Climate Change Impacts on the Water Sector

4

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Abstract

The regional impacts of global climate and socio-economic change will heavily influence the future balance of water availability (supply side) and water demand in the Metropolitan Region of Santiago de Chile (MRS). Reduced run-off in the Maipo-Mapocho river catchment coupled with natural precipitation variability will pose a major challenge for water resource management in the coming years. This chapter elaborates on an impact assessment for the year 2050, which combines two climate scenarios for the supply side with two explorative socio-economic scenarios for the demand side. While adaptive measures for water supplies also involve increasing water storage or recycling grey water in the urban area, adaptive options for water demand focus on upgrading water efficiency in both agriculture and private domestic households. In addition to technical aspects, institutional/policy-based matters and capacity development measures are considered.

Keywords

Climate change • Regional impacts • Water supply • Water demand • Scenarios • Adaptation • Santiago de Chile

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4.1 Introduction

This chapter assesses predicted climate change impacts on the water sector and the attendant societal changes in the Metropolitan Region of Santiago de Chile (MRS). The goal is to design measures to adapt to climate change and to propose shifts in socio-economic parameters until the middle of this century. Following a description of the Maipo-Mapocho water catchment (Sect. 4.2), the status quo and current balance of water availability and water demand will be presented (Sect. 4.3). Based on a description of the applied scenario methodology, future changes in water availability induced by the adverse effects of climate change are assessed. Future water demand patterns are described with two socio-economic scenarios, and a possible future water balance is introduced (Sect. 4.4). Against this background, the need for adaptation to climate change effects in the water sector is derived and possible adaptive measures are presented (Sect. 4.5). The paper closes with some conclusions (Sect. 4.6).

The assessment of climate change impacts faces uncertainties; this study is therefore limited by a number of constraints, which have already been mentioned in Chap. 3 of this book. Uncertainties appear at different levels:

1. data restrictions regarding hydrology and future climate change impacts,
2. unpredictable socio-economic developments, e.g., population growth, economic growth and urbanization patterns, and
3. changes in the infrastructure, e.g., ageing or deterioration of pipe systems, leading to leakage rates in the water supply or sewerage systems.

4.2 The Maipo-Mapocho Water Catchment

The basin of the Maipo river and its main tributary, the Mapocho, lies in Chile's central valley at an approximate mean elevation of 500 m above sea level, surrounded by two Andean cordilleras on the north-western, south-western and eastern side. The catchment area largely corresponds to the area of the MRS, with only a small area belonging to the V and VI region (INE 2008). The Maipo and Mapocho rivers both originate in the glacier zones of the Andes and flow across the MRS (see Fig. 4.1). The Maipo is about 250 km long and its watershed covers approx. 15,400 km^2. The Mapocho is 120 km long, its watershed is notably smaller at about 4,100 km^2 (CNR 2007). The rivers supply 70 % of the potable water demand and around 90 % of the demand for agricultural irrigation in the MRS. In this chapter, water availability and water demand will be analysed for the area of the MRS outside the high Andes, in the west of the Andean cordillera. In the following this area will be referred to as the Santiago Basin. For practical reasons the extent of the Santiago Basin is calculated as the area of the MRS lower than 900 m above sea level, corresponding to approximately 7,000 km^2.

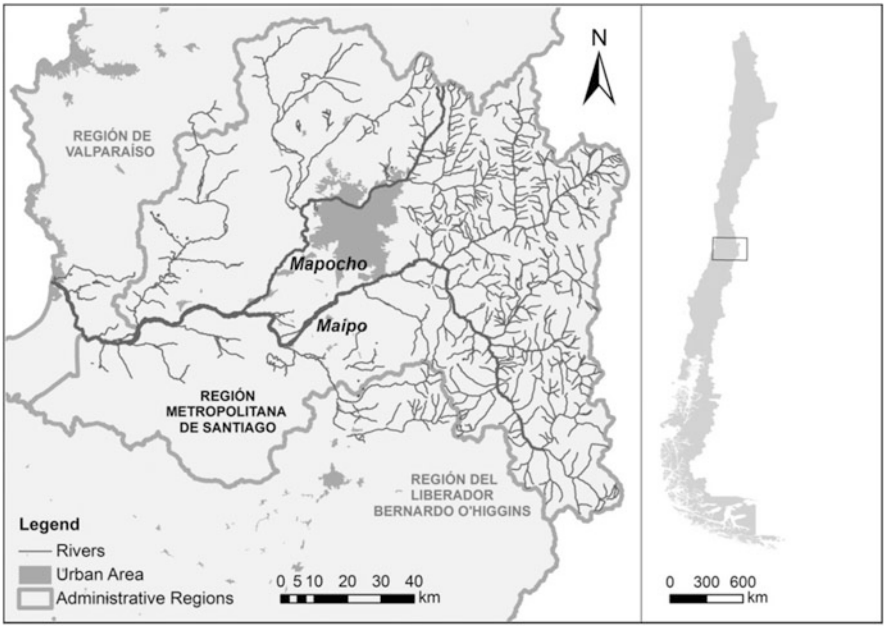

Fig. 4.1 Maipo-Mapocho water catchment (*Source*: SIIT 2013, Cartography: Kiemle)

4.3 Current Status of Water Availability and Water Demand

4.3.1 Current Water Availability

The renewable water resources available in the Santiago Basin are determined by (1) precipitation in the Santiago Basin and (2) the inflow of surface water from the Andes via the Maipo and Mapocho rivers. The temporal availability of water resources in the plains of the MRS is determined mainly by temperature and precipitation, as well as the water storage capacity in the mountainous regions (snow and ice). Precipitation in the MRS varies considerably throughout the year and from one year to another (see Fig. 4.2). This fluctuation is to some extent associated with the El Niño-Southern Oscillation (ENSO). Abundant precipitation can be observed in the course of El Niño events, while precipitation during La Niña events is low (Meza 2005). In the period from 1950 to 2004, the driest year (1968) in Santiago showed precipitation values of 70 mm (Quinta Normal meteorological station) and the wettest year (1987) 713 mm (Lehn et al. 2012).

