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Water governance in Chile: Availability, management and climate change

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SUMMARY

Chile has a unique geography that provides an extraordinary variety of climatic conditions and availability of water resources. The objective of this manuscript was to describe and analyze the spatial and temporal distribution patterns, as well as the management of water resources, along a country with a narrow distance from the Andes Mountains to the Pacific Ocean. This presents challenges to water governance from data collection and analysis perspectives, and for administration of the resource. The Water Resources Directorate (*Dirección General de Aguas*, DGA), is the federal government organization in charge of the water resources of the country. The DGA and other relevant public and private institutions are examined in terms of competition and conflict resolution across different scales and levels of interaction associated with water resources governance. Both monitoring stations (rainfall, streamflow, water quality, groundwater, sediment and snowfall), and the Chilean management and legislation of water resources are also analyzed. Finally, the success (or lack) of the national administration to upgrade its monitoring stations and equalize water resources distribution throughout the country is discussed including the influence of climate change on data collection, and decision making across different scales of water governance.

1. Introduction

The status of water resources in Chile, both qualitatively and quantitatively, is information particularly important for the country, not only because of the relevance of water for the survival of the population, but also because its entire economy relies on the use of this resource to ensure the sustainability of its economy and productivity. This is a serious problem, since an intensive use of the resource requires hydrological efficiency to guarantee economic and environmental sustainability; thus, it is crucial to have appropriate public policies to ensure an efficient governance system, as well as information on the availability of water resources in the country, where precipitation shows significant variability. The national average water availability, is close to 54,000 $m^3\ hab^{-1}\ yr^{-1}$ (World Bank, 2011), positioning Chile in the 20th rank in terms of water resources availability (WWAP, 2003). However, most of Chile's population is located in areas of arid and semiarid climates, where water availability is less than 1000 $m^3\ hab^{-1}\ yr^{-1}$. Therefore, if such natural variability is combined with the possible effects of global warming, which could include the rising of the Zero Celsius Degree Isotherm (ZDI) within the Andes Mountain range (i.e. precipitation switching from snow to rain), the summer water availability could be reduced. This requires efficient public policies to ensure the sustainable use of water resources, in which water governance plays a fundamental role. The objective of this manuscript is to describe and analyze the spatial and temporal distribution patterns of water resources along the country, and how Chile deals with water governance and the management of water resources information, its collection, analysis, and final use.

This paper is divided in 9 sections based on different sub-sections. The territorial division of Chile in terms of administrative regions and basins, as well as topography and the types of climates are described in Section 2. An analysis of the water resources in

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Chile in terms of availability, distribution, and its use is presented in Sections 3–5, considering the current state of precipitation, streamflows, groundwater, glaciers, and the national storage based on dams and lakes. The legal and institutional management of water resources is reviewed in Section 6, from a point of view that deals with water governance aspects i.e. water rights, water regulations, water code, and institutions related to water management. The environmental aspects, as for example the current state of the national monitoring network and the water resources quality is presented in Section 7. A comprehensive review and analysis of water resources and climate change is presented in Section 8; and finally, a critical analysis of the Chilean water governance is developed in Section 9 including a discussion and suggestions to improve future scenarios of national water resources management.

2. Study area

Continental Chile has a long latitudinal extension (more than 4000 km), between latitudes 17°30′S and 56°30′S, and is divided into 15 administrative regions, each headed by a President's appointed Intendant (Fig. 1a). The national territory is compound by around 101 main hydrological basins, with more than 1200 rivers flowing mainly from East to West (Fig. 1b). The geography of the country is mainly dominated by steep mountainous terrains, with only around 20% of the continental territory being flat. The Chilean territory is also characterized by a wide variety of landscapes. It is possible to distinguish, from the morphological point of view, four major geographical units along the country, from East to West: Andes Mountains, Intermediate Depression, Coastal Mountains, and Coastal plains (coastline) (INE, 2011), as shown in Fig. 1c. Using the Köppen's climate classification (Köppen and Geiger, 1954), adapted for Chile by Rioseco and Tesser (2013), a large variety of climates exist through the country, with arid and semi-arid climates in Northern regions, temperate climates in Central-Chile, humid climates in Southern regions, and tundra and polar climates in the Andes Mountains. The oceanic influence can also be observed in the Chilean coastline (Fig. 1d).

3. Water availability

Water availability in Chile is stable. According to World Bank (2010), mean water availability in Chile is 53,953 m^3 hab^{-1} yr^{-1} (Table 1), much higher value than the world average (6600 m^3 hab^{-1} yr^{-1}) and also higher than the threshold value internationally considered for sustainable development (2000 m^3 hab^{-1} yr^{-1}). However, natural water availability in the country is unevenly distributed; since from the capital (Santiago) to the North, the average water availability is about 800 m^3 hab^{-1} yr^{-1}, a value clearly insufficient, but representing the water supply for more than 60% of the national population. Contrastingly, South of Santiago water availability overpasses 10,000 m^3 hab^{-1} yr^{-1} (World Bank, 2011).

Furthermore, a more detailed analysis of water availability shows significant differences in annual volumes. In arid and semi-arid regions, located between 17°30′ and 34° (i.e. Arica y Parinacota and Metropolitan regions, where Santiago is located), water availability can reach, in some cases, 200 m^3 hab^{-1} yr^{-1}. Water demands are larger than the available surface runoff, and the demand is covered by groundwater in order to meet municipal, industrial and mining which severely deplete the resource. Further South water availability begins to exceed the demands between O'Higgins and Los Rios regions (34°S to 40°33′S). South of Los Lagos Region (40°15′S) water supply significantly exceeds demands due to the humid climate, except for the cold semiarid zones on the extreme South of the country. This wide latitudinal variability in water offer represents an alarming future for the country in terms of water resources and management, since demands are expected to increase, while availability is expected to decrease (CONAMA, 2006; Trenberth et al., 2007).

4. Distribution of water resources

4.1. Precipitation

An understanding of the topographic variability in the country is crucial to understand its variability in precipitation. The latitudinal

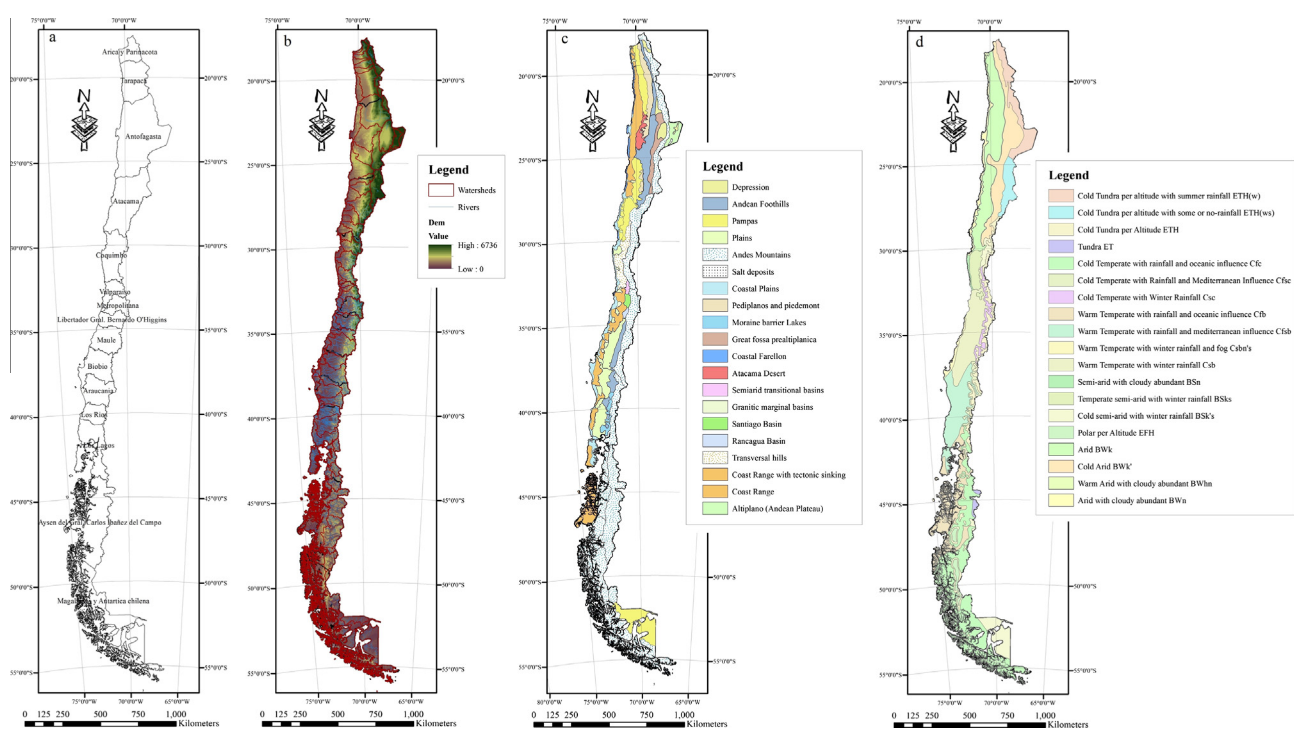

Fig. 1. (a) Administrative Regions, (b) main basins, (c) topography, and (d) climates of Chile. *Source*: Geographic Information was extracted from Albers (2012).

Table 1
Water availability in Chile (m^3 hab^{-1} yr^{-1}). *Source*: Adapted from World Bank (2011).

Region	Availability	Region	Availability
Arica y Parinacota	854*	Maule	23,978
Tarapacá		Biobío	21,556
Antofagasta	52	Araucania	49,273
Atacama	208	Los Ríos	136,207*
Coquimbo	1020	Los Lagos	
Valparaíso	801	Aysen	2,993,535
Metropolitana	525	Magallanes	1,959,036
O'Higgins	6829	*National average*	53,953(*)

* This value considers both regions. Arica y Parinacota began to operate as independent region on October 8, 2007; and Los Rios began to operate as independent region on October 2, 2007.

and altitudinal variability, in addition to factors related to the country's proximity to the Pacific Ocean, such as the South Pacific Anticyclone (SPA), the Antarctic Circumpolar Current (ACC), and the cold Humboldt Current, contribute to a wide variety of climates on a national level (INE, 2006). In general, rainfall in Chile tends to increase with latitude and altitude (Quintana and Aceituno, 2006; Pizarro et al., 2008, 2012). The interannual variability is related to the El Niño-Southern Oscillation (ENSO) (Rutllant and Fuenzalida, 1991; Aceituno and Garreaud, 1995; Garreaud and Batisti, 1999; Montecinos and Aceituno, 2003), which is a coupled ocean–atmosphere phenomenon rooted in the tropical Pacific, characterized by irregular fluctuations between its warm (El Niño) and cold (La Niña) phases, with a periodicity ranging from 2 to 7 years (Diaz and Markgraf, 1992). Montecinos and Aceituno (2003) also indicated that interdecadal precipitation's variability is linked to the Pacific Decadal Oscillation (PDO) (Mantua et al., 1997). Furthermore, Carrasco (2006) stated that the intra-seasonal variability of precipitation in Central Chile is influenced by the Madden and Julian Oscillation (MJO) (Madden and Julian, 1994). Carrasco (2006) found that precipitation patterns in Central Chile are correlated with the MJO. Another source of low-frequency variability is the Antarctic Oscillation (AAO), characterized by pressure anomalies of one sign centered in the Antarctic and anomalies of the opposite sign on a circumglobal band, at about 40–50°S. There is a large response of the surface air temperature south of 40°S, such that warming is associated with the positive phase of the Antarctic Oscillation. AAO-related precipitation anomalies are significant in Southern Chile (largest at 40°S) and along the subtropical East coast of the continent (Garreaud et al., 2009).

Throughout Chile, three types of annual precipitation cycles can be identified: (1) In the Northern Altiplano (altitudes greater than 3000 m) a low precipitation cycle is found, with mean annual precipitation ranging from about 600 mm yr^{-1} in the North-East to 200 mm yr^{-1} in the South-West. However, an extreme arid pattern dominates at lower elevation zones from the upper boundary of the country until 27°S. (2) Central-South regions have a well-defined annual cycle characterized by peaks in winter seasons, and much lower values in summer periods gradually increasing to the South. This climatic type is known as Mediterranean Climate and it extends approximately from 30° to 40°S (CONAMA, 2006). Rainfall is most of the time of frontal origin, and the annual progression of monthly mean rainfall frequency is observed to increase along the territory between 30° and 39°S (Saavedra et al., 2002). Annual rainfall increases southward from around 100 mm at 30°S to nearly 2000 mm at 40°S, and the Andes cordillera isolates this region from the influence of continental air masses (Quintana and Aceituno, 2006). Falvey and Garreaud (2007) indicated that a surprising characteristic of the precipitation in Central Chile is the apparent uniformity of the distribution in the cross-mountain direction. Montecinos and Aceituno (2003) indicated that precipitation concentrates mainly in May–September, and that climate variability is influenced by the Southern Oscillation (SO). Furthermore, ENSO events are associated with above average winter rainfall in Central Chile (30° and 35°S), late spring (35° and 38°S), and below average summer precipitation in Southern-Central Chile (38° and 41°S). Consequently, regional and large-scale circulation features during extreme rainfall conditions share significant similarities with those during extreme ENSO phases. (3) Over the austral region (Southern portion of the Los Lagos Region to Aysen and Magallanes regions 40°S–56°S), another cycle is found, characterized by abundant monthly precipitation through all seasons, reaching up to 5000 mm yr^{-1} West of the Andes mountain peaks. However, a significant precipitation decrease is observed on the Eastern flank (CONAMA, 2006).

Significant variability in annual precipitation occurs in the coastal regions of Chile, with an increasing Southern gradient with annual precipitation of 100 mm yr^{-1} in La Serena (around 29°54′S), greater than 1000 mm yr^{-1} in Concepción (36°46′S), 2000 mm yr^{-1} in Valdivia (39°48′), and 3000 mm yr^{-1} in Chiloé (41–43°). The maximum annual rainfall in Chile is around 7000 mm yr^{-1} in Guarello Islands (50°23′S). Annual precipitation then starts decreasing to the South, reaching 1200 mm yr^{-1} in Cape Horn (55°58′S) (CONAMA, 2006). In general terms, precipitation can vary from around 1 mm $year^{-1}$ in the North (between 26°S and 29°S Latitudes) to more than 4 m $year^{-1}$ in the extreme South (Cereceda and Errázuriz, 2010) (Fig. 2).

To evaluate the past, current and future precipitation patterns in Chile, an important tool is the national rain gauge network. Latitudinal, longitudinal, and altitudinal average monthly precipitation values obtained from the National Water Balance (DGA, 1987) denote clear differences along the country, mainly associated to the latitude influence in precipitation amounts (Fig. 3).

4.2. Streamflows

Chile has 1251 rivers located in 101 main basins within the national territory (MOP, 2011). Due to the geographic characteristics of Chile, its rivers are short, steeply graded, and very torrential, and are generally not navigable but have high potential for hydroelectric energy production. The National Water Balance (DGA, 1987), indicates that the mean annual runoff for Chile is 928 km^3 yr^{-1}, representing 2.1% of the worldwide runoff, and a 7.9% of that from South America. Most of the rivers run from East to West, except for some intermittent streams in the arid and semiarid zones located in the North, as well as some rivers in the South. As expected, numerous tributaries feed the main watercourses. Runoff volume is strongly related to the latitudinal distribution of precipitation and, therefore, increases from North to South (Table 2).

The rivers in the North of the country are predominately snowmelt-fed, while those in the center are mixed snowmelt- and rainfed, whereas those in the South are primarily rain-fed. With a few exceptions, streams in the Northern desert are ephemeral, i.e. they receive hydrologic contributions but do not discharge surface flows into the ocean. River's stream flows in the temperate climatic zone, located in the center of the country, increase with snowmelt, reaching their peak flows on late December, during Southern Hemisphere's summers. In the South-Central regions of Chile, hydrologic regimes are influenced by both snow and rain, and have smaller springtime flows than in the North, but larger streamflow rates during winter. In the South, streamflow volumes are larger as a consequence of frequent rain and the regulatory effect of numerous natural lakes existing in the region, through which rivers usually flow. In Patagonia, rivers generally have their headwaters located in the extensive icefields on the Eastern slopes of the Andes and run through fjords before reaching the Pacific Ocean (INE, 2011) (Fig. 4).

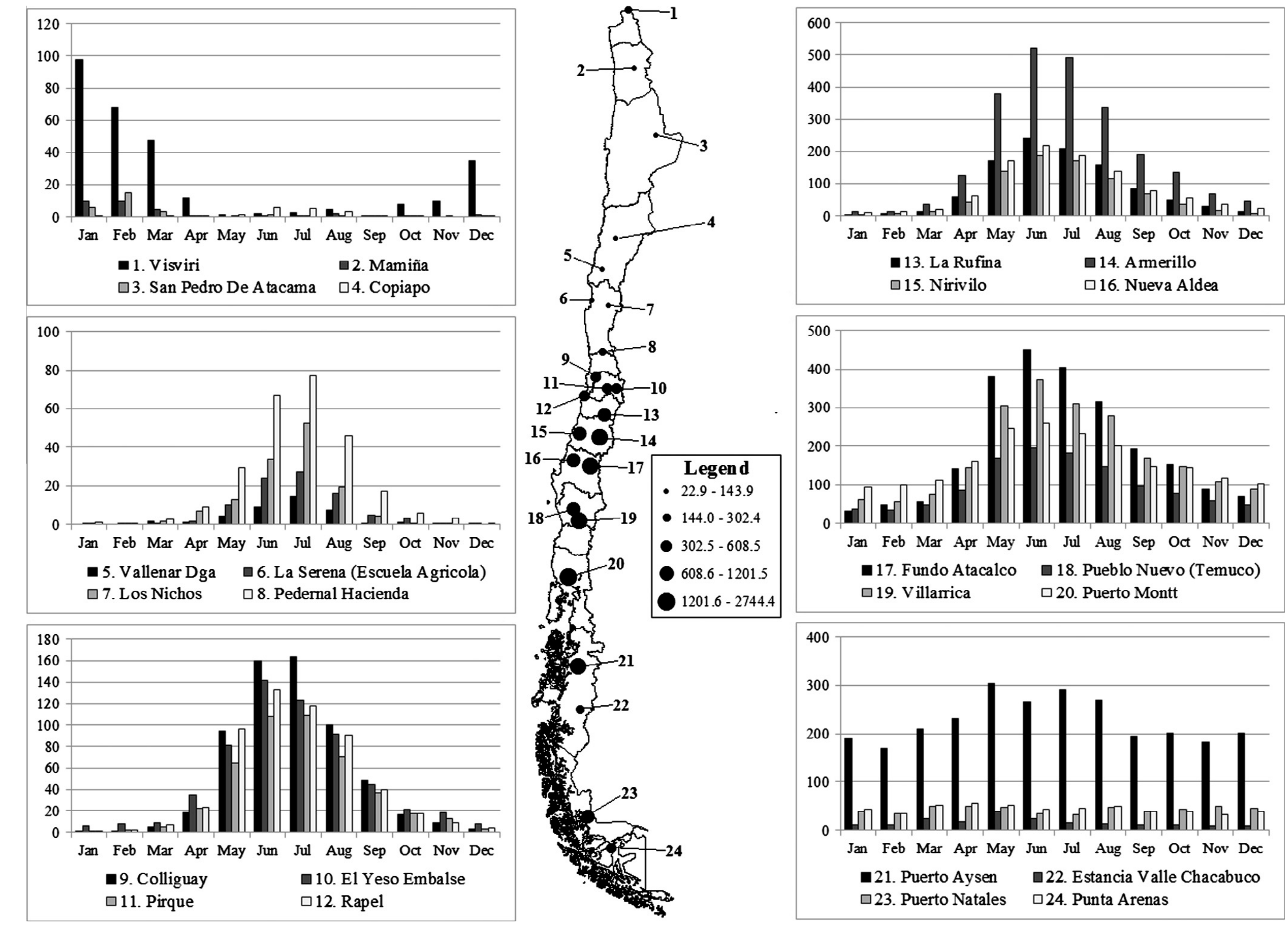

Fig. 2. Latitudinal monthly distribution of precipitation in Chile (mm mth^{-1}), obtained from 24 gage stations installed along the country for different lengths of records between 1929 and 2013. The Legend represents the mean annual precipitation (mm yr^{-1}).

4.3. Aquifers and groundwater

The first national aquifers inventory was developed by DGA (1986), through the elaboration of the National Hydrogeological Maps (1:1,000,000 and 1:1,250,000), as a contribution of the Chilean Committee for the International Hydrological Programme (IHP) of UNESCO, to the International Hydrogeological Map of South-America. The hydrogeological formations known in Chile are basically non-consolidated quaternary sediments with fluvial, glacial, and alluvial-type origins, among others, mainly distributed over three hydrogeological provinces: (1) Altiplanic; (2) Andean Gradients to Pacific Ocean, and (3) Coastal Basins. In general, the aquifers are unconfined or semi-confined, with shallow water tables (mostly less than 50 m) (Brown and Saldivia, 2000). River–aquifer interaction in Chile is usually very active (Peña, 1992). However, aquifers in the extreme North of the country (Arica y Parinacota and Tarapacá Regions) are located mostly in the Pampa and coastal valleys; therefore, low natural recharge rates due to the high evaporation and low rainfall contributions imply a practically null river–aquifer interaction, and most of the groundwater storage can be found as fossil water (Arumí and Oyarzún, 2006). DGA (2011b) estimated the sustainable volume for groundwater intakes as about 3,153,600 m^3 yr^{-1} (100 L s^{-1}) for the Concordia Ravine (Arica y Parinacota Region).

Though coastal aquifers can be found, most aquifers in the Atacama and Coquimbo Regions are located in fluvial valleys. Natural aquifer recharge is mainly provided by precipitation and surface runoff infiltration during snow melting season (Arumí and Oyarzún, 2006). Natural recharge rates (also called the sustainable volume for groundwater intakes), were estimated for Carrizal Ravine (Atacama Region) as about 2,554,416 m^3 yr^{-1} (81 L s^{-1}) (DGA, 2009b). In basins as Limari and Choapa (30°15′S to 32°15′S) river–aquifer interactions are much higher than those occurring in Northern regions; thus, approximately 60–90% of the water pumped from aquifers can originate from rivers. In these cases, sustainable groundwater intakes are calculated by the DGA taking in consideration the River–Aquifer Interference Criteria, which assumes that the level of interaction between the river and aquifer has to be less than 10% of the annual surface flow represented by an 85% probability of exceedance. Based on this criterion, available sustainable volumes of 12,141,360 m^3 yr^{-1} (385 L s^{-1}) were estimated for groundwater intakes in the Choapa Basin (DGA, 2007), and 68,117,760 m^3 yr^{-1} for the Limari Basin (DGA, 2008c).

Central Chile aquifers are over an alluvial-originated sedimentary fill, deposited by Andean rivers (González et al., 1999). The sustainable volume for groundwater intakes is at about 1,264,643,809 m^3 yr^{-1} (40,075 L s^{-1}) for the Aconcagua River Basin (around 32°54′S) (DGA, 2004b). Additionally, between 34°S and 35°S, a sustainable volume of 240,653,118 m^3 yr^{-1} (7626 L s^{-1}) was estimated for O'Higgins Region, considering both Cachapoal and Tinguiririca Basins (DGA, 2003).

