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Guillermo Donoso *Editor*

Water Policy in Chile

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To my wife, Paz, son, Rodrigo, and daughter,
Beatriz, for their lifelong support

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Abbreviations

AC	Asociación de Canalistas – Channel User Associations
AGIES	Análisis General de Impacto Económico y Social – General Analysis of the Economic and Social Impact
Casen	Encuesta de Caracterización Socioeconómica Nacional – National Socioeconomic Characterization Survey
CA	Comunidades de Aguas – Water Communities
CAS	Comunidades de Aguas Subterránes – Groundwater Communities
CBR	Conservador de Bienes Raíces – National Real Estate Agencies
CIREN	Centro de Información de Recursos Naturales – Center for Natural Resources Information
CGC	Coordinación General de Concesiones – General Concessions Coordination Department
CGR	Contraloría General de la República – Comptroller General of the Republic
CMS	Consejo de Ministros para la Sustentabilidad – Council of Ministers for Sustainability
CNE	Comisión Nacional de Energía – National Energy Commission
CNR	Comisión Nacional de Riego – National Irrigation Commission
CONADI	Corporación Nacional de Desarrollo Indígena – National Indigenous Development Community
CONAF	Corporación Nacional Forestal – National Forestry Corporation
CONAMA	Comisión Nacional de Medio Ambiente – National Environmental Commission
COREMA	Comisión Regional del Medio Ambiente – Regional Environmental Commission
CPA	Catastro Público de Aguas – Public Water Registry
CPR	Constitución Política de la República de Chile – Political Constitution of the Republic of Chile
CRH	Consejo de Recursos Hídricos – Water Resource Council at the basin level

DAA	Derechos de Aprovechamiento de Aguas – Water Rights
DDU	División de Desarrollo Urbano – Urban Development Division
DIPROREN	Dirección de Protección de los Recursos Naturales – Natural Resource Protection Directorate
DFL	Decreto con Fuerza de Ley – Decree with Force of Law
DGA	Dirección General de Aguas – National Water Directorate
DMC	Dirección Meteorológica de Chile – Meteorological Direction
DOH	Dirección de Obras Hidráulicas –Waterworks Directorate
DR	Dirección de Riego – National Irrigation Directorate
DS	Decreto Supremo – Supreme Decree
FNDR	Fondo Nacional de Desarrollo Regional – Regional Development Fund
FPIR	Fondos de Provisión de Infraestructura Rural – Rural Infrastructure Provision Funds
GORE	Gobiernos Regionales – Regional Governments
GWC	Ground water user committees
HA	Hectáreas – Hectares (10,000 m^2)
HM^3	Hectómetros cúbicos – Cubic hectometres
INDAP	Instituto Nacional de Desarrollo Agropecuario – Institute of Agriculture and Livestock Development
INIA	Instituto de Investigación Agropecuaria – Institute of Agriculture and Livestock Research
INH	Instituto Nacional de Hidráulica de Chile – National Hydraulic Institute
ISP	Instituto de Salud Pública – Public Health Institute
JdV	Juntas de Vigilancia – Vigilance Committees
MASL	Meters Above Sea Level
ME	Ministerio de Energía – Ministry of Environment
MEF	Minimum Ecological Flow
MI	Ministerio de Interior – Ministry of Interior
MINAGRI	Ministerio de Agricultura – Ministry of Agriculture
MINECON	Ministerio de Economía, Fomento y Turismo – Ministry of Economics, Development and Tourism
MINDEF	Ministerio de Defensa – Ministry of Defense
MINSAL	Ministerio de Salud – Ministry of Health
MINVU	Ministerio de Vivienda y Urbanismo – Urbanism and Housing Ministry
MM	Ministerio de Minería – Ministry of Mining
MMA	Ministerio de Medio Ambiente – Ministry of the Environment
MOP	Ministerio de Obras Públicas – Ministry of Public Works
MT	Metric Tons
kMT	Thousands of Metric Tons
M^3	Metros Cúbicos – Cubic meters
MMT	Millions of Metric Tons
MS	Ministerio de Salud – Ministry of Health

NRW	Non-Revenue Water
OCL	Cortes ordinarias de justicia – Ordinary Court of Law
ONEMI	Oficina Nacional de Emergencias – National Emergency Office
PAPR	Programa de Agua Potable Rural – Rural Water Supply Program
PJ	Poder Judicial – Judicial Power
PMG	Programa de Mejoramiento de la Gestión – Management Improvement Program
SAG	Servicio Agrícola y Ganadero – Agriculture and Livestock Service
SDAPR	Subdirección de Servicios Sanitarios Rurales – Sibdirection of Rural Water Supply and Sanitation Services
SEA	Servicio de Evaluación Ambiental – Environmental Assessment Service
SEIA	Sistema de Evaluación de Impacto Ambiental – Environmental Impact Assessment System
SEREMI	Secretaría Regional Ministerial – Regional Ministerial Secretariat
SERNAGEOMIN	Servicio Nacional de Geología y Minería – Geological and Mining Service
SERNAPESCA	Servicio Nacional de Pesca – National Fisheries Service
SERVIU	Servicio de Vivienda y Urbanismo – Urbanism and Housing Service
SI	Subsecretaría del Interior – Undersecretary of Interior
SISS	Superintendencia de Servicios Sanitarios – Urban Water Supply and Sanitation Regulator
SMA	Superintendencia del Medio Ambiente – Superintendence for the Environment
SS	Servicio de Salud – Health Services
SUBDERE	Subsecretaría de Desarrollo Regional – Undersecretariat for Regional Development
SUBPESCA	Subsecretaría de Pesca y Acuicultura – Undersecretary of Fisheries and Aquaculture
TA	Tribunal Ambiental – Environmental Court
TDLC	Tribunal de la Defensa de la Libre Competencia – Free Competition Defense Court
UT	Unidad Técnica para los APR – Rural Water Supply Technical Unit
WC81	Código de Aguas de 1981 – 1981 Water Code
WR	Water Rights
WSS	Water and Sanitation Services
WUA	Organizaciones de de usuarios de agua – Water User Associations
WWTP	Wastewater treatment plants

Chapter 1
Introduction, Objectives, and Scope

Guillermo Donoso

Abstract The field of water resources is interdisciplinary in nature, covering hydrological, economic, institutional, legal, environmental, social and political aspects. This diversification has led, in many cases, to partial treatment of water issues, or incomplete analysis of the various challenges at stake. This contributed book offers a selfcontained interdisciplinary overview of water policy in Chile. The book is organized in four sections.

Keywords Chile · Chilean · Hydrology · Water policy · Water sectors

1.1 Introduction

The field of water resources is interdisciplinary in nature, covering hydrological, economic, institutional, legal, environmental, social and political aspects. This diversification has led, in many cases, to partial treatment of water issues, or incomplete analysis of the various challenges at stake. This contributed book offers a self contained interdisciplinary overview of water policy in Chile. The book is organized in four sections.

The first section sets the context by offering a detailed examination of the main sources of Chile's water, its principle consumers, the gap between supply and demand, hydrological droughts, decreasing water quality, deterioration of aquatic ecosystems, and future projected impacts of climate change. The interrelation between the country's socio-economic context and water consumption is also analyzed.

The second section describes, analyzes and evaluates the performance of water policies, laws and institutions, identifies the main challenges that Chile needs to face and derives lessons learnt from Chile's reform experience. Expert contributors discuss such topics as Chile's water policy, the reasoning which explains its policy

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reform, and presents the performance evaluation of the legal and institutional framework of water resources.

Water challenges faced by different users such as urban and rural water, agriculture and mining are presented in the third section.

The final section presents a global assessment of Chile's water policy and its challenges to face increasing water scarcity. This section draws from the significant analysis and perspectives offered by all contributors.

The following sections include a description of the main content of the various chapters.

1.2 Setting the Context

Located between the parallels 17° 29′ and 55° 58′ South latitude of the South American continent, Chile has 4300 km of extension. Its population is approximately 17,000,000 inhabitants, 65% of which is concentrated in the center of the country (INE 2017). From a Hydrometeorological point of view, Chile can be divided into 4 Maroregions: North, Center, South, and Austral (Fig. 1.1).

As Chap. 2 relates, Chile's average precipitation is 1525 mm/year, with significant variability throughout the country, increasing more than 500% from the North to the Austral Macroregion (Fig. 1.2). Water runoff is also heterogeneous varying from 510 m^3/person/year in the North Macroregion to 2,300,000 m^3/person/year in the Austral Macroregion, with a national average of 51,218 m^3/person/year (Fig. 1.3).

Average annual recharge of groundwater resources in Chile also varies geographically. In the North Macroregion, aquifer's recharge is approximately $55m^3 / s$, while it is three times that level in the Southern Macroregion (160 m^3/s). However, estimated groundwater extractions in the North Macroregion reaches an average of $88m^3/s$, hence groundwater use in this area is unsustainable.

As is discussed in Chap. 3, surface water quality has improved significantly in the last 20 years, mainly due to the important increase in wastewater treatment; wastewater treatment coverage passed from 10% in 1990 to over 99.8% in 2016. However, only 5% of wastewater treatment includes nutrient removal and 29% of the generated wastewater is discharged in the Chilean coast by marine outfalls. At present, there exists a diverse range of challenges related to water quality throughout Chile. The main issues are elevated salinity and concentrations of metals and metalloids in Northern and Central Macroregions. The natural presence of copper and arsenic from geological sources in addition to anthropogenic activities explain heavy metals enrichment. Reservoirs and lakes in Central Chile show mesotrophic and eutrophic conditions linked mainly to diffuse pollution from agriculture.

Chapter 4 describes the interrelation between the country's socio-economic context and water consumption. Chile implemented important structural economic policy reforms in the 80's, promoting an export-based growth strategy and a stable macroeconomic environment so as to attract foreign investments. These significant

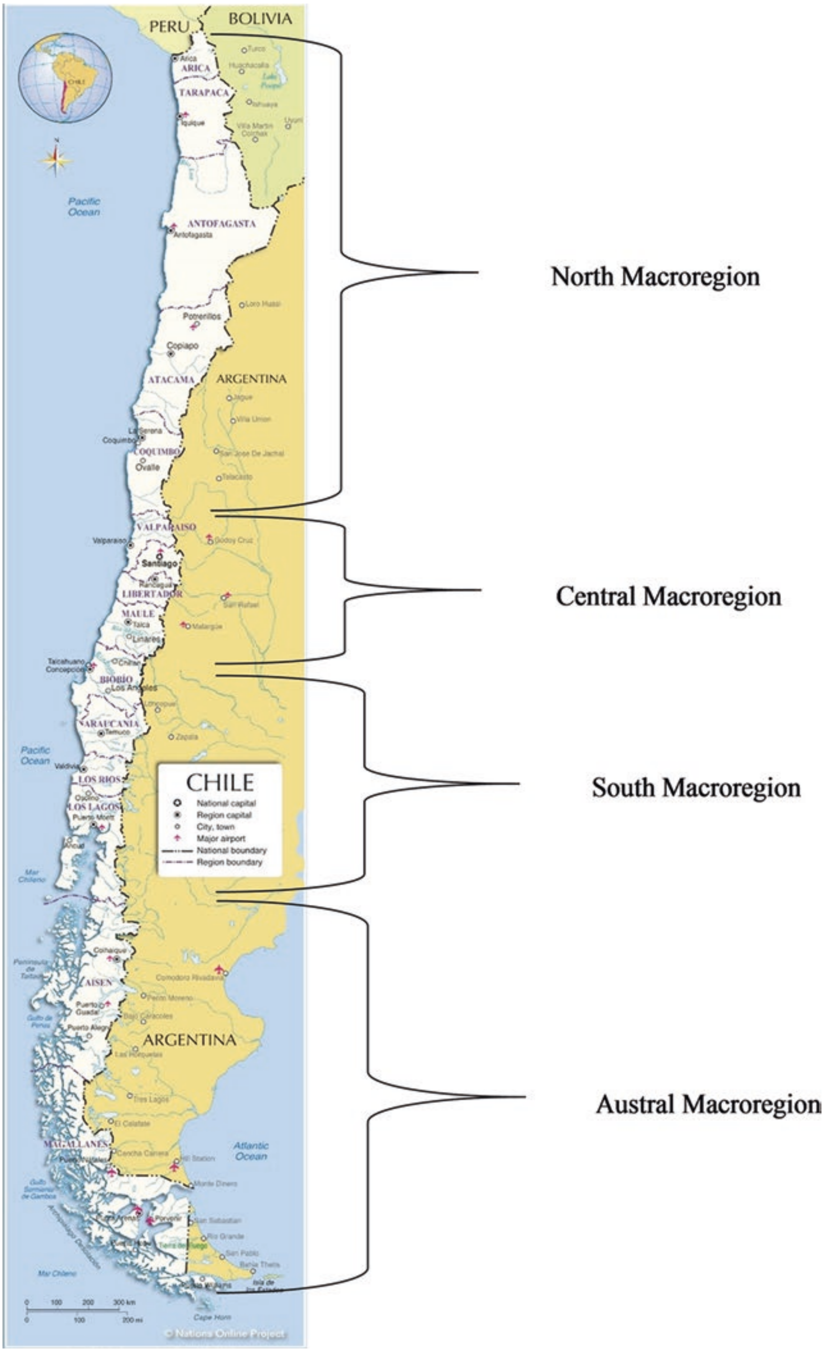

Fig. 1.1 Map of Chile. (Nations Online Project, http://www.nationsonline.org/oneworld/map/chile-administrative-map.htm)

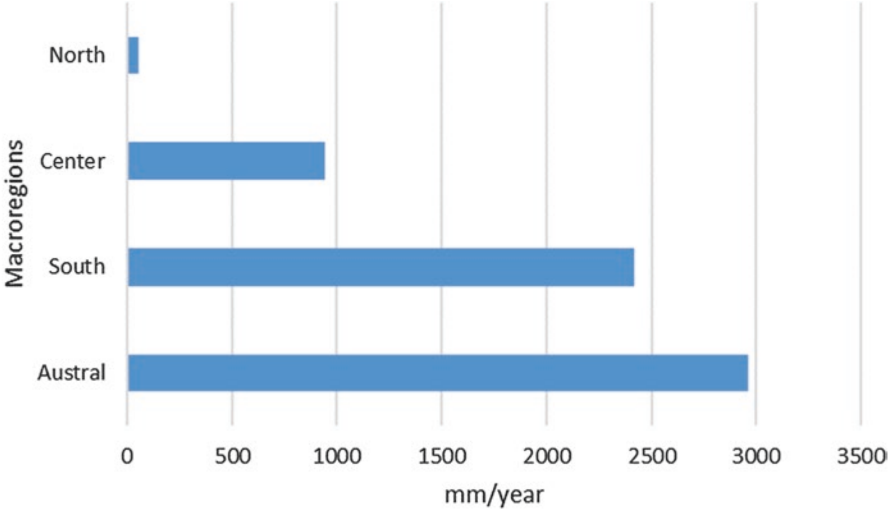

Fig. 1.2 Average rainfall (mm/year). (DGA 2016)

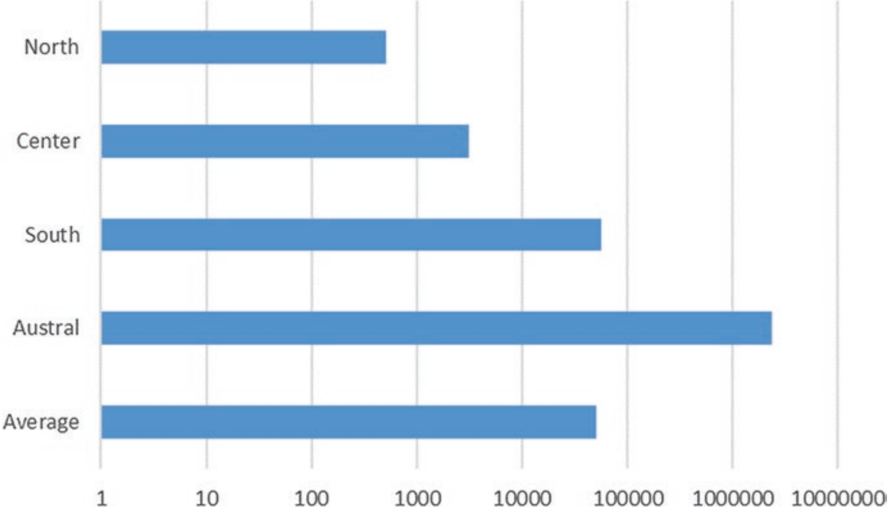

Fig. 1.3 Average water runoff per person per year (Logarithmic scale). (DGA 2016)

reforms underpinned the successful economic growth of the country over the last three decades. As a result, real per capita GDP increased more than 100% (Banco Mundial 2017), which has translated in an increasing water consumption. Water withdrawals in Chile average approximately 4.000 m^3/second/year (DGA 2016), of which consumptive water use is concentrated in the Central Macroregion, representing 70% of total use (Fig. 1.4). Given that water availability is relatively low in this macroregion, important water stress situations have increased triggering conflicts and social, economic, and environmental vulnerability. The above phe-

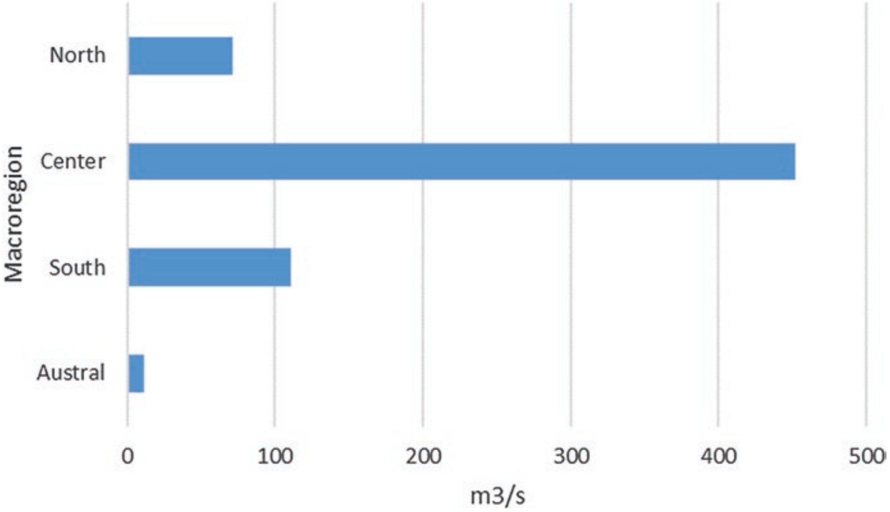

Fig. 1.4 Consumptive water use by Macroregion (m^3/s). (DGA 2016)

nomena will be exacerbated by climate change that is expected to affect Chile in a complex fashion, with increased temperatures throughout the country and decreased annual precipitation in the Central and South Macroregion; there is no clear signal regarding precipitation in the North and Austral Macroregions (Cepal 2012). Thus, Chile requires dedicated policies to decouple economic growth from water consumption in Chile, so as to not limit future economic growth.

1.3 Water Policy and Its Implementation in Chile

As competition for water has grown, Chile has sought better institutional arrangements for water management, coordinate use and resolve conflicts. Water policies, in existence prior to the structural economic policy reforms of the 80's were limited in their ability to reach an economically efficient water allocation. These limitations were primarily related to the definition of water rights, the information available to users, and transaction costs. Additionally, these policies were not consistent with the many structural reforms introduced during the 80s. Thus, the water sector in Chile underwent major changes as a result of decentralization and market reforms. Chapter 5 analyzes the details of Chile's legal and institutional framework for water resources.

The legal framework of Chilean Water Law is structured on the basis of a normative trilogy, of which the Water Code of 1981 (WC81) is the main regulation governing terrestrial water use and water rights (WR) in Chile.

Water legislation in Chile was designed, in essence, to regulate the use of surface waters. The WC81 did not pay much attention to the sustainable management of groundwater because at that time, groundwater extraction was a marginal water source. However, given the uncertainty of surface water supply, there has been a growing reliance on groundwater sources, leading to concerns of groundwater use sustainability. The 2005 amendment of the WC 1981 introduced procedures to reach a sustainable management of groundwater water resources. However, there is evidence that these regulations have not been fully implemented over time and thus, various problems associated with groundwater management still persist (World Bank 2011).

The implementation of the WC81 did not establish new institutions; however, it significantly modified their existing powers for consistency with the vision that the state has a subsidiary role. Nevertheless, in order for it to deliver its full potential as an efficient allocation mechanism, Chile requires a significant institutional reform (World Bank 2013).

Similarly, water quality and ecosystem protection were not objectives of the WC81, its focus was and still is on water quantity and allocation. Therefore, changes in water quality in the past 30 years cannot be attributed to WC 1981. Chapters 6 and 7 describe and analyze water quality and environmental flow policy. Chile's water quality regulatory system is led by the Ministry of Environment, since its creation in 2010, and is currently regulated by the Environmental Law (Law 19,300) and its guidelines. The main regulatory water quality instruments are: (a) environmental water quality standards, (b) decontamination plans and strategies, (c) emission standards, and (d) environmental impact assessments for new investments. However, water resources that have improved water quality are, to this date, only a very small fraction. Thus, a more decisive push to add more areas is needed.

The 2005 reform of the WC81 was a turning point to reduce damages to aquatic ecosystems, by incorporating minimum ecological flows (MEFs) explicitly. This was further reinforced with the 2010 reform of Chile's Environmental Law, which establishes that MEFs must be established for the protection of aquatic ecosystems. These requirements have been applied in the last decades, establishing MEFs only when new WR are granted. However, in spite of these advances, Chile has not been able to revert the deterioration of aquatic ecosystems in its main basins.

The WC81 established that water rights are transferable in order to facilitate markets as an allocation mechanism. The framers of the WC81 sought to achieve efficient water allocations. Chapter 8 documents the existence of water markets and concludes that WR transaction frequency has increased throughout the nation during the last decade, with more frequency during relative dry years. An important result is that WR markets have allowed for the expansion of mining, agriculture, and growing cities without the need to invest in alternative sources such as major water infrastructures or desalinization.

Many WR transactions have been for relatively small amounts of water and for low transactions amounts. This implies that transactions costs have often not been prohibitive. Market transactions for non-consumptive WRs have also shown many transactions for relatively small quantities of water and low prices. However, prices have been highly variable, with more experienced buyers and sellers negotiating favorable prices. This is mainly due to the lack of an efficient WR price revealing mechanism.

1.4 Water Sectors in Chile

Of the total water withdrawals, 85% is used for non-consumptive hydroelectric generation. Hydroelectricity has been part of Chile's energy history since the end of the nineteenth century. Significant developments of the hydroelectrical infrastructure have taken place. However, the relative participation of large hydroelectric plants in Chile's energy matrix has decreased from 44% in 2005 to 26% in 2015 (Deloitte 2016). This reduction is due to two main factors: (i) increasing conflicts (Bauer 2015; Rivera et al. 2016), and (ii) increasing social and environmental costs of large hydroelectric projects (Ministry of Energy 2017).

As is the case in most developing nations, consumptive water use is dominated by agriculture with 82% of total consumptive water (Fig. 1.5). Mining is the activity with the lowest consumptive water use (3%). Notwithstanding, water consumption for mining purposes can be comparatively significant in some northern regions, such as in the Antofagasta Region (II), where the mining industry is the main consumer of water resources representing 49% of total consumptive water use (DGA 2016). Urban water supply represents only 7% of total consumptive water extraction.

As Chap. 9 relates, the current legal and institutional framework of the Chilean water and sanitation sector is the result of several reforms carried out across the years. These led to a significant improvement of Chilean water and sanitation services (WSS). By 2016, WSS coverage levels improved, reaching 99.9%, 96.8% and 99.8% for drinking water supply, wastewater collection and wastewater treatment, respectively.

One of the objectives of the Chilean tariff model is to set tariffs so as to ensure full cost recovery of an efficient model operator. In the majority of the cases, WSS

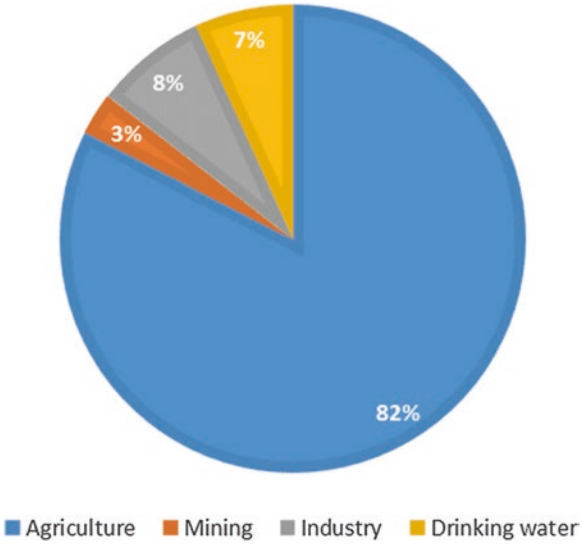

Fig. 1.5 Water consumption by economic sector. (DGA 2016)

operators recover their costs of operations, maintenance, capital replacement, and system expansion. Operators that do not recover operating and maintenance costs (O&M) are those with higher O&M costs than the efficient model operator (Donoso 2017). Water affordability criteria are met by the provision of subsidies directly to the most vulnerable households.

The author shows that Chile's policy of providing WSS services through privatized regional and local water companies has been a notable success, but faces new challenges. The most important of these are the need to (i) reduce non-revenue water, which is associated to the low reposition rates of both water and sewer networks, (ii) improve wastewater treatment, replacing maritime outfall by more effective wastewater treatment systems, and (iii) develop and implement climate change adaptation plans, to reduce the vulnerability to extreme events.

Rural water supply has also improved in the past 30 years. Chile's national Rural Potable Water (APR) program has been successful in increasing water supply coverage from 6% in the 60s to 58% in 2016. Chapter 10 presents an overview of the legal and institutional framework of Chile's APR program, as well as its performance assessment. The authors conclude that although the APR organizations show high performance indicators in various aspects of providing drinking water to rural populations, certain features could be improved in order to deliver a more sustainable and quality service. For example, the fact that rural water supply and sanitation sector has not been subject to regulation like urban services. As pricing is unregulated, each APR organization has their own mechanisms for price setting. In general, this has led to tariffs that have not allowed for adequate maintenance and to invest so as to satisfy growing demand (Navarro et al. 2007; Donoso et al. 2015). Based on their analyses, legal and institutional framework challenges and necessary reformulations are identified.

The agricultural sector in Chile has continuously grown in the past 30 years, often at a rate greater than the rest of the Chilean economy and, thus, the value of water in irrigation has remained high. An overview of Chile's irrigation and investment support program are presented in Chap. 11. The analysis indicates that Chilean agriculture has improved its irrigation efficiency (Fig. 1.6), due to an 85.1% increase in higher efficiency technological irrigation methods and a 298.2% increase in the area in which micro-irrigation was used, largely bolstered by Law 18,450. However, the authors identify that the Ministry of Agriculture's declaration of the goal for Chile to become a world agricultural and food production power in the twenty-first century, raises water needs since, in order for this objective to be reached by 2020, the total area under irrigation must grow by at least 36%.

Mining contributes 11.2% of GDP, being Chile the largest worldwide producer of copper, natural nitrate, lithium and iodine. Most mining operations in Chile occur in (semi-) arid zones and geographical high altitude sites, aspects that are critical for the type of water management that mining uses, which are analyzed in Chap. 12. Although national mining is the productive sector that consumes the least amount of water, in some arid areas of Northern Chile it is a relevant user ranking second behind the agricultural sector. In these areas, water withdrawal from mining is mainly from aquifers that recharged hundreds or even thousands of years ago, which

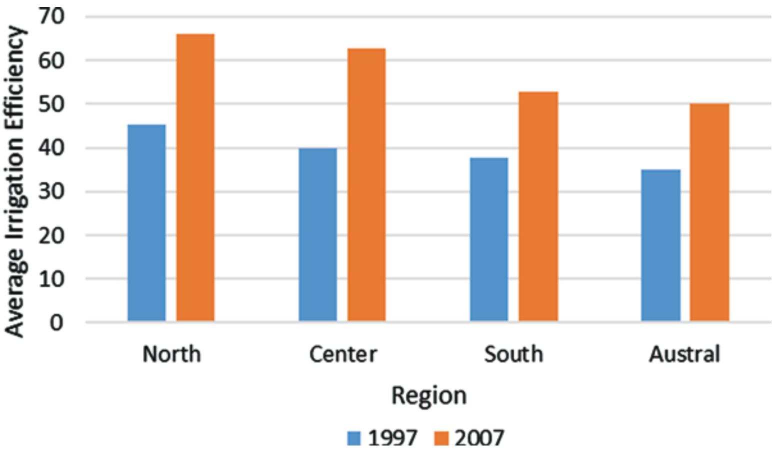

Fig. 1.6 Increase in irrigation efficiency between 1997 and 2007, by macroregion. (INE 1997, 2007)

are also hydraulically connected with conspicuous High-Andes wetlands. Chile's WC81 and its 2005 reform, as well as its Environmental Law of 1993 and its 2010 reform, allowed for a vigorous development of the mining industry at growth rates never seen before. However, currently this legal framework is challenged by Chilean society, which has expressed its lack of agreement. To meet future challenges, both the regulatory framework of water and the way the mining industry designs and implements mining projects in Chile, must adjust to ensure that the Chilean mining activity successfully and sustainably develop.

1.5 Water Management Challenges

The actual state of water resources in Chile has been more influenced by Chile's national development strategy, macroeconomic and other sectors' policies, than by the water sector itself. The main crosscutting issues, identified include (i) growing water demand from all sectors, (ii) variable water supply that will be further aggravated due to climate change, (iii) unsustainable groundwater management, and (iv) policy objectives that have been set without consideration of the implications for other water users and without consultation across sectoral and institutional boundaries.

Chapter 13 relates the evolution of Chile's water management, in order to face these challenges, from an approach limited to meeting certain sector-based requirements to a more comprehensive perspective such as integrated water management (IWRM). A number of advances and reforms of Chile's institutional and legal framework for water management have fallen short of what is needed to address these in Chile's current phase of development. This is mainly due to the inability to deal with water management problems that affect the entire river basin and involve multiple stakeholders and sectors. Hence, adopting integrated water resources management should be a priority for Chile in order to face its current and future water management challenges.

Chapter 14 presents conclusions and a global assessment of Chile's legal and institutional framework of water resources and its challenges, based on the significant contributions of all contributors.

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Part I
Setting the Context

Chapter 2
Hydrological Setting

James McPhee

Abstract From a hydrological perspective, Chile is a country of extremes. Its rivers and aquifers exist in a wide array of geographical settings, and are characterized by presenting regimes of extraordinary variability in space and time. From the driest desert on Earth to Patagonia, communities and ecosystems have adapted to endure periods of persisting drought, relentless precipitation, as well as favorable conditions for the emergence of a burgeoning agricultural sector. With mounting evidence of global change processes, it is still unclear how these regimes will evolve in the future, and what are the challenges that water managers will need to face in order to balance increasing water demand and the need for water security. This chapter describes the major hydrological regimes associated with water resource relevant regions in the country, highlighting the hydrological processes, variability and uncertainties pertaining to water resource management. A global assessment of the state of hydrologic knowledge, data availability and future directions for research and management are provided.

Keywords Chile · Chilean watersheds · Hydrology · Hydrometeorological regions · Water regimes

2.1 Chile and Its Climate

Chile's location and latitudinal span determine one of the most extremely variable climatic settings worldwide. From north-to-south precipitation increases and temperature decreases (Donoso 2017).

Well into the subtropical circle, Chile's Northern Macroregion holds the world's driest desert, the Atacama, where annual precipitation averages less than 25 mm/year. The hyper-aridity of this region is due to the "South Pacific High" anticyclone, which blocks moist air masses traveling from the west, preventing frontal precipitation from occurring between the latitudes of 15 and 25 °S. Despite this condition,

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the eastern border of the Atacama, neighboring with Southwestern Bolivia and Northwestern Argentina, is influenced by the climate of the South American High Plateau. There, convective precipitation systems significantly increase annual precipitation to 200 mm–800 mm, which can sustain aquatic ecosystems. These precipitation events occur during the austral summer, typically between the months of December and February (Minvielle and Garreaud 2011).

Further South, the Central Macroregion of Chile (25–40 °S) presents a classical Mediterranean climate, with an average annual precipitation of 940 mm, which is heavily concentrated during the winter months of June through September (Southern hemisphere). Semi-arid conditions prevail in what is known as Chile's *Norte Chico (25–33* °S). The high elevation of the Andes Cordillera [4000–6000 meters above sea level-(masl)] sustains a seasonal snowpack that accumulates during the winter and melts rapidly at the beginning of spring. A climatic threshold has been identified at 34 °S, whereby precipitation increases significantly and interannual variability shows different characteristics. An important terrain feature in Central Chile is the presence of two mountain chains, the Andes and the Coastal ranges, which run parallel to each other in a north-south direction. They are separated by a central depression that holds a rich agricultural region. These mountain ranges induce the orographic enhancement of frontal systems approaching from the west, also generating rain shadows in the areas immediately to their east. The southern edge of Central Chile is characterized by larger precipitation amounts, with a more extended rainy season.

The Southern Macroregion of Chile (40–45 °S) is characterized by large annual precipitation amounts over an extended rainy season, reaching on average 2963 mm/year. Here, a broken coastline coexists with relatively high mountains, which induce strong precipitation orographic gradients such that annual precipitation amounts can vary one order of magnitude along a distance of less than 200 km.

Finally, the Austral Macroregion, is characterized by slightly lower precipitation amounts without a clearly defined rainy season, as well as a highly eroded landscape and low temperatures throughout the year.

2.2 Hydrometeorological Regions

The climatic situation described above, combined with the severe topographical and geological changes, proper to the mountainous characteristics of the country, result in a wide range of hydrological regimes throughout the different river basins in Chile. In a very broad sense, it is possible to group these river basins into 4 Macroregions – North, Central, South, and Austral – listed below. By no means is this grouping intended to be the definite categorization, but it is provided here as a way of simplifying to some extent the understanding of the patterns of variability existing in the country. Figure 2.1 identifies sample watersheds, representative of Chile's Hydrometeorological Macroregions.

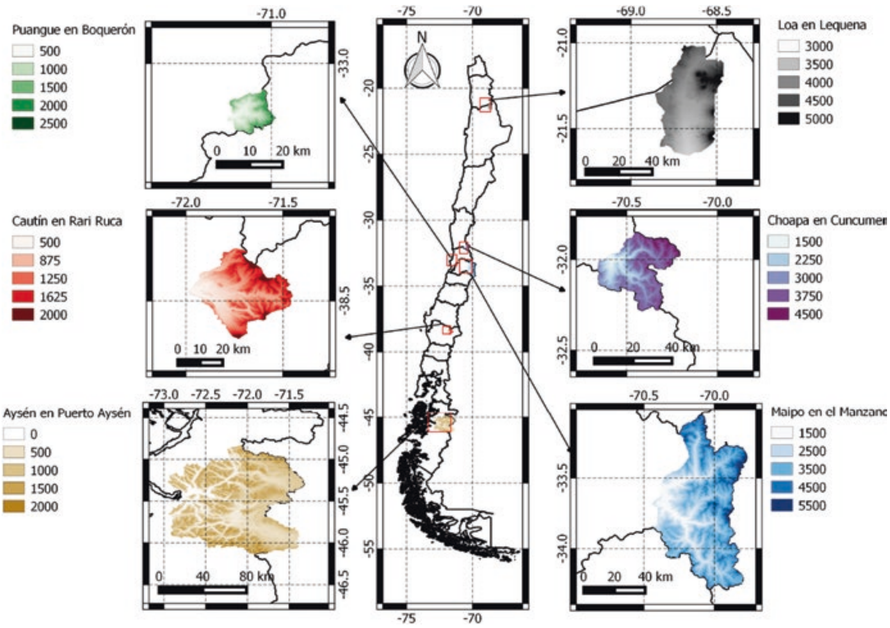

Fig. 2.1 Altitude (masl) of sample watersheds representative of Chile's Hydrometeorological Macroregions. (Elaborated based on public data)

2.2.1 North Macroregion: Edorheic and Exorheic Atacama Desert Waterseds

Non-negligible precipitation in the high elevations in the Andean High Plateau generates surface and subsurface water flows that feed endorheic and exorheic[1] basins in the hyper-arid North Macroregion. Endorheic basins typically present surface water bodies such as shallow lagoons, or salars, within them. Evaporation from these lagoons is usually the only water outlet in the basin, which yields highly saline surface waters. At some locations, groundwater flows west from the high-plateau and seeps to the surface in the steep hillslopes leading to the Atacama Desert. These flows constitute oasis where human populations have been established for centuries. These exorheic basins cut through the desert, and streams are fed from intense convective storms occurring during the southern summer or fall, and sometimes from snowmelt streaming from the upper reaches of the desert Andes, where a shallow snowpack can usually be found in the winter months. The average daily annual flow is very low in watersheds of this Macroregion. For example, as can be seen in Fig. 2.2 annual average daily water flow during summer months in the Loa Basin is

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[1] Endorheic is a closed drainage basin that allows no flow to external water bodies; exorheic, is a basin that drains to other water bodies such as the ocean.

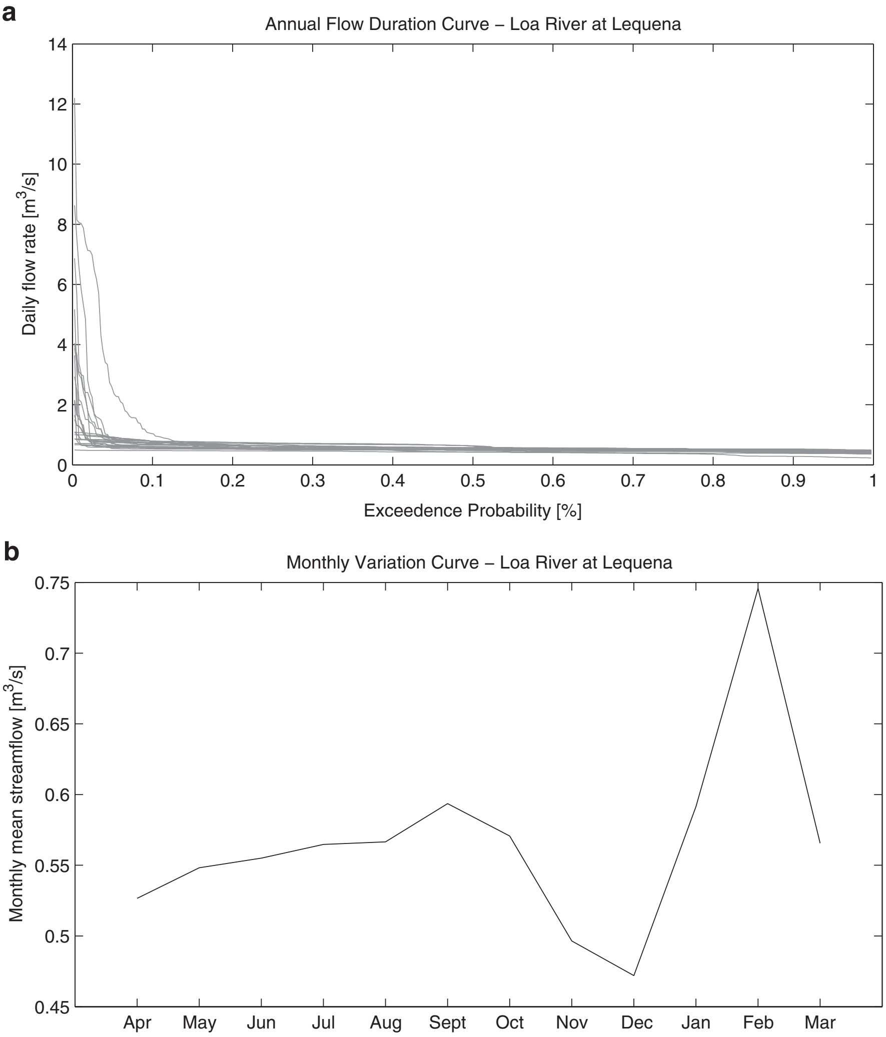

Fig. 2.2 (**a**) Ensemble of annual flow duration curves of mean daily flows, (**b**) Mean monthly flow climatology, Loa River at Lequena station. (Elaborated based on public data)

0.7 m^3/s[2] during 20–80% of the time. In these northern basins, surface-subsurface water interaction is a significant component of the hydrological cycle, and this in turn signifies a heightened role of groundwater as a water source in many river basins where surface streams run dry for extended periods of time. Because precipitation in this zone occurs mainly in remote, unpopulated regions, predominantly in the form of convective storms, a great deal of uncertainty in water resource

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[2] 1 $m^3/s = 259 \times 10^6$ m^3/month.

availability stems from the difficulty in estimating areal precipitation, as well as effective groundwater recharge.

In this Macroregion, aquifers have a significant role as a source of water resources, mainly for mining and agricultural activities. Annual estimated recharge is 10 m^3/s while average discharge ranges between 10 m^3/s and 20 m^3/s. Thus, sustainability of actual groundwater use is a major concern in these regions.

2.2.2 Central Macroregion

2.2.2.1 Snow-Dominated Central Chile Watersheds

Between latitudes 25 °S and 40 °S the most salient hydrological processes are the accumulation and melt cycles of snow and ice (cryosphere) in the Andes Cordillera, which result in the snow- and ice-dominated hydrological regimes of most of the watersheds that supply water to human and environmental systems. The Andes, whose peak elevation in this region is in the order of 4000–6000 masl, generates an orographic enhancement effect that favors snow accumulation on the western slope of the cordillera. Mean annual precipitation values here more than doubles what can be observed in the lower elevation central valley, and range between 500 and 2500 mm per year in the mountain reaches (Cornwell et al. 2016). With more than 1000 individual glaciers, and covering a surface area exceeding 900 km^2, glaciers are able to reduce the interannual variability observed in precipitation, sustaining base flows in mountain watersheds; thus, playing a relevant hydrological role. Their effect is most significant during the dry late-summer months of February and March, and under drought conditions their hydrological input may exceed 50% of dry-season flows in large mountain basins (Ohlanders et al. 2013; Rodriguez et al. 2016). Like other mountain regions of the world, the cryosphere of the Andes is rapidly disappearing due to recent trends in temperature, and less significantly, precipitation. The effect of global warming can be especially seen in the areal extent of glaciers in this region, which have been shrinking rapidly since records were first established (Masiokas et al. 2016). Annual average daily flow in these watersheds is 500 times that of the North Macroregion. Figure 2.3 presents the Maipo basin's annual average daily water flows. These range between 100 m^3/s and 300 m^3/s during 20–80% of the time, concentrated in spring and summer months.

Groundwater resources in this macroregion are replenished by a combination of precipitation and riverbed infiltration during the high-melt flow season (McPhee et al. 2012) and, thus, recharge is significantly greater reaching 50–100 m^3/s. There is limited information on average annual discharge, and thus there is uncertainty with respect to the sustainability of groundwater use in these regions.

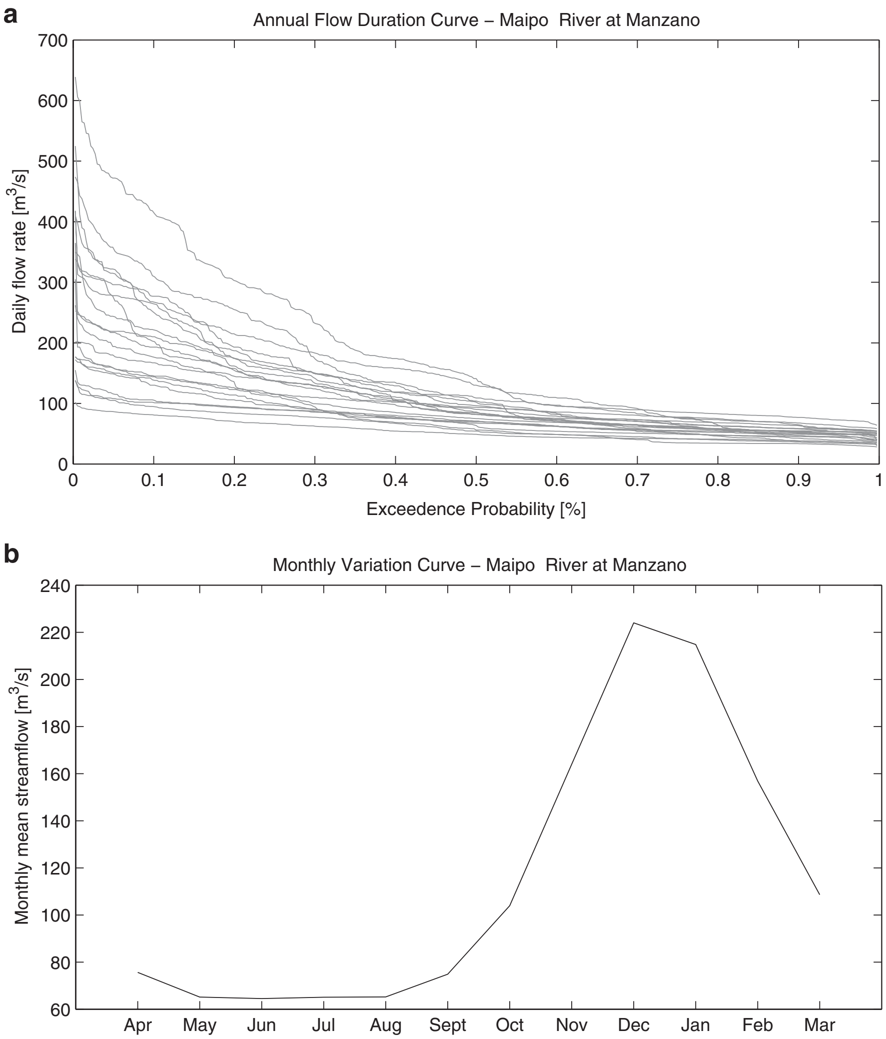


Fig. 2.3 (**a**) Ensemble of annual duration curves of mean daily flows, (**b**) mean monthly flow climatology, Maipo River at El Manzano station. (Elaborated based on public data)

2.2.2.2 Mediterranean Coastal Rivers

Along the Chilean coast, between latitudes 33 and 40 °S, the coastal range is of sufficient height to generate an orographic enhancement effect that sustains many small and medium size watersheds. Many of these coastal range watersheds lack stream gages, but are nevertheless relevant for sustaining small rural communities and ecologically relevant hydrological systems.

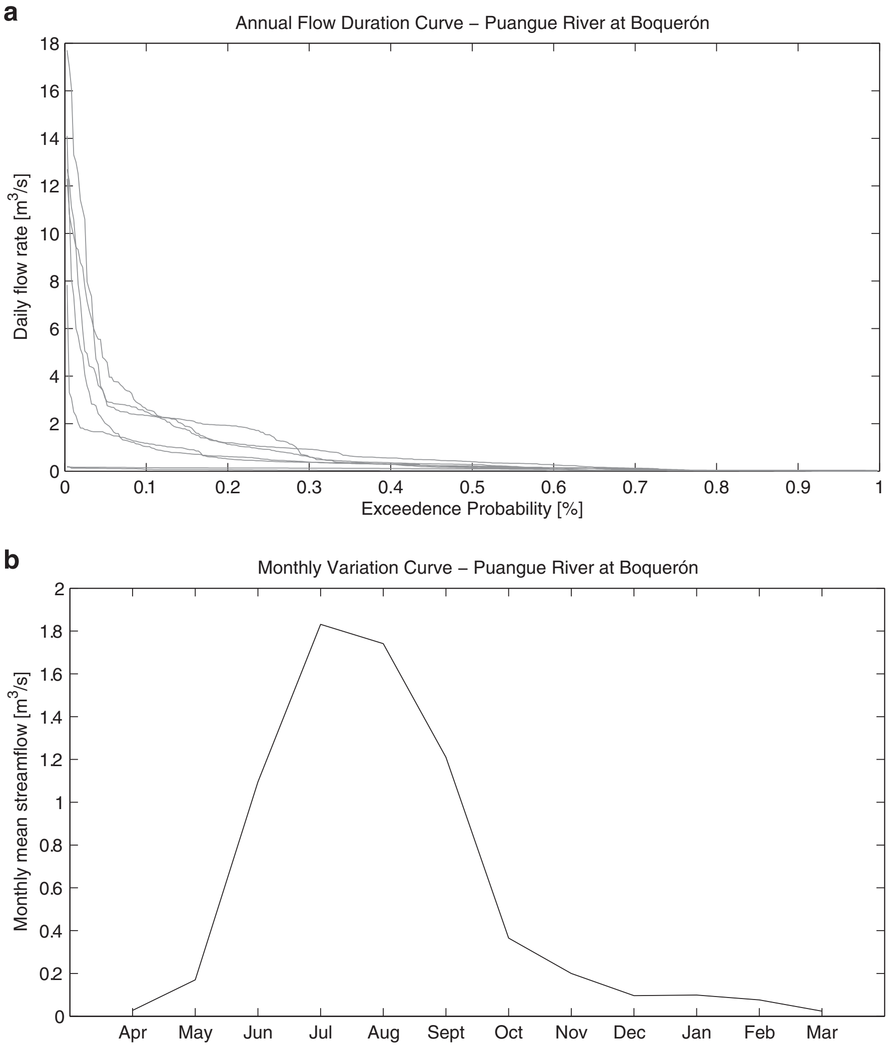


Fig. 2.4 (**a**) Ensemble of annual duration curves of mean daily flows, (**b**) mean monthly flow climatology, Puangue Creek at El Boquerón station. (Elaborated based on public data)

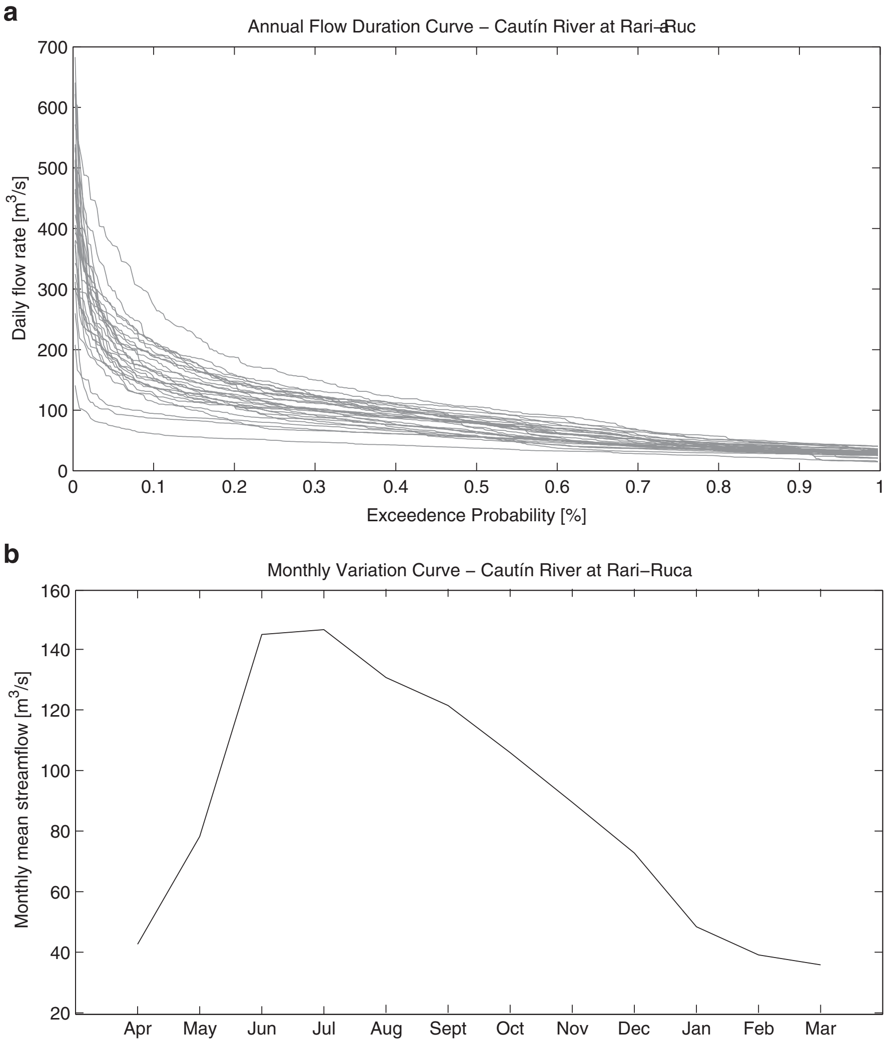
No significant snowpack can accumulate at the low elevation of the coastal range, so the hydrological regime here is exclusively rain-fed, with peak flows during storms in the winter months between June–August. Base flows are sustained mostly by subsurface flows, and depending on the amount of annual precipitation and catchment area, both intermittent and perennial streams can be found. Thus, annual average daily water flows in these rivers is significantly lower than in the Snow-dominated Central Chile watersheds. The Puanque river has an average daily water flow between 0.5 m^3/s and 1.6 m^3/s during 40% and 80% of the time (Fig. 2.4).

