Chapter 12
Risks and Opportunities for Sustainable Management of Water Resources and Services in Santiago de Chile

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Abstract This chapter analyses the sustainability performance of water resource and water service management in the Metropolitan Region of Santiago de Chile, adopting water resource and water service perspectives. By comparing the targets with the current situation, we address sustainability deficits and identify potential risks to and opportunities for sustainable development. On the basis of this assessment, we summarize some of the most pressing issues that pose risks to sustainability and suggest mitigation alternatives. On the basis of population projections and historical fresh water data, we find that per capita availability could decrease from 767 to 1,100 today to 575–825 m^3 per capita and year by 2030 for a normal water year, shifting Santiago de Chile from a position of water stress to one of water scarcity. This could become critical for semi-rural localities surrounding the urban core, which are currently outside the concession area of the major drinking water utilities. Although sewage treatment has improved considerably in the last 10 years, several reaches of natural streams remain at risk as a result of unregulated liquid emissions and solid waste disposal. Storm water management is still mostly confined to the development of a vast collection and disposal infrastructure, without significant investment in distributed management systems. Hence the risk of flooding in the lower areas of the city remains high, compounding other social problems in the city.

Keywords Drinking water • Integrated water resource management • Irrigation • storm water management • Sustainable use of water • Waste water management • Water resources • Water services

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12.1 Introduction

The development of cities, i.e., dense settlements of human beings within a restricted area, requires – among other conditions – the delivery of sufficient quantities of water to the settlements, and the collection and removal of different kinds of waste water from these settlements to avoid the emergence of epidemics. The safe functioning of the water supply and waste water transport technologies were thus prerequisites for the development of cities 8,000 years ago in the ancient civilizations of the Indus valley, Mesopotamia, Greece and Rome.

Referring to the Brundtland Report (WCED 1987), which delivers the widely accepted modern definition of sustainable development, water-related sustainable urban development entails meeting the water-related needs of today's city inhabitants without compromising the ability of future generations to meet their own water related-needs (intergenerational justice) or that of people currently living outside the city to meet theirs (intragenerational justice). Hence sustainable water management must take city water services (present and future) into account and the impact on these services in other urban areas upstream and downstream, as well as on water resources outside the city (e.g., long-lasting ecological functions).

The purpose of this contribution is to define the relevant features for sustainable urban water management in Santiago de Chile and to assess whether and to what extent the performance of both urban water services and water resources management can be regarded as sustainable in the aforementioned sense. Section 12.2 presents the research approach and methods utilized to identify opportunities and risks to sustainability. In Sect. 12.3 we indicate the principal findings of our research, which include a current status analysis of water resources and services, and a distance-to-target assessment. Some of the most pressing issues of water resource management in the Metropolitan Region of Santiago are identified in Sect. 12.4, where we suggest possible courses of action to mitigate risks to sustainability. Finally, Sect. 12.5 presents major conclusions of this study.

12.2 Research Approach

12.2.1 Conceptual Framework: Sustainability Assessment and Risk Concept

To answer the question raised above on the sustainability of the water sector, the Helmholtz Integrative Sustainability Concept (Kopfmüller et al. 2001) was applied and contextualized (see Chap. 4). Following Kopfmüller and Lehn (2006), a distance-to-target analysis was adopted (see Fig. 12.1) and modified to a three-step procedure: (1) target definition, (2) status analysis and (3) distance-to-target evaluation. Within the target definition, appropriate sustainability criteria and

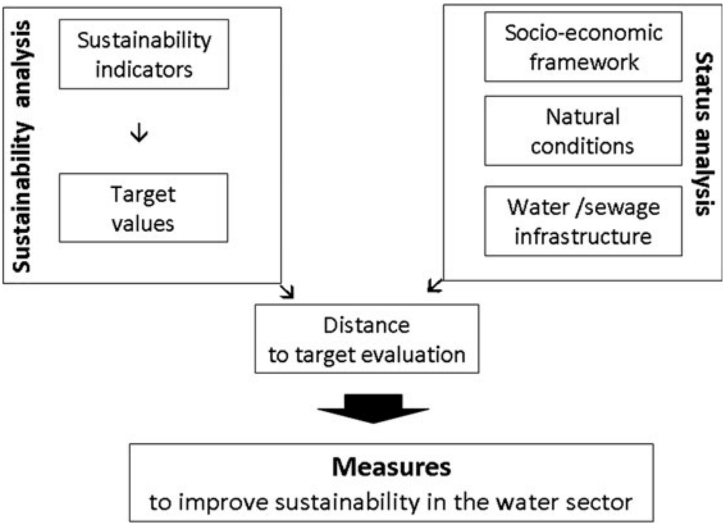

Fig. 12.1 Distance-to-target approach (Source: The authors)

indicators pertaining to the water sector (state and non-state) were developed jointly with regional stakeholders. In the status analysis actual data for these indicators was collected, and a snapshot of the city in terms of sustainability metrics was obtained. The distance-to-target evaluation sets this data in relation to the specifically defined or generally accepted target values of the indicators previously identified. The variance (distance) between the intended target value and the status quo value marks the extent of the sustainability deficit.

The risk dimension of the problem is directly correlated to the distance-to-target analysis, where greater distance to targets is associated with enhanced risk to sustainability. This connection is not yet quantitative in the sense traditionally employed in other risk analysis applications. However, the extension can easily be made once hazard factors and at-risk populations are identified – for example, in the case of local flooding or water shortages that impact on peri-urban localities. Sustainability deficits with a vast temporal or spatial range (including the number of people affected) or with irreversible impacts are regarded as significant risks to the sustainability of water resources and services in the megacity and its surrounding regions.

12.2.2 *The 'Water System' of the Metropolitan Region of Santiago de Chile*

The description of the 'water system' in the RM Santiago includes a brief geographical and institutional outline. The geographical boundary of the Maipo-Mapocho river watershed largely defines the boundaries of the water system in the metropolitan region. As seen in Fig. 12.2, the catchment areas of these two

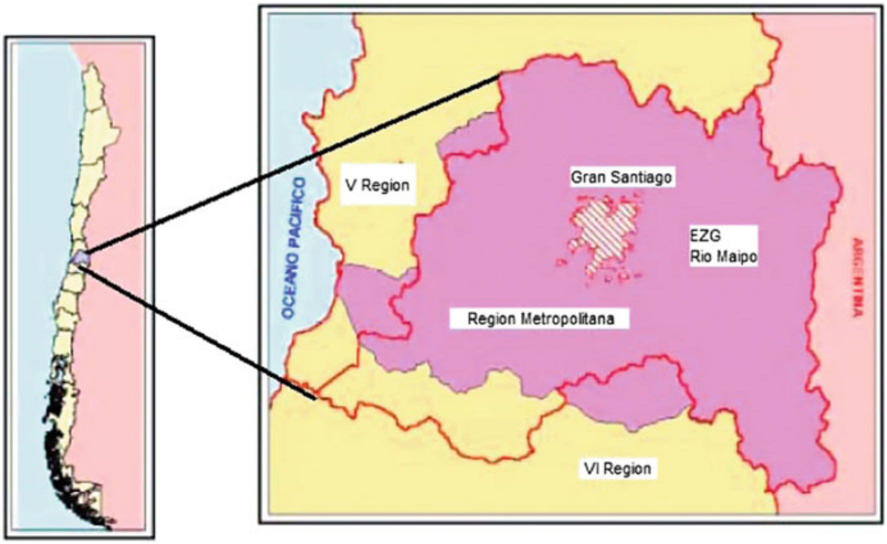

Fig. 12.2 The Santiago Metropolitan Region (within the black bold line) and the catchment area of the Maipo-Mapocho River System (grey) (Source: Bartosch 2007, after DGA 2003)

rivers coincide for the most part with the area of the RM Santiago. Thus, socio-economic data based on the RM Santiago can be related to data on the water resources of the Maipo-Mapocho catchment.

