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Sustainable Development Threats, Inter-Sector Conflicts and Environmental Policy Requirements in the Arid, Mining Rich, Northern Chile Territory

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ABSTRACT
Northern Chile has been an N–S arid to semiarid belt for more than 100 million years. Also, it is one of the world's most richly endowed territories in terms of Cu(Mo) porphyric deposits. Its mining output has steadily grown since the 1980s and has recently benefited from increased Asian demand and high Cu prices. The scarce water resources are allocated according to the 1981 act that emphasizes economic efficiency based on free transference between water-right owners. As a result, water rights have attained peak market prices, at the US$200 000 level per l/s. Besides the consequences of the uneven mining–agricultural competition for water rights and the environmental effects of accelerated groundwater withdrawal, social unrest has locally attained serious levels, in particular in the Atacama Region. Therefore, the central government is considering significant changes to the present legislation, allowing a stronger participation of the state in water management issues. Copyright © 2009 John Wiley & Sons, Ltd and ERP Environment.

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Introduction

Copper mining is the main economic activity in Chile, with sales over US$30 000 million (2007), which represent 55% of the country exports and about 37% of the total copper mined in the world. Besides, several ventures worth US$14 300 million are pending final approval, and will be probably carried out in the coming years despite current copper price fluctuations. These projects are supported by *ca*. 38% of the World reserves, that is, about 250 Mt (million tons) of metallic Cu (Minería Chilena, 2006a). However, the geological evolution of the Chilean territory determined that an overwhelming proportion of its metallic ore deposits, including the Cu(Mo) porphyries, are located in the arid to extremely arid northern part of the country. The scarcity of water resources in this region hampers the feasibility of new projects and expansions, and menaces the sustainability of ongoing operations responsible for 67% of the current Chilean copper production (Minería Chilena, 2005a). In turn, the pressure for water resources reaches the farmers community in the form of high

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bids for their water rights, with the subsequent social and environmental effects. In fact, conflicts have arisen in recent years in relation to excessive water withdrawals and pollution by mining companies to the detriment of the farming operations. On the other hand, given that the 1981 National Water Act left the allocation of water resources to the free market driving forces, the national agencies can do very little or nothing regarding these conflicts. A proper understanding of this situation may serve as a first step towards the development of new schemes, in which farmers, mining companies and the government should work together to ensure the sustainable development of this richly endowed but fragile arid region. Indeed, as shown by Luken and Hesp (2007), there is still much work to be done in order to allow effective policy integration and enhance the contribution of industry and economic sectors such as mining and agriculture to sustainable development in Chile.

This work describes the geological, morphological, climatic and hydrological setting of the region. The following discussion focuses on (1) the interplay between the water demands from the mining industry and the needs of the agricultural sector, (2) the social responsibility to guarantee the fulfillment of the basic water requirements of the indigenous communities, (3) the potential environmental consequences of over-allocation and/or impairment of water resources, (4) the alternatives open to the mining industry to cope with current water restrictions and (5) the global climatic processes that may add further stresses to this part of the Chilean territory. The understanding of the interactions and competition between these drivers is of vital importance, because conflicts are likely to increase in the next years. Furthermore, careful examination of the economic development pressures in northern Chile may hold important warnings for other arid regions of the world, many of which may be facing similar decisions and challenges regarding the allocation of water resources in times of increasing scarcity.

Geology and Mineral Resources in Chile

Chile has a peculiar geography involving a narrow, 4500 km long N–S strip of mountainous territory between 17°30′ and 56° S, which is flanked by the Pacific Ocean and the Andean Mountains. The main physiographic features of the Chilean territory include (from west to east) a coastal cordillera, a central tectonic basin, and the high Andes. This simplicity is broken only between 23° and 25°30′ S, with the addition of a central N–S block (the so-called Domeyko Ranges), and between 26 and 33° S, where the tectonic basin is absent (Figure 1).

The Chilean geology exhibits the strong imprint of subduction related processes, in terms of both magmatism and tectonics. Subduction of oceanic plates began during the Paleozoic time and was accelerated by the opening of the Atlantic Ocean, some 160 Ma (million years) ago. As a consequence of this, calc-alkaline magmas were emplaced from the plutonic to the volcanic levels, in a series of almost continuous episodes, each of them endowed with a rich provision of copper–molybdenum, in addition to important gold, silver and iron deposits (Oyarzún, 2000).

