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Global Demographic and Climate Challenges in the City
An interdisciplinary assessment of impacts, needs and strategies

Herausgegeben von:
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Content

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Climate change in central Chile – Challenges for the urban and agricultural sector

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Abstract

The Central Valley in the Metropolitan Region of Santiago is the most densely populated area in Chile, but also an important agricultural area. In recent years, a rapid process of urbanization, increasing population rates and economic growth have led to growing pressure on water resources, leading to competition for water between different users. Changes in the regional climate and hydrology will even intensify the harms: Downscaling of climate models predicts reduced run-off of the Maipo River in summer months up to 40 %. Facing the shrinking water resources the identification of suitable measures for climate change adaption is a pressing need. This paper presents in a first step the current water demand in the region, the expected changes in water availability in future and concludes with the elaboration of suitable adaption measures to climate change for the agricultural and urban sector. These measures will be implemented within a long term climate adaptation strategy for the region.

1 Introduction

The Metropolitan Region of Santiago de Chile (MRS), located in central Chile, is the most densely populated area in Chile with approximately 6.7 million inhabitants. It is home to 40 % of the national population, representing 43.5 % of the country's GDP and is the political, economic, financial and industrial center of the country (BCC 2011). Further, the region is an important agricultural area. Although only close to 1.2 % of the regional gross domestic product GDP corresponds directly to agriculture, exportation goods like quality fruits, contribute to the financial and merchandise GDP of the region and shapes the landscape significantly (INE 2007). In recent years, a rapid process of urbanization, increasing population rates and economic growth have led to growing pressure on water resources. Changes in the regional climate and hydrology even intensify the harms: In dry years like in 2008, 209 communities had to declare 'agricultural emergency' and 72 announced 'water scarcity' (MOP 2009) [1]. This had negative impact on agricultural

1 total of 346 communities.

productivity and yields, causing hydroelectric shortfalls, electricity rationing and has led to growing competition for water among agricultural and urban purposes. Further, adaptive capacity in the water sector is constrained by institutional context, like the 'Chilean water code' and its market mechanism for water allocation with private water rights.

These forces cause a rise in societal vulnerability and create huge challenges in the near future. Therefore, the elaboration of suitable adaptation measures with effective policies is an important challenge. This paper focuses particularly on the impact of future hydrological changes on the agricultural and urban sector, as they are the most water demanding and competitive sectors. The aim is to elaborate on the basis of the current situation and future climate scenarios appropriate adaptation options. Underlying research question are:

How will climate change and variability affect availability of water resources for urban and agricultural purposes within the MRS?

What measures should local government, politicians and private individuals take to adapt water management to climate change?

2 The Maipo Basin and its water resources

The Maipo Basin is matching to a large extent with the administrative borders of the MRS (INE 2008). The main rivers in the catchment are the Maipo and Mapocho, both coming from the Andes flowing to the west (see Figure 1). The Maipo, 250 km long, covers with its watershed about 15,400 km². The Mapocho is 120 km long and its watershed is notably smaller with 4,100 km² (CNR 2007).

Most of the run-off from Maipo River results from melt of snow and ice of the winter-accumulated snowpack, therefore it is called 'snow dominated regime' (SOUVIGNET et al. 2012) and shows high flow rates in summer months. This regime is important for a Mediterranean climate type, as most of the water flows during the dry months, allowing irrigation and water supply during the hot and dry season (CORTES et al. 2012).

In this paper, water availability and water demand is analyzed for the urban and agricultural area of the MRS outside the high Andes, in the west of the Andenian Cordillera. In the further text, this area is called 'Santiago Basin'. For practical reasons, the extent of the Santiago Basin is calculated as the area of the MRS below 900 m.a.s.l., corresponding to 7,000 km².

The available renewable water resources of the Santiago Basin are composed of 1) precipitation in the Santiago Basin and 2) inflow of surface water via the Maipo and Mapocho River. The temporal availability of water resources is mainly determined by the existing climatic patterns (temperature and precipitation) during winter and the storage capacity for water in the mountainous regions (snow and ice) during early summer.

