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Authors

Ortiz-Partida, J. Pablo
Sandoval-Solis, S.
Arellano González, Jesús
et al.

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Managing water differently: Integrated Water Resources Management as a framework for adaptation to climate change in Mexico

White Paper for the Environmental Working Group of the UC-Mexico Initiative

J. Pablo Ortiz-Partida [1], S. Sandoval-Solis [1], Jesús Arellano González[1], Josué Medellín-Azuara[1], J. Edward Taylor[1]
1. University of California, Davis

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Abstract

Climate change is expected to impact water availability and its management, with more frequent and extended droughts, more severe floods, and lower water quality. Water allocation policies, regulations and infrastructure in Mexico were not designed for changing future climate conditions. This document reviews the implications of climate change in water resources systems in Mexico, and evaluates how management strategies from California can serve as potential adaptation schemes towards an Integrated Water Resources Management framework in Mexico.

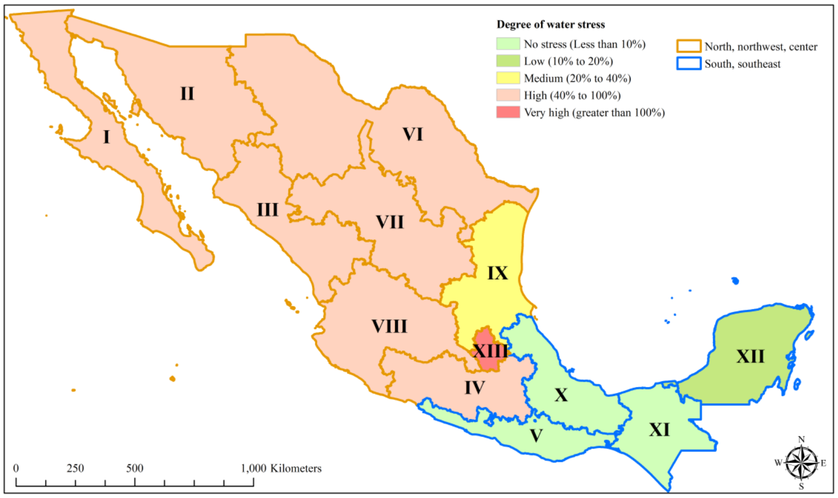
Introduction

In Mexico, reduction on water availability as consequence of climate change not only compromises water reliability for industries and agriculture, but also augments the challenge to provide the most basic human right, drinking water. The understanding of the magnitude and extent to which human and natural systems will be affected by climate change is critical to better design policies that prepares for effective adaptation. According to the Intergovernmental Panel on Climate Change (IPCC), rising temperatures are expected to reduce renewable surface water and groundwater resources, vital inputs for people, agriculture, industry, and aquatic and riparian ecosystems (IPCC, 2014). As a result, Mexico is expected to experience major impacts on water availability and supply, compromising food security, infrastructure, and agriculture income. In this context, Integrated Water Resources Management (IWRM) is a powerful and important framework to examine adaptation to climate change. IWRM is defined as “a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (Global Water Partnership, 2000).

In addition, changes on climate patterns are expected to increase drought years, having particular impacts on agriculture; and at the same time intensify rain events, augmenting flood risks in certain areas (Herrera-Pantoja & Hiscock, 2015). Mexico is already facing other water problem expected to aggravate as the changes on climate occur. The Water Advisory Council (CCA, 2016) using data from the National Water Commission of Mexico (CONAGUA) noted a series of facts to be considered for improving the current situation and prepare for the upcoming water issues: (1) 22.7 % of surface water is heavily contaminated; (2) national potable water and sewage coverage are 91.6% and 90.2% respectively; (3) 77% of water is used by agriculture; (4) conveyance and distribution of water have an efficiency of 86% and 76% respectively; (5) 16.2% of aquifers are under overdraft conditions; (6) about 40% of urban water is lost through system leaks; and (7) less than 50% of waste waters are treated.

México has an extensive territory with varied climatic conditions where water availability does not match with water demands. The two thirds of the territory with the highest economic development (north, northwest, center Mexico) is also the area that displays the lowest mean annual precipitation (Figure 1) (CONAGUA, 2015). This spatial and temporal distribution of water resources represents different challenges for different areas. The most contrasting examples are the Baja California Peninsula which on average receives 168mm of precipitation, while in the south east, in the area of Tabasco and Chiapas, the normal precipitation is around 1,842mm. Between these extremes, there is a spatial distribution of available water resources in the country, and each particular area requires its own analysis and solutions (CONAGUA, 2015).

With the purpose of water management and preservation of Mexico’s water resources, CONAGUA designated 13 Hydrological-Administrative Regions (HARs) (Figure 1).