This inter-annual variation interferes with the intra-annual variation (see Fig. 4.3, left side), leading to highly variable monthly precipitation amounts. The two main water supply sources in the Santiago Basin—precipitation and inflow of surface waters from the Andes Mountains—complement each another (see Fig 4.3).

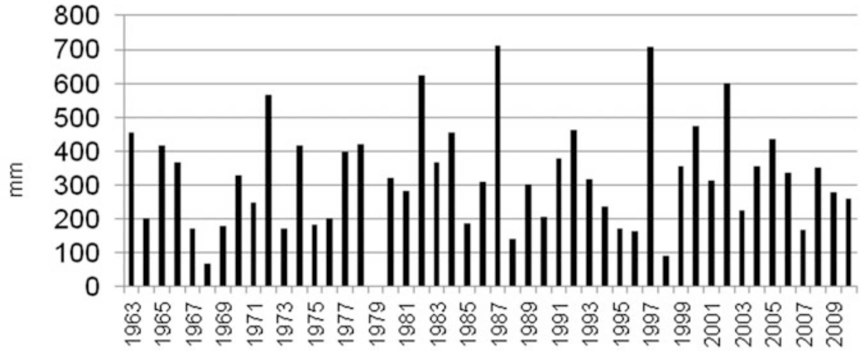

Fig. 4.2 Variations in total annual precipitation in Santiago over time—Quinta Normal station (*Source*: DMC 2012, modified by authors)

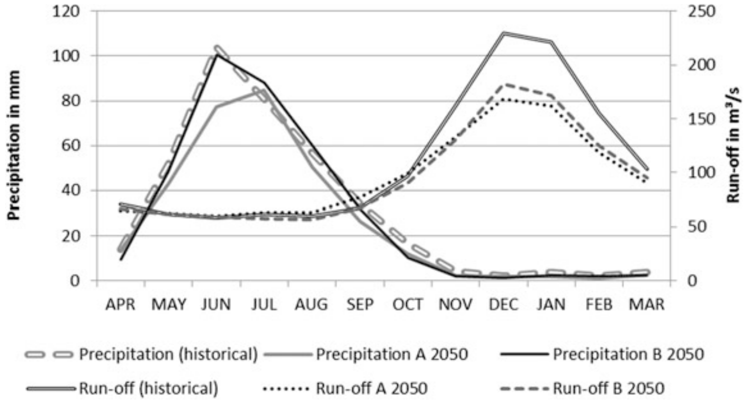

Fig. 4.3 Average precipitation rates from three stations (*left*) and run-off distribution from the Maipo River station at El Manzano (*right*) during the year (historical and A and B 2050 values) in the Santiago Basin (*Source*: Cortés et al. 2012, modified by authors)

When the winter rain ceases, rising spring temperatures induce ice and snow melt in the Andes, and inflowing surface waters take over the water supply in spring, summer and autumn (Kopfmüller et al. 2009).

In general, annual precipitation increases with ascending elevation. As a result of low average annual precipitation values (480 mm) and the fact that almost all of the rainfall is concentrated in the winter months between April and September (Cortés et al. 2012), most water-related needs in the Santiago Basin in spring, summer and autumn depend heavily on melt waters from glaciers and snowfields in the High Andes. In addition to the latter, important water reservoirs are the natural lagoon 'Laguna Negra' and the 'El Yeso' dam, both located in the Andes.

Due to the high inter-annual variability of rainfall in the MRS, the annual mean precipitation and run-off of inflowing rivers is subject to substantial variation. The renewable water resource from precipitation in the Santiago Basin varies between 0.5 and 5 km^3/a. The run-off of the Maipo river varies in the range from 60 to 80 m^3/s in drier and 150 m^3/s in wetter years, averaging at 110 m^3/s (1951–2005).[1] The corresponding data for the Mapocho river is 2–3.5 m^3/s in drier and 9–14 m^3/s in wetter years, averaging at 6 m^3/s (Bartosch 2007). Calculations based on this data reveal that the total annual available amount of renewable fresh water (availability) in the MRS varies between 3 km^3 and 10 km^3, with an average of 6 km^3 (see Table 4.1).

4.3.2 Current Water Demand

The current water demand in the MRS is primarily driven by agricultural needs. In 2007, this sector accounted for approx. 74 % of the total water demand in the region. The share of drinking water of the total annual water demand is about 18 % and for industrial purposes about 8 % (see Fig. 4.4).

According to the latest agricultural census, the MRS accounts for a total of approx. 1,130,000 ha of classified agricultural land, with 136,000 ha (13 %) irrigated by systems such as gravity, sprinkler and micro-irrigation systems (INE 2007; PUC 2011). Irrigation is clearly a water-intensive activity, since this relatively small area accounts for more than two-thirds of the entire water demand in the region. More than 90 % of the irrigated area depends on water withdrawals from surface flows. The total annual agricultural irrigation volume is calculated at 3.2 km^3 (PUC 2011).

