Forecast for water consumption in the copper mining industry, 2018-2029

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Executive Summary

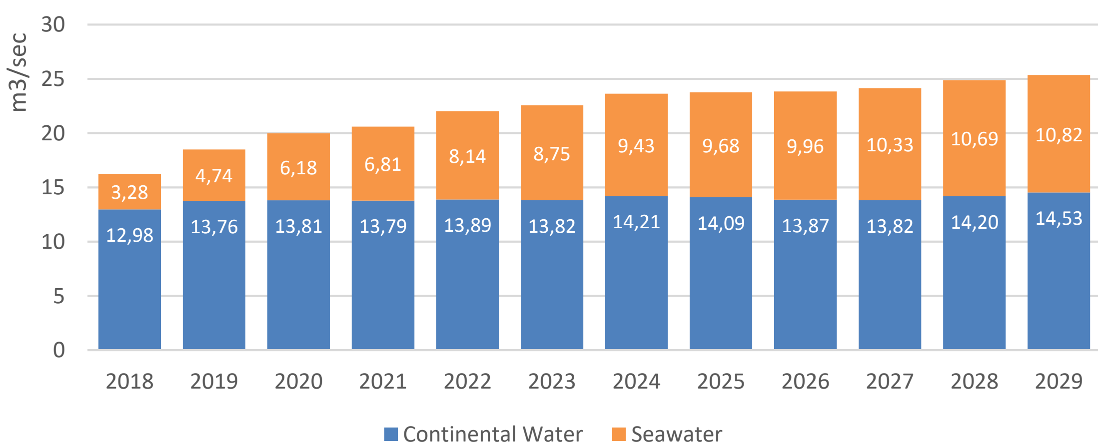
This forecast for the mining industry's water consumption is calculated using COCHILCO's projections for copper production and the corresponding unit coefficients of consumption in order to estimate future demand for water in a specific period. Water consumption by source is also estimated, based on the different categories of projects, including planned supply from desalination plants.

The methodology applied uses the unit consumption of each operation in each of its processes, their maximum production profiles calculated using COCHILCO's survey of mining investments and the probability of the investments' materialization based on historical information.

The key input for forecasting the industry's water consumption is the expected level of copper production which determines the amount of mineral processed and output of fine copper in the form of concentrate and SX-EW cathodes between 2018 and 2029. It is important to note that Chile's copper production matrix is expected to change over the coming years, shifting towards sulfide mineral whose treatment involves the water-intensive flotation process.

This study seeks to forecast demand for continental water and seawater in the copper mining industry, analyzing it in detail by region, process, stage of advance, condition and the status of projects environmental permits.

Forecast water consumption in the copper mining industry, 2018-2029



According to the results obtained using the Monte Carlo method, the industry's consumption of continental water would reach 14.53 m^3/sec in 2029, equivalent to an increase of 12% on expected consumption in 2018. Seawater would then account for 43% of the water used in copper mining, reflecting the fact that, in response to water shortages, ever more mining companies are building their own desalination plants or using seawater directly, insofar as this is technically and economically feasible. By 2029, the industry's seawater consumption is, therefore, forecast to reach 10.82 m^3/sec, up by 230% on its expected level in 2018.

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DISCLAIMER

For English version, the data in graphs, figures and tables are in national format. (##. ###, 00)

(.) for separation of thousands (,) for decimals

Introduction

According to the United Nations Development Programme (UNDP), the 2030 Agenda for the Sustainable Development Goals (SDGs) is a global action plan to increase social inclusion, environmental sustainability and economic development. It reflects a belief that the mining industry has an unprecedented opportunity to mobilize considerable human, physical, technological and financial resources so as to advance towards achievement of the SDGs (Mapping Mining to the Sustainable Development Goals: An Atlas, July 2016).

In analyzing the relationship between mining and the SDGs, the aim is to encourage mining companies of all sizes to incorporate these goals into their activities and operations, consolidating existing efforts and seeking new ideas. In order to be successful, it will also be necessary to form a permanent and substantive alliance between governments, the private sector, communities and civil society in order to take advantage of the transformational power of collaboration and partnership between the mining sector and the other stakeholders[1].

Specifically in the case of water, mining activities often have consequences for the land, water, the climate and flora and fauna as well as for those who depend on these resources. The opportunity, therefore, arises for the industry to seek to mitigate or avoid those effects and to increase its efficiency in the use of resources.

Mining is related to many of the SDGs but, in the case of Goal 6 on clean water and sanitation, it is apparent that the industry can act in different spheres (Mapping Mining to the Sustainable Development Goals: An Atlas, July 2016).

a) Integration into core business:

- Water conservation and recycling
    - Recycling and recovery of metals from wastewater
    - Reduction of water consumption
    - Use of alternative water resources

- Monitoring of water quality
    - Monitoring of water resources both near the mine and downstream
    - Community involvement in monitoring and sharing water data openly

- Managing water holistically
    - Alignment with government water management policies
    - Integration of technical, social, economic and political water concerns
    - Identification of high-value water areas

[1] http://www.undp.org/content/dam/undp/library/Sustainable%20Development/Extractives/Mapping_Mining_SDGs_An_Atlas_SP.pdf

- Maintenance of a long-term water balance throughout projects
- Incorporation of water reporting and disclosure mechanisms

b) Collaboration and leverage
- Support for drinking water and sanitation planning and infrastructure
- Clear delineation of watershed management responsibilities
- Sharing of benefits of water infrastructure
- Exploration of co-financing arrangements
- Support for local capacity-building in water and sanitation management.

In Chile, the principal mining operations are mainly located in the north of the country down to the Santiago Metropolitan Region, precisely the area with the most acute situations of water stress. This is why water is a fundamental resource for development and, like all countries, Chile must ensure its proper extraction and use in a sustainable manner in order to prevent its shortage from hampering the country's development.

In this context, this report seeks to provide, from a technical standpoint, information that is useful to water-consuming companies in their planning and decision-making and to public sector authorities.

This information constitutes a signal for the water market about potential water consumption in one of Chile's fastest growing and economically most important sectors: the mining industry.

The report's forecasts for future water use are based on assumptions that could be considered uncertain since copper production will depend on companies' decisions about the viability of projects.

The forecasts refer to consumption by the copper mining industry in the regions where it has the greatest important - that is, between the Arica y Parinacota Region in the north and the O'Higgins Region of central Chile - in the period from 2018 to 2029.

The forecasts are reported at the national level, by region, by type of process for treatment of the mineral, by condition of the different projects or operations, by their stage of advance and by projects' progress in obtaining environmental permits.

Chapter 1:

Methodology

Chapter 1 Methodology

The methodology used to forecast the Chilean copper mining industry's water consumption comprises four stages: (i) update of the forecast for copper production, both in terms of concentrate and fine copper, during the forecasting period; (ii) calculation of unit water consumption by process and mining company; (iii) calculation of the probability that copper production will reach its forecast level, distinguishing between a maximum, a most probable and a minimum scenario; and (iv) modeling of expected water consumption in the forecasting period.

In the case of copper production, the survey of projects which COCHILCO carries out each year was used, with updated information about operations and projects through to 2029, in order to forecast output in the form of concentrate and SX-EW cathodes and at smelters and refineries.

The copper mining industry's unit consumption of freshwater was obtained from COCHILCO's annual survey of companies. Using the information gathered by this survey, it is possible to calculate unit consumption of continental water per metric ton of mineral treated in the case of concentrate and per metric ton of fine copper produced in the case of cathodes, consumption of continental water by the mine area per metric ton of fine copper produced and unit consumption at smelters and refineries and for other uses.

The probability of copper output reaching its forecast level was calculated using historical information about the materialization of projects, identifying three water consumption scenarios.

Finally, these scenarios were subjected to a model using functions of probability and the random generation of scenarios.

1.1 Production forecast

On the basis of existing operations and projects in the copper mining industry, including copper as a by-product of iron and gold mining, a production vector can be obtained for forecasting the industry's demand for continental and seawater.

The production forecast is the pillar of the water consumption forecast because it determines the amount of mineral that would be processed in concentrate and the fine copper produced in concentrate as well as in SX-EW cathodes between 2018 and 2029.

1.2 Unit coefficients

Unit consumption of continental water refers to the amount of water used to process or obtain a unit of raw material or product. It is expressed in cubic meters of continental water per ton.

Using the annual information provided by the different copper-producing operations, unit consumption can be obtained for each of the two main methods used to process mineral, based on tons processed in the case of concentrators and electro-obtained cathodes in the case of hydrometallurgy plants.

In calculating the coefficients of operations and projects, the following criteria were used:

- For current operations, the coefficient of continental water consumption reported for 2017 was used.
- For expansion projects, the coefficient of the parent operation or of operations with similar characteristics was used.
- For the purposes of forecasting, these coefficients were kept constant.
- For new projects, the coefficient of similar operations or the industry average were used.
- In the case of seawater, coefficients similar to those for operations currently using seawater were used.
- For projects envisaging the use of seawater, the capacity of the plants and pumping systems was incorporated.

1.3 Construction of scenarios

Given the uncertainty intrinsic to mining operations and their investment projects, the probability that they will reach their expected nominal capacity on the tentative dates established was estimated.

For this purpose, three different scenarios were constructed: a minimum one, corresponding to conditions in which decisions on investment in projects are postponed and production remains unchanged; a more probable scenario based on COCHILCO's historical information about actual versus estimated production since 2005; and a maximum scenario in which operations and projects reach their estimated production at their scheduled date.