2.2.3 South Macroregion: Temperate Humid Watersheds

The northern edge of the Patagonia region is characterized by a marked increase in annual precipitation, which allows for the existence of dense deciduous and evergreen forests. The Andes Cordillera drops significantly in height in this region, reaching elevations in the order of 2000 MASL. Nevertheless, lower winter temperatures associated with the higher latitude here allow for the accumulation of a sizeable snowpack at the higher reaches of the Andes. This leads to the fact that the hydrological regime here is of a mixed nature, with rainfall-runoff processes dominating in winter months and snowmelt contributing to river flows in spring and early summer. Intense past volcanic activity originated a peculiar type of soils in this region, such that a low-permeability ash layer of volcanic nature can be found underneath medium to shallow organic soils. Therefore, groundwater storage is generally assumed to be of little importance in this area, as infiltration may not penetrate to the lower strata, limiting the available volume for groundwater storage. However, the influence of root systems and high organic content of the upper soil layer favors high porosity conditions, which are also supposed to allow for a significant shallow-subsurface flow component. Interannual variability in precipitation is lower here compared to what can be observed in the northern half of the country. Therefore, annual streamflow distribution tends to be quite consistent; the Cautin Basin has average daily water flows between 80 m^3/s and 120 m^3/s during 20% and 80% of the time (Fig. 2.5). Also, even though many of these rivers are rain-fed, the prevalence of spring and summer frontal systems sustains fairly significant base flows even during the driest season of the year (Fig. 2.5).

2.2.4 Austral Macroregion: Cold Humid Patagonia Watersheds

Patagonia's climate is characterized by precipitation that is fairly distributed throughout the year, with a somewhat rainier season during the austral winter but generally showing significant rainfall throughout the year. Low temperatures at these higher latitudes allows for snow peaks to exist longer in many river basins, even when the Andes Cordillera seldom exceeds 1000 masl in elevation here. These snowy peaks and glaciers that cap many volcanoes in the region contribute to sustain base flows at the end of the very short dry season, between January and March. During the rest of the year, consistent precipitation feeds streamflow in river networks that respond quickly to storms due to the generally high moisture content of soils. Many large rivers in the Patagonia region show a distinctly glacial hydrological regime, as they are fed by ice-melt from the Northern and Southern Patagonian Ice Fields, the largest ice masses in the southern hemisphere outside Antarctica. The eastern portion of this region is located in a rain shadow, because the Andes here is



Annual Flow Duration Curve − Cautín River at Rari−Ruca

Monthly Variation Curve − Cautín River at Rari−Ruca

Fig. 2.5 (**a**) ensemble of annual duration curves of mean daily flows, (**b**) mean monthly flow climatology, Cautín River at Rari Ruca station. (Elaborated based on public data)

highest near the Pacific Ocean. Therefore, vegetation is usually scarcer there and significant erosion can be observed in some areas. Streamflow interannual variability is even smaller as we travel south, as the close disposition of daily flow duration curves can attest (Fig. 2.6). Given the increased surface water supply, groundwater is not an important water source.

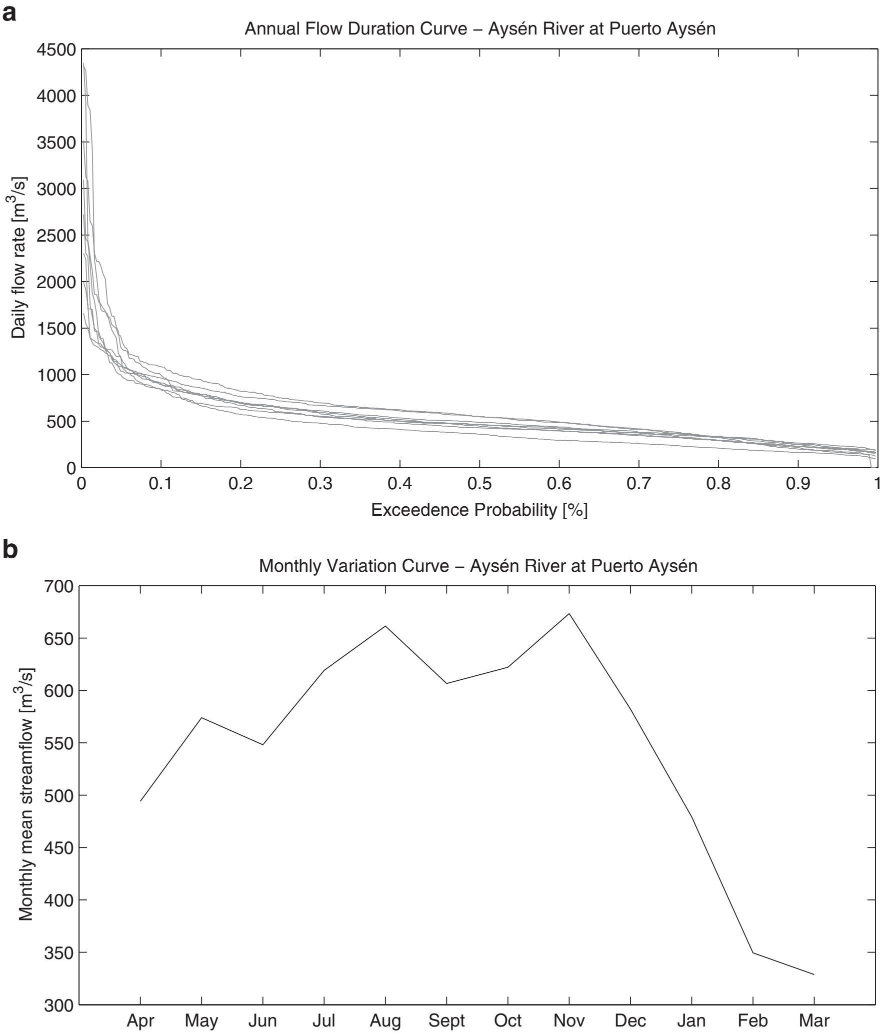


Fig. 2.6 (**a**) ensemble of annual duration curves of mean daily flows, (**b**) mean monthly flow climatology, Aysén River at Puerto Aysén station. (Elaborated based on public data)

2.3 Conclusions

The material presented in this chapter demonstrates the dramatic diversity of hydrological settings in Chilean watersheds. Drastically different runoff generation mechanisms, as well as distinct patterns of seasonal and interannual variability, emerge. Precipitation input is a major source of uncertainty when attempting to issue hydrological predictions, because the monitoring network is limited in high-elevation upstream areas, where usually runoff generation is more effective. A second source of uncertainty in the northern half of the country is the extent, capacity, and natural recharge rate of major aquifer systems. A limited observation well network, and a potentially large volume of un-gauged groundwater extractions hinder severely the ability of public and private actors to quantify the water balance of groundwater systems. In mountainous snow and glacier dominated watersheds, remote sensing technology has increased significantly the ability of monitoring valuable resources. Nevertheless, challenges still exist, since most satellite-based platforms can only quantify the areal extent of snow and ice, whereas actual water equivalent volumes are still only measurable at discrete, point locations. In temperate humid regions, land use change represents the largest source of uncertainty in predicting future hydrological behavior.

Throughout the country, extreme events have a high destructive potential. Short, intense storms in northern Chile are known to generate large flash floods and debris flows events that affect with some recurrence many populated areas in the arid north and central Chile. Warm storms and convective summer events may mobilize large volumes of soils from mountain watersheds, interfering with water supply and representing a danger to people and property. Large winter floods are common in low-laying areas in Southern Chile, often affecting both urban and rural populations.

The above phenomena may be exacerbated by climate change which is expected to affect Chile in a complex fashion, both through increased temperatures year-round and through decreased annual precipitation in the central region of the country, between latitudes 25 and 45 °S (Donoso 2017).

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Chapter 3
Water Quality: Trends and Challenges

Alejandra S. Vega, Katherine Lizama, and Pablo A. Pastén

Abstract The complex dynamics of the interactions between natural factors (geology, hydrology, biogeochemistry) and human factors (mining, agriculture, urban space, infrastructure) underlie a diverse range of challenges related to water quality throughout Chile. Water quality in Northern Chile is characterized by high local concentrations of dissolved salts, metals, and metalloids in surface and groundwater. Salts and metals show decreasing concentrations towards Central Chile due to higher water discharge; yet still local enrichments are observed in some tributaries (notably copper). Reservoirs and lakes in Central Chile show mesotrophic and eutrophic conditions with chronic episodes of algal blooms and fish kills from the high influx of nutrients linked mainly to diffuse pollution from agriculture and urban wastewater discharges without tertiary treatment. Water quality in Southern Chile is characterized in general by low dissolved salts concentrations and oligotrophic to oligo-mesotrophic conditions, with local exceptions in streams and bodies of water that receive industrial and treated urban wastewater discharges or that are used for fish farming. Several challenges to water policy arise when considering water quality issues: (i) integrated management approach to water quality; (ii) a more comprehensive and dense monitoring network; (iii) protection and improvement of the trophic state of Chilean lakes and reservoirs; (iv) promote the use of more sustainable treatment alternatives like enhanced natural attenuation and constructed wetlands.

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Keywords Chile · Diffuse pollution · Point source pollution · Water quality · Water trophic conditions

3.1 Introduction

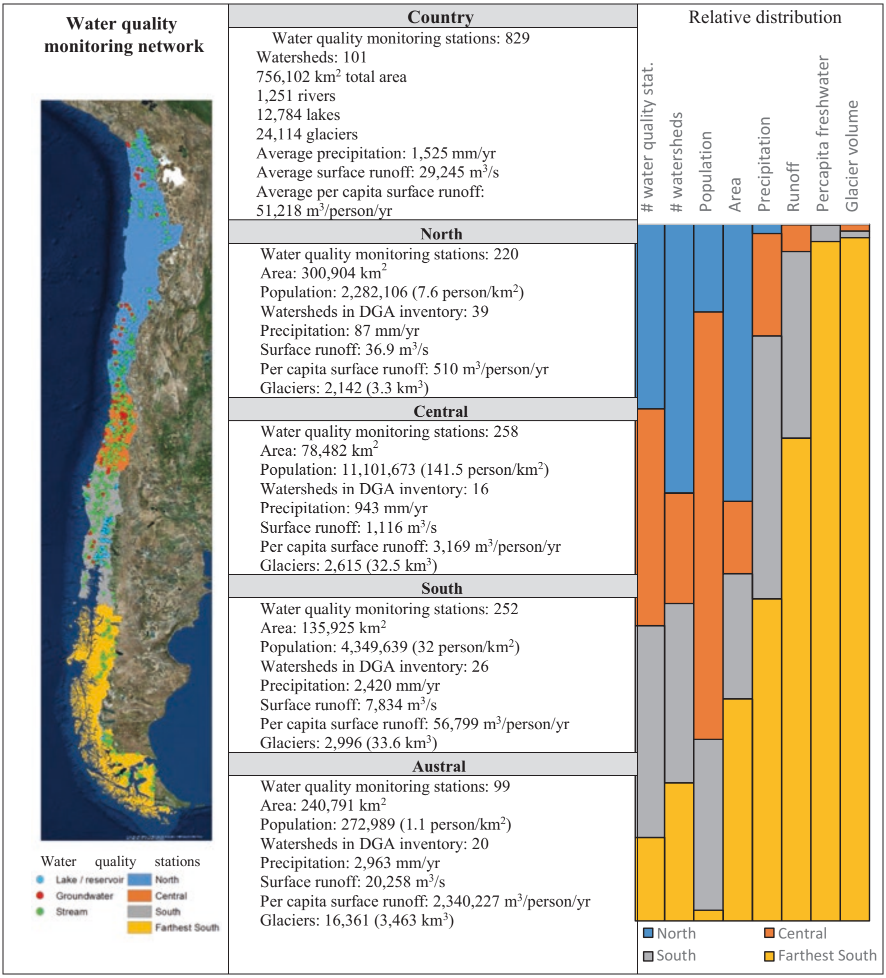
Water quality is assessed by a set of physicochemical and biological characteristics of water in relation to an intended use, such as human consumption, irrigation, supporting natural ecosystems, and recreation. Water quality parameters are controlled by the complex interaction of natural and human factors across the territory, which, in the case of Chile, reflects a wide variety of hydrological and geochemical settings interacting with a range of socioeconomic activities, notably mining, agriculture, aquaculture, forestry, hydroelectricity, urban soil use, and the operation of urban sanitary infrastructure. These activities thrive on sufficient and safe water, yet they also impact water quantity and quality, shaping a formidable challenge for water policy, particularly for the sustainable use of water resources and the protection of ecosystems.

Much has been advanced in characterizing and understanding water quality in Chile, notably since the early work by Klohn (1972) that presents a first description of water quality in Northern Chile up to the recent atlas published by the Chilean water agency—DGA (Dirección General de Aguas 2016) that provides an overview based on the DGA's national monitoring network. Despite considerable advances in water quality monitoring and a growing number of works revealing how geochemical and hydrologic processes control water quality, advances in decision and public policy making are still hampered by insufficient data and integrated processes understanding. To that extent, this chapter aims to: (i) provide a synopsis of key parameters determining the quality of continental waters (i.e., surface and groundwater) across different Chilean regions using datasets from the government and scientific studies; (ii) discuss case studies that portray the complex interaction between natural and anthropogenic factors controlling water quality; and (iii) summarize the trends and challenges in water quality for Chilean water policy, with emphasis in areas of mineral enrichment and aridity, urban areas, and pristine environments.

3.2 Water Quality Across Chilean Regions

3.2.1 The Water Quality Monitoring Network in the Context of the Chilean Hydrography, Hydrology, and Geochemistry

A striking characteristic of the Chilean hydrography and hydrology is the variety of climatic conditions ranging from those of the hyper arid Atacama Desert in Northern Chile to those of the rainy cool oceanic climate. The DGA inventory includes 101 watersheds with 1,251 rivers, 12,784 lakes, and 24,114 glaciers (Dirección General de Aguas 2016). Chilean water resources may be divided for descriptive purposes in four regions according to its hydrographic and hydrologic traits: North, Center,



Country

Water quality monitoring stations: 829
Watersheds: 101
756,102 km^2 total area
1,251 rivers
12,784 lakes
24,114 glaciers
Average precipitation: 1,525 mm/yr
Average surface runoff: 29,245 m^3/s
Average per capita surface runoff:
51,218 m^3/person/yr

North

Water quality monitoring stations: 220
Area: 300,904 km^2
Population: 2,282,106 (7.6 person/km^2)
Watersheds in DGA inventory: 39
Precipitation: 87 mm/yr
Surface runoff: 36.9 m^3/s
Per capita surface runoff: 510 m^3/person/yr
Glaciers: 2,142 (3.3 km^3)

Central

Water quality monitoring stations: 258
Area: 78,482 km^2
Population: 11,101,673 (141.5 person/km^2)
Watersheds in DGA inventory: 16
Precipitation: 943 mm/yr
Surface runoff: 1,116 m^3/s
Per capita surface runoff: 3,169 m^3/person/yr
Glaciers: 2,615 (32.5 km^3)

South

Water quality monitoring stations: 252
Area: 135,925 km^2
Population: 4,349,639 (32 person/km^2)
Watersheds in DGA inventory: 26
Precipitation: 2,420 mm/yr
Surface runoff: 7,834 m^3/s
Per capita surface runoff: 56,799 m^3/person/yr
Glaciers: 2,996 (33.6 km^3)

Austral

Water quality monitoring stations: 99
Area: 240,791 km^2
Population: 272,989 (1.1 person/km^2)
Watersheds in DGA inventory: 20
Precipitation: 2,963 mm/yr
Surface runoff: 20,258 m^3/s
Per capita surface runoff: 2,340,227 m^3/person/yr
Glaciers: 16,361 (3,463 km^3)

Fig. 3.1 Water quality monitoring stations and Chilean continental waters at a glance (Authors elaboration based Dirección General de Aguas (2016))

South, and Austral. The DGA monitoring network for water quality includes 829 stations, for streams, for groundwater, and for lakes and reservoirs. For each site, 1–12 samples per year are taken, depending on operational definitions and constraints (typically 3 for streams and groundwater and 2 for lakes and reservoirs). Figure 3.1 shows the distribution of water quality monitoring stations at the national level and for each region, including some basic statistics for each region. In 2014, about 39% of the 101 watersheds in the DGA inventory were not actively monitored, 19% had only 1 water quality monitoring station, and only 19% had 10 or more water quality monitoring stations (Dirección General de Aguas 2014).

The distribution of monitoring stations concentrates on areas of water scarcity, higher population density, and areas of human activity. Its distribution in surface water streams aims to depict water quality upstream and downstream from potential anthropogenic "pressures" (activities that may impact water quality), thus it could

Table 3.1 Parameters measured in surface waters by the national water quality monitoring network operated by the DGA. The parameters measured in the laboratory include their detection limit as of 2014

Parameters measured in the field			
Temperature, pH, electrical conductivity, and dissolved oxygen (O_2)			
Parameters measured in the laboratory			
Analyte	Detection limit (mg/L)	Analyte	Detection limit (mg/L)
Ag	0.01	K	0.2
Al	0.3	Mn	0.02
As	0.001	Mg	0.1
B	1.0	N	0.01
Ca	0.4	Na	0.2 at 589 (nm); 12.0 at 330 (nm)
Cd	0.01	Mo	0.05
Cl^-	1.0	Ni	0.02
Co	0.01	Pb	0.05
COD	1 (lakes); 3.0 (other types)	PO_4^{3-}	0.012 (lakes); 0.003 (other types)
Cr	0.01	Se	0.001
Cu	0.02	SO_4^{2-}	3.0
Fe	0.02	Zn	0.01
Hg	0.001		

Source: Dirección General de Aguas (2014)

help contrast a “natural state” and a possible impacted condition. Nevertheless, in many Andean watersheds it is difficult to establish a “natural state”, since a high natural enrichment may occur and human interventions may be located in the upper sections, especially for metals and dissolved salts in mining areas in Northern and Central Chile. In such cases, careful geochemical studies involving the analysis of geochemical tracers and models are needed to discriminate between the natural background and human pollution.

Table 3.1 shows the parameters considered in the national water quality monitoring network for streams and groundwater. It includes parameters that are measured in the field (temperature, pH, electrical conductivity, and dissolved oxygen) and those measured in the DGA laboratory (ISO17025 accredited): a wide range of metals, anions, nutrients (nitrogen, phosphate), and one aggregate organic parameter (chemical oxygen demand, COD). Table 3.1 also shows the detection limits in place in 2014 for those parameters measured in the DGA laboratory (Dirección General de Aguas 2014). Depending on the intended water use, this list of parameters may be insufficient for assessing the water quality of streams and groundwater. In some cases, the detection limit of the measurement may be larger than the value against it will be compared to.

The DGA monitoring network is not the only source that reports measurements of water quality parameters. Other sources of water quality information include:

(a) *Secondary water quality standards surveillance plans:* just recently, several watersheds and lentic waters have in place secondary water quality standards (known as NSCA by its Spanish acronym). This framework includes a surveillance plan for a predefined set of parameters, locations and monitoring frequency. The current secondary standards in place are for the following watersheds: Serrano, Maipo, Biobío, and Valdivia, and for the Villarrica and Llanquihue lakes. For the following watersheds, secondary water quality standards are being prepared[1]: Aconcagua, Mataquito, Elqui, Rapel, and Huasco.

(b) *Environmental impact assessment platform:* the Chilean law 19.300 Bases for the Environment enacts the Environmental Impact Assessment System (known as SEIA by its Spanish acronym) which requires that a range of new investment projects or modifications conduct an environmental impact assessment. When activities entering the SEIA have the potential to impact water, they are required to consider a water quality baseline and a water quality surveillance program. Such information is available through the SEIA and the Superintendence of the Environment (known as SMA by its Spanish acronym) platforms.

(c) *Superintendence of Sanitary Services (known as SISS by its Spanish acronym)*: all water companies that provide drinking water and wastewater treatment according to the Chilean concession system are required to comply with drinking water and treated wastewater discharge standards. Although not available through a web platform, specific data may be requested via the transparency law that compels the public service agencies to respond to public data requests.

Despite the high costs of not having a complete water quality monitoring network, Chile still does not have an integrative water quality clearinghouse that takes advantage of different monitoring programs from miscellaneous data sources. Furthermore, the approach to water quality is mostly statistical, without systematically supporting conceptual and quantitative models helping to frame data interpretation. An improved approach for water quality monitoring and data management should be coherent with an integrated watershed management approach.

3.2.2 Water Quality Trends for Streams, Groundwater and Lakes in Selected Watersheds

The DGA water quality database contains more than 50 years of water quality measurements across the country and over 1 million reported values for 63 watersheds (out of 101). Here, we provide a broad overview of the spatial trends for 21 selected watersheds and key water quality parameters for each type of water source (i.e. streams, groundwater and lakes). The selection of watersheds considered area, population, and/or geographic representativeness. For each monitoring station within the 21 selected watersheds, we discarded entries reported anomalous by the DGA and entries dated before 1980. We also discarded for each station data series the extreme outliers, defined as values lower than Q_1–3*IQ or greater than Q_3 + 3*IQ, where Q_i refers to the ith quartile and the interquartile range IQ = Q_3−Q_1. Only

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[1] Information retrieved from the Ministry of the Environment public expedient http://planesynormas.mma.gob.cl on 06/20/17.

sampling stations with 10 or more values were considered in the statistics. For lakes, a database previously distilled by DGA was used.

Figures 3.2, 3.3, and 3.4 show the water quality snapshot of key parameters for streams (pH, EC, COD, As, B, NO_3^-), groundwater (pH, EC, Cl^-, As, B, NO_3^-), and lakes (pH, EC, COD, NO_3^-, total P, chlorophyll a) throughout Chile, respectively. Boxplots were used to provide a graphical representation of the variability of each parameter within the watershed. It is important to emphasize that the aim of these figures is to render a broad view at the country level, and not to reveal specific site or temporal trends. A few studies have looked into the DGA database to study specific sites, processes and trends (e.g.,Pizarro et al. 2010a, b).

3.2.2.1 Streams

Streams pH values fluctuate in general between 6.5 and 8.5 with two watersheds in Northern Chile showing remarkable low pH values: the Lluta River and the Elqui River watersheds, both related to tributaries seriously impacted by acid drainage (Galleguillos et al. 2008; Oyarzun et al. 2012; Leiva et al. 2014; Ribeiro et al. 2014; Guerra et al. 2016a, b; Abarca et al. 2017; Arce et al. 2017; Flores et al. 2017). The pH value[2] indicates how acidic ($pH < 7$) or alkaline ($pH > 7$) is the water. It is a central parameter that controls the bioavailability of nutrients and the toxicity and mobility of metals, impacting the extent of aquatic life and transport of contaminants.

Electrical conductivity accounts for the dissolved salts concentrations. High EC may restrict water for irrigation purposes and as drinking water sources. Besides acid drainage, high EC may be linked to geothermal sources, exchanges with groundwater (i.e. return flows from irrigation), high evaporation and poor dilution in arid climates. Thus, high EC values are observed preferentially in watersheds in Northern Chile with extreme values above 15 mS/cm[3] (e.g., Loa River watershed) associated to geothermal springs. El Tatio geothermal field is a world attraction that contributes elevated dissolved salts and arsenic concentrations to the drainage network downstream via the Salado River (Bugueño et al. 2014). El Tatio geothermal field is not a case of acid drainage, as pH values of the springs are circumneutral to alkaline. Groundwater further contributes alkaline, saline and arsenic-rich waters to the lower Loa River watershed.

High boron concentrations are also observed in the Lluta and Loa watersheds (Fig. 3.2). Boron is a well-known phytotoxic. Thus, poor water quality due to boron enrichment may become a serious threat to agricultural development in the impacted watersheds.

Further south, local metal enrichment and saline conditions that become diluted downstream by favorable hydrological conditions may be found in the Aconcagua (Gaete et al. 2007), Maipo (Yerba Loca-Mapocho system (Segura et al. 2006; Montecinos et al. 2016; Pasten et al. 2015), Rapel (Pizarro et al. 2010b; Pizarro et al.

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[2] pH is a logarithmic measure of the effective concentration of hydrogen ions ($pH = -\log\{H+\}$).

[3] mS/cm = milliSiemens/centimeter = deciSiemens/meter = dS/m.

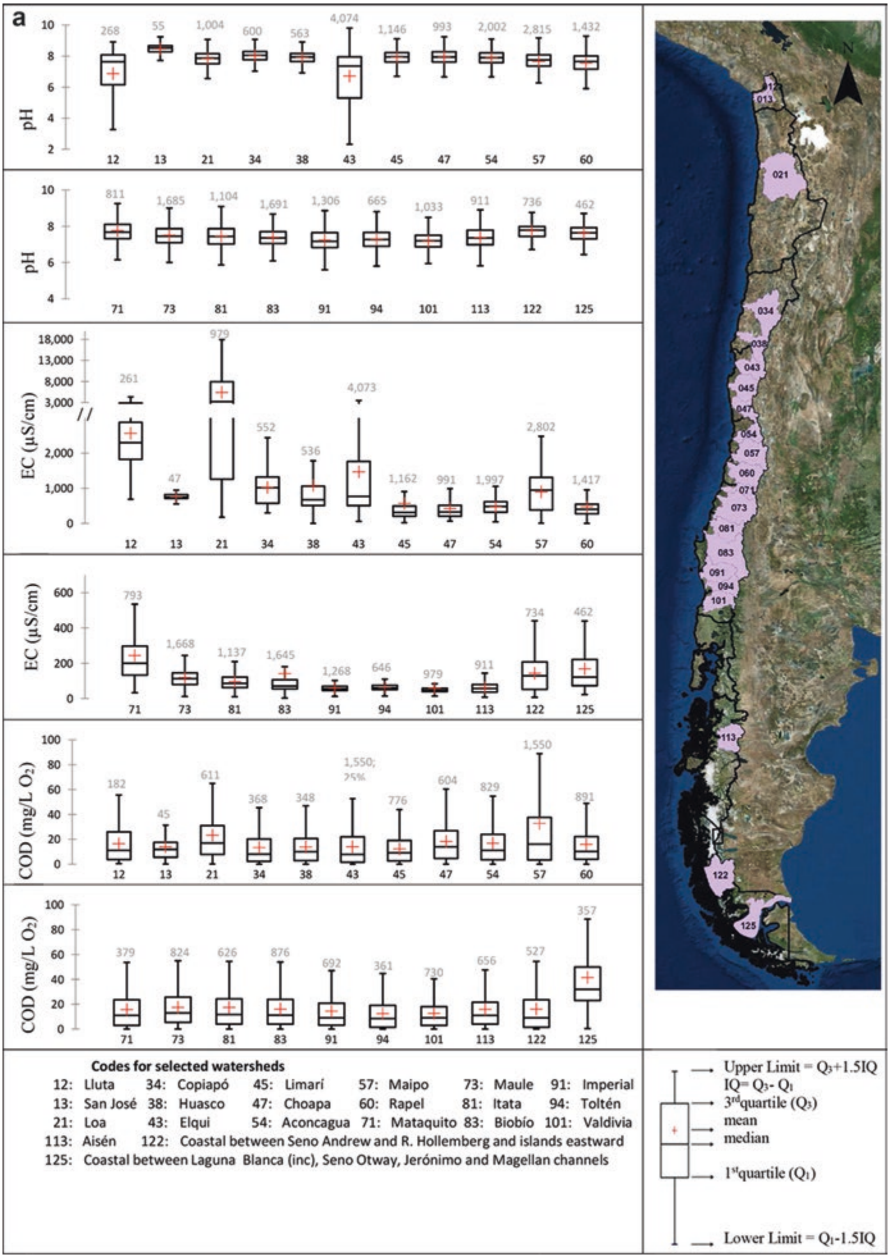


Fig. 3.2 Overview of water quality in Chilean streams across 21 watersheds. Two scales are used to highlight different ranges across watersheds. (**a**) pH, electrical conductivity (EC), and chemical oxygen demand (COD), (**b**) Arsenic (As), boron (B), and nitrate (NO_3^-) (Authors elaboration using raw data from DGA database)

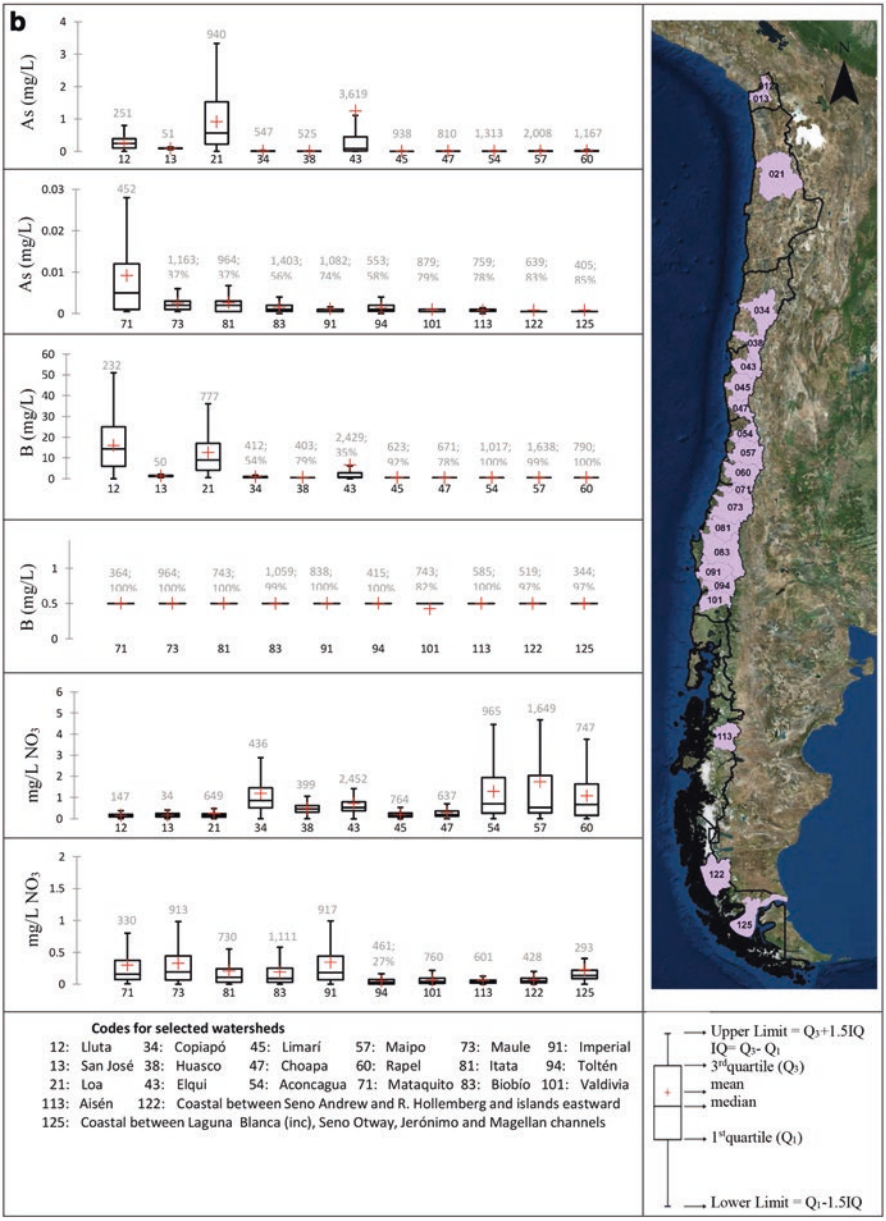


Fig. 3.2 (continued)

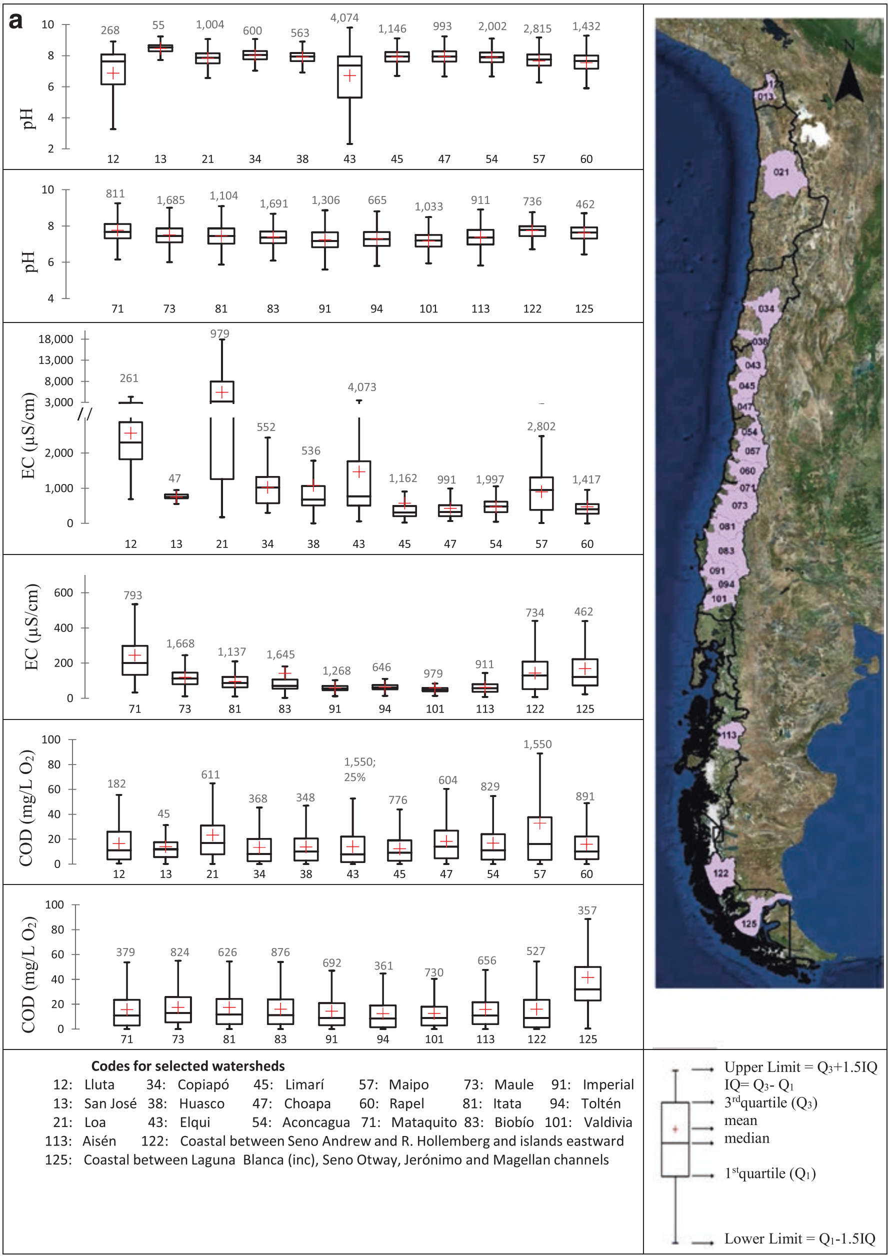


Fig. 3.3 Overview of water quality in Chilean groundwater across 21 watersheds. Two scales are used to highlight different ranges across watersheds. (**a**) pH, electrical conductivity (EC), and chloride (Cl$^-$), (**b**) Arsenic (As), boron (B), and nitrate (NO$_3$$^-$) (Authors elaboration using raw data from DGA database)

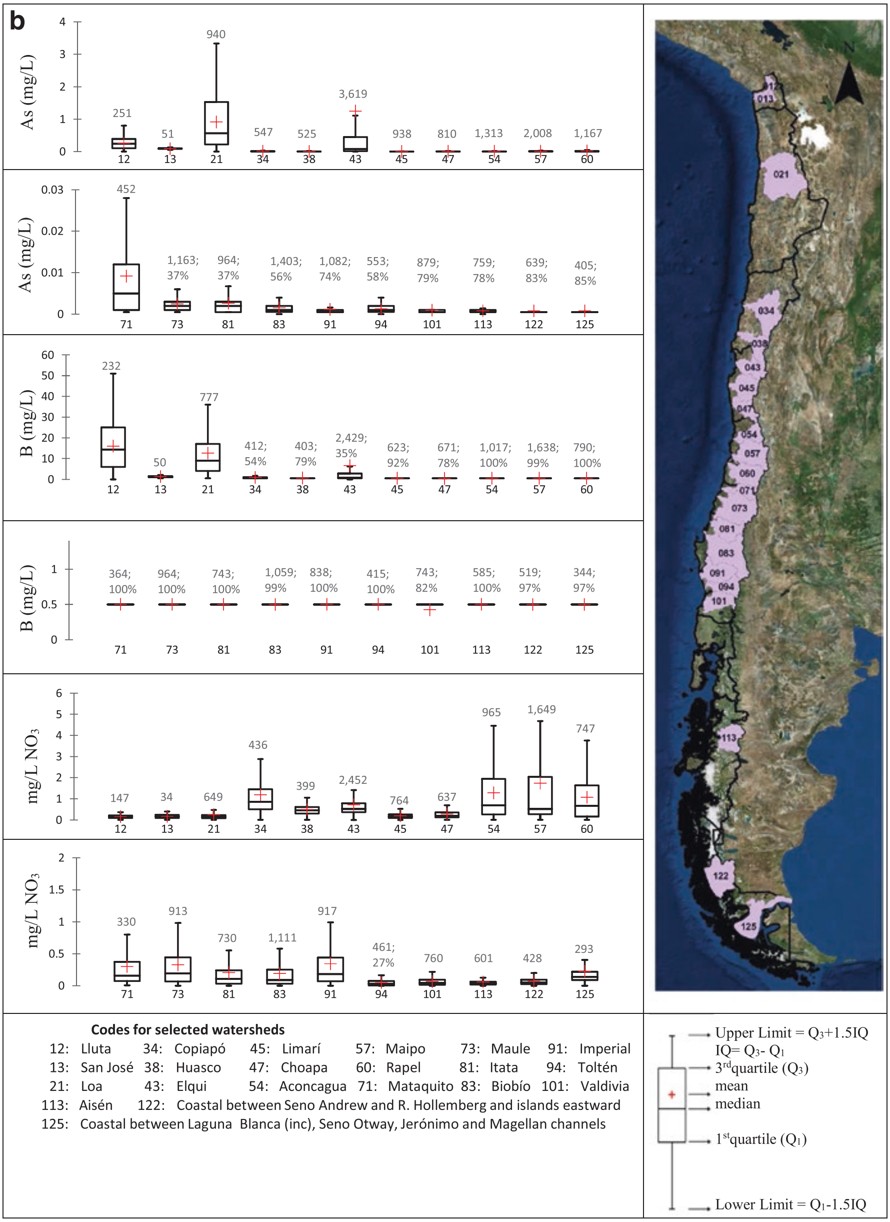


Fig. 3.3 (continued)

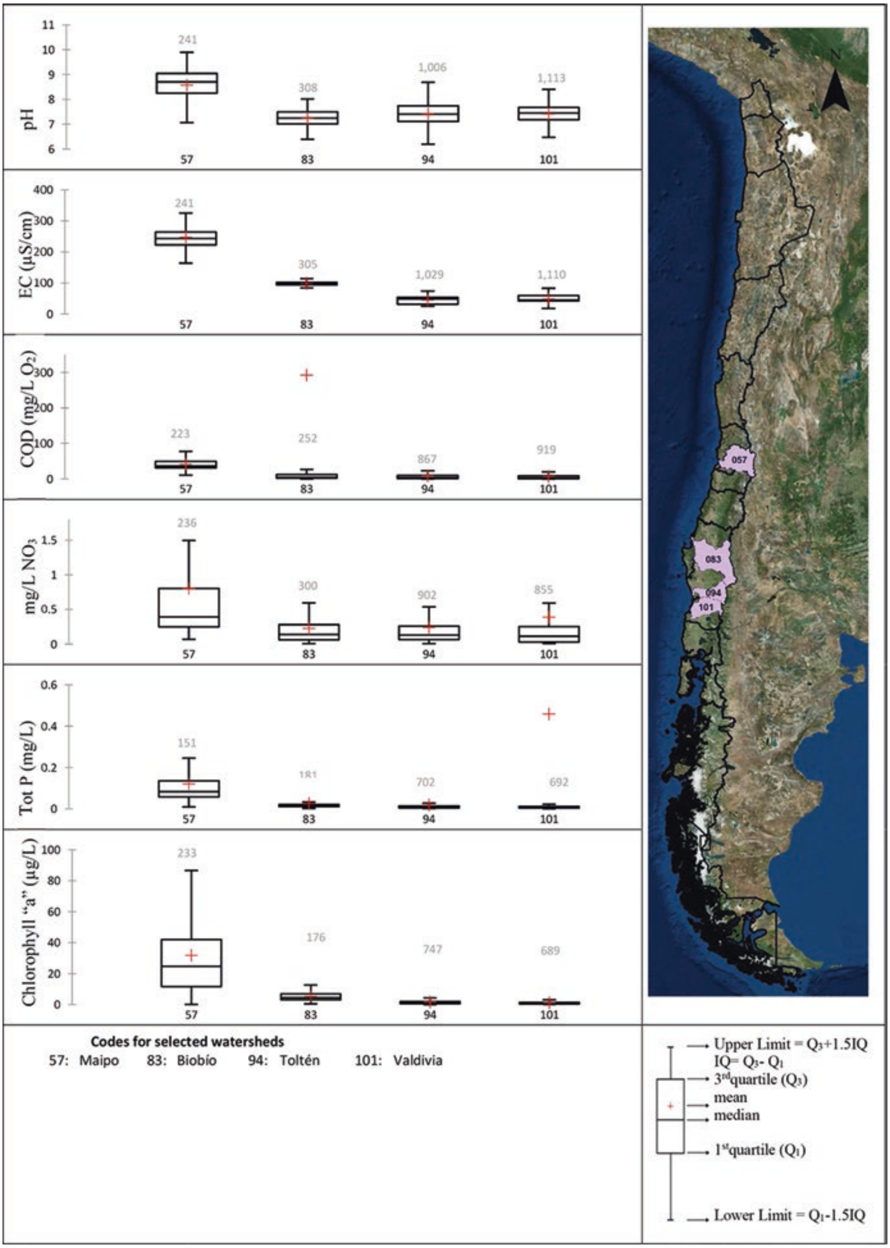


Fig. 3.4 Overview of water quality in Chilean lakes across 4 watersheds. Two scales are used to highlight different ranges across watersheds. (Authors elaboration using processed data from DGA)

2003), and Mataquito watersheds (Tapia et al. 2009). Despite these, watersheds in Central Chile show lower metal concentrations and salinities compared to those in Northern Chile. However, the concentrations are still quite high and pose a serious challenge to drinking water production and to irrigation. Furthermore, it is expected that the biggest mining developments in Chile will occur in Central Chile, thus understanding and monitoring metal enriched systems in this area is a high priority.

Nitrate enrichment in surface waters is observed in three Northern Chile watersheds (Copiapó, Huasco, Elqui) but the highest concentrations are observed in three Central Chile watersheds (Aconcagua, Maipo and Rapel). Although in a lower range, five watersheds in Southern Chile (Mataquito, Maule, Itata, Biobío, and Imperial) show some nitrate enrichment when compared to other watersheds further south (Toltén, Valdivia, Aisén and the coastal watersheds in the Farthest South region). Nitrate enrichment is generally associated to diffuse pollution from agricultural practices, a relationship that has been demonstrated in Chile (Ribbe et al. 2008).

With respect to COD, the highest values are found in two watersheds (Maipo and the Southernmost coastal area) with two different origins. The first is associated to the urban environment (likely raw and treated wastewater discharges during the considered timeframe) and the second is likely associated to livestock production (mainly bovine). Since COD quantifies the concentration of oxygen required to oxidize organic matter, COD indicates the presence of substances that will lead to consumption or even depletion of dissolved oxygen, such as those present in human and animal waste.

The Lluta River Watershed: A Model for the Interaction Between Natural and Anthropogenic Controls of Water Quality

In the case of the Lluta river watershed, the Azufre River drains an area with legacy elemental sulfur mining that ceased operation in the 1960s and that did not consider a proper mine closure program. Common pH values in the Azufre River are around 2, which means that the concentration of H^+ ions is 100.000 times that of neutral pH. Acid drainage that generates low pH values seriously impairs water uses like freshwater ecosystem services, drinking water sources and irrigation. It promotes highly reactive conditions that lead to the dissolution of geomaterials, increased dissolved heavy metals (notably arsenic), and with concurrent increased dissolved salts (notably sulfate). Pollutants from acid drainage are persistent and propagate through the drainage network. Natural attenuation processes mitigating dissolved toxic metal concentrations occur at river confluences receiving acid drainage (Guerra et al. 2016a; Abarca et al. 2017; Arce et al. 2017) and in wetlands where bacteria favor the immobilization of arsenic (e.g.,Leiva et al. 2014). Shifts in metal speciation (the chemical form of a metal, for example dissolved vs particulate chemical species) are key to understand the toxicity and mobility of metals. In the case of the Lluta River, the performance of water infrastructure strongly depends on water quality (e.g.,Rios et al. 2011).

(continued)

The Colpitas River in the Lluta watershed also shows high salinities associated to the Colpitas geothermal springs (known as “borateras” due to their high boron content) (Ramila et al. 2015). The high boron concentrations in the Lluta watershed have a strong negative effect on agriculture as it is a well-known phytotoxic and it restricts agriculture to salts and boron tolerant species like corn. A striking contrast may be observed when comparing to the neighbor San José watershed, where water rights and property value are about four times those in the Lluta River watershed.

The dependence of water quality from hydrological conditions in Andean watersheds seriously challenges water quality monitoring strategies as intra daily variations induced by snow melt can trigger dramatic changes in metal concentrations (Guerra et al. 2016b). The Chironta reservoir currently considered for irrigation and flooding control in the Lluta River valley will be a natural settling basin for arsenic rich particles and it will likely become an arsenic repository if preventive measures are not considered in its design and operation. The accumulation of metal rich sediments in reservoirs and lakes occurs in other metal-impacted watersheds like the Elqui River watershed (Galleguillos et al. 2008).

3.2.2.2 Groundwater

The variations of pH values in groundwater show a narrower and more uniform range throughout the country, even in watersheds impacted by acid drainage (Fig. 3.3). This is likely due to the buffering effect by the porous material in contact with groundwater. Watersheds in Northern Chile exhibit lower pH and broader ranges likely due to lower alkalinity and buffering capacity.

Electrical conductivity follows in general the trend of EC in surface waters, which is also shown in the chloride concentrations. Watersheds with high evaporation and agricultural practices exhibit the highest conductivities (e.g. Lluta, San José, Loa, Copiapó, Huasco). South from the Elqui River, EC is notably lower, with higher values in the Elqui, Limarí, Choapa and Maipo watersheds.

Nitrate and dissolved salts in groundwater may arise from a combination of natural geological formations in Northern Chile, while in Central and Southern Chile this may be associated locally with urban pollution and more broadly with agricultural practices (e.g., Fernandez et al. 2017; Yevenes et al. 2016; Fuentes et al. 2014; Arumi et al. 2005; Donoso et al. 1999).

3.2.2.3 Lakes and Reservoirs

Two issues have become important for Chilean lakes and reservoirs: eutrophication and metal enrichment in sediments. While the limited lake monitoring network focusses on assessing the trophic state through the measurement of nitrogen forms, phosphorus and chlorophyll a in the water column, it does not include systematic measurements of sediments. As shown in Fig. 3.4, nutrients and chlorophyll “a” levels are notably higher in Central Chile -Rapel reservoir and Aculeo Lake-, reflecting the trophic state of these water bodies as detailed in the following section.

Eutrophication

Eutrophication refers to the enrichment of an ecosystem with nutrients, typically nitrogen or phosphorous compounds. This phenomenon may occur naturally, but it is often enhanced by anthropogenic activities due to point and nonpoint pollution sources. Point sources include municipal and industrial wastewater discharges, whereas nonpoint sources include agricultural and urban runoff. Since nonpoint sources are diffuse and much more difficult to monitor and regulate, appropriate control of this phenomenon is a challenge. The relative contribution of point and nonpoint pollution sources varies substantially, depending on land use and local human population densities (Smith et al. 1999). The main consequence of the elevated nutrient levels is the occurrence of algal blooms, a rapid increase of the population of phytoplankton algae in a water body. Main effects of the excessive presence of algae include aesthetic effects and limited sunlight availability required for photosynthetic organisms, due to the increase in turbidity in the water column.

