COCHILCO
CHILEAN COPPER COMMISSION

BEST PRACTICES AND EFFICIENT USE OF WATER IN THE MINING INDUSTRY

"This document has been translated from the original version in Spanish"

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LETTER FROM THE MINING MINISTER

The limited availability of water resources in northern Chile has become one of the most important topics in the country's agenda due to the importance of the resource for the development of all economic activities, care for the environment and the quality of life in the communities.

For mining, which will continue to be one of the most important production activities in Chile, the availability and proper management of water is key to its long term sustainability. Thus, the challenge is both enormous and strategic, since precisely this activity is concentrated in the northern region of the country, where periods of scarcity and drought are recurrent.

The government of Chile, through the Mining Ministry , decided in April 2007 to create the "Public-Private Board for Water Resource Management", to generate proposals and address the challenges the country will inevitably face regarding water availability and use.

The Minister of the Environment, Minister of Public Works, Minister of Agriculture, Mining Vice Minister, General Director of Water, Executive Vice-President of COCHILCO and National Director of SERNAGEOMIN will participate on this Board. Private sector representation rests on the Presidents of the Mining Council, National Mining Association, National Agriculture Association and National Health Service Company Association. It is worth emphasizing that this initiative, initiated by the Mining Ministry, has grown over time and finally incorporated all sectors linked to water management.

This Board represents an opportunity for the public and private sectorsto come together, which creates a new avenue for solving problems and working togetherand developing cooperation in dealing with such a strategic topic as water resource management.

One of the Board's priorities was to develop a joint document by the public and private sectors which describes water management practices that permit the mining industry to take a leap forward in efficient use of the resource, which becomes evident when comparing the consumption numbers from 2000 to 2006. These numbers were initially raised by the mining sector itself, and were later validated by the General Directorate of

Waters, representing another very relevant outcome of the Board.

That is how this document was created. "Best Practices and the Efficient Use of Water in the Mining Industry" describes the advances in water resource management and practices that have led to the mining industry increasing its efficiency over the past 5 years. It is also a means of disclosing core aspects of the mining industry regarding water use, bringing these water resource management activities to the attention of the national community.

This document compiles the efforts made by the mining industry to reduce water consumption in production processes through operational improvements and complete management. Consumption numbers and utilization rates are included, comparing two moments in time, 2000 and 2006. Good water management practices at mines are described qualitatively, based on specific documented cases from information and visits to the mines, underscoring the Michilla Mine, Escondida Mine's Coloso Plant, Spence Mine, Candelaria Mine, Pelambres Mine and CODELCO Norte. These good practices include technological alternatives, as well as management models for the efficient use of water resources at the mine.

In conclusion, I want to acknowledge the effort of all those who were involved in this important task, especially the Chilean Copper Commission, which, in its capacity as the Executive Secretary of the Board and technical entity specialized in mining, created this document; the Mining Council and the National Mining Association, which managed the visits to the mining sites mentioned in this document and which also made an important contribution so the interesting material could be published; and all the members of the Board, both authorities and technicians, who with their commitment assume one of the most important challenges for Chile's development.

Santiago González Larraín
Minister of Mining

CHAPTER 1:

INTRODUCTION

INTRODUCTION

1.1 GENERAL BACKGROUND

1.1.1 Overall availability of water resources

Freshwater is a unique and scarce natural resource, essential for life and productive activities, and therefore directly related to economic growth.

On earth, water is mainly found in the seas and oceans, which cover 71% of the earth's surface. However, 97% of all existing water is salt water and only the remaining 3% is freshwater. Nearly 2% of the world's 3% of freshwater is frozen at the poles, and only 1% is natural liquid freshwater, which is mainly found in very deep, and difficult to reach aquifers.[1]

Besides the limited availability of freshwater in the world, there is an unequal distribution of this resource in the different continents, creating abundance zones and scarcity zones.

An example of the latter is the north of Chile, which is one of the driest areas on the planet, with scarce superficial water resources and where there is an increasing demand for water by the different production activities as well as human consumption.

1.1.2 Mining – a key production sector for Chile

Ever since colonial times, mining in Chile has been a great source of funds. In the 19th Century it was key to the country's economic development with the exploration of sodium nitrate, and it continues to today, mainly with the copper mines.

In 2007, the mining ector's contribution to the Gross Domestic Product reached 21.8%, measured at current prices. In turn, the country's mining export values exceeded 44 billion dollars, representing nearly 2/3 of total exports. Copper exports in particular exceeded 37 billion dollars, or 55.8% of the national total.

At the same time, mining's contributions in terms of taxes for 2007, through income tax and specific mining taxes, totaled 31.5% of tax monies for the Consolidated Central Government, without taking into account the Additional Tax, thanks mainly to copper and molybdenum production.

Therefore, the mining sector is a strategic production sector that provides great support to the Chilean economy and also has important economic perspectives for future growth.

Indeed, Chilean Copper Commission projections indicate that mining investments for 2007-2011 represent US$ 22 billion dollars, which will permit increasing copper production from 5,560,000 tons of fine copper in 2007 to 6,700,000 tons in 2015.

1.1.3 Mining and water resources

One of the most significant variables for the entire mining project, in terms of current operations as well as the materialization of future projects, is the availability of water. The entire process for mineral processing requires water, whether it be flotation, leaching or any other kind used.

[1] ***Source**: http://epa.gov/region01/students/pdfs/ww_intro.pdf, Document "All the Water in the World"*

Therefore, the availability and appropriate management of water is key to mining activity sustainability. The challenge is greater for mining in Chile since in our country mining is concentrated in extremely dry areas.

The scarcity of this resource in northern Chile is the source of conflict not only among production sectors that compete for its use (mining vs. agriculture), but also in terms of its availability for human consumption. The increasing water demand projections add even more pressure to an already stressed system.

This situation forces the search for deep solutions and long-term actions regarding water availability in the north of the country, due to the perspectives for growth in the mining sector as well as the growing demands from other water consumption sectors. Consequently, and notwithstanding individual and other actions users could carry out to face the issue, it is considered appropiatet to develop joint actions, mutually agreed upon by the different players, whether public or private, as well as among the production sectors.

Currently the mining industry assigns essential importance to the reasonable and efficient use of water in its operations, adopting actions to optimize consumption through best management practices and/or the introduction of better technologies that reduce demand and thus free up resources within the same supply of water. These include: recirculation of water in operations; desalinization and direct use of salt water; improved tailing operation management through the development of thickening techniques that increase concentrations of solids (and lower percentages of water) for large scale industrial production, the selection of sites with easy filtration control, among others.

At the end of 2000, the Mining Council and the qualified public entities signed a Framework Agreement on Clean Production. The Agreement was geared towards promoting productivity improvement and competitiveness of the mining industry, as well as introducing the best practices for pollution prevention and clean production in areas of mutual interest. The creation, in 2002, of the document "Efficient Use of Water in the Mining Industry and Best Practices", was one of the issues of this Agreement. It included recommendations and examples for optimal management of water resources at the mines.

Regarding water consumption in the mining industry, itis important to point out that , those currently available figures presented in the above document which were extracted and audited by external companies in 2006, show that on average, unit consumption of water per ton of processed mineral at the copper mine has fallen. In other words, in 5 years, the mining sector has reduced system water loss, increasing recirculation and improved process efficiency.

It is also worth noting the efforts to reduce effluent discharges into the environment, which has resulted in investments in treatment plants that return water resources to the quality demanded by norms.

Even though these improvements in water management efficiency by the mining industry in Chile are noteworthy, the structural and growing water shortage being faced in the north of our country makes it necessary to continue striving towards further increasing efficiency in water use.

Thus, in face of the limited availability of the resource, efforts to continue increasing efficiency levels from technological solutions, the use of new sources and the commitment by each of the companies to implement management models regarding the efficient use of resources, like water, must be a permanent and synergic concern of companies for maximizing profits over the long term.

1.1.4 Public-private partnerships

The Government of Chile, through the Ministry of Mining, has decided to address the challenges being faced by the country

with regard to water availability and use at the Public-Private Board of Resources, giving special attention to mining activity. The Chilean Copper Commission, through the Research Directorate, has assumed the function of the Board's Executive Secretary.

This Public-Private Board on Water Resources, established in April 2007, is presided over by the Minister of Mining. The Minister of the Environment, Minister of Public Works, Minister of Agriculture, Assistant Secretary of Mining, General Director of Water, Executive Vice-President of COCHILCO and National Director of SERNAGEOMIN also participate on this Board. Private sector representation rests in the Presidents of the Mining Council and of SONAMI. It is worth emphasizing that starting in May 2008, other water consumption sectors were added to the Board through the Minister of Agriculture, the President of the National Agriculture Association and the President of the National Health Service Company Association.

In the first phase, which ended in June 2007, the Executive Secretary prepared the diagnosis document: "Water Resource Management and Mining in Chile, a Diagnosis for the National Public-Private Board." This study included the gathering of available information and other information being generated, a compilation of initiatives by other entities, topics for discussion and an account of conflicts associated with this problem. In the second phase, the Executive Secretary met to articulate actions to validate water consumption data from mining companies as well as develop and monitor initiatives on the subject.

In this context, the need to create a document was raised, which after validating the water consumption figures bythe mining sector, also done by the Board, would describe those water management practices that provided the mining industry with increased efficiency, shown in comparison to sector consumption numbers between 2000 and 2006. These good practices include technological alternatives, as well as management models for the efficient use of water resources at the mine.

This is how the creation of this document was overseen, with the objective of describing the advances in water resource management and practices that have led to the mining industry increasing its efficiency over the past 5 years. It is also a means to disclose core aspects of the mining industry regarding water use, bringing these water resource management activities to the attention of the national community.

This document shows how the mining industry currently uses and consumes water nowadays, and it outlines the efforts made to reduce water consumption through operational improvements and complete management. It describes the best practices in water management at the national level, including technological alternatives, as well as management models for the efficient use of water resources at the mine. Thus, Chapter 2 describes water consumption at the mine. Chapter 3 shows the consumption numbers and utilization rates comparing two time periods, 2000 and 2006. Chapter 4 describes good water management practices at the mine based on specific cases that were documented from gathered information and visits to the sites. And Chapter 5 presents the main conclusions of this study.

CHAPTER 2:

WATER CONSUMPTION IN MINING

2. WATER CONSUMPTION IN MINING

2.1 DEFINITION OF WATER CONSUMPTION

Water consumption includes all those activities where water use produces losses in relation to the initially supplied quantity. For example, urban and industrial consumption.

Water used in industrial processes, for example in mining, can be increasingly reused by society thanks to new processes that permit eliminating the contaminants these waters have incorporated during industrial processes.

That is how mining companies conduct efforts to reuse the resource in their processes, as well as to carry out proper treatment of generated effluents2, due to the potential contamination of the water and the consequent effect on human health and the environment.

2.2 WATER CONSUMPTION IN COPPER MINING

In copper mining, water is fundamentally used in the traditional flotation benficiation process, in smelting and electro refining or in the hydro-metallurgical process, which consists of leaching, solvent extraction and electro winning (LX-SX-EW).

However, every joint process or operation in mining uses a greater or lesser volume of water to contribute towards process efficiency.

The main areas of water consumption and loss associated with each process.will be identified and described below.

2.2.1 Water consumption at camps

Human water consumption is for drinking, cooking, washing, irrigation and bathing. These are not very significant volumes compared to total consumption at a mining site.

2.2.2 Consumption at the mine

The main use of water in open pit mining is for wetting roads in order to reduce suspended dust.

Many factors influence dust reduction: exposed surfaces, land morphology, annual precipitation, natural vegetation, etc. Available numbers indicate that the water used in wetting roads can vary between zero and 15% of total water consumption at a mining site.[3]

In underground mining, water consumption is reduced and the problem mainly consists of extracting natural water that gathers at the bottom of the pits, which can come from rain or the surfacing of underground water sources.

The mineral extraction site may be characterized by the internal circulation of water, which may have its origin from underground sources (surfacing) or rains. This water movement can increase or decrease depending on whether the site has a greater or lesser capacity for the flow to circulate.

[2] *Effluents or liquid industrial residues from mining-metallurgical activity are the flows discharged into the environment and generate a series of processes that occur in the production process for obtaining the desired metal or salt*
[3] *Document: "Efficient Use of Water in the Mining Industry and Good Practices", 2002*

This flow must be evacuated from mine installations since it is acidic and contains high levels of metal concentration, which can be corrosive, reactive or abrasive, depending on the type of installation materials. Conduction works are generally designed and constructed for this, which permits treatment of the effluent, discharging it or filtering it to a superficial or underground course.

2.2.3 Consumption in beneficiation plants

In the copper production chain, the water used in mineral processing represents the greatest consumption of water in terms of total volume.

In beneficiation plants, sulfurated mineral treatment involves the crushing and grinding of the mineral, followed by flotation, classification and thickening. The most significant water consumption is in flotation, transportation of concentrates and tailings and the evaporation and infiltration in dams.

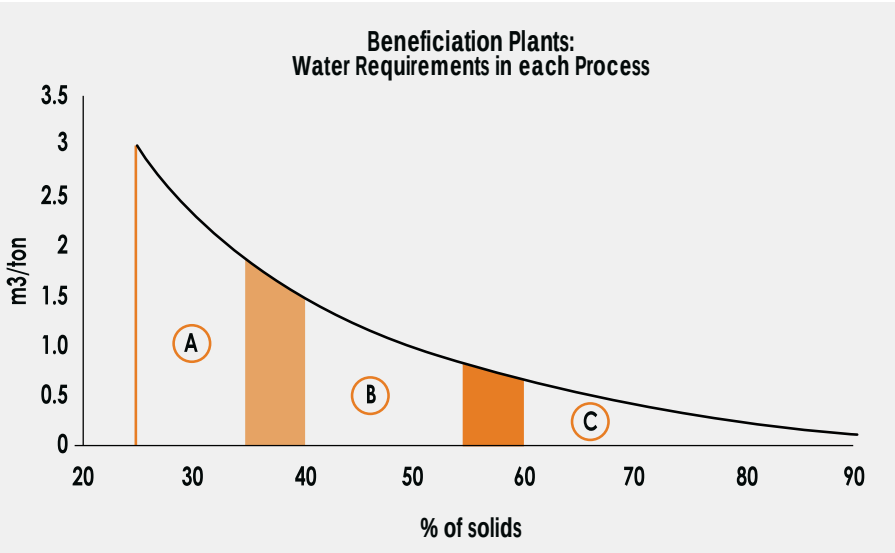
The mineral is frequently prepared prior to grinding. Flotation of the copper mineral is done using physical-chemical procedures that consist of extraction, not of the copper itself, but rather the particles of the mineral that contain sulfur. That means water and some reactive agents are added that are important in flotation.