- **Maximum production scenario.** In this scenario, operations continue as planned and all projects are completed at the date estimated by their owners with their estimated production capacity. This is clearly an optimistic scenario.
- **Most probable production scenario.** In this scenario, the production profiles expected and reported by mining companies are weighted at less than unit value since there is a high probability that projects will suffer changes and not be completed at the date or with the production capacity initially estimated. This weighting was calculated by COCHILCO on the basis of historical information about the materialization of mining projects obtained from its past surveys of projects.
- **Minimum production scenario.** To calculate this scenario, the figures used in the most probable scenario were reduced within the limits of a reasonable technical criterion. This is, in other words, a pessimistic scenario.

Water consumption in year *t* is calculated as shown in equation (1):

$$\boldsymbol{Water\_Consumption_t} = \sum_i \boldsymbol{E}\big[\boldsymbol{f}(\boldsymbol{X_{ijkt}}; \boldsymbol{Y_{ijkt}}; \boldsymbol{Z_{ijkt}})\big] \qquad (1)$$

where,

- *i*: Operation considered
- *j*: Type of end product considered
- *k*: Condition/status of mining project considered[2]
- *t*: Year considered in the forecasting period
- *f*: Distribution of probability indicating the range of values that can be taken by water consumption and the probability assigned to each value according to the input variables
- Z_{ijkt}: Maximum fine copper production by operation *i*, in process *j*, according to the condition/status *k* of the project in year *t*. The unit of measurement is ktpy.
- Y_{ijkt}: Most probable fine copper production at operation *i*, in process *j*, according to the condition/status *k* of the project in year *t*. The unit of measurement is ktpy.
- X_{ijkt}: Minimum fine copper production at operation *i*, in process *j*, according to the condition/status *k* of the project in year *t*. The unit of measurement is ktpy.

The weighting used for the capacity of an operation or project depends on the status and condition of the project and the scenario being generated. Table 1 shows the probability vectors used by scenario and status and condition of projects. The vectors were calculated based on historical information, obtained from the historical surveys of projects published by COCHILCO. It should be noted that, in the case of projects, year 1 corresponds to the start-up year envisaged in COCHILCO's 2018 survey.

Table 1: Project materialization scenarios

Minimum Scenario

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Potential Prefeasibility	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Potential Feasibility	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Possible Feasibility	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Probable	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Base	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84

[2] For the purposes of this report, the conditions/status of projects are Base, Probable, Possible Feasibility, Potential Feasibility and Potential Prefeasibility.

Most Probable Scenario

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Potential Prefeasibility	0.16	0.28	0.32	0.37	0.42	0.45	0.49	0.55	0.69	0.70	0.72	0.80	0.81	0.83
Potential Feasibility	0.32	0.37	0.42	0.45	0.49	0.55	0.69	0.70	0.72	0.80	0.81	0.83	0.84	0.84
Possible Feasibility	0.49	0.55	0.69	0.70	0.72	0.80	0.81	0.83	0.84	0.84	0.85	0.88	0.92	0.92
Probable	0.72	0.80	0.81	0.83	0.84	0.84	0.85	0.88	0.92	0.92	0.92	0.93	0.93	0.93
Base	0.84	0.85	0.88	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93

Maximum Scenario

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Potential Prefeasibility	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Potential Feasibility	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Possible Feasibility	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Probable	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Base	1	1	1	1	1	1	1	1	1	1	1	1	1	1

In the case of the most probable scenario, it is implicit in the information that a potential prefeasibility project will take two years to reach the feasibility stage, another two years before it can be classified in the possible category, then three years to become probable and two more years to become a base project.

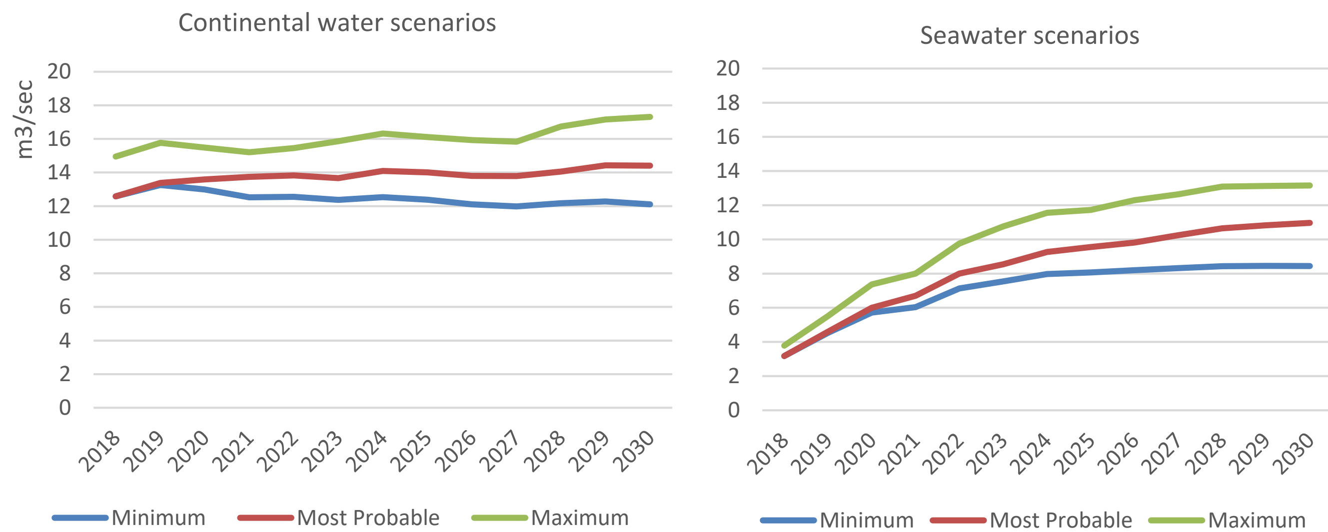
In the case of the minimum scenario, a greater delay on investment decisions is considered for possible and potential projects which, while not eliminating them, means they have a lower probability of materialization.

1.4 Calculation of expected value

Based on these three scenarios, three values were obtained for the annual water consumption of each particular process. The Monte Carlo method was then used to obtain a probabilistic distribution of annual consumption, calculating its expected value. The expected values of each of the distributions obtained were then added to obtain expected water consumption.

These scenarios correspond to the inputs of the Monte Carlo simulation, which gives as its result the vector of expected value.

Figure 1: Water consumption scenarios, 2018-2029



Source: Calculated by COCHILCO.

Chapter 2:

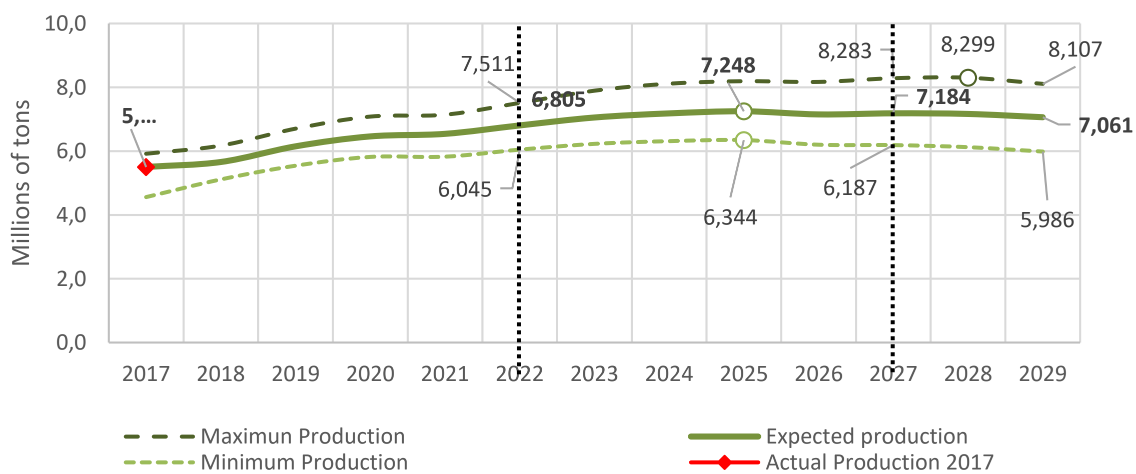
Expected water consumption by 2029

Chapter 2 Expected water consumption by 2029

The results obtained from the simulation carried out using the methodology described in the previous chapter are shown below by origin of the water, at the national level, by region, by process, by project condition, by stage of advance and by status of environmental permits.

In order to analyze the trend of water consumption in the copper mining industry, it is necessary to understand, first, the expected behavior of copper production. As forecast for the next ten years, based on the conditionality of materialization of the projects included in the 2018 survey, it shows an increase of 28.3% by 2029 as compared to actual production in 2017, implying a fine copper output of 7.06 million metric tons in 2029, with a peak of 7.25 million tons in 2015.