Eutrophication is one of the main water quality threats in the world and Chile is not an exception. Lakes and reservoirs throughout the country have been classified according to their trophic state using the definition of Smith et al. (1999). The definition of the trophic state of lakes is based on total nitrogen (TN), total phosphorus (TP), chlorophyll a, and Secchi disk transparency. Waters having poor nutrient supplies are defined as oligotrophic, whereas those having relatively large nutrient supplies are defined as eutrophic. Waters having intermediate levels are defined as mesotrophic. Some examples of Chilean lakes and reservoirs having different trophic states are El Yeso reservoir (oligotrophic), the Aculeo Lake (mesotrophic), the Peñuelas reservoir (hyper-eutrophic) and the Rapel reservoir (mesoeutrophic) (Ministerio de Obras Públicas 2014). The Rapel reservoir is known for its algal blooms, and the link between the operation of the hydropower plant and the water quality of the reservoir has been recently studied (Guzmán 2013; Ibarra et al. 2015; Rossel and de la Fuente 2015; Carpentier et al. 2017). These studies showed that the inclusion of environmental constraints in the operation of the hydropower plant such as the definition of minimum instream flow or maximum ramping rate of the turbine outflow, reduces both hydrological and thermal alteration of the river downstream. However, these environmental constraints also strengthen stratification, which may produce anoxic conditions thus aggravating water quality issues.

Metals in Sediments

The chemical composition of sediments has not been traditionally measured in monitoring campaigns as part of water quality assessments. Nevertheless, sediments play an important role in controlling the contaminant fluxes in waters. Ample evidence is available showing the enrichment of lakes and reservoirs with metals in Andean watersheds (Contreras et al. 2015; Galleguillos et al. 2008; Pizarro et al. 2009; Pizarro et al. 2006). Furthermore, the analysis of sediment cores may provide a historic registry of the metal dynamics in lakes and reservoirs. This is a central issue for reservoirs with metal enrichment as interactions between the metal and nutrient cycles may be observed. Events causing anoxic conditions may mobilize metals from oxidized sediments to the solid phase, notably by the microbial reduction of manganese and iron oxides.

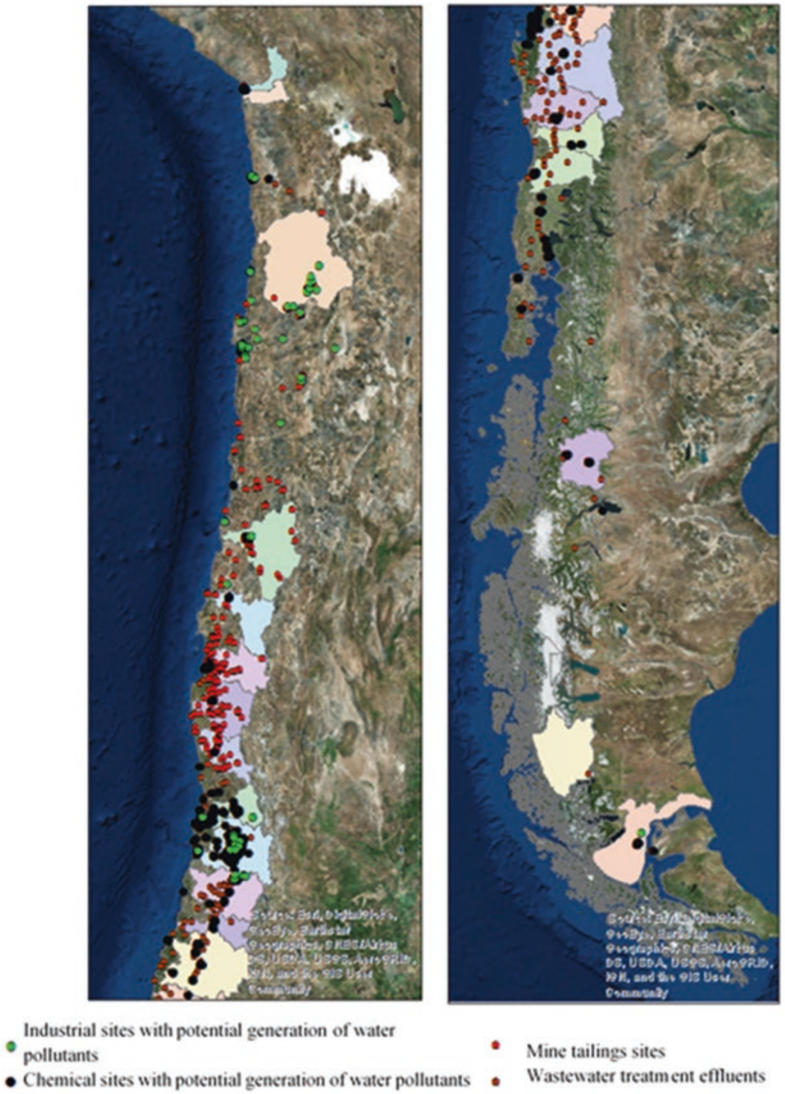
3.3 Water Quality Challenges with Implications to Water Policy

3.3.1 Integration of Water Quality Monitoring with Conceptual and Quantitative Models for Decision Making and Public Policy: Addressing Water Quality Conflicts in a Context of Climate Change

Water quality is at the center of water conflicts and sustainability agendas. Access to sanitation and safe and sufficient water is the obvious starting issue. However, the interdependencies of socio-environmental systems also prompts the need for public policy and decision making in issues related to water quality and food, ecosystem services, natural patrimony, and environmental justice.

A prime example of this challenge is the collision between mining, agriculture and cities that compete for soil and water in Central Chile. The largest copper reserves, considered currently in the expansion programs of mining companies, are located in Central Andes, right on the upper section of the most populated watershed in the country (Maipo), the main sources of water for urban and agricultural use for the Metropolitan and Valparaíso regions. Insufficient knowledge of the long term dynamics of metals from natural sources and acid drainage sources, and the uncertain fate of the glaciers potentially impacted by mining in a context of global change, challenge the sustainability of mining development in Central Chile.

A major caveat of the current state of the art in managing water quality in Chile is the lack of an integrated approach that articulates water monitoring (quantity and quality) with working conceptual and quantitative models. An integrated understanding of the dynamics of the interactions between watersheds and human pressures could provide a robust science-based approach for public policy and decision-making in issues involving water quality. Figure 3.5 shows the location of key human pressures, including mining, industry, and urban effluents. Feedback between conceptual models, quantitative models, and monitoring would drive continuous improvement, where local communities, industries, government agencies, and research institutions should play a fundamental role, as it is suggested in Fig. 3.6. The development of secondary water quality standards for priority watersheds and lakes sets a perfect stage for assembling integrated quantitative and conceptual models with surveillance plans.



Data sources:

a) Industrial and chemical sites from the registry of emissions and transfer of contaminants (Registro de Emisiones y Transferencia de Contaminantes, RETC);

b) Mine tailings sites obtained from the Chilean Geology and Mining Agency database (Servicio Nacional de Geología y Minería, SERNAGEOMIN);

c) Treated wastewater effluents were obtained from the Superintendence of Sanitary Services database (Superintendencia de Servicios Sanitarios, SISS).

Fig. 3.5 Overview of key anthropogenic pressures for water quality

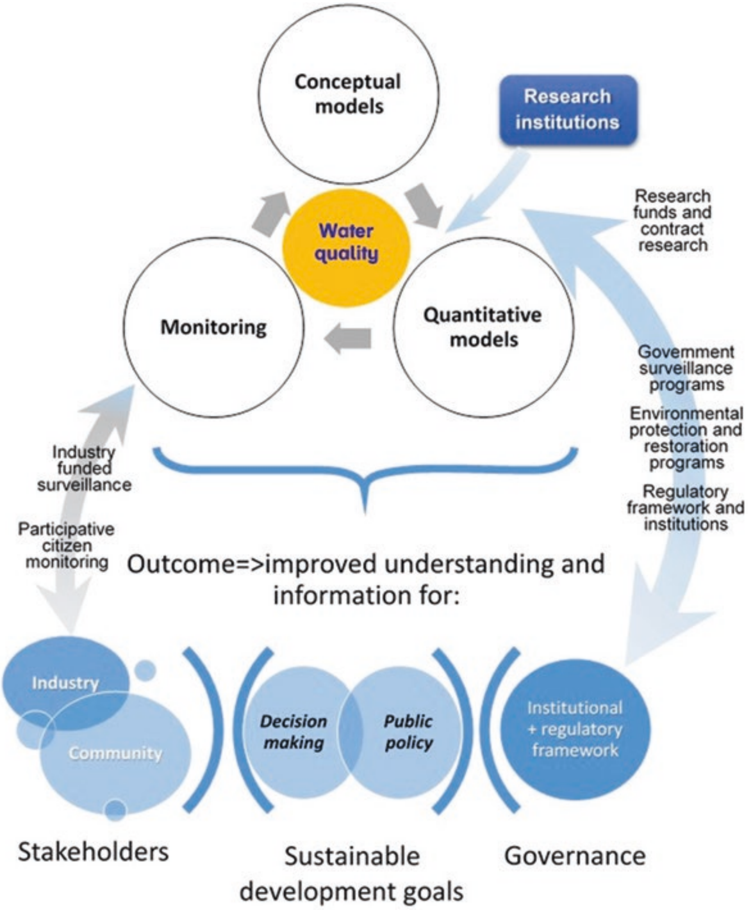


Fig. 3.6 Towards a science-based approach for public policy and decision making in water quality. Feedback between conceptual models, quantitative models, and monitoring drives continuous improvement and feeds public policy and decision making. Private stakeholders, government agencies, and research institutions actively participate (Authors elaboration)

3.3.2 A more Comprehensive and Dense Monitoring Network

The approach proposed in Fig. 3.6 requires a strong monitoring network. Some important parameters and information should be systematically considered for future enhancements of the monitoring network, based on international practice and also on specific issues that are relevant for the Chilean case:

(a) *Total alkalinity:* it is a general parameter that provides a measurement of the sensitivity of waters to acidification and it is measured by many water monitoring agencies in other countries (e.g., United States Geological Survey, USGS). The characteristic enrichment with metallic sulfides of the Andean geology in

Northern and Central Chile makes Chile's waters prone to acidification due to mixing with acid drainage. Although acid drainage may originate from natural sources, active and legacy-mining operations may strongly enhance its production. This threat to water quality is supported by ample evidence in Chile (Flores et al. 2017; Guerra et al. 2016a; Ribeiro et al. 2014; Oyarzun et al. 2012; Parra et al. 2011; Dold and Fontbote 2002).

(b) *Chemical speciation and total vs. dissolved metals*: the mobility and toxicity of metals is controlled primarily by their chemical speciation. Dissolved metals (operationally defined as the fraction that passes a 0.45 μm[4] pore size membrane) are more mobile and toxic than particle-bound metals. Particle bound metals may settle and form contaminant repositories in reservoirs or become part of the fine river sediments depending on the kinetic turbulent energy available for their transport (e.g., Contreras et al. 2015; Tapia et al. 2014; Sepulveda et al. 2009; Pizarro et al. 2006). Furthermore, the reactivity of metals controls their potential impact on natural ecosystems: metals that are loosely bound to solids may be transferred to the dissolved phase, becoming more toxic and mobile. Metals that are loosely adsorbed to oxides or precipitated as carbonates may be released to the water when low pH or anoxic conditions prevail, while metals associated to silicates or forming crystalline sulfides are less likely to dissolve in the short term. Therefore, it is important to consider a systematic approach to metal speciation, starting from the distinction between total and dissolved metals (Guerra et al. 2016a; Abarca et al. 2017; Arce et al. 2017). Again, the Andean metal enrichment in Northern and Central Chile makes it relevant to start considering metal speciation to assess the trends in water quality and the processes that control it.

(c) *Turbidity*: it is associated with suspended inorganics (e.g., clay, silt), organics (e.g., plant litter decomposition by-products) and organisms (e.g. algae, bacteria). This indicator is commonly used in many countries to evaluate the environmental health of water bodies (it is also a basic parameter measured by the USGS). Beyond giving a complementary measure of the suspended solids with respect to total suspended solids (TSS), turbidity is a key parameter for the quality of fish habitats; it is relevant for recreational uses of water; it helps reveal hydrological (e.g., erosion) and pollution processes (e.g., acid drainage, eutrophication); and it is important as a quality measurement for industrial and drinking water sources. Thus, turbidity is an easy-to-measure general water quality parameter that should be systematically measured within the surface water quality monitoring network. This parameter is measured in lakes but not in streams neither groundwater.

(d) *Nutrients*: phosphorus (e.g., total P and orthophosphate) and nitrogen forms (e.g., nitrate, nitrite, ammonia nitrogen) are limiting nutrients for photosynthetic biomass growth, thus increased values of nitrogen and phosphorous indicate a deterioration of water quality, leading to algal blooms, anoxia, and fish kills typically in lakes and reservoirs. The Chilean monitoring network includes

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[4] 1 um = 1 micrometer = 1 × 10^{-6} m.

sampling and analyses of nutrients for lakes and reservoirs, and the surface water quality network measures nitrogen forms only. It is important to monitor systematically nitrogen forms in streams because it helps track and control nutrient sources within each watershed. Agricultural diffuse pollution and treated wastewater effluents are prime suspects for nutrient discharges. This information is critical to argue for more stringent standards for treated wastewater discharge. A lower standard for nutrients in treated effluents will likely lead to an upgrade of wastewater treatment plants to include biological nutrient removal, as it is the practice in developed countries.

(e) Sediment chemistry: sediments in rivers and lakes can help reveal the dynamics of natural and anthropogenic contaminants. Sediments may also behave as sources or repositories of contaminants, a process that may be driven by the chemistry of the water column. This aspect is extremely important in mining-impacted areas. Very few studies are available that provide measurements of sediment chemistry, while sediment composition is not systematically monitored by the DGA.

(f) Emerging contaminants and agrochemicals: Chilean nitrates are known to co-occur with perchlorate, an endocrine disruptor when it is found in trace levels in drinking water (Calderon et al. 2014; Bohlke et al. 2009; Gibbs et al. 2004; Urbansky et al. 2000). Evaluating perchlorate occurrence in groundwater used as source for drinking water production is important since it is not very reactive in groundwater. Traditional groundwater treatment technologies used in Chile do not remove perchlorate significantly. Other emerging contaminants for surface waters include disinfection by products from wastewater treatment, personal care products, hormones and pharmaceuticals. Last but not least, the monitoring of agrochemicals in groundwater and surface waters should be strengthened to unravel the real extension of this type of pollution.

3.3.3 Protecting and Improving the Trophic State of Chilean Lakes and Reservoirs

In recent years, Chile has been developing water quality guidelines for watershed and lakes management (NSCA). Relevant examples are those guidelines for the Villarrica Lake and the Llanquihue Lake. In the first case, the objective is to avoid the accelerated increase of the trophic state of the Villarrica (Ministerio del Medio Ambiente 2013), while in the second case the objective is to keep the water quality status of the lake, contributing to maintain the current oligotrophic condition of the Llanquihue (Ministerio del Medio Ambiente 2010). This is a big step in preserving aquatic ecosystems and preventing changes in their water quality, especially because these lakes are also important tourist attractions.

Other oligotrophic lakes in Central-Southern Chile are also threatened due to tourism activity. Recently, a decrease in temperature and conductivity, alongside an increase in N and P levels were reported in ten lakes in that region, over a period of 18 years. Those lakes include Llanquihue, Villarrica, Caburgua, Calafquén and Riñihue. This decrease in the water quality of the lakes may be explained by a combination of land use change due to urban areas expansion, deforestation, exotic plantations, and regional climate change such as decreased rainfall and rapid melting of glaciers- (Pizarro et al. 2016). Evidence for eutrophication in oligotrophic lakes in Central Chile has also been identified (von Gunten et al. 2009). This is a concern since these lakes are located in remote high-elevation basins (2680–3250 m altitude), where direct anthropogenic effects are not observed, and one of the lakes -Laguna Negra- is part of the drinking water system for Santiago. Use of hydrodynamic and water quality models such as those used in the Rapel reservoir and Riñihue lake (Campos et al. 2001) may be useful to simulate these and/or other water bodies at risk under different scenarios.

To avoid excessive nutrient discharge and thus eutrophication of receiving water bodies, nutrient removal in wastewater treatment plants is required. This is a common practice in countries such as USA, Italy and Australia. In Chile, only 5% of the wastewater treatment plants include biological nitrogen and phosphorous removal, and 2.5% include chemical phosphorous removal (Barañao and Tapia 2004). More efforts should be made regarding this matter so important to aquatic ecosystems health, especially for those lakes and reservoirs whose trophic state may be directly affected by wastewater discharges.

3.3.4 Enhanced Natural Attenuation and Constructed Wetlands as Sustainable Treatment Alternatives

On-site infiltration ponds and wetlands are examples of natural wastewater treatment systems. In these systems, the removal mechanisms depend on their natural components and thus do not rely on an external energy source for treatment purposes. Pond systems are the oldest and most applied technology. Facultative ponds represent 3% of the wastewater treatment systems in Chile, where the treated effluents are discharged in rivers such as Limarí and Elqui in Northern Chile (SISS 2017b). Nevertheless, the effectiveness of pond treatments should be critically assessed considering their operational flexibility, space requirements, and capacity to adapt to different inflow conditions.

Natural wetlands have been found to improve water quality due to the interaction between vegetation, water and soil. Various physical, chemical and biological processes occur in different wetland compartments. Wetland soils filter and retain solids, also capturing dissolved pollutants. Vegetation growth requirements fosters nutrients uptake. Vegetation may also accumulate metals and metalloids in roots and shoots due to active and passive mechanisms. Decaying organic matter from vegetation is used as a source of organic carbon for microorganisms. Despite that wetlands often provide optimal conditions for different types of microorganisms to thrive, pathogens are commonly eliminated due to predation, natural die-off, and UV radiation. Plant roots provide surface for biofilms to attach. Roots also transfer oxygen to the rhizosphere, where aerobic and anaerobic zones may be found. This micro environment favors the formation of iron plaque on the roots surface, making this surface highly reactive and thus a sink for pollutants. Combinations of these processes explain the effect of wetlands on water quality parameters such as total suspended solids (TSS), TN, TP, dissolved oxygen (DO), COD, and also on pathogens, and metal and metalloids concentration and speciation.

The Ministry of Environment (Ministerio del Medio Ambiente, MMA) has defined ecosystem services as “the direct and indirect contribution of ecosystems to human wellbeing” (Ministerio del Medio Ambiente 2017). Wetland ecosystems provide us with services worth trillions of US dollars at a worldwide scale (RAMSAR 2017). These services include water purification, recreation and tourism, flood control, reservoirs of biodiversity and climate change mitigation and adaptation. Considering the importance of wetlands, the MMA developed a National Inventory of Wetlands which is now available, aiming to support conservation and protection plans (Centro de Ecología Aplicada 2011).

Constructed wetlands are engineered systems that mimic natural wetlands for wastewater treatment or other purposes. Around 99.8% of the wastewater collected and generated by the urban population in Chile receives treatment in wastewater treatment facilities (SISS 2017a), being the urban sewage coverage 96.8%. However, many rural zones have no access to sewage or treatment facilities. Therefore, on-site, low-cost, easy to maintain treatment systems such as constructed wetlands have potential to be implemented. Some of these systems have recently being implemented in Chile for black and grey[5] water treatment in various locations at domiciliary and small community scale. Some examples include a wetland system to serve 12 houses in Pucón, and another wetland system at a public square in San Pedro de Atacama. A notable application is a horizontal subsurface flow constructed wetland pilot system in Hualqui, Biobío Region, which treats municipal wastewater from a treatment plant that serves a rural community of 20,000 inhabitants (Casas Ledón et al. 2017). Areas of research at the laboratory level include different local applications such as treatment of sewage (Burgos et al. 2017), swine wastewater (Plaza de los Reyes and Vidal 2015) and arsenic and metal-contaminated water (Lizama Allende et al. 2014). This evidence suggests that constructed wetlands may be a sustainable option for water treatment, with further efforts required to evaluate their performance depending on water quality requirements and local conditions. Plans for future implementations of constructed wetlands include a wetland that aims to repair environmental damage associated to industrial wastewater discharges of a pulp mill in Santuario de la Naturaleza Carlos Anwandter (SNCA), Valdivia. This wetland will receive the treated effluent from Valdivia wastewater treatment plant after tertiary treatment and before it is discharged to the Cruces River. The

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[5] Black water refers to wastewater and sewage from toilets, whereas grey water refers to wastewater from baths, sinks, washing machines and other kitchen appliances.

design includes plant species representative of the Cruces River wetland, such as *Typha angustifolia* (narrowleaf cattail) and *Scirpus californicus* (bulrush).

The National Forestry Corporation (CONAF) is responsible for the oversight of 9 RAMSAR sites (out of 13 total RAMSAR sites in Chile), including SNCA. Recently, a handbook for monitoring wetlands included in the National System of Wild Protected Areas of the State (SNASPE) was developed (Zamorano, et al. 2016). The aim of the handbook is to strengthen the institutional monitoring capacities of these wetlands so as to contribute to their effective conservation. Given the role of wetlands in water quality control, biodiversity and provision of ecosystem services, their protection is required, especially considering the current and future scenarios regarding water resources availability and quality. Currently, a legislative project by the MMA that creates the Biodiversity and Protected Areas Service is still under evaluation. This project stems from the lack of specific regulation for protecting wetlands, since the declaration of a site in the RAMSAR category does not imply an official protection category at a national level (Ministerio del Medio Ambiente 2014), unless the wetlands are included in the SNASPE, which is the case of 7 out of the 9 RAMSAR sites under the administration of CONAF (CONAF 2010).

3.4 Conclusions and Implications for Water Policy

Water quality of Chilean waters varies widely due to the different climate conditions and the complex interactions between natural and human factors. Main issues include elevated salinity and concentrations of metals and metalloids in Northern and Central Chile and eutrophication primarily in Central Chile. The natural presence of copper and arsenic from geological sources in addition to anthropogenic activities explain heavy metals enrichment. Wastewater treatment coverage in urban areas is close to 100% but only 5% includes nutrient removal and 29% of the generated wastewater is discharged in Chilean coast by marine outfalls[6].

An integrated approach that articulates water monitoring (quantity and quality) with working conceptual and quantitative models of water quality is needed. Understanding the patterns of the dynamic interactions between Chilean watersheds and human pressures will provide a robust science-based approach for public policy and decision-making in issues involving water quality management.

A compelling policy that assures the access to thorough and reliable water quality data is necessary. This will likely be achieved by (1) strengthening the coverage (spatial representativeness, water quality parameters), density, and sampling frequency of the national water monitoring network, (2) coordinating the efforts of water stakeholders (public, industry, NGOs) in water quality monitoring and protection; and (3)

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[6] Information retrieved from SISS webpage http://www.siss.gob.cl/577/w3-article-11091.html on 09/29/17.

supporting the role of research institutions in elucidating the complexity of water quality interactions in socioenvironmental systems.

Although progress has been made in priority watersheds and lakes by NSCA, current institutions and policies will not necessarily ensure that the target water quality standards are maintained (Melo and Pérez 2018). Future public policies aiming for the protection of water resources and aquatic ecosystems need to be consistent with relevant regulations and institutions, as highlighted in other chapters of this book. In addition, further efforts to target main water quality issues, for example by promoting sustainable water treatment alternatives, are required to move forward in the successful implementation of these policies.

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Chapter 4
The Socio-Economic Context of Chilean Water Consumption and Water Markets Growth: 1985–2015

Gustavo Anríquez and Oscar Melo

Abstract Chile was one of the early economic reformers in Latin America, instituting a series of pro-market policies. These reforms included, liberalization of the capital accounts, steep reduction and harmonization of import tariffs, liberalization of foreign exchange markets, and aggressive privatization of state-owned companies, including public utilities. During the 1990s Chile promoted a strong trade liberalization agenda that reinforced the export-based model by subscribing a series of *Free Trade Agreements.* Chile entered a virtuous cycle of strong economic growth led by exports, and strengthened by the return to democracy which put an end to social unrest. This growth is also reflected in fast poverty alleviation. However, unequal income distribution has only improved marginally. The economy is based mainly on exports that are highly dependent on water, such as mining and agriculture. Water withdrawals in Chile average approximately 4300 m^3/s, equivalent to 136,000 million m^3/year. Of this, almost 85% is used in non-consumptive hydroelectric generation. Consumptive water use in Chile is dominated by irrigation representing 82%, followed by industrial, mining and potable water supply, which account for 8%, 3% and 7% of total water consumptive water use, respectively. Since the 1990s total consumptive water use has increased 13%, mainly driven by economic growth.

Keywords Chile · Consumptive water use · Economic growth · Water withdrawals

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4.1 Introduction

Chile was one of the early economic reformers in Latin America, instituting a series of pro-market policies in a reform package usually referred to as *structural reforms.* These structural reforms promoted an export-based growth strategy that has been underpinning the successful economic trajectory of the country over the last three decades.

The structural reform package varied among Latin American countries (Lora 2012), but in the case of Chile the most important reforms included, liberalization of the capital accounts, steep reduction and harmonization of import tariffs, liberalization of foreign exchange markets, and aggressive privatization of state-owned companies, including public utilities like public water systems. These profound reforms had a large impact on relative prices of the Chilean economy, forcing massive reallocation of productive assets including labor. The transition was far from frictionless, GDP growth in 1982 was −14%, and official unemployment (in this period, likely underestimated) stood at 24%. However, after this economic crisis, Chile entered a virtuous cycle of strong economic growth led by exports, and strengthened by the return to democracy which put an end to social unrest. After the return to democracy, during the 1990s Chile promoted a strong trade liberalization agenda that reinforced the export-based model by subscribing a series of *Free Trade Agreements*, among them we highlight given market size, agreements with, Canada (1996), México (1997), European Union (2002), United States, Korea (2003), and China (2005).

Table 4.1 presents a set of selected socio-economic indicators that describe the path of the Chilean economy over the past 25 years. The table shows the strong growth of the economy, with real GDP per capita more than doubling in real terms in less than 25 years. This strong growth also reflected in fast poverty alleviation: poverty was essentially halved in 8 years between 1990 and 1998, and then was halved again in 11 years between 1998 and 2009. This fast poverty alleviation was mostly the result of mean income growth, as economic growth has been accompanied by marginal improvements of a notoriously unequal income distribution (post tax GINI of about 0.55). The meager progress in income distribution has occurred in spite of the fact that governments, since the return to democracy, have promoted social policies to improve welfare distribution.

The growth in population has translated in an increasing demand for drinking water especially in urban areas. The growth in agriculture and mining has translated in a higher demand for water. This has resulted in an increasing activity of water rights markets and the development of new sources of water. But this pressure for more water has also led to an over-allocation of rights in some areas, in particular for underground water. The higher income brought by economic development has meant that people care more for the environment and thus, society's demand has translated into stricter water regulation.

Table 4.1 Evolution of selected socio-economic indicators from Chile

	1990	1994	1998	2003	2009	2013[a]
GDP per capita (constant 2010 $)	6,106	7,864	9,727	10,410	12,222	14,364
Annual growth rate (%)		6.5	5.5	1.4	2.7	4.1
Poverty rate % (National Poverty line)	38.3	27.5	21.6	18.6	11.4	7.8[b]
Population, total (000 s)	13,141	13,988	14,789	15,729	16,830	17,576
Annual growth Rate (‰)		15.7	14.0	12.4	11.3	10.9
Urban population (000 s)	10,943	11,781	12,641	13,672	14,873	15,673
Annual growth rate (‰)		18.6	17.8	15.8	14.1	13.2
Mining Value added (constant million $ 2010)	5,868	7,067	10,778	13,136	13,018	13,722
Annual growth rate (%)		4.8	11.1	4.0	−0.2	1.3
Mining export value index (2005 = 100)	21	24	29	39	133	201
Annual growth rate (%)		3.6	4.6	6.4	22.7	10.8
Agriculture, Value added (constant million $ 2010)	3,716	3,955	4,460	5,773	6,916	7,593
Annual growth rate (%)		1.6	3.0	5.3	3.1	2.4
Agriculture export value index (2004–2006 = 100)	25	37	56	76	159	231
Annual growth rate (%)		10.3	10.9	6.3	13.1	9.8

Source: World Bank Economic Indicators, FAOSTAT, and Ministry of Social Development data

[a] Statistics are presented between 1990–2013, given that some indicators aren't available up to 2015, particularly FAO and Ministry of Social Development data

[b] Using non-official poverty estimator comparable with previous estimates

4.2 Water Consumption by Economic Sectors

According to the latest estimations of the National Water Directorate (DGA 2015), national available water per capita is 51,218 m^3/person/year, but this figure varies enormously within the country: 510 m^3/person/year in the North Macroregion to 2,340,227 m^3/person/year in the Austral Macroregion. Also, total consumptive water use is estimated at 645 m^3/s (20,000 million m^3/year), representing only 2.2% of the total runoff in the country at 29,245 m^3/s (DGA 2015).

The agricultural sector is by large, the main water using sector in Chile, employing 526 m^3/s, equivalent to 17,000 million m^3/year, approximately 85% of consumptive water use. Household and industrial water uses, are second and third with around 7 to 8% of consumptive water use, respectively, as shown in Fig. 4.1.

The mining industry only consumes 3% of the consumptive water use in Chile. This low water consumption with respect to total consumptive water consumption, is rather surprising given the economic weight of this sector, both in terms of national exports (52% of exports in 2015), and GDP. This can be explained since mining activities in Chile have a high-water use efficiency, currently at 0.75 m^3/ton of copper ore, compared with nearly 2 m^3/ton of copper ore in the 1980s (McPhee et al. 2012; Peña et al. 2011). The mining industry grew very strongly, its value added expanded by nearly 124%, between 1990 and 2003 (Table 4.1). Exports (in

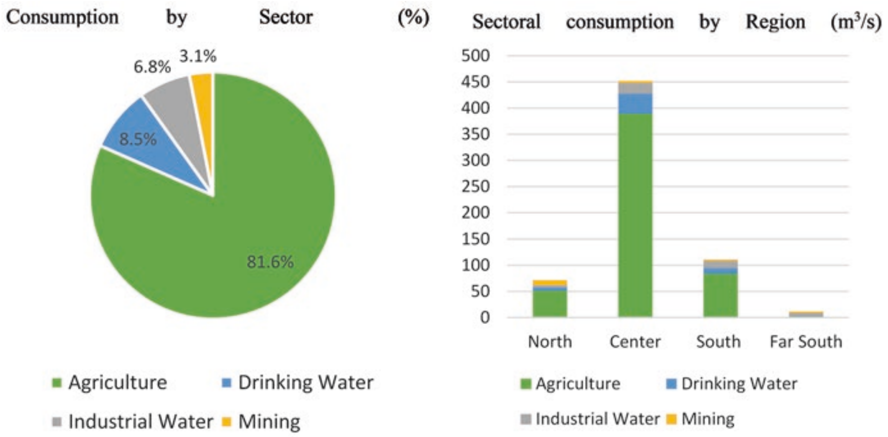

Fig. 4.1 Water consumption per sector (Dirección General de Aguas 2015)

monetary value) continued strong growth after these years, mostly driven by a higher commodity price period. Currently, the sector exhibits very low growth, weathering a period of low commodity prices.

Not included in this water consumption accounting is the power generating sector. Chile has comparative advantages in the generation of electricity using hydropower, which is one of the main suppliers of electricity to the Chilean grid. However, since hydropower generation is a non-consumptive water use, it is not included in water consumption accounting.

4.2.1 Agricultural Water Consumption

As shown in Table 4.1, the agricultural sector has also displayed a very dynamic trajectory, growing a bit slower than the national income (as is the norm for a developing country), but growing fast nonetheless. However, outpacing both national income and sectoral value added, exports have been the main driver of growth in the agricultural sector, growing at an annualized rate of 10% per year over the last 23 years. Trade reforms pursued by Chile in the early 1980s revealed comparative advantages in agriculture, but particularly in the export of fruits and wine, which promoted new investments and overall modernization of the agricultural export sector. The winning sectors of trade liberalization include fruits and wine products, while the import competing crops, mostly cereals (maize, rice, and wheat) and sugar beets receded as economically viable crops in the new economic environment. In practice, the sustained growth of the agricultural sector has been achieved by intensification of production, constant land use transition from agricultural use in import competing crops into higher value crops (fruits and nuts), accompanied by a marginal expansion of agricultural land (Fig. 4.2). Labor intensity in fruit production is

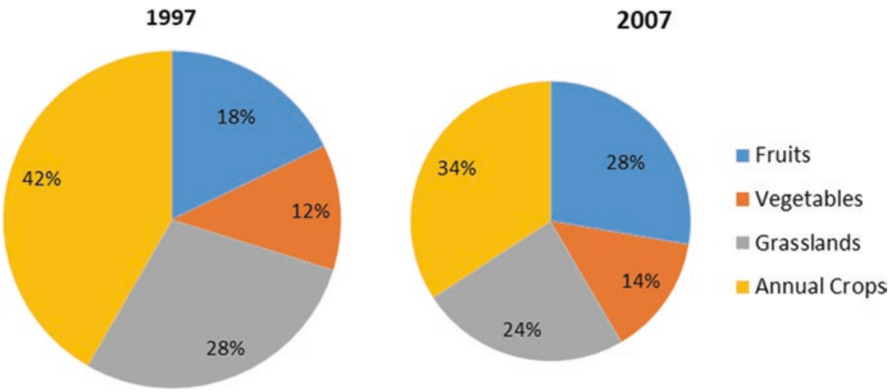

Fig. 4.2 Evolution of agricultural land use between agricultural censuses (Anríquez et al. 2016)

very high, which initially acted as a comparative advantage for Chile, but as labor costs have risen with overall economic growth, crops that are more easily mechanizable (e.g. nuts and olives) are recently growing in popularity.

From the perspective of water consumption, the transition from import-competing cereal to higher-value fruits, has been occurring in the irrigated, and more productive, central valleys of Chile. In the South of the country, import competing rain-fed cereal production has transitioned mostly into forestry. In terms of water consumption, fruit production has a lower water footprint of 967 m^3/ton compared with cereal production at 1644 m^3/ton, (Mekonnen and Hoekstra 2010 and Donoso et al. 2016). Hence, this trade-induced transition has reduced water consumption by agriculture, in the central, and most productive valleys of Chile.

In terms of water usage, agricultural growth must be viewed from the perspective of a subsidy to irrigation works that has been in place since 1985, i.e. concomitant with trade liberalization. Law 18,450 officially aims to encourage investments in irrigation and drainage, to increase the area under irrigation, improve water supply and increase irrigation efficiency. A key component of this public support are subsidies that promote “technified irrigation,” modern irrigation systems such as drip irrigation, micro-sprinklers, bubbling, etc. (Martin and Saavedra 2018). These systems are intensively used in fruit-export crops, and have improved efficiency of water use, but at the same time have reduced the amount of water (surface and underground) that is returned into the watercourses.

4.2.2 Mining Water Consumption

Chilean copper mining experienced an exponential growth between 1990 and 2015, driven by Chile’s stable regulatory framework and a favorable environment for private investment (Acosta 2018). This drove an equally exponential increase in water

Table 4.2 Evolution of urban water supply and wastewater collection and treatment

Year	Drinking water coverage[a]	Urban sewerage coverage[a]	Wastewater treatment coverage[b]
1985	95.2	75.1	0
1990	97.4	81.8	12.1
1995	98.6	89.4	15.7
2000	99.7	93.2	20.9
2005	99.8	94.9	77.2
2010	99.8	95.9	90.7
2014	99.9	96.8	99.8

Source: Dirección General de Aguas (2015) and SISS (2015)

[a] Percentage of urban population

[b] Percentage of collected sewerage that is treated

consumption to process this growing production. Most water consumption associated with copper and other mineral mining is located in the North Macroregion.

In 2015, mining's consumption of continental water resources was almost 18.1 m^3/s (DGA 2015; COCHILCO 2016; Consejo Minero 2017), equivalent to 571 million m^3/year. This consumption represents 3% Chile's total consumptive water consumption. Even in the northern region, where most of Chilean mining operations are located, only 16% of water consumed is used by the mining sector. Moreover, even in this macro region where agriculture is relatively small (confined to a few narrow valleys and subsistence agriculture in the highlands/Altiplano), this productive sector consumes 72% of all freshwater used in the region.

4.2.3 Domestic Water Consumption and Sanitation

Chile was already an urbanized country when structural reforms were enacted. Urbanization rate was measured at 82% in 1982 when a national population census was conducted. Currently, almost 90% of the Chilean population lives in urban areas. This means that urban population still outpaces the growth of national population, but the rate of urban population growth is low and falling, standing currently at roughly, 1.3% per year (see Table 4.1). Furthermore, given that in 1985, already 95% of urban population had public drinking water connections (see Table 4.2), urban public drinking water demand (based solely on demographics) has been growing at about 1.5% per year.

Urban water demand also has an income elasticity, whereby income driven demand growth is expected. A study of urban water demand in Chile using data from 1998 to 2010, (Fercovic et al. 2013) shows that the income elasticity of urban water demand lies around 0.2. The Chilean economy currently has an estimated long-term growth rate of 4.5%, without discounting population growth. This means that the expected long-term real income growth of the country is about 3.5%. Given the estimated income elasticity, urban water demand would grow, due to income growth by 0.7% per annum. Altogether, these numbers suggest that the expected

Table 4.3 Rural water consumption by source (% of rural households)

	1990	1996	2000	2006	2011	2015
Water system	35.6	35.2	38.6	53.4	55.6	65.3
Well water	N/A	40.0	37.5	31.0	28.4	23.3
Other	N/A	24.8	23.9	15.7	16.1	11.5

Source: Authors' calculations using Casen national surveys

annual growth of urban water demand lies around 2.2%. Considering, that total drinking water demand is 8.5% of total freshwater consumption, human consumption will remain a minor source of total water demand, which, as we have shown is dominated by agriculture.

Another important aspect of residential water use relevant for overall water availability is the treatment of wastewater. Until 1990, there was practically no wastewater treatment, and residential water flowed back into water systems and were re-used by agriculture without treatment. Starting in 1990, when the first large wastewater treatment plants were inaugurated, there has been strong investment in wastewater treatment, as can be seen in Table 4.2. Today, a postusage treatment rate of almost 100% has been achieved; the driver of this progress in water treatment was the significant reforms implemented in 1988 to improve urban water and sanitation services (Molinos 2018).

Residential water use in rural areas is much lower than in urban areas, given national demographics. Overall rural population is slowly dwindling, so rural water consumption is falling, however, there is a fast transition in rural areas among drinking water sources. The coverage of water systems has grown from 6% in 1960 to 53% in 2014 (Fuster and Donoso 2018). In 2015, 65.3% of rural households with access to potable water were served by water systems (Table 4.3). This change in water systems has translated into better water quality assurance in rural areas.

4.2.4 Hydropower Water Demand

Although water usage in hydroelectric power generation is non-consumptive, a complete picture of water usage in the country requires an understanding of the recent history related to hydroelectricity in Chile and a future outlook. Hydroelectricity has been part of Chile's energy history since the end of the nineteenth century. Significant developments of the hydroelectrical infrastructure have taken place, however evidencing significant deficits in their social and environmental sustainability. In recent years, both regulatory requirements and industry practices have improved, and the reality of the sector is much better than that of the 1990s. However, as the recent sustainable hydroelectricity government committee concluded, there are still challenges to move towards more sustainable hydroelectricity with the environment, communities and territory (Ministry of Energy 2017).

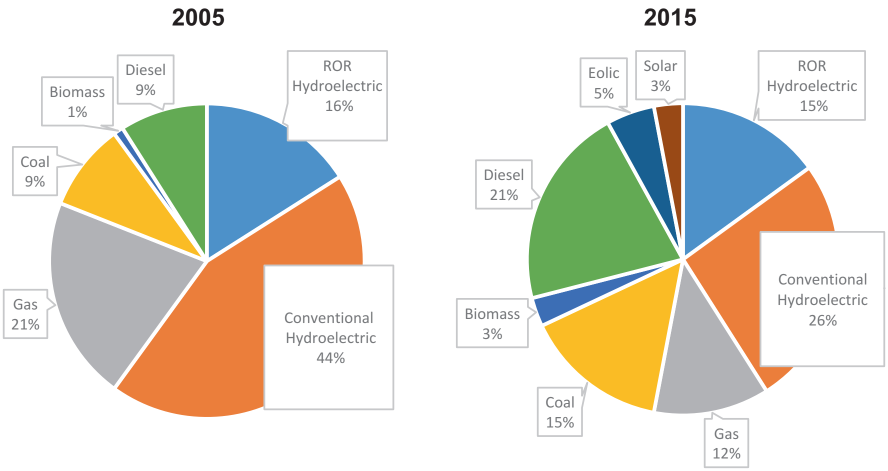

Fig. 4.3 Change in power generation sources in the Central Chilean Electric Grid between 2005 and 2015 (Deloitte 2016)

Hydroelectricity is losing popularity in Chile due to two main factors: (i) increasing conflicts (Bauer 2015; Rivera et al. 2016), and (ii) increasing social and environmental costs of large hydroelectric projects (Agostini et al. 2017). The last two large projects were Pangue, inagurated in 1996, and Ralco inagurated in 2004, both in the Biobio Basin. This last project was accompanied by strong social opposition from environmentalist groups, which succeeded in stopping another large and controversial project, Hydroaysén. On the other hand, the increasing cost-efficiency of other renewable energy sources, in particular, wind and solar energy, which have a growing participation in the Chilean power grid, have reduced the attractiveness of hydropower generation. In contrast, run-of-river (ROR) hydroelectric plants, with much lower environmental footprint, have been growing in importance in Chile.

The evolution of the Chilean power grid illustrated in Fig. 4.3, reflects the diminishing role that hydroelectric power generation has on the Chilean electric grid over the last decade. These trends are likely to continue. While ROR hydroelectric projects are likely to continue growing, the overall contribution of hydroelectric power to the national electric grid will continue to diminish as alternative energy sources continue to grow.

4.3 Policy Environment for Water Rights Markets

The Chilean legal tradition has always recognized water as a national property for public use, but at the same time has granted private water use rights. The Civil Code that came into effect in 1857 is the first instrument to define that *"rivers and all waters flowing through natural riverbeds are national property of public use"*, besides regulating that the access to waters shall be carried out through the "*Mercedes* [assigned rights]", which *"are conferred by the competent authority*".

The Water Code of 1951 continues with the principles of the above mentioned Civil Code, the most important of which is that waters continue being national property for public use. This code establishes that "*The Water Right may only be acquired by virtue of a merced conferred by the President of the Republic in the manner established herein.*"

The Water Code of 1967—because of a change in the macroeconomic and political context towards a more centralized political system—strengthens the concept of waters as public property and "*changes the juridical nature of the Water Right*". The new juridical nature of the Water Right consists of giving it the nature of a real administrative right, where the State confers the use of the national property of public use subject to public right rules. The State confers the use of waters but never the title over them. Water Rights are therefore administrative rights that expire, and the water reallocation process subjects water to planning, so that the water right is exercised on the basis of the *"beneficial and rational use rate."* The Code eliminates the list of preferences and gives priority to drinking water and potable water.

After the political changes that took place in Chile in 1973, and particularly the structural economic reforms started in 1979, the economic paradigm changed from one where the State was responsible for protecting and making an optimal allocation of resources, to one where the market is responsible for the efficient allocation of resources. The authorities and ministers of the time who managed the country's economy provided the guidelines to draw up a new Water Code. This work was commissioned to a team of lawyers and hydraulic engineers, and the underlying philosophical principal was "entrepreneurial freedom". The different instruments and ordinances mentioned above, including the Codes prior to 1981, contained restrictions for the creation and operation of an efficient water market consistent with the new economic system. These restrictions were related mainly to the definition of Water Rights, the degree of information available to users, transaction costs, the eventual damage to third parties, the methods used to settle disputes, the speculation over water, and the legal framework necessary for the market to operate properly. Therefore, as Hernan Büchi, a former Minister of Finance, stated, "*the purpose of the government in that area was creating solid property rights, not over water itself but over the use of water and to facilitate as much as possible an orderly operation of the market.*" In synthesis, the underlying philosophy of the Water Code of 1981, in simple words, is establishing permanent, tradable water rights to permit efficient water use. Efficiency means that water is used by the agent that has the highest value attributed to it. A competitive water rights market that operates without transaction costs will guarantee, in principle, optimum water allocation according to the terms indicated above.

This is the legal context that has enabled the creation of water markets since the early 1980s. In practice land and water rights are separate goods that are traded separately. All water users, including water supply and sanitation companies, need to obtain water rights in order to use the limited renewable resource.

4.4 Conclusions

This chapter has presented the main economic sectors that use fresh water and the recent consumption evolution. We show that residential water usage, represents a small proportion of total freshwater consumption, and that it is growing at a slow rate given declining demographic pressures and a relatively low income elasticity. We show that agriculture is the main freshwater user sector in the country. Agriculture, driven specially by export crops is growing very fast. This growth does not translate to an equivalently fast growth in water consumption, due to improving efficiency in irrigation technologies used, and also due to a transition towards crops, that although are water intensive, are usually less water intensive than the crops that they replace. Nonetheless, the continued growth of agriculture and its intensification will be the main drive of freshwater use in the country.

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Part II

Water Policy and Its Implementation in Chile

Chapter 5
Legal and Institutional Framework of Water Resources

Alejandro Vergara and Daniela Rivera

Abstract The water sector in Chile underwent major changes as a result of decentralization and market reforms. The Water Code of 1981 is the main regulation governing terrestrial water use and water rights (WR) in Chile. Water is national property for public use. However, the Water Code grants permanent and transferable WR to individuals in order to achieve an efficient allocation of water through market transactions of water rights. Once water rights have been granted, they fall under the jurisdiction of private civil law, rather than administrative law. This chapter provides an overview of legal water regime in Chile, based on the review of six central topics: normative framework; regulatory model and legal nature of waters; origin of water rights; water management and administration; groundwater regime; and, finally, the most common conflicts that occur in the sector. On this basis, and considering legal and jurisprudential elements, we identify the defining features of Chile's Water Law, which mixes powers of a centralized State Administration, market tools and water user organizations.

Keywords Chile · Water code · Conflicts · Water law · Water institutionality · Water rights

5.1 Introduction

The water sector in Chile underwent major changes as a result of decentralization and market reforms. At present, the legal framework of Chilean Water Law is structured on the basis of a normative trilogy:

1. DL N° 2603 of 1979, which gave rise to the Water Code of 1981, and conferred legal recognition to customary and granted WR.

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2. The Political Constitution of 1980, which, following the aforementioned DL N° 2603, distinguishes between “constituted” and “recognized” rights and establishes that water right (WR) holders have ownership over them and are constitutionally protected under warranty of private property.
3. The Water Code of 1981 (WC81), which has remained in force for more than 35 years, having been reformed in 2005.

The WC81 guarantees freedom in the use of water to which an agent has WR; thus, WR are not sector specific (Donoso 2015). Similarly, the WC81 abolishes the water use preferential lists, present in the previous Water Codes of 1951 and 1967. Additionally, WR do not expire and do not consider a “use it or lose it” clause.

Seeking to achieve efficient water allocations, the WC81 established that water rights are transferable in order to facilitate markets as an allocation mechanism. Hence, Chile’s WC81 is illustrative of a transition from water management based on command and control to one based on economic policy instruments.

5.2 Normative Framework

The study of water law in Chile requires a brief description of the following three normative bodies[1]:

1. DL N° 2.603 of 1979 (Gobierno de Chile 1979);
2. Decrete N° 100 Political Constitution of the Republic of Chile of 1980 (Gobierno de Chile 1980); and,
3. DFL N° 1.122 of 1981 (Gobierno de Chile 1981), current Water Code of 1981 (WC81), which has undergone several reforms over the 35 years that it has been in force.

5.2.1 DL N° 2.603 of 1979: Recognition of Effective Water Uses

The purpose of this legal text was to start the process of normalizing all that is related to water and its various forms of exploitation (Gobierno de Chile 1979). To do so, it established a status that guarantees water rights (WR), granting their holders ownership over them. The content of this norm was quite brief, but very categorical. On one hand, it established that WR over water could be granted by the

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[1] This section lists the main regulatory bodies on water in Chile. Notwithstanding, it should be noted that there are additional legal and regulatory regulations, As is, for example, the Supreme Decree N° 203 of 2014, establishing rules on exploration and exploitation of groundwater, to which reference will be made later in this chapter.

State/Administration, or recognized (obtained under immemorial use of the resource). On the other hand, it gave its holders constitutional protection over those rights and separated WR from land ownership, thus, setting the foundations for a future WR market.

The most relevant contribution of this legal body is contained in its 7th Article, which considers an *ownership presumption* over WR in favor of those who use the waters and are owners of the land or, if the foregoing does not apply, in favor of whoever is effectively using the water. Thus, this rule reflects the purpose of the legislator to consider that customary water uses, complying with corresponding requirements, constitute a real and effective right, worthy of constitutional protection, under the warranty of property rights. This premise supports the regularization process of customary water rights, which would be later established in the Transitory Article 2 of the WC81.

Finally, it is necessary to mention that DL N° 2.603 of 1979 authorized the President of the Republic to dictate the necessary rules to establish the "general water regime", which was materialized in the current Water Code of 1981 (WC81).

5.2.2 Political Constitution of the Republic of Chile of 1980 (Constitución Política de la República de Chile – CPR)

Following the guidelines of DL N° 2.603, Chile's CPR (Gobierno de Chile 1980) addressed water regulation in two manners: *explicitly*, in numeral 23 and final clause of numeral 24 of Article 19, and *implicitly* in numerals 1 and 8 of Article 19.

5.2.2.1 Water Regulation in the Realm of Public Goods (Article 19 No. 23 CPR).

This article establishes the so-called *summa divisio* of goods and natural resources in the Chilean legal system, outlining the legal regime to which property may be subjected, distinguishing between *public* goods and *private* goods[2], leaving aside the common goods (*res communis omnium)*. Water is classified as "national good of public use" (bien nacional de uso público) in articles 595 of the Civil Code (Gobierno de Chile 1857) and 5 of the WC81, but not in the CPR. It is important to point out that a reform proposal of the CPR, originally submitted in 2007 and currently being debated in Congress, proposes to explicitly establish in the CPR that "water is a national good of public use".

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[2] From a legal point of view.

5.2.2.2 Water Regulation and the Explicit Protection of Water Rights (Article 19 No. 24 CPR).

Although the CPR does not incorporate a special chapter on natural resources regulation, numeral 24 of Article 19 deals with the specific cases of mines and waters. Regarding waters, the final section of this numeral points out that the rights of individuals over recognized or constituted waters in accordance with the law, will grant their owners property over them.

