Chapter 14
Climate Change and Vulnerability of Water Resources in Mexico: Challenges for Basin Management

Eduardo Ríos Patrón, Daniel Iura González Terrazas, and Ignacio Daniel González Mora

Abstract In this chapter we will review the importance of water resources, the development of the Mexican public policy (within the framework of water management), the risk to which availability is subject (in the face of climate change scenarios), and how, in front of a differentiated approach by basins and ecosystems, can be a model, from actions of adaptation and conservation of the functionality of the basins, for the reduction of water vulnerability and a crosscutting element of public policies in Mexico, which allows to adapt to climate change and meet the international commitments that Mexico has signed.

Keywords Water resources · Vulnerability · Basin management · Climate change

14.1 Introduction

Water is and has been the fundamental basis for life and development, considering that it is necessary to support biogeochemical processes, which preserve the ecosystems that are a source of direct and indirect benefits for human societies. It is also a necessary input for the functioning of cities as well as industrial processes and food production. However, the uncertainty of a relative scarcity level regarding its existence, use, and renewal represents a major challenge toward the larger

E. Ríos Patrón (✉)
Mexican Network of Hydrographic Basins (Remexcu), Ministry of Environment and Natural Resources (SEMARNAT), Morelia, Michoacán, Mexico
e-mail: eduardoriospatron@gmail.com; eduardo.rios@semarnat.gob.mx; coordinacion@remexcu.org

D. I. González Terrazas
National Institute of Ecology and Climate Change (INECC), CdMx, Ciudad de México, México
e-mail: daniel.iura@inecc.gob.mx

I. D. González Mora
Mexican Network of Hydrographic Basins (Remexcu), World Wildlife Fund (WWF México), CdMx, Ciudad de México, México
e-mail: coordinacion@remexcu.org; igonzalez@wwfmex.com

H. R. Guerrero García Rojas (ed.), *Water Policy in Mexico*, Global Issues in Water Policy 20, https://doi.org/10.1007/978-3-319-76115-2_14

demand of the vital liquid, as a consequence of an increasing population and an increase in the levels of production and new satisfiers. Additionally, climate change and its differentiated impacts, which intensify year after year, are enhanced by an inadequate management of the territory in the basins of Mexico.

Reducing impacts on natural and human systems due to changes in the availability of the water resource as a result of climate change and territory management is a national challenge that aligns with recent global agendas that have emerged as a recognition of the global priority of accelerating and guiding the actions of nations toward a sustainable development. This way, the 2030[1] Agenda emerges, with 17 sustainable development objectives, as well as the Paris Agreement[2] intended for preventing the planet from increasing the average global temperature in more than 2 °C from the reduction of greenhouse gases (GHG); and if it cannot be done, there would be huge economic, social, and environmental impacts.

Besides this international commitments signed by Mexico and which are systematically reflected in the national public policies and regulatory framework; there is the constitutional recognition that "everyone has the right to water access, disposal and sanitation for personal and domestic consumption, in a sufficient, safe, acceptable and affordable manner,"[3] which, in front of a climate change context, represents a huge commitment of the state for achieving the effective fulfillment of such human right.

This huge commitment implies the relevance of the design and implementation of integral and regional public policies that in a synergic manner and, from scientific information in an effective framework of participation and governance, consider (i) attention of vulnerability to climate change from the strengthening of local and national capabilities; (ii) integration and strengthening of the preservation policy to increase resilience from the functional maintenance and improvement of water resource production zones; (iii) the strengthening of early warning systems (SAT – Sistema de Alerta Temprana) and the integrated risk management; and (iv) the insertion of the basin approach in public policies from the development of norms,

[1]In September 2015, more than 150 heads of state and government met in the Sustainable Development Summit in New York, EU at UN headquarters, where the 2030 Agenda was approved. This Agenda includes 17 universal application objectives that, since January 1, 2016, govern the efforts of the countries to achieve a sustainable world in 2030 (Source: http://www.un.org/sustainabledevelopment/es/la-agenda-de-desarrollo-sostenible/).

[2]The Paris Agreement was adopted on December 12, 2015, in the 21st, session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris, France. The Paris Agreement came into force on November 4, 2016. One hundred ninety-five out of 197 parties of the UNFCCC signed the Agreement, and 169 have already ratified it (Source: http://unfccc.int/paris_agreement/items/9444.php).

[3]The recognition of this human right was added by a Decree, published in the Official Gazette of the Federation on February 8, 2012, in the sixth paragraph of Article 4 of the Political Constitution of the United Mexican States (Source: https://www.juridicas.unam.mx/legislacion/ordenamiento/constitucion-politica-de-los-estados-unidos-mexicanos#10539).

programs, and projects linking supply and demand of water environmental services under climate change scenarios and anticipate actions for their maintenance over time.

Climate change is evident and unequivocal, and its consequences are an unprecedented challenge for the design and implementation of public policies for water resources management in Mexico. This challenge implies adapting and generating governance conditions to changes in water availability, as well as against an increase in extreme meteorological events and its consequences, from the acknowledgement of basins functionality and the relation of hydrological environmental services (SAH) with the local and regional economic, social, and environmental dynamics. Maintaining the SAH implies the improvement of human well-being and the reduction in the vulnerability of human and natural systems toward hydrometeorological phenomena and must come from (i) inserting the basin integral approach in the planning and implementation of actions for the preservation and restoration of ecosystems, (ii) inserting the design and effective use of early warning systems, and (iii) exploiting the synergies of coordination platforms posed by existing laws on water and climate change, in order to face the consequences of climate change in the basins in Mexico and to reduce the vulnerability by collaborating and articulating efforts in different scales and levels.

14.1.1 Water Resources in Mexico

Only 0.77% of total water in the world is estimated as accessible to human beings as fresh water (CONAGUA 2016); nevertheless, it is subject to high pressures as a result of a continuous increase in the demand, contamination, and climate change. Facing these pressures in quality and quantity of the vital liquid, the World Water Development Report 2017 concludes that "it would be unthinkable not to take advantage of the opportunities of a better management of waste water" (WWAP 2017), and obviously, this better management implies an integrated management approach considering the basin as a convenient territory for water management resources.

Mexico, within its 1959 million km^2 continental surface, has 1471 watersheds (INEGI-INE-CONAGUA 2007) integrating a 633 thousand kilometer network of rivers and streams. Among those, 1389 are exorheic basins flowing into some point of its 11,122 kilometers of coastline; 77 are endorheic and 5 arheic in the Yucatan Peninsula, sharing 8 basins with neighboring countries, 4 with Guatemala (Grijalva-Usumacinta, Suchiate, Coatan, and Candelaria), 1 with Belize and Guatemala (Hondo River), and 3 with the USA (Bravo, Colorado, and Tijuana). It has 653 aquifers that supply 38.9% of the volume for consumptive uses, 105 of those are overexploited, 32 with the presence of saline soils and brackish water, and 18 with seawater intrusion (CONAGUA 2016).

According to data from the National Water Commission, Mexico receives around 1,449,471 million square meters of water as rainfall. From this water, 72.5% is evapotranspired back to the atmosphere, 21.2% drains through rivers or streams, and the remaining 6.3% naturally infiltrates to the subsoil recharging aquifers. Taking into account output (exportations) and input (importations) water flows with neighboring countries, the country has 446,777 million cubic meters of renewable freshwater, data estimated for 2015, giving an availability of 3592 cubic meters per inhabitant per day.