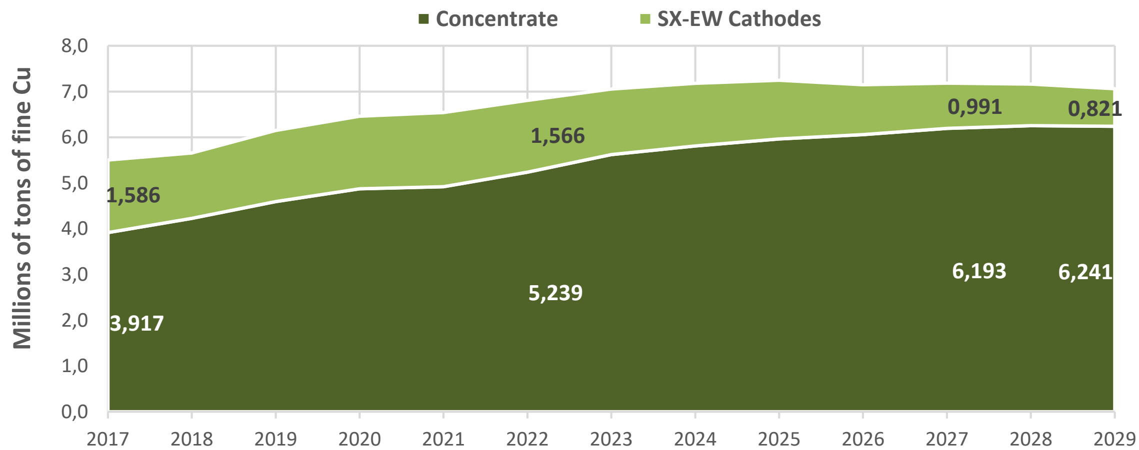
Figure 2: Mine copper production in 2017 and forecast for 2018-2029



Source: Calculated by COCHILCO.

When disaggregated by type of product - that is, concentrate and SX-EW cathodes - the forecast confirms a trend, seen for several years now, under which hydrometallurgical production is falling while production of concentrate is growing quickly. In line with this, hydrometallurgical production as a share of total output would drop from 28.8% in 2017 to 11.6% in 2029 and that of concentrate would increase from 71.2% to 88.4% while smelting and refining production lines would show little change. The increase in production of concentrate would imply an increase in processing of sulfide minerals in concentrators. If production of concentrate increases by 59.3% between 2017 and 2029, processing of sulfide mineral in concentrators would increase by 75% in the same period, representing an annual growth rate of 4.4%. As a result, the mineral treated in concentrators would increase from an estimated 574 million tons in 2017 to 1,004 million tons in 2029.

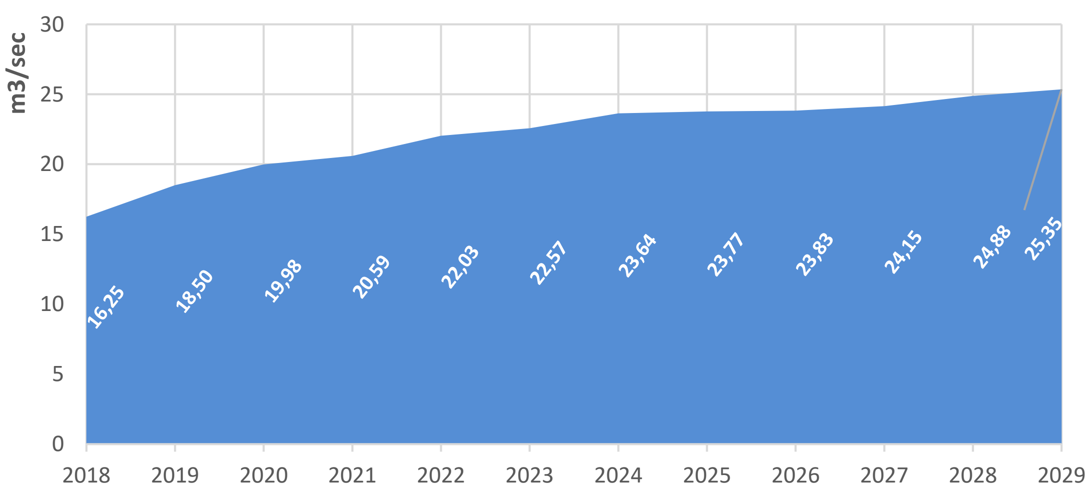
Figure 3: Copper production in 2017 and forecast production 2018-2029, by product



Source: Calculated by COCHILCO.

When analyzing forecast production from the standpoint of water resources, it can be seen that, in 2018-2029, while copper production would grow at an average annual rate of 2.1%, water consumption would increase at a rate of 4.2%. This partly reflects the shift in the production matrix towards sulfide minerals, which have to be processed using flotation, a process that is much more intensive in water use. In addition, the decline in ore grades means that more water must be used to obtain a ton of fine copper since a larger amount of mineral has to be processed.

Figure 4: Forecast water consumption in copper mining, 2018-2029



Source: Calculated by COCHILCO.

2.1 Water consumption by origin

When analyzing water consumption, it is necessary to distinguish between continental water, which is also referred to as freshwater, and seawater.

The use of continental water includes withdrawals from surface sources such as rainwater, run-offs, surface reservoirs, lakes and rivers and the use of groundwater in the form, for example, of wells and aquifers as well as water purchased from third parties. Seawater, in turn, can either be desalinated or used directly. For details of these terms, see Appendix 1.

Figure 5: Forecast water consumption in copper mining, 2018-2029, by origin

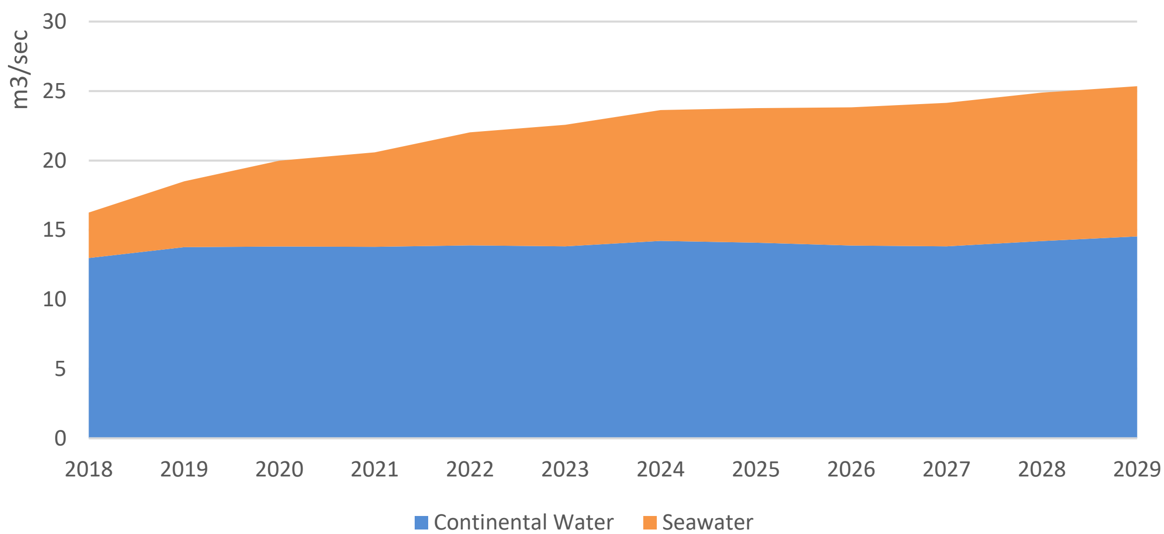


Table 2: Forecast water consumption in copper mining, 2018-2029

(m^3/sec)	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Continental water	12.98	13.76	13.81	13.79	13.89	13.82	14.21	14.09	13.87	13.82	14.20	14.53
Seawater	3.28	4.74	6.18	6.81	8.14	8.75	9.43	9.68	9.96	10.33	10.69	10.82
TOTAL	**16.25**	**18.50**	**19.98**	**20.59**	**22.03**	**22.57**	**23.64**	**23.77**	**23.83**	**24.15**	**24.88**	**25.35**

Source: Calculated by COCHILCO.

Water of continental origin is a scarce resource. This represents not only a hydrological limitation but also, increasingly, an economic problem that could restrict the development of the vast majority of industrial activities.

Management of water resources is, therefore, ever more important for companies' long-term sustainable development.

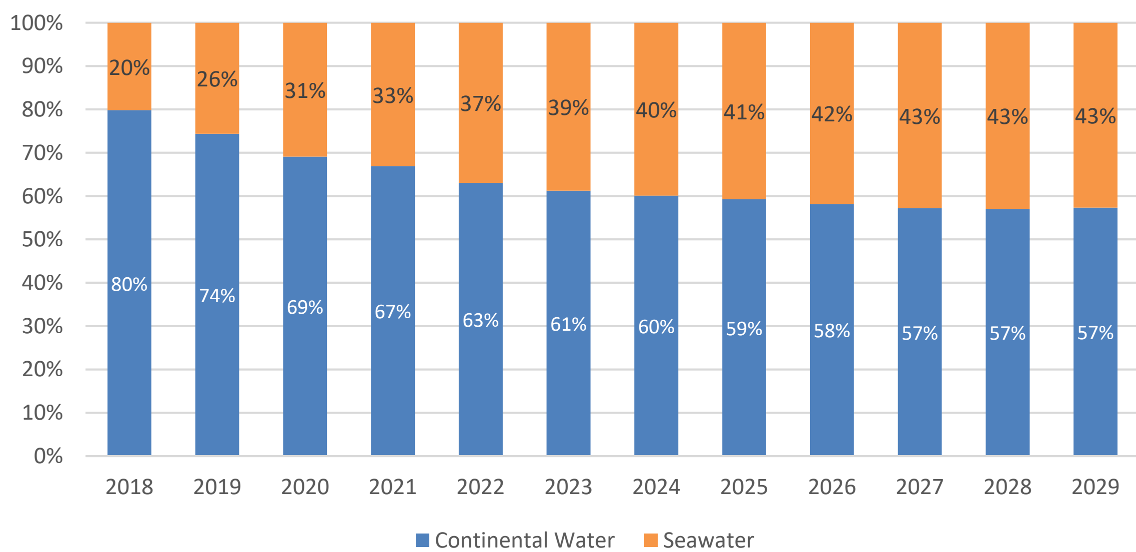
In general terms, consumption of continental water is expected to reach 14.53 m^3/sec in 2029, up by 12% on expected consumption in 2018.

