailings deposits increase over time due to: (i) increased evaporation area of the pond of clear water, and (ii) increased consolidation of the deposited tailings, which implies higher seepages also involving seasonal variations.

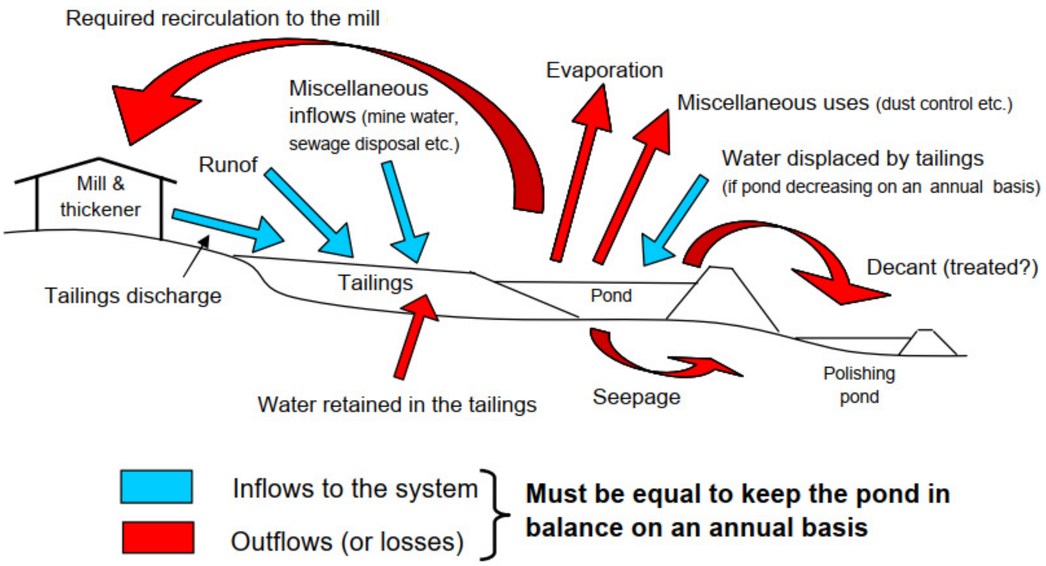


Figure 4. Typical Flows into and out of a mine tailings disposal facility.

The application of tailings dewatering technologies for increasing tailings water recovery is a relevant step to reduce water losses (resource from freshwater or seawater supplies) caused by evaporation, infiltration and retention at interstitial voids on tailings storage facilities; for this reason, it is necessary to implement new designs in order to make an environmentally friendly tailings management focus on efficiency water use.

Figure 5 shows different dewatering tailings technologies that focus on water recovery and efficient water management:

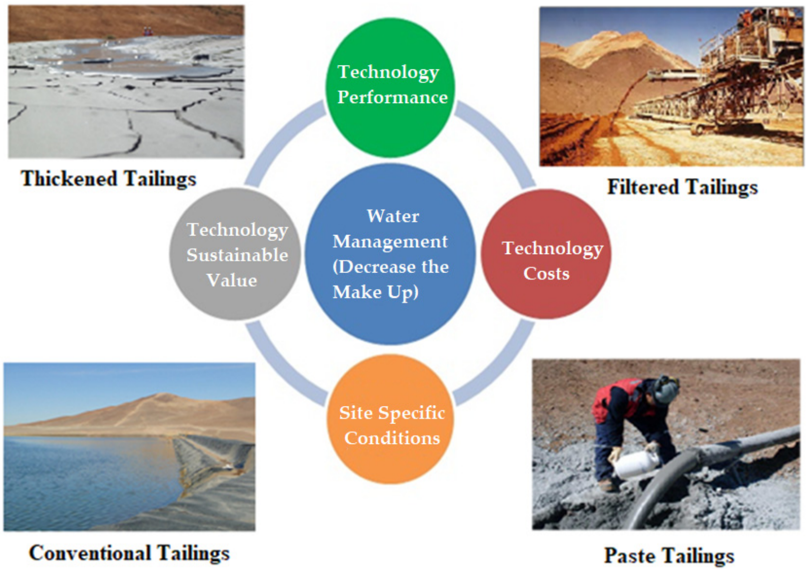


Figure 5. Dewatering Tailings Technologies—Efficient Water Management.