Although metallic ore deposits are distributed throughout the Chilean territory, most of them, including the giant and high grade Cu porphyries, with annual production of *ca*. 4.9 Mt Cu and 43 300 t Mo (COCHILCO, 2007), are located north of 34°10′ S, where water resources range from short to extremely scarce. The major Cu(Mo) porphyries are distributed between 20°10′ and 34°06′ S, in N–S belts of Cretaceous to Pliocene age (Figure 1). A northern belt (21° S–26°30′ S) hosts the giant Cu porphyries of the Chuquicamata district and Escondida. Another rich cluster is located in the high Andes, from 31°40′ to 34°06′ S, where three younger, Pliocene world-class porphyry copper deposits are located: Los Pelambres, Rio Blanco–Los Bronces and El Teniente, each one containing several thousand Mt of Cu(Mo) ore (Camus and Dilles, 2001).

Climate and Water Resources

The Chilean territory exhibits a strong N–S climatic polarity, a consequence of its expanse between 17°30′ and 56°30′ S. While the influence of the Pacific Ocean and the Humboldt Stream moderates the range of temperatures, there is an extreme variation in precipitation along the coast, ranging from almost 0 mm/year in the northern regions (Tarapacá and Antofagasta) to over 5000 mm/year in the southern ones (Aysen and Magallanes) (Errázuriz

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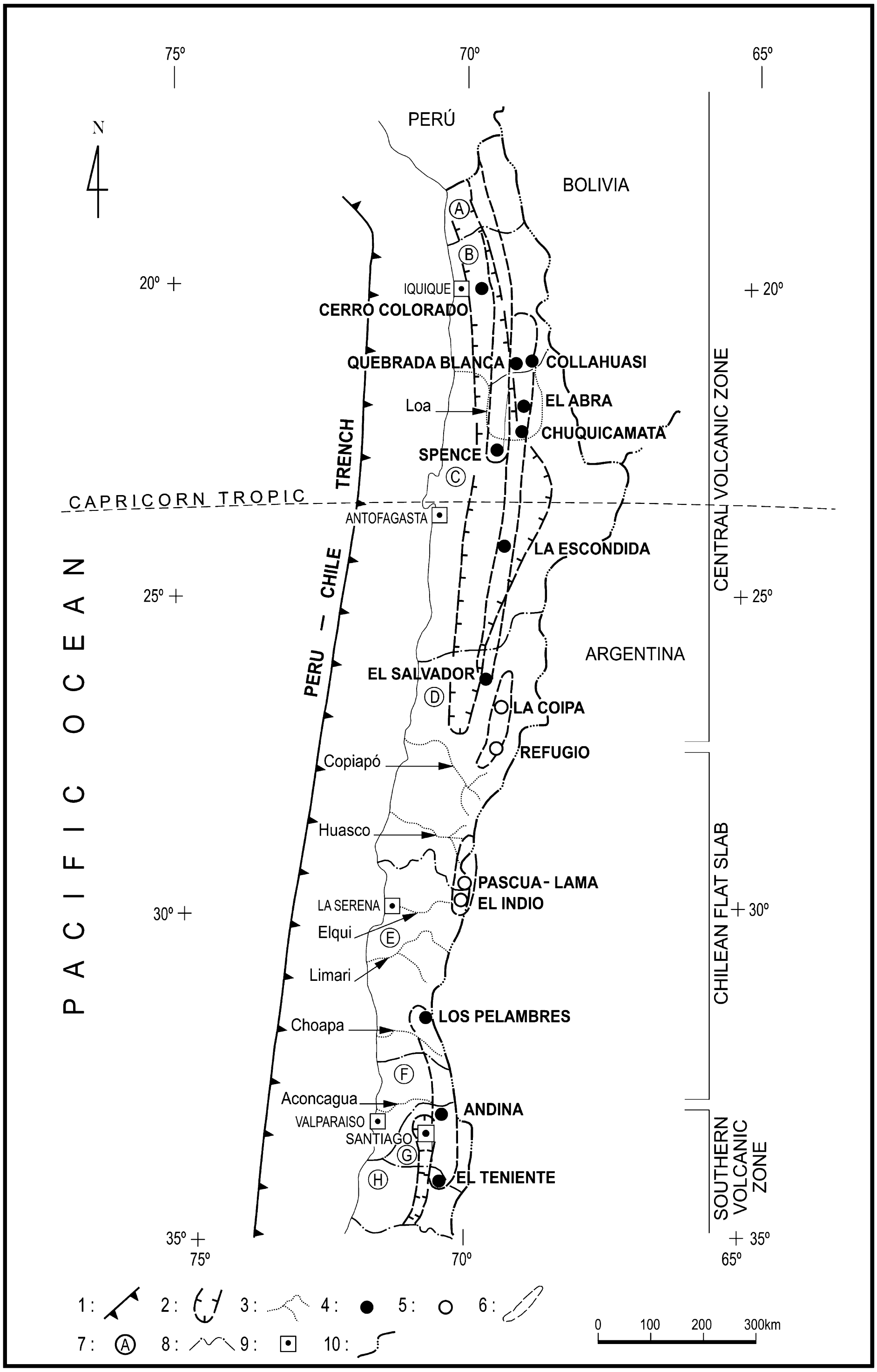