Chile also has the potential to use seawater in the short term. This represents an alternative for addressing the limitation that this transcendental resource poses for many areas of the country and not only for mining, but also many other economic sectors.

While consumption of continental water is estimated to grow at an average annual rate of around 1%, the figure for seawater rises to 12.2%, with consumption reaching 10.82 m^3/sec by 2029.

As a result, seawater consumption in 2029 is expected to be up by more than 230% on 2018, accounting for 43% of the water required by the country's copper mining industry (Figure 6).

Figure 6: Percentage distribution of water consumption in copper mining, 2018-2029, by origin



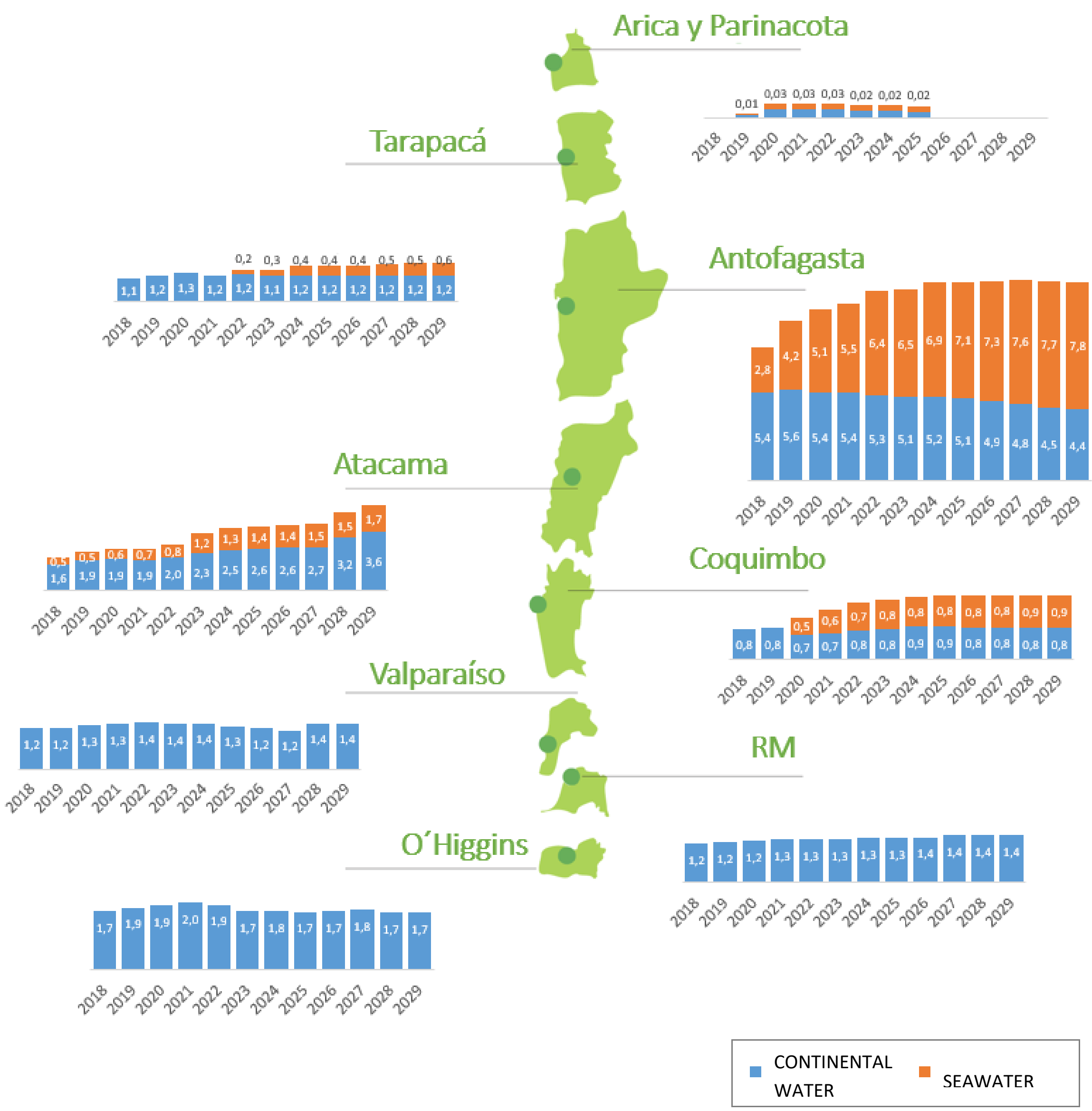
Source: Calculated by COCHILCO.

2.2 Water consumption by region

In Chile as a whole, the mining industry accounts for only 3% of consumptive water use[3] but its operations are often located in dry areas or basins where the head of a source is located. Due to the industry's location in the center and north of the country, its regional and local impact, therefore, can be greater than suggested by its consumption nationally. As a result, this report analyzes the situation at a regional level.

[3] http://www.dga.cl/DGADocumentos/Atlas2016parte4-17marzo2016b.pdf

Figure 7: Forecast water consumption in copper mining, 2018-2029, by region



Source: Calculated by COCHILCO.

The proportion of the industry's needs that are supplied by continental water shows a very marked decline in the Antofagasta Region but increases in the Atacama Region and shows little change in other regions.

The use of seawater is most important in the Antofagasta Region, followed at a considerable distance by the Atacama, Coquimbo and Tarapacá Regions.

Over the coming years, use of seawater will show the greatest development in the Antofagasta Region where it will permit a decrease in consumption of continental water. In this region, the operations already using seawater are Escondida, Centinela, Antucoya, Michilla (currently closed), Mantos de la Luna, Las Cenizas Taltal, the J.A. Moreno plant and Sierra Gorda. A number of projects in this region also envisage use of this resource, including a possible new expansion of Escondida's desalination plant, modernization of the Esperanza plant and its subsequent expansion to supply the Encuentro project, Codelco's North District plant which would gradually begin to supply its Radomiro Tomic, Ministro Hales and Chuquicamata operations, the El Abra Mill project and the Spence Growth project.

In the case of the Coquimbo Region, seawater would account for 51% of the industry's water consumption by 2029, due principally to the expansion of Los Pelambres in the framework of the INCO project. This envisages the construction of a reverse osmosis plant in the Los Vilos municipal district, submarine infrastructure for the intake of seawater and the discharge of brine and a system to transport the desalinated water from the pumping station in the company's industrial installations in Puerto Punta Chungo and the recycling station already in operation in the El Mauro industrial area. The desalination plant will have the capacity to produce 400 l/s of industrial-quality desalinated water and would be used as back-up in periods of drought. The Dominga project of Andes Iron also envisages the use of seawater for processing.

Use of seawater is also important in the Atacama Region. Due to the severe drought affecting this area, some mining projects that would use seawater are also located there. They include principally the current Mantoverde plant and its planned expansion, Candelaria and its Candelaria 2030 expansion, Santo Domingo and the Diego de Almagro project and, as from this year, the NuevaUnión project, with its Phases I, II and III, and the Hot Chili project known as Productora.

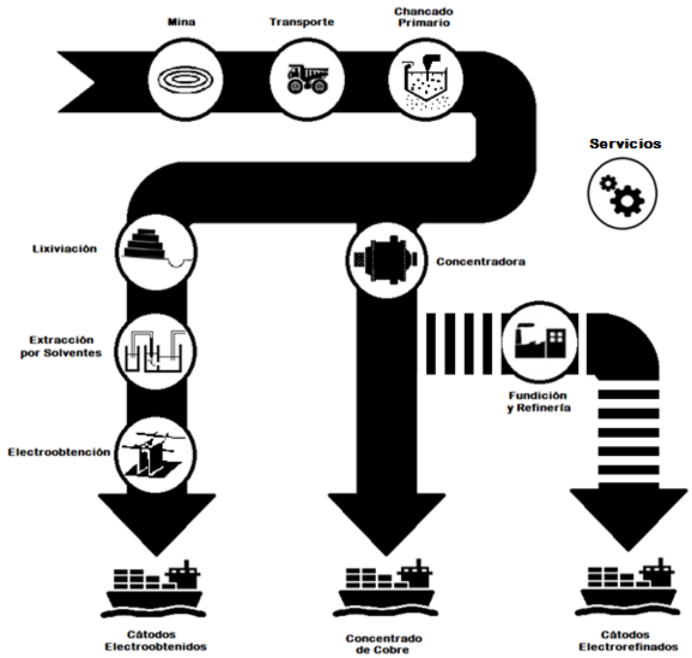
In the Tarapacá Region, the Quebrada Blanca Hypogene or Phase II project would use desalinated seawater. This would be pumped up into the mountains through an aqueduct. In addition, the project includes mechanisms for the reuse of water in order to increase the efficiency of its use.

By 2029, seawater is expected to account for 32% of the copper mining industry's water consumption in the Tarapacá Region, 64% in the Antofagasta Region, 32% in the Atacama Region and 51% in the Coquimbo Region.

2.3 Water consumption by type of process

The processes involved in copper production in Chile are summarized in the figure below. Each of the points represents a center of water consumption, with some being more intensive than others.

