2 Mexico's Water Challenges for the 21st Century

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2.1 Introduction

2.1.1 Mexico in the World Context

Mexico is the eleventh most populous nation in the world after countries such as China, India and the United States of America; it has the second biggest city after Tokyo, Japan, and it ranks 54th in gross domestic product. In terms of water availability per capita – resulting from dividing overall water resources by the total population – Mexico ranks 89th worldwide, with 4,291 cubic meters per inhabitant per annum. Water abstraction puts the country in 36th place, with an average annual precipitation of 743 m³ per capita.

Weather and topographic conditions have led to the construction of dams to increase the country's water storage capacity, and Mexico occupies 19th place worldwide with a water storage capacity of 150 km³ and 667 big dams. Linked to these structures are irrigation areas, where Mexico ranks 6th, with 6.9 million hectares with irrigation facilities. Finally, the country occupies 90th place for potable water, 67th for the volume of sewage, and 39th for water treatment (CONAGUA, 2008).

2.1.2 Water Balance

Mexico has a land area of 1.964 million km² and a total population estimated at 106.7 million (Villagómez/Bistrain, 2008), of whom 75 per cent live in urban areas. In addition, there are 196,328 villages with less than 2,500 inhabitants (Arreguín, 2005). The average annual precipitation is 775 mm or 1,513 km³, with most rainfall taking place in the period between June and September (figure 2.1). The spatial distribution of rainfall is also uneven, with great differences between the north and south of the country (figure 2.2).

Average evapotranspiration is about 1,084 km³. Aquifers recharge 78 km³, whilst 28 km³ are extracted from them. Average run-off is 400 km³ and surface water extraction reaches 47 km³. The balance in terms of water imports (from the United States of America and Guatemala) is 50 km³ contrasted with exports at 0.44 km³ mainly to the United States of America (figure 2.3).

2.1.3 Water Availability in Mexico

Demographic growth projections up to the year 2030 show that urban areas will grow more than rural areas. If water availability is calculated per capita and per annum in 1950, for each Mexican 17,742 m³ were available compared with the year 2009 when availability declined to 4,261 m³. Estimates predict that for the year 2030 water availability per annum will be 3,783 m³ per inhabitant, taking as a value the yearly average of 458.1 billion m³ into account, which corresponds to the average precipitation from 1950 to 2005.[1]

The distribution of the population in the national territory also creates pressures for water availability. As can be seen in figure 2.4, 77 per cent of the population and 31 per cent of natural water availability is concentrated in the north, centre, and north-east. This also comprises the regions that account for 87 per cent of *gross domestic product* (GDP). This situation in terms of water, population and economics represents an important challenge both in terms of technical and human development.

The problem becomes more complex given that, according to the National Water Law (LAN), the definition of the average water availability of surface water in hydrological basins "is the value that results from the difference between the average volume and

1 The medium availability per capita = the total availability/population. Thus, for the year 2007 the total availability = virgin run off + importation - exportation + recharge = 483,560 m³/year. This availability is considered the same for 2009 and the estimated total population for this year is 113,458,097 inhabitants which gives 4,261 m³/inhabitant/ year.

Ú. Oswald Spring (ed.), *Water Resources in Mexico: Scarcity, Degradation, Stress, Conflicts, Management, and Policy*, Hexagon Series on Human and Environmental Security and Peace 7, DOI 10.1007/978-3-642-05432-7_2,
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Figure 2.1: Average monthly rainfall in Mexico (1971-2000). **Source:** CONAGUA (2008b).

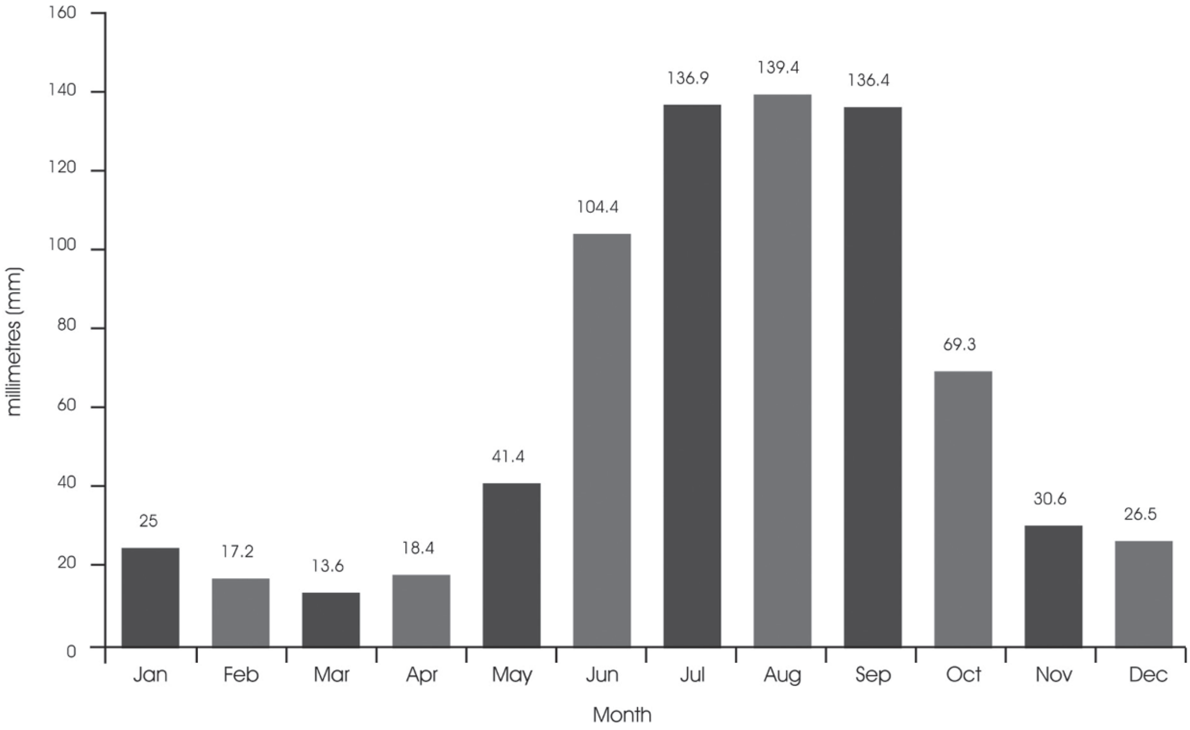


Figure 2.2: Spatial distribution of annual precipitation. **Source:** CONAGUA (2008b).

the actual annual run-off in a basin". This means the legal availability of water for the general population, i.e., the water the general population may use.

Figure 2.3: Water balance of Mexico. **Source:** Arreguín et al. (2007).

