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Summary report on Copiapó water yields and demands

A report submitted to AusAID as part of the study:

Copiapó River Basin, Chile – analysis study of shortfalls in water rights, industrial usage and social requirements

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McFarlane, D., Trefry, M, Moffat, K. and Lacey, J. (2012). Summary report on the current water rights framework in Chile. Unpublished report to AusAID as part of the study: "Copiapó River Basin, Chile – analysis study of shortfalls in water rights, industrial usage and social requirements' from the Minerals Down Under Flagship, CSIRO

Moffat, K. and Lacey, J. (2012). Summary report on stakeholder perspectives on Copiapó water management issues. A report submitted to AusAID as part of the study: 'Copiapó River Basin – Analysis study of shortfalls in water rights, industrial usage and social requirements' from the Minerals Down Under Flagship, CSIRO.

Trefry, M., McFarlane, D., Moffat, K., Littleboy, A. and Norgate, T. (2012). Copiapó River Basin Water Management: Terms of Reference for Future Governance and Research Activities. Report to AusAID and Chilean stakeholders from the Minerals Down Under Flagship, CSIRO

Executive summary

The Copiapó River Basin, located in the world's driest desert, the Atacama, is facing both an acute and a chronic water shortage for its people and industries. Rain and melting snow in the high Andes results in the river flowing through narrow valleys which once contained local flora and fauna but is now mainly used for irrigation. Export table grape production, which started in the mid 1960s, largely replaced food crops by 1983 to become the dominant user of water, especially in the upper basin where surface water irrigation from canals is common. Olives, pomegranates and vegetable crops are grown further down the basin using groundwater associated with riverine sediments.

In the early 1990s, mining increased in importance which resulted in groundwater rights being obtained for use in mining and mineral production. The need to house workers resulted in a rapid expansion of Copiapó City and increased demand for drinking water. A sequence of dry years and heavy exploitation of groundwater since 1998 has resulted in levels falling around the river and it ceasing to flow past the town where it would normally recharge aquifers in the lower basin. Improved irrigation practices have resulted in leakage from the river, canals and below crops being reduced. The widespread use of trickle irrigation has resulted in a much greater production per unit of water used than in the past. These leakages however provided the main sources of groundwater so it is a 'zero sum game'.

The lack of significant recharge to aquifers in Sectors 4, 5 and 6 and the increasingly widespread use of groundwater to meet residential water supplies, mining and lower basin agricultural may have resulted in a change in hydrological processes. Groundwater levels are no longer connected to the river bed in many areas (a 'losing stream') and future runoff may not extend as far down the catchment before it infiltrates as a result. Whether this is a long term change (and whether the current drier climate is likewise) would require more monitoring and research. Some direct recharge to lower aquifers occurs during occasional storms in the lower basin but these are a fraction of annual extraction volumes.

Miners have a greater capacity to purchase water rights and people living in Copiapó City, where most agriculturalist and miners reside, need a reliable supply of high quality water. Groundwater quality has significantly declined as deeper water is extracted which is causing chronic health concerns for the resident population and also degradation of soils where it is used for irrigation.

The Water Code encourages the issuing of water rights if a supply of water can be demonstrated although not all issued rights are being used. Many water rights were issued during comparatively wet periods in the 1980s and to a lesser extent in the 1990s when there was also additional demand for water. The Code does not make it easy for rights, once issued, to be withdrawn and it is generally accepted that the amount of rights exceeds the available water by 4 to 5 times. Not every holder of a water right uses their full allocation because either the water is not available to surface water irrigators (mainly Sectors 1 to 4), bores have gone dry (especially in Sector 4), it is too expensive to deepen bores or to pump from depth (mainly Sectors 5 and 6), users hold their rights in the hope they will become more valuable (including speculation) or holders want to keep water in reserve. Unused water cannot be reissued in a new license. Despite this, all surface water is diverted and used within the upper four sectors and groundwater storages are declining by 60 to 80 GL per annum. It is possible that reduced groundwater levels in Sector 4 will reduce future streamflows reaching Sectors 5 and 6 making the problem worse unless aquifer storages are replenished. Modelling has indicated that a reduction of groundwater pumping by 50 per cent is required to stop levels from falling further. The nature of future precipitation and resultant runoff is unclear given the run of below average years since 1998.

Although it is only about one-third of agricultural water use, mining water use is probably the most controversial given that large-scale agricultural water use has been established in the Basin for some time. Mining companies have improved their water use efficiency in recent years through various water reduction strategies, although there is still scope for further improvement , particularly for concentrator plants. Significant reductions in freshwater consumption for mining in the future are more likely to come from the use of alternative water sources (e.g. seawater, desalinated water) rather than implementation of water reduction technologies, as these are already well advanced. A number of mining companies are building or planning several desalination plants on the coast to reduce their need to rely on basin water supplies, with the Candelaria desalination plant expected to begin operation next year. Mining water use can be expected to increase in the future due to increased production and falling ore grades, although as already noted, this demand is expected to largely met by the use of desalinated water which should significantly improve groundwater availability. A small desalination plant will improve drinking groundwater quality but a larger plant to increase supplies may be needed by 2017 unless water that is currently used for agriculture becomes available. There are issues associated with increased cost of drinking water (40 to 100 per cent) and the ability of some resident to pay for desalinated water. There is also not enough energy available for everyone to use desalinated seawater.

This report summarises the water supply and demand issues in the Copiapó River Basin so as to develop the Terms of Reference for a larger investigation that examines basin-wide options. This report was prepared after a two week visit to Chile to speak to stakeholders to gain their understanding of the current water issues in the basin. A week return visit was made to report on the findings in October 2012. The report has also draws upon reports written in Spanish. It is a therefore preliminary in nature and is intended to highlight major issues only so that the Terms of Reference can be developed.

1 Introduction

The project entitled 'Copiapó *River Basin, Chile – analysis study of shortfalls in water rights, industrial usage and social requirement'* was developed jointly by AusAID, part of the Australian Government's Department of Foreign Affairs and Trade (DFAT), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Dirección General de Aguas (DGA) within the Chilean Ministerio de Obras Públicas. The project is being conducted between 1st May and 30th September 2012 including two trips to Chile by Australian scientists and a return trip by Chilean government managers.

An **outcome** of this AusAID-CSIRO-DGA project is to:

'*Produce a preliminary integrated assessment of industrial, agricultural, environmental and social water use profiles and demand projections for the Copiapó Basin which will be a crucial starting point for future water technology integration/optimisation and management tools. Preliminary assessments of the hydrological and hydrogeological resources in the Copiapó Basin, together with preliminary assessments of water regulatory framework and stakeholder perspectives on water management and water needs must also be produced'*.

The **output** being met by this report is '*a preliminary Summary Report of Copiapó Basin water use developed in collaboration with the Chilean Government, and mining and agricultural sectors, including elements of:*

- *water resource assessment at the basin scale;*
- *water life-cycle analysis, through the custody chain (industrial-agricultural-social-environmental);*
- *water efficiency and water technology assessment; and*
- *knowledge and data gap assessments'.*

This report examines aspects of water resource yields and demands in the Copiapó River Basin as determined from reports and through interviewing stakeholders during a twelve day visit to Chile in May-June 2012. The report is a synthesis of readily available information rather than a comprehensive analysis of all data.

The report summarises the main issues in the Basin in a way that:

- Integrates material from different discipline areas
- Respects the time that people gave in presenting their concerns and understanding of the situation as expressed through an interpreter. Where this information is personal experience and opinion it is identified as such so that it is not included with more quantitative material
- Makes material in Spanish reports more accessible to English readers
- Identifies areas where uncertain or conflicting things could not be resolved while realising that this may reflect the time available to integrate material in this short study rather than that the material being uncertain. Reviews of the report by DGA experts will hopefully have removed the most serious errors and omissions.

This report is input into a '*Final Activity Report and Terms of Reference which will be developed in collaboration with and endorsed by key stakeholders including am Inter-Ministry CSIRO Project Advisory Group'*.

The report's structure is:

Chapter 2 outlines the geographic setting of the Basin, its climate and population. The main hydrological and hydrogeological features are detailed in **Chapter 3**, drawing on a number of technical reports by the DGA and consultants. These reports are very detailed and only the most important aspects have been summarised so that the subsequent chapters on water use areas can be interpreted. The main sources used were:

1. An analysis of water quality in the Basin which was carried out by engineering consultant Cade-idepe (2004): *Diagnostico y clasificación de los cursos y cuerpos de agua según objetivos de calidad. Cuenca del Rio Copiapó*
2. A major study of the water resources of the Basin was by Golder Associates (2006): *Diagnóstico de los Recursos Hídricos de la Cuenca del Río Copiapó y Proposición de un modelo de Explotación Sustentable*.
3. A future scenario modelling report was completed by a subsidiary of the Pontifical Catholic University of Chile, DICTUC S.A. (2010) *Análisis integrado de gestión en Cuenda del Rio Copiapó, Departamento de Estudios y Planificación, División de Ingeniería Hidráulica y Ambiental*.
4. Hydrogeological modelling has been carried out by The National Service of Geology and Mining in Chile, Sernageomin (2011) *Modelación hidrogeológica Cuenca del Rio Copiapó*.

A complete list of references is included at the end of this report.

Chapter 4 is an analysis of mining water demands and use. This chapter is longer that other chapters as it was considered that mining was one of the most contentious water use in the Basin as it had occurred more recently and put heavy pressure on an already very heavily committed water resource. A number of solutions have also been developed to reduce the demand for water by the companies.

Agricultural water use is examined in **Chapter 5,** residential (drinking water) use in **Chapter 6** and social, cultural and environmental water use in **Chapter 7.** Separate sections in these last three chapters separate data from reports and presentations from verbal comments made during interviews carried out in late May and early June 2012.

Conclusions drawn from the material are drawn in **Chapter 8** while technical knowledge and data gaps are presented in **Chapter 9**. Recommendations for further work are made in a separate report.

2 The Copiapó River Basin

2.1 Geographic setting and population

The Copiapó River Basin is located about 800 km north of Santiago in the Atacama Desert between latitudes 27 and 29^{o}S[1] (Figure 1). The Atacama may be the oldest desert on earth having experienced extreme aridity for at least 3 million years and probably 15 million (Houston 2006a and references therein).

The basin has an area of 18,540 km^2 being wider in the east where it arises in the Andes mountain range narrowing at the outlet at the Pacific Ocean. The basin's shape arises from the lower Basin receiving less than 30 mm of annual rainfall and therefore there are no lower tributaries to contribute water to the main river channel.

The elevation of the eastern parts of the Basin rises to over 5000 m above sea level with about 11% being below 1000m. The Andean snow line is very high in northern Chile (about 5,800m) so there is no permanent snow and few glaciers in this Basin, although they are common elsewhere, especially to the south.

The population of the city of Copiapó is over 130,000[2] and is expected to rise to 187,000 by 2022 according to data provided by the Intergovernmental Working Group. Tierra Amarilla has an additional 10,000 and Los Loros, about 1,100 residents (DGA 2011). Caldera (population 50,000 which can double in summer) is located outside the Basin but uses water from within it. It was reported that 97.6% of all people live in cities in the Basin. There are about 254,000 people overall in the Atacama Region (Region III).

Estimates of population and especially the growth in population as a result of the mining boom varied in reports and interviews that were conducted. While the city was reported to have 129,000 in the 2002 census, urban planners we spoke with assumed it was about 170,000 and it would rise to 300,000 in future. Some individuals talked of the population 'doubling in the next few years'. The mining boom is resulting in very rapid expansion and keeping track of numbers is very difficult. This makes estimating future drinking water consumption uncertain. The cities' water service provider, Aguas Chañar can estimate growth between census dates though its residential supply statistics, although residential occupancy rates and the number of un-serviced premises would also need to be known. They reported an additional 15,000 residences to service in recent years (see later).

The main body of the report should be succinct, providing merely enough detail to inform readers of validity of results and recommendations. It should include information stated in the executive summary but give more detail and justification of results.

The methodology used in the research should be outlined. This includes any conceptual and analytical methods developed or applied, datasets used and the key technical outcomes of the research. The strengths and weaknesses of the approach should be discussed. It is important to outline the key findings of the research, as well as a summation of implications and recommendations for further research.

[1] For comparative purposes, these latitudes are equivalent to 80 km north of Kalbarri to Greenough in Western Australia

[2] The Chile National Statistics Institute indicated that there were 129,091 people in Copiapó in the 2002 census. The 2012 figure is likely to be greater

Figure 1. Location of the Copiapó River Basin in the Atacama Region (III) of Chile. Adapted from Golder Associates (2006).

2.2 Climate and Topography

The average annual precipitation for the Copiapó Basin is estimated to be only 28mm (DGA 2011). Descending dry air in the sub-tropical Hadley Cell at this latitude reduces convection while the cold Humboldt or Peruvian Current reduces the ability of cold fronts to bring winter rainfall. In addition, the Andes prevent any precipitation coming from the east. The influence of the cold ocean current can be assessed from Table 1 which shows that rainfall on the west coasts of Australia at similar latitudes is far higher due to the warm Leeuwin Current. Chile is more similar to the west coast of Africa which has an equivalent cold current, the Benguelan Current (see Table 1).

Both precipitation and potential evaporation increase with altitude as shown in Figure 2. An increase in precipitation is expected due to the orographic effect of the Andes, although precipitation at 2000m is still less than 60 mm. Potential evaporation is 1.5 to 4 m, presumably due to strong winds. There is also a slightly higher mean temperature at 1000 to 1200 m relative to both the coast and to higher altitudes (DICTUC 2011).

Table 1. Rainfall at equivalent latitudes on the west coasts of Australia, Chile and Africa.

Chile	Rainfall mm/y	Australia	Rainfall mm/y	Africa	Rainfall mm/y
Copiapó 27°22'S	12	Geraldton 28°47'S	460	Alexander Bay 28°35'S	46
La Serena 29°54'S	96	Lancelin 31°01'S	599	Lambert Bay 31°40'S	140
Canela 31°24'S	170	Perth 31°96'S	868	Elands Bay 32°18'S	170
Valparaiso 33°03'S	462	Bunbury 33°33'S	871	Cape Town 33°55'S	515

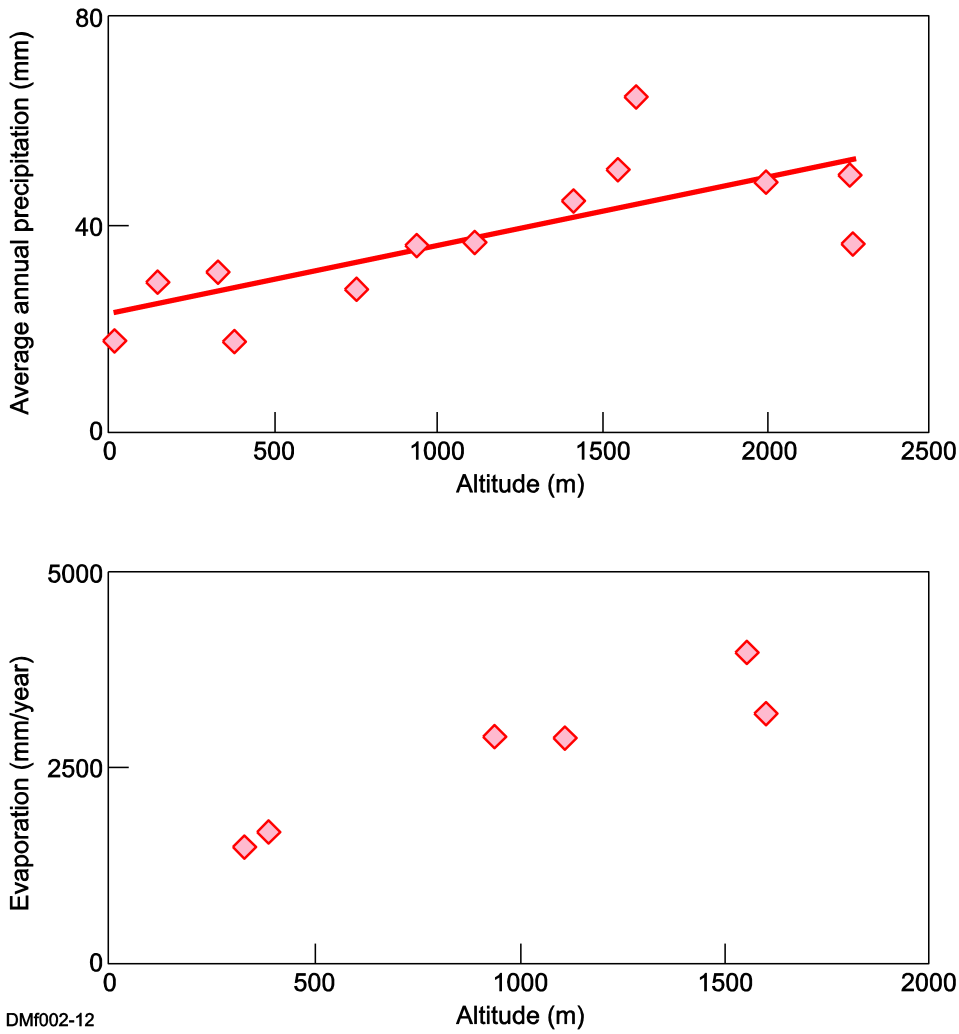


Figure 2. Mean precipitation (top) and potential evaporation (bottom) both increase with altitude in the Copiapó Basin (DICTUC 2010).

A map of rainfall isohyets, topography and the location of aquifers around Copiapó's six management sectors is shown in Figure 3. Only the highest parts of the Basin receive more than 200 mm per annum of precipitation. The high potential evaporation results in snow sublimating (i.e. evaporating from a solid state). Attempts to capture snow against fences and in trenches have been made to increase infiltration and recharge. Note how narrow the near river aquifer zones are in Sector 1 to 3. Only in Sectors 5 and 6 does the aquifer extend more than about 5 km from the main channel.

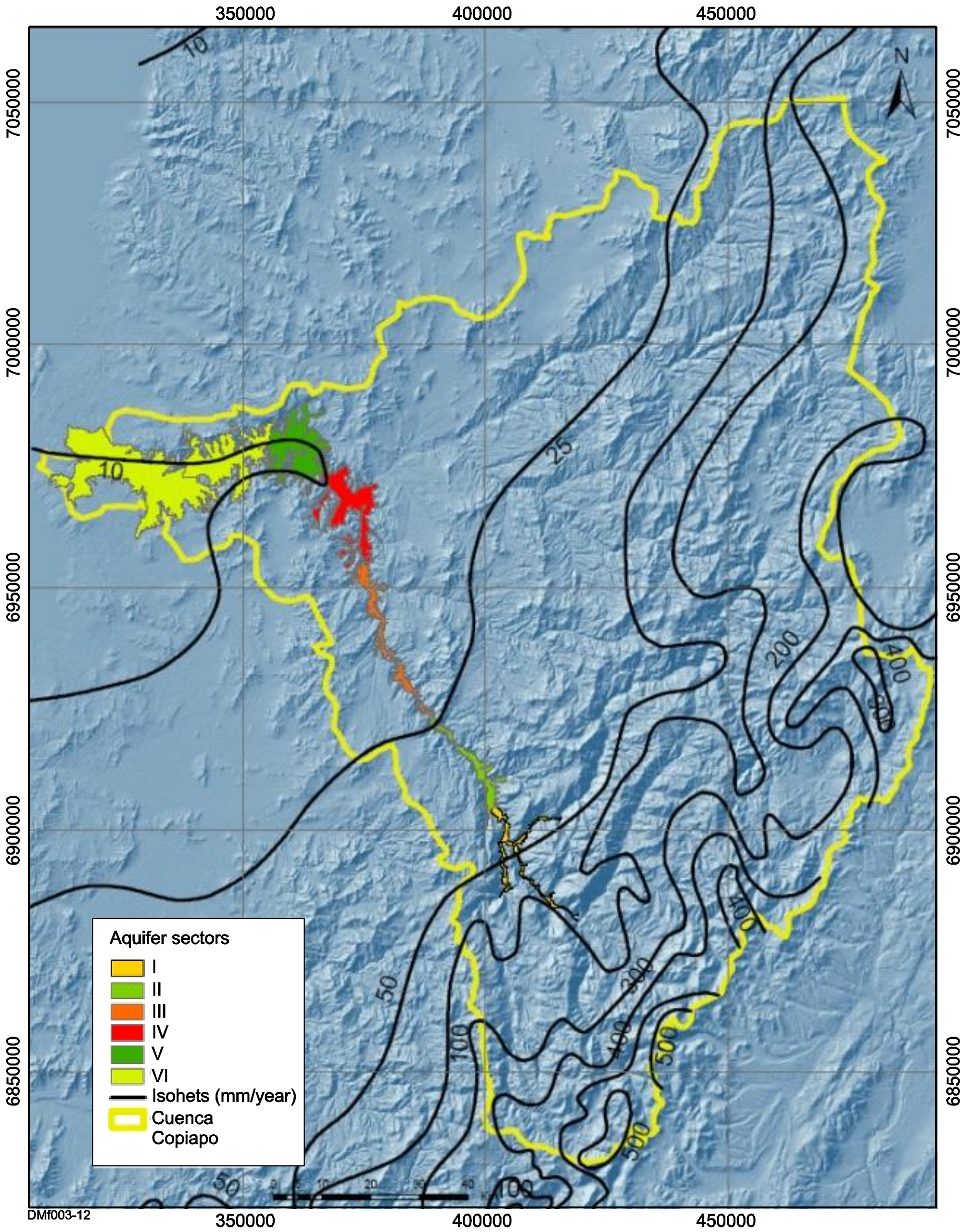


Figure 3. Rainfall isohyets, topography and aquifer widths in the six management sectors in the Copiapó River Basin (Sernageomin 2011).