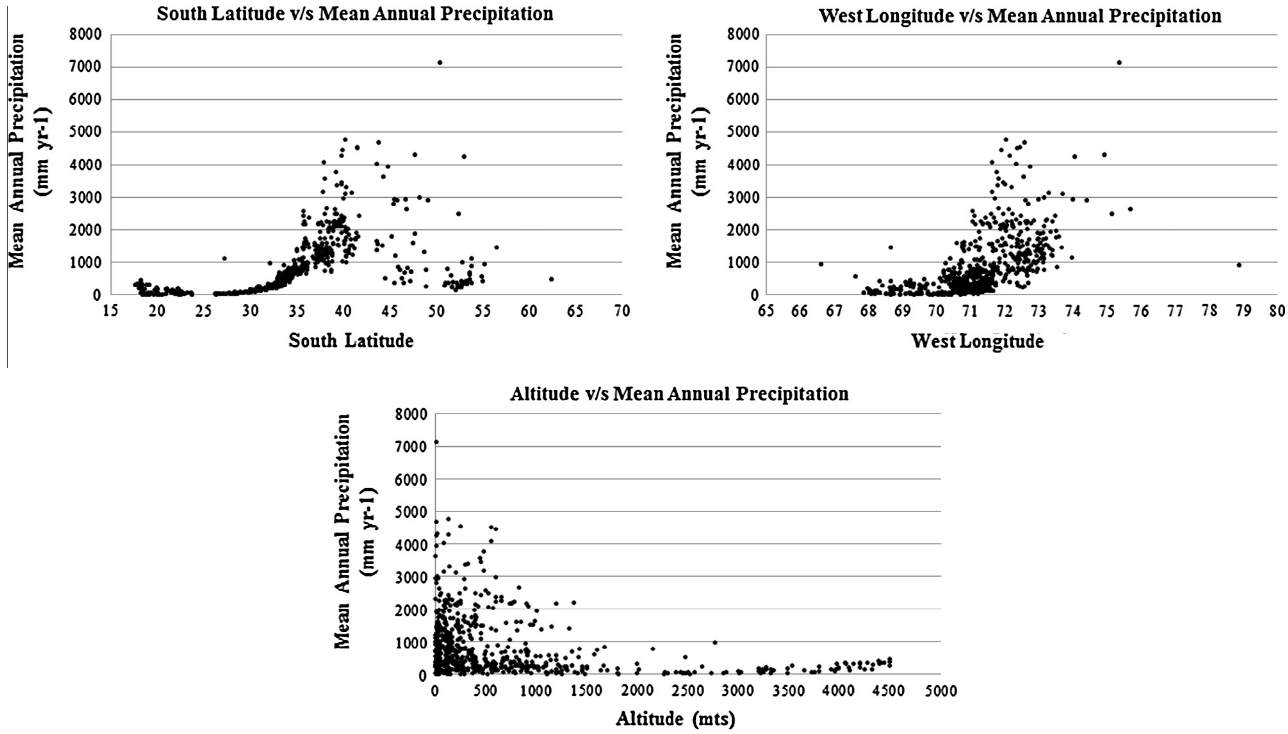

Fig. 3. Spatial distribution of mean annual precipitation in Chile, on 662 meteorological stations distributed along the country for the period 1951–1980. *Source*: Rainfall information was extracted from the last National Water Balance (DGA, 1987).

Table 2
Spatial distribution of mean annual runoff in Chile, at 27 monitoring stations installed along the country. *Source*: Adapted from INE (2012).

Macrozone	Administrative region	Station/location	Basin surface (km^2)	River length (km)	Mean annual flow ($m^3\ s^{-1}$)
Far North (17°30′S–25°40′S)	Arica y Parinacota	Río Lluta en Panamericana	3437	147	0.3
		Río San José en Ausipar	3193	83	0.6
	Antofagasta	Río Salado en Sifón Ayquina	2210	80	0.4
		Río Loa en Finca	33,082	440	2.43
Near North (25°40′S–32°15′S)	Atacama	Río Copiapó en la Puerta	18,704	162	0.8
		Rio Huasco en Algodones	9813	90	1.84
	Coquimbo	Río Elqui en Algarrobal	9825	75	4.1
		Rio Grande en Puntilla San Juan	544	115	2.3
		Rio Choapa en Cuncumén	7630	97	4.1
Central Chile (32°15′S–36°33′S)	Valparaiso	Rio Aconcagua en Chacabuquito	7338	142	18.6
	Metropolitana	Rio Maipo en El Manzano	15,303	250	91.7
		Rio Mapocho en Los Almendros	4230	76	3.6
	O'Higgins	Rio Cachapoal en Junta Cortaderal	6370	170	28.1
		Rio Tinguiririca bajo Los Briones	4730	167	35.6
	Maule	Rio Teno después junta con Claro	1590	102	30.6
		Rio Mataquito en Licantén	6357	95	67.8
		Rio Maule en longitudinal	21,074	240	79.7
South (36°33′S–44°06′S)	Biobío	Rio Itata en General Cruz	11,293	130	34.8
		Rio Biobío en Rucalhue	24,264	380	334.5
	La Araucanía	Rio Cautín en Cajon	3100	174	103.9
		Rio Toltén en Teodoro Schmidt	8397	123	433.7
	Los Ríos	Rio Calle-Calle en balsa San Javier	5267	55	465.4
	Los Lagos	Rio Pilmaiquén en San Pablo	2467	68	153.01
Far South (44°06′S–56°00′S)	Aysén	Rio Simpson bajo junta Coyhaique	3712	88	68
		Rio Aysen en Puerto Aysen	11,456	26	654.8
	Magallanes y La Antártica	Rio Serrano en Desembocadura	7347	38	275.1
		Rio San Juan en desembocadura	860	60	15.9

The importance of groundwater resources is clearly understood by the government but there is limited information on the groundwater systems, especially South of Santiago (Arumí and Oyarzún, 2006). The implementation of a National Groundwater Monitoring Network (NGMN) dates back to 1990, when the DGA started a long-term modernization plan. However, the implementation was postponed for more than 20 years, due to budget cuts. The current NGMN is mainly distributed between Arica y Parinacota and

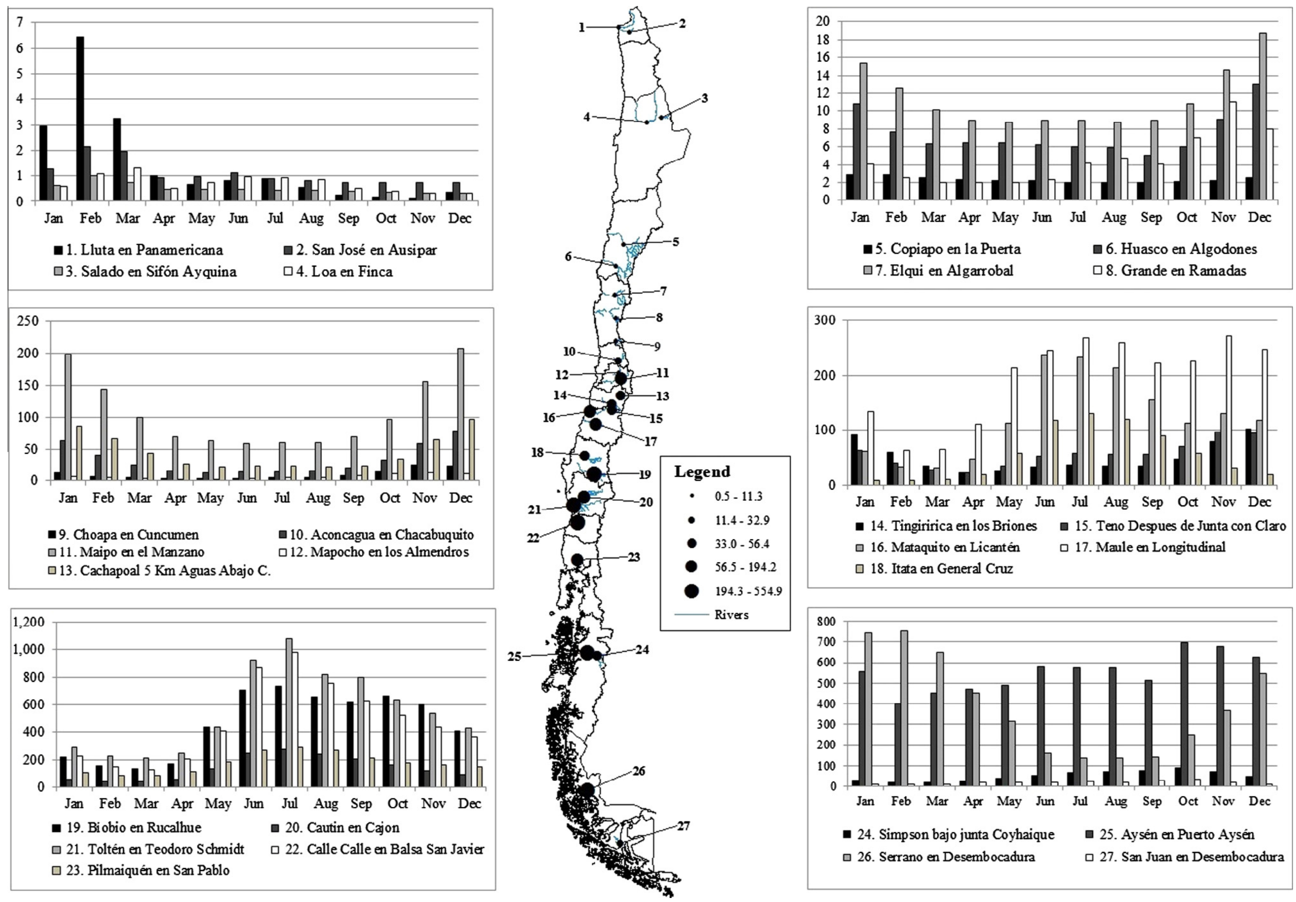

Fig. 4. Latitudinal monthly distribution of mean annual runoff in Chile ($m^3 s^{-1}$), obtained from 27 stations installed along the country for different lengths of records between 1937 and 2011. The Legend represents the mean annual runoff ($m^3 yr^{-1}$).

O'Higgins regions (17°30′S–35°S) (Fig. 5), with a significant lack of information about Chilean aquifers located in Southern regions. Acknowledging this, the DGA (2010b) developed a report "Improvement and Expansion of the Groundwater Monitoring Network between O'Higgins and Los Lagos regions (35°S–44°S)", to complete the missing NGMN data for this part of the Chilean territory.

4.4. Glaciers: ice caps and ice fields

The glaciers area in South America is approximately 25,700 km^2 (Casassa et al., 2007, cited by Zemp et al., 2007). Most of the glaciers located in South America are in Chile (Zemp et al., 2007). At a national scale, 76% of Chilean glaciers are concentrated in the Northern Patagonian Ice Field (Rivera et al., 2007), the Southern Patagonian Ice Field (Aniya et al., 1996), and the Darwin Mountain Ice Fields (DGA, 2008a). Ice caps and mountain glaciers can be usually found covering the highland areas of the whole Chilean Andes, except for the Antofagasta region (21°28′S to 25°40′S), due to extreme arid conditions (Lliboutry, 1958). Ice caps include white glaciers (without detritus) and rock glaciers (high detritus content). Rock glaciers are mainly located in arid zones of North and Central Chile. In general, they can be found in lower topographic zones with less snow accumulation (Brenning and Trombotto, 2006). There is a large concentration of continuous ice masses denominated Ice Fields in Southern Regions (44°06′S–56°00′S), representing 66% of South America's total ice area (Zemp et al., 2007). The national glaciers inventory is still in development because there still remain glaciers to be surveyed in Southern regions. However, 3636 glaciers were surveyed along Chile by 2009, corresponding to an area of 18,715 km^2 (Table 3). The non-inventoried glacial area was estimated to be around 2280 km^2 (DGA, 2009a), located mostly between 41°S and 55°S.

This large water storage and the uncertainty associated with future climate change scenarios, prompted the Chilean Government to create a National Glacier Policy (DGA, 2009a). In 2009 the *Centro de Estudios Científicos* (CECS) developed the National Glacier Strategy, including scientific and technical requirements for 5, 10, and 20 years. The main objective of this Strategy is to provide long-term research guidance, based on methods and models for different climate zones of Chile, including climate change scenarios (DGA, 2009a). The strategy deals with the need to study and monitor glaciers in Chile as well as future glacier response to global warming. The strategy contains five hierarchical observation levels; intensive monitoring and multidisciplinary studies are developed in Level 1 (detailed analysis of a few national glaciers); while glacier inventory including rocky glaciers correspond to Level 5 (basic information in most of the national glaciers) (Barcaza, 2011). The country was divided into 4 glaciological zones (North, Center, South, and Austral), to achieve the proposed levels. Additionally, an operative classification of glaciers was stated, defining them as "all surfaces with ice and permanent snow, generated on the ground and present for at least 2 years, with an area equal to, or greater than, 0.01 km^2 (one hectare). Also, any rocky surface, with evidence of surface viscous flow, due to high ice content in the underground". According to suggestions of the strategy, the information related to national glaciers inventory was systematized during 2012 and the current approximation of the national

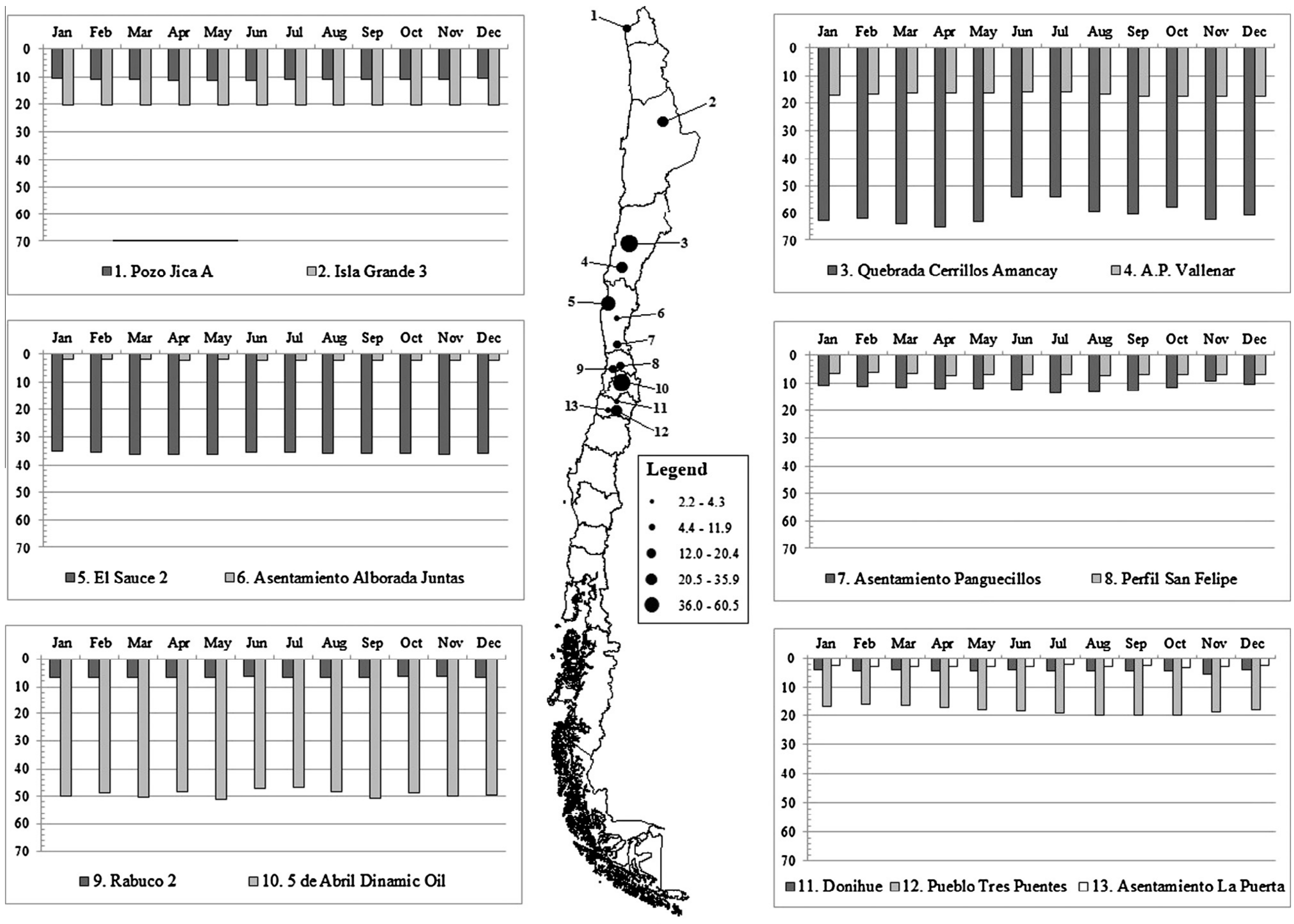

Fig. 5. Latitudinal mean monthly distribution of water table depths in Chile (m), obtained from 13 monitoring wells installed along the country for the period 2004–2013. The legend represents the mean annual water table depth (m).

glaciers area was estimated about 23467.62 km^2. Moreover, 3.1% of Chile's surface was declared as being covered by glaciers (DGA, 2012b). The current inventory has been the result of more than 20 years of research, using different sources and techniques, such as aerial photography or satellite images, among others.

4.5. Dams and lakes

According to DGA (2013), the current artificial storage capacity in Chile is almost 13,000 million cubic meters (Table 4). Most of the water stored in these dams is located in three of the fifteen regions (Coquimbo, O'Higgins, and Maule Regions represent approximately 80% of surface water storage).

Lakes represent around 1.5% of the national territory and more than 70% of them are located between 44°S and 56°S. Salazar and Soto (1999) identified 380 lakes in Chile with water mirror surfaces greater than 3 km^2. INE (2012), on the other hand, indicated that natural surface water storage is represented by 355 natural lakes with an estimated capacity of about 7000 million m^3, and more than 8000 km^2 in water mirror surface. The Southern regions have numerous lakes, some of which are shared with Argentina (Table 5).

It should be mentioned that relevant results related to dams and lakes were recently published by Pizarro et al. (2013a), who found that rainfall intensity around bodies of water (dams and lakes) distributed along Chile, is much higher than similar areas without them. This behavior was indicated to be more accentuated in arid and semiarid regions of Chile located between (18° and 33°S). Furthermore this could generate larger impacts to hydraulic structures, since they are designed without taking this influence into account.

5. Water use

5.1. Economic growth and water resources demands

During the last three decades (1980–2010), Chile has had a significant economic development, with an annual real Gross domestic product (GDP) growth of 6.2%. Most of the Chilean economy is based on natural resources, with a strong export-focused activity (Central Bank of Chile, 2006, 2010). Such economic growth has required increasing amounts of water, in such a way that current production processes are linked to past water intakes practices, surface water being the main source. However, Arumí and Oyarzún (2006) indicated that these particular changes produced in the country are also generating increased demand on groundwater. Therefore, the constant economy's growth and social development during the last few decades has produced increasing demands of both, surface and groundwater resources. Such sustained economic growth has occurred in a way that water resources uses are almost fully allocated for different economic activities in the regions from Santiago to the North, where water demands are greater than the availability (Ayala, 2010 cited by World Bank, 2011). The ratio between demand and availability of water (analyzed as surface flows) is very favorable for the

Table 3
Glacier Inventory of Chile. *Source*: Adapted from DGA (2009a).

Geographic zone	Region	Basin or location	Number of glaciers	Area (Km^2)	Used sensor	Image or photography year	Method	Source
Far North (18°56′S–26°05′S)	Arica y Parinacota	Arica y Parinacota[3]	14	29.7	Aerial photography	1955/1961/1980	Aero-photogrammetry	Garín (1987)
	Antofagasta	Antofagasta[3]	14	12.13			Aero-photogrammetry	
Near North[1] (26°00′S–32°15′S)	Atacama	Atacama[3]	31	25.13	Aerial photography	1955/1961/1981	Aero-photogrammetry	Garín (1987) [5]
		Copiapó River	92	23.04	ASTER	2001/2002	Multiespectral classification	Vivero (2008)
		Huasco River	112[4]	16.86[4]	ASTER	2004	Manual digitalization	Nicholson et al. (2009)
	Coquimbo	Coquimbo[3]	10	7.01	Aerial photography	1955/1961/1981	Aero-photogrammetry	Garín (1987)
		Cerro Volcán Glacier[3]	1	0.1	Aerial photography	1955/1961/1982	Aero-photogrammetry	Garín (1987)
Central Chile (32°02′S–36°33′)	Valparaíso	Aconcagua River	101[4]	59.89[4]	ASTER	2003/2008	Multiespectral classification and manual digitalization	DGA (2008a)
	Metropolitana	Maipo River	647	421.9	Aerial photography	1955/1956	Aero-photogrammetry	Marangunic (1979)
	O’Higgins	Cachapoal River	146	222.42	Aerial photography	1955/1956	Aero-photogrammetry	Caviedes (1979)
		Tinguiririca River	261	106.46	Aerial photography	1955/1956	Aero-photogrammetry	Valdivia (1984)
	Maule[6]	Mataquito River	81	31.91	Aerial photography	1954/1955/1957	Aero-photogrammetry	Noveroy (1987)
		Maule River	98	35.32	Aerial photography	1966/1967/1978/1985/1994	Aero-photogrammetry	Tapia (2004)
South[2] (36°00′S–44°14′S)	Biobío	Itata River	21	7.6	ASTER	2004	Multiespectral classification	Zenteno et al. (2004), Zenteno (2008)
		Biobío River	29	52.37	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
	La Araucanía	Imperial River	13	18.72	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
		Toltén River	14	68.48	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
	Los Ríos	Valdivia River	6	42.33	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
		Bueno River	11	19.35	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
	Los Lagos	Petrohué River	12	60.57	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
		Maullín River	1	2.84	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
		Chamiza River	1	1.05	Aerial photography	1955/1961/1979/1981	Aero-photogrammetry	Rivera (1989)
		Machimahuida Volcano	9	81.4	ASTER	2007	Multiespectral classification	Masiokas et al. (2009)
Far South (43°38′S–56°30′S)	Aysén	Northern Patagonia Ice Field	70	3953	ASTER and LANDSAT	2001	Multiespectral classification and manual digitalization	Rivera et al. (2007)
	Magallanes	Southern Patagonia Ice Field[6]	40	9659	LANDSAT	1986	Multiespectral classification	Aniya et al. (1996)
		Muñoz Gomero peninsula	75	252.5	Aerial photography	1998	Manual digitalization	Schneider et al. (2007)
		Riesco Island	45	215	Aerial photography and LANDSAT	1984/1986	Stereoscopia and multiespectral classification	Casassa et al. (2002)
		Sarmiento Mount	165	273.06	Aerial photography and LANDSAT	2001/2002/2004/2005/2006	Manual digitalization and false color composition	DGA (2008a)
		Santa Ines Island	258	273.76	Aerial photography and LANDSAT	2001/2002/2004/2005/2007	Manual digitalization and false color composition	DGA (2008a)
		Darwin Mountain	627	2333.14	Aerial photography and LANDSAT	2001/2002/2004/2005/2008	Manual digitalization and false color composition	DGA (2008a)
		Hoste Island	631	409.46	Aerial photography and LANDSAT	2001/2002/2004/2005/2009	Manual digitalization and false color composition	DGA (2008a)
		Total	3636	18715.5				

Note: The numbers in parenthesis are: (1) Inventory from Elqui, Limari and Choapa Basins (175glaciers = 10.43 km^2) carried out by Glaciology and Snow Unity of DGA is not included. (2) Inventory for Continental Chiloe Island (2552 glaciers = 737.81 km^2), carried out by Glaciology and Snow Unity of DGA is not included. (3) Preliminary Inventory. (4) Exclude Rocky Glaciers. (5) Inventories for Copiapó and Huasco River Basins are not included in this study. (6) It considers only the Chilean territory Glaciers, not those shared with Argentina.

Table 4
Spatial distribution and storage capacity of dams in Chile. *Source*: Adapted from DGA (2013).

Macrozone	Administrative region	Dam	Watershed	Storage capacity (Mm^3)	Historic mean (Mm^3)	Main use
Far North (17°30′S–25°40′S)	Antofagasta	Conchi	Loa	22	17	Irrigation
Near North (25°40′S–32°15′S)	Atacama	Lautaro	Copiapó	26	12	Irrigation
		Santa Juana	Huasco	166	122	Irrigation
	Coquimbo	La Laguna	Elqui	40	23	Irrigation
		Puclaro	Elqui	200	130	Irrigation
		Recoleta	Limari	100	63	Irrigation
		La Paloma	Limari	748	388	Irrigation
		Cogoti	Limari	150	68	Irrigation
		Culimo	Quilimari	10	2.9	Irrigation
		El Bato	Choapa	26	n/a	Irrigation
		Corrales	Choapa	50	33	Irrigation
Central Chile (32°15′S–36°33′S)	Valparaiso	Aromos	Aconcagua	35	27	Drinking water
		Peñuelas	Peñuelas	95	23	Drinking water
	Metropolitana	El Yeso	Maipo	220	178	Drinking water
		Rungue	Maipo	1.7	0.8	Irrigation
	O'Higgins	Convento Viejo	Rapel	237	120	Irrigation
		Rapel	Rapel	695	495	Power generation
	Maule	Colbun	Maule	1544	1046	Power generation and irrigation
		Laguna Maule	Maule	1420	938	Power generation and irrigation
		Bullileo	Maule	60	31	Irrigation
		Digua	Maule	220	103	Irrigation
		Tutuven	Maule	22	6.5	Irrigation
South (36°33′S–44°06′S)	Biobío	Coihueco	Itata	29	8.6	Irrigation
		Lago Laja	Biobío	5582	3167	Power generation and irrigation
		Ralco	Biobío	1174	578	Power generation
		Pangue	Biobío	83	70	Power generation
			Total	12955.7	7650.8	

Central-South regions (O'Higgins and Araucania 34°S–39°′S), and significantly improves South of Los Rios Region (39°S) (Fig. 6a).