Based on the above, the CPR:

1. Establishes and guarantees ownership of water rights, which are real administrative rights[3]. Thus, WR ownership falls under the private property legislation being able, unlike in *rerum natura waters* (in themselves), to be transferred, transmitted, prescribed and freely renounced, as of the 2005 WC81 reform.
2. Classifies WR as granted and recognized. As already established by DL 2.603 of 1979, the CPR establishes that WR may be "recognized or constituted in accordance with the law”, constitutionally ratifying the dual origin of WR.
3. Implicitly considers water as a public good, from a legal point of view. The fact that Article 19 N° 24 of the CPR refers to WR as “constituted” [by the authority], implies that only the State can grant WR over public waters (neither private nor *res nullius*), through a concession procedure.

5.2.2.3 The Right to Live in a Pollution-Free Environment (Article 19 N° 8 CPR).

This article complements the legal framework of public property and natural resources established in the CPR. This numeral adds that the use and exploitation of natural resources must consider the protection, care and preservation of these, in order to ensure the constitutional guarantee of living in a pollution-free environment.

5.2.2.4 Human Right to Water (Article 19 N° 1 CPR).

The CPR protects life as a right and thus, implicitly considers the human right to water. The judicial power has used this constitutional guarantee, which protects and recognizes people’s right to water for consumption and subsistence, as legal

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[3] WR as a “real administrative right” is (i) a subjective public right, to the extent that it is a clear legal power recognized to its owner; (ii) a real right, insofar as it is exercised over a public good, such as waters, and has *erga omnes* efficacy; and, (iii) has an administrative nature, since it is the State, through the Dirección General de Aguas (DGA. General Water Directorate), that grants the WR.

arguments in court cases[4]. The proposed reform of the CPR, aims to declare that water is a resource for public use and establishes a priority for human consumption, adding new grounds to appeal for the protection of the right to water for domestic human consumption and sanitation[5].

5.2.3 Water Code of 1981 and Its Amendments

The main guidelines of the WC81, the regulatory core of Chilean Water Law, are the:

1. Consideration of waters as a national good of public use when they are available in their natural source. This character is a manifestation of the regulatory power of the State/legislature, which declares them public (neither appropriable by the state nor directly by individuals) by means of *publicatio*.
2. Existence of a concession procedure, through which the competent administrative authority grants or constitutes WR in favor of individuals. In parallel, and with the same value and hierarchy, establishes a procedure for the legal recognition of WR based on customary uses of waters and other special situations. This is a manifestation of the State's authority (Administrator/Legislator) in the original allocation of water rights.
3. Existence of real administrative rights, named Water Rights, which empower their owners to use the water in a private and exclusive way, and can be freely transferred. This gives WR legal security, intangibility, and transferability, allowing for a market based WR reallocation mechanism.
4. Establishment of a dual water institutional system. A centralized administration, exercised by the competent administrative authority, the National Water Directorate (DGA). A functionally decentralized management, corresponding to users collectively organized in each river basin in water user associations (WUA). Here the State is manifested through an administrative body, and society, through the *self-management* of water resources.

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[4] For example: Reyes Barraza, Pablo and Aguas Andinas S.A (2011): Court of Appeals of San Miguel, Rol 101-2011, October 14, 2011; Larraín Amaya, Luis and Valenzuela Díaz, Mario (2014): Court of Appeals of San Miguel, Rol 252-2014, November 11, 2014; Dougnac Cordero, Vivianne and Comité de Administración del Condominio Las Vertientes de Zapata (2015): Court of Appeals of San Miguel, Rol 53-2015, March 26, 2015; Montes Arancibia, Alberto and Parcelación Piedra Molino (2015): Court of Appeals of San Miguel, Rol 1106–2015, December 11, 2015; and, Reyes Zapata, Jorge (2016): Court of Appeals of San Miguel, Rol 2052–2015, April 14, 2016.

[5] More background can be found in Bulletins N° 6.124-09, 6.141-09, 6.254-09, 6.697-07, 7.108-07, 8.355-07, 9.321-12, 10.496-07 and 10.497-07 whose unified status can be seen in http://www.senado.cl/appsenado/templates/tramitacion/index.php

5.2.3.1 Legal Nature of Waters

Article 595 of the Civil Code (Gobierno de Chile 1857), which was reinforced by Article 5 of the WC81, establishes that water is a "national good of public use". This follows a general tendency in Comparative Law that gives water a public character. While the 1981 Code considers water to be in the public domain, it grants WR through a concession in perpetuity, conceding WR holders total freedom to use the allocated water for the purpose they wish. The need for a concession as an enabling and legitimating requirement for WR arises from the final section of numeral 24 of article 19 of the CPR, which speaks of "constituted" rights, alluding to those that come from a concessionary act. In addition, Articles 22 and 140–141 of the WC81 refer to the action of "constituting" WR, carried out by the competent administrative authority, which ratifies the concession requirement in this field.

A WR holder is not required to justify the future water use once the WR is constituted. In addition, the current legislation does not privilege any use over the other; thus, when granting new rights there are no legal preferences among different possible uses. The granted WR is formalized in a resolution of the DGA that must be reduced to public deed. They must also be registered in the National Real Estate Agencies (Conservador de Bienes Raíces, CBR) and recorded in the Public Water Registry (Catastro Público de Aguas, CPA).

However, there are WR constituted under a concession by the authority, which, despite having been formally granted, lack registration. These are, in essence, old rights granted prior to the entry into force of the WC81, which were affected by the abolition of the conservatory-registration function established by the Agrarian Reform Law of 1967, which was only resumed in 1981. Thus, between 1967 and 1981 there was a registration parenthesis of WR, which gave rise to uncertainties and disorders, which, to a significant extent, remain until today.

Additionally, many recognized WR have a different origin from this concessional procedure. These are WR that were born from customary uses of water, which over time are considered a genuine right, both by the State and water users themselves. They are most common in the agricultural sector, where farmers irrigate with WR devoid of all formality. The lack of formality is due to the fact that customary WR are not registered in any official registry (Rivera 2013).

The transitory second article of the WC81 establishes the procedure to inscribe and register these customary WR. The regularization procedure has two stages: an administrative stage where the DGA publishes and informs other water users of the regularization request, and a judicial stage where the water user must legally demonstrate the existence of an effective customary water use. The regularization of the customary water use right is finalized when the WR is registered in the CBR and CPA, under the specifications established in the WC81. Efforts have been made to regularize and register customary WR in order to resolve overlapping claims of water. This is especially important for WR that were redistributed under the Agrarian Reform and might be contested by previous owners. However, the regularization procedure has not been effective (Donoso 2015). This lack of regularization and registration can be explained by the following reasons (World Bank 2011; Rivera 2013):

1. The lack of incentives and penalties to regularize and register customary WR. Even though the second transitory article of the WC81 allows users to regularize their customary WR, there are no impediments to exercise their rights even though they are unregistered[6].
2. Costly and lengthy regularization procedures, due to the complexity and strictness of the verification process. However, it is also due to an excessive judicialization; of the customary WR that have been certified by the DGA since 1981, between 40% and 65% are still awaiting a court ruling.

5.2.3.2 WR Typology and Characteristics

The distinctive elements that characterize a WR are the specification of a geographical extraction point, the requested water flow, indication of whether they are consumptive or non-consumptive, permanent or contingent, and exercised continuously, discontinuously or alternating. Consumptive WR are granted to uses that do not require water to be returned to the natural source after being used. On the other hand, non-consumptive WR obliges water users to return the water in the same quantity and quality. Additionally, non-consumptive WR must be used in a manner that does not interfere with or limit the exercise of consumptive rights.

Permanent WR are rights that authorize the extraction of a specified water flow, unless when water supply is insufficient to satisfy all permanent WR and they are recognized as shares of water flows. Contingent WR only authorize the user to extract water once permanent rights holders have extracted their quota. Continuous rights are those WR that allow users to extract water continually over time. On the other hand, discontinuous WR are those that only permit water to be extracted at given time periods. Finally, alternating WR are those in which the use of water is distributed among two or more people who use the water successively.

The legal security, intangibility, and transferability of WR allows for a market-based WR reallocation mechanism. In order to control potential negative effects on third parties due to the transfer of WR, the DGA must authorize the WR transfers in natural water sources.

5.2.3.3 Initial WR Allocation Procedure

The procedure to acquire a WR starts with an application presented to the DGA that must meet the following requirements:

1. Identification of the water source from which the water is to be extracted, specifying whether the source is surface water or groundwater;

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[6] The actual WC reform, currently in Second constitutional process (Senate), is processed under Bulletin N° 7.543-12, registered in 2011. Its status can be seen in http://www.senado.cl/appsenado/templates/tramitacion/index.php

2. Definition of the quantity of water to be extracted, expressed in liters per second;
3. Yield and depth in the case of groundwater;
4. Specification of the water extraction points and the method of extraction; in the case of non-consumptive WR it is mandatory to indicate the point of restitution of the water; and
5. Definition of whether the right is consumptive or non-consumptive, permanent or contingent, continuous, discontinuous or alternating.

The requested WR is granted as long as there is water availability to satisfy the total water flow demanded, without affecting the rights of third parties. In the absence of competition for the same WR the right is granted free of charge. It is important to point out that there is no legal or even regulatory concept, regarding what should be understood as "water availability". Therefore, the Courts of Justice have had to give content to this notion, a task in which they have shown to be rather deferential to the DGA's criteria. The Courts have given a dual notion of "water availability". Firstly, they state, there must be "material" provision, that is to say, physical presence of the resource. Secondly, there must be "judicial" availability, which means that the natural source must be free of WR saturation.

When there are two or more requests and the available flow is insufficient for the total requested streamflow, WR are granted to the highest bidder (highest price) in an auction procedure. The auction mechanism is also used to resolve competing claims on the right to explore a specific source of groundwater located in fiscal territory. Contrary to what was expected, a minimum proportion of the new granted WR were allocated via an auction. In addition, there is evidence that in a relevant proportion of the auctions that have occurred there are signs of little rivalry (Peña et al. 2017).

5.2.3.4 Non-use Tariff

The State's concern about a significant lack of effective water use, particularly in the case of non-consumptive WR, led to the introduction of a non-use tariff in the WC81 reform of 2005. Due to the difficulties of monitoring the effective use of all WR, the non-use tariff is applied to all WR that do not count with the necessary water intake infrastructure to extract the granted water flow (Gobierno de Chile 1981, articles 129 bis 4–129 bis 21).

The non-use tariff takes into account the macroregion where the WR is located, so as to consider water scarcity in its calculation. Additionally, it contemplates a temporal factor that increases the non-use tariff if the WR remains without use.

Due to the lack of evidence on the effectiveness of this policy instrument, the actual WC81 reform under debate in the Senate, contemplates the implementation of a "use or lose it clause".

5.2.3.5 Regulation of Transfers of WR

Normally, the transaction of WR implies a change of water intake location. This last operation must be authorized by the DGA, in order to prevent potential negative effects on third parties. Transfer requests are broadcast three times and published in a newspaper at the national and provincial levels, so that other users will be informed and can analyze whether this transfer could affect them. Additionally, if it is a WR associated with projects that have been environmentally evaluated (through an environmental qualification resolution), the Environmental Impact Assessment Study System (*SEIA*) requires water users to mitigate or compensate environmental damages that may result from the transfer of WR.

5.2.3.6 Legal Status of Groundwater

In Chile the WC81, keeping the heritage of legal texts that preceded it, was essentially designed to regulate surface water, even though it included both surface and groundwater. However, the particularities of groundwater resources require, in several aspects, specialized legislation, which, in general is not considered in the WC81. In what follows, we review the main characteristics of the Chilean groundwater regulation model (Rivera 2015, 2016).

The Water Codes of 1951 (Gobierno de Chile 1951: Article 5°), of 1967 (Gobierno de Chile 1969, Article 5°) and 1981 (Article 2°) defined groundwater as "*those that are hidden within the core of the earth and have not been found*". This conceptualization is part of the general provisions of all Water Codes dictated since 1951 in our country. The fact that they are not naturally visible complicates not only the knowledge and understanding of their characteristics and dynamics, but also their use, administration and control.

The current Water Code contains insufficient rules to effectively regulate groundwater resources. Thus, groundwater development has taken place in an institutional setting that placed no or few limits on groundwater use. In order to overcome this situation of regulatory scarcity, in 2014, the Supreme Decree N° 203 of 2013 of the MOP (Gobierno de Chile 2013), established regulation on groundwater exploration and exploitation. In this decree, the Executive recognizes the need to "*regulate the exploration and exploitation of groundwater, setting certain legal and technical regulations, within a framework of sustainability and efficiency without affecting the exercise of rights of third parties constituted on the same waters*".

Article 58 of the WC81 establishes that any person can explore in order to find groundwater on their property. However, exploration on public property requires an authorization by the DGA; should two or more petitions for exploration be presented for the same geographic area, the DGA will allocate the right through an auction.

If the exploration is successful and groundwater is found, the user can petition the DGA for a new groundwater right. The groundwater right petition must:

(a) Identify the aquifer from which the water is to be extracted;
(b) Define the quantity of water to be extracted, expressed in liters per second;
(c) Yield and depth of the extraction well;
(d) Specify the water extraction points and the method of extraction; and
(e) Define of whether the right is permanent or contingent, continuous, discontinuous or alternating.

The administrative procedure requires that this groundwater right petition must be published in the Diario Oficial, in a daily Santiago newspaper, and in a regional newspaper, where applicable. If there is competition for the solicited water rights, they are to be allocated through an auction.

The current regulation establishes that groundwater resources can be classified as: free, under restriction, or under prohibition. A groundwater resource classified as free implies that new WR can be granted to petitioners. Groundwater declared under restriction[7] only allows provisional WR to be granted; meanwhile, if it is under prohibition[8], no new WR can be granted[9].

At present, Articles 63 and 65 of the WC81 and Article 39 of the DS N° 203 establish that a Groundwater Association (GWA) must exist when groundwater is classified as restricted or prohibited. Even though 153 aquifers have a declaration of restriction and 4 aquifers have a declaration of prohibition, only 11 GWA are registered in the Public Water Registry or Catastro Público de Aguas (DGA 2016). This low number of GWA reveals the lack of understanding of the potential benefits of an effective collective management (Rivera 2016). In the absence of GWAs, the WC81 establishes that the DGA is responsible for controlling and monitoring groundwater withdrawals. However, evidence has shown that the DGA does not have the necessary resources (human, technical, and financial) to monitor all groundwater extractions (Montginoul et al. 2016; World Bank 2011).

Lastly, at present there is no conjunctive management of surface and groundwater, even though the WC81 reform of 2005 establishes that surface and groundwater must be jointly managed. Therefore, more than 12 years after the WC81 reform of 2005, groundwater continues to be individually managed, without effective controls and without joint management strategies with surface waters (Rivera 2016).

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[7] The DGA can declare an aquifer under restriction if there is a risk of negative impacts of new WR on existing WRs.

[8] The DGA can declare an aquifer under prohibition if there is clear evidence of a risk of resource depletion due to over extraction.

[9] The DGA has the authority to provisionally grant groundwater rights in those areas that have been declared under restriction. The effects of these provisional WR on other groundwater use rights holders are studied. Should negative impacts be identified in these areas, these provisional WR are annulled by the DGA; *i.e.* groundwater may no longer be extracted with these WR. However, if no effects are identified after 5 years of water extraction, these provisional WR can become definite WR.

5.2.3.7 Legal Status of Desalinated Water

The WC81 only regulates inland waters, ruling out its application to maritime waters. However, both have the same basic legal nature of public goods[10]. In the case of inland waters, a WR granted by the DGA empowers its holders to exercise a right for its use. Maritime waters, on the contrary, do not require a use right. Investment and implementation of desalinization plants, however, require a license granted by the Ministry of Defense (MINDEF) to use an area of Chile's coastline[11].

Desalinization investment proposals must present an environmental impact assessment to the Environmental Impact Assessment System (SEIA). Thus, they must obtain the respective environmental authorization for its construction and operation, after an analysis of the compliance with environmental rules.

However, the lack of specific regulation on the matter, as well as the lack of planning can constitute an important barrier for the adequate development of this industry in Chile.

5.3 Water Quality and Environmental Regulation

Water quality and ecosystem protection were not relevant objectives of the WC 1981, its main focus was and still is on water quantity and allocation. The 2005 reform of the Water WC81 considered the environment as a special water-using sector incorporating the requirement to establish minimum ecological flows (MEF). This was reinforced with the 2010 reform of Chile's Environmental Law, Law 19,300, which regulates the protection of aquatic ecosystems through the implementation of ecological water flows. Article 129 bis 1 of the WC81, stipulates that when issuing new surface WR, the DGA must ensure the preservation of the environment, and for these purposes must establish MEF, which shall only affect newly constituted surface WR. However, it has been pointed out that before the WC81reform of 2005, most river basins located in the North and Central Macroregions were fully allocated, in some cases overallocated, and, thus, it has not been possible to fully implement minimum ecological flows due to the lack of water (Riestra 2018). River basins that have protected minimum ecological flows are mainly located in the Southern Macroregion where water is more abundant.

Chile's water quality regulatory system is led by the Ministry of Environment, since its creation in 2010, and is mainly regulated by the Law N° 19.300 of 1994, the Law N°20.417 of 2010 and the Law N° 20.600 of 2012. The basic regulatory water quality instruments are: (a) environmental water quality standards, (b) decontamination plans and strategies, (c) emission standards, and (d) environmental impact assessments for new investments.

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[10] From a legal point of view.

[11] The use of Chile's coastline is responsibility of the Ministry of National Defense (MINDEF) – especially the Deputy Ministry of Navy- whose mandate is to control and supervise the entire coast and territorial sea.

5.4 Water Governance

Water governance in Chile has evolved throughout history according to the natural and social context in which water resources management has been developed. It has gone from a simple structure in the Colony to a model that is characterized by the coexistence of centralized and decentralized institutions (Vergara 2014; World Bank 2013). Centralized organizations comprise the administrative bodies of the State, in which the DGA plays the most important role. These centralized institutions include water quantity and quality management bodies and the judicial system that resolves most water conflicts. Decentralized bodies, on the other hand, are represented by Water User Associations (WUA), which are private organizations that manage and distribute water at the local level and are not part of the State administration.

World Bank (2013) identified 43 institutional actors in the form of institutions, management units or groups of users or stakeholders involved in the management of water resources in Chile (Fig. 5.1).

5.4.1 Centralized Institutions

Under the WC81, the State reduced its intervention in water resources management to a minimum and increased the management powers of WR holders that are organized in water user associations. The water resource management roles assigned to the State include the:

1. The constitution of WR.
2. Measurement and determination of water resources availability.
3. Generation and maintenance of the necessary water resources and WR market information that permits for a well-informed management of water resources.
4. Regulation of water resource uses avoiding third party effects and their overexploitation. For that purpose, the State must analyze the availability of water resources and potential water use conflicts before granting new WR and other authorizations such WR transfers.

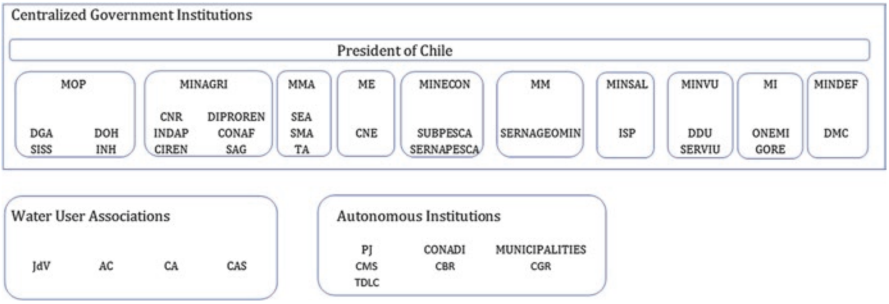

Fig. 5.1 Water institutionality. (World Bank 2013) (Institutional abbreviations are defined in the Acronyms Lists)

Table 5.1 Functions of the DGA

1. Surface and groundwater regulation	2. Develop and enforce national water policy
3. Granting WR	4. WR transfer authorization
5. Water resources information	6. WR market information
7. Update the public water registry	8. Promotion and oversight of WUA
9. Determine minimum ecological flows	10. Water rights use modification (e.g. water sharing)
11. Management of emergency situations due to flooding and droughts	12. Oversight and sanction in the hypotheses contemplated in the law
13. Water use monitoring and enforcement	

Source: Based on Donoso (2014), World Bank (2013), and Vergara (2014)

5. Conservation and protection of water resources and ecosystems, by means of an environmental impact assessment system and environmental policies.

The DGA, as the leading government agency in water resources management, develops and enforces national water policy. In this role, it has led efforts to amend the WC81 and developed a National Water Policy. Its main functions are presented in Table 5.1.

In general, the DGA has maintained a limited role in accordance with the paradigm of limited state interference on which the WC81 is inspired.

As previously pointed out, there are various institutions involved in water management, whose functions complement and/or compete with those of the DGA. The Waterworks Directorate (DOH) is a unit of the MOP that plans, designs, coordinates and supervises the construction of major hydraulic public works, such as water dams. Its programmes include not only infrastructure investment for water management, but also storm-water infrastructure, flood control, and infrastructure for rural drinking water supply. A third important institution is the National Irrigation Commission (CNR) of the Ministry of Agriculture (MINAGRI) that establishes the policies and plans for irrigation uses. The CNR is headed by a Council of Ministers and an Executive Director. The Council of Ministers that includes the Ministers of Agriculture, Economy, Development and Tourism, Finance, Public Works, and Social Development coordinates the institutions involved in irrigation and drainage. The CNR conducts research and implements projects in order to submit proposals to the Council of Ministers. The CNR also administers the subsidy whose objective is to encourage the adoption of water conservation technology by farmers (Law 18.450 of 1985).

An assessment of Chile's centralized water governance evidenced a low performance (World Bank 2013). This is mainly due to the following institutional weaknesses:

1. Limited institutional role of the DGA.
2. Lack of institutional coordination.

3. Deficiency in strategic water planning and management formulation and monitoring.
4. Problems in the generation and dissemination of relevant information for water management.
5. Lack of participatory instruments for an integrated water management.
6. Insufficient institutional budgets.

5.4.2 *Decentralized Institutions*

The WC81 entrusts water management, administration, and distribution, to water rights (WR) holders that are organized in WUA. These do not form part of the administration of the State, but exercise public functions (Rojas 2016). Water user management has existed in Chile since the colonial era (Melo and Retamal 2012).

Three types of WUA exist in Chile that are recognized by the WC81: water communities (comunidades de aguas – CA), channel user associations (associaciones de canalistas – AC), and vigilance committees (juntas de vigilancia – JdV). CA are comprised by two or more WR holders that (i) share the same water distribution channel or (ii) extract groundwater from the same aquifer or hydrogeological section of an aquifer. The AC considers all WR holders and CA that depend on the same channel system. Finally, JdV are comprised of all the water users, AC and CA that extract water from a shared river, river section, or stream. Table 5.2 presents the main functions of these WUA

According to official figures released by the DGA, as of December 2015, a total of 3489 water user associations were registered in the CPA: 46 JdV, 200 AC, 3232 CA and 11 GWA (DGA 2015). These figures do not include WUA that are organized but have not yet completed their formalization and registration process.

Many of these WUA have professional management (Donoso 2015). The effectiveness of some of these institutions in managing irrigation systems and reducing transactions costs for water market transactions has been noted (Hearne and Donoso 2005). However, according to the DGA and the CNR, a large percentage of these institutions have not updated their capacity to meet new challenges. Additionally, Bauer (1998) and Vergara et al. (2013) point out that WUA have not been effective in resolving conflicts.

In general, the performance of the WUAs is regular (World Bank 2011, 2013). This can be explained by the fact that an important proportion of WUAs do not fully satisfy Ostrom's 8 principles for an effective collective groundwater management. The main difficulties that limit WUA effective water management are (Vergara et al. 2013):

1. Legal and administrative obstacles in the determination of their statutes and rules of operation.
2. Lack of adequate professional management.

Table 5.2 Main functions of WUA

	Water communities	Channel associations	Vigilance committees
Water source on which they have influence	Artificial channels	Artificial channels	Natural surface water and groundwater sources
Jurisdiction	They act over the water flow that does not exceed the capacity of its channels	They act over the water flow that does not exceed the capacity of its channels	They have jurisdiction on the entire basin or watershed or an independent section of a natural stream or aquifer
Members	Two or more WR holders that extract water from a water channel	WR holders that extract water from a water channel system	Water Channel associations, water communities and individual water rights holders
Functions	Channel maintenance	Channel system maintenance	Water distribution and management in natural water sources – Both surface and groundwater
	Water distribution and management	Water distribution and management	Establish water sharing system under water scarcity
	Conflict resolution	Conflict resolution	Maintain water intake infrastructure
	Monitoring, enforcement, and penalties	Monitoring, enforcement, and penalties	Conflict resolution
			Monitoring, enforcement, and penalties
			Transfer of WR between different water intake structures
			Ensure that upstream water management decisions do not affect downstream users

Source: Author's elaboration based on articles 186 – 293 of the WC81

3. Insufficient budgets for an effective water management and to maintain and improve their water infrastructure.
4. Strong administrative presence and intervention in some basins where hydraulic works have been built by the State.
5. River and aquifer sections with autonomous and independent WUA, limiting an integrated water management.
6. Lack of effective integration of all water users in the JdV, especially groundwater user associations and non-consumptive WR holders.
7. Lack of complete registry of WR.

To address some of these concerns, the CNR, DGA, and DOH have implemented programmes to strengthen WUA (Peña 2001; Puig 1998).

5.5 Conflict Resolution

The main water conflict resolution bodies are

1. Ordinary Courts of Law (OCL): Given the inexistence of Specialized Administrative Litigation Courts in the country, water disputes are resolved by the Ordinary Courts of Law. The competent court is defined according to the type of conflict, but most water conflicts are concentrated in the Courts of Appeals (one in each regional capital) and in the Supreme Court, without prejudice to the intervention of Civil Courts that exist on the basis of each municipality or group of municipalities.
2. Comptroller General of the Republic (CGR): Although the essential function of the CGR is to review and control the legality of administrative acts, it is not unusual that this entity reviews certain disputes that arise between individuals and applied administrative procedures.
3. DGA: While the DGA also has no jurisdictional powers, in the facts it acts as a judge when conflicts arise in certain administrative procedures (whether during the constitution of new WR or relating to the exercise of WR). There are two rebuttal mechanisms for the DGA resolutions. One is the appeal for reconsideration, which is brought before the same administrative authority (Article 136 WC81), and a second one is a claim resource brought to the competent Court of Appeals (art. 137 WC81).
4. WUAs: These organizations have jurisdictional powers with express basis and legal support, corresponding to their board of directors the exercise of conflict resolution. These boards of directors of WUAs should act as an arbitral tribunal to resolve conflicts arising between its members on water allocation or exercise of their rights and those arising between their members and the user organization itself (Articles 244 to 247, 258 and 267 WC81).
5. Environmental Courts (TA): In 2010, the TA was created; these are a specialized environmental conflict resolution body. An important percentage of the conflicts resolved by the TA refers to water issues, focusing on resource quality issues.

WUAs are responsible for resolving conflicts of disputes among their members regarding the use of water rights WR (Rivera et al. 2016; Hearne and Donoso 2014). The power and ability to cope with conflicts within a WUA largely depends on the level of organization, such as budget, staff, and members' schooling (Rivera et al. 2016).

Water conflicts in Chile have increased during the past years (Vergara et al. 2013; Bauer 2015). Most of these controversies occur between the DGA and WR holders. In recent years, it is possible to identify some common focus and notes in water conflicts that are resolved by the OCL. There is evidence of a certain deference of the OCL to the DGA and, thus, few times the OCL sentence is in favor of the individuals. In the past years, however, the Supreme Court has shown a more energetic judicial control regarding DGA's action, especially with regard to standards, rules and principles governing the actions of the State's Administration.

There are multiple sources of conflicts. One of them are the conflicts that have arisen between users and the DGA with respect to the WR granting procedure and the definition of water availability. The procedures to regularize customary WR has generated conflicts between customary WR holders and the DGA, as well. The application of the non-use tariff has also been conflictive, in particular with respect to the definition of water extraction infrastructures.

In relation to all these sources of legal conflicts it is possible to note a lack of and need for water expertise by the Courts, in spite an improvement in the approach of High Courts of Justice to some of them in the last years. Therefore, and considering Chilean legislative tendency towards the creation of specialized Courts with administrative jurisdiction, consideration should be given to the incorporation of specialized water Courts, with a collective and interdisciplinary composition (law, hydrology, hydrogeology, engineering, and economics, among others) (Vergara et al. 2013).

5.6 Conclusions

The legal framework of Chilean Water Law is structured on the basis of a normative trilogy. In first place the DL N° 2.603 of 1979, which gave rise to the Water Code of 1981, and conferred legal recognition to customary and granted WR. Secondly, the Political Constitution of 1980, which, following the aforementioned DL N° 2.603, distinguishes between "constituted" and "recognized" water rights and establishes that WR holders have ownership over them and are constitutionally protected. In third place, the WC81, which has remained in force for more than 35 years, having been reformed in 2005. At present, a new reform of the WC81 is under consideration in Congress[12].

The Chilean water management model is characterized by the domains of the State, the WUAs and market in the fundamental functions of water use and management. Its essential characteristics are, (1) the WR ownership regime which guarantees to the owner the use and possession as any other good capable of private appropriation; (2) the application of a WR market; (3) the concept of a subsidiary State, and (4) the essential role of WUAs in the management of a common good.

Water legislation in Chile was designed, in essence, to regulate the use of surface waters. The WC 1981 did not pay much attention to the sustainable management of groundwater because at that time, groundwater extraction was a marginal water source. Even though special regulatory groundwater management regulations have been issued in recent years, groundwater has a terse legal treatment and several issues and problems persist, limiting an effective and sustainable groundwater management.

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[12] Bulletin N° 7.543–12, registered in 2011 (http://www.senado.cl/appsenado/templates/tramitacion/index.php

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Chapter 6
Water Quality Policy

Oscar Melo and Javiera Perez

Abstract This chapter describes and analyzes water quality policy in Chile. To this end, the Chilean institutions and regulations of greater relevance to water quality issues are described. Subsequently, the main regulatory instruments used, and their implementation, are presented together with the definitions of the main existing prevention or remediation instruments. Finally, the decrees that conform the environmental regulation of the country are outlined. The policies that regulate the environmental quality of the waters in Chile have advanced significantly and a system that potentially will guarantee the quality of the waters is already in place. However, water resources that have secondary quality standards in place are to this date only a very small fraction. Thus, a more decisive push to add more areas is needed for the regulation to have a significant effect in the country.

Keywords Water quality · Secondary standards · Water policy · Water regulation · Chile

6.1 The Chilean Environmental Institutional Framework

Chile‘s environmental institutional framework is constituted both by elements of coordination and by a hierarchical authority represented by the Minister of the Environment. This environmental institutional arrangement has organizations of different hierarchy, in a vertical and functionally-decentralized structure. The Ministerio de Medio Ambiente (MMA – Ministry of the Environment) is in charge of defining policies and norms of environmental regulation. Additionally, the MMA is supported by the Consejo de Ministros para la Sustentabilidad (CMS – Council of

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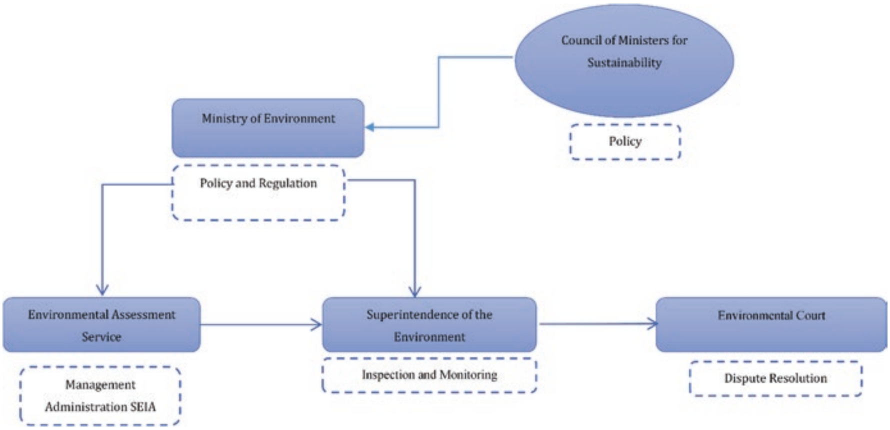

Fig. 6.1 Environmental institutional framework (Source: Adapted from Boettiger 2010)

Ministers for Sustainability), which provides a multisectoral characteristic to the discussion of environmental issues and is responsible for approving the policies and regulations proposed by the MMA. The CMS is chaired by the Minister of the Environment and is integrated by the Ministers of Agriculture, Finance, Health, Economy, Development and Tourism, Energy, Public Works, Housing and Urban Planning, Transport and Telecommunications, Mining and Planning. Among the functions of the CMS, is to propose to the President of the Republic policies for the sustainable management and use of renewable natural resources, together with the associated sustainability criteria.

On the other hand, the Servicio de Evaluación Ambiental (SEA – Environmental Assessment Service) is responsible for administering the Sistema de Evaluación de Impacto Ambiental (SEIA – Environmental Impact Assessment System), which is one of the main environmental management instruments in Chile. The audit of environmental instruments and standards is a function of the Superintendencia del Medio Ambiente (SMA – Superintendence for the Environment), which establishes an integrated system of environmental control with a single sanctioning system, consisting of a sanctioning procedure with exclusive competence of the SMA. Finally, the Tribunal Ambiental (TA – Environmental Court) has the power to resolve environmental disputes, claims of illegality, and requests for authorizations. Figure 6.1 summarizes Chile's environmental institutional framework.

The functions of the MMA include the creation, promotion and enforcement of policies, norms, plans and environmental programs related to environmental management and sustainable use of renewable natural resources at a national level. The MMA also develops policies on waste management, contaminated soils, climate change, and recovery and conservation of biodiversity.

Likewise, the MMA is responsible for generating environmental quality and emission standards, together with the establishment of prevention and decontamination plans. In turn, proponents of new projects must submit environmental impact assessment reports, so as to determine whether or not the environmental impact of an activity or project conforms to current standards.

The main environmental legal body is Law N° 19.300 (1994), initially approved in 1994 but later modified multiple times. The 2010 reform created the SEA and the SMA, which are functionally decentralized bodies, subject to the supervision of the President of the Republic through the MMA. The objective of the SEA is to manage and administer the environmental protection tool, the SEIA, along with managing information on environmental permits and unifying various environmental criteria, requirements and conditions. According to the same law, the SMA fulfills the function of supervising compliance with environmental management standards and instruments, along with sanctioning in case of non-compliance. The SMA manages an integrated environmental control system to ensure compliance with the environmental regulations contained in the management instruments. The responsible body for oversight and sanctioning powers of the SMA is the TA, which resolves all conflicts or legal disputes of an environmental nature. Although not part of the ordinary judiciary system, the TA depends on the Supreme Court's directive, correctional and economic superintendence.

Within the agencies dependent or coordinated by the MMA, are the Regional Ministerial Secretariats, the National Advisory Council, and the Regional Advisory Councils. In each region of the country, there is a Secretaria Regional Ministerial (SEREMI – Regional Ministerial Secretariat), technically and administratively dependent of the Minister of the Environment. Each SEREMI is responsible of exercising the Ministerial duties stipulated by the environmental laws, together with assisting the regional government in the incorporation of environmental criteria for the elaboration of plans and strategies for regional development. In addition, they must collaborate with the respective municipalities in matters of environmental management. Part of the function of the SEREMI is the coordination of the procedure of declaring zones of the territory as latent or saturated, as long as the target area is in the region of the Secretariat. The SEREMI is also responsible for providing information for elaborating prevention or decontamination plans, together with providing the material means for the operation of the Regional Advisory Council.

The purpose of the National Advisory Council is to resolve the consultations made by the MMA and the CMS. The Council is also requested to express its non-binding opinions on draft laws and supreme decrees setting standards of environmental quality, preservation of nature and conservation of environmental heritage, prevention and decontamination plans, special emission regulations and emission standards submitted to them. In each region of the country, there is a Regional Advisory Council for the Environment, which is responsible for resolving the consultations made by the Intendant (a sub-regional authority), the Regional Government or the SEREMI.

6.2 Environmental Regulation in Chile

The regulatory framework for the control of air, water and soil pollution in Chile is based, in part on primary and secondary environmental quality standards. The primary quality standards establish pollutant concentration levels and their respective maximum or minimum duration, whose presence or absence in the environment may constitute a risk to the life or health of the population. Meanwhile, the secondary quality standards establish pollutant concentrations levels and maximum or minimum duration, whose presence or absence in the environment may constitute a risk for the protection or conservation of the environment.

In order to dictate environmental quality standards, the authority must carry out a General Analysis of the Economic and Social Impact of the proposed quality standards (Análisis General de Impacto Económico y Social – AGIES) and consultations with competent bodies and stakeholders. The Minister of the Environment, who manages the information in order to control the environmental quality of air, water and soil, must review all environmental quality standards.

As shown in, Fig. 6.2 the primary quality standards depend on the Ministry of the Environment and the Ministry of Health. On the other hand, the secondary quality standards depend on both the Ministry of the Environment and the sectoral ministries concerned according to the subject matter. The same is true in the case of emission standards, which establish the maximum permitted amounts of a pollutant in emissions, effluents or waste. These emission standards can be used when implementing a prevention or decontamination plan. These plans are used to prevent the quality standard level from being reached or exceeded.

Through an initiative or mandate from the Government, a surveillance analysis is activated that determines the need to create an environmental quality control program. Once the analysis is completed, the criteria to establish various regulations are set. Once the quality standards are established, the affected area is declared as: latent zone, saturated zone, or without effect. The latter category is declared when the concentration of pollutant found corresponds to less than 80% of the standard set by the Ministry. A latent zone is declared when the concentration of pollutant is higher than 80% of the set level. If a zone is declared as latent, a prevention plan is developed aiming at re-declaring the zone as without effect, that is, with a contamination level between 0 and 80%. In the case of an area with a level of 100% or more pollutant than the standard, the zone is declared saturated. Under this category, a Decontamination Plan is carried out in order to lower pollutant levels and return to the latent zone category, and then to the zone without effect.

In accordance with Law N° 19.300 (1994), both prevention and decontamination plans may use emission standards, tradable emission permits, emissions taxes, or user fees, along with other management-oriented instruments to promote environmental improvement and repair actions.

While this legislation seeks to regulate pollutant levels, the regulations do not cover all types of pollutants and are only used in certain sectors of activity (CEPAL –

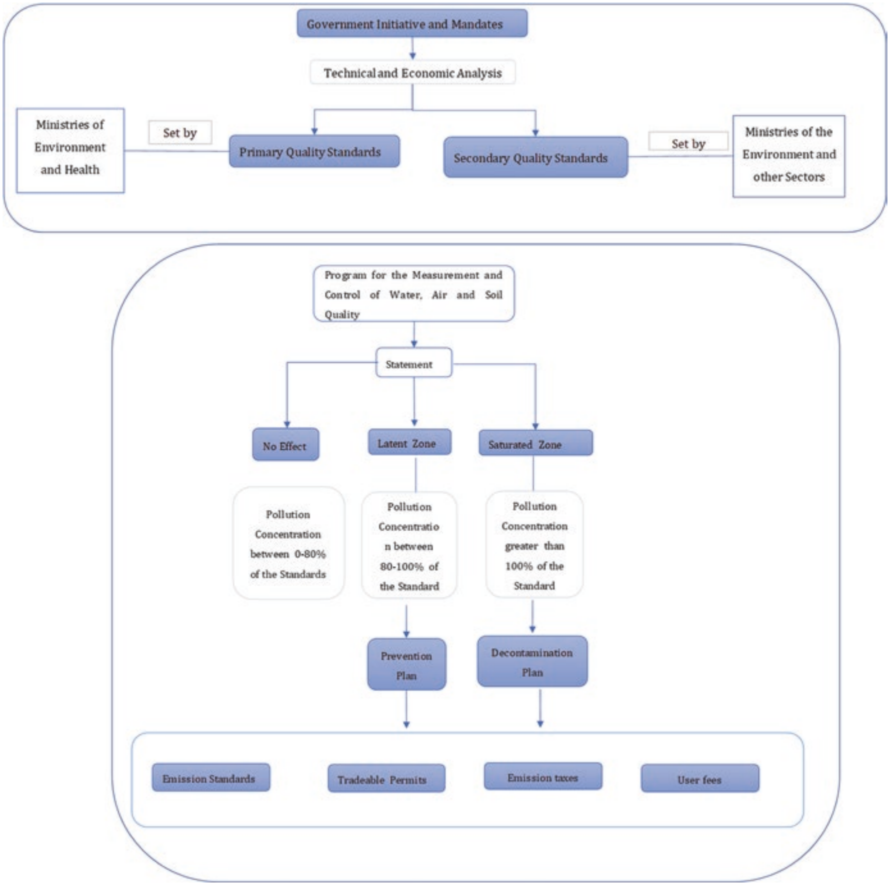

Fig. 6.2 Environmental regulatory scheme (Source: Adapted from Villalobos 2016)

OCDE 2016), thus Chilean regulations on emissions of air pollutants and wastewater discharge are incomplete.

According to Chilean legislation, a primary environmental quality standard must be the same throughout the national territory. This corresponds to the principle that guarantees that all citizens have the right to the same minimum level of environmental quality (Brzovic and Almazora 2006). On the other hand, secondary quality standards are established for specific geographic areas, taking into account the environmental peculiarities of the area in which they will be applied.

Both emission standards and quality standards must be reviewed every 5 years. Compliance with a primary quality standard is verified by measurements where human settlements exist. Secondary quality standards are measured in the corresponding medium and emission standards are measured in the effluent of the source and within a given period of time.

6.3 Quality Standards Enactment Procedure

According to Law N° 19.300 (1994), the issuance of environmental and emission quality standards must comply with a procedure specified by a guideline which is illustrated in Fig. 6.3 (Decreto 38, 2012). This process comprises a step for the elaboration of the preliminary draft, which includes the creation of operational committees that intervene in the dictating of the norms. The processing of the issuance gives rise to a public dossier containing the decisions issued, the consultations evaluated, the observations, as well as all the antecedents, data and documents related to the dictation of the norm. Subsequently, the Minister has to commission scientific studies and request background information necessary for the formulation of the standard. Once the studies and other required antecedents are received, their merit is analyzed.

A General Analysis of the Economic and Social Impact (AGIES – Análisis General de Impacto Económico y Social) is carried out, which evaluates the costs and benefits of the emission or quality standards for the population, for the owners of regulated sources or activities, and for the State as responsible for the audit of the same.

Once the preliminary draft has been prepared, the Minister dictates the resolution where he approves it, and then submits it for consultation. The Minister then requests

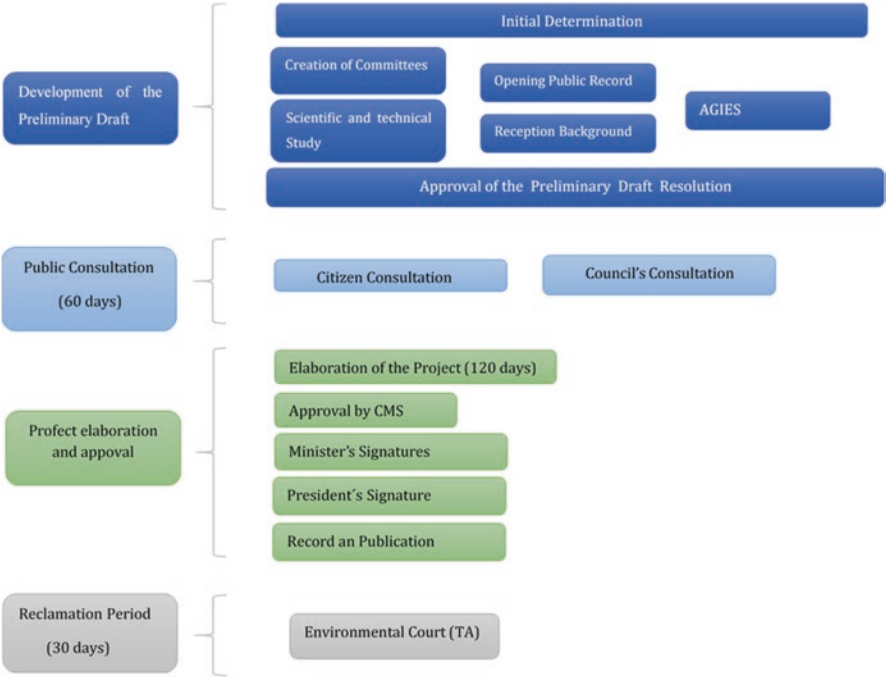

Fig. 6.3 Regulation for the dictation of environmental quality and emission standards (Authors own elaboration based on Decree 38)

the opinion of the National Advisory Council and the Regional Advisory Councils, which have 60 working days for the dispatch of their opinion to the Ministry. Within the same days, any natural or legal person may comment on the contents of the draft standard.

In the next 120 days, the final draft of the standard is elaborated, which is sent to the Council of Ministers of Sustainability (CMS) for discussion. In the event that the CMS pronouncement is favorable, the final draft of the standard is submitted to the consideration of the President of the Republic.

Finally, a supreme decree establishing primary or secondary environmental quality, or emission standards are subject to a complaint to the competent environmental court for a period of 30 days after the publication in the Official Newspaper by any person who considers that it does not conform to law.

6.4 Environmental Water Standards in Chile

The previous sections presented the institutional framework, regulatory scheme, and procedure for enacting environmental standards in Chile. This section presents the current water quality regulations in the country.

6.4.1 Emission Standards for Waters

Table 6.1 presents the four emission standards for water in effect in Chile. The objective of these standards is to control the amount of pollutants present in the effluents of each sector in which the standard is applied. Three of these standards are of general geographical application and seek to regulate the amount of pollutants discharged as liquid waste to: marine and continental waters, sewage systems, and aquifers. Meanwhile, the fourth standard applies to a particular area (Caren estuary) and regulates the discharges of molybdenum and sulphates from deposits of mining tailings to the estuary. The regulations also establish the agencies responsible for the oversight.

6.4.2 Primary Quality Standards for Water

The two primary water quality standards in effect in Chile, whose area of action covers the entire national territory, are presented in Table 6.2. Both standards came into force in 2009 and its supervisory body is the sanitary authority. In order to ensure the health of people, these standards aim to protect both the quality of inland surface waters, and marine and estuarine waters.

Table 6.1 Emission standards for waters

Standard	Description	Objective	Regulated parameters	Supervisory body	Entry into force
Decree N° 90	For the regulation of pollutants associated emission standard to discharges of liquid waste to marine and inland waters.	Prevent contamination of marine waters and continental surface of the Republic, through the control of pollutants associated with liquid wastes that are discharged to these bodies.	PH, temperature, total suspended solids, settleable solids, oils and fats, hydrocarbons fixed, total hydrocarbons, volatile hydrocarbons, BOD5, aluminum, arsenic, boron, cadmium, cyanide, chloride, copper, total chromium, hexavalent chrome, Tin, fluoride, total phosphorus, iron, manganese, mercury, molybdenum, nickel, total kjeldahl nitrogen, nitrite more nitrate, pentachlorophenol, lead, selenium, sulfate sulfur, tetrachloroethene, toluene, trichloromethane, xylene, zinc, phenol index, to foam, SAAM, fecal coliforms or thermotolerant.	Superintendence of sanitary services, General Directorate of the maritime territory and merchant marine and health services, as appropriate.	September 2000. In the review process. A 2011, after 5 years, is in the final stage of review of continuous improvement
Decree 609	Establishes emission standard for the regulation of contaminants associated with discharges of industrial waste liquids to sewage systems.	Improve the environmental quality of wastewater, public provision of these services running into terrestrial or marine water bodies through the control of polluting fluids of industrial origin, which discharged into the sewer.	Oils and fats, aluminum, arsenic, boron, cadmium, cyanide, copper, total chromium, hexavalent chromium, BOD5 phosphorus, total hydrocarbons, manganese, mercury, nickel, ammonia nitrogen, PH, lead, power foam, settleable solids, total suspended solids, sulphate (dissolved), sulfur, temperature.	Superintendence of health services and health services	August 19, 1998. Currently in the review process.

Decree 46	Emission standard that determines maximum concentrations of contaminants allowed in liquid residues that are download – two by the source, through the soil, areas saturated aquifer, through works aimed to infiltrate it.	Prevent contamination of groundwater, through waters the control of the disposal of liquid waste which seep through the ground into the aquifer. With the above, helps to maintain the environmental quality of groundwater.	Oils and fats, aluminum, arsenic, benzene, boron, cadmium, cyanide, chloride, copper, total chromium, hexavalent chromium, fluoride, manganese, mercury, molybdenum, nickel, total nitrogen, pentachlorophenol, lead, selenium sulphates, sulphides, tetrachloroethene, toluene, trichloromethane, xylene and zinc.	Superintendence of sanitary services and the services of health, as appropriate.	January 7, 2003. In the review process. A 2011, after 5 years, is in the final stage of review of continuous improvement.
Decree 80	Emission standard for molybdenum and sulphates of downloads effluents from tailing dams to the Caren estuary.	Protection of the water resources of the Caren estuary, located in the municipality of Alhué in the metropolitan region, through the regulation of discharges to the Caren estuary of liquid waste from of tailing dams, containing sulphate and molybdenum.	Molybdenum and sulphates	Superintendence of health services	August 26, 2006

Source: MMA (2011)

Table 6.2 Primary water quality Standards

Standard	Description	Objective	Regulated parameters	Supervisory body	Entry into force
Decree 143	Primary standards of environmental quality of inland surface waters in the territory of the Republic, suitable for recreation with direct contact.	Protect the quality superficial continental waters in order to safeguard the health of the people.	Color, PH, cyanide, polychlorinated biphenyls (PCBs), benzo (a) pyrene, carbon tetrachloride, dichloromethane, 2,4-diclorofeno acid xiacetrico (2,4-D), aldrin and dieldrin; altrazina; carbofuran; chlordane; chlorothalonil; cyanazina; heptachlor, lindane, simazine; trifluralin, arsenic, cadmium, chromium, mercury, lead, fecal coliforms.	Health authority	March 27, 2009
Decree 144	Standards primary environmental quality of marine waters and estuary, in the territory of the Republic, suitable for recreation with direct contact.	Protect the quality of marine waters and estuary in order to safeguard the health of the people.	Color, PH, cyanide, arsenic, cadmium, chromium, mercury, lead, fecal coliforms.	Health authority	April 7, 2009

Source: MMA (2011)

6.4.3 *Secondary Quality Standards for Surface Continental Waters in Chile*

Secondary water quality standards have the function of protecting, maintaining or recovering the quality of surface inland waters, to protect and conserve aquatic ecosystems, maximizing social, economic and environmental benefits (CONAMA 2004). To date, there are six secondary quality standards related to water resources (Table 6.3): two for lakes (Lake Llanquihue and Lake Villarrica) and four for river basins (Serrano River, Maipo River, Valdivia River and Biobío River).

