CLIMATE CHANGE IMPACTS ON MUNICIPAL, MINING, AND AGRICULTURAL WATER SUPPLIES IN CHILE

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Agricultural and municipal water supply interests in Chile rely heavily on streams which flow from the Andes Mountains. The highly productive Copiapó agricultural region, on the southern edge of the Atacama Desert, is a major supplier of fruit and other crops for the Northern American market during winter. This region relies entirely on snow and ice-melt streams to provide irrigation water. Santiago, the Chilean capitol, is the country's major metropolitan area with a population of 5.5 million. Rainfall that averages 330 mm/year is nearly twice that of Phoenix.

Santiago is very similar to Phoenix in a number of ways. It has a rapidly expanding population of 5.5 million, and it relies on water supplies derived from surrounding or more distant mountain ranges. Santiago and Phoenix are located at similar latitudes north and south of the equator (33°27' South for the former and 33° 31' North for the latter). Recent changes in the climate in South America are resulting in decreased snowpacks and glacier volumes in the Andes Mountains. This paper discusses the current water supply situation in Chile in light of its growing demand for water and declines in supply due to climate change.

CLIMATE AND ECOSYSTEMS

Chile has one of the widest ranges of climates and ecosystems in the world because of its north-south latitude range (4,300 km from 17 ° to 56° South Latitude) and large altitudinal gradient (0 to 6,880 m) in a short distance from the Pacific Ocean (<240 km ocean to Andes Mountains crest). It contains arid deserts, semi-arid deserts, Mediterranean-like areas, humid subtropical regions, temperate zones, oceanic-dominated climates, sub-polar areas, alpine tundra, and ice caps. These climates are often combined into the arid North, the Mediterranean Central, and cool and wet South zones. Chile is home to one of the driest deserts in the world, the Atacama Desert, where rainfall averages less than 1 mm/year, and one of the wettest regions on the planet, Isla Chiloé (>4,000 mm/year) (Table 1). The climate is characterized by a wet winter (May to August) and a dry summer (November to March). Mean annual temperatures range from 18° C at Arica in the North to 6° C at Punta Arenas in the South. Maximums can reach 46° C in the Atacama Desert.

HYDROGEOGRAPHY

Water Resources

Chile's total land area of 756,950 km^2 is about 1% freshwater, amounting to a total volume of 922 km^3. Of Chiles's total renewable water resource, groundwater accounts for 15%, and surface water 85% (FAO 2001). About 15% is shared between the two resources. There are no flows into Chile from other countries and the only outflows are to the Pacific Ocean. Groundwater withdrawals total 20.3 km^3 annually, or about 15% of the actual annual groundwater recharge (140 km^3). Most of these withdrawals are for mining in the North and agriculture in Central Chile. These figures don't tell the whole story since the groundwater withdrawals are in the arid North with low recharge rates. Surface water withdrawals are currently mainly for agriculture irrigation (64%). Although domestic uses of total surface water is low (11%), the presence of most of the population in the Mediterranean climate of the Central zone places a lot of stress on local water resources.

Water is a scarce commodity from the Rio Bío-Bío northward (Wollman 1968). This is virtually the northern half of the country, including the major metropolitan areas of Santiago, Valparaiso, and Concepcíon. Water supplies in the Central and South zones are predominantly surface in nature, originating in snow and glacier melt in the Andes. In the North, high evaporation rates of the Atacama Desert consume most rainfall and the limited surface

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Table 1. Average annual precipitation by major city and region, Chile (CIA 2008, FAO 2001).

CITY	AVERAGE ANNUAL PRECIPITATION	LOCATION	REGION
	mm		
Arica	<1	North	Arica
Copiapó	21	North	Atacama
Santiago	330	Central	Santiago
Concepcion	1320	Central	Bío-Bío
Valdivia	2535	South	Los Rios
Puerto Aisén	2973	South	Aisén
Chiloé National Park	>4000	South	Los Lagos

waters, leaving dry riverbeds or large salt playas. Groundwater is the most important water source in this region.

