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REPORT TO THE NATIONS

Water security in Chile:
Characterization and future perspectives

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Introduction

Introduction

Water security (WS) is defined in the Chile's Climate Change Framework Law as the "possibility of accessing water in adequate quantity and quality, considering the natural particularities of each basin, for its sustenance and use over time for human consumption, health, subsistence, socioeconomic development, conservation and preservation of ecosystems, promoting resilience against threats associated with droughts and floods and pollution prevention."

Achieving WS is a complex challenge that requires understanding the climate system, its regional manifestation, and its relationship with human activities. Likewise, an adequate governance is needed to establish WS goals and implement actions to meet them, following the **precautionary principle**[(g)]. This implies taking preventive measures to reduce the impacts of **climate change**[(g)] on WS, even when there is uncertainty in the projections of water availability.

This report gathers and synthesizes relevant scientific evidence to support WS decision-making. In the first part, information is presented to characterize and understand WS in Chile. In particular, the availability and uses of water in the country are described (Chapters 1 and 2), considering the evolution of these variables from the mid-20th century to the present, as well as their projection towards the end of the 21st century. Based on this evidence, Chapter 3 evaluates the historical and future levels of WS in Chile, as well as the causes of changes in these levels. Chapter 4 analyzes the case of the basins in central Chile with high water demand for human consumption and agriculture, where the gap between water use and availability is narrower. It is discussed how the reduction of this gap has led to the unsustainable use of groundwater.

Considering the prioritization of access to water for human consumption established in the Water Code and the Framework Law on Climate Change, Chapter 5 evaluates the conditions in rural areas, where a significant part of the population lacks drinking water service provided by a sanitary company. In these cases, water supply depends on community organizations or the direct management of households, which face difficulties in accessing water through multiple strategies.

In light of the evidence and challenges arising from the evaluation of WS, the second part of this report identifies opportunities to strengthen existing governance in Chile in order to advance toward WS in a context of climate change. To this end, the main laws and instruments focused on the management of water resources in the country are analyzed, ranging from a national and centralized focus to a more local one.

Chapter 6 provides an overview of current WS governance. Then, the Water Code is analyzed based on the system for assigning **water use rights**[(g)] and safeguarding ecological flows (Chapter 7), and the application of measures to address the impacts of drought (Chapter 8), revealing its unforeseen effects on WS. Chapter 9 focuses on the management of drinking water in rural areas, with emphasis on the recent legislative reform in this field. Along the same lines, Chapter 10 describes transformative community actions that emerge as a response to problems of access to water in rural areas. Chapter 11 examines the Strategic Plans for Water Resources in Basins (PERHC, for its acronym in Spanish), an incipient and more integrated water management instrument that represents an opportunity to achieve WS goals.

Finally, specific conclusions and recommendations are provided to advance toward WS, considering the territorial reality in terms of water use, availability, and governance.

The report has a Glossary that describes the terms highlighted in blue color and with a superscript (g) and a Methodological Notes section of the analysis described in various chapters.

Part 1:
Characterization and evaluation of water security in Chile

Chapter 1: Water availability and climate change in Chile

Chapter 2: Water uses

Chapter 3: Historical and future changes in water security levels

Chapter 4: Unsustainable use of groundwater

Chapter 5: Water security of the rural population

Part 1: Characterization and evaluation of water security in Chile

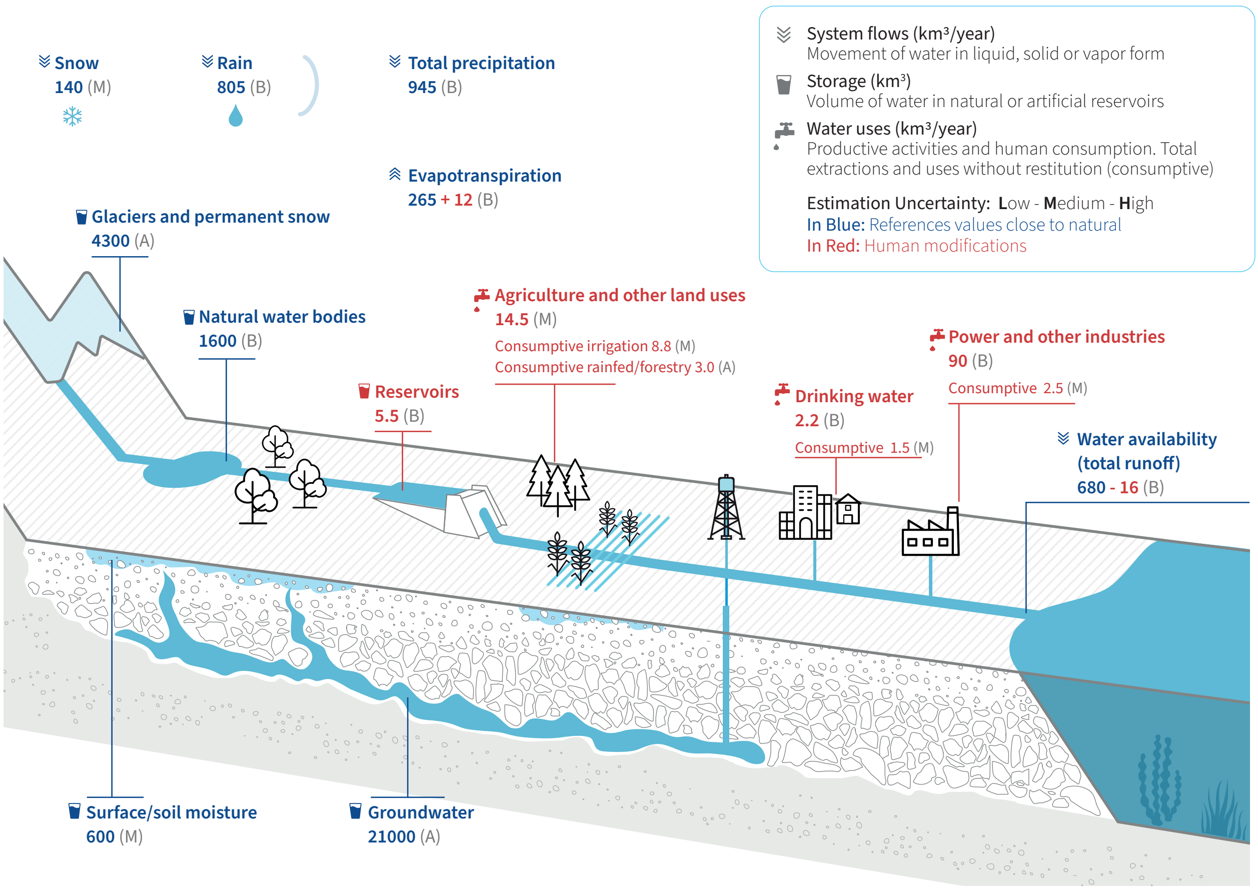


Figure I: Water balance, availability, and uses of water in Chile. *The values correspond to sums over the continental territory of Chile, averaged over the period 2000-2020. Information sources: CR2, Boisier (2023), DGA (2017, 2022), Gleeson et al. (2016), Millan et al. (2019), Muñoz-Sabater et al. (2021).*

Through a synthesis of original information from independent sources, Figure I schematizes the hydrological balance and the estimated anthropogenic uses of water in Chile, discussed in detail in the first part of this report. As aggregate quantities over the entire territory, the scheme describes large water flows (expressed in km3/year) and storages (km3). Note that 1 km3 corresponds to a volume of water similar to the capacity of the Rapel reservoir in the O'Higgins region (0.7 km3).

In the interaction between the surface and the atmosphere, two main flows of water with opposite directions are recognized: **precipitation**, manifested as snow and rain, and **natural evapotranspiration**, which includes evaporation from the ground, water bodies and other surfaces, as well as the transpiration of the vegetation. The balance between these flows determines the **availability of surface freshwater**, as described in Chapter 1. The other flows and storages of water in the hydrological system depend on this availability, which is mainly expressed as surface **water runoff,** feeding rivers, lakes, and coastal ecosystems. Water availability is also reflected in the accumulation of snow that sustains glaciers, and in the infiltration that allows groundwater aquifers to be recharged. In addition to groundwater reserves, Chile is characterized by hosting large **natural water reservoirs** in lakes and glaciers, mainly in the Patagonian ice fields.

The balance between water flows and storage variations is modified by human activities. In Chile, these disturbances are small on a national scale, but highly significant at the basin level, as discussed in several chapters of this report. **Anthropogenic disturbances** are mainly associated to changes in land cover due to agriculture and forestry, whose effect on the water balance is manifested as changes in evapotranspiration.

Chapter 1:
Water availability and climatechange in Chile

Available water is essential to understand water security since it determines the volume of water for sustaining ecosystems, recharging aquifers and meeting the human requirements over a territory. Due to climate change, water availability is decreasing in central Chile, a trend that will continue in the coming decades.

Juan Pablo Boisier, Camila Álvarez Garretón

Chapter 1: Water availability and climate change in Chile

Natural water availability depends on the climatic and geographical conditions of a region. On the surface, this variable can be considered as the difference between total precipitation and natural evapotranspiration. In continental Chile, the mean annual rates of precipitation and natural evapotranspiration are estimated at 1200 and 430 mm, respectively, which is equivalent to a surface water availability of approximately 770 mm per year (see methodological note 1.1).

Is this water availability low or high? Comparatively, Chile's average exceeds the global average in continental areas, close to 300 mm per year (Oki and Kanae, 2006). Added over the entire territory, the country's average availability is equivalent to 680 km3/year, a water flow that would allow approximately 1,000 reservoirs the size of Rapel to be filled in one year.

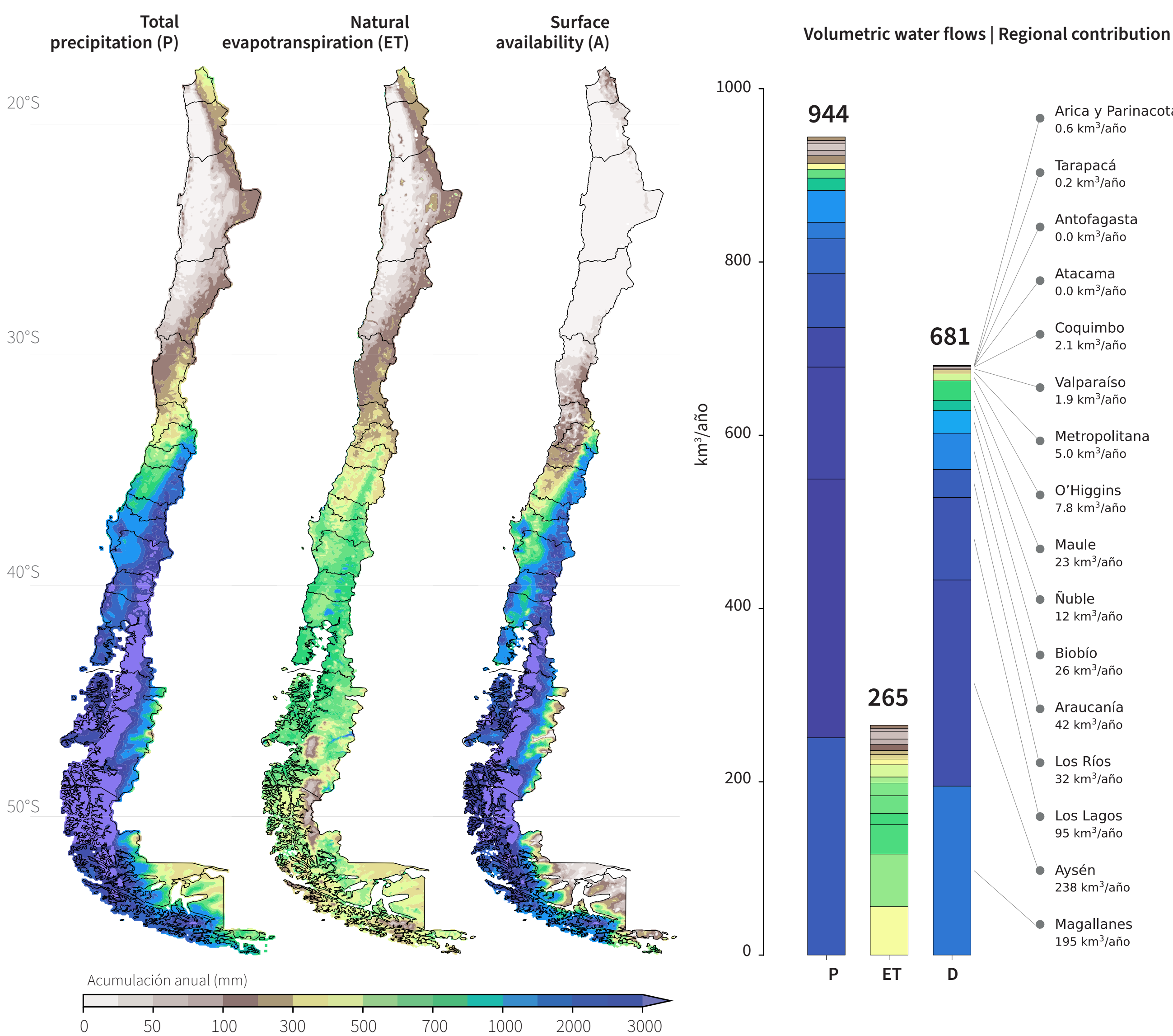


Figure 1.1: Precipitation, natural evapotranspiration, and water availability in Chile. For the three variables, average annual rates are indicated (1990-2020, colors on maps and bars), and the corresponding volumetric water flows (in km³/year) for the 16 regions of the country.

Although water availability on a national scale is comparatively high, the realities are very different across regions. In the hyper-arid zones of Atacama, there is practically no precipitation, while in the southern Andes, more than three meters of precipitation can accumulate in a year (Figure 1.1).

The resulting balance between precipitation and evapotranspiration defines a marked north-south gradient of water availability. Specifically, **the regions of Los Lagos, Aysén, and Magallanes together account for more than 75% of the total volume of available water, while the regions of Valparaíso to the north account for less than 1% of the total**, leading to very different challenges in terms of WS. For example, the lower availability of surface water and the high demand for water in central Chile has resulted in the exploitation of aquifers in a non-sustainable way, while keeping several basins in critical conditions of water stress (see Chapters 2, 3, and 4).

Along with geographical variations, water availability exhibits notable changes over time, including seasonal cycles, interannual variability, and long-term changes.

The geographic location, physical characteristics of the territory, and the seasonal climate cycle determine the hydrological regime of a basin. Thus, the surface and subsurface runoff that generates the river's flow depends on the magnitude and distribution of precipitation and evapotranspiration during the year. In areas such as the Andean Altiplano, all flows peak during the summer (e.g., Lluta River, Figure 1.2), while in the south, precipitation and evapotranspiration are concentrated in different seasons of the year (e.g., Toltén River).

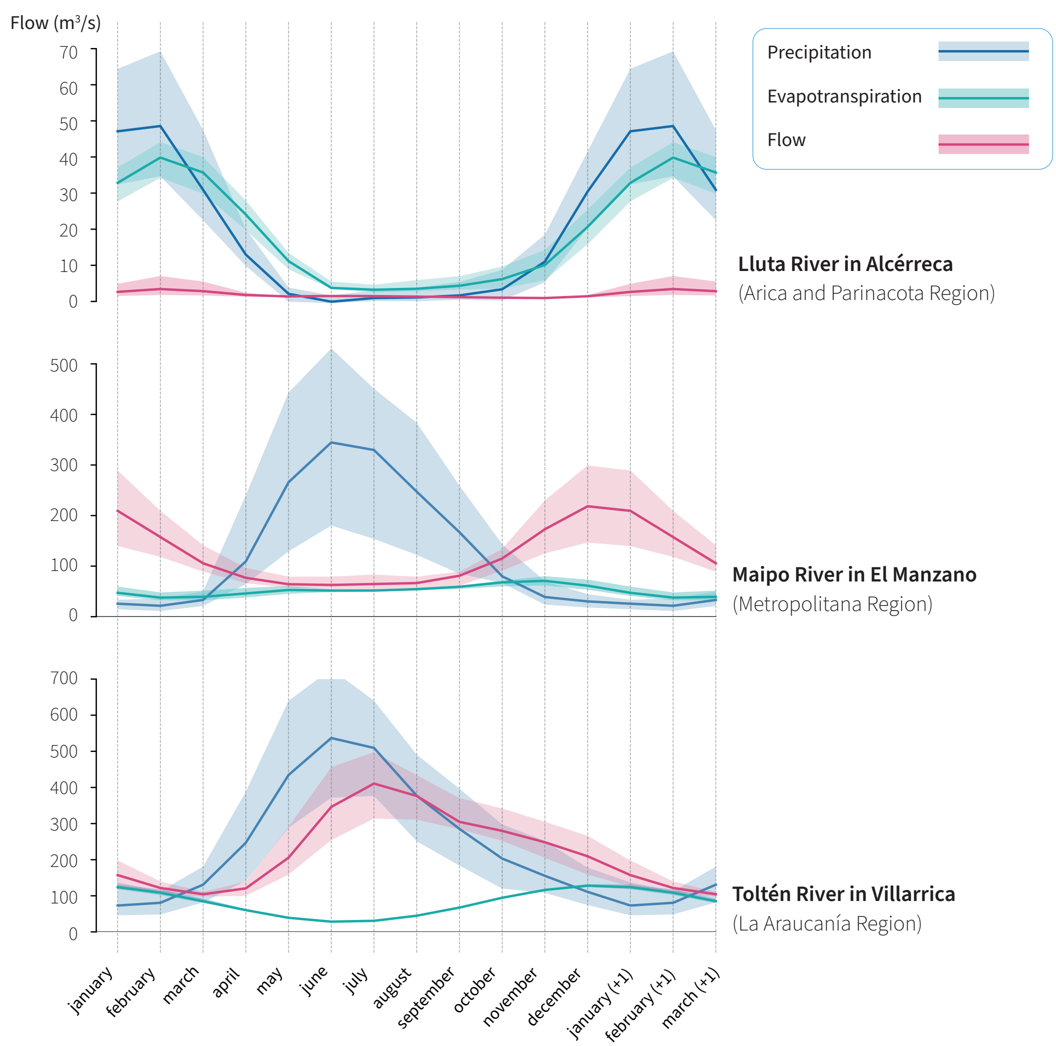


Figure 1.2: Hydrological regime of three basins in Chile. Lines and shadows indicate the medians and the 25th and 75% percentiles of precipitation, evapotranspiration, and monthly flow in the period 1980-2020.

In cold or high mountain climates, the accumulation of snow in winter and subsequent melting modulate surface water availability, shifting the peak runoff to the spring and summer months, as observed in the snow-driven basins of the central Andes. (e.g., Maipo River in El Manzano).

Superimposed on the seasonal cycle, important changes are observed in precipitation and streamflow from one year to another. Due to the influence of the Pacific Ocean on Chile's climate, this interannual variability is linked to large-scale natural phenomena, such as the El Niño and la Niña Oscillation[(g)] (Aceituno et al., 2021). The central and northern regions of the country, with very few precipitation events during the year, are more likely to experience extremely dry years and are, therefore, more exposed to water availability problems due to natural climate variability. For example, in the upper part of the Maipo River basin, it is common to have winters with either a deficit or a surplus of precipitation above 50% compared to the mean (see ranges in Figure 1.2).