In flotation, there is an excess of water in relation to the mineral, and it is done generally at an alkaline pH (10 to 11). Therefore, it is necessary to add some reactive agent, usually lime, to increase pH from 7, found in natural water, to 10 or 11.

The resulting product of these flotation plants is a copper concentrate that contains between 20 and 40 percent copper, depending on the types of mineral involved (chalcopyrite, copper sulfide, chalcosine, etc.).

As can be observed in Graph 2.1, flotation is carried out normally at a rate that varies between 25% and 40% of solids, to obtain the highest recovery of the metal. With these values, water requirements during flotation can vary between 3 and 1.5 m3/ton of mineral.

Graph 2.1 Typical graph of water requirements in beneficiation plant processes



Source: *Document: "The Efficient Use of Water in the Mining Industry and Good Practices", 2002.*

The A zone corresponds to ranges of typical operations in the flotation process. Once this process is concluded, the pulp concentrate is taken to thickening (zone B), which means increasing the percentage of solids to between 40% and 60%, with the consequent recovery of water, and finally the pulp concentrate is taken to filtration (zone C), where water is once again recovered, leaving the concentrates with moisture percentages of around 10%.

Water from the flotation process is also used to transport the concentrates and the residues to the tailings dams. When necessary, the concentrate is transported first to installations farther away from the site and then the water is extracted.

Depending on the distance between the concentrator plant and the filtration and storage installations, the residual water may or may not be recirculated to the process. When recirculation is not possible, part of the water is sent for industrial use and the rest is returned to the environment under controlled conditions.

However, a large part of the water used in flotation becomes part of the tailings[4], which is sent to the thickening stage to recover part of the water it contains. The tailings are then discharged into dams (like reservoirs), whose function it is to contain the effluent, permitting sedimentation of fine particles in the deposit and retaining the thicker solids at the retaining wall. This way, the maximum amount of clear water is recovered, which, when economically feasible, isreturned to the flotation process, thus reducing freshwater consumption.

The most modern dams use waterproofing systems from the starting wall, and at the bottom or base of the retaining wall, they use drains (drainage beds) to intercept possible infiltration at the water source. However, the older dams do not include waterproofing systems in their designs, nor monitoring pools of underground waters. The losses associated with tailings include unrecovered liquid that evaporates, discharges, retains or infiltrates.

Actual consumption of water at the concentrator plants for the country is around 0.79 m3/ton of mineral[5]. By maximizing recirculation from the thickeners and dams, avoiding leaks and minimizing evaporation, it is possible to achieve values of around 0.36 m3/ton of mineral[6]. Details on these numbers are shown in Chapter 3.

In short, water loss during mineral processing varies due to the complexity of the concentrator plants[7]:

- Evaporation, especially in tailing dams, thickeners and storage of minerals and/or concentrate. Concentrate or mineral moisture is variable.
  In general, the sale of concentrates is done with moisture levels of between 8 and 12%. The evaporation that can be produced from a concentrate with that level of moisture in the desert is severe, whereas in places closer to the sea, that moisture level tends to remain stable.
  The evaporation rate that can be observed in a tailing dam also varies substantially, depending on its location.

- Infiltrations produced in underground water sources that can be absorbed in the soil or evaporate. However, part of that water can be recovered from the water sources.

- Drying process of the concentrate prior to fusion.
  The mineral is fed into fusion ovens with the least amount of water possible (extremely dry) in order to take maximum advantage of the fuel and the exothermal reactions produced during fusion.

- In cases where the dam and/or thickeners are located further below sea level than the respective concentrator plant, it is too expensive to pump water back into the process. Examples of that include the Carén dam, which belongs to the El Teniente de CODELCO Division, located east of Rapel Lake, and the Ovejería Dam, which belongs to the CODELCO Andina Division and is located in the central valley of the Province of Chacabuco.

On the other hand, when the tailing dam or thickener is located at about the same sea level as the flotation plant, the recovered water can be reused in the process. Examples of this are the Chuquicamata, Escondida, Candelaria and Pelambres dams.

[4] *The tailings are crushed rock, transported in the form of pulp, that is, rock plus water. The tailings are concentrator plant residues.*
[5] *Numbers estimated by the Mining Council and DGA from 2006.*
[6] *Average numbers from the Candelaria Mine for 2006.*
[7] *Source: Document: "Efficient Use of Water in Copper Mining" Gustavo Lagos, Mining Center, Pontificia Universidad Catolica of Chile,1997.*

In the case of tailing dam water disposal, it is important to consider that the levels of metals or salts in these waters, called "clear water", are not always appropriate for agricultural use. These "clear waters" are reused at the flotation plant and in some cases, at high economic costs (great distance between the dam and the plant); they are used in irrigation (after prior compliance with norms) or the dampening of roads that see vehicle traffic (less frequent). The physical-chemical volumes and characteristics of this flow depend on the season, meteorological factors and the site.

In the case of the Las Tórtolas and Ovejería dams, the water is used to water woods planted by companies in the areas surrounding the dams.

2.2.4 Transportation of minerals or concentrate

There are two ways to transport concentrate from the plants to the foundries or a port, trucks or trains, or a mineral duct.

There are three large concentrator plants in Chile that send the concentrate to a port by a slurry duct. These are the plants at the Escondida, Collahuasi and Pelambres Mines. In these cases, the concentrate is transported over 150 kilometers, from heights of around two thousand meters above sea level to a port. It is necessary to add water for the concentrate to flow along the slurry duct. On average, the water used in the slurry duct represents between 4% and 6% of all water consumed at the respective concentrator plants.

2.2.5 Foundries

The fusion of concentrates is carried out in two steps (fusion and conversion) in diverse reactors and results in blister or anode copper.

The concentrate obtained at the concentrate plants dries until reaching 0.2% moisture and then casts at high temperatures. In order to make fusion reactions more efficient, it is necessary to produce oxygen, a process that requires water.

A fundamental part of the fusion consists of recovering the sulfur from the concentrate, which is transformed into sulfur dioxide (SO2).

The gases generated in the process (with a temperature of over 1200°C) are captured using a water-cooled bell. The gases are then cooled in an evaporation chamber with atomized water (350°C to 400°C) and sent to the acid plants where they are washed with water to remove remaining solid particles.

Consumed water is used for cooling gases, whether directly in fusion or in the sulfuric acid production section. Water consumption for cooling gases can vary considerably from one foundry to another. For example, a foundry close to the sea can use sea water for almost all cooling, returning it to the sea after it is used when it is certain no environmental impact will be produced due to temperature changes. On the other hand, more efficient heat exchangers can be used for cooling, thus reducing consumption.

The fusion product, called matte, is taken to the next phase, or conversion. However, the slag is taken to the dam.

Conversion eliminates a large part of the impurities, producing liquid metal copper in the form of unrefined blister copper, which is taken to a pyro-refining phase, where RAF copper is obtained. This is molded into thick plates in the shape of anodes, which are sent to the electro-refining process.

National foundries currently have an average consumption of freshwater that varies around 3.6 m3/tms of cast concentrate.

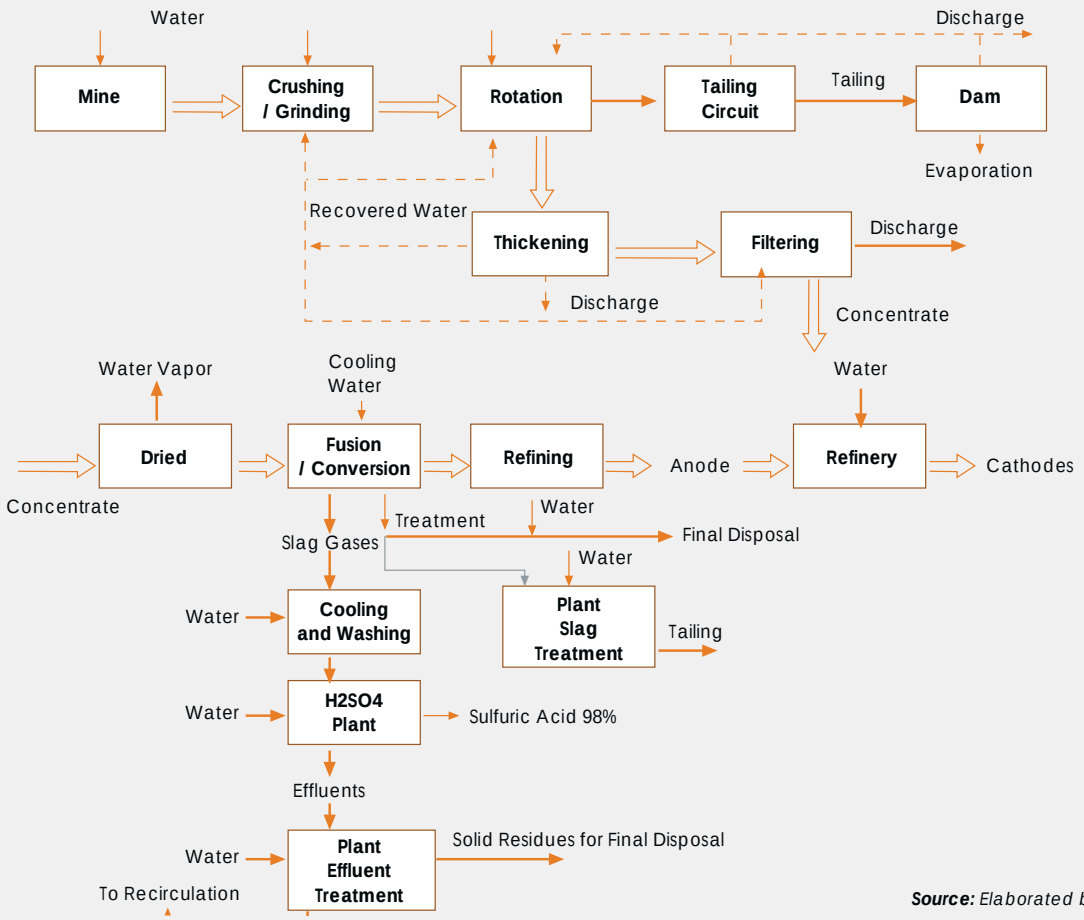
2.2.6 Electrolytic Refineries

Electrolytic refining is the last pyro-metallurgical process for recovering copper.
It consists of electrochemically dissolving anodes from casting with

the objective of eliminating impurities, mainly metallic ones, which range between .01% and 0.3%, and selectively depositing pure copper on the cathodes. Water losses in electro-refining are mainly a result of evaporation and the disposal of solutions. The first occurs in the upper part of the electrolytic cells and is exacerbated by the electrolyte's temperature, which is approximately 60°C. Nowadays, small plastic spheres are used that float over the electrolyte and substantially reduce evaporation. Solution disposal must be carried out due to the concentration of undesired metals and elements in the electrolyte, such as arsenic and antimony, and it must be cleaned using special cells in an electro-winning process. At the end of the diverse cleaning phases there are always solutions that contain impurities and therefore cannot be recycled.

Figure 2.1 shows a diagram of flotation processing of sulfurated minerals and pyro-metallurgical processes that indicate freshwater consumption, recirculation, discharging and/or effluent generation. The most significant water consumption and losses in foundries

Figure 2.1 Processing of sulfurated minerals by flotation and pyro-metallurgical processes



Source: *Elaborated by COCHILCO*

and refineries are due to the generation of oxygen, which is needed to make fusion reactions, drying of concentrate, evaporation, fusion of concentrate, washing of gases more efficient in the acid plant, aimed at removing solid particles that are trapped in the gases, producing an acid effluent and disposal of solutions.

2.2.7 Hydro-metallurgical process

The leaching, solvent extraction and electro-winning processes for producing copper have used this since the 1960s. Copper recovery was initially done with copper oxide minerals. Since the 1980s, copper has also been produced using hydro-metallurgy from some secondary sulfurs, mainly chalcosite.

During the 1990s, this process was used in a growing number of mines since its operational cost is lower than when using pyro-metallurgy.

The process basically consists of crushing the extracted mineral and then binding it so that when building the leaching heaps, the lixiviating solution can percolate and get in contact with the diverse particles that contain the mineral. During agglomeration, the mineral is in contact with a solution that contains sulfuric acid in order to begin the copper dissolution process.

Soon after agglomeration, the mineral has amoisture content of approximately 10%. It is gathered in heaps a few meters high (two to ten meters), depending on the mineral's characteristics and site and if the upper surface is watered with an acid solution. This solution percolates in the heap and with the oxygen it produces secondary sulfur and copper oxide oxidation. This process can be accelerated with the inclusion of other oxidating agents, such as ferrous ions and/or bacteria.

The heaps are built on a waterproofed surface in order to recover all the solutions and at the same time it avoids the contamination of surface and underground waters.

The recovered solution at the bottom of the heaps contains a slight concentration (1 to 3 g/l) of copper, and before recovering it using electro-winning, it is necessary to increase its concentration in the solution.

The increase in the concentration is achieved by the solvent extraction (SX) process, which consists of extracting the copper from the aqueous to the organic phase and then re-extracting the copper from the copper loaded organic phase to the new aqueous phase. The copper concentration in this new aqueous phase, at the end of the solvent extraction process, is about 40 g/l. This solution is called the "loaded phase" and it feeds the electro-winning plant.

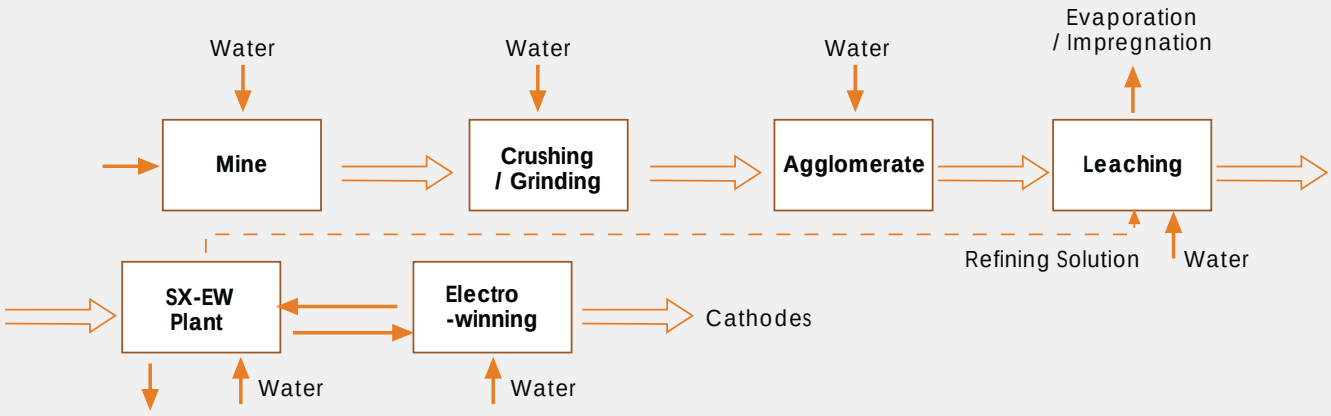
In solvent extraction (SX), as soon as the copper has been unloaded from the leaching solution, its pH is returned and it is reused in heap irrigation. After a few cycles, the solution contains a few impurities that had been incorporated by heap dissolution. These solutions are normally disposed of by adding them to a heap from which all the presupposed copper has been extracted. Since the base of these heaps is waterproofed, the disposal solution evaporates. The impurities are trapped in the rejection heap, called debris.