However, there are large temporary and spatial variations in the territory, requiring an analysis per basin to characterize and to identify the particular situation of the water resource, since in the northern and central regions of the country, there is less water availability, more contribution to the gross domestic product (GDP), and larger population, while the southern area of the country presents a larger water availability, lesser contribution to the GDP, and less population. Besides, it is worth noting that each basin presents unique socioecosystemic characteristics, and hence the management should be differentiated and reflected in water and climate change policies.

In 2015, a volume of 266,559 million cubic meters was in concession, 180,895 of which were for non-consumptive use (which does not affect the volume), that is, for hydroelectric use, and 85,664 million cubic meters for consumptive uses (the difference between extracted and discharged volume while conducting an activity). The water source of the latter was 37.9% of underground origin and 61.1% of superficial origin (CONAGUA 2016). Available water in the country requires satisfying the population growing demands of about 120 million inhabitants and a globally integrated economy with strong pressure on production and consumption in a climate change context.

14.1.2 Climate Change and Vulnerability: Commitments of Mexico

The Agreement in the United Nations Framework Convention on Climate Change reached in Paris, France, in December 2015 recognizes climate change as “an urgent and potentially irreversible threat to human societies and the planet” (Naciones Unidas 2015).

It is evident and unequivocal that the planet has presented a 0.85 °C increase in average temperature[4] that the Arctic ice extension in the North Pole is being lost between 3.5% and 4.1% each decade,[5] that glaciers have decreased at a rate of

[4]Measure conducted from 1850 to 2012.

[5]Measure conducted from 1972 to 2012; this means that just in the last 10 years, 3.5 million km^2 have been lost.

275 giga tons per year,[6] and that the sea level has globally increased 0.18 m.[7] Likewise, the evidence is compelling, and carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O) have demonstrated an increase of 40, 150, and 20%, respectively, since 1750.[8] At the same time, an increase in the industrial activity has caused that almost 30% of carbon dioxide is absorbed by oceans causing acidification (Conde 2016; IPCC2013). It is also alarming to confirm year after year a new maximum temperature record; the global mean temperature for the period between January and September 2017 was 0.47° ± 0,08 °C warmer than 1981–2010 mean (estimated in 14.31 °C), which represents a temperature increase of around 1,1 °C from the beginning of the preindustrial period (OMM 2017). These changes in the global climate system have important and differentiated local impacts, especially in Mexico, which is a country that due to its geographic location and social conditions is especially vulnerable to climate change.

Climate change in Mexico is also evident and unequivocal, and its impacts are already being noted. Thus, according to data from the National Institute of Ecology and Climate Change (INECC), "in a little more than 100 years terrestrial and marine surface temperatures have increased in all the territory, however, in certain areas in the north of the country, changes have been greater, ranging from 1.2 and 1,5 °C above its historical average." The global warming observed is joined by an increase in the number of extreme hot days and a decrease in extreme freezing days and frost. All this is added with the impact of a growing number of extreme hydrometeorological phenomena, as tropical cyclones and hurricanes. Between 1970 and 2013, 10 out of 22 category 3 cyclones in the Saffir-Simpson scale that affected the Pacific and Atlantic coasts of Mexico occurred in the last 12 years. In the case of droughts, so far this century, five important events have occurred between 2000 and 2003, in 2006, between 2007 and 2008, in 2009, and between 2010 and 2012. In some cases, drought has been so severe that it has affected large extensions in the country, as in 2011, when 90% of the territory was affected.[9] Sea level has also been raised in many coastal areas in Mexico. Seventeen sites were studied in the Gulf of Mexico and the Pacific, between 1950 and 2000, standing out the elevations observed in Ciudad Madero, Tamaulipas (up to 9.16 millimeters per year) and Guaymas, in Sonora (4.23 millimeters per year)" (INECC 2015).

According to INECC in Mexico, for the near horizon 2015–2039, annual temperatures 2 °C above in the north, and between 1 and 1.5 °C, are estimated in most of the territory. On average, the forecast is an average reduction between 10 and 20% in rainfall (INECC 2015); these scenarios require action and the development of

[6]Measure conducted from 1993 to 2009. A giga equals 10^9 or 1,000,000,000 (thousand million).

[7]Measure conducted from 1901 to 2010. At a 1.7 mm/year rate in 1901–2010, 2.0 mm/year between 1971 and 2010, and 3.2 mm/year in 1993–2010.

[8]Percentage of increase of CO_2, CH_4, and N_2O from 1750 to 2011.

[9]From this situation 74% of the territory presented severe, 47% extremely, and 22% exceptional drought. See http://smn.cna.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico.

comprehensive public policies that allow us to reduce damage from an effective management of the water resource.

Within the commitments derived from the Paris Agreement, an adaptation component to climate change is included. The non conditional commitments of Mexico to 2030 are to (i) reduce the high vulnerability of at least 160 municipalities considered as very vulnerable to climate change, (ii) reach a zero deforestation rate and strengthen actions for the protection and restoring of ecosystems, and (iii) generate prevention and early warning systems before extreme hydrometeorological events.

14.2 Response Strategies to Changes in Water Availability Associated to Climate Change

Climate change can be interpreted either as a compelling problem that threatens biodiversity and world population or as a factor that aggravates the effects of other existing threats. In this sense, climate change affects the provision of water resources in the ecosystems, by modifying rainfall and temperature patterns. For instance, with the reduction of forests and the increase of urban land use, the eco-hydrological functionality of basins is modified, and the water provision for society and ecosystems is reduced in a faster manner in the context of climate change (Ríos et al. 2016).

Impacts on rainfall and temperature variations have an effect on the components of the hydrological cycle, in runoff, evaporation and infiltration, as well as in the intensity and frequency of extreme hydrometeorological phenomena and their consequences as droughts and floods.[10] The strategies for responding to water availability changes associated to climate change must be designed to ensure the water balance of the basin, either by improving infiltration processes and reducing flood, by decreasing runoffs velocity, or by recovering the catchment functionality of land ecosystems and lotic and lentic systems. To reach the improvement of hydrologic functionality, it is important to have the information of rainfall and temperature scenarios, as well as their impact in the water balance components for proper actions and decision-making. It is essential to consider differentiated strategies before such scenarios of water abundance or scarcity, with drought or flooding risks, or with water increase or decrease for the development of economic activities in the basins of Mexico. Strategies should also link – from the knowledge of water balance considering different rainfall and temperature scenarios – trends in water resource use or demand for the activities of the basin and the actual offer, in order to determine impact mitigation strategies in an advanced and concerted manner, through a participation process promoting present and future governance.

[10]Idem.

Mexico, particularly, has established international commitments with important challenges in climate change adaptation, which emerge from three differentiated strategies (INECC 2015):

- Adaptation of the social sector to climate change
- Adaptation based on ecosystems
- Adaptation of productive systems and strategic infrastructure

Integrated management of basins implies an understanding of a certain region functioning, its ecosystems, and socioeconomic processes that take place in there. In this manner, anticipated and well-informed strategies can be developed to implement measures of adaptation, considering possible vulnerabilities of the population and ecosystems (Lampis 2013). Planning, based on scientific evidence, may contribute in the reduction of vulnerability in front of local impacts of climate change, ensuring decision-makers have the ability and information needed for the prevention and adaptation to changes associated to this phenomena.

Strategies for the reduction of water vulnerability to climate change imply a search for sustainable development, which, "cannot be achieved without a world with safe water, A safe water world appropriates the productive power of water and minimizes its destructive force" (GWP 2017). In a climate change context, water security implies (i) having clean, sufficient, and affordable water for a healthy life and responding to the human right for water access and sanitation; (ii) protecting the community from flooding, droughts, landslides, erosion, and water-related diseases; (iii) addressing environmental protection and the negative effects of a bad management; and (iv) eliminating the fragmenting responsibility of an integrated management of water resources in all sectors. Integration must be the core of the strategy and should be supported in good governance.