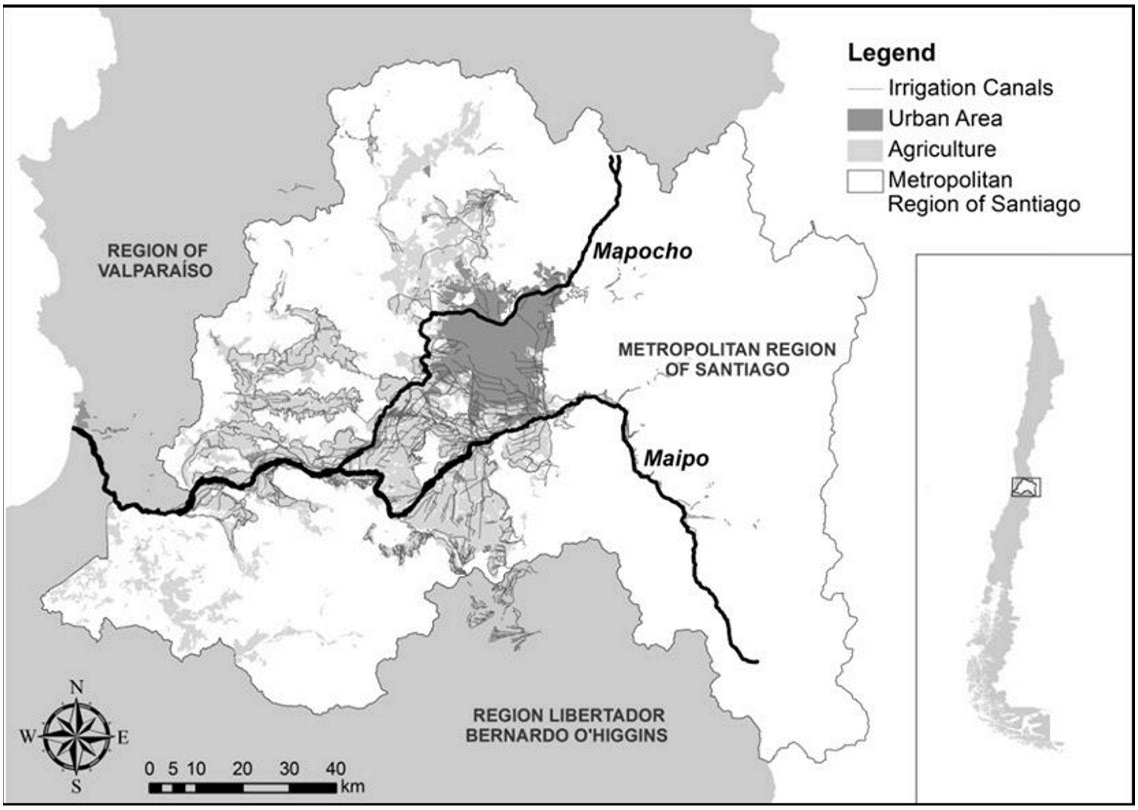

Figure 1: Administrative borders and hydrology of the Metropolitan Region of Santiago de Chile (Biblioteca del Congreso Nacional de Chile)

Glaciers and snow fields are a large storage of fresh water and therefore play a significant role for the water supply for the Metropolitan Region. The central Chilean glaciers are directly affected by temperature and precipitation changes. The response of the glaciers to changing climate conditions is not immediate and time lags vary from years to several decades (Paterson 1994). A hydrological monitoring network, covering the whole watershed, just recently has been established in the high elevated regions of the Andes; hence data about the contribution of glaciers to the water supply of the MRS are not yet evaluated. Nonetheless, several investigations have documented huge fluctuation of Andean glaciers as a response to climatic perturbations (Sagredo and Lowell 2012).

Precipitation shows considerable variations in the MRS within a year. Almost 85 % of annual precipitation falls between May and June. Rainfall variability is even stronger between different years (see figure 2) as precipitation is strongly influenced by the El Niño-Southern Oscillation (ENSO) Phenomena with El Niño (usually more wet) and La Niña (usually more dry) years (Aceituno 1988, Souvignet et al. 2012). This precipitation pattern leads frequently to droughts, intensifying the competition for water use between agriculture and urban purposes.

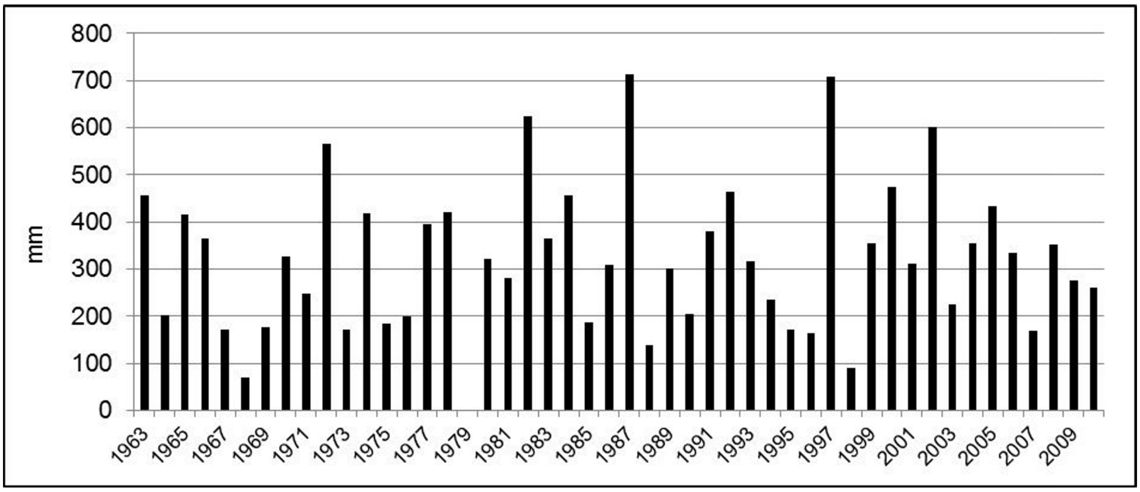

Figure 2: Long lasting variations of precipitation in the MRS at station Quinta Normal between 1962-2010 (DMC 2012) remark: missing the data for 1979