Finally, the solution is loaded with copper that enters the electro-winning plant after filtering to eliminate solid impurities and it undergoes electro-deposition, generating oxygen in the insoluble anode (lead alloy) and depositing metallic copper on the cathode. Highly pure copper is obtained from the electro-winning plant.

At the solvent extraction plant (SX), due to the degradation of organic reactive agents and solution contamination, the organic solutions are rejected after several cycles. These solutions are washed during their useful life and the required water volume is high.

Figure 2.2 shows a diagram with the hydro-metallurgical process phases for copper production, indicating the

Figura 2.2: Hydro-metallurgical processing of copper production



Source: *Created by COCHILCO*

freshwater consumption, the phases where water recirculated and where effluents are generated.

The most variable factors regarding water consumption are evaporation in the heaps, solution rejection (which depends, among other factors, on the mineral's dilution kinetics) and the washing of organic solutions.

Related to the hydro-metallurgical process, effluents are generated in the drainage of mines and solutions exhausted in the hydro-metallurgical process, such as on-site or heap leaching, solvent extraction and electro-winning.

The effluents from mine drainage and exhausted solutions are preferably recycled. If this is not possible, they are neutralized or detoxified before disposed of in dams for evaporation.

CHAPTER 3:

WATER CONSUMPTION RATES IN THE MINING SECTOR

3 WATER CONSUMPTION RATES IN THE MINING SECTOR

3.1 BACKGROUND

With regard to the mining sector's role in the consumption of water, the National Public-Private Water Board delegated the coordination of actions needed for the DGA to begin a more detailed sectorial work plan with the mining sector to the Executive Secretary, aimed at validating water consumption data from mining companies and having a better definition of sector usage conditions, which would require greater efforts in compilation, systematization, desegregation and validation of the information.

That is how the DGA worked with the Mining Council and the National Mining Association (SONAMI) in 2007 to compile and systematize the information on the mining sector's water usage rights, establish the flow of extractions employed by the mining sites such as freshwater (or make-up) and the unit consumption rate of freshwater in copper mining processes (concentration and hydro-metallurgy). The results of these public-private efforts in making existing information transparent are reflected in the study entitled "Rights, Extractions and Unit Consumption Rates of Water in the Mining Sector: Central –North Regions of Chile", of March 2008, by Proust Consultores for the DGA Studies and Planning Division, and published by General Water Directorate in the S.I.T. Document No. 146 of March 2008.

3.2 FRESHWATER EXTRACTIONS IN COPPER MINING

Among the main results derived from the study mentioned in the section above, what stands out is that the greatest consumption of freshwater by the mining sector is in Region II, with 4854 l/s, followed by Region VI and III, with 2100 l/s and 1441 l/s, respectively (see Graph 3.1).

It is worth mentioning that the values shown in Graph 3.1 come from the mining companies located in the central-north region of the country (from Region VI to the north), where national mining activity is concentrated and represents more than 90% of national copper production. Furthermore, these values do not include seawater extractions, water from third parties (not mining) or water found in mining work.[9]

At the end of mining sector water extractions, the numbers reported by the mining companies for 2006 average about 11.9 m3/s for the entire sector. As a comparison, observe that in 2002, with copper production of 4.6 million tons, the industry's water extraction was 15 m3/s, whereas in 2006 with production increasing to 5.4 million tons of fine copper, water consumption fell to 11.9 m3/s.[10] These numbers reveal that mining companies have increased efficiency in resource usage compared to previous years.

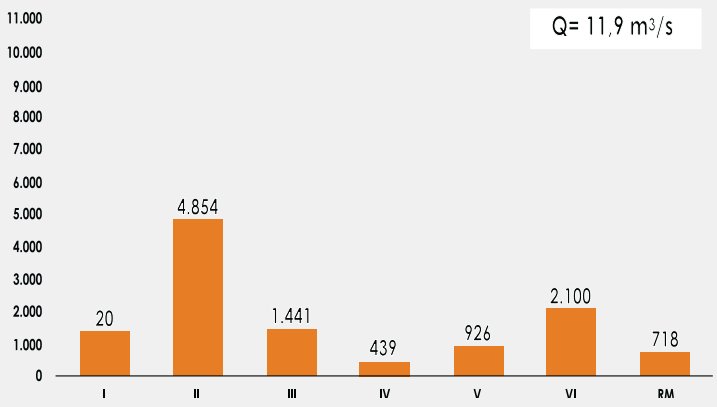
Indeed, in recent years, mining companies have adopted actions to optimize consumption through better management practices such as improvements in tailing operation management; optimization of existing installations; study of recovery technologies at the plant, or the introduction of new technologies, such as osmosis, the direct use of sea water in

[9] *With regard to the last two types of water, there is no precise information about the quantity they mean given the non-existence of any obligation to inform them. Nevertheless, experts believe they are volumes that although in specific cases could be relevant, do not alter the correct representation of DGA numbers when considering the mining sector as a whole.*

[10] *Rights, Extractions and Unit Consumption Rates of Water in the Mining Sector: Central North Regions of Chile", March 2008, DGA-ProustConsultores.*

processes (depends on mineral characteristics, among others), the development of thickening equipment that guarantees high concentrations of solids, the development of models and instruments to control percolation in leaching heaps and research on alternative uses of supernatant water, for example, in agriculture, flower-growing, etc. These efforts are seen in water consumption reductions in the national copper mining industry.

Graph 3.1 Total informed extraction by region (l/s)



Source: *"Rights, extractions and unit consumption rates of water in the mining sector: central-north region of Chile", DGA-Proust Consultores, March 2008.*

3.3 COMPARISON OF WATER CONSUMPTION NUMBERS IN COPPER MINING

Table 3.1 is a comparison between average unit consumption of water in copper mining for 2000 and the projected numbers by the Mining Council and the DGA from 2006. What can be seen in this table is that on an average, freshwater consumption in the process fell from 1.1 m3/tms to 0.79 m3/ tms and in mineral processing through hydro-metallurgy, from 0.30 m3/tms to 0.13 m3/tms over the past 5 years.

Tabla 3.1 Average water consumption in national mining by treated mineral

Process	unit consumption of freshwater Year 2000 (1) m3/ton mineral	Year 2006 (2) m3/ton mineral
Concentration	1,1 (0,4 - 2,30)	0,79 (0,3 - 2,1)
Hydro-metallurgy	0,3 (0,15 - 0,4)	0,13 (0,08 - 0,25)

*(1)**Source:** "Efficient Use of Water in the Mining Industry and Good Practices", APL 2002*
*(2)**Source:** "Rights, extractions and unit consumption rates of water in the mining sector: central-north region of Chile", DGA-Proust Consultores, March 2008.*

In the table above, between parentheses we show the range of unit consumption of freshwater the mining sites operated in from 2000 to 2006.

Unit consumption of freshwater in copper processing, including concentration (flotation) and hydro-metallurgy (leaching, solvent extraction and electro-winning) shows a notable difference between processes and operating conditions at the different mining sites. The freshwater consumption rate in concentration processes ranged between 0.4 and 2.3 m3/ton in 2000 and 0.3 and 2.1 m3/ton in 2006. The higher values correspond to operations where it is not possible to recirculate water from tailing dams.

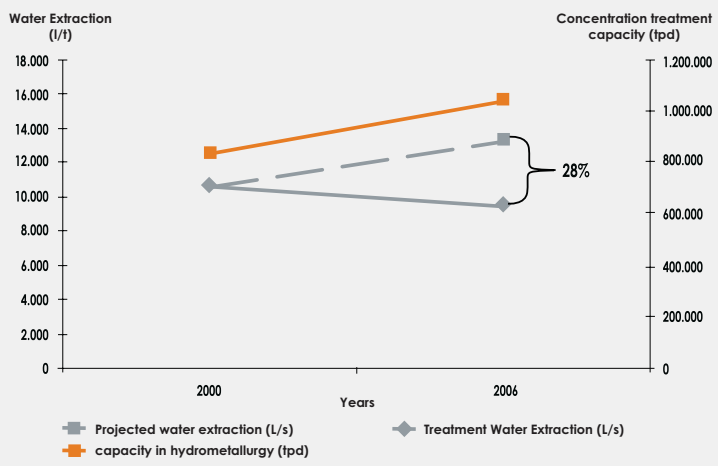
In turn, the freshwater consumption rate in hydro-metallurgy processes ranged between 0.15 and 0.4 m3/ton in 2000 and 0.08 and 0.25 m3/ton in 2006. In general, Gran Minería del Cobre hydro-metallurgical plants have made substantial advances in recent years in terms of water consumption optimization. Using solution recirculation, avoiding infiltrations and minimizing evaporation have led to an average consumption of freshwater of around 0.13 m3/ton of mineral.

Graph 3.2 shows the water efficiency of the copper concentration process in percentages, comparing the information for 2000 and the information for 2006, where we see an increase in water efficiency of around 28%, considering the linear increase in copper concentration treatment capacity (tons per day). It is worth emphasizing that the goal proposed in the 2002 Clean Production Framework Agreement over the mid-term is for unit consumption of water in the concentration of 0.60 m3/ton, which implies the challenge remains and the efforts must increase efficiency levels by means of technological solutions.

Graph 3.3 shows the water efficiency of the hydro-metallurgical process in percentages, comparing the information for 2000 with 2006, where we see an increase in water efficiency of about 49%, considering a linear increase in the copper hydro-metallurgy treatment capacity (tons per day). The goal proposed by the 2002 Clean Production Framework Agreement for the mid-term is for unit water consumption in the hydro-metallurgy process of 0.25 m3/ton. In this case, the goal proposed in the aforementioned Framework has been exceeded with a surplus.

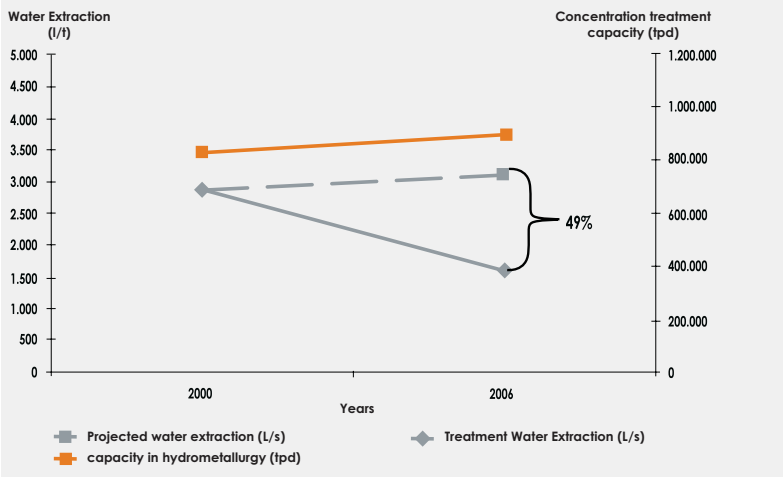
In the previous graphs, an important separation can be observed between the production capacity and water consumption curves for both the concentration and hydro-metallurgy processes, thus showing that over the past 5 years there has been a sustained increase in water resource use efficiency by the mining sector.

Gráfico 3.2 Water efficiency in the concentration process



Source: *"Rights, extractions and unit consumption rates of water in the mining sector: central-north region of Chile", March 2008.*

Gráfico 3.3 Water efficiency in the hydro-metallurgical process



Source: *"Rights, extractions and unit consumption rates of water in the mining sector: central-north region of Chile", March 2008.*

Among the success stories in the efficient management of water resources at mining sites, Michilla Mine can be mentioned, where sea water is used directly in copper production; CODELCO Norte, which has invested about US$ 33 million in projects to increase process water recovery, which has permitted an increase in concentrator treatment levels over recent years, without increasing freshwater demand levels; the Los Pelambres Mine, which has achieved efficient water use at the Los Quillayes tailing dam and also has a unit water consumption of 0.35 m3/s, one of the lowest in Chilean mining; Candelaria Mine, which has an efficient water resource management system that allows it to obtain water recycling of around 87% of total consumption and a unit consumption of 0.36 m3/s; and Escondida Mine, with the start-up of the sea water desalinization plant in Coloso, which supplies the demand for water in the production processes, especially the Los Colorados concentrator plant.

CHAPTER 4:

BEST PRACTICES FOR THE EFFICIENT USE OF WATER RESOURCES IN MINING

4 BEST PRACTICES FOR THE EFFICIENT USE OF WATER RESOURCES IN MINING

4.1 Introduction

In the north central part of the country, where there is a limited availability of water resources and a growing demand that competes with other sectors of the economy, the rational and efficient use of water is key to the future of the mining business.

That is how the mining sector has reacted in face of the strict water situation, adopting actions to optimize consumption through best management practices or the introduction of better technologies and/or investing in new alternatives that reduce demand and increase water supply, such as the efficient use of water in operations, including recirculation; improvements in tailing operation management, such as the development of thickening equipment that guarantees high concentrations of solids for industrial productions on a large scale and the selection of sites where it is easy to control filtering; the use of new sources, such as desalinized water and the direct use of sea water, among others.

The numbers seen in the previous chapter show that on average in the north central region of Chile, the unit consumption of water per ton of processed mineral at the copper mine has fallen, minimizing system losses and making the technologies implemented in the processes more efficient. However, experts at the institutional level and in many mining companies believe there is still room for improvement in the efficient use of such a strategic resource as water for developing mining activity in each of the areas of development, operation and closing of the project.

Later on, successful cases will be described regarding the efficient management of water resources at mining sites.

