Chapter 2
Mexican Water Sector: A Brief Review of Its History

Hector Manuel Arias-Rojo and Roberto Fernando Salmón-Castelo

Abstract In Mexico, there are wide conditions in terms of the sources and utilization of water resources. A brief description is presented, on the first part, to show technology level, water institutions, and water legislation through different periods of Mexico, showing the evolution of the water sector in the country. The current situation of the water sector is described based on an administrative zoning. Since agriculture is the main user, an emphasis is made on the description of its hydraulic infrastructure available. Water governance is accentuated due to its importance in terms of the continuous decrease of water availability and continuous increase in water demand. The future of the water sector is analyzed in terms of the commitments of Mexico in international treaties (Millennium Development Goals and Climate Change) and water governance; this one is considered for a proposal about what water sector needs to focus on in the future, searching poverty alleviation, efficient water use, and resolution of water conflicts.

Keywords CONAGUA · Mexico's water statistics · Water legislation in Mexico · Evolution of water institutions in Mexico · Hydraulic infrastructure in Mexico · Water governance

2.1 Introduction

All living organisms need water. Since water is not homogeneously distributed on earth, living organisms develop adaptation mechanisms to local conditions. The same is true for humans. When resources are scarce, conflicts develop, and to reduce

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conflicts, cultures have developed rules to minimize problems on the utilization of resources.

The right for water is a key element in human rights and is the main goal of global initiatives. This chapter describes the physical conditions of Mexico and how its population has responded to the environmental conditions. In the first part, we want to acknowledge that our country is one of the most diverse in terms of biological resources and our ancestors dealt with these extreme conditions with technology and ways of organization to endure the wide range of environmental conditions they found.

Later, we describe the institutional arrangements made to face new challenges and new technologies. Although the environmental conditions are as extreme as in the past, new technological developments have influenced on the way society organizes in creating new rules and/or new approaches.

Water resources are key elements in civilization and its survival. At the end of the chapter, the story is not finished, because new technology will bring new challenges, but we want to address what the situation is, how can we cope with the future, and what are the best possible approaches.

2.2 Context

The geographical location of Mexico has influence on the country diversity, not only biological but cultural and economic as well. Geographically, the southern part of Mexico, from 14°32′27″ N latitude up to the Tropic of Cancer, is in the tropical region, while the northern part of the country, from the Tropic of Cancer up to 32° 43′ 06″ latitude, is in the temperate region.

2.2.1 Climate

Although temperate and tropical climates are expected from the geographical location of Mexico, the northern part is in the high-pressure zone where the driest deserts of the world are located that include the deserts of Sonora and Chihuahua, which are shared with the United States (CONAGUA 2016, p. 13). The climate in the temperate region, in more than half the land, is dry, and only a small portion, the highlands, is temperate. Most of Southern Mexico has a tropical climate.

Climate is defined as the average annual atmospheric conditions in a given region over 30 years or more. In Mexico, we use the Köppen classification (INEGI 2000). The classification is based on the native vegetation and uses mean annual temperature and mean annual rainfall. According to those two indicators, the main climate units are tropical, dry, and temperate.

Figure 2.1 shows climate units according to Köppen classification adjusted to Mexican conditions (INEGI 2000). On the average, a good climate will have an

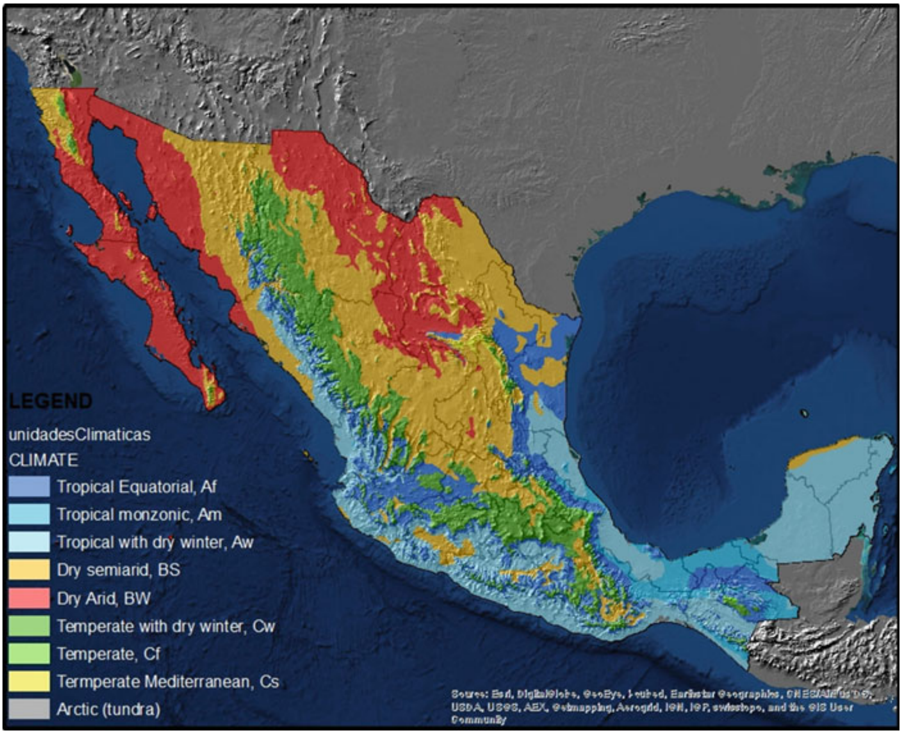

Fig. 2.1 Climate units of Mexico (modified from INEGI 2000)

average annual rainfall of 800 mm, and a wet climate is above 2000 mm; Northern Mexico is dry, Southern Mexico is wet, and Central Mexico is temperate. The average annual rainfall for the country is 760 mm, close to the ideal precipitation; however, annual rainfall distribution shows a bimodal distribution: 65% of rainfall in the summer (May–October) and 35% of rainfall in the winter months (November–February).

Climate in part is related to extreme events, which are a main concern at the national level. Droughts and floods are almost the rule in Mexico. Droughts are less frequent than floods, but their effects are devastating due to the lack of water in a significant portion of the nation. Floods are associated with atmospheric disturbances, tropical cyclones, in the Pacific and Atlantic oceans.

Damage assessment is conducted with the Saffir-Simpson scale, which has been used to measure tropical cyclones, as described in Table 2.1.

It is possible to add tropical depressions and tropical storms to moderate (H1 and H2) and intense (H3–H5) cyclones, since some of the damages have also been related to the first two categories. Table 2.2 shows that in 45 years, Mexico has had 224 major storms, most of them in the Pacific side, as well as the most destructive ones.