The largest water and sanitation company in the MRS is the privately owned Aguas Andinas S.A. (public limited company), which is majority owned by AGBAR (Aguas de Barcelona). As a result of buying up three smaller companies (among them Aguas de Manquehe and Aguas Cordilleras), Aguas Andinas, which is controlled by international corporate groups, dominates the market. Aguas Manquehe and Aguas Cordillera still operate under their former names. The company provides fresh water for over 1,500,000 households in the MRS. In addition, the municipal enterprise SMAPA serves the south-western municipality of Maipú with approx. 180,000 households (SISS 2011). From the data in Table 4.2, an average per capita consumption in the MRS of 79.2 m^3 per year or 217 l per day can be calculated. However, there is a vast difference in consumption between more prosperous households in the eastern parts of the city and low-income households in the more western parts. Areas in the east of Santiago served by Aguas Manquehue reach a consumption level of about 805 l per capita and day, mostly due to irrigation of private green areas and the filling in of swimming pools, while the demand for areas served by the public water and sanitation company SMAPA amounts to roughly 180 l per capita and day (SISS 2011). Water losses in the distribution systems vary

[1] Related to the precipitation rates at Quinta Normal station. Years with precipitation values between 200 and 400 mm are regarded as 'normal years', those above 400 mm as 'wet years', and below 200 mm as 'dry years'.

Table 4.1 Water availability in the Santiago Basin (number of inhabitants: 6.88 million, 2010) (*Source*: modified after Bartosch 2007, data base DGA 2007a)

	Annual renewable fresh water (km^3/a)	Specific available fresh water resource per capita (m^3/cap.*a)
Average	6.2	901
Max (wet) years	10.2	1,483
Min (dry) years	2.8	407

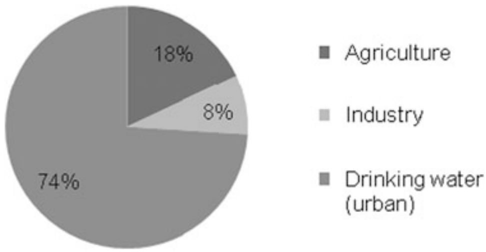

Fig. 4.4 Current share of water demand differentiated by sectors in the MRS (*Source*: own calculation based on SISS 2010; PUC 2011)

considerably from 11.4 % in the Aguas Manquehue network to 42.9 % in the SMAPA network. The average loss in all networks of the MRS was 31.2 % in 2010 (SISS 2011). Since a volume of 253.5 m. m^3 was lost in the network in that year, the four water companies were obliged to produce a total of 790 m. m^3 to provide the end user with 536.5 m. m^3 (SISS 2011).

Information on industrial water use is rare. The MRS is dominated by the manufacturing industry; in 2004, 30.24 % of all manufacturing in Chile was located in this area (INE 2005). The dominant industries are food, textiles, paper, chemicals, metal, rubber and plastic. Industrial water demand has been on the increase since 1990, reaching approximately 0.32 km^3/a (10 m^3/s) in 2006 (DGA 2007a). Since most industries have their own water sources, they are independent of drinking water companies.

4.4 Future Water Demand and Availability

4.4.1 Combining Climate Scenarios with Socio-Economic Scenarios

Similar to Chap. 3 of this book, a scenario-based approach is applied here to address climate change adaptation planning under future hydrological conditions in the light of uncertainty. As water availability heavily depends on the regional climate, the focus was on downscaling the A2 and B1/B2 scenarios referred to in the IPCC IV report (see Chap. 2). In addition to climate change, such variables as demography, economic development and types of consumption play a major role in the further development of the MRS. In this sense, two socio-economic scenarios were

Table 4.2 Specific features of the four largest water and sanitation companies in the MRS (2010) (*Source*: SISS 2011)
Note: Three companies use ground and surface water, SMAPA uses ground water only

Company	Water supply network	Production capacity (max.)	No. of people	Per capita consumption in 2010		Consumption	Water losses	Production
	km	m^3/s	served	l/cap. *d	m^3/cap. *a	m. m^3/a	%	m. m^3/a
Aguas Andinas	11.67	30.9	5,642,630	201	73.37	414.0	31.6	605.3
SMAPA	1.5	4.3	720,903	181	66.07	47.6	42.9	83.4
Aguas Cordilleras	1.2	5.3	378,446	469	171.2	64.8	15.1	89.9
Aguas Manquehue	221.0	0.9	34,336	805	293.8	10.1	11.4	11.4
Total	235.4	41.4	6,776,315			536.5		790.0

designed for the MRS: ‘Business As Usual’ (BAU) and ‘Collective Responsibility’ (CR) (see Chap. 3). Here future water demand depends on the specific socio-economic, institutional and technical development in the MRS. Adopting the BAU and CR scenarios allows for a perspective on the state of the MRS in 2050. The time span from 2045 to 2065 is used for climate predictions (A2, B1/B2). According to these predictions, A2 can be interpreted as the ‘worst case’ and B1/B2 as the ‘best case’—bearing in mind sustainable development for the future. Since climate change is strongly interlinked with water supply and demand, a combination of framework scenarios (Chap. 3) and climate predictions was subjected to a qualitative assessment. Assuming a smaller population, the installation of water-saving technologies in households and agriculture, and rehabilitation of the water pipe system, water demand in the CR scenario is remarkably low compared to the BAU scenario. The results of the A2 climate scenario were related to those of the BAU scenario to produce a ‘worst case’ model for both supply and demand. The ‘best case’ was formulated by combining the results of B1/B2 with the CR scenario. Using these combinations the potential water balance range can be described for the future and the extent of the challenges indicated. Estimated values for future climate and hydrological conditions (A2 and B1/B2) were taken from the work of Cortés et al. (2012, cf. Chap. 2) and used to estimate the water supply side for the time span 2045–2065. Demand estimates were made by contextualizing the socio-economic BAU and CR scenarios to the specifics of the water sector.

