Chapter 12
Water and Mining

Orlando Acosta

Abstract Mining is one of the main activities of the Chilean economy, contributing 11.2% of GDP. Most mining operations in Chile occur in (semi-) arid zones and at geographical high-altitude sites, aspects that are critical for mining water management. Although national mining is the productive sector that consumes the least amount of water, in some arid areas of Northern Chile it is a relevant user ranking first or second followed by the agricultural sector. In arid northern regions, water withdrawal from mining is mainly from aquifers that recharged hundreds or even thousands of years ago, which are also hydraulically connected with important High-Andes wetlands. Water use in mining has generated various social and environmental conflicts in the past two decades. Chile's Water Code of 1981 (WC81) and its 2005 reform, as well as its Environmental Law of 1993 and its 2010 reform, allowed for a vigorous development of the mining industry at unseen growth rates. However, currently this legal framework is challenged by Chilean society. To meet future challenges, both the regulatory framework of water and the way the mining industry designs and implements mining projects in Chile must adjust to ensure that the Chilean mining activity can develop successfully and sustainably.

Keywords Chile · Mining · Mining water use · Water sources

12.1 Introduction

As a consequence of Chile declaring independence from the Spanish Crown in 1810, the country's mining industry gradually opened up to international trade. Since that time, stronger relationships were forged with foreign businesses introducing improved technologies, and foreign immigration as well as rural migration from Chile's center and south towards the mining north were generated (Guajardo 2007).

Forty years later, midway through the nineteenth century, the mining industry had already begun to change demographic and social characteristics of the country,

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marking widely the course of the economy and even the national politic framework. By 1870 Chile had positioned itself as the leading copper exporter worldwide (C. Minero 2015a), as the country benefited from the growing demands of the Industrial Revolution. The chief mining product of the nineteenth century was undoubtedly Chilean nitrates (*salitre*), which by 1890 had come to represent 56% of the country's revenues through export customs duties.

Chile's favorable natural conditions for mining are due to the geological structure of its territory. The subduction of the oceanic crust below the continental plate causes continuous magmatic activity which has been especially significant during the last 200 million years. This activity is also responsible for hydrothermal processes, which create the majority of the country's mineral deposits and account for their size and metal grade (Guajardo 2007).

This chapter presents a brief description of Chile's mining sector, focusing on its relationship with water resources as well as the major future challenges it will face to ensure sustainable water use.

12.2 General Characteristics of Chilean Mining

Chilean mining is characterized by a varied production of mineral compounds, which include iron, sodium chloride, calcium carbonate and copper. Categorized according to their metallic or nonmetallic origin, the contribution of each of these compounds in relation to Chile's national production is displayed in Fig. 12.1. Of all the metallic elements, iron and copper stand out most at 9.15 and 5.76 MMT annually, while the leading non-metallic composites include sodium chloride, at 11.83 MMT and calcium carbonate, at 6.69 MMT.

To this day, mining continues to be one of the country's most important economic activities. Between 2011 and 2015, the mining industry contributed 11.8% to Chile's GDP and produced 58.9% of the total export value (COCHILCO 2016a, b).

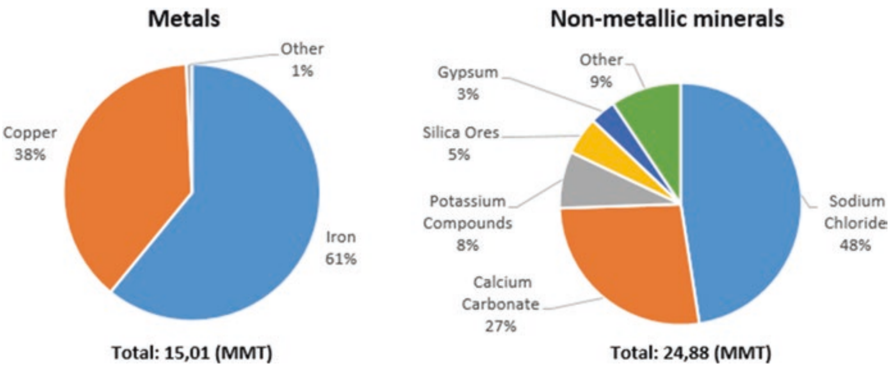

Fig. 12.1 Mining production in Chile in 2015 (COCHILCO, 2016a, b)