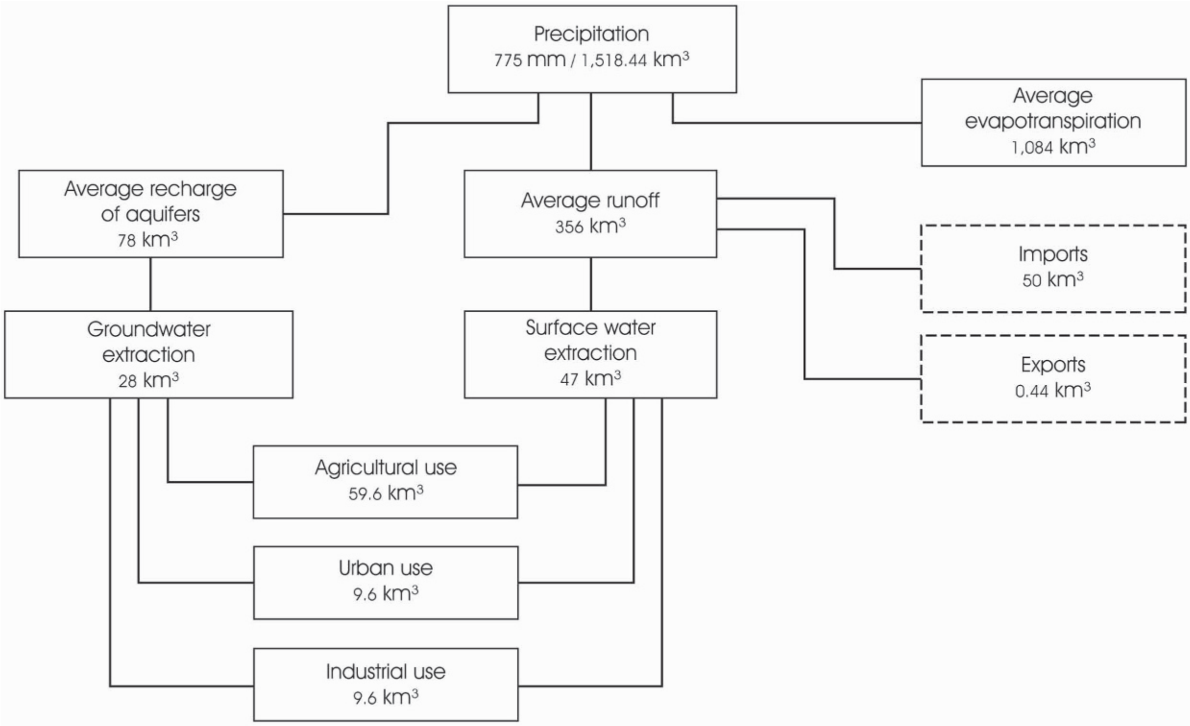
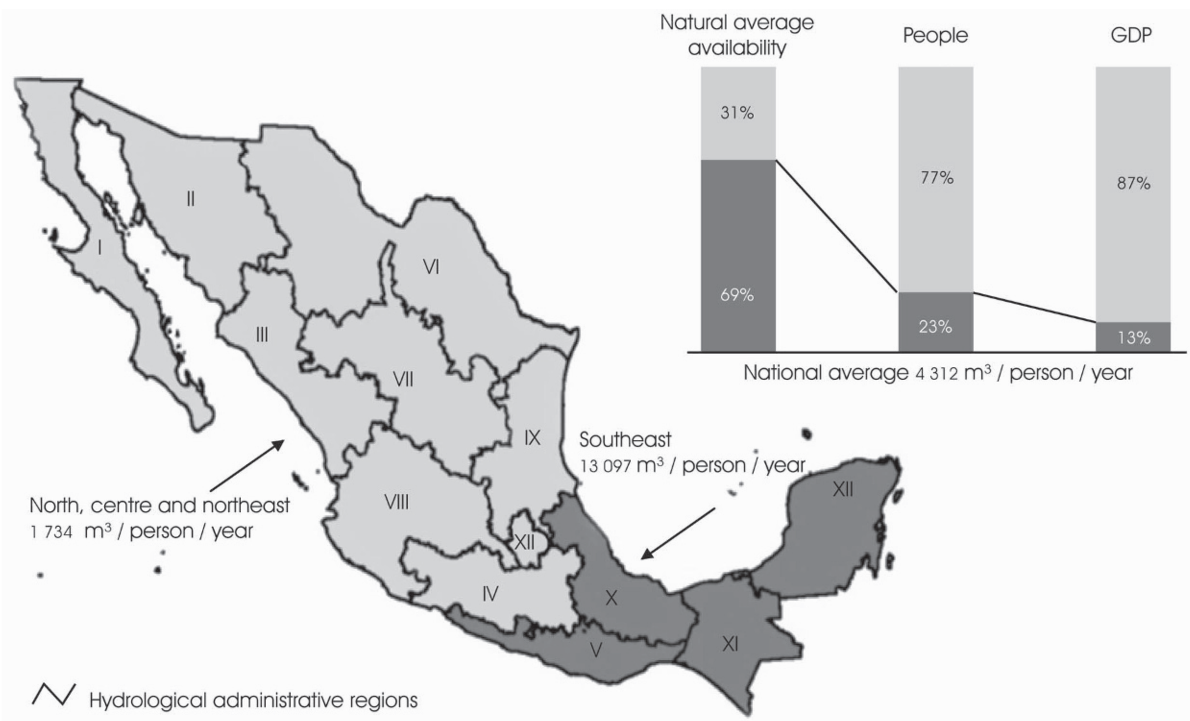


Figure 2.4: Regional contrast in terms of development and water availability. **Source:** CONAGUA (2008).



In Mexico, water availability in the 722 basins has been published in the Official Gazette of the Federation (Diario Oficial de la Federación, 2010) in the years 2003, 2005, 2007 and 2009. As can be seen in

Figure 2.5: Water availability in Mexico. **Source:** CONAGUA (2008b).

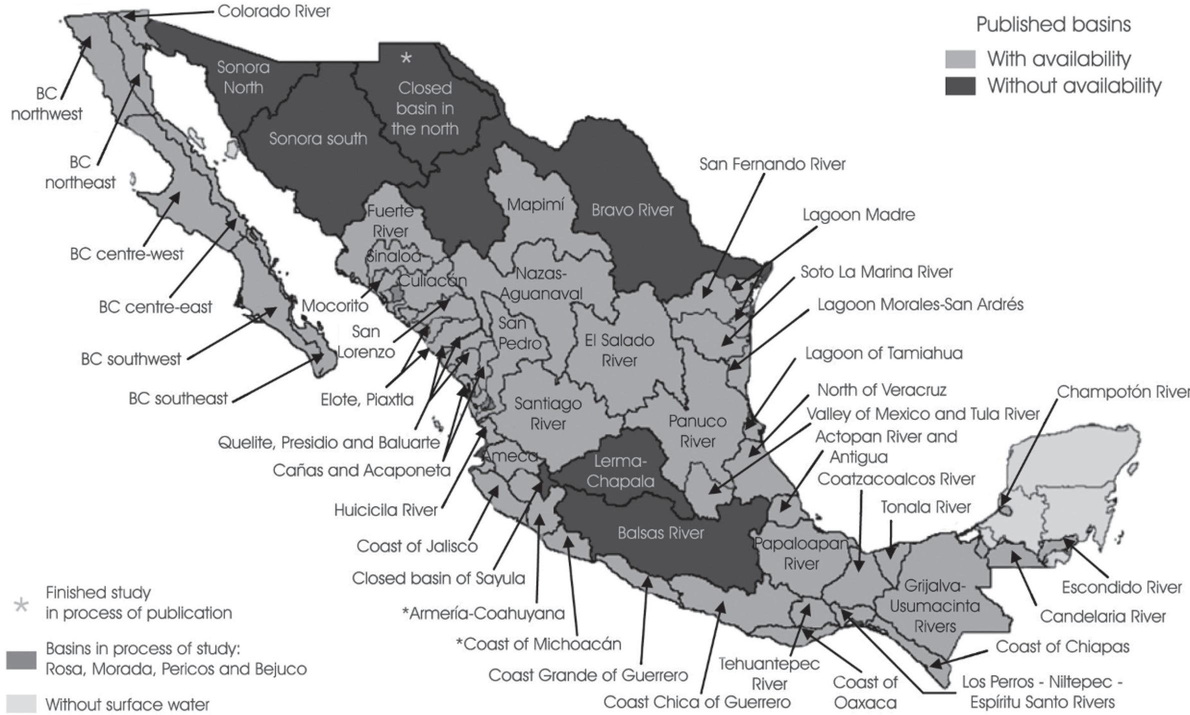


figure 2.5, some basins no longer have water availability because of over-exploitation. In this regard, the basins in the regions of the Bravo River, Lerma-Chapala, Balsas and the Peninsula of Baja California may be mentioned. Also, in almost all of the Yucatan Peninsula there are no surface currents.

Not only do the basins with greater socio-economic development have a deficit, but many other aquifers have also been over-exploited. In the Official Gazette of the Federation (Diario Oficial de la Federación, 2003, 2007a, 2007b and 2008) the average available water capacity of 282 aquifers out of the total of 653 (figure 2.6) was published, representing 93 per cent of total groundwater extraction. Again, aquifers in the centre and north of the country have a greater water extraction rate than the average rate of natural recharge.

2.2 Water Use

Out of the 78.9 km^3 of water used for different economic activities in the country, 77 per cent is destined for agricultural use, 14 per cent for urban use, 4 per cent for industrial use, and the remaining 5 per cent goes to cooling systems in thermoelectric plants (figure 2.7). Sixty three per cent out of all consumptive water is extracted from surface sources, whereas the remaining 37 per cent comes from underground sources. It is noteworthy that 122,800 million m^3 of water are used in hydroelectric stations in Mexico (non-consumptive water use).

2.3 Risks and Challenges

Mexico, like many other countries in the world, faces great water challenges. The most important are: the impact of climate change that will be addressed only in its relation to the water cycle, water pollution, water scarcity, poor water administration, lack of resources for research and technological development, and lack of environmental planning.

2.3.1 Climate Change

Perhaps the most important water challenge (and risk) that Mexico faces is the impact of climate change on water resources. These effects, as a consequence of global warming, refer to hydro-meteorological events in many regions of the planet: torrential rain, drought, changes in rainfall patterns, and more destructive tropical storms as well as hurricanes, among many others. Most scientists attribute global warming to the effects of greenhouse gases, especially

Figure 2.6: Availability of groundwater. **Source:** CONAGUA (2008b).