Figure 8: Copper mining processes



Source: Elaborated by COCHILCO.

The mine area includes the mine itself - open-pit or underground - and transport of mineral to the primary crushing plant. Here, water is used principally to mitigate dust from roads and in extraction and pumping from underground operations.

The concentrator plant area involves the processing of the mineral and represents the largest consumption of water in terms of volume. It includes comminution of the mineral, followed by flotation, classification and thickening. Depending on the distance between the concentrator and the filtering and storage installations, the wastewater may or may not be recycled in the process. An important part of the water used in the flotation process is contained in the tailings which are thickened in order to recover part of this water.

The hydrometallurgy plant area includes the heap leaching, solvent extraction and electrowinning processes used to produce cathodes. Here, the main water consumption is a result of evaporation from the leach pads which are irrigated with a sulfuric acid and water solution in order to dissolve the copper contained in the oxide mineral.

In the smelting and refining process, the dry concentrate undergoes a pyrometallurgy process to obtain thick plates in the form of anodes. These are either marketed directly or sent for refining. This latter process takes place in electrolytic cells in a sulfuric acid solution, with high-purity cathodes obtained by applying an electric current which causes the copper in the anode to dissolve and become deposited on the initial cathode.

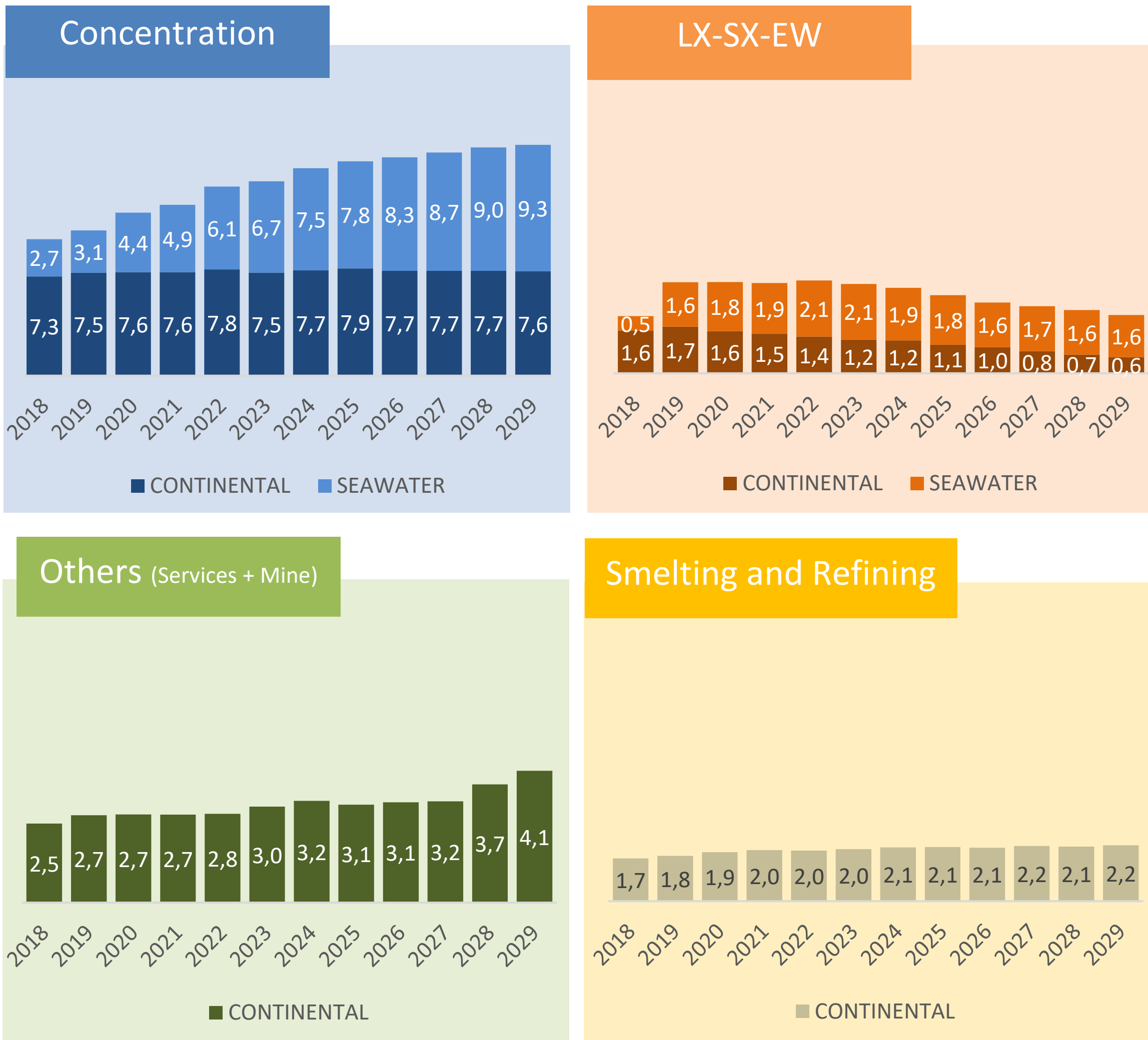
Finally, the services area corresponds to activities which account for a very small part of the volume of water used by a mining operation as a whole. The main uses in this area are for drinking, cooking, washing and watering in camps and in molybdenum plants, if they exist, as well as other minor consumptions.

For the purposes of this report, the mine and services areas are grouped together in Others.

COCHILCO's latest survey of mining investment indicates that Chile's copper production matrix will change over the next ten years, becoming ever more intensive in concentrate.

When analyzing the outlook for demand for continental water by production process, it can be seen that concentrate accounts for a large part of the water required in copper mining, due to both the shift into concentrate in response to the natural exhaustion of oxide resources and their replacement by sulfide resources and to the water intensity of the concentration process.

Figure 9: Water consumption in copper mining, 2018-2029, by type of process



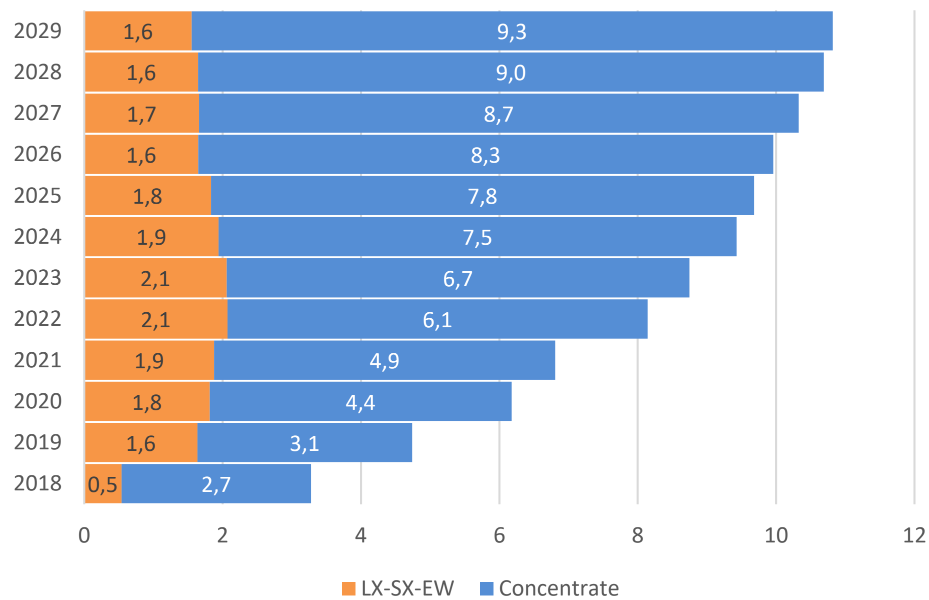
Source: Calculated by COCHILCO.

By 2029, the concentration process is expected to account for 53% of the continental water used in copper mining, the production of cathodes for 4%, other uses for 28% (5% in the mine area and 23% in services) and smelting and refining for 15%.

Similarly, in the case of seawater, the heaviest use is in the concentration process which, as indicated above, is the most water-intensive process and its role is expected to increase considerably in the coming years.

By 2029, more than 86% of seawater is expected to be used in the production of concentrate through treatment of sulfides.