3.1. *Water Recovery from Tailings with Conventional Technologies (WRCT)*

In current Chilean and Peruvian large-scale mining in dry climate areas, most typical tailings disposal schemes consist of conventional or slightly thickened at modest levels of tailings solids weight concentration (Cw 48–52%). Conventional TSFs have dams built of coarse fraction of tailings obtained by hydrocyclones, or have slightly thickened tailings deposits with dams built of borrow material. Conventional tailing dams (Figure 6) may have water recoveries as high as 65–75% in very well operated TSFs, which means they have appropriate tailings distribution, good control of the pond (volume and location) and adequate seepage recovery. In conventional dams, water at the settling pond is decanted and by floating pumps, or decant towers, and dam seepages is collected by a drainage system and cutoff trench systems. However, a high seasonal evaporation rate can substantially reduce water recovery from the pond area, and infiltration from the pond in contact with natural soil can produce water losses [7].

Figure 6. Conventional Tailings Technology—Quebrada Enlozada TSF Cerro Verde Mine Peru [8].

3.2. Water Recovery from Tailings with Thickening Technologies (WRTT)

Thickened Tailings Disposal (TTD) technology (Figure 7) requires more background data than conventional tailings disposal. In the conventional approach, the properties of tailings are fixed by the concentrator plant, whereas in a TTD impoundment, the properties of the tailings and their placement are "engineered" to suit the topography of the disposal area [9]. The behavior of tailings in the two approaches is entirely different. In conventional disposal, tailings segregate as they flow and settle out to an essentially flat deposit, whereas in TTD technology, a sloping surface is obtained. The principal difference is that, in TTD technology, tailings are thickened before discharge to a homogeneous heavy consistency that results in laminar non-segregating flow. In this way, TTD produces high water recovery (80 percent of tailings water recovery) and a self-supporting deposit with sloping sides, requiring small dams [10].

Figure 7. Thickened Tailings Technology—Esperanza TSF Centinela Mine Chile [11].

3.3. Water Recovery from Tailings with Paste Tailings Technologies (WRPTT)

Paste Tailings Technology has been applied at a small production scale because a limitation of equipment manufacturing ability exists. This method permits obtaining medium make-up water requirement. However, in some cases, there are difficulties in tailings transportation requiring the use of positive displacement pumping, resulting in the highest capital/operating costs [9]. The main advantage of this method is that large dams are not required, only small dams are needed (Figure 8).

Figure 8. Paste Tailings Technology—Paste Tailings Demo Plant at Collahuasi Mine Chile [12].

3.4. Water Recovery from Tailings with Filtering Technologies (WRFT)

In the last 20 years, many mining projects around the world have applied a tailings disposal technology called filtered dry stacked tailings (Figure 9). This technique produces an unsaturated cake that allows storage of this material without the need to manage large slurry tailings ponds. The application of this technology has accomplished: (i) an increase of water recovery from tailings (90 percent), (ii) reduction of TSF footprint (impacted areas), (iii) decrease in the risk of physical instability, because TSFs are self-supporting structures under compaction (such as dry stacks), and (iv) a better community perception.

Figure 9. Filtered Tailings Technology—Tailings Filters at Mantos Blancos Mine Chile [11].

The improvements of filtering technologies (pressure and vacuum filtering) in recent years have allowed operational reliability to increase and the development of large capacity filters, reaching in some projects 50,000 metric tonnes per day (mtpd) of filtered tailings [13].

3.5. Water Recovery from Tailings with Hybrid Technologies (WRHT)

The future trend in mining will be the complementary supply of sea water and fresh water, the greater supply being sea water. Along with this, the implementation of dewatering tailings technologies depending on the characteristics of the mineral (grain size, hardness, specific gravity, chemical composition of tailings, etc.), promote a high water recovery. An alternative process to obtain filtered tailings consists of the recovery of the coarse fraction of tailings (cycloned tailings sand) through two cycloning stages, followed by a drainage stage in dewatering vibratory screens to reduce tailings moisture and turn tailings into a paste that can easily be transported to an adjoining dumping facility (Cacciuttolo et al., 2014). On the other hand, the Sand Slimes Split (SSSTT) method is a known tailings technology. SSSTT is a combination of the conventional cyclone tailings classification and thickening, a variant of the construction of a TSF dam using tailings sand. The primary aspect of SSSTT is that the total tailings are separated to produce two streams: (1) "underflow" corresponding to the tailings coarse fraction (sand); and (2) "overflow" corresponding to the fine tailings fraction (slimes). These streams are conveyed to two independent sites: (i) a Sand Stack Facility (SASF) for the coarse fraction of tailings (Figure 10); and (ii) a Slimes Storage Facility (SLSF) for the fine fraction of tailings, which is thickened before depositing (Figure 11). The main benefit of this technology is the increase of the total water recovery by managing different particle size distribution of tailings [14–17].