Figure 1. Major tectonic, metallogenic and geographic traits of North Chile (modified after Skewes and Stern, 1996; Camus and Dilles, 2001). 1, Peru–Chile trench; 2, central graben; 3, river; 4, porphyry copper deposit; 5, epithermal Au(Ag) deposits; 6, metallic belt; 7, regions (A, Arica-Parinacota; B, Tarapacá; C, Antofagasta; D, Atacama; E, Coquimbo; F, Valparaíso; G, Metropolitana; H, O'Higgins); 8, administrative boundary; 9, city; 10, international boundary

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et al., 1987). The extreme dryness of the northern domain is due to the combined action of the cold Humboldt Stream, and the subtropical high-pressure belt, where descending stable air (Hadley Cell) reduces convection and thus precipitation (Houston, 2006). A complementary W–E climatic polarity is a consequence of the huge Andean Cordillera, which reaches over 6000 m of altitude north of 36°30′ S, and acts as an effective water collector barrier.

North of 26° S, most of the precipitation is related to the warm summer atmospheric fronts originated in the Atlantic Ocean, which cross over the Amazonia region and the Bolivian territory and are responsible for the so-called 'Bolivian Winter' (*Invierno Altiplánico*). Contrary to what the name suggests, it behaves as monsoon rains during the austral summer (Aravena *et al.*, 1989; Houston and Hartley, 2003) that fall over the Andean heights but do not accumulate in glacier deposits due to low humidity conditions (Ammann *et al.*, 2001). However, they are responsible for the existence of surface and groundwater bodies, and even sporadic flash flood episodes that may reach the Atacama Desert (Houston, 2006). There is a strong correlation between precipitation and altitude, the former being negligible below 2000–2500 m of altitude (Figure 2(A)). Besides, runoff is also insignificant for precipitations lower than 50 mm/year (Figure 2(B)). Precipitations of up to 300–350 mm over the upper altitude belt may account for some replenishment of the aquifers (Houston, 2001; Houston and Hartley, 2003).

Only one Andean river (the Loa) reaches the Pacific Ocean, whereas a large number of small to large basins act as groundwater reservoirs and evaporation sites (the so-called *salares*, i.e. playa deposits). These reservoirs are mostly interconnected (Herrera *et al.*, 2006), allowing water flow along an E–W altitude gradient. A typical setting (Figure 3) includes an upper tectonically controlled recharge zone, which connects downward to a wetland (the so-called *bofedal* or *vega*) and finally to a *salar* (McKittrick, 2006). A major portion of these groundwater resources accumulated during past stages of more humid conditions, such as the late glacial episode between *ca.* 13 000 and 8500 years BP (Grosjean and Veit, 2005), aridity having been a dominant condition in this northern belt since Mesozoic times (Clarke, 2006).

South of 26° S most of the precipitations are related to SW winter atmospheric fronts, the Southern Westerlies (Veit, 1996; Montecinos and Aceituno, 2003; Vuille and Milana, 2007). Precipitations for the costal belt reach (mm/year) 27 at 28°27′ S, 84 at 29°54′ S, 114 at 30°34′ S and 247 at 31°55′ S (DGA, 1987). A different case is

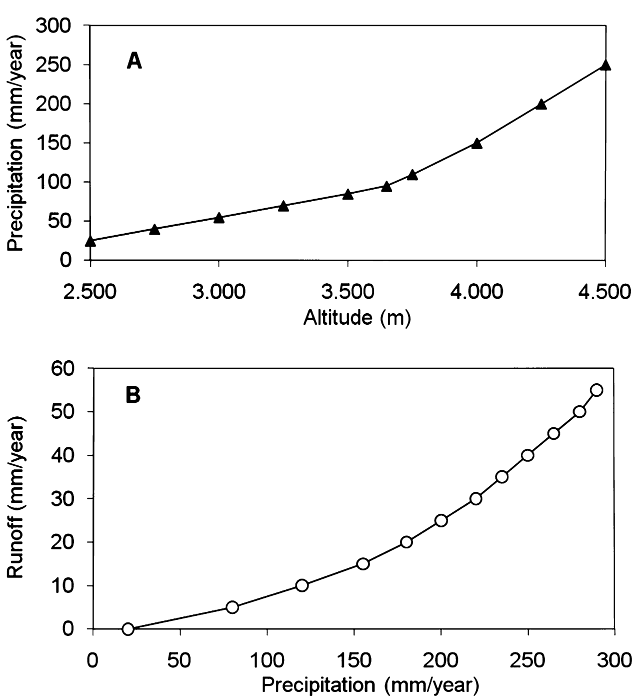

Figure 2. Altitude–precipitation–runoff relationships in Northern Chile (modified after Grilli, 2001)