Table 2.1 Saffir-Simpson scale to assess tropical cyclones

Category	Maximum winds (km/h)	Storm tide (m)	Description	Further information
H1	119–153	1.2–1.8	Very dangerous winds will produce some damage	Well-constructed framed homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result
H2	154–177	1.8–2.5	Extremely dangerous winds will cause extensive damage	Well-constructed framed homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks
H3	177–208	2.5–4.0	Devastating damage will occur	Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes
H4	209–251	4.0–5.5	Catastrophic damage will occur	Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possible months. Most of the area will be uninhabitable for weeks or months
H5	>252	>5.5	Catastrophic damage will occur	A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possible months. Most of the area will be uninhabitable for weeks or months

Source: Modified from CONAGUA (2016, p. 37)

Table 2.2 Tropical cyclones that have impacted Mexico in the period 1970–2015

Ocean	Tropical depressions (TD)	Tropical storms (TS)	Moderate cyclones (H1 and H2)	Intense cyclones (H3–H5)	Subtotal
Atlantic	27	31	14	12	84
Pacific	32	49	46	13	140
Total	59	80	60	25	224

Source: CONAGUA (2016)

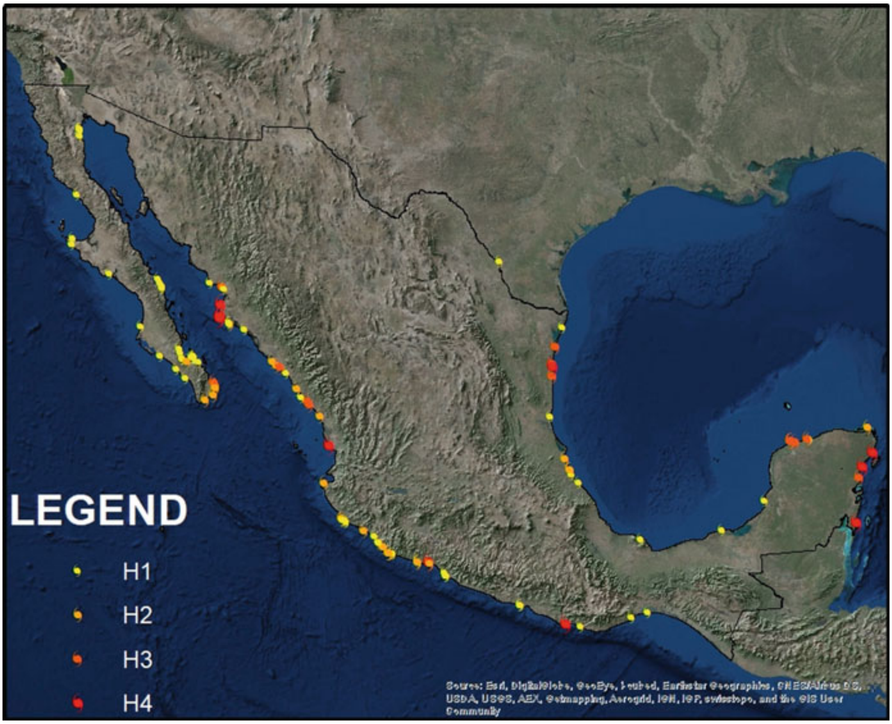

Fig. 2.2 Tropical cyclones impact location in the coasts of Mexico (CONAGUA 2016, p. 38)

Figure 2.2 shows the impact zones of tropical cyclones from 1970 to 2015 in the coasts of Mexico showing that the cyclones in the Pacific Ocean are more frequent and destructive.

A very important portion of the national budget is spent to control and manage those catastrophic events.

2.2.2 Land Resources

Climate and relief are factors that contribute the most to Mexico's biological and cultural diversity, but land and water resources play a significant role in the economic conditions due to the ability of man to transform the land.

2.2.2.1 Terrain

Mexico's terrain is rough due to the presence of large mountain ranges that cross south-north, *Sierra Madre Occidental* and *Sierra Madre Oriental*, and mountain ranges east-west in the south, *Sierra Juárez*, *Sierra del Sur*, and *Sierra del Lacandon*. The rough country is about 40% of the surface, and it is combined with high plains and coastal plains where human activities are concentrated. Fortunately, rough terrain is also responsible for the presence of rivers that provide water for human consumption and economic activities.

2.2.2.2 Soils

Relief and climate influence soils, and as a result, about 40% of the land has good productive soils, especially in the dry zones and the high plains. On the average, high-clay content soils or vertisols predominate in the plains, independently of the climate, and are the basis for agriculture and livestock production. Desert soils are productive, too, but water is a limiting factor.

2.2.3 Water Resources

The presence of mountain ranges has a very strong influence on Mexico's water resources. Rainfall is converted in runoff, surface water, and some portion infiltrates the soil and percolates to aquifers, turning into groundwater. Surface and groundwater resources play a major role in the regional development. Surface water and groundwater are separately described, but they are connected. Also, since water quality is as important as water quantity, a brief description is included, too.

2.2.3.1 Surface Water

Fortunately, even the largest deserts of Mexico have a river system, which in the arid and semiarid regions are ephemeral or intermittent, while in the temperate and tropical zones, the rivers are perennial. In the Sonoran Desert, the Colorado River, shared with the United States, is the main supply; while the Chihuahuan Desert has

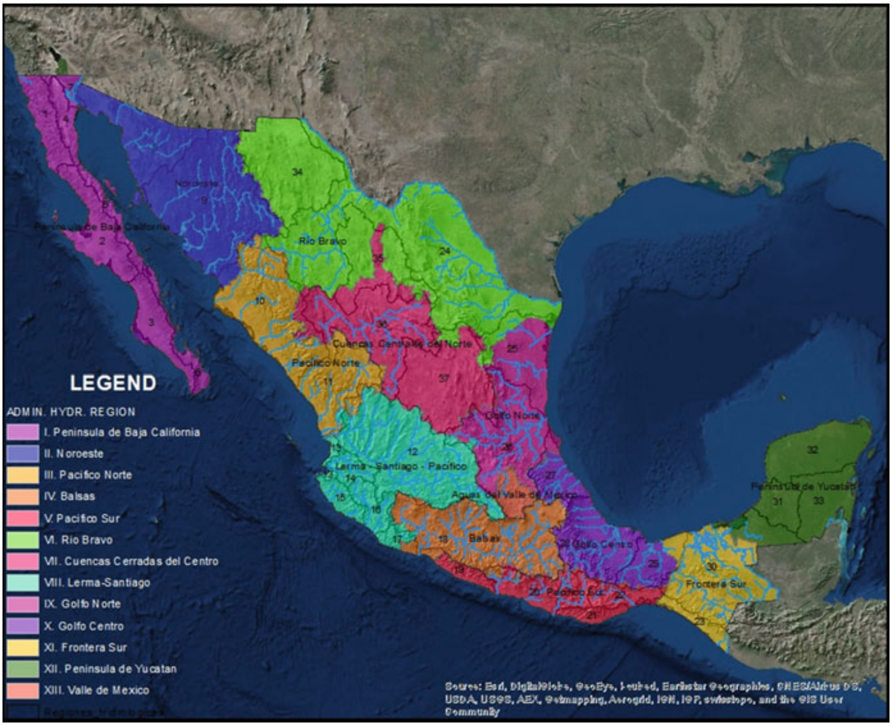

Fig. 2.3 Hydrologic Administrative Regions (RHA in Spanish) and 37 subregions (CONAGUA 2016, p. 29)

the Rio Bravo (Rio Grande) and its tributaries, as the main source of water. Lakes are more common along the Lerma and Balsas basins that drain into the Pacific Ocean, in the temperate areas. Finally, in the tropics, the rivers are not just perennial but have large discharges, enough to house large hydropower plants in their reservoirs. Although there are 1471 river systems, 731 basins are managed for hydrological balances, grouped in 37 hydrological regions (Fig. 2.3). Some river systems are shared with neighboring countries, three with the United States (Tijuana, Colorado, and Bravo) (CILA 1944), four with Guatemala (Grijalva-Usumacinta, Suchiate, Coatan, and Candelaria), and one with Belize and Guatemala (Río Hondo).