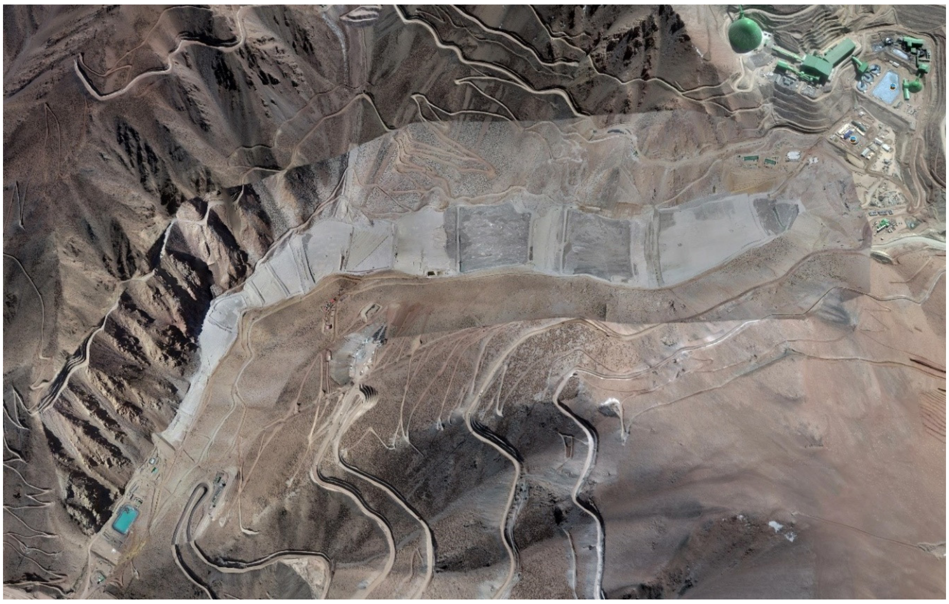


Figure 10. Sand Stack TSF (Cycloned Sand Tailings) SSSTT—Caserones Mine, Chile [18].

Figure 11. Slimes Storage Facility (Cycloned Fine Tailings) SSSTT—Caserones Mine, Chile [18].

4. Water Recovery Performance Tailings Management Technology Comparison

In recent years, the improvements in tailings dewatering technologies (thickening and filtering) have allowed an increase in water recovery. These technologies have been successfully applied for production rates up to 25,000 mtpd. There is still a need for more reliable equipment for the thickening and filtering processes at large-scale, focused tailings water recovery and reuse in mining processing.

Studies, operational experiences, and TSF water balances performed in the last decades show that make-up water requirement for projects without slimes thickening is in the range of 0.35–0.70 m^3/t (Conventional Tailings Technology), while make-up water requirement for slimes thickening (SSSTT) is in the range of 0.30–0.40 m^3/t.

Table 1 shows a comparison between different tailings management technologies, considering water make-up requirements (TSF water losses). Data come from some projects located in extremely dry areas of Chile and Peru.

Table 1. Tailings management methodologies and average water make-up (TSF water losses).