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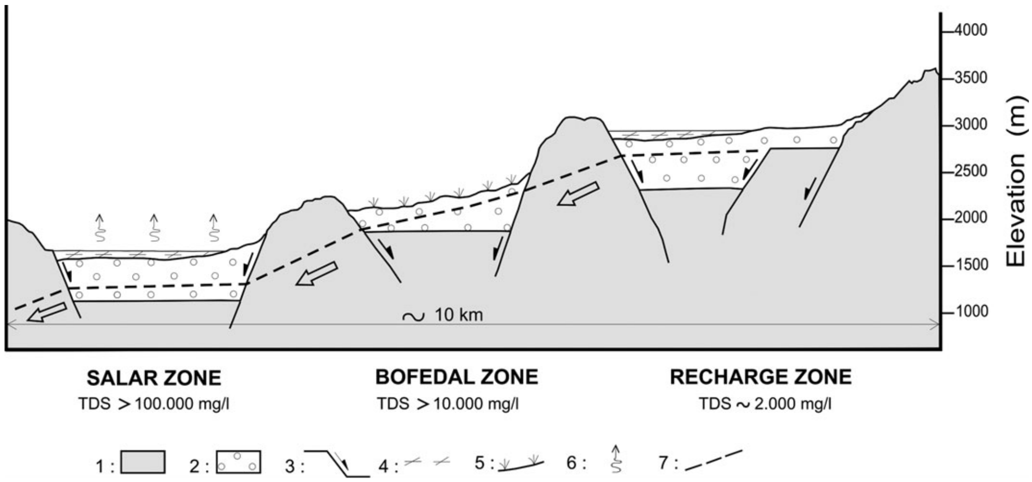

Figure 3. Conceptual scheme for groundwater recharge–discharge zones in the Andes of Northern Chile (modified after McKittrick, 2006). 1, country rock; 2, Cenozoic sediments; 3, normal faults; 4, salar's sediments; 5, wetlands (*bofedales*); 6, evaporative process; 7, regional water table; TDS, total dissolved solids

observed at the Andean mountains (200–300 km from the coast), where most of the precipitation occurs in response to the cooling of rising air masses. The lack of a suitable meteorological network in this domain has prevented the collection of accurate figures. However, a rough estimate indicates Andean precipitation double that of the coastal belt. Both the Andean and coastal precipitation increase two- to threefold during ENSO (El Niño Southern Oscillation) episodes, which occur with a periodicity of five to seven years. In exchange, they may diminish to a half or less during the dry La Nina years, which are characterized by the dominance of cold oceanic waters (Fernández, 1999; Montecinos and Aceituno, 2003). Increased activity of the Southern Westerlies, with more frontal activity during winter, is well correlated to El Niño years. At least eight very important El Niño flood events have been observed during the last 50 years (Jenny *et al.*, 2002).

Except for scattered strong winter rainy episodes, generally related to the El Niño cycle (Santibañez and Uribe, 1999; Montecinos and Aceituno, 2003), river flows increase during the summer season as a consequence of snow melting at the high Andes. This process allows the existence of six river systems that flow from the high Andes to the Pacific Ocean between 26 and 32° S. Except for the northernmost river (Salado), the rest support an important agricultural activity. Average river flows (m^3/s) range between 2.9 for the Copiapó (27°20′ S) and 13.2 for the Choapa (31°37′ S) rivers (Salazar, 2003). Besides, there is a network of nine water reservoirs, with a total capacity of *ca.* 1500 Mm^3 (Table 1), and an extensive water channel system that mitigates the shortage of precipitations during the rather normal dry periods. Since most of this realm consists of highlands formed by granitic batholiths or volcanic formations lacking N–S elongated sedimentary basins, groundwater resources are confined to alluvial sediments in the narrow E–W oriented valleys (the so-called *Valles Transversales* system) and to fractured rock massifs (Arumí and Oyarzún, 2006; Oyarzún *et al.*, 2008). Therefore, groundwater plays here a minor role in comparison to that of the northernmost regions, where N–S elongated sedimentary basins behave as important reservoirs.