14.2.1 Water Resource as an Integrating Axis in Territorial Management: An Approach from Basin Management

A way to understand that water resources management is subject to territorial management is through the basin approach. This involves making explicit the relation among territories and users of high and low basins, considering all generated impacts resulted from activities in the high basin toward the lower side, and recognizing the services that ecosystems provide to the basin (Sanjurjo et al. 2017). In these territories, there is a spatial and temporary interrelation and interdependence among the biophysical surrounding (aquatic and terrestrial ecosystems, crops, water, biodiversity, geomorphological and geological structure), appropriation modes (technology and/or markets), and institutions (social organization, culture, regulations, and/or laws) (Cotler et al. 2013).

Hydrographic basins are considered the basic territorial unit for planning and managing natural resources and as a spatial and temporary dimension for the adaptation to climate change (Biestroek et al. 2009; SEMARNAT-INECC 2013).

The watershed approach is considered both in the National Waters Law (LAN), in the acknowledgement of water resources management units, in the preservation of the hydrologic cycle in the territory, and in water availability and governance, and in the General Law on Ecological Balance and Environmental Protection (LGEEPA) to guarantee the sustainability of economic activities through official Mexican norms in environmental issues, for the sustainable achievement of natural resources, as well as to prevent contamination, fundamentally. But its articulation is an area of opportunity in the Mexican regulations. Basin has been relevant in water planning and management issues, but not in the regulation of territorial management from the perspective of terrestrial and aquatic ecosystems in permanent interaction, which provide ecosystemic services needed for the well-being of human societies. In this sense, water has been treated as a material resource and not as an asset that results from the functionality and integrity of terrestrial and aquatic socio-ecosystems.

14.3 Analysis of Demand and Supply of Hydrological Environmental Services (SAH)

A way to change the wrong approach of considering water as a resource with no territorial connection is through the incorporation of the supply and demand analysis of hydrological environmental services, identifying in detail the contribution of hydrological and ecosystemic processes in water "production" for socioeconomic activities in a basin facing different scenarios of climate change. This necessarily involves the implementation of the basin approach, the functional link of territorial management, as well as the zone prioritization for its preservation and protection.

This approach of linking supply and demand of water resources, from areas where physical, chemical, and biological processes are involved for the functioning of the hydrological dynamics of a basin, includes reducing risks and maintaining and improving the quality and quantity of water in a climate change context, so it should be a common approach at the local level for conducting the management of water resources. Fulfillment requires the strengthening national and local capabilities, from entities that plan, participate, and coordinate the water policy and climate change policy.

14.3.1 Evolution of the Instruments of Environmental Policy in Mexico that Promote Conservation and Sustainable Use of the Hydrological Environmental Services (SAH)

In Mexico, environmental protection is directly bonded with the social function notion of private property, substituting property as an absolute right: it is expressed in the 1917 Constitution, where the principle of use and conservation of natural resources is introduced, particularly in constitutional Article 27, Section 3, where the foundations for the territorial planning of the nation are mentioned:

> the necessary measures shall be declared to order human settlements and to establish proper provisions, uses, reserves, the purpose for lands, waters, and forests, in order to execute public works and to plan and regulate funds, conservation and improvement, and growth of population centers; to preserve and restore the ecological balance

The first manifestations of territorial planning considering water resource appear in the postrevolutionary times for infrastructure reconstruction, with a boost on agriculture, developing an integrating vision of regional planning (Calderon 2001).

In 1947, during the presidential administration of Miguel Alemán, and seeking an impulse on the agricultural and industrial development of the country, the first hydrographic basin commission was created, the Tepalcatepec River basin, dependent of the Ministry of Water Resources in charge of planning and conducting the necessary works for the integral development of natural resources in that basin. However, efforts were minimal in relation to the industrial-urban tax model of the following 30 years, when industrial growth policies began around Mexico City and regional economy poles. In the administration of Luis Echeverría (1970–1976), the so-called specific regional planning begins (Calderón 2001; Gasca 2009), based on the generation of sectoral productivity policies, the socioeconomic planning strategies on territorial basis boosted decentralization efforts, and Gasca (2009) refers to this period as "the golden age" of planning. However, recurring crises from de la Madrid administration (1982–1988) caused by the mobility of oil prices, the flight of capital, economic slowdown, and high inflation forced the Mexican state to sign international loans, deregulate planning processes, and privatize key sectors, actions that initiated a phase of neoliberal policies (Gasca 2009). Decentralized efforts of the public administration were blocked; there was a dismantling process of the institutional structure and programs focused on territorial planning, a loophole that remained in subsequent administrations.

Nevertheless, in the evolution of the environmental policy framework,[11] triggered by an evident degradation of natural systems and an increase in population, it is from the last quarter in the twentieth century that the development of territorial planning instruments oriented to evaluating the satisfaction degree of the social demand from

[11]In Mexico, this has been widely described by experts in judicial (Brañes 2004; Azuela 2006a, b; Quintana 2009) and administrative systems (Rosete 2006).

the evaluation of offer provided by the environment from a territorial perspective, in terms of goods, services, and spaces, began, the latter with the sole purpose of promoting a sustainable development.

Regarding environmental services[12] to consolidate this approach in laws and Mexican normativity, instruments whose objective is to maintain functional interrelations of the landscape elements that intervene in the offer of these services through conservation, restoration, protection, and sustainable use of environmental policies have been materialized. Among the policy instruments that address the continuity of environmental services in space and time are: the National Development Plan (PND), and within the same, Sectoral Programs like the one of Environment and Natural Resources (PROMARNAT) and the Water National Program (PNH), environmental General Laws and deriving programs with a direct effect on the territory. In this sense, the incorporation of the basin approach is a milestone in Mexican environmental policy[13] as one of the main strategies to comply with two of the PROMARNAT 2013–2018 objectives, strengthening integral and sustainable management and guaranteeing access to the population and ecosystems and recovering basins and landscapes functionality through conservation, restoration, and sustainable appropriation of the natural heritage, objectives that are directly related to the safeguard of environmental services demanded by the population, ecosystems, and productive activities. PNH 2014–2018, based on basins and aquifers, proposes the objectives of strengthening integrated and sustainable water management, increasing water security toward droughts and floods, and strengthening water supply and access to drinking water, sewerage, and sanitation services.

Regarding General Laws, in terms of synchrony of precepts and operational instruments with territorial incidence for the conservation of environmental services, the General Law of Ecological Balance and Environmental Protection is worth noting (LGEEPA 1998). In the absence of clear legal rules and norms of the rural territory use, and specifically of conservation-minded territory, in 1987 the constitutional Article 27 was amended by adding "preserving and restoring the ecological balance." Subsequently, LGEEPA was published explicitly incorporating in a Chapter the "Sustainable development of water and aquatic ecosystems."

LGEEPA focuses on environmental planning, through diverse modalities of its ruling instrument, the Territorial Ecological Ordering (OET); inducing or regulating out of the population centers, land uses to protect the environment

---

[12]Regarding the definition of the National Waters Law, it is understood that social interest benefits are generated or emerge from hydrological basins and its components, such as climate regulation, hydrological cycle conservation, erosion control, flooding control, aquifer recharge, runoffs maintaining in quality and quantity, soil formation, carbon capture, purification of water bodies, as well as conservation and protection of biodiversity.