2.1 Droughts

The impacts of droughts can be devastating: hydroelectric generation can fall due to a lack of stored water, drinking water supply can be interrupted for certain periods and crops fail to grow. In the MRS, during the period between 1962 and 2011, 17 episodes with a direct sequence of dry years with precipitation of only 250 mm and below appeared. According to the legal framework established by the 'Chilean Water Code' from 1981 (MOP 39/84) different measures exist to deal with the situation in the case of a drought: The Water Code declares that water is public property for public use, but, to which the state can grant private rights of usage. These rights are not restricted in time, can be sold, rented or bequeathed afterwards. They are separated from land ownership. The national water authority DGA grants requests for new rights free of charge whenever water is physically and legally available (Código de Aguas 1981, Peña 2004). As it is a private right, water as a resource cannot be expropriated without economic compensation (Meza et al. 2012). But, during official drought-emergencies, the DGA possesses authority over private water use, including the power to impound water allocated to rights holders. Water rights may be expropriated, but only in order to satisfy domestic consumption and then only to a certain extent (Código de Aguas 2005). [2]

Water storages, like the reservoir 'El Yeso' or 'Laguna Negra' play an important role for the drinking water supply in the MRS, especially to overcome dry months (Aguas Andinas 2008). Figure 3 shows the average monthly volume in mil. m³ of 'El Yeso' in the period from October 2004 until July 2011 (DGA 2011). The development of the water volume shows two alarming tendencies: 1) the maximum of stored water after snow melt (mostly in April) shows a decreasing tendency indicating that water use is higher compared to the renewing rate, 2) the dramatic loss in volume from October 2010 to August

2 See also Hearne, R. & G. Donoso (2005)

2011 indicates that in very dry years water availability in its catchment is far below the demand which is satisfied by this dam.

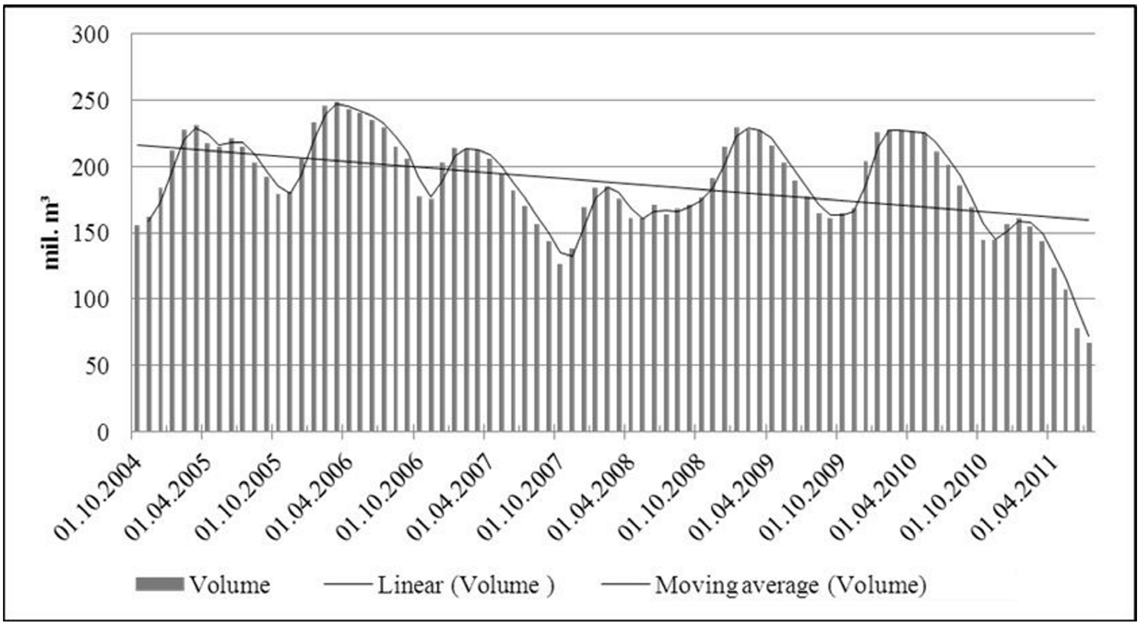

Figure 3: Volume of reservoir 'El Yeso' from 2004 until 2011 (DGA 2011)

3 Current water demand

The water demand in the MRS is mainly driven by the needs of agriculture. In the year 2007, the sector accounted for about 74 % of the total water demand in the region.