4.2 WATER RESOURCE MANAGEMENT AT MINING SITES

For more efficient environmental management of water, it is recommended to include aspects like reduced consumption, the efficient use of water resources and the sustainable management of aquifers and ecosystems that supply them.

In order to manage resources at the site, it is key to have water consumption measurement systems in each step of the mining production process. Some mining sites, like CODELCO Norte and Candelaria already have these types of systems. It is advisable for all mining operations to have a complete water balance that allows them to assess the current situation, provide corrective actions for reducing consumption, assess the impact of these actions and consider these practices in future plans.

Some key aspects to guarantee the success of this management and that permit an integrated management of water resources are:

- Management and appropriate control of available water rights, leading to an updated register of rights

employed, compensations and/or restitutions, if any (consumption and non-consumption rights).

- Have the proper instruments to measure water volumes on-line of inputs and outputs of unit processes to determine the water balance at the site.
- Construct indicators: in those activities identified as key it is necessary to have specific controls for controlling volumes and quality established for the water.

As actions needed to achieve objectives and goals are implemented, it becomes necessary to monitor indicators, following up on their evolution. This monitoring must also include the variables that correspond to the quality of the resource used in the diverse steps and discharged effluents. It is recommended for these measurements to be compared with the applicable norm or the reference standards when this norm does not exist. The information thus obtained and assessed will serve to revise and correct the implemented system.

4.3 CASE STUDIES

As part of the work entrusted to the Executive Secretary by the National Public-Private Board on Water Resources, a series of visits were made to mining sites described below.

Case no. 1 Candelaria Mine – Efficient and sustainable management of the water resource

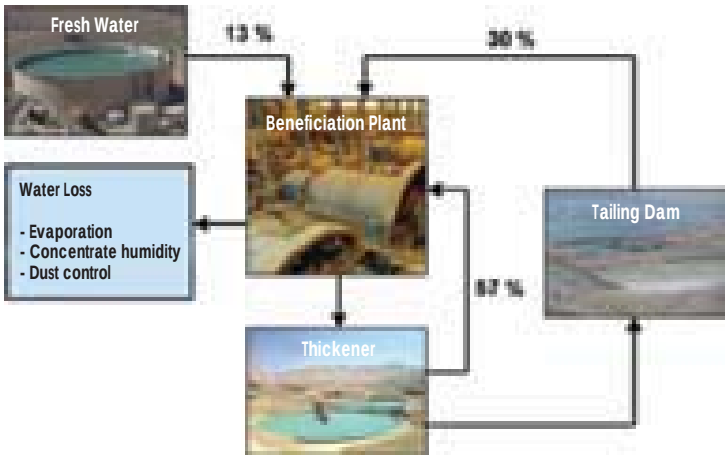
One of the main aspects considered in water management in Candelaria is the efficient administration of water resources at the site. Freshwater from underground sources extracted from wells located at Tierra Amarilla and Paipote. Sitedrinking water is produced by a reverse osmosis plant.

The site reuses the water with a system that permits water recycling of around 87% of all water consumed. About 57% corresponds to water recirculated from copper concentrate thickeners and tailing thickeners. About 30% is recovered from tailing dams, where the freshwater that enters the system represents 13% of all consumed water. In fact, of the 750 liters per second that Candelaria has as water rights, it only uses about 280 l/s.

This permits less water consumption from Valle Copiapó, one of the most affected sectors by the reduction of underground water levels.

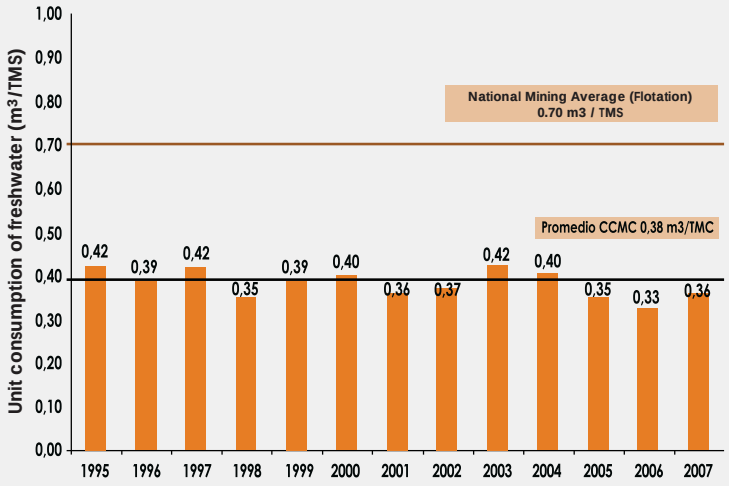
In 2007, freshwater consumption per ton of mineral treated at the Candelaria Mine concentrator plants was on average 0.36 m3/ton of dry mineral.

Figure 4.1 Water balancing processes



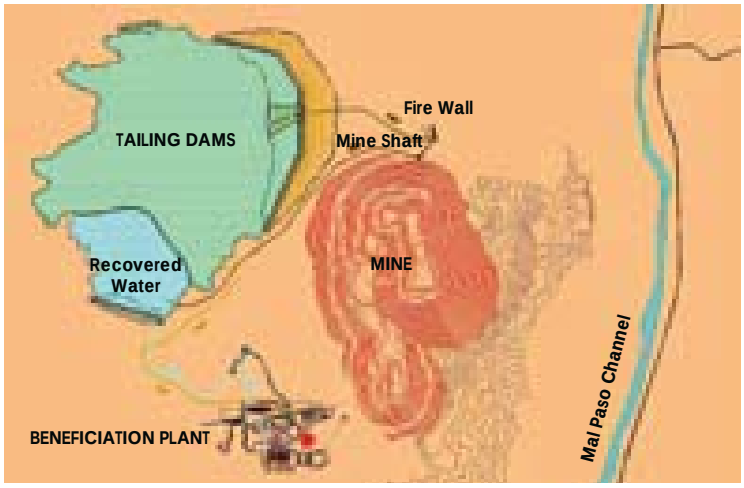
Source: *Candelaria Mine*

Figure 4.2 Unit consumption of freshwater



Source: *Candelaria Mine*

Figure 4.3 Water recirculation system



Source: *Candelaria Mine*

One of the considerations in the project's original design and which contributes towards the recovery of 270 l/s is the construction of drainage that permits recovering water infiltration from tailing dams. This water is channeled via a tunnel and trail from where water is pumped for reuse in the process.

Candelaria Mine has demonstrated a constant concern in the reasonable and efficient use of water to take utmost advantage of its availability, which has no doubt served as an example in water management efficiency.

Notwithstanding the above, the company is convinced that new improvements in water use efficiency are possible. That is why the Candelaria Mine constantly reviews alternatives for the optimal use of the resource, such as water recovery from infiltrations, use of technologies in the thickeners, etc.

Case No. 2 Los Pelambres Mine – Efficient and sustainable management of water resource

The Los Pelambres Mine (MLP) is owned by Antofagasta Minerals S.A. (60%) and a consortium of Japanese companies (40%). It is an operation that produces copper and molybdenum concentrates, located 240 kms north of Santiago. The mineral extracted from the mine located 3600 meters above sea level is transported by trucks to the primary crusher and sent by a 13 km long

conveyor belt to the stock pile in the concentrator plants sector, 1600 meters above sea level. The copper concentrate is mixed with water to permit transportation to the port installations located near Los Vilos over a 121 km long slurry duct, which uses the force of gravity. Excess water from the concentrate is filtered and pumped to six storage pools from where it is extracted to irrigate 72 hectares of eucalyptus woods in the loading port sector.

The sustainable use of water resources is a priority at MLP given its importance as a critical input in the production process and for the economic development and quality of life of those communities that coexist with the mine in Valle del Choapa.

In terms of freshwater consumption, the company reported that on an average it has fallen compared to last year. It also indicated that it has reduced freshwater extraction over recent years. Unit consumption of freshwater is around 0.35 m^3 of water/ton of processed mineral. On an average, recirculated water reached 0.57 m3/ton[11] or a recirculation rate of about 55%.

The water use management model is based on the principle that each management team represents a management unit that must pay for water consumption. There is still no detailed water balance for each process However, a series of flow meters is being installed in each productive installation with which a base line will be constructed from the input and output volume measurements for each operation.

As in other mining operations, management of efficient water use is oriented towards maximizing the recirculation of RILES generated in the process.

Thus, the water that emerges from the face with high sulfate and copper content, and that are not proper for irrigation, is captured and conducted to the concentrator plant to be used in the production process. At the bottom of the face, growing volumes of mineral water have been found, for which the company is considering the replacement of current piping for larger diameter piping.

The recovery of process water from the thickeners totals 70% and from the tailing dams average recovery is around 55%.

At the Quillayes dam and the recent construction of the El Mauro dam they have considered seismic safety and extreme meteorological event criteria.

At the Quillayes dam, the natural waters from the Cuncumén River basin are detoured, starting above the deposit and lead through a five kilometer long tunnel to the natural water course below the dam, so there is no contact with the tailing nor with industrial waters. Water filtration is captured by systems that permit the complete separation of natural waters.

They have leak proof ditches at the foot of the dam wall to capture surface or underground filtrations and wells to monitor natural water quality. The waters from the tailing dam, leak proof walls and drains are captured and recirculated.

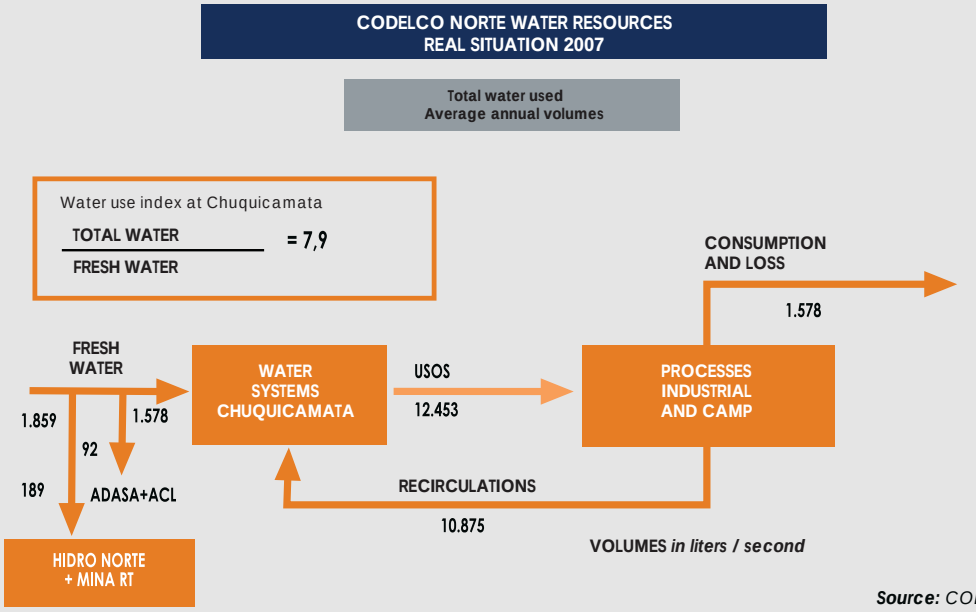
At the El Chinche dam (closed a few years ago) an experimental reforestation plan began that would demonstrate the feasibility in applying this methodology in the closing phase of the Quillayes dam.

Case No. 3: CODELCO Norte Division – Water resource management

Total demand for freshwater by the division is around 2000 l/s. This volume is provided by the adduction of freshwater from dams and wells. The process that consumes 52% of all freshwater is the concentrator plant. The hydro-metallurgical processes from the Sur and Radomiro Tomic Mine consume around 17%. Division freshwater costs range around 0.25 US/ m^3.

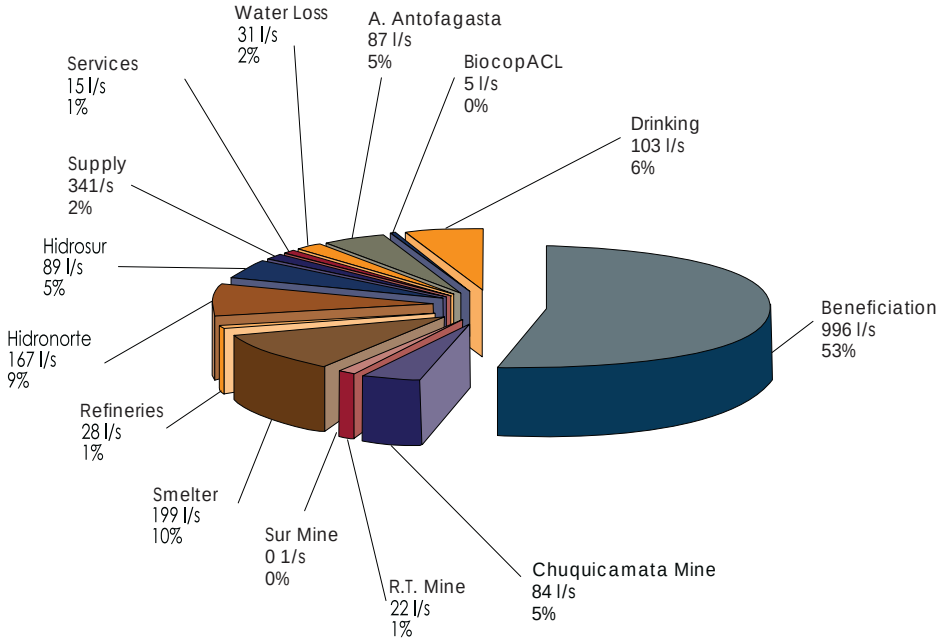
[11] *These 0.57 m3/ton correspond to recirculated water from the Quillayes Dam tray compared to total water that enters it in the tailings.*

Figure 4.4 Uses of water resources at CODELCO Norte in 2007



Source: *CODELCO Norte, reference value for 2007*

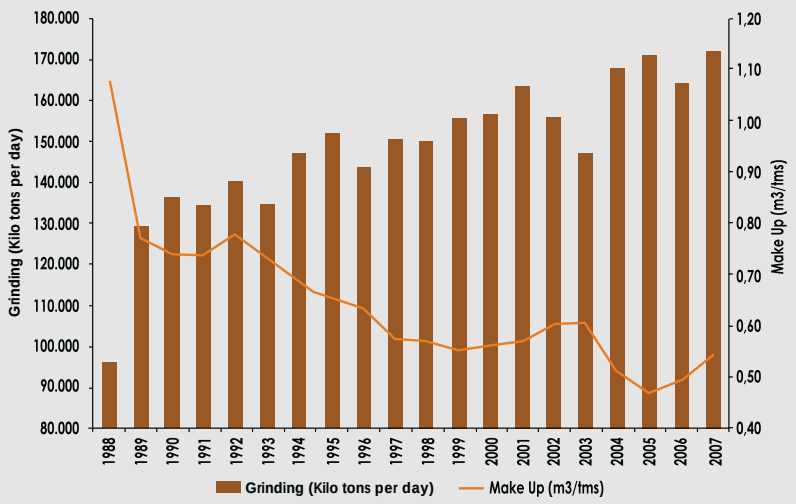
Figure 4.5 Distribution of real water consumption in 2007



Source: *CODELCO Norte*

Management of water resource, supported by investments of US$ 33 million in projects to increase process water recovery has permitted an increase in concentrator treatment levels over recent years without increasing the demand for freshwater.