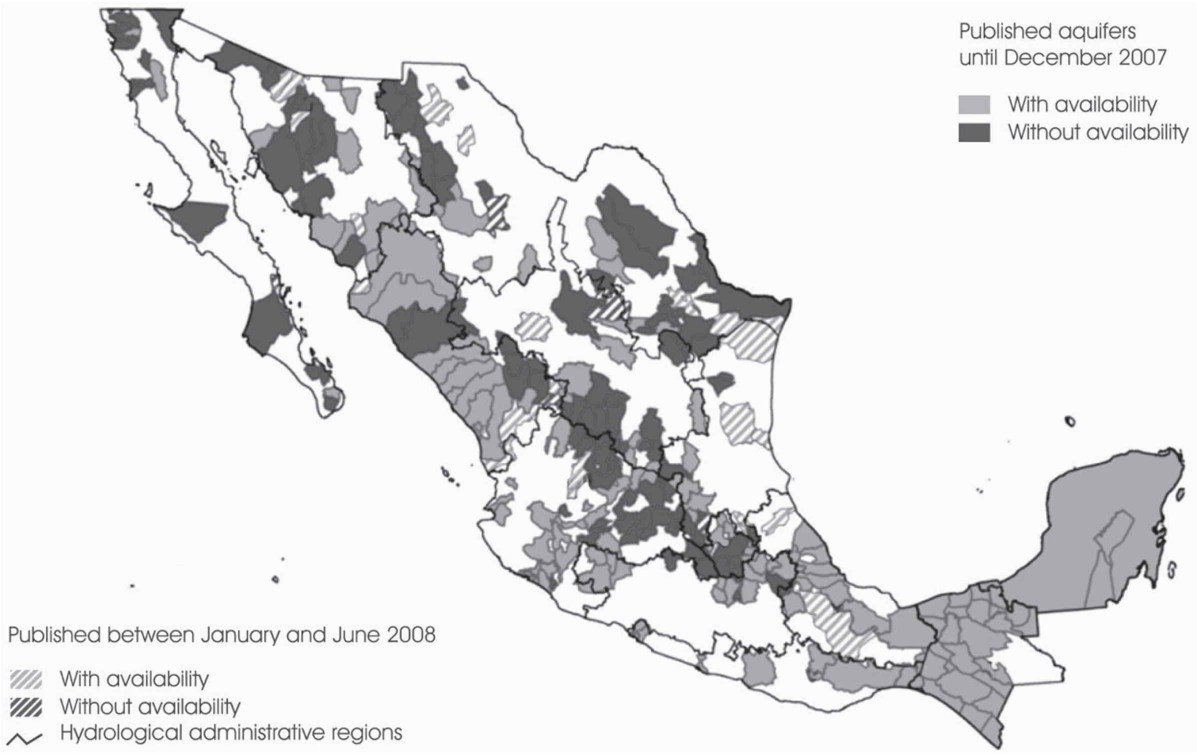
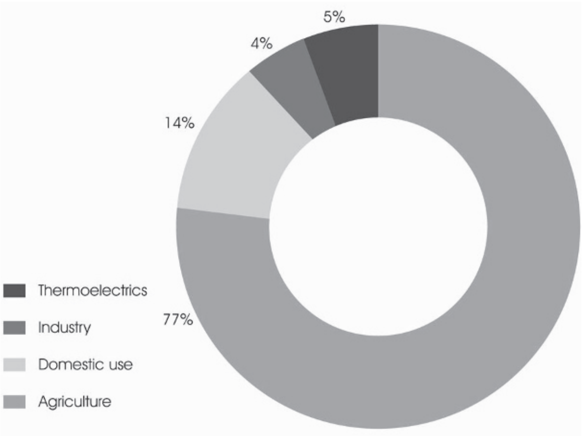


Figure 2.7: Water use in Mexico. **Source:** CONAGUA (2008b).



to carbon dioxide concentrations in the atmosphere (figure 2.8).

An indicator of global climate change is rising sea levels (figure 2.9) due to melting glaciers and polar ice that affect the temperature and mass of sea water. This implies grave risks to life in the North and South Poles, in the sea, and in coastal areas, which will be the first to seriously experience this effect.

Climate change affects the hydrological cycle in many ways, for example through

1. rising sea levels;
2. reduction and loss of perennial and seasonal ice;
3. more intense and frequent heat waves;
4. change in rainfall patterns;
5. more severe and frequent storms;
6. loss of adaptation of the groundcover given these new conditions;
7. more severe and lasting droughts;
8. increasing evapotranspiration and changing precipitation;
9. decreasing water discharge capacity of rivers into the sea;
10. increased rainfall in high latitudes, reduction of rainfall in low latitudes, with emphasis in the world's arid belts;
11. increasing destructiveness by tropical cyclones;
12. changes in areas prone to cyclones and tornados;
13. alteration of the global thermohaline circulation as excess fresh water is being discharged into the sea;
14. more water vapour in the atmosphere causing low or high clouds; and
15. irreversible changes (in the short term) in re-emission of energy to space by areas that have lost their ice cover.

Figure 2.8: Increase of carbon dioxide concentration in the atmosphere and global rise of temperature in the past thousand years. **Source:** Oak Ridge National Laboratory, at: <http://cdiac.esd.ornl.gov/trends/temp/jonescru/jones.html> (based on Johnes/Mann, 2004 for the years 1000-1880, and for the years 1820 to 2005 on Johns/Parker/Osborn/Briffa, 2005).

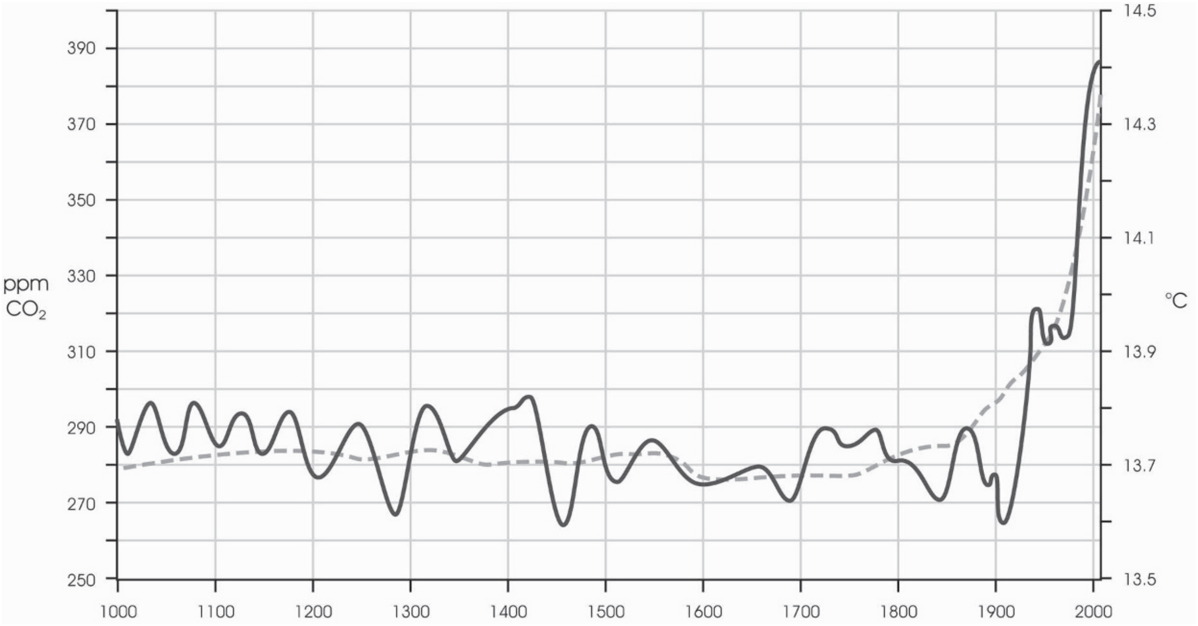
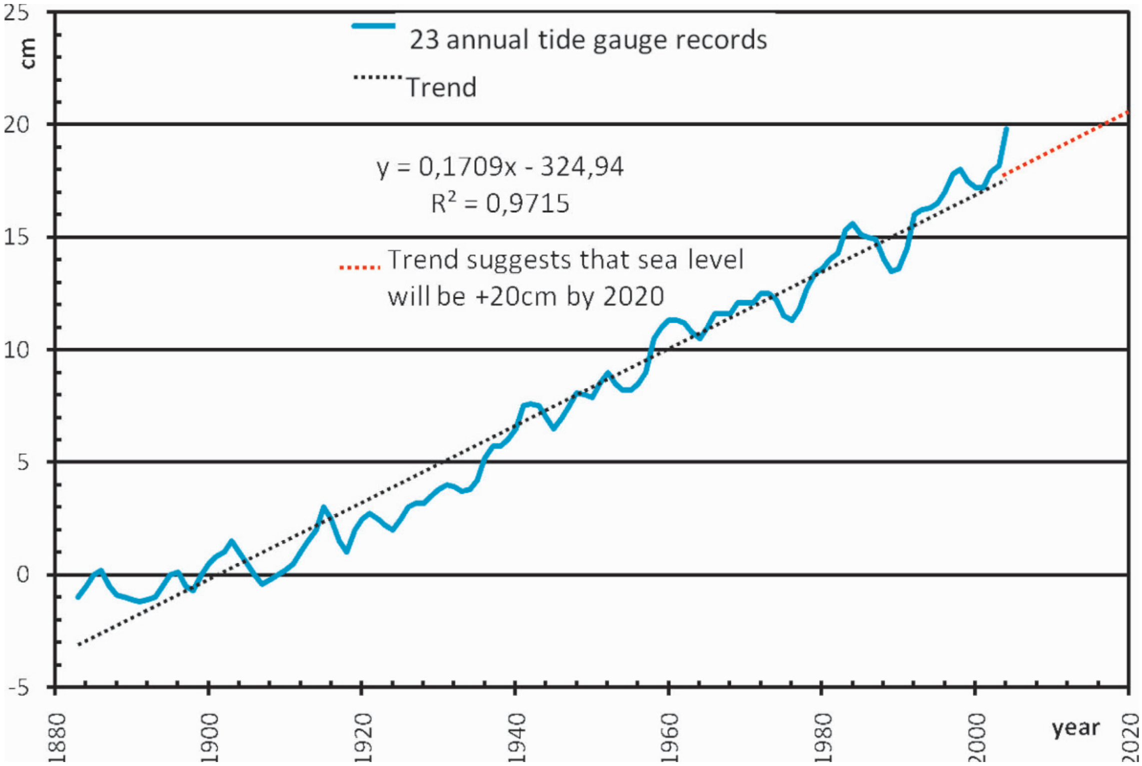