The Chilean Water Management System

Chile is well known for having an active water rights trading market (Honey-Roses, 2009). The 1981 Water Act freely transferred the ownership of rights for water use and trade to private persons and entities. The legal body diminished the government attributions, which are currently restricted to monitoring surface water discharges, groundwater levels and water quality, and granting new water rights. An amendment introduced to the Water Act in 2005 included the mandatory justification for new requested water rights, the taxing of non-used water resources

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Region	Name	Location	Maximum storage (Mm^3)
Atacama	Lautaro	27° 24′ S; 70° 18′ W	35
	Santa Juana	28° 36′ S; 70° 36′ W	168
Coquimbo	La Laguna	30° 08′ S; 70° 04′ W	40
	Puclaro	30° 00′ S; 70° 50′ W	200
	Recoleta	30° 28′ S; 71° 04′ W	100
	La Paloma	30° 44′ S; 71° 00′ W	750
	Cogotí	31° 00′ S; 71° 05′ W	150
	Corrales	31° 52′ S; 70° 56′ W	50
	Culimo	32° 04′ S; 71° 19′ W	10

Table 1. Water reservoirs in the 26°–32° S belt

and the faculty of the DGA (Chilean Water Authority) to restrict groundwater allocations and intervene during drought periods. The amendment also included the faculty of the DGA to restrict the use of new water rights for ecological reasons (Oyarzún *et al.*, 2008).

Given the private character granted to a major part of the Chilean water resources, and the fact that surface and groundwater are two legally separate assets, it is difficult to set up an integrated water management system at the watershed scale. However, the agricultural sector is usually well organized in associations that (1) distribute river waters according to existing rights (*Juntas de Vigilancia*) and (2) manage the irrigation infrastructures and channel networks (*Asociaciones de Canalistas*). Besides, the Chilean Government is currently promoting the establishment of water round tables or *Mesas del Agua* to achieve a harmonic use and protection of water by the different stakeholders, in particular the agricultural and mining sectors. However, an integrated basin management approach still lacks a constitutional and legal frame.

Mining–Farming Competition for Scarce Water Resources in North Chile

Water Requirements of the Mining Industry

Water is required for a wide variety of activities and processes in the mining industry, from the early exploration stage (drilling) to the closure plan operations. In northern Chile, where the amount of mineral resources exceeds that of water demanded for processing, water availability and costs are critical factors for the economic and environmental feasibility of new mining projects and the expansion of the existing ones. Water is used as a dust suppressor in mines and roads, in the flotation–concentration of sulfide minerals, in the transport and deposition of the tailings, in the piping of sulfide concentrates to shipping ports and in the leaching of oxide and sulfide minerals in piles (heap leaching). All these uses are of paramount importance and lack real alternative solutions beyond the levels of improved water recycling. Thus, the modern mining industry, driven both by environmental requirements and by the progressively scant water resources, has developed a number of devices and procedures for improving water recycling and controlling water pollution due to metal rich, acidic or cyanide bearing solutions. However, there are physical and economical limits for these conservative measures.

In 1995 the Chilean mining industry located between the Tarapacá (currently Arica-Parinacota) and Antofagasta Regions required about 25 m^3/s for its copper production (Salazar, 2003), which was then about 2.5 Mt/year and has doubled to attain over 5 Mt in 2006 (COCHILCO, 2007). Therefore, a prudent estimation for current water mining requirements is close to 50 m^3/s. According to the Salazar (2003) report, the figure mentioned represented only 6.8% of the total national water consumption (excluding the non-consumptive use for hydroelectric power generation). However, this percentage drastically increases in northern Chile (Figure 4), where most of the mining is done, water resources are meager and a number of new mining projects are awaiting approval.

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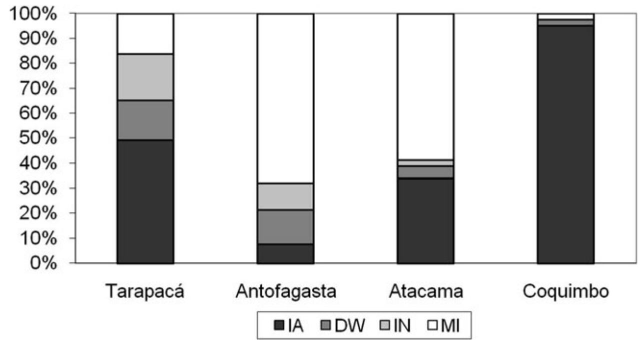

Figure 4. Water consumption pattern in different regions of North Chile. IA, irrigated agriculture; DW, drinking water; IN, industry; MI, mining use

Mining, Agriculture and Water Resource Demands between 18 and 26° S

The Tarapacá (18°–21°30′ S) and Antofagasta (21°30′–26° S) regions comprise the so-called *Norte Grande* (deep north). In 2007 the northern part of the Tarapacá Region was separated into a new administrative region: Arica-Parinacota (Figure 1). Considering that most of the current mining activity is located in Tarapacá, and for the sake of simplicity, we shall address both regions with the historical name.