Figure 10: Seawater consumption in copper mining, 2018-2029, by type of process

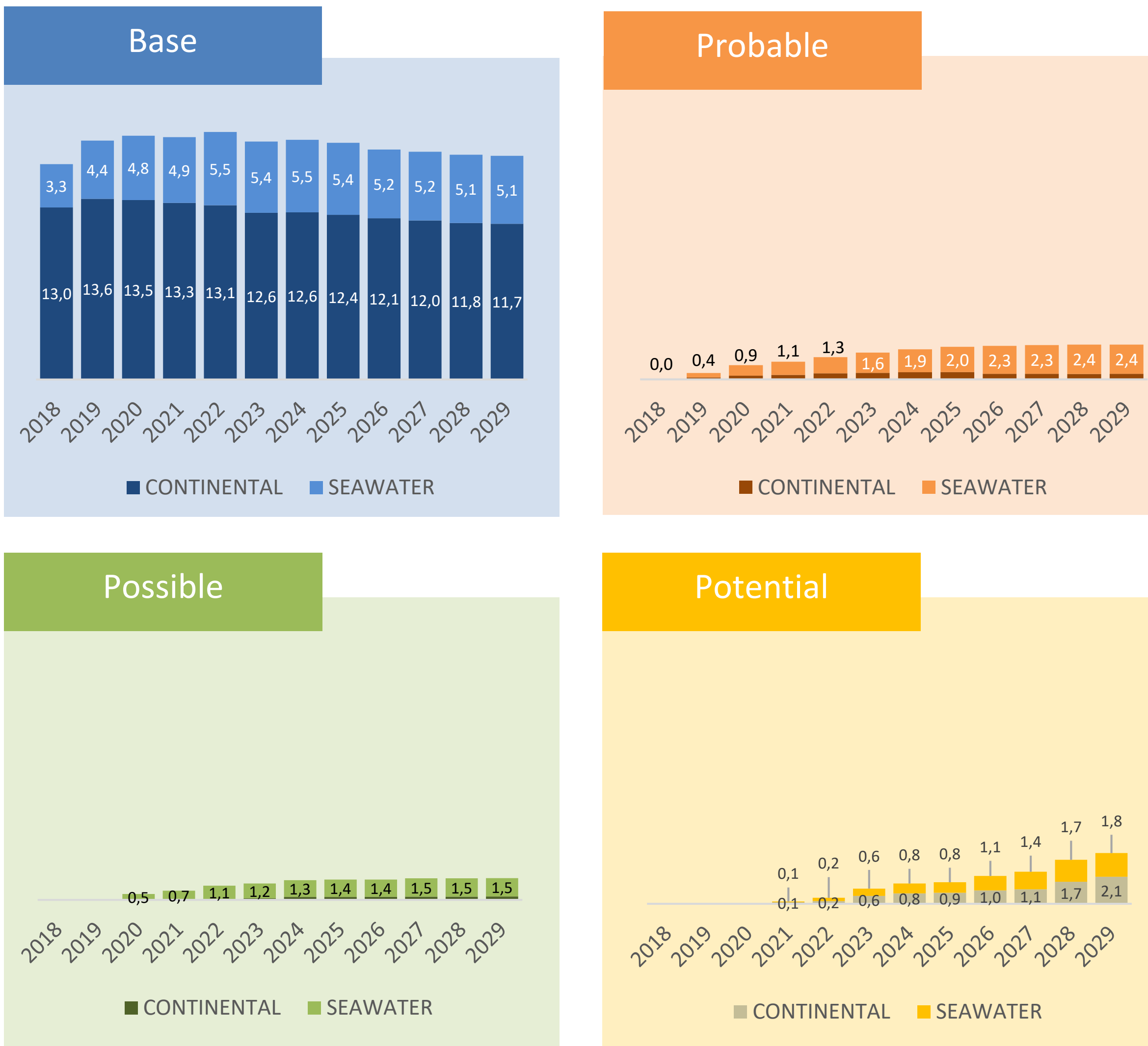


Source: Calculated by COCHILCO.

2.4 Water consumption by condition of projects

Projects are classified into four conditions - base, probable, possible and potential - according to their specific attributes: their stage of advance, their progress in obtaining environmental permits and their estimated start-up date. Each attribute has a gradualness that can be associated with a greater or lesser certainty and, together, they provide an indication of the conditionality of the project's materialization.

Figure 11: Water consumption in copper mining, 2018-2029, by condition of projects



Source: Calculated by COCHILCO.

Base projects - that is, those already in operation or under implementation - would account for most of the continental water consumed by the copper mining industry over the next ten years. By 2029, they would represent over 81% of consumption of continental water. This is consumption about which there is a high degree of certainty while there is less certainty about the remaining 19%.

In the case of seawater, the trend is different. The expected seawater consumption of base operations increased considerably with the start of operation of the expansion of the Escondida EWS desalination plant in 2018. However, projects in a possible, potential or probable condition, implying greater uncertainty about their date of implementation, would account for more than half of expected seawater consumption in 2029.

A larger number of new projects or expansions will start to use seawater and the level of certainty is, therefore, lower since delays or changes in design are possible and the probability of their implementation by the estimated date is less certain.

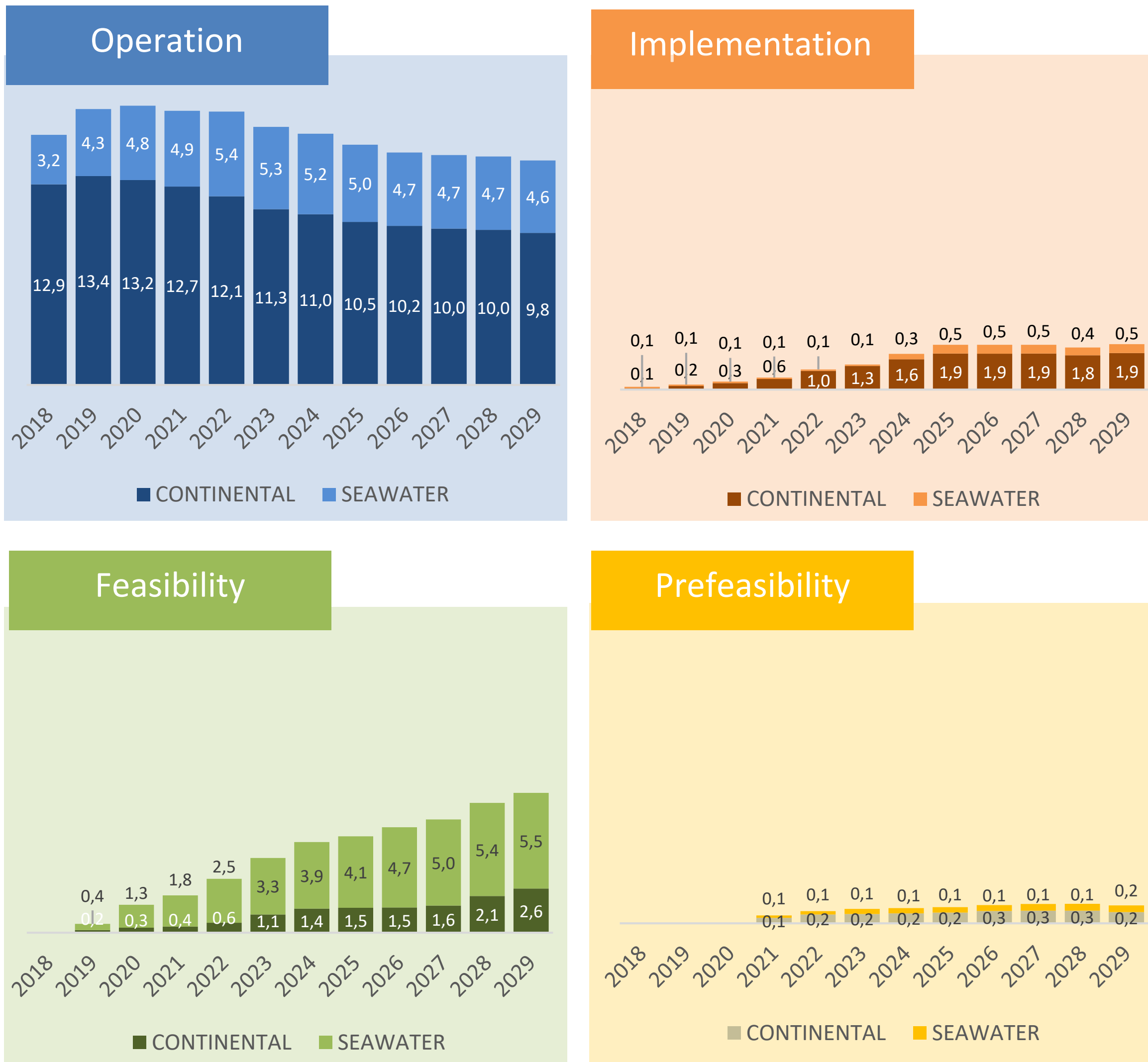
Over the next ten years, the proportion of seawater consumption corresponding to base projects does not vary significantly while forecast consumption by probable, possible and potential projects does change. By 2029, 53% of seawater consumption would be related to projects with a lower degree of certainty, of which 22% correspond to probable projects, 14% to possible projects and 17% to potential projects, the latter with the least certainty.

The main difference with the respect to forecasts as of last year is a reduction in the level of uncertainty related to seawater projects which have advanced in their definition, implying a greater probability of their materialization and compliance with estimated dates.

2.5. Water consumption by stage of advance

In order to analyze expected demand for freshwater in the copper mining industry by the stage of advance of the projects included in COCHILCO's investment survey, four stages of advance were defined: prefeasibility, feasibility, implementation and operation. A project's progress may be affected by some type of suspension, either for internal reasons or situations outside the company's control. In some cases, a project that has been suspended may have to return to an earlier stage to repeat studies in order to address questions raised from within the company or externally.

Figure 12: Water consumption in copper mining, 2018-2029, by stage of advance



Source: Calculated by COCHILCO.

In the prefeasibility stage, which is also referred to as the conceptual engineering stage, different alternatives for a project are drawn up and selected. This is followed by the feasibility stage when the selected alternative is developed in the form of the basic engineering. Projects under implementation are those in the stage of construction, assembly and ramp-up of the new asset. Finally, projects in operation are defined as those that are currently producing.

Analysis of water consumption according to projects' stage of advance shows that most water is consumed by those that are in operation. In their case, consumption of continental water is tending to drop, accompanied by an increase in use of seawater. In the case of projects under implementation, total water consumption is expected to increase by around 10% by 2029. Projects at the feasibility stage, about which there is less certainty, would account for 32% of total water consumption by 2029, with seawater playing an important role, while projects at the prefeasibility stage, whose implementation has a lower probability, would account for 2% of estimated water consumption in 2029.