Figure 2.9: Sealevel variation (period 1883-2004). **Source**: Modified and extended by the authors based on Douglas (1997).



Some changes in meteorological events have already been registered in Mexico; for example, the occurrence of severe storms has significantly increased. In the year 2008 there were 632 heavy storms (with more

Figure 2.10: Behaviour of maximum temperature in Mexico, 1961-2040. **Source:** Arreguín, Chávez and Rosengaus (2008).

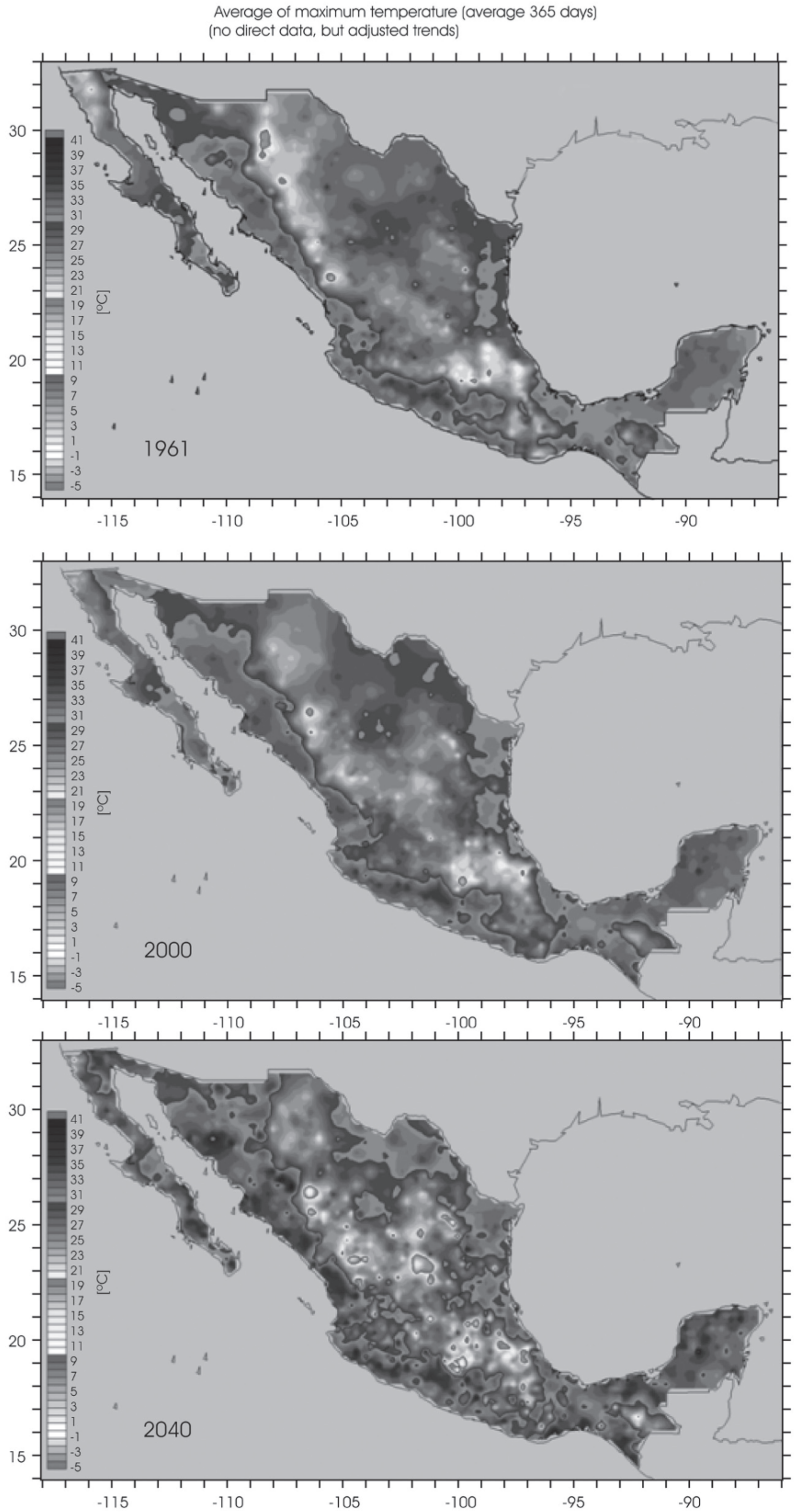


Figure 2.11: Minimal temperature behaviour, 1961-2040. **Source:** Arreguín, Chávez and Rosengaus (2008).