Houston (2006b) reported that flow in the Copiapó River has a primary peak in summer (DJF) due to snowmelt and a secondary peak in winter (July) despite winter rainfall being higher. Considerable winter precipitation in the form of snow in upland areas may go unrecorded. He could detect no significant trend in the winter-rainfall-dominant coastal zone in the Atacama. El Niño Southern Oscillation (ENSO) impacts on rainfall are low in this part of Chile. In addition, floods and major recharge events are less frequent than ENSO events indicating that specific synoptic conditions are required for them to occur. This makes the use of averages unsound for hydrological studies and water resource evaluations (Houston 2006).

Semi arid regions such as southern-coastal Chile, southern Africa and south eastern Australia have experienced a drying trend in April and May since about the late 1970s (Cai *et al*. 2012). While the other regions have recorded a pole-ward shift in the sub-tropical dry zone as a result of global warming, no such shift has resulted in Chile. Other factors must therefore be influencing this trend. This shift is occurring south of the Copiapó Basin at this stage (Figure 4).

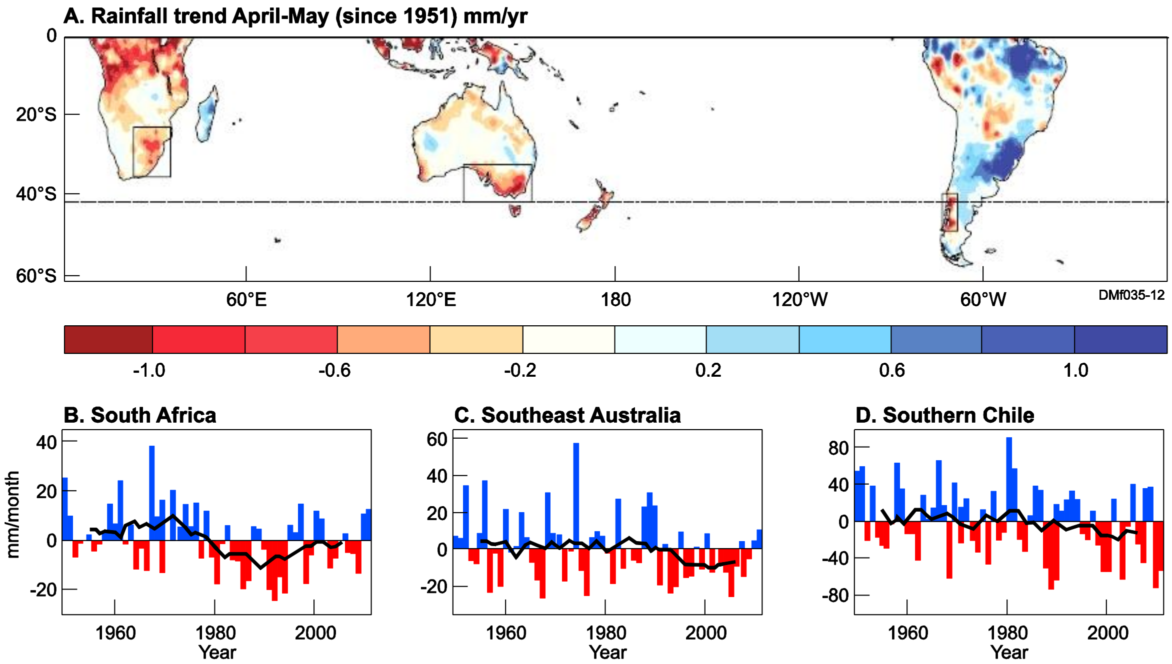


Figure 4. Mid-to-late autumn (April-May) rainfall linear trends across the Southern Hemisphere since 1951 (Cai et al. 2012). In (a) the semi-arid regions are shown in boxes and the 40o mid latitude line is shown

An estimation of the impact of climate change on climate and the economy was reported at the United Nations' Cancun Conference in 2010. Rainfall may decrease slightly by 2040 in the Far North - Antiplano but increase later in the century (Figure 5). On a percentage basis this may still be very little rainfall and it may not be effective as temperatures are projected to rise by 3 to 4^{o}C by 2100.

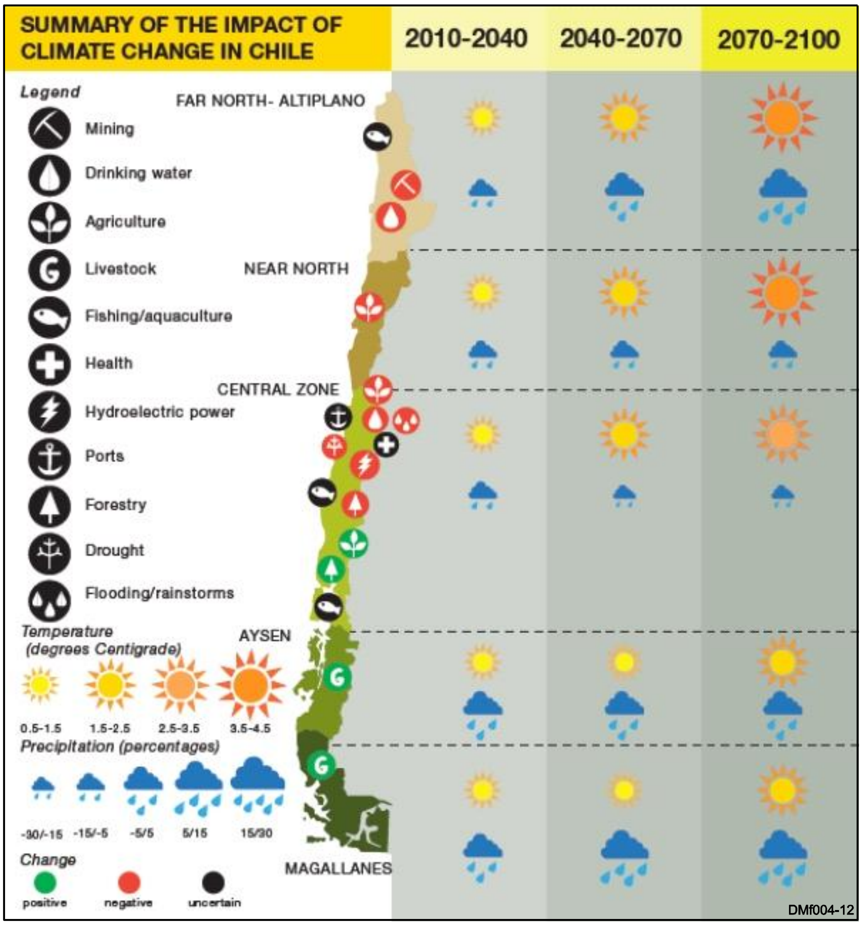


Figure 5. Depiction of climate change impacts and their relations with climate change impacts in Chile (UN 2010).

3 Hydrology

3.1 Surface water

The three main tributaries that provide water to the Copiapó main channel are the Manflas in the South, the Pulido in the central south and the Jorquera further north (Figure 6). A small part of the catchment extends above 4000m and the three main sub-basins that produce runoff all have an average elevation of above 3000m (Table 2) and 400mm precipitation (5). The Lautaro Dam was built in 1920 and has a capacity of 23 GL. While located at an elevation of 1100 m it receives only 40mm rainfall and loses about 2.87m in evaporation each year. The Paipote is an unregulated drainage which rarely contains water. It may however be an important provider of occasional flood flows.

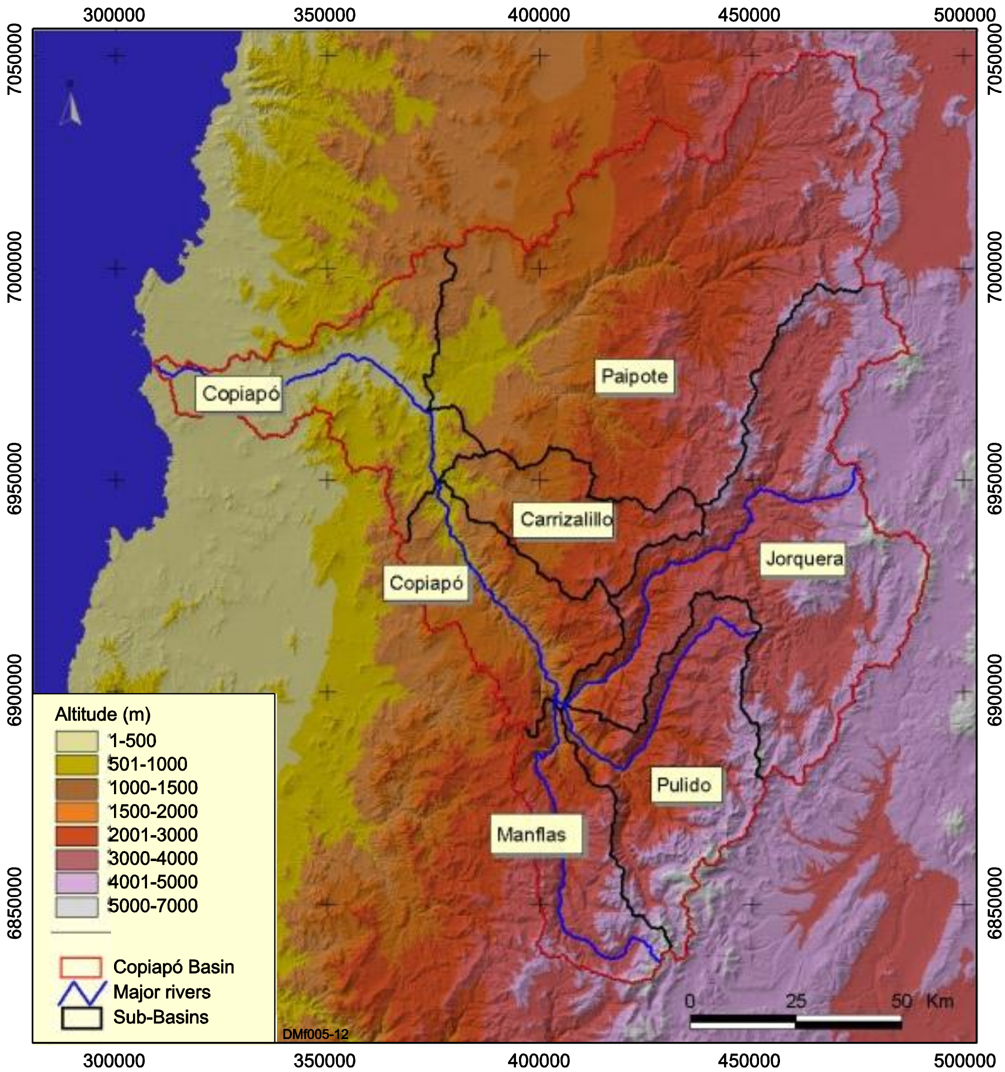


Figure 6. The altitude and main tributaries in the Copiapó River Basin (Golder Associates 2006).

Table 2. Statistics for each sub-basin in the Copiapó River Basin (adapted from Golder Associates 2006).

Sub-basin	Area (km^2)	%	Min Altitude (m)	Max Altitude (m)	Average Altitude (m)	Average slope (%)
Manflas River	1.205	7%	1,198	5,676	3,362	18.7
Pulido River	2.042	11%	1,230	5,765	3,550	20.6
Jorquera River	4.185	23%	1,228	6,050	3,797	16.6
Paipote River	6.661	35%	441	5,291	2,566	12.8
Carrizalillo River	1.117	6%	595	4,240	2,105	13.7
Copiapó River (Lautaro - Paipote)	1.464	8%	582	3,926	1,715	13.9
Copiapó River (Paipote – mouth)	1.862	10%	0	1,775	641	8.2
Total	18.536	100%	0	6,05	2,717	14.6

There are currently 8 river gauging stations and 10 meteorological stations, including one at Caldera on the coast just outside the basin. Surface water quality is measured in 7 stations.

Flow in three gauging stations in the Copiapó River Basin is shown in Figure 7. The stations shown in green and blue are located in the upper – middle part of the Basin below the Lautaro Dam so are partly regulated. High river flows occurred in the mid 1980s, 1988, 1998 and (to a lesser extent) 2003. The station shown in red is at the Basin outlet. The last river flow in the main channel to reach the Pacific Ocean occurred 14 years ago in 1998. As will be shown later, the high flows in the 1980s resulted in substantial increases in the number of water rights being issued. Further rights were issued in the 1996 to 1998 period and a small number in 2003. No rights have been withdrawn as a result of low flow conditions in the river.

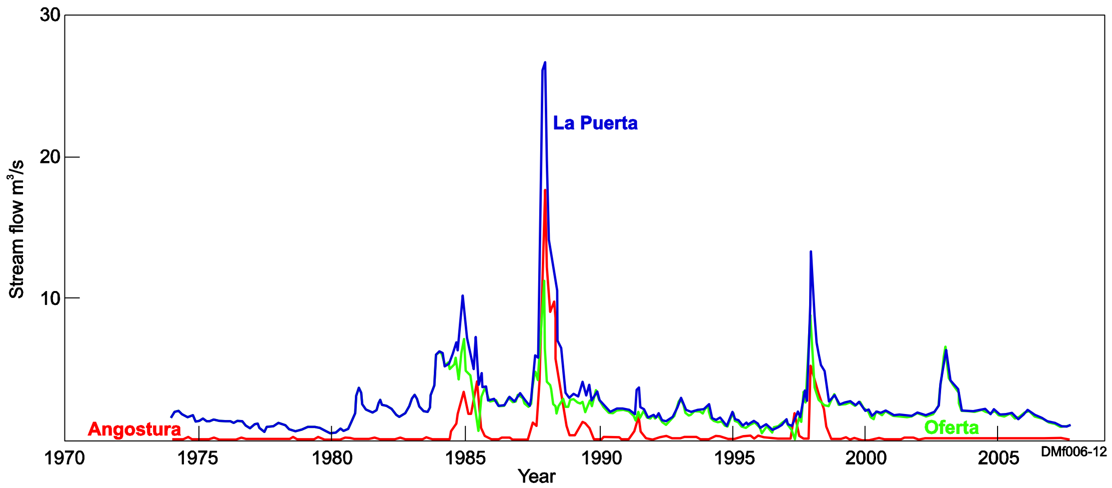


Figure 7. Streamflow in the La Puerta, Angostura and Oferta gauging stations between 1974 and 2008 (DICTUC 2010).

Water is diverted from the main river channel into irrigation canals for use by irrigators in Sectors 1 to 3. Some groundwater is also used but as shown in Figure 3, aquifers are restricted to close to the river channel in these sectors. Allocations are managed by private 'Watch groups' constituted under the 1981 Water Code. The Copiapó Basin Vigilance group manages seasonal water allocation of water rights that have been issued by the DGA in Sectors 1 to 4. In the lower Sectors, 5 and 6, groundwater only is used and rights are managed by CASUB (Comunidad de Aguas Subterráneas de Copiapó). This is the only groundwater management group in Chile and is somewhat of a test case of what may work in other basins. Average annual flows across each gauging station are shown in Figure 8. The Pulido produces the same amount of flow at the Jorquera and Manflas tributaries combined. About 41 GL/y is released from the Lautaro Reservoir in an average year. Additional water crosses the station La Puerta where the geological basement rises at the same time that the valley narrows forcing both groundwater and surface water to be within the river.

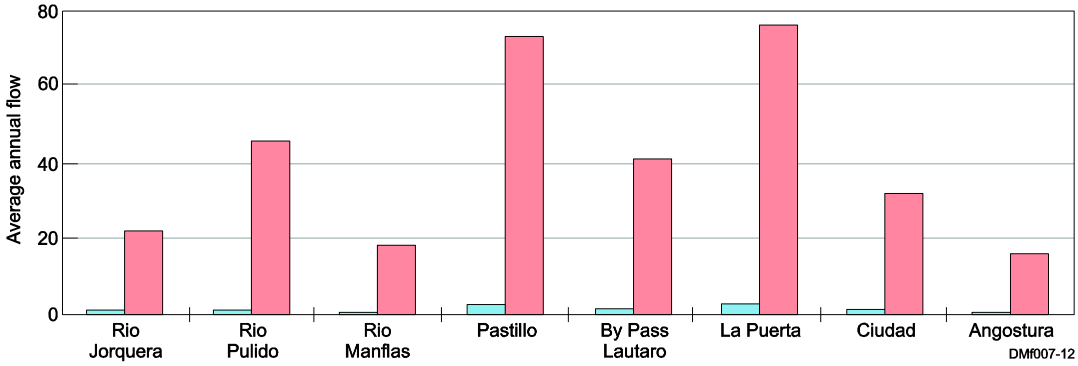


Figure 8. Average annual flows across surface water gauging stations. Blue = m3/s; red = GL/y. (adapted from Golder Associates 2006).

3.2 Groundwater

Groundwater levels are measured in odd months in 9 observation and 26 production (pumping) bores. Eighteen monitoring bores have been abandoned because they are dry or screened at too shallow a depth. Groundwater quality is regularly measured at only three bores, apart from those monitored by private bore owners and Aguas Chañar.

The size of the alluvial aquifers in the six management sectors in the Copiapó River Basin is shown in Figure 9. Sector 1 extends from the upper Basin to the Lautaro Dam; Sector 2 extends to La Puerta or 'the door'. The aquifer gains volume in Sector 4 but is at its greatest extent in Sectors 5 and 6.

The basement rocks are very uneven resulting in groundwater emerging as springs where there are vertical and horizontal restrictions to flow (Figure 10).

Recharge results from river flows entering the alluvial aquifers i.e. it is a losing stream except at La Puerta and near the outlet where restrictions in both the valley floor and the basement cause groundwater to emerge as springs. There is insufficient rainfall in the lower basin to contribute to recharge in anything other that very exceptional circumstances.

Groundwater levels appear to have fallen under the river bed since about 1998 causing leakage to increase. As a result, the river is now transferred into a concrete-lined canal in Sector 4 so that surface water flows can reach irrigation groups that rely on canals for their water. However, the lack of river flows in the lower part of Sector 4 and throughout Sectors 5 and 6 has meant that recharge has effectively ceased to these lower aquifers since about 1998.

Groundwater levels have fallen due to lack of recharge and increased extraction (Figure 11). The wetter period in the mid 1980s and to a lesser extent the late 1990s is reflected in rising levels. Levels in some bores have declined by more than 25m making it much more expensive to pump water even after wells have been deepened which is also very expensive.

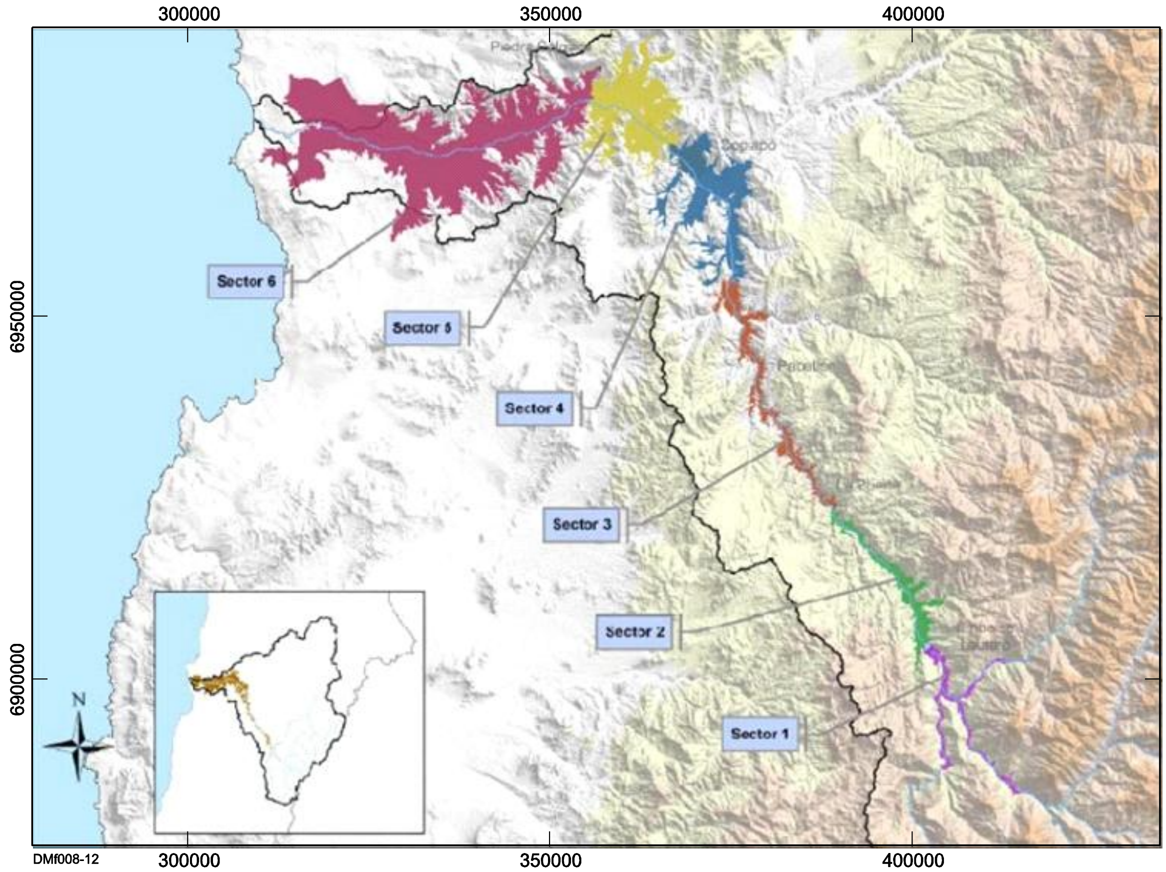


Figure 9. The six management sectors in the Copiapó River Basin showing the width of the alluvial aquifer around the main river channel (DICTUC 2010).