The research perspective in this analysis focuses on a water *resources* and a water *services* perspective. The water resource perspective characterizes ecosystems that provide ground and surface water and the human activities that impact on them. The water services perspective refers to the existing water supply and waste water treatment infrastructure, and its impact on the customers concerned.

The institutional water system is mainly defined by the fact that Chile's water sector is mostly privatized, using a concession model. The Chilean water law and its definition of water user rights is unique. The privatization process of the Chilean water and sanitation sector from 1998 to 2005 represents one of the most far-reaching reforms in Latin America, transferring ownership of assets from the public to the private sector. Water supply and sanitation coverage and quality was to become universal. Investments required to reach the target of treating 100% of Chile's sewage were estimated at approximately US$ 1.5 billion, a sum the Chilean government could hardly afford. Furthermore, service providers should be self-financing with higher tariffs representing real service costs and more efficient performance (Jouravlev and Valenzuela 2007).

The largest water utility in Santiago is the Aguas Andinas Group, which is mainly owned by Aguas Barcelona (AGBAR) with 41.2% of the shares, while the state retains 34.98% through the CORFO agency (CORFO 2010). The Aguas Andinas concession area for drinking water covers most of the urban region, with connections to more than 1,470,000 households. The second biggest utility is the municipal owned SMAPA, which serves 185,473 households in the southwestern commune of Maipú with about 600,000 inhabitants (SISS 2010). As far as waste water collection and treatment are concerned, the concession area of Aguas Andinas includes the commune of Maipú. However, not all inhabitants of the region are connected: rural towns remain outside the concession area, and Aguas Andinas is not obliged to incorporate newly urbanized areas into its network.

The drinking water supply in the concession areas of the two main water suppliers adds up to about 20 m^3/s. Of these, 17 m^3/s (85%) are fed by surface water from the River Maipo, Laguna Negra and River Mapocho; the remaining 3 m^3/s (15%) are supplied from ground water resources primarily extracted by the communal supplier SMAPA in the commune of Maipú (compare Fig. 12.3). Nevertheless, all water utilities and many of the agricultural users own ground-water wells, which are operated when surface resources run dry.

Existing regulatory and planning processes are marked by a pure state-company structure. The Regulation Authority for Sanitation Services (Superintendencia de Servicios Sanitarios (SISS)) allocates concessions, controls the companies, sets tariffs, and defines service and quality standards. It works out investment plans and penalizes non-compliance. Furthermore, it is responsible for consumer protection and represents the customer during the tariff process. Unlike other countries, there is no independent consumer agency in Chile. The Chilean General Water Directorate (Dirección General de Aguas – DGA) is involved in the system to the extent that it grants the water rights required for concession allocation, while the planning ministry MIDEPLAN allocates subsidies and the national environmental ministry MMA (former CONAMA) steers environmental policies.

Water balance challenges and institutional conditions, as well as stream health and the relation between RM Santiago and its hinterland are some of the major water and environmental issues. Water quality can be affected by mining operations in the upper reaches of the Mapocho River; unregulated discharges of liquid effluents and solid waste along the Maipo and Mapocho Rivers threaten the quality of the water at their lower reaches; new hydropower projects (Alto Maipo – AES Gener) have caused conflict among residents of the Upper Maipo Valley; finally, poorly enforced gravel mining operations along the Maipo River pose a threat to other infrastructure facilities, such as bridges and water intakes.

12.2.3 Data and Information Sources

12.2.3.1 Water Budget Investigation

The budget for renewable water resources available, on the one hand, and the anthropogenic need, on the other hand, were calculated via literature research and personal interviews. An extensive bibliographic search was carried out in several organizations related to water distribution. The most important institutions for these investigations are: DGA, Chilean Ministry for Public Works (Ministerio de Obras

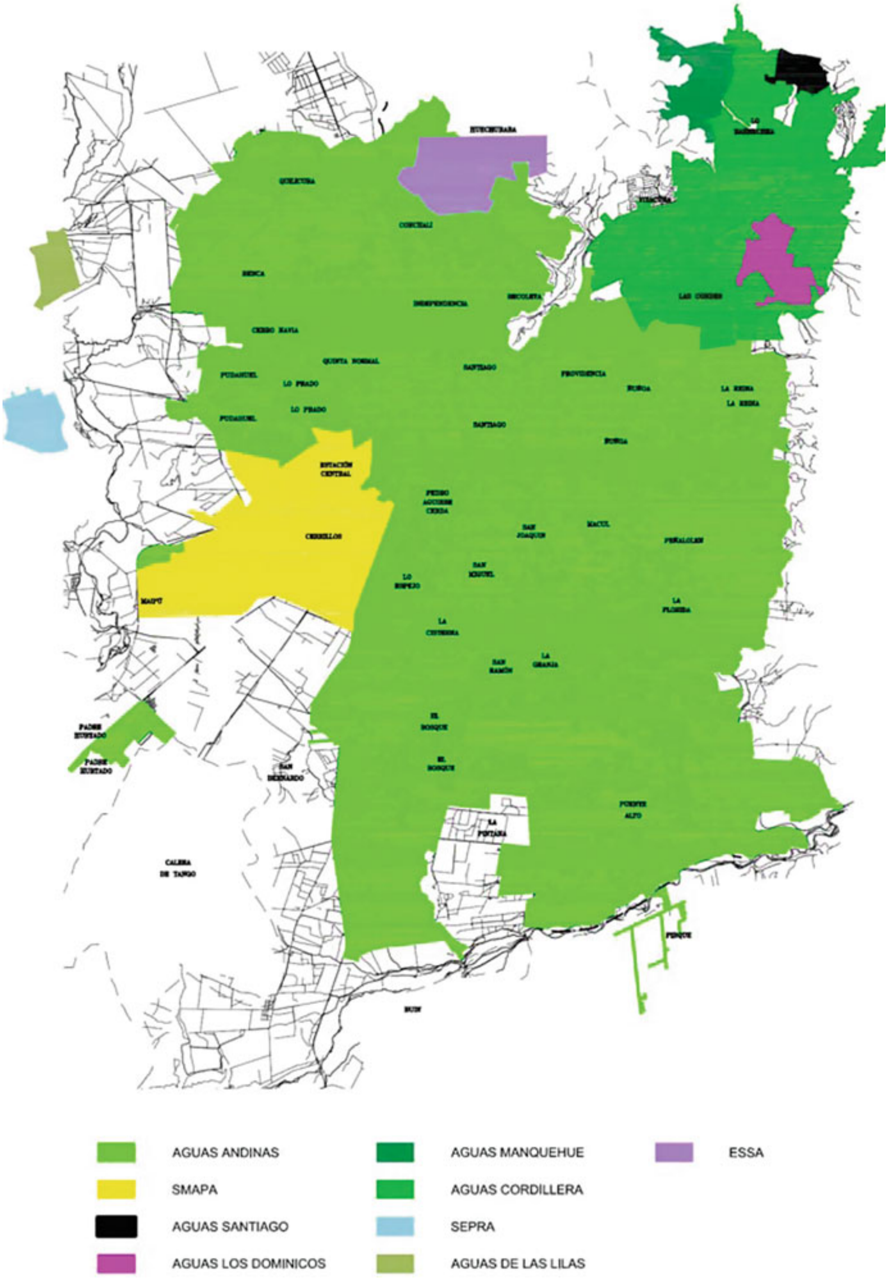

Fig. 12.3 Concession areas of drinking water suppliers in Santiago de Chile (Source: Vogdt 2008)

Publicas – MOP), SISS, MMA at its central and regional branches (SEREMI MMA RM), and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC).