[13]Conceptual and methodological framework which considers characteristics related to the functionality of hydrographical. Especially (i) the relation among users and high and low basin territory, (ii) cumulative impacts devastated by rivers and streams, and (iii) the consideration of water quantity, quality, and temporality as an indicator of territorial management (PROMARNAT 2013–2018)

and preserve, restore and appropriate natural resources in a sustainable manner, basically by conducting productive activities and locating human settlements. In this sense, it is the first time in the history of Mexican environmental policy that the national development goals are harmonized, environmental legislation and a bonding instrument with territorial incidence, represented by the OET in its local feature, to safeguarding balance between supply and demand of environmental services, especially those related to water resources. However, facing the climate change threat, the short-term challenge is to adequate the design of this instrument considering (i) thresholds or limits in ecosystems use, (ii) relations of hydrographic connectivity between environmental services supply and demand zones for the prioritization of conservation zones, and (iii) possible impacts related to pattern changes of the climate that might compromise the functionality of ecosystems and, as a consequence, the associated environmental services.

14.4 Adaptation and Management of Basins: A Strategy to the Reduction of Vulnerability to Climate Change Impacts on the Water Resource

The most immediate effect of climate change is an increase in temperature and alteration of the hydrological cycle with the consequent reduction in rainfall but also an increase in extreme hydrometeorological phenomena.

Undeniably, adapting to climate change is to protect water sources and to maintain water availability for future generations. The impact of climate change on natural water sources can be characterized by an alteration in water quality (e.g., by pollutants, temperature, or dissolved oxygen), water quantity, and the pattern of its cycles (in the regular periods of drought and floods). Worldwide, alterations in the seasonal pattern of water might be the most important consequence for human beings and other species. Unfortunately, this might be also the most uncertain variable according to diverse general circulation models. Hence, water policy should be focused in sub-annual changes, for instance, per season or per month. On the other hand, uncertainty should be no excuse for non-acting (Mathews and Le Quesne 2009).

In Mexico, water availability in the 757 water basins or water management units is published every year and considers no sub-annual or monthly periods, which constitutes an opportunity area for a better integrated management of water resources. In this sense, the Mexican official norm of availability (NOM-011-CONAGUA-2015) and the Mexican norm of ecological flow determinations (NMX-AA-159-SCFI-2012), whose purpose is the ecological conservation of basins and which can be used to know inter-annual periods of variation, shall be harmonized. Publishing the annual availability of all basins in the country has been a breakthrough in water management in Mexico, yet allows non-sufficient detail to have an adaptive management up to the challenge of climate change.

Adaptation to climate change is the process that allows reducing the vulnerability of population, ecosystems, and its environmental services through the adjustment in human and natural systems as a response to projected or actual stimuli. Examples of adjustments include the reduction in the consumption of water to compensate low rainfall indexes, movement of a certain industry in an area with a drought growing trend toward a more humid region, or the modification in the morphology of the urban current to compensate for larger and more frequent flooding. Perhaps the biggest threat of climate change for freshwater aquifers is the interaction between those relatively “traditional” problems, like excessive extraction or habitat fragmentation, and those promoted by climate alterations, like the most frequent droughts (Matthews and Le Quesne 2009). In this sense, the vulnerability analysis to climate-associated problems is the first step toward triggering adaptation processes through the identification of:

– Who or what is vulnerable?
– What makes it vulnerable?
– Where in the territory is that vulnerability expressed?

Thus, in order to reduce climate change vulnerability through adaptation actions, basin integral management must be the approach that transcends Mexican management public policies to maintain ecosystemic services and reach its co-responsible compensation under participation and governance schemes. Under this principles, water management should be based upon instruments as regulated areas and their corresponding regulations and water reserves (Arts. 38, 39, and 41 from LAN and 73–76, 78, and 79 from LAN Regulation), which permit the establishment of administrative actions to those who do not respect the guidelines for a sustainable management of the resource. In this manner, authority acts can be executed to promote and monitor the application of adaptation measures to climate change in water management and its availability in hydrological basins.

14.4.1 Vulnerability Analysis of Populations, Economic Activities, Infrastructure, and Natural Capital to Changes in Water Availability

As a result of its physiographic, bioclimatic, and social characteristics, Mexico is a country particularly vulnerable to climate change. Mexican territory is distributed in the interface between Neartic and Neotropical ecozones; it has direct influence from two oceans, the Gulf of Mexico and the Pacific Ocean, with 11.122 km of coastline and 150 municipalities with coastal front, which constitutes approximately 21% of the continental surface in the country. It also presents four out of five main types of climate, dry (type B), humid-temperate (type C), humid-cold (type D), and polar (E); thus heterogeneous climatic conditions have been developed which can be translated into high endemism and ecosystem particularities that could be sensitive to changes in the hydrological response associated to climate change. Regarding human population, in 1950, a little less of 43% of the population in Mexico lived in urban areas, in 1990 it was 71%, and in 2010 this figure increased to almost 78% (INEGI 2010). This concentration in urban centers trend has been joined with a significant services demand, especially in water supply for urban, agricultural, and industrial public use. In the context of climate uncertainty, degradations of soils and forests, and high social inequity, the relation between supply and demand of the water resource is seriously compromised. Therefore, it is essential to identify differential vulnerabilities in the territory for the design of targeting and prioritization strategies of actions to safeguarding in time and space, the offer of the water resource from ecosystems.

The analysis of climate change vulnerability identifies (i) the main problems in the territory derived from climate, (ii) objects that will or potentially will be affected by these problems, (iii) intrinsic (of the object) and extrinsic (of the territory) characteristics that increase or reduce the impact of previously identified problems, and (iv) the relevant unit of analysis according to the problem and the vulnerable object.

In this sense, the analysis of the vulnerability in a context between supply and demand of environmental services must locate in space and identify the relations of the landscape elements that intervene in the functional relations emerged from these services, as well as the consumption strategies of the demanding objects. In this context, vulnerability to climate change is understood as "the degree of susceptibility or inability of a system to face the adverse effects of climate change and, especially, to climate variability and extreme phenomena. Vulnerability will depend on the exposure of a system to the character, magnitude and speed of climate change, and its sensitivity and adapting capabilities. Thus, vulnerability is a function of three components" (IPCC 2007).

$$Vulnerability = f\,(Exposition + Sensitivity - Adaptive\ Capacity).$$

Exposition: Refers to the type and degree (or nature), to which a system is exposed as a result of significant climate variations (climatic hazards or climatic stressors are considered) (IPCC 2007).

Sensitivity: Degree in which a system may become affected by a particular problem associated to climate variability or climate change. The effects can be direct (i.e., change in crops yield in response to rainfall variations) or indirect (i.e., potential impacts caused by a greater frequency of coastal flooding's) (IPCC 2007).

Adaptive capacity: Set of capacities, resources, and institutions of a country or region that will allow the implementation of effective adaptation measures for reducing impacts resulted from a particular problem associated to climate variability or climate change (IPCC 2007).

Based on this conceptual and operational framework of the vulnerability evaluation, operational variables of the exposed component should be related to climate variables that affect the interrelation of biotic and abiotic factors of the landscape involved in the supply of water environmental services, both in flooding regulation as in the provision of surface water, as an example. Sensitivity variables must be designed to explain why a climate event turns into a problem, both in the vulnerable object level and in the territory where this object is developing, for instance, an increase in urban population and the condition of primary vegetation in the supply basins, respectively, if the identified problem is water availability for public urban consumption.