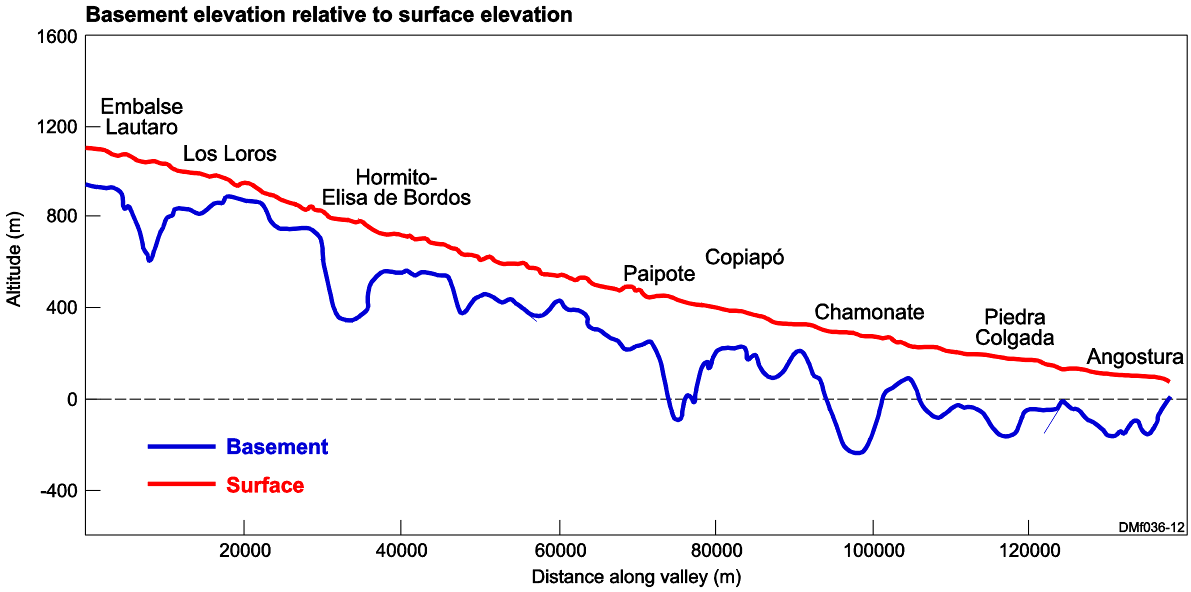


Figure 10. Basement elevation relative to surface elevation from the Lautaro Dam (left) to the Basin outlet at Angostura (right), 140 km to the west (DGA 2003).

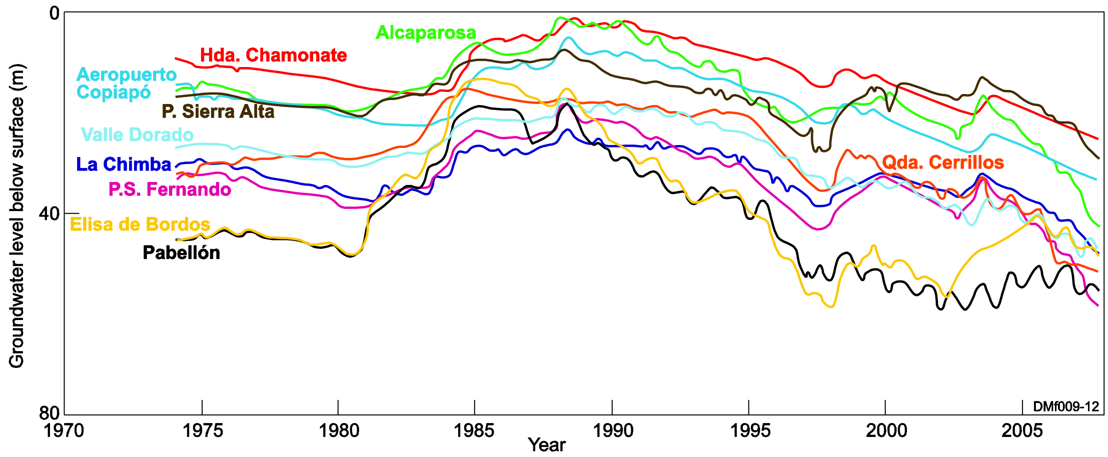


Figure 11. Groundwater levels in bores in the lower part of the Basin between 1974 and 2007 (DGA 2010).

The changes in levels have been converted into cumulative aquifer storage changes between 1974 and 2007 (Figure 12). Compared with 1974, storage had declined by almost 400 GL by 2007. The rate has continued at these levels until 2012 and has been modelled using the AQUATOOL model to continue if current management conditions continue until 2040 as shown in Figure 13.

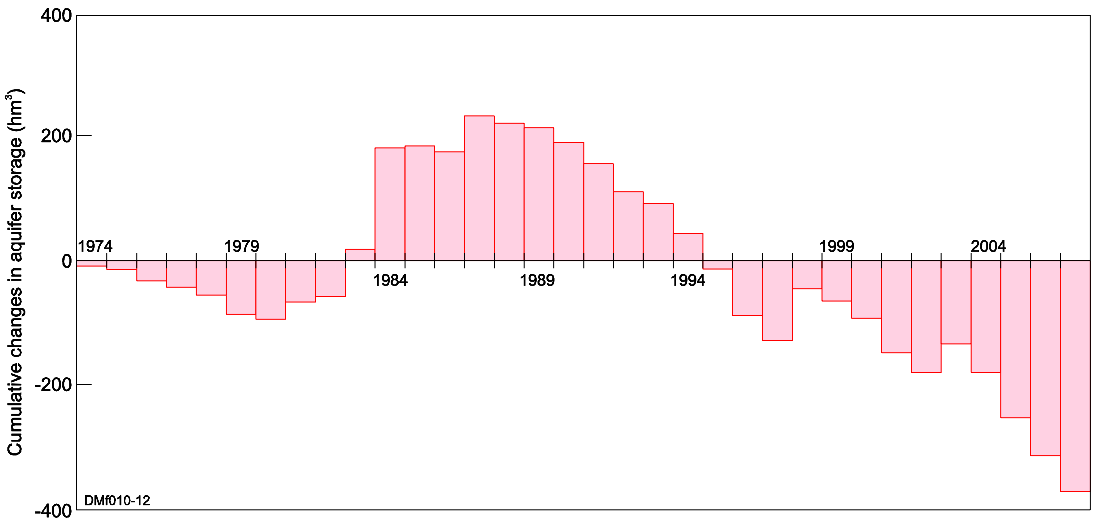


Figure 12. Cumulative changes in aquifer storage (in hundreds of cubic metres) in the alluvial aquifer between La Puerta (start of Sector 3) and Angostura (end of Sector 6) (DICTUC 2010).

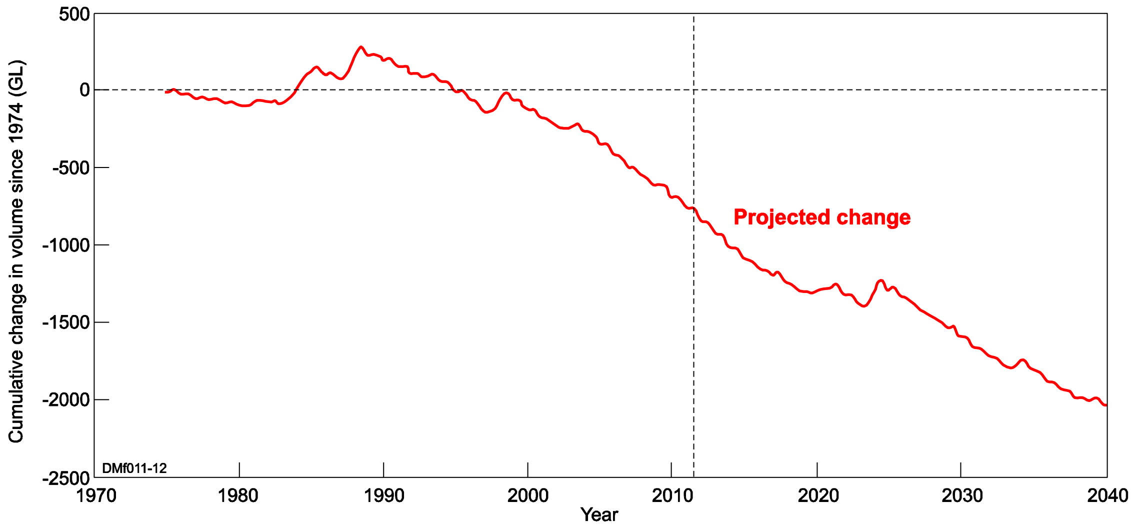


Figure 13. Modelled changes in aquifer volume between La Puerta and Angostura after 2012 under 'business as usual' management (adapted from DGA 2012).

Aquifer volume storages and reductions in the four year period between 2007 and 2011 are shown in Figure 14. Sectors 1 to 3 contain very little water being narrow alluvial valleys. The reduction in storage in Sector 4 is substantial on both a volumetric and percentage basis. Some levels have reached bedrock and it is not feasible to extract all of the water. This resulted in the water service provider for Copiapó City, Aguas Chañar having to switch extraction to Sectors 3 and 5. While sectors 5 and 6 look to contain substantial volumes, the quality of the water has declined substantially as levels have been lowered. As they have not been recharge since 1998 water has been taken from storage over this period. This is possible with aquifers as long as they are recharged at some future time and there are no other consequences of low groundwater levels such as very high costs of extraction or the loss of important groundwater dependent ecosystems.

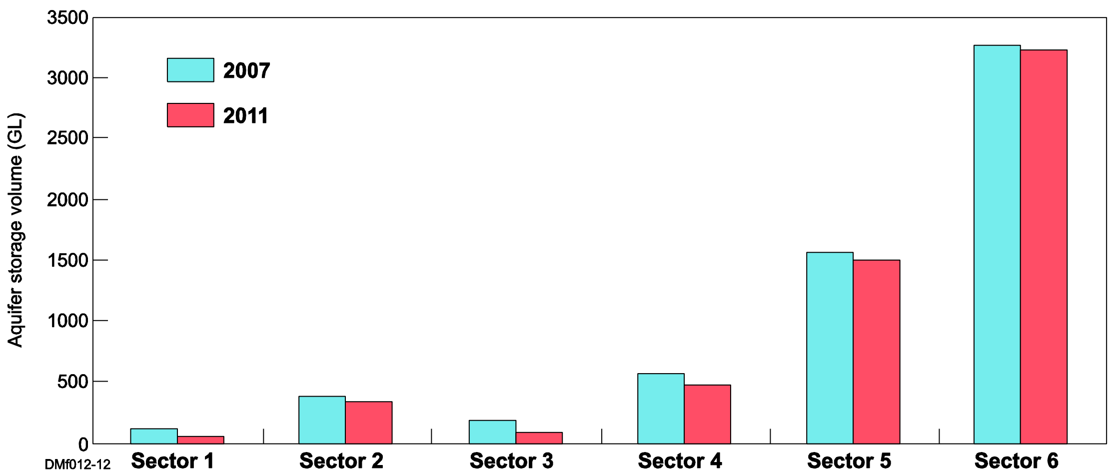
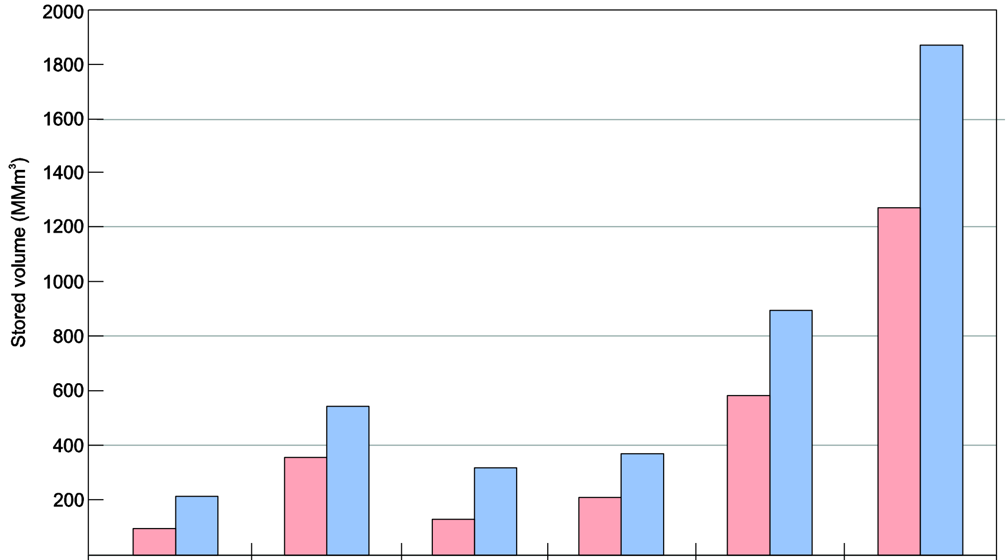


Figure 14. Measured aquifer storage volumes (GL) in 2007 and 2012 in the six management sectors (DGA 2012).

The volume that is able to be used is much less than that in the change of storage graph shown above as indicated in Figure 15. Sector 5 has an estimated usable storage of 578 GL/y and a water rights allocation of 118 GL/y, only some of which is used. Sector 6 has a lower rights allocation (50 GL/y) and larger usable storage ((1268 GL/y) but poorer quality water.



	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
Usable volume	92	353	130	212	578	1268
Total volume 2012	208	543	318	373	898	1869

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Figure 15. Useful volume (red) as a function of total stored volume (blue) in aquifers in Sectors 1 to 6 (DGA 2012).

The AQUATOOL catchment model has been run to assess the effect of reducing extractions on storage volumes in the Basin (Figure 16). The most important simulations are 'business as usual' (Simulation 1.1), 2.2 (a 50% reduction in pumping) and 2.3 (a 30% reduction). Even to retain the current lower groundwater levels, the model showed that current extraction levels would need to be halved. It was found that drinking water extractions could be maintained at current levels with little additional impact on levels because they are relatively small compared with other uses.

The degree of interconnection between the upper catchment (where mining is an important water user) and the river basin below the Lautaro Reservoir is unclear. Extraction from upper areas may have less impact on basin water yields than a similar sized diversion further down the basin. Given the high degree of inter-dependence between surface water and groundwater resources in the basin there may be unintended consequences of extracting one resource on the yield of the other. As mentioned later, this is an important information gap.

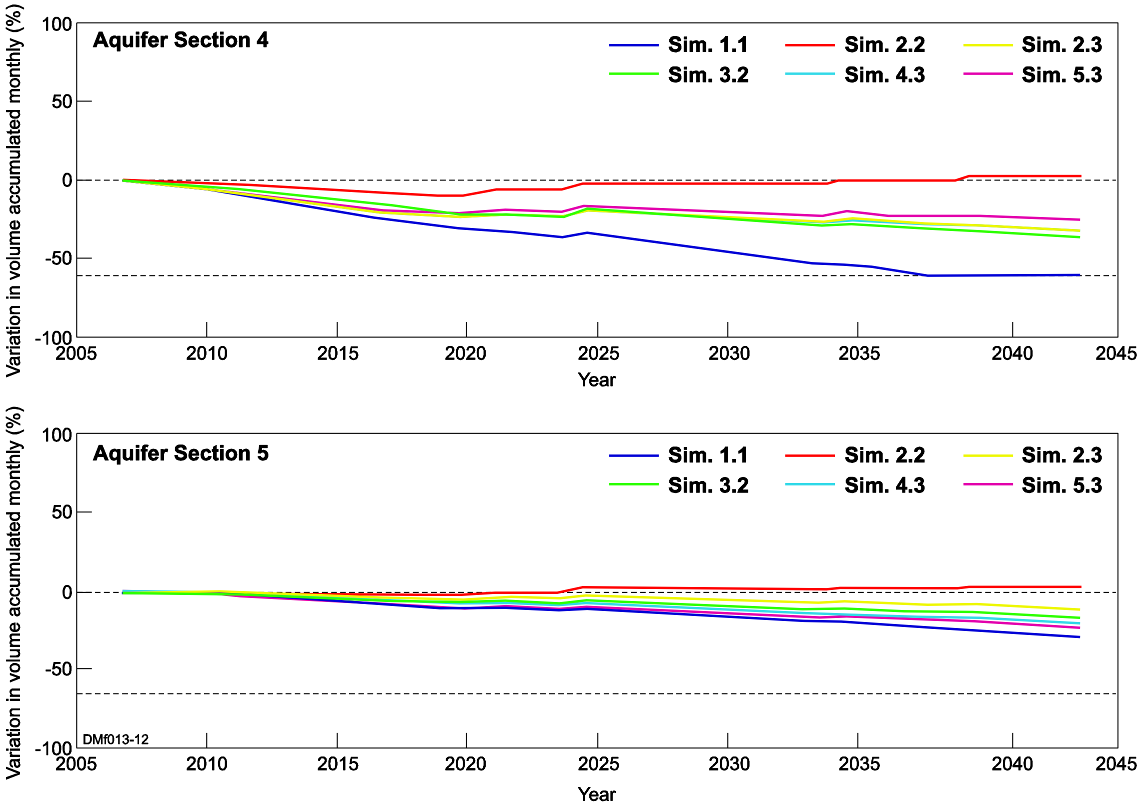


Figure 16. Simulations of the impact of various scenarios on aquifer volumes in Sectors 4 and 5 using the AQUATOOL model. Simulations are 'business as usual' (1.1), a 30% reduction in pumping (2.3) and a 50% reduction (2.2).

3.3 Water rights

The volume of water rights issued in the Copiapó River Basin increased markedly in the mid 1980s, in the mid 1990s and to a much lesser extent, in the early 2000s when a number of small rights were issued (Figure 17). Issuing of rights mainly coincided with periods of higher river flow but also reflected increased demand for water from all water use sectors.

Lists of water rights often include the following limitation "*The list contains all information available to date from the Water Board, but does not consider information from existing wells in the basin that have not initiated a process aimed at obtaining the right to use groundwater, nor considered those ancient rights granted by SAG, or registered in the Real Estate, which to date have not applied for membership to the Public Water Cadastre*"[3].

Therefore additional water rights are recognised in the Basin, although not all may be exercised.

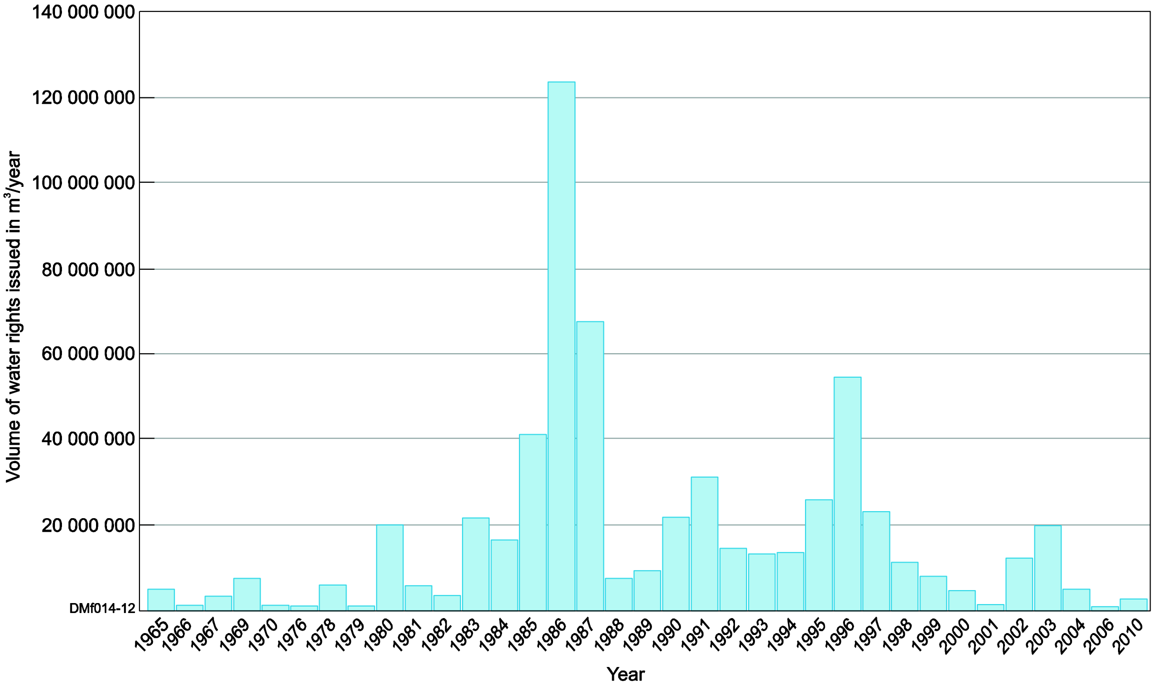


Figure 17. Volume of water rights issued between 1965 and 2010 (DGA 2012).

The largest volumes of water rights that have been issued are in Sectors 2 to 5 (Figure 18). By themselves, Sectors 3 and 4 each have rights equal to the total basin yield of about 129 GL/y. As is shown later, Sector 4 has been heavily impacted by over-use. It contains a number of table grape irrigators, Copiapó City and the Candelaria copper mine.

[3] Carlos Ciappa (pers. comm.): What was expected was a farmer would use 20% of the volume authorized under each of their water rights. Then, if a farmer had a water right for 10 l/s they are allowed to use 10 litres every second of the year but DGA expected that they would use 10 l/s during only 20% of the year. The problem was that usage changed from 20% to 40% or 50%.