Rivers and Lakes

Rivers in Chile are relatively short, flowing from the Andes crest westward to the Pacific Ocean. Few rivers in the North flow to the sea because of high evaporation rates and much diminished precipitation (Table 2). Their main source is Andean snowfall and rain. In the North, the Rio Loa is the only river between Arica on the northern border with Peru and the Rio Copiapó (960 km) that flows to the sea. It reaches the Pacific with very diminished flows (mean flow 2.4 m^3/sec) despite having a large drainage basin (33,570 km^2) and reasonable length (440 km). South of the Rio Copiapó and the Rio Huasco in the Atacama Region, the number of rivers that flow continually to the sea increase dramatically (e.g. Elqui, Limari, Maipo, Rapel, Mataquito, Maule, Itata, Bío-Bío, Imperial, Tolten, Palena, Baker etc.). Rivers such as the BioBío are being developed with dams for hydroelectric and water supply purposes.

Most of the lakes in Chile are in the Araucania Region and South (Table 2). There are 17 lakes with areas >100 km^2. The largest is General Carrera Lake covering 1,850 km^2 with half in Chile and the remainder in Argentina. Two are in the 500 to 1,000 km^2 size class, five are 200 to 500 km^2 in size, and the remainder 100 to 200 km^2 category (Wollman 1968).

There are a number of water supply and power generation reservoirs throughout Chile, mainly in the Central and South regions. For example, El Yeso is a reservoir located in the Andes formed by damming the Rio Yeso, a tributary of the Rio Maipo. The reservoir is located in tandem with Laguna Negra at an altitude above 2,600 m. It provides a storage capacity of 255 x 106 m ^{3}, or about 46.3 m^3/person for the Santiago Metropolitan Region.

WATER ISSUES AND USES

Land use

Most of the issues related to water center around land use and water availability. The major issues deal with population concentration in the Santiago Metropolitan area (33% of Chile's population), agriculture, mining, dam construction for hydroelectric generation, and climate change. The latter interacts with the other land uses and activities. Currently land use in Chile is 3% in arable crops, 16% in meadows and pastures, 21% in forests and woodlands, and 60% in other categories, mostly desert and high mountain lands (CIA 2008). The great disparity in water resource abundance between the arid North and wet South also aggravates the internal water resource situation. Mining in the North and population concentration in the Santiago Region, although separated by great distances from the water rich South are affecting decisions on how to use those water resources.

Agriculture

Agriculture is a key part of the economic mix of minerals, food commodities wood products, and fishing that has been the base of the Chilean economy. Agriculture accounts for only 5% of the

Table 2. Main rivers and lakes by Region of Chile (Wollman 1968, CIA 2008, FAO 2001).

REGION	RIVERS	LAKES
Arica and Parinacota	4	1
Tarapacá	0	1
Antofagasta	4	3
Atacama	7	1
Coquimbo	6	1
Santiago	6	1
Valparaiso	7	2
O'Higgins	3	1
Maule	20	0
Bío-Bío	22	1
Araucania	26	7
Los Rios	25	7
Los Lagos	10	11
Aisén	10	3
Magallanes	11	10

country Gross Domestic Product but employs 14% of the national labor force (CIA 2008). Chilean crop products are becoming increasingly important internationally because of their availability during northern hemisphere winter and freedom diseases affecting other nations. Chile produces 3.9 x 10^6 Mg of fruit, 1.2 x 10^6 Mg of wheat, 0.5 x 10^6 Mg of sugar, and various amounts of vegetables, beef, poultry, and wool. However, 96% of the agricultural lands are irrigated from surface and groundwater supplies (>12,650 km^2). Water flowing out of the Andes Mountains is critical for Chilean agriculture. Thus the recent droughts related to climate change are a big issue since increasingly scarce surface waters have to be reallocated amongst competing economic sectors, including human water supply demands.

Hydroelectric Power

Chile's electric power generation capacity is now highly dependent on water resources in the South. The national energy grid (SIC) has been fragile because of its dependence on water resources. Chile has not been able to keep up with energy demands from the public and mining sectors so that its generation capacity of 48 x 10^9 kWh has to be constantly supplemented (CIA 2008). For awhile Argentine natural gas was supplementing electric power production until rising prices and a restriction on exporting Argentine natural gas forced a switch to diesel fuel for thermoelectric power plants, raising costs four-fold in 2008 (Reuters 2008). Chile currently supplies about 60% of its electrical energy from water (Business News America 2008). Plans have been developed to build five hydroelectric dams on the Rios Pascua, Baker, Del Salto, and Bío-Bío at a cost of $2.4 billion to provide an additional 2,430 Mw of power production capacity. New transmission lines will be needed to move the hydroelectric energy over 3,000 km north to the population and mining centers. However, the scale of this project along with dam placement on ecologically important rivers in the South has created considerable internal political dissent (New York Times 2008). Nevertheless, energy demands keep rising and unless conservation measures reduce demand, Chile will have to add 300 Mw.