Similarly, in the case of continental water, projects about which there is greater certainty, like those in operation and under implementation, account for a large part of expected consumption.

In the case of seawater, projects that are currently at the feasibility stage of their engineering would represent around 51% of consumption by 2029.

Consequently, projects in operation and under implementation, which would account for 57% of seawater consumption by 2029, have a higher degree of certainty while the remaining 43% corresponds to projects at the feasibility stage which can be subject to changes in operational decisions.

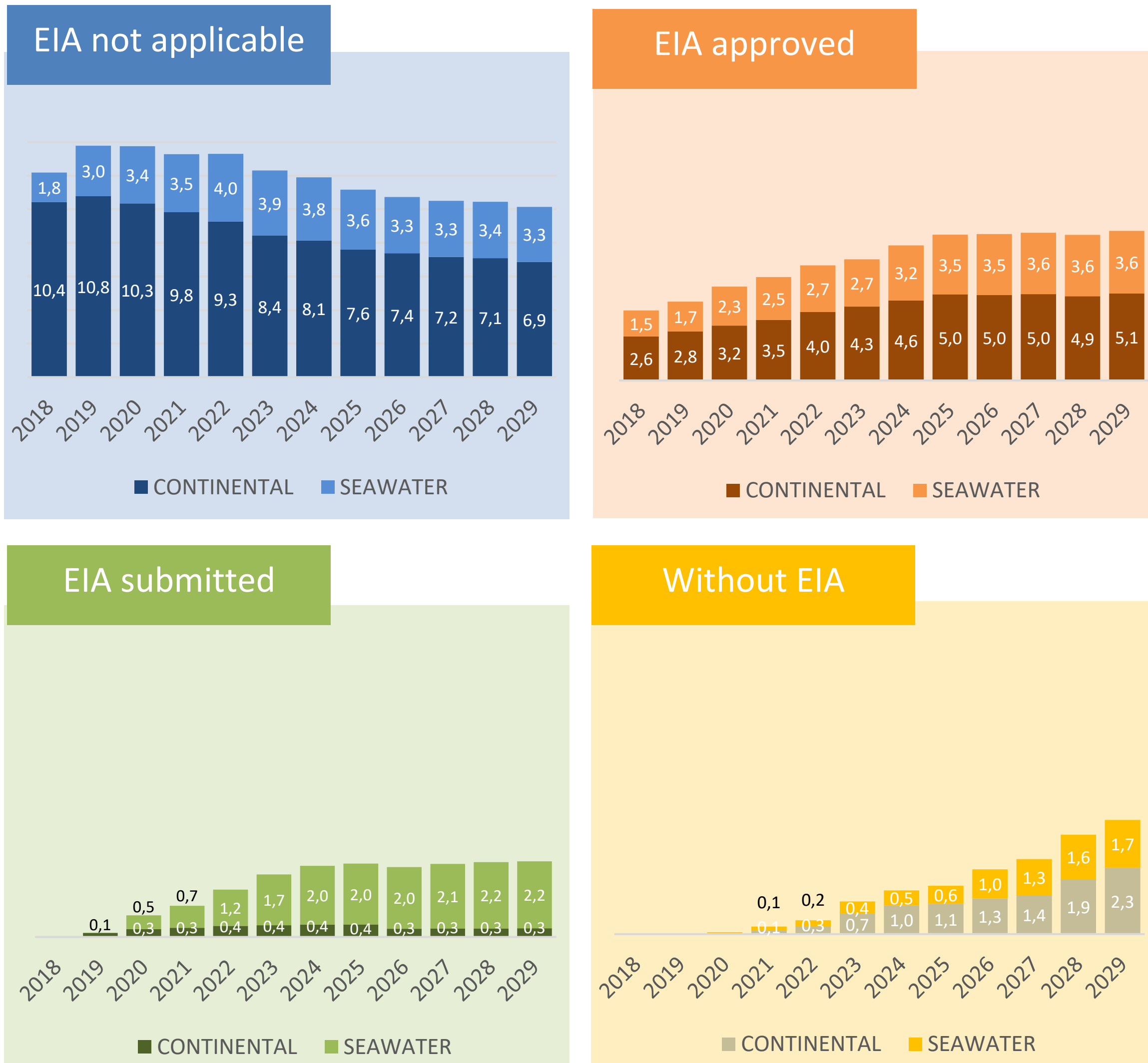
2.6 Water consumption by status of environmental permits

All projects must obtain a Resolution of Environmental Approval (RCA) from the Environmental Evaluation Service (SEA). This is awarded only after an exhaustive technical-administrative process that includes citizen participation as well as analysis of the project's Environmental Impact Study (EIA) or Environmental Impact Declaration (DIA).

Here, projects are classified in three stages from greater to lesser certainty:

- EIA or DIA approved
- EIA or DIA submitted
- Without EIA or DIA.

Figure 13: Water consumption in copper mining, 2018-2029, by status of environmental permits



Source: Calculated by COCHILCO.

Most water consumption corresponds to operations for which environmental permits have already been granted (classified as EIA not applicable). They are followed, in terms of amount of water, by projects whose EIA has been approved or, in other words, mostly projects that are under implementation or that are to replace or expand existing operations. These are, in turn, followed by projects that have not yet submitted an EIA - or, in other words, those about which there is a low level of certainty and which can, therefore, still vary significantly as regards dates, water flows, methods, etc. – and, finally, those projects which have submitted an EIA but on which the authorities have yet to take a decision, that is, projects about which there is also a low level of certainty because their parameters can still vary.

The evolution of expected water consumption by the status of projects' environmental permits indicates a trend similar to that seen in the case of stage of advance, with projects currently in operation or with their EIA approved accounting for 74% of total water consumption by 2029, while the remaining 26% corresponds to projects that have not yet requested or have not obtained an environmental permit, making compliance with their announced dates less certain.

In the specific case of the expected consumption of seawater, the situation is different. With a solid base of new projects, future demand for seawater will depend heavily on the award of environmental permits and the regulatory framework for use of this resource.

In 2029, operations or projects with environmental approval would account for 63% of expected seawater consumption, with the other 37% corresponding to projects without environmental permits, divided into 21% for projects that have already applied for a permit and 16% for those that have not yet done so.

Chapter 3:

Final comments

Chapter 3 Final comments

In order to analyze the trend of expected water consumption in the copper mining industry, it is vital to understand the behavior of expected copper production since this is the model's single most important input. Forecast production has increased since last year, due mainly to three factors: in the intervening period, many operations adjusted their useful life, increasing the long-term output of operations that are currently active; many projects have changed condition from, for example, "potential" to "probable", with the resulting change in their weighting and an increase in the contribution of probable projects to expected production; and the incorporation of a number of small projects that would slightly increase output, particularly of SX-EW cathodes (Delirio in the Atacama Region, between 2019 and 2024, and the reopening of Michilla).

From the standpoint of output by process, a trend seen for some years now persists, with hydrometallurgical production dropping while production of concentrate increases rapidly. Hydrometallurgical production would account for 11.6% of total copper production in 2029, down from 28.8% in 2017, while production of concentrate would increase from 71.2% to 88.4%, due mainly to the Quebrada Blanca Phase II, NuevaUnión Phases I, II and III and Spence Growth Option projects as well as the Los Pelambres INCO project, the Sierra Gorda 230 ktpd project and the Mantoverde Development project whose contribution is, however, still more subject to progress on engineering and obtaining permits.

At the national level, consumption of continental water in copper mining is forecast to reach 14.53 m^3/sec by 2029, up by 12% on its expected level in 2018. In 2018-2029, copper production would grow at an average annual rate of 2.1% while, for total water consumption, the figure would reach 4.2%. This partly reflects the shift in the production matrix towards sulfides, which have to be processed using flotation, which is much more intensive in water use. In addition, the decline in ore grades means that more water must be used to obtain a ton of fine copper since a larger amount of mineral has to be processed.

The trend in consumption of seawater differs from that for continental water. While the latter would show an average annual growth rate of around 1%, consumption of seawater would grow at an average of 12.2%, reaching 10.82 m^3/sec by 2029, an increase of 230% on 2018. By 2029, seawater would account for 43% of all the water used by the country's copper mining, with the increase driven by the Antofagasta Region, particularly between 2019 y 2024, with the expected start-up or expansion of a number of desalination plants such as the Escondida EWS plant, inaugurated at the beginning of 2018, Codelco's North District plant, the expansion of the pipelines for the Centinela District of Antofagasta Minerals, the use of seawater for the expansion of Sierra Gorda by KGHM and the gradual start-up of the Dominga iron project as from 2020. As from 2023, the use of seawater is also expected to show an important increase in the Atacama Region, led by the Santo Domingo project of Capstone Mining, the NuevaUnión project of Goldcorp and Teck and the medium-scale Productora project of Australia's Hot Chili, adding to the desalination plants that already exist in the region such as those of Lundin Mining and Mantos Copper.

The importance of seawater as a percentage of total water consumption is highest in the Antofagasta Region, followed at some distance by the Atacama, Coquimbo and Tarapacá Regions.

As regards use of water in the copper mining industry's different processes, the processing of concentrate would account for 53% of its consumption of continental water in 2029, with cathode production accounting for 4%, other uses for 28% (5% by the mine area and 23% by services) and smelting and refining for 15%. In the case of seawater, over 86% of consumption would correspond to the treatment of sulfides to produce concentrate.