Megadrought and climate change

Precipitation rates in central Chile have been repeatedly below average from 2010 to date. **This period, which we call megadrought[(g)], overlaps with and intensifies a multi-decade trend towards a drier climate observed from the Coquimbo region to the Aysén region** (Figures 1.3 and 1.4).

Studies on megadrought and long-term climate trends indicate that precipitation changes in Chile are due to a combination of factors, natural climate variability, and anthropogenic climate change. The signal of climate change is more prevalent in trends over longer periods (Boisier et al., 2016, 2018; Garreaud et al., 2017, 2019). These conclusions are based on the contrast between observations and simulations from global climate models[(g)]. In response to anthropogenic climate forcing[(g)], particularly changes in concentrations of greenhouse gases[(g)] (GHG) and stratospheric ozone[(g)], models systematically simulate a decrease in precipitation over the South Pacific (IPCC, 2021), affecting the regions of the country where the trends towards a drier climate are observed (Figures 1.3 and 1.4).

By combining global climate simulations, regionalized to adequately represent Chile's climate, and hydrological models, the effects of climate change on water availability at the basin scale can be evaluated (see methodological note 1.2).

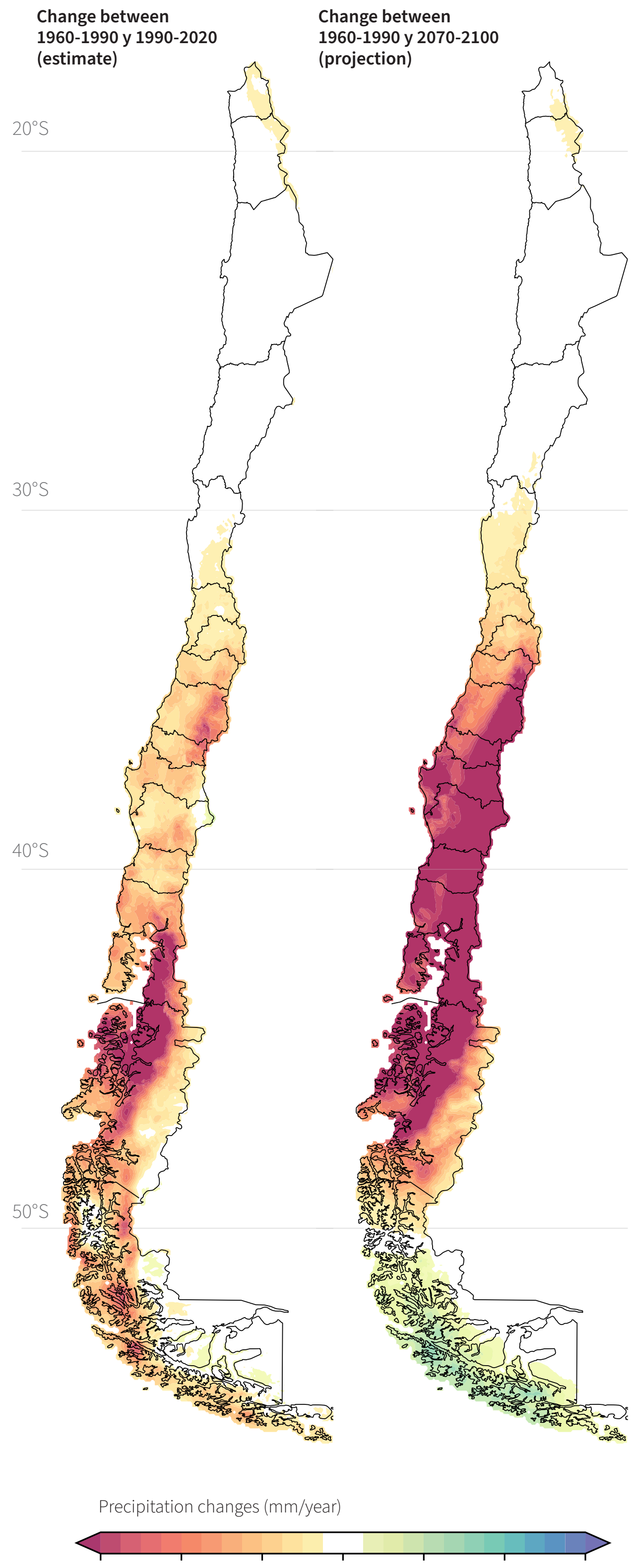


Figure 1.3: Precipitation changes in Chile between the periods 1960-1990 and 1990-2020, and projections towards the end of the century (2070-2100) under a scenario of medium to high global GHG emissions (SSP3-RCP7.0).

The projection of change for a particular period is variable (Figure 1.4) and depends on three main sources of uncertainty: (1) the superposition of the climate change signal with phases of natural variability that can last decades, (2) the intensity of the regional climate change signal, with differences between various climate models, and (3) the global socioeconomic scenario considered. Taking these factors into account, in an optimistic case, a decrease in precipitation of less than 10% can be expected in the central zone of Chile towards the end of the 21st century. This projection is based on a global scenario with high mitigation in GHG emissions (SSP1-RCP2.6, O'Neill et al., 2016) and models with low regional climate sensitivity. I**n a pessimistic case, precipitation deficits can exceed 30%, that is, a condition similar to the megadrought, but in a permanent regime.** This scenario is projected with medium to high global GHG emissions (SSP3-RCP7.0, O'Neill et al., 2016) and high climate sensitivity models.

In addition to the decreas in precipitation rates, the increase in temperature implies that snow-dominated basins transition towards more pluvial regimes, as shown in Figure 1.5 for the Maipo Alto River basin. It is important to highlight that the **loss of natural water storage capacity in the form of snow implies a decrease in water availability in spring and summer when the water demand is highest** hapter 2).

Additional sources of water availability

The surface water availability described in this chapter represents the renewable water that ecosystems and society rely on for their long-term functioning. Natural water reserves, in aquifers, snow, and glaciers, as well as artificial reservoirs (dams), complement water availability, mainly through a timing regulation. The ability to save water by these means also allows for accessing to larger volumes, but this is limited by recharge rates from the surface. **Given this limit, water consumption at rates close to or above surface availability will not be sustainable over time, regardless of whether the access is from groundwater, surface water, or reservoirs** (see Chapters 3 and 4).

Thus, groundwater reserves and reservoirs play a crucial role in water accessibility, although they are subject to thementioned natural availability restrictions. From an infrastructure perspective, it is important to note that there are other ways to increase water availability, such as inter-basin water transfer and seawater desalination. The implementation of these solutions entails economic, social, and environmental benefits and costs that, except for access to water through tank trucks (Chapter 5), are not evaluated in this report.

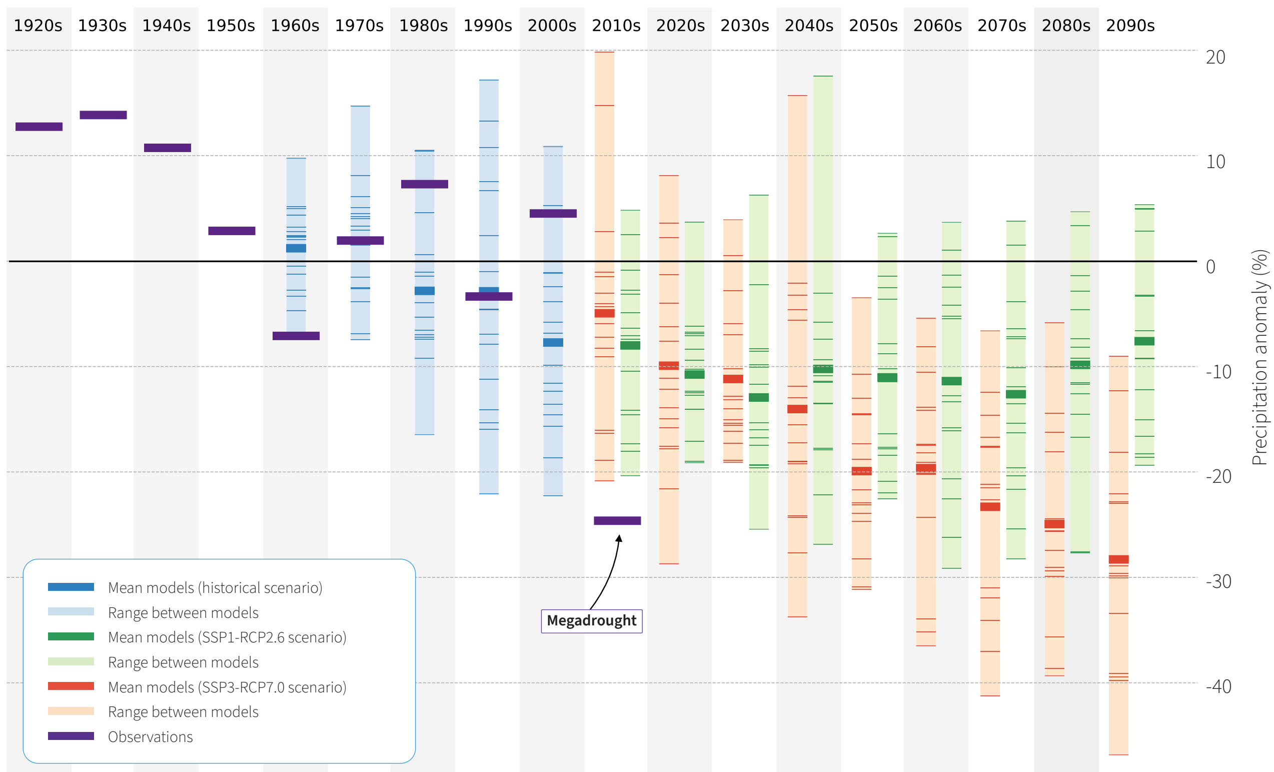


Figure 1.4: Precipitation changes in the central zone of Chile (30°- 40°S). ecadal changes are indicated in relation to the 1960-1990 average, based on observations (purple bars) and regionalized simulations of 15 climate models (thin lines). The simulations include a historical scenario (blue) and two future projections: one with high (SSP1-RCP2.6, green) and one with low (SSP3-RCP7.0, orange) mitigation of global GHG emissions.

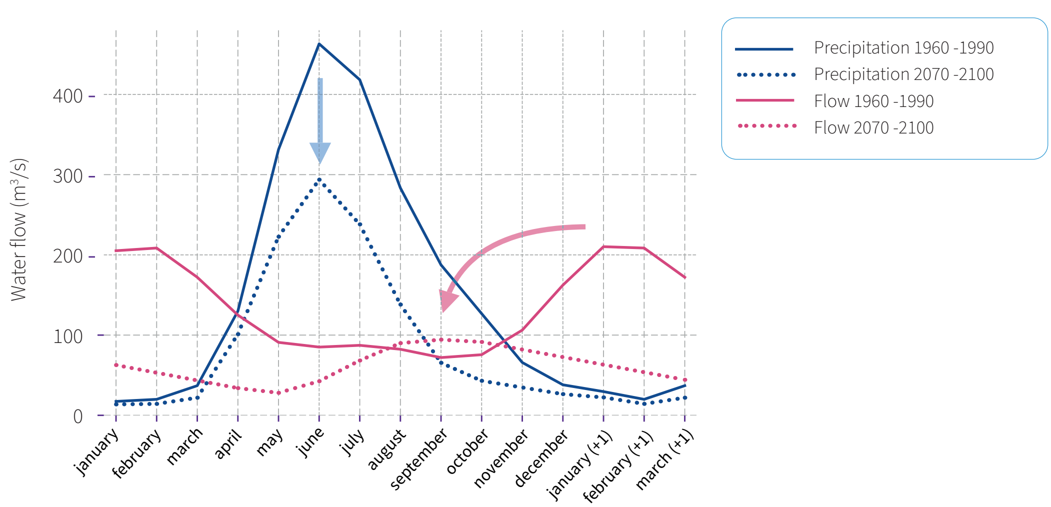


Figure 1.5: Extreme case of projected hydrological changes in the Maipo Alto river basin in El Manzano. Scenario based on the projections of the CanESM5 climate model and the SSP3-RCP7.0 scenario, with a strong decrease in precipitation (close to 40%) and flow (close to 55%), in addition to a clear shift in the season of maximum flow towards spring and winter (hydrological simulation obtained with the mHM model, see methodological note 1.3).

Chapter 2: Water uses

Water withdrawals affect water balances and are a key factor in water security. A historical reconstruction shows a sustained increase in water uses in Chile since the mid-20th century, driven by the development of agriculture and forestry.

Juan Pablo Boisier, Camila Álvarez Garretón, Rodrigo Marinao

Chapter 2: Water Uses

Water withdrawals for human consumption and productive sectors affect water balances in various ways. Their impacts depend, to a large extent, on whether the used water is returned to the intervened basin. Water uses with restitution, such as that of a hydroelectric plant, are called non-consumptive. Whereas water uses without restitution, such as water evaporated in industrial processes, are called consumptive . To robustly characterize WS, a complete quantification of these water uses is required. However, up to date, the information on this matter was limited in Chile, particularly regarding the historical evolution of water extractions.

This chapter presents a reconstruction of sectoral water uses based on various sources of information, including national inventories and satellite indicators of vegetation and land cover (see methodological notes 2.1 and 2.2).

Current uses of water in Chile

Considering consumptive and non-consumptive uses, total water extraction in Chile is estimated at around 100 km^3 per year (Figure 2.1). This value is similar, though slightly higher than, other independent estimates (DGA, 2017; Fundación Chile, 2018; FAO and UN Water, 2021).

Compared to other countries, the total use of water in Chile is high, which is mainly explained by the important role played by hydroelectric power generated in headwater basins in the central-southern region (Figure 2.1). This process involves the use of large volumes of water, but, except for evaporation from the reservoirs, they are almost completely returned to the system. Thus, hydroelectric water use mainly alters the streamflow dynamics of the intervened river, but not the long-term water balance of the basin at its outlet to the sea.

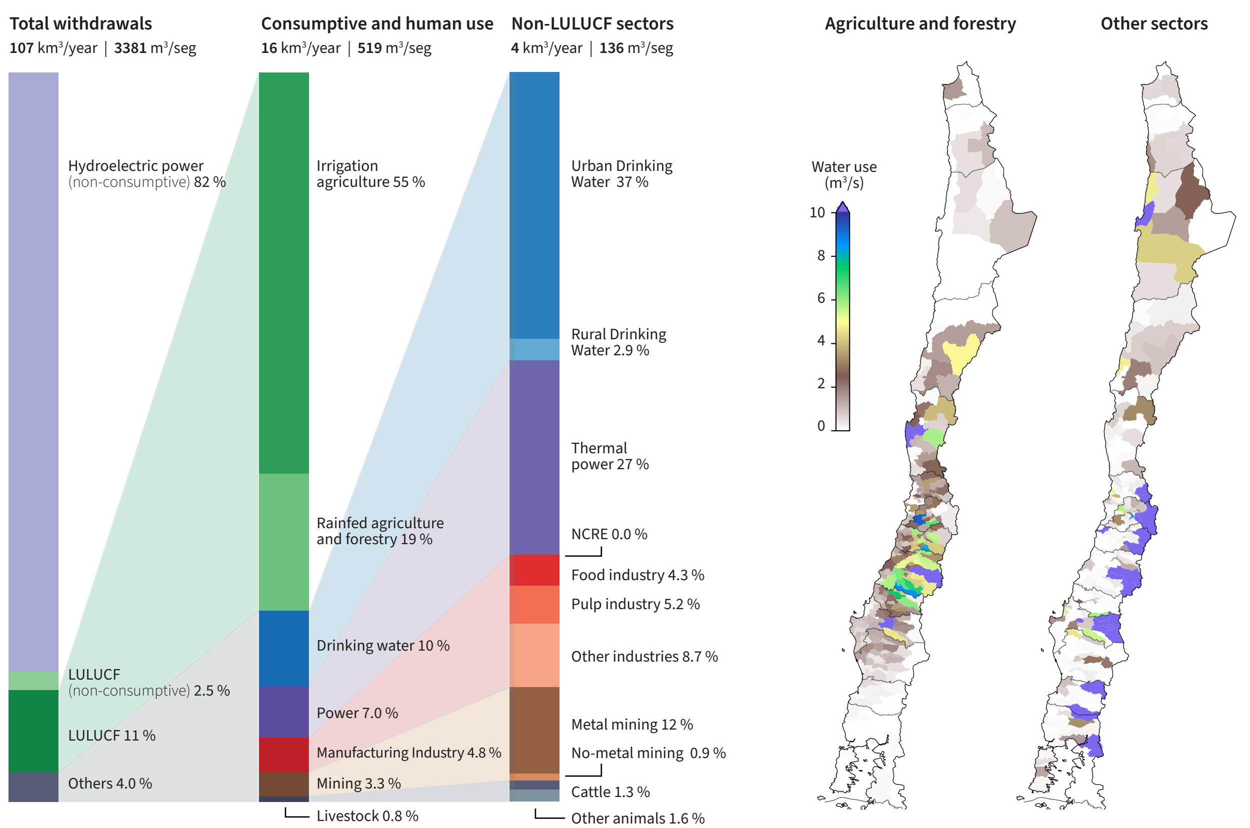


Figure 2.1: Current water uses in Chile (2010-2020 mean). National totals and sectoral contributions are indicated. The maps show the details of total water uses (consumptive and non-consumptive) in the communes of the center and north of the country, for the LULUCF sectors and the remaining set of sectors, including hydroelectric power, drinking water, and mining.

Consumptive water uses are mainly attributed to the sector of land use, land use change, and forestry (LULUCF). **With a total consumption close to 12 km3/year (400 m3/s), this sector represents 75% of all consumptive uses and the drinking water sector.** In particular, irrigated agriculture entails high water consumption (9 km3/year, equivalent to 290 m3/s) due to the high evapotranspiration rates of crops, in many cases located in areas with water limitation and high potential evaporation[g]. Rainfed LULUCF activities also represent an important part of consumptive water use (close to 20%). This use is mainly associated with forest plantations and, to a lesser extent, with rainfed agriculture and evaporation from artificial water bodies.

Given the seasonal cycles of climate and vegetation, water use in the LULUCF sector is very uneven throughout the year (Figure 2.2). This use maximizes during the summer period, reaching rates close to 800 m3/s, which is higher than the annual mean of all consumptive uses in Chile. The asynchrony between water consumption from this sector and surface water availability (concentrated in winter) highlights the importance of natural reservoirs and dams for the agricultural industry and food security[g] and emphasizes the need to take action to face the greater vulnerability of natural reservoirs due to climate change (Chapter 1).

Agriculture also has a non-consumptive water use component, since a part of the irrigated water returns to the system through infiltration. This component depends on irrigation technology and efficiency, as well as management practices.

Drinking water systems, from extraction to treatment and return of wastewater, constitute a partially consumptive water use sector that totals around 55 m3/s in Chile. This use is mainly associated with water supply in urban areas, of which 30 m3/s (equivalent to 145 liters per person per day) correspond to domestic consumption. That is, on average, drinking water supply for human consumption in Chile is above the minimum standard of 100 liters/person/day, although there are important differences within the territory, including areas with serious supply problems (see Chapters 5 and 8).

The consumptive water uses in the energy sector (mainly through thermoelectric generation), mining, livestock, and manufacturing industries, play a secondary role in the national total , but are relevant – in many cases dominant – at the local or basin scale.