Mining

Mining has a major effect on the water resources of Chile because large quantities are needed for ore processing. In addition, smelting is a big consumer of electrical energy. For instance, daily use of water in the mining and processing stages at El Salvador is 65 x 10^3 m^3/day (2.5 m^3 of water per ton of ore processed). The source of this water is groundwater since the mine is in the Atacama Desert.

CLIMATE CHANGE EFFECTS

The effect of the El Niño/Southern Oscillation on Chilean weather has been well documented (Nuñez 1992; Haylock et al. 2006). Long-term trends investigated by Minetti (1998) documented a steady decrease in annual rainfall for a large area west of the Andes Mountains under La Niña conditions. Rusticucci and Penalba (2000) described a large decrease in total annual precipitation at Valdivia in the Los Rios Region (Table 1) due to a decrease in winter precipitation. Winter snowpacks observed by the authors in mid-August, 2007, at elevations above 2,000 m were shockingly low. North-facing areas at >3,000 m that should have been entirely snow-covered in August were devoid of snow. These trends have been evident in extreme southern Chile where glacial melt rates are some of the fastest in the world and account for nearly 10% of global sea level change from mountain glacier melt. Some Andean glaciers are expected to disappear in 15-25 years (Vidal 2006). The effects will be major, reducing municipal water supplies and agricultural irrigation sources. However many effects are occurring now, not in the future. The current La Niña Began in May, 2007, and is expected to end in August, 2008 (Estrada 2008). It has been atypical in that areas such as Araucania, which normally get heavier rainfall in a La Niña, have been experiencing drought as well.

In March, 2008, Chile's Public Works Ministry Undersecretary J.E. Saldivia described the current drought as the worst in 100 years, threatening water supplies for over 200,000 people (Vargas et al, 2008). He stated that the drought was intensifying, and that even if rainfall improves this year, the resulting hydroelectric energy shortage could become critical. Chile's major hydroelectric reservoir levels are far below their historic levels, and will need at least one year to rise to normal levels even if this year's rainfall is normal. Mr. Saldivia was quoted as saying that "*reservoir levels will not recover normal levels and that means (crop) irrigation in 2008-2009 will be difficult.*" Rainfall deficits have been in the 35 to 100% range from Arica in the North all the way south into the Bío-Bío and Aisén regions of the far South. Shallow wells supplying many small towns and farms have dried up.

Agricultural production in Chile this year has been seriously affected by both the shortage of water and the high cost of pumping groundwater for irrigation (Vargas 2008). Fresh produce production has declined significantly and animal forage is in short supply. Drying up of shallow groundwater wells (6 – 10 m) has resulted in significant animal mortality (Martinez 2008). Fruit growers have not been impacted yet due to their deep wells (>50 m). Over 144 municipalities have declared agricultural emergencies because of the current drought (Estrada 2008). There are indications that the current year-long La Niña droughts may become due to the Pacific Decadal Oscillation (Mantua and Hare 2002). So, agricultural impacts could be much greater in years to come.

Agriculture has already been impacted by power costs and shortages (Vargas et al. 2008). President Bachelet ordered voltage reductions during the Chilean summer of 2008 and extended daylight savings time. Also ominous is the potential threat to mining, a mainstay of the Chilean economy and a large consumer of power. In March, hydroelectric reservoirs were dangerously low. Energy supplies will remain uncertain until 2010 when more hydroelectric production comes on line from current dam and power line construction in the southern areas of Chile. At a time when prices for minerals such as copper are rising due to world-wide demand, prices could rise much higher if Chilean production is significantly reduced by the lack of hydroelectric power.

SUMMARY

Chile has a tremendous diversity of water resources as a result of its geographical position in South America. It contains both the driest desert in the world and one of the wettest regions. The country is highly dependent on Andes Mountains annual snowpacks and glaciers for water used for municipal, agricultural and mining activities. In addition, a large portion of the Chilean energy market so important for cities, agriculture, and mining comes from hydroelectric sources that are also subject to the oscillations in climate. The current La Niña is abnormally dry across the entire 4,300 km of Chile. This ENSO event may be a harbinger of droughts to come as global climate change becomes more pervasive. Recent understanding of the Pacific Decadal Oscillation (Mantua and Hare 2002) indicates that future droughts could be on the order of decades-long durations rather than 1- to 2-years. Impacts on the major water-using sectors of the Chilean and global economy could be significant.

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