4.4.2 Future Water Availability

Future water availability in the MRS is influenced by the regional impacts of global climate change, notably shifts in temperature, precipitation and/or run-off rates. The Maipo river run-off tends to decrease as much as 40 % in both climate scenarios in the summer months (Chap. 2). Precipitation likewise decreases, with a projected reduction in A_{2050}[2] of minus 10–30 %, whereas in B_{2050}[3] no significant decrease is assumed (see Fig. 4.4).

Climate scenarios also show a decline in water availability. On the whole, the expected future water availability is lower in scenario A_{2050} than in B_{2050}. The comparison states 1.03 km^3 less for A_{2050} and 0.65 km^3 less for B_{2050} in normal years compared to today. Even in the B_{2050} climate scenario, which has less water reduction than A_{2050}, the lower availability of water corresponds to almost three times the storage capacity of the El Yeso reservoir.[4] As described in Sect. 4.4.1, the results of climate and BAU/CR scenarios are combined in order to identify possible future relationships between natural water supplies and water demand for the MRS.

[2] Synonym for downscaled climate scenario A2 for the time span 2045–2065.

[3] Synonym for downscaled climate scenario B1/B2 for the time span 2045–2065.

[4] Reservoirs like ‘El Yeso’ are crucial to the drinking water supply in the MRS, particularly in terms of dry months.

Table 4.3 Water-relevant parameters of the two scenario alternatives for the year 2050 (*Source:* Authors' own water-specific development based on framework scenarios: Barton et al. 2011a, b)

Business as usual (BAU)	Collective responsibility (CR)
The MRS in 2050 is characterized by consequences of continuing recent trends in population, economic growth, urbanization, technology and human behaviour. BAU assumes that current market-based policies remain and environmental health and ecological integrity are of less interest.	The MRS in 2050 is dominated by a strong state presence and market regulation. Environmental protection, social justice and equity are major political goals. Slower economic growth and the introduction of clean and resource efficient technologies are key determinants. CR assumes less population growth and decentralization processes that change the urban planning processes.
Urban development	
• Urban population of 8.5 million • Introduction of new technologies, but without focus on water saving • Decreasing agricultural and irrigated area • Access rate to water and sanitation 99 % • More paved areas → more flooding • Irrigation efficiency in agriculture approx. 60 % • Urban water demand is 180 l per capita and day • Tertiarization processes increase in addition to industrial sector	• Urban population of 7.9 million • Irrigation of private gardens and per capita demand is reduced by new water-saving technologies in the household and for irrigation including grey water re-use • Constant agricultural and irrigated area • Access rate to water and sanitation 99 % • Growth of green spaces → increase of living quality, better air quality • Irrigation efficiency in agriculture approx. 75 % • Urban water demand is 150 l per capita and day • Industries grow in balance with eco-systems
Institutional framework	
• Privatization with monopolistic structures • Weak government influence • Conflicts between water users caused by private water rights	• Stronger state presence and regulation by government institutions • Water saving technologies promoted • New water law is implemented
Infrastructure	
• Insufficient maintenance of water infrastructure – increase of water losses (40 %) • Multiple use of water is uncommon • Combined sewer system (waste and storm water) without retention basins – sewage often pollutes rivers	• Improvement of water infrastructure – water losses decrease (10 %) • Sewage used as resource (e.g., warmth for buildings; grey water for irrigation, treated waste water for agricultural irrigation) • New technologies at treatment plants – safe environmental disposal • New urban areas are equipped with semi-decentralized water infrastructure

Table 4.3 summarizes the key aspects of the two socio-economic scenario alternatives BAU and CR, contextualized in accordance with the overall framework for the water sector.

According to the two scenarios presented and their specific socio-economic and technological development, changes are expected in the drinking water supply and in the water demand from the agricultural and industrial sectors. Key determinants are the advancement of agricultural irrigation efficiency by implementing new technologies, the development of agricultural and irrigated areas, population growth and public policies. Data for the current water demand is combined with assumptions about changes in population size, irrigation efficiencies, water-saving efforts and rehabilitation of the pipe network in accordance with the two socio-economic scenarios (Table 4.3), allowing for quantitative assessments of future water demands.

Both scenarios show evidence of a decrease in the total water demand, notably as a result of a lower demand for water in agriculture. Figure 4.5 shows the water demand values in 2011 and for both future scenarios.

4.4.3 Future Balance of Water Availability and Demand

Both water availability and water demand will undergo change in the MRS in the future due to climate change effects and demographic, economic and technological adjustments. In line with the shifts in precipitation and stream flow (compare Chap. 2), renewable water resources in the Santiago Basin will be more modest than they are today, varying between 1.9 and 9.5 km^3 per year. The difference between the two climate scenarios with regard to average availability is comparatively small, with A_{2050} averaging 0.4 km^3 less than $B_{2050.}$

The total water demand in both socio-economic scenarios (BAU and CR) is in decline (see Table 4.4). Calculations are based on the assumption that efforts have been made in both scenarios to introduce new water-related technologies (according to Table 4.3), notably in agriculture. The introduction of such technologies, however, often coincides with an additional demand for a supply of electricity (e.g., drip irrigation pumps for agricultural use or systems to press waste water through membranes), which should be based on renewable energy sources. In the year 2050, the total water demand accounts for approximately 60 % of the total availability in an average year. The dry years pose the greatest challenge here: water demand exceeds availability by far (between 150 and 180 %). The key issue is how to enable the MRS to maintain a sustainable water balance.