According to the most recent Chilean agricultural census (INE 2007), the MRS accounts for a total of about 1,130,000 ha classified as agricultural lands. Nevertheless, 980,000 ha (87 %) corresponds to shrub land, natural forests, improved and natural pastures and non-profitable lands. The remaining 150,000 ha (13 %) destined to crops are divided in three principal categories (PUC 2011):

1. annual crop and fruit orchards (113,270 ha)
2. permanent and rotation fodders (16,678 ha)
3. fallow lands (23,443 ha)

Agriculture is oriented towards the production of high-value crops, such as table grapes, avocados and citrus fruits, mainly for export to USA, Europe and Asia. In the case of alfalfa and corn, it is expected that those are produced for animal feeding (SOUVIGNET et al. 2012, PUC 2011).

Irrigation is necessary and constitutes the largest used amounts of water in the MRS. 88.7 % of the total cultivated area is irrigated (136,144 ha) by a channel network that allows the distribution of surface water resources from major rivers to the different irrigation districts (MEZA et al. 2012, INE 2007). More than 90 % of the irrigated area in this region depends on water withdrawals from surface flows.

Estimations of irrigation efficiency made by the National Irrigation Commission (CNR) range from 20–90 % depending on used technologies (CNR 2007, PUC 2011). In the MRS export-oriented fruit orchards, as table grapes and avocados are equipped with drip irrigation systems with high field application efficiency close to 90 %. Nonetheless, the way of operation and maintenance of the different systems influence the real efficiency strongly. The average irrigation efficiency is still low and ranges about 36 % (PUC 2011).

Table 1: Irrigation systems and their efficiency and share at the MRS (INE 2007)

Irrigation System	Field Use Efficiency	Number of Hectares by Irrigation System
Surface irrigation (border)	20 %	33,817.74
Surface irrigation (furrow)	35 %	57,072.38
Sprinkler irrigation	75 %	3,799.83
Drip Irrigation	85 %	37,281.32
Micro irrigation	90 %	4,761.07

Season and climate situation influence the specific demand for irrigation of different plants; reference evapotranspiration values vary from 6.5 mm/day in summer to 1.5 mm in winter (MEZA et al. 2012). Figure 4 compares the variation of average water demand for avocado and corn during the year, compared with the average run-off of river Maipo. All crops have their highest water demand during summer. Avocado, as an evergreen plant, needs be irrigated during the whole year. Corn does not have water demand in winter; only from September to late February it is necessary to irrigate these crops. It is obvious that the average hydrograph from river Maipo and water demand of the main crops correspond to each other in their seasonality.

The residential sector is the second largest water consumer with about 17 % of the total share. The private water and sanitation company Aguas Andinas, mainly owned by the transnational company AGBAR-Suez, together with its subsidiary companies Aguas Cordillera and Aguas Manquehue, is the main supplier for drinking water in the MRS. It withdraws 87 % from surface water by using predominantly water from rivers Maipo and Mapocho. Groundwater is a further source for drinking water production, with a smaller share of about 13 %. Additionally, Aguas Andinas possesses the reservoir 'El Yeso' with a storage capacity of 256 mil. m³ and the 'Laguna Negra' with 600 mil. m³ (Aguas Andinas 2008). The input from the reservoir 'El Yeso' is important for the drinking water production of the concession area of Aguas Andinas and is the main source for drinking water in dry periods (Aguas Andinas 2010). The only municipal owned company SMAPA, located in the southwestern commune of Maipú, is serving drinking water mainly obtained from groundwater (SISS 2011).

