Introduction

1 Water Resources in Mexico: A Conceptual Introduction

Úrsula Oswald Spring and Ignacio Sánchez Cohen

1.1 Introduction

Water use and management is of crucial importance for everyday life and also for productive processes, as well as for the conservation and recovery of ecosystems. In only two decades (1990–2010), water consumption on the planet has doubled. In Mexico, due to population growth and agricultural and industrial production, water availability per person has become increasingly limited. This shrinking water availability is partly a consequence of the geo-ecological distribution of the population given that 58 per cent of its national territory has drylands – semi-arid, arid and hyper-arid (desert) ecosystems – that are below the average national rainfall. Due to climatic uncertainty all processes of planning for human demand and for production requirements are highly uncertain. Furthermore, it is precisely in these drylands that the main irrigation districts are located, that 70 per cent of the Gross Domestic Product (GDP) in the agricultural sector is generated, and that 92 per cent of the irrigated lands are located, with an overall efficiency of water use of below 40 per cent. Agriculture consumes most of Mexico's water reserves (77 per cent), followed by domestic consumption with 13 per cent and industrial use with 10 per cent (CONAGUA, 2009).

The second problem for water availability in Mexico is that of periodic variations, as most rainfall occurs during the rainy season between June and October, compared with the rest of the year which is characterized by a dry season that forces peasants and agribusinesses to use water from dams, rivers and aquifers. The wide variability of the spatial and temporal distribution of rainfall has increasingly been influenced by an anthropogenically-induced *climate change* (CC; UNFCCC), something that has made equitable water management more difficult. Therefore, it is necessary to develop technologies that increase productivity per water drop, as well as to promote a culture of water saving, especially for agricultural, industrial and domestic activities. As water can be reused in households and for agriculture, this contributes to the challenge of developing efficient water treatment processes and the reuse of treated water.

1.2 Objectives

The complexity of water management encompasses the varied uses and reuses of water, including human, productive, agricultural and environmental factors. The objective of this book is to develop an interdisciplinary, inter-institutional and inter-sectorial diagnosis of research, institutions and infrastructure relating to water in Mexico. The *Scientific Network of Water* (RETAC) of the *National Council on Science and Technology* (CONACYT) addresses many new scientific, political, social, cultural and business challenges. Its goal is to contribute to a more sustainable administration of water, and to a more responsible and equitable water management policy. RETAC is also responding to a novel scientific policy within CONACYT, where synergies are being created between researchers, institutions, social movements, civil organizations and enterprises in order to solve complex water issues in a collective and peaceful manner. The distinctive feature of this effort is its multidisciplinary and multi-institutional outlook, featuring studies with multiple objectives in order to integrate areas of expertise and methodologies to solve complex contemporary problems relating to water.

Mexico has already been severely affected by climate change and large parts of its territory are covered by arid lands, where water availability is limited due to temporal and regional factors that are linked to the rainy season. Given these complex challenges, researchers from different disciplines have converged in order to engage in an open and honest dialogue guided by common interests so as to learn from their respective viewpoints, techniques and analytical tools. Integrating businessmen and public servants into this dialogue opens the possibility of suggesting alternatives, of offering sincere critiques of water policies, of devising strategies for mitigating the effects of more

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severe droughts and extreme hydro-meteorological events, and of contributing to processes of adaptation for coping with global climate change. In the social domain, the book provides many resources to stimulate groups to organize themselves and to improve their capacities for resilience, with the goal of protecting themselves against new and unknown risks, thus reducing their environmental and social vulnerability.

This book is the result of a systematic review by a group of water specialists who are active not only in many academic fields, but also as public servants and entrepreneurs. All chapters were anonymously peer-reviewed by at least three and up to five experts. The authors whose papers were accepted for publication incorporated the many suggestions of the peer-reviewers and revised their texts accordingly.

RETAC, the results of whose work during the first two years are presented in this book, aims to better understand the complex problems relating to water by developing new technologies and analytical tools, by homogenizing scientific methods to enable comparisons, by reflecting on water policies in Mexico in the face of climate change and by disseminating scientific results to governments and businesses with the goal of implementing them in safe water and sanitation systems, in agricultural and industrial processes, in the conservation of aquifers and surface water resources, as well as in the preservation and recovery of ecosystems.

During its first national meeting from 21 to 23 January 2009 at the Ex-Hacienda of Cocoyoc in the state of Morelos, various sectors were represented including researchers, institutions, federal, state and municipal water management authorities, civil servants in charge of drinking water and sanitation, entrepreneurs, and members of civil society. Following a meticulous analysis of the complex interrelations between social and environmental factors related to water, the discussions assessed gaps in knowledge and deficits in existing public policies. This led to the development of certain general thematic areas and their current shortcomings that organized research and public policies should address. This included problems such as the lack of an integrated socio-environmental approach, deficits in water administration and management, or where partial and short-term interests prevail over general interests and processes, thus leading to negative outcomes in the middle and long term.

A clear example of this is that over-exploitation of aquifers has occurred in dry areas, where intense pumping at great depths has generated subsidence, intrusion by sea and brackish water, pollution by metals that imperil human and environmental health, and most importantly, encumbrance of water supply for productive and domestic processes. Given the complexity of the topics that have been addressed, the authors have tried to pave the way towards an unknown yet promising path. The authors hope the reader will also join in this effort by enriching this work with additional reflections that should not only focus on the water situation in Mexico, but also be useful for other countries facing similar problems.