Tarapacá and Antofagasta share a number of important characteristics, including the hyperaridity of their coastal and central domains, the physiographic organization in N–S elongated basins and ranges, dominance of the Altiplano (high plateau) summer monsoon and the presence of abundant copper resources in the coastal and pre-Andean ranges. However, the two regions exhibit contrasting conditions regarding the current use of water resources (Figure 4). This is due to the magnitude of the copper reserves and the number of high tonnage mining operations, which is very large in Antofagasta (Newbold, 2003). Besides, the Tarapacá Region has been conservative regarding the granting of water rights for mining expansions, and its agricultural sector is still an important consumer of water resources.

Increasing copper prices in the 2004–2007 span, combined with a number of new discoveries and reserve expansions at active districts, propelled a number of important mining projects in Tarapacá and Antofagasta. Considering only the latter region, mining projects worth US$4500 million are starting or close to start (Minería Chilena, 2005b). Besides, CODELCO Norte (the main branch of the state-owned copper mining company) has announced investments of US$6000 million for its Antofagasta Region operations during the 2006–2015 period (Minería Chilena, 2005c). Although these situations are rather cyclic (Newbold, 2003) and the current world's financial crisis may lead to a delay of some of these projects, several of them are already in progress and will increase the demand for the already scant water resources.

However, the present environmental regulations included in the 2005 amendments to the Water Act indirectly limit the access of mining companies to new water resources. For example, in November 2007 the environmental authority of Antofagasta refused an application of La Escondida mining company to pump 1027 l/s from two Andean sites (Minería Chilena, 2007a). The reasons behind this refusal relate to the fact that the water sources are close to springs and saline lakes, which are the natural habitat of local populations of Andean flamingos (e.g. *Phoenicoparrus andinus, Phoenicopterus chilensis*) and other wild species. Besides, these water reservoirs provide the flow for water springs and the survival of the Andean wetland ecosystems (*bofedales*), which in turn are directly related to the pastoral activities of the Aymara native communities. Therefore, a strong tension exists between the mining industry demands and the enforcing of current regulations, which is not immune to changes in the political scenario.

Mining, Agriculture and Water Resource Demands between 26 and 32° S

There is an important increase in water precipitation and surface runoff in this segment, which includes the Atacama (26–29° S) and Coquimbo (29–32°15′ S) Regions. Agricultural activities, which benefit from favourable

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solar radiation conditions, have incorporated modern crop practices and irrigation technology, allowing the production of valuable exportable crops. Also, a number of water reservoirs (Table 1) contribute to mitigate the risk of arid periods due to the ENSO cycle. Thus, the agricultural sector competes here with the mining industry in rather equal terms for water resources.

Important copper mining operations are carried out in both regions (e.g. Manto Verde, El Salvador and Candelaria in Atacama; Andacollo and Los Pelambres in Coquimbo). While current competition for scant water resources is mainly located in the Atacama region, other controversial consequences of the mining activities (e.g. abandoned tailing deposits) are or have been present in both regions.

Two rivers (Copiapó and Huasco) sustain the agriculture in the Atacama region. In this respect, a conflict has arisen between the farmer's association and the mining companies just as new copper and gold projects worth US$4532 million are close to start (Minería Chilena, 2007b). The new projects include the porphyry copper deposits of Caserones (Copiapó river watershed) and the huge epithermal Au–Ag–Cu deposit of Pascua Lama (Huasco river watershed). The conflict arises from the current water shortage in the Atacama Region, which has also affected its availability for human consumption in the cities of Copiapó and Caldera. Besides, there is a notorious decrease in groundwater heads in the Copiapó river basin, and a decrease in the Lautaro (Copiapó river) reservoir levels (Minería Chilena, 2007b). In addition, the US$2000 million Pascua-Lama project on the Andean headwaters of the Huasco River, at the Chilean–Argentinean border (Minería Chilena, 2004), has raised controversy and public opposition in the region, as well as international awareness. The farmers of this river basin have raised objections to the project, based on the potential pollution by heavy metals and chemicals, as well as on water shortage impacts (Minería Chilena, 2006b). Considering the location of the deposit, the existence of highly fractured and altered rocks and the high arsenic contents associated with the gold–copper mineralization (Chouinard *et al.*, 2005), the risk of pollution is real. In fact, the geological, structural and mineralogical setting is very similar to that of the neighbouring El Indio district (Elqui watershed, Coquimbo Region), where massive contamination of waters and sediments by Cu–As–Zn is observed (Oyarzún *et al.*, 2003; Oyarzun *et al.*, 2004, 2007). On the other hand, the mining operation threatens the stability of about 200–250 Mm^3 of ice deposits located in the surrounding area (Minería Chilena, 2005d), which act as semi-permanent snow packs. These deposits contribute with their partial melting to mitigate low runoff periods during dry years. Three of these snow packs are right on top of or close to the future mining operations, and as a consequence of natural conditions as well as the continuous human activities in the area of the project a significant part of these ice masses (about 70% according to preliminary reports) has already melted.