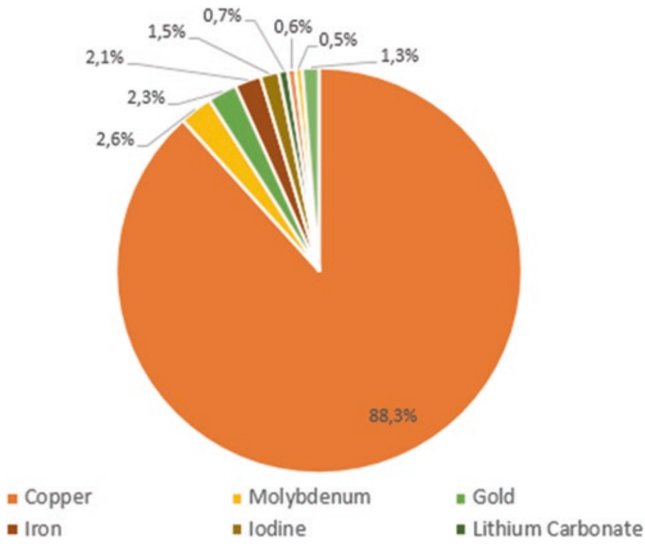

Fig. 12.2 Mineral composite production, 2015, in terms of export percentages (COCHILCO, 2016a, b)

Of all the mineral compounds exported, copper represents the largest percentage (Fig. 12.2), reaching 88.3% ($30,371,000) of Chile's total mining exports ($34,400,000), followed far behind by molybdenum and ore at 2.6% (906,000) and 2.3% ($800,000), respectively.

On a global scale, Chilean mining has historically occupied a prominent position. In 2015 Chile was the world's leading producer of copper and iodine and was second in lithium and third in molybdenum production. Chile has the largest copper and lithium deposits on the planet, representing 29% and 52% (respectively) of the world's total reserves. Table 12.1 presents Chile's global ranking in mineral composites production and its contribution to production and reserves worldwide.

Chilean mining – especially copper mining – solidified its prominent position on the global scene beginning in the 1990s. During this period, copper mining experienced an unprecedented exponential growth that was driven by Chile's stable regulatory framework and a favorable environment for private investment. This expansion process began to stabilize between 2005 and 2015 during a worldwide upswing in copper prices. Figure 12.3 shows the evolution of Chilean copper production beginning in the year 1960.

The rapid increase in copper production brought with it an equally exponential increase in water demand needed for processing this element. Most water consumption associated with copper and other mineral mining is located in the semi-arid zones of the country where the vast majority of mining operations have taken place.

Table 12.1 Production, shipping, and reserves for leading mineral composites

Element	Global production ranking	Contribution to global production (%)	Contribution to global reserves (%)	2015 production	2015 shipping values (M FOB)
Copper	#1	30	29	5.76 (MMT)	30,371
Iodine	#1	66	24	21.17 (kMT)	507
Lithium	#2	36	52	56.370 (TMT)	245
Molybdenum	#3	18	17	52.58 (TMT)	906
Silver	#5	6	13	1.50 (TMT)	213
Gold	#14	1	7	42.50 (MT)	800
Iron	s/i	1	1	9.15 (MMT)	718

Source: Prepared by the author based on information from COCHILCO (2016a, b) and USGS (2015)

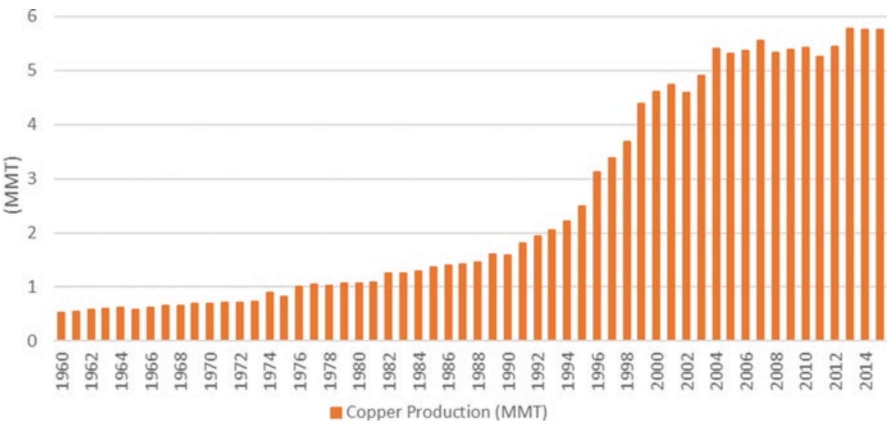

Fig. 12.3 Progress of Chilean copper mining (MMT) (COCHILCO 2016a, b)

12.3 The Geographic and Hydrological Characteristics of Chile's Mining Regions

The most important mining operations developed between the Tarapacá Region (I) in the north and the O'Higgins Region (VI) in the central/southern zone (Fig. 12.4). Figure 12.5 shows the distribution of each region's leading mining products. The Antofagasta Region (II) is highlighted here as the region producing the most copper, molybdenum, gold, silver, and lithium. Only in iron production does the Coquimbo Region (IV) outstrip the Antofagasta Region (II).