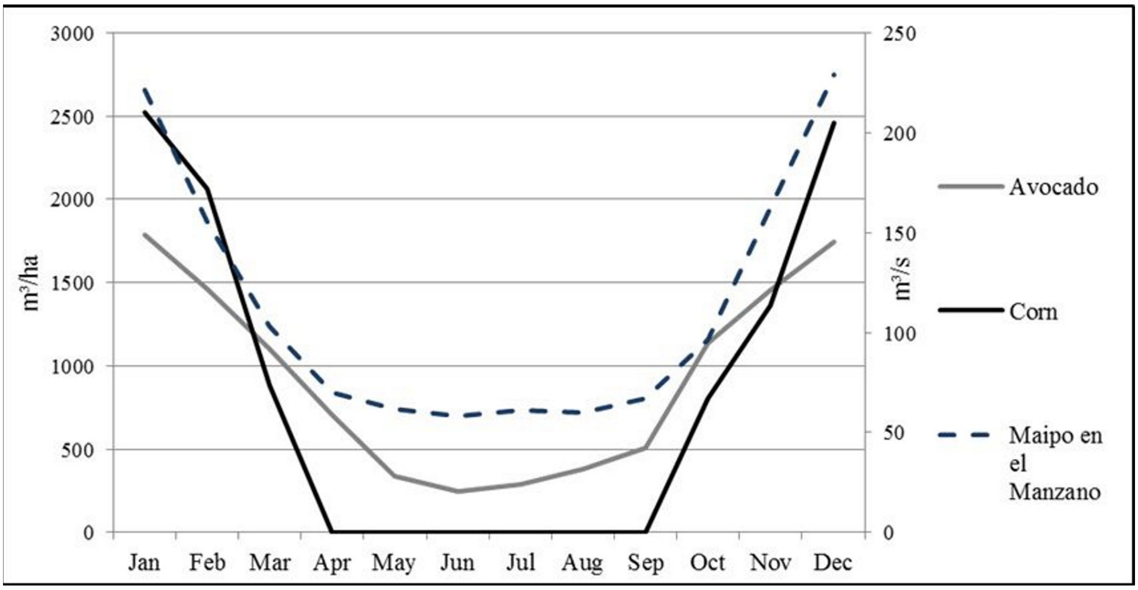

Figure 4: Calculated water demand (m³/ha) during the year for crops in the MRS in comparison with run-off from river Maipo (PUC 2011)

Variability of water use is high, daily per capita consumption ranges between 180 l in low-income areas provided by the water and sanitation company SMAPA and about 850 l in high-income areas provided by Aguas Manquehue. The high demand of the latter is assumed to be caused by irrigation of huge private green spaces and filling of swimming pools. According to the national regulatory agency SISS, the average specific drinking water consumption in the MRS is 201 l per capita and day. Water losses in the different distribution systems vary considerably between 11.4 % at Aguas Manquehue and 42.9 % in the network of SMAPA. The average loss in all networks in the MRS is with 32.1 % quite high (SISS 2011).

4 Regional impacts of global climate change

Snow-melted dominated Mediterranean regions are highly vulnerable to the impacts of climate change (Meza et al. 2012). Future water availability in the MRS is mainly influenced by the regional impacts of global climate change noticeable in changes of temperatures, precipitation and run-off rates. So far, modeling of climate scenarios has reached a high and precise standard and several models are available but uncertainties will remain present even in the presentation of results.

As a first step, it is necessary to understand the historical climate of a specific water resource and to use all available data (LUDWIG 2009). During the last years, the sources of information and tools related to manage climate variability and change have brought a wide range of model options. Global climate models (GCMs) have been developed to study the earth´s past and future climate system, driven by assumptions on the evolution of drivers of climate change. Dynamic downscaling represents the use of high-resolution regional climate models (RCMs), which are nested within GMCs (JACOB and VAN DEN HURK 2009). For climate change impact studies, it is therefore necessary to downscale the GCM simulations to the spatial scales relevant for the particular study being conducted (CORTES et al. 2012). For water resource projections and adaptation strategies at a river basin level RCMs are more suitable. Such models calculate hydrological responses to changes in key climatic variables based on local features for instance soil characteristics, the type and density of vegetation cover, and land use characteristics (UNECE 2009). For projections of climate change impacts in the MRS, gained results of a study from CORTES et al. (2012) serve as basis for this paper. Downscaling methods with projections given in the IPCC IV report (A2 and B2 scenario) and using data from regional measuring stations were applied as input data.

To gain comparable results ten to 15 different models for any particular variable or indicator of climate change (for example the average annual precipitation for the 2045-2065 time window) were applied and outcomes for temperature, precipitation and run-off according to the models are given here.

4.1 Temperature

An increase of temperature of about 1.5-2 °C is a consistent result across all models. The obtained results show for the near future a 30 % increase in days with extreme temperatures above 30°C, and a significant decrease in days with temperatures below freezing point. Even the view from the optimistic scenario (according to B2 at IPPC IV report) shows a significant increase of days with high temperatures across measuring stations. This may severely affect during summer the quality of life of people in Santiago. The same increase can be stated for minimum temperatures; nevertheless their increase is less than for maximum temperatures.

Minimum temperatures also show a consistent increase; nevertheless this increase in temperature is lower than at maximum temperatures. Climate change impact on minimum temperatures will not be so intense, but the change is still positive: more than one degree for most of the studied stations for the A2 and B2 scenarios. A further impact of higher temperature is the shift in the zero isotherm line to higher elevations, thus increasing storm runoff from higher elevation catchments.

4.2 Precipitation

A reduction of precipitation during the year of about 20-100 mm/a is expected.

Precipitation amounts probably decrease for all months, while the year relevant rainfall appears between March and October (during winter).