Changes since 1960

Along with the increase in population and socioeconomic development, water use in Chile has had significant growth in the last six decades (Figure 2.3). During the second half of the 20th century, non-consumptive uses have grown more than four times as a result of the increase in energy generation through hydroelectric plants. In the 21st century, energy generation has continued to grow, but through thermoelectric plants, with significant consumptive use of water at the local level and, more recently, through solar and wind power plants that have very low water consumption (Figure 2.3).

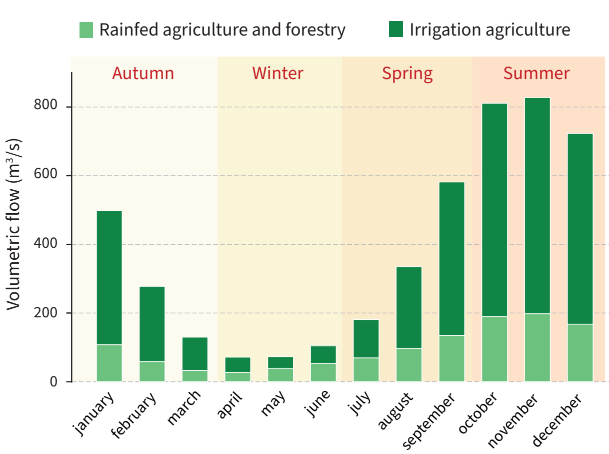
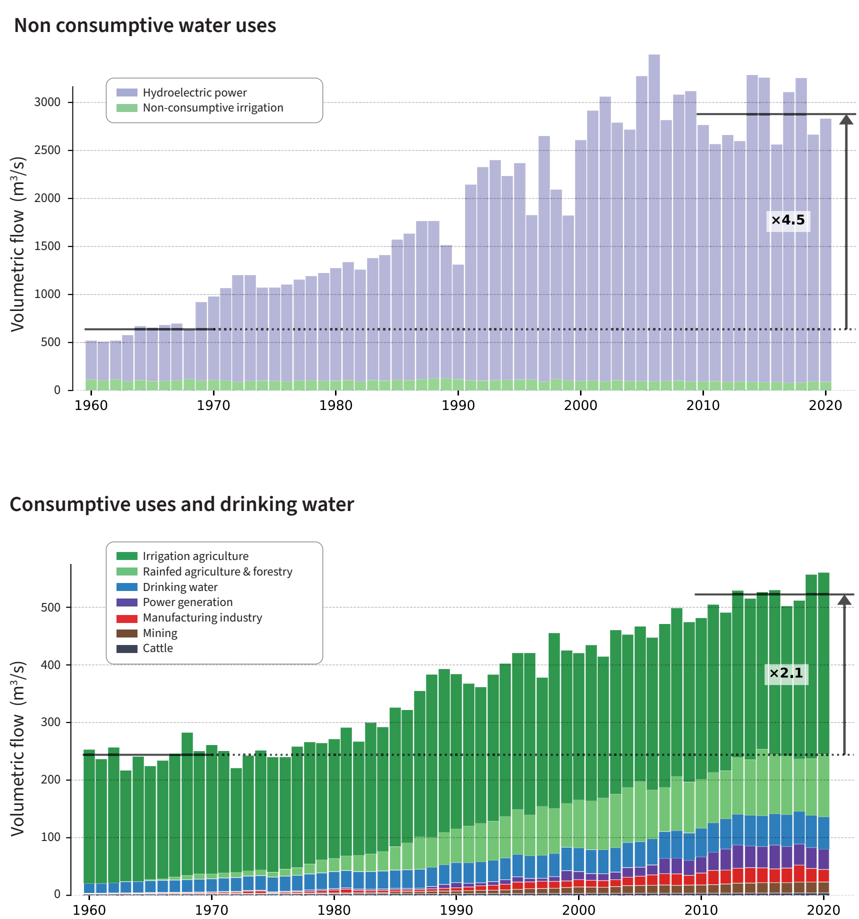


Figure 2.2: Seasonal detail of water uses in the LULUCF sector (average 2010-2020).

It should be noted that non-consumptive water use in irrigated agriculture has been the only sector with a downward trend. This is due to the change in irrigation technology, from gravitational to sprinkler and localized irrigation systems, which significantly increased irrigation efficiency over the last four decades. **Despite this improvement in efficiency, the total consumptive water use from this sector has increased by approximately 30% since the 1960s due to the increase in production of annual crops and strong development of the fruit industry.** In part, these changes can be explained by the irrigation efficiency paradox.

This paradox indicates that the reduced non-consumptive water use associated with increased efficiency does not translate into effective savings at the basin scale. Instead, it results in greater consumptive use, as it allows for the irrigation of more crops when total water withdrawals are not restricted (Grafton et al., 2018).

The forestry industry, with a great development between the 1970s and 2000s, has also contributed to the increase in water use in Chile. This has caused a large pressure on water resources in basins with intense forest use (Galleguillos et al., 2021).



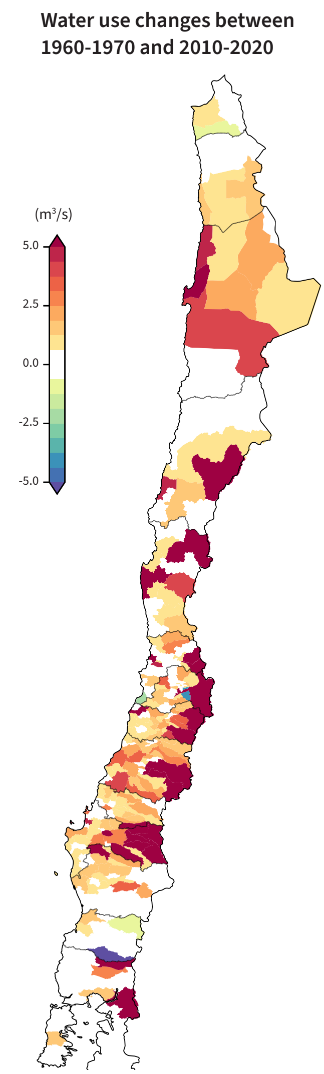


Figure 2.3: Annual evolution of water uses in Chile for different sectors of non-consumptive and consumptive use.

The growth of LULUCF sectors, together with other industrial sectors, and the uses of drinking water, **have doubled the national consumptive water use from the 1960s to date**. The largest increases in water uses have been concentrated in regions with high agricultural and forestry activities, between the regions of Coquimbo and La Araucanía, in addition to communes with strong urban and industrial development (Figure 2.3).

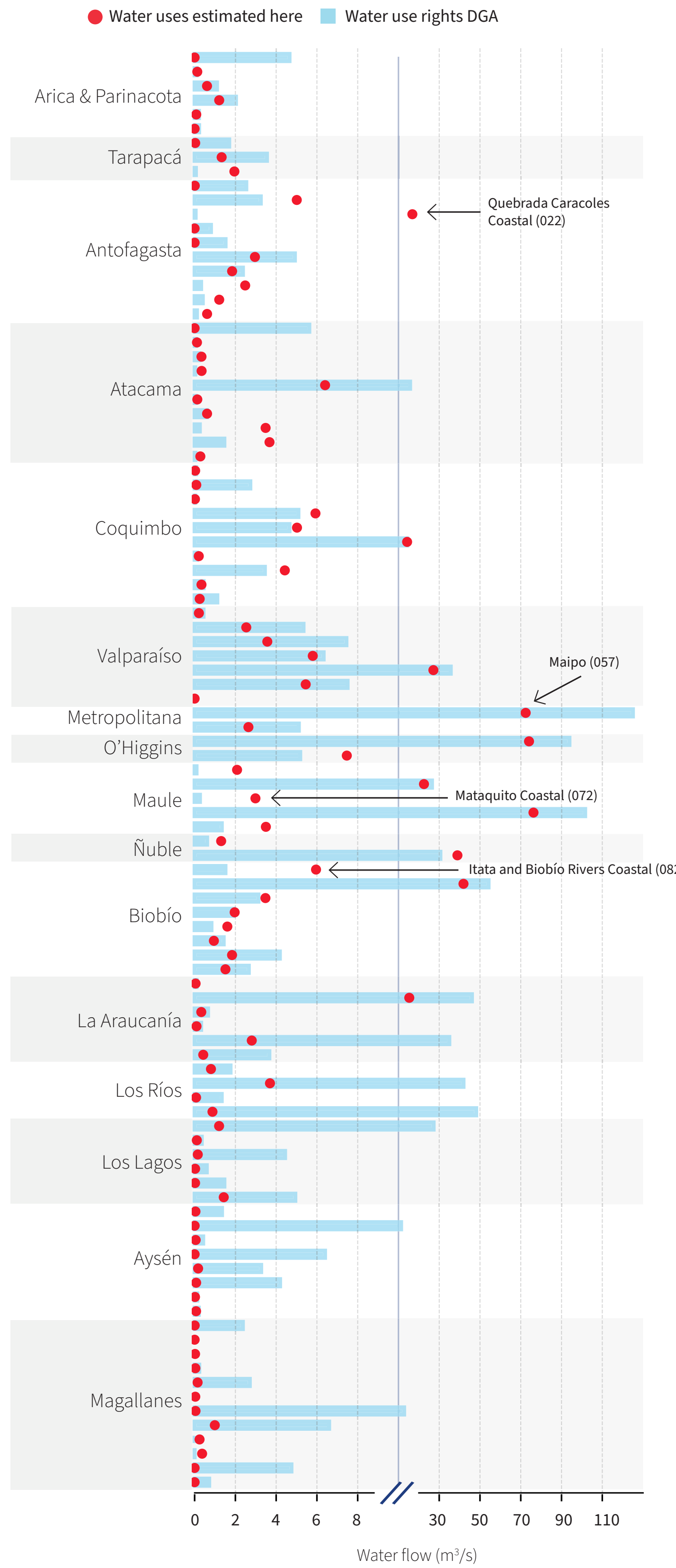
Water uses and allocation rights

The water uses presented in this chapter are estimated from existing human activities in the territory, regardless of whether or not they have water use rights (WUR) granted by the General Directorate of Water (DGA, for its acronym in Spanish).

Currently, consumptive WURs sum 31 km^3/year in the country, of which 17 km3/year are surface rights and 14 km^3/year correspond to groundwater rights. As expected, the estimated uses are lower than the potentially usable volumes according to the granted WURs. However, at the basin level, exceptions are observed (Figure 2.4), such as cases where water uses are supplied by desalinated water, and therefore not recorded as WUR (WURs consider only terrestrial fresh water sources). An example is the Quebrada Caracoles coastal basin in the Antofagasta region, where the water use is primarily for thermoelectric industry purposes and supplied by desalination plants.

Other cases of basins where the estimated water uses exceed the WUR are those with intense forestry activities, as observed in coastal basins between the Maule and Biobío regions. This is because it is not required to have a WUR to use the water contained in the soil coming directly from precipitation. However, **both rainfed agriculture and forest plantations have water consumption that affects the water balance of the basin** (Galleguillos et al., 2021; Alvarez-Garreton et al., 2019), and this impact is considered in the estimates described in this report.

Figure 2.4: Water uses and consumptive and permanent WUR (includes surface and groundwater) in the 101 major basins of Chile defined in the National Water Bank (BNA for its acronym in Spanish) inventory from the DGA. The values represent the average in the period 2010-2020. Some basins stand out whose BNA code is shown in parentheses. Note the scale jump on the x axis.



Chapter 3:
Historical and future changes in water security levels

The balance between water uses and availability reveals a high degree of water stress in most basins in central and northern Chile. The growth in water demand emerges as the main cause of the long-term increase in water stress since the mid-20th century and acts as an amplifier factor during droughts.

Juan Pablo Boisier, Camila Álvarez Garretón

Chapter 3: Historical and future changes in water security levels

There are multiple ways to evaluate water security (WS). Regardless of governance and water access factors (see Chapter 6), a basic approach to quantify WS is to contrast water availability with water uses at the basin scale. In general, a basin is considered to have a high water-stress condition when the ratio between water use and surface availability, known as the Water Stress Index (WSI), exceeds 40% in the medium term (5 to 10 years). (UN, 1997; Vörösmarty et al., 2000; Oki and Kanae, 2006). A high WSI value increases the risk of experiencing water scarcity [(g)] problems.

What is the level of water stress in Chile?

Considering the entire territory, consumptive and drinking water uses represent between 2 and 3% of total water availability. However, given the strong regional contrast in water availability, **WS levels at the local scale are very unequal, with basins where water demand approaches or exceeds surface water availability.**

A relevant case with high levels of water stress is the Aconcagua River basin (Figure 3.1). In this basin, urban and rural areas coexist, along with multiple productive activities with high and growing water consumption, sometimes greater than surface availability. Thus, in Aconcagua, as in other territories with natural water limitations, access to water depends strongly on reserves from dams and aquifers (see Chapter 4).

During the decades before the megadrought, consumptive water uses in the Aconcagua basin represented close to 40% of water availability in the basin; this meant a medium to high level of water stress according to the standards of this metric. The margin between water uses and availability narrows in periods of drought, as observed during the second half of the 1960s or the megadrought (2010-2020), periods when the WSI reached an extreme level and overuse condition in the Aconcagua basin, respectively (Figure 3.1).

On average, between 1960 and 2010, most of the basins from Coquimbo to Biobío (regions with the highest water scarcity risk), maintained medium or low levels of water stress (Figure 3.2). Only Aconcagua, as well as some coastal basins, were already experiencing high levels of stress during that period. **After the megadrought onset in 2010, the combination of the low water availability and the high water use rates severely raised the levels of water stress in the central zone.**

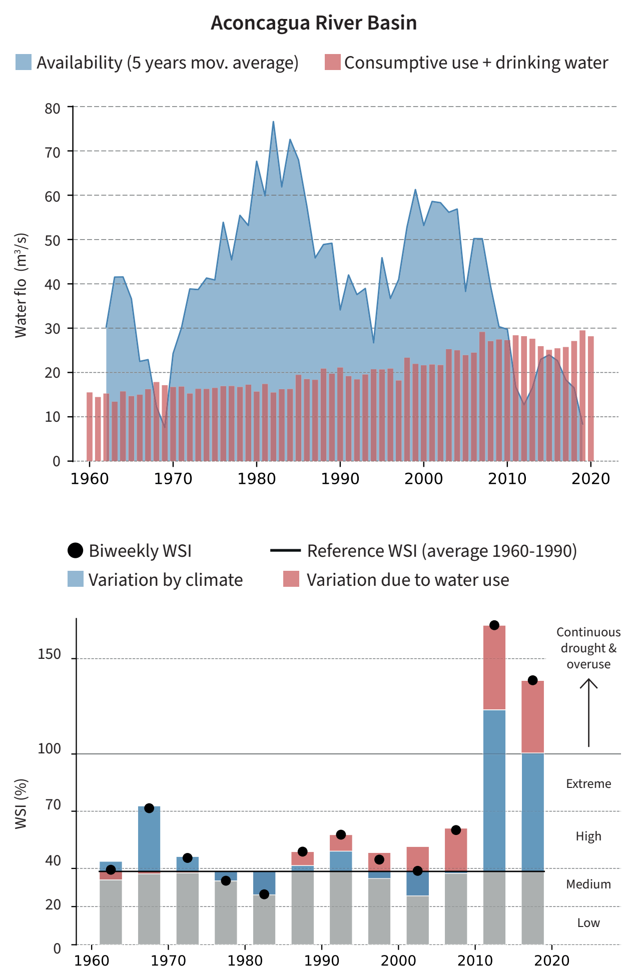


Figure 3.1: Water availability, consumptive uses of water, and water stress in the Aconcagua River basin. The upper panel shows water availability and consumptive water use between 1960 and 2020. The lower panel shows the mean WSI computed every five years in the basin. The associated anomalies of each period are attributed to changes in climate (in blue) and to changes in water uses (in red).

During the megadrought, the Maipo River basin reached an extreme level in WSI. In basins such as La Ligua and Aconcagua, even more critical levels of WSI were reached, with uses greater than the water available on the surface (WSI > 100% in Figure 3.2). These levels of water stress imply unsustainable use of groundwater reserves, which is evidenced by sustained decreases in the **water table**[(g)] in this area of the country (see Chapter 4).

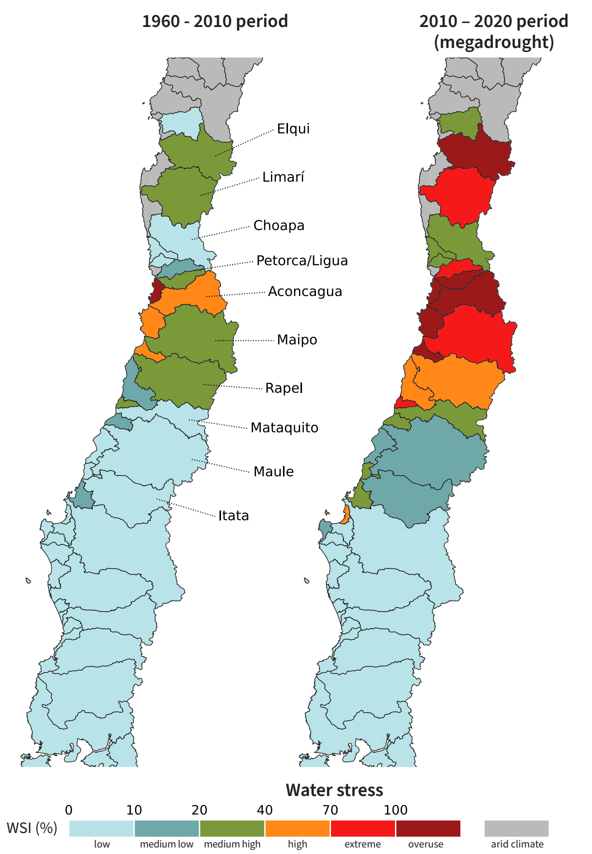


Figure 3.2: Water stress index in basins of the BNA inventory of the central zone of Chile for the periods 1960-2010 and 2010-2020.

Is it a problem of supply or demand?

Drawing a parallel with the principle of supply and demand from economics, the WSI allows to directly estimate the relative impacts of climate variability and associated water availability (supply), and water uses (demand) on water security. This attribution exercise is carried out by setting average usage or availability rates relative to a reference period (see methodological note 3.1).

In the case of Aconcagua, in addition to the increase in water stress during periods with precipitation deficits, the growing use of water has played a predominant role, progressively increasing the WSI between 1960 and 2020 (Figure 3.1). **In particular, the increased water use has had an amplifying effect on water stress levels during 2010-2020, significantly intensifying the impact of the megadrought.**

In general, in central Chile, the growth in water demand since 1960 has narrowed the gap between water availability and uses (Figure 3.3). The major basins in Coquimbo, Valparaíso, and Metropolitan regions show high levels of water stress on average between 1990 and 2020. Compared to the previous 30-year period (1960-1990), **the increase in the WSI is mainly attributed to the growth in water uses, and to a lesser extent to the decrease in water availability between both periods.**

Future scenario

WS levels in central Chile become more critical when we look into the future due to the decrease in water availability projected under climate change scenarios. This decrease is mainly associated with lower precipitation rates and, to a lesser extent, with the increase in evapotranspiration as a result of higher temperatures.