The first surface secondary quality standard was published in March 2010, for the Serrano River Basin, located in the Magellan and Chilean Antarctic region. The Serrano River Basin covers an area of 6673 km^2 and includes almost the entire surface of the Torres del Paine National Park and part of the Bernardo O'Higgins National Park. According to the Froward Center for Environmental and Antarctic Law (2009), the signal given by the publication of the first secondary standard was

Table 6.3 Secondary quality standards for surface water

Standard	Description	Objective	Regulated parameters	Supervisory body	Entry into force
Decree 75	Environmental quality standards for the protection of inland surface waters of the basin of the Serrano river.	Protect and maintain the bodies or water courses of exceptional quality in the basin of the Serrano river, which secure their qualities as site of tourist, scenic and environmental value in order to safeguard the use of water resources, the aquatic communities and ecosystems; maximizing the environmental, social and economic benefits.	Aluminum, cadmium, chloride, copper, fecal coliform bacteria, conductivity, chromium, iron, manganese, mercury, molybdenum, nickel, dissolved oxygen, ph, lead, ras, selenium, sulfate and zinc.	Directorate-General for water and agricultural and livestock service.	March 19, 2010
Decree 122	Environmental quality standards for the protection of the waters of Lake Llanquihue.	Maintain the quality of the waters of Lake Llanquihue and prevent anthropogenic eutrophication, providing management tools to contribute to the maintenance of current oligotrophic condition.	Conductivity, ph, dissolved oxygen, turbidity, silica, cod, transparency, total nitrogen, total phosphorus, chlorophyll.	Directorate-General water and General Directorate of maritime territory and merchant marine.	June 4, 2010
Decree 19	High standards of environmental quality for the protection of inland surface waters of Lake Villarrica.	Protect the quality of the waters of the Lake, in way of preventing an accelerated increase in trophic status, caused by anthropogenic activity within its watershed.	Target Trophic level, transparency, dissolved phosphorus, total phosphorus saturation of oxygen, dissolved nitrogen, total nitrogen, and chlorophyll.	Superintendence of the environment, in coordination with the Directorate General of water and the General Directorate of the maritime territory and merchant marine.	October 16, 2013
Decree 53	High standards of environmental quality for the protection of inland surface waters of the Maipo River basin	Conserve or preserve water ecosystems and its ecosystem services through the maintenance or improvement of the quality of the waters of the basin.	Oxygen dissolved, electrical conductivity, pH, chloride, sulfate, biochemical demand of oxygen, nitrate, orthophosphate, dissolved lead, lead dissolved, dissolved nickel, dissolved zinc, dissolved chromium.	Superintendence of the environment, with the collaboration of the Ministry of the environment, the Directorate General of water and the agricultural and livestock service.	July 4, 2014

(continued)

Table 6.3 (continued)

Standard	Description	Objective	Regulated parameters	Supervisory body	Entry into force
Decree 1	High standards of environmental quality for the protection of inland surface waters of the Valdivia River basin	Conserve or preserve water ecosystems and its ecosystem services, through the maintenance or improvement of the quality of the waters of the basin.	pH, oxygen dissolved, electrical conductivity, sulphate, sodium, chloride, DOD, total aluminium, dissolved aluminum, total copper, dissolved copper, total copper, dissolved copper, total chromium, total iron, dissolved iron, total manganese, dissolved manganese, total zinc, dissolved zinc, nitrate, phosphate, halogenated organic compounds.	Superintendence of the environment, with the collaboration of the Ministry of the environment, the Directorate General of water and the General Directorate of the maritime territory and merchant marine.	27 November, 2015
Decree 9	High standards of environmental quality for the protection of inland surface waters of the Bío-Bío River basin	Conserve or preserve aquatic ecosystems and their ecosystem services, through the maintenance or improvement of the quality of the waters of the basin.	Total aluminum, ammonium, organic compounds halogenated, chloride, fecal coliforms, electrical conductivity, biological oxygen demand, demand chemical oxygen, total phosphorus, total iron, phenol index, nitrate, nitrite, total nitrogen, orthophosphate, dissolved oxygen, pH, total suspended solids, sulphate.	Superintendence of the environment, with the collaboration of the Ministry of the environment, the Directorate General of water and the agricultural and livestock service.	27 November, 2015

Source: MMA (2011)

to emphasize the fact that environmental conservation does not have human health as the ultimate goal, but rather the conservation of environmental resources. The objective of this standard is to protect and maintain water bodies of exceptional quality, ensuring their qualities as a site of scenic and touristic environmental value, to safeguard the use of water, aquatic communities and ecosystems (Decree 75).

The next secondary standard was published in June 2010, for Lake Llanquihue. Located in the Los Lagos region (Macroregion South), it is the largest lake in the region and the second nationally, and has as only drainage the river Maullín, which is a priority site for biodiversity conservation in the region. The objective of the secondary standard of Lake Llanquihue is to constitute an instrument for the sustainable development of the lake, to prevent environmental deterioration, along with the protection and conservation of aquatic biodiversity and the prevention of antropic eutrification, maintaining the quality present in the lake to the date of the publication of the standard (Decree 122).

In October 2013, the secondary standard of environmental quality for the protection of Lake Villarrica located in the region of Araucanía (Macroregion South) entered into effect. It is a lake of glacial origin that occupies a basin at the end of an extensive mountainous valley, molded by the action of the glaciers. Its main effluent is the Trancura river, which contributes almost 90% of the incoming flow to the lake. The objective of the standard is to protect the quality of the waters of the lake, in order to prevent an accelerated increase of its trophic state, caused by the anthropic activity, notably tourism, within its watershed (Decree 19).

In July 2014, the Maipo river (Center Macroregion) secondary standard was created with the aim of preserving the water ecosystems and their ecosystem services through the maintenance or improvement of the quality of the waters of the basin. The environmental importance of creating the secondary standard for the Maipo basin lies in the fact that this basin is located in the central Mediterranean zone of Chile, which has been described as one of the 25 biodiversity hotspots at a global scale. At the landscape level, the Maipo river basin is heavily degraded, a fact that has significantly modified the composition and vegetative structure of the lower areas of the basin. The Maipo river basin is home to approximately 40% of the national population, which explains the great pressure for the use of water resources (Decree 53).

The basin of the river Valdivia is located in the regions of La Araucanía and Los Ríos (Macroregion South), and is composed of the sub-basins of the rivers Cruces and Calle-Calle. In November 2015, the secondary standard for the Valdivia river basin was created, with the objective of conserving or preserving water ecosystems and ecosystem services by maintaining or improving the quality of waters in the basin. The basin has a high biodiversity of species and on its banks, inhabits a population of about 370 thousand people. The main economic activities associated with the basin are agricultural, industrial and, to a lesser extent, aquaculture. The estuary systems formed in this basin, besides being one of the most important of the southern zone of Chile, have an irreplaceable biological function in the production and development of numerous species. In addition, in the lower part of the Cruces river, a wetland was formed as a result of an earthquake in 1960, which was declared a nature sanctuary. This basin is of great tourist importance for the region, with recreational fishing activities carried out, and its water is also used for drinking supply. The urban population of the lower part of the basin is mainly concentrated in the city of Valdivia, which has sewage and wastewater treatment services. All these activities have a negative impact on the quality of the waters of the Valdivia river basin. Therefore, according to Decree 1, regulation is essential through environmental management instruments that allow to protect the quality of its waters and ecosystems.

The last secondary standard, enacted in November of 2015, and which is currently in effect, corresponds to the Biobío river basin located in the Biobío and La Araucanía regions (Macroregion South). The Biobío river water-uses include drinking water and industries, hydroelectric generation, irrigation, urban and industrial effluent assimilation, aquaculture, recreation and tourism, aggregate extraction and biodiversity conservation. The main risks for the protection and conservation of the environment correspond to anthropic interventions at the level of the Biobío river basin. These hazards mainly correspond to slope deforestation, soil erosion and loss, aggregate extraction, changes in flow rates and river regime due to hydroelectric generation and irrigation supply, and to diffuse and point sources that discharge to recipient bodies. The purpose of the standard is to conserve or preserve aquatic ecosystems and their ecosystem services, by maintaining or improving the quality of waters in the basin (Decree 9).

6.5 Surveillance Programs

According to the MMA, the monitoring of the secondary water quality standards has to be implemented through a program which should include monitoring at the points where quality parameters are measured following a technical guide. The monitoring program is structured through two measurement networks, the official control network, and the observation network or unofficial network. The official control network, allows to evaluate the compliance of the standards and is the responsability of the competent authorities. On the other hand, the informal network allows to evaluate other conditions necessary for the management of water quality, such as the environmental impact of anthropic order, the intervention of subsistence productive activities and ecological states.

Subsequently, it is necessary to evaluate whether or not the parameters measured through the official network exceed the value established for each parameter. Once this information is obtained on the physicochemical and biological state of the water body, the information is systematized for the general public's knowledge.

6.6 Conclusions

The policies that regulate the environmental quality of the waters in Chile have advanced significantly and a system that potentially will guarantee the quality of the waters is already in place. However, it took about 22 years since the first pre-eminently environmental law to introduce the basic institutional framework and regulation to manage water quality and, at present, there are significant water quality problems and challenges (Vega et al. 2017). This delay is in part due to the lack of systematic and reliable water quality information, differences in the technical criteria and discretion of the authority in its application.

At the same time, water resources that have a secondary standard are to this date only a very small fraction. It is difficult to unify secondary water quality criteria and objectives, generating confusing and even conflicting water quality scenarios of rivers and basins. A more comprehensive methodology should be sought, which can account for the health status of the ecosystem, characterizing scenarios, models and acceptable limits in social consensus acceptable to the development of the country.

Thus, a more decisive push to add more areas is needed for the regulation to have a significant effect in the country. Because this means more funding, it would probably make sense to continue prioritizing those areas where the standards would yield the highest net benefits to society.

Even if more areas are covered by the standards, this by no means suggests that current policies and institutions ensure that target levels of quality will be maintained. On the contrary, this is a system that is recently being tested; thus, further enhancements will undoubtedly require greater investments and adjustments to meet the hydro-environmental demands of Chilean society. As shown in the cases for each Decree presented above, the standards can be challenged by stakeholders, who may demand more or less stringent limits. Therefore, it can be expected that more standards will be challenged in the future. To face this situation the environmental authority should become more careful in the justification of the level set for the standard. Which again translates in more resources and proficiencies for the institutions in charge.

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Chapter 7
Environmental Flow Policy

Francisco Riestra

Abstract The interest in environmental flows in Chile significantly grew over the last 15 years, paralleling the interest in and development of environmental flows globally. This can be explained by growing concerns for conservation and restoration of healthy river ecosystems in Chile, due to extensive ecological degradation and loss of biological diversity resulting from high levels of water extraction for consumptive as well as non-consumptive uses. The first steps to establish some values for minimal ecological flows (MEFs) in the Chilean water rights (WR) granting process, where given during the 80s. Later on, the 1994 Environmental Law, allowed to incorporate environmental flows (EFs) into the environmental impact assessment process. However, the 2005 reform of the 1981 Water Code could be considered as a turning point since it assumes the environment as a special water-using sector incorporating explicitly the concept of minimum ecological flows (MEFs). These requirements have been applied in the last decades, establishing MEFs values when new water rights (WR) or EFs are granted in environmental licenses. In spite of these advances, Chile has not been able to revert the deterioration of aquatic ecosystems in its main basins yet.

Keywords Aquatic ecosystem protection and conservation · Chile · Minimum ecological water flows

7.1 Introduction

Environmental flows are flow regimes needed to maintain important aquatic ecosystem services. They are central to support sustainable development, share benefits, and address poverty alleviation (Hirji and Davis 2009). Although there is broad scientific consensus that river continuity and flow rate comprises the most significant structural variable for freshwater ecosystems, a combination of other factors (water quality, energy sources, habitat diversity, and biological interactions) may be

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are also decisive in determining a species' survival and a river's ecological integrity (Poff et al. 1997). Of all ecological factors, flow rates take first place, followed by temperature (Angelier 2002). Water quality is another vital factor for aquatic species, encompassing not only concentrations of pollutants or the nutrient balance that the ecosystem needs, but also aspects such as turbidity and concentrations of oxygen and carbon dioxide.

While there are numerous definitions of environmental flows, this chapter follows the definition of The Nature Conservancy (TNC 2006); hence, they are defined as "the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems which provide goods and services to people".

Despite Chile's wide-ranging, complex, and diverse geography, it is home to only a few freshwater species. Different authors and sources give figures ranging from 44 to 46 for the number of fish species present in the country. Over 70% of these species are endemic, and around 32 (some 70%) are found in Central Chile (Habit et al. 2006; Vila and Pardo 2008; Vila and Habit 2015). The latest updates on mainland Chile's freshwater fish, indicates that only one is critically endangered, while 23 are endangered and 13 are classified as vulnerable; thus, 90% of all species are listed for conservation, with 50% facing a risk of extinction (MMA 2014).

There is consensus that low flow rates or the lack of them, as a consequence of anthropogenic water extractions, and riverbed alterations are the most significant variable that explains the actual state of fresh fish population in Chile. However, it is also important to recognize the threats that stem from the introduction of more than 25 invasive species (fish, amphibians, and mammals), which were released accidentally or deliberately through a number of activities (such as salmon farming, mosquito control, sport fishing, research, farming, and as aquarium pets). Insufficient research has been conducted to be able to present a full evaluation of the resulting impacts of these introductions (Iriarte et al. 2005; Habit et al. 2006; Vila and Pardo 2008; Vila and Habit 2015).

The interest in environmental flows in Chile significantly grew over the last 15 years, paralleling the interest in and development of environmental flows globally. This can be explained by growing concerns for conservation and restoration of healthy river ecosystems in Chile, due to extensive ecological degradation and loss of biological diversity resulting from high levels of water extraction for consumptive as well as non-consumptive uses.

In the 1980s and early 1990s, conservation and protection were only considered within protected areas, and water was only an issue in the aquifers that nourish Northern Chile's wetlands and Andean meadows. These ecosystems are areas of global significance, as here migratory birds, en route to their breeding grounds, find a dearth of major coastal lakes and estuaries, leaving them with no refuge other than high altitude salt lakes and wetlands to rest and feed.

The first steps to establish some values for minimal ecological flows (MEFs) in the Chilean water rights (WR) granting process, where given during the 80s. Later on, the 1994 Environmental Law, allowed to incorporate environmental flows (EFs) into the environmental impact assessment process (SEIA). However, the 2005 reform of the Water Code of 1981 (WC81 – Gobierno de Chile 1981), Law 20,017 (Gobierno de Chile 2005) could be considered as a turning point since it considered the environment as a special water-using sector incorporating minimum ecological flows (MEFs) explicitly. This was further reinforced with the 2010 reform of Chile's environmental law, Law 19,300 Sobre Bases del Medio Ambiente, (Gobierno de Chile 2010). This law establishes that renewable resources must be used in such a way as to ensure the regeneration of associated biological diversity, in particular for species classified as endangered, vulnerable, or rare, and species for which insufficient information is available. These requirements have been applied in the last decades, establishing MEFs values when new water rights (WR) or EFs are granted in environmental licenses. In what follows, this chapter describes the evolution of Chile's environmental flow policy.

7.2 Evolution of Chile's Environmental Water Flow Policies

In its beginning, Chile's WC81 failed to address environmental aspects, water quality, or other mechanisms that could help protect in situ usage, protection, and conservation of freshwater ecosystems. Its focus was and still is on water quantity, allocation, and management. Indeed, environmental issues were only introduced into the country's legislation in 1994 with the passing of Law 19,300, and were first added into the WC81 with the 2005 reforms (Davis and Riestra 2002).

Law 19,300 introduced the main instruments available for water quality management; these instruments are: (a) environmental water quality standards, (b) decontamination plans and strategies, (c) emission standards, (d) environmental impact assessments for new investments, and (e) EFs. Therefore, changes in water quality in the past 30 years cannot be attributed to WC81.

The term MEF first appeared in the early studies commissioned by the Dirección General de Aguas (DGA) (Vargas et al. 1998) and implemented with the support of the Universidad de Chile in 1998. In order to implement flow rates in the country's different river basins, the following hydrological methods were analyzed:

1. Q_{347},[1] Q_{330},[2] 10% of average annual flow(AAF), and
2. 50% of the minimum dry season's flow in the 95th percentile of years ($Q_{95\%}$).

The 2005 reform of the WC81 (Law 20,017) formally established the term MEF for the issuance of new WR, confirming the practices that the DGA had been developing for over 15 years (Riestra 2007).

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[1] Q_{347} is the flow rate which, averaged over ten years, is reached or exceeded on an average of 347 days per year and which is not substantially affected by damming, withdrawal or supply of water

[2] Q_{330} is the flow rate which, averaged over ten years, is reached or exceeded on an average of 330 days per year

The DGA formally introduced minimum ecological flows in 2007 (DGA 2007 and DGA 2008) into internal procedures manuals, which remains in force and stipulates that "ecological flows will be defined as the flow rate that must be maintained in a watercourse such that abiotic effects (reduction of wetted area, depth, current speed, increase in nutrient concentration, and other variables) resulting from the reduction in flow rate do not alter the ecological conditions in the watercourse or impede the development of the ecosystem's biological components (flora and fauna) or alter its dynamics and functions, thus allowing biodiversity to be conserved". In addition to this, since 2017, the Environmental Impact Evaluation Service (SEA) of the Ministry of Environment (Ministerio de Medio Ambiente MMA), together with the DGA, and other environmental impact assessment related organisations, use the same EF definition indicated on the Brisbane Declaration (2007): "environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems". This EF definition and the difference between MEF and EF are explained on the SEIA Guideline to Determine EF for Hydroelectric Projects (SEA 2017):

1. The requirement whether a project must propose or establish an environmental flow must be evaluated on a case-by-case basis.
2. The term "environmental flow" was adopted so as to distinguish this parameter from the MEF referred to in the WC81.
3. The obligation of maintaining the SEIA's "environmental flow" may correspond to a mitigation measure or a voluntary environmental commitment.
4. The MEF stipulated by the DGA when issuing WR is based mainly on hydrological factors.
5. Under the SEIA, project owners may commit to maintaining an "environmental flow" that differs from the MEF as established by the DGA when WR were granted due to specific social and environmental factors.
6. EF may also restrict the use of previously appointed WR on a specific project during its environmental impact assessment.

To date, DGA records show that over 25,000 MEFs have been established throughout the country. The highest concentration is located in the Central and Southern Macroregions. These flow rates were established over the course of four broad periods, described below.

7.2.1 Period 1: 1982–1993

Scattered records show that the DGA began establishing MEF rates as early as 1982, although the term MEF was only formally adopted in the 2005 reform of the WC81.

The first MEFs were governed under the Constitution of the Republic of Chile (CPR – Gobierno de Chile 1980), the Civil Code (Gobierno de Chile 1856), and the

WC81. Article 19 Section 8 of the CPR establishes the right to live in an environment free of pollution. Thus, the State has a duty to protect this right and oversee the protection of natural resources and ecosystems. The law can therefore place specific restrictions on certain rights and freedoms so as to protect the environment. Additionally, article 595 of the Civil Code and Article 5 of the WC81 refer to the condition of waters as national goods of public use, thus allowing the State to regulate how they are managed so as avoid third parties' effects. Lastly, article 22 of the WC81 establishes that when the competent authorities issues WR, water rights of third parties may not be affected or compromised. Article 14 of the same code also stipulates for non-consumptive WR, that "… *water shall always be abstracted and returned so as not to affect the rights of third parties to the same water, in terms of quantity, quality, timeliness of usage, and other factors.*" Thus, although there was no consideration of environmental or ecological parameters, the environment was recognized as a user of the resource.

During this period, the DGA established a few flow rates (no more than ten per year in Central and Southern Macroregions) necessary to maintain "ecological conditions" and/or to "preserve tourism potential" by specifying an amount of water that must not be abstracted by the holder of a WR, operating in a discretionary and unsystematic way. In most cases, a single value was set for a year-round minimum flow rate.

The first two cases were:

1. DGA Resolution 22 of February 22, 1982, in which a permanent and continuous flow rate was established for the Itata River of 130 m^3/s, as part of the WR granted to Sociedad Maderas Prensadas Cholguán S.A. in the Region of Biobio (Southern Macroregion) for the Itata Plant. The prelude to this Resolution highlights "*the importance of preventing the disappearance of the Itata Waterfall, so as to prevent the alteration of the site's ecological conditions and to conserve its tourism potential*". Additionally, Section 4 establishes that "*the WR holder must maintain a minimum flow rate in the current watercourse at the Itata Waterfall of 1.4* m^3/s", so as to preserve its touristic value.
2. DGA Resolution 442 of October 11, 1983, in which a permanent and continuous flow rate was established for the Bío River (292.5m^3/s) and Pangue River (7.5 m^3/s), both in the Southern Macroregion, as part of the WR granted to Endesa, the national electric company. Section 5 of this Resolution specifies that "*the WR holder must allow a flow rate to pass by its water intake in the Pangue River that is not lower than the minimum daily flow necessary to preserve ecological conditions*".

7.2.2 Period 2: 1994–2004

The newly approved environmental law (Law 19,300 – Gobierno de Chile 2010) establishes, in article 41, that renewable resources must be used in such a way so as to ensure the regeneration of associated biological diversity, in particular for species classified as endangered, vulnerable, or rare, and for species for which insufficient information is available. Article 42 adds that the public authority assigned to regulate natural resource use in a given area must require the submission and implementation of a resource management plan in order to ensure conservation, in accordance with the regulations in force.

Law 19,300 also established the SEIA, which may define environmental flows using factors other than hydrological methodologies. During this period, DGA began to issue WR with the systematic application of MEF throughout most of the country. The MEFs were discounted from water availability in corresponding surface watercourses, and thus could not be allocated to other future potential WR applications.

In 1998, a study from the DGA and the University of Chile (Vargas et al. 1998) established that MEFs would be defined as:

1. 10% of the AAF rate (based on French legislation and Tennant),
2. 50% of $Q_{95\%}$,
3. flow rate that is exceeded on at least 347 days per year, or Q_{347}, or
4. flow rate that is exceeded on at least 330 days per year, or Q_{330}.

The first two of these methodologies were the most commonly used by the DGA. Although no explanation has been given for the selection of these methods, both can be estimated directly from a DGA water availability analysis for a watercourse, whereas estimating Q_{347} and Q_{330} requires further studies and are more data intensive.

The DGA followed this procedure regardless of the fact that the WC81 still did not explicitly establish an ecological flow – this amendment was proposed to the national legislature during this period. As pointed out by Boettinger (2013), this led to legal challenges against the DGA's power to establish ecological flows. The Supreme Court's ruling in the cases of Aguas Chacabuco vs. the DGA, 2004, and Prieto Poklepovic vs. the DGA, 2006, validated DGA's actions, based on the following reasoning:

1. Article 19, Section 8 of the Constitution, guarantees an environment free of pollution, and it is the State's duty to protect this right and oversee the protection of natural resources.
2. It is the DGA's obligation to protect the environment, as a State body tasked with the oversight of natural and fundamental environmental resources.
3. The inclusion of possible environmental harm or impacts affecting ecosystems within the concept of "third parties" stipulated in Article 22 of the WC81, implies that the DGA is not only empowered but even obligated to take ecological flow rates into consideration when determining whether water resources were available for the issuance of new WR.
4. The condition of waters as national goods of public use (Article 595 of the Civil Code and Article 5 of the WC81), thus allowing the State to establish restrictions on WR to prevent third parties' effects.
5. Articles 41 and 42 of Law 19,300. The former of which establishes that the use of natural resources must preserve the regeneration capacity of associated bio-

logical diversity, and the latter authorizes the competent public body to regulate natural resource use by requiring the submission and implementation of management plans to ensure the conservation of the resources in question.

6. An extensive interpretation of the DGA's functions as established in Article 299 Part A and Article 300 Part A of the WC81, which, taken together with the Law 19,300, endowed it with this power.

7.2.3 Period 3: 2005–2010

Article 129 Part 1 of Law 20,017, of 2005, which amended the WC81, stipulates that when issuing WR, the DGA must insure the preservation of nature and the protection of the environment, and for these purposes must establish a MEF rate, which shall only affect newly constituted WR. The established MEFs may be no higher than 20% of the average annual flow rate in the corresponding watercourse.

In specific cases, however, following a favorable report from the corresponding Comisión Regional del Medio Ambiente (COREMA – Regional Environment Commission), the President of the Republic may issue a grounded decree specifying a different MEF, not limited by the foregoing limitation, but which may not affect existing WR. If the corresponding watercourse flows through more than one region, the report must be issued by the Comisión Nacional de Medio Ambiente (CONAMA – National Environmental Commission). The MEF stipulated in accordance herewith may be no higher than 40% of the average annual flow rate in the corresponding watercourse." (Gobierno de Chile 2005).

Until 2008, the DGA applied the methodology established in the DARH Manual of 1999 (DGA 1999), and just included the modifications to the WC81 in 2008 in its new upgraded guidelines for Water Resources Management (DGA 2008). The new Guidelines for Water Resources Management (DGA 2008), establishes that the methodology to determine MEF rates must consider at least the seasonal variations in flow rates.

Since ecological flows had already been established in several basins based on the criteria of 10% of AAF or 50% of $Q_{95\%}$, the procedure to define a variable MEF, considers the ensuing scenarios.

1. Rivers where WR were granted considering MEF as 10% of AAF.

   The MEFs will be based on 50% of $Q_{95\%}$, with the following restrictions:

   (a) For those months, in which the flow determined for 50% of $Q_{95\%}$ is less than the flow rate determined for 10% AAF, then the MEF in those months will be 10% AAF.
   (b) For those months, in which the flow determined for 50% of $Q_{95\%}$ is higher than the flow rate determined for 10% AAF but less than the flow rate for 20% AAF, then the MEF in those months will be 50% of $Q_{95\%}$.
   (c) For those months, in which the flow determined for 50% of $Q_{95\%}$ is higher than the flow rate determined for 20% AAF, then the MEF in those months will be 20% AAF.

2. Rivers where WR were granted considering MEF as 50% of $Q_{95\%}$.

   The MEFs will be based on 50% of $Q_{95\%}$, with the following restrictions:

   (a) For those months, in which the flow determined for 50% of $Q_{95\%}$ is less than the flow rate determined for 20% AAF, then the MEF in those months will be 50% of $Q_{95\%}$.
   (b) For those months, in which the flow determined for 50% of $Q_{95\%}$ is higher than the flow rate determined for 20% AAF, then the MEF in those months will be 20% AAF.

3. Rivers where WR were granted without considering MEF.

   In these cases, the criterion established as indicated for the second scenario will be applied with the same restrictions.

Boettinger (2013) points out that the new Guidelines were established as a response to a dispute between the DGA and the Contraloría General de la República (CGR – Comptroller General of the Republic). The conflict regarded the application of Article 129 Part 1 of the WC81, whereby the CGR declined to accept resolutions that granted water rights with a MEF on the grounds of the lack of an administrative act that specified the MEF in the corresponding river or water source (CGR Rulings 30,101/2009, 32,994/2009, 52,415/2009, 52,272/2009 and others). Subsequently, in 2009, the DGA established the criteria to apply in the regions of Los Ríos and Los Lagos, Maule, Araucanía, Aysén, BíoBío and Magallanes through DGA Resolutions No. 4093, 4094, 4095, 4096, 4097 and 4376 respectively. And in 2010 for the Valparaíso and Metropolitan regions (DGA Resolution No. 53/2010) and Atacama (DGA Resolution No. 589/2010). Thus, under these administrative acts, the CGR processed the DGA Resolutions that constituted WR with a MEF.

During these years, although MEFs were expressly established for new WR following the above procedure, when a previous WR was geographically transferred, the DGA established a MEF that was discounted from the allocated water flow. However, this MEF is not formally indicated in the resolution of the transferred WR.

7.2.4 Period 4: 2013–Present (2017)

In 2011, the Consejo de Ministros para la Sustentabilidad (CMS – Council of Ministers for Sustainability) approved new regulations for the determination of MEF, which were accepted by the CGR on July 19, 2013 and published in the Official Gazette on July 30, 2013. They were later revised in 2015 for suitable application, under Supreme Decree 71/2015 (Gobierno de Chile 2015). These Regulations remain in force for the issuance of new water rights, and establish that:

1. The DGA must specify MEF for all newly grated surface WR.
2. MEF will be set following the criteria of the Guidelines for Water Resources Management (DGA 2008), presented previously.

3. MEF may be no higher than 20% AAF (Article 3 of the regulations).
4. A different MEF may be established only with the formal and explicit agreement of the MMA and Ministerio de Obras Públicas (MOP – Ministry of Public Works) as long as no existing WRs are affected.

Additionally, they consider the following cases:

1. In the case of watercourses with hydrological dynamics that render the procedure for setting MEFs established by the Guidelines for Water Resources Management (DGA 2008) inapplicable, such as water falls and cascades, MEFs will be 20% AAF, as a constant value with no monthly variation.
2. Lakes or lagoons. MEFs will be determined by the guidelines applied to the lake's outlet water flow.
3. WRs defined for water stored in reservoirs. MEFs will be determined by the guidelines applied to the dam's outflow. In these cases, compliance will be verified immediately downstream of the dam.

This procedure shall be carried out using hydrological statistics of at least 25 years. In the event this time series does not exist for a given water source, the DGA will propose a known and accepted hydrological method in a technical report.

Furthermore, Article 7 of Supreme Decree 71/2015 (Gobierno de Chile 2015) establishes that the MEFs shall not exceed 40% AAF with the following exceptions:

1. When the goal is to protect or conserve aquatic species classified as almost threatened according to article 37 of Law 19,300 and its habitat allows for the support of this species.
2. When the water course is located in national protected areas established by the Corporación Nacional Forestal (CONAF – National Forestry Corporation) of the Ministry of Agriculture.
3. When there are significant impacts that alter the biotic, abiotic, physical, chemical and biological facts that ensure the protection of the associated ecosystem's structure and dynamics that provide the required environmental services for the species' survival.

Additionally, any individual or legal entity under Article 6 of these regulations, may request the declaration of a MEF for a surface water source. The request must be submitted to the DGA, and does not suspend the procedures for granting WR that are being processed by the institution. All requests must include:

1. Background information of the requesting party
2. The quantity of water to be specified as the MEF (m^3/s or any water flow specification)
3. The geographical areas sectors/sections of the watercourse where the applicant wishes to specify a MEF and the Region, Province, and/or District where these sites are located.
4. Technical justification for the request, supported by technical studies.

5. General characteristics of the watercourse, with particular attention to its hydrological regime, water quality, ecosystems, and current uses and activities.
6. A technical explanation of the effects that the requested MEF would have on the preservation of the aquatic species and ecosystems.

To date, the provisions for MEFs established by Supreme Decree 71/2015 (Gobierno de Chile 2015) have only been applied for newly granted WRs. However, there is no evidence that MEFs that exceed 40% AAF have established for the exceptions established in Article 7.

7.3 Minimum Ecological Flow in the Proposed Amendments to the Water Code

The Chilean legislature is currently analyzing two bills to amend the WC81. The first was published in Bulletin 7543-12 and has been before Congress since 2011. It was passed by the Chamber of Deputies' Agriculture Commission in 2017 and is now under debate in the Senate. This reform proposes one indication regarding MEF. This indication would empower the DGA to apply MEFs to existing previously granted WR if the owner transfers the WR, the owner submits a project for a major work in the channel, and in areas under official biodiversity protection and in ecosystems that the MMA reports to be degraded or threatened. The general rule of applying MEFs to newly granted WRs would be maintained; however, it will allow the DGA to not apply MEFs for WR granted to small-scale farmers.

The second bill comprises the amendments published in Bulletin 8149-09, which was approved by the Chamber of Deputies in 2012 and passed by the Senate in 2017. This bill strengthens the DGA's monitoring and enforcement powers.

Although these amendments may offer a marginal improvement to the current WC81, they fail to address the degradation of aquatic ecosystems.

7.4 MEF Established by the MMA Under the SEIA

The SEIA establishes that an Environmental Impact Declaration or Study must be submitted for specified proposed investments. This study or declaration is submitted by the project proposer for review to the public services that have environmental authority and attributions; these include the DGA, Servicio Agrícola Ganadero (SAG – Agriculture and Livestock Service), SERNAPESCA, Servicio Nacional de Turismo (SERNATUR – National Tourism Service), and CONAF.

The SEIA specifies environmental conditions for projects across the country, which affect the issuance of WRs, restricting water flow extraction levels under environmental criteria, and establishing MEFs that must be maintained at all times. The MEF established under the SEIA is determined on a case-by-case basis, using a wide range of different methodologies. During the early years of the SEIA's existence, values were selected based mainly on hydrological considerations for aquatic species (mainly fish and factors relating to water oxygenation, stream speed, and minimum depth for swimming and migration). More complex, holistic methodologies are now used.

Project owners are responsible for submitting a methodology and specification for MEF to the SEIA, and this document is reviewed by the mentioned services. Since 2010, the corresponding SEIA Evaluation Commission is tasked with approving or establishing conditions for this measure to mitigate impacts on aquatic ecosystems, river hydrology, and site-specific characteristics, allowing for the protection of downstream processes that include species survival, maintenance of aquatic ecosystems, and activities conducted using the river.

In 2008 and 2009, DGA conducted a study on how to determine MEF in river Basins with native fish species listed in need of conservation. Based on this study, DGA Circular 276/2011 was approved, which establishes criteria and methodologies for determining MEF under the SEIA Framework, which remains in force to date.

The Circular establishes the identification of Areas of Environmental Importance (AIA). These areas are identified and water flow requirements for key species, ecosystems, and human uses (sport fishing, tourism, landscapes, recreation, etc.) are established. A suitable MEF is then established for the AIA, focusing on ecosystems with seasonal variability and a number of additional conditions that are required on a case-by-case basis. Finally, a follow-up and monitoring plan is established, in order to verify that the MEF meets the applicable needs in conserving aquatic ecosystems, and activities.

Although the SEIA defines the EF as a mitigation measure, in some cases the mere preservation of a given flow rate at a specific point along a river is not sufficient, in which case complementary measures can be established in the form of a River Management Plan. An example of this is the San Pedro Hydroelectric Plant in 2007, located in Bio Bio Region. There, the environmental flow was not sufficient to maintain the conditions required by native species, and, thus, a number of other measures were needed in order to conserve river conditions downstream of the plant, with the establishment of a Management Plan.

7.5 Conclusions

Chile has partial and unsystematic information on the actual state of its aquatic ecosystems and water quality. Estimates indicate that 90% of Chile's freshwater fish species are in a category of conservation danger and extinction and some rivers do not maintain water flows due to over allocation of WRs when there was no obligation of maintaining MEFs. Ecological assessment, environmental protection and conservation are increasingly considered in Chile's policies ant there has been progress incorporating environmental issues in policies, laws and regulations. The amendments to the WC81 of 2005 established that the DGA is required to establish MEF provisions when granting new WR, an aspect that has been systematically implemented in the past decade. Additionally, the modification of Law 19,300 in 2010 requires that all new investment projects that require an Environmental Impact Assessment must establish EFs in order to protect downstream aquatic ecosystems. These requirements have been applied in the last decades, establishing MEFs when new WR are granted. However, in spite of these advances, Chile has not been able to revert the deterioration of aquatic ecosystems in its main basins.

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Chapter 8
Water Markets

Robert R. Hearne

Abstract Chile's system of water management has traditionally featured user management of rivers and canals and private water rights. Chile's National Water Law of 1981 maintained this tradition and was designed to foster the efficiencies of water markets. In a number of key river basins in northern and central Chile water markets have allowed expanding mines and growing cities to purchase water rights from farmers. The majority of transactions have been between agricultural users, with resulting efficiency gains. The presence of adjustable gates to easily modify flows and well-managed water users' associations have reduced transactions costs and fostered trading. The wide range of transactions' prices demonstrate that markets are imperfect and subject to the individual bargaining power of the buyers and sellers. Despite continued needs to improve market information and formalize customary water rights, the volume of water being reallocated by water markets have continued to grow throughout the nation. In the 35 years after the 1981 National Water Law, water markets have matured.

Keywords Chile · Water management · Water markets · Water rights prices

8.1 Introduction

Water markets have been one of the most distinguishing features of Chilean water policy since the Water Code of 1981 (WC81). Chile has had a system of privatized rights and user investments and management of canals since colonial times. Previous water codes in 1930 and 1951 have formalized the concept that water is a national good for public use but individual rights to use water, granted by the state, would be considered to be private property. However, it was the WC81 – which was written under the market-friendly, neoliberal philosophy of the ruling military government – that was purposefully designed to allow for the efficiencies of market reallocation of water (Hearne and Donoso 2014).

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Since water is scarce and valuable, and thus an economic good, policy makers have been interested in various economic instruments that can utilize water users' incentives to better manage this resource. Economists often promote water markets, as a means of reallocating water from less to more valuable uses. With water market transfers, water can move between users and economic sectors as society changes. This would facilitate urban, mining, and industrial growth as well as more efficient water use within agriculture, which has been traditionally endowed with the predominant share of consumptive water use. More efficient use of water should result with the internalization of water's economic value in the users' decision making. And, key in the Chilean case, the establishment of private water rights (WR) – where the only potential of reallocation is through voluntary market transactions – allows for the security of a resource that enables investment in permanent crops and irrigation technology.

This chapter will focus on Chile's water markets. Previous chapters in this volume discuss, in depth, Chile's geophysical background and the legal and institutional framework, including water user associations (WUAs) that enable these water markets. The second section of this chapter will provide a brief introduction to the economics of water markets. The subsequent section will provide an overview of empirical analyses of Chile's water markets. This section will include an argument that the number of small value transactions challenges the argument that transactions costs are prohibitive. The conclusions will address the evolution of Chile's water markets over time.

8.2 The Economics of Water Markets

Water markets are expected to provide gains from trade when buyers and sellers agree to mutually beneficial transactions, where the value to the buyer is greater than the value to the seller and the transactions costs combined. These gains should be distributed across buyers and sellers, as determined by the negotiated selling price. And with more valuable resource allocation, society as a whole gains. However, water markets are often constrained by market imperfections such as: high transactions costs, assorted externalities, and concentrated market power due to too few buyers and sellers. And gains from trade are often concentrated among those who have better market information.

Transactions costs include: (i) search and information costs; (ii) the costs of the legal formalities of transacting titles; and (iii) the costs of transportation of goods, including the costs of constructing and modifying canal infrastructure. Donoso (2006) considers the first two to be avoidable transactions costs because they are related to market institutions. Of course, it is often argued that markets provide less costly and more rapid information on the value of water in different uses than an administrative allocation system. The costs of changing the location of water use are independent of the allocation system, and considered to be unavoidable transactions costs (Rosegrant and Binswanger 1994; Hearne and Easter 1997; Donoso 2006).

Since water markets are practically, and often legally, constrained to certain water bodies, the numbers of buyers and sellers is also constrained to the water users in the same water body. This does decrease price competition in the market but should reduce search and information costs, especially when buyers and sellers share the same water user associations (WUA). The cost of buying and selling real estate, including WR, includes title searches, mortgages, registries, and title inscriptions. Changing the location of water use can imply new infrastructure, such as canals, or the modification of existing infrastructure. Few gravity flow surface water systems are engineered to provide flexibility, so that the quantity of water flowing down a canal and into any user's intake can be easily modified. Often water is allocated to irrigators by the hour, and gates are opened and closed to distribute a farmer's allotment. The majority of other canal systems are inflexible, and changing the flow of water can be costly.

When transactions costs are high, the number and volume of transactions can be reduced. Also, with high transactions costs the benefits of marginal transactions can be eliminated. Water is valuable when it is scarce. As the quantity of water available increases the value of the next marginal unit of water decreases. Although market transactions of large quantities of water are expected to increase the water's total value, theoretically the transfer of marginal quantities of water would be needed to approach the best resource allocation.

There are a myriad of externalities in water use. The water cycle implies that water use does not imply complete water loss. For instance, water used in irrigation returns to the water cycle through evaporation, percolation into groundwater, and through organic products. Changing the location of irrigation use, and irrigation technology, would cause changes in the return flows that restock both ground and downstream surface water. Also, any change in water flows in a canal would change evaporation and percolation rates. This implies that reducing one irrigator's water in a canal would decrease the neighbors' water.

Because the number of potential buyers and sellers in a particular canal system or river is limited, any active and experienced buyer or seller has the potential to use market power and information to negotiate favorable prices. Also, by extension, sectors with high valued water uses, such as mining, can potentially use markets to control most of the water in a watershed. This would show financial benefits but could have high social costs. However, agriculture has traditionally dominated water use throughout the world, and the social cots to other users has not been highly controversial.

8.3 Water Markets in Chile

Chile's National WC81, was designed to promote water market trading (Buchi 1993). It was part of a broad effort by the conservative military government to strengthen property rights, reduce the state's role in the economy, empower private sector incentives, and promote trade (Hearne and Donoso 2005). As relation to water markets in the western United States and Australia, there is little regulation of market trades and consumptive WR do not necessitate the maintenance of return flows. And the General Directorate of Water (*Dirección General de Aguas* DGA), part of the Ministry of Public Works (Ministerio de Obras Publicas MOP), which is the government's lead water management agency has maintained a very limited role in restricting trade (Hearne and Donoso 2014).

After the 1992 Dublin Statement on Water and Sustainable Development adopted the principle that water should be recognized as an economic good, international interest in Chilean water markets grew (International Conference on Water and the Environment 1992). Some initial research focused on the potential of water markets to reallocate water efficiently with little government interference (Holden and Thobani 1996; Gazmuri and Rosegrant 1996). Other research stressed the inadequacies of the Chilean water allocation system, particularly the lack of regulation, externalities between non-consumptive and consumptive WR, poor conflict resolution, and neglect of river basin associations (Bauer 1998; Dourojeanni and Jouravlev 1999). Early empirical studies identified key impediments to WR market trading in Chile. These include: (i) the lack of registered titles for many WRs; and (ii) fixed flow dividers which distribute water into and through canals, that are not easily adjustable (Hearne and Easter 1997; Donoso et al. 2002). Later studies have shown an overall growth in water markets, with heterogeneous prices (Hearne and Donoso 2014; Donoso 2013).

8.4 Intersectoral Water Market Transactions

Throughout the globe, population, employment, and wealth are shifting from rural to urban and industrial areas. One of the ways that water markets can facilitate economic growth, and secure water supplies for expanding urban areas, is through intersectoral water trading. It is expected that water would have higher value in urban areas, for drinking water and for industry, than in rural areas where most of consumed water is used in irrigation. In general, intersectoral water transfers have not been frequent throughout Chile. Even in the active markets of the Limarí basin, only 2% of transactions from 2000–2016 transferred water out of agriculture. One reason for this is that urban growth often occurs in formerly irrigated areas, and irrigation water is transferred with land. In addition, due to free trade and investments into high-valued permanent crops, the agricultural economy has grown, although, at times, a rate slower than that of the overall economy. The healthy agricultural sector has maintained its demand for irrigation water (World Bank 2016; Hearne and Donoso 2014; Hadjigeorgalis 2008).

Despite a water law that enabled water markets, intersectoral transfers of water have been relatively infrequent. A well-noted transfer of water rights in the Elquí basin, in the early 1990s, demonstrated the potential for urban water systems to utilize water markets for growing water demand. As noted by Hearne and Easter (1997), 28% of the WR controlled by the water company serving the growing La

Serena–Coquimbo metropolitan area in 1994 were purchased from former irrigators in the Elquí basin. This analysis showed that both buyers and sellers received financial gains from these transactions, but the economic gains from the transactions were relatively modest, due to the high opportunity cost of irrigation water in permanent fruit crops. The water company's water market strategy allowed them to abstain from investing in the proposed Puclaro Dam. However, when the dam was constructed in the late 1990s the water company was a principle benefactor, since its WR have increased security as a result of the reservoir storage. Also, much of the land irrigated by Puclaro Reservoir water is adjacent to La Serena–Coquimbo and would be a good source of water upon urbanization (Hearne 2007).

The Maipo Basin is home to the Santiago Metropolitan area with 40% of Chile's population and 41% of its economic activity. It is also home to nearly 145,000 hectares of irrigated areas of high valued fruit and vegetable crops. Analysis by Donoso et al. (2002) showed market transactions of up to 1.5% of WR in certain sections of the river. During the period 1998–2003 agriculture accounted for 57% of WR purchases and 68% of WR sales. Water has maintained high economic value in fresh fruit and wine production, and this high value has provided competition for urban water uses. However, intersectoral transfers have satisfied increased urban demand for water.

In Chile's arid northern Antofagasta Region, mining is the most important economic activity and the mining industry has attempted to meet its water needs through water markets. Although Chile's water law generally allows for unregulated market transactions, any transaction that changes the point of water withdrawal, or threatens minimal ecological flows, must be approved by the DGA. In the Loa River basin, the DGA has disallowed WR transactions, in order to protect some scarce wetland and surface water sources, as well as indigenous communities. One reason for concern is that WR used in agriculture are only utilized seasonally, whereas mining operation use water throughout the year. Uncertainty, delays caused by the transaction approval process, which average over 2 years, and conflicts with communities, have led mining operations to desalinate and pump sea water, instead of using WR markets to meet their needs. In addition, mining operations use less than half of their WR entitlements due to these restrictions. (Cristi et al. 2013). In the Copiapó Basin mining, high-valued agriculture, and small populations centers have competed for increasingly scarce water. Water markets have been relatively active, with over 5% of total rights being traded between 2000 and 2011, with prices rising with increased scarcity. Eventually new desalinization plants were required to meet high demand from mines and urban areas (Bitrán et al. 2014; Moskvitch 2012).

8.5 Water Market Transactions Within Agriculture

Many studies have shown scarce trading and inactive markets throughout most of Chile. Since water rights were initially allocated to irrigators based upon prior use, there was already a functioning distribution of water, and, in many cases, little need

Table 8.1 Frequency of non-consumptive WUR sales by year 2005–2011

Year	2005	2006	2007	2008	2009	2010	2011
Number	44	128	98	104	109	116	218

Source: National Registry of WURs Data

for market transactions. Chilean farmers have maintained the mutual dependence of water and land, despite the legal independence (Donoso 2006). In the Cachapoal River Valley of Chile, a leading region in the production of fruits, grains, and livestock, there were a total of 126 market transactions, independent of land transactions during the period from 1990–1999 (Hadjigeorgalis and Riquelme 2002). Sparse trading was recorded in the Valparaíso Region, which includes the important Aconcagua Basin (Donoso et al. 2010). However more recent analysis shows that WR trading has occurred throughout Chile for the period 1999–2009 (Table 8.1) and agriculture accounts for 57% of all purchases and 68% of all sales. Thus, trading has been quite common during this period (Cristi et al. 2013; Donoso 2013).

An interesting, and well-documented, example of active water markets among irrigators is the Limarí River basin, adjacent to the Elquí basin in Chile's Coquimbo Region. In this valley 50,000 has. of irrigated farmland are supported by a system of three interconnected dams, numerous canals with adjustable gates, and well-established WUA. The valley's location and irrigation system has led to large investments in permanent fruit crops. Some farms still grow annual crops that provide a supply of water available for volumetric trading in spot markets, especially during dry years. The result has been active water markets with low transactions costs in wet and dry years. Transacted WR have, at times, reached 20% of all WR and involved more than a third of all irrigators. Farmers maintained different water market strategies, especially in the spot market, to insure themselves against production risk. Gains from trade that reached 3.4 times transactions prices, and most of these gains were captured by large fruit exporters. Correspondingly, peasant agriculture lost significant control over water and earning potential due to water market transactions, although they have received the same offer prices as wealthier farmers (Hearne and Easter 1997; Romano and Leporati 2002; Hadjigeorgalis 2004, 2008).

8.6 Water Markets for Non-consumptive Use Rights

Among the 2005 Amendments to the WC81, a national registry of WR transactions was established and a fee for unused WR was imposed. Much of the concern for unused WRs was among the non-consumptive WR (Hearne and Donoso 2005, 2014). Non-consumptive use of water is principally for the generation of hydroelectricity. In-stream environmental uses of water are considered to be a non-use of water and subject to the fee for non-use (Donoso 2013). Cristi (2011) estimated that unused WR subject to fee payment in 2009 amounted to 5% of total consumptive WR flows and 95% of total non-consumptive WR flows. In 2008, 11% of WR

Table 8.2 Frequency of non-consumptive WUR sales by cubic meter per second

m^3/s	<0.10	0.10–0.50	0.50–0.99	1.0–4.99	5.0–9.99	>10.0
Number	175	175	131	210	137	15

Source: National Registry of WURs Data

Table 8.3 Frequency of non-consumptive WUR sales by price (2009 $us per cubic meter per second)

$US/$m^3$/s	<$1	$1–10	$10–100	$100–1000	$1000–10,000	$10,000–100,000	>$100,000
Number	149	61	89	39	36	32	7

Source: National Registry of WURs Data

subject to the non-use fee were forfeited. Cristi and Poblete (2011) showed that there can be incentives to maintaining unused WR, including the protection of instream flows and the security of water delivery during particularly dry years. However, as the duration of non-use continues, the fee increases. This would imply increased incentives to either sell or forfeit these rights.

The period immediately subsequent to the 2005 Water Code amendments would be expected to be a period when unused WR would be sold or forfeited. Tables 8.1, 8.2 and 8.3 provides frequency tables of sales-purchases of non-consumptive by assorted criteria using transactions data from the National Registry of WR. Note that this data is incomplete, given that only 60% of local real estate registries forwarded data. Often volumetric flows and prices are not recorded (Cristi et al. 2013). Thus, totals do not match. During the period 2006–2010, the number of transactions remained relatively constant. Many of these sales were of WR for small flows of water. Moreover, many had low prices per cubic meter per second of flow. It is likely that the fee for non-use of water led to the consolidation of many small WR, with flows less than a cubic meter per second into larger assets of potentially greater value.

8.7 Water Markets for Consumptive Use Rights

Although the National Registry of WRs' data is incomplete, Cristi and Poblete (2010) and Cristi et al. (2013), have presented a database of water market transactions for consumptive use rights, which has been cleaned of transactions that also include other real estate. This data, for sales/purchases for the period 2005–2008 shows market transactions throughout the nation. The metropolitan region accounts for 48% of the value of purchased water. However, Central Chile, from the Coquimbo Region through to the Maule Region, has had active markets. This disproves the claim that the active trading in the Limarí Basin is an anomaly. There is more frequent trading during 2007, which was a relatively dry year and accounts for nearly one-half of all traded value during this 4-year period. Nevertheless, trading occurred throughout this period. Indeed, during the 2000s, trading frequency has been higher than in the previous decades. In addition, during 2011, volumes of water equivalent to 5.6% of total consumptive WRs were involved in market trading (Hearne and Donoso 2014). Prices are higher in drier basins. Prices have varied widely, but price variation is lower in more active markets. Moreover, experienced buyers and sellers have been able to negotiate favorable prices reflecting the influence of market experience in price determination (Cristi and Poblete 2010; Donoso et al. 2014; Donoso 2013).