Because of the lack of new major mining projects, only minor water-related conflicts exist in the Coquimbo region. McKittrick (2006) estimated water right prices for the Atacama and Coquimbo regions in the range of US$7500–15 000 l/s. However, a potential problem lies on the different use of hydrological resources when water rights are transferred from farmers to miners.

In fact, water rights have been granted in excess regarding real water availability. This apparently unsustainable situation is explained by the discontinuous use of the water resource by farmers, as well as by the effect of water infiltration during both transport along non-lined channels and soil irrigation practices. Thus, the infiltrated water is then used downstream by other water right owners (Oyarzún *et al.*, 2008). However, when water rights are acquired by a mining company, this irrigation use–recharge–reuse process does not take place. This is the case, for instance, of the recent acquisition by a mining company from local farmers of ca. 400 l/s from La Cantera basin, Coquimbo, a likely non-sustainable withdrawal that has raised local and national concern considering the meagre recharge of this aquifer.

Options for Mining Companies and Likely Consequences

In order to cope with the necessary water requirements two main options have been analyzed by the mining companies besides recycling and other eco-efficiency practices. A first one is the acquisition of water rights from farmers, public water utilities or other mining companies. Giving the free market for water rights established by the Chilean water code (Honey-Roses, 2009), these are legitimate and economically attractive options. However, due to the asymmetrical conditions, a non-equilibrium situation affects these water trades. Thus, the price for

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1 l/s water right has increased from US$2500 (farmer to farmer transfer) or US$2000–3800 (farmer to urban transfer) to approximately US$75 000–225 000 in the Tarapacá and Antofagasta regions (McKittrick, 2006). An extreme example of the high prices attained by water rights corresponds to a water transfer involving two mining companies, Zaldivar and Escondida, the former selling water rights for 631 l/s for the sum of US$135 million to be paid over 15 years (McKittrick, 2006).

This pressure could eventually affect two rather vulnerable sectors in Chile, the environment and the small scale, low income farming in the northern regions. As already explained, the environmental risks relate to the preservation of minimum water resources (stream flows or pond water levels) required to maintain the Andean ecosystems. In turn, these ecosystems are vital for the preservation of small scale agricultural activities and the shepherding of *llamas* and *alpacas* (the well known Andean camelids). Therefore, although non-tapped groundwater resources (already targeted by mining companies) are still available in the Tarapacá and Antofagasta regions, two facts should be taken into account. First, a large part of this water has a fossil, non-renewable character. Second, the complexity of the rock-fracture connected aquifers implies serious risks of water shortages for the Andean communities and ecosystems, even for those located far away from the tapped sources. In addition, water right acquisition from farmers may pose a serious danger to preservation of the cultural heritage of the remaining pre-Hispanic native farmer communities in the Tarapacá and Antofagasta regions. Prior to the Spanish conquest (mid-16th century), the Precordilleran valleys and the Pampa de Tamarugal oasis were inhabited by the Aymara people (farmer-shepherds). This culture retains a strong presence in Tarapacá and Antofagasta regions, and preserves its links with other Aymara communities from Bolivia and Peru (Larraín, 1989; Orellana, 1994; Barrientos, 2003). Key elements for this cultural survival are the agricultural activities in the Precordilleran valleys and the annual religious celebrations and pastoral festivals in the different native villages. Therefore, although the quality and economic output of the Precordilleran agriculture are poor (Alonso, 2001), its extinction could lead to the loss of the Aymara culture in northern Chile. On this regard, Newbold (2004) presents an interesting discussion on Chilean economic development, based on natural resources use, and its effect on native groups in Chile. As she states, 'a balance is needed between the price paid for economic advancement and the destruction of indigenous people's cultural heritage'. Although the mentioned study focuses on the Mapuche people (south-central Chile), the same challenges must be considered and addressed for the Aymara communities of north-central Chile. Moreover, as explained by Hudson (2005), sustainability is inherently multi-dimensional, with cultural and social aspects, as well as politic, economic and environmental issues, being important components. Indeed, as stated by Vargas (2000), 'culture plays a central role in sustainable development in order to ensure the survival of traditional knowledge as well as to build upon the knowledge and experience possessed by indigenous groups'. Thus, this element should be considered with special care at different levels (e.g. local and national government) when dealing with water conflicts and sustainable development for the Chilean arid northern territory.