Figure 4.6 Evolution of the concentrator make up



Source: *CODELCO Norte*

Efficiency increases in water use are obtained from the construction and systematic monitoring of consumption process in each process. In this sense, The CODELCO Norte Division Management model considers the following basic concepts:

- Create a consolidated measurement system that systematizes consumption information in each process.
- From the information gathered, develop process consumption indexes (IP), assessing the quality of the index according to its capacity to detect increases or reductions in consumption.
- Monitor the evolution of every IP. The IP is obtained by dividing consumption by the associated level of activity, which shows the evolution of the IP compared to prior periods and the water consumption difference between the plan and the actual. The fraction that corresponds to a greater or lesser effect on the activity is compared to the plan to determine the real savings from IP management. That which is not explained by less activity would correspond to an increase in efficiency and be explained by the implementation of less intensive processing technologies in water, investments to reduce losses, increased in recirculation in processes and in the tailing dams, among others.
- Assess the effectiveness of actions taken.

CODELCO Norte, located in an area well-known for its shortage of water resources, and in its efforts to increase the availability of this resource, has analyzed alternatives, like investment

Box 1: Consumption Indicators by Process (IP) and the corresponding Units of Measurement

AREA	METRICS	IP	IP 2007
Concentration	Molinera	**m^3/TMS**	0,50 m^3/TMS
Minas			
Chuquicamata	Tons Kilometer	**m^3/MILL TMS**	2.357 m^3/Mill TKS
Sur	Transported		54 m^3/Mill TKS
RT			894 m^3/Mill TKS
Hydro-metallurgy			
Norte	Crushed Mineral	**m^3/TMS**	0.073 m^3/TKS
Sur			0.332 m^3/TKS
Foundry	Total Fusion Concentrate	**m^3/TMS**	4.48 m^3/TKS
Refinery	Total Copper Concentrate	**m^3/TMS**	3.75 m^3/TKS

Source: *CODELCO Norte*

in a desalinizing plant, construction of a concentrator plant where the use of direct sea water or desalinized water does not generate operation problems in the process, among others.

Case No. 4 – BHP Billiton's Spence Mine – limited availability of water resources and supply by third parties

Spence Mine is a site that achieved its first electro-winning cathode (SX-EW) in December 2006. It is located approximately 150 kilometers from Antofagasta and 63 kilometers from Calama.

The site has two water sources. The first is high quality water given the low content of salts and chemical elements, supplied by the Antofagasta-Bolivia Railroad (FCAB). Part of the water from this same source is derived from the water treatment plant where it is chlorinated and stored in a tank to be distributed as drinking water. The water treatment plant produces 5 l/s. Water cost is around 1.9 US$/m3.

The second source is Aguas Antofagasta S.A, with two parallel lines: one for the hydro-metallurgical processes and the other to combat fire. This source represents most of the Spence Mine's total consumption. Its cost is around 1.25 US$/m3.

Besides the external supply sources, Spence Mine is studying the feasibility of constructing a desalinization plant on the coast. The direct use of seawater in the bacterial leaching process is not feasible because it would unfavorably affect reaction kinetics generated therein.

Due to the recent start-up of the operation, it still does not have a platform with enough information to determine the site's water balances. However, it is working on raising enough data to generate a first baseline. In coming months, flow measurement equipment will be acquired, which would complete the necessary instrumentation for raising base information.

Besides the water treatment plant, Spence Mine also has a wastewater treatment plant. The resulting product of this plant is water that complies with norms for use in irrigation. However, this water is used at the mine for watering roads.

At present, the leaching process consumes 160 l/s, and it is estimated it could reach a maximum of 200 l/s. It was observed that the predominant mineral is atacamite, a very heat-resistant rock to chemical reactions and that creates problems with chlorides. The bottoms of the leaching heaps as well as the landfills are covered with geo-membrane that avoids water infiltration, permits recycling and reduces consumption.

Case no. 5 Michilla Mine – Direct use of sea water in the leaching process

The Michilla Mine cathodes plant currently processes copper-oxide minerals from the Lince open-pit mine and sulfurs from the Estefanía underground mine and some sectors of the district that are explored, through leases, by some mining producers. In December 2006, Michilla Mine S.A. had proven and probable mineral reserves of 15.6 million tons with an average of 1.09% total copper.

The mineral from the mines is processed by means of leaching heaps from which solutions rich in copper are obtained and sent to chemical plants for the solvent extraction phases and later electro-winning, where highly pure copper cathodes are produced.

Michilla has been a pioneer in the direct use of seawater in its production processes, such as leaching and agglomeration. Water sources have not been found in the areas surrounding the mine even though several tests have been run.

Michilla is supplied with seawater for all its operations through a water impulsion system to the cathode plant. This supply system has three water transportation phases:

- A first step that captures seawater and sends it to about 10 meters above sea level.
- In the second pumping phase, called main impulsion, the water is filtered with sand and then pumped to a higher site, about 835 meters above sea level.
- The water is then finally lead by gravity to the storage pools located in the cathode plant sector.

The seawater is pumped from the coast, supplying the cathode plant at 6,500 m3/day, at a height of 810 meters and a distance of 15 kilometers.

The seawater is used to suppress dust during the crushing phase, to agglomerate the mineral and to replace losses by impregnation and evaporation in the leaching process. The addition of seawater in the leaching process creates high concentrations of chlorine in the solutions sent to the chemical plant.

In order to maintain acceptable levels of chlorine fromsea water leaching, part of the electrolyte is discarded in the chemical plant and the circuit is refilled with demineralized water. Also in the chemical plant, in the organic washing phases of the solvent extraction process, demineralized water is used to avoid increasing chlorine concentrations.

Demineralized water is obtained through a distillation process using sea water vapor compression for which Michilla has three desalination plants with the capacity to produce 2300 m3/nominal days, one at 1300 m3/dya and two at 500 m3/day.

The demineralized water produced is used to obtain drinking water for the camp and make-up in the solvent extraction and electro-winning processes.

- Distribution of sea -water:
  - Pumped from the coast – 6500 m3/day
  - Fed to desalinizers – 2500 m3/day
  - Crushing-agglomeration-leach process – 3380 m3/day
  - Mine – watering – 620 m3/day
- Demineralized water distribution:
  - SX-EW Plant - 700 m3/day
  - Treatment Plant - 500 m3/day

Case No. 6: Coloso Plant, Escondida Mine (MEL) – Use of desalinized water in the production process

In September 2006, the seawater desalination plant located at Puerto Coloso began operations, with the objective of covering water demands for the sulfur bio leaching plant for the Sulphideleach project. This investment is approved by the project's or Escondida mine's useful life (45 years).

The investment in the desalination plant totaled approximately US$ 200 million, broken down into 50 million dollars for the plant itself and 150 million dollars for the pumping system.

The seawater is captured by underwater pumps and then passes through pipes to a sedimentation system. It then enters the pre-filtered and filtered phase and then enters the Reverse Osmosis Plant.

The plant generates 525 liters/s of desalinized water, which is used in industrial mining processes, specifically in the Los Colorados concentrator plant located 3160 meters above sea level and which processes about 3.7 million tons of mineral per month, with a monthly production of approximately 144,000 tons of copper concentrate. The desalinized water is transported from an aqueduct to the mine, 176 kms away, through four pumping stations

whose energy demands are four times greater than the desalination plant itself.

THE ENVIRONMENTAL ISSUE

The Pacific Ocean has great biodiversity and the captured water contains a great variety of marine flora and fauna.

The sea water capturing pipes are located outside the Coastal Protection Zone and capture water from a depth of 19 meters and 10 meters from the sea bottom, which according to MEL experts considerably reduces environmental impact since it minimizes the extraction of species compared to capturing surface water.

It is worth mentioning that it is of vital importance for the water reaching the reverse osmosis plant to have as little organic matter as possible for optimal performance of the process. Therefore, it is necessary to pre-treat the water before it enters the plant.

PRE-TREATMENT

The captured water feeds a floating decanter called a DAF. Sulfuric acid is added in this phase and thus the se water's pH (8.2) changes to 6.5, when the flocculant works better. Ferrous chloride is used as a flocculant. It decants by trapping the existing organic matter in the water. After that, water with oxygen is added and the oxygen traps the organic matter and the air bubble floats to the surface of the water with the organic matter.

The pre-treated water is pumped to a group of two-layer filters that contain sand and pumice stone and another group of filters that contain sand and anthracite.

Reverse osmosis process

The filtered water is processed by reverse osmosis in groups of 137 fiber pipes, a system called RAC. In this phase, conversion is around 50%. In other words, of all the water that enters the RAC system, 50% will be converted into desalinized water, which will finally go to storage tanks. The water recovered from the Coloso concentrate filter plant joins the water in these storage tanks where the two are mixed and then pumped to the mine.

Coloso thus considers itself as a zero discharge point since no mining effluents are discharged into the sea.

The remaining 50% of water, which corresponds to brine, is transported at high pressure to a turbine that helps generate electricity, with the consequent savings in energy. The brine is then returned to the sea.

The Coloso desalination plantpiping infrastructure undergoes an organic matter cleaning process every 15 days through chlorination at a concentration of 35 ppm. It is important for the filters to backwash for the optimal operation of the plant.

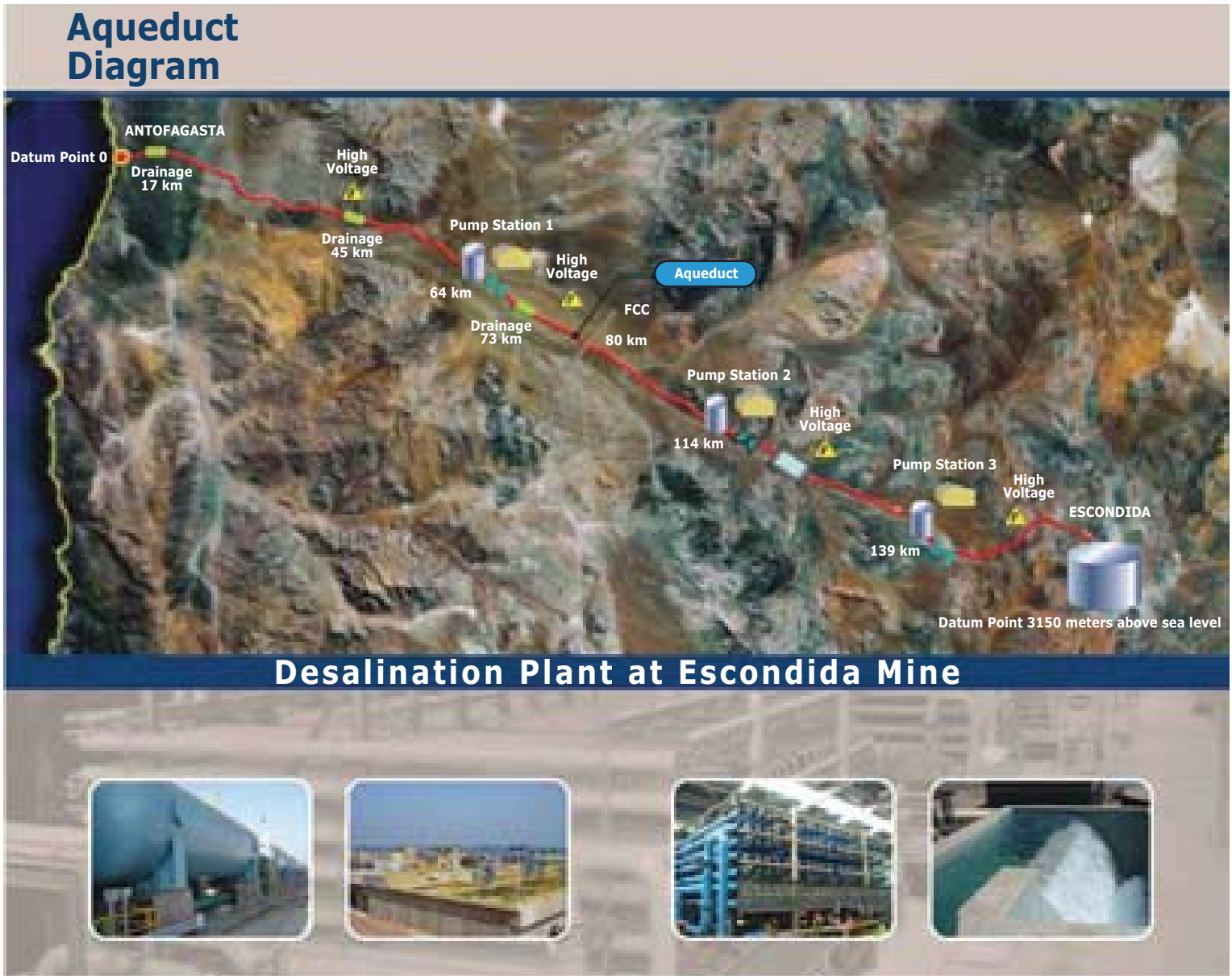
The desalination process consumes 3.4 KWh per m3 of salt water. This energy consumption represents about 80% of desalination cost.

WATER PUMPING SYSTEM

This system consists of 4 pumping stations that on average pump the desalinized water about 170 kms through steel pipes that run along a slope from a datum point of zero to a datum point of 3150 meters above sea level.

Pumping system energy consumption totals 14 KWh/m3, which is considerable energy expense, equivalent to 4 times the consumption to desalinize the water.