Tailings Management Methodology	Tailings Storage Facility Name	Country	TSF Disposal and Water Management Parameters				Reference
			Production Rate (mtpd)	**PSD d_{50} (μm)**	**Solids Content Cw (%)**	**Average Make-Up (m3/mt)**	
FWS—WRCT	Pampa Pabellon TSF	Chile	170,000	52	52 (TT)	0.70	[19]
FWS—WRCT	Talabre TSF	Chile	180,000	70	55 (TT)	0.64	[19]
FWS—WRCT	Los Quillayes TSF	Chile	115,000	36	40 (SL)	0.35	[20]
FWS—WRCT	Mauro TSF	Chile	205,000	36	40 (SL)	0.35	[21]
FWS—WRCT	Candelaria TSF	Chile	75,000	65	51 (TT)	0.34	[22,23]
FWS—WRCT	Candelaria (Los Diques TSF)	Chile	75,000	65	51 (TT)	0.34	[22,23]
FWS—WRCT	Carmen de Andacollo TSF	Chile	55,000	70	53 (TT)	0.44	[24]
SWS—WRCT	Laguna Seca TSF	Chile	370,000	65	50 (TT)	0.66	[25]
SWS—WRTT	Esperanza (Centinela TSF)	Chile	95,000	45	65 (TT)	0.50	[26]
SWS—WRTT	Sierra Gorda TSF	Chile	110,000	40	60 (TT)	0.50	[27,28]
SWS—WRTT	Cerro Negro Norte TSF	Chile	20,000	75	65 (TT)	0.45	[29]
FWS—WRPTT	Las Cenizas (Chinchorro TSF)	Chile	2500	44	65 (TT)	0.39	[30]
FWS—WRPTT	ENAMI (Delta Plant TSF)	Chile	2000	25	60 (TT)	0.48	[30]
FWS—WRPTT	Coemin TSF	Chile	8000	50	60 (TT)	0.42	[30]
FWS—WRPTT	Alhue TSF	Chile	3000	55	65 (TT)	0.40	[30]
FWS—WRFT	La Coipa TSF	Chile	20,000	68	80 (TT)	0.22	[31]
FWS—WRFT	El Peñon TSF	Chile	3000	62	84 (TT)	0.20	[32]
FWS—WRFT	Mantos Verde TSF	Chile	12,000	57	82 (TT)	0.23	[32]
FWS—WRHT	Mantos Blancos TSF	Chile	12,000	86	82 (TT)	0.28	[31]
FWS—WRHT	Caserones (La Brea/Sand TSF)	Chile	90,000	74	60 (TT)	0.37	[15,33]
FWS—WRFT	Cerro Lindo TSF	Peru	7000	65	88 (SL)	0.20	[32]
FWS—WRCT	Quebrada Enlozada TSF	Peru	120,000	45	40 (SL)	0.38	[34,35]
FWS—WRCT	Quebrada Linga TSF	Peru	240,000	45	40 (SL)	0.38	[35,36]
FWS—WRCT	Quebrada Honda TSF	Peru	150,000	75	37 (SL)	0.62	[37]
FWS—WRCT	Quebrada Cortadera TSF	Peru	127,500	75	45 (TT)	0.40	[38]

Note: The following terms mean: TT: Total Tailings, SL: Slimes (fine particle size distribution of total tailings), FWS: Fresh Water Supply and SWS: Sea Water Supply.

Figure 12 shows a comparison between different tailings management technologies, considering make-up water requirements and water recovery results at some projects with desert areas.

Water losses at TSFs come from water retained in deposited tailings and in the evaporation from beaches formed at the TSF. To reduce these losses, new management technologies have been developed, which seek to maximize the reclamation of water before tailings are discharged to the TSF, by cycloning, thickening, and/or filtering tailings. Improvements in conventional, thickened, paste and filtered tailings disposal technologies need to be managed to increase water recovery and decrease water make-up (fresh water) in mining operations. These challenges have been met during the past decade at copper mining.

Table 2 shows a comparative analysis with water recovery quantities obtained with different dewatering tailings technologies.