Fig. 12.4 Locations of Chile's mining regions

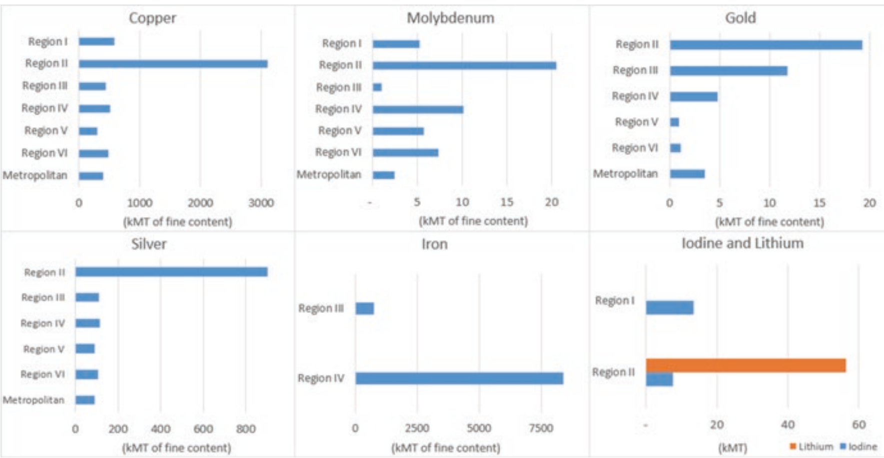

Fig. 12.5 Production of leading mining products by region, 2015, (kMT) (COCHILCO, 2016a, b)

Table 12.2 Location and elevation (MAMSL) of the major copper mines

Job name	2015 production (kMT in fine copper)	Region	Elevation (MASL)
Escondida	1152.5	Antofagasta	3100
El Teniente	471.2	O'Higgins	2500
Collahuasi	455.3	Tarapacá	4400
Los Bronces	401.7	Metropolitana	3500
Los Pelambres	375.8	Coquimbo	3200

Source: Prepared by the author based on information from COCHILCO (2016a, b)

Chile's mining operations are distributed across an area approximately 2000 km of latitudinal extension. They can be found at many altitudes, from near sea level to the Altiplano and the Andes Mountains, where they reach considerable heights exceeding 4000 MASL. As an example, Table 12.2 shows the location and elevation of the country's major copper mines.

The geographic diversity of the Chilean territories where mining takes place can be differentiated into three main areas in terms of their access to water resources, the security of the water supply, and the environmental risks associated with its use. These areas, or macrozones, the North, Central-North, and the Central-South, are described in detail below.

12.3.1 Northern Macrozone

This area includes the extreme north of Chile but does not include the Arica and Parinacota Region (XV), where there is very little mining activity. It is comprised of the Tarapacá, Antofagasta, and Atacama regions. This highly arid area has three major geographic traits: the Chilean Coastal Range, the Central Valley, and the Andean Mountains.

Water supply is defined by the extreme conditions of the Atacama Desert, one of the most arid landscapes in the world which extends over 180,000 km^2. This covers the administrative regions that comprise this macrozone. The coastal zone is hyper-arid with precipitations close to zero. The Central Valley is also characterized by an arid climate with precipitation under 10 mm/year. In the Andes altiplano, precipitation occurs during the summer months and varies between 100 and 250 mm/year. These conditions have triggered some permanent surface water flows which harbor the zone's arid-climate vegetation and wildlife (DGA 2016), thus acting as a small pluvial and nival recharge to the aquifers located above 3500 MAMSL (Acosta et al. 2013).

Despite the relatively higher precipitation in the area encompassing the altiplano mountains, the surface drainage is very poor due to the high permeability of the unconsolidated volcanic formations covering these areas. Salt flats, lagoon bodies and wetlands have formed in the depocenter of these drainage basins. The wetlands are the discharge site for major underground hydrodynamic systems (Acosta and Custodio 2008; Acosta et al. 2013). Between 1980 and 1990, the water resources associated with these basins attracted the attention of project developers because of their close proximity to mineral reserves and the more secure water source in an area characterized by interannual climatic variations.

The average availability of surface and groundwater resources in the northern macrozone is precarious, estimated at 14.7 m^3/s (DGA 1987) and 19.4 m^3/s (DGA 2016), respectively. However, these values may be too high to be used as indicators of availability in practice, as they do not take into account the high interannual variation affecting superficial runoff. It is also impossible to make use of a certain fraction of groundwater that is associated with wetlands of environmental interest. Due to the current levels of demand for water in this macrozone, it has been recently determined that many of the basins in the Tarapacá, Antofagasta, and Atacama regions have structural water deficits (INH 2016).