4.5 Designing Adaptation Measures

4.5.1 The Need for Climate Change Adaptation Measures

In addressing climate issues, climate change management focuses heavily on the mitigation of anthropogenic greenhouse gas emissions. Since current emissions will impact on the severity of climate change in future years (Hulme et al. 2002), it is now widely accepted that mitigation alone will not suffice to deal with the adverse effects of climate change already occurring (Kurukulasuriya and Rosenthal 2003). To a great extent climate change is water change (IPCC 2008). The interference of climate change and the ENSO phenomenon affects drinking water security and agricultural productivity, especially in tropical and Mediterranean regions such as the MRS (Ropelowski and Halpert 1996; Kurukulasuriya and Rosenthal 2003). Consequently, the water supply in the Santiago Basin is highly mutable. Water supplies in terms of

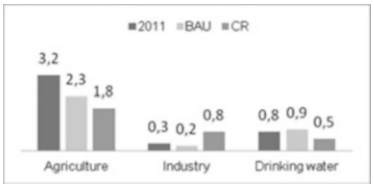

Fig. 4.5 Current annual water demand and projected annual water demand in 2050 for the MRS in km^3 (*Source*: own calculation based on framework scenarios)

Table 4.4 Relationship between future renewable water resources (according to climate scenarios) and demand (according to socio-economic scenarios—see Table **4.3**) in km^3 (*Source*: Authors' own calculation)

		2011	A $_{2050}$	B $_{2050}$
Supply	Min	2.8	1.9	2.1
	Max	10.2	9.3	9.5
	Average	**6.2**	**5.2**	**5.6**
Demand		**2011**	**BAU**	**CR**
	Total	**4.3**	**3.4**	**3.1**

security, productivity and sustainability can be assessed by the by the use of indices. Two of such indices are presented in the following.

4.5.1.1 Assessment According to the Falkenmark Index

The Falkenmark Water Stress Index is a helpful tool to estimate water availability in the Santiago Basin with respect to the number of people to be served and is broadly accepted in the water community (Falkenmark 1989). The index covers basic water demands: drinking water, agricultural, and industrial production. Four water availability categories are defined:

- Sufficient water: >1,700 m^3/cap.*a
- Water stress: <1,700 m^3/cap.*a
- Water scarcity: <1,000 m^3/cap.*a
- Severe water scarcity < 500 m^3/cap.*a

The current overview of available water in the Santiago Basin (407–1,483 m^3/cap*a, cf. Table 4.1) indicates that there is already a scarcity of water, with 'severe water scarcity' in dry years and 'water stress' in wet years.

4.5.1.2 Assessment According to the Water Exploitation Index

Whereas the Falkenmark Index assesses the water situation in the context of the number of people to be served, the Water Exploitation Index (WEI) calculates the ratio between water extraction and renewable water resources, marking the relationship between the natural supply potential and societal needs (Marcuello and Lallana 2010). A WEI >1 indicates that a greater volume of water is extracted than is renewed. In the long run a balance between extraction and renewal will only be possible if sufficient water storage capacities are available. In view of the figures for water demand and annual renewable water resources (see Table 4.4), the WEI currently assesses the Santiago Basin as having medium water stress (0.42) in wet years, high water stress (0.69) in normal years, and very high water stress (1.54) in dry years—according to (Döll 2008) (Fig. 4.6).

Groundwater in the Santiago Basin is an ideal natural facility for water storage: the underground location of this water resource affords greater protection against pollution and warming up compared to surface waters. Due to the slow speed of groundwater (as distinct from rivers), its residence time in the region is higher, thus enabling water storage during periods with little precipitation. The management of this pivotal water reservoir in the Santiago Basin, however, cannot be assessed as sustainable: the constant lowering of the groundwater table (from 12 to 26 m below the surface) in the period from 1969 to 2001 (DGA 2007b) clearly indicates that water extraction exceeds the rate of natural groundwater recharge (Fig. 4.7).

The two indices show that the Santiago Basin is already suffering from water stress and water scarcity in both normal and dry years. The water demands of the population can only be met by neglecting the water demands of nature or of ecological services, and exploiting natural water storage capacities beyond their ability to recharge.

These findings are evidence of the current urgency for demand-related measures to achieve a balance between natural water availability, on the one hand, and the demands of the environment and human society, on the other. Taking into account the results of the water balance assessment, as well as the impacts of climate change, and demographic and economic developments (see Sect. 4.4.3), the water situation in the Santiago Basin will deteriorate in the future if adaptation measures will be waived.

4.5.2 Water-Related Measures to Adapt to Climate Change

In order to respond to the already traceable problems identified in the water sector of the MRS, which will more than likely be aggravated in the future, adaptation measures need to be designed and implemented. The measures presented in this chapter are a combination of stakeholder knowledge in the scenarios, scientific expertise and existing policy guidelines. They were identified, refined and prioritized from a set of possible measures drawn up in a participatory process (see Chap. 9). Generally, adaptation to change in the water sector can be subsumed under institutional measures and measures related to supply and demand. Four of the wide range of measures proposed were studied in detail by Chilean experts, who conducted scoping studies to assess their feasibility in the MRS. Selection of the four measures was primarily based on their effectiveness and/or potential to save water:

1. Water demand in the MRS is highest in the agricultural sector. Upgrading the effectiveness of irrigated agricultural systems has enormous water-saving potential.
2. Reducing the water demand in private households has the positive side effect of increasing public environmental awareness.