8.8 Marginal Transactions in Water Markets

As previously noted economic theory suggests that as the volume of water used increases the value of an additional marginal amount of water decreases. The first units consumed are more valuable than the last units consumed. Thus, economic efficiency relies on marginal decisions and water markets contribute to this efficiency when small quantities of water are transacted. When transactions costs are high, market transactions of small quantities becomes prohibitive. In the Limarí Basin, adjustable canal gates and active WUA have facilitated low transactions costs and active trading for small quantities of water (Hearne and Easter 1995, 1997). However high transactions costs, including the unavoidable cost of modifying fixed canal dividers, have been attributed to reduced trading throughout most of Chile (Donoso et al. 2002; Cristi et al. 2014).

Table 8.4 shows WR purchases/sales transactions, by exchange amounts, for two important Chilean Regions. As noted by Cristi and Poblete (2010) this data is subject to many reporting inconsistencies. Also, buyers and sellers have an incentive to under declare actual values when public notaries' fees are a percentage of transactions values. Nonetheless, this data does demonstrate a large percentage of relatively small transactions. Quantities of water transacted are specified in various measures. Often WR are specified as shares (*acciones*) of a river or canal, so that volumetric equivalencies are reduced proportionally during dry years. Often WR transactions are specified in quantities of one thousandth of a share.

The Valparaiso Region is home of the Aconcagua River Basin, the longest river in Chile and the key basin between the Santiago Metropolitan Region and the Limarí Basin. In the Valparaiso Region, one half of total transactions with reported transactions values were for values less than US $5000. And 19% of reported transactions were for values less than US $1000. For real estate exchanges, these are small sums of money. In this region, of the 4022 transactions, with stated prices, which are denominated as shares, 54% are for less than a share, 37% are for less than a half a share, and 14% are for less than a tenth of a share. Of the 1349 priced transactions that are denominated as liters per second (l/s), 28% are for less than one l/s and 22% are for less than one-half an l/s.

The Maule Region is dominated by the Maule Basin and has the largest value of consumptive water market activity, outside of the Metropolitan Region. In this region, 61% of priced transactions are for values less than US $5000, and 30% are for values less than US $1000. Also, of the 5405 priced transactions denominated as shares, 42% were for less than a share, 29% were for less than a half share and 9%

Table 8.4 Consumptive WUR sales by total transaction amount in selected regions

Year	Not reported	<$1000	$1,000<$5000	$5000<$10,000	$10,000<$50,000	>$50,000
Valparaiso region						
2005	132	119	221	94	147	154
2006	162	152	238	118	223	112
2007	265	143	219	93	175	99
2008	85	105	255	120	169	137
2009	88	257	266	117	209	91
2010	80	268	351	128	278	125
2011	41	139	399	87	277	159
Total	853	1183	1949	757	1478	877
Maule region						
2005	226	269	234	126	166	68
2006	261	393	319	148	120	95
2007	294	379	411	147	231	127
2008	144	474	441	219	300	162
2009	32	213	190	76	69	31
2010	208	344	273	132	203	100
2011	146	264	495	137	260	105
Total	1311	2336	2363	985	1349	688

Source: National Water-Use Rights Registry Data, Central Bank of Chile

were for less than a tenth of a share. And of the 1051 priced transactions denominated as l/s, 20% were for less than one l/s and 11% were for less than a half l/s. Clearly, there are many transactions for relatively small quantities of water. Some of these market transactions may be for all of a seller's total WR, and thus not marginal. But the large percentage of small value transactions challenges the argument that high transactions costs limit market trading.

8.9 Conclusions and Observations

Chile's system of transferable WRs was designed to foster the efficiencies of water markets. Proponents and opponents of water markets have featured Chile as a test case of the good and bad attributes of water allocation. Since the 1981 National Water Code, Chile's economy has grown and its agricultural sector has flourished. The development of permanent fruit crops for the international market has been facilitated by the security that transferable WR provide.

Research has shown that water markets in Chile have been used to enable urban growth through the slow transfer of land and WR to industrial and urban developers. In situations of exceptional water scarcity, the DGA has restricted the market transfers of water. The result was increased desalination to meet the needs of the relatively prosperous mining sector.

Water markets have matured in the 35 years since the WC81 was promulgated. Market transaction frequency has increased throughout the nation during the last decade, with more frequency during relative dry years. Prices have been highly variable, with more experienced buyers and sellers negotiating favorable prices. Many WR transactions have been for relatively small amounts of water and for low transactions amounts. This implies that transactions costs have often not been prohibitive. Market transactions for non-consumptive WRs have also shown many transactions for relatively small quantities of water and low prices.

Water markets play a key role in Chile's water management system, and should not be evaluated in isolation from the institutional and policy context. In Chile, water markets have not eliminated the need for government agencies in water management. The DGA maintains a key responsibility in registering WR, providing market information to buyers and sellers, and in regulating trades that change the location of water-use in arid basins. Chile will face increasing water management challenges that will accompany global climate change. Meeting these challenges may require new infrastructure, will require active public agencies, and can be facilitated using the incentives presented by Chile's water markets.

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Part III
Water Sectors in Chile

Chapter 9
Urban Water Management

María Molinos-Senante

Abstract Over the last 30 years, the Chilean water industry has carried out significant legal and institutional reforms to improve water and sanitation services (WSS), becoming a success example from the point of view of coverage and service quality. One of the most important reforms was the privatization of the urban WWS, so currently fully private and concessionary water companies provide WSS to 95.8% of urban customers. The reform also involved a change in the regulatory model followed to set water tariffs. It is based on the definition of a hypothetical efficient company. However, the Chilean water industry presents important challenges to address in coming years. The average percentage of non-revenue water is larger than the established for the efficient model. It reveals a problem of asymmetric information in the process to set water tariffs among the regulator and water companies. In addition, water tariffs do not integrate effectively the scarcity value of water. Further improvement of wastewater treatment systems is also a challenging issue for the Chilean water companies. As in many areas, climate change has increased the probabilities of droughts, floods and extreme turbidity events which require several adaptation strategies to be managed properly.

Keywords Chile · Cost recovery · Privatization · Urban water · Wastewater treatment

9.1 Introduction

Chile is a middle-income country that has implemented significant reforms to improve urban water and sanitation services (WSS) (Hearne and Donoso 2005), and in 10 years became a success story and an example throughout Latin America

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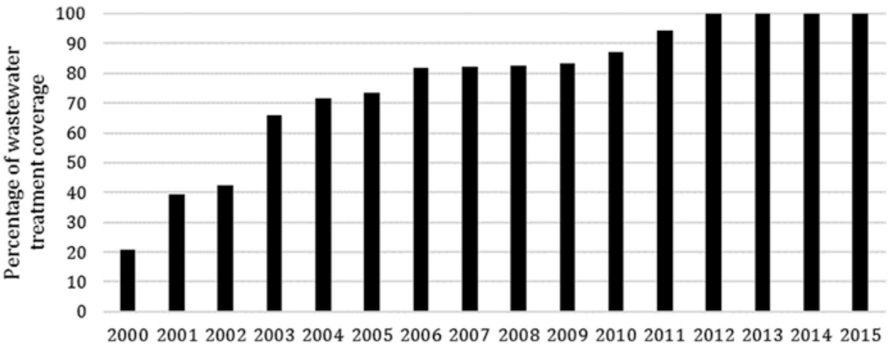

Fig. 9.1 Evolution of the coverage of wastewater treatment for Chilean water companies (Adapted from SISS 2015a)

(Marques 2011). In urban areas, in 2000 the coverages of drinking water supply, wastewater collection and wastewater treatment were 99.69%, 93.19% and 20.9%, respectively. Hence, in terms of coverage, the main problem was associated to wastewater treatment. However, thanks to the reforms conducted since then, the coverage levels have improved up to 99.9%, 96.8% and 99.8% for drinking water supply, wastewater collection and wastewater treatment, respectively. Figure 9.1 shows the evolution of the coverage of wastewater treatment across years.

Currently, these large coverages are provided by 28 main water companies which supply WSS to 16,812,391 people which represent 99.6% of the total urban population. The privatization of the Chilean water industry led to two main types of water companies namely fully private companies (FPC) and concessionary companies (CC). On the one hand, 12 out of 22 main Chilean water companies are FPC and they provide water and sewerage services to 72.7% of the urban population. On the other hand, 22.7% of the urban population is supplied by 10 CC. Moreover, several Chilean water companies belong to the same economic group. Actually, 74.8% of the urban customers are served by water companies belonging just to two economic groups. These figures evidenced the concentration of the ownership of the water companies in Chile.

As in other countries, water consumption per capita shows a downward trend (see Fig. 9.2) and between 1998 and 2015, it reduced from 23.9 to 19.1 m^3 per customer per month. It involves an average water consumption of 137 liters per capita per day. However, water consumption is not uniform across the country since water demand of companies ranges between 73 and 491 liters per capita per day. This finding means that there is a non-negligible room to reduce water use in some urban areas which requires awareness building about the need for more sustainable use of water resources.

The source of raw water depends mainly on its availability and quality. In the North of the country, most raw water is groundwater. By contrast, in the South of

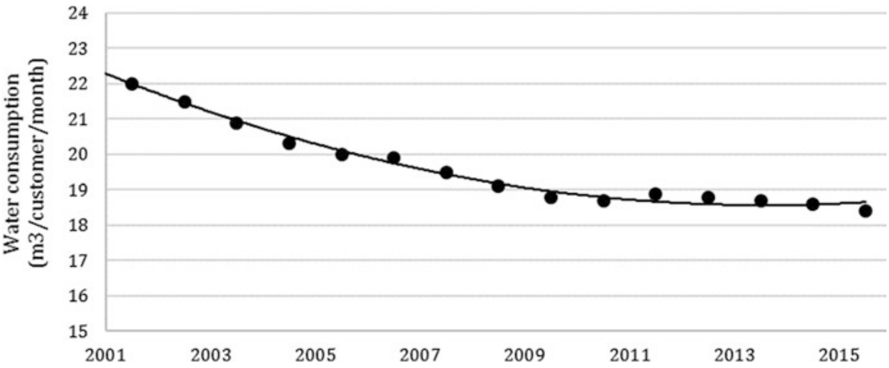

Fig. 9.2 Evolution of the average water consumption in Chile (Adapted from SISS 2015a)

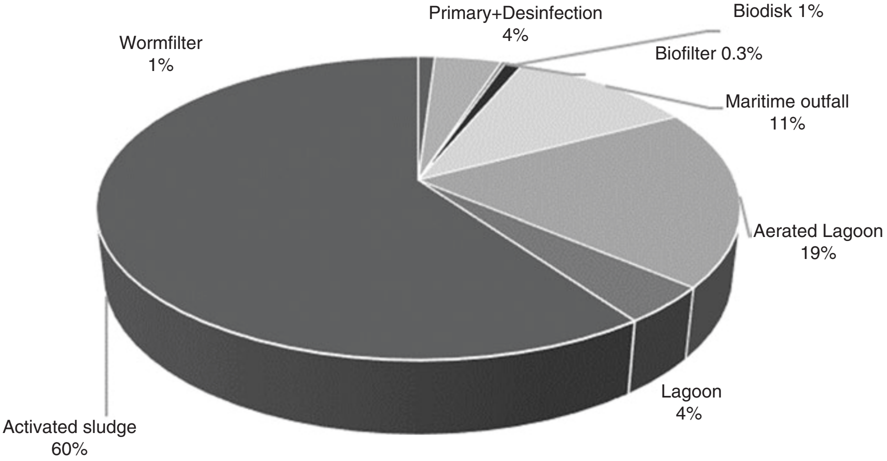

Fig. 9.3 Percentage of wastewater treatment technologies in Chile (Own elaboration based on SISS 2015a)

Chile, surface water is abundant and has good quality; hence, it is the main source of raw water. In the Center of the country, both groundwater and surface water are used. The total capacity of drinking water production is 91,029 l/s of which 47,156 l/s (51.8%) are from groundwater and 43,873 l/s (48.2%) are from surface water.

Regarding wastewater treatment, Fig. 9.3 shows that different technologies are implemented in Chile being activated sludge the most common one followed by aerated lagoons.

9.2 Legal and Institutional Framework

The current and legal framework of the Chilean water and sanitation sector is the result of several reforms carried out across the years. The first reform corresponds to the creation of SENDOS (National Service of Sanitary Works) dependent of the Ministry of Public Works (Ministerio de Obras Públicas, MOP). It was responsible for the administration and operation of the WSS throughout the country, through 11 regional directorates from 1977 to 1989. Only Santiago and Valparaiso regions remained managed by autonomous enterprises (EMOS and ESVAL). SENDOS was responsible of both urban and rural water management. However, in rural areas SENDOS focused its actions on drinking water supply, losing relevance sewerage services (Fuenzalida 2011).

The second reform of the Chilean water and sanitation sector was carried out between 1988 and 1990. In 1988 Law 382 (Gobierno de Chile 1988b) entitled "General Law of Sanitation Services" was adopted. This law established the operation rules of the water companies and the conditions in which WSS should be provided (Calvo and Celedón 2006). Moreover, in the same year Law 70 (Gobierno de Chile 1988a) entitled "General Law of Tariffs" was passed, which determined the procedures to set water and sanitation tariffs. The Law ensured a mechanism for full cost recovery of WSS service provision, introduced incentives to water companies to improve its efficiency and minimized cross-subsidies (Schuster 2017). It is in this second reform when the institutional and legal framework of urban and rural water management were separated. In 1990, SENDOS ceased to exist and the Chilean State started to provide WSS in urban areas through 11 regional companies.

The adoption of Law 18,902 in 1990 allowed for the creation of the national urban water regulator, the "Superintendencia de Servicios Sanitarios" (SISS) as a technical, regulatory and supervisory agency. From 1990 to 1996, the main objectives of the SISS were: (i) the fiscal control of the water companies; and (ii) the dissemination and interpretation of the new regulatory framework (Law 382). In this period, the SISS faced two notable challenges such as the development and implementation of the new process to set water tariffs and the implementation of the Law 18,778 of Subsidies (Gobierno de Chile 1989a). Moreover, important efforts were carried out to prevent cholera by intensifying the monitoring of the quality of drinking water (Molinos-Senante and Sala-Garrido 2015).

The third significant reform of the water and sanitation sector started in 1998 with the adoption of the Law 382 (Gobierno de Chile 1988b) which established the current legal framework for urban WSS. Its main principles are as follows: (i) separate the role of the regulators (SISS) from service providers; (ii) establish efficient tariffs that allow operators to finance operation, investment requirements, and obtain a minimum return on their investments; and (iii) establish a subsidy so as to ensure affordability of WSS to low income and vulnerable families (Donoso 2017). This legislation was the main transformative driver of the Chilean water and sanitation sector shift from public to private ownership.

Table 9.1 Main property transfers of Chilean water companies

Public company	Current name	Year of acquisition	% acquired	Economic group	Last acquisition	Year of last acquisition	% acquired
ESVAL	ESVAL	1998	40.4	Anglian water	Ontario TPP	2007	48.90
						2011	24.40
EMOS	Aguas Andinas	1999	51.2	AGBAR SUEZ	Several investors	2011	29.98
ESSAL	ESSAL	1999	51.0	Iberdrola	Aguas Andinas	2008	53.51
ESSEL	ESSBIO	2000	51.0	Thames water	Ontario TPP	2007	51.00
ESSBIO	ESSBIO	2000	51.0		Ontario TPP	2011	38.40
ESSAM	Nuevosur	2001	Transfer of the right to operate the concession		Ontario TPP	2007	–
ESSCO	Aguas del Valle	2003		Consorcio Financiero	Ontario TPP	2007	–
ESSAN	Aguas Antofagasta	2003		Grupo Luksic	Tracatal	2007	
EMSSA	Aguas Patagonia de Aysén	2003		Hidrosán-Icafal-Vecta	–		
EMSSAT	Aguas Chañar	2004			–		
ESSAR	Aguas Araucanía	2004		Grupo Solari	Marubeni and INCJ	2010	
ESSAT	Aguas del Altiplano	2004				2010	
ESMAG	Aguas Magallanes	2004				2010	

Source: Adapted from SISS (2015a)

The privatization of the Chilean water industry was carried out in two main steps following two approaches (Table 9.1). A first step was undertaken between 1998 and 2000 when some public companies sold strategic participations to private consortia with experience in the water industry, stock exchanges were opened and shares were offered to the employees of the water companies (SISS 2015a). Under this approach the five main Chilean water companies were privatized. The second privatization period was between 2001 and 2004 when the Chilean Government decided that WSS services should be delivered by private operators und a concession. In this context, water companies have the exclusive right to provide WWS in a given urban area for a period of 30 years. The concession holder must satisfy water quality standards, conform to the tariff regime and implement the required investment plans to ensure continuous WSS supply. Finally, in 2011, the Chilean Government sold part of the shareholdings of the largest private water companies.

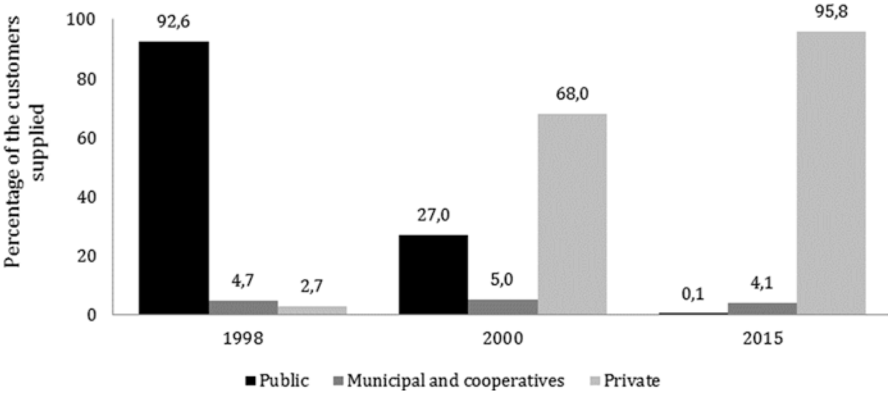

Fig. 9.4 Distribution of public and private water companies by percentage of serviced customers (Adapted from SISS 2015a)

As a result of the privatization of the Chilean water industry, currently 95.8% of the customers are supplied by private water companies and only 0.1% by public companies. In particular, the property distribution of the Chilean WaSCs is shown in Fig. 9.4.

9.3 Regulatory Model and Water Tariffs Setting Process

The privatization of the Chilean water industry involved a new regulatory system managed by the SISS. In this context, it should be noted that the Chilean Law 382 establishes that concessions to supply drinking water and treat wastewater can only be granted in urban or developable areas. On the other hand, rural areas are not subjected to the regulatory framework since they are generally supplied by cooperatives and committees of rural drinking water (see next chapter about rural water management).

As one of the main reasons to privatize Chilean WaSCs was to increase the efficiency of water utilities, the SISS uses a particular process to set water tariffs. The regulator's review of water tariffs is set to take place every 5 years, or if and when any unexpected changes in the contract conditions occur. The process to set water tariffs is based on the definition of a hypothetical efficient firm, i.e., an "ideal firm" (Marques 2011). Under this approach, the performance of the "real" water company is compared with a virtual, efficient company known as the "model" company, which is considered to be the benchmark. It is a theoretical water company created by the regulator which satisfies the demand in an optimal manner taking into account prevailing norms and the geographical, demographic and technological restrictions that characterize the operation of the service (Gobierno de Chile 1988a, b, c). This model corresponds to a water company without assets, which must make the investment to provide WWS and establish a development investment plan (Donoso 2017).

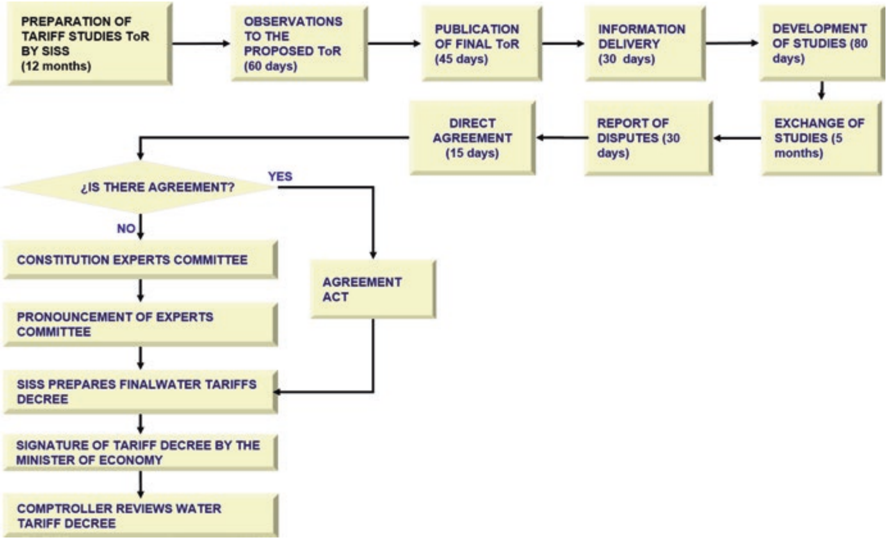

Fig. 9.5 Procedure to set water tariffs (SISS 2015b)

The procedure to set water tariffs is established by the Law 70 and the Tariff Act Regulation 453 (Gobierno de Chile 1989b) as is shown in Fig. 9.5. A year before the end of the tariff cycle, SISS prepares terms of reference (ToR) for the tariff studies to be conducted by the water company as well as the SISS. Based on the estimation of the long-term costs of the hypothetical efficient water company, both the SISS and the water company propose the water tariff to be charged by the regulated firm. If an agreement is reached the tariffs are set in a Decree signed by the Minister of Economy and ratified by the Nation's Controller (Molinos-Senante and Donoso 2016). If the parties cannot agree on the price, the disagreement is settled through an arbitration process. The water company and the SISS do not submit to the arbitrator a single offer for the entire firm but rather they submit an offer for each item cost such as cost of raw water, cost of capital, etc. Thus, the arbitration mechanism looks more like a hybrid between final-offer arbitration and conventional arbitration (Montero 2005). The water tariff set by the arbitrator cannot be appealed either by the SISS nor the water company.

The legal framework of the Chilean water and sanitation tariffs system defines four main principles to set water tariffs: (i) economic efficiency, (ii) water conservation incentives, (iii) equity, and (iv) affordability. In this context, the objectives of the Chilean tariff model are to:

1. Finance the operation and maintenance cost of WSS, investment needs and infrastructure and equipment replacement.
2. Finance a minimum agreed operational margin consistent with the alternative cost of capital of the water company.

3. Incentivize efficiency gains in the provision of WSS which should be transmitted to customers by reducing tariffs.
4. Provide water value signals to promote the rational use of resources.

To achieve these objectives, water and sanitation tariffs in Chile are based on a two-part structure, a fixed part ($) and a variable tariff ($/m^3). The fixed charge is per connection and depends of the connection diameter and metering costs. The variable tariff is almost uniform since an extra charge for over-consumption is applied only in very exceptional cases. However, the variable component internalizes changes in seasonal demand by establishing a peak and non-peak charge. Thus, in summer months when water demand is high but water availability is low, a peak tariff is applied in contrast to the rest of the months. Hence, the difference in the provision costs of WSS during both time periods is covered.

Formally, the tariff (τ) is set such that:

$$\tau = \frac{AI + OMC + MR + T}{V} \tag{9.1}$$

where AI is the annualized value of the required investments by the efficient water company; OMC are the annual operating and maintenance costs; MR is the minimum guaranteed returns; T represents the taxes that the water company must pay, and V is the total annual projected water consumption for the next 5 years in the concession area. It should be noted that the term AI integrates the market value of the required water rights and therefore, water tariffs should, in principle, reflect the scarcity value of water.

9.4 Water and Sanitation Tariffs and Affordability

As a result of the regulation model based on the efficient water company, water tariffs vary across Chilean regions. Figure 9.6 illustrates that the bill that customers pay for consuming 20 m^3 per month varies from less than $ 3 to more than $ 43.5. According to the objectives of the Chilean tariff model described previously, water tariffs should reflect water scarcity value. However, the cost differences observed in Fig. 9.6 are not associated to water availability. Donoso and Molinos-Senante (2017) evidenced that water tariffs and water availability are not always related in Chile resulting in non-sustainable water consumption. Thus, the highest level of water consumption is presented in the Center-North area which consumes 23%, 108% and 105% more water than the Central-South, South and South-South zones. It evidences that in practice, water tariffs do not provide correct signals to customers to achieve sustainable water consumption based on water resources availability (Donoso and Molinos-Senante 2017).

Affordability and water poverty are an important issue in many countries since WSS are essential for human development and for health. In this context, the

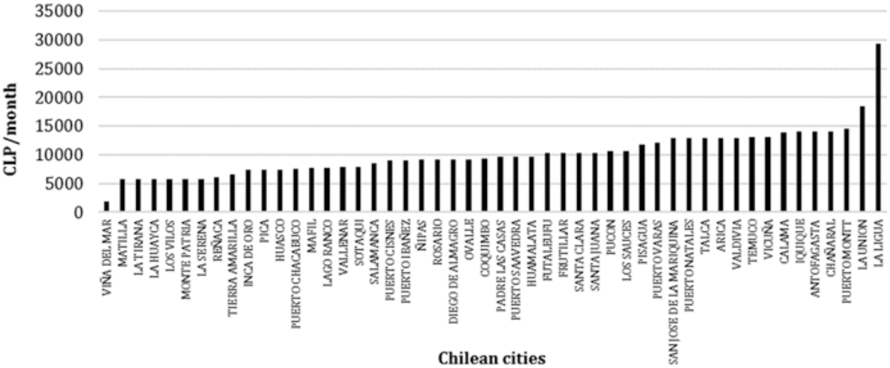

Fig. 9.6 Water supply cost for 20 m^3/month (SISS 2015a)

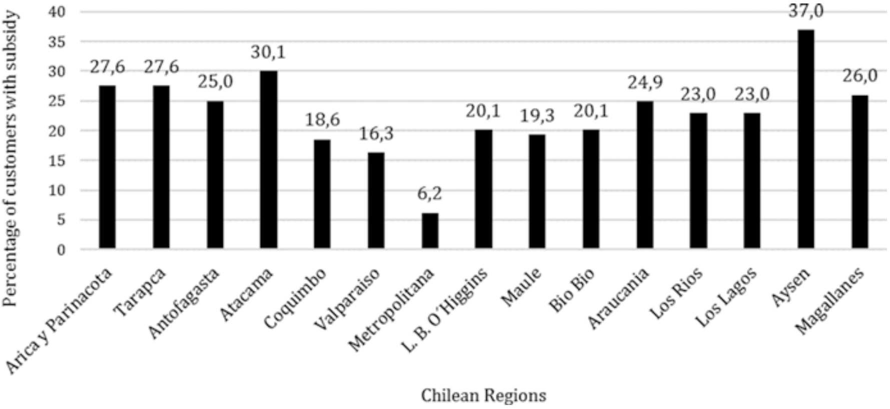

Fig. 9.7 Percentage of customers with subsidy to WSS respect to total number of customers (SISS 2015a)

Chilean Government adopted the Law 18,778 which established subsidies for drinking water and sanitation (Gobierno de Chile 1989a). The system is a direct subsidy to the most vulnerable household which are classified based on an annual survey (Casen). The payment share ranges between 15% and 85% of the water bill, with the poorest households receiving the highest share. The subsidy covers a consumption of up to 15 m^3/household/month. The central Government transfers the subsidy to the municipalities which use this to pay a share of the water bill to each eligible household. In order to not distort price signals to customers, the water company bills the benefiting households for the full consumption cost and then charge the municipalities the subsidies granted.

From its implementation, the subsidy has evolved from a low initial use to the current high levels, making it possible for poor people access to WSS. As is shown in Fig. 9.7, in 2015, 14.8% of customers with WSS were benefited with subsidies (5.2% of total sales). In general, Chile's subsidy performs better in its ability to identify vulnerable households than other countries. However, there is evidence that there have been several errors of inclusion and exclusion. Moreover, the system is expensive to administer and requires high institutional capacity at the local level (Gomez-Lobo and Vargas 2002).

9.5 Quality of Water and Sanitation Services

To improve WSS service and quality, water companies and the regulator implement several measures and policies. Some of them are short-term actions whilst other are focused on long term. Regarding the long-term actions, the fulfillment of the investment commitments proposed in the Development Plans of the water companies is essential. Moreover, SISS uses a basic set of seven indicators to measure the quality of WSS provided by the Chilean water companies. The seven indicators monitored by the SISS are: (i) water supply pressure, (ii) water supply quality; (iii) wastewater treatment quality, (iv) water supply continuity; (v) wastewater treatment continuity; (vi) billing accuracy, and (vii) complaints. Given that Chilean water companies span a range of sizes, the regulator calculates each indicator on a scale from 0 to 1 (Molinos-Senante et al. 2017). This is a benchmarking system that allows for the comparison of the service quality of the main Chilean water companies. The position of each company indicates a greater (closer to 1) or smaller service quality (towards 0) and not necessarily a failure to comply with the standards. Moreover, as it has been reported previously, unlike other countries, information about the quality of service is not considered to set water tariffs.

9.5.1 Development Plans

The construction, replacement and improvement of water supply and sanitation infrastructure committed in the Development Plans of the water companies allows to ensure future provision of WSS, as well as to maintain or increase the quality of the service provided. The Chilean water companies must inform the regulator about the achievement of commitments of their Development Plans. The SISS directly monitors the veracity of the information and when there are breaches of the Development Plans, it may initiate sanction procedures. Figure 9.8 shows the percentage of commitment of Development Plans achieved by the Chilean water companies. It illustrates that between 2007 and 2010 the percentage of commitment improved from 85% to 96%. Unfortunately, from 2012 to 2015 water companies worsened its behavior in relation to this important indicator. This could be explained by hypothesis that the regulator's monitoring has not been exhaustive and few sanctions have been applied to water companies for breaches in Development Plans in the last years; however, SISS has not analyzed this and there is no evidence to support this hypothesis, or others.

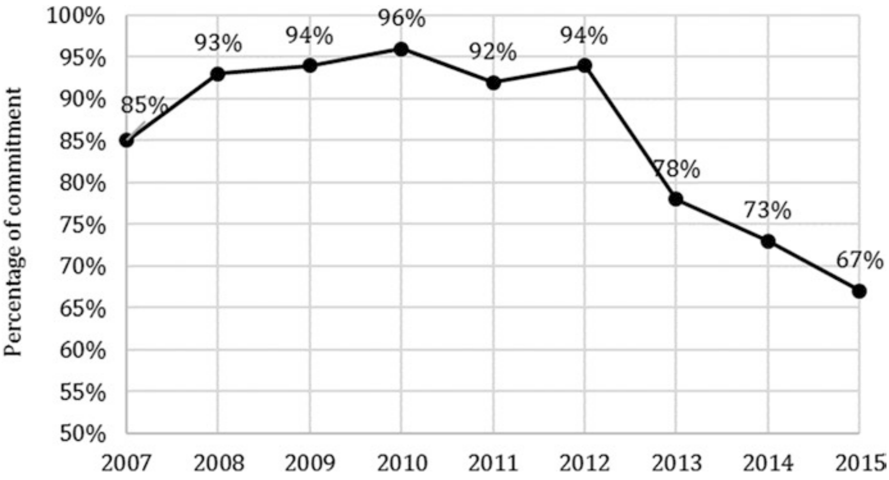

Fig. 9.8 Percentage of commitment of Development Plans by Chilean water companies (SISS 2015a)

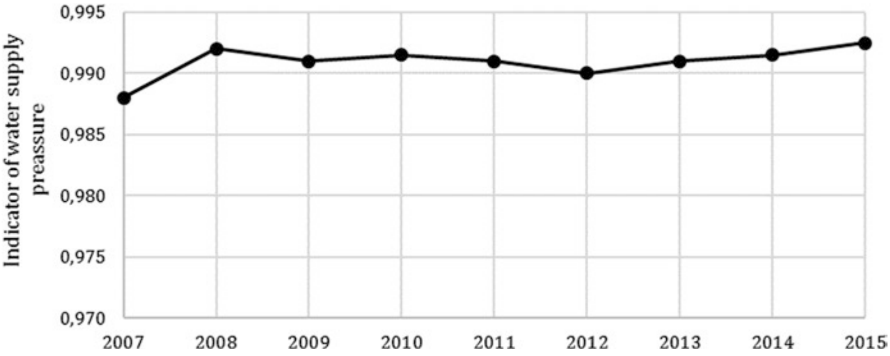

Fig. 9.9 Average indicator of water supply pressure for Chilean water companies (SISS 2015a)

9.5.2 Water Supply Pressure

The Chilean regulation NCh691 (Gobierno de Chile 2015) defines proper water supply pressure as being between 15 and 70 meters of water column. To calculate this indicator, the SISS considers the percentage of customers whose water supply pressure was outside this standard range. Figure 9.9 shows the evolution of the average water supply pressure indicator from 2007 to 2015. In spite that the average indicator of water supply is close to one, some low-pressure events occur; only 0.7% of the Chilean urban water customers present problems of low water supply pressure.

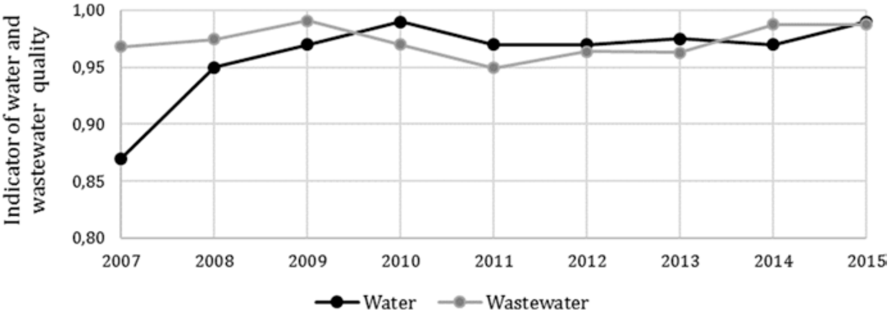

Fig. 9.10 Average indicator of water supply and wastewater treatment quality for Chilean water companies (SISS 2015a)

9.5.3 Water Supply Quality and Wastewater Treatment Quality

The Chilean regulation NCH490 for drinking water quality establishes minimum standards that drinking water must meet to be supplied by the water companies. This indicator is calculated by the SISS based on the degree of compliance with regulatory requirements, in terms of both water quality and verification sampling. Figure 9.10 shows the evolution of the average water supply quality indicator from 2007 (year in which the quality regulation was adopted) to 2015. It is evidenced that from 2009 to present, the water quality improved notably and on average, water companies fulfilled the drinking water quality regulation. Nevertheless, it should be noted that there are still some smaller companies whose indicator of water supply quality is lower than 0.9.

The indicator about wastewater treatment quality is calculated by the SISS based on the degree of compliance with the quality standards defined for each wastewater treatment plant. These standards depend mainly on the water body where the effluent is discharged. The number of people served by the wastewater treatment plant is used as a weighting factor when calculating this indicator for each water company. Although on average terms, the percentage of compliance was good (98.7% in 2015), it should be noted that one-third of the companies monitored presented lower values than average. In general, they correspond to small water companies whose wastewater treatment plants (WWTPs) present some technical problems.

9.5.4 Water Supply and Wastewater Collection Continuity

Chilean Law 19,549 on WSS (Gobierno de Chile 1988c), establishes that water companies must guarantee water supply continuity, except in specific cases determined by the SISS for planned interruptions, which must be communicated to

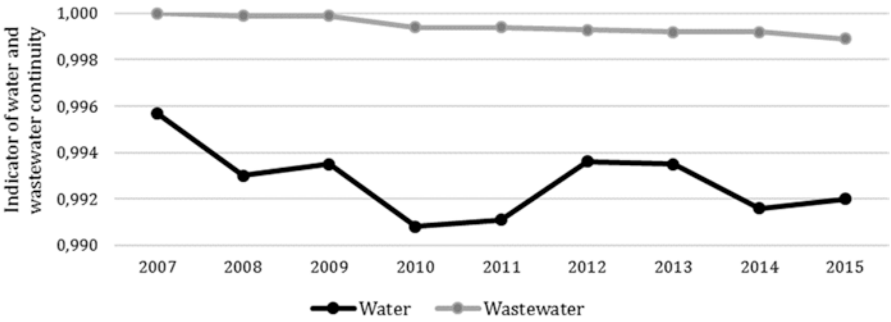

Fig. 9.11 Average indicator of water supply and wastewater collection continuity for Chilean water companies (SISS 2015a)

customers at least 24 h in advance. The water supply continuity indicator is calculated based on the number of customers whose water supply service was interrupted and the duration of the interruptions, with a penalizing factor if customers were not given advance notice of the interruptions. In 2015, the 28 main Chilean water companies presented 51,131 water supply interruptions being 27,436 (52.6%) of them, unplanned interruptions. The average duration of the water supply interruptions was 4 h. Figure 9.11 shows the evolution of the water supply continuity indicator from 2007 to 2015.

Water companies must also guarantee wastewater treatment collection continuity. This indicator is calculated based on the number of customers whose wastewater collection was interrupted due to obstructions in the sewer networks managed by the water company and the duration of the interruptions with a penalizing factor if customers were not given advance notice of the interruptions. Figure 9.11 shows a slight decline in the average value of this indicator between 2007 and 2015. In 2015, there were 110,652 unplanned sewer obstructions affecting each one, on average, seven customers.

The large values of both continuity indicators are associated to their calculation methodology. As has been reported previously, the quality of service indicators are based on a benchmarking approach. Hence, the average values of water supply and wastewater collection continuity close to one do not mean that there are no interruptions in the service, but that all water companies present a similar behavior. To evaluate the continuity of water supply, a complementary indicator is the number of pipe breaks. In this context, 20.8 breaks per 100 km of pipes is the average for the Chilean water companies for 2015. However, an analysis at local level illustrates that the problem of pipe breaks is concentrated in some particular customers (SISS 2015a). In other words, within a city, the quality of service in terms of water supply continuity differs notably by areas.

9.5.5 Billing Accuracy and Complaints

In Chile, user fees for WSS are calculated based on measurements of household-level drinking water consumption. Water companies have the obligation to reimburse customers for any payments associated with improper or erroneous charges. The indicator of billing accuracy is calculated based on errors made in reimbursements, with a penalizing factor if failures were repeated throughout the year for the same customer. Figure 9.12 shows that since 2010 the indicator of billing accuracy has remained almost constant and close to one. In the Chilean water industry, in 2015, on average, 1.1% of the bills presented some reimbursement requirement. Most of them were associated to incorrect measurement of water consumption and non-applicable charges. In 2015, 75% of the reimbursements were due to revisions made by the water companies themselves, 21% to customers' complaints and 4% by order of the regulator.

Customers dissatisfied with WSS have the right to file complaints with water companies and the regulator. The indicator of complaints is based on the number of complaints received by both water companies and the SISS and also takes into account the response time of the water companies which should be at the most 10 working days, the maximum response time allowed by Chilean standards.

On average, Chilean water companies received 125 complaints for every 1000 customers. Nevertheless, there are notable differences among water companies since the minimum value of this indicator was 3 while the maximum was 406. Most of the complaints were associated to water supply continuity problems and excessive water consumption measurement. Moreover, 62% of the complaints were solved in favor of the customers.

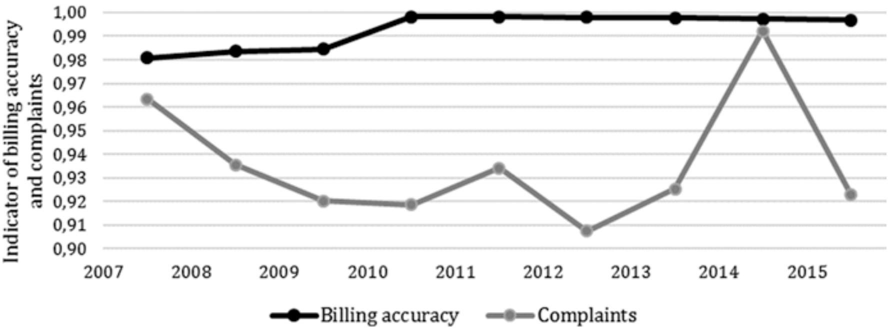

Fig. 9.12 Average indicator of billing accuracy and complaints for Chilean water companies (SISS 2015a)

9.5.6 Water and Sanitation Industry Challenges

Over the last 20 years, the Chilean urban water and sanitation industry has achieved significant improvement in both WSS coverage and quality. However, several challenges should be addressed by the water companies and the regulator in the coming years.

Non-revenue water (NRW) is water that has been produced (consuming energy and other materials) and is “lost” before it reaches customers. Losses can be physical losses (leakage) or apparent losses (water theft or metering inaccuracies). In other words, high levels of NRW reflect large volumes of water being lost through leaks, not being invoiced to customers, or both (Ferro and Mercadier 2016). Moreover, NRW means lower income for water companies which in many countries (not according to the regulatory model applied in Chile) can result in an increase in the tariffs paid by citizens. Therefore, minimizing NRW is essential to improve the environmental, financial and social sustainability of the urban water cycle (Hernández-Sancho et al. 2012). From a management point of view, a high NRW level is normally a surrogate for a poorly run water utility that lacks the governance, autonomy, accountability, and technical and managerial skills necessary to provide reliable service to their population (World Bank 2016).

Given the importance of this indicator, the SISS considers that the efficient water company has a maximum of 20% of NRW. This means that tariffs are set based on this value and therefore, water companies with a larger percentage of NRW receive less revenue than the estimated amount for the model company (Donoso 2017). In spite of this incentive, most of the Chilean water companies (20 out of 28) present percentages of NRW larger than 20%. In 2015, the average NRW was 33.6%. Moreover, the values of NRW are notably different among water companies since they range between 9.9% and 50.2%. This low performance of water companies, as illustrated in Fig. 9.13, has remained almost constant between 33.5% and 35.4% for the last 9 years.

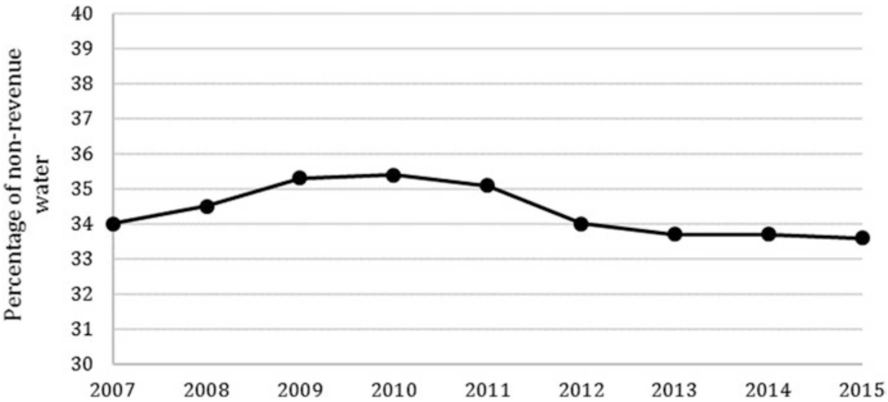

Fig. 9.13 Average percentage of non-revenue water for Chilean water companies (SISS 2009, 2010, 2011, 2012, 2013, 2014, 2015a)

According the SISS, 74% of the NRW corresponds to physical losses, i.e., to leakages whose origin are breaks or cracks in networks. This issue is related also with an important challenge for the Chilean water companies namely infrastructure replacement. Urban water supply and sewer networks in Chile have deteriorated over time reaching the end of its useful life and therefore, large investments and time are required to replace them. However, water companies have postponed networks replacement investments in favor of more profitable investments (Celedón and Alegría 2006). For example, in 2014 and 2015 the reposition rates of the water supply network were 0.57% and 0.56%, respectively. For sewer networks, the reposition rates were even lower, 0.24% and 0.22% for 2014 and 2015, respectively. These low reposition rates imply that the replacement of existing networks would take approximately 180 years for water supply and 500 years in the case of sewers. An increase of the reposition rate of networks is essential to improve the quality of service provided by water companies. On the one hand, it is essential to reduce the percentage of NRW contributing positively to the efficiency of the water companies. On the other hand, it contributes to improve the continuity of water supply and wastewater collection since unplanned water interruptions and sewer obstructions are minimized.

Before the 1990s, Chile did not have a legal framework for wastewater treatment and therefore, only 10% of the urban wastewater generated was treated (SISS 2016). In 2001, the Decree 90/00 was adopted which regulates wastewater treatment. Since then, important efforts have been carried out to improve the coverage of wastewater treatment reaching 99% of the wastewater collected in 2015 (SISS 2015a). In spite of this large coverage of sanitation service, the Chilean water industry presents two important challenges in the framework of wastewater treatment, namely: (i) replace maritime outfalls by more effective treatment systems and; (ii) increase the number of WWTPs that remove nitrogen and phosphorus from wastewater before its discharge into water bodies.

In Chile, there are 278 wastewater treatment systems using different technologies (see Fig. 9.3); 32 of these systems are maritime outfalls (11.6% of total number of wastewater treatment systems) treating 254 millions of cubic meters of wastewater (SISS 2016). Maritime outfalls are located mainly in the coastal cities of the North of Chile representing 73% of the wastewater flow treated in the Arica-Parinacota, Tarapaca, Antofagasta, Atacama, and Coquimbo Regions (CEDEUS 2015). The SISS considers maritime outfall as wastewater treatment systems and therefore, they are included in the computation of the coverage of wastewater treatment. Nevertheless, maritime outfall do not carry out any physical, chemical or biological treatment but they use marine dilution and dispersion to comply with environmental regulations. In other words, maritime outfalls do not remove pollutants from wastewater but they dilute them in the ocean. In this context, the discharge of wastewater without previous elimination of its pollutants can alter the composition of the marine sediment (De la Ossa et al. 2016). Hence, maritime outfalls cannot be considered as effective wastewater treatment systems. The challenge for the Chilean water industry is to replace the maritime outfalls by effectively wastewater treatment systems.

The second challenge related to wastewater treatment is generalize the removal of nitrogen and phosphorus from wastewater before its discharge into water bodies. This is not only a technical challenge but a regulatory one. Decree 90/00 establishes different quality standards for the discharge of treated wastewater depending on the discharge area. In this context, only when treated wastewater is discharged to wetlands or lakes, the concentration of nutrients in the effluent is comparable with international standards such as the European Directive 91/271/EEC. Hence, the first step to protect Chilean water bodies of eutrophication is to modify the Decree 90/00. Subsequently, WWTPs should be updated to be able to eliminate larger concentrations of nitrogen and phosphorus from wastewater.

The process to set water tariffs and its structure is a challenging issue for the water regulator. As has been reported previously, the process to set water tariffs is based on an efficient model operator. It assumes that the regulator has enough information to estimate the costs of the efficient company. However, usually this has not been the case (Donoso 2017). In other words, the Chilean water industry presents asymmetric information problems. Legislation should enforce water companies to supply precise and validated information to the regulator to calculate efficient water tariffs. Moreover, the quality of the service is ignored when setting water tariffs and therefore, water companies have few incentives to improve service quality provided to customers. In the context of water tariffs, a second challenge is that tariffs reflect water scarcity value. In spite that one of the objectives of the Chilean water tariffs is to provide signals to promote the rational use of resources, water scarcity value differences across regions are not, in general, reflected on urban water tariffs. This is because water tariffs infrastructure investment and operational costs are comparatively much larger than the market value of the necessary water rights (Molinos-Senante and Donoso 2016). The replacement of the current uniform volumetric charge by an increasing blocks tariff strategy might help to internalize the scarcity value of water.

Climate change impacts on water resources pose an important challenge for the Chilean water industry. Water companies face increased probabilities of extreme events such as droughts, floods and extreme turbidity events. The latter are particularly relevant for the water supply of the metropolitan area of Santiago which concentrates around 40% of the total Chilean population. Currently, there is evidence that the frequency of turbidity events has increased in recent years (Suarez 2017). In the case of some extreme turbidity events, the production of drinking water has had to stop leaving a large number of customers (85% of the people living in the metropolitan area of Santiago) without access to drinking water. To face this challenge and increase the resilience of the urban water supply under extreme events, several adaptation strategies from different perspectives such as water supply, water demand, infrastructure and urban and territorial planning should be implemented. However, these strategies require high levels investment that will impact water tariffs.

9.6 Conclusions

Chile's urban water and sanitation system represents a successful and interesting case study given that virtually universal levels of coverage have been achieved in both drinking water supply and wastewater collection and treatment. It is characterized by two main features: (i) private water companies provide WSS to most urban customers (95.8%) and; (ii) the process to set water tariffs is based on the efficient water company model.

The privatization of the Chilean water industry was a gradual process that was carried out in two main phases and following two different approaches. As a consequence, currently in Chile there are two types of water companies namely: fully private and concessionary water companies. The Chilean process to set urban water tariffs is unique worldwide and compares the costs of the real water company with a virtual, efficient company which is considered to be the benchmark. This model has been successful in providing WSS to most of urban customers. However, it presents notable asymmetric information problems and does not integrate quality of service variables in the tariff setting process.

Some of the quality of service variables such as water supply pressure or quality of drinking water and wastewater have significantly improved across years. Nevertheless, the Chilean water industry presents an important challenge related to NRW which is associated to the low reposition rates of both water and sewer networks. Chilean WSS companies must also improve wastewater treatment, replacing maritime outfall by more effective wastewater treatment systems and by removing nutrients from wastewater before it's discharge into water bodies. Moreover, water companies and the regulator should develop and implement plans for climate change adaptation given that extreme events such as droughts, floods and extreme turbidity are already a reality in Chile.

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Chapter 10
Rural Water Management

Rodrigo Fuster and Guillermo Donoso

Abstract In 1960, only 6% of the rural population had an adequate water supply system. At present rural water coverage has increased to 53%; however, considering only concentrated and semi-concentrated rural towns, 88% the rural population has access to water supply systems. This increase is the result of Chile's national Rural Potable Water (APR) program, which has provided rural water infrastructure to concentrated and semi-concentrated rural towns. This infrastructure is managed by user committees or cooperatives, which operate and invest in maintenance, improvement and expansion of the systems. Over time several APR have presented problems in supplying potable water in quantity, quality and continuity. This is due to the lack of management capacity. This chapter presents an overview of Chile's national Rural Potable Water (APR) program and identifies its actual challenges and necessary reformulations.