12.2.3.2 Heavy Metal Trace Analysis

For heavy metal analysis (see Sect. 3.2 for results) at each sampling point, a pair of water samples was taken between March 28 and April 10, 2009. They were conserved by nitric acid in suprapure quality and analysed using atomic absorption spectroscopy. Results were obtained by calculating the arithmetic mean of the individual measurements and assessed by comparing them to the Chilean drinking water guidelines (NCh409/1 2005).

12.2.3.3 Modelling of Sediment Management of the Maipo River Basin

A specific activity regarding water and stream bed management was carried out in the form of a Decision Support System (DSS). The DSS involves a simulation model that couples a management model with the Model for Sediment Transport and Morphology, MOSSEM (González 2006; Abarca 2008). The model development considers several modifications, mainly to include gravel extraction from the

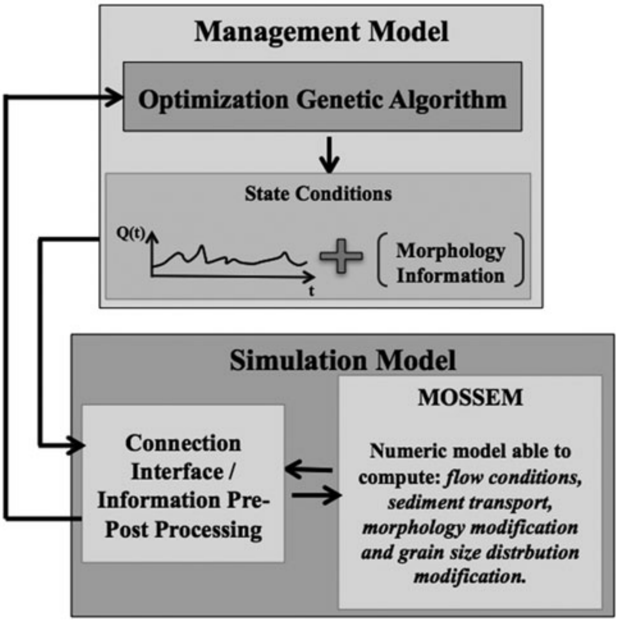

Fig. 12.4 Connectivity implementation between the numerical model (MOSSEM) and the management mode (Source: Melo et al. 2010)

stream bed in the local sediment mass balance. Thus, the modified model can evaluate the dynamic change in morphology as a result of gravel extraction. Based on optimization, the management model is developed, adapting an open source Genetic Algorithm (GA) code. A general scheme of the model is given in Fig. 12.4. It is worth emphasizing that the methodology used in this study for coupling the models can be applied to any morphological model that is based on binary files for inputs/outputs (similar to MOSSEM).

12.3 Results

12.3.1 Target Definition: Development of Sustainability Indicators

In a first step, 64 sustainability indicators for the water sector were developed and discussed with institutional stakeholders. They address the following dimensions (number of indicators related to each dimension in brackets):

- Human life (5)
- Equal opportunities (7)
- Natural resources (17)
- Governance (10)
- Social and cultural resources (12)
- Global stewardship (3)
- Securing society's productive potential (10)

From these 64 indicators, 14 core indicators (shown in Table 12.1) were deduced according to relevance and data availability during a participatory process that included the relevant governmental and non-governmental organizations. Five of these indicators are specifically related to water *resources*. Six indicators address water *services*. Three indicators serve other purposes. The definition of target values proved to be the working step with the highest need for discussion during this process.

12.3.2 Status Analysis

12.3.2.1 Water Resources

Water Supply in the RM Santiago

With the exception of deep ground-water resources and glaciers, the residence time of fresh water resources within a watershed ranges from days (atmosphere, rivers) to years (ground water) (Lehn and Parodi 2009). This means that within the space of

Table 12.1 Core sustainability indicators for the water sector

Indicator
Water resources
Relation between natural water offer and human demand, differentiated by aquifer or river basin
Existence of environmental quality norms (secondary norms) related to natural quality of water bodies (expressed in percentage of total number of existing water bodies in the region)
Percentage of length/area of the water bodies suitable for recreation
Degree of norm fulfilment concerning industrial and domestic emissions towards superficial waters
Degree of norm fulfilment concerning industrial and domestic emissions towards ground water
Water services
Percentage of children under the age of five affected by water-related diseases, measured as DALYs according to the WHO definition (sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability), differentiated by commune
Percentage of water samples that fulfil the Chilean drinking water norm, differentiated by supplier
Percentage of the population connected to a safe and hygienic sewage system, differentiated by commune
Percentage of drinking water loss in the distribution system
Cost of domestic water services as percentage of the total income, differentiated by socio-economic groups (quintile)
Tariff rates for the collection of storm water according to the degree of sealed surface of real properties
Others
Water use per capita, differentiated by commune
Participation of NGO/civil society in sanitary sector decisions
Percentage of participation processes where stakeholders are content with the outcome

Source: The authors

one human generation all of the water in the Santiago watershed will have been renewed. Hence fresh water can be considered a renewable resource. According to the former chief economist of the World Bank, Herman Daly (1996), renewable resources should be harvested only at the speed at which they regenerate. Fresh water resources are naturally replenished by precipitation and the inflow of ground and surface water from upstream regions. In the case of the urbanized area of Santiago de Chile this refers to precipitation (primarily in winter) and inflow from the River Maipo and the River Mapocho, both of which originate in the Andes Mountains near the Argentinian border.

Meteorological input is highly variable in the Metropolitan Region. As a result of the ENSO phenomenon with wet (El Nino) and dry (La Nina) years, annual precipitation fluctuates substantially. In Santiago (Quinta Normal meteorological station) the driest years in the period from 1950 to 2004 had values as low as 100 mm/a and as high as 700 mm/a and more (DGA 2007a after Bartosch 2007) – compare Fig. 12.5. The long-term precipitation average in the Central Valley (between the coastal Andes in the west and the high Andes in the east) varies between 261.6 mm in the west of Santiago (Pudahuel) and 347.2 mm in the east at the foot of the Andes (Tobalaba).