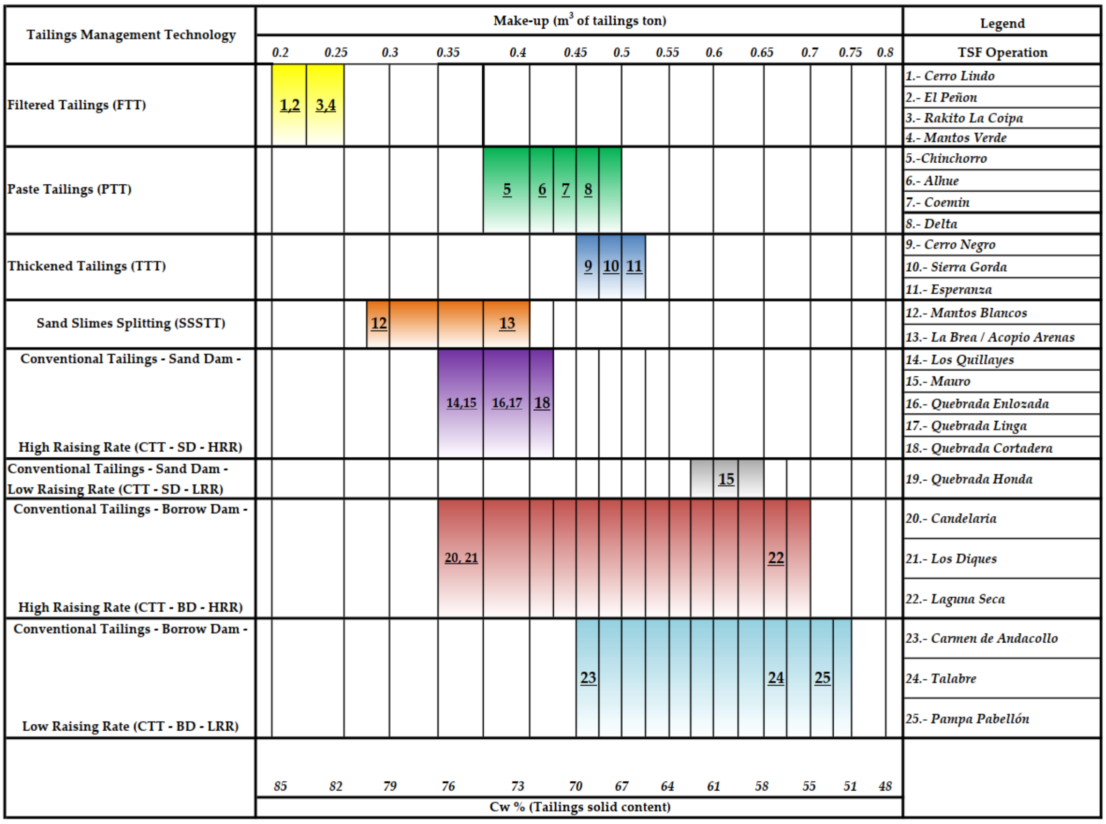


Figure 12. Make-up tailings management technologies comparison of performance.

Table 2. Water Recovery Comparison between Tailings Management Methodologies.

Description	Unit	Conventional Tailings Management	Thickened Tailings Management	Hybrid Tailings Management	Filtered Tailings Management
Tailings Production	mtpd	100,000	100,000	100,000	100,000
Cw before Thickening	%	28	28	28	28
Water on Conventional Tailings	L/s	2976	2976	2976	2976
Cw after Thickening	%	50	60	70 (*)	80
Water on Dewatered Tailings	L/s	1157	772	496	289
Water Recovery from Thickeners	L/s	1819	2205	2480	2687
Water Recovery from TSF	L/s	382	255	164	95
Total Water Recovery	L/s	2201	2459	2644	2782
Water Recovery Efficiency	%	74	83	89	93

Note: The following terms mean: Cw: Tailings solid content by weight (%). (*): 70 % signifies a mean target Cw value, considering dewatering tailings technologies applied.

5. Case Study of Evaluation Dewatered Tailings Methodologies and Different Sources of Water at Large-Scale Mining Sites

A case study is presented, based on a typical large copper mine that processes 100,000 mtpd, with 20 years' mine life and current deposition of conventional slurry tailings with 50% of solid content by weight. Water recovery from the TSF is very low, mainly because of a high evaporation rate in the extreme dry area and infiltration. Different tailings management alternatives need to be evaluated to select a cost-effective solution, considering fresh water and sea water supply options, focused on obtaining a high water recovery from tailings and the proper disposal of tailings. Table 3 presents the parameters considered for Alternatives Comparison.

Table 3. Parameters considered for Alternatives Comparison.

Parameters	Value	Unit
Tailings Production Rate	100,000	mtpd
Sea-Concentrator Plant Distance	150	km
Sea-Concentrator Plant Difference of Level	2000	m.a.s.l.
Mine Lifetime	20	years
Discount Rate for Cost Estimate	10	%

Considering this comparative analysis, Figure 13 shows the graphical view of a mining project with the use of sea water for the metallurgical process and tailings management.

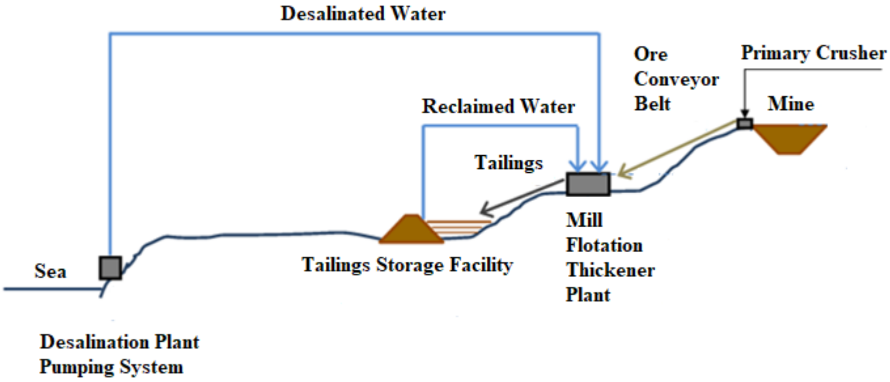


Figure 13. Schematic view of mining project with desalinated water use.

Table 4 presents the results of total cost of comparative analysis of alternatives of this study case.

Table 4. Comparative Analysis—Tailings Management Methodology Alternatives Cost Estimate.