Figure 2.3 shows that the Hydrologic Administrative Regions (RHA in Spanish) of the two peninsulas are different than in the continental regions. In Peninsula de Baja California (RHA I), streams are short and abrupt in slope, while Peninsula de Yucatan (RHA XII) has no surface streams due to the geology of the region, karstic. Overall, the annual surface water adds up to 80% of the water availability as will be later described.

Fig. 2.4 Location of aquifers in Mexico by Hydrologic Administrative Regions (RHAs) showing overdrafted aquifers (modified from CONAGUA 2016, p. 30)

2.2.3.2 Groundwater

There are 653 aquifers (Fig. 2.4) that provide with about 20% of the water supply on an average annual basis. Aquifers started to become a secure water source in the arid regions with the arrival of pumps in the 1940s. Since then and with the support of power lines to agricultural areas, in the 1970s, many areas were heavily pumped. By 1975 there were 32 overdrafted aquifers; by the 1980s there were 80. Currently there are 105 overdrafted aquifers, 17 of which have already saline intrusion and 32 are responsible for soil salinity and/or with low-quality regimes.

Figure 2.4 shows the location of the aquifers, and it can be seen that most of the overdrafted aquifers are in the arid and semiarid regions as well as in the most populated areas.

2.2.3.3 Water Quality

Water quality has been classified based on three indicators, biochemical oxygen demand (BOD5), chemical oxygen demand (COD), and total suspended solids

Fig. 2.5 Surface water quality monitoring sites in Mexico (Source: modified from CONAGUA 2016)

(TSS), and 21 basins have segments where one or several indicators do not comply with the limits established on the Official Mexican Norm (SEMARNAT 2003).

Figure 2.5 shows rivers, lakes, and coastal monitoring sites. The Hydrologic Administrative Regions with most problems due to water quality are RHA XIII, RHA IV, and RHA VI, located in Central Mexico, the most densely populated area.

2.3 History of Water Legislation and Institutional Framework

In the history of the social organization to cope with food and water challenges, the Mexican cultures have evolved. This is a description of the arrangements and main techniques used from pre-Hispanic to current times. Water has played a relevant role in the history of Mexico. Dams, aqueducts, canals, wells, and other water works were built before Europeans arrive to the continent. Some works were for flood control, but most of them for domestic use and rainfed or irrigated agriculture. The hydraulic works and the arrangements to its construction, operation, and maintenance have changed since then.

2.3.1 Pre-hispanic Times: 800 BC–1521

Climate not only influenced flora and fauna but man, too. Early cultures used technology to provide food for the early settlements. Anthropologists recognize Mesoamerica, the temperate and tropical climate cultures of Mexico, but little is known of Aridoamerica. Braniff Cornejo (2009) called those cultures as "La Gran Chichimeca." It corresponds to Northern Mexico, including Southwestern United States.

Mesoamerican cultures were distributed in the temperate region where Olmec, Aztec, Purepecha, and Zapotecs, as well as Tlaxcallan cultures, were dominant and the tropical region where Mayan cultures dominated. Aridoamerican cultures vary from the Hohokam in Arizona (USA), Pueblo in New Mexico (USA), and Chihuahua (Mexico) to Trincheras culture, Rio Sonora culture (Sonora), and the Yoreme culture (Sonora and Sinaloa) (Braniff Cornejo 2009) that diverted river streams to grow their crops. Mesoamerican cultures have been deeply studied, and there are several references on the hydraulic works used. Rojas Rabiela (2009, pp. 7–20) mentioned hydraulic works that involved surface and groundwater sources for domestic use. The main source was surface water and rainfall. Groundwater sources were more common in the Yucatan Peninsula due to the geology of the area in the Mayan culture. Other than rainfall collection for domestic and/or agricultural use, surface water involved storage, conveyance, and application techniques on gravity irrigation. Subsurface irrigation was mainly in chinampas around Xochimilco, near Mexico City.

In the Mesoamerican or Aridoamerican cultures, (1) water was diverted from streams to irrigate neighboring areas with masonry, rock, or earthen levees, and (2) terraces were formed to collect and distribute rainwater in the land. Variations depended on the level of development of each culture.

In terms of the social organization, Palerm and Wolf (1972) mentioned that most pre-Hispanic cultures have an "Asiatic mode of production," where water technicians played a major role due to the importance of the construction and maintenance of the hydraulic works so dearly needed. Water works were a very intensive work that required coordination and cooperation among the members of those cultures. It is possible to say that the Asiatic mode of production created a specialized group that had an authoritative scale in those cultures in the collection and distribution of water.

2.3.2 Colonial Times: 1521–1824

When the Spaniards came to America, they claimed the lands they visited in the name of the Castile Crown and declared the Catholic faith. Those cultures that represented some gain to the crown's treasure and/or did not accept the Catholic faith were conquered by force. The arid zones were not of special interest, and the harsh conditions were claimed in the name of the King by the Order of Jesus of the Catholic Church. On May 3, 1493, Pope Alexander VI, gave power to the Catholic Kings to the land they claimed (cited by Molina Enríquez 1909, pp. 166–167). The first legislation on land and water resources in Mexico was on the "Compilation of the Laws of the Kingdoms of the Indies" published in 1681, where water was considered a common good. Under this legislation, the crown gave power to their representatives, viceroys, to concede land and water grants ("mercedes") to individuals for a given period of time. Later these grants were changed to ad infinitum on October 15, 1754 (Molina Enríquez 1909, p. 167).

Rarely, the colonial legislation separated water from land. The reported cases belonged to irrigation concessions, industrial use, or water supply for human settlements. Other than those mentioned, land and water belonged to the crown (Molina Enríquez 1909, p. 171).

Colonial hydraulic works were modified with the introduction of wheels, steel, and animal traction in more efficient and powerful tools, but the basic concepts of extraction or diversion, storage, conveyance, and application of water in the domestic services or agricultural activities did not change much but the scale (Rojas Rabiela 2009, pp. 20–21). What changed were the organization and goals of the hydraulic works. The goals changed from collective or communal to private, and the work organization that used to be voluntary and orderly changed into forced labor provided from local indigenous communities for their lords. Indian rights for land and water were provided in the legislation but not observed. Conflicts on water distribution were solved as in Spain with water judges that in some places in Mexico were still in use until very recently. Water judges were elected, and they had the authority to solve water conflicts.

2.3.3 Independent Times: 1824–1880

After the independence from Spain, and to counteract potential foreign invasions, a colonization decree was published on August 18, 1824, aimed at promoting human settlements, especially in the northern arid zones. Early developments diverted streams through canals; they were called *acequias*. However, as more people arrive and in dry years, conflicts arose and became a major problem. In 1843, the decision process was granted to the municipal authorities (ayuntamiento), especially conflicts among different settlements. No major changes than those conducted during the colonial times were arranged. The major progress in those times were:

- Establishment of the metric system on August 2, 1863. Before there were a lot of local measurement systems that complicated calculations. The introduction of the metric system marked a large improvement and eased calculations and engineering works.
- Publication of the "Código Civil" (Civil Code) in 1870 where water was declared property of the nation.