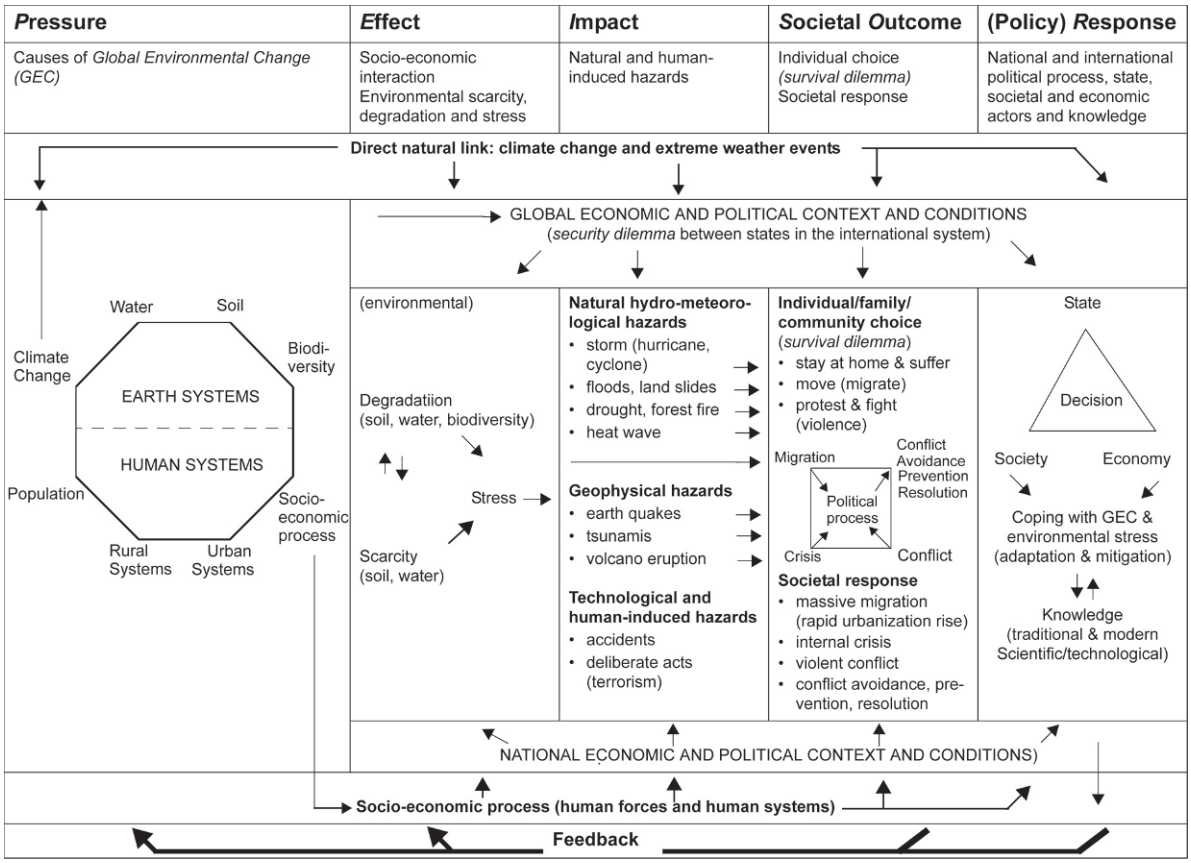
1.3 Some Conceptual Reflections

Climate change and more extreme hydro-meteorological events will have consequences for drylands and they will result in changes to agricultural demand and to productive processes. Water-saving systems and the higher efficiency of drop-by-drop irrigation in food production require adequate technologies such as mulching, micro-irrigation tunnels, bio-fertilizers, reuse of agricultural by-products, sensors to measure soil humidity, and the development of efficient irrigation plans according to specific crop needs. Nevertheless, the existing waste of water in agriculture, the lack of trust in government activities, the corruption and the attitudes of traditional producers limit the use and promotion of such technologies, thus impacting adversely on the quality of life of producers, and accounting for both technological and social gaps.

Integrated water management means transforming the current remedial 'end-of-pipe' sanitation policies by actions geared to prevent pollution and to foster clean production processes. The prevailing chaotic urban development and the lack of sustainable rural policies urgently require territorial planning with comprehensive environmental management that involves all actors to their mutual benefit. Financial and legal mechanisms to quantify environmental services are also necessary. Environmental services are usually provided by people living in the upper basin who often represent the poorest groups in Mexico.

The analytical goal is a complex study of providing a transverse diagnosis of water research that can translate into just and sustainable public policies. This book constitutes a first step in this direction, linking different disciplines to begin weaving a fine set of interrelations. This also implies combining the different levels of analysis to prevent the fallacy of the equivocal level. To better understand the interdisciplinary complexity and the dynamic of global environmental

Figure 1.1: PEISOR Model. **Source:** Brauch and Oswald Spring (2009: 9).



changes, particularly of climate change, the PEISOR model[1] was gradually developed (figure 1.1). It consists of five elements:

P: *Pressure* including the interaction among at least eight socio-environmental factors constituting global environmental change;

E: *Effects* of the relationship between scarcity, environmental degradation and environmental stress;

I: *Impacts* of extreme hydro-meteorological events that turn into disasters due to human activities;

SO: *Social consequences* such as hunger, forced migration, shanty towns, environmental conflicts, resource wars and failed states;

R: *Policy Response* by actors and institutions involved and affected while facing the dynamic processes of global environmental change.

Pressure links the four natural factors (air, water, soil and biodiversity) with the four human processes (demographic growth, rural systems, urban systems and productive socio-economic processes). As part of the *Earth System*, the air is affected by an intensive burning of hydrocarbons since the start of the industrial revolution, which has been the primary cause of anthropogenic climate change. Reduced precipitation rates combined with torrential rains have eroded soils and thus contributed to desertification. Water scarcity, temporary floods, soil fertility loss and desertification also constrain biodiversity. This destructive impact of the *Human System* on the *Earth System* has resulted in air pollution, in extreme temperatures,

1 The PEISOR model evolved gradually, stimulated by various stimulus-response models that have been used over the years by OECD, the UNCSD and the European Environment Agency (Brauch, 2005, 2009). It addresses the complex interactions between natural and social factors, taking existing global and specific national socio-economic and political conditions into account. The present version of the PEISOR model was first presented at a Special Event of the *United Nations Convention to Combat Desertification* (UNCCD) during the 17th Session of the *UN Commission on Sustainable Development* (UNCSD) on 14 May 2009 in New York when a study on soil security was launched written by Hans Günter Brauch and Úrsula Oswald Spring on *Securitizing the Ground, Grounding Security* (2009: 9).

drought, water scarcity and water degradation, multiple forms of soil erosion, destruction of ecosystems and loss of biodiversity. At the same time, social systems due to demographic growth have put pressure on natural resources. Changes in land use and the intensification of socio-productive processes have significantly transformed rural and urban systems. The increasing demand for natural resources (water and food) has caused scarcity, while intensified industrial processes have led to pollution. Both processes have severely affected the Earth as well as the human systems.