Tailings Management Methodology	Conventional Technology Cw 50%		Thickened Technology Cw 60%		Hybrid Technology Cw 70%		Filtered Technology Cw 80%	
(a) **Tailings Disposal**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
CAPEX, million US$	225	225	150	150	250	250	450	450
Total SUSTAINING Cost, million US$	100	100	200	200	125	125	50	50
OPEX, million US$ per year	15	15	25	25	35	35	50	50
Make-up water flow rate, L/s	691	691	432	432	346	346	173	173
Tailings Disposal Cost, US$/t	0.9	0.9	1.2	1.2	1.5	1.5	2.1	2.1
(b) **Make-Up Water Supply**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
CAPEX, million US$	50	750	25	650	15	500	5	250
Make-up water, m3/t	0.8	0.8	0.5	0.5	0.4	0.4	0.2	0.2
Water Cost, US$/m3 (Fresh Water)	1.7	-	1.7	-	1.7	-	1.7	-
Water Cost, US$/m3 (Sea Water)	-	4.0	-	4.0	-	4.0	-	4.0
OPEX, million US$ per year (Fresh Water)	50	-	31	-	25	-	12	-
OPEX, million US$ per year (Sea Water)	-	117	-	73	-	58	-	29
Make-Up Water Cost US$/t (Fresh Water)	1.4		0.9		0.7		0.3	-
Make-Up Water Cost US$/t (Sea Water)	-	4.2	-	2.9	-	2.3	-	1.1
(c) **Integral Tailings/Water Management**	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**
Unit Cost, US$/t	2.3	5.1	2.0	4.1	2.2	3.8	2.4	3.2
Net Present Cost, Million US$	925	2197	852	1834	899	1670	934	1424

Note: (1) Par number cases considers fresh water supply, and impair number cases consider sea water supply. (2) Capex considers the following items: process equipment, pipelines/conveyors, embankment, direct/indirect costs, owner costs, and contingency. (3) Sustaining Costs considers the following items: deferred equipment, pipelines/conveyors and installations. (4) Opex considers the following items: power, flocculant, labor, maintenance, and earth-moving equipment.

Costs are evaluated on the basis of water usage relative to the production efficiency of the mine. In copper ore deposits where the quality of ore grade is low, the cost of water used per unit weight of metal obtained is high. Therefore, mining companies have to assess the cost effectiveness of using brackish or desalinated water. To avoid the costs of desalination or brackish water use, mining companies are attempting to improve the efficiency of their water use in operations, by reducing water losses due to infiltration, evaporation or effluent generation.

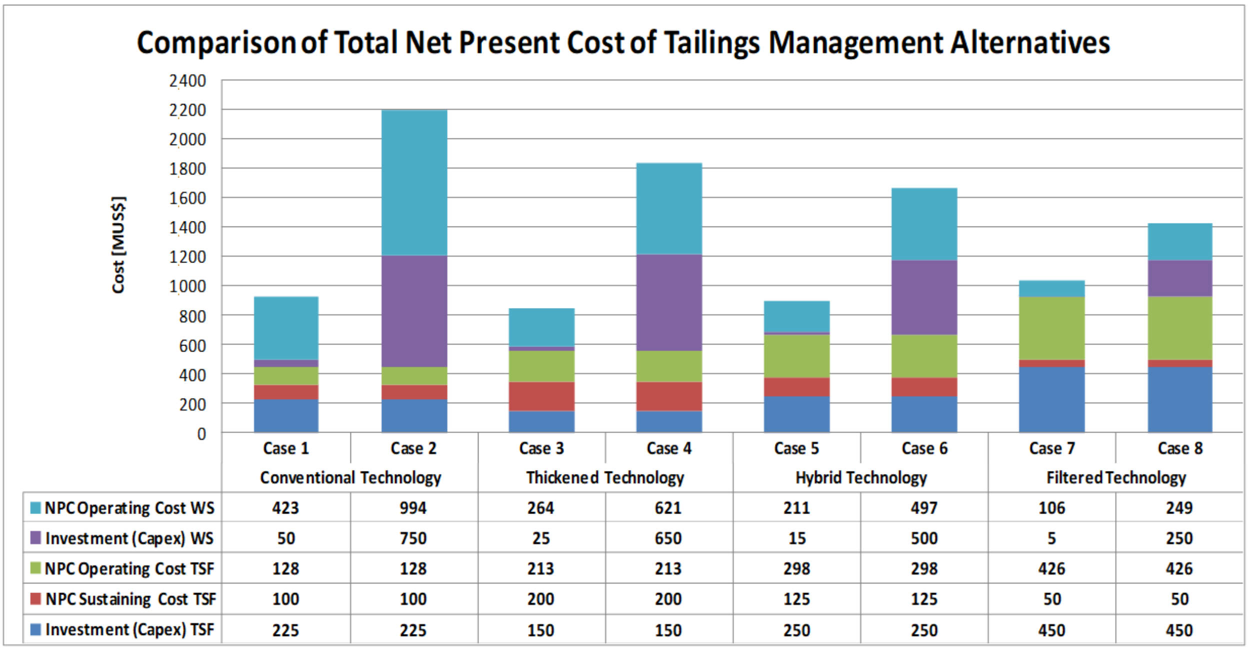
Because average copper grades of copper sulphide ores in Chile and Peru have decreased from 1.18% to 0.90% over the period of the last 2 decades, greater consumption of water, energy and chemical reagents is required to efficiently process low-grade copper sulphide ores. In particular, the consumption of collectors, frothers and modifiers in froth flotation is increasing because higher amounts of low-copper grade ore are processed [39]. For example, the average concentration of collectors and frothers being used in 2012 was 50 g/t ore and 30 g/t ore, respectively. These concentrations correspond to 26,243 tonnes of collectors and 15,745 tonnes of frothers per year [39].