In this sense, the evaluation of the vulnerability is the first step toward the design and approach of actions to reduce current and potential impacts of climate change; it is directly framed in the monitoring and evaluation processes of the implemented actions by different levels of government and of the civil society organized through the guiding question: the implemented adaptation actions are efficient in diminishing the vulnerability of an object and of a specific problem related to climate. One of the main challenges is to incorporate in the regulation of the territorial planning in Mexico the results of the vulnerability analysis under an environmental services supply and demand approach, in the current context and under climatic uncertainty scenarios.

14.5 Targeting Actions to Reduce Vulnerability to Changes in Water Availability: Examples

One of the distinctive elements in our country is the wide diversity in social, cultural, and environmental, and in terms of the vulnerability degree to climate change, such diversity and special characteristics of the territory and basins are interrelated to a trend in the demand of natural resources and its management, especially the water resource. All this has an influence on the risk of suffering damages or not satisfying the demand from the reduction of supply due to changes in rainfall and/or temperature or as a result of an increase in the water resource demand or a combination of both.

Thus, one of the main challenges for Mexico is to build the capacities to prevent and react in an anticipate manner to water scarcity or abundance and in particular before drought and flooding scenarios. These capacities, which are an element of vulnerability, must be constructed in different spatial and temporal spheres and emerge from the design and implementation of normative, planning, and prioritization instruments, some of which are mentioned in this chapter, as well as an active participation of social stakeholders in the basin, understanding their functional integration from the watershed to the lake or the sea.

There are cases of targeting of actions that have a water resources supply and demand approach and its relation and anticipation of scenarios of rainfall and temperature decrease or increase, and which may generate a participative methodological basis to promote, from scientific information and watershed management; adaptations to climate change to reduce the vulnerability of the water resource toward climate change.

14.5.1 Instruments for Action Planning and Prioritization to Reduce the Vulnerability to Climate Change

Main instruments are specifically included in the General Law for Climate Change, issued on June 6, 2012, and initiated with the creation of the National System for Climate Change.

14.5.1.1 National System for Climate Change

The National System for Climate Change is created from the General Law for Climate Change to act as a permanent mechanism of concurrency, communication, collaboration, coordination, and agreement about the national policy for climate change and to promote its transversal application in the short, medium, and long term among the authorities of the three levels of government, in their respective competence scope, coordinating the federation, state, and municipal efforts for conducting actions toward the adaptation, mitigation, and reduction of vulnerability, to cope with the adverse effects of climate change, promoting concurrence, connection, and coherence of programs, actions, and investments of the federal government, states, and municipalities, with the National Strategy and the Special Program on Climate Change (LGCC 2012). The System is formed by:

- Interministerial Commission on Climate Change (CICC), integrated by 14 Federal State Secretariats
- Climate Change Council, as a permanent CICC consulting entity, integrated by members with recognized merits and experience in climate change from social, private, and academic sectors
- National Institute of Ecology and Climate Change (INECC), agency that coordinates the Climate Change policy
- Congress
- States and Municipalities

This National System for Climate Change will use public policy instruments especially:

- Planning: National Strategy on Climate Change, Special Program on Climate Change that will integrate the National Policy on Climate Change, as well as State Programs on Climate Change that will side with the National Policy
- Financial: Emissions Trading and the Climate Change Fund
- Informative and regulating: the inventory of national and state greenhouse gases effect emissions, National Registry of Emissions, Information System on Climate Change, and Mexican Official Norms

14.5.1.2 Information System on Climate Change (SICC)

It is one of the information instruments which integrate the National System on Climate Change,[14] and it is in charge of the National Institute of Statistics and Geography, in accordance with the provision of the Law of the National System of Information, Statistics and Geography, that must generate, with the support of governmental agencies, a set of key indicators that will address at least the following issues as stated in Article 77 of the General Law on Climate Change:

I. Emissions from the national inventory, state inventory, and registry
II. Projects for the reduction of emission of the Registry or those who participate in the agreements of which Mexico is a party
III. Atmospheric conditions of the national territory, weather forecasts in the short-term and long-term projections and characterization of climate variability
IV. Vulnerability of human settlements, infrastructure, islands, coastal areas and river deltas, economic activities, and environmental effects, attributable to climate change
V. Average elevation of sea level
VI. Estimation of costs, in a given year, attributable to climate change that will be included in the Ecological Net Domestic Product (PINE)
VII. Soil quality, including carbon content
VIII. Protection, adaptation, and management of biodiversity

14.5.1.3 Atlas of Water Vulnerability to Climate Change

It is a key instrument for planning, prioritization of actions, and development of public policies for reducing the water resource vulnerability in Mexico toward climate scenarios. This Atlas was created by the Mexican Institute of Water Technology (IMTA) in 2010 and was updated in 2015, considering social, agriculture, and hydrometeorology sectors (quality of water, superficial drain off, and extreme events) (Arreguín Cortés 2015).

Particularly, the Atlas of Water Vulnerability to Climate Change emphasizes the relevance of sustainable management of aquifers, preventing its overexploitation and promoting its natural or induced recharge, since it could be a strategic reserve for the improvement of the degree of adaptability during drought. And as a part of the Atlas results, in the vulnerability issue of water resource, the challenge on the current generation is stressed to ensure that adaptation proposals are environmentally sustainable – with due respect to the ecologic expenditure in rivers and preventing overexploitation of aquifers – since an overexploited aquifer may generate sanitation problems to society and a possible collapse in economic activities (Rivas 2015).[15]

---

[14]SICC is available online at http://gaia.inegi.org.mx/sicc2015/

[15]The Atlas, in its updated 2015 version, is available at https://www.imta.gob.mx/biblioteca/libros_html/atlas-2016/

14.5.1.4 System of Early Warning of Hydrometeorological Risks

Climate change in Mexico has been accompanied by human loses and high economic and social costs. Just between 2001 and 2013, those affected by meteorological phenomena nearly reached 2.5 million people, and the economic costs amounted 338.35 million pesos (INECC 2015).

These systems are meant to protect the population and mitigate damages caused by hydrometeorological phenomena. An effectiveness improvement in the application of these systems toward the greatest and most intense incidence of hydrometeorological phenomena resulted from a modification in the global and regional climate system is one of the main challenges that Mexico faces, a highly vulnerable country because of its geographic location and social vulnerability.

Improvement in the basin functionality from integral management increases the resilience to suffering damages by reducing downpours, improving infiltration processes and generating participation processes to respond to risks and adapt to them. This functionality improvement with a work per basin along the implementation of early warning systems against hydrometeorological risks will allow synergistic results to prevent damage and to adapt in an effective manner from the social, ecosystems, and protection of productive systems and infrastructure.

These systems are composed of four components (CENAPRED 2017) that should be integrated in a coordinated way for the functioning of the system: (i) prior knowledge and identification of meteorological phenomena associated risks, to take measures in the preparation and self-protection, (ii) measurement and monitoring system to conduct forecasts or science-based risk warnings, and (iii) plans of response or contingency to know what to do against the impact of perturbing phenomena and public alert issuing with clear and precise information. In Mexico, there are early warning systems for tropical cyclones and tsunamis, from the National Meteorological Service, which is an agency of the National Water Commission (CONAGUA) that also operates a Drought Monitor.