Over-granting of groundwater rights is observed from Arica and Parinacota (17°30′S) to the ÓHiggins Region (35°S) (MOP, 2013), where over-exploited aquifers are generating water conflicts. Under this framework, the DGA has been developing a preliminary approach in the evaluation of the national groundwater resources during the last decade (see Section 4.3); with the purpose of obtaining natural groundwater recharge rates in the aquifers and determining sustainable volumes to be extracted, with respect to current and future demands. For instance, the methodology of Infiltration Coefficients is being used as reference framework for future detailed research in this field.

It should be mentioned that the government has determined five different conditions for rivers and aquifers in the current legal regulations: (1) *River Depletion Declarations*: DGA is allowed to stop the granting of new permanent consumptive water rights (defined in Section 6) in any national basin due to a depletion of the river resources. Using the information from DGA's database, there are currently 11 depleted rivers in the country, all located from 17°30′S to 38°30′S (North-Central Chile); (2) *Environmental Flow Reserves:* following the national interests, DGA has declared some environmentally conserved rivers, where practically not granted water rights exist. These are located mostly in Southern Chile (Cochamó Basin located around 41°30′S, for example) (Riestra, 2010); (3) *Protected Aquifers that sustain meadows and wetlands:* during 1992, legal regulations prohibited the exploration and exploitation of aquifers located in Arica and Parinacota, Tarapacá, and Antofagasta regions (17°30′S–25°40′S), according to the Ramsar Convention of Wetlands (http://www.ramsar.org/pdf/sitelist.pdf), and because they correspond to the main sustain for farming and ranching activities for local communities; (4) *Restricted Areas*: it refers to hydrogeological sectors of common use with a strong risk of aquifer depletion, or an affection of the water quality, and therefore is only possible to provide temporary water rights. The DGA's database indicates that there are currently 124 restricted areas, located mostly from 17°30′S to 35°S; (5) *Prohibited Areas:* is not possible to establish new exploitations for groundwater use, because there is a depletion of the aquifer, or an affection of its water quality. In this case, DGA's database indicates that there are six prohibited areas, all located between 17°30′S and 32°15′S (Fig. 6b).

It is important to add that groundwater withdrawals were non-significant before 1990; however, the evolution of granted groundwater rights between 1990 and 2011 has increased when comparing the last two decades (Fig. 7). Also, a cyclic pattern can be observed, possibly due to water availability, as a result of inter- and intra-annual precipitation and runoff variability (World Bank, 2011).

Ayala (2010) cited by World Bank (2011), on the other hand, indicated that Chilean water use during 2006 reached 4710 $m^3\ s^{-1}$, where 89% of this corresponded to non-consumptive uses and 11% to consumptive uses. According to McPhee et al. (2012), irrigation represents 77.8% of total consumptives uses (Fig. 8a) with an irrigated areas of approximately 1.1 million hectares (INE, 2007), concentrated mostly between 29°20′S and 44°14′S (Coquimbo to Los Lagos regions). The government plans to increase the irrigated area by 57% aiming to reach 1.7 million hectares by 2022 (CNR, 2011). Domestic use is 6% of the water use and represents 99.8% of the urban and rural population supply. Mining and Industrial uses represent 9% and 12% of total consumptive uses (Table 6). It is important to mention that the use and demand of water in the various productive sectors has experienced significant growth, about 100%, between 1990 and 1999, and 160% between 1990 and 2002. Similar growth is observed between 1990 and 2006 (DGA, 2008b).

Table 5
Spatial distribution and water mirror surfaces of main lakes and lagoons in Chile. *Source*: Adapted from INE (2012).

Macrozone	Administrative region	Lakes and lagoons	Water mirror surface (km^2)	Number of lakes and lagoons	Total area of lakes and ponds (km^2)
Far North (17°30′S–25°40′S)	Arica y Parinacota	Laguna Chungara	20.6	7	45.7
		Laguna Blanca	13.8		
	Tarapacá	Laguna de Parinacota	0.4	2	1.6
		Laguna Huasco	1.2		
	Antofagasta	Laguna Miscanti	15	6	27.9
Near North (25°40′S–32°15′S)	Atacama	Laguna del Negro Francisco	29	7	59.1
		Laguna Verde	16.3		
	Coquimbo	Laguna del Pelado	3.1	1	3.1
Central Chile (32°15′S–36°33′S)	Valparaiso	Lago Peñuelas	11	2	14.1
	Metropolitana	Laguna de Aculeo	11.7	4	19.6
		Laguna Negra	4.7		
	O'Higgins	Laguna Cauquenes	4.8	2	8.8
	Maule	Laguna del Maule	68	4	88.9
		Lago Vichuquen	11.9		
South (36°33′S–44°06′S)	Biobío	Laguna de La Laja	124	8	219
		Lago Lleulleu	40.6		
		Lago Lanalhue	31		
	La Araucania	Lago Villarrica	177	6	359
		Lago Colico	56.5		
		Lago Budi	56		
	Los Rios	Lago Ranco	401	14	1239.1
		Lago Calfquen	119		
		Lago Panguipulli	111		
	Los Lagos	Lago Llanquihue	850	38	1610.2
		Lago Puyehue	156		
		Lago Rupanco	223		
		Lago Todos los Santos	183		
		Lago Palena	135		
		Lago Yelcho	116		
Far South (44°06′S–56°00′S)	Aysen	Lago Óhiggins	1058.8	124	4754.1
		Lago General Carrera	1840		
		Lago Cochrane	320		
		Lago Presidente Rios	313		
		Lago San Rafael	122		
		Lago Bertrand	67.5		
	Magallanes and Antártica	Lago Fagnano	639	130	2595.5
		Lago del Toro	191		
		Lago Blanco	144		
		Laguna Blanca	136		
		Lago Muñoz Gamero	105		
		Lago Sarmiento	87		
		Lago Anibal Pinto	78.8		
		Lago Balmaceda	70		

The biggest demand on non-consumptive uses is in hydropower production (Palma et al., 2009). The national power generation capacity is 12,847 MW, and a 38% is hydropower generated in the Central Interconnected System (CIS) (Fig. 8b and c). CNE (2009) stated a 52.3% of the total power generation capacity installed in CIS (9118 MW) corresponds to conventional sources like hydropower, and a 44.3% to thermal power plants. Only a 3.4% corresponds to non-conventional renewable energies (biomass, hydraulic less than 20 MW, and eolic sources).

Regarding water rights, DGA (2010a) indicated that both surface and groundwater rights are mostly requested for irrigation (consumptive uses) and for industrial practices (non-consumptive uses). However, a great portion of the allocated water rights do not fall into an assigned category of use in the DGA's database. Therefore, it is not always possible to detect changes when all the information is updated (Table 7).

5.2. Water balance

Determining water balances at a country level is difficult in a country like Chile, since due to the heterogeneous information in terms of quantity, quality, time, and location. Furthermore, the DGA has developed simplified hypotheses to establish relationships between water availability and demand, in order to identify water availability deficiencies on different *macro zones*, i.e. regions of the country with similar climates. These macrozones are named Far North, Near North, Central Chile, South, and Far South. The evolution of water availability in these zones, as well as projections by the year 2025, is specified in Table 8, and in percentual form in Fig. 9. Based on them it is easy to see the alarming projections for the arid and semiarid macro zones (Far North, Near North and Central Chile), where water deficits are expected to increase dramatically. The Southern macro zones do not experience any water deficit; however their water availability is expected to decrease by 2025.

6. Water governance: legal and institutional management of water resources

6.1. Legal regulations related to water resources use

The national legislation on water resources has been closely linked to contemporary economic planning (Bauer, 2002). In this context, the legislation regulates management, availability,

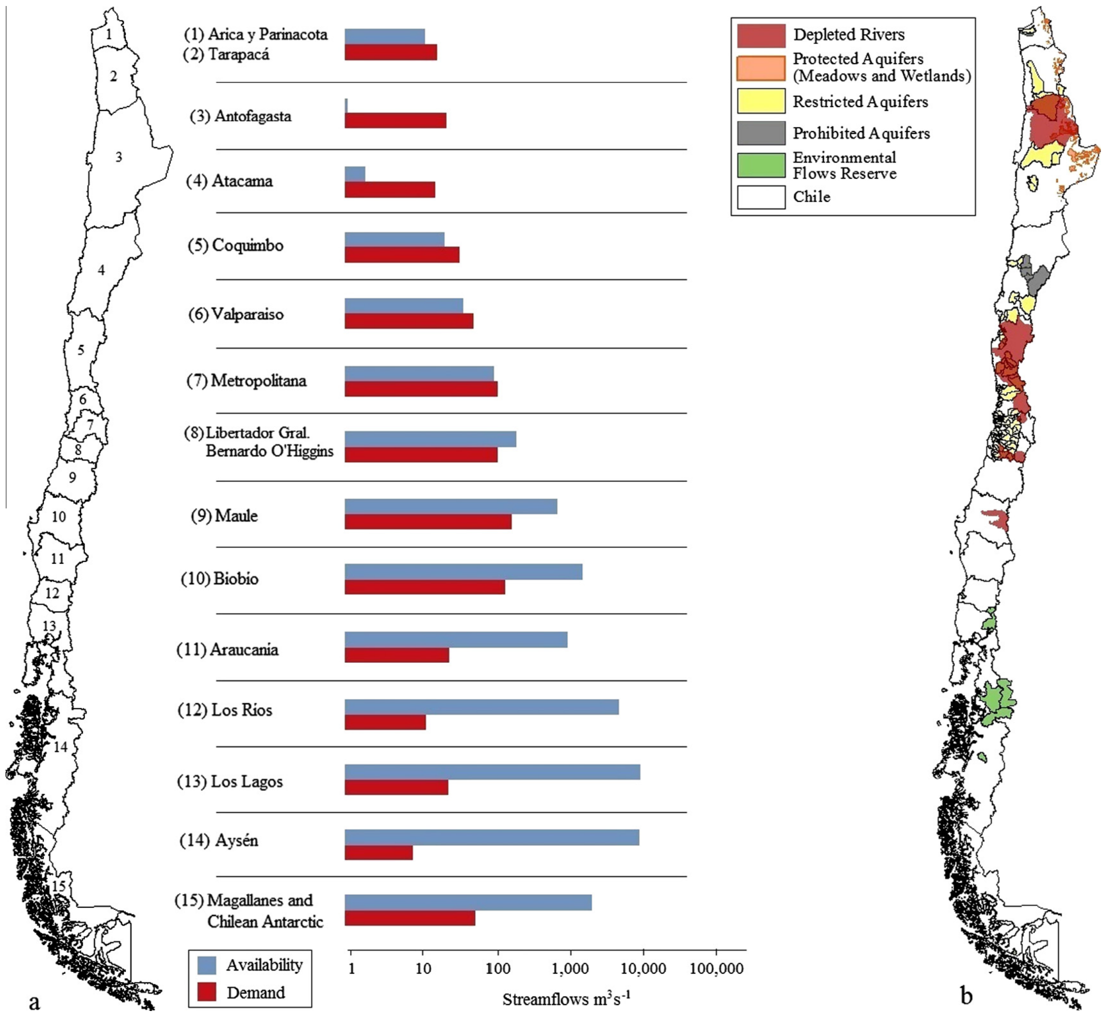

Fig. 6. (a) Relation between mean annual surface flows and demand of extraction ($m^3\,s^{-1}$) for each administrative region. The demands correspond to registered non-consumptive water rights described in Section 6. (b) Legal conditions determined by the Chilean Government for rivers and aquifers. *Source*: Adapted from MMA (2011) and DGA's database.

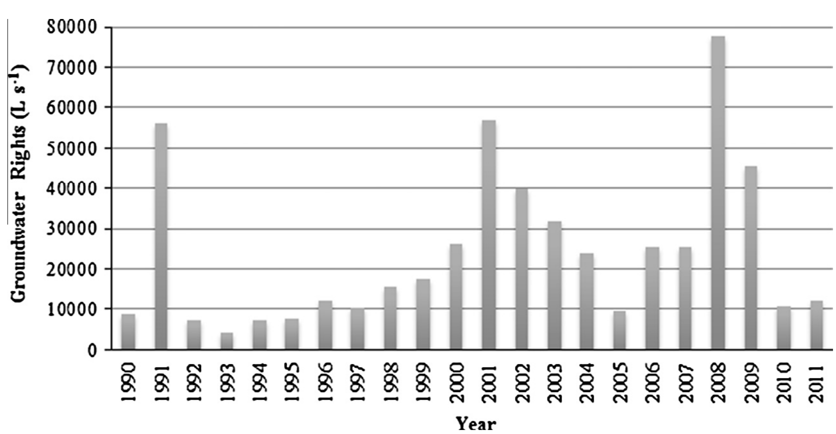

Fig. 7. Evolution of granted groundwater rights per year in Chile. *Source*: Adapted from DGA (2011a).

efficient uses, environmental conservation, the protection of third party rights, designation of areas for different purposes, recovery and conservation, and protection of water for indigenous communities. Current legislation also establishes the roles that private and public sectors should play in water resources management (Table 9). Water resources management takes place within the context of Water Markets, mainly under the concept of "Water Rights", introduced in Chile during the 1930s (Donoso, 2008). The legal definition for the use of water is based on Water Rights, which are divided into those referred to actual water consumption (*consumptive uses*, mostly irrigation and drinking uses) and those in which the user simply utilizes water to produce something else

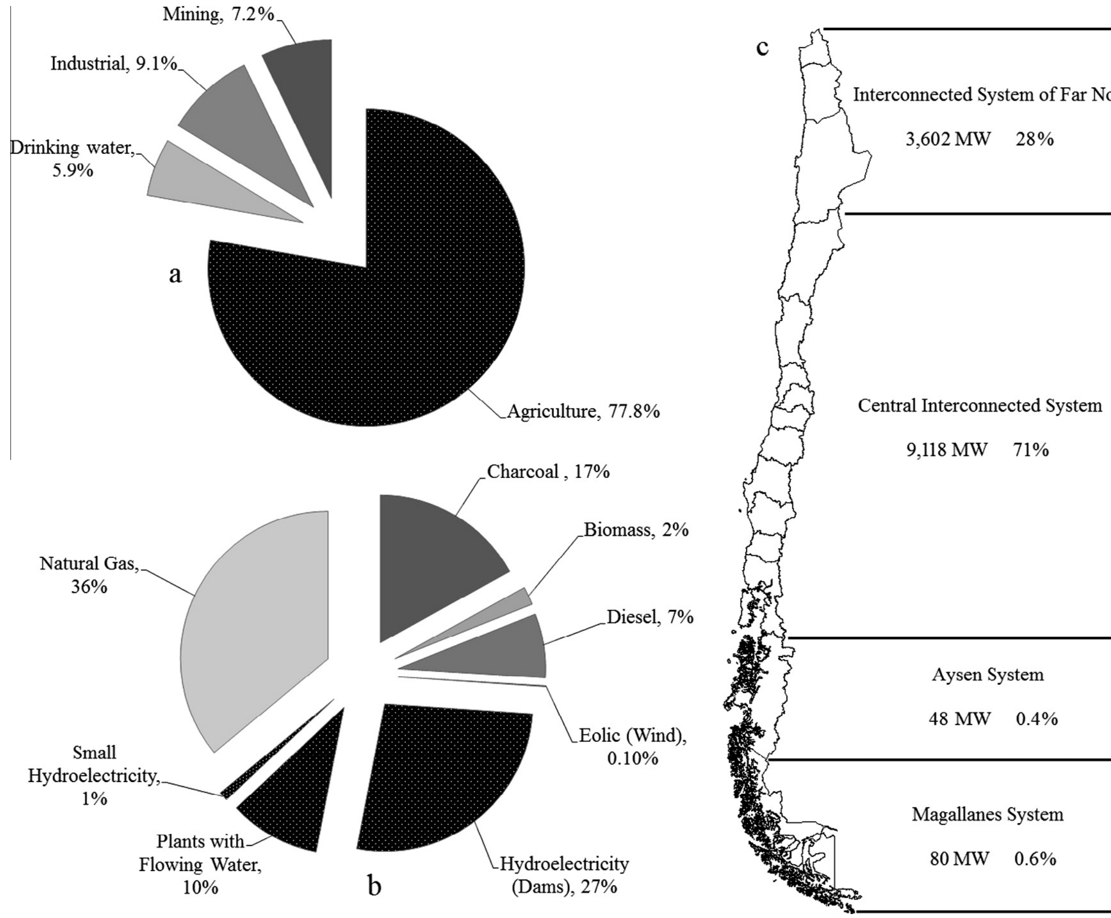

Fig. 8. (a) Consumptive water uses in Chile. *Source*: Adapted from McPhee et al. (2012). (b) installed capacity by generation technology, and (c) Interconnected systems of Chile. *Source*: Adapted from Palma et al. (2009) and CNE (2009).

Table 6
Growth in water consumption in Chile by industry. *Source*: Adapted from University of Chile (2010).

Sector	Demand in $m^3 s^{-1}$			
	1990	1999	2002	2006
Agriculture	515.8	611.4	647	526.7
Drinking water	27.4	34.1	36.7	40.1
Industrial	47.1	68.2	77.2	83.8
Mining	43.2	50.5	53.2	62.8
Energy	1189	2914	3929	3997.2
Total	1822.5	3678.2	4743.1	4710.7

(*non-consumptive uses*), such as industrial and hydroelectric uses (Vergara, 2010; DGA, 2008b). Additionally, Water Rights are classified according to the type of use as: *eventual* (the extraction is allowed only when a determined flow threshold is exceeded), or *permanent* (when the extraction is made from non-depleted sources). Water rights are also classified in *continuous* (when extraction can be uninterrupted all day), *discontinuous* (when extraction is allowed in determined periods), or *alternated* (when extraction is done by two or more users in an alternate way). The current national regulatory framework on water resources is the 1981 Water Code. However, modifications were

Table 7
Consumptive and non-consumptive surface water and groundwater rights in Chile (DGA, 2010a).

Water use	Surface water		Underground water	
	Consumptive (%)	Non-consumptive (%)	Consumptive (%)	Non-consumptive (%)
Potable, domestic use, sanitation	12.2	1.9	7.2	0.7
Hydroelectricity	0.1	11.2	0	0
Observation and analysis	0	0.1	0	0
Fish farming	0.5	11.7	0.2	0
Irrigation	27.5	2.5	13.7	0
Industrial	0.1	14.8	0.3	91.2
Medicinal	0	0	0	0
Mining	0.2	0.4	1.2	1.4
Other uses	2.8	5.9	0.6	0.7
Non-registered use*	56.7	51.5	76.7	6.1
Total	100	100	100	100

* This percentage indicates that the actual use is not registered in the DGA's database.

Table 8
National water balance (MM m^3 $year^{-1}$) for each macro zone and its evolution with time. *Source*: Adapted from World Bank (2011).

Macrozone	1996	2010	2025
Hydrologic balance (MM m^3 $year^{-1}$)			
Far North (17°30′S–25°40′S)	−40	−928	−1602
• Arica y Parinacota			
• Tarapacá			
• Antofagasta			
Near North (25°40′S–32°15′S)	−397	−873	−1299
• Atacama			
• Coquimbo			
Central Chile (32°15′S–36°33′S)	−1393	−1988	−2844
• Valparaíso			
• Metropolitana			
• Libertador General Bernardo	16,452	15,173	12,688
• ÓHiggins			
• Maule			
South (36°33′S–44°06′S)	189,204	186,763	164,517
• Biobío			
• Araucania			
• Los Rios			
• Los Lagos			
Far South (44°06′S–56°00′S)	526,801	526,005	525,708
• Aysen			
• Magallanes			

introduced in 2005, to ensure an efficient use of the resource and proper allocation of water rights. Among those modifications adopted by the Law Nº 20,017, is the implementation of a payment system to those holders with unused water rights, with the objective to regulate the monopoly exercised by them before the enactment of the law. Additionally, the amendment states that in the case of requests for the establishment of new water rights, they will be granted based on the original requested usage, and will always be granted when available and are not in conflict with the rights of others, considering both surface and groundwater. Also, in the case of new water rights "minimum ecologic flows" (minimum streamflow rate able to sustain the watercourse ecosystem), are required to be set, in compliance with Law Nº 20,017, art. 129 bis 1°, which requires "ensuring the preservation of nature and protecting the environment".

The Chilean experience related to legal regulations of water resources has been evaluated under different perspectives to determine: (1) Current Water Rights market and number of transactions; (2) Water Rights market efficiency; bargaining, cooperation, and strategic behaviors from market participants; and the marginal gains from trade (Donoso, 2008). In general terms, some studies indicate that the water market mechanism has an efficient water allocation system, supported by the evidence of active trading for water-use rights (Ríos and Quiroz, 1995; Hearne and Easter, 1995; Gazmuri and Rosegrant, 1996; Gómez-Lobo and Paredes, 2001; Cristi and Trapp, 2003; Hadjigeorgalis, 2004). Additionally, it has been stated that water markets are more active in the areas where water is a limited resource, with a high economic value. The presence of low transactions has also been stated and associated to a poor efficiency of water markets (Bauer, 2004; Hadjigeorgalis and Riquelme, 2002). On the other hand, Donoso (2008) indicated that the 1981 Water Code has been efficient from an investment point of view, mainly due to the security of Water Rights granted by the legislation. This is evidenced by significant investments that have been undertaken by several economic sectors to improve water

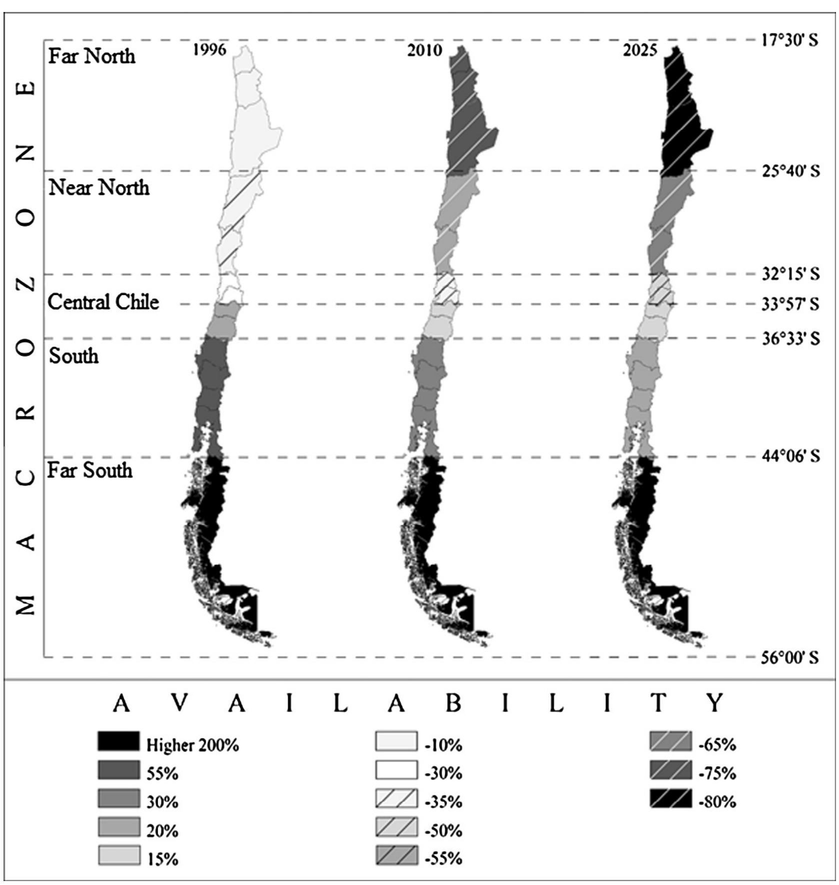

Fig. 9. Percentages of increase/decrease of water availability over time, by Macrozone. *Source*: Adapted from World Bank (2011).

Table 9
Chronology of Chilean water resources regulations.