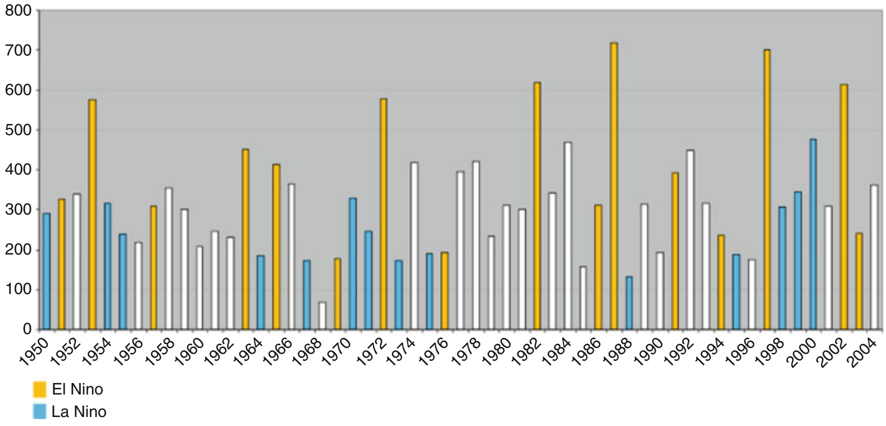

Fig. 12.5 Long-lasting precipitation variations in Santiago – Quinta Normal Station (Source: DGA 2007; Bartosch 2007)

Table 12.2 Absolute and specific amount of renewable fresh water available (supply)

	Available fresh water (km/year)	Specific offer of available fresh water – 6 million people (m/capita year)	Specific offer of available fresh water – 8 million people (m/capita year)
Normal year	4.6–6.6	767–1,100	575–825
Wet year	6.3–7.3	1,050–1,217	788–913
Dry year	2.8–3.2	467–534	350–400

Source: Bartosch 2007

The amount of inflowing water from the Andes can be measured at two gauging stations, El Manzano for the Maipo River and Los Almendros for the Mapocho River. The inflow of the River Maipo varies between 60 and 75 m^3/s in dry and 140 m^3/s in wet years. The corresponding data for the River Mapocho is 2–3 m^3/s in dry and 9–14 m^3/s in wet years (DGA 2007a, after Bartosch 2007).

On the basis of this data we conclude that the supply of renewable fresh water available in the RM Santiago varies between 3 km^3 in dry and 6.8 km^3 in wet years – see Table 12.2. If we consider these values as fixed in time and take into account the population projections for the city of Santiago de Chile, we can compute *specific supply* in terms of m^3 per capita per year for current and future population estimates. The corresponding specific values vary between 467 and 1,217 m^3/capita and year in the case of six million, and between 350 and 913 m^3/capita and year in the case of eight million inhabitants in the region (own estimation for the year 2030). These estimates would transfer Santiago from water stress conditions today to water scarcity conditions in the course of 30 years according to the Falkenmark Index (Falkenmark 1989), not considering hydrologic trends and climate projections. These projections involve the warming and drying of central Chile's climate under most emission scenarios as defined by the IPCC (DGF 2007; Melo et al. 2010).

Water Demand in the RM Santiago

The water demand in the RM Santiago is driven first and foremost by agricultural needs. In the year 2007 this sector accounted for about 74% of the total water demand in the region. The share of drinking water amounted to 17%, while water demand for industrial purposes reached about 9.4% (see Table 12.3). The absolute water demand in the region varies between 3.2 km^3 (wet years) and 4.4 km^3 (dry years), depending on irrigation needs (INE 2002 after Bartosch 2007).

According to Aguas Andinas (2005c), the average specific drinking water consumption per capita in Santiago is 222 l per capita and day. A slight decrease of 6% to 207 l per capita and day is expected by the year 2019 (compare Table 12.4). In contrast, the per capita daily consumption of private households in Berlin in 2006 was 116 l. Specific data on drinking water consumption in various municipal districts of Santiago can be estimated on the basis of development plans for drinking water supplies (Aguas Andinas 2003a, 2005a, b, 2006a, b; Aguas Cordillera 2005; Aguas Los Dominicos 2005; Aguas Santiago Poniente 2006), based on historical and empirical consumption analysis. Waste water quantities are estimated by calculating

Table 12.3 Water usage by different economic sectors in the Metropolitan Region of Santiago in 2007 and the prediction for 2017 and 2032

Usage	2007 km^3/year	2017 km^3/year	2032 km^3/year
Agriculture	2.60	2.54	2.54
Drinking water	0.58	0.74	0.78
Industry	0.33	0.49	0.87
Mining	0.02	0.04	0.06
Total	3.52	3.80	4.25

Source: DGA 2007b

Table 12.4 Per capita drinking water consumption in the concession area of Aguas Andinas S.A for the year 2005 and predictions for the future

Year	Consumption (l/capita day)
2005	222
2006	221
2007	219
2008	218
2009	217
2010	216
2011	215
2012	214
2013	213
2014	212
2015	211
2016	210
2017	209
2018	208
2019	207

Source: Aguas Andinas 2005c

losses arising from, e.g., hosing of gardens, of which there are many in some of the eastern Santiago areas (e.g., Las Condes).

The calculated variation between poor and prosperous areas of the city is striking: estimations of water use variability indicate a per capita consumption of 120 l per capita and day in Bosques de San Luis, for example, and more than 850 l in Santa Rosa del Peral (Vogdt 2008).

Heavy Metals in Surface Waters

In line with Santiago's geological conditions upstream (Frikken et al. 2005), copper mining takes place on a large scale at 'Minera Los Bronces' – more familiar under its previous name 'Minera Disputada de las Condes' – in the Mapocho catchment (Spürk 2010). Smaller mining activities are carried out on the upper reaches of the Maipo River ('Minera Erfurt'). Natural resources and anthropogenic processes suggest the presence of heavy metal in the environment. Due to the high degree of surface water in the drinking water supply (see above), a random test on trace metals was conducted at certain points in the Maipo/Mapocho catchment.[1] Copper concentrations in the Maipo sub-catchment show values below 5 μg/l, similar to the drinking water sample measured for Providencia, which is far below the threshold value of 2,000 μg/l. In the Mapocho sub-catchment, on the other hand, concentrations are higher by a factor of 100–1,000, and occasionally even exceed the drinking water threshold. This indicates the need for a careful analytical survey at regular intervals to guarantee the fulfilment of drinking water norms in the Mapocho supply area (Fig. 12.6).

Arsenic concentrations in water samples taken at the Mapocho, El Volcán and Yeso Rivers in the Maipo sub-catchment range between 1 and 6 μg/l, or approximately 10–60% of the drinking water threshold. Water samples from the upper Maipo River show arsenic concentrations within the range of 15 μg/l. After inflow from the River El Volcán and the River Yeso, these concentrations decrease to a level of 12 μg/l but still exceed the threshold value for drinking water. The fact that concentrations of less than 2 μg/l have been detected in the drinking water in Providencia, which is supplied by water from the Maipo System, and that the water works of La Florida and Las Vizcachas have no purification technology specifically for arsenic leads us to conclude that most arsenic is removed during the drinking water treatment process. The concentration of arsenic in the drinking water sample analysed undercuts the threshold value of 10 μg/l, now called for in the Chilean drinking water guideline.

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[1] The authors are immensely grateful to Adnan Al-Karghuli and Gerd Schukraft from the Geographical Institute of the Heidelberg University (Germany) for their detailed analysis of heavy metal concentrations.