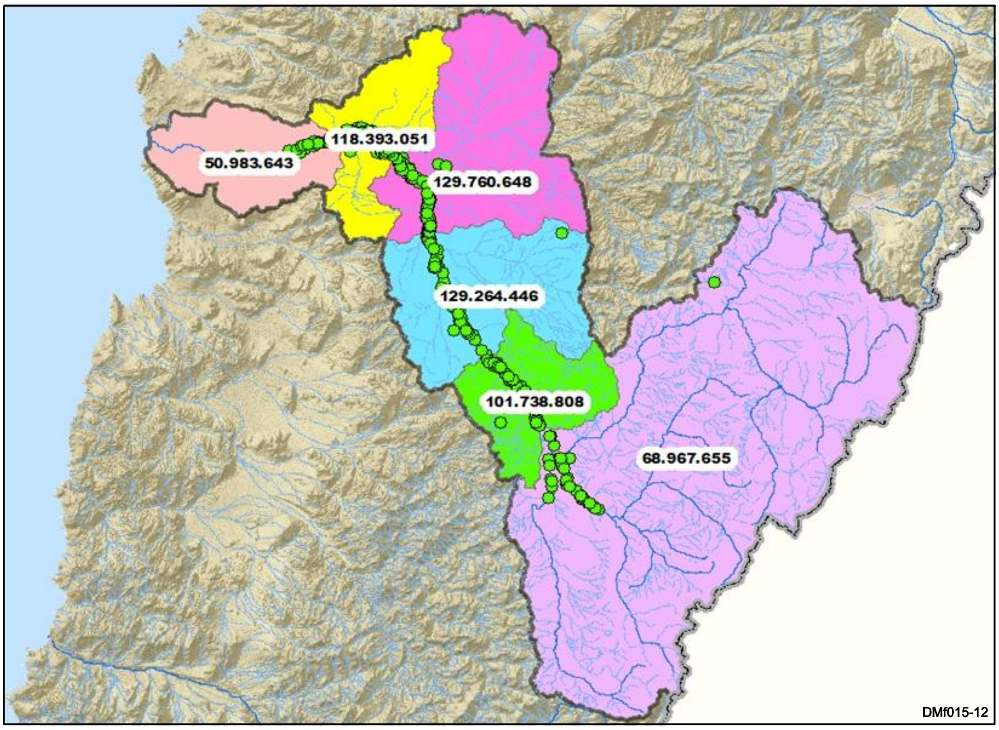


Figure 18. Distribution of rights between the six sectors. Figures are m3. For example Sector 4 (pink) which contains Copiapó City has a rights allocation of 129 GL (Source: Marco Larenas Conteras 2012).

The annual water allocations and cumulative rights issued since 1965 are shown in Figure 19. Total volumetric rights have reached over 600 GL/y (19,622 l/s), about 4.5 times the long term rate of basin water yield. About the entire basin yield was issued in 1986. Reasons given for the over-allocation include:

1. Early reports (e.g. Álamos y Peralta 1995) indicated that water was available to allocate. Under the Water Code the DGA is bound to issue rights in a specified time if water is shown to be available.
2. Surveys had shown that agricultural users were not using their complete entitlement. Return flows were also occurring to the river and leaking past the root zone of crops was recharging the aquifers. Some of this water was re-issued to new users, especially miners who were requesting water rights.
3. Agriculturalists also sold some of there underutilised rights to the miners either as temporary trades (swaps) or as permanent sales. There were suggestions made that after some trades had occurred, water may have continued to have been used. The DGA has very limited rights to enter properties for enforcement purposes. Also trades are often not well documented or publically notified.

The Basin Vigilance Group oversees irrigation water allocations and this is mainly surface water irrigation via canals in Sectors 1 to 4. No basin-wide manager is responsible for allocating each year's available water to irrigators, miners and drinking water supplies. No body seems responsible for retaining some water for environmental flows. As mentioned previously, CASUB is responsible for managing groundwater allocations against rights in Sectors 5 and 6. With groundwater levels falling far below the river channel in Sector 4, irrigators found it necessary to transfer the river water to a concrete-lined channel to provide water to irrigation canals (Figure 20). This reduced recharge in the lower parts of this sector.

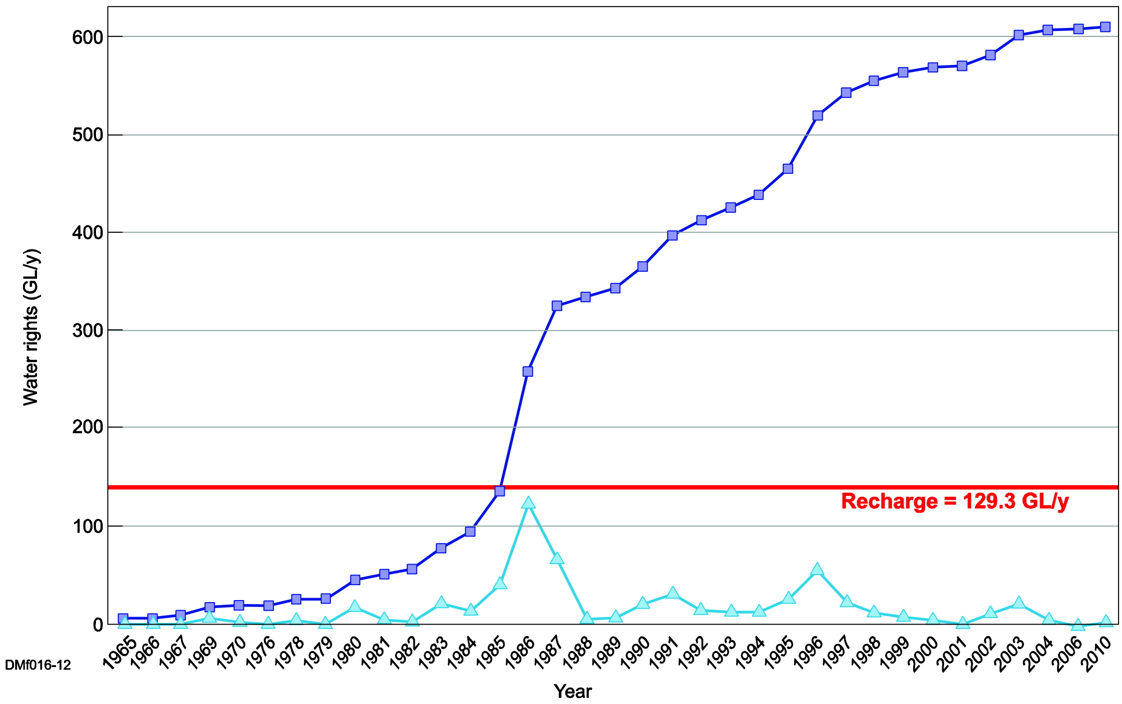


Figure 19. Annual (light blue) and cumulative (dark blue) allocation of water rights between 1965 and 2010 compared with the long term average yield of the basin expressed as a recharge volume (DGA 2012).

Figure 20. Water in the Copiapó River being distributed in concrete lined channels to prevent leakage which is also recharge to the alluvial aquifers.

A schematic of the current basin water balance prepared by the DGA in March 2012 is shown in Figure 21. Inflows are shown as about 120 GL/y, extraction is about 200 GL/y comprising 142 GL/y to agriculture, 45 GL/y to mining, 13GL/y to drinking water and 2 GL/y to other uses. This shows an annual deficit of about 80 GL/y, which matches well with the 50 to 70 GL/y that is being lost from aquifer storage. Water rights of over 600 GL/y (19,622 l/s) have been issued meaning that the Basin is overused by about 70% and over-allocated by about 400%.

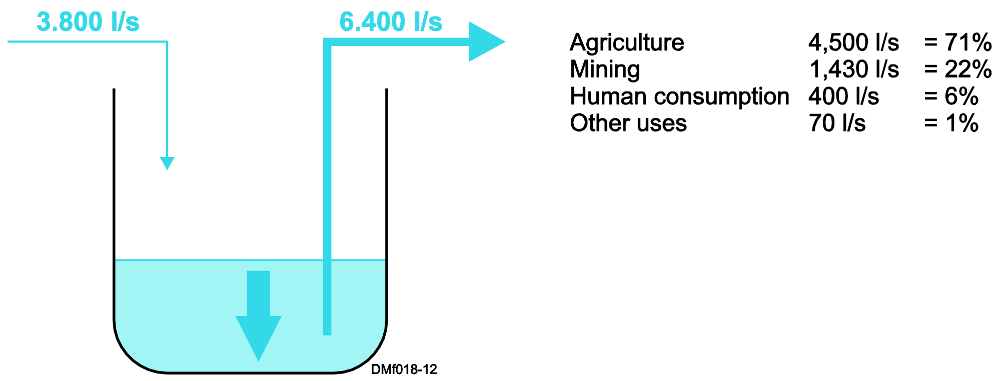


Figure 21. Depiction of the current use and imbalance (DGA, March 2012).

The number of people employed in agricultural in the Copiapó Basin (Copiapó and Tierra Amarilla statistical divisions) declined by over 40 per cent between 2005 and 2011 while mining employment increased until 2008 before becoming stable (Figure 22). The nature of the Basin has almost certainly changed from one dominated by agricultural interested to one that is more balanced as a result of this rapid change. It was reported that most mining positions were occupied by new arrivals to the Basin rather than people moving form one industry to the other. Total employment in the Basin in 2011 was 64,105 meaning that the services sector is probably large.

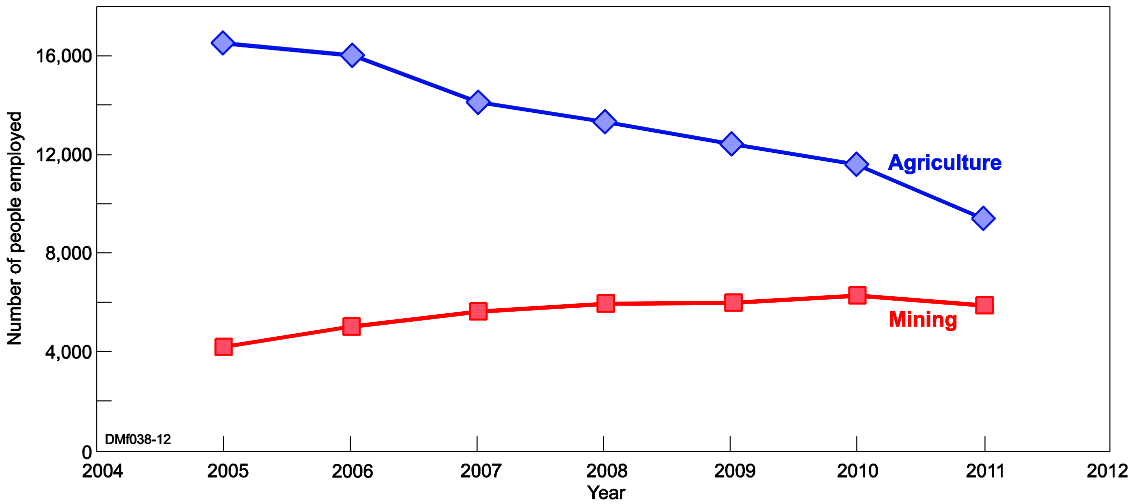


Figure 22. Number of people employed in agriculture and mining between 2005 and 2011 in the Copiapó Basin (Source: data from the Ministerio de Economía, Fomento y Turismo 2012).

While the number of people employed in mining is still less than that in agriculture, wage earnings in the two industries in the Basin have markedly diverged (Figure 23). Total mine wages are now more than four times agricultural wages which was reflected in comments about agriculture being unable to match the wages paid by mining companies. However it also reflects that agricultural work is more seasonal and these numbers may results from agriculture including part time working earnings.

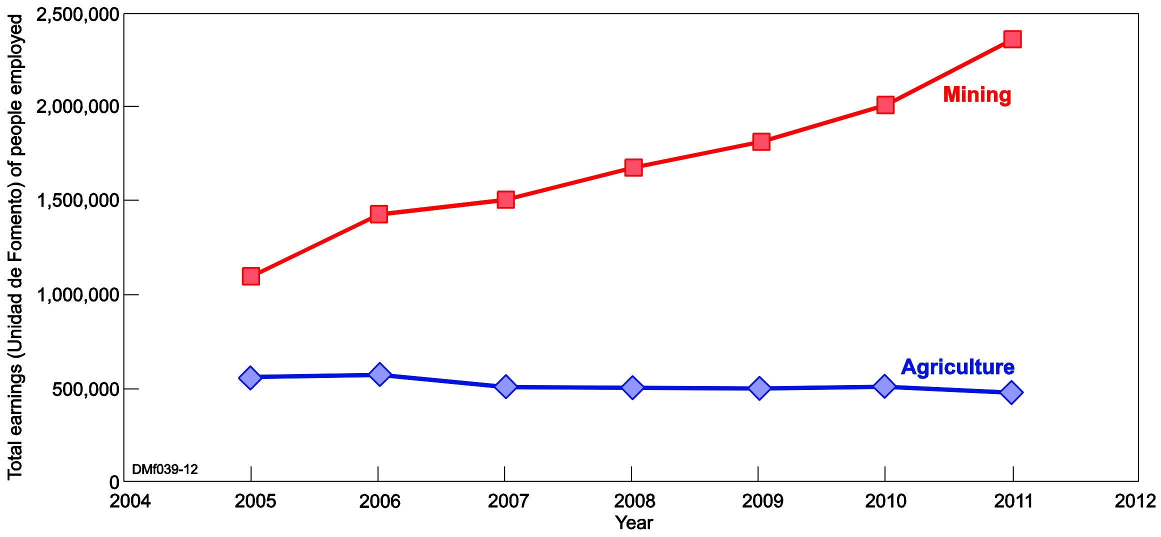


Figure 23. Total earnings (UF or 'unidad de fomento') of people employed in agriculture and mining between 2005 and 2011 in the Copiapó Basin (Source: data from the Ministerio de Economía, Fomento y Turismo 2012).

The earnings per worker can be shown in UF(Unidad de formento) or CLP (Chilean pesos) units as plotted in Figure 24. Agriculture is lagging behind mining in this measure as well.

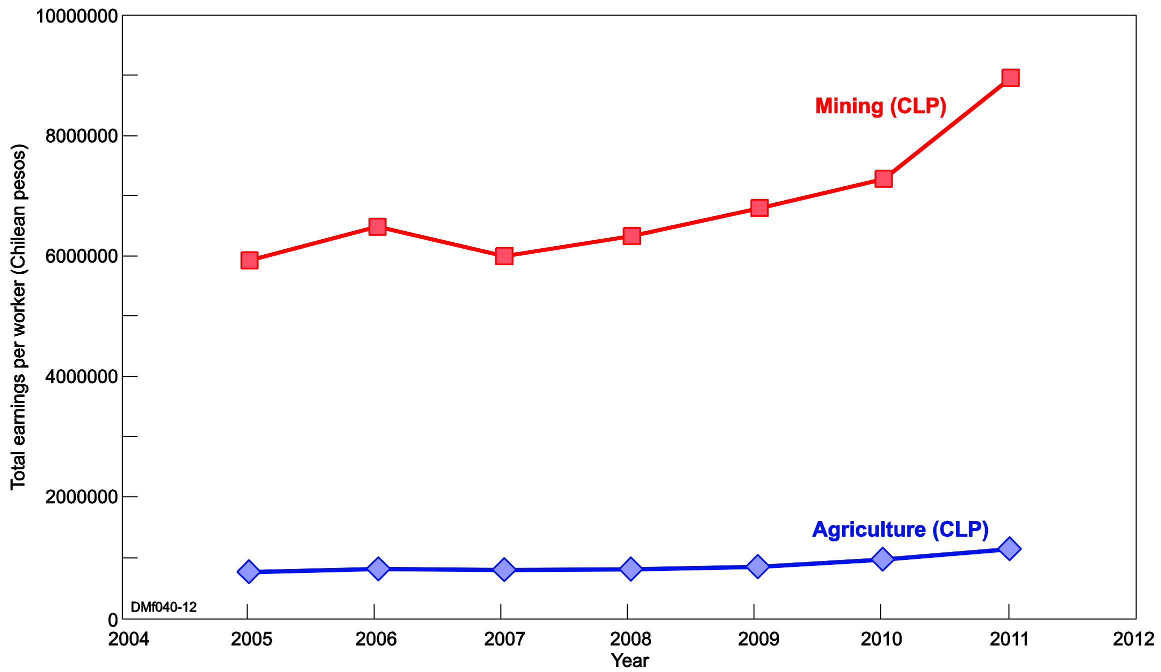


Figure 24. Total earnings per worker (CLP) of people employed in agriculture and mining between 2005 and 2011 in the Copiapó Basin (Source: data from the Ministerio de Economía, Fomento y Turismo 2012).

As well as water, flat land suited to irrigation can be a limiting factor in Sectors 1 to 3. Large irrigation farmers have been able to develop land in side valleys to the Copiapó River valley (Figure 25). This requires large storages and pumps to be installed; the energy and cost of raising the water from the valley can be considerable.

Figure 25. Table grapes grown in side valleys. This requires water to be pumped several hundreds of metres elevation above the main river valley. Photo by Kieren Moffat, 2 June 2012.

Because most agricultural water use is on perennial plants (grapes, olives, pomegranates) there is almost no flexibility in reducing the area irrigated in dry years as would be the case were seasonal crops such as vegetable crops grown. Stopping the irrigation of perennials usually results in serious losses of income over the medium term because of the need for several years of irrigation of new plants to recover production. A year of low water availability can reset this process each time. There is similar lack of flexibility in the mining and residential water sectors which makes the adjustment of water demands to account for seasonal availability very difficult once high water use efficiencies have been reached.

4 Mining and industrial water

4.1 Mining water

Mining is probably the most controversial water use given large scale agricultural water use in the Basin preceded it by about 25 years. Its impact both through direct use in the mines and indirectly through the many workers and their families now resident in Copiapó City has been significant in the 10 to 15 years which has been drier than usual. Its use has also been more closely documented than more traditional uses and therefore this report examines water use by the mining sector in more detail than for other sectors.

Northern Chile is one of the world's most important mining regions. In 2010, Chile remained the world's leading producer of copper, accounting for 34% of world mine production (USGS, 2010). Chile is also a major producer of molybdenum (15% of world production, ranked third), silver (6% of world production, ranked fifth) and gold (2% of world production, ranked fourteenth). Mining is a significant contributor to the Chilean economy, and in 2010 total mine production accounted for about 19.2% (US$39 billion) of the country's gross domestic product (GDP) compared with 15.6% (US$25 billion) in 2009. Of this, copper mine production was valued at about US$35 billion compared with about US$22 billion in 2009 (USGS, 2010). Planned investment in Chilean copper and gold mining, including projects under construction and those likely to begin construction in 2010-2015 is estimated at US$50 billion. This includes US$41.4 billion in copper mining (83%) and US$8.6 billion in large-scale gold mining (17%).

Northern Chile receives its fresh water primarily via a network of groundwater aquifers. Much of the water contained in these aquifers is legacy water and thus not replenished via rainfall (Niechcial and Radakovic (2007). Currently, many of the copper operations in the northern region of Chile utilise groundwater resources via water rights granted by the Chilean government. However, recent studies and the continuous monitoring of water wells in different locations have shown that the water levels in the groundwater aquifers are dropping at an appreciable rate, resulting in the Chilean government limiting the granting of new water rights. Furthermore, for mining companies this can mean that holding water rights for any given volume does not guarantee that the resource will be available when needed. The availability, or lack thereof, of water in this region is a significant limiting factor in the development of some of the world's richest mineral deposits, hence there is tremendous pressure on the water resources. The limited availability of water and rising cost of water access (rights and licenses) has stimulated interest in:

- improved water use efficiency
- better water resource management
- advanced water technologies, e.g. paste tailings thickeners
- alternative water sources, e.g. seawater and desalination.

The total annual average freshwater extraction for copper mining in Chile in 2006 was 11.2 m^3/s (11,200 l/s), while in 2010 it was 12.4 m^3/s (12,400 l/s), an 11% increase, with the breakdown for the various regions shown in Figure 26 (Cochilco, 2011). The corresponding numbers for Region III were 1217 l/s and 1406 l/s respectively, a 16% increase. The total annual average of 12.4 m^3/s corresponds to 391 million m^3/year.

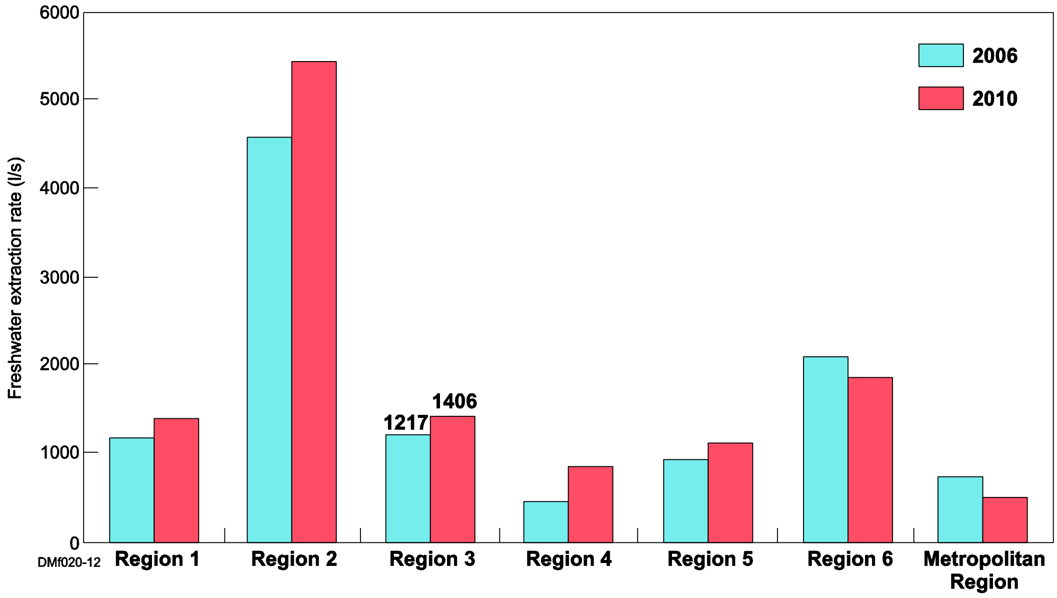


Figure 26. Freshwater extraction for copper mining in 2010.