Year	Name	Major features
1819	Executive Decree	The first Chilean text to regulate the use of water was an Executive Decree which defined the dimensions of an irrigating system, form of sale, and responsibility for water intakes (Donoso, 2008)
1857	Chile's Civil Code	It was inherited from Spanish law, and recognized that "the rivers and all waters running within natural banks are national goods for public use", and access to them was granted by "competent authority". But the terms of use were restrictive: water could only be utilized for the single use for which it had been approved, and the authority could revoke its grant if the terms of use were not respected (Domper, 2009)
1908	First Water Law of Chile Law N° 2139	It was focused in the creation of legal regulations for Water Channels Owners Associations
1951	First Water Code Law N° 9909	All water is considered a public good. Water Users require water rights treated as real state. This Water Code was different to current version because Government had a strong regulatory mechanism with authoritative conditions; for example, water rights were legally linked to land ownerships, impeding the development of an independent water market (World Bank, 2011). In this Code, the law defines water uses, making a list of the preferential areas on which there is a political interest to develop. In the event of competition in the same area, the relevant authority chose the most important and useful company. This was left to the criterion of the relevant Administrative Authority (Donoso, 2008)
1967	Second Water Law of Chile Second Chilean Agricultural Land Reform* Law N° 16,640	Swung toward greatly expanded governmental authority over water use and water management, at the expense of private property rights, by passing a new water law as part of an ambitious agricultural land reform (Bauer, 2004). The Water Code of 1967 reinforces the concept of water as public property and changes the judicial nature of water use rights, giving it the character of an actual administrative right, where the State grants the use of the national good of public use subject to public right regulations. The State grants the use of the waters, but not their ownership. It was not fully implemented due to lack of institutional capacity and resources during the Allende government (1970–1973) (Donoso, 2008)
1973	Military Regime	End of land reform. Water Code was too centered in the State, and therefore incompatible with new economic policies. The legal insecurity about the water rights unmotivated the private inversions. The water use rights titles and their trades were unknown from 1967 due not availability of records (World Bank, 2011). Based on the political changes occurred in Chile in 1973, the economic paradigm changed from one in which the State must protect and oversee optimal allocation of resources to one in which the market is responsible for allocating resources in an efficient manner (Donoso, 2008)
1979	Decree-Law N° 2603	Reestablishment of Water Rights Market. At the end of 1970s decade the necessity to clarify the situation of water rights became a priority. This decree tried to increase the irrigation efficiency through private inversion in public works and maintenance for new irrigation areas. It separated the water rights from land ownerships for the first time in Chilean history, and declared them to be freely tradable. The water rights registration was again considered as a real state (World Bank, 2011)
1981	Current Water Code Decree-Law N° 1122	According to principles of Chile's 1980 Constitution, Water Code strengthened private property rights, increased private autonomy in water use, and favored free markets in water rights to an unprecedented degree. The new code also considered a separation of water rights from land ownership and declared them to be freely tradable: they can be bought, sold, mortgaged, inherited, and transferred like any other real estate. As a corollary the code sharply reduced the government's role in water resources management, regulation, and development (Bauer, 2004). The underlying philosophy of the Water Code of 1981 was to establish permanent and tradable water use rights so as to reach efficient water allocations (Donoso, 2008)
2005	Current Water Code Reform Law 20,017	The objective of this reform was to ensure an efficient use and allocation of water rights; such as minimize the hoarding. A series of amendments to the Water Code were introduced: (1) Implementation of an annual non-use fee for surface water to reduce water use rights hoarding; (2) possibility of waiving the water right; (3) an explanatory report on the use for water rights is requested in the application for water rights; (4) the period to close a call for water rights auction was extended from 30 days to 6 months (Barrientos, 2007). Therefore, the auction system employed to allocate water use rights when there are multiple demands over the same rights was improved. (5) The reform also defined minimum ecological flows, and depending on the situation can be estimated from a 10% to 40% of the mean annual flow, or as 50% of the dry season flows represented by the probability of 95%

* Process of land ownership restructuring that occurred through different phases between 1962 and 1973.

use efficiency and to increase the availability of groundwater through exploration. The irrigation sector has invested in irrigation technology and expanded the production of permanent fruit crops.

Besides the Water Code, Chile has a set of important legal frameworks that regulate water uses, access, and management, such as the regulation of water services for human consumption, regulation for domestic drinking water, and sewerage installations, among others (Table 10).

Water management in Chile has also environmental standards, such as: (1) *Forests Law*, which prohibits the cutting of vegetation in the basin headwaters and edges and slopes of streams; (2) *General Law of Environment Basis N° 19,300*, which requires an environmental assessment for watersheds and environmental flows according to existing species; (3) *Secondary Standards* (Aquifers Quality). Additionally, Chile has adopted international/bilateral conventions, for example, the United Nations Convention on Climate Change; the United Nations Convention to Combat Desertification; the Convention on Conservation of Biodiversity, the Ramsar Convention to protect wetlands; the Washington Convention to protect National Parks and Scenic Values; and the Bi-national Agreement between Chile and Argentina for shared water resources (Larraín et al., 2010).

6.2. Institutions related to water resources management

Chile has a set of institutions and governmental agencies that regulate the use and management of water resources. Larraín et al. (2010) specified that the responsibility of Chile over water resources management is: (1) *Researching and monitoring water resources*, which is fulfilled by technical studies carried out by Government-run institutions as well as private organizations. The monitoring of hydrologic information is carried out on a daily, weekly, and monthly basis and is registered in a national database system, called the National Hydrometric Network. (2) *Regulation of water use*, which grants water use rights through the use of legal means, and in turn protects the resource against deterioration and overexploitation. (3) *Regulation of services associated to water resources*, which involves regulating the companies that provide water for both consumptive and non-consumptive uses. Therefore, the Government assumes the role of guaranteeing the quality of services,

Table 10
Other legal frameworks that regulate water uses, access, and management in Chile. *Source*: Adapted from Larraín et al. (2010).

Regulation	Law number	Publication
Regulation of water services for human consumption	Decree Nº 735, Ministry of Health	12/19/1969
Establishes consumer subsidy payment of water and sewerage wastewater	Law Nº 18,778. Ministry of Finance. Decree-Law Nº 195, July 17th, 1998.	2/2/1989
Regulation for domestic potable water and sewerage installations	Decree Nº 50, Ministry of Public Works	1/28/2003
Regulations for the control of water pollution	Decree Nº 1, Ministry of Defense	11/18/1992
Establishes liquid waste emission standards for groundwaters	Decree Nº 46, Ministry General Secretary of Presidency	1/17/2003
Establishes emission standards for pollutants associated to the discharge of liquid waste into shallow marine and inland waters	Decree Nº 90, Ministry General Secretary of Presidency	3/7/2001
Regulation of the Public Water Cadaster	Decree Nº 1220, Ministry of Public Works	7/25/1998
Regulation for rainwater evacuation and drainage systems	Law Nº 19,525. Ministry of Public Works	11/10/1997
Approves standards to foment private investment in irrigation and drainage	Law Nº 18,450. Ministry of Agriculture	10/30/1985
Establishes standards for the execution of irrigation works	Decree-Law Nº 1123, Ministry of Justice, Decree Nº 285, Ministry of Public Works, January 11th, 1995	12/21/1981
Regulation for Mineral Springs	Decree Nº 106, Ministry of Health	6/14/1997
Regulation for Thermal Springs	Decree-Law Nº 237, Ministry of Social Welfare	5/28/1931
Establishes Terms of reference for Environmental Impact Assessment Studies for projects of dredging waste dumping in the aquatic environment under the jurisdiction of the DIRECTEMAR (General Directorate of Maritime Territory and Merchant Marine)	Resolution Nº 12,600/324 VRS/94	12/16/2004

defining fees, and in turn promoting efficient economic development. (4) *Conservation and protection of water resources*, which involves developing actions related to water quality and quantity, using control programs for the natural sources of water to ensure sustainable development. (5) *Subsidiarity*, providing access to drinking water, sewage, and wastewater treatment to the most impoverished citizens, through the implementation of financial support programs. (6) *Promotion, management, and assistance to the country's hydraulic infrastructure related to irrigation and waterworks*, whose responsibility cannot be entirely assumed by the private sector due to its complexity and cost. In terms of support for irrigation, it is channeled mainly through the National Irrigation Commission (CNR), an organization that has the responsibility to coordinate the formulation and realization of national irrigation politics, in order to achieve optimum use of water resources.

The main Government organization in charge of water resources in the country is the Ministry of Public Works, having under its umbrella the General Directorate of Water Resources (DGA), the Directorate of Hydraulic Works (DOH, 2010), and the Superintendence of Water and Sanitation Services (SISS). Those

Table 11
Institution directly linked to water resources management. *Source*: Adapted from Larraín et al. (2010).

Ministry	Institution	Function	Legal regulations associated to functions
MOP	DGA	Promote the management and administration of water resources. Provide and disseminate the information generated by the hydrometric network contained in the Public Water Cadaster. Monitoring and control of the quantity and quality of the resource in its natural sources	• Water Code (Law Nº 1122, Ministry of Justice) • Decree Nº 1220, Ministry of Public Works
MMA MOP MDN	SMA and SEREMI-MMA DGA DIRECTEMAR	Environmental protection and conservation of water resources. Implementation of environmental regulations related to water resources	• Law Nº 20,417, Ministry General Secretary of Government • Law Nº 19,300, Ministry General Secretary of Government • Decree Nº 1, Ministry of Defense • Decree Nº 90, Ministry General Secretary of Presidency • Decree Nº 46, Ministry General Secretary of Presidency
MOP	SISS PAPR-DOH	Regulation of Water Drinking and Sanitation Services	• Law Nº 18,778, Ministry of Finance • Decree Nº 50, Ministry of Public Works • Decree Nº 195, Ministry of Finance
MINAGRI MOP	CNR DOH	Foment and Development of Irrigation Activities, and Water Infrastructure	• Law Nº 18,450, Ministry of Agriculture • Decree Nº 7, Ministry of Finance • Decree Nº 1123, Ministry of Justice • Decree Nº 179, Ministry of Economy • Decree Nº 285, Ministry of Public Works • Decree Nº 397, Ministry of Agriculture
MINAGRI MINSALUD MEFT	SAG SNS SERNAPESCA SUBPESCA	Supervision and Control of water quality with specific objectives	• Decree Nº 237, Ministry of Social Welfare • Decree Nº 106, Ministry of Health • Decree Nº 735, Ministry of Health Not available
MOP MINSALUD	SISS SNS	Supervision and control of effluents	

MOP: Ministry of Public Works, DGA: General Directorate of Water Resources, MMA: Ministry of Environment, SMA: Sub-secretary of Environment, SEREMI-MMA: Ministerial Regional Secretary of Environment, MDN: Ministry of National Defense, DIRECTEMAR: General Directorate of Maritime Territory and Merchant Marine, SISS: Superintendence of Sanitary Services, PAPR: Rural Drinking Water Programme managed by DOH, MINAGRI: Ministry of Agriculture, CNR: National Commission of Irrigation, DOH: Directorate for Hydraulic Works, SAG: Agricultural and Livestock Service, MINSALUD: Ministry of Health, SNS: National Service of Health, MEFT: Ministry of Economy, Foment and Tourism, SERNAPESCA: National Service of Fishing, SUBPESCA: Sub-Secretary of Fishing.

institutions interact to regulate and manage water resources, mainly through the *Water Code* and the *General Law of Environment Basis*. However, according to DGA (1999b), Chile has a strong dispersion regarding water resources management functions. OECD (2011) indicated that Chile is the country with the highest diversity of administrative authorities related to water resources management and, consequently, it is difficult for the country to ensure a coordinated development plan. Given this diversity of actors, DGA is diminished in its autonomy and loses decision-making effectiveness due to the lack of supremacy over other institutions. Additionally, water resource management is hampered by overlapping powers existing on certain issues (Table 11), such as water quality protection (MOP, 2013).

Vergara (2010) indicates that there is a difference between centralized and decentralized institutions. Centralized institutions are part of the Government's administration and, therefore, are involved with the management of water quality and quantity, the legal system, and other functions. Decentralized institutions, on the other hand, are mainly Organizations of Water Users (OWU), described by Ríos and Quiroz (1995) as: (1) *Surveillance Boards,* in charge of supervising water resources use in natural sources (rivers), (2) *Associations for Water Channels*, in charge of the administration of main infrastructure (dams and main irrigation channels), and (3) *Water Communities*, in charge of secondary infrastructure (distribution channels). All of these are watershed-scale private organizations not part of Government administration. However, in the case of Surveillance Boards, the demand distribution could be defined in a context of public administration.

On the other hand, Retamal et al. (2013) proposed a governance structure based on a description of aquatic ecosystems (Fig. 10a), denominated Goods and Ecosystems Services (GES), and identifying priority uses, indirect uses, and non-uses. In addition, the authors identified three types of users (Fig. 10b): (1) *Users with water rights*, who are mainly private institutions that administrate water demands through the OWU and constitute local managers of the resource, developing water rights transactions and resolving demand conflicts among users. If conflicts are not resolved, the Justice Tribunals are the next step to achieve the resolution of such conflicts. Similarly three types of institutions are regulators of water supply: the DGA that regulates all uses, the Institutions that regulate specific uses, and finally those that control negative externalities generated by inappropriate uses. (2) *Users in Transition* are those who must normalize their situation through the Ministry of National Goods, the National Commission of Indigenous Development, or regional Municipalities, because the current legislation has not established a relationship between GES and users, for example, the indigenous communities with land ownership but without water rights, the farmers with customary rights, and the population without participation in decision-making of sanitary authorities. Thus, while they tend to resolve gaps in Water Rights tenure, it is unclear how the cultural value of water resources may have a type of tenure of equal importance to Water Rights. (3) *Users without water rights* are those who can have indirect uses and non-uses, for example, navigation, fishing or recreation carried out by individuals or public institutions. They can also participate in OWU and in the management of local water resources. They are protected by environmental regulations applied on priority uses and their externalities. However, these regulations are newer than the implementation of the Water Code and, therefore, it is practically impossible to apply them in some depleted basins located in North-Central Chile, because it is very difficult and expensive to diminish current users' Water Rights due to the constitutional character of the tenure (Retamal et al., 2013). Finally, it is important to mention that different institutions regulate each type of tenure. For example, users with water rights may be two different kinds of stakeholders: those regulating the supply and those regulating the demand. Users in transition are related to institutions that can regularize their situation, and users without water rights are related to institutions that have regulations based on conservation-promoting standards (Fig. 10c). More information about Chile's water governance can be found in diverse studies and reports, such as DGA (1999a), Matus et al. (2004), Larraín et al. (2010), World Bank (2011), OECD (2011), and MOP (2013).

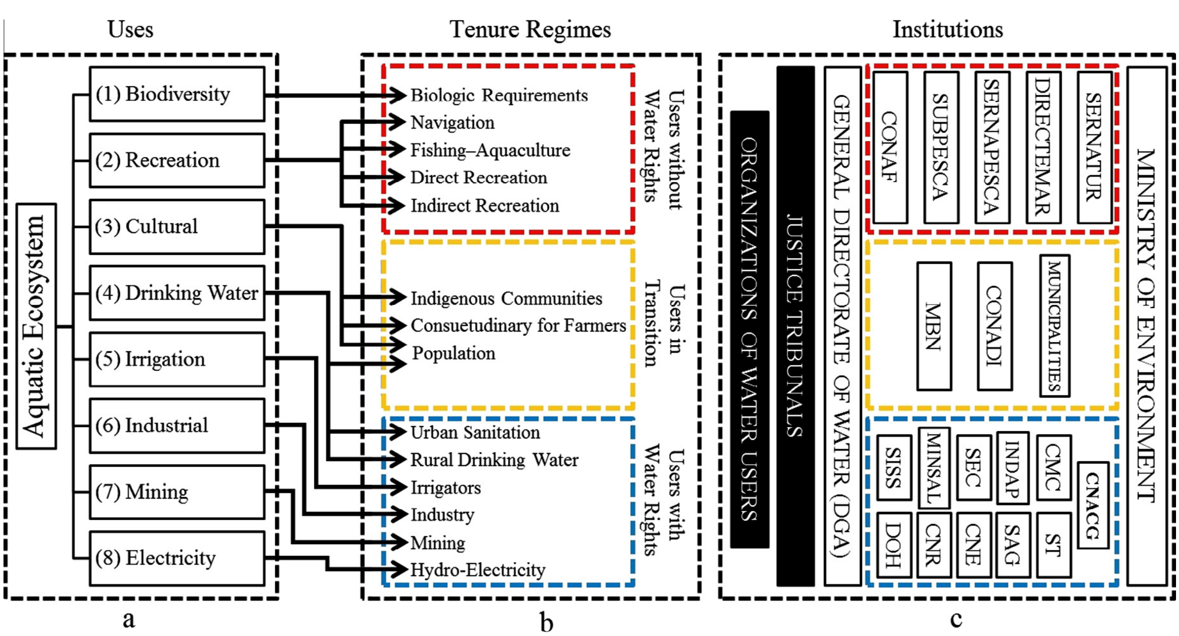

Fig. 10. (a) Uses, (b) users, and (c) institutions related to Water Resources Management in Chile. (a) Goods and Ecosystem Services (GES) provided by the aquatic ecosystems. (b) Users related to GES, and (c) National Institutions related to GES. SERNATUR: National Service of Tourism, DIRECTEMAR: General Directorate of Maritime Territory and Merchant Marine, SERNAPESCA: National Service of Fishing, SUBPESCA: Sub-Secretary of Fishing, CONAF: National Forest Corporation, CONADI: National Commission of Indigenous Development, CNACG: National Advisory Committee on Global Change, CMC: Basin Ministerial Council, ST: Technical Secretary, INDAP: National Institute of Agricultural Development, SISS: Superintendence of Sanitary Services, DOH: Directorate for Hydraulic Works, SEC: Superintendence of Energy and Fuels, CNR: National Commission of Irrigation, CNE: National Commission of Energy, DGA: General Directorate of Water Resources. *Source*: Adapted from Retamal et al. (2013).

7. Environmental aspects of inland water management

7.1. Water cycle data system

Most of the meteorological and hydrologic information of the country is provided by two institutions: the *General Directorate of Water Resources* (DGA), whose function is to evaluate qualitatively and quantitatively the country's water resources through the National Hydrometric Network; and the *Chilean Meteorological Directorate* (DMC), based in the Ministry of Defense. Additional government institutions also collect hydrologic information, which include the *Navy Hydrographic and Oceanographic Service* (SHOA) supported by the Ministry of Defense; and other institutions supported by the Ministry of Agriculture, including: the *National Irrigation Commission* (CNR); the *Agricultural and Livestock Service* (SAG), the *National Forestry Corporation* (CONAF), and the *National Agricultural Research Institute* (INIA). However, their information is not as extensive as that provided by the DGA, which has the most comprehensive network nationwide.

DGA has significantly improved the quality and quantity of their monitoring stations in the last few years, training its personnel and updating many stations with automated data collection, as well as satellite transmission. For example, the number of rain gauges increased 16% in 2012, with respect of 2011. Similarly, during the same year, meteorological stations increased 15%, sedimentary stations 19% groundwater stations decreased 12%, and satellite platforms increased 64%. These improvements represent high hydrologic and meteorological data collection standards at a national level (DGA, 2012a). Table 12 shows the historical evolution of the type and number of stations improved by the DGA in the last few years. Additionally, the continuous improvement of the quality and quantity of monitoring stations on a regional basis is important when describing their representation at a national level. Fig. 11 shows the current DGA monitoring stations distribution in Chile.

7.2. Water quality

The main regulation for water quality related to drinking water to meet physical, chemical, bacteriological, and radioactive properties is prescribed in the NCh409/2005 norm. Irrigation water quality is also regulated by the same standard, through the NCh1333 norm. The Ministry of the Environment, on the other hand, is currently working on the development of secondary norms, for secondary uses. Núñez (n.d) mentioned that secondary regulation of water quality is not controlled directly, only indirectly through regulation of coastal and inland water emissions. Moreover, these emission standards are not site-specific, but constant throughout the country. This creates significant differences on surface water quality, and consequently different localized water quality

Table 12
Evolution in the number of DGA stations between 2005 and 2012 (DGA, 2012a).

Year	Fluviometric[a]	Meteorologic	Snow	Sedimentary	Groundwater	Satellite platforms[b]
2005	403	502	21	70	592	141
2006	414	464	13	70	581	162
2007	439	539	22	84	614	183
2008	439	543	21	84	614	188
2012	467	577	21	83	519	232

[a] Satellite platforms are capable of measuring different parameters, which are added to the corresponding network.
[b] Intermittent measuring stations not included.

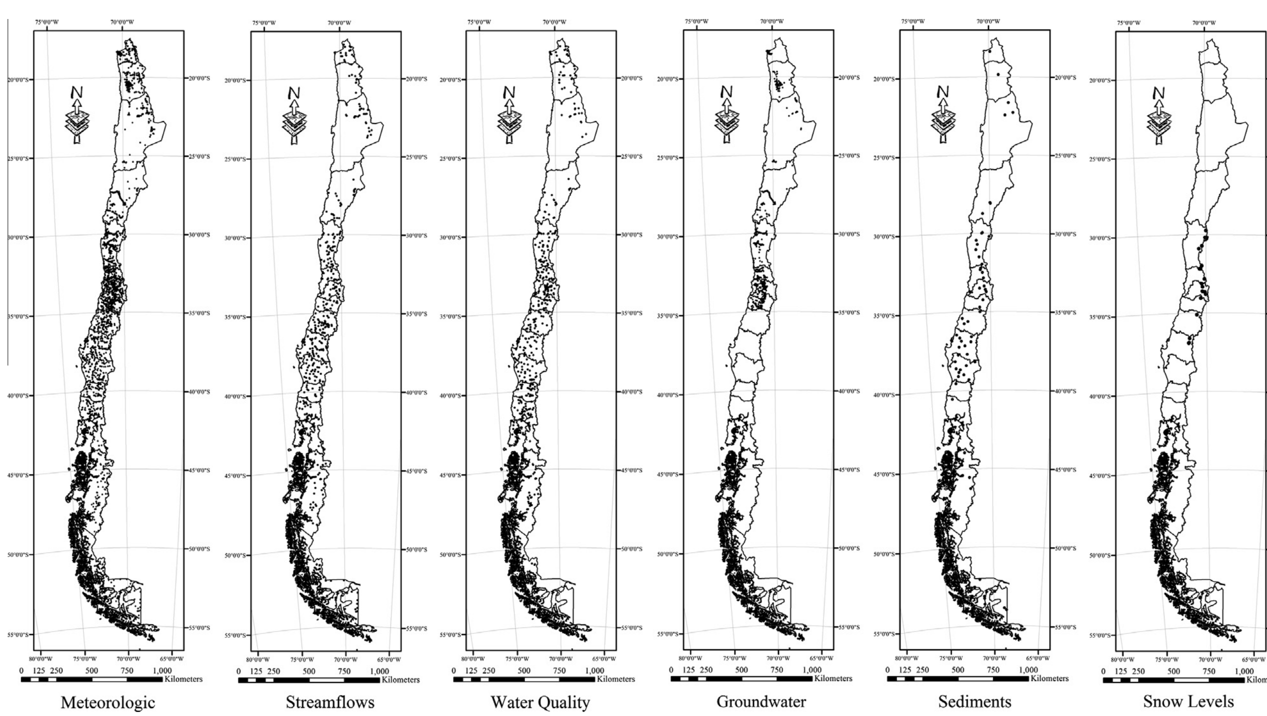

Fig. 11. DGA's National Hydrometric Network. *Source*: Adapted from DGA's Database.

problems. Chile has a large percentage of its population with access to drinking water (99%), sewage (95%), and wastewater treatment (80%). Thus advances in setting standards for water quality beyond human consumption (secondary use) have been rather slow, and not an urgent matter of public health. However, there are some advances toward the development of site-specific secondary water quality standards.