As discussed in Chapter 1, climate projections have various sources of uncertainty, and the actual water availability will depend on the global climate change scenario, in addition to regional sensitivity to large-scale climate perturbations. However, considering a large set of projections, an unfavorable scenario is consistently obtained. **Only due to the effects of changes in water availability, in an adverse climate scenario, permanent levels (30-year averages) of high and extreme water stress are projected towards the middle of this century in Elqui, Limarí, Petorca/La Ligua, Aconcagua, and Maipo basins** (blue bars in Figure 3.3).

Given the little control over climate evolution in terms of local governance and actions, and considering a precautionary principle regarding projections of water availability, the effects of water uses on WS are of particular relevance. As has happened with water stress levels in recent decades, the unfavorable conditions projected into the future due to climate change could be significantly amplified if the increase in water demand continues in basins with greater risk of water scarcity (red bars in Figure 3.3). To evaluate this risk, a trend scenario in water uses towards the middle of the century was considered, with which **several basins may reach extreme levels of water stress, in some cases surpassing the threshold of physical unsustainability (WSI = 100%)**. This implies a structural condition of overconsumption with a high impact on groundwater reserves (Chapter 4).

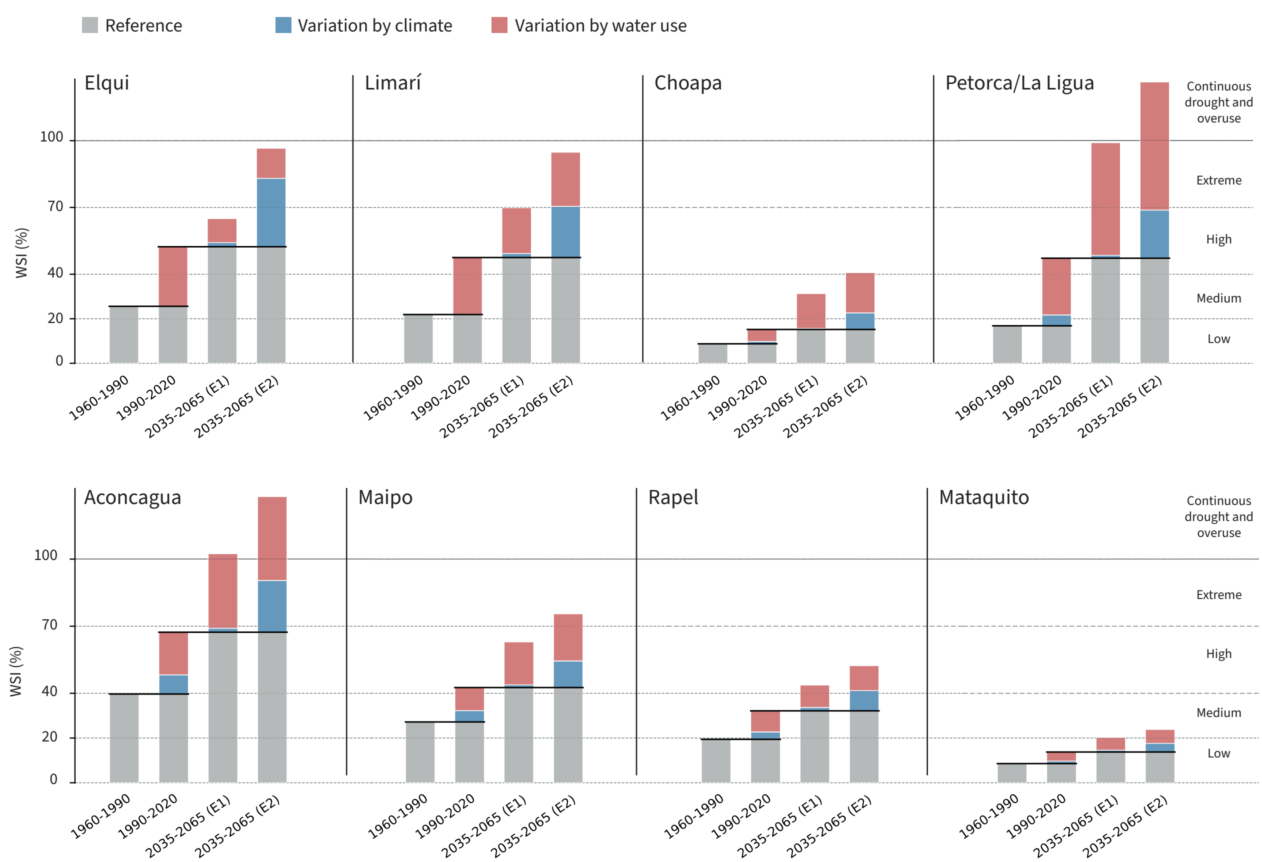


Figure 3.3: Water stress index (WSI) in BNA basins in the central zone of Chile for three periods: 1960-1990, 1990-2020, and 2035-2065. Increases in WSI with respect to a reference period (black lines) resulting from changes in water availability and water uses are highlighted in blue and red, respectively. Projections towards the middle of the 21st century contemplate seven climate models (the average is indicated) and two socioeconomic scenarios with high (E1, SSP1-RCP2.6) and low (E2, SSP3-RCP7.0) global mitigation of GHG emissions. The projection of changes in water demand considers a linear extrapolation of the trend observed between 2000 and 2020.

Chapter 4:
Unsustainable use of groundwater

Groundwater reserves are essential for water security in areas and periods of low surface water availability. However, current water uses in central Chile are causing a sustained decline in these reserves. This can lead towards the depletion of groundwater resources, or day zero, while causing socioeconomic and environmental impacts long before reaching it.

Camila Álvarez Garretón, Juan Pablo Boisier

Chapter 4: Unsustainable use of groundwater

When surface freshwater is the main source of supply, the intersection between water availability and water use (i.e., WSI greater than 100%) would indicate a ***day zero*** ituation, a time when further water demands can no longer be met. This often leads to restrictions on water supply to prioritize human consumption. The arrival of day zero has been announced in large cities whose drinking water supply depends on dams that have approached their minimum levels. An emblematic case almost occurred in Cape Town (South Africa) in 2018, and in Montevideo (Uruguay) in 2023.

The high levels of water stress in central Chile described in the previous chapter suggest that a *day zero* condition would be occurring in the country's capital. However, there have been no major supply cuts and water uses have not decreased despite water stress. Below we explore the reasons of this.

Are we approaching a day zero in Santiago?

The metropolitan area of Santiago, located in the Maipo basin, is home to almost six million inhabitants, equivalent to 30% of Chile's population. This basin currently has a total water consumption of approximately 75 m^3/s, which represents 15% of the country's consumptive use. 60% of this consumption comes from irrigated agriculture, while 35% corresponds to the supply of drinking water.

Water availability in the basin has decreased in recent decades due to climate change and the megadrought. This has caused an increase in the extraction of groundwater to meet water use requirements, according to the increase of groundwater WUR granted in the basin. In line with the rising water stress over the last decades, the water table[(g)] from observation wells in the Maipo basin show a sustained decrease (Figure 4.1). **This indicates that the rate of water withdrawals from the aquifer is greater than its recharge, which represents a condition of non-sustainable groundwater use in the long term** (Alvarez-Garreton et al., 2024; Taucare et al., 2023).

Unlike computing the time it takes for the water stored in a dam to be depleted, estimating the time for depleting groundwater reserves and reaching an absolute day zero is highly uncertain, as it depends on variables that are difficult to quantify, such as the volume of the aquifer, in addition to groundwater recharge and extraction rates.

Previous studies have estimated a water volume of 30 km3 for the main aquifer of the Maipo basin (Araneda et al., 2010), and recharge rates in the range of 10 to 30 m^3/s (Döll and Fiedler, 2008). If we consider the current uses of water in the basin and a portion of groundwater to total water use in a range of 30 to 65% (the upper limit corresponds to the proportion given by the ratio of groundwater to total WUR allocated within the basin, Figure 4.1), the time to deplete the aquifer would range between 50 and 200 years. **While these are rough estimates, they provide an order of magnitude of several decades to a few centuries to reach an absolute day zero in Chile's capital.**

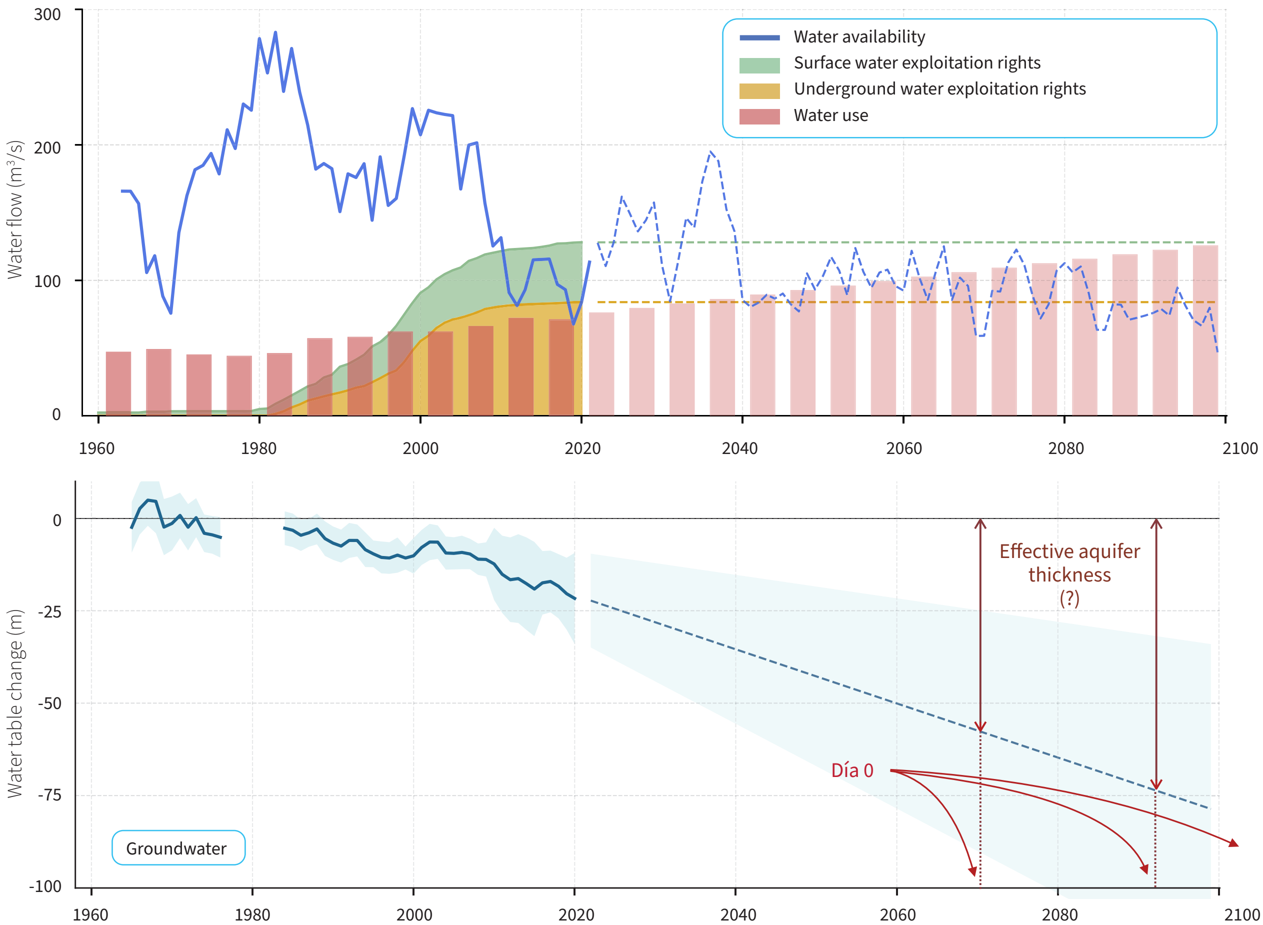


Figure 4.1: Water availability, uses, WUR, and groundwater levels in the Maipo basin. The upper panel shows the water availability, uses, and WUR allocated in the Maipo basin (code BNA 057) for the period 1960-2020 and its projection towards the end of the century. The lower panel shows the median (blue line) and standard deviation (shaded area) of the water table anomalies from 89 observation wells in the basin. The projections of water use and decrease in groundwater levels towards the end of the century are based on historical trends. Projections of water availability are based on simulations with the CanESM5 climate model, following the SSP3-RCP7.0 socioeconomic scenario (see methodological note 4.1).

Impacts of declining aquifers on water security

In contrast to other day zero timescales associated with surface water sources, typically on the order of months, a horizon of several decades to centuries may seem a long time for the arrival of an absolute day zero. However, the partial or total depletion of aquifers represents extreme environmental damage due to the long recharge times of these systems. **This situation also poses intergenerational dilemma: future generations will bear the potentially irreversible impacts of current rates of groundwater use.**

Moreover, the decrease in groundwater levels due to water extractions has impacts on WS long before reaching a day zero.

For example, the need to deepen pumping wells to reach the water table brings socioeconomic costs and exacerbates social inequalities. In rural areas, declining groundwater levels have caused disruptions in water supply for basic needs and small-scale agricultural activities, representing a day zero condition for those communities (Barría et al., 2021; Duran -Llacer et al., 2020; Muñoz et al., 2020).

This decrease can also generate the disconnection of surface and groundwater sources, ecologically affecting rivers, wetlands, and water bodies, as has happened in several basins of central Chile, such as La Ligua, Petorca, and Maipo.

Condition of basins in north-central Chile

As described in Chapter 3, most basins in north-central Chile have increased their water stress levels, with current water uses that meet or exceed water availability. In the period 1980-2000, the basins between the Elqui and Rapel rivers had a moderate level of water stress (Figure 4.2). However, **between 2000 and 2020, most basins reached high or extreme stress**, which is also manifested as a sustained decline in water tables (Figure 4.2, lower panel). The most significant case is the reduction of up to six meters per decade in the Aconcagua river basin.

The Rapel basin is the only one that has maintained a moderate level of water stress, which is due to its greater water availability compared to the basins of the Coquimbo, Valparaíso and Metropolitana regions. The Rapel basin has a consumptive use of 73 m³/s, similar to the Maipo basin, however, it depends less on groundwater sources (47% of the 94 m³/s granted WUR are from groundwater sources, while in the Maipo basin this percentage is 65%).

The levels of water stress and the decline of groundwater in the basins of central Chile reveal a structural imbalance: **permanent uses of water depend on unsustainable extractions of groundwater, as they exceed natural recharge rates.** As mentioned above, this has socioeconomic and environmental impacts long before reaching an absolute day zero. This situation is likely to persist or worsen due to the decrease in aquifer recharge rates, according to the lower precipitation projected in this region (Chapter 1), and the eventual increase in water use in Chile.

It should be noted that the water uses of these basins are lower than the granted WUR Figure 2.4). This suggests that the overuse (total water use that exceeds the long-term water availability of a basin) would be associated with water management that does not consider decreases in availability, as analyzed in Chapter 7.

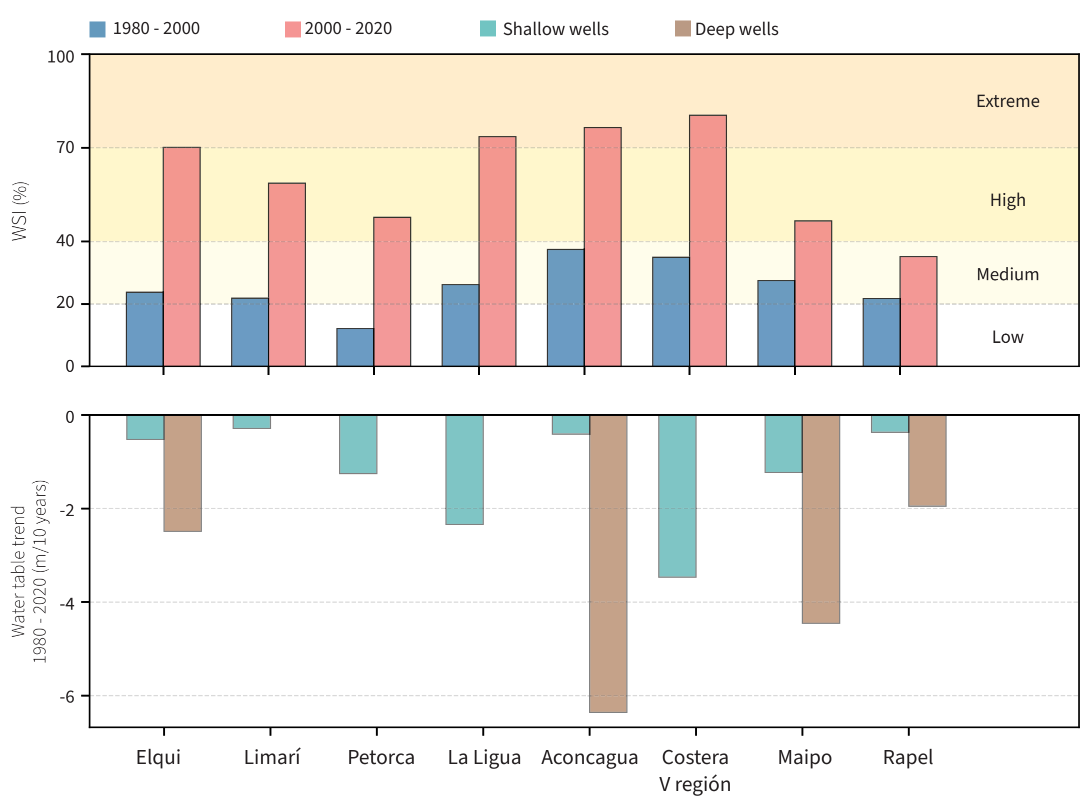


Figure 4.2: Water stress and aquifer decline in basins of central Chile. The top panel shows the WSI in eight BNA basins calculated for the periods 1980-2000 and 2000-2020. The lower panel shows the trend (1980-2020 period) of the phreatic levels of shallow and deep observation wells in each basin (see methodological note 4.1).

Chapter 5: Water security of the rural population

In faced of a prolonged megadrought and water scarcity situations, water use and access at the domestic level for Chile's rural population has become more complex and diversified. Tank trucks have become normalized, turning into a solution that does not address the structural problems of water management.

Gustavo Blanco, Chloé Nicolas-Artero

Chapter 5: Water security of the rural population

Access to water for domestic use in rural areas does not only depend on water availability, but also on the type of supply and its management. In the context of the recognition of the priority of access to water for human consumption in the Water Code and the Framework Law on Climate Change of Chile, it is important to understand the factors that affect WS of the population of these areas, where the greatest difficulties and challenges have arisen in recent years.

Domestic water use requirements of the rural population respond to several needs, including human consumption, sanitation, irrigation of gardens and orchards, animal feeding, and filling swimming pools. In many cases, domestic uses are intertwined with productive uses of a family economy dedicated to various agricultural activities.

It has been increasingly difficult to satisfy the needs of the more than 2.2 million people living in rural territories (CASEN, 2017), residing in communities of different population density, availability of water resources, and infrastructure. **Of this population, only 54% have a drinking water supply provided by a sanitation company through a home connection.** The remaining 46% is supplied through community management, such as rural drinking water committees (APR, by its Spanish acronym) or another type of organization, or through individual household management, extracting water directly from the source and not undergoing a purification process supervised by the State (Figure 5.1). Regarding the type of source, these can be underground, surface, or cistern trucks, among others.