4.1.1 MINING OPERATIONS IN REGION III

According to Garcia et al. (2009) there are over 200 mining operations in the Third Region, and their contribution to total national production is shown in Figure 27. These contributions are: 8% copper, 3% molybdenum, 45% gold, 33% silver and 71% iron. Mining is the main activity of the region and generates 49% of the region's gross domestic product. The Third Region has historically been the main small-scale mining producer of gold-bearing minerals for concentration. There are seven major copper mining operations in the Copiapó Basin of Region III as indicated in Figure 28, with most mining operations located in Sector 4. Further details of these copper mining operations are given in Table 3. Another major mining operation in the Copiapó Basin is Compania Minera del Pacifico (CAP) which operates the Los Colorados iron ore mine and a magnetite concentration plant (1.69 Mt concentrate/y in 2010) in the Basin. The company also plans to start up its Cerro Negro Norte iron ore mine in the Copiapó Basin in 2013.

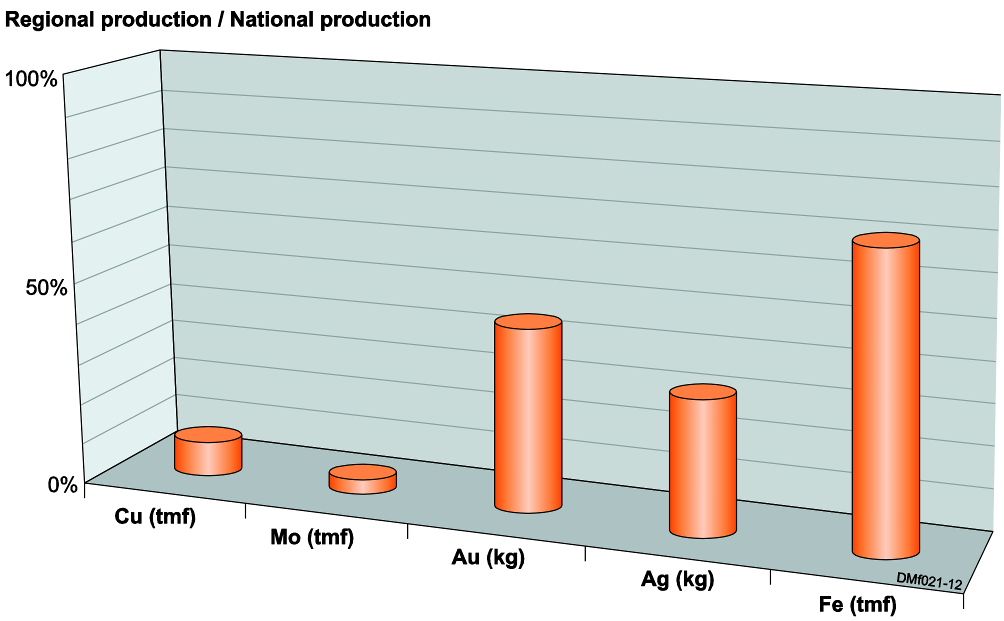


Figure 27. Contribution of Region III mining production to national production.

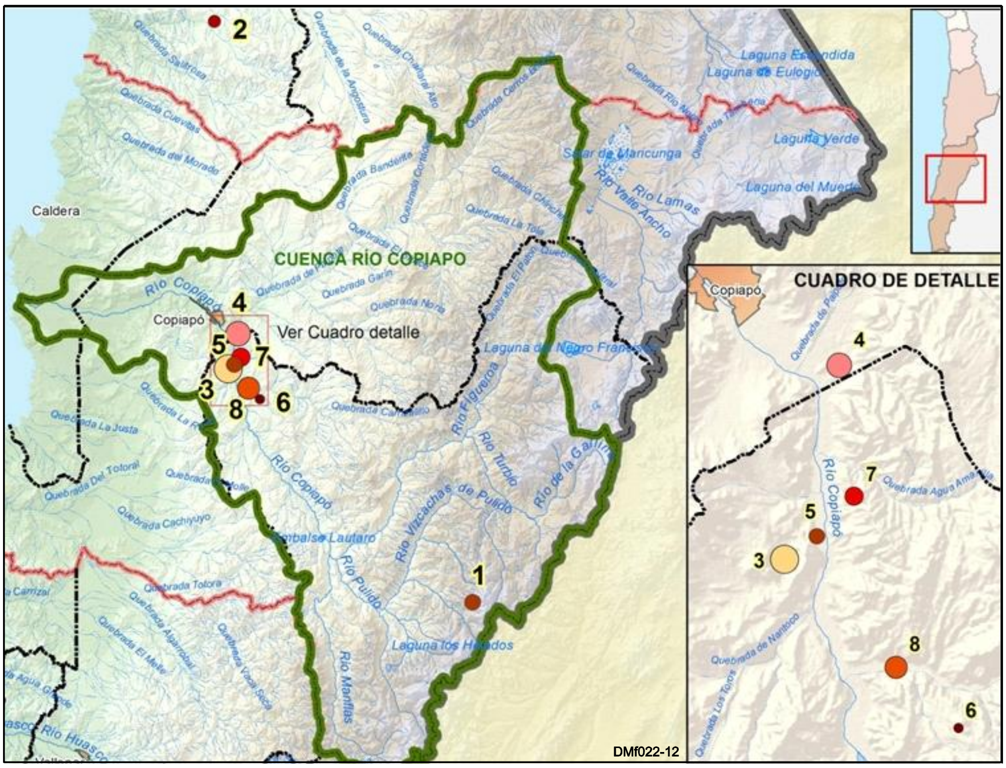


Figure 28. Major mining operations in the Copiapó Basin (DGA, 2012).

Table 3. Copper mining operations in the Copiapo River Basin.

MINE/CONCENTRATOR	PRODUCTION (TONNES/Y)	COMPANY	PROCESS*
Candelaria	148,000 Cu 2410 kg Au	Freeport-McMoran	C
Plant Manuel Antonio Matta	7200 t Cu	ENAMI (Chilean National Mining Corporation)	C & SX/EW
SCM Atacama Kozan	28,000 Cu concentrate	Sociedad Contractual Minera (SCM)	C
Minera Catania Verdes S.A.	8000 t Cu cathode	Minera Catania Verdes S.A.	SX/EW
Mina Punta del Cobre, Venado Sur, Planta San Jose, Biocobre	80,000 Cu concentrate 10,000 t Cu cathode	Sociedad Punta del Cobre S.A.	C & SX/EW
Cerrillos	2,640,000 t ore	Compania Exploradora y Explotadora Minera Chilena Rumana (COEMIN)	C
Caserones	150,000 Cu concentrate 30,000 Cu cathode 3000 Mo concentrate	SCM Minera Lumina Copper Chile	C & SX/EW

* C = concentration to produce concentrate; SX/EW = solvent extraction/electrowinning to produce cathode copper

4.1.2 CURRENT WATER USE FOR MINING IN THE COPIAPÓ BASIN

Freshwater consumption data for mining operations in the Copiapó Basin are not widely published in the public domain. Some published data are given in Table 4. However, recent data provided to DGA by the seven copper mining operations in Table 3 as well as the Compania Minera del Pacifico (CAP) iron mining and processing operations, indicates that these values have changed noticeably. Based on the data supplied to DGA, the sum of the freshwater consumption in the Copiapó Basin by these eight companies amounts to 1240 l/s.

Table 4. Water use for mining in the Copiapo River Basin.

MINE	WATER USE (L/S)	WATER RECYCLING (%)	REFERENCE
Candelaria	207 (Y2011)		Freeport McMoran: Carbon Disclosure Project (www.fcx.com)
	220 (Y2010)		
	280 (Y2007)		Cochilco (2008)
Caserones*	518	80	JX Nippon Mining & Metals Corporation Sustainability Report 2011
CAP magnetite	151 (Y2010)		CAP 2010 Sustainability Report

* At full-scale operation (expected to commence production in 2013.

It is generally accepted that no new mining operation in the Copiapó Basin would receive environmental approval without plans for alternative water supplies (e.g. desalinated water) that do not draw on the surface or groundwater of the Copiapó Basin. This will impose additional operating costs on new mining operations due to the additional cost of desalinating seawater and the associated pumping costs (which depending on the distance and the elevation in sea level required, can be many times the desalination cost – see following section). It was suggested that the cost of bringing desalinated water into the Copiapó Basin could be in the order of 5-10 times current water costs. It is likely that even when fully operational on desalinated water, mining companies will retain their water rights rather than sell them to other parties. This approach to water rights is generally viewed as being more corporate responsible, as the mining companies would not utilise these rights, unlike what is likely occur if the rights are sold, which would add to the existing water stress in the Basin.

Most mines have established overall water balances for their operations – these are essential tools for improved water management and to identify opportunities to reduce water consumption. Using water reduction technologies such as better control of water losses (e.g. by evaporation), re-use and recycling, and improved tailings dewatering systems (high density or “paste” thickeners), the Chilean mining industry reduced its average water consumption by 25% (from 15 m^3/s to 11.2 m^3/s) despite a 17% increase in copper production (from 4.6 Mt to 5.4 Mt) between 2002 and 2006 (Cochilco, 2008, 2011). If significant reductions in freshwater consumption are to be realised in the future, it is more likely that these will result from the use of alternative water sources rather than the implementation of water reduction technologies, as these are already well advanced.

4.1.3 WATER REDUCTION TECHNOLOGIES AND ALTERNATIVE WATER SOURCES

Growing concerns over water availability have seen mining companies in the Copiapó Basin looking at water reduction technologies to reduce their water consumption, and alternative water sources to provide a reliable water supply into the future.

Tailings paste thickeners

Paste-thickening technologies are emerging as a way of reducing the water consumption of mineral processing operations. Paste thickeners thicken tailings to a consistency (5-10% concentration by weight) above that of conventional thickeners, thereby minimising the amount of water sent to the tailings dam and recovering the maximum amount of water from the system. New mining operations such as the

Esperanza mine in the Antofagasta region use state-of-the-art paste thickener technology for thickened tailings (Chadwick, 2009). Some mining companies in the Copiapó Basin are also implementing or considering this technology. The JRI Engineering study, supported by Innova Chile Corfo (JRI-INNOVA CORFO project), developed a database of the physical and rheological characteristics of a large number of tailings samples from large, medium and small-scale mining operations in all regions, which is aimed at facilitating the implementation of tailings paste thickeners in Chilean mining operations.

Water re-use and recycling

The re-use and recycling of process and mine waters has become a significant means of minimising overall water consumption. However, the effect of recycled water properties on plant performance, particularly the build up of contaminants, must be considered prior to implementing a water recycling process. It has been reported (Table 4) that about 80% of water will be recycled at the new Caserones mine, while an even higher water recycling rate of 87% of all water consumed has been reported (Cochilco, 2008) for the Candelaria mine. As high quality water is not always required, the water strategy that should be adopted by mining operations is to use water that is “fit for purpose”, i.e. water quality matched to application.

Alternative water sources

The three most common alternative water sources to surface and groundwater for use in mining operations in the Copiapó Basin (and in other regions) are reclaimed water, seawater and desalinated water.

Reclaimed water

The Candelaria mine contracted with a nearby municipal wastewater treatment plant in the City of Copiapó for reclaimed water to provide an interim supply of water while longer-term water supplies (ie. desalinated water) are being developed. In 2010 a pipeline was constructed to convey the reclaimed water from the wastewater treatment plant to the Candelaria mine, which has been accessing this water since March 2011. The quality of the water has been variable, so the amount taken has also been variable as it has affected plant performance. The average amount of reclaimed water used is in the order of 160 l/s.

Desalination

Despite the high cost of desalinated water supply, the uncertain long-term availability of groundwater has seen most mining companies in the Copiapó Basin (and northern Chile in general) considering desalinated seawater as the sole source to provide a secure and reliable supply of water for mining operations in the long-term. According to Philippe (2012), it is expected that by 2017 more than 20 mining operations in northern Chile will be processing their minerals with seawater, with the majority of these already in various stages of development. However, seawater/desalinated water supply projects for the mining industry in Chile face several engineering, design, political and economic challenges. These challenges include local geography, community relations, environmental impacts and energy requirements to support the implementation of large seawater treatment and conveyance systems (Philippe, 2012). With regard to the Copiapó Basin, there are currently six desalination projects under development (Abarca, 2012), with five of these associated with mining companies. These projects are shown in Figure 29, with further details of some plants given in Table 5.

Table 5. Seawater desalination projects in the Copiapo River Basin.

PROJECT	CAPACITY (M3/D)	DISTANCE TO MINE SITE (KM)	MINE SITE ELEVATION (M)
CandelariaPlanta Compania	17,000 (initial)	120	
Minera del Pacifico (CAP)	52,000 (final)	100	
SCM Candelaria	43,000	80	550-600
Central Thermoelectrica Castilla	71,000		
Proyecto El Morro	64,000	200	4000

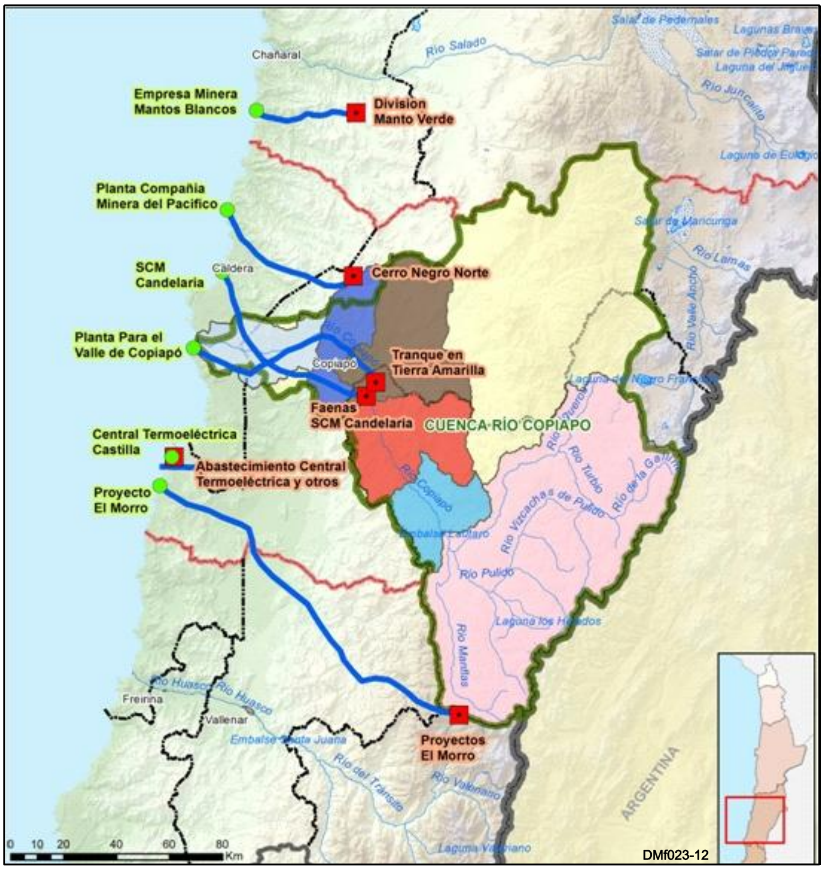


Figure 29. Seawater desalination projects in the Copiapó Basin (DGA, 2012).

While the distance from the coast to most inland mining sites is relatively small, eg. Candelaria (80 km), for some sites the pumping distance is considerably further, eg. the El Morro copper project (200 km). Furthermore, the increase in elevation from sea level can be significant (eg. El Morro 4000m), requiring appreciable energy consumption for pumping purposes. According to Fleming and Radakovic (2009) 50-80% of the operating cost of a desalination plant is related to energy consumption, and for the water conveyance system energy consumption represents over 90% of the operating cost. Cochilco (2008) reported that the energy consumption for the desalination process of the Puerto Coloso desalination plant was 3.4 kWh/m^3 of seawater, while energy consumption for pumping to the Escondida mine (170 km and 3150 m above sea level) was 14 kWh/m^3 water, about four times that for the desalination process. Based on an average regulated price of electricity in the northern part of Chile for 2011 of US$0.106/kWh, Edwards et al. (2012) estimated that pumping costs added about US$1.50/m^3 to desalination operating costs. Gonzalez et al. (2010) provide more details for calculating pumping energy requirements.

Seawater

A more sustainable option than desalinated water is the use of seawater directly (ie. without being desalinated) in mineral processing operations. A number of operations in Chile already use direct seawater in their operations. The Esperanza mine in the Antofagasta region which commenced operation in 2011 uses seawater for the bulk of its operations (including flotation), with a small UF/RO plant installed to provide desalinated water for potable and final wash needs at the site. The Las Luces mine in Region II also relies heavily on seawater for process water use (Moreno, et al., 2011). The use of seawater is not without its problems – it can adversely affect metallurgical processing efficiency depending on the ore type, and can corrode pipelines and machines much more than fresh water, requiring special linings and paint to reduce these corrosive effects. Furthermore, as noted above, the major cost of supplying desalinated water to mine sites is the pumping cost, and this cost still applies to raw seawater. Nevertheless, direct use of raw seawater is generally a cheaper alternative to desalinated water.

4.1.4 COMPARISON WITH BEST PRACTICE

It is useful to compare water consumption data for mining operations with similar ore types, grades and processing routes with current best practice to identify if opportunities exist to reduce water consumption. However, due to a paucity of current, publicly reported, water consumption data for mining operations in the Copiapó Basin, it is not possible to make such comparisons for many operations at present. It is likely that mining companies operating in the Copiapó Basin do this internally. It is reported (JX Nippon Mining & Metals Corporation Sustainability Report 2011) that the new Caserones mine in the Copiapó Basin will operate with a water consumption of 0.30 m^3/t ore which is claimed to be the lowest water consumption value compared with other copper mines in the world. Cochilco (2009) reported water consumption values of 0.39 m^3/t ore and 0.31 m^3/t ore for the Los Pelambres (Region IV) and Candelaria mines respectively. Table 6 lists some reported specific water consumption (m^3/t ore) data for various mining operations both within Chile and globally. Figure 30 shows that the Chilean mining industry has reduced specific water consumption over the last decade, but this appears to be levelling off in recent years for both concentration and hydrometallurgical (SX-EW) processing routes. According to Brantes (2009), the medium-term water consumption target for beneficiation/concentration processes in the 2002 Cleaner Production Framework Agreement was 0.60 m^3/t ore. The results in Table 6 indicate that while this target has not been met nationally and further efforts are needed to improve water efficiency, some operations in the Copiapó Basin already have, or are projected to, met this target. On the other hand, the medium-term water consumption target in the above agreement for hydrometallurgical copper processing was 0.25 m^3/t ore, which has already been met nationally according to the data in Table 6.

Table 6. Specific water consumption (m3/t ore) for various mining operations.

LOCATION	YEAR	CONCENTRATOR (M3/T ORE)	SX/EW (M3/T ORE)	SOURCE
Chile	2000	1.1 (0.4-2.3)	0.3 (0.15-0.4)	Cochilco (2011)
	2006	0.79 (0.3-2.1)	0.13 (0.08-0.25)	
	2009	0.72 (0.3-2.0)	0.13 (0.07-0.92)	
	2010	0.70 (0.3-2.9)	0.13 (0.06-0.80)	
Candelaria (III)	2006	0.31		Cochilco (2009)
Salvador (III)	2006	2.07		
Ojos del Salado (III)	2006	1.96		
Caserones (III)*	-	0.30		JX Nippon Mining & Metals Corporation Sustainability Report 2011
El Soldado (IV)	2006	0.31		Soto (2010), Cochilco (2009)
Los Pelambres (IV)	2006	0.39		Soto (2010, Cochilco (2009))
World	2006	0.96 (0.34-2.07)		Gunson et al (2012)

* New mine

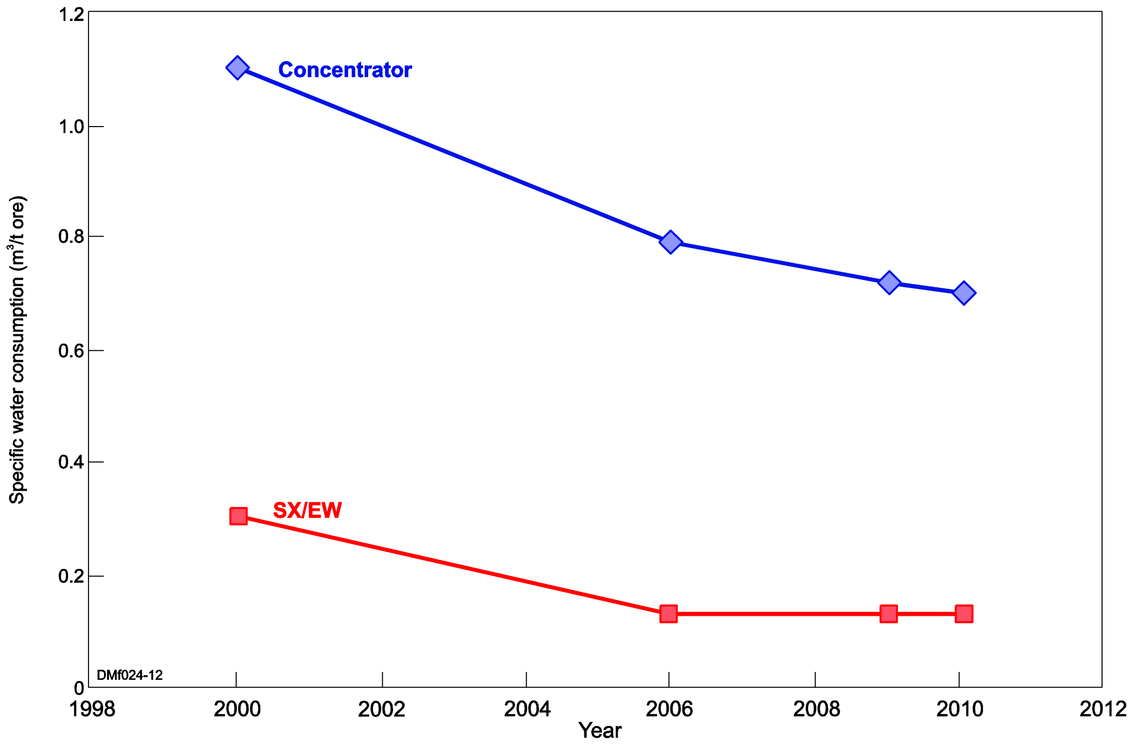


Figure 30. Decrease in specific water consumption of Chilean mining industry over last decade.