For the worst case, projected reductions in precipitation appear in a range between ten and 30 %. Additionally, most models project fewer days with precipitation and lower precipitation intensities in days with precipitation.
Between May and August precipitation rates will be higher; from December until February (during summer) precipitation rates will decrease. According to CORTES et al (2012) standard deviation is high, indicating that precipitation is characterized by high variability. The influence of the ENSO phenomenon could be one reason for those fluctuations. In this sense, higher intensity storms may be expected, so most of the precipitation will come from such events rather than usual light rain events.

4.3 Water availability

An increase of temperature of about 1.5-2°C and a reduction of precipitation of about 20-100 mm/a lead to a decrease of the mean water availability up to 40 % in the summer months. In future, drier and warmer months are expected.
The analyzed rivers (Maipo and Mapocho) are the most important streams within the MRS and in the future they show dramatic changes in their hydrological regime. The Mapocho run-off will shift to an earlier seasonal peak due to earlier melting of snow and ice caused by higher temperatures during spring and summer in the middle high elevations. The results show an increase of peak flows during winter because higher temperatures reduce snow accumulation and glacier-formation in the Andes. The warning signal is that the increase in run-off is only due to an increase in snow and ice melt and the higher elevation of the isotherm zero line.

Due to lower precipitation rates, a general decrease in streamflow magnitude is expected for the Maipo and the Mapocho rivers (figure 5). The runoff is directly linked to parameters such as the precipitation that has fallen during winter or wet season, the temperature at which snow accumulated and the temperatures during the melting season. Beside this, also groundwater is recharged by surface sources and accordingly changes in the hydrological regime will affect the availability of groundwater.

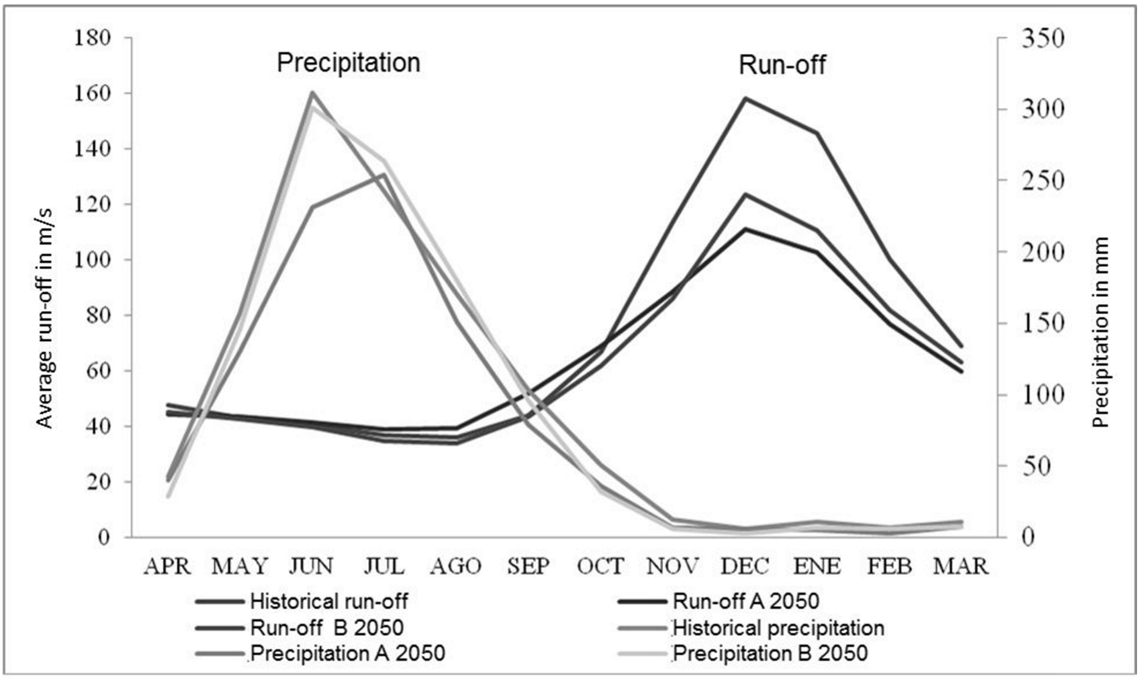

Figure 5: Comparison between historic and future annual run-off of the Maipo River and precipitation for scenario A 2050 and B 2050 (Cortes et al. 2012)

The overall conclusion is that in the near future Santiago will be a dryer and hotter city, with a high number of days with extreme temperatures and increased drought during the winter and summer (CORTES et al. 2012). The expected decrease and seasonal shift in water availability will affect water availability and demand, representing a huge challenge for the region. Regarding the existing developments of a growing population, economy and urbanization a strong increase in water demand seems realistic. Urban water demand will rise due to several aspects: higher demand within households for more showering and washing, for irrigation of public and private spaces, and for cooling purposes in the industry. Agricultural irrigation water demand will increase as well. Increasing temperature affects rates of evapotranspiration and, depending on soil characteristics, can modify crop irrigation water demand. According to MEZA et al. (2012), reference evapotranspiration increases, depending on the scenario, between ten to almost 20 %. Further, more water is needed to avoid crop failures and to prevent drought events.