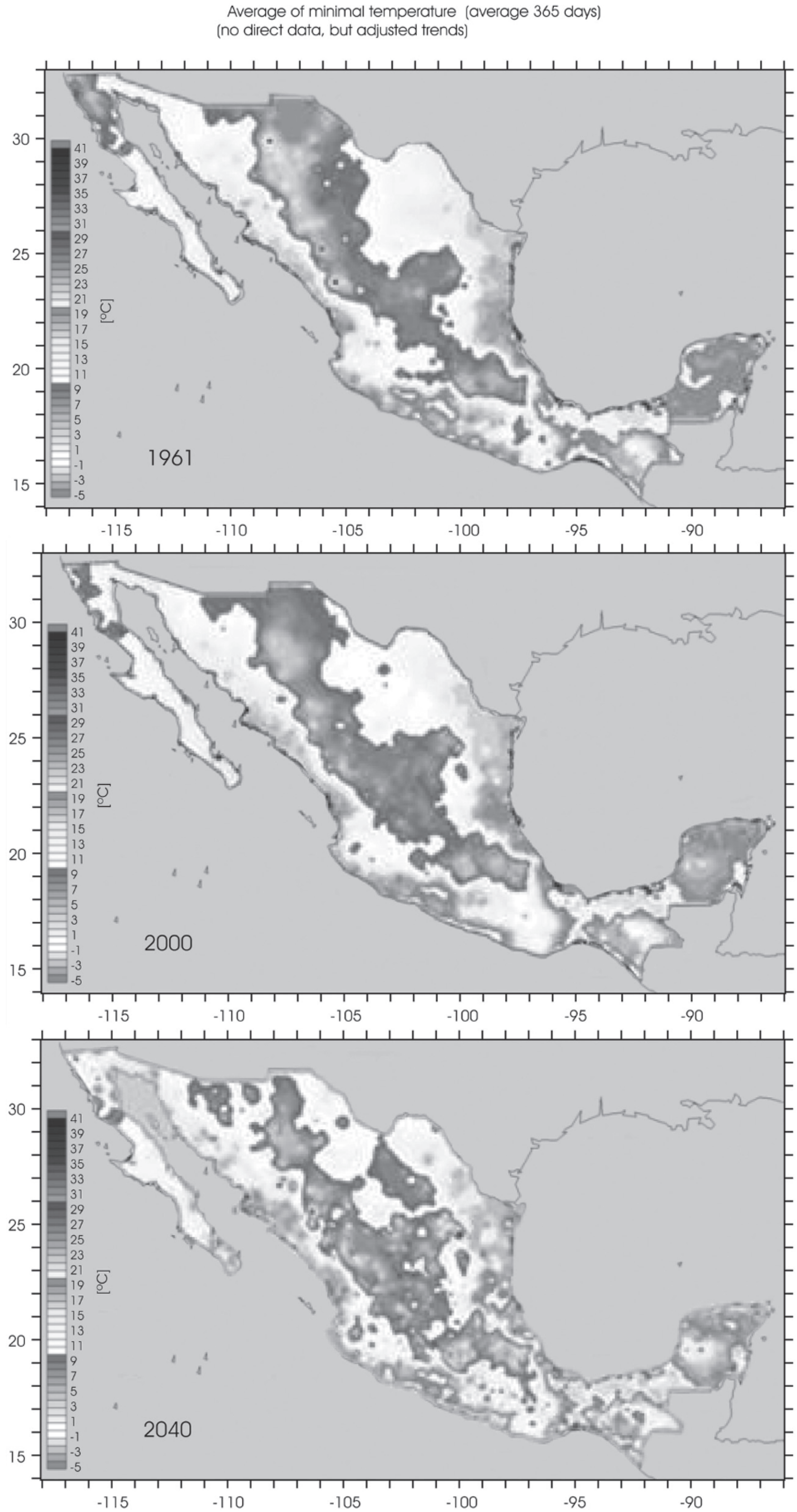
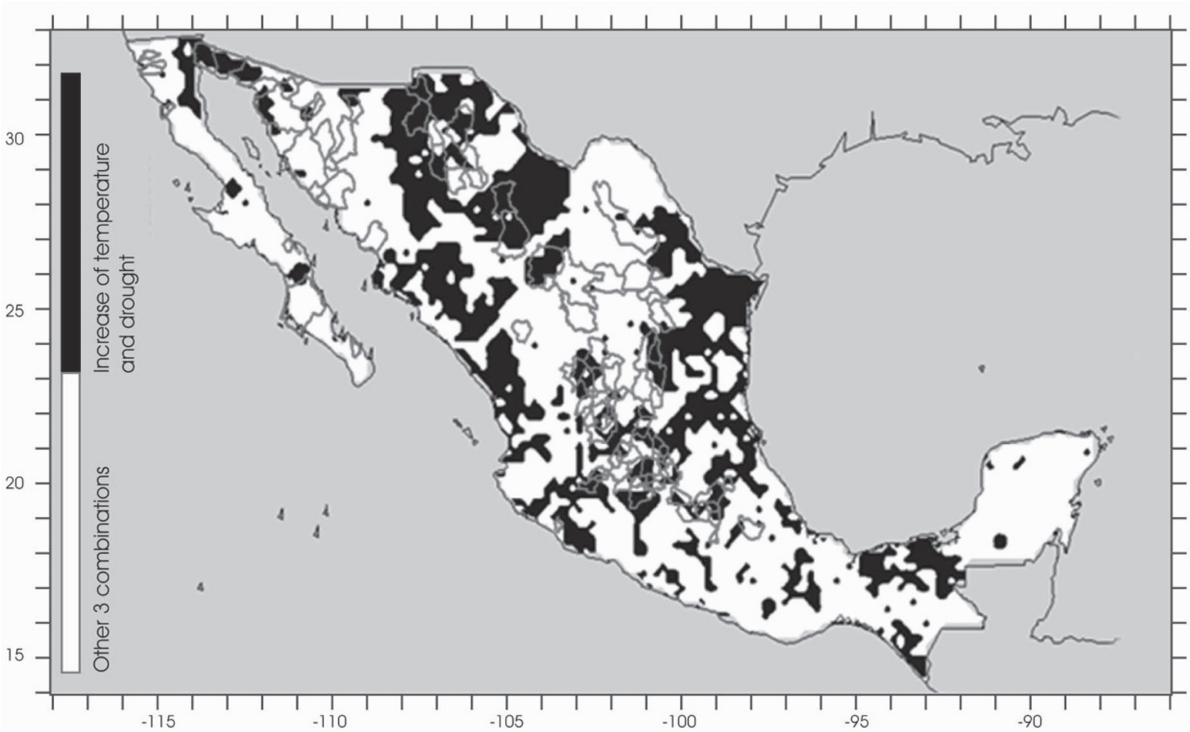


Figure 2.12: Currently over-exploited aquifers where an increase of temperature and a decrease of rainfall is expected in the year 2040. **Source:** Arreguín, Chávez and Rosengaus (2008).



than 70 mm of rainfall within 24 hours), compared to an average of 469 registered storms between the years 1996 and 2007; that is, an increase of 34.75 per cent. The year 2008 surpassed the year 2003 that held the historical record with 544 severe storms.[2]

Taking measures obtained from the meteorological web of the National Water Commission for the period 1961–2000, a database called *Maya v1.0* was constructed. This is a structured and ordered database for the purposes of conceptual analysis with useful data, such as "4,542 weather series, each of 14,600 days" or "14,600 maps". Graphically, it is a regular web with a resolution of 20 km between each node (Rosengaus, 2007). The values between the nodes were mathematically calculated with the data measured by the web, using sound statistical techniques.

This database allows us to graphically portray the patterns of rainfall and temperature in the national territory and to make projections for the following forty years (figures 2.10 and 2.11). However, caution must be exercised as these calculations have not included the chemistry and physics of the atmosphere.

2 National Meteorological Service (2009); at: <http://smn2.cna.gob.mx/SMN2/Default.aspx>.

Based on this information, predictions can be made by combining the maps of temperature and rainfall with those of over-exploited aquifers to identify the areas where temperature will increase and rainfall decrease, thus impacting on water availability. In this case, the areas of the north-west, central north, north-east and south-east of Mexico will be the most affected, as water availability will decline (Arreguín/Chávez/Rosengaus, 2008; figure 2.12).

Aquifers will also be affected by rising sea levels as this will increase the risk of saline intrusion into coastal aquifers. The situation is particularly grave in the aquifers that are already threatened by this phenomenon (figure 2.13).

Given its geological and hydrological characteristics, the Yucatan Peninsula is especially vulnerable to saline intrusion. It is made of karstic material, has no surface currents, and all rain water that is not evaporated infiltrates the ground. Groundwater is abundant but the aquifer is shallow; the salt wedge penetrates widely. Given these characteristics, water moves through fissures or fractures that make formations such as cenotes and underground rivers. Thus, any increase in the average sea level will easily infiltrate inside the territory and significantly reduce fresh water.

Figure 2.13: Aquifers currently affected by sea water intrusion. **Source:** CONAGUA (2008b).

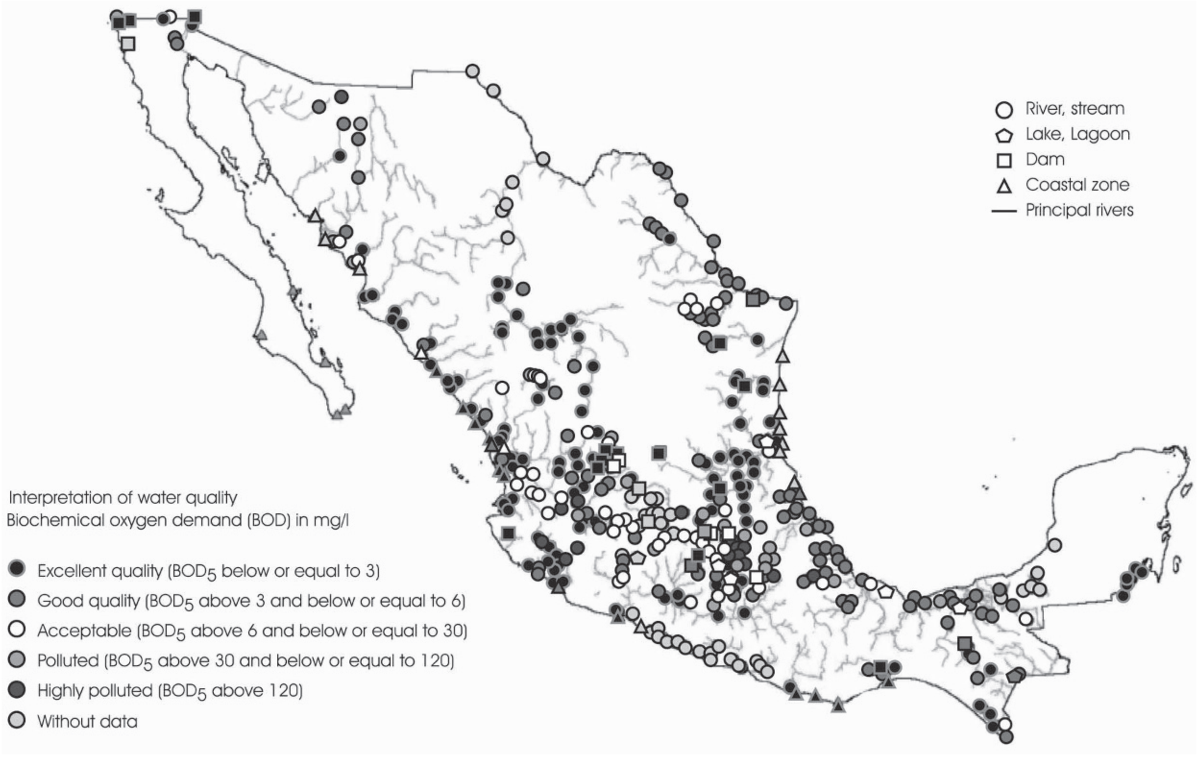
In addition, an increase in the average sea level will reduce the natural discharge of rivers, causing floods in lowlands. As a consequence, the coast will move inwards into what today is considered as terra firma. Given their devastating impact, tropical cyclones are among the most important hydro-meteorological phenomena affecting Mexico. Most scientists foresee an increase in their frequency, as well as in their level of destructiveness. Growing populations settled in high risk areas will be especially vulnerable due to the lack of environmental planning.