Considering that most mining operations in Chile are not farther than 200 km from the ocean, the use of saline or desalinated water has been envisaged as a second option by the industry. Concentration of sulfide minerals using saline water is feasible but problematic, and water desalinization involves important energy expenses. Besides, most porphyry copper deposits are close to the Andean Mountains, at thousands of meters altitude, demanding additional energy costs for water pumping. Consequently, Antofagasta Minerals, an important Chilean mining holding, which also owns the Antofagasta coastal city water utility company, decided to supply the city demands with reverse osmosis desalinized water in order to use its Andean head-water rights for their inland mining operations. Also, another initiative for using desalinized water has been implemented in this region by Escondida, the largest Chilean mining operation. However, the future of this initiative or similar ones will depend on the relative levels of copper and energy prices. In environmental terms, it would be also important how this energy is produced (in terms of CO_2 emissions).

Prospects on Additional Stress Factors on Water Availability

In addition to the already described conditions stressing water use in North Chile, the Altiplano summer monsoon yields could be seriously affected by the progressive destruction of the Amazonia wetlands and forests. These precipitation fronts depend on tropospheric winds, carrying increased water contents supplied by the Atlantic

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Ocean, and partly by the Amazonia region (Vuille, 1999), that maintain humid atmospheric conditions. Thus, the Amazonia performs as a sustaining mechanism, allowing atmospheric water movement over 3000 km of continental territory. In consequence, dry conditions on the Amazonia pose a serious threat to the Altiplano summer monsoon, the only source of precipitations for the Chilean northernmost regions. Unfortunately, this is a likely scenario considering that about 40% of the Amazonia forest could be destroyed and an additional 20% deteriorated in the next 20 years (Wallace, 2007).

Moreover, although rising water demands might greatly overweight the effect of natural factors such as water shortages due to global warming or disturbances related to the ENSO cycle (Fernández, 1999; Vörösmarty *et al.*, 2000; Montecinos and Aceituno, 2003), the combined action of anthropic and natural factors poses an even more threatening scenario. In addition, an increase in atmospheric CO_2 levels could also affect the ENSO cycle (Collins *et al.*, 2005; McPhaden *et al.*, 2006), and therefore the hydrological resources of North Chile, in particular the 26–32° S belt.

Finally, global climate change might also affect the future availability of water resources in north Chile. A recent study on climatic variability forecast for the Chilean territory carried out by the National Environmental Authority (CONAMA, 2006) considered potential scenarios for greenhouse gas emissions for the 2071–2100 period. In the worst case scenario, the 2046–2065 period registers a 300–500 m rise of the 0 °C isotherm, severely reducing the snow storage capacity of the Andes mountains during the winter season. Thus, in general terms, global climatic change predictions are not favorable for this already stressed region.

Conclusion

The current situation regarding the allocation and usufruct of water resources in Chile basically responds to economic criteria, and the system has indeed been efficient in transferring water flows according to the variable demands. Recently, environmental considerations that limit the free use of new water rights have been introduced, and water roundtables have been installed as a rather voluntary, informal resort to coordinate the activities of the various users at the hydrological basin level.

However, the current and foreseeable demands for water resources, the uncertainties concerning future water availability and the conflicts arising at the river-basin scale require a stronger institutional framework. Therefore, an integrated management approach for the basins should be established in order to allow a sustainable development for their different stakeholders. Thus, at the national political level, the Public Works Ministry is currently proposing to raise the concept of water as a national public resource to a constitutional hierarchy. The project also considers additional faculties to the national government, including authorizations to reserve surface and groundwater flows, to establish conditions for the expiring of water rights and to create managing corporations of water resources at the watershed scale. Thus, social and environmental criteria will probably limit the present water rights, based only on economic efficiency, in the coming years.

Finally, in North Chile, in addition to eco-efficiency practices, water demands per ton of copper or ounce of gold produced should be a criterion in the selection of alternative mining projects, and a fact to consider in its environmental impact assessment.

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