As result, increasing competition for water resources between the urban and agricultural users is expected and requires the development of adaptation measures.

5 Possible adaptation measures

Changes in global climate will have significant impact on local and regional hydrological regimes, which will in turn affect ecological, social and economic systems (DIBIKE and

Coulibaly 2005). Resulting pressure depends always on local conditions and asks for approaches and methodologies for water management within individual catchments. Future adaptation strategies, which need to balance water availability and use, as well as protection and risks (Jacob and van den Hurk 2009), will be challenging. Thinking about adaptation measures easily brings up a potpourri in mind and questions like: What are frame conditions, applicable technologies, financial possibilities and is it realistic in implementation?

A set of possible measures were identified, developed, and prioritized. Generally, these measures can be differed into supply- and demand side and institutional adaptation measures. Four of these measures were studied more intensely by conducting scoping studies in order to assess their feasibility. In the following, these four measures will be described in more detail.

5.1 Increasing irrigation efficiency

Today, the most applied irrigation method in the MRS is furrow irrigation with a very low efficiency rate of about 36 %. According to expected changes of climate mentioned above and the high water demand in agriculture the need for adaptation is clear. The water saving potential by applying more efficient technologies is huge. Switching to e.g. sprinkler or drop irrigation (depending on the type of crop) with efficiency rates between 70-90 % is recommended. By this, a general water efficiency of about 50 % in 2025 and 75 % in 2050 could be a possible aim.

For successful adaptation, a wider view on the topic is necessary. Some aspects that need to be considered are: financial support for the implementation of new technology (e.g. subsidies), allocation of water rights, availability of technologies, or farmer awareness. Energy demand needs to be considered as well: In recent years, many modernization processes of irrigation systems in med. regions caused an increasing energy demand (and energy costs), as pumping for pressurized systems is much higher compared to gravity fed systems used previously. Therefore, urban planning needs to be integrated in order to regulate e.g. the development of irrigated agricultural areas. It is necessary to establish a regulating framework, which prevents that amounts of saved water will lead to an increase in irrigated agricultural area and assures farmers no economic losses (investment costs vs. remaining price for harvests). One proposal is that subsidies for the implementation of new irrigation technologies shall preferably be granted in areas equipped with low-efficient technologies. Further support is restricted to recipients, who are returning voluntarily their saved water volumes (in terms of water rights) to the state instead of increasing their irrigated areas. Such adaptation measure would minimize the pressure for demands on water resources, reduce groundwater exploitation and increase ecological flows in the rivers. By surveying the existing institutional and administrative structure, it was found that ‘only’ a re-orientation of agricultural policies would be necessary.

Beside this, several other topics in the agricultural sector could be adapted as well, such as: 1) crop diversification and changes in timing of farm operation: adjusting the cropping sequence, including changing the timing of sowing, planting, spraying and harvesting to take advantage of the changing duration; 2) insurance mechanisms for farmers and 3) development of new technologies. As water becomes more valuable than farming it is also possible that farmers will sell their water rights to be used for other purposes. Such a development needs to be in conformity with an intended sustainable water management for the region.

5.2 Implementation of integrated governance structures for the watershed Maipo/ Mapocho

The pressure on water resources caused by climate conditions, population growth, increasing water demand, water pollution etc. highlights the hydrological, social, economic and ecological interdependencies in the Maipo watershed. An integrated management system with the involvement of all basin stakeholders (private and public) is demanded. The aim of this measure is to set up appropriate administrative structures, which could serve as a central contact point for the whole Maipo catchment. The existing regulatory and institutional framework in the water sector is not clearly defined, as many different stakeholders from ministries, authorities or institutions from different levels (regional, national) are involved in this topic. Institutional and legal gaps and overlays complicate sustainable water resource management, which is not clearly defined and it is not part of the policy paradigm. Further, low financial resources and thin personal coverage hamper the situation. For this reason, among others, it is difficult for the civic society to identify the responsibilities for a specific issue, which reduces an active participation - necessary for successful implementation e.g. for an adaptation strategy. A consistent "paradigm shift" in relation to sustainable water resources management and governance shall be achieved. An institutional system, which is easier to understand for the citizen and more transparent and simply structured, increases the participation and flow of information amongst state and civic society and would contribute to a more sustainable water management in the MRS. Thus the establishment of two entities is recommended:

1. *Regional Water Council*: political instance, with the aim to bring together the different public and private actors. It plays an active part in shaping and accompanying the dialogue and participation process for the adaptation strategy, with the aim of ensuring a consistent conceptual approach by the regional government.
2. *River Basin Entity*, executive instance, responsible for coordinating relations between the different services and hydrological planning in the Maipo watershed. Concrete fields of activity shall be the integrated regulation and control of all water based needs in the catchment, according to sustainability principles e.g. regulation and control of surface and groundwater water extraction according to the available supply, regulati-

on and control of water quality for different purposes and promotion of the sustainable water use practices. The entity shall safeguard the interests and regulate the water flow between up- and downstream users.