The *effects* of this interaction between human and natural systems generate scarcity, degradation and environmental stress. During the 20th century the world's population tripled while the water demand increased sixfold with no increase in efficiency. Besides the increasing demand for food, the increasing use of some foodstuffs for biofuels (e.g. of sugar cane as ethanol, cereals as biodiesel) and a chaotic urbanization have generated many new risks (floods, landslides, soil fertility loss, soil erosion and desertification). This environmental stress puts greater pressure on natural systems, and this has affected social systems as well. The greater the impact of climate change, the greater the damage to water, air, soil and biodiversity. A polluted natural environment reduces the capacity of the ecosystems for resilience, putting pressure on socio-political systems through illness and human losses during disasters, as well as through the high cost of reconstruction.

The *impact* of environmental stress, exacerbated by climate change, has increased the intensity of hydro-meteorological events. While droughts have caused forest fires, wind erosion, sandstorms, more severe cold spills and heatwaves have harmed human health and the ecosystem. At the same time, droughts and hurricanes have caused a deterioration of environmental services, affecting socially vulnerable groups most, especially women and children.

Societal consequences are many, and this has sometimes created a vicious circle. Greater socio-environmental vulnerability affects personal and socio-economic development. Processes of desertification, drought and floods destroy agricultural production and cause deterioration of the means of subsistence of often marginal and poor rural populations. The diminution of water and foodstuffs, due to a loss of the soils' natural fertility, has generated hunger in many countries. When people migrate to improve their life conditions, conflicts over land, water and jobs sometimes develop and escalate. These complex interrelations between environmental and social phenomena have also deepened existing conflicts in Mexico, generating confrontations about the possession of the land or rights to cultivate it, and the use of springs, wells and other water resources. According to data supplied by the Mexican Agrarian Attorney, in 2007 there were approximately 390,000 agrarian conflicts, due to changes to article 27 of the Mexican constitution that allows *ejido*[2] land from 1992 on to be rented, sold and transferred in association with agribusiness. There have similarly been an equal number of water conflicts.

Response refers to the political processes where three core actors interact: the state, the business community and society as a whole. Mitigation and adaptation policies and measures dealing with global environmental change derive from traditional and modern scientific knowledge based on technological and scientific research and innovation. Decisions are the results of negotiation processes, where consensual agreements between the three social sectors respond to the complex interrelationships between natural and social systems. Climate change, the worsening condition of water, soils, biodiversity, changes in urban and rural systems, the intensification of productive processes, and increasing demographic growth rates produce multiple risks for national and international security, as well as for human security. Thus, good governance responds to anticipated learning processes due to an increased awareness of the population regarding both environmental and social threats. It also calls for proactive politics to prevent and reduce negative interactions between environmental and socio-political processes.

The history of Mexico offers an illustrative example. Since the collapse of the Maya civilization – due to an over-exploitation of scarce natural resources in fragile ecosystems that resulted in a series of famines and pandemics, but also due to the genocide of the native populations from the Spanish conquest until Independence (1810) and the Mexican Revolution (1910) – repeated and prolonged periods of severe droughts require a clear understanding of the relationship between natural and socio-political factors (Sánchez Cohen et al. 2011; Blümel, 2009). These past

2 Ejido is the term created for the land that was assigned after the Mexican revolution in 1910 to the peasants who had fought for this land. From 1992 on, President Salinas declared that the land reform had been completed and announced that no more land would be distributed.

experiences should serve as a warning signal for Mexican society as a whole, given the sensitivity of the current socio-environmental and political situation. A severe drought has affected large parts of Mexico from 1994 to 2010. Since 2005, an increasing number of hurricanes of greater severity have occurred, as well as floods and a deepening poverty among rural populations, which has forced many affected people to emigrate to the USA (Oswald Spring 2011). The tightening of controls along the border between Mexico and the United States and also the Anti-immigration Law SB1070 that was adopted in Arizona in 2010 have also resulted in a greater number of Mexicans being deported and jailed, where they had only sought work and better living conditions in the US. This undocumented migration has become increasingly complex due to the involvement of criminal organizations in drug and human trafficking as well as the arms trade, and has resulted in mounting public insecurity.

The diagnosis of these complex interrelationships between natural and human systems using the PEISOR model represents a first step in addressing these problems with a transverse and interdisciplinary approach, to which this book hopes to contribute. The hope is that it will also help overcome the vicious circles of natural resource degradation and the loss of quality of life. In Mexico, risk reduction and long-term food sovereignty is rooted in the dynamic interrelationship between water, soil, reduction of greenhouse gas emissions, sustainable agricultural production, affordable food prices, and the quality of education, as well as subsidies and policies for rural and industrial production and job creation. This would prevent the undesirable social outcomes and forced survival conditions currently reflected in forced environmental migration, public insecurity, violent conflict, hunger and obesity. Undoubtedly, analyzing water management is highly complex and obliges government, society and the business community to negotiate an alternative development model, where sustainable peace prevails, mitigating conflicts through hydrodiplomatic models, and where an integrated and sustainable water culture helps create a less hazardous future in the environmental, social and political realm.

1.4 Organization of the Book

With the aim of contributing to the objectives described above, this book is divided into nine sections. It starts with a preface and after this introduction, part I is devoted to hydrological processes, the management of water basins and the interaction between climate, land and biota. Part II addresses water use and availability, scarcity, and alternative water resources for productive processes. Part III deals with water quality, natural and anthropogenic pollution, and its repercussions for human and environmental health. Different water cleaning technologies are suggested, departing from the hypothesis that changing productive processes to prevent pollution is cheaper and more efficient than treating discharges 'at the other end of the pipe'. Water quality, water availability and water scarcity have so far had important social effects, sometimes resulting in conflicts, but also in negotiation processes that are analysed in part IV.