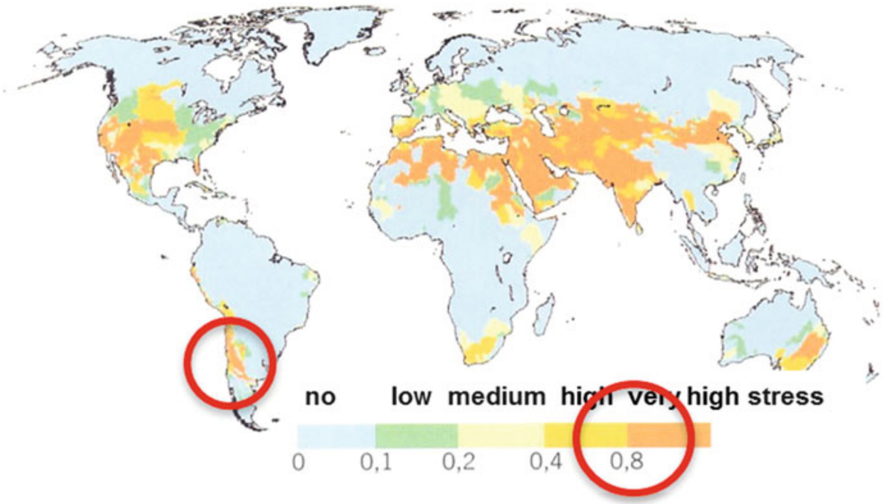

Fig. 4.6 Water stress in river catchments in the year 2000 according to the Water Exploitation Index (WEI) (*Source*: Döll 2008)
Note: A catchment value of more than 0.4 indicates high water stress and WEI>0.8 very high water stress

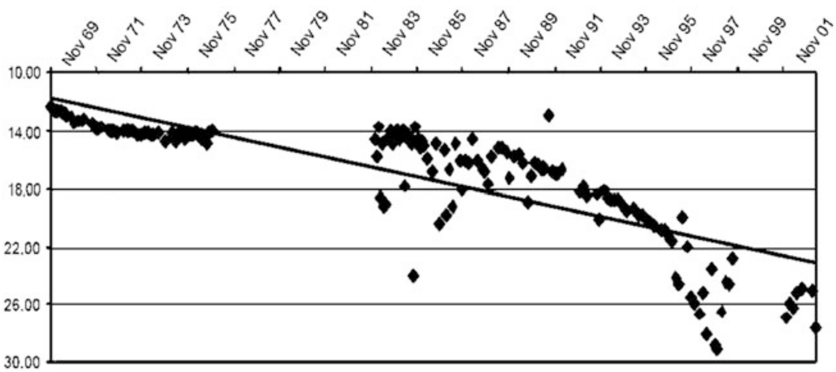

Fig. 4.7 Groundwater table from 1969 to 2001 within the Sector Santiago Central at Estación Consejo Nacional de Menores (*Source*: DGA 2007b)

3. Re-using grey water systems in new built-up areas also contributes to public awareness.
4. Implementation of a new policy structure for the water sector is recommended in order to embed measures in the changing institutional background.
The four measures are described in more detail below.

4.5.2.1 Reduction of the Total Agricultural Water Demand by Introducing Water-Efficient Irrigation Technologies

According to the latest agricultural census, irrigation efficiency[5] in the MRS is in the order of 36 %, which is quite low compared to international standards (INE 2007; PUC 2011). The agricultural sector in Chile could therefore make great strides to save water. The proposal for this measure is based on the assumption that the irrigated agricultural area will remain constant in the future and that irrigation efficiency can be improved, ultimately leading to compensation for reduced water availability resulting from the adverse effects of climate change. Hence the utilization of efficient irrigation technologies such as pressurized water application techniques (sprinkler and micro irrigation) (Kulkarni 2011) should be accompanied by measures to ensure that the water saved is not transferred to other agricultural areas or other sectors (e.g., mining). This could be achieved by introducing a decree to prohibit the allocation of new irrigated agricultural areas in the MRS. It is furthermore proposed that subsidies for new irrigation technologies should be dedicated to areas currently equipped with low-efficient technologies. Financial support to install specific systems with at least 75 % efficiency, such as sprinkler or drip irrigation systems,[6] should be restricted to recipients who voluntarily return to the state the volume of water they save (in terms of water rights). A bonus system should be established to motivate farmers to yield their unused water rights to the state (as a civil law contract). Expected co-benefits are reduced water costs for farmers due to lower water consumption, less exploitation of groundwater resources and a water flow rate that maintains healthy aquatic ecosystems (ecological flows). Identification of the main agricultural areas with low-efficient irrigation technologies—a priority in terms of modernization—should precede the measure.

An irrigation subsidy programme was established in Chile by the National Irrigation Commission (CNR) (CNR 2009). It seems unnecessary to implement a new funding scheme. Instead, efforts should be made to improve existing agricultural policies. The policies in place focus mainly on increasing agricultural productivity and contain no incentives to reduce water demand, a prerequisite for long-term sustainable production. Neither do existing policies include incentives to seek alternative water resources or uses (e.g., water re-use) or to strengthen the capacity of user associations. As a rule these policies are highly inflexible. It is therefore recommended that future agricultural subsidy policies guarantee the stability of the total agricultural area to be irrigated.

Actors from a number of government institutions, such as CNR, the Ministry of Environment (MMA), the National Office for Regional Development (SUBDERE) and the Institute of Agricultural Development in Chile (INDAP), should be

[5] 'Irrigation efficiency' is defined as the relationship between the amount of water plants require for optimum growth and the amount of water brought to the field by irrigation (INE 2007).

[6] The INE (2007) defines efficiencies as follows: 75 % for sprinkler irrigation, 85 % for drip irrigation and 90 % for micro-irrigation.

involved in the implementation of this measure. A barrier to its successful implementation could be the expected lack of cooperation by farmers. It is assumed that the latter fear financial cuts following a potential drop in agricultural production. Hence gaining their confidence and participation, and ensuring their financial needs is of the utmost importance.