12.3.2 Central-Northern Macrozone

The Central-North macrozone is comprised of the Coquimbo and Valparaíso regions. The desert climate presents gradual increases in winter rainfall in a southerly direction, towards the dry steppe. The annual precipitation varies between 100 mm/year in Coquimbo and 300 mm/year in the Anconcagua basin – the most important basin in the Valparaíso Region – while south of the Valparaiso Region's mountain range, rainfall can exceed 500 mm/year.

In this macrozone, the Central Valley and altiplano terrain disappear in the middle of the Atacama Desert. The most salient geographic features of the area include the inner mountain range, with its narrow transverse valleys furrowed by the erosion of water from the Andes, and coastal plains marked by marine abrasions (DGA 1986).

The water structure is dominated by transversal valleys housing permanent runoff and exoreic basins open to the sea; the most import of these within reach of the Andes, present a mixed, regime, but fundamentally nival, with increasingly- volumetric flow rates, ranging between 2 and 30 m^3/s (DGA 1986).

The water availability in the Central-Northern macrozone is estimated at 63.2 m^3/s from superficial sources (DGA 1987) and approximately 24.6 m^3/s from groundwater sources (DGA 2016). Although the water availability of this macrozone is better than that of the North macrozone, it faces structural and intermittent water deficits in the majority of basins (INH 2016).

12.3.3 Central-South Macrozone

The central-south macrozone includes the Metropolitan and O'Higgins regions, being comparatively smaller than the previously described (29,939 km^2). Although this macrozone is also semiarid, average precipitation ranges between 350 and 1200 mm/year (DGA 2016).

In Chile's central-south zone, river basins expand considerably as the Central Valley expands. The high peaks of the Andes mountains in this sector accumulate snowfall, acting as natural reservoirs, which feeds rivers during the spring and summer when it melts.

The availability of water in the central-south zone is estimated at 308.0 m^3/s from superficial sources (DGA 1987) and around 65.8 m^3/s from groundwater sources (DGA 2016). Intermittent water deficits are a frequent occurrence during dry years. The severity of such deficits depends on the magnitude and duration of the drought (INH 2016).

12.4 Water Consumption in the Mining Industry

12.4.1 Water Sources and Flows

In 2015, total mining industry's water consumption in Chile reached a flow rate of almost 22.6 m^3/s (DGA 2016; COCHILCO, 2016a, b; C. Minero 2017). Eighty-eight percent of these flows was supplied by continental water resources, while raw sea water and desalinated seawater supplied the remaining 12%. Figure 12.6 indicates total water consumption of the mining industry in 2015, disaggregated by source type.

Although Chile engages in a significant amount of mining activity, the total continental water consumption (19,99 m^3/s) of this sector represents only 3% of the consumptive water use from natural sources. Despite this, water consumption for mining purposes can be comparatively significant in some northern regions (Fig. 12.7), such as in the Antofagasta Region (II), where the mining industry is the main consumer of water resources with a flow rate of 6.26 m^3/s (DGA 2016).

The majority of the water consumed by Chile's mining industry is consumed in copper mining, with a total flow rate of 15.2 m^3/s (COCHILCO, 2016a, b; C. Minero

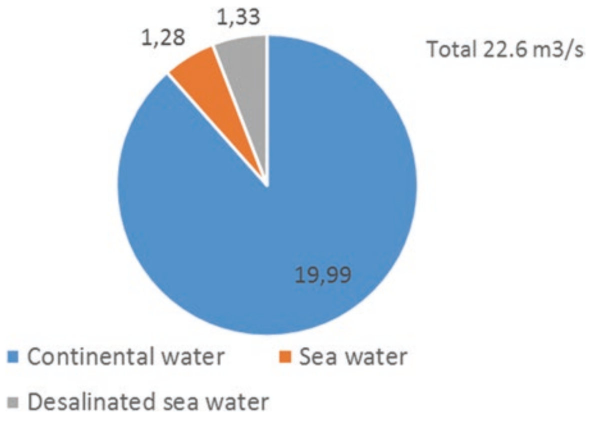

Fig. 12.6 Total water consumption by the Chilean mining industry in 2015, disaggregated by source of origin (m^3/s) (Prepared by the author based on information from DGA, 2016; COCHILCO 2016a, b; C. Minero 2017)

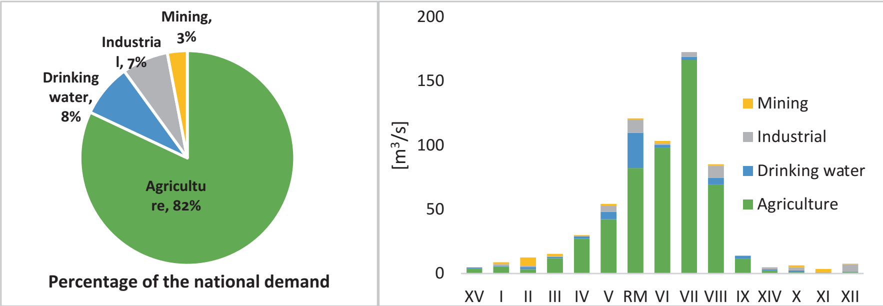

Fig. 12.7 Consumptive water use by productive sector and region (DGA 2016)