The field of international relations and issues related to the border extending to more than three thousand kilometres between Mexico and the USA are also addressed, in conjunction with the microsphere of community struggles over the control of rivers, wells or springs. In all these cases, alternative processes of organization and a hydrodiplomatic model are proposed to avoid future conflicts and to solve existing ones peacefully.

Part V includes novel public policies, institutional designs, water economy and legal aspects in order to improve water administration and basin management. Participatory governance demands readjustments to the traditionally authoritarian politics of Mexico, involving a willingness to find new ways on behalf of existing interests and some insensible authorities responsible for water management at the federal, state, municipal and local level.

In the concluding remarks, the editor offers a balance sheet between new achievements and deficient areas related to water research in Mexico. This book is complemented by a thematic index, the biography of the authors, and a list of abbreviations.

1.4.1 Part I: Hydrological Processes and Basin Management

Part I (chapters 2 to 6) addresses hydrological processes, the management of basins and the interaction between climate, land and biota. It comprises a variety of structural topics related to an integrated management of water for diverse uses where various experts have developed and validated algorithms to quantify water availability and quality. The importance of this topic combines the scientific analysis of different case studies throughout Mexico to identify similar behavioural patterns and cause-effect relations that

could be replicated elsewhere. Here, the use of physical methods prevails.

This part starts with chapter 2 by *Felipe Arreguín*, the Deputy Director of the National Water Commission, who was assisted by *Mario López Pérez* and *Humberto Marengo Mogollón*. The authors offer an assessment of the water challenges that Mexico faces in the 21st century. Mexico has a territory of 1.964 million km^2 and an average annual precipitation of 775 mm for a total population in 2010 103.3 million inhabitants, of whom three-quarters live in urban areas. Nevertheless, 77 per cent of water is used for agriculture and ANUR (Asociación Nacional de Usuarios de Riego; National Association of Irrigation Users) is the association representing the farmers who are using water for irrigation in Mexico. This is part of a water balance that relates rainfall and population growth to water use and pollution. The authors offer a critical evaluation of surface and groundwater management. The most important challenge is climate change, as both coasts are threatened by rising sea levels, and higher temperatures will increase regional and temporal water scarcity and degradation.

Using many figures and tables, the authors suggest an integrated water management. They explore alternatives such as the creation of a new infrastructure, water saving, reuse, recycling and water treatment. The National Water Plan (2007–2012) focuses on a vision that integrates all water available and used in Mexico, including 'virtual' water savings through imported crops, as well as water used for agricultural exports, soil humidity, and desalination of salt water. The overall vision is to achieve a water balance where an integrated water management satisfies the demand of present and future generations, accounting for population growth and new social and productive needs.

In chapter 3, *Ignacio Sánchez Cohen, Úrsula Oswald Spring, Gabriel Díaz Padilla* and *José Luís González Barrios* propose an integrated water management model. They take the hydrological basin as the basic planning unit for regional development, where actions that integrate all stakeholders are undertaken including planning related to surrounding tributary rivers and aquifers. The authors include the planning for and organization of a new infrastructure, as well as control over water allocations. They also promote the development of new laws and regulations that deal with the challenges posed by climate change, water scarcity and pollution. Through a multi-institutional and multidisciplinary outlook, they seek to involve decision-makers at different stages of water processes, replacing old authoritarian models of water management.

In chapter 4, *Gabriel Díaz Padilla, Ignacio Sánchez Cohen* and *Rafael Alberto Guajardo Panes* put forward an algorithm for the analysis of rainfall time series for Mexico, using data supplied by the five thousand weather stations distributed throughout its territory. With mathematical and statistical processes as well as interpolation techniques, gaps are estimated and maps are generated based on databases using refined information from atypical registers, making estimates through a climatic generator, assessing the viability of adjusting data and critically evaluating interpolation techniques. The authors observe that the 4.3 version of the ANUSPLIN software developed by Hutchinson (1995) provided the best results for continuous surfaces, followed by the Kriging method, Co-kriging method and finally the inverse of the square distance.

In chapter 5, *Miguel Rangel Medina, Rogelio Monreal Saavedra* and *Christopher Watts* argue that economic growth in the state of Sonora depends on water availability for agricultural production and domestic use. Water supply both in the capital and in agricultural lands depends on groundwater from Mesa de Seri, La Victoria, La Sauceda, and from the coast of Hermosillo. Over-exploitation of the aquifers on the coast of Hermosillo caused by the lack of electric and water tariffs has generated a drop in the static level from 20 to 65 m, leading to saline intrusion from the sea. In order to reverse this trend, it is necessary to balance water costs for domestic and agricultural use, end subsidies, and benefit all inhabitants equitably.

In chapter 6, *Eugène Perry, Guadalupe Velázquez Oliman* and *Niklas Wagner* analyse hydrostratigraphy in the Peninsula of Yucatan. Studying the presence of chloride, sulphate, and strontium ions the authors determine the extent of saline intrusion. Groundwater in and near the valley of the Rio Hondo has high concentrations of sulphate and strontium but unusually low concentrations of chloride. In much of the southern part of Campeche, groundwater ion chemistry is dominated by the dissolution of extensive beds of gypsum/anhydrite-bearing evaporites of probable Palaeogene age that release sulphate and chloride ions to the aquifer. The authors found that given its geo-hydrological composition, surface water may be a suitable source of potable water for communities in the area.

1.4.2 Part II: Water Use, Availability and Alternative Sources

Part II (chapters 7 to 13) of the book deals with water use and water availability and explores alternative water sources. The main beneficiary of available water in Mexico is the agricultural sector, especially for the irrigation districts and units in the arid and semi-arid regions. But water efficiency for irrigation reaches at most 40 per cent. In the management of groundwater a series of poor management practices were detected in a wide range of processes. Surprisingly, the electromechanical efficiency of pumping equipment is extremely low at an average of 28 per cent, which indicates great losses in the process of transforming mechanical energy into hydraulic energy. Throughout this section, researchers deal with the topic of water use guided by very different approaches ranging from methods of remote sensing, to *in situ* water quality evaluation, pollution processes, and water use, treatment and reuse for agricultural purposes and human consumption. Irrigation engineering is a common topic in research linked to the amounts of water used; however, it also addresses questions such as when and how water should be used for crops.