Generally, in rural localities that have a Regulatory Plan, the water service is concessioned to a water company. In the rest of the territories, the operation of the water supply depends on the availability of the resource, as well as the sociotechnical systems[(g)] installed and the management of the supply service, the combination of which we call modes of access.

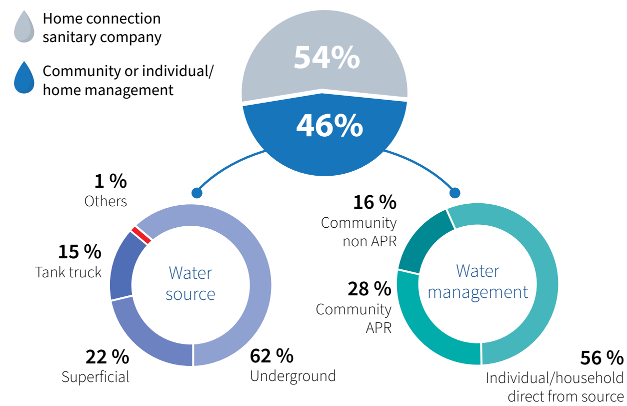


Figure 5.1 Breakdown of sources and forms of water management in the rural population not supplied by a sanitation company(data obtained from CASEN, 2017).

The different access modes existing in rural areas of Chile are summarized in Table 5.1, where three main groups are distinguished that are characterized according to their sociotechnical system: 1. those that rely on a collective distribution network; 2. those who depend on individual household supplies; and 3. those that combine both (Nicolas-Artero et al., 2022).

Table 5.1. Modes of access to water.

Modes of access to water		Characteristics		Example
Socio-technical systems	Management type	Financing origin	Technical support type	
Collective drinking water distribution network	Organization attached to the APR Program	Public APR Program	Directorate of Hydraulic Works and technical units	Rural drinking water committee or cooperative
	"Formal" Organization	Public institutions (other different to MPW or private)	None	Drinking water organization
	"Autonomous" organization	Private actors (real estate companies, inhabitants)	None	In rural condominiums or created by inhabitants
Individual home supply	Private	Private	None	Direct access by well or slopes
Combination of network and individual supply	Combined	Depends on access mode	Depends on access modee acceso	In a situation of scarcity, access to watershed complement the service of an organization

Collective access modes

APR organizations correspond to those attached to the Program of the same name created and financed by the State in 1964. As of 2020, these organizations are renamed as Rural Sanitary Services (SSR, by its Spanish acronym), after the promulgation of the law that regulates them (see Chapter 9). In general, the APR Program financed supply networks in rural areas with high population density, however, the insufficiency to cover the needs of the inhabitants of less populated and more isolated localities is recognized. In fact, as Table 5.1 and Figure 5.1 show, APR organizations represent only one variant of the plurality of existing collective modes of access . There are also formal organizations not affiliated with the APR Program, which in some cases are organized to obtain municipal or private funds, and autonomous organizations, financed and created on the initiative of private individuals (mainly neighbors themselves). This heterogeneity shows that the State has had a variable role in rural areas, thus limiting its capacity to guarantee the WS of the population.

Complementing the WS evaluation described in Chapter 3, and emphasizing access to water in rural areas where the population organizes for its supply, the level of WS of a community organization or individual management in a household can be evaluated according to its capacity to provide water in sufficient quantity and quality to its members.

In the case of community organizations, this evaluation is based on the Composite Indicator of **Composite Indicator of Water Security**[g] (CIWS, see https://www.cr2.cl/seguridadhidrica), which includes aspects of quantity, quality, supply system, organizational capacity, support networks, and institutional framework (Nicolas-Artero and Blanco, 2024). In the context of this report, this indicator was applied to ten collective network organizations located between the regions of Coquimbo and Los Lagos (see methodological note 5.1), showing that WS varies depending on the characteristics of the installed mode of access. in each organization (Figure 5.2). In particular, the lowest levels of WS, ordered from highest to lowest degree of vulnerability, were found in the following cases of collective networks:

- Autonomous organizations located in isolated localities.
- Small APR cooperative organizations operating in urban areas (with Regulatory Plan).
- APR Committee organizations that operate the service in isolated rural locations with loss of organizational dynamism and demographic decrease.
- Large APR Committee organizations, which due to changes in land use were left on the periphery of a metropolis.

The individual mode of access in isolated homes

he population that has an individual mode of access at the household level, which corresponds to 56% of the rural population not supplied by sanitation companies (Figure 5.1), has been particularly affected by the reduction in water availability during the megadrought, since they depend directly on a surface or underground collection point. The lower availability of the last decade, together with greater demands for water within the basin, have generated the disappearance of springs or the decrease in groundwater levels (Figure 4.2). This has forced the population to look for new sources of water by purchasing bottled water, hauling it from other slopes or rivers, new pumping wells, increasing the depth of existing ones, or using cistern trucks.

Combined mode of access: living in an emergency

The search for new water sources also occurs in homes that are supplied by collective networks that provide insufficient service, giving rise to combined mode of access. For example, in the same home, a family can be connected to an APR network, receive water by cistern truck, and consume bottled water. These situations are multiplying in rural areas of the country, which has several negative effects on the population, such as the high cost of water in bottles, whose price per liter is on average 400 times more expensive than that of a sanitation company (Amulén Foundation, 2019). Exposure to the consumption of contaminated water also increases due to multiple transfers between reservoirs or the increase in time spent obtaining water, a task that is mainly carried out by women (Salinas & Becker, 2022).

Figure 5.2. Collective mode of access and their level of water security WS. Adapted from Nicolas-Artero y Blanco, 2022.

The supply of water by tanker trucks emerges as a solution in isolated areas to respond to emergencies caused by extreme events that affect the quality or quantity of available water. However, **this solution has become normalized and generalized in most of the country's rural communes.** On average, a cistern truckr delivers 50 liters per day per person (Undersecretariat of the Interior, 2016), well below the 145 liters that constitute the country's average drinking water consumption (Chapter 2) and corresponds to the minimum volume that the World Health Organization recommends only for human consumption and sanitation (WHO, 2022). Furthermore, between 2014 and 2018, state spending on cistern trucks exceeded 150 billion pesos (Fundación Amulén, 2019).

It should be noted that, with time, the way this type of supply is organized has diversified. Financing not only comes from central state departments, but also from rural municipalities, community organizations, local families, and even private companies dedicated to extractive activities, as part of corporate social responsibility programs. The companies that provide water transportation services in trucks have multiplied, as have water sellers, where the sale of bulk water by health companies stands out. Figure 5.3 shows the diversity of financing for water tank trucks: each column corresponds to two possibilities of financing and distribution circuits depending on who finances (state, company, household) or who receives the water (organizations or isolated homes).

Supply through tank trucks entails problematic aspects, such as the opening of drinking water markets without established regulation. For example, a WUR owner who manages to access his water source despite low availability (using a deep well) can sell the water to community organizations in the same locality that do not have the necessary infrastructure to access the water. resource (Fragkou et al., 2022). This can lead to an increase in the price of water and has associated risks in terms of its quality. Despite these problems and the normalization of a response considered an emergency, there is evidence of social acceptance of the cistern truck, since it provides a concrete response in the daily life of rural families.

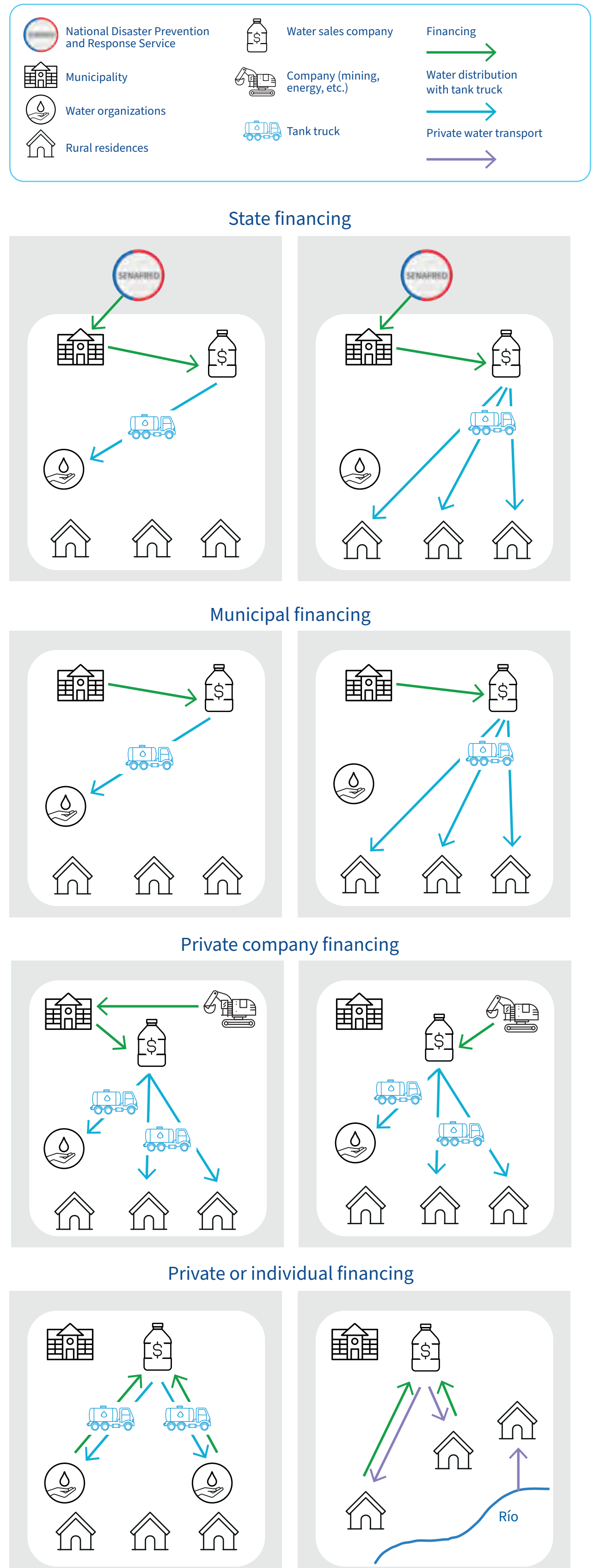


Figure 5.3. The diversity of tank truck financing.

Part 2:
Governance opportunities to achieve water security in Chile

Chapter 6: Water governance and water security

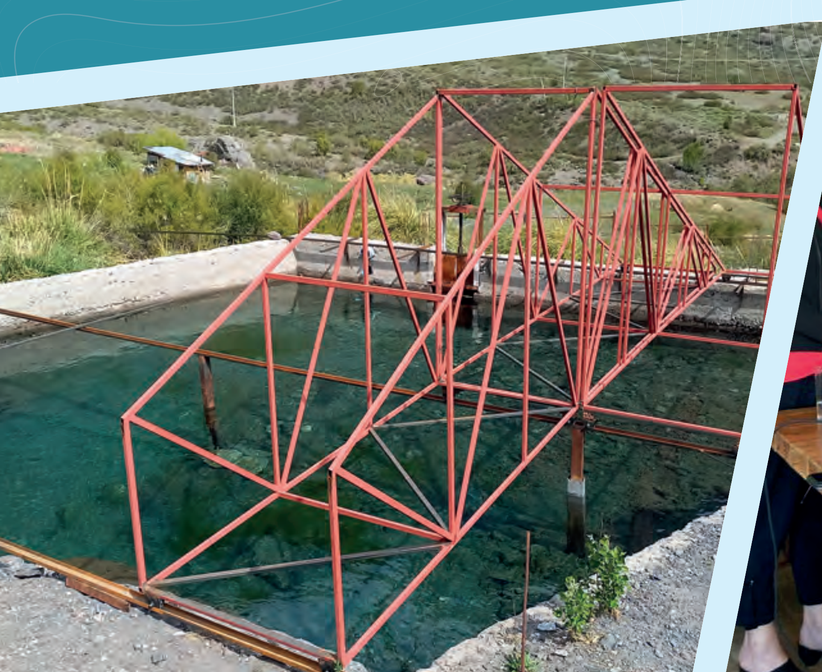
Chapter 7: Water use rights and protection of ecological flows

Chapter 8: Declaration of Water Scarcity Areas

Chapter 9: Law on Rural Sanitary Services

Chapter 10: Transformation as a response in rural communities

Chapter 11: Strategic plans for water resources in basins (PERHC)



Part 2: Governance opportunities to achieve water security in Chile

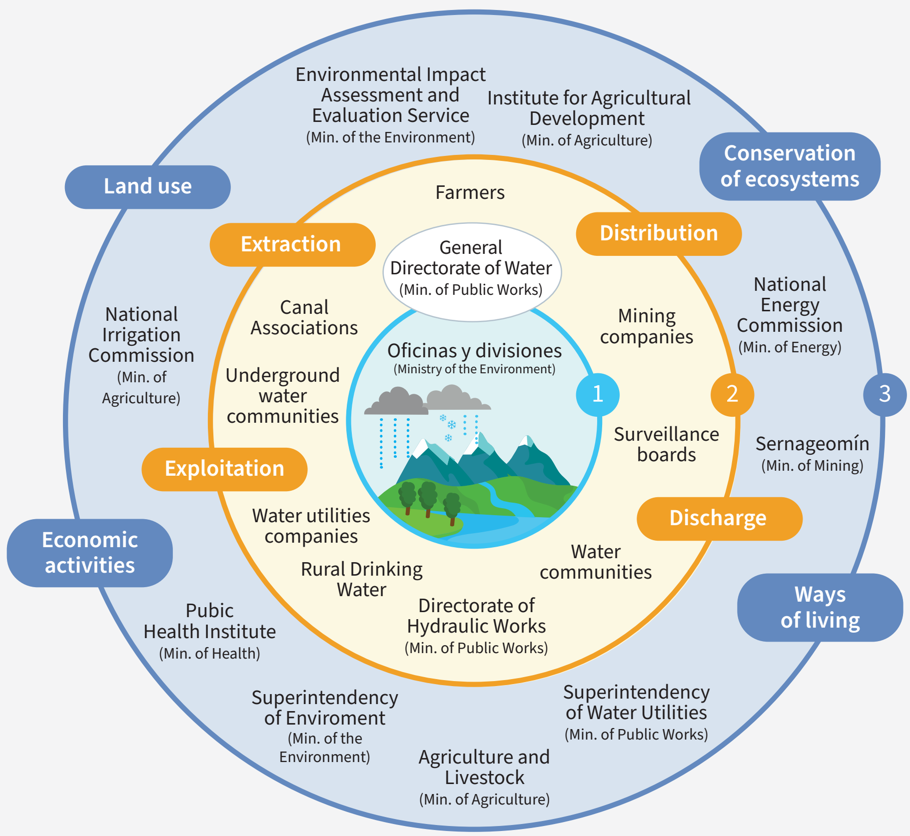


Figure II: Diagram of the different management areas that make up water governance and some of the relevant actors involved.

Achieving WS means taking actions that promote a sustainable and resilient balance between water availability and consumption, as well as sufficient and equitable access for all users, including the conservation of ecosystems. This requires acting in a comprehensive and coordinated manner in different management areas, including:

1. **Water management as an element of nature,** which includes, among other actions, the management, preservation, and care of water flows, and storage associated with the water cycle (Figure II).
2. **Management of water as a resource,** which includes the practices, knowledge, valuations, and ways of relating to water that exists in a territory, from its extraction, treatment (e.g., purification), distribution, and distribution among different users, its consumptive and non-consumptive use, to the treatment of wastewater, as well as the management of rainwater and prevention of risks associated with water.
3. **Water management as a socio-ecological system,** which includes all other territorial activities and processes that influence the demand and use of water, such as the definition of productive activities, land uses and coverage, ways of living, property regimes, flows of people and materials, conservation of ecosystems, etc.

The totality of the actions, public and private, involved in these different levels and how they are coordinated, articulated, and oriented among themselves make up what is known as water governance.

Chapter 6:
Water governance and water security

Water governance in Chile has made progress in terms of water security, however, there are still limitations due to its fragmentation, the reactive nature of some instruments, and gaps in participation, transparency, and use of evidence.

Marco Billi, Antoine Maillet

Chapter 6: Water governance and water security

After evaluating WS levels in Chile and future climatic challenges, in this chapter we examine opportunities and challenges to achieve WS, considering the current governance. It is worth ecognizing that this is not a simple task, considering the expected decrease in water availability in the coming decades, the pressure on water resources concentrated in the central zone of Chile and the vulnerability to water access in rural areas illustrated in previous chapters. To achieve WS, it is necessary to coordinate different types of measures and solutions associated with the management areas outlined in Figure II, which implies coordinating a large number of institutions and actors, the State, the private sector, social organizations, and communities

National and international evidence shows that there is no single governance model suitable for every situation and that it is necessary to have arrangements that fit specific territorial contexts. To provide adequate responses to the challenges of WS and climate change, these governance arrangements must pursue some minimum conditions: fair climate action, anticipatory approach, territorial and socio-ecosystemic approach, and good administration, which are the principles of **Climatic Governance of the Elements**[g].

According to the analyzes developed by the Center for Climate and Resilience Science (CR2 2021, 2022), these conditions, in general, are not currently met in our country - even considering some important reforms, which are mentioned at the end of this chapter -, so it is necessary to overcome the following challenges to advance in this matter at different scales and management sectors: :

- **The Water Code**, which defines the framework and instruments for water resources management in Chile, in its 2022 reform included important considerations regarding WS, however, these remain insufficient to guarantee equity in water access and the sustainability of the resource over time. On the one hand, the Water Code recognizes that surface and groundwater flows within a basin are part of the same hydrological system (Art. 3) and that these flows are national assets for public use whose use must safeguard human consumption and ecosystem preservation (Art. 5). However, some regulations within the Water Code do not allow these principles to be fully complied with. An example of this is the insufficient protection of ecological flows and the separation of management of surface and groundwater sources (Chapter 7). The above can result in communities with drinking water supply problems and prosperous forestry, agricultural, and industrial activities in the same basin. Along these lines, it is highlighted that the WUR allocation system established in the Code does not incorporate changes in water availability, which can generate an over-granting of WURs and can lead to overexploitation of basins and aquifers (Chapter 7).

- **The institutional framework is** fragmented, with a multiplicity of agencies, regulations, and territorial management instruments disjointed from each other (more than 40 public agencies, plus local organizations such as water users organizations[(g)], water communities or canal associations, surveillance boards, etc.), which makes coordination difficult. The little articulation between these entities, between urban and rural territories, between public and private actors, and within the same State between national and local institutions, leads to a management that is not very synergistic, with contradictory measures or the lack of enough resources and actions.

- **Strategic planning** is limited, with a water management framework that focuses on reactive and emergency measures. These measures are not designed for prolonged drought conditions such as the megadrought or the drier climatic conditions projected for central Chile during this century (see Chapters 1 and 3). An example of this is the successive application of water scarcity decrees (Chapter 8) and the persistent and unregulated use of cistern trucks to supply water in areas where the resource is scarce or infrastructure is lacking (Chapter 5).

- **Public participation** of territorial actors, including local and indigenous communities, farmers, and forestry entrepreneurs, among others, is scarce. For example, the right to vote in water management assemblies is conditioned on the owned WUR. This means that those with fewer resources are marginalized, despite their interest and potential contribution to local adaptation mechanisms to face water scarcity (Chapter 10). Likewise, not all the diversity of modes of access to water are currently recognized, which may increase the vulnerability of rural populations (Chapter 9).