4.5.2.2 Introduction of Water-Efficient Fixtures in Private Houses

The current per capita water demand in the MRS of approximately 220 l per day is comparatively high (SISS 2011). The aim should be to reduce the future water demand to about 150 l/cap-day, i.e., 100 l/cap-day for household purposes and 50 l/cap-day for the irrigation of private green spaces under Mediterranean climate conditions. In 2004, for example, the per capita water demand in 88 cities and villages of the south-western German state of Baden-Württemberg was less than 100 l/cap-day (Bühringer 2006). This clearly indicates that even today 100 l/cap-day is an achievable level for existing buildings. According to the Bayerische Landesanstalt für Weinbau und Gartenbau (Bavarian Regional Office for Viniculture and Horticulture) (2007), one square metre of high quality lawn requires 3.3–4 l of water under German summer conditions. Assuming that the latter are akin to weather conditions prevailing throughout the year in the MRS, 50 l of water should suffice to irrigate a lawn of 12–15 m^2 in size. In other words, with the technologies already in operation in Chile, 150 l/cap-day should cover household requirements, including a green area around the house. To presume that flowering plants need less water than lawns and that the reported consumption of less than 100 l/cap-day in German cities includes a certain amount of irrigation water illustrates the conservative character of this assessment. The introduction of water-efficient tap fittings in bathrooms or kitchens, and of efficient toilet-flushing systems in existing buildings reduces water consumption at a comparatively low cost. Implementation of this measure would consequently reduce water and sewage bills. Lower water consumption (e.g., while showering) likewise leads to lower energy-related costs. Additionally, more efficient water use combined with water-saving technologies could serve to avoid expensive investment costs otherwise needed to adjust water supplies and waste water treatment facilities to a growing population. Lowering human water consumption with water-saving measures is a prerequisite to assuring ecological flows in natural water bodies and thus to guaranteeing water-based environmental services—particularly in water scarce regions like the MRS.

Experience in Germany shows that the per capita water demand of hotels is higher than that of private households (Lehn et al. 1996). The installation of water-saving fixtures in hotels could reduce the per capita water demand even more efficiently than in private households. Since the high per capita water demand in hotels results from intensive showering, saving water here will lead to energy saving when the demand for warm water declines.

The overall aim of the measure is to:

- Reduce approx. 30 % of urban water demand by introducing water-efficient installations up to 2050.

- Draw up strategies for existing and new houses: (1) Gradual exchange of installed sanitary fixtures in existing houses accompanied by awareness-raising campaigns and economic incentives when the pay-back period exceeds 1 year. (2) Setting obligatory water efficiency standards for sanitary systems.
- Create an efficiency label for a range of water efficiency products (percentage of water saving) and limit the maximum flush volume for each of these fixtures (with readjustment every five years) as the basis for incentives.
- Establish an adequate subsidy system: depending on the price of water-saving fixtures and the attendant pay-back periods, subsidies could be made available for the refitting of installations in existing buildings.

The expected co-benefits are energy saving due to less (warm) water, reduced water and energy costs, and growing public awareness of the need and opportunity to save water. Since the amount of soap or shower gel is expected to remain constant with water-saving fixtures and the composition of excreta is unlikely to change with water-saving toilets, the relation between water and its ingredients will result in higher concentrations of ingredients in waste water. Thus waste water treatment plants are expected to achieve greater efficiency as a result of less diluted sewage.

4.5.2.3 Treatment and Re-use of Grey Water in New Built-Up Areas

Approximately 19 % of the total MRS superficies is vegetal material in the form of lawns, plants, bushes and trees (Moya 2009). The water demand in this area is approx. 250,000 m^3/day. According to a survey[7] carried out by the Observatorio de ciudades OCUC, 60 % of consulted households were prepared to improve their irrigation systems with more efficient, water-saving technologies, while around 46 % would agree to irrigate with treated grey water[8] (OCUC 2010). Grey water recycling is an appropriate measure to adapt water management to the impacts of climate change, and its gradual integration at all levels of legislation, planning, construction and management of urban green areas is the overall aim of the measure. Successful grey water management includes both technical methods, and institutional and legal aspects (e.g., user participation in planning, running and maintaining the systems). The overall objective of these measures is:

- in the short run to raise awareness among architects, planners and investors of the interrelation between the drinking water supply and the re-use of grey water and its potential for irrigation of green spaces when they plan green areas, building dimensions and technical installations.
- to establish a water quality norm for recycled grey water and a technical guide for the certification of domestic grey water systems for irrigation needs.

[7] Three hundred households in 15 different communities were consulted between 4 and 27 June 2009. The survey was conducted with people over 18 years of age from different socio-economic backgrounds.

[8] Generally, grey water includes all household waste water with the exception of toilet and kitchen effluents.

- in the long run to substitute drinking water with treated grey water for irrigation of urban green spaces.

A key issue in the planning process is synchronization of the amount of recycled grey water with the availability of irrigated areas (size, water demand of plants) to adopt grey water for irrigation.

Expected co-benefits for the future are the saving of drinking water and reduced water bills, optimization of waste water treatment plants due to less dilution of waste water, and the enhanced environmental image of Santiago de Chile. In a first step, this measure should be realized with pilot projects in newly built housing areas. Capacity development and education campaigns to raise awareness of the topic (notably, for example, among architects, investors, planners) are of the utmost importance for the success of this measure. Further, implementation will require determining an institution to be responsible for grey water recycling (ability to lead and coordinate existing regional policy and the institutions involved) and a suitable financing facility to support the implementation of grey water recycling systems. It is impossible to specify the installation costs of a grey water recycling system, since the complexity of treating grey water depends on its quality and on the specific system and its design.

If the relation between built-up areas and green spaces is aptly designed, storm water can be seeped decentrally onto the latter. The grey water infrastructure can also be used to transport storm water from the built-up area to green spaces. Since storm water requires pre-treatment, its inclusion in the grey water system is feasible. In this case, storm water collectors would no longer be necessary and the attendant costs saved.