Chapter 7 by *Jaime Garatuza, Julio César Rodríguez* and *Christopher Watts* is the result of ten years' research experience in the north-east of Mexico measuring the evapotranspiration of wheat, cotton, safflower, sorghum, potatoes, beans, chickpeas, chili/pepper, vines and walnuts, using the technique of turbulent correlation and linking crop factors with vegetation indexes determined by satellites with various spectral, temporal and spatial resolutions. Environmental monitoring in the estimation of evapotranspiration allows the establishment of regional water balances and helps optimize irrigation for agriculture. The results suggest the use of meteorological stations and remote sensors, applying them to bigger areas such as irrigation districts.

In chapter 8, *Enrique Palacios Vélez* and *Enrique Mejía Sáez* develop a balance of water uses in Mexico, highlighting the importance of water in agriculture that uses 77 per cent of reserves. The authors discuss the lack of measuring and monitoring schemes, stressing that without precise measurements it is impossible to make sustainable decisions on water and irrigation. They compare cases in different irrigation districts of Mexico where advanced measuring technologies through satellite images have been deployed. Thus, it is possible to know the balance between total areas given to users with concessions and real irrigated land. The results are useful for regulating water concessions in irrigation districts, for learning about groundwater use, and for making the best use and management of this vital liquid.

Felipe Omar Tapia shows in chapter 9 the advantages of using advanced methods of analysis for the study of water. Geomatics is a scientific discipline stemming from the convergence of other disciplines such as *Geographic Information Systems* (GIS), cartography, remote sensing, geodesics and photogrammetry. In common terms, it combines a series of methods for the acquisition, processing, representation, analysis and systematization of knowledge and information with a geographical reference, i.e., where a specific spatial environment is located. The approach is systemic; information is generated by means of remote and geospatial sensors to increase the possibility of finding, analysing and communicating the developments that take place in a specific site. These methods are an important tool for decision-making; they are crucial in order to save important amounts of water in irrigation without negatively impacting on productivity.

For the valley of Mezquital in the state of Hidalgo, *Francisco Peña* analyses in chapter 10 the case of urban wastewater coming from the Valley of Mexico. He distinguishes the quality of water that can be used for irrigation and designs a research agenda. The evaluation of irrigation with wastewater, associated with urban growth and rural development, seems to have collapsed. The author characterizes the parties to the conflict, both for the consolidated cases of irrigation with wastewater as well as for the defenders of clean water for irrigation. Evaluations of public performance are marked by extremely slow sanitation processes, a backlog in execution of public works, and an evident incapacity to implement existing laws. The research agenda links the regional water crises to the failure of national agricultural policies.

Lyssette E. Muñoz Villers, Miguel Equihua Zamora, Conrado de Jesús Tobón Marín and *Francisco Gutiérrez Mendieta* analyse in chapter 11 the hydrological effects caused by the damage of the mesophilic mountain forest. They address how it has been turned into pasture lands and its effects on run-off patterns, temporal, and year-round exports from the high basin of the La Antigua River in the Cofre de Perote-Pico mountain range in Orizaba. Pasture lands produce higher run-off and as a consequence a greater loss of natural soil fertility which in turn decreases productivity. Besides this, the authors show that in regeneration, the forest is able to recuperate its

hydrological functionality and generate water flows comparable to those of a mature forest in a relatively short time span.

In chapter 12, *José Luis González Barrios, Ignacio Sánchez Cohen, Eduardo Chávez Ramírez, Guillermo González Cervantes, Jean Pierre Vandervaere and Luc Decroix Jambon* reinforce the hypothesis that groundcover affects hydrological variables. Using the *Suction Disc Infiltrometer* method they study the impact of land-use changes in the surface hydrodynamics of a water receiving basin in the higher Nazas River. The authors quantify water infiltration in well-preserved forest surfaces and compare it to surfaces degraded by deforestation and over-grazing. They argue that changing forest areas into agricultural lands degrades soils in a context where reforestation should prevent deforestation in the hydrological basin instead.

Eduardo Chávez Ramírez, *Guillermo González Cervantes* and *Alejandro López Dzul* in chapter 13 analyse the evapotranspiration in the lower and medium basin of the Nazas River, obtaining important findings for the region. Their work is based on automated capturing of climatic information in order to use it in real-time forecasts for irrigation processes. Their studies have allowed them to get to know the real water demands of crops as walnuts and fodder crops such as alfalfa. With this information it has been possible to plan optimal irrigation times and amounts, congruent with the location in the basin and with weather conditions.

1.4.3 Part III: Water Quality, Pollution and Health

The third part (chapters 14 to 22) deals with water pollution and its repercussions for human and environmental health. The problems derived from water quality are many and some of them are quite alarming. Human health problems derived from the consumption of water of poor quality have been widely documented; nevertheless, today, the main cause of death is polluted water, especially in young infants. Sources of water pollution and their special and temporal variation are the topic of multiple studies across Mexico. Particularly relevant have been anthropogenic factors given that most causes linked to changing water quality have to do with human actions. This is the case observed in national ground and surface water resources, but also in an over-exploitation of aquifers, where dissolved mineral compounds are important limits of water quality standards. Furthermore, polluted water chronically affects the health of users, given that it is often their only water source. In this part, researchers present results linked to geochemical weathering, management of chemical waste, disposal of organic pesticides in agriculture, breaches of the law, and the overall need to establish an efficient official law in this regard.

In chapter 14, *Juana Enriqueta Cortés Muñoz* and *César Guillermo Calderón Mólgora* review a wide range of pathogen microorganisms and chemical polluters that may be present in wastewater and in solid waste. The knowledge of these contaminants (some are regulated and some are known to be emergent) and their impact on water reuse programmes is mixed. When water is recycled as potable water or used to recharge an aquifer via agricultural lands there are four important challenges to bear in mind:

a.) determining the exact concentration of organic compounds, especially emerging or non-regulated ones;
b.) identifying opportunistic and pathogen microorganisms in various taxa;
c.) establishing an efficient and cheap water potabilization treatment system;
d.) preventing possible impacts that post-potabilization residues might have on public health and the environment. The authors suggest a sanitary risk approach in order to determine the various alternatives ways of treating wastewater and reusing it.