On the other hand, new trends consider the reprocessing of historic tailings that can have important economic and environmental benefits, as these materials have already been mined and ground, reducing the operating costs and the energy required to reprocess them. The reprocessing of these old tailings, however, entails considerable challenges, such as processing fine particles containing complex ores and gangues. The reprocessing methodologies, therefore, vary depending on the requirements of each TSF [40,41].

Technologies available to treat or reprocess copper mine tailings fall into the three categories below.

- Flotation/concentration: The copper is separated from the gang material using froth flotation collected and dewatered using thickening and filtration.
- Leach hydro-metallurgical: Copper mine tailings are leached using sulfuric acid (or other agents) and the pregnant Leach solution is sent to a solvent extraction—electro winning (SXEW) circuit.
- Biological treatment: Bacterial action is used in mine tailings to transfer the copper from the solid matrix to a solution which subsequently is sent to SXEW.

Figure 14 shows the graphical results of the 8 alternatives and a comparative analysis of costs estimate.



	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
	Conventional Technology		Thickened Technology		Hybrid Technology		Filtered Technology	
🟦 NPC Operating Cost WS	423	994	264	621	211	497	106	249
🟪 Investment (Capex) WS	50	750	25	650	15	500	5	250
🟩 NPC Operating Cost TSF	128	128	213	213	298	298	426	426
🟥 NPC Sustaining Cost TSF	100	100	200	200	125	125	50	50
🟦 Investment (Capex) TSF	225	225	150	150	250	250	450	450

Figure 14. Results of Cost Estimate for Tailings Management Alternatives.

The results indicate that fresh water supply use, given the specific characteristics of this large-scale mining production study case, thickened tailings technology is the most cost-effective alternative. The second options, not too far from the first place, are conventional tailings technology and hybrid tailings technology. Competitiveness of these alternatives against thickened tailings technology will depend heavily on the unit cost of fresh water and the efficient management performance to control water loss.

On the other hand, filtered tailings technology is the less cost-effective alternative with the use of fresh water. However, when the cost of sea water is incorporated, the situation changes and the technology becomes the most cost-effective alternative. Finally, depending on the characteristics of the project being evaluated (distance/level from the coast, cost of energy, equipment cost and reliability, etc.), the filtered tailings alternative could become the most feasible alternative.

Although the development of thickening and filtering technologies has advanced significantly in the last years, more investigations/studies need to be conducted to understand their behavior, focusing on obtaining good performance at a larger production scale with different tailings particle size distributions and mineralogy. This shows the high variability of the characteristics of treated ore in the grinding and flotation process in the metallurgical plants.

6. New Mine Operation Cases—Greenfield Projects

Greenfield projects are defined like new mining projects that are starting operations, where greenfield projects have additional complications because of the limited knowledge of project conditions. For example, early ore samples may not appropriately reflect the final source of tailings. For this reason, in a greenfield project evaluation, it is necessary to include a risk analysis of the water use and the technologies considered for tailings management. These projects, in particular, would do well to consider options and experiences from existing projects at the same production scale. Community, environmental and social issues should be given significant consideration.

The main economic and environmental drivers to consider the conversion to thickened/paste or tailings/filter cake deposition systems are:

- Major increase in water losses from the tailings in conventional technologies (slurry tailings) at extreme dry climates.
- Eliminate high capital/operation costs for new water sources (sea water desalination) to maintain and/or increase production.
- Substantial capital/operation cost reduction in the TSF as compared to conventional slurry tailings disposal.
- It is important to note that for some specific cases, extracting water from the tailings has the potential to be a better option than sourcing water make-up from the sea.
- The main economic and/or environmental drivers to consider a seawater supply are:
- Potential depletion of freshwater make-up, and/or the need of a major increase in water recovery from tailings.
- Sustainable use of water, promoting economic, environmental and quality life development of stakeholders in the region.