Obstacles can be expected: the current lack of awareness and knowledge of these issues among the authorities, investors, planners and inhabitants needs to be overcome. The introduction of economic incentives depends on the public budget and the economic stability of public households.

4.5.2.4 Establishment of Integrated Governance Structures for the Maipo-Mapocho Watershed

The pressure on water resources caused by climate conditions, population growth, increasing water demand and water pollution highlights the hydrological, social, economic and ecological interdependencies in the Maipo-Mapocho watershed. This calls for an integrated management system involving the basin stakeholders concerned (private and public). The aim of the measure is to set up appropriate administrative structures. As a rule, the public authorities remain the final supervisory level. Private stakeholders are more 'involved in decision-making processes' than in 'making decisions'. Hence the establishment of two entities is recommended:

1. Regional Water Council: a political institution that seeks to bring the different public and private actors together. It could play an active part in shaping and accompanying the dialogue and participation process for the adaptation strategy. This would ensure a consistent conceptual approach by the regional government.

2. River Basin Entity: an executive board responsible for coordinating the relationship between the various services and hydrological planning in the Maipo watershed. The integrated regulation and control of all water-based needs in the catchment according to sustainability principles, e.g., of water extraction in relation to available supplies, of water quality for different purposes, and of the promotion of sustainable water-use practices, could be some of the concrete activities of this body. Apart from public participation in decision-making processes, expected co-benefits are the reinforcement of regional administrative structures and enhanced participation by the stakeholders concerned.

4.6 Conclusions

From a historical point of view, the founders of the city of Santiago made a fitting choice of place to settle as far as water supply and sewage disposal is concerned. The complementary character of rainfall in the winter months and the inflow in spring, summer and autumn of melt waters from vast natural water storage facilities (glaciers and snowfields) in the high Andes guaranteed a water supply throughout the year. As a result of the steep slopes of the western valleys in the Andes, the velocity of river waters was high, allowing sewage to be discharged rapidly downstream from the city to the Pacific Ocean.

Over time the inhabitants altered these favourable framework conditions, leading ultimately to the more risky situation that prevails today. Due to the growth in population and increased economic activities all of the available water resources have been allocated to a specific use. Water storage capacities have been augmented by the construction of dams—notably the *El Yeso* dam—to overcome dry annual periods and dry (La Niña) years in particular. Despite these efforts, the Maipo riverbed dries up regularly in the summer months after it leaves the city, and the groundwater table has been subsiding for decades. From an integrative perspective and taking into account ecological services and/or a balanced relationship between upstream and downstream riparians, this river basin management is clearly unsustainable. Measures to adapt water-use patterns to the water supply regime are thus crucial even today.

The interrelationship between climate change effects and the ENSO phenomenon—with increasing intra-annual water supply variations—will in the future lead to a widening of the gap between water availability and water demand. Hence, there is an urgent need for adaptation measures if depletion of water resources in the MRS is to be avoided. The vast potential to reduce water demand without lowering the quality of life has been demonstrated. Adaptation measures should be taken into consideration on the demand and the supply side in both urban and rural areas, and involve residents, farmers, industries and water supply companies. Technical, institutional and behavioural measures are proposed in order to engineer integrative and adaptive water management.

As far as the demand side is concerned, the greatest water-saving potential exists in the agricultural sector, since irrigation efficiency is currently at a very low level.

In line with the scenarios and the specific climate setting in the MRS, raising efficiency to international standards would mean saving between 0.9 and 1.4 km^3 of water or between 900 and 1,400 m. m^3. In contrast, the actual total drinking water demand in the urban area of Santiago accounts for 700–800 m. m^3 (see Fig. 4.5). Upgrading efficiency alone, however, will not suffice. Technical measures in the field of irrigation must also be flanked by an improved regulation scheme, which in turn guarantees that the volume of water saved is not wasted in other sectors or regions. In addition, the urban sector has considerable potential to save water on the demand side. Yet another adaptation measure is the improvement of the drinking water network, which was not discussed in depth during the participatory process (see Chap. 9).

According to the calculations described in Sect. 4.4, drinking water losses of approx. 175 mil. m^3/a could be avoided if the leakage rate were reduced to 10 %. This is an ambitious but achievable target, as seen in the case of Aguas Manquehue (see Table 4.2), which reports a leakage rate of 11 %. In the urban area, an annual saving potential of approx. 350 m. m^3 seems realistic and can be achieved without the introduction of new technology. What is merely required is the installation of water-saving fixtures and the rehabilitation of the pipe network. The application of new methods and technologies, such as grey water recycling, could lead to an estimated annual saving of a further 100–120 m. m^3 of drinking water.

The climate scenarios indicate that water supplies could decrease in the year 2050 by about 1 km^3 or 1,000 bn. m^3 (see Table 4.4). Mobilizing the above-mentioned potential could mean saving more than 1,500 m. m^3 of water in the Santiago Basin, leaving a slightly higher volume of water for ecological services to nature. This calls for a new integrated governance structure for the Maipo watershed, which would control and regulate all water-based needs in the catchment in a manner that is both comprehensive and in compliance with the principles of sustainability.

The proposed technical and institutional adaptive measures are at risk of failing if public awareness of water issues remains at its current level. The high per capita consumption in households (especially in high-income areas), exorbitant losses in the pipe network and low irrigation efficiency in the agricultural sector and urban domestic garden watering clearly indicates that large sections of society are unaware of the current dramatic imbalance between natural water supplies and anthropogenic water demands. To counteract this deficit a structured and long-term awareness campaign is recommended.

Overcoming the gap between water supply and water demand in the Metropolitan Region of Santiago poses a huge challenge today and even more so in the future. Santiago's natural features and its ability to cope, however, give reason to hope that this challenge will be addressed.

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