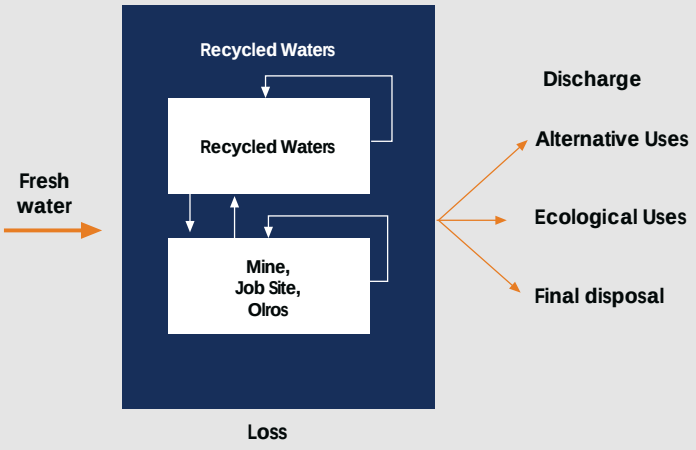
Figure 4.8 Diagram of the Escondida Mina Coloso Plant Aqueduct



4.4 EFFICIENCY INDICATORS

As a consequence of the aforementioned visits to mines, the indispensable need arises to measure water consumption in each of the processes and to develop efficiency indicators that permit monitoring the evolution of consumption and the results of actions adopted to improve efficiency.

Figure 4.9 Water balancing



Source: *Document: "Efficient Use of Water in the Mining Industry and Good Practices", APL 2002*

Concepts such as total water consumption, total freshwater consumption and recirculation rates can serve as efficiency indicators since they help to clearly quantify water use at the mine, and are thus a quantitative and comparable tool that permits evaluating performance compared to other mines or in the face of technological innovations or management within the same company.

Considering the difficulty in precisely measuring all recirculated water in the different phases and processes, an approximation method to obtain a Recirculation Rate (%) is:

((Total Water – Freshwater)/Total Water)*100

Notwithstanding the ability some companies have to measure all process flows and to obtain the real value.

Likewise, other water consumption or quality indicators can be defined depending on the processes you want to control and applicable norms. Effective management of water resources at the company requires indicators to be officially established and for goals to be agreed upon with the team responsible, that means challenges in optimizing resource uses. One of the ways to establish these goals is to benchmark companies with similar characteristics and processes.

Given the need to develop mining activity in a sustainable manner, besides efficiency indicators, in the future it is advisable for mining companies to create and set other sustainability indexes, including water resource management, which aims at measuring and assessing the social, economic and environmental interactions and repercussions of efficient water use and thus establish mutual agreements regarding sustainable development principles.

At present, several mining companies publicly report their water consumption data as per GRI guidelines and instructions.[13]

4.4.1 Sustainability reports

Over the past 5 years in Chile, mining companies, members of the International Council on Mining and Metals (ICMM)[14], have incorporated the practice of establishing sustainability reports based on Sustainability Reporting Guidelines of the Global Reporting Initiative (GRI).

[13] *Global Reporting Initiative. www.globalreporting.org*

[14] *Alcoa, Anglo American, AngloGold Ashanti, BHP Billiton, Falconbridge Limited, Freeport-McMoRan Copper & Gold Inc, Lonmin, Mitsubishi Materials Corporation, Newmont Mining Corporation, Nippon Mining and Metals, Placer Dome Inc., Rio Tinto, SumitomoMetal Mining, Umicore, ZinifexLimited, Camara Minera de México, Chamber of Mines of South Africa, Consejo Minero de Chile, Eurometaux, Euromines, Federation of Indian Mineral Industries, IndonesianMiningAssociation, Instituto Brasileiro de Mineraçao, International Aluminium Institute, International Copper Association (ICA), International Lead Zinc Research Organization (ILZRO), International Wrought Copper Council, International Zinc Association, Japan Mining Industry Association, Minerals Council of Australia, Mining Association of Canada (MAC), Mining Industries Associations of Southern Africa,Nickel Institute, Prospectors and Developers Association of Canada, Sociedad Nacional de Minera Petróleo yEnergía (SNMPE), Sociedad Nacionalde Minería (SONAMI), The Cobalt Development Institute, World Coal Institute.*

Sustainability reports are documents based on verifiable records, validated by the administration that generates them, whose creation is voluntary by those companies that want to transparently and systematically make their environmental, social and economic performance known.

GRI Guidelines were created to care for the quality, rigor and utility of sustainability reports. The principles of these Guidelines are concepts that describe a report's characteristics, the information it must contain and how to establish it.

These GRI Guidelines are accompanied by specific Supplements[15] by the industrial sector. In relation to the mining sector, in a joint effort by ICMM and GRI, a specific Supplement was created for the Mining and Metals sector; a document issued in February 2005.

It is worth pointing out that GRI indicators[16] are internationally validated for creating sustainability reports, permitting a standardization of information and making it comparable between companies as well as between different periods of time.

Raw materials, energy, water, biodiversity, emissions-dumping and residues, providers, products-services, compliance and transportation are among the GRI Environmental Performance Indicators considered in the Guidelines.

With regard to water resource management, Table 4.1 shows the Environmental Performance Indicators established in the GRI Supplement for Mining and Metals related to water management.

The core indicators are those of greater interest for most organizations and more importance for interested parties. In turn, additional indicators are those that represent a highlighted practice in measuring economic, environmental and social aspects. The offer information of interest to certain interested parties and are especially important for the organization.

It is deemed advisable to include such information in the basic indicator category in the future.

Table 4.1 Environmental performance indicators related to water resources`

Environmental Performance Indicators	Core Indicators	Indicators Additional
Water	EN5. Total water consumption	**EN20.** Water sources and ecosystems/habitat significantly affected by water consumption. It is necessary to include the Ramsar List wetlands and the general contribution to environmental tendencies. **EN21.** Annual extraction of underground and surface waters as a percentage of the annual renewable quantity of water available at the sources. Must be broken down by region. **EN22.** Total calculation of water recycling and reutilization. Residual water and other types of water used must be included (such as water for cooling)
Emissions, spillage and residues	**EN12.** Spillage into important water, by type **EN13.** Spills involving chemical substances, oils and fuels of importance. Importance refers to the size of the spill and the impact caused on the Environment.	

Source: *GRI Supplement for the Mining and Metals Sector. Pilot version 1.0, Global Reporting Initiative (GRI), February 2005.*

[15] *These Sectorial Supplements function as a complement for GRI Indicators andoffer interpretations and assistance for developing reports on the sector and include specific performance indicators for the sector. The idea behind the Supplements is to use them together with the GRI norms, and not in place of them.*
[16] *Qualitative and quantitative measure of operations.*

The Sustainability Reports offered by ICMM mining companies are completely tied to the GRI Supplement for the Mining and Metals Sector and are audited by external entities prior to publication. Information can be found in them regarding water consumption, recirculation rates, discharges, etc.

4.5 ACTIONS TOWARD EFFICIENT MANAGEMENT OF WATER RESOURCES

4.5.1 Supervision

Supervision is a fundamental point in water resource management and should be carried out from the exploratory phase to the end. It is indispensable to continuously control operations in order to assess process efficiency, plan necessary activities for optimization and keep authorities and interested parties in general informed of the water resource management system behavior and its efficient use.

Some activities that should be considered in water resource supervision plans are:

- Supervision of supply sources, wells, basins, etc. Photo and video records of their state throughout useful life, measurement and record of extracted volumes and qualities, supervision of associated ecosystems, etc.
- Constant supervision of basins and sub-basins, wells, waterwheels and slopes to control availability.
- Supervision at the pool level regarding solutions to avoid spills, infiltrations and water losses.
- Supervision of the aquifer from which the resource is extracted by controlling underground water levels at observation wells, sampling underground waters and modeling aquifer operations.
- Supervision of inputs and outputs at treatment plants, for internal use as well as final disposal.
- Supervision of seismic stability at tailing dams, gravel bed, etc.
- Supervision of underground water sources to control the filtering of solutions from different accumulations of material (tailing deposits, leaching heaps, landfills, etc.).

The measurements made, with the water system baseline, are of great use when designing an appropriate closing plan. Some of the topics to control at mine closure include water balancing (incorporating normal and flood volumes), projected flooding, dam stability and long-term risk assessment.

In general, it is worth noting that the practices during process abandonment refer to preventative measures in the face of a possible negative effect on remaining water at the site as soon as operations finish.

4.5.2 Management of sources

In the area where most mining sites are located in Chile, the shortage of water is a limiting factor for regional development and thus the proper management of resource supply sources, whether surface or underground, is just as significant as reductions in consumption.

In the north, due to the predominant weather and hydrological conditions, water is mainly obtained from underground sources, taking advantage of storage capacity in closed and sandy basins in aquifers. Towards the south, surface run-off and reservoirs play a leading role in mine supply.

The use of surface waters in the north can have an impact on local flora and fauna, which like the water, is characterized by its shortage and generally represents

unique and sensitive expressions. Likewise, the use of underground waters in a basin17 can have an effect on its equilibrium whose magnitude and duration will depend on the flows, the extraction period and the characteristics of the aquifer, among others.

With regard to the use of diverse water sources, it is possible to indicate that water stability from underground sources is much greater than surface run-off since the latter depends on hydrological year characteristics and conflicts may arise with other consumers in the event of prolonged droughts. The effect storage can have on the aquifer (which will depend on the geological configuration) confers greater supply security for the mining site.

The following are among the best practices related to water source management:

- Given the surface run-off water source is vulnerable; the sites that use this type of source must have backup sources like wells and/or inter annual reservoirs.
- Keep in mind that the underground water has a limited reload capacity and must be permanently monitored to ensure that the established extraction rates are maintained, as are the appropriate aquifer levels and quality.
- Seek new sources of freshwater, like seawater, underground water, possible water resources, etc., privileging those sources that have less impact.
- Permanently control the state of ecosystems that supply the same sources. Responsible management conserves the habitat and the species living therein.
- Determine the natural markers that indicate the degree ecosystems are affected
- Use hydro geological models that permit projecting impacts and monitoring and developing biochemical research needed to identify and implement mitigation measures that permit using the resource and the natural or assisted continuity of the environments.
- Administer and appropriately maintain water extraction systems from underground wells, implementing sensors to monitor suctioned volumes and control the quantity of water from the wells in question, depending on real supply needs.
- Work with authorities and the community to control and inspect established water use rights.

All good practices mentioned above, with regard to source management, are used to a lesser or greater degree by mining companies, especially in the north of the country.

4.5.3 Extraction, Transportation, Storage and Distribution

The objective of this phase is to effectively administer the mine's water resources to satisfy the needs of all internal consumers in terms of required quantities and quality, and in a timely manner.

Conducting the water resources to the mining sites depends on the type of extraction source. Thus, the mining companies supply themselves with water from the site's own piping, whether from the surface (salt flats, slopes, rivers), underground (wells) or sea sources.

The water resource to be used at the site is arranged in pools or storage tanks, which contain a specific capacity and a specific minimum level with the objective of avoiding any emergency situation related to water shortage.

The water is distributed through pumps, valves and piping at the mine. The most significant losses in this phase are from evaporation due to uncovered surfaces and leaks associated with breakage or improper maintenance of such mechanisms.

[17] *The basin is the area drained by a river and its different affluents. Its limits are given by the high summit line of the mountains that divide the waters (National Basin Strategy).*

The following are among the best practices related to extraction, transportation, storage and distribution of the water resource:

- Correctly assess and plan associated installations, considering the capacity and potential for breakage, the probability and frequency of flows that go against its design and the impact of an emergency on the water resource, both inside and outside the mine.
- Carry out proper preventive maintenance for the installations.
- Install mechanisms for the timely detection of leaks in process water lines.
- Monitor and constantly record the level, quality and volume of distributed flows.
- Always seek a reduction in drinking water consumption, eliminating losses in the fitting system in restrooms and encouraging efficient use in household consumption, etc.

4.5.4 Reduction of consumption in operations

One of the first aspects to be considered when designing a Water Resource Management System is the reduction in freshwater consumption, which implies a reduction in residual water volume and the respective treatment costs.

In order to reduce freshwater consumption, it has been determined that the following steps should be considered:

- Analysis of historical consumption records and its relation to production levels to determine the plant's real water requirements.
- Analysis of residual water discharges to determine water quantity and quality lost in the process and is not part of the final product.
- Analysis and assessment of installation and current work methodologies to study possible improvements, changes in procedures, equipment, etc.
- Check water losses in the different lines. Correct detected problems and conduct a feasibility study regarding the implementation of possible improvements.
- Analysis of the possible water recirculation circuits, considering the flows that stem from different operations and unitary processes that could be used in the same or another step according to the conditions required for each.

The most significant water consumption at Mediana and Gran Minería del Cobre are in the following mineral-metallurgical process steps:

- Concentrator Plants:
- Hydro-metallurgical Plants; and
- Foundries / Refineries

However, there are also other activities whose accumulated consumption can be as significant as the above and deserve to be considered in water resource management plans.

Man, as a living being, requires an significant quantity of water to satisfy his needs. These include water for drinking, bathing, washing of food and kitchen utensils, washing of clothes and for personal hygiene, etc. As can be observed, most of the water used by man is not consumed, but rather used and then disposed of with a different quality than its original.

Water is also required in other activities within a company, mainly road maintenance and watering, camps and offices, watering green areas and always having water available in reserve for fighting fires.

4.5.5 General practices

Water can be recovered at different moments, including the thickening and filtering of tailings; clear waters of the tailing tanks;

thickening and filtering of concentrates; water recirculated in hydro-metallurgical processes; well-to-wheels; washing equipment and installations, etc.

The cooling water for several pieces of equipment, from acid plants, laboratories and thermoelectric plants can also be recirculated, treated waters in the waste water and RILES plants, etc.

In general, mining sites can opt for one or more of the following mechanisms for the efficient use of the resource at the operational level:

- At the concentrator plant:
  - Install high density thickeners for concentrate binders.
  - Install pressure filters at the concentrator plant.
  - Privilege water transportation for the concentrate.

- At the tailing dams (recirculation):
  - Improve design to obtain a higher level of water recovery since the biggest losses in the dam are from evaporation, infiltration and retention.
  - Cover the bottom and wall of the dam with waterproof material such as gravel, clay or spent ore from leaching.
  - Accumulate fine material at the bottom of the dam to waterproof it and avoid infiltration.
  - Install a basin drain in the tailing dams to reduce losses by filtration.
  - Install tailing thickeners to increase concentration in tailing pulp weight to be transported.
  - Filter tailings.

- In the leaching heaps:
  - Install an irrigation system immediately below the surface to avoid evaporation.
  - Ensure the seismic stability of the heaps.
  - Control drainage at the leaching heaps.
  - Construct basal drains, intermediate drains and drainage pipes.

Other general practices to increase water use efficiency are:

- Cover the process solution pools with floating covers to avoid evaporation.
- Automate the pump and mill rooms.
- Install leak detection systems.
- Load the tanks, tank trucks and installations using the proper procedures to avoid spills.
- Use valves to interrupt supply aimed at avoiding water losses in the case of emergencies.
- Optimize road watering. Watering must cover at least half of the road's width and should be done during periods of low evaporation and high vehicle traffic.