2.3.4 Porfirian Times, 1880–2011

The continuous threat of foreign invasions persisted during Porfirian times. Three laws were published that played a major role in the use of land and water resources in Mexico:

1. *Ley sobre Terrenos Baldíos* (*Law of Wastelands*). The law was published on December 15, 1883, and it allowed the presence of foreign settlers on wastelands and the investment in infrastructure to improve the economic conditions of the arid and semiarid unproductive lands in Northern Mexico.
2. *Ley sobre Vías Generales de Comunicación* (*Law of Transportation*). Published in 1888, it not only allowed the terrestrial communication and railroads but the improvement of ports and fluvial and marine transportation. It was modified on June 15, 1888, to include the role of the federal government on the taxation of concessions for the use of marine and fluvial routes and hydropower plants.
3. *Ley General de las Instituciones de Crédito* (*General Law of Credit Institutions*). Issued on March 19, 1897, it allowed foreign capital to invest in productive activities, such as mining, railroads, and large irrigation and hydropower plant projects.

As a result, several colonization projects based on irrigation started and were finished years ahead. Here are five examples:

- In 1865, José de Jesús and Martín and Juan Francisco Salido were granted a loan to build the first channel in Camoa, Sonora, to divert water from the Mayo River. That was the start of the irrigation district DR-038 Río Mayo, Sonora, currently with about 80,000 ha (Kroeber 2009).
- In 1886, a group of American colonizers, led by or Albert Kimsey Owen, arrive to Topolobampo and started the construction of Canal Taxtes, by diverting water from Rio Fuerte, and Benjamin Francis Johnston started the construction of a sugar mill, *Sinaloa Sugar Company* (Infante 2011). Those are the beginnings of DR-074 Río Fuerte, currently with 230,000 irrigation hectares.

- In 1889, Charles R. Rockwood, associated with Guillermo Andrade, through the *Sociedad de Irrigación y Terrenos de la Baja California*, *S.A.*, was allowed for the construction of Canal El Álamo to divert water from the Colorado River to the Imperial Irrigation District, in California, USA (Hundley Jr. 2000). Irrigation district DR-014 Rio Colorado has currently 180,000 ha with water imported from the Colorado River (CILA 1944).
- In 1890, Carlos Conant Maldonado was granted to irrigate 400,000 ha in rivers Fuerte, Sinaloa, Mayo, and Yaqui in Sonora, through the *Sonora and Sinaloa Irrigation Company*. He could not finish the project and sold his company to the *Richardson Irrigation Company* (Luna Escalante 2007). This was the beginning of irrigation districts DR-018 Colonias Yaquis and DR-041 Río Yaqui, currently covering 245,000 ha.
- On May 7, 1906, a concession was issued to Pablo Ginther and Joaquin Cortazar to build La Boquilla Dam, on the Conchos River, to generate electricity for neighboring mining companies, and the water released was sold for farmers in what is now DR-005 Rio Conchos, Chihuahua (Kroeber 2009).

However, the irrigation and the hydropower plant projects conducted and run by foreign companies increased the conflicts for water, forcing the Porfirio Diaz administration into the creation of an office with trained personnel to make decisions. It also promoted the creation of a hydraulic engineer in the National School of Agriculture, to improve the presence of trained personnel because the water conflicts multiplied (Kroeber 2009).

Diaz started the formation of “Scientific Commissions” with trained personnel who started the field reconnaissance studies and continued on the design and construction of large hydraulic works. Those were the basis for the following stages in the creation of large irrigation and hydropower projects. The “Comisión Geográfica Exploradora” (Geographic Exploration Commission) was responsible for surveys, land adjudication, and zoning in indigenous communities, besides the design and construction of irrigation canals, land clearing, and improvement works.

2.3.5 Revolution Times: 1911–1926

In this period, the situation of the country was very unstable, and not much was done until it settled down, by the 1920s. Before that, the basis of the Mexican Constitution was established in 1917. Among some of the regulation changes was article 27 that established that land and water belong to the nation and only an authority invested by the federal government will take decisions about granting concessions to individuals or groups of individuals.

2.3.6 Large Irrigation Projects: 1926–1940

In 1926, the *Ley sobre Irrigación con Aguas Federales* (Law of Irrigation with Federal Waters) was published. This law established the basis for the national agricultural development. Hydraulic works were considered of *public interest*, which allowed the expropriation and purchase of large parcels of land to design and construct large irrigation and hydropower plant projects. To conduct the water policy, the *Comisión Nacional de Irrigación* (National Irrigation Commission) was created. This institution was an administration office that trained personnel, conducted and improved survey studies, as well as conducted the construction and supervision of large irrigation projects.

On August 6, 1929, that law was modified as *Ley de Aguas de Propiedad Nacional* (Law of National Waters), which granted the *Secretaría de Agricultura y Fomento* (Ministry of Agriculture and Economic Development) the authority in water issues but navigation. It started granting water concessions and included "a compensation to the federal government for the use and utilization of national Waters."

The 1929 law is the basis of the current water legal framework. It has only been updated or modified. Among the main issues included there were the rights and obligations of the legally bonded user associations (*sociedades de usuarios*). This is the first time that "national hydraulic reserves" are mentioned to protect and secure water volumes of the irrigation districts and hydropower plants.

On October 19, 1934, it was modified to assign penalties and fines due to unauthorized construction of dams or derivations, especially if there were damages on private property. This modification introduced temporary permits for water use, exploration permits, authorizations for the use of water in humid years on non-granted lands, and the public register of the Water Users Associations. It also introduced water rights suspensions due to pollution and lack of compliance with the volumes assigned.

2.3.7 Ministry of Hydraulic Resources, 1947–1976

The agrarian reform created a group of new farmers with good cropland and irrigation, access to credit, agricultural machinery, and technical assistance. Not only the agricultural land increased from 3.0 Mha in 1930 to 5.2 Mha by 1940 but the land productivity, too. *Ejido* land increased from 800,000 ha to 3.5 Mha.

In 1947, the new presidential administration created the Ministry of Hydraulic Resources (*Secretaría de Recursos Hidráulicos*, SRH), and the government responsibility was concentrated in this institution. Water supply and sanitation were incorporated to the duties of SRH aimed at building a strategy to abate the water services. Multipurpose hydraulic projects were designed, constructed, and operated to generate electricity, flood control, and irrigation. New water management models were instituted based on the recent progress in the United States, the formation of integrated watershed management projects through River Basin Commissions.

Executive commissions were formed to conduct regional development projects in several basins often affected by destructive floods in Southern Mexico. The Papaloapan River Basin Commission was the first to be established by presidential decree; then the Commission for the Tepalcatepec River, later known as the Balsas River Basin Commission; Rio Fuerte River Basin Commission; and Rio Grijalva Basin Commissions in 1952. Those were organizations with administrative autonomy that went beyond hydraulic works into regional economic development. A very special case was the Hydrological Commission of the Mexico Valley Basin in 1951. Within this framework, the Lago de Texcoco Commission was decreed in 1974. Several hydraulic progresses were made, and many personnel trained within this approach conducted several projects once the commissions were repealed.

By 1948, the *Dirección General de Agua Potable y Alcantarillado* (General Direction of Drinking Water and Sanitation) established the regulations for the *Juntas Federales de Agua Potable* (Federal Potable Water Boards), which started the design and construction of wastewater treatment and potable plants throughout the country.