Anne M. Hansen and *Carlos Corzo Juárez* summarize in chapter 15 water politics: having enough quality water, recognizing the water's strategic value, efficient water use, protecting water bodies, and guaranteeing sustainable development and environmental conservation (PNH 2007–2012, 2007). They emphasize needs and priorities for evaluating pollution in water basins, with specific reference to Mexican politics, norms and laws regarding water management. The authors insist that there are no programmes to monitor *persistent bioaccumulative toxic substances* (PBTS) and thus there are no inventories or formal evaluations regarding risk and exposure to these substances. Their work puts forward a methodological tool for selecting substances in a PBTS monitoring programme.

Water quality destined for human consumption in the state of Aguascalientes has been severely affected. Thus, *Francisco Javier Avelar, Elsa Marcela Ramírez López, Ma. Consolación Martínez Saldaña, Alma Lilián Guerrero Barrera, Fernando Jaramillo Juárez* and *José Luis Reyes Sánchez* in chapter 16 present the results of the systematic characterization of ground

and surface water in Aguascalientes. They correlate the findings of micro-biological and physico-chemical studies of water quality for human consumption with the health problems of the population. They observe various pathologies in exposed populations, including early kidney damage in children.

In chapter 17, *Laura Arreola Mendoza, Luz María del Razo Jiménez, Oliver Barsbier, M. Consolación Martínez Saldaña, Francisco Javier Avelar González, Fernando Jaramillo Juárez* and *José Luis Reyes Sánchez* also find that water destined for human consumption in the State of Aguascalientes contains high levels of lead, cadmium, arsenic, fluorides, and other minerals exceeding limits established by the Mexican Official Standard (NOM) relating to water. Children are an especially vulnerable group, developing chronic renal diseases leading to hospitalization, medical treatment, dialysis and kidney transplants. Given this scenario of health deterioration and renal illness the authors suggest preventive measures to reduce levels of toxic minerals in waters destined for human consumption. In general, this implies reducing the over-exploitation of aquifers and purifying water destined for human consumption, paying particular attention to children.

In the Yucatan Peninsula, *Julia Pacheco Ávila, Armando Cabrera Sansores, Mercy Pacheco Perera, Manuel Barceló Quintal* and *Ligia Alcocer Can* establish in chapter 18 a protocol for measuring cadmium in groundwater. Their conclusions are geared to assessing the efficiency of the model they put forward and the results appear to be reliable. According to their findings, the highest concentrations of cadmium are found in the north-east, the east and the coast of Yucatan. This contamination can be due to agricultural farms or to the use of phosphate fertilizers with high levels of cadmium, as well as to open dumps that contain cadmium residues in porous lands where infiltration is possible.

In chapter 19, *Catherine Mathuriau, Norman Mercado Silva, John Lyons* and *Luis Manuel Martínez Rivera* use fish and macroinvertebrates as bioindicators to assess the quality of aquatic ecosystems in Mexico. They present the state of the art and analyse different perspectives. Their work has focused on studying the structure and composition of aquatic communities in five micro-basins located in the tropical dry forest in the Chamela-Cuixmala biosphere reserve. The authors highlight the importance of pools originating from rainfall in the Chamela basin for the biota. The main findings of this study relate to the description of aquatic communities and the preservation of the conditions best suited for their existence.

Salvador Israel de la Garza González and *Raúl Herrera Mendoza* describe in chapter 20 the types of pollution found in the aquifers of the semi-arid regions in the north-east of Mexico. They map the zones of domestic and industrial pollution, according to the permeability, porosity and depth of the soil. Filtration of hydrocarbons occurs at depths of 2 to 12 metres. They also propose a model of bioremediation of contaminated soils and aquifers in order to bring pollution levels below the limits established by Official Standard NOM-138.

Ramiro Vallejo Rodríguez and *Alberto López López* make in chapter 21 an exhaustive study and present the techniques of identification and analysis of *endocrine disrupting compounds* (EDC) and their degradation through *advanced oxidation processes* (AOP). According to their work, AOP-O_3 promises to be one of the most suitable technologies not only for treating surface water with EDCs such as hormones and chemicals, but also for all kinds of effluents of industrial origin with low biodegradable compounds.

In chapter 22 *Linda González Gutiérrez* and *Eleazar Escamilla Silva* present a study of the biodegradation of a reactive azo red dye from the textile industry in an upflow anaerobic bioreactor with axial dispersion. The results show concentration profiles in the entire reactor and in the bioparticle at distinct concentrations of the dye and at different residence time values; they show a quick saturation and the rapid reaching of equilibrium, and they predict a lower removal when dye concentrations are increased, given that the degradation of the azo dye in this process is abiotic-biotic.

1.4.4 Part IV: Social Effects, Conflicts and Hydrodiplomacy

The fourth part (chapters 23 to 28) of the book addresses the interrelationship between social effects, conflicts, negotiation and strategic planning, in order to augment water availability and deliver quality water for all. For the northern frontier region, complex links between climate change and water scarcity may be observed that are exacerbated by demographic pressure and rising water demand from the agricultural, industrial, service and domestic sectors. Although this region generates a quarter of Mexico's GDP, agriculture consumes 87 per cent of water supply, and it is precisely virtual water exports through the sale of commercial crops that strongly impact on

natural and scarce resources, as this is an arid and semi-arid region of Mexico. The coast of Sonora already shows processes of saline intrusion into the aquifers; together with a lack of adequate water and electricity tariffs that reflect real costs and scarcity, this situation will further exacerbate a fragile equilibrium that privileges select groups and might increase existing conflicts. In the central and southern region, new models of integrated water management are proposed, emphasizing social participation. Unfortunately, resistance from the authorities and the interests of a bourgeoisie that is used to over-consumption prevent the emergence of a rational ecological economy that could pave the way for a new water culture. Instead, corruptible authorities and actors with special interests in water resources have led to increasing poverty, scarcity and inequality.