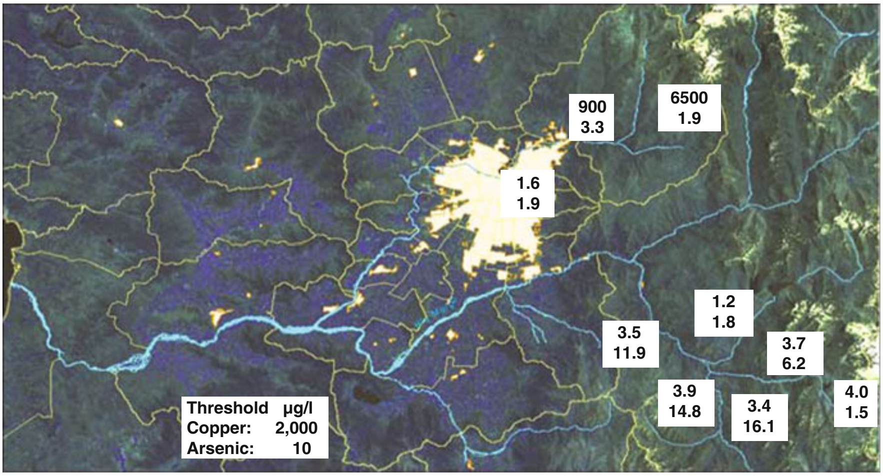

Fig. 12.6 Copper (upper value) and arsenic (lower value) concentrations in the surface waters of the Maipo/Mapocho catchment and drinking water in Providencia (µg/l) (Source: The authors)

12.3.2.2 Water Services

Water services are essential for the smooth running of cities. In terms of sustainability analysis, water services are an indicator of whether the needs of the present urban population are being met. If services are efficient and their performance in compliance with the appropriate indicators, a prerequisite for sustainability has been fulfilled.

Drinking Water Supply

Over 99% of the inhabitants within the urban confines of Santiago have been connected to drinking water supplies since the 1990s (Vogdt 2008). Santiago has therefore reached the drinking water coverage level of developed countries. No sustainability deficit could be detected with regard to current access to drinking water. Aguas Andinas S.A. – along with its subsidiary companies Aguas Cordillera, Aguas Manquehue and Aguas Los Dominicos – is the chief supplier of drinking water in the RM area, using surface water from the River Maipo, Embalse El Yeso, Laguna Negra and the River Mapocho. In the southwestern commune of Maipú, which has about 600,000 inhabitants, the municipal company SMAPA supplies drinking water obtained mainly from ground water. The water supply is steady and water pressure adequate (according to Nch 409/1 2005) (Simon 2009).

Outside the concession areas of the above-mentioned drinking water companies, specific population groups in the more rural periphery of the RM could be at risk of exclusion from basic water services (Durán 2009). These peri-urban settlements rely on self-managed *Rural Drinking Water* supply systems that operate under a cooperative management system with technical assistance from the government. However, technical expertise is frequently a scarce commodity and operations are further complicated by lack of resources. Moreover, these rural systems usually rely on ground-water wells as their sole source of water, making them vulnerable to intense drought, which reduces ground-water levels. The inclusion of these localities in the concession area of the utility company would probably mean improved service quality and reliability, albeit at higher cost. In many instances, however, economic constraints prevent utility companies from expanding their coverage areas. A few of the non-concession localities are adjacent to zones with drinking water supplies provided by a private utility; this stresses the economic origin – rather than geographic nature – of this spatial variability in sanitation coverage status.

According to the SISS (2008a), Santiago drinking water has been fulfilling WHO international quality standards (WHO 2006) since 2005. Recent quality census results show that urban drinking water is 96.1% safe to drink. Water quality, which has increased steadily since the 1990s, is strongly connected to the low child mortality rate in Santiago; the child mortality here is the lowest in South America and comparable with European rates (SISS 2008a). Random water analysis of samples taken in the context of the RHM project revealed low copper concentrations in the drinking water despite elevated concentrations of this heavy metal in the Mapocho River.

Sewage Treatment

By 2006, approximately 90% of the urban population was connected to sewer systems. Waste water collection and treatment is performed by the Aguas Andinas Group (compare Sect. 2.2) for the entire urban area of RM Santiago. The heavy concentration of inhabitants and industrial production in the city results in huge amounts of sewage of a highly complex composition. Total sewage production in Grand Santiago is estimated at 18 m^3/s (equivalent to 1.6 mill. m^3/day or 584 mio. m^3/year). In 2008, 13.2 m^3/s (73.3% of total sewage) were treated in the two large sewage treatment plants, El Trebal and La Farfana. Effluents from these plants and untreated sewage from northern districts such as Colina, Batuco and Lampa are discharged into the Mapocho River. The purification capacity of both plants is comparable to European standards with regard to the decomposition of carbon compounds: the COD is reduced by 92–94% (Berlin: 96.7%), the BOD by 95–97% (Berlin: 99.2%). Nutrient decomposition (nitrogen and phosphorous) is low (25–35%) compared with modern German plants (Berlin: 85–97%) (Lehde 2010).

Current legislation requires disinfection of semi-treated sewage by chlorination in a final treatment step to remove pathogenic micro-organisms. Chlorination of semi-treated sewage carries the risk of synthesizing new chlorinated hydrocarbons in the sewage. Due to inadequate laboratory capacities to analyse these compounds in Chile (Vogdt 2009, personal communication) no information is available on these substances in the watercourses.

To improve the environmental situation within the confines of the city (offensive odour near the river), a large sewer was recently built parallel to the riverbed of the Mapocho River that cuts across the city. Its purpose is to collect sewage from the northern parts of Santiago (5 m^3/s) and conduct it to the southwest where three-fifths of the sewage is released into the river and two-fifths treated in the treatment plants mentioned above (Projecto Mapocho Urbano Limpio). A third purification plant with a capacity of 6.6 m^3/s on the site of the El Trebal plant, called Los Nogales or Mapocho, is in the planning stage. When it begins operations (expected in 2015), Gran Santiago will have a total purification capacity of 19.8 m^3/s, which exceeds the amount of waste water currently collected.

The treatment of sewage sludge has a negative impact (offensive odour) on the neighbourhood of the Maipú commune. For this reason a large share of the sludge is now dumped at the 'Lomas Los Colorados' landfill approx. 100 km north of Santiago. In the long run sewage sludge from altogether three purification plants will be treated in the new sludge treatment plant 'El Rutal' located close to the 'Lomas Los Colorados' site. Sewage sludge production is expected to reach an annual 139,000 tons (dry matter), which is equivalent to roughly 14,500 truckloads of 25 t. If the sludge is dried beforehand, it would yield a dry matter proportion of 38%.

Rural and semi-rural settlements co-exist on the periphery of Santiago, outside the Aguas Andinas Group concession areas. Here, more decentralized waste water treatment systems are in place (septic tanks and compact treatment plants), which are typically beset by problems related to odour, maintenance and operation of the plant, and especially sludge disposal (Inter-American Development Bank 2007). According to a recent SISS study (IASA 2007) nationally reported issues on odours emanating from sewage treatment plants did not refer to the size of the plant. However, most problems associated with offensive odours did relate either to the sewage system or sludge treatment.

Finally, practical/field experience described in a number of studies (e.g., IASA 2005) also indicates that treatment could be improved in terms of comfort and the security of the population.

12.3.3 Distance-to-Target Analysis

12.3.3.1 Water Resources

Quantitative Aspects

As far as the sustainable use of water resources in the RM Santiago is concerned, the most important deficit is the relationship between available fresh water and water usage. A comparison of the data in Tables 12.2 and 12.3 clearly indicates that current and future water demands cannot be met in dry years. The water demand of

3.5 km^3 in 2007 accounts for 53–76% of the total fresh water available in a normal year. The estimated demand of 4.3 km^3 in 2032 represents even 66–92% of the freshwater offer available in a normal year. The water demand in dry years now already exeeds the amount of renewable fresh water.