Although groundwater pumping started with the first vapor motors in the early 1900s (Moreno Vázquez 2006, p. 118), the arrival of submersible pumps by the early 1940s, powered with diesel, significantly increased the use of groundwater and, therefore, aquifer depletion. This situation forced regulations to control aquifer pumping (Moreno Vázquez 2006). A law was decreed on December 30, 1947, to control groundwater pumping and to establish aquifer bans. The first aquifer ban was established in 1951 in the Sonoran Desert.

By the 1960s, farmers were organized to introduce power lines to their fields to electrify their pumping systems. This skyrocketed the use of groundwater in Mexico, and consequently, many aquifers have been severely affected and conflicts have surfaced. Over 100 aquifer bans have been established since then.

2.3.8 Federal Waters Law: 1972–1992

On January 11, 1972 the Federal Waters Law was published, where SRH is the water authority. All past water laws were repealed including potable water and sanitation and groundwater. For the first time, surface and groundwater are united in a single general law. Aquaculture was recognized as a water use. The maximum irrigated land tenure was reduced from 50 to 10 ha.

In this water legislation, three hydro-agricultural administrative units were created:

1. *Distritos de Riego* (irrigation districts)
2. *Unidades de Riego para la Producción Rural*, URDERALES (irrigation units)

3. "*Distritos de Drenaje y Protección de Inundaciones*" (drainage and flood protection districts or drainage districts)

The farmers were organized in *Comités Directivos* (Directive Committees) that were created to participate in the hydraulic planning. Aquaculture districts were created, too, but most of them used seawater. Finally, SRH was the sole authority to grant water concessions.

By 1973 SRH serviced 1405 locations through 1120 systems, which weakened the municipal governments.

In 1976, SRH was derogated, and all hydro-agricultural infrastructures were transferred to the new *Secretaria de Agricultura y Recursos Hidráulicos* (Ministry of Agriculture and Hydraulic Resources), and the drinking water treatment and sanitation was transferred to a ministry that dealt with urban services and later was returned to the municipalities by 1983.

2.3.9 Water Decentralization: 1992–2004

In December 1992, the *Ley de Aguas Nacionales* (Law of National Waters) was decreed, and other laws were repealed. The *Comisión Nacional del Agua* CONAGUA (National Water Commission) was created as a decentralized administrative institution part of the SEMARNAT (Secretary of Environment and Natural Resources). The *Registro Público de Derechos de Agua* REPDA (Public Register of Water Rights) was created to have a public register of water concessions as part of CONAGUA. The River Basin Councils were created to promote the participation of water users. For the first time, environment is considered a nonconsumptive water user, and environmental flow is described as the part of river flow that must be maintained to conserve freshwater ecosystems. The integrated river basin management approach was back as one of the strategies in the application of water policies by CONAGUA, the water authority.

Finally, a decentralization process started in 1997 by empowering the 13 Hydrologic Administrative Regions, now called *Organismos de Cuenca* (River Basin Organizations).

2.3.10 Water Democratization: 2004

In less than 12 years, modifications to the National Waters Law were made again and published on April 29, 2004. Most of the modifications were additions and/or clarifications of the old version. For example, the constituency of the River Basin Councils is clearer. The main chapters are as follows: 1st Preliminary Dispositions; 2nd Water Administration; 3rd Water Policy and Planning; 4th User Rights or Utilization of National Waters; 5th Zoning, Bans, or Reserves; 6th Water Uses;

7th Prevention and Control of Water Contamination and Responsibilities on Environmental Damage; 8th Investment on Hydraulic Infrastructure; 8th bis. Water Financial System; 9th National Goods in Charge of CONAGUA; and 10th Infractions, Penalties, and Recourses.

2.4 Current Situation of the Water Sector

Currently, to manage the water resources of the country, administrative divisions have been created, based mostly on hydrologic units, like basins, but in larger areas. For each region, the water availability and its quality are described to analyze the situation of the water sector.

2.4.1 Administrative Division of Water Resources

In 1997 the country was divided in 13 Hydrologic Administrative Regions (RHA in Spanish). Those regions were formed on large basins or the group of several basins, adjusted by state and/or municipal limits to integrate socioeconomic issues (CONAGUA 2007). Table 2.3 lists the 13 RHAs, showing the area, average annual surface and groundwater, population, water availability, and contribution to gross domestic product (GDP). Figure 2.6 shows the location of each RHA.

2.4.2 Water Sources

There are two main sources of water, surface and groundwater. Although they are managed separately, they are connected. Reduction of surface water will reduce the recharge of aquifers, while an excess of surface water will replenish aquifers. The effect may not be instantaneous, but it will be shown depending on the size of the water system.

2.4.2.1 Surface Water

Surface water is by far the most abundant source. Table 2.3 shows that almost 80% of the water consumed in the country comes from rivers or lakes, sometimes stored in reservoirs or diverted from rivers.

Surface water is climate dependent and its effect is almost instantaneous. Rivers in the southeast of the country are perennials, while rivers in Northern and Central Mexico are ephemeral and even intermittent. Therefore, surface water is sufficient in

Table 2.3 Administrative division of water resources and the sources of water, their distribution, and contribution to global domestic product (GDP)

Hydrologic Administrative Regions (RHA)	Continental area (km^2)	Average annual surface water (hm^3 /year)	Average annual aquifer recharge (hm^3/year)	Average annual renewable water (hm^3/year)	Population (millions)	Renewable water per capita (m^3/cap/ year)	Contribution to GDP (%)
I	154,279	3300	1658	4958	4.45	1114	3.61
II	196,326	5066	3207	8273	2.84	2913	2.86
III	152,007	22,519	3076	25,595	4.51	5675	2.88
IV	116,439	16,805	4873	21,678	11.81	1836	6.14
V	82,775	28,629	1936	30,565	5.06	6041	2.29
VI	390,440	6416	5935	12,351	12.30	1004	14.29
VII	187,621	5529	2376	7905	4.56	1734	4.19
VIII	192,722	25,423	9656	35,079	24.17	1451	19.08
IX	127,064	24,016	4108	28,124	5.28	5327	2.24
X	102,354	90,424	4599	95,023	10.57	8990	5.62
XI	99,094	121,742	22,718	144,460	7.66	18,859	4.93
XII	139,897	4008	25,316	29,324	4.60	6375	7.38
XIII	18,229	1112	2330	3442	23.19	148	24.49
	1,959,247	354,989	91,788	446,777	121.00	3692	100.00

Source: Modified from CONAGUA (2016, p. 20)

Fig. 2.6 Hydrologic Administrative Regions, lately River Basin Organizations, and the renewable water per capita (Source: modified from CONAGUA 2016, p. 21)

the humid tropics but not in the arid and semiarid regions, where groundwater must be pumped to supplement the population needs.

2.4.2.2 Groundwater

Table 2.3 shows that about 20% of the total water available is pumped from aquifers. Three regions are highly dependent on groundwater: RHA XII *Peninsula de Yucatan*, with arid climate and karstic geology, RHA XIII *Valle de Mexico*, and RHA VI *Region Lagunera*, closed basins in semiarid climate.