Keywords Chile · Rural water sanitation · Rural water supply

10.1 Introduction

Beginning in the 1960s, a large portion of the rural population did not have access to drinking water. During this decade, only 6% of Chile's rural population had a potable water supply system, which had significant consequences for public health. The infant mortality rate, which was 120.3 deaths per thousand children under 1 year old (Kaempffer and Medina 2006) was higher than rates in countries with a lower socio-economic development (Castañeda 1996). In addition, 8.6% of infant mortality was caused by illnesses of the digestive tract (Castañeda 1985).

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In response to limited access to drinking water in rural areas, the Rural Potable Water Program (PAPR in its Spanish acronym) was born in 1964. The infrastructure provides rural potable water (APR) to concentrated[1] and semi-concentrated[2] rural towns, which must comply with the methodology and evaluation standards established by the Ministry of Social Development (MDS).[3] The infrastructure's administration, operation, and maintenance were turned over to APR[4] committees and cooperatives which already existed or were newly created for this purpose. The Program also invests in system improvement and expansion as necessary. Finally, consulting, training, and supervision will be provided to aid the work of the committees and cooperatives through each APR system's respective Technical Unit (UT), the concessionaire of Regional Water Supply Services.

The APR program considers the population living in rural areas in broad terms as a potential population. This is slightly larger than a "rural" population according to its official definition (INE), which is used by the MDS for its Socioeconomic Description (CASEN) surveys.[5]

Since its founding until 1964, the program has provided APR infrastructure to 1685 concentrated and semi-concentrated towns (Fig. 10.1), serving 1,900,000 beneficiaries and increasing the rural APR coverage from 6% in 1960 to 53% by the year 2014[6] (Donoso et al. 2015).

The rural sector's supply of potable water has fallen under the purview of APR organizations. These organizations, comprised mainly of committees and cooperatives, number 1685[7] throughout Chile (Fuster et al. 2016). Community-based management has allowed members of the organizations to administrate, operate, and

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[1] Minimum concentration is defined as a population of 100/150–3000 inhabitants and a concentration of at least 15 homes per kilometer in the potable water network.

[2] Having at least 80 inhabitants and a concentration of at least eight homes per kilometer in the future network.

[3] Since 2015, the "scattered" rural population expanded to encompass the entire rural population. A scattered rural population is defined as having at least 80 inhabitants and a concentration of at least eight homes per kilometer in the future network.

[4] The APR committees and cooperatives organize their beneficiaries into groups and are responsible for the administration, operation, and maintenance of APR systems. They manage the APR systems' operational, accounting, and community organization aspects.

[5] INE does not directly define rural, but only defines it in negative terms in terms of what is not "urban". An "urban area is defined as a group of homes with a concentration of upwards of 2000 inhabitants, or between 1001 and 2000, when 50% or more of the population is involved in secondary or tertiary economic activities. In special cases, in areas where there are centers for tourism and recreation and more than 250 homes but the population requirement is not met, these are considered as 'urban entities.' As such, an urban area is comprised of urban entities" (Donoso et al. 2015). Anything outside these definitions would be understood as rural (having less than 2000 homes, or having between 1001 and 2000 homes where less than 50% of the population is involved in secondary or tertiary economic activities, except for tourism and recreation centers hosting over 250 homes).

[6] Coverage is calculated without considering the concentrated rural towns served by the program which are defined as urban according to the CASEN/INE classification.

[7] New APR systems are always being set up so this number may change with time.

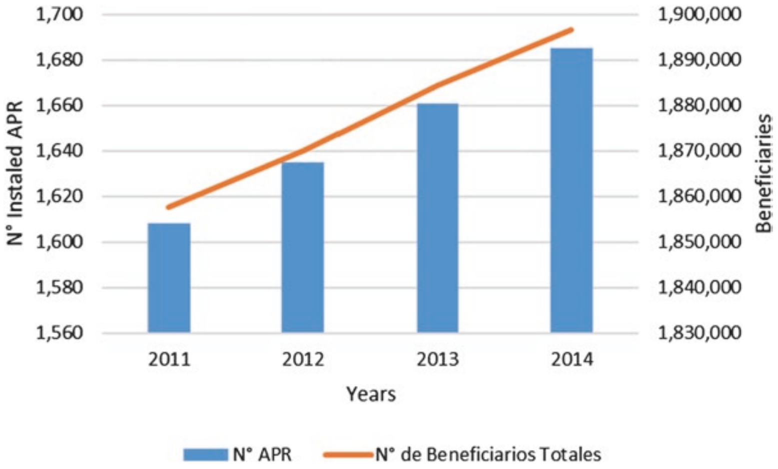

Fig. 10.1 Number of towns and beneficiaries with rural water supply systems (APR) (Donoso et al. 2015)

maintain potable water services. However, they have not been without problems in terms of the water quantity, quality, and continuity.

In terms of service continuity, more than half of APRs report at least one unscheduled water outage in the past 6 months (Fuster et al. 2016). APR committees and cooperatives are also responsible for ensuring that water quality is up to par with the Chilean Standard No. 409. To guarantee the safety of drinking water, APR committees and cooperatives must monitor the quality of water provided. Eighty-four percent of committees and cooperatives have monitored the bacteriological quality of their drinking water supply within the past five (5) years, but 9.3% have not done any such analysis during this time period (Donoso et al. 2015).

Furthermore, the APRs' ability to respond to scarcity during times of drought has become increasingly relevant. APRs supplied with lorries because of the 2015 drought represent 6% of the total. It is estimated that about 200 thousand people living in rural areas receive a variable and insufficient quantity of water, according to minimum standards established by the OMS.

As seen in Fig. 10.2, the majority of APRs affected by a lack of water in their supply sources are located in regions that experience prolonged droughts: Coquimbo Region and Valparaíso.

In addition, aspects of these systems must be improved in order to provide a permanent service with high standards; Trenkle (2012) states that the APR committees and cooperatives have administrative, technical, and financial deficiencies. These organizations' technical and administrative functions must be improved (Fuster et al. 2016). This is to say that problems with the servicing of the drinking water supply managed by the Committees and Cooperatives are mainly associated with organizational administrative issues.

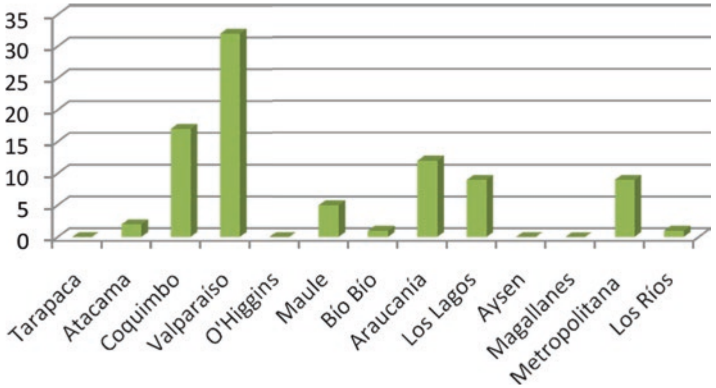

Fig. 10.2 Number of APRs supplied with tank trucks 2015 (Donoso et al. 2015)

In addition, Law 20.998 (Gobierno of Chile 2016) was recently passed, regulating rural water supply services and delegating new responsibilities to the APR organizations. In this context it is relevant to consider the current status of these organizations, especially given their great diversity countrywide. Areas for improvement should be studied in order to improve management and thus the organizations' ability to provide drinking water and confront new sanitation challenges.

10.2 Legal Aspects of Organizations Managing Rural Drinking Water

Once created, APR systems are managed by one of two types of administrative entities: committees and cooperatives. These community organizations are comprised of the same people who receive the water supply. They fulfill an important social and solidarity-based role, which benefits the organizations' members. The main objective of these entities is the administration, operation, and maintenance of the drinking water systems in order to provide water supply to their local recipients. According to the new standards, these organizations will start taking on new duties in the future, including the collection, disposal, and treatment of wastewater. Many have already started these tasks with the support of the government.

10.2.1 Rural Drinking Water Committees

The APR committees are governed by the Law 19,418 on "Neighborhood Meetings and Community Organizations" (Gobierno of Chile 1995). The law states that the organizations must be not-for-profit and that members may only participate as volunteers. Membership in a committee cannot be denied to any person who is interested in joining, as long as they comply with the requirements established in the law and the committee statutes.

The "poverty privilege" statute gives committees certain benefits such as being exempt from taxes, municipal and fiscal dues, and being required to pay only 50% of the costs of notarial proceedings, real estate registrars and archivists.

Committee members must select board members to be the system administrators. Board members have a 2-year term, after which they are eligible for reelection.

Committees may be dissolved by the unanimous agreement of members with voting rights, the expiration of their legal status, having less than the minimum number of members, or for infringement of the organization's statutes.

10.2.2 Rural Drinking Water Cooperatives

The APR cooperatives are governed by Law 19,832 on General Cooperatives (Gobierno of Chile 2004); specifically, Title III's application to Service Cooperatives.

Cooperatives are "associations which, according to the principle of mutual help, have the objective of improving the life conditions of their members," which can be applied to any service or activity.

These have a legal personality, which means that unlike committees, they are not excempt from taxes, dues, and municipal patents and taxes; however, the law provides for a 50% discount on all contributions, taxes, fees, and other dues to the Treasury.

To administrate drinking water systems, cooperatives must conform to the General Stakeholders Meeting, elect a Board of Administration and Supervision Committee, and have a Manager. The General Stakeholders Meeting consists of a meeting of members in which each has the right to a vote. The Board of Administration is responsible for the management of social businesses and represents the cooperative both judicially and extra-judicially. The Manager is the executor of agreements and instructions coming from the Board of Administration. Finally, the Supervision Board is responsible for accounting, inventory, and other financial actions taken by the Board of Administration.

The General Cooperatives Law allows surplus to be distributed among the associates, allocating it towards service improvement or contributions to other institutions for local development.

In this legal context, both cooperatives and committees have an important social impact. With the government's heavy investment for more than five decades and the organizations' management of the potable water systems, safe drinking water has reached a significant portion of Chile's rural population. This is why it is relevant to understand the role played by other state institutions in the functioning of APR systems.

10.2.3 Major Entities Involved in APR Operation

10.2.3.1 Ministry of Public Works

The Ministry maintains a close relationship with the APR organizations mainly through the Hydraulics Works Department (DOH in its Spanish acronym), which provides technical and administrative support as well as trainings. It also oversees and regulates water rights associated with APR through the General Water Department (DGA in its Spanish acronym). The supervisory powers of the Ministry of Public Works (MOP) over the APR organizations is limited, while its administrative and promotional functions have a wider scope.

The DOH is responsible for the APR program. The DOH supervises the operation and management of APR organizations through a regional water supply operator, UT. The UT provides operational and technical support as well as management support to the APR organizations through annual/biannual visits from specialists.

10.2.3.2 Rural Drinking Water Subdirectorate

The Subdirectorate for Rural Potable Water (SDAPR in its Spanish acronym) was placed under the purview of Ministry of Public Works when it was created in November 2011 to replace the Sanitary Programs Department. The SDAPR implements actions based on the PAPR, managing and promoting the development of APR organizations, but is not involved with wastewater sanitation in rural areas. It does not have oversight or regulatory powers over the APRs, nor does it carry out audits on technical or administrative management. Thus, no rights or obligations have been formally established, except minimal standards on water quality and continuity of service (Villaroel 2012).

Its functions and powers, detailed in Exempt Resolution No. 7.904-11 and No. 2.696-14, include

1. Planning PAPR investment initiatives, developing and proposing budget projects each year;
2. Following up on budget implementation and financial control of projects in the regions and at a national level;
3. Developing and proposing policies for APR functioning;
4. Establishing procedures for continuous program management improvement;
5. Coordinating and managing agreements with sanitation businesses;
6. Monitoring and evaluation.

They also regulate program management, (according to institutional commitments) collective performance agreements, the management improvement program (PMG in its Spanish acronym), and the creation of governmental programs and presidential commitments.

10.2.3.3 Funding Organizations

Two major institutions fund APR development: the MOP acting through the Hydraulics Works Department (DOH) with the annual budget; and the Regional Governments (GORE), operating through the National Regional Development Fund (FNDR) and the Rural Infrastructure Provision Fund (FPIR in its Spanish acronym). These funds can often be associated with the Subsecretariat for Regional Development (SUBDERE) (SAPAG 2014).

Based on the PAPR, the SDAPR implements the budget in accordance with the Budget Act. This budget is presented by the Treasury Department and approved annually by National Congress. Among its many functions, the SDAPR is responsible for the development of project portfolios, which are carried out in each region according to their specific needs:

1. New systems for rural towns that meet program requirements
2. Maintenance, growth, and improvement of existing systems
3. Relocation planning and changes in regulations for units receiving water services.

The objective of the FNDR is to finance regional development programs and projects. These resources are administrated by each region's GORE, which is also empowered to choose projects to fund.

The FPIRs are state funds annually provided for APR projects, which are then allocated by the respective GORE. Technical supervision is carried out by the DOH.

The Undersecretariat for Regional Development (SUDERE) has authority over the FNDR in the distribution of funding throughout the country in accordance with the Public Sector Budgetary Act. It is also involved in loans between the Inter-American Development Bank, the World Bank, and the Chilean government (Balbontín et al. 2017).

Other funding sources for APR systems include the President of the Republic's Social Fund, which is managed by the Subsecretary of the Interior's social fund. Municipalities have the power to tender or execute community infrastructure/equipment projects through the Urban Improvement Fund.

10.2.3.4 Ministry of Health

Supervisory powers fall on other public entities, such as the Ministry of Health (MINSAL in its Spanish acronym) and MOP, through the DOH, DGA, SISS.

The supervisory unit over water monitors drinking water and sewage projects, specifically their location, layout, technical, and sanitary aspects. It also inspects APR organizations for water purification, residual chlorine, and sample analysis (bacterial and physicochemical).

When compliance failures are discovered, the organizations will not be fined or sanctioned. Rather, the supervisory unit will provide recommendations and corrective measures with deadlines for their correct implementation (SAPAG 2014; Villaroel Bloomfield 2012).

10.2.3.5 Technical Support Institutions: Water Supply Operators

Water and sanitation services planning in Chile's urban areas falls under the auspices of water supply and sanitation operators (WSS) both private and public, which must operate according to the General Law of Sanitation Services Law, DFL No. 382, from the Ministry of Public Works (Gobierno of Chile 1988). APR organizations are exempt from the DFL No. 382 standard because they are outside the zoning definition of urban territories.

The WSS companies facilitate support through the UTs to the committees and cooperatives in each region. These are contracted by the DOH to perform technical and administrative assistance and to facilitate trainings.

Water quality monitoring through sample analysis is generally undertaken by private companies and labs belonging to health organizations to monitor the water's bacteriological and physicochemical status. These are inspected by the regional Health Service.

Evaluations of these institutions by APR committees and cooperatives have been relatively positive. According to Fuster et al. (2016), UTs were positively evaluated in 65% of cases, and the DOH received a 56.4% approval rating. These evaluations of the UT and DOH are relevant from a management perspective in which the State has a secondary role. The APR organizations say that the UTs should continue doing their current work or that the DOH could do the UTs' work. These results demonstrate the clear need for a secondary entity to play a supportive role in the running of APR systems.

10.3 Situation of Rural Potable Water Organizations (APR)

The current status of APR system infrastructure depends on how long they have been operating. The majority of APR systems (66.1%) started operations between 1981 and 2005, while 16.4% began before 1980. The number of new APR organizations being created has gradually declined as greater coverage has been achieved. The average age of current APR systems is 23 years. It is to be expected that these require improvements and constant maintenance in order to be able to provide quality services to their population.

At the same time, an organization's ability to run its own APR system is mainly dependent upon its economic ability to address needs for facility maintenance/renovation and having the human resources necessary to undertake the task of providing drinking water to its members.

Since an organization's economic capacity comes from its profits from supplying water, self-sufficiency largely depends on the quantity of homes receiving water (the number of units served by the organization) and the rates charged for this service. Nationally, 63% of APR systems serve fewer than 250 units, which does not generate enough revenue to pay for their own investments and costs and thus become self-sustaining[8] (Navarro et al. 2007; Donoso et al. 2015).

However, as pricing is unregulated, each APR organization has their own mechanisms for price setting. This lack of regulation makes it difficult to evaluate whether expected revenues system operations are sufficient to cover expenses.

There is also a cultural factor which affects the organizations' ability to procure adequate resources: a certain resistance to upgrading user rates. In a community context, raising the rates of service can have an impact on the relationships between an organization's officers and members. This factor may affect the decision to charge a higher rate which would establish the organization's economic self-sufficiency. For this reason, only about 50% of APR organizations apply an annual rate increase. This percentage decreases as the number of units served increases.

Thus, approximately 65.1% of APRs would have revenues higher than their operational costs, though only 29% of APRs state that they are able to cover all costs of operation, administration, maintenance, equipment replacement, and system expansion (Fuster et al. 2016). This explains why only 43% of APR systems installed since the beginning of the program have undergone improvements. It is clear that a problem of the APR system is that a certain number of these systems are not financially self-sufficient currently. The organizations with the best performance are those with a higher number of units served.

When management faces problems such as not being able to acquire the resources and hire the staff necessary to operate the system, both the delivery process and water purification are affected. This is why the water purification and delivery processes taking place in rural areas should not be considered as technical capacities but rather as a system in which management and economic capability affect delivery.

Generally speaking, the APR organizations function well in terms of their ability to successfully deliver water to users. Seventy-eight percent of these systems have no problems in their distribution network and 88% are without issues in the acquisition and storing of water (Fuster et al. 2016). Despite these high percentages, more than half of APRs have experienced unplanned water outages in the past 6 months (Fuster et al. 2016; Villaroel Bloomfield 2011).

In 2013 and 2014, unplanned water shortages were experienced by a respective 20.3% and 23.7% of existing APRs. This affected 29.07% and 32.3% of the total population relying on APR systems. However, these figures are still lower than those of other Latin American countries. Triana Soto (2013) states that many countries in the region have an irregular drinking water supply. Sixty percent of rural populations with rural potable systems in Latin America receive an irregular supply. In some countries, this figure rises to 95%.

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[8] Donoso et al. (2015) states that using fixed rates allows 75% of the organizations to cover the costs of operation, maintenance, and minor repairs, and that 57% of existing systems have never undergone such improvements.

In terms of water purification, organizations currently demonstrate a high level of compliance with standards. 94.6% of the organizations carry out residual chlorine sampling, 88.7% conduct physicochemical analysis, and 92.6% perform bacteriological analysis (Fuster et al. 2016). Thus, 87.2% of organizations have a sanitation operations authorization.

Although national access to drinking water has increased significantly in rural areas and water purity is very good, supply continuity is an uncertain variable in the management system. One indicator of this weakness in APR management is that, though 86% of them claim to have a system maintenance and improvement plan, only about 50% have carried out the work promised in their plan.

Besides the organizations' economic capacity, another relevant aspect of APR functioning concerns the level of education reached by the officers who manage these systems. More than 65% of officers possess a level of education that is equal to or superior to a high school education (Fuster et al. 2016).

Another aspect affecting general functioning of the organization has to do with how long the APR officer has been in the position. Most officers have been in their position for a long enough time to be knowledgeable about the system's operations and maintenance. However, considering their educational level, it is to be expected that external support is necessary to improve efficiency, quality of service, and other aspects of management such as effective technology use.

10.4 Law 20,998 for the Regulation of Rural Water Services

Until 2016, access to water in rural areas was not governed by a legislation specific to rural water services. In 2016, Law 20,998 (Gobierno de Chile 2016) which regulates rural water services was promulgated. This created the Subdirectorate of Rural Health Services (SSR in its Spanish acronym) as an extension of the MOP's Dirección de Obras Hidráulicas (DOH). SSR will be responsible for carrying out studies, community management, investments in drinking water and sanitation, projects in sanitation and drinking water, and developing a registry of operators.

Once the law is implemented, APR committees and cooperatives must have a license, which is valid for 5 years. To be granted a license they must certify the following:

1. Water Rights (WRs);
2. The quantity, quality, and continuity of their water supply;
3. Reserve funds as a guarantee of service;
4. An investment plan approved by the Subdirectorate;
5. Approval of financial statements by the Subdirectorate;
6. A positive report on management by the Subdirectorate;
7. An approved pricing schedule.

APRs that do not comply with these requisites will be given an additional 5 years to do so. To reapply, they must have an action plan approved by the Subdirectorate. If they are out of compliance with the action plan, the license will expire.

Licenses will also expire if tasks from the investment plan are not implemented or are out of compliance with the action plan.

One important aspect of the new law establishes that pricing should at least account for recoup of operating costs. However, the law does not require pricing to cover maintenance costs nor the different costs of investment and replacement. This is concerning because it makes it very likely that the same issues with an irregular water supply will continue into the future due to a lack of proper APR maintenance.[9]

One area, which still needs defining, is the content of regulations stipulating the procedures outlined in the new law. The regulations should define and explain the procedures required in order to apply for a new license and the conditions which would cause expiration of said license. These procedures, which remain undetermined, will be key to implementation of the new law.

10.5 Opportunities for Improvement

Although the APR organizations show high performance indicators in the various aspects of providing drinking water to rural populations, certain aspects could be improved in order to deliver a more sustainable and quality service. In particular, administrative aspects, which would allow these systems to function more profitably, need work.

In general, all indicators of APR economic and managerial capacity tend to improve in relation to the number of units served. Thus it can be seen that a certain level of structural development exists which allows service delivery while leaving room for improvement, especially in smaller organizations.

In terms of management ability, which affects both task performance and the level of dependence on outside institutions, there is a training gap in APR leadership. Training would allow leadership to improve their own ability to manage their systems so that they can be self-sufficient and cost effective. This would also reduce the current dependency on the DOH and UT which is viewed as a weakness in management.

The law presents new complexities which focus on the weakest structural aspects through sanitizing residual waters. These challenges should be addressed through further training so long as APR organizations remain dependent on UTs or the DOH. The problem is that many of these organizations do not have the economic resources needed to fund this type of professional development.

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[9] Art. 57, Law 20,998.

There is also a cultural element affecting the issue. Within the organization, members will have to take on new responsibilities, which may become problematic if they experience difficulty adapting to new situations. The current educational level of officers may be a restrictive factor for members trying to take on new job functions. For this reason, it is recommended that an educational threshold be established for officers to ensure that they have the tools needed for the tasks associated with the delivery of potable water.

Although organizations have done maintenance work and/or have made improvements in the past, these are not sufficient to keep up the system. Maintenance plans with timelines over a year are necessary to ensure system continuity, before system failures can cause water outages.

On the other hand, to provide quality water service, potable water must comply with current quality standards. One important aspect of compliance with current legislation has to do with whether the organization has a sanitation operations authorization. Here another gap can be seen, as at least 13 of every 100 APR organizations do not have the sanitation operations authorization needed for potable water delivery (Fuster et al. 2016).

The current status of sanitation infrastructure is even more complicated, with only 11% of organizations claiming to have a sewage system (Saavedra 2013). This shows the vulnerability of the vast majority of organizations, which do not have an adequate wastewater management system, especially when only 9.45% have a treatment system for wastewater.

All these tasks require economic resources. Management capacity becomes even more precarious inasmuch as economic resources become scarce. The situation requires new mechanisms to improve the pricing structure, especially for smaller APRs. The goal is for organizations to be able to recover the costs of delivery so they can provide a continuous, quality, sustainable potable water service without needing to seek help from the government.

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Chapter 11
Irrigated Agriculture

Felipe Martin and Felipe Saavedra

Abstract Consumptive water use in Chile is dominated by irrigation with 82% of consumptive water use. The agricultural sector in Chile has continuously grown in the past 30 years, often at a rate greater than the rest of the Chilean economy and, thus, the value of water in irrigation has remained high. There is an incentive for the adoption of water saving technologies by farmers (Law No. 18,450). This program subsidizes small scale, private irrigation investments and WUA distribution channel systems. It has supported much of the installation of drip irrigation systems in the dry north and spray systems in the humid south. There are estimates that at present about 30% of agriculture uses water conservation technologies, concentrated in the northern water scarce agricultural regions. However, irrigated agriculture faces challenges due to climate change and growing water stress due to economic and population growth. In response, Law No. 18,450 was reformed to incentive private investments to increase water storage and improve distribution, with a total investment cap of US $ 10.2 million. This chapter presents an overview of Chile's irrigation and investment support program and identifies its actual challenges.

Keywords Chile · Irrigation · Irrigation efficiency · Irrigation institutionality · Irrigation policy

11.1 Introduction

Out of Chile's contiguous total land area of 75.6 million hectares (has), 35.5 million are used for agriculture, livestock, and forestry. However, the area of land under cultivation is considerably smaller, currently amounting to approximately 26,000 km^2. The breakdown of land usage has also varied significantly over the past 60 years. Since 1955, the country has seen a reduction in the area used for growing cereals, pastures, and forages, and a significant increase in forestry and fruit production (Fig. 11.1). The latter increase was greatest in the central region,

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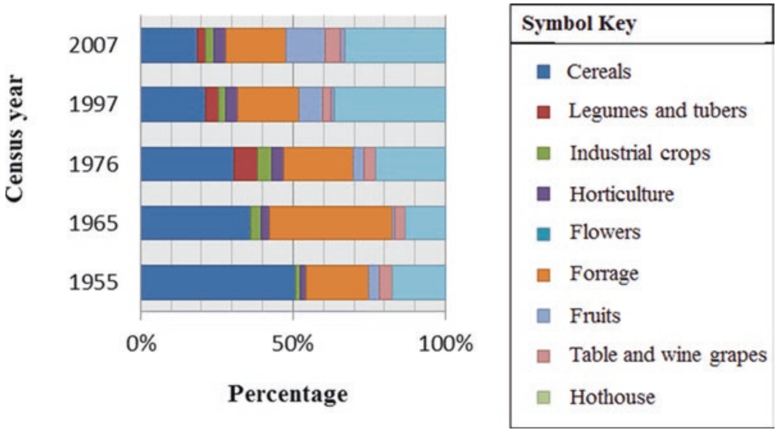

Fig. 11.1 Changes in agricultural land use (Donoso et al. 2016)

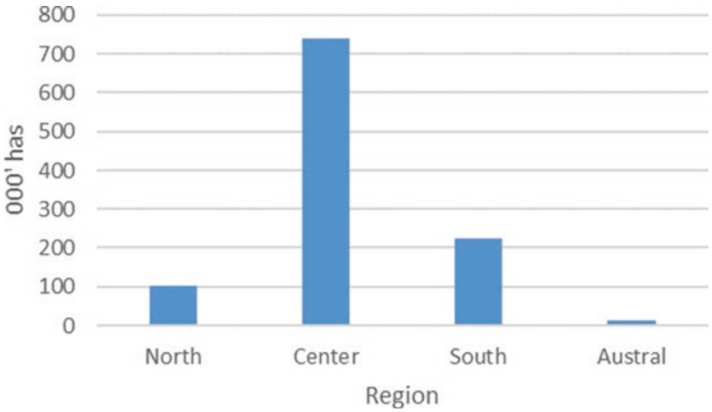

Fig. 11.2 Irrigated area by region, 2007 (Apey 2012)

followed by the north. Donoso et al. (2016) argues that had these changes not occurred, water demand for agriculture would be even greater, as cereals and pastures, and forages require more water consumption than deciduous fruit trees and forestry.

Irrigation and its development have provided a vital resource in the changing conditions of Chile's agriculture sector, and have thus contributed to the country's development as a whole. Irrigated lands are responsible for 60–65% of the agriculture sector's GDP. Meanwhile, irrigated land accounts for more than 80% of the country's agricultural exports. Irrigation is therefore vital for crop production and quality, so as to boost the country's growth.

Some 1,100,000 hectares of land are currently under irrigation (27% of the land area, and 42% of all cultivated land). 68.4% of this area is located in the central macroregion, followed by the south macroregion region with 20.9% and the northern macroregion with 9.4% of the total area irrigated (Fig. 11.2).

The area under irrigation has increased in response to public policies launched in the mid-1980s with that goal in mind. The total area under irrigation grew by some 70% between 1970 and 1990 (World Bank 2011). This growth slackened between 1997 and 2007, with the area increasing just 3%. The Ministry of Agriculture (MINAGRI) declared its objective of transforming the country into a world agricultural and food production power in the twenty-first century. This represents a challenge since MINAGRI's estimates indicate that if this goal is to be achieved by 2020, 1,500,000 hectares of land must be irrigated, which represents a 36% increase with respect to the current situation.

It is important to bear in mind that the agricultural sector is the greatest water user, accounting for 82% of all consumptive water consumption nationwide. It is therefore vital for this sector – which produces 12% of the country's GDP – when considering the positive effects of agricultural's growth on the rest of the economy (Foster and Valdés 2013) – to increase its water use efficiency.

11.2 Characteristics of Irrigation in Recent Years

The 7th National Agriculture, Livestock, and Forestry Census, published in 2007 (INE 2007), provides the most recent overview of irrigation in Chile. The most frequently used irrigation system in the country is gravity fed irrigation, representing 72% of the total area. This is followed by micro-irrigation, which is used for 23% of the total area, with sprinkler technologies making up the remaining 5%. As can be seen in Fig. 11.3, flood irrigation is the most commonly used gravity fed irrigation technique in Chile, accounting for 58% of all gravity-irrigated land; this is also the least efficient method (30%).

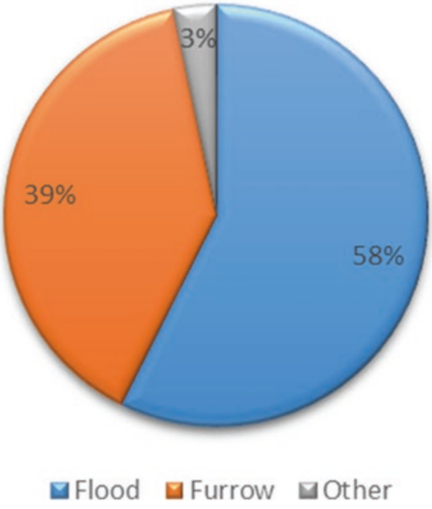

Fig. 11.3 Gravity fed irrigation systems (INE 2007)

Overall irrigation efficiency increased by 17% between 1997 and 2007, rising from 48.6% to 56.9%. This is due to a 17.8% reduction in the area irrigated with gravity-fed methods in parallel with an 85.1% increase in sprinkler technology methods and a 298.2% increase in the area with micro-irrigation. The greatest increases were achieved in the regions where water is scarcest (Fig. 11.4). The Central macroregion featured the largest increase, at 57.9%, followed by the northern, austral, and south macroregions with 45.6%, 42.9%, and 40%, respectively.

The northern macroregion, which is also the most arid, achieves the highest irrigation efficiency. Efficiency declines between the north and south of the country, due to an increase in usage of gravity fed techniques (Fig. 11.5).

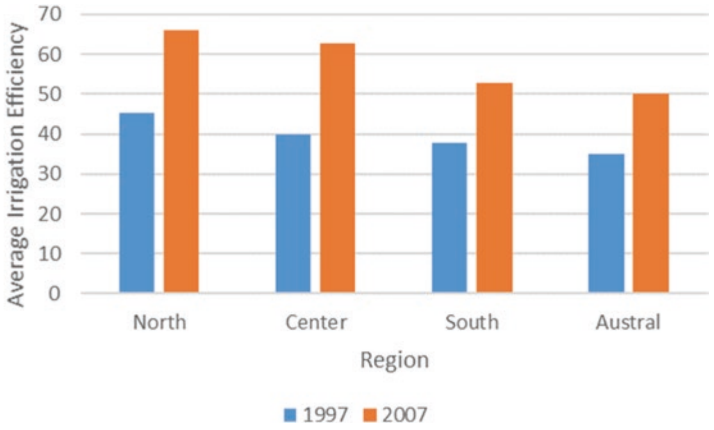

Fig. 11.4 Increase in irrigation efficiency between 1997 and 2007, by macroregion (INE 1997, 2007)

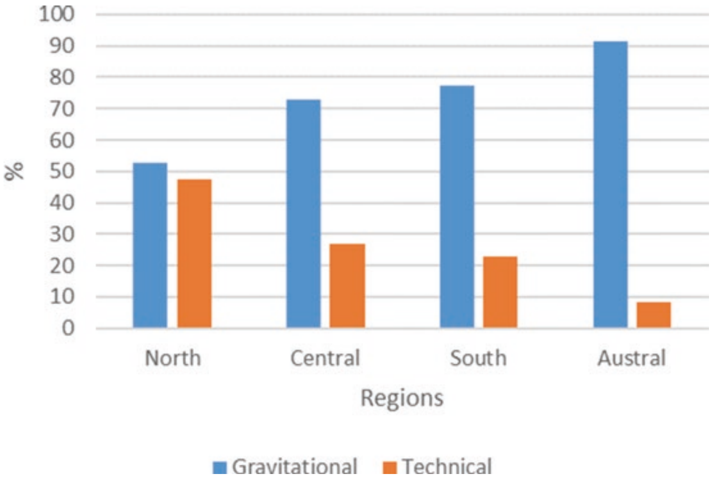

Fig. 11.5 Relative usage of irrigation systems by region (INE 2007)

However, water use efficiency (WUE), defined from an economic perspective as the economic return per unit of water used for crop production, is on average low; Molinos-Senante et al. (2016) finds that average WUE score is 0.450[1] for farmers in the Limary basin, even when irrigation efficiency is 69%. This finding implies that there is a considerable possibility of reducing water consumption in the Limary basin, without affecting production levels.

11.3 Regulatory and Institutional Framework for Irrigation

11.3.1 Institutions Involved in Irrigation

Vergara and Rivera (2018) present a detailed analysis of Chile's water institutional framework, so in this section we cover the public institutional mechanisms that apply to water for use in irrigation.

The lead public institution governing such water usage is the National Irrigation Commission (CNR), a MINAGRI body that was created in 1975 to serve as the public agency tasked with coordinating efforts and overseeing investments in this area. Additionally, in 1985 it was further tasked with the administration of Law 18,450, on the Promotion of Private Investment in Irrigation and Drainage Infrastructure (minor irrigation and drainage projects). CNR's principal functions include:

1. Contributing to the formulation of national irrigation policies;
2. Improving irrigation efficiency through adoption of efficient systems;
3. Focusing development efforts in the country's most remote regions and farmers living in vulnerable situations;
4. Promoting private investment in irrigation by means of investment optimization and allocation of irrigation and drainage subsidies; and
5. Evaluating the technical and economic feasibility of irrigation investments in the country's different river basins.

The CNR follows guidelines established by the CNR's Council of Ministers, chaired by the Minister of Agriculture and also comprised by the Ministers of Finance, Public Works, Social Development, and Economy, Development, and Tourism. The main functions of this Council are:

1. Planning, studying, and preparing integrated irrigation projects;
2. Supervising, coordinating, and complementing the actions of public and private bodies involved in irrigation management; and
3. Evaluating irrigation projects submitted to the CNR.

Other MINAGRI institutions involved in the irrigation sector comprise:

1. Instituto Nacional de Desarrollo Agropecuario (INDAP), which promotes irrigation amongst small-scale farmers;

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[1] WUE scores are between 0 and 1, where WUE = 1 indicates full efficiency.

2. Instituto de Investigación Agropecuario (INIA), through research and technology transfer.
3. Servicio Agrícola y Ganadero (SAG), which engages in actions to preserve and improve renewable natural resources, which affect agricultural, livestock, and forestry production, by preventing the pollution of irrigation water.

Meanwhile, the Ministry of Public Works is involved in the subsector through the actions of DGA, DOH, and the Departamento de Coordinación General de Concesiones (CGC). The DGA is the state body tasked with ensuring that the country's water resources use is developed in accordance with the legal framework, with full information available to users. Meanwhile, the DOH is tasked with designing, building, maintaining, repairing, and operating large irrigation infrastructure using public funds. Finally, the mission of the CGC is to create water use infrastructure for national development, by strengthening public-private partnerships for construction projects.

Within the private sector, water users organizations (WUAs) play a significant role. These include Juntas de Vigilancia (JdV) for the management of natural surface and groundwater sources tasked with administering flow in a given watercourse or a segment of one. Conversely, artificial channels are managed by Asociaciones de Canalistas (AC) and Surface and Groundwater Comunidades de Aguas (CA), tasked with distributing and administering water, conserving and improving water intakes, channels, and distribution infrastructure.

11.3.2 Regulatory Framework

The regulatory framework for irrigation development in Chile is as follows:

1. 1981 Water Code;
2. Ley Base de Medio Ambiente (Law 19,300) and its corresponding regulations;
3. Decreto con Fuerza de Ley (DFL) 1123, on the state's creation of irrigation infrastructure;
4. MOPs Supreme Decree 900 (Concessions Law); and
5. Law 18,450, on promoting private investment in irrigation and drainage infrastructure subsidies.

As Vergara and Rivera (2018) and Melo and Pérez (2018) present a detailed analysis of the 1981 Water Code and the provisions of Law 19,300 that relates to water quality, respectively, we describe DFL 1123, MOP's Supreme Decree 900, and Law 18,450.

11.3.2.1 DFL 1123 (1981), Establishes Regulations on the Investment of Irrigation Infrastructure by the State (Gobierno de Chile 1981)

This regulation establishes that the State may invest in irrigation infrastructure, subject to prior coordination with potential beneficiaries, so long as no fewer than 33% of these are in agreement with the planned project. When the State builds infrastructure with the objective of increasing water security, the beneficiaries must be organized as a JdV, in accordance with the regulations specified in the 1981 Water Code.

Once irrigation infrastructure has been built, the State manages it on a provisional basis for 4 years. During this period, the irrigation works are operated by mutual agreement with the JdV. After this period, operation of the infrastructure is then transferred to its users; thus, the model for the investment in irrigation infrastructure by the state is Build, Operate, and Transfer (BOT).

An important provision of the Decree stipulates that the beneficiaries of the new irrigation works are responsible for financing them; it therefore establishes that they must reimburse the State's infrastructure investment and operating costs (DFL 1123 articles 7, 9, 10, and 11). The State only covers the costs of infrastructure design and pre-investment studies. Article 4 thus establishes that this mechanism may only be used to build infrastructure that is privately profitable. The amount that beneficiaries must pay for the infrastucture, as well as the terms and conditions for payment, the payment and grace periods, the applicable interest rate, and the value of the subsidy in question are agreed by the CNR's Council of Ministers. The irrigators or their organization's payment commitment is ensured with a repayment deed and payment commitment letters.

However, these mechanisms have not proven to be fully effective, as their contractual value has been found to be weak in ensuring such payment and inefficient in cost recovery. The DOH has therefore advised the CNR's Council of Ministers to create a new reimbursement deed (Mesa de Coordinación Interinstitucional Subsector Riego 2003).

Chile currently has a reduced capacity for yearly hydrological regulation (World Bank 2011). The country's total irrigation water storage capacity stands at 4460 hm^3 (millions of m^3), with 74% concentrated in the northern macroregion (Fig. 11.6).

In light of the current situation of growing water scarcity and projected climate change impacts on water resources, Chile's National Water Resources Policy calls for an enhancement in agricultural irrigation water storage capacity through the:

1. Construction of at least two large reservoirs with a combined capacity of 37 million m^3 in the northern macroregion, and another in the south macroregion with a capacity of 625 million m^3 between 2015 and 2020;

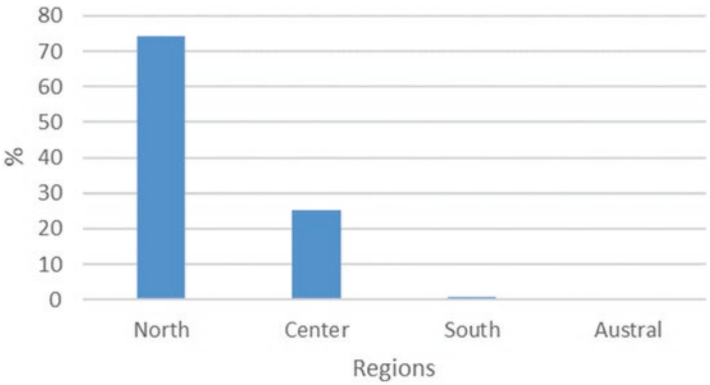

Fig. 11.6 Relative irrigation water storage capacity by macroregion (Donoso et al. 2012)

2. Construction of 15 smaller irrigation reservoirs in the north and south macroregions between 2015 and 2018; and
3. Maintenance, renovation, and repair of both publicly and privately built water accumulation and distribution infrastructure (Delegación Presidencial para los Recursos Hídricos 2015).

11.3.2.2 Decree 900 (1996) Revised, Coordinated and Systemized DFL Mop No. 164, 1991 Public Works Concessions Law (Gobierno de Chile 1996)

The Concessions Law establishes the regulatory framework for private sector funding for the construction and operation of public works. The investment cost recovery is ensured by means of water tariffs for the use of the services provided by the infrastructure for a duration period agreed between the private investor and the State.

This instrument has only been used sporadically. Indeed, up to 2017 only two projects have received concessions under this law: (1) Convento Viejo, in O'Higgins Region, and (2) Punilla, which was tendered in 2016 and is located in Ñuble, Biobío Region. However, the MOP plans to tender five more reservoirs, located in Catemu, Los Angeles, Los Aromos (expansion), and Las Palmas, all in the Aconcagua River Basin in Valparaíso, and at Las Trancas, on the Cogotí River in Coquimbo Region.

11.3.2.3 Law 18,450, Approving Regulations for Irrigation and Drainage Infrastructure Promotion (Gobierno de Chile 1985)

Law 18,450 (Irrigation and Drainage Infrastructure Promotion), which came into force in late-1985, provides subsidies for private irrigation and drainage projects for both off-farm irrigation investment projects for water channel distribution and drainage, and farm irrigation technology adoption and improvement. This law sets out to encourage farmers and water users' organizations to increase the total area irrigated and/or increase the water security and application efficiency, with an emphasis on small and medium scale farmers. The goal is to increase the country's irrigated area, enhance water storage in irrigated areas with water scarcity, incentivize more efficient water usage, and expand farming to lands that are currently non-cultivable by improving drainage (Gobierno de Chile 1985). The law's specific objectives are (CNR 2016):

1. Subsidizing the cost of studies, construction, and renovation of irrigation and drainage infrastructure and multipurpose integrated irrigation and drainage, and
2. Subsidizing investments in technified irrigation equipment and materials, and all irrigation infrastructure in general.

It is important to underscore that Law 18,450 also allows for initiatives that strengthen WUAs through the improvement of irrigated water quality, while also promoting non-conventional renewable energy generation for irrigation projects.

The program allocates subsidies for projects through applications to CNR grants. The maximum subsidy ranges from 70% for large projects (>40 weighted hectares benefiting) to 90% for small-scale farmers[2]. The value of infrastructure works and on-farm investments, can reach $ 1,300,000, however tender averages do not exceed $ 500,000, although total cost may be greater as long as the difference is covered by the applicant.

In order to increase the capacity of water accumulation for irrigation, Law 18,450 was amended so as to include subsidies for (1) building and renovating water intakes, distribution, and storage infrastructure with construction costs not exceeding $1,300,000, and (2) investments in integrated multiple-user irrigation and drainage projects valued at sums between $1,300,000 and $10,200,000. Applicable projects for subsidy applications are shown in Table 11.1.

The concept of integrated and multi-purpose irrigation projects applies to:

1. Integrated Irrigation Projects; All irrigation and hydraulic infrastructure, from initial studies through to completion.

Table 11.1 Projects that may be submitted (Gobierno de Chile 1985)

Projects	Types of projects
Storage	Reservoirs, regulation ponds
Distribution	Channels, cladding, pipelines
Management efficiency improvement	Hydraulic infrastructure, water quality, telemetry
Drainage	Drainage infrastructure
Infiltration	Aquifer infiltration
Technological enhancement	Enhanced irrigation technology systems such as sprinklers, microjet and drip irrigation
Non-conventional renewable energy sources	Small hydroelectricity, wind power, solar

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[2] Defined as established in the organic law of INDAP.

Table 11.2 Maximum subsidies (Gobierno de Chile 1985)

Investment cost	INDAP farmers	Small scale farmers		Medium and large scale farmers	
Millions $	Irrigation (%)	Multipurpose integrated projects (%)	Multipurpose irrigation projects (%)	Multipurpose integrated projects (%)	Multipurpose irrigation projects (%)
Up to 1.2	90	90	80	70	70
1.2–2.5	85	88	40	25	53

Table 11.3 Maximum bonus for Farmer Associations and Water User Associations (Gobierno de Chile 1985)

Investment cost	Smallholder organizations		Water User Associations	
Millions $	Multipurpose	Irrigation	Multipurpose	Irrigation
Up to 1.2	90	90	80	80
1.2–2.5	68	85	50	80
2.5–3.7	51	80	40	75
3.7–5.0	38	76	30	70
5.0–6.1	28	73	25	65
6.1–7.4	21	70	20	60
7.4–8.6	16	67	15	55
8.6–9.8	12	63	10	50
9.8–10.2	9	60	8	45

2. Multi-Purpose Irrigation Projects: These are irrigation projects that include complementary benefits such as drinking water, hydroelectric power, flood management, ecotourism, and aquifer infiltration.

The category of multi-purpose irrigation projects allows projects to be submitted that feature associated complementary infrastructure not specifically intended for irrigation, or in collaboration with non-agricultural entities, which can contribute resources for major irrigation infrastructure. The maximum subsidy percentage is maintained for projects valued at up to $ 1,200,000 (Tables 11.2 and 11.3). For larger investments, the maximum subsidy percentage diminishes in proportion to the value exceeding $ 1,200,000 (Tables 11.2 and 11.3).

Law 18,450 performance indicators show that between 2000 and 2014 the number of financed projects and beneficiaries increased 32% and 34%, respectively (Fig. 11.7). The largest number of beneficiaries were Small Farmers Organizations (41%), followed by medium-sized farmers (31%) and Small Farmers (19%). As a result of the program's targeting, only 2% of the bonus has been allocated to large entrepreneurs.

During the same time period, 400,000 farmers have implemented 13,000 irrigation projects with support of Law 18,450, for a total investment cost close to $ 770,000,000, of which the State has subsidized more than 500,000,000 (64,6% of

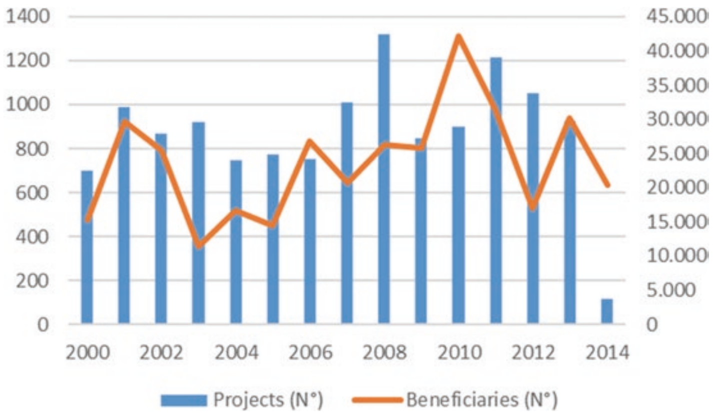

Fig. 11.7 No of investment projects and subsidy recipients (CNR 2015)

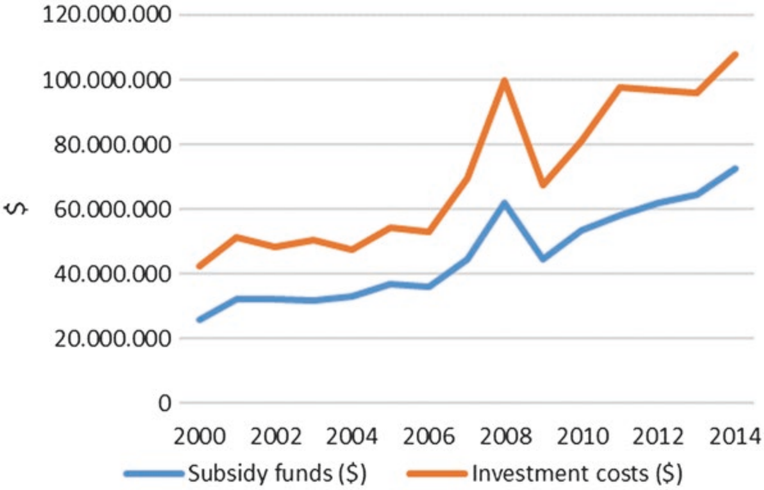

Fig. 11.8 Total investment and subsidies ($) (CNR 2015)

the total cost); subsidies/project fluctuated between 60% and 70%, presenting an average of 65%. In 2014, investments in small and medium irrigation works was 153% higher than in 2000 (Fig. 11.8). In addition, granted subsidies increased 181% between 2000 and 2014.

The program's focus on small and medium scale farmers also shows positive results (particularly amongst medium scale producers), in compliance with the Minagri's goal of prioritizing these sectors in its public policies.

11.4 Conclusions and Challenges

Irrigation and its development have provided a vital resource in the evolution of Chile's agriculture sector, and has thus contributed to the country's development as a whole. The area under irrigation grew between 1970 and 2007 to a total of 1,100,000 hectares, incentivized by the public policies launched in the mid-1980s.

Chile has achieved an average irrigation efficiency of 57%. This is due to an 85.1% increase in higher efficiency technological irrigation methods and a 298.2% increase in the area in which micro-irrigation was used, largely bolstered by Law 18,450. The evidence shows that the implementation of this law has served to energize Chilean agriculture, with broad-based acceptance and demand amongst farmers of all sizes. The coming challenge is to achieve advances in the implementation of modifications to increase irrigation water storage. This requires studying and promoting multifunctional infrastructure projects, combining installations for irrigation with hydroelectricity, drinking water, and recreational and tourism investments.

The declaration of the goal for Chile to become a world agricultural and food production power in the twenty-first century, raises new growth challenges for the sector: in order for this objective to be reached by 2020, the total area under irrigation must be increased by at least 36%. This goal can only be achieved if the following challenges are overcome:

1. Implement integrated water resources management at the basin level;
2. Develop policies that incentivize greater water reuse;
3. Strengthen water users associations so that they are able to undertake effective and collective water management;
4. Increase water productivity (tons of product per m^3);
5. Strengthen water rights markets so as to internalize water's scarcity value in decision making; and
6. Promoting public-private partnership in new irrigation agriculture investments.