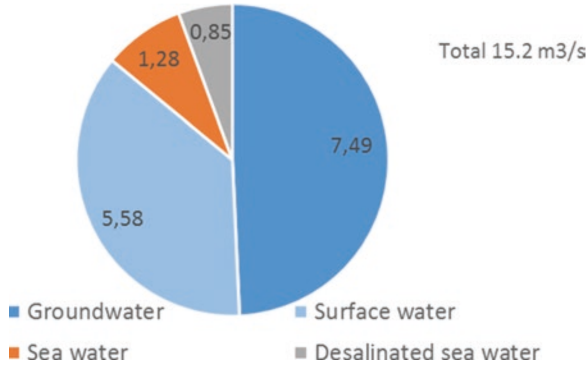

Fig. 12.8 Water consumption in Chilean copper mining in 2015, by source of origin (m^3/s) (Prepared by the author based on information from COCHILCO, 2016a, b; and C. Minero 2017)

2017). Groundwater is the main water resource in areas where copper mining takes place, accounting for 49% of the flow rate required by this economic sector, while surface water accounts for 37% (Fig. 12.8). These percentages are consistent with the relative availability of groundwater and surface water in the previously mentioned mining macrozones, thus confirming the relevance of these hydrogeological water sources for Chilean mining.

It is relevant to highlight the increase in raw and desalinated seawater usage during the period spanning 2010–2015. During this time, its usage in copper mining doubled, such that sea water comprised 14% of all water employed for these purposes in 2015 (COCHILCO, 2016a, b). It is estimated that by 2026, seawater will represent 50% of the total water used in Chile's copper mining industry (COCHILCO, 2016b).

Of the many processes associated with copper mining, the concentration process requires the most water at about 9 m^3/s, followed far behind by hydrometallurgy at 2 m^3/s (see Fig. 12.9). No significant changes in the relative importance of the different copper processing are expected in the future.

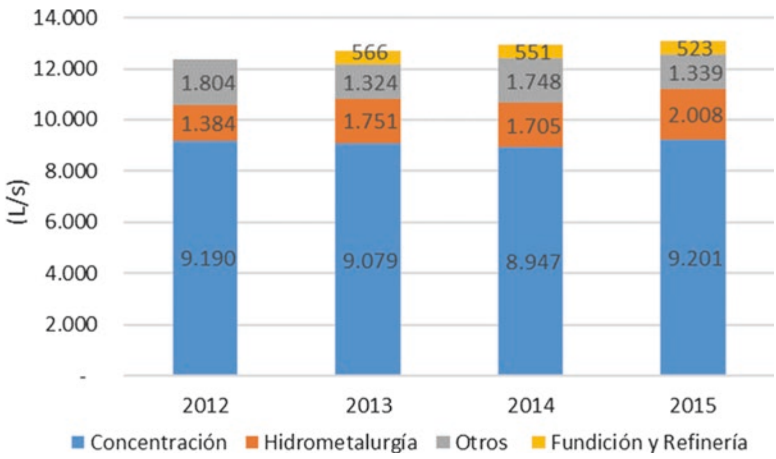

Fig. 12.9 Consumption of continental waters by process type in copper mining (COCHILCO 2016a, b)

Table 12.3 For reference purposes: the chemical quality of groundwater in the II, IV and VI regions

Element	II region	IV region	VI region
Sodium (mg/L)	100–600	50–100	20–30
Magnesium (mg/L)	30–50	30–40	10–20
Calcium (mg/L)	50–150	100–200	70–100
Chloride (mg/L)	100–1500	40–100	20–30
Sulfate (mg/L)	300–400	200–300	300–500
Conductivity(μmhos/cm)	1500–5000	700–1500	300–800

Source: www.dga.cl

12.4.2 Age and Quality of Used Water

Continental waters used by Chilean mining companies possess diverse chemical qualities, which depend on geographic location and the geologic and hydrologic characteristics of each basin. Generally speaking, waters from the north of Chile are more mineralized than those in the south. The degree of water mineralization is directly related to the climate hydrodynamics of each zone. The chemical quality of groundwater from the II, IV and VI regions is shown in Table 12.3 as a reference. The waters have a lower concentration of ions as they progress towards the southern regions where the climate is comparatively more humid, with a higher annual precipitation.

The surface water and groundwater used in mining is often freshwater; with an electric conductivity below 1500 μmhos/cm, which is suitable for human consumption and agricultural use. However, some of the current mining operations have adapted their processes using brackish continental waters or saltwater, with total dissolved solids reaching 40,000 ppm (Acosta et al. 2010).