Part IV starts with chapter 23 by *Úrsula Oswald Spring* relating water security and its links to other security concepts such as health and food security. Water scarcity, pollution and a major pressure on water resources have caused an increasing number of water-related conflicts. The author proposes a hydrodiplomacy model where parties in dispute negotiate technical alternatives within an integrated water management process that encompasses all levels, from the household to the basin. Through a peaceful process of conflict negotiation, the parties involved resolve their differences, save water and become actively involved in a water management culture based on human rights and sustainable and rational water use, with the goal of guaranteeing the survival and water governance of everyone, leading to sustainable development.

In chapter 24, *Vicente Germán Soto* and *José Luis Escobedo Sagaz* evaluate information collected by the *International Commission of Limits and Water* (ICLW; CILA in Spanish) about average water flow in twelve measuring points located throughout the Bravo River from 1933 to 2005. Following regression analysis, the authors indicate that both nations have respected international agreements relating to water use. This reflects the fact that variations in water flow correspond with modifications to the agreements, construction of hydraulic infrastructure and times of drought. With this analysis, the authors show that water flows were stable and international agreements have been respected.

In chapter 25, *Antonina Galván Fernández* analyses the productivity of coastal lagoons, which are a product of a mixture of sweet water – from hydrological basins – and salt water from the sea which have gained an entrance because of changing tides. The author studies the basin in the coastal lagoon of Carretas-Pereyra on the coast of Chiapas. These are highly productive areas that generate subsistence and income to the population living on the shore. Also, they constitute natural systems that rapidly degrade due to the silt and low circulation together with non-natural sediments coming from the basin.

Claudia Rocío González Pérez and *Antonina Galván Fernández* develop in chapter 26 a social intervention in order to generate a culture of sustainability and resilience in the face of hydro-meteorological emergencies. Dengue and gastrointestinal illnesses are caused by rising temperatures and changing rainfall patterns. A community in Pijijiapan in Chiapas designed prevention strategies. Also, the community optimized water management, maintenance of the water infrastructure and sanitation of water collection points, and its inhabitants became aware of the importance of keeping water clean. Nevertheless, in order to improve community health, work still needs to be done on productive processes, livestock and pen cleaning, overall sanitation and sanitation of water discharges.

David Barkin documents urban water management research in Mexico in chapter 27. The author highlights the water authorities' incapacity to guarantee an adequate and accessible urban water service, as well as the lack of protection of the ecosystems on which the water supply depends. Also, there is resistance to enabling social participation in terms of water management and oversight of public services, especially in Mexico City. In the theoretical framework of a 'New Water Culture' and an 'Environmental or Sustainable Economy', the author concludes that these problems are part of a strategy to put water in the hands of the elites and of international companies, even if the most pressing social needs are unmet; this generates social conflicts and environmental problems.

Jorge Morales Novelo and *Lilia Rodríguez Tapia* analyse in chapter 28 water scarcity in the *Metropolitan Area of the Valley of Mexico* (MAVM). They conduct a historical review of the evolution and gravity of scarcity, focusing their research not only on water management in the aquifers of the Valley of Mexico, but also on the Lerma and Cutzamala basins. Given current consumption patterns, the capital and its suburban areas will not have enough water to satisfy demand by the year 2025. This calls for a new water policy, based on efficient water use, modifying water consumption patterns, using new technologies, and

changing the current water administration rationale and water costs, as well as transforming the prevalent water culture to one where all users participate equally.

1.4.5 Part V: Public Policy, Institutions and Legal Aspects

Part V (chapters 29–33) is dedicated to exploring public policy and existing institutions that deal with water, and to assessing their performance. Past and present legal aspects, together with norms and standards relating to water, have undergone changes due to population growth and a more sustainable management of natural resources. A hierarchical administration with authoritarian elements prevails, hindering civil participation. Thus, this section also contributes to the provision of technical and organizational support to municipal water operating systems. It is the staff of these operating systems who try to comply with regulations and services regardless of the lack of resources, obsolete and dysfunctional facilities, debtors, and pressure by federal and state authorities.

A crucial topic is diffuse agricultural pollution and points of discharge relating to livestock, where a lack of legislation and breaches of existing agreements damage existing resources. Also, in arid and extremely arid zones, water is extracted exclusively from aquifers that are in the process of exhaustion. Existing laws have given priority to surface water, relegating the integrated management of aquifers in their relation to surface water, groundcover, productive processes and contamination. In the face of global climate change, groundwater reserves have become increasingly important. Furthermore, most operating systems in the country are supplied by groundwaters, and it is therefore crucial to work within an integrated management of aquifers, including prevention strategies and a rational price for water use.

New management of water resources calls for new methods of civil participation. Thus, the RETAC team has sought to integrate different actors in a basin management project, where geohydrological, flow and groundcover aspects combine with agricultural, domestic and industrial use factors, especially as rivers have become sewage conduits. Participative processes have been hindered by existing laws and government practices, where special interests have impeded the conservation and recuperation of microbasins and a sustainable use of natural resources. However, budgetary limitations and political timing have also truncated well-designed projects. In order to overcome these limitations, master plans are proposed, designed in such a way as to overcome political timing constraints and to leave projects in the hands of organized civil society. Thus, government and private resources can be linked to resources from citizens and other sources, always within the framework of joint projects. Also, an ongoing monitoring of projects is crucial to avoid mistrust and misunderstandings and to stimulate civil participation. With time, it also limits corruption by protecting scarce resources.

Arsenio Ernesto González Reynoso and *Itzkuauhtli Zamora Sáenz* present in chapter 29 a master plan for the management of the River Magdalena in Mexico City, which includes the restoration and rehabilitation of the basin, environmental and water works, and cultural aspects, as well as the political, social and economic participation of all the actors that live along the basin of the river. Through transverse, interdisciplinary and intersectorial processes, an integrated diagnosis is achieved, conciliating the interests of divergent social classes and designing a flexible and adaptable plan in order to promote public works and generate an environmental culture. However, current participation structures are insufficient given that interests, representation and aspirations force the identification of social actors and entail the need to delimit the space and process as negotiated and not as 'natural'. Also, the rehabilitation of water bodies needs a socially feasible model, where future obstacles are foreseen, and the coordination and cooperation between relevant government offices is guaranteed.