On the average, groundwater quality is hard (excess of carbonates), but some aquifers may carry potentially harmful substances like fluoride and arsenic, so human consumption must be regulated. The problem with groundwater is that it has been irreversibly depleted causing a series of problems that varies from high pumping cost, high treatment cost, and land subsidence, among others.

2.4.3 Water Availability and Water Users

Table 2.3 shows the water availability per hydrologic region. The area with least available water is RHA XIII, *Valle de Mexico*, where the most populated city is located, Mexico City, as well as several industries and services.

The influence of large cities on the gross domestic product contribution can also be detected: Mexico City is in RHA XIII, with 24.49% GDP; Guadalajara is in RHA VIII with 19.08% GDP; and Monterrey is in RHA VI, with 14.29% GDP. Those regions are more industrialized than other RHAs, and the size of the cities is correlated with the contribution to the GDP.

2.4.3.1 Water Availability

The annual surface water availability is 354,989 hm^3/year, while groundwater availability is estimated at 91,788 hm^3/year. However, their distribution is not homogeneous: it decreases as population increases. The annual water availability per capita has decreased over time; for example, the average availability in 1950 was 18,035 m^3/cap/year, and it dropped to 4422 m^3/cap/year in 2010. According to international standards, water availability per capita is low.

2.4.3.2 Water Users

Although the total water available is 446,777 hm^3/year, not all the water is used. In Mexico, water belongs to the nation. The nation, through the authority invested in *Comisión Nacional del Agua* (CONAGUA), grants water concessions, through *Registro Público de Derechos de Agua* (REPDA or the Public Register of Water Rights). The titles allow an applicant for the concession of a given volume of water, if available, for a period. Water concessions add 266,560 hm^3/year.

It is very important to recognize that there are two types of water users: consumptive, those where water is consumed during the process, and nonconsumptive, those where water is consumed at zero to nonsignificant amounts. Table 2.4 describes the classification of water users in Mexico and grouped water users, either consumptive or nonconsumptive use, as well as the annual figures.

Table 2.4 shows that the concessions for consumptive uses add to 85,665 hm^3, while concessions for nonconsumptive users total to 180,895 hm^3, for a total of 266,560 hm^3/year. It can also be identified that agriculture (including livestock, aquaculture, and other users) represents 76.3% and domestic sums 14.6%, adding 91% of water conceded for consumptive users.

Table 2.4 Grouped water uses and water concession volume per water use

Key	Repda classification	Volume of water concessions (Hm^3)	Grouped uses	Definition	Volume of water concessions (Hm^3)
A	Agriculture	58,450	Agriculture	A+D+G+I+L	65,360
B	Agroindustrial	4	Domestic	C+H	12,480
C	Domestic	39	Industrial	B+E+F1+K	3676
D	Aquaculture	1136	Power plants	F2	4149
E	Services	1474	Subtotal consumptive		85,665
F	Industry	6347	Hydropower plants	J	180,895
F1	Industry except thermal power plants	2198	Subtotal nonconsumptive		180,895
F2	Thermal power plants	4149	Total		266,560
G	Livestock	207			
H	Public urban	12,441			
I	Multiples	5566			
K	Commerce	0.1			
L	Others	0.5			
	Subtotal consumptive	85,665			
J	Hydropower plants	180,895			
	Subtotal nonconsumptive	180,895			
	Total	266,560			

Source: CONAGUA (2016)

2.4.3.3 Water Resources Stress

Water resource stress is defined as percentage of water consumed with regard to renewable water, and it was designed as an indicator of the water situation in a region. There are four categories: less than 10% is *NO STRESS*, 10–20% of renewable water consumption is a *LOW DEGREE*, the range from 20 to 40% the pressure is *MEDIUM*, the range from 40 to 100 is *HIGH*, and higher than 100% then of the pressure is *VERY HIGH*. Table 2.5 shows the values for each administrative region.

It can be seen that the most stressed area is RHA XIII *Valle of Mexico* that concentrates population and economic activities. It is followed by the desert regions and temperate regions heavily populated (Fig. 2.7).

Table 2.5 Stress over water resources indicator per Hydrologic Administrative Region (RHA)

Hydrologic Administrative Regions (RHA)	Total volume licensed (hm^3/year)	Renewable water (hm^3/year)	Stress over water resources (%)	Classification of stress
I	3958	4958	79.8	High
II	6730	8273	81.3	High
III	10,770	25,595	42.1	High
IV	10,798	21,678	49.8	High
V	1555	30,565	5.1	No stress
VI	9524	12,351	77.1	High
VII	3825	7905	48.4	High
VIII	15,724	35,079	44.8	High
IX	5742	28,124	20.4	Medium
X	5560	95,023	5.9	No stress
XI	2505	144,460	1.7	No stress
XII	4200	29,324	14.3	Low
XIII	4774	3442	138.7	Very high
Total	85,665	446,777	19.2	Low

Source: CONAGUA (2016)

2.4.4 Hydraulic Infrastructure

To supply water to 121 million people and support associated economic activities, an impressive hydraulic infrastructure has been built and continuously improved to attend the needs of a fast-growing economy. The largest water users are agricultural and municipal uses, but other activities need energy and water in their processes; therefore, the construction of dams to store water, produce energy, control floods, or other services has been a national priority. CONAGUA is responsible for the construction, operation, and maintenance of the larger hydraulic works, i.e., the storage and conveyance of water, the basis for the direct supply of water to households or agricultural lands. There are more than 5000 dams or reservoirs in the country, 180 have capacities over 20 hm^3. The potential water capacity of all the dams is estimated at 150,000 hm^3. A complete list and characteristics of the 180 dams is provided by CONAGUA (2016, p. 99).

There are over 3000 km of aqueducts that serve the largest cities. The discharge of those aqueducts is over 112 m^3/s. CONAGUA (2016, pp. 118–121) provides a very extensive list of the aqueducts and their characteristics. The extension of the aqueducts is a measure of local deficits, especially in relation to large cities. Most of the aqueducts are water transfers to serve large cities. The most outstanding examples are Mexico City and the Cutzamala System, Monterrey, Guadalajara, Ixtapa-Zihuatanejo, Tijuana, Ciudad Victoria, León, and Hermosillo, among others (CONAGUA 2016, p. 98). Most of those cities have populations above 1 million people. In most cases, water conflicts have aroused between the water source and the water delivery.

Fig. 2.7 Stress on water resources per Hydrologic Administrative Region (Source: modified from CONAGUA 2016)

2.4.4.1 Potable Water Supply and Sanitation

The water supply and sanitation services to the households are provided by municipalities, but CONAGUA funds, trains, and provides advice to the municipalities. Municipal services are straightforward in urban areas but in rural areas it is a big challenge, so it is important to analyze it separately. The water supply infrastructure consists of 874 drinking water treatment plants that yields 97.9 m^3/s to cover 94.4% of the population, 97.2% urban, and 83% rural (CONAGUA 2016, p. 112). Most importantly is the evolution of coverage of water supply and sanitation. Figure 2.8 shows the evolution of the potable water supply to households from 1990 to 2015, where it jumped from a 75.4% to 94.4% at the national level, but the coverage in the rural areas almost doubled from 46.5% to 83.0%.