The **Drought Monitor** acquired its national character by issuing fortnight drought maps, since February 2014. This important early warning system is based in obtaining and interpreting diverse drought indexes or indicators as the Standard Precipitation Index (SPI) which quantifies the precipitation deficit or surplus conditions (30, 90, 180, 365 days), Rain Anomaly in Percent of Normal (30, 90, 180, 365 days), Satellite Vegetation Health Index (VHI) which measures the degree of stress in vegetation through observed radiance, Leaky Bucket Soil Moisture Model CPC-NOAA which estimates soil moisture through a one layer hydrological model, Normalized Difference Vegetation Index (NDVI), Mean Temperature Anomaly, and Water Availability Percentage in dams in the country and input from local experts. This indexes are deployed in layers through a geographic information system (GIS), and by consensus, drought-affected regions are determined according to a scale of intensities ranging from abnormally dry (D0), moderate drought (D1), severe drought (D2), extreme drought (D3), up to exceptional drought (D4) (SMN 2017).[16]

In Mexico, the development of effective flooding early warning systems associated with Flooding Risks Atlas and in simulators through rainfall monitoring and simulators of hydrologic behavior in the basins is essential. Likewise, it is very important to strengthen the Early Warning Systems on the local level, in order to reduce vulnerability against hydrometeorological risks.

14.5.2 Initiatives and Actions to Reduce the Vulnerability to Climate Change

Strategies of adaptation to climate change based on ecosystems have been developed in Mexico as pilots in order to develop and refine methodological schemes of measurement and implementation that allow the development of synergistic strategies of preservation and restoration actions, associated to climate change mitigation actions, and that permit the strengthening of the national policy of climate change adapting in Mexico. Consider some cases.

14.5.2.1 Interinstitutional Platform for the Attention of Coastal Wetlands[17]

One of the most important ecosystems in Mexico is the coastal wetlands; they are transition ecosystems between terrestrial and aquatic environments and constitute transitory or permanent flooding areas. Their environmental services include, among others, being the support of a characteristic biodiversity, reproduction and feeding site of numerous species of ecological and fishing interest, contribution to water supply, carbon catchment, and absorbing the impact of extreme hydrometeorological events, all of which give them a growing social and economic value now and in the context of climate change. The biological richness and strategic environmental services that wetlands provide place them among the most significant natural resources of more than 11,000 kilometers of coastline in the country.

As part of a conservation, restoration, and sustainable management strategy of coastal wetlands in Mexico, a Digital Platform of Institutional Coordination was designed to access, visualize, and analyze information from the federal government agencies on the subject of coastal wetlands. The objective is to establish a coordination of efforts that

[16] Information of Drought Monitor is available at http://smn.cna.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico

[17] INECC-CONAGUA. Priorización de cuencas hidrológicas para la atención de humedales costeros. Coordinación interinstitucional para la Atención de Humedales Costeros. Disponible en: http://sigagis.conagua.gob.mx/atencion_humedales/

converge in time and space the actions from diverse government institutions, academic institutions, and civil society organizations that are committed to the preservation of wetlands under the approach of basin integral management.

INECC along with CONAGUA conducted a prioritization to geographically locate potential areas of joint intervention, to coordinate efforts of institutions with attributions for the attention of coastal wetlands. A territorial vision was considered when incorporating the cartographic base of hydrological basins as prioritization unit. Prioritization considers three main criteria:

i. Ecological importance of coastal wetlands and the anthropic pressure on them
ii. Exposition to current extreme events and vulnerability to climate change
iii. Current environmental policy instruments on coastal wetlands

This methodology makes it possible to conduct different basin prioritizations depending on the objective and the institutional and financial natural resources for the attention of wetlands included. For instance, wetlands with many instruments of attention may be considered as a priority in areas of high exposition to climate events, or of high ecological value and need to reinforce the implementation of conservation policy instruments.

Results of this prioritization identify basins with coastal wetlands of high ecological value, with high exposition to tropical cyclones, with those municipalities most vulnerable to climate change and where federal efforts meet for its management. The complementarity of rehabilitation activities of forest masses in high grounds, sustainable productive activities in the middle grounds, and wetland protection in low grounds of basins ensure the supply of wetlands environmental services, essential for the vulnerability reduction through mitigation promotion, triggering of adapting processes against climate change and preserving biodiversity.

Of the 304 hydrological basins with coastal wetlands, 46 present priority category according to the considered criteria, 19 correspond to the Gulf of California region, 11 to the Gulf of Mexico, 5 to Northeast Pacific, 10 to Tropical Pacific, and 1 to Caribbean Sea region.

14.5.2.2 Action Plans for Basin Management (PAMIC)

One of the main challenges in territorial planning is the implementation of instruments that incorporate the territorial dynamics of hydrographical basins. As a response to this need, PAMICs were created; their objective is to promote the functional connectivity of the territory by providing information to focus conservation programs for important areas of water environmental services. Currently, it is used to identify better areas for the payment of environmental services of CONAFOR, in the implementation of preservation actions the National Commission of Protected Natural Areas (CONANP) and diverse projects with an environmental approach operated by regional funds.

PAMICs are an instrument of territorial planning designed by the Directorate of Hydrological Environmental Services and Adaptation of the Institute of Ecology and

Climate Change (INECC). Its objective is to promote the functional connectivity of hydrographical basins through the identification of territorial relations between supply and demand areas of SAH. Allowing, through cartographic products, to focus on actions for the conservation, rehabilitation, and sustainable use of high potential SAH areas and which are hydrographically related to areas with a high demand for those services. The instrument has three components; one analytical, one relational, and another participative. The first one corresponds to the geographic modeling and identification of high potential areas for the supply of superficial waters and preservation of soils, that is, supply priority areas of SAH. The relational component identifies water uses and volumes and licenses and determines the hydrographic relation between supply and demand areas of SAH for the identification of priority intervention areas. The participative component covers the local traditional knowledge, the community and institutional capacities for implementing actions focused on the conservation of natural capital, and the adequacy of productive practices in priority supply areas of SAH.

In the context of climate uncertainty, the proposal of implementing conservation actions in PAMICs prioritizes areas with a high supply of SAH and with a potential change in the vegetation structure considering the projections of climate change, contributing in the reduction of the population vulnerability and productive activities of basins.

Up to date, in the "Conservation of Coastal Basins in the Context of Climate Change" (C6) framework, the PAMICs that have been developed on the coastal basins are: Tuxpan, Jamapa, and Antigua Rivers, in the state of Veracruz; the basin systems that flow into Bahia de Banderas, in Jalisco; and San Pedro and Baluarte River basins, in Nayarit and Sinaloa.

C6 operates with a grant from Global Environmental Facility (GEF) managed by the World Bank. Three public institutions (the Institute of Ecology and Climate Change, CONANP, CONAFOR) and a private entity, the Mexican Fund for the Preservation of Nature (FMCN), collaborate. The architecture of the project coordination constitutes an innovative component that seeks the initiation of collaboration processes and synergies in the territory for promoting the integrated management of coastal basins, preserving their biodiversity, triggering adaptation processes, and contributing in the mitigation of climate change. All the actions in the C6 framework seek to contribute in the recovery of basins functionality and the maintenance of ecosystem services of regulation and provision.

14.5.2.3 National Program Against Drought (PRONACOSE)

PRONACOSE, coordinated by CONAGUA, emerges at the beginning of the administration in 2014 as a planning or programming scheme of actions or preventive and mitigation measures against droughts, which, as mentioned before, began its fortnight monitoring through the National Meteorological Service of the National Water Commission (SMN-CONAGUA) since February 2014. These measures or actions inserted in programs according to basin councils, or cities, or metropolitan areas establish a pathway toward a severe drought program. There are already programs for Preventive Measures and Drought Mitigation (PMPMS) in 26 basin councils as well as in 13 major cities or metropolitan areas. Consistent with CONAGUA (2015), these programs seek to:

– Guarantee water availability required to ensure health and life of the population: public, domestic, urban, and rural supply
– Prevent or minimize the negative effects of drought on the environment, especially on ecological flow regimes
– Minimize negative effects on economic activities, according to prioritization of uses established in the water legislation and in water programs

This program necessarily links the measures established in the PMPMS, in basin approach and with the analysis of supply and demand of hydrological environmental services, in the face of scenarios of low water availability due to meteorological drought seeking to avoid socioeconomic drought.