The above gaps also allow us to identify opportunities to address the challenges involved in achieving WS. Multiple reforms have been carried out in recent years, such as the reform of the Water Code adopted in 2022 (Law 21,435), the new Climate Change Framework Law (Law 21,455), Law 20,998 on Rural Sanitary Services, the extension and reform of the Irrigation Law (Law 18,450), the new National Territorial Planning Policy (PNOT), Law 21,364 that establishes the National Disaster Prevention and Response System (SINAPRED), among others. Most of these explicitly incorporate principles and guidelines that can help to address the challenges indicated above. However, it is necessary to review and monitor some of their specific regulations and articles so that they are translated into adequate instruments and implementation capacities.

For example, the Climate Change Framework Law introduces new instruments associated with water resources, which include, among others, the Climate Change Adaptation Plan for Water Resources and Strategic Plans for Water Resources in Basins (PERHC, for its acronym in Spanish, Chapter 11). Likewise, various regional or local authorities have begun to develop planning processes to address the chronic deficit of water resources. Additionally, there is a growing empowerment of non-state organizations linked to water, in terms of their management and negotiation capacity. For its part, the private sector has also been showing greater awareness, opening opportunities to improve the governance of the WS.

The following chapters show some of the advances in current legislation or local initiatives, analyzing their opportunities, limits, and challenges.

Chapter 7: Water use rights and protection of ecological flows

Since its modification in 2005, the Water Code establishes that any new right to use surface water must protect an ecological flow. Despite being an improvement, this protection does not meet minimum environmental requirements and allows water uses that can lead to extreme water stress levels.

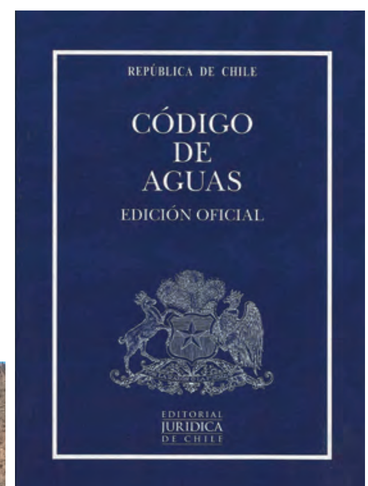
Camila Álvarez Garretón, Juan Pablo Boisier, Marco Billi, Rocío Urrutia Jalabert

Chapter 7: Water use rights and protection of ecological flows

The ecological flow refers to the minimum streamflow necessary to maintain healthy ecological processes and aquatic habitats in a river. In this way, ecological flows contribute to WS by ensuring the health of aquatic ecosystems and their ability to provide clean water and resources over the long term.

In Chile, the role of ecological flows in water management and environmental protection was recognized for the first time in 2005, when a modification to the article 129 bis 1 of the Water Code established minimum flows to be safeguarded when granting new surface WURs. In addition to setting these minimum values, the article also established an upper limit, corresponding to 20% of the mean annual streamflow of the river, except in some exceptional cases defined in current regulations (Water Code, 2022).

The current calculation of ecological flows is defined in the Decree 71 of the Ministry of the Environment (MMA, for its acronym in Spanish), where a monthly ecological flow is defined as the lowest value between 50% of the streamflow with a 95% probability of exceedance (which is exceeded 95% of the time) and 20% of the mean annual streamflow (Decree 71, 2015). This calculation requires streamflow observations with at least 25 years of records at the WUR extraction point or estimates of these if observations are not available. To evaluate the compatibility of this WUR allocation system and WS, we analyze some of the environmental and water stress risks associated with the current allocation system.



Environmental risk

The current regulation defining the minimum ecological flow that should be safeguarded when new surface WUR are allocated does not include a scientific or technical support for the criteria used in its calculation. In particular, the maximum limit of 20% of the mean annual streamflow established in the Water Code is not justified. Imposing this limit implies that the protected flow may not follow the seasonal cycle of a river, as in those cases where the maximum flows are concentrated in a few months (see Figure 1.2, Chapter 1).

By comparing the current regulations with the annual ecological flows obtained through other methodologies available in the literature (obtained from a bibliographic review, Alvarez-Garreton et al., 2023), it is confirmed that **ecological flows protected in Chile are insufficient to meet minimum environmental requirements, causing serious degradation and modification of aquatic ecosystems** (Figure 7.1).

Insufficient protection of ecological flows, especially in the long term, have impacts beyond the freshwater ecosystem. The persistence of riparian vegetation, which helps preserving water quality, depends on the maintenance of this flow. Furthermore, insufficient flows lead to lower contribution of nutrients and sediments to the sea, which negatively impacts coastal biodiversity and has a direct effect on the geography of fjords and estuaries (Masotti et al., 2018).

Risk of water stress and overexploitation

The protection of the ecological flows is directly related to the levels of water scarcity at the basin scale. The flow safeguarded in the current law implies that the Water Stress Index (WSI) can exceed 80%, that is, a high level of this index (see Chapter 3). In effect, if all WURs permitted by law (between 80 and 100% of the average annual flow of the river) were granted and exercised as effective use, all of Chile's basins would be in a category of extreme risk of water stress.

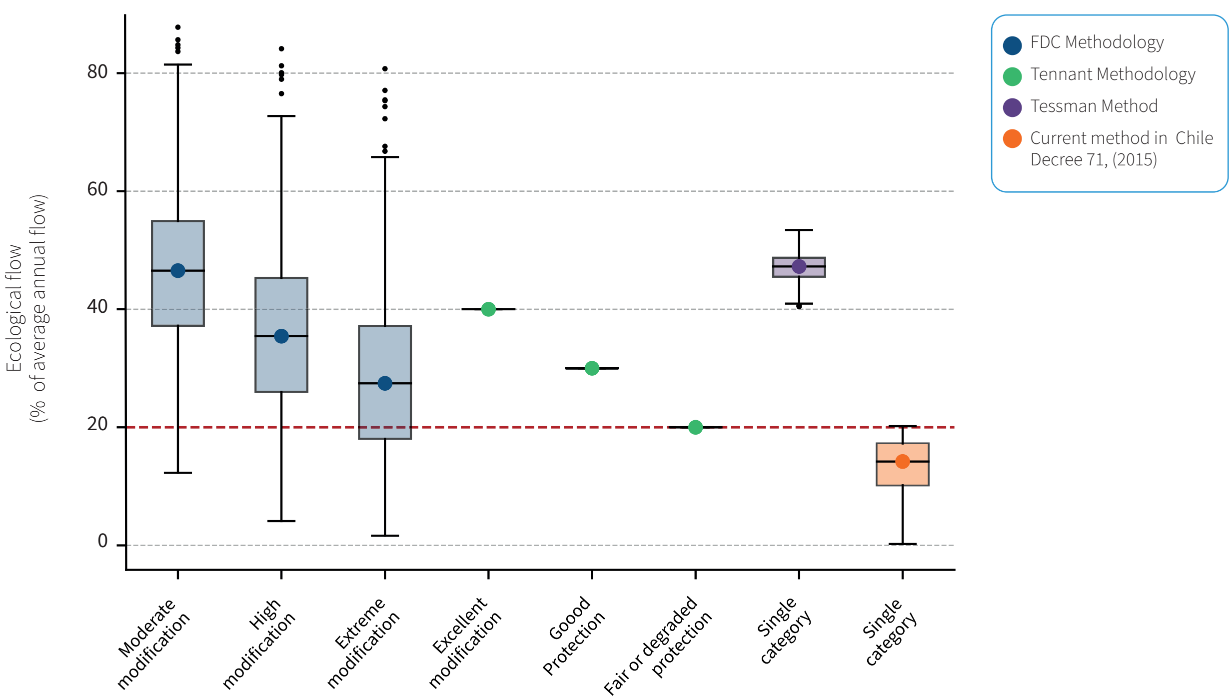


Figure 7.1: Comparison of ecological flows estimations. The figure presents ecological flows for 277 rivers in Chile, computed from applying different methodologies to the observed streamflow of each river, including that established in Decree 71 of the MMA in force in Chile. The FDC and Tennant methodologies establish environmental categories that account for the degrees of modification and protection of ecosystems, respectively. The Tessman method and that of Decree 71 of the MMA establish a single calculation category that does not have an associated environmental characteristic. Adapted from Alvarez-Garreton et al. (2023).

Furthermore, surface WURs are granted as fixed monthly or annual flows. However, interannual variability of streamflow is around 50% of the mean annual streamflow in the basins of central Chile (Figure 1.2). **For this reason, a fixed volume assigned as surface WUR, which can reach 80% or more of the mean annual streamflow, will frequently be above the actual water availability of a basin.** This condition of overallocation is further exacerbated if we consider the decrease in water availability projected for the coming decades in central Chile (Figure 1.4).

The discrepancy between an allocated surface WUR and the actual water available in a river entails uncertainty for water users and makes water management difficult. On the other hand, the current water allocation system separates the allocation of surface and groundwater WUR. Therefore, given that the allocation of groundwater WUR does not consider the situation on the surface, the sum of both can exceed the water availability of a basin, as already observed in the Maipo River basin (Figure 4.1). As discussed in Chapter 4, this can lead to sustained declines in groundwater levels, which entails socioeconomic impacts for users who must deepen their wells to reach deeper water tables.

Finally, it should be noted that revisions and modifications made to the Water Code are not retroactive. This implies that the 370 m3/s granted as surface WUR before 2005, which corresponds to 72% of the total surface WUR granted at present, were not modified to include the protection of ecological flows (Figure 7.2).

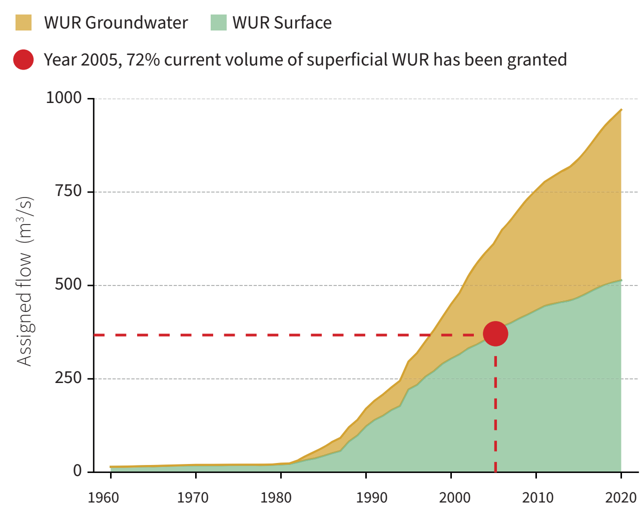


Figure 7.2: Flow granted as consumptive and permanent water use rights (WUR) on a national scale between 1960 and 2020.

Chapter 8:

Declaration of water scarcity areas

The declaration of an area of water scarcity is an instrument that seeks to confront the impacts of severe droughts and guarantee human consumption. However, its successive implementation has (unforeseen) negative effects on water security, including the increase of water stress at the basin scale and the threat of river ecosystems.

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Chapter 8: Declaration of Water Scarcity Areas

To minimize the damage derived from drought, the Water Code establishes the declaration of areas of water scarcity (Art. 314 and 315), an instrument that defines management tools to guarantee human consumption and facilitate access to new water sources. This instrument is activated by a decree signed by the President, at the request and with a prior report from the General Directorate of Water (DGA). This DGA report is based on an analysis of the hydrometeorological conditions of a territory. Once decreed, the instrument is applied to a basin, region, province or commune, for a maximum duration of one year, extendable successively as long as the DGA presents a report for each extension period.

There are three types of procedures that emerge from a water scarcity decree, which focus on: redistribution of water uses, budget allocation, and authorization of new extractions.

While a water scarcity decree is in force, the DGA may require the surveillance boards (organizations responsible for managing and distributing water among their members) to draw up a water redistribution plan among the users of a basin, where uses for human consumption, sanitation or subsistence must prevail. If a surveillance board does not achieve a redistribution agreement within the established period established, or does not comply with the priority for human consumption, the DGA may order the suspension of the board activities and directly carry out the redistribution of the available surface or groundwater.

The water scarcity decrees also allow the central, regional, and provincial governments to use emergency resources to solve critical water access situations, such as financing tank trucks.

During the duration of the decree, the DGA may also authorize extractions of surface or groundwater intended primarily for human consumption, sanitation, or domestic subsistence use, without the need to establish a WUR and without safeguarding the minimum ecological flow established in article 129 bis 1°.

Impacts of water scarcity decrees on water security

The measures described above were conceived as temporary and reactive solutions in the event of an emergency. However, water scarcity decrees have been applied for several consecutive years between the Atacama and Maule regions (Figure 8.1), which may have unforeseen impacts on the WS.

Firstly, the new extractions permitted by the DGA are mainly made from surface or groundwater sources within the same basin, which does not represent an additional source of water in terms of balance at the basin scale. For example, when a user modifies a well to reach deeper water tables or installs new intakes from surface sources near their property, the water extracted is part of the same natural water availability or the groundwater reserves of the basin (see section on additional sources in Chapter 1).

In this way, the successive declaration of water scarcity decrees over the last decade (Figure 8.1) may have promoted the intensification of groundwater use during the megadrought. In the basins of the central-northern area of Chile, access to these reserves has allowed water uses to be maintained despite the reduction in water availability during the megadrought (Chapter 4). From the perspective of satisfying the demand, the above can be seen as an effective mitigation of drought impacts and, therefore, an accomplished objective of the water scarcity decree. However, maintaining these uses has costs (for example, due to the deepening of wells), and increases water stress level at the basin scale (there is an increase in the WSI).

The problem is that **when the low water availability is projected over time, the successive application of an instrument that focuses on maintaining the uses that existed in times of greater availability can generate a structural condition of overuse.** This entails socioeconomic impacts and risks associated with the unsustainable use of groundwater reserves.

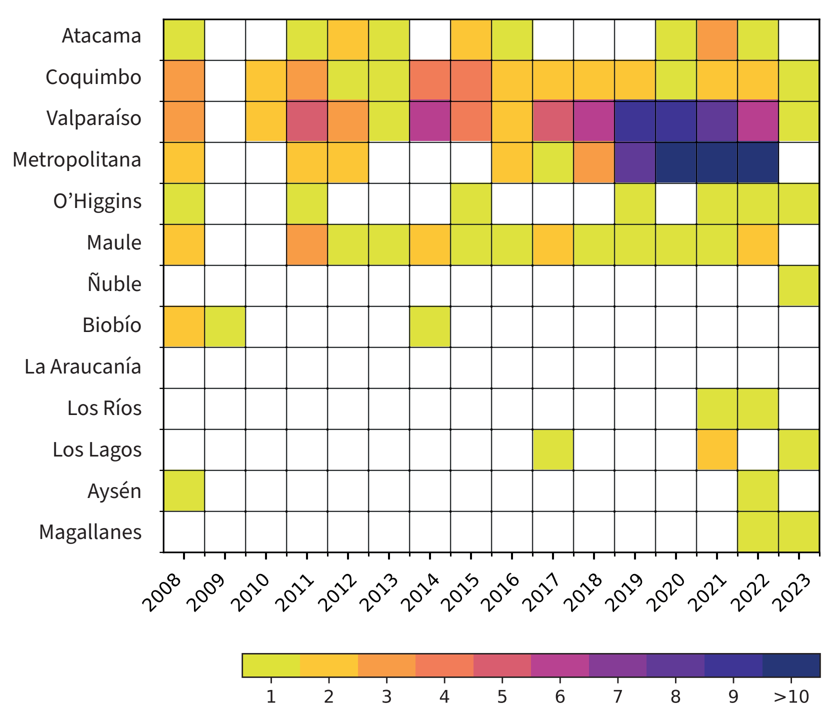


Figure 8.1: Number of water scarcity decrees issued per year and per region since the beginning of records in 2008. The regions of Arica and Parinacota and Antofagasta do not record decrees. Data obtained from https://dga.mop.gob.cl

Furthermore, **the successive application of water scarcity decrees implies that years may pass when all surface water is used without safeguarding an ecological flow.**

This contradicts the importance that the Water Code itself recognizes to this environmental protection in its article 129 bis 1. As seen in Chapter 7, an insufficient protection of ecological flows has serious consequences on ecosystems and WS.

In summary, the water scarcity decree follows a reactive intervention perspective that does not reduce total water uses in periods of drought. Although this can be considered as a viable measure to ensure domestic water use during limited periods, its successive implementation has unforeseen negative effects on WS. In particular, it may increase water stress levels at the basin scale and degrade ecosystems.


Chapter 9:
Law on Rural Sanitary Services

The Law on Rural Sanitary Services, which came into effect in 2020, promises progress in rural water management; however, there are aspects of community management and other modes of access to water that must be considered to facilitate compliance with the new requirements.

Chloé Nicolas-Artero, Gustavo Blanco


Chapter 9: Law on Rural Sanitary Services

As discussed in Chapter 5, **access to water in rural areas that are not supplied by sanitation companies depends both on the management of community organizations and of households with individual supply modes**. These organizations and households face great challenges, among which the insufficiency of the socio-technical system to provide water in proper quantity and quality, the economic sustainability of the organization, and the management challenges stand out.

In response to these challenges, Law 20,998 on Rural Sanitary Services (SSR, by its Spanish acronym) came into force in 2020, which corresponds to the greatest institutional advance in water management in rural areas. This law creates a general regulatory framework for access to water in these areas that until now had only been partially regulated in the APR Program.

The SSR Law allows for an increase in state spending aimed at strengthening all community organizations in charge of water service in rural areas, including those that were not created by the APR Program. In that sense, since October 19, 2021, organizations recognized by the State become, de facto, Rural Sanitary Services, that is, service operators protected by the Law. To this end, the Superintendency of Water and Sanitation Services (SISS, by its Spanish acronym) carried out a registry of the community organizations attached to the Program, the "formal" and the "autonomous" ones throughout the country. In this way, the Law covers all organizations with a collective mode of access (Table 5.1), without including services in private condominiums and individual household supply modes.

The regulation establishes that, after two years of its publication, the SSRs have a period of two years to obtain the license and remain as operators recognized by the State. To have this authorization, they must obtain legal personality, delimit their concession area, and meet various formal requirements, such as, for example, applying the fee set by the SISS.