HAR Code	Name	HAR Code	Name
I	Península de Baja California	VIII	Lerma-Santiago-Pacífico
II	Noroeste	IX	Golfo Norte
III	Pacífico Norte	X	Golfo Centro
IV	Balsas	XI	Frontera Sur
V	Pacífico Sur	XII	Península de Yucatán
VI	Río Bravo	XIII	Aguas del Valle de México
VII	Cuencas Centrales del Norte		

Figure 1 Hydrologic Administrative Regions and water-stress in Mexico, adapted from (CONAGUA, 2015)

The HAR with less renewable water resources (XIII) is the second most populated (as it includes Mexico City), consequently having the lowest per capita renewable water in the country (

Table 1) and is catalogued as an area of very high water stress. A situation of water stress arises when the percentage of water diversion is above 10% of the annual renewable water resources. The degree of water stress varies as this ratio increases; above 40% is considered as a high water stress, and above 100% it is catalogued as a very high water stress. Eight of the 13 HARs are at or above the high water stress classification, one on medium, two on low, and only another two are not under stress (Figure 1) (CONAGUA, 2015). Under those conditions, demands are met by excessive groundwater extractions that generates overdraft on the aquifers (more extracted water than recharge). In Mexico, 15% of aquifers are overdrafted (CONAGUA, 2015). Groundwater overdraft brings complications, such as sea water intrusion in coastal zones, land subsidence, infrastructure damage, and depletion of water supply resources during drought periods.

There is a big paradigm in some of the largest cities of Mexico, particularly in Mexico City. The large impermeable extent of the city makes it hard for the already overdraft aquifers to recharge. The constant land subsidence (5 to 10cm/year) due to excessive groundwater extraction reduces storage capacity and damage sewages and water supply systems (among other infrastructure). Water infrastructure is in such bad conditions that 40% of potable water is estimated to be lost before reaching its destination (De la Peña, Ducci, & Zamora, 2013). The conveyance systems for waste water are insufficient and inefficient; only about 30% of waste water from Mexico City is currently treated (60% once the Atotonilco Waste Water Treatment Plant Project is finished) (De la Peña et al., 2013).

Table 1 Water availability by Hydrologic Administrative Region

HAR	Normal Precipitation from 1971 to 2000 (mm/yr)	Renewable water resources (mcm/yr)	Total mean natural surface runoff (mcm/yr)	Total mean aquifer recharge (mcm/yr)	2015 population (millions)	Per capita renewable water resources (m^3/person/yr)
I	169	4,681.7	3,244.3	1,437.4	4.37	1,271.2
II	445	8,226.7	5,201.4	3,025.3	2.80	3,168.1
III	747	25,422.6	22,386.8	3,036.0	4.47	6,197.6
IV	963	24,276.1	19,665.0	4,611.8	11.69	2,251.5
V	1187	32,492.0	30,730.3	1,761.7	5.02	7,473.3
VI	438	12,796.5	7,357.7	5,438.8	12.15	1,176.7
VII	430	7,620.3	5,357.9	2,262.4	4.52	1,829.9
VIII	816	35,680.7	27,524.8	8,155.8	23.89	1,680.8
IX	914	25,562.8	23,543.4	2,019.6	5.23	5,109.3
X	1558	98,301.5	94,213.4	4,088.1	10.48	10,047.3
XI	1846	157,743.9	138,541.8	19,202.2	7.57	23,519.5
XII	1218	29,338.6	4,036.8	25,302.0	4.52	7,473.3

XIII	606	3,535.8	1,432.5	2,103.4	23.01	165.3
National	872	465,679.1	383,235.6	82,443.7	119.71	4,285.4

Source: Statistics on Water in Mexico reports from their first edition on 2003 to 2015
mcm = million cubic meters.

Most of the consumptive water use in the country (77%) is for agriculture (CONAGUA, 2015). Therefore, changes in water supply from climate change need to have a special focus on the possible effects in agricultural systems to develop adaptation strategies.

In the Pacífico Norte HAR (mainly the state of Sinaloa), agriculture is the main economic sector and represents the largest agriculture industry for Mexico. This region produces not only the breadbasket for Mexico, but also exports fruits and vegetables to the United States. This region has a high irrigation efficiency, however this is not a common patter; a large share of the irrigation systems in Mexico are still surface irrigation systems (wild flood and furrow). An important amount of water used in these surface irrigation systems does not benefit the crops; instead, it is loss due to evaporation and infiltration to aquifer recharge. Water lost in infiltration can be recovered by pumping; however, more energy is needed to recover this water.

The remaining uses are urban with 14 % (domestic and municipal) and industrial with 9% (including hydropower). Urban water use requires a constant water supply throughout the year. Naturally, there is temporal water availability, resulting in a mismatch of water supply and water demand for this use. Typically, large cities, e.g. Mexico City, Guadalajara, and Monterrey, meet their water demand through water imports from other basins (Cutzamala, Lerma-Chapala, and Cerro Prieto). As a result, the large use and sustainability of water resources is threatened by urban water demands importing water from neighbor basins.

Since the beginning of the 20’Th century, the model to meet increasing water demands across the country is mainly focused on infrastructure development: reservoirs, diversion channels, extraction wells, and water delivery systems. As consequence, there has been a continued degradation of ecosystems as the environmental and social impacts of some of these projects divert or altered natural flow patterns intensively and through extensive regions (i.e. reservoirs that flood thousands of hectares). Environmental protection has been focused in specific portions of rivers and mangroves. However, protection throughout rivers is not present or enforced. River fragmentation has happened and will continue happening in the form of construction of large reservoirs and infrastructure (canals and irrigated land). Typically environmental protection and economic development has been seen as opposed activities, nonetheless, novel techniques have proven the contrary, and it is possible to promote economic development while conserving or restoring aquatic and riparian ecosystems (Ortiz-Partida, Lane, & Sandoval-Solis, 2016).