In the northern hydrologically closed basins, where salt flats have developed, significant groundwater reserves exist (both brackish and salt); these are used in mining in the context of management plans approved by environmental authorities (Acosta 2010), which seek to reduce fresh groundwater usage to protect the basins' wetlands.

To manage groundwater resources well in terms of quality and long-term supply security, it is important to understand that the resource's availability relates directly to its recharge rate and therefore its age. Diverse studies show that during past geological periods, Chile's north was not always arid (Abbott et al. 2003; Nester et al. 2007; Herrera and Custodio 2013; Acosta et al. 2013). It is relevant here to mention two periods or "climate windows" characterized by higher rainfall: one more pronounced in the Late Pleistocene era (13,000–17,000 years BP) and a smaller one in the recent Holocene era (1100–700 years BP), which has been associated with Pre-Columbian archaeological remains (Nester et al. 2007). Outside of these two epochs, Chile's northern climate has remained as arid as it is currently, and sometimes dryer (Abbott et al. 2003; Acosta et al. 2013).

The apparent radiometric age of certain basins in the north (JICA-DGA 1995; Herrera and Custodio 2013; Acosta et al. 2013) confirm that groundwater reserves stored in Chile's northern aquifers were recharged thousands of years ago during the rainy climate periods. A carbon isotope study of these waters indicates groundwater renewal times between 5000 and 15,000 years, which is compatible with a heavy paleo-recharge period and current, low-intensity recharge rates. The oldest age measurements obtained are from deep borehole samples, a result of their long, slow circuit flows; meanwhile, the most superficial groundwaters are associated with more recent recharges and shorter circuits (Acosta et al. 2013).

It is thus plausible to propose that a significant proportion of groundwater used in Chilean mining is a mixture of recent and millenarian waters, some superficial and others deeper, extracted many times over from full-slotted screen borehole water wells. However, it is important to note that the fact that extracted apparently old groundwater does not necessarily imply that only non-renewable, fossilized water resources are being pumped (Acosta et al. 2013). The sustainable use of millenarian water reserves is possible with well-designed hydrogeologic management plans.

12.4.3 Water Rights

As presented in (Vergara and Rivera 2018), in Chile, the use of continental waters from natural sources requires granted water rights (WR). While a great number of WR have been granted for mining purposes since the beginning of the twentieth century, the majority were granted during the 1990s and 2000s. Tejos and Proust (2008) found that by 2006, the mining industry already possessed consumptive water rights equivalent to a flow rate of 30.7 m^3/s. This study considered mining

Table 12.4 Water rights granted for Chilean mining between the Tarapacá and O'Higgins regions

Region	Groundwater rights	Surface water rights	Total (m^3/s)
I – Tarapacá	3.162	553	3.715
II – Antofagasta	13.035	2.039	15.074
III – Atacama	9.080	3.045	12.125
IV – Coquimbo	3.031	2.532	5.563
V – Valparaíso	2.458	1.211	3.669
RM – Metropolitana	1.696	2.255	3.951
VI – O'Higgins	306	9.001	9.307
Total (m^3/s)	32.768	20.636	53.404

Source: Prepared by the author based on information from the Public Water Registry (DGA 2016)

companies from the Tarapaca (I) and the O'Higgins (VI) Region, which together represent about 96% of the country's metal production and 70% of its non-metal production.

At present, an estimation of the number of consumptive water rights granted to the mining industry up to 2016, has been possible with information available from the Public Water Registry (CPA), administered by the DGA. This registry shows that WR granted to mining before 2016 were approximately 53.4 m^3/s. Table 12.4 shows the regional distribution of surface and groundwater water rights granted to mining. Groundwater rights outweigh surface water rights in the northernmost regions extending up to the Valparaiso Region (V); this predominance changes in the Central-South macrozone as surface water becomes more available, which is easier to obtain, and cheaper to extract.

The increase in total granted water rights for mining since Tejos and Proust (2008) report is explained by new water rights granted for approximate 11 m^3/s, between 2008 and 2016, and regularized water rights not considered in the 2008 study. It is important to consider the estimate of granted water flow 53.4 m^3/s as a reference, as the CPA is currently being updated by DGA.

It is also relevant to highlight that the nominal granted water flow for mining is more than two times greater than this industry's average consumption. This fact is not abnormal when one considers that nominal granted water flow sets an extraction cap, which is higher than the median extracted water flow.

12.4.4 Environmental Evaluation on Water Usage

Following the enactment of the 1993 Environmental Law, Ley 19300 – Bases del Medio Ambiente, new mining projects had to undergo an environmental impact evaluation according to the Environmental Impact Assessment System (SEIA). This assessment considers an initial technical evaluation phase conducted by a licensed body of governmental agencies that have environmental competence, and a final qualification phase by a multi-sectoral board comprised of political authorities.