Asphalt surfaces can also be constructed or the roads can be chemically stabilized.

- Optimize the watering of green areas. Drip watering is one of the alternatives involving the least consumption.

Plants that require less water can also be used.

- Encourage savings in household consumption.
- Implement a water taxation and consumption information policy. This activity requires:

  - Flow gauges for the main consumers.
  - Measurement of water consumption to identify current needs of the different users and periodically inform the results.
  - Study existing information to establish a process diagram according to water quantity and quality requirements (distribution flow and water consumption diagram).
  - Monitor and record consumption by area and estimate losses.
  - Establish "fines" for excess consumption and "awards" for achievements giving positive feedback for resource savings.

4.5.6 Alternative Uses and Availability of Surpluses

Not all discharged water by the different processes can be reinserted in the production circuit. Due to distance, geographic characteristics or the process itself, the sites often prefer an alternative use for the surplus, whether for green areas, returning the water to natural beds so they can be used by third parties or disposing of it directly into the environment.

In every case, the effluents must undergo strict assessment and periodic control, ensuring the quality does not have a negative impact on the environment in which it will be discharged and that it can effectively be used where designated.

The best practices consider technical, economic and social assessments to determine the possibility of supplying third parties an appropriate quantity and quality of the resource. When this is not possible, the maintenance of green areas becomes the next alternative.

Below are some examples of different ways to use recovered water:

- Water recovered from tailings is reused as process water, for reserve pools and storage tanks for use at industrial sites, mainly the concentrator plant.
- The water recovered from tailing dam drains can also be sent for tailing classification at the wall for dilution.
- The water recovered from thickening and filtering of concentrates is used in pools of recovered waters and processes, watering green areas and the concentrator plant.
- Waste water as well as treated RILES can be recirculated in to the process for industrial use at the concentrator plant and for watering roads and green areas.

4.5.7 Technological Alternatives for Water Resource Management

The best practices in water resource management involve the implementation of additional technologies and greater control of processes, a change in operational culture and a real commitment on the part of all involved sectors.

Table 4.2 and Table 4.3 list a series of ideas or proposals, some more feasible than others, with the objective of instilling in water users the challenge to innovate in terms of efficient use of the resource, encouraging research and development of new technological alternatives and water management. It is worth recalling that the resource must not only be used efficiently but new applications must be sought to increase availability.

Table 4.2 Technologies for optimizing water resource consumption

TECHNOLOGY	GENERAL DESCRIPTION
Automatic control of the thickening system	Optimize water recovery through an intelligent controller, increasing tailing density and thus reducing concentrator water consumption.
Permanent supervision of consumption	Control water consumption by operational area, also carrying out internal audits and charging fines for excess consumption.
Recirculation of waters from distant dams	Recirculate clear waters from tailing dams and dumps to the mine.
Bioremediation treatment of contaminated effluents	Use bio hydro-metallurgical treatments to precipitate contaminants found in effluents of hydro-metallurgical processes in stable salts, using filters and presses to recover water in these processes.
Leaching system drainage control	Use proper software and materials to plan leaching system drainage reducing solution losses by infiltration, leaks or the formation of saturated mineral pockets.
Filtering of tailings	Use band filters to dry the tailings, increasing concentration in weight up to 75% and then sending them to the deposit by conveyor belt or truck.
Optimization of mine consumables	Use technologies and procedures that permit minimizing water use at mining sites for loading ore, watering roads and drilling.
Extreme thickening	Use higher thickeners to produce hyper concentrated tailing discharges, recovering greater quantities of water and using the inclined dam method for deposit.
Dry grinding and pneumatic centrifuge	Grind the mineral until the optimal release size so they can be separated by dry classification before flotation.
Blown and extracted from the remaining aquifer in the tailing dam	Extract the water in the saturated zone of the tailing dams in operation or abandoned, through drainage and blow wells.
Use of drainage pipes	Use a system analogous to those used in water reservoirs and farmlands to capture water from the tailing dams.

Tabla 4.3 Technologies and potential for increasing available water resources

TECHNOLOGY	GENERAL DESCRIPTION
Artificial Precipitation	Optimize water recovery through an intelligent controller, Encourage rains and increase the water volume discharged from clouds by chemically blasting them.
Surface reservoirs for floods	Construct water reservoirs for using possible consumable water resources caused by hydrological flooding.
Underground reservoirs for flooding	Use appropriate geological zones for underground accumulation of water from hydrological floods.
Pumping, desalination of sea water	Use sea water directly or desalinized water as water sources, depending on energy costs and availability.
Purchase water resources from neighboring countries	Purchase and bring water resources from neighboring countries like Bolivia and Argentina.
Unit's channel	Construct a channel from the south to the north of the country to efficiently administer the water resource at the national level.
Transregional aqueduct	Re-gather surplus water from large reservoirs in the central zone and transport it over pressurized pipes to the mining centers.
Capturing from fog	Re-gather water from fog with high humidity from a specific surface.
Exploration of water resources	Locate fossil resources for later exploration.

Source: *"Efficient Use of Water in the Mining Industry and Good Practices", 2002*

Since implementation and operation costs vary depending on required technology and mine characteristics, the applicability of each of the indicated options must be studied by the respective company, so the adoption of new practices could be in a real contribution towards the reduction of freshwater consumption at the mine and not in the implementation of measures that contribute in a not significant way to the system in comparison to the costs involved.

Below some of the best practices proposed are described in detail, divided into 2 large groups:

- Technologies for optimizing water resource consumption, and
- Technologies for increasing available water resources

4.5.7.1 TECHNOLOGIES FOR OPTIMIZING WATER RESOURCE CONSUMPTION

- ***Automatic thickening control***

The thickening of pulp (ground mineral, tailing, concentrate) can be completely automated through proper instrumentation of all flows, monitoring of inter phase height (pulp-water), torque, dragging, as well as the addition of flocculant, all connected to an intelligent controller that permanently optimizes the recovery of water through command of discharge systems, flocculant dosage and dragging spin position and speed.

This automatic control, which would be similar to other mining processes (for example, semi-autogenous grinding), permits a 2% to 3% increase in discharge concentration compared to current manual controls. The automatic thickening scheme can be incorporated into conventional systems and already improved systems, using the same existing thickeners.

The main advantages of the system are the low investment and operation costs, and the fact the technology is broadly known in the country. However, it requires constant and complex instrumental maintenance and a change in work culture.

- ***Recirculación de aguas desde tranques lejanos***

This concerns the recirculation of clear waters that come to the surface of distant tailing dams with significant differences in datum points between the dam and the concentrator. If the recirculation of surplus waters to the concentrator is evaluated, the savings in freshwater consumption can vary between 30% and 50% of the supply to the site.

Among other advantages, the recirculation of water from the dam improves the concentration operation due to the lime and remaining reagents in recirculated water. Furthermore, it improves dam stability by reducing clear water lagoon volumes and avoiding the purchase of land and costs associated with forest / farm management. The disadvantages are found in the degree of complexity and investment cost for the system, which will depend on the distance from the deposit and the geographic difficulties encountered.

It is also necessary to consider that transportation of clear waters from the tailing dams requires some environmental licenses that must be obtained from the Environmental Impact Assessment System.

- ***Permanent supervision of consumption***

Control of water at a complex mining site can be continuously monitored using flow meters and integrators for each operation area or center, defining water consumption goals, whether by period of time or unit of consumption, in order to charge internal fines for punctual excess consumption (leaks, excess washing, infiltration or evaporation).

Monitoring promotes the reasonable use of the resource and helps in creating a change in operational culture, leading to considerable water savings of up to 2% at complex mining sites.
This alternative uses widely known technology (flow meters in the different mine site sections), has low operational cost and provides the public with the perception of optimal management of resources, improving the company's image in the community. However, it requires significant investments in instrumentation and control, and a real change in operational culture.

According to freshwater consumption at each company and the possibility to optimize it, this alternative can be more or less convincing. However, given the magnitude of associated costs and the volume of water saved, it is only applicable to complex and old mining sites, within a Continuous Improvement Plan.

- ***Filtrado de relaves***

Thickened tailings in reservoirs still have high water content, which can be recovered before being sent to the dam by means of partial or total filtering. In the case of total filtering of tailings, unit consumption of freshwater can be reduced to around 0.25 m3/

treated ton. For this, it is necessary to invest in filters and dry tailing management and preparation (conveyor belts / trucks).

This alternative is very attractive due to the amount of water that can be recovered, considering the concentrations when comparing conventional systems and those with a band filter system. However, the technology's high costs, due to recent use at an industrial level, make it not very profitable today, although perspectives improve over the mid-term, with the natural tendency of a drop in investment values for this type of equipment.

Another important factor is related to tailing dumps created through this alternative, because there are some problems regarding stability and erosion. Besides that, it is necessary to consider possible problems with freezing that may impede application in the mountains.

- ***Deep Thickening***

This consumption optimization technology involves the construction of higher than usual thickeners, 15 m to 20 m, which permit discharging high density pulp (65 to 75% in tailings), making it possible to increase the concentration in weight of the tailing by 8% compared to conventional high efficiency thickeners (15% of water savings). Hyper-concentrated tailing discharges should be driven by positive displacement pumps and tailing management in the dams should use an inclined deposit method.

The alternative is applicable to all types of tailings and the inclined deposit method optimizes material arrangement in the dam; however, there are no known industrial applications of this arrangement in seismic countries.

Deep thickening of tailings is a daring technology because it requires modification of the thickeners (which will be taller), of the tailing transportation system and of their final arrangement, which involves high operation and investment costs, as well as risks due to the simultaneous development of 3 very new technologies.

Deep thickening technology has low applicability for mining companies in operation due to the large number of modifications that must be implemented. In new mining projects or considerable expansions, it could be useful to optimize water consumption; however, it is necessary to get the explicit approval of SERNAGEOMIN for constructing inclined dams.

4.5.7.2 TECHNOLOGIES FOR INCREASING AVAILABLE WATER RESOURCES

When the sites can no longer optimize water consumption, the new requirements that emerge from an expansion, a reduction in the amount of water available at the source or the need to share existing resources with other consumers, oblige the company to think of new alternatives for additional resources, including the use of artificial and underground reservoirs for storing new resources generated from the natural swelling of rivers or through artificial precipitation techniques.

- ***Artificial Precipitation***

This alternative involves the chemical blasting of clouds to stimulate rain and/or increase rain volume.

In northern Chile, this would be feasible during the Bolivian winter and in areas where rainwater can be stored efficiently (salt mines, sandy areas, etc.). However, it would be necessary to undertake a climate study to determine the degree of reliability of this method in the area of interest in question. Furthermore, it would require obtaining DGA authorization for mining companies that use this technique to take advantage of newly generated water resources.

- ***Surface reservoirs for floods***

In the north and central areas of the country, waters from the swelling of main rivers are not used, and the waters from these swellings are lost to the sea. Likewise, possible utilization rights

(for a surplus of about 15%) are available or have a very low transaction cost.

The mining companies could acquire these resources to construct annual reservoirs from the Elqui to the Maipo River Valleys, independently or in association with irrigation communities.

Construction of mid to large reservoirs (50 - 100 Mm3), similar to Santa Juana in Valle del Huasco, would make it possible to carry out large mining projects or mixed projects, where the increase in water availability is not only for the mining firm, but also for agriculture, tourism or simply drinking water.

The big disadvantage of this alternative involves the high investment costs required for constructing an annual reservoir as well as the associated piping that would take the resource to the consumption centers. However, the operational cost for these reservoirs, once constructed, is very low. The hydrological variability also represents an uncertain factor that must be considered since there is no certainty in having the resource on a permanent basis.

Underground reservoirs for swelling

In the north of the country, rain during the Bolivian winter produces swellings that run-off until reaching the sea without being used. Water users could identify some geological areas that can be employed as underground reservoirs and direct some of this surplus water to natural underground trays, whether watertight or semi-watertight, which permit reusing the water over a prolonged period.

This type of project would permit the replenishment of regional resources, increasing the aquifer extraction rate from Norte Grande and mitigating the disastrous effects of swellings in the northern river beds. However, the greatest risk in taking advantage of swellings is their likely behavior, which impedes projecting each year's weather conditions with any certainty. It is also necessary to see how suspended solids are managed to avoid the deterioration of existing drainage systems.

- **Pumping sea water**

This option involves capturing seawater, which then undergoes a de-oxygenation process in decanting pools (which eliminate water life). The clear water is then captured and transported from sea level to mining centers over ducts protected against corrosive attack.

The nature of seawater makes it necessary to use special equipment and materials to avoid chemical corrosion or incrustation of organic elements. It is also necessary to consider that 10% or 20% of the flow must be desalinized for unit operations in which is not permitted to have chlorine and salt content.

The problems involved with this new water resources include the high level of investment and the possible early aging of the system since the salts present in the water can affect mining equipment and increase lime and ball consumption. Operational costs are also significant.

It is worth considering that the direct use of seawater can be applied at sites that have the necessary infrastructure to resist the salinity in the water and in those with mineral containing certain required geological characteristics. However, at old sites, it would be necessary to assess technical (depending on the mineral's characteristics) and economic feasibility (replacing old equipment with modern equipment, unaffected by salt corrosion). In Chile, the Michilla Mine is a pioneer in the direct use of salt water in its production processes, an experience that will be repeated in the Esperanza Project, which like Michilla, also belongs to Antofagasta Minerals and whose processes and installations will be designed to operate with sea water.

- **Pumping of desalinized water**

In simple terms, there are three procedures for desalinizing sea water:

- Desalination through membrane processes: electrodialysis and reverse osmosis
- Desalination by freezing
- Desalination by distillation

The desalination process by distillation is a simple and cheap process that consists of heating the seawater using sunshine in a greenhouse. Its main limitation is that it is a low-yield procedure that would not solve mining company or large urban center water requirements. However, it is an attractive alternative for rural areas with scarce water resources and for developing the cultivation of species that can adapt to desert areas.

Desalination by freezing consists of partially freezing sea water, separating the ice and then melting it. Less energy is needed than with distillation. However, its main disadvantage lies in the difficulty eliminating the brine that tends to adhere to freshwater crystals.

The reverse osmosis technique used by Escondida Mine to desalinize seawater is more recent than electrodialysis. It consists of the spontaneous transportation of a dissolvent from one diluted solution to another more concentrated one by means of a semi-permeable membrane.