In her global overview of water stress in river catchments, Döll (2008) assessed the Maipo/Mapocho catchment to be under very high water stress. The ratio between water extraction and renewable water resources (precipitation minus evapotranspiration average for 1961–1990) is higher than 0.8 – the worst classification, and comparable to North Africa or the Middle East. See Fig. 12.7 below.

Falkenmark classifies a region's water status in terms of per capita availability. A fresh water availability of more than 1,700 m^3/capita year is not a cause for concern. Availability ranging between 1,000 and 1,700 m^3/capita year, on the other hand, is defined as water stress conditions. A figure below 1,000 m^3/capita year implies water scarcity, while regions with values under 500 m^3/capita year face severe water scarcity (Falkenmark 1989). In line with the data in Table 12.2, the RM Santiago currently oscillates between water stress and water scarcity. If the statistical prognosis on population growth materializes (INE, CEPAL, no date) by 2050, the situation will deteriorate to oscillation between water scarcity and severe water scarcity levels.

In accordance with these findings, the ground-water table at 'Estación Consejo Nacional de Menores' in the central sector of Santiago fell from 14 to 26 m below the surface in the period from 1971 to 2001, (DGA/MOP 2005). The persistent

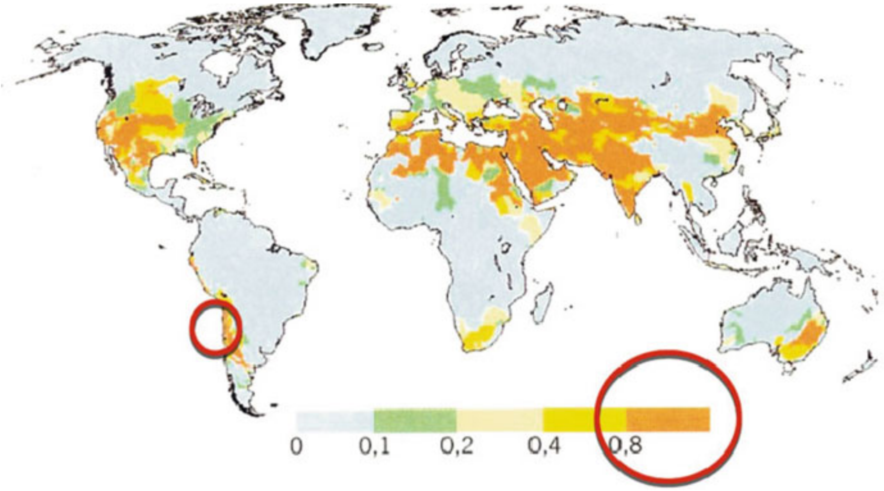

Fig. 12.7 Water stress in river catchments in the year 2000 calculated as the ratio between water extraction and renewable water resources (precipitation minus evapotranspiration 1961–1990) (Source: The authors, based on Döll 2008)

decrease in the ground-water table over decades is a clear indicator that water use exceeds the rate of water renewal. These facts render the situation unsustainable when Herman Daly's above-mentioned criteria are taken into account.

Following a study by Aguas Andinas in 2003, about 94 mill. m^3 (about <20%) of ground water is used by the water suppliers Aguas Andinas, Aguas Cordilleras and Aguas Manquehue, whereas 555 mill. m^3 (about >80%) is surface water from rivers, lagoons and dams (Aguas Andinas 2003b). Since all surface water resources have already been allocated (Simon 2009), the sustainable exploitation of the ground-water resources in the Santiago Valley aquifer is crucial to the Santiago water supply.

Munoz et al. (2003) have evaluated ground-water availability for the upper Santiago Valley aquifer. Recharge by non-point infiltration is sourced from precipitation, river water infiltration, and agricultural and urban irrigation – depending on the degree of urbanization. The latter is a significant measure for decisions on the sustainable exploitation of ground water in the urban region of Santiago. In accordance with assumptions about the efficiency of the water distribution network, seepage recharge contributes to 0.08–0.15 $Ls^{-1}km^{-1}$ (Munoz et al. 2003). The scenario calculations by Munoz et al. allowed for estimation of the reliability of ground-water use under different hydrologic conditions and showed a deficit at the level of maximum demand. The data made it likewise possible to calculate the risk of being unable to cover ground-water demand. The results indicate that simultaneous extraction of ground water by all users would satisfy only 67% of the water rights granted in the basin. Such considerations do not include a potential shift in the water regime in the RM Santiago as a result of global climate change.

Water Quality Aspects

As shown in Sect. 3.2, the negative impact of sewage from the megacity Santiago on downstream areas has continuously been reduced and performance is improving. Now that the third sewage treatment plant has gone into operation, status and target values of norms for treated sewage emissions should no longer differ greatly to treatment levels in threshold countries. The most important open questions in this field concern the effect of chlorinating the residual carbon compounds in semi-treated sewage and the possible new synthesis of chlorinated hydrocarbons and the related environmental and (eco-)toxic effects.

Concerning urban water supply in the future, climate projections indicate that the region will experience an increase of mean temperature ranging from 2°C to 4°C and a reduction in seasonal precipitation from 10% to 25% by the end of the twenty-first century (DGF-CONAMA 2007). Under these conditions surface water will become a scarce resource (Melo et al. 2010). The growing demand for water resources must be met by the sustainable use of ground and surface water.

The growth of Santiago has brought with it an increase in the extent of impervious surface, altering the hydrological behaviour of urban areas. The expansion of the city has impacted on the water cycle in the urban region in the form of sealing recharge areas in the surroundings of the River Maipo and the River Mapocho, the two main rivers. Additionally, there is an enhanced risk of diffuse contamination from leaky sewers.

The impact of urban recharge into urban aquifers can be evaluated with environmental isotopes. Iriarte et al. (2006) show high concentrations of nitrates and sulfate for the alluvial aquifer of the Mapocho River Basin – below the old city of Santiago. As shown from evidence gathered by N-/S isotopes from ground water and surface water, leaky pipes in the sewage collection system were partly responsible for the recharge into the urban ground water (Iriarte et al. 2006).

Our own isotope studies demonstrate that the water in the River Maipo and the River Mapocho springs from the high altitude source region. However, the water quality of both rivers is affected by typical anthropogenic indicators in the surroundings of Santiago such as boron, sodium, chloride and sulphate.

The fulfilment of emission norms (Table 11.1, indicator Nos. 4 and 5) lies at about 90% for industrial direct discharge and >97% for the discharge of municipal waste water (with and without treatment!) (SISS 2008a, b, 2009, 2010). Secondary environmental quality norms (indicator 2) are proposed for the whole catchment area. Appropriateness for human recreation (indicator 3) should be assessed specifically in terms of substances and the related water courses. As seen for the arsenic and copper content measured in the Maipo/Mapocho catchment (Fig. 12.6), a general assessment of the water quality cannot be given. With respect to the improvement of sewage treatment in Gran Santiago, water quality can be expected to improve once the water authorities have been strengthened.

12.3.3.2 Water Services

A comparison between the current situation and the sustainability target shows little or no variation in the water service core indicators 7, 8, 9 and 11. This means that drinking water supply and sewage connection rates, and the attendant hygienic standard attained are satisfactory and affordable. According to the ministry of planning (MIDEPLAN) and the national sanitation authority, Superintendencia de Servicios Sanitarios (SISS), the cost of water services should not exceed 3% of the household income (MIDEPLAN n./a.). As a result of economies of scale, the cost in Santiago varies between 1% and 2.5%, the lowest national value (Simon 2009).