4.1.5 FUTURE WATER USE FOR MINING IN THE COPIAPÓ BASIN

Water consumption for mining in the Copiapó Basin can be expected to increase in the future due to both significant planned industry expansion and production as a result of increased commodity prices, and also as a result of anticipated reductions in ore grade. The effect of these two issues on future water use is discussed below.

Declining ore grades

Soruco and Philippe (2012) report that the average copper ore grade in Chile decreased by 13.6% from 0.81 in 2002 to 0.70 in 2008. On the other hand, data from Jofre (2011) as reported by Benavente and Goya (2011) as shown in Figure 31 indicates a 19% decrease in copper ore grade from 0.95 to 0.77 between 2000 and 2010. Despite the minor differences between these two sets of data, there would appear to be a definite downward trend in Chilean copper ore grades, in line with similar observations globally. Furthermore, Figure 32 projects a similar decrease in ore grade out to 2015. As a result of these falling ore grades, mining companies will have to process more ore if they wish to maintain copper production levels, which means increased water consumption. The effect of falling ore grades on the embodied water (m^3/t Cu) of copper metal production is shown in Figure 33. Based on this latter figure, a fall in copper ore grade from 0.77% in 2010 to 0.68% in 2015 as projected in Figure 32, would increase water consumption in the order of 8.4 m^3/t Cu if the rate of copper metal production (by the concentrator route) is to remain constant. For a mining operation producing 148,000 t Cu/y (e.g. Candelaria in Table 3) this would amount to an additional 1,226,000 m^3/y (or 39 l/s) that would need to be sourced.

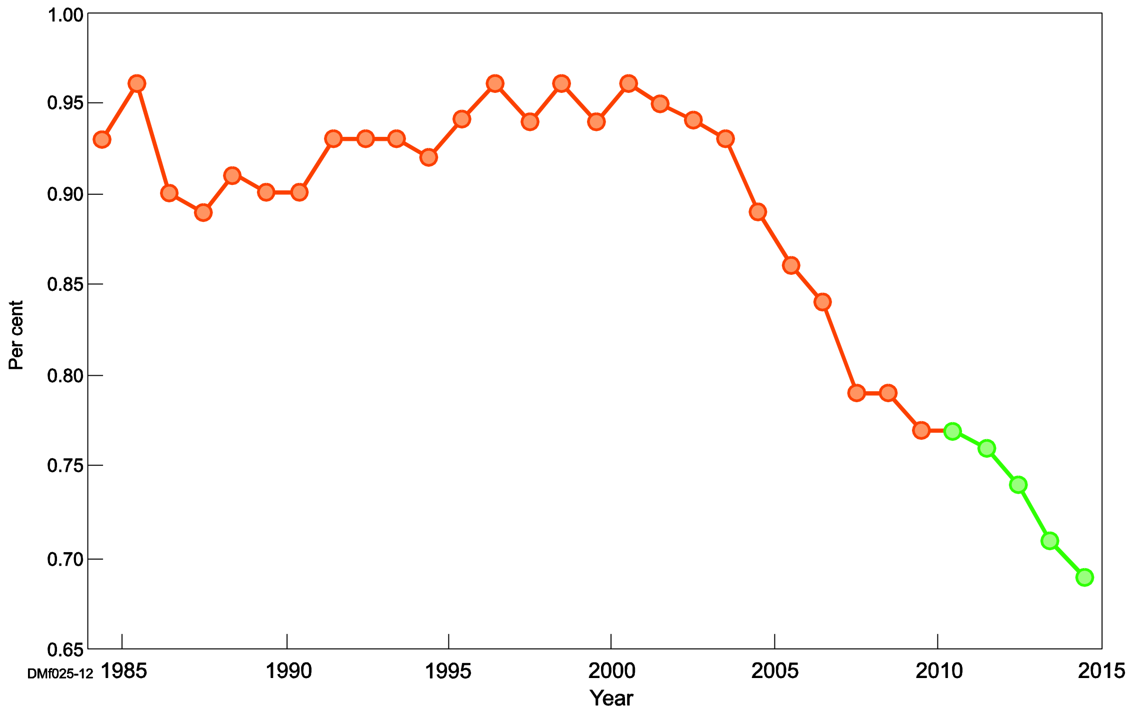


Figure 31. Declining copper ore grades in Chilean mines, with projections to 2015 (Jofre, 2011).

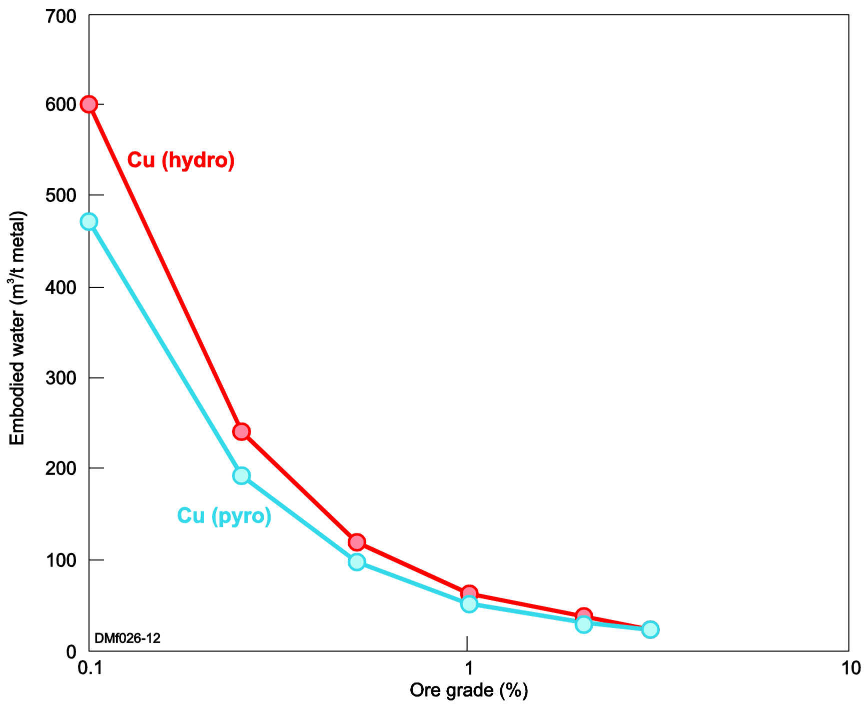


Figure 32. Effect of ore grade on embodied water for copper production (Norgate and Aral, 2009).

Increased copper production

The projected growth in copper production in Region III to 2020 is shown in Figure 33 (Cochilco, 2010), with a projected 180% increase in concentrate production for the period under review (2009-2020) and a 124% increase in total copper production. Figure 34 shows the projected total water demand for copper mining in Region III out to 2020 based on the production data in Figure 33 and the mean specific water consumption values for concentration process (0.70 m^3/t ore) and SX/EW processes (0.13 m^3/t ore) for 2010 from Table 6. Also shown in Figure 34 is the projected water demand for the same period reported by Cochilco (2009) but based on earlier (2009) production forecasts and more site specific water consumption data. The sharp drop in water demand between 2009 and 2012 predicted by Cochilco did not occur in practice, as this was based on the expected closure of the Salvador mine (with a high specific water consumption of 2.07 m^3/t ore), but this did not happen (Brantes, 2012).

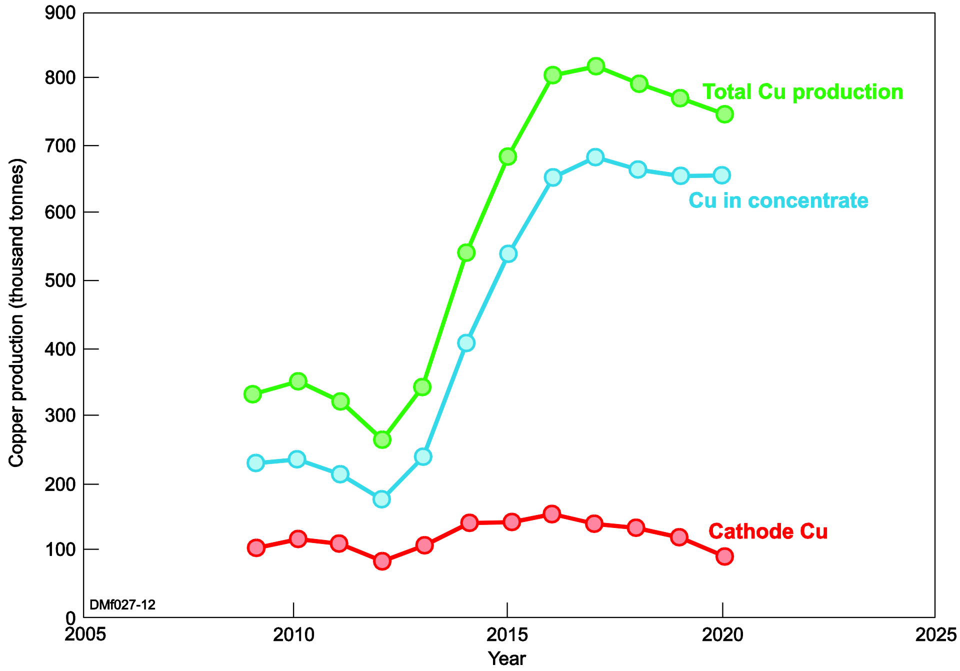


Figure 33. Projected growth in copper production to 2020 in region III.

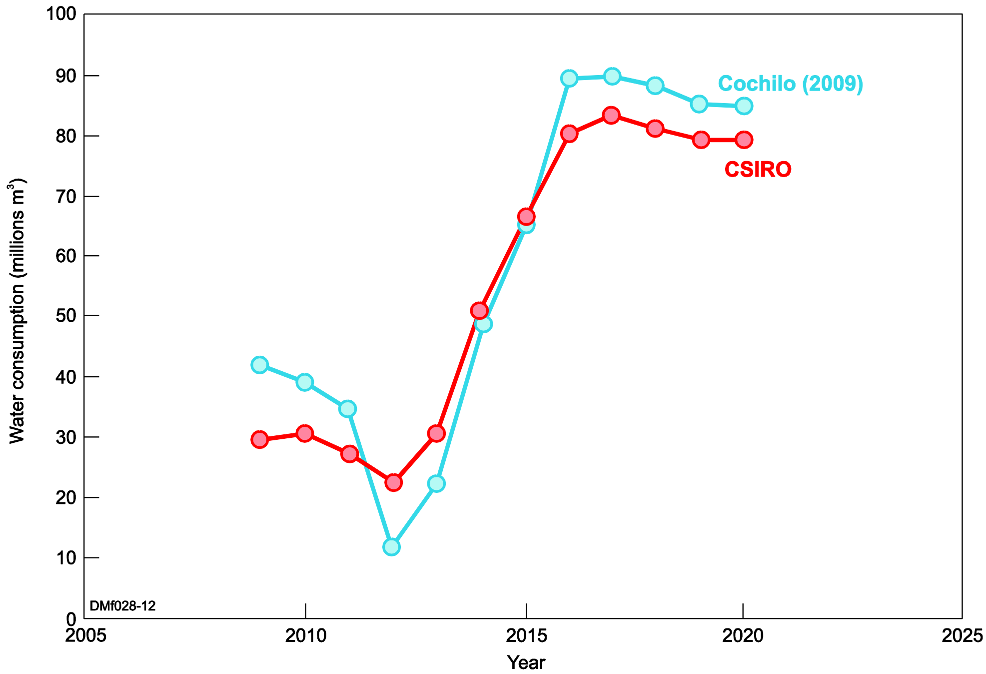


Figure 34. Projected freshwater extraction for copper mining in Region III to 2020.

It should be noted that while the projected water demand in Figure 34 accounts for expected changes in copper production, it does not take into account the following issues which will also influence future groundwater demand in region II, and by extension, the Copiapó Basin:

- likely decrease in ore grades (will increase consumption)
- implementation of water reduction technologies such as paste thickeners (will decrease consumption)
- use of alternative water sources such as seawater or desalinated water (will decrease demand).

Further detailed information regarding these issues for the various mining sites in the Copiapó Basin is required before more definite water demand projections can be made.

4.2 Industrial water

The Copiapó Basin has mainly light industry and some medium industry such as the INACESA cement plant. Of the 17,765 l/s of approved water rights in the Copiapó Basin in 2009, only 0.4% or 67 l/s have been allocated to industry, amounting to 3 in number (DICTUC, 2010). Actual water use by industry was 33 l/s. This value compares with 1240 l/s for mining (see section 4.1.2) and represents only 2.7% of the water used for mining in the Copiapó Basin. This total industrial water use is broken down into sectors in Table 7. Given this relatively low demand for industrial water use, it is unlikely to be a major issue affecting water availability in the Copiapó Basin in the foreseeable future compared with other water supply competitors.

Table 7. Industrial (non-mining) water use in the Copiapo River Basin.

SECTOR	USE (L/S)	RIGHTS (L/S)
Sector 1	0	0
Sector 2	19	0
Sector 3	0	0
Sector 4	0	20
Sector 5	14	47
Sector 6	0	0
Total	33	67

Source: DICTUC (2010).

4.3 Comments made by interviewees

The following comments were made about mining water use, and made by mining companies about water management in the Basin, during a visit to Chile in May-June and October 2012.

- Not many people know of the serious water situation in the valley. There is no lobby group for mining
- Questioned whether the upper basin is connected to the lower basin. Upstream of La Puerta the aquifer is full. Suggested a hydrogeological study to determining links. The implications are that miners could use upper basin groundwater without having to worry about lower basin impacts.
- It may be possible to develop a water supply for both the Cerro Casale mine and Copiapó
- Interest in cloud seeding looks like desperation and the need to be seen to be doing something. Some thought that it had produced nothing and farmers wanted industry and utilities to pay for the experiment
- Questioned whether agriculture in the upper basin had expanded and increased its water diversion, not decreased by 500 ha in the past 5 years as estimated by the Ministry of Agriculture.
- Some large farmers pretend to be small businesses as this is more acceptable in the water debate
- While farmers openly complain about miners being able to pay more for water rights some approach miners about purchasing their rights, especially if they want to retire
- There is currently little social capital in the Basin to build upon.
- Solution could include:
    - Clear and strong leadership from government

    - Basin level intuitional framework as proposed by the natural resources bill that has been delayed in parliament
    - Ability to measure and enforce use / restrictions
    - Bringing more water to Basin
    - Clear swaps in water rights that are strategic
- Miners currently are only using a fraction of their water entitlements (one quoted 20% use) and are developing water sources that will make them largely independent of Basin water issues (apart from domestic water required of their workers in Copiapó and other settlements)
- Desalination is done mine by mine and there is no overall framework. Miners don't cooperate in the region – Mineral Council provides some coordination at the state level. Timing and location needs are different for companies making it hard to coordinate desal options. Copper and iron miners are also different types of companies. At $4/kL it is amongst the highest water prices in the world. Water conservation / management is more important
- Need a model that integrates social, economic and environmental issues with hydrology. Aquatool was a start on this
- French company planning to bring water from Mauli / BioBio to Copiapó using submarine pipeline with a large diameter and low friction – apparently half to a third the cost of desalination (see Section 9)
- Chile concession mechanism for public – private partnerships is a good way of providing capital for projects that have government support. Pension funds are seeking to invest in long term safe projects like the pipeline above
- Too costly to pump desalinated water to upper basin where mines are located at 2000 to 4000m elevation. The cost of pumping could be 3 x desalination if they had to pump to heights
- 90 to 95% of mine workers live in region; fly in – fly out is uncommon
- It may be possible to use desalinated in the lower basin (e.g. Sectors 3 to 6) and allow water in the upper sectors to be largely used for mining. Such arrangements have been possible in Regions I and II but not in Region III (Atacama). This may be because Aguas Chañar is a government-licensed operator of the water supply system rather than a private company with its own capital assets.
- Without water many medium-sized mines will not be viable
- Apparent water surplus in the Huasco valley may be used by new mines starting in that province
- Rainfall mean has dropped in all northern areas near desert in Chile. Rainfall types in the Basin were considered to be: 1) winter cold fronts; 2) Andean winter; 3) cold fronts from the North; and 4) occasional North Bolivian warm fronts in summer
- Dewatering to access mineral deposits ('pit water') in the upper Basin is considered differently from water licenses issued for consumptive use but the impact may be similar according to some users in the lower Basin. Given the very high potential evaporation rates in the upper Basin, exposing groundwater to the atmosphere may increase losses. There may also be 'rejected recharge' in shallow aquifers whereby full aquifers cannot accept further recharge and excess water is lost from the system.
- Miners do know who holds water rights in the Basin and the current management system of rights is not deficient.

5 Agricultural water

According to the Chilean Ministry of Agriculture, farmers in the Copiapó Basin irrigated 12,753 ha of land from 2,073 properties using 5,071 l/s[4] (CNR, March, 2012). Drip irrigation is used on 11,070 ha or 87%. They also estimated that the annual basin yield is about 110 GL/y, use is 160 GL/y which results in a 50 GL/y deficit. The accumulated deficit between 1970 and 2007 was estimated to be about 500 GL.
The breakdown of crops is shown in Table 8

Table 8. Crop areas and sectors in which they are grown in the Copiapó River Basin (CNR, March 2012).

Crop	Area (ha)	Sector grown
Vineyards (mainly table grapes)	9,004	1, 2, 3 and 5
Olives	1,293	6
Vegetables	1,234	4 and 5
Pomegranate	522	5
Other	700	Channels in river outlet

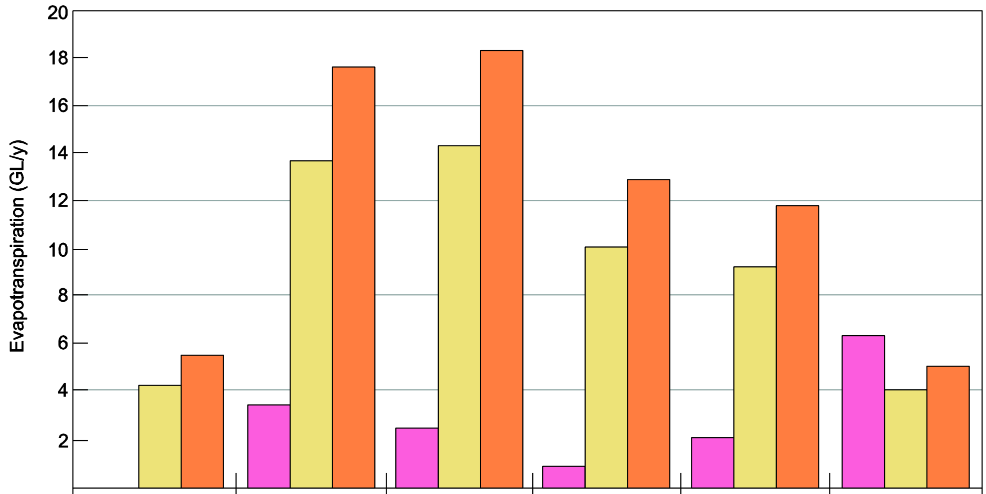
Schemes have been proposed to maximise infiltration of any excess river water in hydrogeological sectors 3b, 4 and 5. This may reduce the need to increase the capacity of the Lautaro Reservoir. While the Sector 5 infiltration basin is located at its boundary with sector 6, diverting all flood flows into the upper sectors would not solve the water depletion problem in the sector furthermost from the source of basin water.

An estimate of evapotranspiration losses by crops and natural losses from the valleys in the six sectors is shown as Figure 35. Most water is lost due to irrigation in Sectors 2 to 5 which corresponds closely with the allocation of water rights (Figure 17). Only in Sector 6 was evapotranspiration from valley vegetation estimated to exceed irrigation water losses. This was in 2003, before levels declined significantly. Groundwater levels are high in parts of Sector 6 and important wetlands are reported to be present by residents within Copiapó. These wetlands occur partly because of the basement becoming shallower towards the outlet. At Angostura the valley is estimated to be only 100 m wide and 180 m deep (Golder Associates 2006).

About ten years ago it was estimated by the DGA that about 78 percent of all recharge to the aquifer comes from the river bed and irrigation canals, with a further 17% from drainage below irrigated crops (Figure 36). The very high water use efficiencies now used in drip irrigation and the low river flows since 1998 has almost certainly reduced recharge to the aquifer in recent years and it is unclear how these proportions may have altered as a result. However it is clear that losses from the surface water system are usually gains to the aquifer so that there is a 'zero sum gain'. Reducing channel leakage and increasing water use efficiencies is a common response to less surface water but the longer term consequences of lower groundwater levels and increased river leakage are not usually considered.

Water is not the only limitation to grape production. In areas where the valley is narrow water is pumped several hundreds of metres in elevation to nearby side valleys where land is flat enough to support production. Some side slopes are incorporated in these plantings.