In general terms, CONAMA (2007) indicated that natural surface waters in Chile show significant spatial variability in chemical properties. For example, waters in the Far North are characterized by high salt contents due to the presence of geological formations; and also possess high levels of arsenic, associated with Altiplanic quaternary volcanism, exceeding in some cases more than 50 times national standards (Queirolo et al., 2000). Differently, salt contents in the Near North are lower than those existing in the Far North, although it usually increases downstream, generating restrictions on water uses. The quality of water in Central-Chile is better, though heavy metals, such as copper from anthropogenic sources, have been detected in the Aconcagua, Maipo, and Rapel rivers (32°02′S to 35 °S). Water quality in Central-South regions is appropriate, according to Chilean standards. Furthermore, Rivera et al. (2004) stated that physicochemical parameters measured in some rivers located between 37°35′S and 39°37′S, such as Cautín and Imperial, do not exceed legal standards. Similarly, Debels et al. (2005) indicated that Chillan River showed good general water quality in most of the sub-watersheds. Nevertheless, exceptions have been observed in some rivers located between 36°S and 44°14′S, such as Biobío, Damas, and Rahue rivers., Water quality in Far South regions has been evaluated as "very good" (CONAMA, 2007). The spatial distribution of different chemical parameters measured during 2006 in different rivers located along the country is illustrated in Fig. 12.

In terms of national initiatives, a National Hydrochemical Map was developed by DGA (1996), containing surface water quality values for a series of watersheds, and their respective chemical parameters. According to the map, the concentrations of macro elements (boron, arsenic, copper, iron, and nitrates) decreases from North to South, possibly due to mining operations in the North and decreasing temperatures (i.e. evaporation rates) from North to South.

DGA developed the project "Classification and diagnosis of streamflows and water-bodies, considering water quality objectives" (http://www.sinia.cl/1292/w3-article-31018.html) in 2004–2010. In this context, 33 priority watersheds were selected in the country to: (1) Determine the factors that affect or might affect future water quality, (2) Determine natural and current quality, (3) Characterize current and future uses *in situ*, such as extractions and biodiversity, (4) Establish a Water Quality Index, (5) Define areas of liquid waste dilution and applying it to the studied rivers, and (5) Identify rivers with water quality below the standards, and (6) Design a standard monitoring plan (DGA, 2004a).

In terms of groundwater quality, Arumí and Oyarzún (2006) indicated that Far North regions have arsenic-related problems. In Near North regions, problems are primarily associated with the presence of sulfate, manganese, and chlorides. Between Maule and Los Lagos regions (34°41′S to 44°14′S) a very common problem is high iron contents (Table 13).

It should be noted that the water quality monitoring network is still insufficient to properly characterize rivers, lakes, estuaries, and coastal areas of the country. Therefore, the lack of systematic data have limited an accurate and detailed assessment of this problem, and it is becoming a serious obstacle to the management of water resources (Contreras, 2010). Additionally, current groundwater monitoring is poor, especially in terms of spatial and temporal distribution. For instance, it is not representative of the chemical conditions, and does not allow adequate monitoring of the groundwater quality. In this context, a new monitoring network was proposed in 2009, increasing the number of monitoring wells, determining the type of parameters to be sampled and their frequency, and defining the protocols for transportation and analysis of samples (DGA, 2009c).

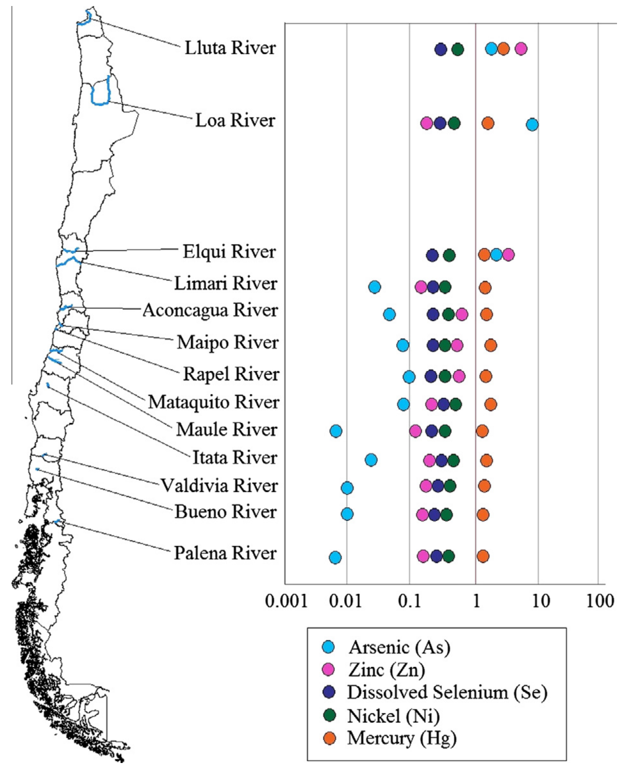

Fig. 12. Chemical parameters measured in 2006 for different rivers along the country. The values in the graph represent the number of times that a contaminant is above or below the recommended standards (logarithmic scale), suggested by the Environmental Protection Agency (EPA), and by using the Water Quality Criteria (WQC), considering the relation: mean annual monitored concentration/suggested concentration (mg L^{-1}). Parameters with low representativeness were not considered. *Source*: Adapted from MMA (2011).

7.3. Drinking water and sanitation

Chile has an Official Standard (Nch409) divided in two parts: Part I establishes the minimum quality requirements to be met by the supplied drinking water, and Part II indicates the sampling

Table 13
Groundwater quality considering parameters that exceed Chilean drinking water standard values. *Source*: Adapted from Arumí and Oyarzún (2006).

Region	Parameter that exceed Chilean drinking water standard
Arica y Parinacota	Chlorine, Arsenic and Manganese
Tarapacá	Chlorine, Arsenic and Manganese
Antofagasta	Arsenic and Sulfates
Atacama	Sulfates
Coquimbo	Sulfates, Iron and Manganese
Valparaíso	Manganese, Sulfates, Iron and Chlorine
Metropolitana	Sulfates, Iron and Manganese
O'Higgins	Manganese, punctually Lead and Mercury
Maule	Iron
Biobío	Iron, some Manganese and punctually Mercury
Araucanía	Iron
Los Ríos	Iron
Los Lagos	Iron
Aysen	w/o problem
Magallanes	w/o problem

procedures for verification purposes. In general, drinking water quality parameters (bacteria, turbidity, free residual chlorine, critical parameters, and non-critical parameters) proposed by the Superintendence of Sanitary Services (SISS, 2009a, 2011) have remained at very good levels during the period 2007–2011. However, there have been particular declining occasions, especially between 2007 and 2008, attributed to modifications in concentrations and sampling requirements during 2006, since the quality norm was updated. Therefore, the decline in the parameters was due to the changing of the norm.

The Chilean water services include all those industries aimed at producing and distributing drinking water. Furthermore, these companies are also responsible to collect, dispose, and treat sewage from all urban areas of the country. The coverage of water services industries, particularly those related to water supply and sewerage, are geared mainly to people living in the concession areas of the water companies. According to current legislations, concessions for these services are defined only for urban areas, regulated by master plans. Some rural areas are also considered because they were supplied by drinking water and sewerage before the regulation was promulgated. In this context, Chile is characterized by supplying more than 99% of its urban population with high quality drinking water, standing among the developed countries in this field worldwide (US 100%, France 100%, New Zealand 100%, and Portugal 99%).

In terms of sewerage systems, Chile is also located among the countries with higher urban coverage, providing service to 98% of urban population, well above most developed countries excepting the US (100%), Japan (100%), France (100%), and Czech Republic (99%) (MMA, 2011). Furthermore, it should be mention that the Chilean urban population had a 91.6% of drinking water coverage in 1997, and by 2011 this value was 99.8% (about 15,315,145 inhabitants). The capacity for drinking water production is about 84,311 l/s, being 47% from groundwater sources and the rest corresponds to surface water (SISS, 2011).

7.3.1. Sewerage

Most of the population in Chile (90.4%) had access to sewerage in 1996, a highly significant situation compared to other Latin American countries. By December of 2011, the percentage of urban population with access to sewerage system reached 95.3%, showing significant increases in the coverage during the period (SISS, 2009b, 2009c, 2011). Similarly, it is expected to obtain 100% of coverage in the coming years (SISS, 2011).

7.3.2. Coverage of wastewater treatment

Wastewater treatment coverage, just like sewerage coverage, is related to the percentage of the population residing in housing, and sewage is collected by water companies and treated at the stage of provision. The types of treatments are mainly existing activated sludge, aerated stabilization ponds, and outfalls. Whatever the method used in the treatment of wastewater, such treatment can recover and improve the quality of fresh watercourses, especially when the main source of water pollution in Chile corresponds to liquid discharges from homes. By the year 2011, 90.6% of the urban population in the country had adequate sewage treatment, amount projected to be around 99% by 2015 (SISS, 2009b, 2009c) (Fig. 13).

8. Climate change and water resources

The scientific community has been working toward developing measurements of climatic patterns around the world, and Chile has not been an exception. Moreover, the possible influence of global warming on the country's water resources has been analyzed mostly in terms of temporal and spatial precipitations trends, stream flows, and glacier retreat. There is not much information on aquifers and water tables levels, though a brief analysis is also presented below.

8.1. Temporal and spatial variability of precipitation

Due to significant inter-annual and spatial variability, precipitation changes throughout Chile are difficult to evaluate (Garreaud, 2011). However, the study of precipitation patterns in the country and the possible influence of climate change have been studied by different authors. Specifically, Fuenzalida et al. (1989) noted that instrument records from La Serena to Valdivia (29°54′S and 39°48′S, respectively) suggested a decrease in annual precipitation during the twentieth century. However, the same authors stated that the information was too fragmented to draw solid conclusions. Similar results were presented by Aceituno et al. (1992), who observed significant decreases in precipitation at subtropical areas of Chile (30°S–37°S) during the 20th century. According to projections developed using an atmosphere–ocean coupled general circulation model (CGCM), Christensen et al. (2007) also indicated that precipitation in the North-Central zone of Chile is decreasing. However, Quintana and Aceituno (2006) analyzed the linear trends for the 1970–2000 period, concluding that annual rainfall does not exhibit a significant trend during this period in Northern Central Chile (30°S–34°S), while in the Southern part of the country

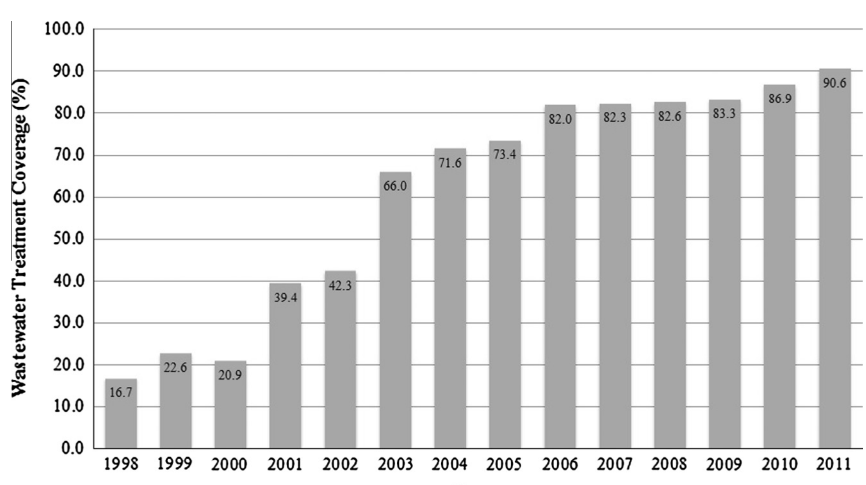

Fig. 13. Historic evolution of wastewater treatment coverage. *Source*: Adapted from SISS (2009b).

(40°S–44°S) a marked negative trend is apparent. Similarly, Garreaud (2011) indicated that annual rainfall in Valdivia (39°48′S) has decreased around 100 mm decade^{-1} between 1960 and 2000. Recently the evolution of annual rainfall along the west coast of Chile (30°–43°S) was analyzed for the period 1900–2007, finding negative trends between 30° and 35°S from the beginning of the 20th century until the mid- 1970s, followed by a significant increase in 1980s. In the southern portion (37°–43°S) a significant downward trend in annual rainfall prevailed since the 1950s, as a direct result of a decreasing frequency of rainfall episodes and a weakening of daily precipitation intensity that lasted until the 1990s (Quintana and Aceituno, 2012).

On the other hand, inter-decadal variability of annual rainfall between 1930 and 2000 was analyzed as changes in the linear trend using 30-year moving averages. A negative trend, which prevailed up to the mid-1970s, followed by a positive trend that reached a maximum intensity between the period 1956–1985, was observed for the subtropical domain. During the most recent 30-year period, annual rainfall regime has remained more or less stationary in the band 30°S–34°S, and the evolution of annual rainfall was generally opposite in the band 33°S–45°S because a positive trend, prevailing up to the mid 1980s, was followed by mostly negative trends (Quintana and Aceituno, 2006). For instance, Quintana (2004) noted that in Los Lagos Region (latitudes 40°14′S to 44°04′S) precipitation decreased between 1930 and 2000, most markedly around latitude 39°S, where a decrease of 450 mm was found in 70 years of measurement.

In order to confirm those studies, the possible influence of climate change on temporal and spatial behavior of rainfall was analyzed in this paper by using the Mann–Kendall (MK) trend test (Kendall, 1938; Mann, 1945; Kendall, 1975), which measures the relative ordering of all possible pairs of data points (Haylock et al., 2006); and Sen's slope test, with the aim to determine the rate of precipitation changes over time (Theil, 1950; Sen, 1968). The analyzed dataset correspond to 271 gage stations distributed between latitudes 26°00′S and 56°30′S. In general the stations showed a low percentage of missed data (Fig. 14a). The analysis considered the trend calculation for the complete records of all selected stations. In this context, 166 stations showed increasing trends with an 11.4% of significant results (alpha < 0.1); on the contrary, 98 stations showed decreasing trends with a 12.2% of significant results (alpha < 0.1) (Fig. 14b). At a regional scale the results showed that precipitation has no clear trends in the Atacama Region (26°S to 29°20′S) between 1960 and 2000, even a 38% of the stations showed no changes due to the low historical annual precipitation amounts. Positive trends were observed in most of the analyzed stations located from Coquimbo to Valparaiso regions (29°20′S to 33°57′S); equivalent results were observed from Maule to Los Lagos regions (34°41′S to 44°14′S), and similarly for Magallanes Region (48°36′S to 56°30′S) The latter showed positive significant trends for 44% of the stations. On the other hand, most of the analyzed stations showed decreasing (but not statistically significant) trends for Metropolitana (1931–2004) and O'Higgins (1960–2004) regions (32°55S to 35°S). Besides negative trends were also observed for most of the stations analyzed in Aysen Region (43°38′S to 49°16′S) between 1931 and 2006, showing significant results (alpha < 0.1) in around 57% of the analyze stations (Fig. 14c, d and e).

Additionally, a multi-decadal analysis of precipitation was carried out by considering overlapping periods from 1930 onwards, and only for those stations with complete records. At the national scale most of the stations showed positive trends when analyzing from 1940, 1950, 1960, 1970 and 1990 decades onwards. On the contrary, negative trends were observed in most of the stations when analyzing from 1930, 1980, and 2000 onwards. The detailed regional results and the statistical significances of each period can be observed in Fig. 14f, suggesting that despite is possible to determine positive or negative trends for the analyzed periods, most of the regions showed a low number of stations with significant results or even without statistical significances. The results stated above suggest that there are little clear patterns of trend emerging along the national territory between 26°S and 43°S; however, south of 43°S significant changes can be observed, especially for Aysen and Magallanes regions. This latter showed more than 30% of the stations with significant positive trends when analyzing from 1990 onwards.

In terms of future projections, Minvielle and Garreaud (2011) suggested a significant reduction (10–30%) in Altiplano precipitation by the end of this century, under moderate-to-strong greenhouse gas emission scenarios Therefore, future changes in summertime temperatures and precipitation will affect water availability for human consumption, agriculture, glaciers, and ecosystems, due to the area's semiarid climate and the strong seasonality of the Altiplano (Bradley et al., 2006). According to results from the PRECIS Model (Providing Regional Climates for Impact Studies), precipitation in the 21th century will be reduced by 60–70% of current values, between the regions of Maule and Los Lagos (34°41′S to 44°14′S), this reduction being more intense during spring months.

Precipitation will increase by 10–20% in the Southern zone, whereas semi-arid and arid zones of Chile will experience smaller changes (Garreaud, 2011). According to Christensen et al. (2007), precipitation will have changes in its spatial and temporal distribution. Besides, GCM simulations indicate a decrease between 10% and 30% from current precipitation to be expected in South-Central Chile by the end of the century (2080–2100).

Finally, it is important to mention that, despite some differences were detected between our observations and previous national studies, the future scenarios of water availability from precipitation are considered non-optimistic. Therefore, water governance in water-scarce areas of Chile will be the most important issue to address in future water management plans.

8.2. Status of glaciers and zero degree isotherm

Glaciers are a very important resource of national relevance since they are fresh water reservoirs, whose melting not only contributes to summer streamflow, but also as the primary source of groundwater recharge during summer months, as well as during periods of drought. To address this DGA and the Ministry of Public Works (MOP) created in 2008 the *Glaciology and Snow Department* (UGN), with the purpose of studying and monitoring past and future glacier variations at national scale. Rignot et al. (2003) indicated that the study of glaciers in Chile has focused primarily on determining glacier front variations, surface areas, and mass balances during the last decades. Actually, available research about Chilean glaciers shows that most of them are in recession. Rivera et al. (2000) evaluated about 100 glaciers in Chile, concluding that 87% of them showed recessions rates associated to climate variability. Most of the glaciers in the Chilean Central Andes (28°S–41°S) have receded in recent decades (Bown et al., 2008), with an important reduction of their surfaces (Rivera et al., 2002). This process is believed to be a response to temperature increases observed at weather stations holding the longest records in the area (Rosenblüth et al., 1997), and also due to decreases in annual precipitation and increases in the elevation of the snowline in that region (Carrasco et al., 2005, 2008). Rabatel et al. (2011) mentioned that precipitation variability is one of the main mass balance drivers around 29°S in the Pascua–Lama region, and also emphasized the relevance of winter mass balance to annual mass balance variability. The same authors show that the total national glaciated surface area was reduced by around 29% between 1955 and a

Region	Missed Data (%)							Total
	0	0.1 - 5	5.1 - 10	10.1 - 15	15.1 - 20	20.1 - 30	30 <	
Atacama	10	5	1	0	0	0	0	16
Coquimbo	28	7	3	3	1	1	0	43
Valparaiso	22	9	3	1	0	0	0	35
Metropolitana	3	5	4	2	1	0	0	15
O'Higgins	14	2	1	2	0	0	0	19
Maule	13	3	2	1	1	0	0	20
Biobio	27	8	1	0	0	0	0	36
Araucanía	29	2	2	0	1	0	0	34
Los Rios	5	1	0	0	0	0	0	6
Los Lagos	7	1	2	0	0	0	0	10
Aysen	4	1	2	2	4	2	2	17
Magallanes	20	0	0	0	0	0	0	20
Total	**182**	**44**	**21**	**11**	**8**	**3**	**2**	**271**

b

Region	Maximum Length of Continuous Records	Maximum Length of no continuous Records	Mean Annual Rainfall (mm yr⁻¹)	Number of Stations			Number of stations analyzed
				Positive	Negative	No Changes	
Atacama	1960-2006	1960-2006	43.46	7(1)	3(0)	6(0)	16
Coquimbo	1930-2004	1914-2004	177.46	25(1)	17(0)	1(0)	43
Valparaiso	1929-2004	1929-2004	337.7	22(0)	13(0)	0	35
Metropolitana	1957-2004	1931-2004	442.98	6(1)	9(0)	0	15
O'Higgins	1960-2004	1960-2004	683.8	6(0)	13(0)	0	19
Maule	1940-2008	1940-2008	1094.8	13(2)	7(0)	0	20
Biobío	1944-2006	1931-2006	1572.3	29(3)	7(0)	0	36
Araucanía	1947-2006	1939-2006	1736.34	26(2)	8(2)	0	34
Los Rios	1958-2006	1940-2006	2353.9	5(1)	1(1)	0	6
Los Lagos	1976-2006	1971-2006	2928.94	8(0)	2(0)	0	10
Aysen	1989-2006	1931-2006	1875.33	3(1)	14(8)	0	17
Magallanes	1973-2006	1973-2006	406.06	16(7)	4(1)	0	20
	Mean and Total		**1137.8**	**166**	**98**	**7**	**271**

f

Region	Period	From this year onwards							
		1930	1940	1950	1960	1970	1980	1990	2000
	Complete Records				1	3	11	15	15
Atacama	Positive Trends				0(0)	2(0)	0(0)	3(0)	1(0)
	Negative Trends				1(0)	1(0)	11(1)	12(0)	14(0)
	Complete Records	1	1	7	11	20	41	43	43
Coquimbo	Positive Trends	0(0)	0(0)	4(0)	11(0)	20(0)	11(0)	41(0)	3(0)
	Negative Trends	1(0)	1(0)	3(0)	0(0)	0(0)	30(0)	2(0)	40(0)
	Complete Records	1	3	4	4	9	32	33	34
Valparaiso	Positive Trends	0(0)	2(0)	3(0)	3(1)	5(1)	3(1)	32(1)	1(0)
	Negative Trends	1(0)	1(0)	1(0)	1(0)	4(0)	29(0)	1(0)	33(0)
	Complete Records		1	2	1	2	7	9	11
Metropolitana	Positive Trends		0(0)	1(0)	1(0)	2(0)	1(0)	8(0)	0(0)
	Negative Trends		1(0)	1(0)	0(0)	0(0)	6(0)	1(0)	11(0)
	Complete Records				1	2	13	18	19
O'Higgins	Positive Trends				1(0)	0(0)	1(0)	14(0)	0(0)
	Negative Trends				0(0)	2(0)	12(0)	4(0)	19(2)
	Complete Records		2	5	8	17	20	20	20
Maule	Positive Trends		2(0)	3(0)	7(0)	2(0)	2(0)	2(0)	1(0)
	Negative Trends		0(0)	2(0)	1(0)	15(0)	18(0)	18(0)	19(0)
	Complete Records		2	5	8	17	20	20	20
Maule	Positive Trends		2(0)	3(0)	7(0)	2(0)	2(0)	2(0)	1(0)
	Negative Trends		0(0)	2(0)	1(0)	15(0)	18(0)	18(0)	19(0)
	Complete Records		1	2	4	11	22	24	36
Biobío	Positive Trends		1(0)	0(0)	4(1)	8(0)	10(0)	19(1)	18(0)
	Negative Trends		0(0)	2(0)	0(0)	3(0)	12(2)	5(0)	18(0)
	Complete Records			2	4	10	17	31	34
Araucanía	Positive Trends			2(0)	3(0)	6(0)	8(2)	20(0)	23(0)
	Negative Trends			0(0)	1(1)	4(2)	9(2)	11(0)	11(0)
	Complete Records				1	1	3	4	7
Los Rios	Positive Trends				1(0)	1(0)	2(0)	3(0)	5(0)
	Negative Trends				0(0)	0(0)	1(1)	1(0)	2(0)
	Complete Records						2	4	10
Los Lagos	Positive Trends						2(1)	3(0)	7(0)
	Negative Trends						0(0)	1(1)	3(0)
	Complete Records							1	17
Aysen	Positive Trends							1(0)	10(0)
	Negative Trends							0(0)	7(0)
	Complete Records						6	19	20
Magallanes	Positive Trends						4(0)	14(5)	13(4)
	Negative Trends						2(0)	5(1)	7(2)

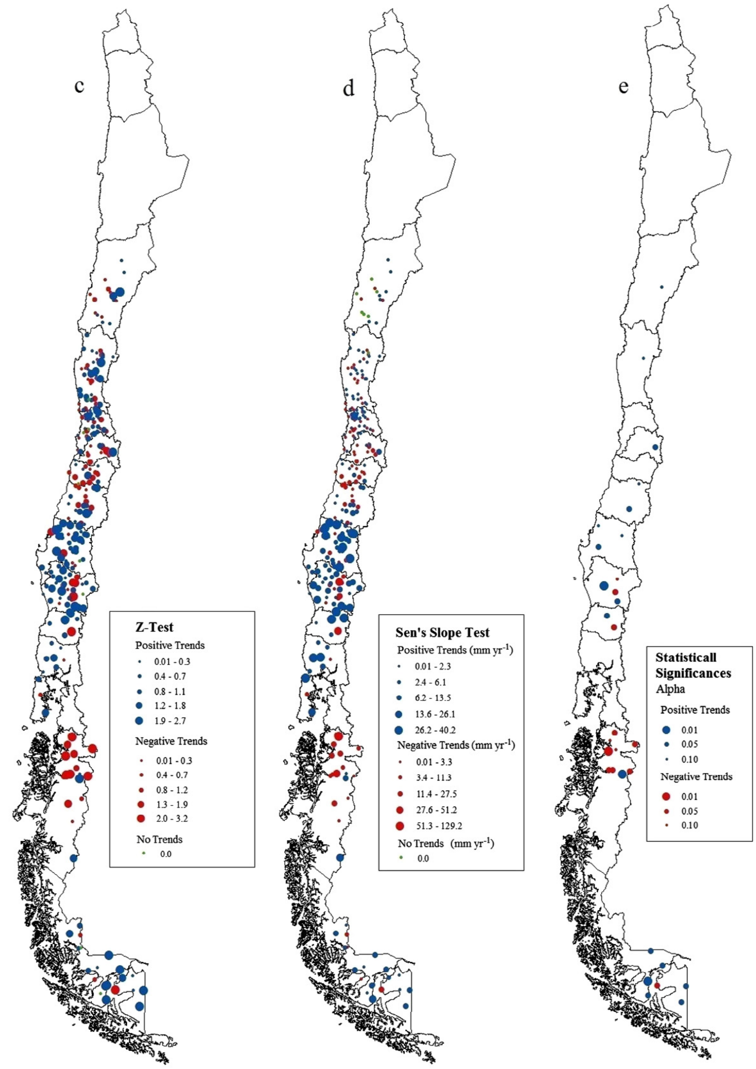

Fig. 14. (a) Number of analyzed stations per region and percentage of missed data. (b) Maximum length of records per region, mean annual rainfall, and Sen's slope test results for annual precipitation. (c) Mann–Kendall results obtained by using the Z-Test. (d) Mann–Kendall results obtained by using the Sen's Slope Test. (e) Statistical Significances. (f) Multi-decadal analysis of precipitation by using Mann–Kendall Z-Test. The integer in parenthesis showed in (b) and (f) represents the number of significant trends for each case ($\alpha < 0.1$). Red dots in (c), (d) and (e) represent the negative trends, and blue dots are the positive trends. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) *Source*: The dataset was obtained from León (2006), González (2007), Pizarro et al. (2008), Olivares (2009), Valdés (2009), Cornejo (2011), and Mendoza (2011).