One of the greatest preoccupations of Mexico related to climate change is the ability of the country to comply with international commitments relating to water, for example the 1944 Water Treaty between Mexico and the United States of America. In general terms, Mexico obtains a higher portion of this water compared with the USA, although it is still difficult to comply with this international commitment because of the poor administration of water resources in the north of Mexico and to the extraordinary droughts in the region. Recently, the basin of the Colorado River has experienced such severe drought that the levels in the dams have reached historically low levels, and both countries are examining the possibility of implementing extraordinary measures such as making use of additional water sources and heavy investment in action to safeguard water resources.

For this reason, several techniques for water conservation are being considered: the recovery of water linked to the exploitation of methane; the control of evaporation in water storage through chemical covers and the operation of dams; water imports through oceanic routes, through water pipelines below sea level from the rivers of northern California and from other basins; with ships from Alaska; with water bags and by towing icebergs; desalinizing brackish waters from aquifers in Yuma, Arizona and Riverside, California, as well as sea water from the Pacific Ocean; the integrated management of surface and groundwater; collecting and storing rain and storm water; removal of vegetation along the river to reduce evapotranspiration; reducing consumptive use by thermoelectric plants; water reuse and recycling; and weather modification by cloud seeding in the basins of the upper Colorado River. These examples indicate both the urgent need to find alternative water sources on the one hand and to extend the possibilities to deal with problems in each basin on the other hand (Colorado River Water Consultants, 2008).

Only a few examples were cited of the impact that climate change may have on the hydrological cycle in some regions of the national territory, although most of them will indeed affect Mexico.

Figure 2.14: Biochemical oxygen demand in Mexico, 2007. **Source:** CONAGUA (2008b).



2.3.2 Water Pollution

Biochemical oxygen demand (BOD) is a domestic and municipal indicator of pollution. The hydrological and administrative regions of the Valley of Mexico, Northern Gulf, Lerma Santiago Pacific and some areas in the Central Gulf show higher pollution (figure 2.14).

The other parameter frequently used to measure water quality is *totally suspended solids* (TSS). The occurrence of TSS in water bodies in Mexico indicates problems especially in the coastal zones from Colima to Guerrero, in the south of Veracruz and Tabasco, as well as important pollution areas in the rivers Santiago, Lerma, Bravo and Soto La Marina. Generally, the core challenges for water quality are that wastewater treatment plants should comply with quality norms, and that standards are established for flows and receiving bodies. Also, studies in the Lerma River sub-basin have reported data suggesting an important impact by diffuse pollution. This constitutes an aspect that has hardly been investigated in Mexico, research that is most pressing in order to adopt the necessary control measures. Beyond the necessary investments, the most important issues at stake are the values and conscience linked to living together in a clean environment.

2.3.3 Water Scarcity

As was mentioned in the first section of this chapter, water scarcity in a country where two-thirds of the national territory is arid or semi-arid implies important problems in terms of water availability, which in turn hinders development. Over-exploitation of aquifers is particularly worrying; current estimates are that there are 102 over-exploited aquifers out of a total of 653. This situation is most notable in the hydrological and administrative regions of the Valley of Mexico, Lerma, Chapala, Central Basins, Bravo and the Northwest (see figure 2.15).

The challenge is to reduce the over-exploitation of groundwater without affecting social and economic activities, allowing a sustainable exploitation of aquifers so that the processes of water extraction and recharge of aquifers fall into equilibrium.

2.3.4 Improving Water Management

Lack of water is not only due to water scarcity and pollution. The cornerstone of water management in

Figure 2.15: Over-exploited aquifers by hydrological and administrative region. **Source:** CONAGUA (2008c).

Mexico is the National Water Law. This law, amended in the year 2004, still requires a profound reform to revert amendments, and perhaps even its derogation and the creation of a new law altogether. This is because when the National Water Law was published in the year 1992, many innovative concepts were included, such as sustainable management and integral planning; social participation in hydraulic planning, in the water market and in concessions; public information in terms of water quality, availability and use; and the Basin Councils. However, using the argument that limited advances had been made in terms of water management, amended concepts and time limits were promoted in order to put pressure on and oblige the water authorities to correct the problems of over-exploitation, pollution and sanitation. The truth was that many concepts of the 1992 Law were never applied, or their implementation was rudimentary, and thus it was impossible to evaluate their usefulness or efficacy. The clearest examples are: the environmental variable, the publication of water availability, the actualization of regulatory instruments (closed seasons, environmental reserves and regulations), the classification of water bodies, the water market, and the Basin Councils and their auxiliary groups. Analyzing what has occurred within the legal framework during the past twenty years, it is evident that efforts were geared towards amending the National Water Law and its regulations in the hopes that those changes by themselves would suffice to transform the water situation in Mexico. The recurrent failure has been to overlook that no law or amendment can be applicable if institutional capacities and the resources of water authorities, state governments, Basin Councils and other agents surrounding water have not been considered.

It is also clear that water administration is not only in the hands of water authorities; looking after water is a task that involves society as a whole. In this regard it is pertinent to mention the observation stated in the UNESCO's 2nd World Water Development Report:

> A basin insight – which has not yet garnered enough attention – is that the insufficiency of water (particularly for drinking water supply and sanitation), is primarily driven by an inefficient supply of services rather than by water shortages. Lack of basic services is often due to mismanagement, corruption, lack of appropriate institutions, bureaucratic inertia and a shortage of new investments in building human capacity, as well as physical infrastructure. Water supply and sanitation have recently received more international attention than water for food production, despite the fact that in most developing countries agriculture accounts for 80 percent of total water use. It is increasingly agreed in development circles that water shortages and increasing pollution are to a large extent socially and politically induced challenges, which means that there are issues that can be

addressed by changes in water demand and use and through increased awareness, education and water policy reforms. The water crisis is thus increasingly about how we, as individuals, and as part of a collective society, govern the access to and control over water resources and their benefits (UNESCO, 2006).

A new National Water Law, with an adequate balance between state and municipal laws, is without doubt the necessary basis for efficient water management in Mexico.

2.3.5 Investment in Research and Technological Development

Over the past years there have been advances in terms of research, technological development and human resource building in the hydraulic sector. However, it is necessary to organize and take advantage of the institutional capacity of technological development and research centres, universities, and businesses, through a wider structure that coordinates all the efforts surrounding a common objective. In Mexico, the total budget allocated to science and technology in relation to the *gross domestic product* (GDP) is 0.37 per cent. This reality reflects an investment that is six times lower than the 2.26 per cent average in OECD member countries. Thus, it is necessary to increase investment in science and technology to at least one per cent of GDP (Ruiz, 2009).

One area of opportunity is the development of synergies between governments, universities and businesses, so as to build the human capital of students, public servants and researchers that the country needs. These types of strategic alliances would facilitate goals such as:

1. preparing the new generation of engineers in order to develop the infrastructure Mexico needs;
2. fortifying schools of engineering in the country;
3. strengthening businesses that deal with project engineering and construction;
4. developing cutting-edge research for both the public and private sector;
5. boosting and updating research capacity;
6. transferring knowledge and technologies to the public and private sectors; and
7. promoting a culture of entrepreneurship and the creation of businesses with a sound technological base.