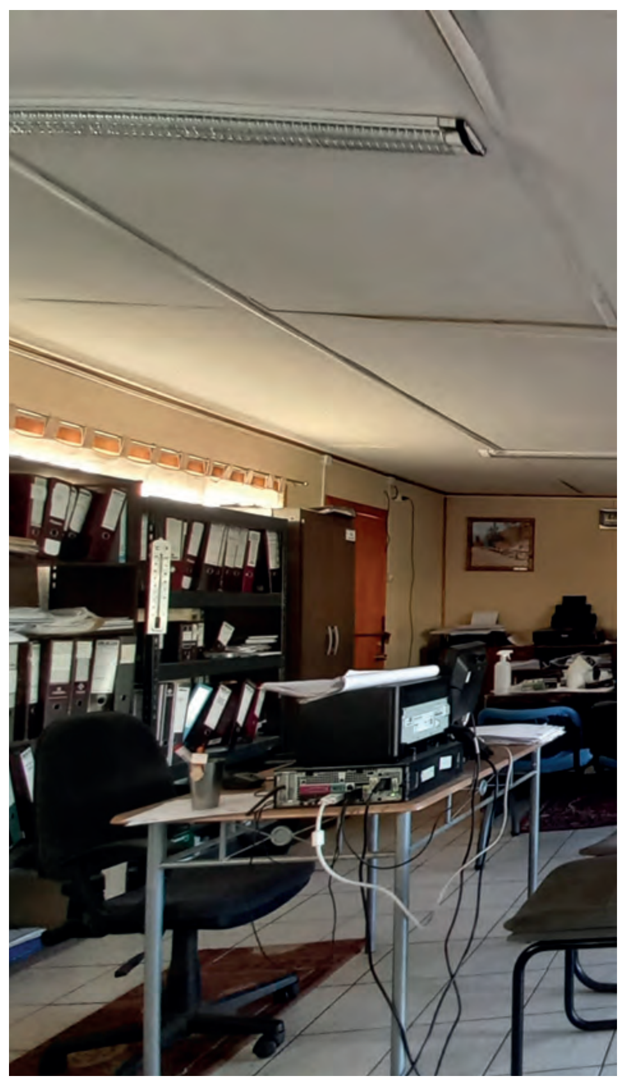
The fact that the State manages to reach all SSRs with financial support represents a great advance in the direction of achieving WS in rural areas, since it strengthens the sociotechnical systems and the management of the organizations. However, this advance would not be transversal to the entire rural population, since the law focuses on modes of collective access, without proposing solutions for isolated homes that manage their access individually. Which represent 56% of the population of rural areas not supplied by sanitary services companies, which is equivalent to about 567 thousand people (Figure 5.1).

A second limitation is related to the supervision of the SSRs, just as it does with urban health companies, to improve the management of the organizations. Although this represents progress in enforcing some minimum criteria to achieve WS in rural areas, local, and union organizations of APR have highlighted some potentially problematic aspects of this mechanism, such as new demands on internal management that, in some cases, may be poorly adapted to the diverse social and technical situations of rural localities.

For example, inspection requires greater use of computer tools and greater connectivity through the Internet and mobile phones, which requires considerable socio-technical progress in some organizations. Many of them do not have a community headquarters or a good network connection in their locality. They are also required to apply fees defined by the SISS, which is perceived as an interference in the organizations, and the population fears a sharp increase in the price that could generate greater late payment and local tensions.

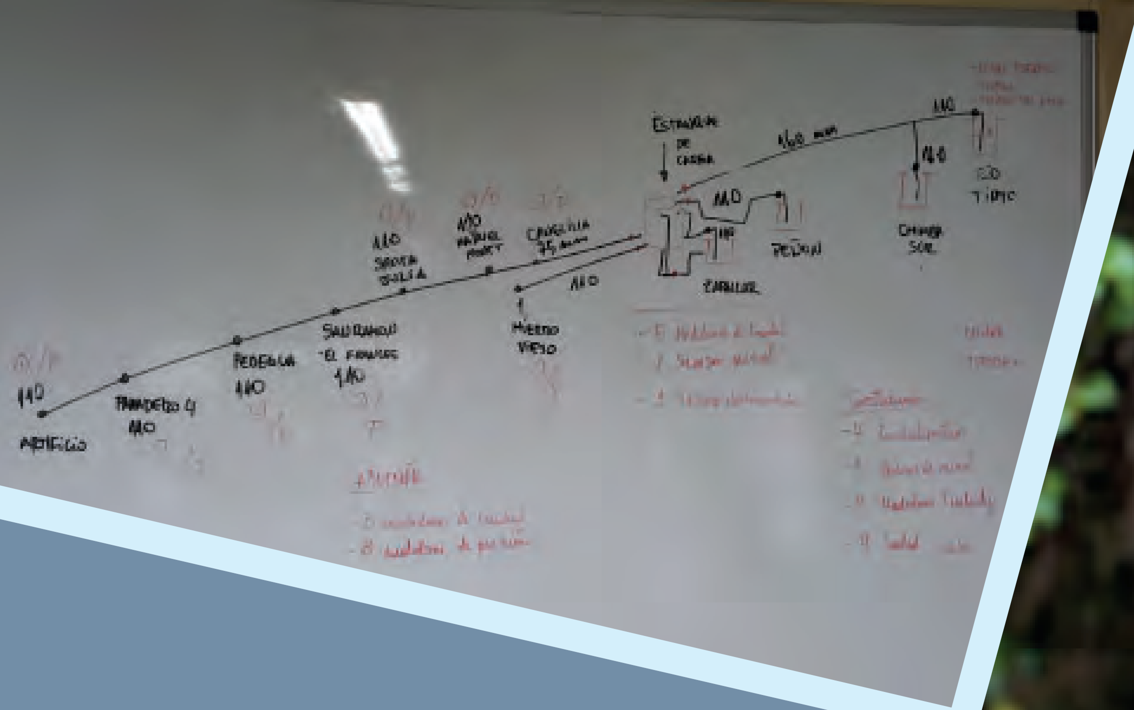
In general, **the marginality of some rural areas, the limited organizational capacities, as well as the perceptions of bureaucratic and technical complexities from rural communities, have not been considered in the application of this law, which can generate specific problems that prevent them from meeting their objectives.**

According to interviews conducted in the public sector, the action plan of the SISS at the national level is to accompany organizations in this transition, and not to apply strict and punitive supervision. However, the current provision of resources would be insufficient for the officials in charge of its application at the regional level so as to work effectively with the organizations and provide them with adequate support based on their needs.



More broadly, the effectiveness of the SSR Law will depend on very diverse factors that are related to water governance in Chile and climatic conditions. For example, the improvement of the water security of the SSR will depend on the available water resources, the flows constituted in favor of the respective organization, the knowledge, and awareness of leadership about water scarcity and climate change, the level of association between committees and the financing they can obtain from the State (Figure 9.1).

Figure 9.1: Synthesis of key elements to ensure efficient implementation of the SSR Law.



Chapter 10:
Transformation as a response in rural communities

While institutions adjust to the challenges posed by water security, rural communities daily develop actions at the local level to ensure human consumption and subsistence.

Paulina Aldunce, Gabriela Guevara, Chloé Nicolás-Artero

Chapter 10: Transformation as a response in rural communities

Moving towards the WS of the rural population not only involves regulatory and institutional aspects, there are also individual and collective responses that emerge and consolidate at the local level. These local actions illustrate the self-management capacity of communities to address water access problems and can serve as examples that can be adapted and applied in other contexts, scales, and territories.

These actions can be adaptive or transformative. Scientific evidence has shown that adaptive actions, which involve incremental changes, are useful when addressing low-severity impacts (Aldunce, 2019). However, these actions may be insufficient if the impacts they face are more severe, complex, or with high levels of uncertainty. In these cases, transformative actions would be necessary, which involve profound changes in the economic, technological, social, and behavioral spheres (Aldunce et al., 2021).

These changes can follow positive trajectories, in which the system adjusts and adapts by acting quickly to avoid deepening vulnerability. But some changes can become negative trajectories when they strengthen dominant interests and conditions, expressing the potential to perpetuate patterns of vulnerability (Few et al., 2017; Aldunce, 2019; Moser et al., 2019).

In this chapter, we present the transformation actions identified in the ten case studies mentioned in Chapter 5. We especially highlight the transformative actions that describe positive trajectories and that have the potential to be adapted and applied in other contexts (see methodological note 10.1).

Of a total of 26 actions identified, 17 were classified as adaptive and nine as transformation actions. The latter imply profound modifications in local organizational systems (see summary in Table 10.1), including innovations in the learning and training of members of the organizations studied; associations with private companies; innovation in the structure of rural organization and its internal management mechanisms; associations with other rural organizations, and monitoring of watershed.

The actions identified in Table 10.1 are characterized by being deliberate and planned rather than reactive, which involves the development and articulation, for example, of new methods of organization, planning, and control. Furthermore, they are supported by strategies that include monitoring and evaluation mechanisms, and are specified in different **transformation domains**[g]. In particular, profound transformations or changes are observed in values (cognitive domain), in institutional arrangements and governance (structural domain), in the relationship between actors (relational domain) or in the behavior of socio-ecological systems (functional domain) (Fazey et al. al., 2018).

The transformative actions were developed in six of the ten organizations studied and respond mainly to difficulties in satisfying water needs in terms of quantity and quality (capture, distribution, and treatment). There is no obvious relationship between the size of the organization and its willingness towards implementation of transformation. In general, the organizations that have carried out these actions have common characteristics, such as the existence of robust management teams with leaders acting as transformative agents.

In several of these cases, a change in values is observed, becoming the main driver of transformative actions. When this occurs, organizations are more likely to formalize the innovations, such as new rules or management agreements.

It is relevant to highlight that although rural communities have the capacity for transformation, it is necessary to strengthen it and provide adequate institutional support, facilitating the eventual scalability of actions. To achieve this, it is essential to identify common characteristics of organizations that have promoted these transformations, and strengthen collaboration between different actors involved in water management. The latter promotes the generation of alliances and the dissemination and exchange of information and experiences between different communities and scales through platforms and networks.

To achieve transformation success on a larger scale, the need for a paradigm shift that addresses existing weaknesses in terms of governance must be recognized. In this sense, the innovation represented by the Strategic Plans for Water Resources in Basins (Chapter 11) can be an opportunity, as long as community water management organizations (SSR) have a degree of representation or participation that allows them to raise their concerns and transformative responses.

Table 10.1: Transformation actions identified. In the study, only six community organizations developed this type of actions. For more details see https://www.cr2.cl/datos-acciones-transformacion

Name or title of the action / type of organization and commune	Action description
Hydroculture Program (APR in the commne of Colina)	Educational campaign to care for water (cognitive domain) through unconventional daily practices and easily accessible technology aimed at contributing to the conservation, reuse, and better use of water (functional domain).
Changes in internal economic management (APR in the commune of Colina)	Significant change in the relationships between members of the APR (relational domain), through the incorporation of new forms of communication and improvement of fees collection.
Improvement of water administration (APR in the commune of San José de Maipo)	Improvement in the administration and quality of the water that comes from the springs, through the construction of a swimming pool and investment in security and water use control systems (structural domain).
Recognition as a Nature Sanctuary to the micro-basin that supplies the APR committee (APR in the commune of Paihuano)	The Agricultural Community, after allying with the University of La Serena, managed to get the State to declare its lands as a Nature Sanctuary with the objective of preserving the source area of the waters that supply the population (functional domain). In addition, the leaders of the agricultural community train and raise awareness among community members and inhabitants regarding the care of the mountain environment (cognitive domain).
Creation of a Rural Drinking Water Union Association (multi-committee supply system) (APR in the commune of Petorca)	The APR leaders, faced with the recognition of a problem of water access and management, grouped together in a trade association that allows them to advance in matters of management and community work (relational domain).
Voluntary Watershed Management Agreement (AVGC, by its Spanish acronym) (APR in the commune of Ránquil)	Program of the Production Development Corporation (Corfo) focused on clean production and sustainable development in basins with productive activities, through successive agreements and commitments (cognitive domain). Among the participants in this agreement there are different public and private institutions (relational domain).
SIMOL River Basin Monitoring Project (APR in the commune of Ránquil)	Tool that aims to strengthen the participation of local communities in the governance of water in their territories (relational domain). This local watershed monitoring and awareness system arises after the experience acquired in the Voluntary Watershed Management Agreement (cognitive domain).
Protection of the quality of the waters of the Itata River (APR in the commune of Ránquil)	The APR leadership, due to the location and damage caused by a drainage pipeline contaminating the Itata River, undertakes an unprecedented negotiation process with the responsible company (relational domain).
Association for ecological restoration and conservation: planting of native species (APR commune of Corral)	The inhabitants of a micro-basin receive support from an international NGO that owns a private reserve (relational domain) to preserve the watershed through a gradual process of native reforestation. The purpose is to achieve sustainable management of the basin that provides drinking water (cognitive domain). A key activity is establishing a fund to secure funding for conservation in the area.


Chapter 11:
Strategic Plans for Water Resources in Basins (SPWRB)

The political and legislative agenda recognizes that achieving water security requires an integrated and climate resilient approach, and incorporates SPWRBs as an instrument to achieve this. This goal presents challenges that require paying attention to the available scientific evidence, both in terms of water security and governance.

Marco Billi


Chapter 11: Strategic Plans for Water Resources in Basins

To move towards integrated management that allows achieving WS, with long-term views and focused on adaptation to climate change, the latest modification to the Water Code (2022) and the Climate Change Framework Law act in a coordinated manner in incorporating a new management instrument called Strategic Plans for Water Resources in Basins (PERHC for it acronym in spanish).

The PERHC replace the previous Strategic Water Management Plans for the Basin, a management instrument that was used by the DGA to know and manage the availability and demand of surface and groundwater, and its projections towards the future. On the other hand, the PERHC are established as an intersectoral management instrument that will be in charge of the Ministry of Public Works, in conjunction with the ministries of the Environment, Agriculture, Science, Foreign Affairs, and territorial organizations, such as the Regional Committees. of Climate Change. Being explicitly covered by the laws that establish them, PERHC enjoy a higher and more solid legal status concerning SWMPBs.

Despite the above, the current law does not establish decentralized support to the application of the SPWRB apart from the aforementioned ministries. This implies that its development and implementation could fluctuate depending on changes in Government, which can make its functioning in the long term difficult. Taking this into account , the Executive Power has committed to generating Basin Councils as an institutional basis to coordinate and promote collaboration between interested parties and carry out the PERHC. However, in the absence of a law that protects them, the Basin Councils have advanced slowly and with an ambivalent reception from local actors, leaving their implementation uncertain .

PERHC Opportunities

The implementation of the PERHC considers three main stages: a characterization of the basin, a prioritization of actions and a management plan. With this, we seek to move towards a more comprehensive and sustainable water management, generating an instrument with the force of law that places hydrographic basins as the base unit of administration. **This allows evaluating the balances between the availability and uses of water, and designing strategies that make uses compatible with WS goals.**

Along with this, the PERHC deepens citizen participation, which means a better resolution of socio-environmental conflicts within a basin. They also advocate for nature-based solutions, such as the recovery of aquifers for the development of ecosystems and to increase water storage in the basin. Furthermore, they are not limited to the strengthening of Water User Organizations for the regulation of the resource, but rather they generate bases for improving its governance, including different actors around the same socio-ecological system.

Based on the current objectives and development phase in which the PERHC are found, it is concluded that **the management system they propose has the potential to bring the current water management model closer to sustainable use, by maintaining the socio-ecological balance and allowing to achieve WS goals.** However, to be effective, they must have robust and up-to-date information, and adequate governance and attributions.

Regarding the first, the scientific evidence made available in this report can be useful: for example, estimates of water availability and uses (Chapters 1 and 2) can be used for the basin characterization stage. Meanwhile, the Water Stress Indicator (WSI) discussed in Chapters 3 and 4 can provide them with an aggregate metric that allows establishing WS goals at the basin scale, or tolerable levels of water stress risks, and thus inform actions to reach those levels. Likewise, the evidence provided regarding the multiple modes of access to water and the challenges that the rural community faces in achieving WS (Chapters 5 and 9), the limits in current ways of addressing scarcity (Chapter 8), and evidence regarding local transformative actions to address water scarcity problems (Chapter 10) can serve as input for the management plan stage.

In terms of governance, the effectiveness of the PERHC will depend on the ability to advance in a coordinated manner with the ongoing reforms in other regulatory and management instruments, to move transversally towards WS governance by the challenges associated with the current scarcity regime and future climate change trends (Chapter 6).

Conclusions

Recommendations

Conclusions

This report provides a scientific-based synthesis that allows to characterize and address water security challenges in Chile. The following conclusions emerge from this evaluation:

- Most basins between the Coquimbo and Maule regions have experienced high to extreme levels of water stress during the 2010-2020 decade. This situation is directly linked to the megadrought and the lower water availability during this period, but it has been substantially worsened by the high levels of water use in these regions.

- From a longer-term historical perspective, the trends over the last six decades indicate a significant increase in water stress levels in central Chile. This increase has been mainly associated with the increase in water consumption and, to a lesser extent, with the decrease in surface water availability. During this period, consumptive water uses have doubled, driven mainly by the development of the agricultural and forestry industries.

- Rainfed agriculture (without irrigation) and forest plantations use the water contained in the soil that comes directly from precipitation, so they do not require water use rights for their operation. This poses a problem for water resource management, as it complicates the registry and quantification of the actual water use of two of the main water-consuming sectors in the country.

- The megadrought, caused in part by natural climate variability, overlaps with – and accentuates – a trend observed for several decades towards a drier climate in central Chile, which we associate with a sign of climate change.

- In an adverse climate change scenario, towards the end of the 21st century, conditions similar to those of the megadrought are projected, but permanently, with precipitation decreases close to 30% and a lower snow storage capacity in the Andes. This scenario represents a significant decrease in surface water availability, particularly during the summer, when vegetation has a greater water demand. This represents a risk for the agricultural industry and food security.

- In an adverse scenario of lower water availability and greater water use, most basins in central and northern Chile will probably experience permanent levels of high and extreme water stress by the mid 21st century.

- The current rates of groundwater extraction in central Chile are greater than the recharge capacity of the aquifers, causing a sustained decline in these reserves. This deepens socioeconomic and environmental impacts, and may lead towards an absolute depletion of water resources (day zero). The moment in which a day zero may arrive is uncertain, in the range of decades to a few centuries, and it represents an intergenerational dilemma .

- Water supply for almost half of the rural population depends on community or individual management at the household level. Their vulnerability to water scarcity varies depending on state support for the different existing supply modes.

- Cistern trucks represent an emergency response for the supply of drinking water in rural areas and does not provide a long-term solution to guarantee water security.

Conclusions

Based on the identification of governance challenges and opportunities to promote public policies and actions that allow advancing towards sustainable management of water resources, the following is concluded:

- There are provisions of the Water Code that conflict with water security goals, in particular:
  - The protection of ecological flows does not comply with minimum environmental requirements. Indeed, if all surface water use rights (WUR) allowed by law were granted and exercised, all basins in Chile would have a water stress index greater than 80%, which represents an extreme level of water stress.
  - The allocation of groundwater WUR does not consider the protection of ecological flows nor the pre-existing surface WUR allocated in the basin.
  - Surface and groundwater WURs are allocated as absolute and fixed volumes, without considering climate-driven changes in water availability.
  - The declaration of water scarcity areas exempts the protection of ecological flows and encourages the maintenance of the water uses that existed in times of greater availability, so its successive application promotes structural conditions of overuse and degradation of ecosystems.
- The effectiveness of the Law on Rural Sanitary Services depends on the actions to support and strengthen rural organizations that manage water and their level of preparation, as well as the possibility of evaluating the extension of its benefits to users who cannot access it.
- Rural communities have developed transformation actions to ensure human consumption and subsistence, which can serve as a guide to strengthen resilience in rural areas.
- The Strategic Plans for Water Resources in Basins (PERHC) represent an opportunity to achieve water security and the evidence presented in this report can serve as input to achieve it.