In the case of the condition of projects, the share of water consumption corresponding to base projects would not vary significantly over the next ten years, but that of probable, possible and potential projects would show a significant change. By 2029, 53% of seawater consumption would be related to projects with a lower level of certainty of which 22%, 14% and 17% are currently probable, possible and potential projects, respectively, with the latter representing the lowest level of certainty.

The principal changes seen with respect to last year's forecasts are a slight reduction in expected seawater consumption over the next decade. This is explained principally by changes in the condition of projects, with their definition in greater detail reducing the related level of uncertainty. As a result, despite the drop in their expected water consumption, certainty about their materialization and compliance with dates has increased.

In general, it can be concluded that desalination and the use of seawater are the solution being adopted by the majority of new copper mining projects and expansions. However, it is necessary to underscore the importance of a clear legal framework for their sustainable development.

Appendices

Appendices

Appendix 1 Condition of materialization of projects

Condition	Type of project	Stage of advance	Environ. permit	Start-up
BASE	Any	Implementation	RCA approved	Within the period
PROBABLE	Any	Implementation suspended	RCA approved or appeal to courts	Within the period
	Any	Feasibility	RCA approved	Within the period
	Replacement or expansion	Feasibility	EIA or DIA under review	Within the period
POSSIBLE	Replacement or expansion	Feasibility suspended	EIA or DIA under review	Within the period
	Replacement or expansion	Feasibility	EIA or DIA not submitted	Within the period
	New	Feasibility	EIA or DIA under review or not submitted	Within the period
	Any	Feasibility	RCA approved	Outside the period
	Replacement or expansion	Feasibility	EIA or DIA under review or not submitted	Outside the period
POTENTIAL	Any	Feasibility suspended	Any	Outside the period
	Any	Prefeasibility	Any	Any

Source: Prepared by COCHILCO.

Appendix 2 Stages of advance of a project

- Operation. Projects that are currently in operation.
- Implementation. Projects for which the investment has been approved and the necessary permits for their development obtained and which have reached a phase between detailed engineering, construction and ramp-up.
- Feasibility study. Projects at a stage between having begun to prepare feasibility studies and environmental studies (EIA or DIA) and having completed them, but without a final decision on the investment having been taken.
- Prefeasibility study. Projects at a stage between the start of prefeasibility studies and a decision to move on to the next stage.

Source: Prepared by COCHILCO.

Appendix 3 Types of mining project

- Replacement projects. Brownfield projects in which the objective is to maintain the production capacity of an existing operation by developing new areas of it as a means of offsetting a drop in ore grades and/or the exhaustion of sectors already being worked. These projects extend the useful life of a mine and its installations.
- Expansion projects. Brownfield projects that seek to increase current operational capacity in order to raise the scale of production and reduce unit costs, particularly in the face of a drop in ore grades.
- New projects. Greenfield projects that involve the construction of a new mine, with the need to obtain environmental and sector permits, develop infrastructure and establish the company in a new location. This category also includes brownfield projects at existing operations that imply a complete change of process (for example, from leaching to concentration) since they are virtually equivalent to the development of a new mine.

Source: Prepared by COCHILCO.

Appendix 4 Total expected water consumption

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Total consumption	16,254	18,499	19,984	20,593	22,034	22,569	23,636	23,767	23,831	24,150	24,885	25,354

Source: Calculated by COCHILCO.

Appendix 5 Expected water consumption by origin

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Continental water	12,977	13,760	13,807	13,785	13,890	13,822	14,207	14,087	13,871	13,822	14,195	14,534
Seawater	3,277	4,740	6,177	6,808	8,143	8,747	9,429	9,681	9,960	10,327	10,689	10,820

Source: Calculated by COCHILCO.

Appendix 6 Expected water consumption by region

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
CONTINENTAL WATER												
Arica y Parinacota	0	5	15	15	14	12	12	11	0	0	0	0
Tarapacá	1,062	1,188	1,0297	1,173	1,205	1,142	1,167	1,171	1,175	1,173	1,178	1,179
Antofagasta	5,399	5,606	5,421	5,370	5,260	5,142	5,192	5,069	4,884	4,751	4,464	4,419
Atacama	1,591	1,855	1,947	1,904	2,028	2,339	2,525	2,607	2,631	2,675	3,226	3,614
Coquimbo	798	825	653	698	776	803	861	861	848	848	827	823
Valparaíso	1,213	1,216	1,309	1,345	1,384	1,360	1,374	1,292	1,234	1,165	1,374	1,373
Santiago	1,173	1,211	1,238	1,290	1,282	1,282	1,323	1,345	1,357	1,414	1,426	1,427
O'Higgins	1,741	1,853	1,929	1,992	1,942	1,742	1,752	1,731	1,743	1,796	1,702	1,699

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
SEAWATER												
Arica y Parinacota	0	4	11	11	11	10	10	9	0	0	0	0
Tarapacá	0	0	0	0	171	282	400	417	435	466	540	550
Antofagasta	2,785	4,211	5,111	5,456	6,387	6,519	6,920	7,066	7,289	7,550	7,748	7,751
Atacama	492	524	600	708	835	1,169	1,309	1,362	1,414	1,464	1,547	1,663
Coquimbo	0	0	455	633	739	767	789	827	822	848	854	855
Valparaíso	0	0	0	0	0	0	0	0	0	0	0	0
Santiago	0	0	0	0	0	0	0	0	0	0	0	0
O'Higgins	0	0	0	0	0	0	0	0	0	0	0	0

Source: Calculated by COCHILCO.

Appendix 7 Expected water consumption by type of process

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Concentration												
Continental water	7,261	7,531	7,576	7,581	7,775	7,548	7,708	7,852	7,675	7,677	7,677	7,634
Seawater	2,736	3,103	4,364	4,930	6,072	6,688	7,488	7,849	8,311	8,668	9,044	9,267
LX-SX-EW												
Continental water	1,572	1,726	1,557	1,457	1,358	1,243	1,216	1,057	969	821	690	601
Seawater	541	1,636	1,813	1,878	2,072	2,059	1,941	1,832	1,648	1,659	1,645	1,552
Mine												
Continental water	810	876	896	933	932	902	862	833	787	777	752	745
Seawater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Others												
Continental water	1,654	1,846	1,854	1,813	1,837	2,089	2,312	2,222	2,340	2,382	2,934	3,363
Seawater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S&R												
Continental water	1,680	1,781	1,924	2,002	1,988	2,040	2,109	2,122	2,101	2,165	2,142	2,192
Seawater	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Calculated by COCHILCO.

Appendix 8 Expected water consumption by condition of project

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Base												
Continental water	12,956	13,602	13,508	13,299	13,112	12,555	12,585	12,397	12,132	11,969	11,783	11,719
Seawater	3,252	4,381	4,849	4,945	5,521	5,355	5,457	5,424	5,181	5,179	5,139	5,125
Probable												
Continental water	21	157	300	364	487	527	575	586	454	455	443	447
Seawater	25	359	855	1,064	1,308	1,633	1,859	2,049	2,259	2,316	2,365	2,369
Possible												
Continental water	0	0	0	0	72	127	239	241	244	267	264	272
Seawater	0	0	474	745	1,070	1,195	1,349	1,400	1,404	1,477	1,480	1,489
Potential												
Continental water	0	0	0	122	219	613	808	862	1,041	1,131	1,705	2,097
Seawater	0	0	0	54	245	563	763	808	1,116	1,355	1,705	1,837

Source: Calculated by COCHILCO.

Appendix 9 Expected water consumption by stage of advance of project

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Operation												
Continental water	12,885	13,413	13,162	12,736	12,116	11,292	10,966	10,476	10,217	10,045	9,957	9,771
Seawater	3,180	4,305	4,770	4,865	5,441	5,278	5,168	4,954	4,707	4,713	4,720	4,646
Implementation												
Continental water	71	189	346	564	995	1,262	1,619	1,922	1,914	1,924	1,827	1,948
Seawater	72	76	78	79	79	77	289	470	474	466	420	480
Feasibility												
Continental water	21	157	300	364	582	1,060	1,401	1,452	1,466	1,574	2,131	2,569
Seawater	25	359	1,328	1,809	2,549	3,282	3,858	4,138	4,650	5,001	5,401	5,544
Prefeasibility												
Continental water	0	0	0	122	197	207	221	238	273	278	280	246
Seawater	0	0	0	54	73	110	114	119	129	147	149	150

Source: Calculated by COCHILCO.

Appendix 10 Expected water consumption by status of environmental permits

l/s	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Operating with permits												
Continental water	10,425	10,772	10,346	9,824	9,262	8,428	8,140	7,605	7,382	7,162	7,085	6,856
Seawater	1,764	3,014	3,405	3,457	4,033	3,879	3,758	3,563	3,344	3,343	3,363	3,281
EIA submitted												
Continental water	0	138	261	307	372	393	412	415	274	283	286	288
Seawater	0	0	461	728	1,201	1,687	1,953	2,025	2,050	2,145	2,200	2,226
EIA approved												
Continental water	2,553	2,849	3,189	3,516	3,973	4,285	4,648	4,999	4,958	5,008	4,891	5,059
Seawater	1,513	1,725	2,257	2,491	2,705	2,745	3,186	3,459	3,540	3,564	3,558	3,623
Without EIA												
Continental water	0	0	12	138	283	717	1,008	1,068	1,258	1,369	1,933	2,332
Seawater	0	0	54	132	204	436	532	634	1,026	1,276	1,568	1,690

Source: Calculated by COCHILCO.

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