Specific water consumption (indicator 10) in the wealthier parts of the city is assessed as unsustainable if it exceeds 230 l per capita and day. This value was put forward after several discussions with local stakeholders and calculated by doubling the according value for Berlin, and is due to irrigation of private gardens and the semi-arid climate of Santiago. Personal observations produced evidence of unsatisfactory irrigation management: the hosing of gardens frequently continues although water has already begun to flow down the streets and footpaths. Furthermore, it tends to take place in the early afternoon when evaporation prevents a high percentage of irrigation water from reaching the roots of the garden plants.

According to the SISS, both water suppliers, Aguas Andinas and SMAPA, have high losses of about 30–40% in the drinking water supply system, which is an indicator for weak infrastructure (indicator 12). These losses are assessed as unsustainable, since a value of 10% is estimated as state of the art (Howard 2002). In 2007, for example, drinking water losses in the pipe network of the state of Baden-Württemberg (Germany) were approximately 12% (Heitzmann 2009). Moreover, water transport distances in this German state are much longer (200 km and more) than those of Gran Santiago. From a systemic perspective, on the other hand, water losses in the supply network recharge ground water resources and become available to other users, occasionally even to Aguas Andinas itself. Hence on a basin-wide scale, water efficiency is probably much higher, albeit difficult to estimate. An approximation of the optimal percentage of distribution losses in the system would require detailed analysis.

At present 72% of domestic sewage in Santiago is treated (El Mercurio 2010). When construction of the large sewer parallel to the Mapocho River (‘Mapocho urbano limpio’) is complete and the third sewage treatment plant goes into operation, between 80% and 100% of the city’s sewage will be treated (El Mercurio 2010). Santiago will then be the Latin American city with the highest degree of treated wastewater. This measure will not only improve the quality of life in the city (offensive odour) but, more importantly, allow for irrigation of 130,000 ha of agricultural land downstream from Santiago, where crops will benefit from the radical reduction in the risk of exposure to fecal micro-organisms resulting from urban waste water (Bernales 2008).

Storm water management is another water service with a performance below par. As economics play a major role in Chile, an economic rather than a technical indicator was chosen to assess storm water management. Indicator 6 suggests fixing tariff rates for storm water collection according to the percentage of sealed real estate. This would provide the necessary financial resources for construction and maintenance of a storm water treatment system and at the same time motivation to avoid or minimize soil surface sealing.

12.4 Water Sector Challenges and Mitigation Alternatives

After several workshops and meetings with local stakeholders associated with the water sector, we identified several challenges facing Santiago and the Metropolitan Region. Beyond appropriate coverage of drinking water and sewage services at the basin scale, more local issues require special attention, since they typically affect economically disadvantaged subsets of the population.

12.4.1 Storm Water Management

Subsequent to the privatization of the water sector in the 1990s, various authorities (e.g., DOH, municipalities, SERVIU) were involved in the management of storm water. With the exception of some inner-urban municipalities that operate a combined sewage system (e.g., Santiago central and Providencia), waste water sewers exist only in other parts of the city. Storm water is discharged by streets and often causes flooding in the lower – mostly poorer – areas of Santiago. Government agencies and the private water/sewage utility Aguas Andinas pursue different strategies to improve the situation. New storm water sewers are in the planning phase or under construction by DOH, and include centralized approaches to storm water management, e.g., temporary flooding of parks. The Aguas Andinas group, the only private water service supplier expected to run the storm water treatment system, has plans for an alternative. The idea is to transport storm water with the sewage, thereby converting the system into a combined sewage system that would serve the entire city.

Decentralized storm water management facilities (e.g., infiltration systems, green roofs, retention systems) are nonexistent. If these technologies were to be legally sanctioned as flood prevention installations (with the relevant financial support), they would spread more rapidly.

12.4.2 Gravel Mining and Sediment Management at the Maipo River Basin

Gravel mining is a common practice in Chile, based on the demand for this type of material for construction. The driving force behind the extraction of aggregates from rivers are: (1) easy access to the source, (2) high quality material, and (3) a wide range of material sizes, reducing the cost of processing the material (Kondolf 2002). In central Chile, sources of fluvial sediments are concentrated in the Andean mountain region, from where they are transported downstream to the river basins.

At the same time, many rivers are subject to extraction of large amounts of water for a number of uses, consumptive and non-consumptive, such as irrigation, drinking water supplies and hydropower generation. As a result of the close relationship between the sediment transport capacity and the flow discharge of the rivers, it is not uncommon for the hydrodynamic behaviour and morphologic development of the latter to be controlled by external activities. These are planned without taking into account the inherent dynamics of these systems in terms of sediment transport processes and the consequent degradation/aggradation of the stream bed.

The issue of gravel extraction is therefore a visible indication of the relationship between the city and its hinterland. Easy access to aggregates is a function of the river, but their extraction is both an operational and an ecological consideration that must be addressed by the city. The economic and ecosystem services provided by the river to the city and its inhabitants becomes seriously endangered when the integrity of its course and riparian habitats is compromised.

12.4.3 Stream Protection

Although significant investment have been made to prevent raw sewage from entering the water courses (e.g., Mapocho Urbano Limpio, sewage treatment plants), many reaches of the Mapocho and Maipo Rivers are continually at risk due to unregulated solid and liquid waste discharges. In the case of solid waste, the stumbling block comes in the form of illegal garbage collectors and informal recyclers who dump unwanted residue along the river banks. The Regional Public Health representative has ranked this situation a major public health concern (personal communication), since contact waters leach contaminants from the garbage and carry them along the river and through the irrigation channel network. In terms of liquid sewage, unregulated discharges originate mostly from industrial activities in the northern part of the watershed. Mellado (2008) and Cox (2007) identified the drawbacks affecting the Batuco lagoon, a wetland located 30 km northwest of downtown Santiago. Here the difficulty is the lack of SISS capacity to enforce environmental regulations. Indeed, most data collected by SISS on liquid residue discharge is self-reported by the dischargers themselves, and the number of personnel available to SISS to enforce compliance is limited.

12.4.4 Water Supply in Semi-rural Areas

According to the regulatory framework, the water utility (in this case Aguas Andinas) retains the right to decide on the areas to be incorporated into its concession zone. Because this decision is based on economics i.e., the balance of connection costs against water sale revenues, less densely populated areas adjacent to the urban zone are often not connected to the utility network. This is true for many localities in the northern and southern periphery of Santiago. They satisfy their water needs with self-managed, cooperative supply systems (Sistemas de Agua Potable Rural, APR, or rural drinking water systems) that generally rely for water on a single ground-water well. Although APRs receive technical support from the state via a special unit of DOH, regional public representatives expressed concern about the reliability of these systems, claiming that as a rule the quality of the service was inferior to what could be achieved if the localities were connected to the main utility network. All of this poses a risk to sustainability, since the combination of population growth and ground-water depletion could render a number of APRs unviable, particularly under drought conditions.

12.4.5 Mitigation Alternatives

In the following we present actions that could alleviate some of the issues identified above. These alternatives are presented here as first-order technical options and not as definitive answers to the water problems identified in Santiago de Chile. An intervention of any kind would naturally require the appropriate technical, economic and environmental assessment before being adopted.