14.5.2.4 National Program of Water Reserves (PNRA)

LAN establishes that for the ecological protection, which includes preservation or restoration of vital ecosystems, and for the preservation of wetlands, the legal solution is the declaration or decree of total or partial reserves of national waters as ecological reserves. Article 41 of that Law establishes that the Federal Executive may declare by decree total or partial reserve of national waters in order to "guarantee minimal flows for the ecological protection, including preservation or restoration of vital ecosystems."

In order to promote water reserves, the National Program of Water Reserves (PNRA) was created, a powerful private-public initiative[18] for strengthening water management for the conservation and adaptation to climate change (BID 2015), based upon the model developed by Alliance WWF-Fundación Gonzalo Rio Arronte, I.A.P. (FGRA) and other partners since 2005 and whose objectives are:

- Establishing a national system of water reserves
- Demonstrating its benefits as an instrument, guarantor of the functionality of the water cycle and its environmental services
- Strengthening the application of the Mexican norm of ecological flow in the country

CONAGUA and the Alliance WWF-FGRA led the study to establish the feasibility of hydrological basins in Mexico, in order to implement water reserves. Results show that 189 basins are feasible to be decreed if the necessary studies are completed, and there would be water available for the environmental protection of

[18]The main partners of PNRA are the National Water Commission, Binational Commission of Protected Natural Areas, WWF Mexico, FGRA, and Inter-American Development Bank.

55 Ramsar sites (41% of the total) and for 97 ANP (50% of the total) (Conagua 2011; González Mora et al. 2014).

14.6 Conclusion

Integrate in an effective manner, the water resources supply and demand approach in the context of climate change in the governance, coordination and participatory spaces of the water and climate change policy, is an unprecedented challenge for the operation of the Mexican environmental normativity. The basic legal and normative framework exists but the interaction and functionality of attributions and the institutions acting in the complex systems that basins mean, not yet. As it is reaffirmed in this chapter, it is an urgent need to make it from a socioecosystemic perspective based on the approach of integral basin management that will translate into a systematic reduction in the vulnerability against impacts, both in human and in natural systems.

However, facing the problem of water resources in the future, with the principles, approaches, and tools of public policy discussed in this chapter in an interdisciplinary environment, intersectoral coordination, with the formation of the required capacities, will allow Mexico to fulfill non-conditioned commitments in climate change adaptation subscribed in the Paris Agreement. Solutions imply a paradigm shift in the design and implementation of public policies integrating a common vision of the territory for all sectors, stakeholders, and levels, as well as the strengthening of national, local, and basin of Mexico inhabitants' capacities.

References

Arreguín Cortés, Felipe, I Coord. (2015), *Atlas de vulnerabilidad hídrica en México ante el cambio climático*, Felipe I. Arreguín Cortés, Mario López Pérez, Olivia Rodríguez López y Martín José Montero Martínez, coordinadores Jiutepec, Mor., Instituto Mexicano de Tecnología del Agua.

Azuela de la Cueva, A. (2006a). Distancias y disonancias del ordenamiento territorial en la legislación mexicana. En Javier Delgadillo (Compilador), Política territorial en México, hacia un modelo de desarrollo basado en el territorio (467–492). SEDESOL y UNAM.

Azuela de la Cueva, A. (2006b). El ordenamiento ecológico del territorio en México: génesis y perspectivas. SEMARNAT.

Banco Interamericano de Desarrollo (BID). (2015), *Programa Nacional de Reservas de Agua en México: experiencias de caudal ecológico y la asignación de agua al ambiente*. BID, WWF México.

Biestroek, R., Swart, R., & van der Knapp, W. (2009). The mitigation-adaptation dichotomy and the role of spatial planning. *Habitat International, 33*, 230–237.

Brañes, R. (2004). *Manual de derecho ambiental mexicano*. Fondo de Cultura Económica y Fundación Mexicana para la Educación Ambiental.

Calderón, M. (2001). *Lázaro Cárdenas del Río en la cuenca del Tepalcatepec-Balsas. En La Tierra Caliente de Michoacán*, Coordinador editorial. José Eduardo Zárate. El Colegio de Michoacán y el Gobierno del Estado de Michoacán. Zamora, Michoacán, pp. 233–264.

Centro Nacional de Prevención de Desastre (CENAPRED). (2017). Sistemas de Alerta Temprana, Contenido de curso de la Escuela Nacional de Protección Civil. En: http://www.cenapred.gob.mx/es/documentosWeb/Enaproc/curso_Alerta_Temprana.pdf

Comisión Nacional del Agua, CONAGUA. (2011). *Identificación de reservas potenciales de agua para el medio ambiente en México* (85 pp). México: Semarnat/Conagua.

Comisión Nacional del Agua, CONAGUA. (2015). Programa Nacional de Combate a la Sequía (PRONACOSE). https://www.gob.mx/conagua/acciones-y-programas/programa-nacional-contra-la-sequia-pronacose-programas-de-medidas-preventivas-y-de-mitigacion-a-la-sequia-pmpms-para-ciudades Consultada el 20 de noviembre de 2017.

Comisión Nacional del Agua, CONAGUA. (2016). *Estadísticas del Agua en México. Edición 2016*, Capítulo 2. Situación de los recursos hídricos, página 31, Capítulo 3. Usos del agua, 70, 71 Capítulo 8. Agua en el mundo, página 195.

Conde, C. (2016). Conferencia: Bases conceptuales y legales de cambio climático y adaptación en México, 21 de septiembre de 2016. *Ciclo de videoconferencias: Manejo de cuencas y cambio climático en México*, Cecadesu/Semarnat/Red Mexicana de Cuencas Hidrográficas.

Cotler, H., Galindo, A., González, I. D., Pineda, R. F. y Ríos, E. (2013). *Cuencas hidrográficas. Fundamentos y perspectivas para su manejo y gestión.* Cuadernos de Divulgación Ambiental (32 pp). México: Cecadesu/Semarnat y Red Mexicana de Cuencas Hidrográficas (Remexcu).

Gasca Zamora, José. (2009). Geografía Regional, La región, la regionalización y el desarrollo regional en México. México: Instituto de Geografía, UNAM.

Global Water Partnership, GWP. (2017). *What is water security*. http://www.gwp.org/en/The-Challenge/What-is-water-security/. Consultado el 20 de noviembre de 2017.

González Mora, I. D., Salinas Rodríguez, S. A., Guerra Gilbert, A., Sánchez Navarro, R. y Ríos Patrón, E. (2014). *Ríos libres y vivos. Introducción al caudal ecológico y reservas de agua.* CECADESU-SEMARNAT, Alianza WWF México y Fundación Gonzalo Río Arronte, I.A.P. y Remexcu.

INEGI. (2010). *Censo de Población y Vivienda 2010*. México.

INEGI-INE-CONAGUA. (2007). Mapa de cuencas hídricas de México (escala 1: 250 000). En: *Cuencas Hídricas de México, escala 1:250,000*. INE 2003, autores Priego A.G., Isunza E., Luna N. y Pérez J.L.

Instituto Nacional de Ecología y Cambio Climático, INECC. (2015). *Compromisos de mitigación y adaptación ante el cambio climático para el periodo 2020–2030.* Gobierno de la República, En: http://www.inecc.gob.mx/descargas/adaptacion/2015_indc_esp.pdf

Intergovernmental Panel on Climate Change, IPCC. (2007). Summary for policymakers. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 7–22). Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change, IPCC. (2013). *Fifth assessment report (AR5). WGI The physical science basis*.