Finally, we highlight that the outputs generated within the framework of this research are free access and are available on the water security platform of the Center for Climate and Resilience Research https://seguridadhidrica.cr2.cl


Recommendations

Recommendations

1

Establish water security (WS) goals and define the water uses that are compatible with these goals:

1.1 Establish WS goals in public policy, first, specifying through an objective indicator a maximum level of tolerable water stress in the basins of Chile, and considering the impacts of exceeding that level on society and ecosystems. The objective of limiting water stress, together with goals focused on other aspects of WS (access, quality, prioritization of uses, etc.), should transversally guide the different public policy instruments, as well as political and sectoral programs.

1.2 Determine the limit of total water use within a basin compatible with the level of water stress established in the WS goal, and design management measures following the precautionary principle that allow limiting the use of water according to this limit. It should be noted that, in addition to the regulation of uses, maintaining water stress at low levels can also be achieved through the inclusion of alternative water sources that allow increasing water availability, which must be evaluated and prioritized based on their socioeconomic and ecosystemic impacts.

1.3 Define mechanisms of evaluation, reporting and verification that allow monitoring compliance and impact of these measures, in a transparent manner and based on scientific evidence.

Addressed to:

Ministry of Public Works

Ministry of the Environment

Adaptation Plan to Climate Change for Water Resources

2

Establish the Water Stress Index (WSI) of basins in the Strategic Plans for Water Resources in Basins (PERHC) :

2.1 The PERHCs should have indices to monitor the level of water stress in Chile's basins, such as the WSI used in this report, which considers the availability and uses projected for the country in the context of climate change.

Addressed to:

Ministry of Public Works

Ministry of the Environment

Recommendations

3

Modifications to the Water Code and associated regulations :

3.1 Modify article 129 bis 1 of the Water Code that defines the ecological flow, eliminating the upper limit of 20% of the average annual flow and highlighting its role in meeting the WS goals established in 1.1.

3.2 Modify Decree 71 of the MMA (2015) which defines the criteria for calculating the ecological flow, adopting a formulation that considers the minimum levels of ecosystem protection (Figure 7.1) and the natural seasonal variation of rivers

3.3 Integrate the allocation of water use rights (WUR) from surface and groundwater sources, in such a way that the total flow granted as WUR within a basin does not exceed the uses compatible with the WS defined in section 1.2.

3.4 Define the water volume allocated as WUR based on the water availability of the basin and not as a fixed value. In parallel, design plans for water users to adapt to variable flows, considering climate change scenarios.

For measures 3.1 to 3.4 to be effective, it must be ensured – through a modification of the domain title – that the modifications to the Water Code are retroactive concerning the WUR already granted.

3.5 Modify Articles 314 and 315 of the Water Code, establishing that, before successively applying a water scarcity decree within an administrative unit or basin, an evaluation must be provided and approved. Such evaluation should focus on the effectiveness that the application of the previous decree had in ensuring human water consumption and sanitation, as well as its impacts on water stress levels at the basin scale. In addition, the redistribution agreement required of the surveillance boards should consider WS goals and ecosystem protection, eliminating the current provision that exempts the protection of ecological flows during the validity of the decree.

For measure 3.5 to be effective, the DGA's oversight capacity must be strengthened to ensure that redistribution plans of the surveillance boards are met.

Addressed to:

Ministry of Public Works (legal initiative)
Ministry of the Environment

National Congress (parliamentary motion)

Water Code (Decree 71 that defines the calculation of the ecological flow)

Allocation provisions (articles 314 and 315)

Recommendations

4

Modifications to the Law on Rural Sanitary Services:

4.1 Include the characteristics of the different modes of access to water in the Rural Water and Sanitation Services (SSR) law, to generate specific supports and regulations that guarantee fair access to this resource. In particular, those who manage their access to water individually must be included, which corresponds to the 56% of the rural population that does not have supplies from water companies.

Addressed to:

Ministry of Public Works (legal initiative)

National Congress (parliamentary motion)

5

Management of Rural Sanitary Services:

5.1 Define an integrated water security index that serves to holistically evaluate the effectiveness of SSRs and report improvements.

5.2 Recognize that supply through cistern trucks is no longer an emergency solution in certain territories and that, therefore, it is necessary to advance in permanent financing mechanisms and specific regulations for the growing water market.

5.3 Consider socio technical realities, local knowledge and capabilities within the institutional support measures established to strengthen organizations.

5.4 Incorporate the adaptation-transformation approach in the rural water management processes of community organizations, with a perspective on the basin.

Addressed to:

Ministry of Public Works

Ministry of the Environment

Adaptation Plan to Climate Change for Water Resources

Recommendations

6

Cross-cutting governance recommendations for Water Security:

6.1 Strengthen alliances and information flows between the different Ministries, State services and scientific institutions to account for the best information available in terms of data and technologies, and to promote the strategic development of new monitoring and information networks.

6.2 Develop and make available integrated platforms that encourage access and consultation of this information by the different actors in a basin, seeking to have the highest possible spatial and temporal resolution, and a visualization format suitable for different groups of users (decision makers, technicians, general public etc.)

6.3 Establish an institutional framework that ensures the implementation, updating and monitoring of the PERHC and that promotes the integrated management of basins, which must be designed considering WS goals and the needs of each territory and in conjunction with local communities.

6.4 Promote public-private collaboration to encourage territorial innovation in service of the WS, taking advantage of and eventually adapting existing instruments from Corfo, INDAP, CNR and others, ensuring better alignment and coordination between these instruments.

6.5 Promote training, education and awareness-raising events on the importance of having integrated and climate-resilient water governance, and having the instruments, information and tools to do so.

Addressed to:

Ministry of Public Works

Ministry of the Environment

Glossary

Methodological notes

References

Glossary

Climate change: Climate change attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that adds to the natural climate variability observed over comparable periods (Law 21.455).

Water use rights (WUR): The law defines it as a real right that rests on water and consists of the temporary use and enjoyment of it, under the rules, requirements and limitations that the Water Code prescribes. They will be temporary and will be granted through a concession. Its duration will be 30 years, but it will depend on both the availability of the supply source and the sustainability of the aquifer. It will be extended by the sole operation of the law and successively, unless the General Directorate of Water (DGA) certifies, through a well-founded resolution, the non-effective use of the resource or that there is an impact on the sustainability of the source that has not been could be overcome.

Transformation domains: The transformation can manifest itself in different domains, which are interconnected and are not mutually exclusive (Aldunce et al., 2021):

- Cognitive domain: It is related to profound changes in beliefs, norms, values and understanding of society. These changes can influence people's perception of the world and their conception of progress.
- Structural domain: It involves significant transformations in institutions and governance processes to promote sustainability. This may encompass substantial modifications in public policies and the implementation of new feedback mechanisms.
- Relational domain: Noticeable changes in the relationships between various actors and institutions. This can manifest itself in the transition from isolated decision-making processes towards integrated approaches, collaboration between diverse actors to strengthen the links between science, public policy and practice, as well as in the emergence of new responsibilities between actors in the public sphere, private and civil society.
- Functional domain: It involves significant changes in the behavior and function of specific systems. An example would be the dissemination of innovative sustainability practices or technological transformations that alter the way we carry out communication, production and consumption activities.

Water scarcity: It corresponds to the situation where the available water is less than that demanded for social and environmental uses, such as human and animal consumption, ecosystem maintenance, agriculture, mining, industry and others.

Potential evaporation: It is the maximum amount of water that can evaporate from an Earth's surface under specific climatic conditions, without limitations of soil moisture or other factors. It represents the potential loss of water due to evaporation and is an important indicator for assessing water availability in a region and for water management planning.

Anthropogenic climate forcing: Factors generated by human activities that drive the climate towards a new state. Anthropogenic forcing includes actions such as burning fossil fuels, clearing forests, or emitting greenhouse gasses such as carbon dioxide, methane, and nitrous oxide. These gasses are released into the atmosphere due to industrial, agricultural and deforestation activities. Unlike natural forcings, such as volcanic activity or variations in received solar energy, anthropogenic forcings are the main cause of climate change since the industrial revolution and are altering the Earth's climate at an unprecedented speed.

Greenhouse gasses (GHG): Gaseous components of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the Earth's radiation spectrum (emitted by the Earth's surface, the atmosphere itself, and by clouds). This property causes the greenhouse effect. Water vapor, carbon dioxide, nitrous oxide, methane and ozone are the main GHGs in the Earth's atmosphere. GHG emissions and increases due to human activities represent the main anthropogenic driver of climate change. In addition, there are GHGs entirely generated by human activity in the atmosphere, such as halocarbons and other substances containing chlorine and bromine, regulated in the Montreal Protocol (based on IPCC, 2018).

Climate governance of elements: This comprehensive management approach aims to address the challenges of climate change by considering the interaction between the various elements of nature and their relationship with the climate. It recognizes the importance of adapting governance to the particularities of each territory and establishes four fundamental principles as a guide:

- Just climate action: It involves carrying out both incremental and transformative actions to mitigate and adapt to climate change. This includes moving towards a more equitable distribution of costs and benefits, protecting the most vulnerable groups and conserving ecosystems. It also focuses on protecting the interests of future generations through inclusive and supportive decision-making processes.

- Anticipatory approach: This principle promotes the transition towards carbon-neutral and climate-resilient development, with short, medium and long-term time horizons. It is based on a preventive and precautionary perspective, acting with prudence even in situations of scientific uncertainty.

- Territorial and socio-ecosystemic approach: Promotes mitigation, adaptation and training measures that are relevant to each territory, considering its unique socio-ecological context. Coordination between different scales and sectors is emphasized.

- Good administration: This principle advocates a rational, objective, coordinated and effective administration. Prioritizes demonstrably effective and efficient evidence-based strategies. In addition, it encourages broad, timely and continuous participation of the community, indigenous peoples and other interested actors. Transparency and accountability are key elements of this approach.

Composite water security indicator: Indicator that integrates information from hydro-social processes to identify levels of water security in the domestic-community interface. This interface is defined as the space of social and technical relations that allow the supply of water from a community organization in charge of the water distribution service to the home connection within homes.

Megadrought: In the case of central Chile, the megadrought corresponds to prolonged periods of low precipitation (over five years) and large geographical extension. The current megadrought began in 2010 and has continued for more than a decade (Garreaud et al., 2017).

Global climate models: Numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and which includes all or some of its known properties. Climate models are used as a research tool to study and simulate climate, and for operational purposes (based on IPCC, 2018).

El Niño – Southern Oscillation (ENSO): It refers to an oceanic and atmospheric phenomenon, characterized by a warming of the tropical Pacific Ocean east of the date line, and associated with a fluctuation of a global-scale surface pressure pattern called the Southern Oscillation. This phenomenon has a time scale of between two and seven years. During a warm ENSO (El Niño) event, the trade winds weaken, reducing deep water rise and altering ocean currents so that sea surface temperatures warm, further weakening the trade winds. with climate effects throughout the Pacific region and in many other parts of the world, through global teleconnections. The cold phase of ENSO is called La Niña (based on IPCC, 2018).

Water table: Depth at which groundwater is found in an aquifer. Corresponds to the level reached by groundwater in observation wells.

Water user organizations (WUO): Private entities regulated by the Water Code that are responsible for the collection, conduction and distribution of water to which their owners are entitled. In natural channels they are organized into Surveillance Boards and in artificial channels (canals, reservoirs) they are organized into Associations of Water Managers or Water Communities. They do not pursue profit goals, they obtain legal personality through their registration with the General Directorate of Water, and they fulfill a fundamental function in the management of water resources.

Stratospheric ozone: Ozone layer in Earth's stratosphere that absorbs most of the sun's ultraviolet radiation, playing a crucial role in protecting life on Earth.

Observation wells: Underground boreholes or excavations designed to monitor the groundwater table, water quality, and other related parameters. Observation wells are important tools in water resource management, providing key data to understand aquifer dynamics and make informed decisions about their use and conservation.

Precautionary principle: Where there is a danger of serious or irreversible damage, the lack of absolute scientific certainty should not be used as a reason to postpone the adoption of cost-effective measures to prevent environmental degradation (Rio Declaration 92).

Food security: When all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their daily energy needs and food preferences for an active and healthy life.

Sociotechnical systems: It is a composite concept that allows us to recognize the inseparability of social and technical components in the functioning of certain systems. In the context of water supply, it refers to systems that not only focus on the infrastructure and technology to supply water, but also consider social, cultural, economic, legal and community participation aspects in an integrated manner. These systems recognize the importance of collaboration between communities and authorities to ensure sustainable and equitable access to drinking water.

Transformation: Change in the fundamental attributes of natural and human systems that imply profound, and often irreversible, innovation in different areas, such as, for example, economic, technological or social.

Methodological notes

Chapter 1

1.1 Estimation of historical water availability: Total precipitation is obtained from the CR2MET, available at https://doi.org/10.5281/zenodo.7529682 (Boisier, 2023). Natural evapotranspiration is estimated using a simplified evapotranspiration model (see methodological note 2.1), forced with CR2MET precipitation and potential evaporation data, with irrigation deactivated and CR-2LUC land cover data from the year 1950.

1.2 Regionalized global climate simulations: Precipitation and temperature data simulated with global climate models were corrected to correctly represent Chile's climate using a revised quantile mapping method (Cannon et al., 2015). The correction was made based on the CR2MET output, with a modification of the method that prevents inconsistencies between precipitation and temperature in snow conditions (Boisier et al., 2022). For this report, 16 climate models and two future socioeconomic scenarios included in the sixth phase of the Coupled Climate Model Intercomparison Project (CMIP6, Eyring et al., 2016) were evaluated. The scenarios considered include one with high and one with low mitigation of GHG emissions (SSP1-RCP2.6 and SSP3-RCP7.0, see O'Neill et al., 2016). Models included are: ACCESS-CM2, ACCESS-ESM1-5, BCC-CSM2-MR, CanESM5, CMCC-ESM2, CNRM-CM6-1, CNRM-ESM2-1, EC-Earth3, FGOALS-g3, GFDL -ESM4, IPSL-CM6A-LR, MIROC6, MPI-ESM1-2-HR, MRI-ESM2-0, NorESM2-MM and UKESM1-0-LL.

1.3 Hydrological simulations: The hydrological simulations are obtained from the Mesoscale Hydrological Model (mHM; Samaniego et al., 2010) with a daily temporal and spatial resolution of 3 km. The model was calibrated for the period 1980-2019 in 90 basins with a low level of intervention selected from the CAMELS-CL database (Alvarez-Garreton et al., 2018), using atmospheric variables from the CR2MET output (Boisier, 2023). and soil properties from the CLSoilMaps product (Denmark et al., 2023; Galleguillos et al., 2022). The calibrated parameters were transferred to 20 BNA basins with varying levels of anthropogenic intervention, to obtain simulations of natural availability. Future mHM projections use precipitation and temperature from the regionalized global climate models described in methodological note 1.2.

Chapter 2

2.1 Estimation of water uses in the LULUCF sector: The estimation of water consumption in agriculture and other LULUCF sectors uses a simplified evapotranspiration (ET) model and different historical land use and cover scenarios, based on the CR2LUC output. This output provides an annual reconstruction (1950-2020) of land cover for continental Chile, with a resolution of 1 km. This reconstruction includes the relative presence of different classes, which represent agricultural types, natural areas, forest plantations, urbanized areas, bodies of water and reservoirs. The methodology used is based on sources that include satellite indicators and national statistics, highlighting the valuable contribution of agricultural censuses that cover almost a century of information. For its part, the ET model is based on a water balance scheme, considering atmospheric variables (precipitation and potential evaporation of CR2MET), soil properties, root depth, crop coefficients and the presence of irrigation, among other factors. , with specific parameters for each type of coverage. In this way, water use in the LULUCF sector is estimated as the difference in ET under the same climatic conditions, but different land covers. For this, a fixed coverage corresponding to the year 1950 was taken as a reference. The water use component in the absence of irrigation (mainly rainfed agriculture and forestry sector) was calculated similarly, keeping the irrigation option deactivated in all scenarios.

2.2 Estimation of water uses of other sectors: Historical estimates of water use in productive sectors were generated, including mining, power generation, livestock and manufacturing industries, as well as the drinking water requirements for the population. The reconstruction covers all the communes of continental Chile, with annual values from 1950 to 2020. The methodology used is mainly based on the definition, analysis of documents and homogenization of the time-space indicators associated with each sector. Similar to DGA (2017), by combining these factors with specific water consumption rates, volumetric water flows were estimated for each case. The data set includes the contribution of consumptive and non-consumptive uses.

Chapter 3

3.1 Attribution of changes in water stress: The water stress index (WSI) is defined as U/D, with U and D the consumptive uses of water over a territorial unit and the natural water availability, respectively. The WSI change components associated with changes in uses and availability are estimated, respectively, as WSIM ΔU/UM and –WSIM ΔD/DM (decomposition into partial derivatives). Terms with Δ indicate the difference between two periods of interest, while terms with subscript M indicate the average of the same periods. Then, a proportional adjustment to both terms is made so that the sum of the components equals the absolute change of the WSI between the evaluated periods.

Chapter 4

4.1 Well Level Processing and Analysis: Groundwater observation data were obtained from the General Directorate of Water website (https://snia.mop.gob.cl/BNAConsultas/reportes). For each observation well, the monthly series of water table levels were estimated as the average of the readings of the same month. Outliers were then removed and a climatology based on the period 1980-2010 was generated. Monthly anomalies were then calculated based on this climatology and missing data were filled. Subsequently, the time series of absolute values were reconstructed from the filled monthly anomalies. The annual mean levels of water tables were calculated from the monthly series with complete years. A second quality check was performed to remove outliers in the annual averages. In addition, annual series with less than 10 years of data in the period from 1980 to 2010 were filtered. Finally, annual anomalies were calculated in comparison with the base period from 1980 to 2010. This process allowed us to obtain more reliable data. and coherent for the analysis of groundwater levels. Observation wells were classified as shallow wells and deep wells if their mean annual water tables were greater or less than 15 meters, respectively.

Chapter 5

5.1 Case studies with different modes of access to water: The preparation of a representative sample meant describing and quantifying the heterogeneity of the ways of accessing drinking water in rural areas. For the description, a systematic review of the literature was carried out in four databases of indexed publications. For quantification, a consolidated database was built that allowed community organizations to be identified at the national level. The result yielded information on 2,802 organizations. A cluster analysis was also applied among the APR Program organizations. Based on this double descriptive and quantitative analysis, a sample composed of ten organizations located between the regions of Coquimbo and Los Lagos was selected: eight that are part of the APR Program, one with regional financing, and another without financing. For those in the APR Program, a profile was considered based on the cluster analysis. In this way, the selected cases meet some combination of the following criteria: (1) type of organization (committee, cooperative, informal organization), (2) water sources (underground, surface, tank truck, several at the same time), (3) type of financing (MPW, SUBDERE, municipality, none, others), (4) number of household connections, (5) geographic location (rural, urban, peri-urban - concentrated, dispersed, semi-dispersed - latitude, longitude), (8) level of annual precipitation, (9) temperature. The selected cases were visited in the field and ethnographic techniques were used, in addition to a structured interview applied through a guideline with hydro-social process variables to build the ICSH (Nicolás-Artero et al., 2022).

Chapter 10

10.1 The transformation actions were carried out through an in-depth interview complementary to the interviews applied to the ten case studies of APR organizations (chap. 5 and methodological note 5.1). The in-depth interview was semi-structured with open and closed questions. Twelve interviews were carried out between 2021 and 2022, and the data collected was subjected to a thematic analysis process and subsequently included in a database that characterizes, through different variables, all the actions identified along with the results. obtained in the analysis.

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