12.4.5.1 Reducing the Flow Speed and Keeping Water Longer in the Catchment

As a result of the vast difference in altitude between the Andes Mountains and the Pacific Ocean, more than 5,000 m for a distance of approx. 100 km, the flow velocity of streams and rivers is high. This may have been an advantage in the past because the hydraulic energy transported water pollution rapidly to the sea. Under today's increasingly unbalanced water situation, this becomes a disadvantage because a surfeit of water is 'lost' to the sea in wet periods.

- The classic option for reducing flow velocity is the construction of dams. This has already been carried out for the upper Maipo catchment area and the Yeso River (Embalse de Yeso). Another option is to build several small dams in the Central Valley where the Maipo River flows into the south of Santiago. The upstream dams could be used to catch sediments, while those further downstream could contribute to water-related recreation close to the city. Both types could help to recharge the ground-water body beneath Santiago by infiltration of surface water.
- With reforestation more water could be stored in the soils of the catchment's mountain area. Since the transpiration rate of trees is much higher than that of agricultural plants, water losses to the atmosphere might increase, making a thorough assessment of reforestation strategies advisable before realizing this option.
- There are other ways of artificially recharging ground-water resources apart from the infiltration of surface water, e.g., the infiltration of storm water in the built-up area of the RM Santiago. Indeed, this connects to option *a* above (dams), as small dams located along the Mapocho River bed could be used to infiltrate storm water to the aquifers during wet periods.

12.4.5.2 Making new Water Resources Available for Anthropogenic Purposes

1. Rainwater harvesting in built-up areas could make use of water quantities that would otherwise gush away to no avail, or worse, cause flooding. Rain can be collected decentrally at the individual real estate level or more centrally along the watercourses and in parks. Since rainfall events in the RM Santiago are concentrated over a few days in winter, the cost effectiveness of the necessary infrastructure (construction and maintenance) is low. It is therefore recommended that the advantage of preventing flood damage be included in the calculation. This alternative also relates to water service issues, as indicated below.

2. The southern part of Chile is rich in water. Technically, as demonstrated in many other countries (e.g., Germany, Libya, Australia), the transport of water in long water pipes or canals is not rocket science. Supplying water to the RM Santiago via long-distance water transport systems is more likely to be an economic or legal rather than a technical issue, given the existing water rights to the prospective source rivers. On the other hand, long-distance water supplies would increase the dependency of the city on distant areas, and carry the risk of externalizing water-related problems to other regions and neglecting the city's local resources.
3. Domestic and industrial water usage does not always imply consumption. Although polluted or heated after use, it may be still available. Household sewage contains carbon compounds, nitrogen and phosphorous, and can be seen as a precious resource for agriculture. Thus more attention should be given to treating urban sewage in such a way that the water and its nutrients can be diverted to agriculture without the risk of microbiologic or toxic poisoning of agricultural soils and products.
4. Water transfers are possible within the current regulatory framework, i.e., in the form of water right transactions carried out on the private market. It is assumed that water transfers from the irrigation to the municipal sector will occur in the future. The price of water in these transactions may affect water tariffs, although to what extent has not yet been calculated.

12.4.5.3 Integrated Institutional Arrangement for Storm Water Management

The appropriate management of storm water could impact on both water resources and water services. From the services point of view, an integrated approach has the potential to reduce the negative outcome of extreme events, e.g., in terms of infrastructure damages, loss of productive time, inconvenience to inhabitants. A number of institutions currently have jurisdiction over this topic, usually through the planning and funding of drainage infrastructure (Municipalities, Housing Ministry-Serviu, Public Works Ministry-DOH). From the resources standpoint, integrated storm water management typically entails a decentralized approach, which in turn includes enhanced infiltration of storm water into the soil. The latter has the double effect of decreasing peak flows (thus reducing the need for large infrastructure) and enhancing the recharge of subsurface sources.

12.4.5.4 Increased Enforcement Capabilities for Water-Related Institutions (SISS, Seremi Salud, DOH)

Many of the quality problems affecting streams in the Metropolitan Region derive from unregulated activities (liquid and solid discharges, excessive gravel mining). Institutional capacities to enforce regulations are limited; increased accountability through enhanced enforcement has the potential to mitigate these problems. A similar effect can be achieved by self-regulation. However, this requires a cultural shift that may take years, intensive environmental education notwithstanding.

12.4.5.5 Incorporation of Stream Uses to Evaluation Processes

Due to the current institutional framework, water-related decision-making is confined to water right holders through a free-market system. Hence, only economic uses are regarded in this process (in-stream flow requirements do not apply in the Maipo-Mapocho Rivers, since all water rights were assigned prior to the passing of the Water Codex modification in 2005). In the Maipo-Mapocho basin, water right holders are mostly farmers or water utility and hydropower companies. As a result water management tends to represent the interests of these stakeholders. Opening the decision-making process to civic participation and giving more weight to non-economic water uses (such as environmental conservation and restoration), increases the potential to enhance environmental water services and make them available to a larger share of the population in the city and its hinterland.

12.5 Conclusions

In this chapter we presented opportunities for and risks to the sustainability of water resources and water services in Santiago de Chile and its surrounding watershed. We adopted a sustainability indicator/distance-to-target conceptual framework to categorize and rank the most relevant aspects of the topic, based on interviews, workshops and meetings with local public and private stakeholders.

From a comprehensive literature review, field measurements and modelling, we characterized the current status of Santiago de Chile in terms of the sustainability indicators. As far as water resources are concerned, attention should be given to the most pressing sustainability deficit: the quantitative relationship between the available fresh water offer and water demand. With respect to anthropogenic water demand, the per capita availability today of 500–1,200 m^3/capita year marks oscillation between water stress and water scarcity. Sheltering eight million inhabitants in the future, the Metropolitan Region of Santiago may find itself in a more dire situation if added resources are not allocated to municipal and industrial supply. Then, by providing a reduced water quantity of a mere 350–800 m^3 per capita and year, the RM Santiago would proceed from being a region with water scarcity to one with severe water scarcity.

Today more than 80% of available water resources have been extracted. In other words, water reserves are at a dangerously low level. Population growth and mounting economic activity speak for an unbalance between the natural water supply and anthropogenic demand. Even without considering the impact of global climate change, the situation may well deteriorate radically in the future.

Table 12.5 Options for measures to overcome water stress and water scarcity in the RM Santiago

Reduce flow speed – keep water longer in the catchment
– Dams
– Afforestation
– Artificial ground-water recharge
Make new water resources available
– Rainwater harvesting
– Long-distance water transport
– Use more virtual water
– Regard waste water as a resource
Improve water efficiency
– Agriculture: more crop per drop
– Industry: from throughput to water cycling
– Households: use water in cascades: drinking – > toilet flushing – > irrigation
Increase water sufficiency
– Propagate 150 l per person
Capacity development

Source: The authors

The findings of this water sector analysis have led to recommendation of the following options (Table 12.5).

From the point of view of water services, aggregated coverage of the drinking water supply and sewage collection is almost complete. Sewage treatment has increased dramatically in the past 10 years due to investments made in the context of water utility privatization. In this sense, Santiago boasts one of the best situations in the region. Yet problems exist on a local scale. These are related primarily to service deficiencies in semi-urban areas, which are located in the immediate vicinity of Santiago but not connected to the chief distribution networks. Likewise, water quality deficits and stream degradation pose a risk to sustainability at some reaches of the Maipo and Mapocho river networks.

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