Lampis, A. (2013). La adaptación al cambio climático: el reto de las dobles agendas. Postigo.

Ley General de Cambio Climático (LGCC), 6 de junio de. (2012). Capítulos V artículos 38 al 97. Cámara de Diputados del H. Congreso de la Unión. México. En: http://www.diputados.gob.mx/LeyesBiblio/ref/lgcc.htm

LGEEPA. (1998). Ley General de Equilibrio Ecológico y Protección al Ambiente 2017. Cámara de Diputados del H. Congreso de la Unión. México. Disponible en: http://www.diputados.gob.mx/LeyesBiblio/pdf/148_240117.pdf Fecha de consulta: 31 de octubre de 2017.

Matthews, J. L. y Le Quesne, T. (2009). *Cómo adaptar la gestión hídrica. Guía para hacer frente al cambio climático*, Serie Seguridad Hídrica de WWF, Vol. 3. Alianza WWF-Fundación Gonzalo Río Arronte, I.A.P. WWF México.

Naciones Unidas/Convención Marco sobre el Cambio Climático. (2015). Aprobación del Acuerdo de París. Disponible en. http://unfccc.int/resource/docs/2015/cop21/spa/l09s.pdf

Organización Meteorológica Mundial, OMM. (2017). *El año 2017 va camino de ser uno de los tres años más cálidos, con registros de tiempo extremo sin precedentes.* 6 de noviembre de 2017. Boletín de prensa número: 06112017 En: https://public.wmo.int/es/media/comunicados-de-prensa/el-a%C3%B1o-2017-va-camino-de-ser-uno-de-los-tres-a%C3%B1os-m%C3%A1s-c%C3%A1lidos-con

Quintana, J. (2009). *Derecho ambiental mexicano, lineamientos generales*. Distrito Federal: Porrúa.

Ríos Patrón, E., González Mora, D., González Terrazas, D., Merino Pérez, M., Mokondoko Delgadillo, P., & Ortiz Paniagua, F. (2016). *Adaptación al cambio climático, fundamentos desde el manejo de cuencas.* CECADESU-SEMARNAT, Remexcu, INECC y Alianza WWF México y Fundación Gonzalo Río Arronte, I.A.P.

Rivas, I. (2015). *Efectos del cambio climático en el recurso hídrico de México (agua superficial).* En: *Atlas de vulnerabilidad hídrica en México ante el cambio Climático*/Felipe I. Arreguín Cortés, Mario López Pérez, Olivia Rodríguez López y Martín José Montero Martínez, coordinadores, Jiutepec, Mor., Instituto Mexicano del Tecnología del Agua.

Rosete, F. (2006). *Semblanza histórica del ordenamiento ecológico territorial, perspectiva institucional: México*, Instituto Nacional de Ecología, SEMARNAT.

Sanjurjo Rivera, E., González Mora, I. D., Ortiz Paniagua, C. F., & Ríos Patrón, E. (2017). *Economía y medio ambiente. Reflexiones desde el manejo de cuencas.* CECADESU-SEMARNAT, Red Mexicana de Cuencas Hidrográficas, Red de Socioecosistemas y Sustentabilidad, Alianza WWF-Fundación Gonzalo Río Arronte, I.A.P.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2013). Programa Sectorial de Medio Ambiente y Recursos Naturales (PROMARNAT) 2013–2018, Gobierno de la República. México, 138 p.

Secretaría de Medio Ambiente y Recursos Naturales/Instituto Nacional de Ecología y Cambio Climático (SEMARNAT-INECC). (2013). Estrategia Nacional de Cambio Climático. Visión 10-20-40 Gobierno de la República, 60 pp.

Servicio Meteorológico Nacional (SMN). (2017). Consulta de la página: http://smn.cna.gob.mx/es/climatologia/monitor-de-sequia/monitor-de-sequia-en-mexico. Consulta el 21 de noviembre de 2017.

WWAP (Programa Mundial de Evaluación de los Recursos Hídricos de las Naciones Unidas). (2017). Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2017. Aguas residuales: El recurso desaprovechado. París: UNESCO.

Eduardo Ríos Patrón is co-coordinator since 2011 of the Mexican Network of Hydrographic Basins. He has participated in the Organizing and Scientific Committee of the III and IV National Congress of Watershed Management. He is a specialist in watershed planning and management. He has extensive experience in the implementation of environmental policy, in the promotion of coordination processes as Head of the Planning and Environmental Policy Unit, and in the Ministry of Environment and Natural Resources, Delegation in Michoacán. He is co-author of publications on issues of integral management of watersheds. He teaches Public Policy and Environmental Legislation at the National School of Higher Studies of the National Autonomous University of Mexico (UNAM), Morelia campus. He holds a Bachelor's degree and a Master's Degree in Administration from the Universidad Anáhuac del Sur and a Master's Degree in Integrated Watershed Management from the Autonomous University of Querétaro (UAQ). He is a member of the Socioecosystems and Sustainability Network (RedSocioecoS).

Daniel Iura González Terrazas earned a Master of Science with a specialization in Natural Resources Management from the International Institute of Earth Observation and Geo-information (ITC), University of Twente, Netherlands, and a Master in Geography from the Research Center in Environmental Geography. Also a biologist graduated from the Faculty of Sciences of the National Autonomous University of Mexico (UNAM). His research areas include the analysis of supply and demand of environmental services for the processes of adaptation to

climate change in the framework of watersheds, incorporation of the basin approach, and climate change in the instruments of territorial planning. He is a specialist in support systems for environmental decisions and geographic information. Since 2012, he is attached to the National Institute of Ecology; currently, he heads the Hydrological Environmental Services Analysis Department of the General Coordination of Adaptation to Climate Change. Among the current projects under his charge include the design of the inter-institutional platform for attention to coastal wetlands, the PAMICs watershed management action plans, and the coordination of the National Atlas of Vulnerability to Climate Change by INECC. He is a member of the Mexican Network of Hydrographic Basins.

Ignacio Daniel González Mora is co-coordinator since 2011 of the Mexican Network of Hydrographic Basins. His academic training was carried out at the UNAM: biologist at the Faculty of Sciences and with subsequent studies of specialization in Applied Statistics at the Research Institute in Applied Mathematics and Systems. He has worked in the National Water Commission (CONAGUA) responsible for the planning and coordination of the National Water Quality Monitoring Network, where he promoted biological and toxicological monitoring and proposed a new system of environmental indicators of water quality. In 2005, he joined the technical team of the World Wide Fund for Nature (WWF). In the development of the WWF-Fundación Gonzalo Río Arronte IAP, he has been responsible for 11 years of the management of the Copalita-Zimatán-Huatulco, Oax. Basins, and coordinator of the interdisciplinary team that determined the ecological flow in 10 representative sites of these basins. Since then he has participated in both the Advisory Council of the Huatulco National Park (CONANP) and the Basin Council of the Coast of Oaxaca and in his auxiliary body the Basin Committee of the Copalita and Tonameca rivers, being a member of the organizations of the civil society. He has participated in projects in other Oaxacan basins, such as Río Verde Atoyac and Tehuantepec. He has collaborated in the Organizing Committees of the National Congresses of Management of Hydrographic Basins III and IV in the capacity building initiatives of CECADESU-SEMARNAT on integrated management of basins. He is a member of the Socio-ecosystems and Sustainability Network (RedsocioecoS).