7. Expansion Mine Operation Cases—Brownfield Projects

Brownfield projects are defined like old mining projects that are continuing or expanding their operation, where brownfield Projects are less risky, as ore composition from the mine is better understood and tailings management methodology is well known, but since most ore resources have been largely exploited, the economical reward is decreasing. The exploitation of a low-grade deposit requires extracting a greater quantity of ore and using more water, to obtain a competitive advantage in the market, which is why the concentration process and use of water resources requires a higher efficiency.

Engineers and mining operators have completed studies for 15 years on highly dewatered tailings disposal methods for a number of large-scale mining operations/projects in northern Chile. The lesson learned is that there are potential cost savings motivating change from conventional slurry tailings disposal systems to alternative highly dewatered tailings disposal systems in existing operations [42].

Make-up water for mining operations has historically been obtained from surface streams and underground water located in the Andes Mountains within environmentally sensitive areas. The majority of these water sources are currently considered to be exploited to their limits, whilst some are nearing depletion or will have to be closed down to limit environmental damage. Mining operations in places with water scarcity that have expansion plans are now turning their attention to the sea as a source of water for their future water needs [43], for this please see Figure 15. Table 5 presents mining operations that have taken the decision to supply their metallurgical processes and tailings management with sea water.

Figure 15. Escondida Mine Sea Water Desalination Plant, Chile [44].

Table 5. Sea water use at mine operations for metallurgical and tailings process.

Mine Operation Name	Country	Tailings Production (mtpd)	Sea Water Pumping Capacity (L/s)	Seawater Supply (%)	Status	Reference
Escondida	Chile	370,000	3800	75	In Operation	[45]
Esperanza (Centinela)	Chile	95,000	1500	100	In Operation	[45]
Candelaria	Chile	75,000	500	85	In Operation	[45]
Cerro Negro Norte	Chile	20,000	200	100	In Operation	[45]
Sierra Gorda	Chile	100,000	1315	100	In Operation	[45,46]
Quebrada Blanca II	Chile	140,000	850	100	In Operation	[47]
RT Sulfuros	Chile	200,000	2000	100	Project	[48]
Cerro Lindo	Peru	15,000	120	100	In Operation	[49]
Bayovar	Peru	15,000	450	100	In Operation	[50]
Shougang	Peru	20,000	231	100	In Operation	[51]
Mina Justa (Marcobre)	Peru	15,000	250	100	In Operation	[52]

8. Conclusions

Water is a resource requested by many stakeholders such as population, industry, agriculture, among others. Inadequate control of freshwater distribution and excessive use of fresh water for industrial purposes may cause a shortage of water for local population in northern Chile and southern Peru in the future.

In this context, mining companies can make a significant contribution to society in terms of water management, with focus on sustainable development and long-term vision. Efficient use of water for industrial purposes should recover as much water as possible, reducing possible losses to the environment, and must be distributed properly between users, according to their demands and requirements with the compliance of local quality standards.

While industrial activities generate economical value and allow businesses transacting goods and services, this activity should also generate social value by improving the quality of life of people, mitigate negative impacts and promote sustainable development. Industrial and wastewater from mining activities should be recycled instead of increasing freshwater make-up. Also, the use of seawater and wastewater reuse should be considered.

In many cases, the ability of a mine to operate is contingent on having sufficient water make-up to compensate for the losses incurred during the operations, which are mostly account in the TSF. For this reason, considering water recovery measures in the design of TSF and developing an accurate water balance model are important factors for the success of the project.

A water management plan can provide an improvement of water recovery from tailings for its reuse in metallurgical process, hydraulic transport of tailings/concentrate and mine site reclamation. The implementation of a good water management plan can significantly reduce water make-up (fresh water) requirements and costs in the long term.

Taking into account the reasons announced above in this article, economic (cost savings) and environmental (less water use and community approval) drivers exist in desert areas of Chile and Peru to: (i) consider the conversion to thickened/paste or tailings/filter cake disposal technology, and (ii) consider the supply of sea water for mining processes. These aspects will be the new design and operation trends of Greenfield and Brownfield mining projects.

The adequate water management is the major challenge for mining, agriculture, industries, population, and authorities nowadays. We have not solved all our difficulties yet, and there are many interesting solutions waiting to be found.

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