[4] This represents about 160 GL/y. DGA (2012) estimates agricultural use as 4,500 l/s or about 142 GL/y



	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
Valleys (DGA 2003)	-	3.5	2.5	0.9	2.1	6.4
Crops (DGA 2003) (*)	4.4	13.8	14.4	10.1	9.3	4.0
Crops (Actualisation 2005)	5.6	17.6	18.4	12.9	11.9	5.1

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Figure 35. Evapotranspiration (GL/y) from the valleys and crops for the six sectors. (Golder Associates 2006).

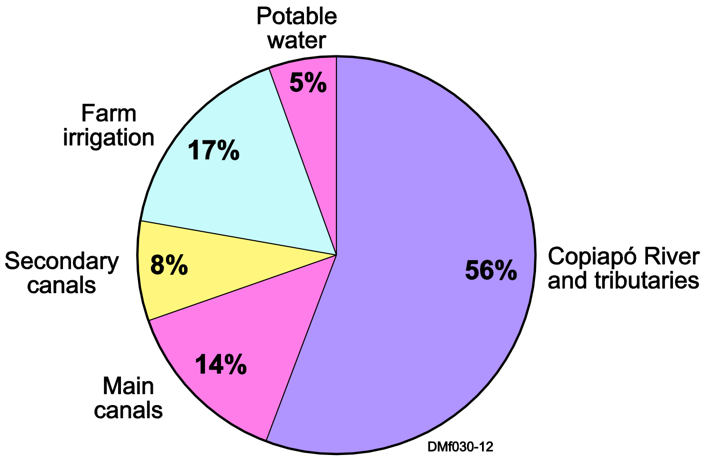

Figure 36. Recharge to the basin aquifer occurs mainly from the river bed (56%), followed by farm irrigation (17%), leakage from main canals (14%), leakage from secondary canals (8%) and drinking water losses from leaks (5%). (Golder Associates 2006 based on DGA (2003)).

The following comments were made about agricultural water use in interviews during a visit to Copiapó in May-June and October 2012.

- Table grape production commenced in about 1965 and became very important after 1983. This increased water diversion and extraction in Sectors 1 to 4 especially. Mining became important after 1992.
- Copiapó has an advantage in being able to produce high quality table grapes for the North American market a month earlier that producers further south where water is more abundant.
- Water use efficiencies in the large farms especially are very high due to the high use of drip irrigation systems and the need to conserve water.
- There is insufficient water to ensure that salts are leached below the root zone, and in areas where water quality is poor the soil is being affected by salt build-up and loss of soil structure. Between 20 and 30% more water is now required to leach salt which is not profitable.

- Pollution of groundwater is an issue below some farming areas. The poor groundwater quality in Sectors 5 and 6 is due to contamination from agriculture (nitrates and sulphates) rather than from mining (heavy metals).
- The viability of table grape production is threatened by competition from Peru which has the following competitive advantages:
    - More water for irrigation
    - Cheaper labour costs, especially now that mining companies near Copiapó are paying high wages
    - Early season production
    - Cheaper and more abundant land suitable for irrigation
- Growing table grapes in such a water-short area is foolish. The region is exporting its scarce water resources in the grapes.
- It was thought by at least one interviewee that the average age of small irrigators were getting higher and some did not have young family members wanting to take over the farm because mining and other professions were more attractive. Some farm businesses lacked the capital to invest in high water efficiency irrigation practices or to deepen their wells as groundwater level fell. Using lower quality water in Sectors 5 and 6 threatened soil fertility. Some were keen to sell their water rights to miners or to sell land for urban development if they lived near the town. It is not possible to verify these observations with statistics. However several people thought that the area under irrigation had contracted by up to 500 ha from its peak[5]. Miners interviewed also said that they had enquiries from farmers wanting to sell some or all of their water entitlements.
- Some small 'subsistence' farmers (i.e. growing crops mainly for their own family's use) were finding it slow to obtain water rights and to pay for deeper wells in Sector 5 and 6. One estimate was that 80% of all farmers are 'small water users' ('small' was not defined).
- Thirty years ago groundwater levels were 30 m deep and it cost $500/ha to irrigate. It is now up to 100 m deep and it costs $3000/ha.
- Some owners of water rights used the income earned from leasing their water rights as a means of financial support. In Sectors 5 and 6 there are companies that buy and sell water rights, a new (speculative) business that may be increasing the cost of acquiring water rights.
- Some farmers were interested in exploring cloud seeding as a means of increasing water yields. A group was formed to seek funds for this activity. The miners and Aguas Chañar were invited to contribute. There was however some scepticism about the efficacy of cloud seeding.
- Demand from agriculturalists is hard to determine. Water rights are relatively well known (although not all are registered and some are leased), demand (which relates to crop areas, crop types, soil factors, irrigation efficiency etc) was less well known and water use is either not measured or reported. There are a number of government and industry support groups that estimate these numbers but none are considered definitive.
- The water rights of surface water irrigators are well protected under the 1981 Water Code as this was the dominant water use when it was prepared. The rights of other water users and of groundwater users are less well defined. For example the Basin Vigilance Group does not include groundwater users in Sectors 5 and 6, Aguas Chañar or the water rights of miners. The DGA has some oversight of the Vigilance Group and can arbitrate disputes but cannot determine who receives water. There are emergency measures but any reductions in water rights need to be

[5] Some interviewees believed that the area under irrigation has expanded by a similar amount in the upper basin

made on an equal basis so that town water supplies would be cut by a similar proportion as any other user group.

- Distributing surface water is easier because it is visible and can be seasonally adjusted. Seasonal adjustment of groundwater cannot be done as storage and annual recharge rates are not obvious.
- Some groundwater users were sceptical that surface water users in the upper basin were only using the water that they were entitled to. Up to 25 percent may be illegally diverted according to one source. It was also alleged that water rights may be sold but continue to be used afterwards.
- Miners pump continuously whereas farmers pumped for only part of the day or seasonally.
- Miners have increased the cost of acquiring water rights such that farmers are unable to buy more water.
- The lack of public capital investment in securing water supplies for agriculturalists was raised on several occasions with the last major investment being the constriction of the Lautaro Reservoir in 1920[6]. However there has been considerable private and public investment in improvements to main and secondary canals to deliver water to surface water irrigators.
- Irrigators in the basin proposed the creation of a 'water bank' which would transact real (wet) water rather than 'paper' rights which were not able to be used because of a lack of water. Under this scheme some users would exit. They saw the lack of land for housing in Copiapó City as an opportunity as this increased farm land prices. They proposed to donate 200 l/s of water to enable the city to grow by up to 90,000 people in the next 3 to 4 years. This would require changes to boundaries, extraction and zoning.
- Many farmers in the basin live in Copiapó City and understand that all parties need water.
- Desalination costs are too high for farmers to consider – at $4/kl it was considered one of the highest prices in the world due to energy costs.
- Some believed that the agriculturalists should undergo the same environmental approval process that miners have to undergo as their decisions can have impacts well beyond their farms.
- Periods of high water abundance resulted in an increase in both the issued water rights and the area being irrigated, but this was not reversed in dry periods.
- AAS time passes, the ability to manage the water resources in the Basin diminishes and there will be irreversible change.

[6] Other interviewees mentioned the dam being built in the 1930s and 1940s.

6 Residential water

6.1 Statistics

As indicated earlier, the population of Copiapó City has been estimated to be between 130,000 and 180,000. While the growth rate is widely perceived to be rapid, estimates vary from 1.3% per annum to a doubling within three years. As provider of drinking water and wastewater services to the City, Aguas Chañar has an estimate of growth rates, as does the Ministry of Planning which supervises zoning and the subdivision of land.

The number of customers affected by unplanned outages has increased 4 times since 2005. A number of measures were taken after repeated cuts in 2006 and 2007; however the problem has not been resolved.

In December 2008, the Superintendence of Sanitary Services (SISS) instructed Aguas Chañar to develop a Water Action Plan and to do additional drilling. A strategic long term plan by Aguas Chañar in 2009 concluded that Sector 4 wells would be depleted in 2012 to 2013 and they should begin moving extraction to Sector 5. In 2011 the SISS directed the deepening of existing wells and additional drilling in Sectors 3 and 5, ahead of planned investments in the plan. Substantial investigations of the nature of the aquifer in the valley around Copiapó City (including geophysical surveys) were used before defining drilling targets.

Figure 37 shows 17 bores (blue) currently provide drinking water and 24[7] bores (red) have been abandoned due to poor water quality or loss of yield. Bores in the most westerly area have resulted in substantial local drawdowns which has concerned nearby irrigators.

The production of drinking water increased by 11 per cent between January 2010 and December 2011, but the proportion of total production from Sector 4 decreased from 89% to only 48 per cent (Figure 38). This move of extraction into highly allocated areas was made possible because of an emergency deficiency act being declared. However deficiency periods have a limited life. In April 2012 the supply capacity from all available bores was only six percent above demand showing that there are few reserves within the system.

Figure 37. Drinking water production bores around Copiapó City. Blue = bores in use; red = abandoned bores.

[7] SISS (2012) note the loss of only 19 wells

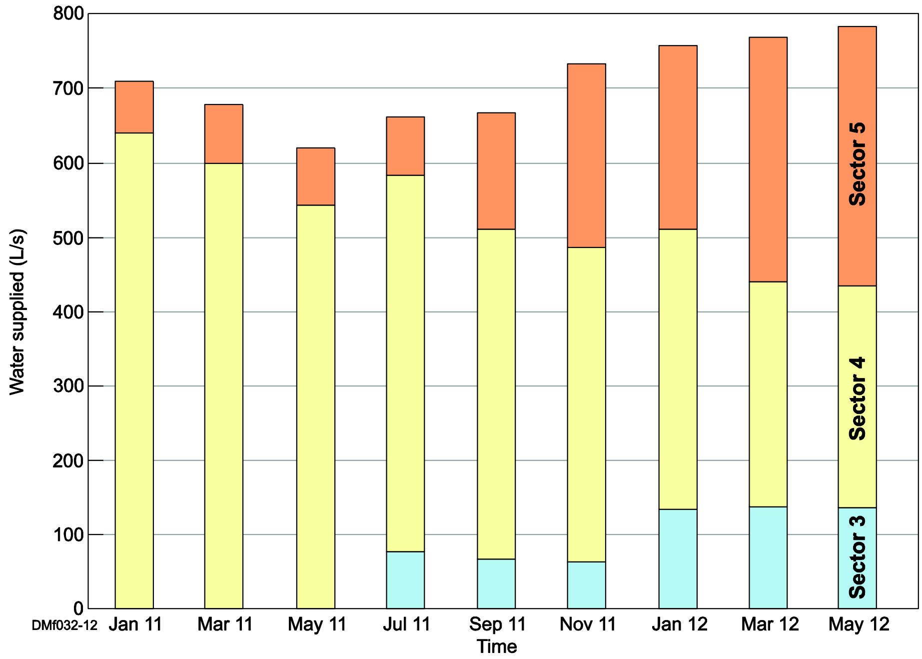

Figure 38. Water supplied from Sectors 3 and 5 have increased as Sector 4 has been depleted (SISS 2012)

Drinking water does not currently meet the Superintendence of Sanitary Services (SISS) standards because of high chloride, sulphate and total dissolved solids (Figure 39). A reverse osmosis treatment plant is being built to improve drinking water quality. Collaboration with mining companies is another option. Many mining company staff live within Copiapó City which provides an incentive for such collaboration.

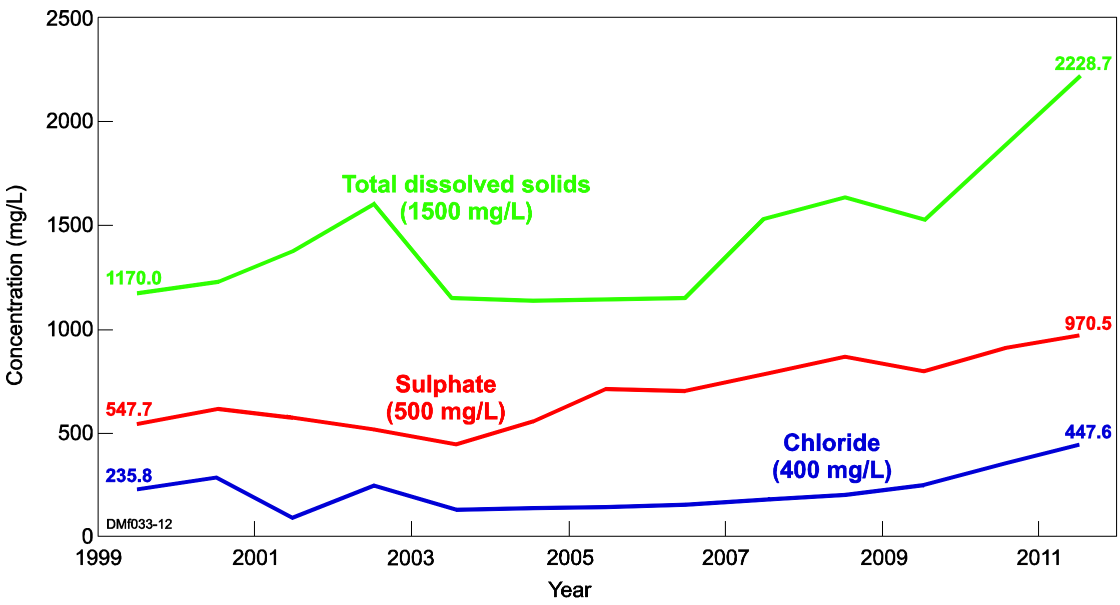

Figure 39. Deterioration in water quality in bores supplying drinking water with recommended standards in brackets (SISS 2012).

6.2 Comments made by interviewees

The following comments were made about town water use during interviews during a visit in May-June and October 2012.

- There are flow meters in all residences but theft and leakage losses are high. Water theft is not considered seriously by the courts, unlike electricity theft. For every 100 litres of water produced, 64 is sold and consumed, 20 is stolen and 16 is lost due to leakages.
- Only one tariff can be charged for drinking water and according to the service provider this isn't cost reflective. The price of water would need to increase by up to three times to provide good service.
- Given the natural monopoly nature of water service provision, the tariff is set by considering competition against an 'ideal company'.
- The tariff charged by Aguas Chañar is the lowest in Chile for supplying water in one of the driest parts of the world. The fact that the aquifer in the surrounding area is already overused and overallocated, as well as demand growing at an unprecedented rate, makes the feasibility of developing a reliable and high quality supply very problematic.
- Salts in the water supply can encrust appliances and result in leakage through valves not closing properly.
- No priority is given for drinking water over other water uses under the current market-based system. Miners have forced up the price of purchasing water rights.
- As Aguas Chañar is effectively owned by the Chilean government it is difficult to raise capital. Tariffs can be requested to be adjusted if new capital investment has occurred as a certain return of capital is required. This can distort investment decisions. Otherwise tariffs are only reviewed every five years.
- Decisions on new water rights are very slow and wells can be dry before approvals are granted.
- There are 15,000 new houses in Copiapó to service; some are in hilly areas which makes them hard to service.
- There is a need to get better community acceptance of reuse. There is some confusion about who owns treated wastewater, the resident who purchased the drinking water from Aguas Chañar or the company that collects and treats the water. This confusion needs to be clarified at the national level.
- Treated wastewater has to be returned to the stream from which it was taken. This makes it hard for a profitable business to be built around treatment which would enable higher quality water to be sold to industry. Once a use has been established (e.g. agriculturalists using treated wastewater downstream from a discharge point) the Supreme Court can require this discharge to continue as it is an historical use of water.
- It is difficult to get approval to do managed aquifer recharge (MAR) due to regulations and costs.
- Agricultural users affected by heavy extraction from drinking water wells have complained. There have been instances of sabotage of wells and electrical transformers as well as roads being blocked.
- There have been large and unexpected drops in groundwater levels in some areas – up to 20 m in 15 days.
- Per capita water consumption has reduced from 200 litres per day to only 170.
- A desalinated water source for drinking water will be required by 2017. However the price of water may need to rise by between 40 and 200 per cent (estimates made by different people) to pay for such an expensive source or water. This would make it difficult for poorer people to be able to buy

water. There is (ca. 50%) support to pay part of the cost of water by 10 to 15% of consumers who need assistance.

- Environmental approval has been obtained by Agbar Latino America for a desalination plant to supply 500 l/s of drinking water[8] and 500l/s to mining companies. The proposal is currently on hold.
- Water demand is considered to be relatively inelastic (i.e. price doesn't have much impact on consumption) as the cost of water is low compared with utilities such as energy.
- While the focus is on water supplies to Copiapó, Caldera has 50,000 residents and this number grows to between 80,000 and 100,000 in summer.
- The high level of salts in the drinking water contributes to losses because taps become encrusted and leak.

[8] 50 l/s is about 15.7 GL/y

7 Social, cultural and environmental water

7.1 Statistics

There is good information available on the environmental threats posed by major industrial and mine developments and monitoring of metals, acidity and other pollutants from mine sites is carried out under strict regulations. There is less information available about overall environmental values in the Copiapó River Basin or of non-point sources of pollution such as intensive agricultural development that could be identified in the time available.

Cade-idepe (2004) analysed water and associated environmental quality in the basin for the DGA. They identified four vegetation types: coastal desert; flowering desert plains; flowering desert foothills, and high Andean steppe. Eight aquatic flora species were identified, none of which were listed as being endangered.

Nine benthic aquatic fauna were identified, none of which were listed as being endangered in 2004 despite them reducing. This included commercial populations of northern shrimp that were distributed downstream of Copiapó (Hanging Stone) to the river mouth. Given the lack of river flow and groundwater development around Hanging Stone, the current status of the shrimp is unclear.

Six fish fauna adapted to conditions in the North were identified. The 'Pejerrey' (*Basilichthys microlepidotus*) was in danger of extinction while the 'Bagrecito' (*Trichomycterus aerolatus*) and the 'Pocha' (*Cheirodon pisciculus*) were considered vulnerable in 2004.

River salinities were reported by Cade-idepe (2004) to be low above Copiapó City but to increase downstream (Figure 40). The water chemistry shows that it is hard (calcium, magnesium, carbonates, high pH) as would be expected in an arid area. The river ceased to flow in Sector 4 since about 1998 so these include historical values.

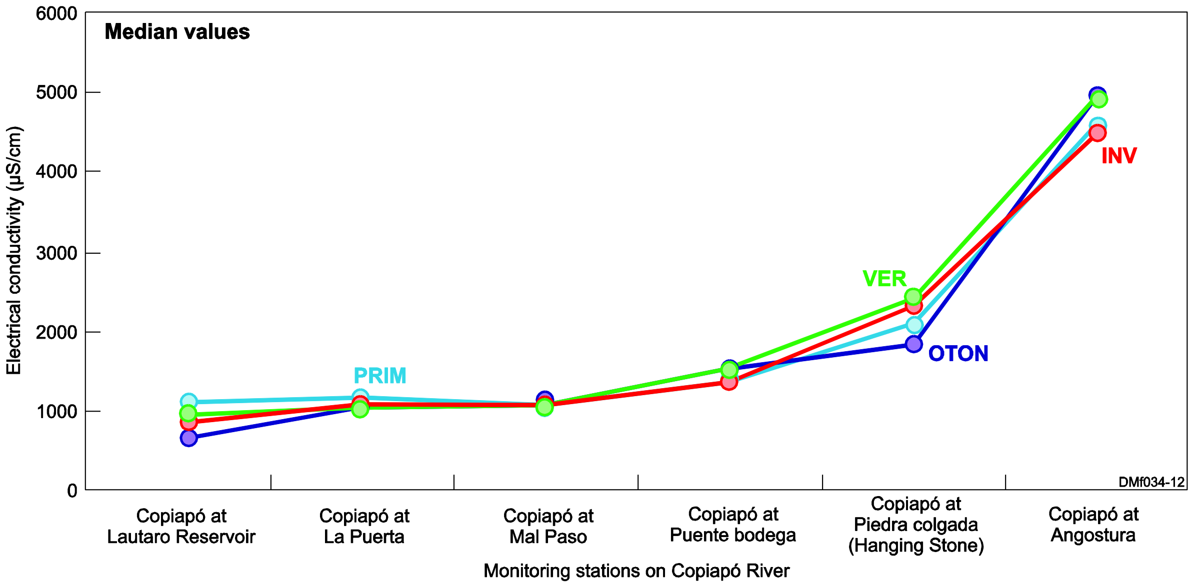

Figure 40. Copiapo River conductivities in six gauging stations (Cade-idepe 2004). Upstream is to the left.

7.2 Comments made by interviewees

The following comments were made about socio-economic, cultural[9] and environmental water use during interviews over a ten day visit in May-June 2012.

- 97.6% of people live in the cities in the Basin and most new residents work on the mines. The nature of Copiapó has changed from being focused on export agriculture to mining.
- Shallow wells (< 15m) have dried up, wetlands closer to the coast have been lost, forests have gone[10], the river now flows in deep gorges and has ceased to flow through Copiapó City which is missed by its longer term residents. Pollution from mine tailings has also impacted on the environment.
- While there is emphasis on mining impacts on water quality and the environment (point sources), non-point source pollution by agriculture is not given as much attention. This is seen by some groups associated with the mining industries as being inequitable as they do not undergo the same degrees of environmental scrutiny.
- The rain has 'just stopped' and snow is also decreasing; it used to be 1.5m per annum and now is only 0.5m. Rainfall before 1987 was more effective.
- The new residents of Copiapo do not have a memory of the river flowing through the town. Many come from wetter parts of Chile and do not understand the importance of conserving water. They miss green landscapes and would like to have a green area for recreation.
- The government is working with Copiapó residents to create a green area along the river bank called Kaukari Park using stormwater and grey water.
- Several interviewees mentioned a low level of trust between water user groups and a lack of social capital. The Water (Negotiation) Table that operated between 2007 and 2011 helped to build understanding of the situation and the position of the different groups. The Water Table formed after a period of level low levels in Lautaro Reservoir but was disbanded to the disappointment of some interviewees[11].
- All major decisions are made in Santiago where each Ministry is internally focussed. Better coordination between Ministries occurs at the regional level.
- Most people interviewed believed that the situation was dire and a drastic response needed to be taken. Few thought that the community understood the seriousness of the situation and many thought that the government's response was inadequate. The legalistic nature of water governance (especially the 1981 Water Code) was seen as causing delays and uncertainty. Some expressed a frustration that things always had to get extremely serious before any action is taken and then it may not be an optimal or considered response.
- There are new instruments that could be used to improve cross ministerial collaboration – a Strategic Environmental Plan and a Strategic Environmental Assessment.
- There is water associated with ravines that extend from the Andes to the Coast.
- Many jobs in the mining industry have gone to people from outside the region. Locals have missed out on opportunities but have to put up with increased pressure on resources and costs of living in the Copiapó Basin
- Water conflicts are not new in the Basin. An attempt by the Catholic Church to monopolise water in the 1800s had to be addressed by the national government after protests by water users.