Sanitation is provided by 2477 municipal wastewater treatment plants that treat 120.9 m^3/s and 2832 industrial wastewater treatment plants that discharge 70.5 m^3/s. The coverage of sanitation in 2015 was 91.4% national average with 96.6% in urban locations and 77.5% in rural locations. The evolution of the coverage of sanitation services for the population is shown in Fig. 2.9. It started from 58.6% to 91.4% in 25 years at a national level. Of course, the big difference was in the rural areas, where

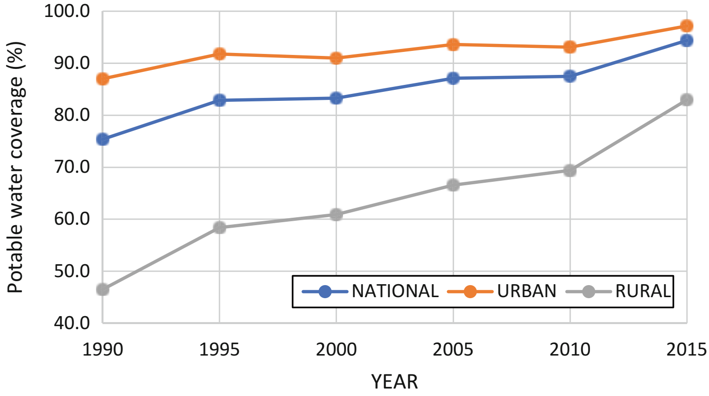

Fig. 2.8 Evolution of coverage of potable water and sanitation services in Mexico (modified from CONAGUA 2016, pp. 112–115)

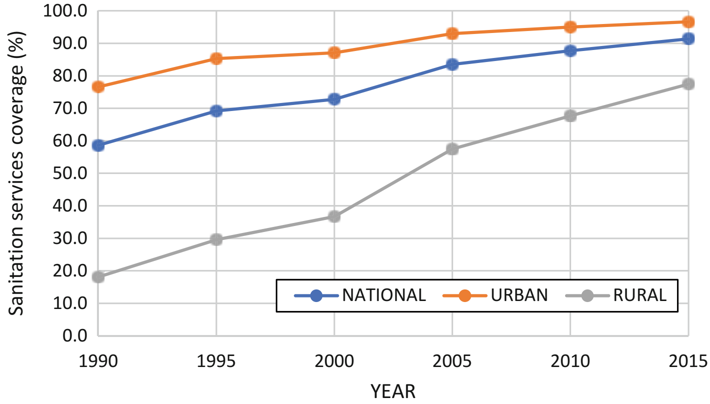

Fig. 2.9 Evolution of sanitation service, for the population in Mexico from 1990 to 2015 (CONAGUA 2016, pp. 114–116)

the coverage in 1990 was 18.1%, and it increased to 77.5%, still below of what is expected. The coverage in urban areas increased from 76.6% to 96.6%.

The major challenge in the future is to increase the water supply and sanitation to rural communities.

2.4.4.2 Hydro-agricultural Infrastructure

Although some of the hydro-agricultural infrastructure is shared with livestock and aquaculture, most of it is merely devoted to agriculture, the main water consumer.

Agriculture is conducted in about 26 Mha (million hectares), but some areas have been supported with infrastructure of two main types: irrigation and drainage work. To be eligible to financial aid, the farmers are organized in three different administrative units that will be called hydro-agricultural administrative units:

1. Irrigation districts. Since 1926, irrigation has been supported by the federal government in providing the means to store, divert, convey, and even apply irrigated water in the field in large areas or with many farmers.
2. Irrigation units. Smaller areas in size, or with few farmers, were organized in what are called *Unidades de Riego para el Desarrollo Rural* (URDERALES).
3. Drainage districts. In the 1970s, the federal government supported farmers in the humid tropics with the construction of drainage networks to control excess water in the field in what were called *Distritos de Drenaje y Control de Inundaciones* (Flood Control and Drainage Districts), and by the 1990s the program was regained and now called *Distritos de Temporal Tecnificado* (Technified Rainfed Districts).

The agricultural land in Mexico is about 26 Mha (million ha), but 7′774,435 ha with water concessions have irrigation works, and 3′375,898 ha have drainage networks. Drainage networks are not only in drainage districts but also in irrigation districts due to the presence of salt-affected soils in irrigation districts that require drainage to control salinity (Table 2.6). Although the area with water concessions of the three administrative units is comparable, irrigation units contribute more to the production and income of the agricultural sector, followed by the irrigation districts and the drainage districts.

A major challenge in the hydro-agricultural infrastructure is salinity in the irrigation districts and units. The salinity rate is in the order of over 10,000 ha/year and there is a potential 1.2 Mha to be salinized, especially in the largest irrigation districts in northwest Mexico (Arias et al. 2017). In the drainage districts, the major challenge is to increase the on-farm drainage to increase productivity and income (Arias Rojo and González 2017).

2.4.5 Water Governance

The ways societies rule their water resources and services have profound impacts on people's welfare and sustainable development. Access to water is a matter of daily survival or breaking the poverty vicious cycle. Therefore, water governance is a keystone to reduce poverty and inequality. Water governance does not depend on the mandate of institutions but the way decisions are made. The existence of democratic processes, the freedom to express opinions/concerns, equality in information sharing, and the right to organize are key elements to make equalitarian and efficient decisions. The 1992 water legislation opened the social participation to water management. There are two main areas where social participation in water governance was opened, at a river basin scale, through the

Table 2.6 Administrative units with collective irrigation and/or drainage infrastructure compared with rainfed agriculture

			Area with water concessions (ha)			National contribution (%)	
Administrative unit	Number	Users	Total	Irrigation	Drainage	Production	Income
Irrigation districts	85	431,602	2,529,510	2,529,510	1,490,709	25	24
Irrigation units	39,492	901,963	2,956,420	2,956,420	No data	40	30
Drainage districts	23	97,518	2,288,505	2,288,505	1,885,189	15	5
Rainfed	No data	No data	18,225,565	No data	No data	20	41
Total			**26,000,000**	**7,774,435**	**3,375,898**	**100**	**100**

Source: Modified from Arias et al. (2017)

Consejos de Cuenca (River Basin Councils), and at the hydro-agricultural administrative units, through the *Comité Directivos* (Executive Committees).

2.4.5.1 Basin Councils

In the 1992 water legislation, River Basin Councils were created with the idea of promoting social participation with an integrated river basin management approach. The social participation was open to elected representatives of the main water users. The main representatives of the Basin Councils are agriculture (representatives of irrigation districts, irrigation units, and/or drainage districts), municipal water service providers, private or municipal authorities, and industrial, energy, and municipal and state officials, all of them with the assistance of CONAGUA officials. The members of the Basin Councils are elected from each water sector, and the group is formalized before attorneys.

The Basin Council has frequent meetings, at least two annually, and they are also supported by other subsidiary representations. The most common subsidiary groups are the following:

- Tributary councils. If the basin is very large and/or there are several river systems, an equally conformed organization is created.
- COTAS (Technical Committee of Groundwater). When groundwater is extracted, each aquifer can be represented, too.

Despite the participation of water users' representatives in River Basin Councils, water conflicts are still growing. The lack of clear rules and responsibilities of the civil representatives, unequal information level, as well as lack of transparency in those projects might be associated with the low impact of these institutions on those conflicts.