5.3 Water saving fittings

The per capita demand in the MRS of about 220 l per day and capita is comparatively high. An achievable target is to reduce future water demand to about 150 l per day and capita what seems to be achievable with respect to the additional water needs for irrigation of private green spaces under Mediterranean climate conditions. In already existing buildings the introduction of water efficient tap fittings in bathrooms and kitchens and efficient toilet flushing systems can reduce water consumption at comparatively low costs. By this measure, water and sewer bills can be reduced. Due to less demand of hot water, energy demand and costs can be saved as well. In addition, efficient water use can avoid expensive investment costs otherwise needed in order to adjust water supply and wastewater treatment facilities to a growing population. In regions under water stress - like the MRS - ecological flows of water bodies can be assured easier if human water consumption would be reduced. Taken the situation of today and comparing saving potentials of fittings a reduction of 30 % of the water demand in households seems realistic. An idea for such an implementation is as establishment of different strategies for existing and for new houses: 1. gradual change of installed sanitary fixtures in existing houses supported by economic incentives and by campaigns for awareness rising, 2. setting water-efficiency standards as a statutory duty for new hardware, 3. creation of an 'efficiency label' for certain products (% of water saving) as a base for incentives accompanied by an adequate financing facility. Another possible co-benefit is a higher efficiency at waste water treatment plants due to less diluted waste water.

5.4 Grey water recycling

Of about 19 % of the MRS superficies is vegetal material (lawn, plants, bushes, trees). The water demand of this area is about 250,000 m³/day. In average, 60 % of all consulted households would agree to improve their irrigation system with more efficient and water saving technologies, and further around 46 % of them, would agree to irrigate with treated grey water (OCUC 2010). Therefore, the recognition, and further its implementation, of grey water recycling as an adequate adaptation measure to impacts of climate change. For such an infrastructural measure, integration step by step at all levels of legislation, planning, construction and management is required. Successful management of grey water includes both technical methods and user participation in running and maintaining the systems. Further, it needs to be coordinated and planned if the produced amount of grey water fits with areas available for irrigation. Benefits of this measure are saving of drinking water used for irrigation purposes and so with reduced water bills for the consumers. Similar to installed water fittings, a better efficiency in waste water treatment plants due to less diluted water can be expected. Also the environmental image of Santiago de Chile could enhance. Sure, this proposed measure needs preliminary studies on technical, infrastructural, institutional and financial aspects but it has the potential to contribute to a reduction of urban water demand as well as positive effects on the regional water cycle. As further idea the grey water infrastructure can be used as well for the infiltration of storm water. Storm water needs also a pre-treatment; therefore its inclusion within the grey water system is depending on the suitability of treatment. By this application, the cost for storm water collectors could be saved.

6 Conclusion

Current projections of future climate conditions show various challenges for the Santiago Basin. Changes in precipitation, snow or ice melt and evapotranspiration will affect water resources and will lead to reduced water availability in the future and to a higher frequency of dry years. Additionally, changes on the water demand side can be expected due to the population and economic growth as well as changes in economic structure and life styles. In the agricultural sector, a significant conversion is likely to take place, because climate-related factors will increase the future demand for irrigation as a result of reduced precipitation and higher evapotranspiration. Facing these challenges for the water sector, it becomes apparent that projections regarding the water supply side need to be combined with more detailed scenario planning for the demand side. Key questions to be addressed will be, for instance, how demand will develop across different sectors or what will be main impacts if irrigated areas will increase or decrease. The results of the socio-economic scenarios carried out by the authors show that technological progress and a changing behavior of water consumers could lead to an increasing water use efficiency and thus compensate the reduced water availability (LEHN et al. 2014).

In order to respond to the identified problems in the water sector, technical, policy and market based adaptation measures are proposed. The selection of measures was based on urgency considerations or the expected degree of water saving potentials: As the agricultural sector is the main water user in the MRS, the biggest water-saving potential exists in improving irrigation efficiency there. The second largest potential was identified in private households. Realization of this potential is combined with the positive side effect of an increased public environmental awareness. This effect can be as well with the implementation of grey water reuse systems in new built up areas. All these measures should be embedded in a changing institutional framework including modifications in policy structures and the water allocation system.

Acknowledgements

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