Reverse osmosis uses less energy in relation to electrodialysis, but it requires high investment.

Escondida Mine invested nearly 160 million dollars to construct a seawater desalination plant with an extraction capacity of 525 l/s. This sum includes the construction of the plant and pumping and piping infrastructure.

Different mining companies are assessing the construction of sea water desalination plants. Some of the initiatives mining firms are working on include:

- Escondida Mine is studying the feasibility of constructing a second reverse osmosis desalination plant.
- White Mountain Titanium, a company seeking financing for its titanium project in Region III, has planned to invest about US$ 7 million in a desalination plant that avoids conflicts involving water rights.

Desalination is an interesting alternative for mining companies facing water shortages and deserves further exploration. However, there is an important difficulty associated with the need to transport the desalinized water to the mining site, which is generally high above sea level. Besides requiring investments in infrastructure, this transportation demands high energy consumption, which in a restricted energy availability scenario leads to significant cost increases.

CHAPTER 5:

CONCLUSIONS

5 CONCLUSIONS

In recent years, the limited availability of water resources in northern Chile has become one of the important topics in the country's agenda due to the importance of the resource for every economic activity, care for the environment and quality of life in the communities.

Although it is certain that the public and private sectors have assumed an active role in tackling the fundamental aspects involved in the water shortage problem in the north, the urgency and complexity of the topic demands a broad-based view, a proactive attitude and greater coordination of efforts to define the actions and control milestones that guarantee economic and sustainable development.

The mining activity is carried out in specific conditions since it must operate where the deposits are located, in changing global economic scenarios and with environmental norms that demand high standard performances with the least possible impact on neighboring areas.

In Chile, an important part of these deposits are located in uninhabited areas but with difficulties such as high altitude and extreme temperature conditions. During the exploration, project development and operation phases, water becomes a critical and even strategic component.

The mining industry therefore attributes fundamental importance to it, where the reasonable and efficient use of water is key to the business' future. Thus, in face of a situation involving limited availability and growing demand for the resource, competing with other sectors of the economy, efforts to increase efficiency levels through technological solutions, new sources and commitment by each of the levels at the companies to implement management models geared towards the efficient use of resources, such as water, is a permanent and synergistic concern in the maximization of company surpluses over the long term.

In line with the recommendations in "Efficient Use of Water in the Mining Industry and Good Practices" of 2002, available numbers show that on an average, unit consumption of water per ton of processed ore at a copper mine has fallen, minimizing system losses and making the technologies implemented in the processes more efficient.

Indeed, on an average, over the past 5 years freshwater consumption in the concentration process has fallen from 1.10 m3/tms to 0.79 m3/tms and hydro-metallurgical mineral processing has also fallen from 0.30 m3/tms to 0.13m3/tms.

On the other hand, recirculation rates in processes have increased and the efforts to reduce effluent discharges into the environment, which has resulted in investments in treatment plants that return water resources to the quality demanded by norms.

Nevertheless, based on the information gathered, COCHILCO estimates it is still possible to make some improvements in water use efficiency in the mining industry. The progress achieved since 2002 is both objective and convincing. However, the satisfaction of a job well done should be but an incentive to continue advancing towards continuous improvement.

It is expected that the creation of this document, requested by the National Public-Private Board for Water Resource Management, will contribute information to encourage decision making by mining companies with regard to increasing efficient water management.

CHAPTER 6:

REFERENCES

6 REFERENCES

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CHAPTER 7:

GLOSSARY

7 TECHNICAL GLOSSARY

Aquifer: Underground water reservoir. Permeable formation capable of storing and sending usable quantities of water.

Artificial feeding (Artificial loading): Increase in the natural underground water feeding of underground water aquifers or reservoirs supplying water to wells, flooding or changing natural conditions.

Artificial rain: See also Cloud seeding. Precipitation of water particles in liquid or solid form, attributable to human action on clouds, as in cloud seeding.

Basin management: Controlled use of a basin according to predetermined objectives.

Casting: Process that permits separating the copper concentrate from other ores and impurities by applying high temperatures in reverberating furnaces and converters.

Clean production: Concept that internalizes the environmental variable as part of a preventive business management strategy applied to products, processes and work organizations, emphasizing greater efficiency in material and energy resource use in order to simultaneously increase productivity and competitweness.

Cloud seeding: See also artificial rain. Introduction of particles of an appropriate material (for example, carbon dioxide, silver iodide) in a cloud with the intention of modifying its structure and causing dissipation or precipitation.

Concentration: This is the copper production process phase that follows extraction of the sulfurated ore. In this phase, crushing, grinding and flotation are carried out from which the copper concentrate is obtained.

Concentrator (Concentrator plant): mineral processing or treatment plant where the concentration of copper ore particles or other element is produced, resulting in a concentrate on one side and a tailing or binder on the other.

Contaminant: 1) Substance that produces the deterioration of water's fitness for a specific use. 2) This includes all solid, liquid or gaseous elements that have been introduced by means of human activities and that affect the environment.

Contamination: Direct or indirect alteration in biological, physical or chemical properties of any part of the environment that may create a harmful or potentially harmful effect for survival, health or well-being of any living species. Contamination can have a cultural definition that does not necessarily imply potential risk for survival.

Copper concentrate: Thick pulp obtained from the flotation phase in which a mix of copper sulfate, iron and a series of salts from other metals is found. The proportion depends on the mine's mineralogy.

Crushed: Process through which the size of mineral rocks is reduced by grinding them in equipment called crushers.

Density: Ration between the mass of any volume of a substance and the mass of an equal volume of water at 4°C.

Desalination: Any process through which the water's salt content is reduced enough to make it fit from human, animal, industrial or other specific use.

Drinking water: Water fit for human consumption without harmful effects to health. It must meet physical, chemical and bacteriological requirements and norms that ensure innocuousness and fitness for consumption. NCh409. Of. 1984 establishes the requirements for drinking water and its sampling.

Ecosystem: Ecological surroundings in which all of the populations of a community are in interaction with each other and with the environment. Balance equation: See also Water balance. Equation that expresses the balance between inputs, outputs and changes in the storage of any mass of water over a period of time.

Effluent: Water or residual water that flows out of a reservoir or treatment plant. It also refers to the discharge of liquid residues, generally contaminants, from an industry or other site.

Electrorefining: The electrometallurgical process that alternately has a blister copper anode and an initial pure copper cathode in a solution of sulfuric acid. A continuous low intensity electric current is applied to this installation that dissolves the anode copper and deposits it on the initial cathode.

Electrowinning (EW): Electrometallurgical process that alternately has an anode and a cathode in a previously concentrated electrolytic solution. The process is carried out by applying a low intensity electric current, which causes the Cu cations to be attracted to a cathode, where they are deposited in metallic form.

Estimation of water resources: Determination of sources, extension, reliability and quality of water resources for use and control.

Evaporation (of water): Emission of water vapor from a free surface ata temperature below boiling point.

Evapotranspiration: Quantity of water transferred from the ground to the atmosphere by vegetal evaporation and transpiration.

Exploration of water resources: Development, distribution and planned use of water resources.

Flotation: Process that permits concentrating the copper from the mineralized material pulp that comes from the grinding process. Oxygen bubbles from the bottom of the flotation cells so the copper particles present in the pulp adhere to the air bubbles and rise with them.

Freshwater: Natural water with a low concentration of salts, or generally considered appropriate, after treatment, for producing drinking water.

Gauging section: Without. Measuring section. See also Gauging station. Transversal section of an open channel where speed and depth measurements are performed.

Gauging station: See also Gauging section. Place in the water course where regular measurements are taken of level and volume.

Grinding: Process through which the size of the mineralized material that comes from the crushing plant is reduced by using equipment called grinders. Water needs: See also Water demand. Amount of water needed to guarantee known or estimated demands for a given period.

Hydrographic basin: Its limits are given by high summit lines of the mountains that divide the waters.

Hydrological cycle: Water cycle. Succession of phases through which water passes in its movement from the atmosphere to earth and its return to the same: evaporation of water from the ground, sea and continental waters, condensation of water in form of clouds, rain, accumulation on the ground or in water masses and re-evaporation.

Hydro-metallurgy: Branch of metallurgy where the element of interest is extracted from a solution that contains it. In copper metallurgy, this methodology is applied to oxide ores by means of heap or pan leaching.

Infiltration: Water flow that penetrates a porous medium through the ground surface.

Inlet: A work aimed at controlling, regulating, deriving and directly admitting water through an inlet constructed upstream.

Landfills: Places especially set aside to receive sterile open-pit mining material and the waste obtained from taking down leaching heaps.

Leaching: hydrometallurgical process in which an element is dissok/ed from an ore and then recovered in later stages through electrolysis.

Losses by infiltration: Water losses by infiltration in the ground from a channel or other water mass.

Mineral: (mineral, ore) Mining term that refers to a mineralized mass of rock or resource susceptible to extraction and processing with an economic benefit. Thus the difference between mineral and sterile, slag or gravel, which has no economic value.

Natural freshwater: Non-recycled water obtained from several natural sources such as wells, reservoirs, surface run-offs, sea, etc.

Non-consumption use: Use of water that takes place in its own current, for example, hydroelectric generation, navigation, improvement of water quality, aquaculture and recreation.

Over-exploration: Quantity of water extracted from a water resource system that exceeds optimal extraction.

Percentage of solids: Quantity of solids contained in pulp.

Percolation: Wthout filtering. See also infiltration. Flow of a liquid through an unsaturated, porous medium, such as water on the ground, through the action of gravity.

Plant: This refers to all industrial installations where mineral processing is carried out to extract the species of interest, such as copper, gold or silver. Plant is also the name given industrial installations where processes are carried out such as the crushing plant, filter plant, etc.

Process Water: Water that does not have drinking quality and is used in industry. It may or may not be recirculated water.

Recirculated water: Water used in a process whose source is the same or a different process, but whose characteristics permit its reuse. In some cases, this water must recewe prior treatment.

Recirculation: Process that tries to reuse something in a same process. In other words, the water is reused in the same process that eliminated it or in another process at the same site.

Refined Cu: Corresponds to the real quantity of copper contained in the product for cathodes as well as for concentrates.

Reloading an aquifer: Process through which outside water is added to an aquifer's saturation zone, directly using the same formation, or indirectly, using another formation.

Reservoir: Natural or artificial place used to store, regulate and control water resources.

Residual water: Water that contains residues, that is, solid or liquid matter evacuated as waste from an industrial process.

Riles: Abbreviation in Spanish for "liquid industrial residues".

Run-off: Part of precipitation that presents itself in natural form as flow in a water course.

Salinity: Measure of the concentration of dissolved salts, especially sodium chloride, in saltwater and sea water.

Salt water: Water where the concentration of salts is relatively high (over 10,000 mg/l).

Slag: Material comprised of 90% or more of silica and iron, with a little residual copper, which is separated from the cast mixture inside fusion furnaces or converters.

Solvent extraction (SX): Method to separate one or more substances from a mixture by using sok/ents. In the copper extraction process, the organic resin permits capturing copper in solution, leaving the impurities, such as iron, aluminum, manganese and others in the original solution. The organic solution loaded with copper is separated in another tank where it is put in contact with a highly acidic electrolyte. This loosens the copper from the resin and transfers it to the electrolyte solution, which is finally sent to the electrowinning plant.

Surface run-off: (Surface flow): Part of the precipitation that flows over the ground's surface.

Surface water: Water that flows or is stored on the earth's surface.

Surplus water: Quantity of water that exceeds demand in a reservoir or supply system.

Sustainable development: "The process of sustained and equal improvement of the quality of life of people based on appropriate measures of conservation and protection of the environment in order to not compromise the expectations of future generations" (Law No. 19.300 of the General Basesforthe Environment).

System for the Exploration of water resources: See also water system. Group of hydraulic structures and related hydrological entities that have one or more purpose and that work in conjunction.

Tail: Refers to material that results in residue after all the copper has been leached from it. It is the binder for the leaching process and it is disposed of in special areas or tail landfills.

Tailing: The residue, ground mineral mixture with water and other compounds, that results from the extraction of sulfurated minerals in the flotation process.

Underground water: Water found underground that occupies a saturated zone.

Unit consumption: Amount of water (fresh, recirculated or total) used to process or obtain 1 unit of raw material or product, as applicable. For example: m3/ton treated mineral, lt/kg refined Cu.

Volume: Flow measurement. Volume of water that flows through a transversal section of a river or channel in a unit of time. It is measured in liters per second (lt/sec) or other unit that involves volume per unit of time.

Waste water: Generally household water that has been used in different functions (washing, showers, toilets, urinals) and commonly sent to the sewage system, but that can also be treated and recirculated into the process.

Water balance: See also balance equation. Water balance based on the principle that for a certain amount of time, total contribution to a water basin or table should be equal to the total outflow of water, plus the net variation in water storage at the water basin or table.

Water consumption: Amount of surface or underground water absorbed by plants and transpired or used directly by them in the form of vegetal tissue, plus losses from evaporation in the cultwated area expressed in volume units by surface units. It also includes all those activities where water use produces losses in relation to the initially supplied quantity such as urban and industrial consumption.

Water contamination: Introduction of undesirable substances in the water that are normally not present, such as microorganisms, chemical products, residues or waste that make it inappropriate for intended use.

Water course: Natural or artificial channel along or through which water can flow.

Water demand: See also water needs. Real quantity of water needed for diverse uses during a given period, conditioned on economic, social and other factors.

Water loss: 1) In a water balance, the sum of water losses in a specific area during a certain time by vegetation transpiration (crops or natural vegetation) and development of vegetal tissue, by evaporation of water surfaces, ground moisture and snow, and by interception.

Water quality: Physical, chemical, biological and organoleptic properties of water.

Water requirement (supply): Necessary quantity of water to carry out an activity or process, or for a job site to function.

Water resource conservation: Measures taken to reduce the amount of water used for a specific purpose and/or protecting it from contamination.

Water resources: Available or potentially available resources in sufficient quantity and quality in a place and during an appropriate period of time to satisfy an identifiable demand.

Water supply system: All of the reservoirs, pumps, piping and necessary works to supply water in appropriate quantities and quality for the different consumption sectors.

Water system: See also System for the Exploration of water resources. Group of related hydrological entities that behave as a whole.

Water use: Use of water: use or alteration of water's natural condition with the intention of increasing the production of goods and services.

Water: Liquid phase of a chemical compound comprised of approximately two parts hydrogen and 16 parts oxygen, in weight. Nature contains small quantities of heavy water, gases and solids (mainly salts) in dissolution.

Well: Aquifer or perforation dug or drilled into the ground to extract water.

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