2007, and that the rate of surface area shrinkage increased in the late 20th century. Similar results were found by Le Quesne et al. (2009), who indicated that all glaciers in Central Chile exhibited a negative trend during the 20th century with mean frontal retreats between 50 and 9 m yr^{-1}, thinning rates between 0.76 and 0.56 m yr^{-1}, and a mean ice area reduction of 3% since 1955. On the other hand, an extensive review of glacier fluctuations during the past millennia in the extratropical Andes of South America (17° to 55°S), confirmed that most areas have experienced a general pattern of glacier recession and significant ice mass losses (Masiokas et al., 2009).

In Southern Chile, Casassa et al. (1997) analyzed the O'Higgins Glacier in Patagonia, presenting a century-long recession record. The variations of Patagonian glaciers have also been analyzed by Aniya et al. (1999) and Casassa et al. (2000), observing shrinkages in most of them. However, the largest glacier of the Southern Patagonia Icefield (Pío XI) was analyzed for the period 1945–1995, showing a net advance of 10 km, a unique behavior considering that virtually all neighboring glaciers were retreating (Rivera and Casassa, 1999). The same situation was observed by Rivera et al. (2012) in Jorge Montt glacier, who concluded that tidewater calving glaciers can experience large fluctuations, not necessarily in direct response to climatic factors such as temperature. Thus, in some areas of Southern Chile, decreased precipitation has also contributed to glacier regression (Carrasco et al., 2008).

On the other hand, it is important to add that rising temperatures noted throughout the Andes are producing an increase in the ZDI altitude, which in turn can result in strong glacier recession, as well as a reduction in seasonal snow cover at higher elevations. In the tropical Andes (5°N to 25°S), an increase of the freezing isotherm (ZDI) elevation of about 25 m per decade has been detected since the 1980s (Vuille et al., 2003). In the Andes of Central Chile (from latitudes 29° to 38° South) ZDI elevation has increased on average 23 m per decade for the period between 1958 and 2006 (Carrasco et al., 2005, 2008). These conclusions can be validated with the information presented in Table 14 that shows mainly negative trends, calculated using the Spearman (Haan, 1977) and Mann–Kendall annual tests (Kendall, 1938; Mann, 1945; Kendall, 1975) for snow stations (snow water equivalent) distributed in the temperate zone of Chile (29°20′ to 38°30′). In this analysis only 15% of the stations showed significant statistical differences.

Finally, it should be mentioned that glaciers have been recognized as an important contributing factor to summer runoff for many of the rivers located in Central Chile, between 33°S and 36°S (the most inhabited part of the country). However, most national and international studies on the topic have reported a shrinkage situation of the glaciers, and the increasing of altitude of the ZDI and snowline in these areas. Casassa et al. (2007) indicated that this critical point has already been reached in many small Andean glaciers with surface areas of less than 1 km^2, and larger glaciers are expected to be affected during the coming decades. Therefore, the glacier contribution to water availability could be also highly affected in the coming years.

8.3. Temporal and spatial variability of streamflows

Fuenzalida et al. (1989) theorized that a 500-meter increase of the snowline elevation in Central Chile as a result of warming the area by 3 °C could affect the patterns of the main rivers located in this area. The author also concluded that such change could result in 50% more rainfall, replacing what before fell as snow. Similarly, DGA (1999b) stated that, due to increases of temperatures and decreases of precipitation, less water is expected to be available in Chile if the planet continues to warm up, phenomena much more accentuated in regions located between Near North and Central Chile. Recently, an increase of the ZDI elevation have been reported by Casassa et al. (2003) and Carrasco et al. (2005, 2008), and it has been associated to both increased and decreased streamflow as a result of changing glacial contributions, depending on the season (Pizarro et al. (2013b) (Fig. 15). In the same context, Pizarro et al. (2013c) compared annual maximum flows for a 30-year return period, observing that streamflow decreased by an average of 19.5% in the stations located under semi-arid climates (29°S to 32°S), and increased by an average of 22.6% in the stations located in temperate zones (36°S to 38°′S). The Mann–Kendall test was also used to investigate the temporal changes in streamflows observing negative trends at 87% of the analyzed stations, located in semi-arid zones, whereas positive trends were observed in 57% of the stations located in temperate zones. Statistical differences were observed in almost 20% of the stations analyzed, for each case. Conversely, Rubio-Álvarez and McPhee (2010) found significant decreasing trends in 44 rivers, affecting the regions located in Southern Chile between 37.5°S and 40°S in the period 1952–2003, and Cortés et al. (2011) compiled a database of 40 unimpaired average monthly streamflow records from Central and Southern Chile (30°S to 40°S), for the period 1961–2006. Their results showed a significant (95% confidence level) negative trend for 23 out of the 40 analyzed series.

On the other hand, Fuenzalida et al. (1989) theorized that streams in the arid and semiarid Northern regions could suffer an increase in streamflow during winter and spring seasons, and a decrease in summer and autumn seasons, with an increment in temperature and associated acceleration of snowmelt. In relation to this, Fiebig-Wittmaack et al. (2012) indicated that the analysis for semiarid zones for winter flows suggested that

Table 14
Snow water equivalent trends in temperate zone of Chile (29°20′S to 38°30′S).

Administrative region	Basin	Station/location	UTM East	UTM North	Altitude	Time series	n	Spearman trend	Spearman Slope	R^2	Mann–Kendall trend	Test Z	Statistical significancy (α)	Sen's slope estímate
Coquimbo	Elqui River	Cerro Olivares	408599	6653081	3550	1974–1977/1979–2001/2003–2004/2006–2007/2010–2011	33	Negative	−1.34	0.01140	Negative	−0.67	n/s	−0.57
Coquimbo	Limari River	Cerro Vega Negra – DCP	355069	6578597	3600	1972–1999/2002–2005/2010–2011	34	Negative	−3.02	0.00840	Negative	−0.42	n/s	−1.94
Coquimbo	Limari River	Quebrada Larga	369133	6600950	3500	1956–1969/1972–2001/2003–2004/2006–2011	52	Positive	0.11	0.00008	Positive	−0.11	n/s	−0.08
Coquimbo	Choapa River	El Soldado – DCP	374049	6458734	3200	1969/1977/1979–2000/2003/2006–2007/2010–2011	29	Negative	−296	000870	Negative	−054	n/s	−200
Valparaíso	Aconcagua River	Portillo – DCP	395482	6366581	3000	1951–1979/1982–1997/1999–2011	58	Positive	1.35	0.00430	Positive	0.74	n/s	1.62
Metropolitana	Maipo River	Laguna Negra – DCP	394924	6274168	2768	1965–2007/2009–2011	46	Negative	−1.09	0.00160	Negative	−0.26	n/s	−0.85
Metropolitana	Maipo River	Barros Negros	382133	6309137	3380	1965–2000/2002–2007/2009–2011	45	Positive	2.08	0.00840	Positive	0.80	n/s	2.63
O'Higgins	Rapel River	Chapa Verde	369239	6231336	2370	1987–1997/1999–2003/2005/2010	18	Negative	−7.23	0.06220	Negative	−1.21	n/s	−6.85
Maule	Mataquito River	La Dormida	340488	6114404	1800	1983–2000/2003–2006/2009–2011	25	Negative	−12.19	0.06830	Negative	−0.91	n/s	−7.99
Maule	Maule River	Lo Aguirre – DCP	358788	6014852	2000	1953–2011	59	Negative	−6.34	0.06150	Negative	−1.94	0.1	−5.90
Biobío	Itata River	Cerro La Gloria	288298	5946825	1500	1969–1999/2002–2007/2009–2010	39	Negative	−3.84	0.01510	Negative	−0.71	n/s	−4.09
Biobío	Biobío River	Alto Mallines – DCP	300827	5889766	1720	1967–1969/1975–1985/2000/2004–2011	23	Negative	−3.34	0.01840	Negative	−0.58	n/s	−4.04
Biobío	Biobío River	Volcán Chillan	284525	5918974	1923	1966–2000/2002–2007/2009–2011	44	Negative	−9.39	0.09870	Negative	−2.21	0.05	−10.26

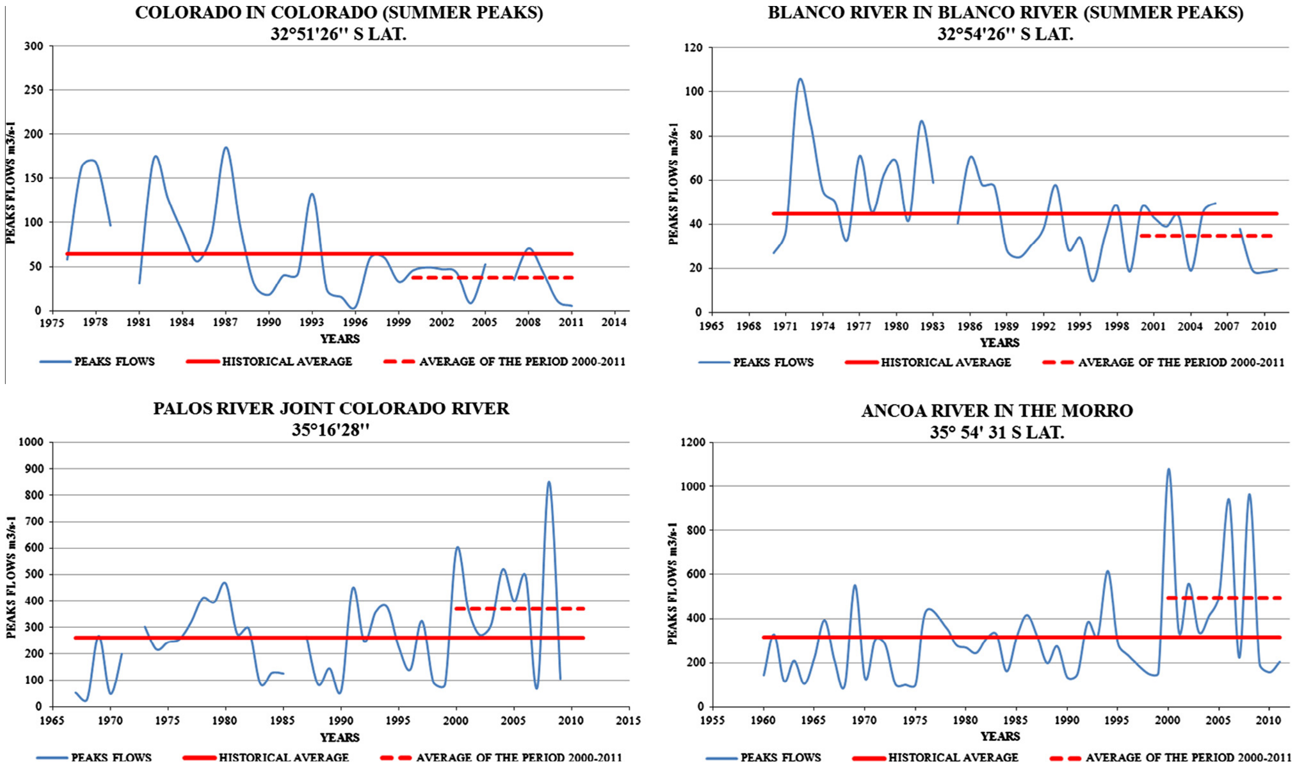

Fig. 15. Recent peak flow behavior in first order streams of temperate zones of Chile between 32°S and 36°S.

a decreasing trend is not evident for this season, despite the fact that a 0 °C isotherm trend could result in changes in the ice and snow regime, generating a shorter melting season with less runoff in spring and summer seasons. Moreover, the trend is analogous to the total annual river runoff time series. Fuenzalida et al. (1989) also indicated that preliminary modeling of snowmelt conditions using the predicted 3 °C increase in mean annual temperature, suggests that summer streamflow could decrease by up to 20%, depleting the irrigation capacity of rivers for agriculture, requiring new infrastructure for seasonal regulation. This becomes a critical point between 29°S and 30°S (Elqui River Basin), where most of the streamflow comes from snowmelt on the high Andean Mountains (Favier et al., 2009). A similar situation can be observed in the Maipo River, which supplies Santiago's municipal water, where up to 67% of its volume is generated by ice melt-water from glaciers during summers (Peña and Nazarala, 1987). In Fig. 16 is possible to observe the trends calculated on 27 stations using the Mann–Kendall with the Sen's slope test.

These changes on streamflow volumes and seasonality will accordingly require the retrofitting of existing infrastructure and the construction of new ones, to protect inhabited forested, and agricultural areas, as well as many other water-dependent activities, mainly because the uncertainty generated by future scenarios of climate change and water availability, and also because an important portion of the Chilean economic growth is dependent on these activities. In this context, Vicuña et al. (2012) noted that these changes would affect the availability of freshwater in North-Central Chile, causing serious implications on the already precarious biological productivity of semiarid ecosystems. It is also expected that a decrease in annual precipitation will result in less streamflow volumes, altering the form of the hydrographs of semi-arid streams (Stewart et al., 2005). These results are consistent with other studies done in regions where streamflow regimes are dominated by snow and glacial melt during summers (e.g. Barnett et al., 2005; Vicuña and Dracup, 2007; Pellicciotti et al., 2007; Vicuña et al., 2010).

8.4. Temporal and spatial groundwater variability

Currently there is no available scientific information on the influence of climate change in Chile's groundwater availability. However, the major problem is the increasing demand for the resource, especially in the North-Central portion of the country. There is some evidence of marine intrusion on Northern coastal aquifers, contaminating them with salt water. Besides, future scenarios of decreasing precipitation and glacial retreat are one of the major concerns, since they are both associated with natural aquifer recharge, which in addition to increasing pumping rates, could extinct groundwater availability in the near future. As illustrated in Fig. 17, it is possible to observe negative tendencies over time as a result of excess pumping rates, in most of the aquifers located in North-Central Chile.

9. Critical analysis of water governance

Water resources consumption increases with limited supply augmentation can produce several conflicts/problems within multipurpose watersheds: (1) it limits compatibility among different water uses (Parra et al., 2009), and (2) it alters the integrity of the ecosystem that lets water production and water consumption to take place (Tuvendal and Elmqvist, 2011). In this context, Dourojeanni and Jouravlev (2001) proposed that water management must be intended to achieve the harmonization of the different users' interests, so that they affect each other as little as possible, without harming the environment. Currently, the water management system in Chile (SGACH) is under transition, from a use-based to a watershed-based management system (Retamal et al., 2013). To accomplish this objective, it is necessary to see a

Map Number	Time series	Period	n	Missed Data (%)
1	Lluta en Panamericana	1985-2011	27	0.00
2	San Jose Auspiciar	1990-2011	22	0.00
3	Salado Sifon Ayquina	1975-2011	35	5.41
4	Loa en Finca	1971-2011	40	2.44
5	Copiapo en la Puerta	1947-2011	61	6.15
6	Huasco en Algodones	1975-2011	32	13.51
7	Elqui en Algarrobal	1948-2011	64	0.00
8	Grande en Ramadas	1961-2011	50	1.96
9	Choapa en Cuncumen	1966-2011	46	0.00
10	Aconcagua en Chacabuquito	1937-2011	75	0.00
11	Maipo en el Manzano	1946-2011	66	0.00
12	Mapocho en los Almendros	1948-2011	62	3.13
13	Cachapoal 5km	1989-2011	22	4.35
14	Tinguiririca bajo Briones	1937-2011	66	12.00
15	Teno d/j Claro	1948-2011	64	0.00
16	Mataquito en Licanten	1987-2011	25	0.00
17	Maule en Longitudinal	1962-2011	49	2.00
18	Itata en Gral. Cruz	1956-2011	56	0.00
19	Biobio en Rucalhue	1937-2011	72	4.00
20	Cautin en Cajon	1952-2011	60	0.00
21	Tolten en Teodoro Schmidt	1991-2011	21	0.00
22	Calle-Calle en San Javier	1987-2011	21	16.00
23	Pilmaiquen en San Pablo	1978-2011	34	0.00
24	Simpson en Junta Coyhaique	1985-2011	26	3.70
25	Aysen en Pto Aysen	1996-2011	16	0.00
26	Serrano en Desembocadra	1995-2011	17	0.00
27	San Juan en Desembocadura	1970-2011	36	14.29

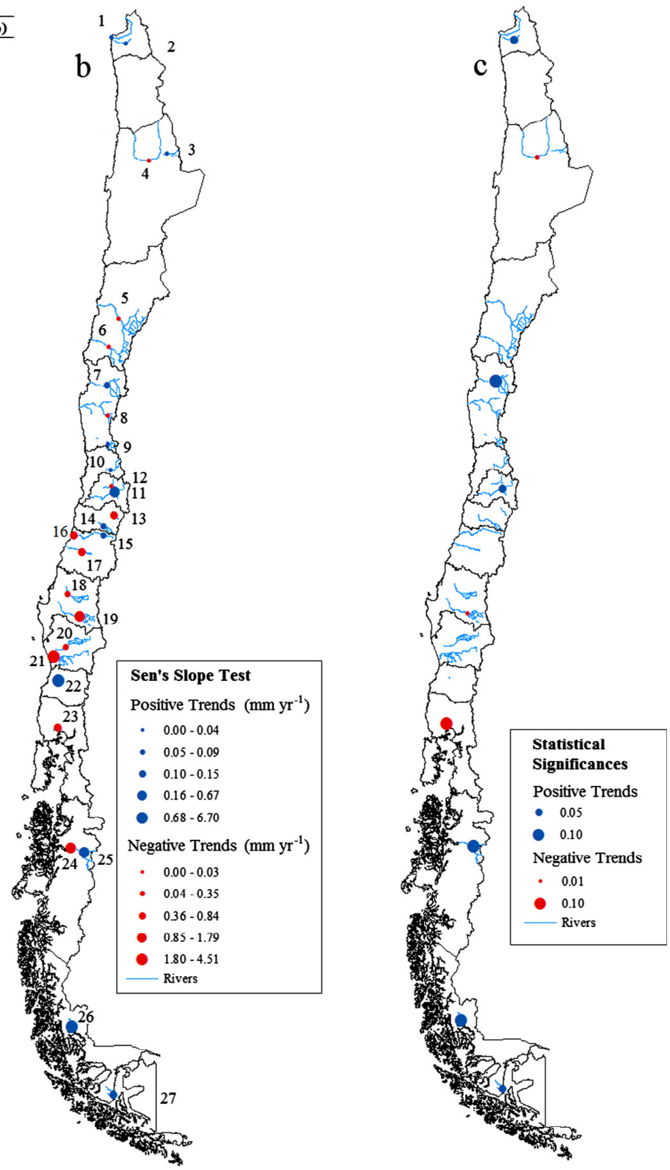

Fig. 16. (a) Percentage of missed data per station. (b) Mann–Kendall results obtained by using the Sen's Slope Test. (c) Statistical Significances.

water governance from different social perspectives, which are described in the following sections.

9.1. Research, Development, and Innovation

Water Resources knowledge in Chile has become a matter of importance, mainly because the availability of the resource and short- and long-term projections. Even so, despite the presence of important funding sources for universities and Government institutions (e.g. FONDECYT, FONDEF, CORFO, and INNOVA), the percentage of research focused on water resources is still low compared to agricultural research, for example. In fact, there is no R&D focused directly on water, even though there is a clear evidence of climate change and its effects on water resources, as well as an increasing demand for water within the country. This justifies the creation of R&D programs focused exclusively on water resources.

9.2. Institutional aspects

The laws that regulate the use and management of water resources, especially those focused on water rights are handled by the *Water Code*, recognize water as a public good and coordinate the institutions that regulate the resource. However, the growing demand for water has been intensified by the changes already affecting water supply as a consequence of climate change, leading to a period of increasing uncertainty. Moreover, water-related institutions in the country are highly fragmented, resulting in coordination and funding problems. Hence, the need arises to have a unified and centralized institution, with a wider view than DGA, DOH, and SISS, and with more authority and more resources, in order to enforce water-related regulations, the establishment of operational standards, and joint actions with water users. Currently, this is limited by the provisions of the Water Code, which allowed the monopolization of water resources, and should be extensively revised to allow such institutional mechanisms and water governance instruments.

9.3. The economic aspects of water rights

In general terms, Chile has a very efficient water market with several industries using water resources as a central component of their development activities. Furthermore, recent investments

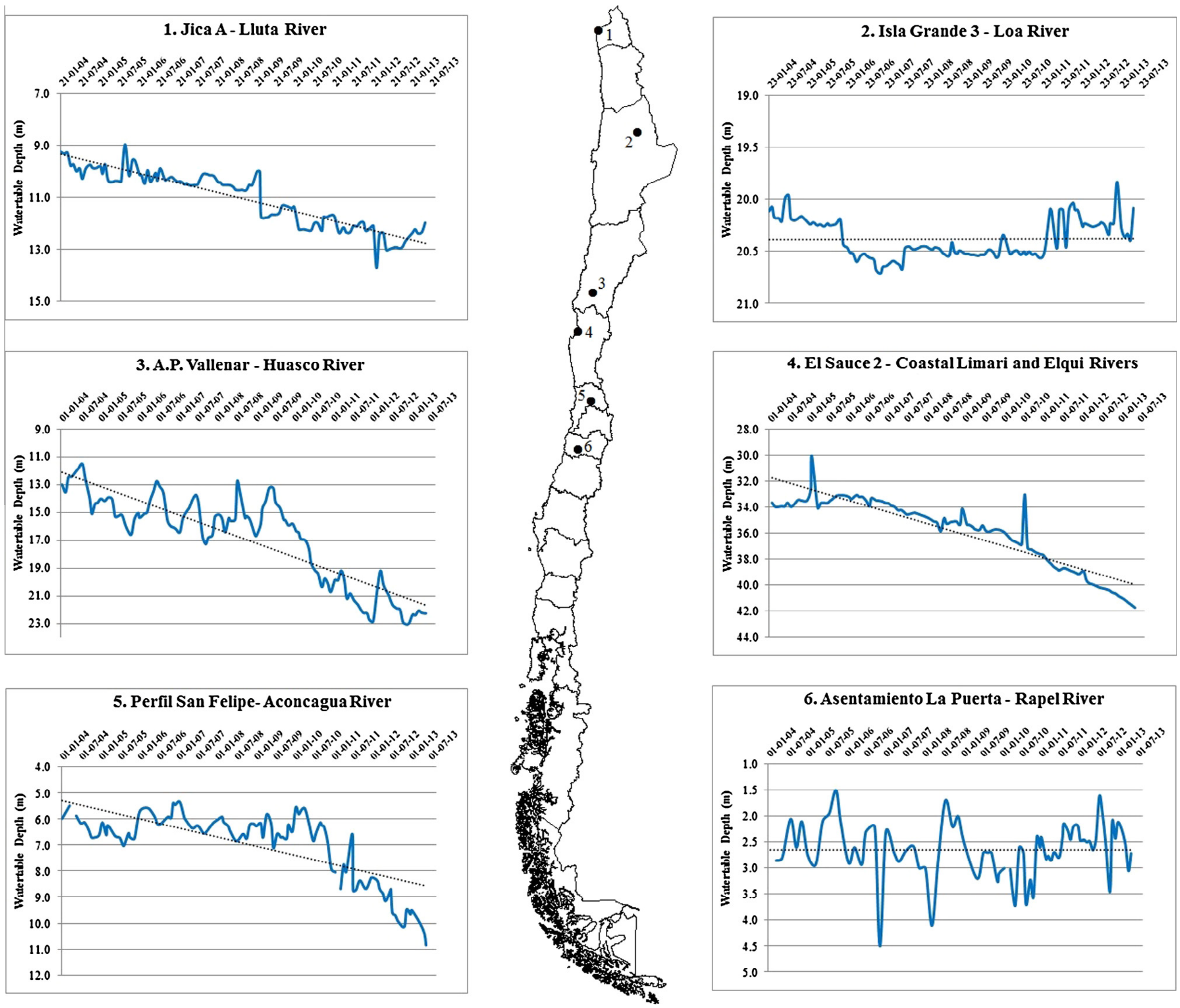

Fig. 17. Linear trends of water tables (m) along Chile.

made by private entities to recover non-productive industries for the development of diverse economic activities have changed the market system positively, not only for the water market itself, but also for other industry markets, such as agriculture, mining and forestry. Thus, the economic development has enabled the efficient use of water and it has contributed to significant economic growth in these sectors.