2.4.5.2 Hydro-agricultural Administrative Units

Starting in 1991, farmer associations operate all hydro-agricultural administrative units – irrigation districts, irrigation units, and drainage districts – through their *Comité Directivos* (Executive Committees). Planning, operation, and maintenance works of the hydraulic infrastructure of each administrative unit are agreed among them. CONAGUA is still responsible for the major infrastructure, but timing and volume releases, as well as other activities, are discussed in those *fora*.

The frequency of their meetings is at least once a year, but generally, and depending on their size and complexity, they have at least four annual meetings. The more complex administrative units are large irrigation districts, since they are subdivided in *Módulos de Riego* (Irrigation Modules), where they are represented by the same procedure in terms of the selection and duration of the module authorities.

The selection process is through open elections among all users, whether a module or representatives of modules in a large irrigation district or drainage district, and the term is about 3 years. Although there is no information about the performance of the Comités Ejecutivos of the administrative units, it is clear that those committees that are transparent and allow free participation of stakeholders are in better conditions than those who are not transparent or do not allow free and open participation.

2.5 Future of the Water Sector

In general, the future of the water sector in Mexico looks promising. There are still several issues to be considered to reduce water conflicts and inequalities. Fortunately, Mexico has signed several international agreements where water is the strategic resource. The Millennium Development Goals and the Global Change Strategy are two of them. The commitments made have been added to the CONAGUA 2030 Water Agenda.

2.5.1 2030 Water Agenda

The 2030 Water Agenda identified four goals to attain.

2.5.1.1 Basins and Aquifers in Equilibrium

There are serious misbalances in some basins and aquifers due to either an excessive demand or short supply. On the average, the agricultural sector exerts the major demand, and therefore, activities are focused on a more efficient water use and/or reduced water consumption with different crops. Several hydraulic works have been designed to reduce water consumption either by improving the conveyance losses, applying more efficient irrigation systems, or using less water-demanding crops. In overexploited aquifers, water supply has been reduced and/or recharge techniques have been applied (CONAGUA 2011, pp. 13–15).

2.5.1.2 Clean Rivers

Currently, wastewaters reach 6.7 hm^3/year and it is expected to increase up to 9.7 h m^3. The main emphasis is on wastewater treatment to increase from 36.1% to 60%, though by 2012, it was established on 45.7%.

Sanitation is close to the goal established, 90%, but it needs a better monitoring system by the increase in the establishment of 4600 water quality monitoring sites to secure water quality.

2.5.1.3 Universal Coverage

This goal is related to improve water supply and sanitation in rural locations. Currently, the national water supply coverage is 94.4%, with 97.2% urban and 83% rural. The goal is 90% coverage, which means an extra effort in rural areas. As for sanitation, we have 91.4% coverage, 96.6% in urban and 77.5% in rural areas, which also reflects a major effort in the rural areas.

2.5.1.4 Security Before Catastrophic Events

After the identification and prioritization of critical areas, funds have been allocated to improve the infrastructure for flood control, as well as the relocation of human settlements in risk zones. The national weather service has improved their warning systems, and the level and cost of those events have been reduced, but not to zero.

2.5.1.5 Principles and Strategic Lines

Four principles and strategic lines have been devised to attain the following goals:

Sustainability The main idea is development without compromising future generations in three dimensions: environmental, by controlling overdrafted aquifers and establishing environmental flow and water pollution control, among others; economical, in the sense that natural resources have an economic value that needs to be addressed in the decision processes; and social, in relation to provide clean water and a safe environment to all citizens.

Integrated River Basin Management This approach is the most appropriate since whatever happens in the uplands of a river basin is reflected in the lowlands; therefore, measures must be made to analyze and operate at a river basin scale.

Water as a Finite and Strategic Resource With the current population growth and global warming, we need to consider water as a finite resource since the rate of degradation of water and the cost will increase in time.

Land Use Planning and Water Resource Allocation The more efficient way to work is to maximize land use to obtain the maximum gains, so efforts need to be taken to use land resources to its maximum capacity.

2.5.2 Global Warming Preparation

Although globally, climatological records have been collected in less than 150 years, indirect ways to estimate climatological variables show that they fluctuated so widely in the very last 1000 years. A human life is not enough to perceive the extremes that had already affected the earth; however, the impact of human activities with the generation of greenhouse gases undoubtedly is warming the surface of the earth. We need to identify what and to what extent global warming will affect us in order to develop strategies that will reduce or ease negative impacts.

The groups in charge of the global warming identification and prevention are getting information of unknown effects for the future; the question is, are we in time? And, do we have the resources to reduce or control those effects?

2.5.3 Water Governance

Water governance deals with the determination of who, how much, and how often water will be serviced. The representation of interesting parties in the decision-making process and the role of politics are important components of water governance. Finally, since the decisions are anchored in the interaction among government, civil society, and private sector, the implementation of good water governance implies the establishment of processes and rules of decisions that allow free and open participation of all sectors to solve water conflicts.

Water conflicts, like those for the water supply to cities, can be discussed and solved in the institutions created to promote participation. However, the role of Basin Councils has not made a difference, yet.

Therefore, good water governance is critical for the future of the water sector in Mexico.

Although the current water governance in Mexico has produced positive impacts, it is far from complete. Some of the areas that need improvements are discussed:

- *Decentralization of the decision-making process*. Although there is decentralization on the decision-making process, it is only in paper. There are remnants of central decisions over regional needs.
- *Participation of stakeholders*. The last legislation improved the composition of the River Basin Councils; however, there are deficiencies in the selection process of the representatives of water users and the percentage of representatives, and there is a lack of rules for conflict resolution, among others.
- *Integrated river basin management*. Although it is recognized in the new legislation, how is integrated river basin management conducted? And who is responsible to do it? Each river basin should have some way to represent the hydrologic processes and ways to compare or verify the interventions.

- *Clarification of roles and responsibilities*. What are the roles and responsibilities of the water user's representatives within the Council and what is the procedure to involve them in the decision-making processes? Regularly, CONAGUA officials oversee most of the organization, agenda, and recording of the meetings, with little participation of the nongovernment representatives.
- *Transparency in decision-making processes and information sharing*. The decision-making process is difficult when there is a lack of information and data collection and/or the information is not available to all stakeholders.

We can say that, although we are establishing the basic principles to good water governance, we need to do more.

2.6 Conclusions

Water resources in Mexico are so widely distributed due to its geographical location associated with climate. Northern Mexico is hot and dry, Central Mexico is temperate, and Southern Mexico is hot and humid. The location, combined with the relief, yields a wide variation in terms of surface and groundwater resources.

Although climate variation influenced on the pre-European cultures, water technology, institutions, and regulations were very similar. Changes in technology and changes in social conditions yielded new institutions and new regulations. They evolved to the current situation. What we can foresee is that new technology and/or new social conditions will continue evolving in terms of water legislation and institutional framework.

A description of the current situation of the water sector shows a higher stress on water resources in heavily populated areas, especially in arid or semiarid regions. It is possible to say that in those conditions, water efficiency is a key factor, since water transfers will only bring more conflicts and more stress on water resources.

Although Mexico is complying in terms of international commitments, like the Millennium Development Goals and Climate Change, water conflicts are getting more complicated. The best response is in the establishment of new water governance. Current water governance was introduced in the last legislation, but more work is to be done to reduce water conflicts, alleviate poverty, and improve water efficiency.

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