In chapter 30, *Alejandra Martín Domínguez, Víctor Javier Bourguett Ortiz, Flor Virginia Cruz Gutiérrez, Miguel Ángel Mejía González, Juan Maldonado Silvestre, Gustavo Armando Ortíz Rendón, Petronilo Cortés Mejía, Arturo González Herrera, Martín Piña Soberanis, María de Lourdes Rivera Huerta, Leticia Montellano Palacios, Víctor Hugo Alcocer Yamanaka, Carlos Eduardo Mariano Romero* and *Velitchko Georguiev Tzatchkov* evaluate water operating organizations in a valley located in the Central Plateau of Mexico. Through a diagnosis of water supply sources and of water demand, of the operation of purification units, the water quality laboratory, and the commercial and accountable system of the operating organizations, as well as the analysis of alternative sources of water supply for the city and suburban zones, the authors elaborate an action plan that is also useful for other regions in the country. It addresses issues such as poor water availability and poor water quality supply sources, the rapid deterioration of water infrastructure that prevents efficient water extrac-

tion, and the outdated tariff system that does not even cover operational costs and limits access to the financial resources necessary for efficient operation of the system.

Rosario Pérez Espejo discusses in chapter 31 problems presented by the design of agro- environmental policies for controlling water pollution. She presents the preliminary results of a study undertaken in Irrigation District 011 in the state of Guanajuato, where the main goal was to collect and analyse information for decision-making. She discusses the role of agriculture in degradation processes from an economic perspective, and reviews the implications of agricultural waste in the politics of different sectors. The author highlights the need to design consensual policies, and to integrate the interests of various stakeholders in irrigation and water resources with environmental concerns to keep a balance between the ecosystem and individual and social well-being.

Nicolás Pineda Pablos and *Alejandro Salazar Adams* analyse in chapter 32 water scarcity in arid and desert zones of the north of Mexico and the southwest of the USA that have been affected by climate change. As population and groups in urban centres increase, appropriate institutions are required to manage water efficiently, thus contributing to the quality of life and to social and environmental sustainability. Existing norms, procedures, and traditional 'uses and customs' limit sustainable water-related behaviour in daily activities, agriculture, livestock and industry. Instead, the authors propose decentralizing levels of autonomy, social participation, assigning responsibilities and self-management, as well as responsible payment, efficient market schemes to determine water quantity and quality *per capita*, and measured volumes of water discharges.

Finally, in chapter 33 *Judith Domínguez Serrano* summarizes a study of the institutional, legal and social changes necessary in Mexico to reach effective water governance after the reform of the *National Water Law* (NWL; LAN in Spanish) in 2004, particularly in the Hydrological and Administrative Region X of the Central Gulf. This area is one of the most polluted regions in Mexico, with important federal funding and yet poor coverage of water services, where the most marginal areas are still lacking potable water and sewage facilities. Besides this, the creation of infrastructure has impeded the development of local capacities and the emergence of responsible authorities and social actors in charge of water management. Even wastewater treatment plants cannot stop pollution as they lack well-trained operators. These old problems relating to water pollution and the lack of infrastructure could be resolved through water governance based on social actors, promoting greater participation, institutional changes and legal reforms.

1.4.6 Concluding Remarks

In her concluding remarks, Úrsula Oswald Spring offers a synthesis of the proposals that were put forward at the First Meeting of the *Scientific Network of Water* (RETAC) in Cocoyoc, Morelos (Mexico) in January 2009. It is noteworthy to see the complex and contradictory – at times even chaotic – interrelationship between the factors of the environmental (air, biodiversity, soil and water) and the social quartets (population growth, rural and urban systems, socioproductive processes). Among the topics that have been insufficiently covered in water research are scant comparative research and methodologies relating to pollution and their repercussions for human health, epidemiological outbreaks and their environmental impacts. The scarcity of surface and groundwater, exacerbated by global climate change, must be assessed in all its details, accounting for health repercussions and environmental degradation as well as for resilience and adaptation mechanisms. Adequate technologies generated in Mexico, an efficient water administration, and socially negotiated water tariffs that cover water management costs and protect the most vulnerable groups could be among the first steps towards a new water culture. Integrating institutions, multidisciplinary research and social participation in water management would create mechanisms to reduce environmental conflicts and guarantee good water quality for all, without generating environmental conflicts or affecting public financial resources. The privatization of water management has been unable to solve the problems of infrastructure and of unequal access to water. Therefore, different norms and laws are necessary to optimize the convergence of public, private and social resources and interests.

Climate change and more severe hydro-meteorological events and their consequences for drylands and agricultural production require changes in productive processes. Systems of water saving and 'every-drop-efficiency' in terms of virtual water require, among other things, the introduction of technological packages such as plastic mulching, micro-irrigation, micro-tunnels, the reuse of agricultural by-products, and the use of biofertilizers and of probes to monitor soil humidity and to identify suitable irrigation times for each crop. Nevertheless, the introduction of these technologies and

the subsequent improvement of the quality of life of peasants are hindered by the prevailing culture of producers, characterized by distrust of the government, corruption, and outdated traditional attitudes.

For an integrated water management the transformation of sanitation policies is crucial, especially at the end of the pipe, in order to avoid pollution and to generate clean processes. Chaotic urban development and the abandonment of a sustainable rural politics call for a territorial ordering and an environmental management, benefiting all parties directly involved. It is also necessary to develop legal and financial tools in order to quantify and pay for environmental services generated at all levels of the basin. In order to reach food sovereignty in the future, in a time of mounting uncertainty, it is important to understand the interaction between water, soils, agricultural production, food, prices, subsidies and hunger, in order to prevent complex social emergencies such as high-risk survival conditions, forced environmental migrations, famine, and escalation into violence. Without any doubt, water management is a highly complex issue. It calls for governments, society and businesses to negotiate an integrated development, where sustainable peace prevails (Oswald Spring, 2008; 2005), where conflicts are resolved using models of hydrodiplomacy and of water peace, and where an integrated water culture will lead to a more sustainable and less uncertain future, both in environmental and social terms.

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