Currently the system is not capable of allocating or prioritizing different water uses, leading to conflicts between the private industries and local communities. This also leads to a situation where water rights are purchased for speculative purposes, i.e. to ensure the future use of water. Consequently, it arises as a legal necessity to avoid distortions that the market exerts on the resource allocation, specifically when water supply is extremely limited, as the market tends to favor those who have more resources to obtain additional water rights. In summary, the Government should have the most powerful tools to play the role of regulator, and to implement actions for the efficient use of water, as the market fails to meet its goals in times of low supply.

It can be also observed that the current water right allocation system may be inefficient and inequitable from a social and environmental perspective, in which those individuals or entities with more money tend to get such rights. A relevant example of this is the mining industry in the arid and semiarid zones of Northern Chile, which is constantly exerting pressure to buy water rights due to the large quantities of water needed in the extraction and processing of minerals. In fact, such industry has purchased up to US$100,000 for water rights corresponding to 1 l/s, meaning that many holders are willing to sell their water rights.

9.4. Environmental aspects

The increasing pressure over the use of water affects directly ecological flows, creating an argument around which activity is causing the greatest proportion of the problem. Hydropower dams, for example, often decrease river flows, producing important ecological and social problems downstream.

The *Sewage Treatment Plants* (PTAS), that serve almost 95% of the country's urban population, have been tremendously beneficial to water quality. However, there are still many industries that dispose wastewater directly into streams, requiring a stricter enforcement of regulations by authorities. Furthermore, a major problem associated with the implementation of the PTAS is the disposal of sludge, which currently has neither use nor solution outside of disposal on landfills, causing problems due to the lack of storage capacity. The use of such residual material as a fertilizer on forest plantations has tremendous potentials in Chile, though it has only been applied in isolated cases.

UNEP (2006) has indicated that the main problems of pollution to be addressed in Chile are: (1) *Pollution from domestic sewage,* due to the discharge of large quantities of untreated sewage at specific points of water resource systems, or along the coastline. (2) *Pollution from mining effluents and liquid industrial wastes (tailings)*, existing major mining operations, mainly in North and Central Chile, which generate major pollution. The treatment and disposal of mining residues continue to concern authorities in those regions. Over 60% of industrial discharges flow into sewerage networks, where it mixes with domestic sewage, and is deposited in rivers through water systems and irrigation channels, or is discharged into the soil, or directly into the sea. (3) *Pollution from farming diffused into underground water*, as a result of soil salinization associated with farming irrigation and the increase of nitrates in groundwater caused by irrigation with sewage, as well as nitrates from the use of fertilizers in agriculture.

9.5. Climate change

As exposed in Section 8, several studies have analyzed the past and current situation of water resources in Chile, and some differences have been found in terms of their results. Despite this, it is clear that future scenarios have a high hydrological uncertainty, which is much more pronounced when considering the influence of climate change; in this context, future scenarios are not auspicious from a water availability perspective; subsequently, it is necessary to increase the capacity of sustainable water resources management, in order to appropriately mitigate potential impacts of climate change in Chile.

9.6. Final comments

Chile has a good water management system, which can be improved with a better articulation and coordination among Government institutions, as well as better policies and more research. Moreover, and considering the geography of the country, the Government is giving more relevance to water resources management, though conflicts are advancing faster than solutions. Governance models applied to current uses indicate that water resources management is reaching its limits and, therefore, some actions could be implemented to help avoid future water governance problems are:

(1) To create a Water Resources Undersecretary with the objective to give more relevance to water management in the Government.
(2) To create policies to encourage the Integrated Water Resources Management (IWRM) based on watershed management, to ensure the availability and quality of surface and underground water. To do so, it is important to encourage watershed management plans, i.e. the management of a watershed based on its water availability.
(3) To emphasize Water Use Organizations (WUO), that includes irrigation groups, water communities, and channel associations, i.e. all those that have the right to use water within a watershed or aquifer, and that are responsible for the administration of natural and artificial watercourses. In this context, the Government needs policies to favor the creation, registration, and strength of WUOs, to develop a better water management system in the country.
(4) To improve water use efficiency through private investment incentives toward irrigation technologies. It is also important to improve irrigation-related infrastructure to improve the quantity and quality of the resource, as well as a more efficient management of water, such as aqueducts, channels, aquifer recharge, desalinization, cloud seeding, reservoirs, dams, and quality control systems. Also, illegal extraction of water must be minimized. All of this must be done on a watershed scale and considering local impacts of climate change and future demands.
(5) To define new legal instruments to reach quality goals and decontamination plans to avoid the degradation of water bodies. For instance, a detailed evaluation of the quantity and quality of water bodies is a must, situation far from the current reality.
(6) To improve the quantity and quality of instrumentation throughout the country, for a better understanding of surface and underground water resources, their uses and legal implications in terms of water rights, for a proper management and adequate politics and decision-making.
(7) To increase funding sources for water-related research, infrastructure, and administration projects.
(8) To promote a water-conservation-oriented culture, using communitary campaigns, school programs, and events in general, among others.

Despite the above, a clear problem in Chile is the fact that there is abundance of water in the sparsely populated South, and not enough in the densely populated Central region and the North. For instance, the Government is currently analyzing several options to transfer water from the South. Among the most relevant ideas are the submarine aqueduct, the subterranean aqueduct, and through aquifers. Each solution has its own advantages and limitations, and each one offers different costs, life expectancy, and flow rates. For example, while the creation of a combined system seems to be the best alternative, a logical fact is that Chile will be exporting water from the South in a few decades, eliminating significantly the adverse effects of global warming and droughts. In this context, the success or failure about the future of water governance in Chile will directly depend on the interaction between different national institutions, and how they resolve competition and conflicts across different scales of governance, i.e. spatial, temporal, institutional, jurisdictional, management and knowledge; and also across various levels of interaction, i.e. national, regional or local. The design of precise boundaries for water resources management and co-management structures including knowledge, production, mediation, and negotiation across the scales and levels of management is fundamental to solve current and future complex problems associated to water resources governance.

References

Aceituno, P., Fuenzalida, H., Rosenbluth, B., 1992. In: Mooney, H.A., Kronberg, B., Fuentes, E.R. (Eds.), Climate Along the Extratropical West Coast of South America: Earth Systems Responses to Global Change. Academic Press, pp. 61–69.
Aceituno, P., Garreaud, R., 1995. Impacto de los fenómenos el Niño y la Niña en el régimen pluviométrico Andino. Revista Chilena de Ingeniería Hidráulica 9, 12–20.
Albers, C., 2012. Coberturas SIG para la enseñanza de la Geografía en Chile. Universidad de La Frontera. Temuco. <www.rulamahue.cl/mapoteca> (accessed June 2013).
Aniya, M., Sato, H., Naruse, R., Skvarca, P., Casassa, G., 1996. The use of satellite and airborne imagery to inventory outlet glaciers of the Southern Patagonian Icefield, South America. Photogramm. Eng. Remote Sens. 62, 1361–1369.
Aniya, M., Naruse, R., Casassa, G., Rivera, A., 1999. Variations of Patagonian glaciers, South America, utilizing RADARSAT images. In: Proceedings of the International Symposium on RADARSAT Application Development and Research Opportunity (ADRO), Montreal, Canada, October 13–15.
Arumí Ribera, J.L., Oyarzún Lucero, R.A., 2006. Las aguas subterráneas en Chile. Boletín Geológico y Minero 117 (1), 37–45, ISSN: 0366-0176.
Ayala, L., 2010. Aspectos técnicos de la gestión integrada de las aguas (GIRH) – Primera etapa diagnóstico. Informe preparado para el diagnóstico de la gestión de los recursos hídricos. Santiago, Chile.
Barcaza, G., 2011. Inventario y Monitoreo de Glaciares en Chile. Presentación Power Point. Taller Derretimiento de Nieves y Glaciares: Ciencia, Tecnología y Políticas

para Enfrentar los Desafíos de la Región Andina en un Contexto de Cambio Climático. Santiago, Chile, 13-15 de Septiembre de 2011. <http://www.dgf.uchile.cl/rene/ACCION/Tuesday/barcaza.pdf> (accessed July 2013).

Barnett, T.P., Adam, J.C., Lettenmaier, D.P., 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 438, 303–309.

Barrientos, E., 2007. Impacto de la Reforma al Código de Aguas en la constitución originaria de derechos de aprovechamiento de aguas, en la Región de Los Lagos y Región de Los Ríos. Universidad Austral de Chile. Facultad de Ciencias Jurídicas y Sociales. Escuela de Derecho. Tesis, 41 pp. <http://cybertesis.uach.cl/tesis/uach/2007/fjb275i/doc/fjb275i.pdf> (accessed June 2013).

Bauer, C., 2002. Contra la corriente. Privatización, mercados de agua y el Estado en Chile, Lom Ediciones, Santiago.

Bauer, C., 2004. Results of Chilean water markets: Empirical research since 1990. Water Resour. Res. 40, W09S06. http://dx.doi.org/10.1029/2003WR002838.

Bown, F., Rivera, A., Acuña, C., 2008. Recent glaciers variations at the Aconcagua basin, central Chilean Andes. Ann. Glaciol. 48, 43–48.

Bradley, R.S., Vuille, M., Díaz, H.F., Vergara, W., 2006. Threats to water supplies in the tropical Andes. Science 312, 1755–1756.

Brenning, A., Trombotto, D., 2006. Logistic regression modelling of rock glacier and glacier distribution: topographic and climatic controls in the semi-arid Andes. Geomorphology 81, 141–154.

Brown, E., Saldivia, J., 2000. Informe Nacional sobre la gestión del Agua en Chile. Comité Asesor Tecnico de America del Sur (SAMTAC). Global Water Partnership (GWP). <http://www.eclac.org/samtac/noticias/documentosdetrabajo/8/23338/InCh01100.pdf> (accessed July 2013).

Carrasco, J., Casassa, G., Quintana, J., 2005. Changes of the 0°C isotherm in central Chile during the last quarter of the XXth Century. Hydrol. Sci. J. 50 (6), 933–948.

Carrasco, J., 2006. Precipitation events in Central Chile and its relation with the MJO. In: Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24–28, 2006, INPE, pp. 1719–1722.

Carrasco, J., Osorio, R., Casassa, G., 2008. Secular trend of the equilibrium line altitude in the western side of the southern Andes derived from radios on de and surface observations. J. Glaciol. 54 (186), 538–550.

Casassa, G., Brecher, H., Rivera, A., Aniya, M., 1997. A century-long recession record of glacier O'Higgins, Chilean Patagonia. Ann. Glaciol. 24, 106–110.

Casassa, G., Rivera, A., Carrasco, J., 2000. Glacier variations in the Southern Patagonia Icefield and their Relation with Climate. In: Sixth International Conference on Southern Hemisphere Meteorology and Oceanography, pp. 312–313.

Casassa, G., Smith, K., Rivera, A., Araos, J., Schneider, C., Schnirch, M., 2002. Inventory of glaciers in isla Riesco, Patagonia, Chile, based on aerial photography and satellite imagery. Ann. Glaciol. 34, 373–378.

Casassa, G., Rivera, A., Escobar, F., Acuña, C., Carrasco, J., Quintana, J., 2003. Snow line rise in central Chile in recent decades and its correlation with climate. EGS – AGU – EUG Joint Assembly, Abstracts from the meeting held in Nice, France, 6–11 April 2003, abstract #14395.

Casassa, G., Haeberli, W., Jones, G., Kaser, G., Ribstein, P., Rivera, A., Schneider, C., 2007. Current status of Andean glaciers. Global Planet. Change. http://dx.doi.org/10.1016/j.gloplacha.2006.11.013.

Caviedes, J., 1979. Inventario de Glaciares en la Hoya del río Cachapoal y Predicción de la Escorrentía del Deshielo. Universidad de Chile, Departamento de Geología, Andes Centrales.

Central Bank of Chile, 2006. Producto interno bruto regional 2003-2006, base 2006. Banco Central de Chile. Santiago, Chile. <http://www.bcentral.cl/publicaciones/estadisticas/actividad-economica-gasto/aeg07.htm> (accessed June 2013).

Central Bank of Chile, 2010. Síntesis de estadística de Chile 2005-2009. Banco Central de Chile. Santiago, Chile. <http://www.bcentral.cl/publicaciones/estadisticas/informacion-integrada/iei05.htm> (accessed June 2013).

Cereceda, P., Errázuriz, A.M., 2010. Atlas geográfico de Chile y el mundo. Vicens Vives Ediciones.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, R.T., Laprise, R., Magaña, V., Mearns, C.G., Menendez, C.G., Raisanen, J., Rinde, A., Sarr, A., Whetton, P., 2007. Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.

Comisión Nacional de Energía (CNE), 2009. Las Energías Renovables no convencionales en el Mercado Eléctrico Chileno. Santiago, Chile, 124 pp. <http://www.giz.de/de/downloads/sp-ERNC-mercado-electrico-chileno.pdf> (accessed July 2013).

Comisión Nacional del Medio Ambiente (CONAMA), 2006. National Environment Commission of Chile. Project: Climatic Variability study for 21th century in Chile. Geophysics department. Physics and Mathematics Sciences Faculty. University of Chile. <http://www.sinia.cl/1292/articles-50188_recurso_8.pdf> (accessed July 2013).

Comisión Nacional del Medio Ambiente (CONAMA), 2007. Estrategia nacional de gestión integrada de cuencas hidrográficas. Santiago, Chile.

Contreras, M., 2010. Calidad de aguas y contaminación: etapa diagnóstico. Informe preparado para el diagnóstico de la gestión de los recursos hídricos. Santiago, Chile.

Comisión Nacional de Riego (CNR), 2011. Política Nacional de Riego, una Mirada a largo plazo. Power Point Presentation. <http://aquasec.org/wp-content/uploads/2012/03/02_seminario-seguridad-h%C3%ADdrica.pdf> (accessed July 2013).

Cornejo, C.G., 2011. Análisis de la distribución temporal de las precipitaciones en la Región del Maule. Tesis Ing. Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 166 p. Available at: http://eias.utalca.cl/Docs/pdf/Publicaciones/tesis_de_grado/MEMORIA%20CARMEN%20GLORIA%20CORNEJO%20SALDIAS.pdf (accessed Aug 2013).

Cortés, G., Vargas, X., McPhee, J., 2011. Climatic sensitivity of streamflow timing in the extratropical western Andes Cordillera. J. Hydrol. 405 (1-2), 93–109, doi: http://dx.doi.org/10.1016/j.jhydrol.2011.05.013 (Accessed July 2013).

Cristi, O., Trapp, A., 2003. Mercado de Agua para Irrigación y Uso Urbano: una Aplicación a la Cuenca del Río Elqui, Chile. World Bank-Netherlands Water Partnership Program (BNWPP), Water Rights System Window, July 2003.

Debels, P., Figueroa, R., Urrutia, R., Barra, R., Niell, X., 2005. Evaluation of Water Quality in the Chillan River (Central Chile) using physicochemical parameter and a modified Water Quality Index. Environ. Monit. Assess. 110, 301–322. http://dx.doi.org/10.1007/s10661-005-8064-1.

Diaz, H.F., Markgraf, V., 1992. El Niño Historical and Paleoclimatic Aspects of the Southern Oscillation. Cambridge University Press, pp. 1–4.

Dirección de Obras Hidráulicas (DOH), 2010. Balance de Gestión Integral Año 2010. Santiago de Chile.

Dirección General de Aguas (DGA). 1986., Mapa Hidrogeológico de Chile. Escala 1: 2.500.000. Texto Explicativo. Contribución del Comité Chileno para el Programa Hidrológico Internacional, al Mapa Hidrogeológico de América del Sur. Santiago, Chile. <http://bibliotecadigital.ciren.cl/gsdlexterna/collect/bdestudi/index/assoc/HASH6700.dir/DGA054.pdf> (accessed July 2013).

Dirección General de Aguas (DGA), 1987. Balance Hídrico de Chile, Santiago de Chile, Ministerio de Obras Públicas, Dirección General de Aguas, 24 pp.

Dirección General de Aguas (DGA), 1996. Mapa Hidroquímico Nacional. Dirección General de Aguas, Ministerio de Obras Públicas. Santiago, Chile.

Dirección General de Aguas (DGA), 1999a. Organización y funciones M.O.P. Ministerio de Obras Públicas. Santiago de Chile.

Dirección General de Aguas (DGA), 1999b. Política Nacional de Recursos Hídricos. <http://www.bvsde.paho.org/bvsarg/e/fulltext/chile2/chile2.pdf>.

Dirección General de Aguas (DGA), 2003. Evaluación Recursos Hídricos Subterráneos de la VI Región. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 160. Santiago, Noviembre, 2003. <http://www.agrosuper.cl/estudios/rapel/Evaluacion-de-los-recursos-hidricos-subterraneos-de-la-VI-region-Santiago-2003.pdf> (accessed July 2013).

Dirección General de Aguas (DGA), 2004a. Diagnóstico y Clasificación de cursos y cuerpos de agua según Objetivos de Calidad. Informe Final. Realized by Cade-Idepe. <http://documentos.dga.cl/CQA4432v1.pdf> (accessed July 2013).

Dirección General de Aguas (DGA), 2004b. Evaluación Recursos Hídricos Subterráneos de la Cuenca del Rio Aconcagua. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 182. Santiago, Septiembre, 2004. <http://documentos.dga.cl/SUB4201.pdf> (accessed July 2013).

Dirección General de Aguas (DGA), 2007. Evaluación Recursos Hídricos Subterráneos de la Cuenca del Choapa. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 248. Santiago, Agosto, 2007. <http://documentos.dga.cl/SUB4843.pdf> (accessed July 2013).

Dirección General de Aguas (DGA), 2008a. Balance glaciológico e hídrico del glaciar Nef, Campo de Hielo Norte, y catastro de glaciares de algunas cuencas de la zona central y sur del país. Serie de Informes Técnicos 166 (1s–2).

Dirección General de Aguas (DGA), 2008b. Manual de normas y procedimientos para la administración de recursos hídricos. Serie de Informes Técnicos (SIT) N° 156. DGA, Santiago de Chile.

Dirección General de Aguas (DGA), 2008c. Evaluación Recursos Hídricos Subterráneos de la Cuenca del Rio Limari. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 268. Santiago, Diciembre, 2008. <http://documentos.dga.cl/SUB5027.pdf> (accessed June 2013).

Dirección General de Aguas (DGA)., 2009a. Estrategia Nacional de Glaciares. Fundamentos. Realizado por Centro de Estudios Científicos (CECS). S.I.T. No 205.

Dirección General de Aguas (DGA), 2009b. Evaluación Recursos Hídricos Subterráneos de la Quebrada Carrizal. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 272. Santiago, Mayo, 2009. <http://documentos.dga.cl/SUB5149.pdf> (accessed June 2013).

Dirección General de Aguas (DGA), 2009c. Diagnóstico y clasificación de sectores de acuíferos, 43p. <http://documentos.dga.cl/CQA5168v3.pdf> (Accessed Jul 2013).

Dirección General de Aguas (DGA), 2010a. Estimación de recargas de aguas subterráneas en cuencas de las Regiones VII, VIII, IX, XIV y X. DGA, Gobierno de Chile.

Dirección General de Aguas (DGA), 2010b. Mejoramiento y Ampliación de Red de Aguas Subterráneas, Regiones VII a X. Informe Final. S.I.T. N° 223. Santiago, Diciembre 2010. <http://documentos.dga.cl/FLU5240v1.pdf> (accessed August 2013).

Dirección General de Aguas (DGA), 2011a. Balance de Gestión Integral Año 2011. Santiago de Chile. <http://www.dga.cl/acercadeladga/informesgestion/Documents/BGI_2011_DGA.pdf> (accessed September 2012).

Dirección General de Aguas (DGA), 2011b. Evaluación Recursos Hídricos Subterráneos en el Sector Acuífero de La Concordia. Informe Técnico. Departamento de Administración y Recursos Hídricos. SDT No 314. Santiago, Mayo, 2011. <http://www.bienesnacionales.cl/wp-content/uploads/2012/04/Evaluacion-de-los-recursos-hidricos-subterraneos-en-el-sector-acuifero-de-la-Concordia.pdf> (accessed June 2013).

Dirección General de Aguas (DGA), 2012a. Red Hidrométrica Nacional. Santiago de Chile.

Dirección General de Aguas (DGA), 2012b. Balance de Gestión Integral Año 2012. <http://www.mop.cl/acercadelmop/BalancesdeGestionIntegral/Documents/2012/BGI%202012%20DGA%20Version%20Congreso.pdf> (accessed September 2013).

Dirección General de Aguas (DGA), 2013. Información Pluviométrica, Fluviométrica, Estado de Embalses y Aguas Subterráneas. Boletín No 422. *On Line*. <http://www.dga.cl/productosyservicios/informacionhidrologica/Paginas/default.aspx> (accessed July 2013).

Domper, M., 2009. Chile: A Dynamic Water Market. Libertad y Desarrollo. http://www.policynetwork.net/sites/default/files/Chile_March09.pdf (accessed June 2013).

Donoso, G., 2008. Water use rights markets and water allocation: the Chilean case. Expo Zaragoza 2008. Thematic Week: Water Economics and Financing. Thematic Axis: Water Markets. <http://www.zaragoza.es/contenidos/medioambiente/cajaAzul/24S7-P3-Guillermo%20DonosoACC.pdf> (accessed August 2013).

Dourojeanni, A., Jouravlev, A., 2001. Crisis de Gobernabilidad en la Gestión del agua. Division de Recursos Naturales e Infrastructura. Santiago, Chile: ECLAC.

Falvey, M., Garreaud, R., 2007. Wintertime precipitation episodes in Central Chile: associated meteorological conditions and orographic influences. J. Hydrometeorol. 8 (2), 171–193.

Favier, V., Falvey, M., Rabatel, A., Praderio, E., López, D., 2009. Interpreting discrepancies between discharge and precipitation in high-altitude area of Chile's Norte Chico region (26–32°S). Water Resour. Res. 45, W02424. http://dx.doi.org/10.1029/2008WR006802.

Fiebig-Wittmaack, M., Astudillo, O., Wheaton, E., Wittrock, V., Perez, C., Ibacache, A., 2012. Climatic trends and impact of climate change on agriculture in an arid Andean Valley. Climatic Change 111 (3), 819–833. http://dx.doi.org/10.1007/s10584-011-0200-.

Fuenzalida, H., Villagrán, C., Bernal, P., Fuentes, E., Santibañez, F., Peña, H., Montecino, V., Hajek, E., Rutllant, J., 1989. Cambio climático global y eventuales efectos en Chile. Amb. y Des. V (2), 37–42.