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Chapter 12
Water and Mining

Orlando Acosta

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

Keywords Chile · Mining · Mining water use · Water sources

12.1 Introduction

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

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

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

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

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

12.2 General Characteristics of Chilean Mining

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

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

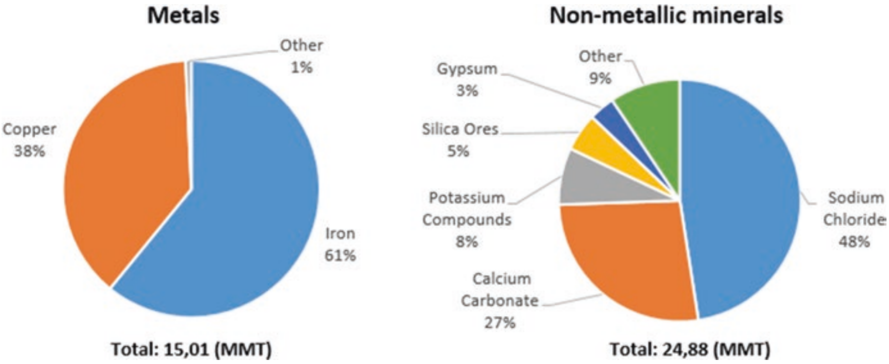

Fig. 12.1 Mining production in Chile in 2015 (COCHILCO, 2016a, b)

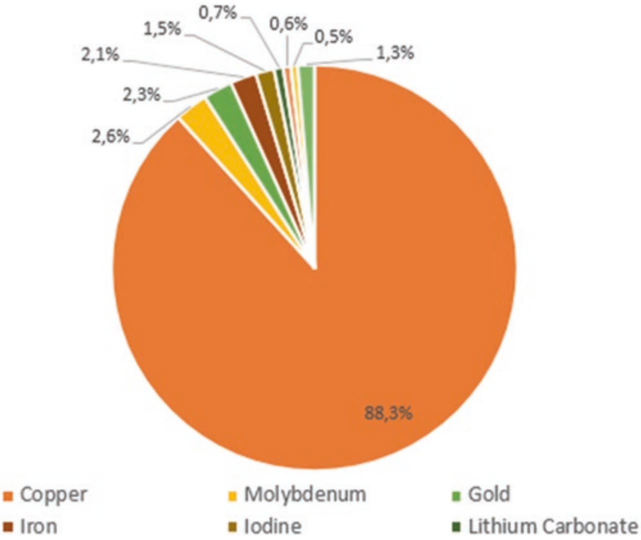

Fig. 12.2 Mineral composite production, 2015, in terms of export percentages (COCHILCO, 2016a, b)

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

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

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

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

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

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

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

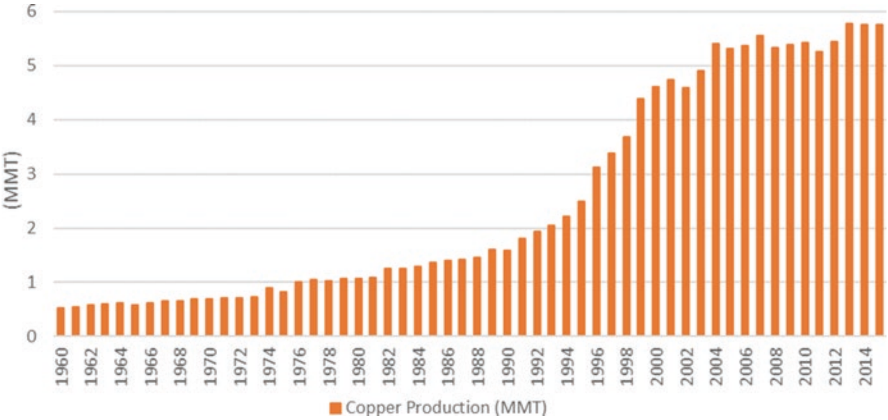

Fig. 12.3 Progress of Chilean copper mining (MMT) (COCHILCO 2016a, b)

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

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

Fig. 12.4 Locations of Chile's mining regions

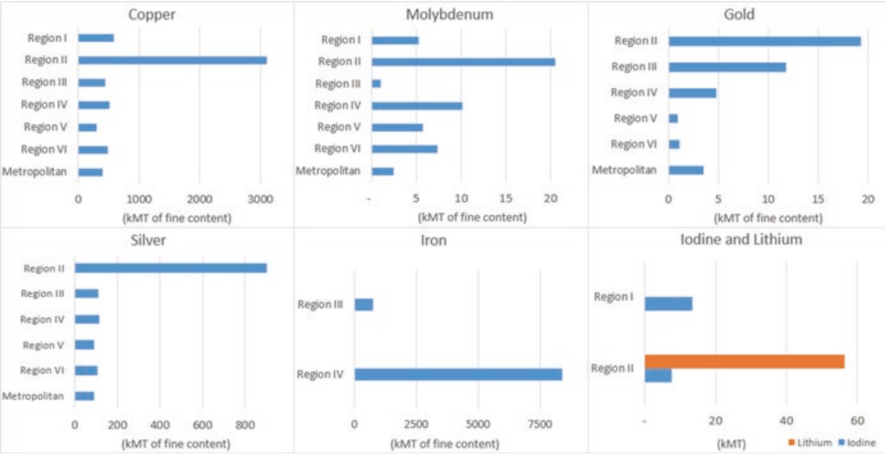

Fig. 12.5 Production of leading mining products by region, 2015, (kMT) (COCHILCO, 2016a, b)

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

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

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

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

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

12.3.1 Northern Macrozone

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

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

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

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

12.3.2 Central-Northern Macrozone

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

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

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

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

12.3.3 Central-South Macrozone

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

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

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

12.4 Water Consumption in the Mining Industry

12.4.1 Water Sources and Flows

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

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

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

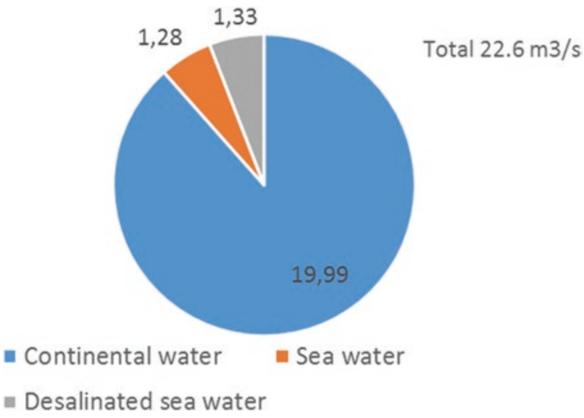

Fig. 12.6 Total water consumption by the Chilean mining industry in 2015, disaggregated by source of origin (m^3/s) (Prepared by the author based on information from DGA, 2016; COCHILCO 2016a, b; C. Minero 2017)

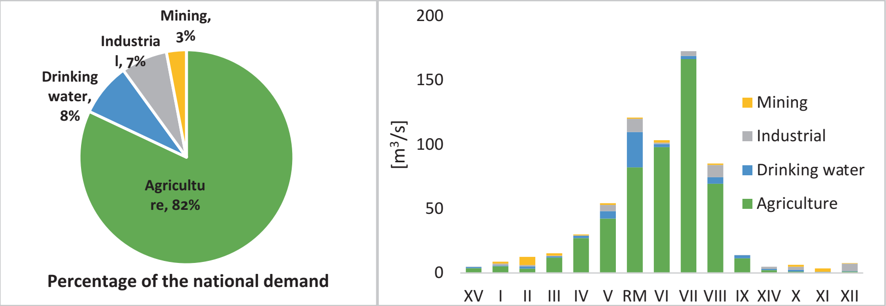

Fig. 12.7 Consumptive water use by productive sector and region (DGA 2016)

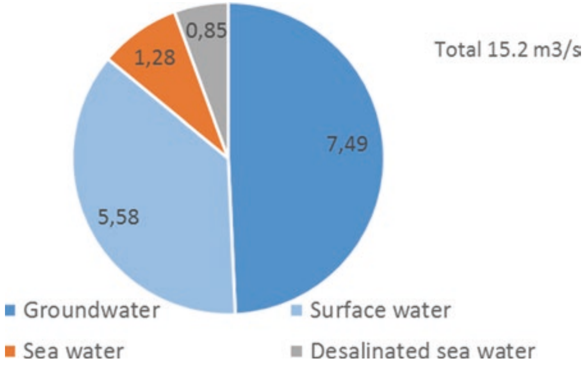

Fig. 12.8 Water consumption in Chilean copper mining in 2015, by source of origin (m^3/s) (Prepared by the author based on information from COCHILCO, 2016a, b; and C. Minero 2017)

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

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

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

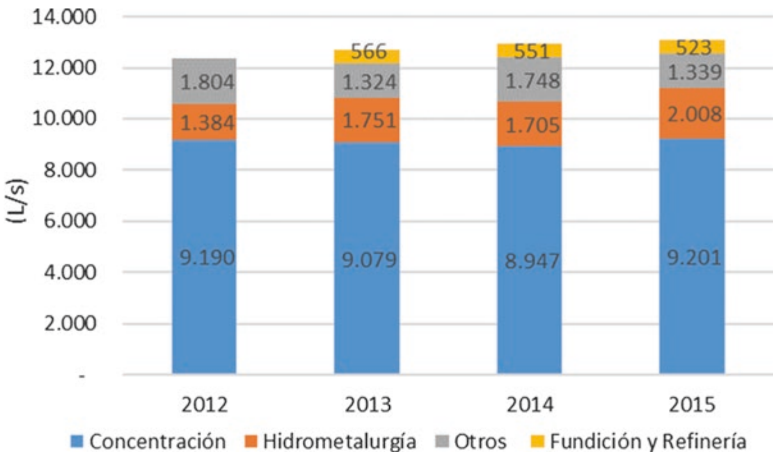

Fig. 12.9 Consumption of continental waters by process type in copper mining (COCHILCO 2016a, b)

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

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

Source: www.dga.cl

12.4.2 Age and Quality of Used Water

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

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

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

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

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

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

12.4.3 Water Rights

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

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

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

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

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

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

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

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

12.4.4 Environmental Evaluation on Water Usage

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

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

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

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

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

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

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

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

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

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

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Part IV
Water Management Challenges

Chapter 13
Integrated Water Resources Management in Chile: Advances and Challenges

Humberto Peña

Abstract There are significant obstacles that have prevented a decided adoption of an integrated water management framework in Chile. This chapter provides an overview of how water management has evolved in Chile, showcasing the advances that have allowed its scope to gradually expand, moving from an approach limited to meeting certain sector-based requirements to a more comprehensive perspective. The limitations of the current institutional system are also analyzed, highlighting a number of existing challenges in water management, where the institutionality has been found to be incapable of providing suitable responses and an efficient and equitable management, in a framework of environmental sustainability, in view of the needs imposed by Chile's development. Finally, a number of basic elements that must be incorporated into the current legal and institutional framework in order to advance towards an IWRM in Chile are discussed.

Keywords Basin organizations · Chile · IWRM · Water management

13.1 Introduction

Integrated Water Resources Management (IWRM) was the international community's response to the complex relationship between water and social development, and the generalized environmental and scarcity problems. This response, which emerged within the framework of social equity, economic efficiency, and environmental sustainability that underpins sustainable development, was recognized in the section on water in Agenda 21 of the Río de Janeiro Earth Summit in 1992, and has since been incorporated into a number of national, regional, and global forums, conferences, and seminars.

The Global Water Partnership (GWP 2011) defined IWRM as: "a process which promotes the coordinated development and management of water, land and related

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resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment". It is important to note that IWRM consists of a suite of activities that evolve over the course of time and depends on socio-economic development conditions and the situation of water resources. It is a concept centered on water; references to other aspects such as the environment, plant coverage, or land use are only included inasmuch as they are directly related to water resources or associated benefits, in terms of both quantity and quality. This means that IWRM must not be confused with initiatives that set out to resolve the limitations or urban or land planning or related fields, which have their own management mechanisms and purposes, and are only somewhat marginally linked to water management. It is therefore not synonymous with integrated river basin management, but rather integrated management of water resources within a given basin.

This chapter provides an overview of how water management has evolved in Chile, showcasing the advances that have allowed its scope to gradually expand, moving from an approach limited to meeting certain sector-based requirements to a more comprehensive perspective. The limitations of the current institutional system are also analyzed, highlighting a number of existing challenges in water management, where the institutionality has been found to be incapable of providing suitable responses and an efficient and equitable management, in a framework of environmental sustainability, in view of the needs imposed by Chile's development. Finally, a number of basic elements that must be incorporated into the current legal and institutional framework in order to advance towards an IWRM in Chile are discussed.

13.2 Evolution of Water Management in Chile

Water management in Chile comprises a long history of sector-based administration centered on agricultural surface water use, which began with the significant development of irrigation in the 19th and 20th centuries. Thus, the 1870 ordinances passed to govern resource usage in certain river basins and the 1908 law on Irrigation Channel Users' Associations, which regulated water users' management of both natural and artificial watercourses, were concerned mainly with resolving problems arising from the distribution of water amongst irrigators.

Similarly, the first water code, passed in 1951, dealt in depth with water conflicts arising from agricultural water use and irrigation channel users' organizations, but was far less thorough in its treatment of issues relating to groundwater and made no mention of issues relating to environmental conservation and pollution. In line with this sector-based approach, the competent administrative body was the Dirección de Riego (DR – National Irrigation Directorate).

Changes in water resource management over the past 50 years have been a slow, progressive, and difficult process moving towards a more integrated approach to water management. The first major change was the development of an institutional framework to regulate the area independent of water user sectors, with the creation of the Dirección General de Aguas (DGA) in 1969. Meanwhile, water use development and promotion policies for specific sectors remained grounded in sectoral ministries. For example, the creation of policies for irrigation, the country's leading water use sector, was delegated to the Ministry of Agriculture through the creation of the Comisión Nacional de Riego (CNR) in 1975.

The following set of changes were motivated by the need to meet growing water demands associated to an economic development strategy based on highly water dependent exports such as mining and agriculture. The Water Code of 1981 (WC81) was passed so as to promote economically efficient water transfers between users, and incentivized efficient water use, incorporating market based allocation mechanisms and incentivizing private investments. Granted water rights (WR) were no longer sector specific and water rights became fully transferable, allowing for intra and inter-sectoral water transfers, including water supply and sanitation. The WC81, however, paid little to no attention to environmental and groundwater issues.

Environmental concerns were incorporated into Chilean water management in the 1990s, with the promulgation of Chile's environmental law (Ley 19,300 de Bases del Medio Ambiente), which, following its 2010 amendment, is the current environmental regulation policy in the country. It created a suite of articulated mechanisms to prevent and control pollution and conserve the environment, the most significant of which include environmental standards, emission norms, decontamination and pollution prevention plans, and the creation of the environmental impact evaluation system (SEIA). The 2005 reform of the WC81 also incorporated environmental considerations into water legislation, such as the obligation to establish minimum ecological flow rates and the establishment of environmental requirements for the issuance of new water rights (Riestra 2018).

Despite this increase in the State's regulatory function, recognizing water's cross-sectoral role in the country's economic, social, and environmental development, little legal and institutional progress has been made towards the incorporation of medium and long-term water planning and management at the basin level. This weakness is directly related to the historically minimal role of water management planning. Indeed, Chile is almost completely devoid of hydrological planning proposals that adopt a more integrated view.

Up until the 1970s, planning exercises were mainly limited to investments in large-scale infrastructure, for inter-annual water regulation mainly for agricultural users. Although this framework did include multipurpose projects, these were the result of negotiations between sectors (and between institutions) to specify rules that would allow for the autonomous development of the irrigation and energy sectors. The development of the Upper Maule River, which is regulated by the Laguna del Maule Reservoir (Endesa Irrigation Agreement, 1947), or the Laja River, regulated by the Laguna del Laja (Endesa Irrigation Agreement, 1957) are examples of such negotiations. The construction of the Teno-Chimbarongo Canal (1972) was subject to a similar process.

The profound changes of Chile's water legal and institutional framework that arose with the passing of the WC81, imposed significant limitations on resource planning. This framework established that the DGA is responsible for water resource planning development; however, its role was limited to formulating water use recommendations, with no specific mechanisms to play an effective role in water planning and management. Overtime, the importance of incorporating planning mechanisms focused on IWRM became ever more self-evident.

This led to a number of studies to implement IWRM in Chile, financed by multilateral institutions such as the World Bank (WB) and the Interamerican Development Bank (IAD), among others. However, none of these initiatives resulted in full implementation, largely due to the lack of governmental support and the need to allocate both financial and human resources over and above those normally available to the public services. Notwithstanding, the importance assigned to the issue is clearly reflected in water policy documents prepared by the DGA since the 1990s. The National Water Policy (Política nacional de aguas, DGA, 1999) provides short-term and long-term development guidelines for the implementation of IWRM in Chile. Later, government agencies formulated several strategic documents including IWRM amongst their main recommendations.[1]

Additionally, during the 1990s several river basins prepared indicative integrated water planning mechanisms to orientate and coordinate private and public decisions at the basin level. Nevertheless, these documents failed to constitute effective guidelines for integrated water management considering the participation of all stakeholders of the basins. Furthermore, some regional governments created “Water Boards” (Mesas de Aguas y Directorios de Aguas), as pilot initiatives to establish water strategies and plans, voluntary coordination and stakeholder participation. Dourojeanni et al. (2010) and CONAMA (2009) present the limitations these institutions faced. In first place, the Water Boards’ direct dependence on the Regional Governments significantly reduced their autonomy and left them subject to the will of whichever public authorities were in office at the time. This limited the continuity of efforts and plans, and even threatened the very existence of the boards. In second place, under the current regulatory framework it has been difficult to provide these bodies with a legal formal structure, ensure their financing, specifying their role, and guaranteeing their representative nature.

These entities have often centered their actions on situations in a reactive mode, with little capacity to agree and implement medium- and long-term strategies. The non-binding and relatively informal nature of these organizations, the lack of incentives and mechanisms for action to offset their non-binding situation, and the lack of capacity to follow up on their agreements have together been seen by their members as major limitations for their consolidation and the implementation of their objectives.

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[1] See, for instance, the Integrated National Strategy for Hydrographic Basin Management (Estrategia nacional de gestión integrada de cuencas hidrográficas, Conama 2007), 2012 – 20120 National Water Resources Strategy (Estrategia Nacional de Recursos Hídricos 2012–2025, DGA 2013), and the 2015 National Policy for Water Resources (Política Nacional para los Recursos Hídricos 2015, Delegación Presidencial para los Recursos Hídricos, 2015).

13.3 The Need for Integrated Water Resources Management in Chile

Although the need for IWRM arises in different contexts and situations around the world, in Chile its importance related to the country's current stage of national development. Indeed, the economic and social modernization that the country has achieved over recent decades has run alongside the growing complexity in the relationship between water and society. The emergence of new problems has led to fragmented institutional development in a bid to solve problems sector by sector, creating multiple bodies and mechanisms each with a limited and partial perspective and operating independently of each other, in stark contradiction to the integrated way in which hydrological processes occur. This is clearly reflected in the 43 institutional stakeholders that are all involved in different areas of water management (World Bank 2013).

Meanwhile, the country's development is closely linked to the export of water dependent products, thus creating a scenario of heightened impact on the natural environment, and in particular growing water demands. In the past, river basins with relatively low intensity natural resource usage experienced only marginal impacts (or impacts that had been accepted by the community over the course of time), and each action could be considered in isolation, by means of a sector-based approach to water issues. However, the intensity of impacts on natural resources is now no longer marginal in many river basins, actions have mutual influences (externalities), and feedback effects arise between different resource usage initiatives that move situations away from the starting condition, such that proposals based on a purely sector-based perspective are beginning to show their limitations.

The growing divide between the nature of problems in a complex society with severe pressure on natural resources and the responses that traditional management structures are able to deliver is, thus, leading to increased conflicts, inefficiencies, and missed opportunities for progress. This unfavorable situation, which creates the need for the implementation of mechanisms to promote integrated management, is exacerbated by the legal and economic framework of water resource use.

The current water legislation that was passed in 1981 was designed to enhance the legal security of private sector actions, to establish the conditions for the creation of water markets, and to limit the scope of State action. Therefore, water rights (WR) issued to private sector parties were defined as absolute rights, with strong constitutional protections and freely transferable (Peña 2004).

Furthermore, the historic definition of WR (since the nineteenth century) as an authorization to abstract a given flow rate from the natural environment (watercourse or aquifer), measured at the intake point and without any consideration of the holder's effective consumption flow rate, created a source of externalities. The WC81 did not stipulate any use obligations or mechanisms to enforce such requirements and created an unregulated market for water rights without safeguards for the public interest. This scenario is also linked to a reduction in the State's role in planning and oversight, together with a management culture across all private and

Table 13.1 Reuse factors (RF) in river basins in the Coquimbo region

Basins	Elqui	Limarí	Choapa
Total annual average RF	2.4	3.8	1.6
Total drought RF	2.0	3.8	2.7

Source: CAZALAC/Rhodos (2006)

public-sector stakeholders that promotes isolated actions, above and beyond the limitations that can actually be attributed to current legislation.

These general issues led to specific problems partially due to the lack of integrated and participatory water resource management. A summary of the problems that have arisen from these situations is presented below:

13.3.1 Externalities Associated with Consecutive Water Use

Water resources of many Chilean basins are normally used consecutively by different users along the course of a given river, where the same resources are abstracted and returned by more than one user between ridge and reef. This is because water users consume only a fraction of the water that flows through their intakes and return the rest to the system through return and runoff flows and the recharge of aquifers. WR have been created for these return flows, many of which have been in use for more than a century.

As shown by way of example in Table 13.1, this cascade system for water resource use implies that during times of drought in river basins located in the Coquimbo of Chile, water is used between 2 and 4 consecutive times, as reflected in the value of the water reuse factor (RF). Similarly, this system permits an extremely high effective water resource usage rate. Indeed, in the north macroregion, 88% of effective runoff is used before it reaches the sea, on average, considering years of both water abundance and scarcity (Peña 2016).

In this context, changes in upstream use intensity have both direct and indirect effects on downstream water use; for example, increased irrigation efficiency together with the expansion of irrigated areas, reduces downstream water availability. This externality, that can lead to severe and complex imbalances in river basins, is not considered in current legal regulations.

13.3.2 Administration of River Basins by Sections

Since the nineteenth century, water resources in river basins located in Northern and Central Macroregions have been managed at the level of river sections as if they were independent of other sections. In this system, each section of the river can use the entire flow rate in that stretch, with no obligation to conserve flow for downstream

Table 13.2 Number of administrative sections in rivers of selected basins

Basin	Number of administrative sections for main watercourse	Number of administrative sections in basin
Elqui	4[a]	5
Limarí	1	14
Choapa	2	8
Aconcagua	4	5
Maipo	3	15
Rapel	4[b]	11
Mataquito	2[c]	5
Maule	2	15

Source: Peña et al. (2011)

[a]Turbio and Elqui Rivers. [b]Cachapoal and Rapel Rivers. [c]Teno and Mataquito Rivers

sections. This system arose as a practical means of making use of flow rates recovered in downstream sections due to return flows. Table 13.2 shows the number of administrative sections in selected basins and for main watercourse of the basin.

The system presents limitations for the implementation of an integrated management since it does not address issues that naturally affect all sections of a river, such as pollution, flooding, droughts, and the interaction between surface and underground water.

13.3.3 Joint Usage of Surface and Underground Water

The geological and geomorphological features of many Chilean river basins, with steep gradients, sections of rocky rapids, and narrow valleys, lead to extremely active natural interactions between surface and groundwater throughout the length of the watercourses. Thus, between ridge and reef, rivers have stretches in which surface water flows into aquifers and others where groundwater flows back to the surface.

Despite the unitary hydrological nature of surface and groundwater resources, in practice Chile's WC81 established that surface and groundwater are managed separately and independently. This approach has led to multiple conflicts between users of different river or aquifer sections and has prevented the adoption of conjunctive surface and groundwater management (Donoso 2014). For instance, this regulatory weakness implied that access to new groundwater abstraction has been limited in many aquifers in Central Chile, so as not to affect surface WR holders, when the best solution would have been to promote heavier usage of groundwater, had joint management with surface water been considered. This is the case, for example, in the Aconcagua and Maipo River basins.

13.3.4 Quality Management for Water and Associated Ecosystems

Environmental management of water resources requires a multi sectoral, dimensional and participatory process. However, there are no instances at the river basin level that insures the participation of all stakeholders to determine environmental objectives and to design and implement environmental remediation plans. Additionally, most of the institutions related to water quality management are separated from those that manage water quantity, which has led to overlapping and unclear allocation of responsibilities and competition of powers between ministries.

13.3.5 Cross-Sector Water Usage

Chile has sought to create institutional arrangements in which each economic sector has a defined regulatory framework, with incentives for the efficient management of resources in their particular area. The wide array of important linkages between sectors that present many synergies, explains why pursuing each goal separately has led to a series of conflicting, and unsustainable interventions. In addition, water resource policies in Chile have evolved in a fragmented and piecemeal fashion, without consideration of the implications for other water users and a fully participative consultation process involving all stackeholders. This traditional approach to water management has, in general, proven to be an ineffective policy strategy (Donoso 2014).

This approach has made it difficult to implement multisectoral and multiobjective water use projects. This is evidenced by the fact that the only projects devised for multiple water use objectives that are currently operating are the results of initiatives implemented more than 40 years ago (Laguna de Maule, Lago Laja, Teno-Chimbarongo Canal). It is only in recent years that attempts have been made to incorporate hydroelectric power as an ancillary benefit in a number of irrigation projects. Nonetheless, project design has still been strongly rooted in a single sector, as irrigation has been prioritized. In view of the nature of the challenges now facing water resource management, as indicated above, there is a need to design integrated projects with impacts in a range of dimensions, stemming from cross-sector agreements between stakeholders. No expedited mechanisms exist to devise, analyze, and implement such projects in the current management framework.

13.3.6 Water Management and Land-Use Management

The perfomance of the water resources systems is affected by basin-level iniciatives regarding land use planning, vegetation coverage and agricultural practices due to their significant impact on hydrological variables. For example, the large expansion of urban areas in Chile generated an important increase in the flood discharges of certain basins, and the increase in the surface and changes of agricultural practices altered the quantity and quality of the aquifers recharge (Peña et al. 2011).

Accordingly, water management plans need to integrate the broader group of actors who intervene in land-use management, beyond the narrow scope of the direct water users and specialized water and environmental institutions, making necessary the development of an IWRM approach.

13.4 Roadmap for the Future

Adopting integrated water resources management is a priority so that Chile can face its current and future water management challenges. A number of advances and reforms of Chile's institutional and legal framework for water management have fallen short of what is needed to address the issues that Chile faces in its current phase of development. This is due to its inability to deal with water management problems that affect the entire river basin and involve multiple stakeholders and sectors. At present, there are no participatory instances that bring together public, private and civil society. Additionally, water users of different sectors rarely interact although they are part of water user associations.

Thus, Chile's water management must incorporate participatory planning and decision-making with full public consultation and involvement of users. Through this process, each basin (or group of basins) should propose a Master Basin Water Management Plan, considering:

1. Future changes in water resources and demand, including changes in hydrological availability and economic dynamics, technological changes, public policies, and new investment projects;
2. Identification and characterization of current and potential externalities and conflict situations between stakeholders; and
3. Actions, plans, programs, and projects of mutual interest relating to water resource management.

This master plan should promote the public interest, which is a core objective of managing a critical resource such a water, and incentivize the economic and environmentally efficient utilization of the water resources by the users. To achieve this, the plan needs to be mandatory for all public entities related to the definition of normative criteria or relevant regulations for the basin; enable public investment programs linked directly or indirectly with the water management; and be indicative and informative for decisions made by private parties.

In order to develop and implement the Master Basin Water Management Plan, the current institutional framework requires a reform that allows for the creation of a basin organization. Along these lines, Peña et al. (2012) proposes the creation of a Water Resources Council at the basin level (Consejo de Recursos Hídricos - CRH). The CRH would be an autonomous formal body, independent of the current government, with its own legal statute, composed by

1. Public institutions belonging to the central government that relate directly or indirectly to water management;
2. Water user associations;
3. Private companies, business organizations, and producer organizations relating to water management in the basin, either as users or through their impact on water quantity or quality;
4. Local citizens who benefit from water resources, represented by their municipal governments, neighborhood groups; and
5. Local indigenous communities.

Its main task would be the development and implementation of the Master Basin Water Management Plan so as to increase water security and sustainability. More specifically, it will:

1. Collaborate with the other agencies to coordinate actions between national, regional and local bodies, and other public and private interests, with competence or interests within the basin and whose activities are directly or indirectly related with water resources;
2. Promote the effective participation of civil society in the planning, conservation and sustainable development of water and environmental resources of the basin;
3. Conserve and protect water resources and ecosystems of the basin;
4. Ensure adequate water availability and quality so as to meet user requirements;
5. Secure the financial resources required to implement the actions and measures proposed in the Master Basin Water Management Plan and to cover its operational costs.

This would lead to the improvement of:

1. Intersectoral use of water;
2. Intersectoral coordination of public and private institutions at the basin level;
3. Conjoint surface and groundwater management;
4. Sustainable water use;
5. Water quality management and environmental conservation; and
6. Water conflicts resolution and prevention.

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Chapter 14
Overall Assessment of Chile's Water Policy and Its Challenges

Guillermo Donoso

Abstract Chile was one of the early economic reformers in Latin America, instituting a series of market based policies. As a result of the structural policy reforms, since Chile's return to democracy, real per capita GDP per capita increased in real terms over 100%. In response to this accelerated growth, total granted consumptive and permanent surface and groundwater water flows grew. Water rights markets in Chile have also enabled this economic growth by facilitating the reallocation of water use from lower to higher value users and providing access to water resources at a lower cost than alternative sources such as investment in water infrastructure and desalination. Water markets have not eliminated the need for government agencies in water management in registering WR, providing market information to buyers and sellers, and in regulating trades that change the location of water-use in arid basins. Higher income has increased the demand for stricter regulation for water so as to increase water quality and reduce aquatic ecosystem deterioration. Policies that regulate the environmental quality of the waters in Chile have advanced significantly. However, it has taken about 22 years to be implemented and thus, at present, there are significant water quality problems and challenges. A number of advances and reforms of Chile's institutional and legal framework for water management have fallen short of what is needed to address the issues that Chile faces in its current phase of development. Adopting an integrated water resources management approach is a priority so that Chile can face its current and future water management challenges.

Keywords Chile · Water resources · Water markets · Water policy · Water sectors

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14.1 Introduction

Chile was one of the early economic reformers in Latin America, instituting a series of market based policies. These reforms included, liberalization of the capital accounts, steep reduction and harmonization of import tariffs, liberalization of foreign exchange markets, and aggressive privatization of state-owned companies, including public utilities. Increased private-sector investment was encouraged by Chile's focus on maintaining its macro-economic equilibrium, coupled with the many safeguards in place to protect foreign capital.

During the 80's, 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. Thus, natural resources policies shifted from command and control to market based management policies. Since water policies in existence prior to 1980 were inconsistent with this paradigm shift, a new water code was adopted in 1981.

The essential characteristics of the Chilean Water Code of 1981 (WC81) are

1. Water rights (WR) granted in perpetuity which can be consumptive or non-consumptive, permanent or contingent, and exercised continuously, discontinuously or alternating;
2. Transferability of WR;
3. Protection of traditional and customary WR;
4. Fostering economically beneficial reallocation through market transfers;
5. The subsidiary role of the State, and
6. The essential role of water user associations (WUA) in the local management of water resources.

The legal security, intangibility, and transferability of WR allows for a market-based WR reallocation mechanism. In order to control potential negative effects on third parties due to the transfer of WR, the WC81 established that the National Water Directorate (DGA) must authorize the WR transfers between natural water sources.

Water governance in Chile has evolved throughout history according to the natural and social context in which water resources management has been developed. It has gone from a simple structure in colonial times to a model that is characterized by the coexistence of centralized and decentralized institutions. Centralized organizations comprise the administrative bodies of the State, in which the DGA plays the most important role. These centralized institutions include water quantity and quality management bodies and the judicial system that resolves most water conflicts. Decentralized bodies, on the other hand, are represented by Water User Associations (WUA), which are private organizations that manage and distribute water at the local level and are not part of the State administration.

The macroeconomic, sectoral and natural resources policy reform was far from frictionless, GDP growth in 1982 was −14%, and official unemployment was approximately 24%. However, after this economic crisis, Chile entered a virtuous cycle of strong economic growth led by exports. After the return to democracy, Chile pursued a development model based on three major themes:

1. Maintaining macro-economic equilibrium;
2. Strengthening the market based allocation of resources, including water; and
3. Opening the economy to world markets and exporting products for which the country had a comparative advantage such as copper, fruits, wood pulp, and salmons, among others.

It is important to point out that the water sector itself has not exerted the greatest influence on water resources and their management. Instead, social and macro-economic policies and concomitant decision-making in trade, agriculture, and other sectors, had an even more profound effect. This is particularly true of policies related to the country's national development strategy, even though such policies have often seemed to be completely unrelated to water.

The remained of this chapter presents a global assessment of Chile's water policy and its challenges to face increasing water scarcity, drawing from the significant analysis and perspectives offered by all contributors.

14.2 Chile's Water Policy Performance

As a result of the structural policy reforms, since Chile's return to democracy, real per capita GDP per capita increased in real terms over 100%. In response to this accelerated growth, during the same period, total granted consumptive and permanent surface and groundwater water flows (m^3/s) grew 1083% and 633%, respectively (DGA 2017). Hence, there has been a clear correlation between the growth of the country and its water consumption. Consequently, decoupling of economic growth from water consumption has not been an automatic by-product of growth in national incomes.

Water rights markets in Chile have also enabled this economic growth by facilitating the reallocation of water use from lower to higher value users and providing access to water resources at a lower cost than alternative sources such as investment in water infrastructure and desalination. Water markets have matured in the 35 years since the WC81 was promulgated. Market transaction frequency has increased throughout the nation during the last decade, with more frequency during relative dry years. Agriculture is the sector with the largest number of transactions as buyers and sellers WR. Additionally, farmers mainly trade WR within the agricultural sector.

WR prices have been highly variable, with more experienced buyers and sellers negotiating favorable prices due to asymmetric information. Many WR transactions have been for relatively small amounts of water and for low transactions amounts. This implies that transactions costs have often not been prohibitive.

It is important to point out that water rights markets have not eliminated the need for government agencies in water management. The National Water Directorate (DGA) must maintain a key responsibility in registering WR, providing market information to buyers and sellers, and in regulating trades that change the location of water-use in arid basins.

Chile's urban water supply and sanitation (WSS) system represents a successful case given that virtually universal levels of coverage have been achieved in both drinking water supply and wastewater collection and treatment. It is characterized by three main features:

1. Separate role of the regulators from service providers;
2. Establishment of efficient tariffs that allow operators to finance operation, investment requirements, and obtain a minimum return on their investments; and
3. Implementation of a subsidy so as to ensure affordability of water supply and sanitation to low income and vulnerable families.

The privatization of the Chilean water industry was a gradual process that was carried out in two main phases and following two different approaches. As a consequence, currently in Chile there are two types of water companies namely: fully private and concessionary water companies. At present, private water companies provide WSS to most urban customers (95.8%).

The Chilean process to set urban water tariffs is unique worldwide and compares the costs of the real water company with a virtual, efficient company which is considered to be the benchmark. This model has been successful in providing WSS to most of urban customers. However, it presents notable asymmetric information problems and does not integrate quality of service variables and water scarcity in the tariff setting process.

Nevertheless, the Chilean water industry presents an important challenge related to nonrevenue water which is associated to the low reposition rates of both water and sewer networks. Chilean WSS companies must also improve wastewater treatment, replacing maritime outfall by more effective wastewater treatment systems and by removing nutrients from wastewater before it's discharge into water bodies. Moreover, water companies and the regulator should develop and implement plans for climate change adaptation given that extreme events such as droughts, floods and extreme turbidity are already a reality in Chile.

Beginning in the 1960's, a large portion of the rural population did not have access to drinking water. The Rural Potable Water Program implemented during the 60s has provided drinking water infrastructure to approximately 1,900,000 beneficiaries, increasing rural water coverage from 6% in 1960 to 53% by the year 2016. However, unlike urban service providers, rural water supply and sanitation sector has not been subject to regulation. This has led to tariffs that have not allowed for full cost recovery and adequate investment and maintenance so as to satisfy growing demand.

The current status of these rural water drinking systems (APR) depends on how long they have been operating. The average age of current APR systems is 23 years old and it is to be expected that these require improvements and constant maintenance in order to be able to provide quality services to their population. Although several systems have had maintenance work and/or made improvements in the past, these have not been sufficient; more than half of APRs report at least one unscheduled water outage in the past. Maintenance plans with timelines over a year are necessary to ensure system continuity. On the other hand, at least 13 of every 100 APR organizations do not have a sanitation operations authorization needed for potable water delivery. Hence, not all comply with current drinking water quality standards.

Rural drinking water system's ability to respond to scarcity during times of drought has become increasingly relevant. During the drought between 2011 and 2016, 6% of all APRs had to be supplied with lorries. It was estimated that about 200,000 people living in rural areas received a variable and insufficient quantity of water to satisfy basic human needs. Thus, rural WSS systems are precarious and vulnerable.

Growth of the agricultural sector has been achieved by intensification of production, constant land use transition from agricultural use in import competing crops into higher value export crops (fruits and nuts), accompanied by a marginal expansion of agricultural land, and increases in water use efficiency. Overall irrigation efficiency increased by 17% between 1997 and 2007, rising from 48.6% to 56.9%. The greatest increases were achieved in regions where water is scarcest. However, water use efficiency, defined from an economic perspective as the economic return per unit of water used for crop production, is on average low, indicating that there is substantial improvement potential without an increase in water consumption. Agriculture will continue putting pressure on water resources since the declaration of the goal for Chile to become a world agricultural and food production power in the twenty-first century by 2020, requires an increase of the total area under irrigation by at least 36%.

The mining industry only consumes 3% of the consumptive water use in Chile. This can be explained since mining activities in Chile have a high-water use efficiency, currently at 0.75 m^3/ton of copper ore, compared with nearly 2 m^3/ton of copper ore in the 1980s. This efficiency increase was motivated by increased prices for water rights in the arid macroregion, due to increasing water scarcity over the last 20 years. However, the use of water in mining has produced several socio-environmental conflicts over the past two decades. These problems mainly concern the environmental impacts on wetlands and riparian areas.

The increase in consumptive water use has led to important water stress situations that are triggering a greater number of conflicts and social, economic, and environmental vulnerability. The above phenomena will be exacerbated by climate change that is expected to affect Chile in a complex fashion, with increased temperatures throughout the country and decreased annual precipitation in the Central and South Macroregions.

The increase in granted non-consumptive permanent water flows mainly for hydroelectric generation was explosive between 2001 and 2017, increasing 50,000 times (DGA 2017).

Hydroelectricity has been part of Chile's energy history since the end of the nineteenth century. Significant developments of the hydroelectrical infrastructure have taken place, however evidencing significant deficits in their social and environmental sustainability. In recent years, both regulatory requirements and industry practices have improved, and the reality of the sector is much better than that of the 1990's. However, as the recent sustainable hydroelectricity government committee concluded, there are still challenges to move towards more sustainable hydroelectricity with the environment, communities and territory.

Twenty years ago, Chile's electricity supply presented a markedly hydroelectric component, with a participation of 76% of the total generated energy. Hydroelectricity has lost popularity in Chile due to two main factors: (i) increasing social conflicts, and (ii) increasing environmental costs of large hydroelectric projects. On the other hand, the increasing cost-efficiency of other renewable energy sources, in particular wind and solar energy which have a growing participation in the Chilean power grid, have reduced the attractiveness of hydropower generation. In contrast, run-of-river hydroelectric plants, with much lower environmental footprint, have been growing in importance in Chile. This has led to an important decrease in the participation of hydroelectricity in Chile, accounting for 36% of the total energy generated in the main system in 2016.

14.3 Water Policy Challenges

Chile's legislative and regulatory framework would seem to be adequate to effectively manage water resources. In the following section we analyze those aspects which have limited its performance.

Achieving water security is not only a question of adequate legal frameworks, but equally a matter of good governance. An assessment of Chile's centralized water governance evidenced a low performance (World Bank 2013). This is mainly due to the following institutional weaknesses:

1. Limited institutional role of the DGA.
2. Lack of institutional coordination.
3. Deficiency in strategic water planning and management formulation and monitoring.
4. Problems in the generation and dissemination of relevant information for water management.
5. Lack of participatory instruments for an integrated water management.
6. Insufficient institutional budgets.

The WC81 entrusts water management, administration, and distribution, to WR holders that are organized in WUA. In general, the performance of the WUAs is regular (World Bank 2011, 2013). This can be explained by the fact that an important proportion of WUAs do not fully satisfy Ostrom's 8 principles for an effective collective groundwater management.

The main difficulties that limit WUA effective water management are (Vergara et al. 2013):

1. Legal and administrative obstacles in the determination of their statutes and rules of operation.
2. Lack of adequate professional management.
3. Insufficient budgets for an effective water management and to maintain and improve their water infrastructure.
4. Strong administrative presence and intervention in some basins where hydraulic works have been built by the State.
5. River and aquifer sections with autonomous and independent WUA, limiting an integrated water management.
6. Lack of effective integration of all water users in WUAs, especially groundwater user associations and non-consumptive WR holders.
7. Lack of complete registry of WR.

Improving the performance of the water institutional system in Chile requires strengthening of horizontal and vertical inter-institutional coordination as well as institutions themselves. This would require reallocating part of the functions and activities that multiple actors currently develop, so as to avoid inefficiencies, duplicities and gaps. Some specific institutional modifications have been studied in the matter such as the creation of an Under-secretariat of Water Resources or a National Water Agency. Governance of WUAs must also be strengthened by increasing their organizational and management capacity moving towards an effective collective water management.

Due to the exponential growth in both granted consumptive and non-consumptive permanent WR, at present, several basins in the north and central macroregions are overallocated. With respect to surface water, up until 2015, the DGA had declared 11 water basins as water depleted, 4 in the north and 5 in the central macroregion (DGA 2016), representing 35% of the main basins and 11% of Chile's total number of water basins. In these depleted watersheds surface WR are recognized as shares of water flows. Groundwater overallocation was more serious; over the past two decades, the use of wells in agriculture has increased sixfold and the use of wells for drinking water and mining fourfold and twofold, respectively. 153 aquifers or hydrogeological sectors were declared under restriction and 4 under prohibition, all in the north and central macroregions. In the absence of public interest, the state is not allowed to intervene directly to restore groundwater balance. WR holders can petition their groundwater association or the DGA to impose a water sharing mechanism; however, this has not occurred. Thus, the hydrogeological balance has been increasingly negative and the sustainability of aquifers in the north and central macroregions are compromised.

A major concern is the general lack of information about groundwater and insufficient knowledge about its dynamics, in particular its interaction with surface waters. An additional challenge for a sustainable groundwater management is the fact that at present ground and surface waters are managed independently despite their recognized interrelations and regulation that calls for joint management. This implies that there has been no conjunctive management of surface and groundwater, which has proven to be an effective adaptation mechanism for climate change.

In response to growing water scarcity, Chile has concentrated on water supply management policies focusing on three priority areas

1. Regulate variable surface water flows by investing in major reservoirs;
2. Implement groundwater artificial recharge projects; and
3. Investment in desalination plants.

The State has proposed to invest US $ 1300 million in small and large water reservoirs, as well as US $ 265 million in desalination plants (Delegado Presidencial para los Recursos Hídricos 2014). On the other hand, the private sector has also proposed to solve its water scarcity challenges by investing in projects to increase water supply. Most of these have to do with water desalination. By 2015 there were 20 desalination plants in operation of which 11 are used in mining, 8 are used to supply water for human consumption, and 1 plant destined for industrial use. Most of these plants are located in the north macroregion, being the Region of Antofagasta the one that concentrates the greatest number of plants, with a total of 12. There are an additional 16 projected plants, with different stages of progress.

However, this policy on its own is unsustainable, given that as water availability increases so does water consumption, leading to the initial problem of water scarcity. The private sector, as a measure of water demand management, has increased its water use efficiency. As pointed out previously, agricultural irrigation and mining water use efficiency increased by 17% and 63%, respectively. In the industry there is also evidence of improvement in water use efficiency. However, there has not been significant increases in urban water supply water efficiency.

As competition for water has grown, Chile has sought better institutional arrangements for water management, coordinate use and resolve conflicts. Although the WC81 was successful in promoting investments related to water and improving water use efficiency in many economic sectors, it also led to new difficulties which were partially addressed in the reforms of 2005. The 2005, reform sought to establish a more stable balance between the public interest and the rights of private individuals and among social and productive demands and environmental considerations. Key reforms addressed concerns regarding speculative hoarding of unused water-use rights by implementing a non-use tariff on all WR that were owned but remained unused. This was particularly evident in the case of non-consumptive WR where entry barriers were created for new hydroelectric plants, discouraging competition in hydroelectric power generation. As a result of the 2005 reform, non-use of non-consumptive permanent WR has been reduced, but not significantly. Due to the lack of evidence on the effectiveness of this policy instrument, the actual WC81 reform under debate in the Senate, contemplates the implementation of a "use or lose it clause".

In the past years conflicts among multiple water users have increased. More importantly, current regulations have been ineffective to resolve these conflicts. There are multiple sources of conflicts. One of them are the conflicts that have arisen between users of different economic sectors in water stressed basins.

Increased consumptive permanent WR market activity between economic sectors has generated increased conflicts with downstream and other groundwater users due the reduced return flows and infiltration. A l/s used in agriculture with an efficient irrigation system consumes approximately 16,000–18,000 m^3/year, whereas the same l/s used for urban water supply or mining consumes 32,000 m^3/year. For this reason, in rivers with significant return flows, there have been attempts to prohibit or restrict the transfer of WR from agricultural users to non-agricultural users in earlier sections of these rivers. During the drought between 2011 and 2016 significant conflicts arose among rural water supply systems and agriculture and mining. The reduced hydrological flows due to the drought coupled with overallocation of WR and WR transfers led to important water shortages in rural areas with less impact on the productive sectors. This sparked the argument to reform the WC81 to prioritize drinking water over productive water uses; this proposed reform is under debate in Congress. As of 2007, the DGA has declared 28 water reserve decrees to insure water supply for the population because of increasing water scarcity and lack of other means to obtain water[1].

Other conflicts have arisen between water users and the DGA with respect to the WR granting procedure and the definition of water availability. The procedures to regularize customary WR has also generated conflicts between customary WR holders and the DGA. The application of the non-use tariff has similarly been conflictive, in particular with respect to the definition of water extraction infrastructures to determine water use.

Higher income brought by economic development has meant that Chileans care more for the environment and this has increased the demand for stricter regulation for water so as to increase water quality and reduce aquatic ecosystem deterioration.

Policies that regulate the environmental quality of the waters in Chile have advanced significantly. New water and environmental laws and regulations have been put in place. The main environmental legal body is Law N° 19.300, initially approved in 1994 but later modified multiple times, focuses on command and control policy instruments such as primary and secondary environmental quality standards. Primary quality standards establish pollutant concentration levels and their respective maximum or minimum duration, whose presence in the environment may constitute a risk to the life or health of the population. Meanwhile, secondary quality standards establish pollutant concentrations levels and maximum or minimum duration for the protection and conservation of the environment. Thus, in principle, Chile's environmental policy potentially guarantees water quality. However, it has taken about 22 years to be implemented and thus, at present, there are significant water quality problems and challenges.

The main water quality issues include elevated salinity and concentrations of metals and metalloids in Northern and Central Chile and eutrophication primarily in Central Chile. The natural presence of copper and arsenic from geological sources

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[1] The Reserve Decree is a faculty of the President of the Republic to reserve water resources to supply the population when there are no other sources.

in addition to anthropogenic activities explain heavy metals enrichment. Wastewater treatment coverage in urban areas is close to 100% but only 5% includes nutrient removal and 29% of the generated wastewater is discharged in Chilean coast by marine outfalls. An integrated approach that articulates water monitoring (quantity and quality) with working conceptual and quantitative models of water quality is needed.

This delay in implementation of water quality regulation has been, in part, due to the lack of systematic and reliable water quality information, differences in the technical criteria and discretion of the authority in its application. A more decisive push to add more areas is needed for the regulation to have a significant effect in the country. Because this means more funding, it makes sense to continue prioritizing those areas where the standards would yield the highest net benefits to society.

The high levels of water extraction for consumptive as well as non-consumptive uses, has led to important aquatic ecosystem degradation and loss of biological diversity. Estimates indicate that 90% of Chile's freshwater fish species are in a category of conservation danger and extinction and some rivers do not maintain water flows due to over allocation of WRs.

The 2005 reform of the Water Code of 1981 was a turning point incorporating minimum ecological flows (MEFs) explicitly. This was further reinforced with the 2010 reform of Chile's Environmental Law, which establishes that MEFs must be implemented for the protection of aquatic ecosystems. These requirements have been applied in the last decades, establishing MEFs when new WR are granted.

Environmental sustainability in Chile has actually improved in recent years. This was largely the result of factors outside the water sector, including economic growth, which has provided the financial and technological resources needed to bring about environmental improvements, and an ideological shift, which resulted in greater attention to social and environmental issues on the part of the government and Chile's citizens. However, in spite of these advances, Chile has not been able to revert the deterioration of aquatic ecosystems in its main basins.

A compelling policy that assures the access to thorough and reliable data on water quality and status of aquatic ecosystem is necessary. In addition, further efforts to target main water quality issues, for example by promoting sustainable water treatment alternatives, are required to move forward in the successful implementation of these policies. Future public policies aiming to the protection of water resources and aquatic ecosystems need to be consistent with existing regulations and institutions.

14.4 The Need for Integrated Water Resources Management in Chile

A number of advances and reforms of Chile's institutional and legal framework for water management have fallen short of what is needed to address the issues that Chile faces in its current phase of development. The growing divide between the nature of problems in a complex society with severe pressure on natural resources and the responses that traditional management structures are able to deliver has led to increased conflicts, inefficiencies, and missed opportunities for progress. This is due to its inability to deal with water management problems that affect the entire river basin and involve multiple stakeholders and sectors. At present, there are no participatory instances that bring together public, private and civil society. Additionally, water users of different sectors rarely interact although they are part of water user associations.

This unfavorable situation creates the need for the implementation of mechanisms to promote integrated management; however, this is limited by the legal and economic framework of water resource use. Thus, adopting integrated water resources management is a priority so that Chile can face its current and future water management challenges. For this, Chile's water management must incorporate participatory planning and decision-making with full public consultation and involvement of all water users as well as civil society.

This would lead to the improvement of:

1. Intersectoral use of water;
2. Intersectoral coordination of public and private institutions at the basin level;
3. Conjoint surface and groundwater management;
4. Water quality management and environmental conservation;
5. Water conflicts resolution and prevention; and
6. Sustainable water use.

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