2.3.6 Environmental Planning

Recent floods in many regions of the country, the impossibility of offering drinking water and sewage due to the dispersion of the population, environmental law violations such as invading river beds and flood-prone areas, excessive deforestation throughout the national territory, and other similar actions are the main obstacle to a sound water management. Urban growth and competition for land use have led to the occupation of flood-prone areas (and also to those that were originally not flood-prone), river beds, and to the invasion of areas within natural and artificial water bodies.

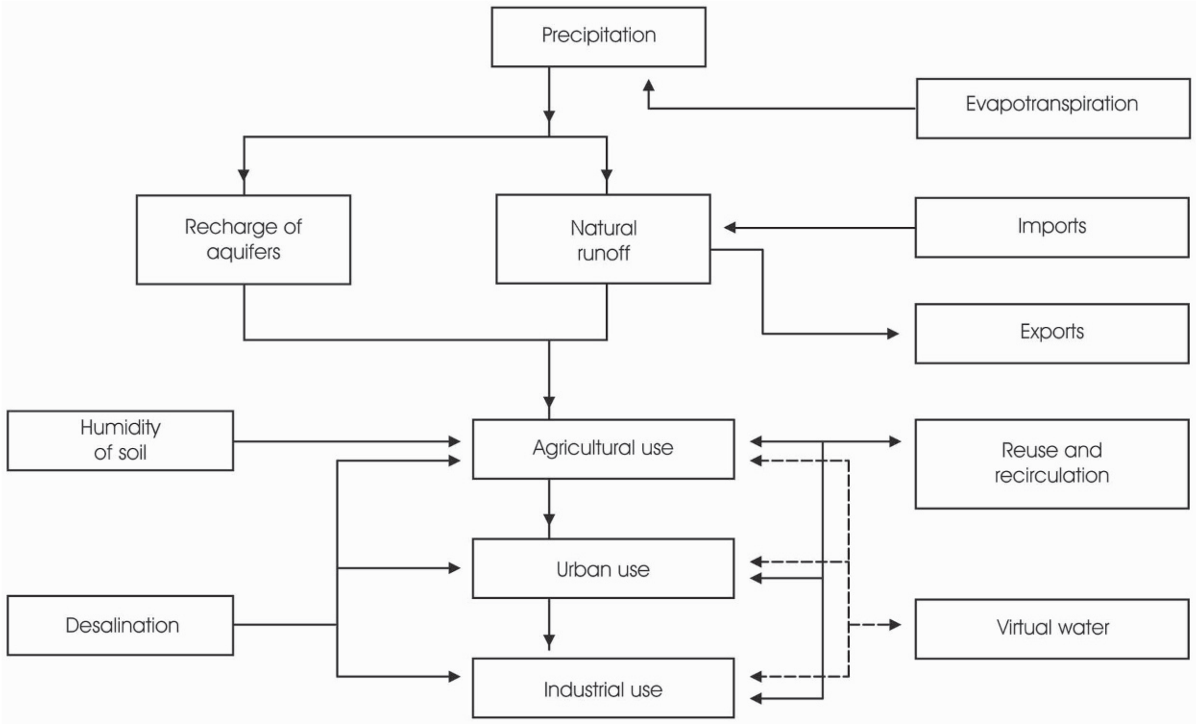
2.4 The National Water Programme (2007-2012)

To solve these problems, the National Water Commission developed the National Water Programme 2007–2010 (PNH, 2008) under the present federal public administration following the Planning Act (LP, 83), in accordance with the National Development Plan 2007–2012 (PND, 2007), in order to face present and future water challenges. The objectives of the National Water Programme are:

1. improving water productivity in the agricultural sector;
2. increasing access and quality of potable water services, sewage and sanitation;
3. promoting an integral and sustainable water management in basins and aquifers;
4. improving the technical, administrative and financial development of the hydraulic sector;
5. consolidating the participation of water users and organized society in general in water management, and promoting a culture of efficient water use;
6. preventing risks posed by hydro-meteorological events and overcoming their effects;
7. evaluating the effects of climate change in the hydrological cycle; and
8. forging a participatory culture and fostering compliance with the National Water Law in administrative terms.

Each of these objectives is further split into different strategies and programmes with clearly outlined goals. To date (2009), developments have come very close to meeting targets.

Figure 2.16: Proposal for a national water balance. **Source**: Arreguín et al. (2007).



2.5 Proposal for a New Water Balance

The national water balance should be re-evaluated in order to make better use of water where it is available, and to take it to regions where it is scarce. The proposal is to amend the traditional water balance scheme of the country (figure 2.16). The four elements added to the conventional scheme are outlined below.

2.5.1 Water Reuse and Recirculation

According to estimates annually 431.7 m^3/s of wastewater are produced. Of these 243 m^3/s come from municipal sources and 188.7 m^3/s from non-municipal sources. From the municipal wastewater sources, 207 m^3/s are collected, namely 85 per cent, of which 83.8 m^3/s are treated. In the case of non-municipal wastewater discharges, 29.9 m^3/s are treated, representing 15.8 per cent of the total. It is also noteworthy that 63.52 m^3/s of non-municipal wastewater discharges come from sugar refineries and that they are used for the irrigation of fields with sugar cane.

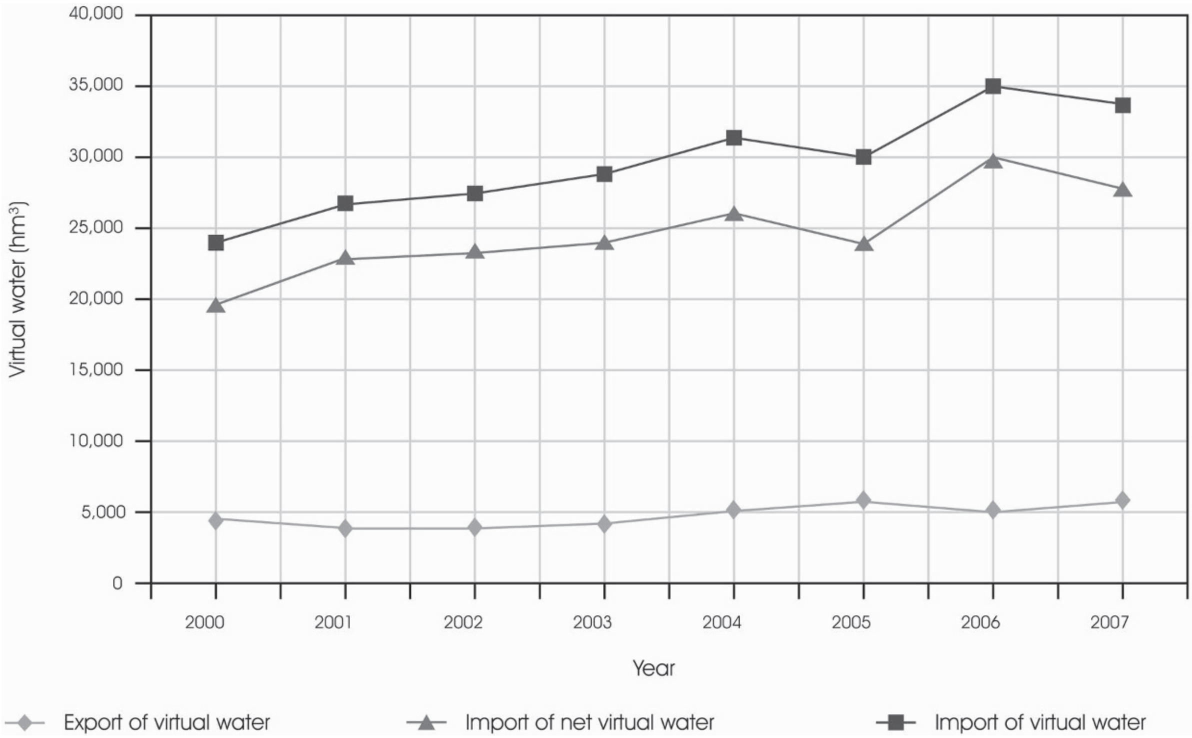
So, even though we are dealing with the reuse of 60 per cent of municipal water, at a later stage the plan is to reuse non-municipal wastewaters also. If the amount of the collected wastewater discharges should increase, this water could be reused in industry or for irrigation. Although in absolute terms the overall amount of reused water would seem minor, it is important to note that wastewater discharges are near human settlements or irrigation areas, making them easily suitable for that purpose. Besides this, water recirculation could add new water sources to industries instead of their depending on the habitually overexploited freshwater sources.