Garín, C., 1987. Inventario de Glaciares de los Andes Chilenos desde los 18°a los 32°de latitud sur. Revista de Geografía Norte Grande 14, 35–48.

Garreaud, R., Batisti, D., 1999. Inter-annual (ENSO) and inter-decadal (ENSO-like) variability of the Southern Hemisphere tropospheric circulation. J. Clim. 12, 2113–2123 (PDF).

Garreaud, R., Vuille, M., Compagnucci, R., Marengo, J., 2009. Present-day South American climate. Palaeogeogr. Palaeoclimatol. Palaeoecol. 281 (3-4), 180–195, doi: http://dx.doi.org/10.1016/j.palaeo.2007.10.032 (Accessed Aug 2013)..

Garreaud, R., 2011. Cambio Climático: Bases físicas e impactos en Chile. Revista Tierra Adentro (INIA-Chile), No. 93. (Mar-Abr 2011), 13–19. <http://www.dgf.uchile.cl/rene/PUBS/inia_RGS_final.pdf> (accessed August 2013).

Gazmuri, R., Rosegrant, M., 1996. Chilean water policy: the role of water rights, institutions, and markets. Resour. Develop. 12, 33–48.

Gómez-Lobo, A., Paredes, R., 2001. Reflexiones sobre el proyecto de modificación del Código de Aguas. Estudios Públicos 82, 83–91.

González, L., Mardones, M., Silva, A., Campos, E., 1999. Hidrogeoquímica y comportamiento del agua subterránea en la cuenca del río Claro, Región de Biobío, Chile. Revista Geológica de Chile 26 (2), 145–157.

González, M., 2007. Comparación de las Tendencias Espaciales y Temporales de las Variables Precipitación y Temperatura para las Zonas Áridas y Semiáridas de Chile. Tesis de Ingeniero Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 108 p. Consultado el 6 de Agosto de 2012. Disponible en: <http://eias.utalca.cl/Docs/pdf/ Publicaciones/tesis_de_grado/MEMORIA%20MARIA%20A%20TAPIA.pdf> (accessed August 2012).

Haan, C.T., 1977. Statistical Methods in Hydrology. The Iowa State University Press, Ames.

Hadjigeorgalis, E., Riquelme, C., 2002. Análisis de los Precios de los Derechos de Aprovechamiento de Aguas en el Río Cachapoal. Ciencia e Investigación Agraria 29 (2), 91–99.

Hadjigeorgalis, E., 2004. Comerciando con Incertidumbre: Los Mercados de Agua en la Agricultura Chilena. Cuadernos de Economía 40 (122).

Haylock, M., Peterson, T., Alves, L., Ambrizzi, T., Anunciacao, Y., Baez, J., Barros, V., Berlato, M., Bidegain, M.M., Coronel, G., Corradi, V., Garcia, V., Grimm, A., Karoly, D., Marengo, J., Marino, M., Moncunill, D., Nechet, D., Quintana, J., Rebello, E., Rusticucci, M., Santos, J., Trebejo, I., Vincent, L., 2006. Trends in total and extreme South American rainfall in 1960–2000 and links with sea surface temperature. J. Clim. 19 (8), 1490–1512.

Hearne, R., Easter, K.W., 1995. Water Allocation and Water Markets: An Analysis of Gains-From-Trade in Chile. Technical Paper #315. World Bank, Washington DC.

Instituto Nacional de Estadísticas (INE), 2006. Compendio Estadístico. Síntesis geográfica Nacional, 44 pp.

Instituto Nacional de Estadísticas (INE), 2007. Censo Agrícola. Santiago, Chile. <http://www.ine.cl/canales/chile_estadistico/censos_agropecuarios/censo_agropecuario_07.php> (accessed September 2012).

Instituto Nacional de Estadísticas (INE), 2011. Compendio Estadístico. Síntesis geográfica Nacional, 44 pp.

Instituto Nacional de Estadísticas (INE), 2012. Informe Anual Medio Ambiente 2010. Subdirección de Operaciones. Departamento de Estadísticas Agropecuarias y Medioambientales; Unidad Estadísticas Medioambientales; Departamento de Comunicación Estratégica, pp. 65–71.

Kendall, M., 1938. A New Measure of Rank Correlation. Biometrika 30 (1–2), 81–89. http://dx.doi.org/10.1093/biomet/30.1-2.81.

Kendall, M., 1975. Rank Correlation Methods. Griffin, London.

Köppen, W., Geiger, R., 1954. Klima der Erde (Climate of the Earth). Wall Map 1:16 Mill. Klett-Perthes, Gotha.

Larraín, S., Aedo, M., Navarrete, K., Villarroel, C., 2010. Marco Jurídico para la Gestión del Agua en Chile. Diagnóstico y Desafíos. Programa Chile Sustentable and Fundación Heinrich Böll. I.S.B.N.: 978-956-7889-44-0. <http://www.chilesustentable.net/2011/07/14/marco-juridico-para-la-gestion-del-agua-en-chile-diagnostico-y-desafios/> (accessed August 2013).

León, L., 2006. Análisis Comparativo del Comportamiento Espacial y Temporal de las Precipitaciones a través del Índice de Fournier y Fournier Modificado, en las Regiones de Coquimbo y Valparaíso. Tesis de Ingeniero Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 107 p. <http://eias.utalca.cl//Docs/pdf/Publicaciones/tesis_de_grado/MEMORIA%20LASTENIA%20LEON.pdf> (accessed August 2012).

Le Quesne, C., Acuña, C., Boninsegna, J., Rivera, A., Barichivich, J., 2009. Long-term glacier variations in the Central Andes of Argentina and Chile, inferred from historical records and tree-ring reconstructed precipitation. Palaeogeogr. Palaeoclimatol. Palaeoecol. 281, 334–344.

Lliboutry, L., 1958. Studies of the shrinkage after a sudden advance, blue bands and wave gives on glacier Universidad (Central Chilean Andes). J. Glaciol. 3 (24), 261–270.

Madden, R., Julian, P., 1994. A review of the intraseasonal oscillation in the Tropics. Mon. Weather Rev. 122, 814–837.

Mann, H., 1945. Nonparametric tests against trend. Econometrica 13, 245–259.

Mantua, N.J., Hare, S., Zhang, Y., Wallace, J.M., Francis, R.C., 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78, 1069–1079.

Marangunic, C., 1979. Inventario de Glaciares. Hoya del río Maipo. Dirección General de Aguas, Publicación G-2, Santiago.

Masiokas, M., Rivera, A., Espizúa, L., Villalba, R., Delgado, S., Aravena, J.C., 2009. Glacier fluctuations in extratropical South America during the past 1000 years. Palaeogeogr. Palaeoclimatol. Palaeoecol.. http://dx.doi.org/10.1016/j.palaeo.2009.08.006.

McPhee, J., De la Fuente, A., Herrera, P., Niño, Y., Olivares, M., Sancha, A., Tamburrino, A., Vargas, X., 2012. El sector del agua en Chile: su estado y sus retos. Diagnóstico del Agua en las Américas. Foro Consultivo Científico y Tecnológico, AC. FCCyT. ISBN: 978-607-9217-04-4. <http://www.foroconsultivo.org.mx/libros_editados/agua_2012/chile.pdf> (accessed July 2013).

Matus, N., Fernández, B., Aedo, M., Larraín, S., 2004. Recursos Hídricos en Chile: Desafíos para la Sustentabilidad. Programa Chile Sustentable. Chile.

Mendoza, R., 2011. Análisis Comparativo del Comportamiento de las Precipitaciones y su Agresividad Climática en Zonas Áridas y Semiáridas Frías. Tesis de Ingeniero Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 104 p. <http://eias.utalca.cl/Docs/pdf/Publicaciones/tesis_de_grado/MEMORIA%20ROMINA%20MENDOZA.pdf> (accessed August 2012).

Ministerio del Medio Ambiente (MMA), 2011. Informe del Estado del Medio Ambiente, 511 p. <http://www.mma.gob.cl/1304/w3-article-52016.html> (accessed July 2013).

Ministerio de Obras Públicas (MOP), 2013. Estrategia Nacional de Recursos Hídricos. Chile cuida su agua. <http://www.mop.cl/Documents/ENRH_2013_OK.pdf> (accessed July 2013).

Minvielle, M., Garreaud, R., 2011. Projecting rainfall changes over the South American Altiplano. J. Clim. 24, 4577–4583.

Montecinos, A., Aceituno, P., 2003. Seasonality of the ENSO – Related rainfall variability in central Chile and associated circulation anomalies. J. Clim. 16, 281–296.

Nicholson, L., Marin, J., Lopez, D., Rabatel, A., Bown, F., Rivera, A., 2009. Glacier inventory of the upper Huasco valley, Norte Chico, Chile: glacier characterisitcs, glacier change and comparison to central Chile. Ann. Glaciol. 50 (53), 111–118.

Noveroy, C., 1987. Inventario de Glaciares de la hoya del río Mataquito. Dirección general de Aguas, Publicación Interna, EH 87/1, Santiago.

Núñez, J., n.d. Issues in Coastal and Continental Water Quality in Chile (PowerPoint slides). Department of Economics, University of Chile. <http://www.pecc.org/resources/doc_view/1081-issues-in-in-coastal-coastal-a-continental-water-quality-in-chile> (accessed July 2013).

OECD, 2011.Water Governance in OECD Countries: A Multilevel Approach. OECD Studies on Water, OECD Publishing. <http://dx.doi.org/10.1787/9789264119284-en> (accessed July 2013).

Olivares, C., 2009. Determinación del Comportamiento de las Precipitaciones y de su Agresividad Climática, en las Regiones del Biobío y la Araucanía. Tesis de Ingeniero Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 108 p. <http://eias.utalca.cl/Docs/pdf/Publicaciones/tesis_de_grado/MEMORIA%20CLAUDIO%20OLIVARES.pdf> (accessed July 2013).

Palma, R., Jiménez, G., Alarcón, I., 2009. Las energías renovables no convencionales en el mercado eléctrico chileno. Published by Comisión Nacional de Energía (CNE) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Parra, O., Valdovinos, C., Habit, E., Figueroa, R., 2009. Long term study of the Biobío River: a complex multiuse fluvial system in Chile. In: Proc. 7th ISE & 8th HIC, 10 pp.

Pellicciotti, F., Burlando, P., Van Vliet, K., 2007. Recent trends in precipitation and streamflow in the Aconcagua River Basin, central Chile, vol. 318 IAHS, 17–38.

Peña, H., Nazarala, N., 1987. Snowmelt-runoff Simulation Model of a Central Chile Andean Basin with Relevant Orographic Effects. In: Large Scale Effects of Seasonal Snow Cover (Proceedings of the Vancouver Symposium), IAHS Publ. 166: 161–172.

Peña, H., 1992. Caracterización de la calidad de las aguas naturales y contaminación agrícola en Chile. Prevención de la contaminación del agua por la agricultura y actividades afines. Anales de la Consulta de Expertos. FAO, ONU, 75–86.

Pizarro, R., Cornejo, F., González, C., Macaya, K., Morales, C., 2008. Análisis del comportamiento y agresividad de las precipitaciones en la zona central de Chile. Ingeniería Hidráulica en México 23 (2), 91–109.

Pizarro, R., Valdés, R., García-Chevesich, P., Vallejos, C., Sangüesa, C., Morales, C., Balocchi, F., Abarza, A., Fuentes, R., 2012. Latitudinal analysis of rainfall intensity and mean annual precipitation in Chile. Chilean J. Agric. Res. 72 (2), 252–261.

Pizarro, R., Garcia-Chevesich, P., Valdés, R., Dominguez, F., Hossain, F., Ffolliott, P., Olivares, C., Morales, C., Balocchi, F., Bro, P., 2013a. Inland water bodies in Chile can locally increase rainfall intensity. J. Hydrol. 481, 56–63, http://dx.doi.org/10.1016/j.jhydrol.2012.12.012.

Pizarro, R., Balocchi, F., Vera, M., Aguilera, A., Morales, C., Valdés, R., Sangüesa, C., Vallejos, C., Fuentes, R., Abarza, A., Olivares, C., 2013b. Influence of climate change on peak flow behavior in central Chile. Water Technology and Sciences (no. 2), vol. IV, April–June, 2013, pp. 5–19 (in Spanish). <http://www.imta.gob.mx/tyca/revistadigital198237645imta_comunicacion/rev-02-2013/> (August 2013).

Pizarro, R., Vera, M., Valdés, R., Helwig, B., Olivares, C., 2013c. Multidecadal variations in annual maximum peak flows in semi-arid and temperate regions of Chile. Hydrol. Sci. J.. http://dx.doi.org/10.1080/02626667.2013.803182.

Queirolo, F., Stegen, S., Mondaca, J., Cortés, R., Rojas, R., Contreras, C., Munoz, L., Schwuger, M.J., Ostapczuk, P., 2000. Total arsenic, lead, cadmium, copper, and zinc in some salt rivers in the northern Andes of Antofagasta, Chile. Sci. Total Environ. 255 (1–3), 85–95, http://dx.doi.org/10.1016/S0048-9697(00)00451-4.

Quintana, J., 2004. Estudio de los factores que explican la variabilidad de la precipitación en Chile en escalas de tiempo interdecadal (M.Sc. thesis, Universidad de Chile).

Quintana, J., Aceituno, P., 2006. Trends and Interdecadal Variability of Rainfall in Chile. Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24–28, 2006, INPE, p. 371–372.

Quintana, J., Aceituno, P., 2012. Changes in the rainfall regime along the extratropical west coast of South America (Chile): 30–43°S.Atmósfera 25 (1), 1–22.

Rabatel, A., Castebrunet, H., Favier, V., Nicholson, L., Kinnard, C., 2011. Glacier changes in the Pascua-Lama region, Chilean Andes (29 degrees S): recent mass balance and 50 yr surface area variations. Cryosphere 5 (4), 1029–1041.

Retamal, M., Andreoli, A., Arumi, J., Rojas, J., Parra, O., 2013. Gobernanza del Agua y Cambio Climático: Fortalezas y Debilidades del actual Sistema de Gestión del Ag ua en Chile. Análisis Interno. Interciencia. 38 (1), Jan 2013.

Riestra, F., 2010. Experiencia en la Implementación de Caudales Ecológicos en Chile. Power Point Presentation. Jefe Nacional de Fiscalización. Dirección General de Aguas. Ministerio de Obras Públicas, June 2010. <http://200.69.103.48/comunidad/dependencias/facultades/medioambiente/Documentos/Eventos/CongresoCaudal/2-Francisco%20Riestra.pdf> (accessed July 2013).

Rignot, E., Rivera, A., Cassasa, G., 2003. Contribution of Patagonian icefields of South America to sea level rise. Science 302 (5644), 434–437.

Ríos, M., Quiroz, J., 1995. The market of water rights in Chile: major issues. Cuadernos de Economía 32, 317–345.

Rioseco, R., Tesser, C., 2013. Cartografía Interactiva de los climas de Chile (on line). Instituto de Geografía. Pontificia Universidad Católica de Chile. <www.uc.cl/sw_educ/geografia/cartografiainteractiva> (accessed June 2013).

Rivera, A., 1989. Inventario de Glaciares entre las cuencas de los ríos Biobío y Petrohué. Su relación con el volcanismo activo: Caso Volcán Lonquimay. Memoria de Título, escuela de Geografía, Universidad de Chile, Santiago.

Rivera, A., Casassa, G., 1999. Volume Changes on Glaciar Pio XI, Patagonia: 1975–1995". Global Planet. Change 22 (1–4), 233–244.

Rivera, A., Casassa, G., Acuña, C., Lange, H., 2000. Variaciones recientes de glaciares en chile. Revista Investigaciones Geográficas 34, 25–52.

Rivera, A., Acuña, C., Casassa, G., Bown, F., 2002. Use of remote sensing and field data to estimate the contribution of Chilean glaciers to the sea level rise. Ann. Glaciol. 34, 367–372.

Rivera, N., Encina, F., Muñoz, A., Mejías, A., 2004. Water quality in the Cautín and Imperial Rivers, IX Region-Chile. Facultad de Recursos Naturales. Ingeniería Civil Ambiental – Ingeniería en Recursos Naturales Renovables. Información Tecnológica 15 (5), 89–102.

Rivera, A., Benham, T., Casassa, G., Bamber, J., Dowdeswell, J., 2007. Ice elevation and areal changes of glaciers from the Northern Patagonia icefield, Chile. Global Planet. Change 59, 126–137.

Rivera, A., Corripio, J., Bravo, C., Cisternas, S., 2012. Glacier Jorge Montt (Chilean Patagonia) dynamics derived from photos obtained by fixed cameras and satellite image feature tracking. Ann. Glaciol. 53 (60), 147–155.

Rosenblüth, B., Fuenzalida, H., Aceituno, P., 1997. Recent temperature variations in southern South America. Int. J. Climatol. 17, 67–85.

Rubio-Álvarez, E., McPhee, J., 2010. Patterns of spatial and temporal variability in streamflow records in south central Chile in the period 1952–2003. Water Resour. Res. 46 (5), W05514. http://dx.doi.org/10.1029/2009WR007982.

Rutllant, J., Fuenzalida, H., 1991. Synoptic aspects of the Central Chile rainfall variability associated with the Southern Oscillation. Int. J. Climatol. 11, 63–76.

Salazar, C., Soto, M., 1999. Caracterización y Monitoreo de Sistemas Lacustres en Chile. VI Jornadas del CONAPHI – Chile. Dirección General de Aguas. Santiago. Chile, 12 pp. <http://documentos.dga.cl/LGO1797.pdf> (accessed June 2013).

Saavedra, N., Müller, E., Foppiano, A., 2002. Monthly mean rainfall frequency model for the Central Chile coast: some climatic inferences. Int. J. Climatol. 22, 1495–1509.

Schneider, C., Schnirch, M., Casassa, G., Acuña, C., Kilian, R., 2007. Glaciology at Gran Campo Nevado (53°S), Chile—Part II: glacier inventory and glacier change during recent decades. Global Planet. Change 58. http://dx.doi.org/10.1016/j.gloplacha.2006.11.023.

Sen, P., 1968. Estimates of the regression coefficient based on Kendall's tau. J. Am. Stat. Assoc. 63, 1379–1389, JSTOR 2285891, MR 0258201.

Superintendencia de Servicios Sanitarios (SISS), 2009a. Informe anual de los resultados calidad de agua potable. Variación de la calidad del agua potable entre los años 1997 y 2008. Superintendencia de servicios sanitarios. Chile.

Superintendencia de Servicios Sanitarios (SISS), 2009b. Informe anual de coberturas de servicios sanitarios entre los años 2005 y 2008. Superintendencia de servicios sanitarios. Chile.

Superintendencia de Servicios Sanitarios (SISS), 2009c. Informe de gestión del sector sanitario 2008. Cobertura Histórica de Agua Potable de las Principales Empresas Sanitarias. Superintendencia de Servicios Sanitarios. Chile.

Superintendencia de Servicios Sanitarios (SISS), 2011. Informe de gestión del sector sanitario 2011. Superintendencia de Servicios Sanitarios. Chile.

Tapia, G., 2004. Inventario de Glaciares del Río Maule. Unpublished report, DGA/MOP, Santiago, 41.

Stewart, I., Cayan, D., Dettinger, M., 2005. Changes toward earlier streamflow timing across western North America. J. Clim., 1136–1155, <http://earth.boisestate.edu/home/jmcnamar/seltopics/2006/stewart_timing.pdf> (accessed August 2013).

Theil, H., 1950. A rank-invariant method of linear and polynomial regression analysis. I, II, III, Nederl. Akad. Wetensch., Proc. 53: 386–392, 521–525, 1397–1412, MR 0036489.

Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B., Zhai, P., 2007. Observations: Surface and atmospheric climate change. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK, pp. 237–336.

Tuvendal, M., Elmqvist, T., 2011. Ecosystem services linking social and ecological systems – river brownification and the response of down-stream stakeholders. Ecology and Society.

United Nations Environment Programme (UNEP), 2006. Water Resources in Chile (PDF), pp. 1–5. <http://www.unep.org/GC/GCSS-VIII/Chile-e.pdf> (accessed August 2012).

University of Chile, 2010. Informe País. Estado del Medio Ambiente en Chile 2008. Geo Chile. Instituto de Asuntos Públicos. Centro de Análisis de Políticas Públicas, Director Nicolo Giglio. Capítulo 2, Aguas Continentales, pp. 38–58. <http://www.uchile.cl/publicaciones/64137/informe-pais-estado-del-medio-ambiente-en-chile-2008> (accessed July 2013).

Valdés, R., 2009. Análisis del Comportamiento Espacial y Temporal de las Precipitaciones en la Región de los Ríos, la Región de los Lagos y la Región de Aysén. Tesis de Ingeniero Forestal. Talca, Chile. Universidad de Talca, Facultad de Ciencias Forestales, Centro Tecnológico de Hidrología Ambiental, 111 p. <http://eias.utalca.cl/Docs/pdf/Publicaciones/tesis_de_grado/MEMORIA%20RODRIGO%20VALDES.pdf> (accessed August 2012).

Valdivia, P., 1984. Inventario de Glaciares, Andes de Chile Central (32°-35°lat. S). Hoyas de los ríos Aconcagua, Maipo, Cachapoal y Tinguiririca. In: Jornadas de Hidrología de Nieves y Hielos en América del Sur. Programa Hidrológico Internacional, Santiago de Chile 1: 6.1-6.24.

Vergara, A., 2010. Diagnóstico de problemas en la gestión de recursos hídricos: aspectos institucionales para una futura propuesta de modificaciones legales, reglamentarias y/o de prácticas administrativas. Informe preparado para el diagnóstico de la gestión de los recursos hídricos. Santiago, Chile.

Vicuña, S., Dracup, J.A., 2007. The evolution of climate change impact studies on hydrology and water resources in California. Clim. Change 82 (3–4), 327–350.

Vicuña, S., Garreaud, R., McPhee, J., 2010. Climate change impacts on the hydrology of a snowmelt driven basin in semiarid Chile. Climatic Change.. http://dx.doi.org/10.1007/s10584 - 010-9888-4.

Vicuña, S., McPhee, J., Garreaud, R., 2012. Agriculture vulnerability to climate change in a snowmelt driven basin in semiarid Chile. J. Water Resour. Plann. Manage. 138 (5), 431–441.

Vuille, M., Bradley, R.S., Werner, M., Keimig, F., 2003. 20th century climate change in the tropical Andes: observations and model results. Clim. Change.

Vivero, S., 2008. Inventario de glaciares descubiertos de la cuenca del río Copiapó y variaciones recientes en sus frentes. Informe final de práctica profesional. DGA/Universidad de Chile, 51 pp.

World Bank, 2010. World Development Indicators 2010. Washington, DC. USA.

World Bank, 2011. Chile. Diagnóstico de la Gestión de los Recursos Hídricos. Departamento de Medio Ambiente y Desarrollo Sostenible, Región para América Latina y el Caribe. Chile, 88 pp. <http://water.worldbank.org/node/83999> (accessed July 2012).

World Water Assessment Programme (WWAP), 2003. Water for People Water for Life, USA.

Zemp, M., Haeberli, W., Bajracharya, S., Chinn, T.J., Fountain, A.G., Hagen, J.O., Huggel, C., Kääb, A., Kaltenborn, B.P., Karki, M., Kaser, G., Kotlyakov, V.M., Lambrechts, C., Li, Z.Q., Molnia, B.F., Mool, P., Nellemann, C., Novikov, V., Osipova, G.B., Rivera, A., Shrestha, B., Svoboda, F., Tsvetkov, D.G., Yao, T., 2007. Glaciers and ice caps. Part I: Global overview and outlook. Part II: Glacier changes around the world. In: UNEP: Global outlook for ice and snow. UNEP/GRID-Arendal, Norway, pp. 115–152.

Zenteno, P., Rivera, A., García, R., 2004. Glacier Inventory of the Itata Basin Derived from Satellite Imagery: Historical Trends and Recent Variations at nevados de Chillán volcano (36°56'S–71°20'W). VIII Congreso Internacional de Ciencias de la Tierra, Santiago, Chile, Octubre.

Zenteno, P., 2008. Variaciones recientes de los glaciares en la zona centro sur de Chile y su relación con los cambios climáticos y la actividad volcánica. Memoria para optar al título de Geógrafo. Universidad de Chile, Santiago, 288 pp.