Thus, the rapid growth experienced by Chile's mining industry in the 1990s was coincident with a young and inexperienced environmental institutionality, which had to assume the challenge of evaluating a high number of large-scale mining projects, many of which were to take place in extreme geographic and climatic environments. In many occasions, the complexity of the presented projects exceeded the technical capability of the governmental agencies evaluating them, since they had to take on the new responsibilities without the qualified manpower and financial resources needed to do so. During this first decade of SEIA's operations, acquiring the permit became a goal in itself for many project developers, while the reality of the projects' decades-long existence in context of the proposed hydro-environmental hypotheses and commitments went largely unappreciated. As a result, it was not uncommon for badly-designed environmental follow-up plans and weak evaluation processes to be accepted. In many cases, these measures did not include appropriate contingency plans for unexpected events and continuous rigorous monitoring was not guaranteed for some projects.

In order to correct these (and other) situations, environmental law was reformed in 2010, to the effect that current projects must undergo more rigorous evaluations and more stringent follow-up activities. In addition, the Superintendence for the Environment (SMA) was created, a new devoted exclusively to overseeing environmental standards compliance, monitoring projects approved in the SEIA framework, and apply sanctions for non-compliance. However, there appears to be an incongruity between the wide scope of SMA's national mission and its tight budget and staffing, which in 2015 consisted of $9 MM/y and 154 staff members. (Ministerio de Medio Ambiente 2015). Before the 2010 legal reform, monitoring was conducted by about 15 sectoral agencies, with an operational network spread across the entire national territory. At present, these agencies currently just provide technical support according to SMA specific requirements.

12.5 The Future of Chilean Mining: Water Challenges and a Model for Future Development

The WC81 and the Environmental Law of 1993, reformed in 2005 and 2010, respectively, allowed the Chilean mining industry to grow at an unprecedented rate. The most relevant case is copper mining, which more than tripled its production in the last 25 years, increasing from 1.6 MMT in 1990 to 5.8 MMT in 2015. The enormous effort of the private and public sector behind the high growth of the Chilean mining industry can be evidenced when one considers that it normally takes more than 10 or even 20 years between a project proposal and its implementation. The mining growth contributed directly and indirectly to the important increase in Chile's per capita income, which during this period grew fourfold from $6106/capita in 1990 to $23,564/capita in 2015.

Meanwhile, during this final stretch of the second decade of the twenty-first century, the Chilean mining industry is confronted by the paradox facing the mining industry worldwide: although this industrial activity is indispensable to the continuance of our civilization, it seems that citizens look on the sector with a critical eye. The regulatory framework that permitted the growth of the industry is currently being challenged by Chilean society, which has expressed a lack of confidence in it.

The use of water in mining has produced several socio-environmental conflicts over the past two decades (Acosta 2005, 2010; Ch. Sustentable 2010). These problems mainly concern the environmental impacts on wetlands and riparian areas which have been affected to varying degrees; these include changes in the area's water security, in the chemical quality of water as a result of mineral and metallurgical extraction processes, and in the groundwater and surface water runoff systems impacting previous water right holders.

Oftentimes, the impact of large mining operations establishment affecting the sociocultural dynamics of towns and cities, increase the local community's negative perspective about mining's water usage, based more on emotions than empirical data.

It is likely that Chile's regulatory framework and environmental institutionalization, as well as the way in which the mining industry designs and implements projects, will have to undergo adjustments in order to ensure that Chilean mining can continue sustainably developing.

The impacts of the mining industry's water usage will be minimized, contributing to greater public consent, in the extent that water management plans are developed by experts on the basis of high-level scientific and technical information, accountability and transparency regarding water usage, and under strict environmental monitoring in full view of the community.

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References

Abbott, M., Wolfe, B., Wolfe, A., Seltzer, G., Aravena, R., Mark, B., Polissar, P., Rodbell, D., Rowe, H., & Vuille, M. (2003). Holocene paleohydrology and glacial history of the central Andes using multiproxy lake sediment studies. *Paleogeography, Paleioclimatology, Paleoecology, 194*(1), 123–138.

Acosta, O. (2005). Intensive use of aquifers by mining activity in northern Chile. Groundwater intensive use. 7: 177–185.

Acosta, O. (2010). El Caso Coposa: Cómo pasar del conflicto ambiental a la gestión hídrica proactiva y transparente. In G. Delaveau, M. Muñoz, & R. Noriega (Eds.), *Transparencia en el ámbito público privado: balances y desafíos pendientes* (pp. 117–123). Santiago: Chile Transparente, Capítulo Chileno de Transparencia Internacional.

Acosta, O. y Custodio, E. (2008). Impactos ambientales de las extracciones de agua subterránea en el Salar del Huasco (norte de Chile). *Boletín Geológico y Minero, 119*(1), 33–50.