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[9] Including by the indigenous Colla (or Coya) people

[10] The original name of Copiapó 'San Francisco de al selva' refers to a jungle (selva), possibly of chañar trees (*Geoffroea decorticans)*.

[11] Another version of the Water Table has been proposed to improve communications and to seek consensus decision making

8 New water source options

Given the high degree of resource over-use, the recent 14 – 24 year dry period and the permanent nature and high water use efficiency of most existing demands, attention is focused on the feasibility of finding new water sources for the Copiapó Basin. Priority has been placed by the DGA on souring drinking water for residents given the health aspects of having an inadequate supply of poor quality water. This would require a change to the Water Code to provide a preference for human consumption.

As outlined in Section 4.1.3, six desalination plants are under consideration or development in the Copiapó Basin, five of them for mining. The main impact of these plants would be to reduce extraction from the aquifers in sectors 3 to 6. However even if extraction was reduced to zero, this would just delay the depletion of these aquifers unless the climate became wetter and recharge occurred in the Copiapó floodplain. In other basins, miners have been granted to more water rights in the upper Basin if they provided desalinated water to coastal towns (e.g. Antofagasta). It is not clear whether this is an option in the Copiapó Basin (e.g. for the new Caserones mine).

The Planta Para el Valle de Copiapó (Plant for the Copiapó Valley) scheme has been proposed by Agbar Latino America, the water service company for the Santiago area. This could provide 500 l/s for Copiapó City and a similar amount for a mining company. The supply distance would be about 64 km and the cost between US$ 1.44 and 2.98 per m^3. As mentioned in Section 6.2, environmental approval has been obtained but the project has been put on hold.

The Candaleria Mine currently uses half of the treated wastewater from Copiapó City. It will not require this water source once its desalination plant commences in late 2012. Proposals to improve the quality if this water are being considered. Managed aquifer recharge seems applicable for this water source but some is already being used for irrigation as a surface water source. As the city expands, this water source should also grow. It is also largely climate independent as domestic water use is relatively inelastic.

A 155 km water pipeline to bring up to 700 l/s of water from the Huasco Valley has been proposed. The water would be sourced by improving irrigation efficiencies in the valley (currently only 50%) releasing the water for use in the Copiapó Valley. Transferring seasonally-used irrigation water rights for those that are used continuously have created problems and this proposal may face a similar issue. Inter-basin transfers are also controversial. The cost of supply may be similar to that of the Planta Para el Valle de Copiapó desalination plant.

There is groundwater in storage in Sector 6 but accessing this would result in hardship for irrigators with shallow wells. This water also requires treatment to remove nitrates, sulphates and salts before it could be used for drinking. Compensating farmers for deepening their wells could release some of this water but if it is not being recharged it is not a long term solution.

Increasing infiltration in flood periods has also been investigated. This requires infiltration pits to be constructed near the Copiapó river bed to increase temporary storage and infiltration. As mentioned previously, the creation of a strong losing stream has already increase infiltration rates in the lower basin, such that flows no longer pass Sector 4.

A seawater pipeline of up to 2,500 km length to be built in 200 – 300 km stages has been proposed to bring water from the Bio-Bio River about 250 km south of Valparaiso to the north of Chile (GWI 2012). The pipeline could provide 30 m^3/s (or 2.6 GL/d) with about 67% destined for agriculture, 23% for mining and 10% for municipal use. The cost has been estimated to be about $0.70/$m^3$ with a government subsidy required to make it feasible for farmers to buy this water. Called the Aquatacama Project or 'water pipeline', it is proposed by Via Marina (a subsidiary of VINCI Construction Grands Projects) and Fundación Chile. The 'Submariver' system would pump water through a submarine pipeline of up to 4m in diameter coming to the coast every 200 km to be re-pressurised (VINCI 2012). The feasibility of the cost effectiveness of this project was questioned by some interviewees in the October 2012 visit.

Allowing more river water to pass Sectors 1 to 3 would also increase recharge in the lower basin. This may have been foreshadowed in the following press release / interview between Juan Andres Abarca of BNamericas and Mr Patricio Crespo, President, National Society of Agriculture (SNA) in October 2012:

Juan Andres Abarca of BNamericas:

One of the areas that would potentially benefit from this project [the water highway] is the Copiapó valley, which has been overused for many years, what happened there?

Mr Patricio Crespo:

What happened there was a combination of factors - water rights were granted in excess, a situation in which [national water authority] DGA failed because it made an estimation of the capacity of the aquifer and its extraction that didn't reflect the reality of the aquifer, so it was overexploited.

You also have to consider that rainfall has decreased, so the aquifer hasn't been recharged naturally, and the Lautaro reservoir has never been back to its full capacity.

In the end, I think that water in the area will be used mostly by the mining industry because of economic reasons. Agricultural production in the region is not that significant, while the mining industry is making the city grow and bringing jobs.

We don't need to worry that much about this fight, as it will be solved in favour of what is most [economically] beneficial for the country.

9 Conclusions

This report summarises material from reports, most of which are written in Spanish, and opinions expressed in a number of interviews and a field trip conducted over a ten day period. Where possible it integrates written, often quantitative information with oral, often qualitative interviews so that as broad a picture of the water situations as possible can be provided for later use. Given time constraints it is possible that some numbers are not accurate or as up-to-date as would be achieved over a longer period. Some statistics are apparently contradictory but there was insufficient time to research which were more likely to be reliable. Despite these limitations the following conclusions can be reached:

1. Water rights currently exceed annual long-term water yield by more than four times and by even more than the actual catchment yield since 1998. There are a number of mitigating factors that led to this situation, one being that the Water Code makes it easy to issue rights in times of apparent water surplus but it is very hard to remove rights when yields are low.
2. Expressing water rights as a maximum instantaneous withdrawal rate (l/s) rather than as an annual volume (ML/y), or as a share of the available annual recharge, may have also contributed to over allocation. Farmers may only use their maximum withdrawal rate at certain times of the year whereas miners and town water suppliers are able to extract at this maximum rate and store the water throughout the year.
3. It is unclear whether the low flow periods since about 1998 is cyclical or due to a longer term change in precipitation or runoff mechanisms (see next section).
4. Current water diversion and extraction is resulting in groundwater storages decreasing by between 50 and 80 GL/y. This is mostly impacting on Sectors 4, 5 and 6, where most groundwater is found. Lower levels are contributing to higher extraction costs (deepening or replacement of wells, pumping costs) and poorer water quality which is in turn damaging soil fertility.
5. Surface water diversions in Sectors 1 to 4 and groundwater pumping in Sector 4 have resulted in the Copiapó River ceasing to flow past about Tierra Amarilla since 1998. As a consequence the river has contributed almost no recent recharge to the basin's main aquifers located in Sectors 5 and 6. Increased extraction from these aquifers, and the lower parts of Sector 4, are taking water from storage that is not being replenished. Dewatering in Sector 4 may be resulting in less streamflow reaching Sectors 5 and 6 because the gradient away from the river bed is now much greater. Unless groundwater levels recover this may be a long-term change in streamflow behaviour with only large flows reaching Sectors 5 and 6 to provide much needed recharge and lowering salinities in these aquifers.
6. Irrigation water diversions in the upper basin are managed by the basin Vigilance Group and pumping for irrigation in Sectors 5 and 6 are managed by CASUB. There appears to be no overall basin-wide perspective which considers all irrigation users' rights. In addition, there appears to be little consideration of non-agricultural water users by these two committees. As a result, extractions by miners and for town water supplies often cause conflict with prior agricultural users. Miners and to a lesser extent the town have the capacity to pay more for water than do the agriculturalists.
7. There are some unresolved technical questions such as the degree to which the upper and lower basin are connected and the amount of surface water that is recharged under the improved water efficiency irrigation systems. However most people agree that the main issues are a lack of inadequate integrated water planning, poor understanding of each group's situation and a need for a timely and strong response to the problem.
8. Unless the next few years have higher rainfall and consequent runoff and recharge, acute water problems will develop for supplying water to Copiapó City and irrigators in the lower three sectors. The

mining companies are able and prepared to separate their industrial water demands from the basin but their workers will still require adequate and high quality drinking water supplies. The most obvious solutions appear to be a reduction in water available to agriculture and/or a desalination plant for supplying water to Copiapó City. Both raise issues of equity, cost (especially of energy if a seawater desalination plant is built) and the ability of people to pay for more costly services.

9. Mining water use is currently about one-third of agricultural use and can be expected to increase in the future due to increased production and falling ore grades. Mining companies have improved their water use efficiency in recent years through water reduction strategies such as better control of water losses, re-use and recycling, and improved tailings dewatering systems. While the mining industry has reduced its specific water consumption (m^3/t ore) over recent years, there is still scope for further improvement particularly for concentrator plants, although some of the newer mines are already at, or close to, best practice.

10. If significant reductions in freshwater consumption for mining are to be realised in the future, it is more likely that these will result from the use of alternative water sources such as seawater or desalinated water rather than the implementation of water reduction technologies, as these are already well advanced.

11. A number of mining companies already have desalination projects in various stages of development, with the Candelaria desalination plant expected to begin operation next year. However, the use of desalinated water will add considerably to the cost of water currently paid by mining companies, particularly those some distance from the coast and considerably above sea level.

12. The use of seawater or desalinated water by mining companies as their major or sole water supply in the future should improve groundwater availability significantly, although the extent of this improvement is difficult to predict at present due to a lack of relevant data.

10 Technical knowledge and data gaps

1 Runoff into Lautaro Reservoir is crucial for basin industries and for over 200,000 people living in the Basin. The amount and nature of precipitation in the high Andes and the nature of runoff mechanisms is not well described in any report. How (and whether) the upper and lower basins are hydraulically connected was mentioned as being uncertain by several people. High altitude area have localised precipitation which can then be influenced by infiltration, exfiltration, sublimation, movement of snow by wind etc. Basin isohyets have been developed from a relatively few metrological stations and may not be an accurate guide to types and amounts. Understanding precipitation and runoff mechanisms may help understand how climate change and sequences of below average precipitation may affect runoff into the Reservoir. Also, mine dewatering may be impacting on catchment yields but are handled differently from diversions for consumptive use. Their impact is controversial but poorly understood by water users lower in the Basin. A PhD or post-doctorate study may help identify management options to improve water yields in the basin and assess future risks.

2 The last time that aquifer storages increased substantially was in the mid 1980s when the river flowed past Copiapó to recharge Sectors 5 and 6. Since then aquifer storages have declined substantially and it is unclear what quantity of runoff, and period of bed inundation, would be required to fill the aquifer in Sector 4 and then those lower in the Basin. Some studies of enhanced infiltration basins have been made in Sector 4 as a means on ensuring than any flood flows are not lost to the ocean. Similar analyses may be required if recharge to Sectors 5 and 6 (the main water storages in the Basin) are to be replenished. The nature of surface water – groundwater interactions may have changed as a result of aquifer storages being lower than previously recorded by measurements. Quantifying these fluxes in each sector through a catchment model would be useful for assessing management options. It is possible that the nature of streamflow through Sector 4 has changed as a result of dewatering of the aquifer and future small flows will infiltrate through the river bed and fail to reach Sectors 5 and 6. This relationship would require aquifer storage volumes to be recovered or it will be a long term change with consequences for Sector 5 and 6 water users.

3 An investigation of the impact of irrigation of low quality water on soil properties and plant growth may indicate whether long term damage is being done to soils as a result of using poor quality groundwater and using low leaching fractions to improve water use efficiencies.

4 The feasibility of converting agricultural land to residential land near Copiapó City could be investigated as this would help reduce the current shortage a building land and reduce groundwater extraction in Sector 4 at the same time. It would provide funds for farmers wanting to exit agriculture at no cost to the government.

5 It is unclear how many water rights are being used and whether they have been traded between user groups. There is a lack of clarity between water rights, (met and unmet) demands and use in the current statistics. Also, having an estimate of the value of water used in each industry (e.g. the gross value produced per ML of water used) would assist understand the highest value uses of water over time and whether the market is reflecting these values.

6 Understanding water use and returns for small, medium and large irrigators would be useful for understanding the impact that may result from a failure of surface water and groundwater supplies or the whether supplies from alternative sources would be viable.

7 While water consumption data has been provided by mining companies to DGA, regular public reporting of such data including all water sources (fresh water, seawater, desalinated water, reclaimed water) and amount of water re-used/recycled with each being reported separately, not aggregated, would be useful in providing some consistency between data sources and be of value in assessing water availability issues.

8 Similar to the JRI Engineering study carried out to establish a database of tailings properties to assess suitability for paste thickening, a similar study could be carried out to establish a database of ore suitability for direct processing with seawater (as opposed to desalinated water). This would allow mining companies to decide if the desalination option was required.

9 To help identify where the maximum benefit of water use lies, it could be useful to carry out a study to determine the economic value (\$/m^3 water) of the embodied water in the various products produced for export (minerals, metals, table grapes, etc.) in the Basin.

11 References

Abarca, J A. (2012). Desal plant alone won't close region III water gap - CNR. Business News Americas, April 18 2012 (www.bnamericas.com).

Álamos y Peralta (1995). - Alamos y Peralta Ingenieros Consultores Ltda, Análisis evaluación de los recursos hídricos en el valle Del Rio Copiapó, III Región. Informe Técnico. S.I.T. Nº 30. Dirección General de Agua.

Benavente, J M and Goya, D. (2011). Opening up natural resource-based industries for innovation: exploring new pathways for development in Latin America. Sectorial report: Copper mining in Chile, June 2011.

Bitran, E., Rivera, P. and Villena, M. (2011). Water Management Problems in the Copiapó Basin Chile: Markets, Severe Scarcity and the Regulator. OECD Global Forum on Environment: Making water reform happen. http://www.oecd.org/dataoecd/4/54/49012553.pdf

Cade-idepe (2004): Diagnostico y clasificación de los cursos y cuerpos de agua según objetivos de calidad. Cuenca del Rio Copiapó.

Brantes, R. Best practices and efficient water use in the Chilean mining industry (2009). Proceedings 1st International Seminar on Environmental Issues in the Mining Industry (Enviromine), 30 September-2 October 2009, Santiago Chile.

Brantes, R (2012). Email to T. Norgate 28/7/12.

Cai, W., Cowan, T. and Thatcher, M. (2012). Rainfall reductions over Southern Hemisphere semi-arid regions: the role of subtropical dry zone expansion.

CNR (March 2012). National Irrigation Commission, CNR, Mejoramiento del sistema de aguas, subterráneas para su utilización en riego en el Rio Copiapó. Reunión de trabajo DGA 15 marzo 2012.

Cochilco (Chilean Copper Commission) (2008). Best practices and efficient use of water in the mining industry. October 2008.

Cochilco (Chilean Copper Commission) (2009). Gestión del recurso hídrico y la minería en Chile: Proyección consumo de agua en la minería del cobre 2009-2020, DE/09/2009. October 2009.

Cochilco (Chilean Copper Commission) (2010). Copper and gold mining investment in Chile: Estimations for 2010-2015. May 2010.

Cochilco (Chilean Copper Commission) (2011). Water consumption in copper mining, DE/06/11, October 2011.

Consejo Minero (2010). Informe Social, Ambiental y Económico del Consejo Minero 2010 (www.consejominero.cl)

DGA. (2003). Evaluación de los Recursos Hídricos Subterráneos del Valle del Río Copiapó.

DGA (2011). Copiapó River Basin Situation. Unpublished report: 4pp.

DGA (March 2012). SolucionCopiapó_mar2012_29-03def2.pdf

DGA (Dirección General de Agua) (2012). Meeting with CSIRO, 23/5/12.

DGA (2012). Recurso hídrico en Chile. Presentation.

DICTUC S.A. (2010). Análisis integrado de gestión en Cuenda del Rio Copiapó, Departamento de Estudios y Planificación, División de Ingeniería Hidráulica y Ambiental. http://documentos.dga.cl/ADM5220v1.pdf

Edwards, G, Cristi, O and Diaz, C. (2012). The effect of regulation uncertainty on water-right prices: The case of the Loa Basin in the Antofagasta region of Chile. Pontificia Universidad Católica de Chile, Instituto de Economía, June 2012.

Fleming, H and Radakovic, R. (2012). Water management in mining operations (www.miningcongress.com/pdf/presentations-downloads/Hatch-Rob_Radakovic.pdf)

Garcia, F, Saavedra, J P, Gonzalez, A (2009). Copiapó case: Great challenges for water management and the mining role. The 5th International Water technologies & Environmental Control Exhibition & The 2nd International Conference (WATEC 2009), Tel Aviv, Israel, 17-19 November, 2009.

Gonzalez, S, Encalada, M, Daughney, S and Vece, T. (2010). Selection of pipeline corrosion control strategy and impact on economics of water conveyance. Water in Mining 2010 conference, June 2010, Santiago, Chile.

Gunson, A J, Klein, B, Veiga, M and Dunbar, S. (2012). Reducing mine water requirements. Journal of Cleaner Production, 21, 2012, 71-82.

Hiam-Galvez, D, Fleming, H, Ghobeity, A and Osores, O. (2012). Water supply in Peru and Chile – the challenges and the solutions. Water in Mining 2012 conference, June 2012, Santiago, Chile.

Golder Associates (2006). Diagnóstico de los Recursos Hídricos de la Cuenca del Río Copiapó y Proposición de un modelo de Explotación Sustentable.

GWI (2012). Global Water Intelligence. Justifying Chile's eternal water pipeline. http://www.globalwaterintel.com/archive/13/10/general/justifying-chiles-eternal-water-pipeline.html. Accessed 5 November 2012.

Houston, J. (2006a). Evaporation in the Atacama Desert: an empirical study of spatio-temporal variations and their causes. Journal of Hydrology 330: 402-412.

Houston, J. (2006b). Variability of precipitation in the Atacama Desert: its causes and hydrological impacts. International Journal of Climatology 26: 2181-2198.

Jofre, G. (2011). Chile en el Mercado Mundial del Cobre: Proyecciones y Oportunidades Profesionales. Santo Tomas University inaugural speech. Antofagasta, April 2011.

Marco Larenas Contreras (2012). Derechos de aprovechamiento se aguas subterráneas otorgados en la Cuenca del Rio Copiapó. Presentation.

Marchese, M and Arrueste, J. (2007). Water availability for mining usage in Northern Chile: A challenging scenario. Proceedings of the 6th International Copper-Cobre Conference, August 2007, Toronto, Canada, 397-403.

McFarlane, D., Trefry, M, Moffat, K. and Lacey, J. (2012). Summary report on the current water rights framework in Chile. Unpublished report to AusAID as part of the study: "Copiapó River Basin, Chile – analysis study of shortfalls in water rights, industrial usage and social requirements' from the Minerals Down Under Flagship, CSIRO

Moffat, K. and Lacey, J. (2012). Summary report on stakeholder perspectives on Copiapó water management issues. A report submitted to AusAID as part of the study: 'Copiapó River Basin – Analysis study of shortfalls in water rights, industrial usage and social requirements' from the Minerals Down Under Flagship, CSIRO.

Moreno, P, Aral, H, Cuevas, J, Monardes, A, Adaro, M, Norgate, T and Bruckard, W. (2011). The use of seawater as process water at Las Luces copper-molydenum beneficiation plant in Taltal (Chile). Minerals Engineering, 24, 2011, 852-858.

Niechcial, R and Radakovic, R. (2007). Seawater as a resource for sustainable copper operations. Proceedings of the 6th International Copper-Cobre Conference, August 2007, Toronto, Canada, 379-388.

Norgate, T and Aral, H. (2009). Towards sustainable water use in the minerals industry: Opportunities and technologies. Proceedings Sustainable Development Conference, Adelaide, October 2009 (Minerals Council of Australia).

Philippe, R. (2012). Seawater supply for the mining industry: Lessons learned in project development. Water in Mining 2012 conference, June 2012, Santiago, Chile.

Sernageomin (2011). Modelación hidrogeológica Cuenca del Rio Copiapó.

SISS (2012). Vulnerabilidad del abastecimiento de agua potable en Copiapó. Presentation.

Soruco, L and Philippe, R. (2012). Upcoming trends in water supply costs for copper mining in arid regions. Water in Mining 2012 conference, June 2012, Santiago, Chile.

Trefry, M., McFarlane, D., Moffat, K., Littleboy, A. and Norgate, T. (2012). Copiapó River Basin Water Management: Terms of Reference for Future Governance and Research Activities. Report to AusAID and Chilean stakeholders from the Minerals Down Under Flagship, CSIRO

UN (2010). The impact of climate change on Chile. In: The economics of climate change in Latin America and the Caribbean: Summary 2010, 49-54.

USGS (United States Geological Survey) (2012). Minerals Yearbook: The mineral industry of Chile, May 2012.

VINCI (2012). Via-Marina: inter basin water transfers in large quantities and over long distances by underwater pipeline. http://www.vinci-construction-projects.com/via-marina. Accessed 5 November 2012

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