2.5.2 Virtual Water

There is a way of transporting water without using aqueducts, ships or tankers, and of storing it without needing dams, cisterns or tanks - what is called *virtual water*. Virtual water is the amount of water used in the production of a product, good or service. For example, in order to produce a ton of wheat it is necessary to use 1,000 m^3 of water on average.

Thus, countries with important industrial or oil developments but with scarce water resources for producing food, goods and services may use their financial resources to purchase them from other countries that have enough water to produce and export them. Thus, instead of using their scarce water resources to

Figure 2.17: Amount of net virtual water imported into Mexico (2000-2007). **Source:** Arreguín et al. (2009).



produce agricultural or industrial goods, by importing them, these countries reduce the pressure on their water resources.

The concept of virtual water has strengthened with the increasing importance of the environmental, economic, social and political value of water. In the period between 1995 and 1999, 1,031 km^3 of virtual water were negotiated annually in the international market (Hoekstra/Chapagain, 2006).

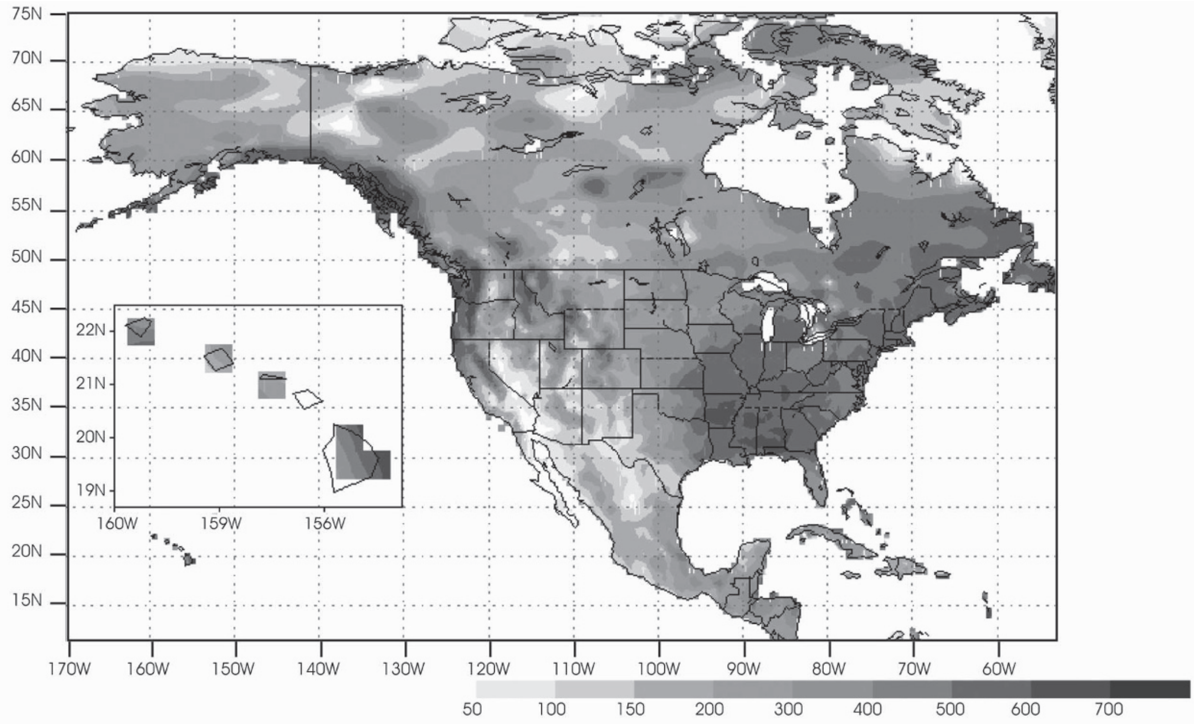
Thus, virtual water has been very important in countries that lack water resources for producing food, goods and services on a permanent basis. However, it has also played a decisive role in countries that have faced extreme weather events such as droughts and hurricanes. In several other countries virtual water has been useful in reducing the pressures on the environment. But virtual water also depends on other factors such as international trade agreements and treaties, on the population and economic growth, on technological advances, agricultural subsidies, international prices of agricultural products and inputs, on the countries' macroeconomic policies relating to imports and exports, on microeconomic policies, on the culture and religion of the producers, and on efficiency in agricultural and industrial production.

Figure 2.17 documents the evolution of imports and exports of virtual water in Mexico. In 2007 Mexico exported 5,884 hm^3 of virtual water but it imported 30,097 hm^3, which amounts to a net virtual water import of 24,213 hm^3 (Arreguín et al., 2007, 2008a, 2009).

2.5.3 Desalination of Water

Water desalination is a technology that has been used in Mexico for a long time, especially in tourist areas where water is scarce, such as Cancun in Quintana Roo, Acapulco in Guerrero, and Los Cabos in Baja California Sur. However, it has only been since the construction of a desalination plant for municipal use in Los Cabos that consideration of the use of this technology has become widespread throughout the country. Currently, desalination has been considered for agricultural use in cases where crop economics make it feasible (for example, to grow flowers and vines). Furthermore, desalination is at present being contemplated for big development projects in Rosarito and Ensenada in Baja California, in Puerto Peñasco in Sonora, and even in the Colorado River Basin to enable Mexico to comply with the requirements of its international water treaty with the USA. The progressive decrease in the cost of a cubic metre (m^3) of desalinized water and the increase in water demand position this technology as one of the main

Figure 2.18: Soil moisture for May 2009 (in mm). **Source:** CPC and NOAA (2009); at: <http://www.cpc.ncep.noaa.gov/soilmst/leaky glb.htm>.



sources of water supply in places where it is economically, environmentally and socially sound to implement it. In Baja California, there are cases where a cubic metre of desalinated water costs 9 or 10 pesos on average.

However, it is important to bear in mind that, out of the 435 desalination plants in Mexico, 137 are inactive due to a lack of adequate training and on-going training, long lead times, shortage of stock of specialized tools and reserve pumps and their being close to enterprises with high levels of oil, grease and organic waste discharges. These elements should be considered in order to prevent the abandonment of those desalination plants that are effective in areas of water scarcity such as the Yucatan Peninsula, Baja California and Sonora (ITSON, 2008/2009).

Environmental impact: Installing and operating a desalination plant has the potential of negatively impacting on air quality, aquifers, marine and aquatic environments, and possibly also on other aspects of mitigation. All these factors should be considered when assessing desalination plants in local and national regulation policies. Also, studies to evaluate potential construction sites should be undertaken and complemented by monitoring programmes after installation.

Among the relevant aspects to be considered are:

- *Construction:* the ecology of coastal zones and sea bottoms, habitat of mammals and birds; erosion and pollution effects far away from the point of discharge;
- *Energy:* fuel sources and transportation, discharge of cooling waters, air emissions as a consequence of fuel burning, and electric energy production;
- *Air quality:* links to energy production;
- *Marine environment:* components of discharges into the ocean, thermal effects, sea water extraction processes, effects of biocide compounds and toxic metals in discharged waters, oxygen levels, cloudiness, salinity, water mixing zones, impact on commercial fishing, recreation and tourism, amongst others;
- *Aquifers:* increase in soil salinity and possible toxic metal deposits in unconfined deposits.

2.5.4 Soil Moisture

Soil moisture is frequently based on peasants' knowledge, although it is rarely derived from a sound scientific base. In hydrology, soil moisture is defined as the liquid water content in a given earth surface. The *Climate Prediction Center* (CPC) of the *National Oceanic and Atmospheric Administration* (NOAA) of the

US publishes official maps on a monthly basis such as the one displayed below (figure 2.18).

2.6 Conclusions

Mexico faces considerable water challenges such as pollution, the impact of climate change on the hydrological cycle, water scarcity, the strengthening of water management to involve all users, and the need to revise and fortify science and technology in the country, as well as to promote sound environmental planning. However, Mexicans have the means to meet these challenges such as the National Water Programme, which governs all matters relating to water. It is essential to face these challenges as soon as possible and policies should be based on scientific grounds, always taking the environmental, social, economic and political aspects of water governance into account.

The current problems in Mexico have old historical roots, deriving from the country's socio-economic evolution and from water abuses, over-exploitation of aquifers, scarcity of surficial waters, pollution, and especially the low value that society confers on this most precious resource. Nevertheless, these are also the existing areas of opportunity, the challenges and menaces the country faces, which must be overcome if the country is to guarantee water for its future generations.

Technologies are constantly improving; this also applies to new forms of organization and articulation that include all actors related to water. It is imperative to strengthen the number of students, public servants, entrepreneurs and researchers working on issues that relate to Mexico's water challenges. This is the way forward and Mexico cannot afford to miss this opportunity.

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