Acosta, O., Rengifo, P. y Dzogolyk, E. (2010). Saline groundwater: An alternative for the sustainable exploitation of Andean highland groundwater reserves. *Water in Mining Congress, Water Supply,* 157–165.

Acosta O., Guimerà J., Custodio E., Ansón I. y Delgado J. L. (2013). Contribución al conocimiento de la hidrogeología de las cuencas intraandinas del N. de Chile. In N. González, E. E. Kruse, M. M. Trovatto, & P. Laurencena (Eds.), *Aguas Subterráneas Recurso Estratégico* (Tomo I, pp. 118–125). Buenos Aires: Editorial de la Universidad de la Plata.

COCHILCO (Comisión Chilena del Cobre). (2016a). *Anuario de Estadísticas del cobre y otros minerales 1996–2015*. https://www.cochilco.cl/Lists/Anuario/Attachments/15/cochilco_anuario_2015.pdf

COCHILCO (Comisión Chilena del Cobre). (2016b). *Proyección del consumo de agua en la minería del cobre al 2026*. https://www.cochilco.cl/Listado%20Temtico/2%2023%20Proyeccion%20de%20consumo%20de%20agua%20en%20la%20mineria%20del%20cobre%202016-2027.pdf

DGA. (1986). *Mapa Hidrogeológico de Chile*. Santiago: Dirección General de Aguas, Ministerio de Obras Públicas. http://documentos.dga.cl/SUB435.pdf.

DGA. (1987). *Balance Hídrico Nacional. Santiago de Chile*. Santiago: Dirección General de Aguas, Ministerio de Obras Públicas. http://sad.dga.cl/ipac20/ipac.jsp?session=1349N4543565L.131053&profile=cirh&uri=link=3100006~!1527~!3100001~!3100002&aspect=subtab13&menu=search&ri=1&source=~!biblioteca&term=Balance+h%C3%ADdrico+de+Chile+%2F&index=ALTITLE.

DGA. (2016). *Atlas del Agua de Chile*. Santiago: Dirección General de Aguas, Ministerio de Obras Públicas. http://www.dga.cl/atlasdelagua/Paginas/default.aspx.

Guajardo, J. C. (2007). *La agenda minera en Chile: revisión y perspectivas. Series recursos naturales e infraestructura* (60 p). Santiago: CEPAL.

Herrera, C. H. y Custodio, E. (2013). Origen de las aguas de pequeños manantiales de la costa del norte de Chile, en las cercanías de Antofagasta. *Andean Geology, 41*(2), 314–341.

INH. (2016). Análisis de Requerimientos de Largo Plazo en Infraestructura Hídrica. Estudio elaborado para DIRPLAN-MOP.

JICA-DGA. (1995). *The study on the development of water resources in Northern Chile. Supporting Report B*: Geology and groundwater.

Consejo Minero. (2015a). *Minería en números*. Cecilia Valdés Editora. http://www.consejominero.cl/wp-content/uploads/2015/09/Libro-Consejo-Minero-miner%C3%ADa-en-n%C3%BAmeros.pdf

Consejo Minero. (2015b). *Panorama económico y regulatorio de la minería*. http://www.consejominero.cl/chile-pais-minero/panorama-economico-de-la-mineria/

Consejo Minero. (2017). http://www.consejominero.cl/agua/2015/todas

Chile Sustentable. (2010). *Conflictos por el agua en Chile: entre los derechos humanos y las reglas del mercado* (S. Larraín & P. Poo, Eds., 360 p).

Ministerio de Medio Ambiente. (2015). *Cuenta Público Participativa 2015*. Concepción: Superintendencia del Medio Ambiente. Gobierno de Chile. 24 p. http://publico.mma.gob.cl/cuentapublica/doc/2015/cuentapublica_2016_baja.pdf.

Nester, P. L., Gayo, E., Latorre, C., Jordan, T. E., & Blanco, N. (2007). Perennial stream discharge in the hyperarid Atacama Desert of northern Chile during the latest Pleistocene. *Proceedings of the National Academy of Sciences, 104*(50), 19724–19729.

Tejos, M., & Proust, J. (2008). *Derechos, Extracciones y Tasas Unitarias de Consumo de Aqua del Sector Minero Regiones Centro-norte de Chile*, *Proust Consultores, Direccion General de Aguas y División de Estudios y Planificación*. Santiago: Ministerio de Obras Públicas.

USGS (United States Geological Service). (2015). *Commodity statistics information*. http://minerals.usgs.gov/minerals/pubs/commodity/

Vergara, A., & Rivera, D. (2018). Legal and institutional framework of water resources. In G. Donoso (Ed.), *Water policy in Chile*. New York: Springer.