Water quality also raises concern related to human health and the conditions of aquatic and riparian ecosystems. In spite of regulation that forbids discharge of raw water into rivers (CONAGUA, 2016), unfortunately, this practice still exists. Problems are not only related to the organic content in water (BOD and coliforms) but also to other water quality parameters that are above the limits for human consumption.

Water problems in Mexico are very diverse, and thus need to be addressed considering a variety of adaptation strategies. This paper identifies some of the human welfare implications from climate change in Mexico, and a series of adaptation strategies that would be applicable to transition from the current situation towards an IWRM.

Human welfare implications

Individual water problems lead to different human welfare implications. Human welfare is compromised when there are negative aspects on the general condition of a population in terms of diet, housing, healthcare, or education. According to CONAGUA (2015), about 92% of the population has access to potable water, however, in Mexico, potable water is not synonym of drinking water. Under "drinking" water coverage, CONAGUA (2015) considers "all those who have tap water in their household, outside their household, but within their grounds, from a public tap or from another household". However, this definition does not specify if the water has to be indeed drinkable. Even under that percentage, considering a population of almost 120 million, it means that almost 10 million people doesn't have access to tap water (drinkable or not) not even from their neighbors. Climate change is expected to increase the number of people without access to drinking water given the reduced water supply and the impacts on water quality that facilitates conditions for water-borne diseases.

The agricultural sector will also be highly affected by climate change due to an increment on crop water demand, droughts, water scarcity and changing climate conditions. Given the increase in temperature, more water will be needed to meet crop evapotranspiration requirements. This condition will put agriculture at a higher risk because droughts are expected to be more severe and frequent, affecting the water availability for the agriculture. Population growth will reduce or limit water availability for agriculture. In addition, changing climate conditions can bring new diseases to crops not present before. Farmers, ranchers and farmworkers are usually in the lower quartiles for annual income. Climate change will put at risk this economically disadvantaged communities and the economic viability of corporations and family companies, exacerbating the economic vulnerability of these groups.

Floods are expected to be more frequent and severe. Furthermore, floods will happen in locations where they did not use to occur. Population will be at higher risk of floods, greater likelihood of losing life in places where water reclaims its floodplains, as well as losing family assets such as homes and other material valuables. Large infrastructure will be compromised, demanding more investment or a change in policy such as incentivizing local infrastructure for water detention and recharge.

Poor land management, such as deforestation can impact the quantity and quality of water sources putting at risk people and the ecosystems. Without the protection of water sources, such as forest, springs, rivers, lagoons, and aquifers, water quality is expected to decrease for the population and the environment. These conditions will be exacerbated by climate change, due to a higher likelihood of forest fires and severe and frequent droughts affecting the viability of forests. Communities depending on local water sources will be at risk of having a reduction or no water available to meet their needs. In addition, raw water will continue to be discharged in rivers, affecting the ecosystems and the populations that rely on these resources at downstream areas. Water scarcity will be translated into less or no water in rivers for sustaining aquatic and riparian ecosystem, as well as less water for dilution of contaminants. Rivers will be fragmented by infrastructure, such as dams, for harvesting water as much as needed to meet human requirements. However, this will come at a high price for environmental degradation and/or extinction of certain species.

Binational context

Increasing water demands and reduction of water supply are some consequences of climate change that create new challenges for international treaty compliance. Mexico has eight transboundary watersheds, three in the northern border with United States, and five in the southern border with Guatemala and Belize. The Convention of 1906 and the Water Treaty of 1944 between U.S. and Mexico determine how water is allocated within the two countries. However, there are no transboundary policy tools among Mexico, Guatemala, and Belize.

The Convention of 1906 purpose was to stablish an equitable distribution of the Rio Grande water for irrigation purposes. Through this agreement, U.S. shall deliver to Mexico a total of 74 million cubic meters [mcm] (60,000 acre-feet) per year. Such water is distributed throughout the year according to a stablished schedule and accounted for at the point of the Acequia Madre canal, north of Ciudad Juarez (IBWC, 1906). In this areas, rising temperatures will reduce water availability, augmenting the probability to impact water deliveries to Mexico. This negative impact is aggravated by the constant overdraft conditions in the Hueco-Mesilla Bolson aquifer that supplies drinking water to almost two million people in both sides of the border.

The Water Treaty of 1944 establishes the water allocation for the Rio Grande/Bravo, Colorado, and Tijuana rivers. The Treaty also changed the International Boundary Commission (IBC) to the International Boundary and Water Commission (IBWC) as a binational entity to solve issues related to water quantity, water quality, flood management, and the international boundary. Originally, the Treaty did not include aspects related to groundwater, water quality, or water for environmental purposes; however, these last two issues have been addressed through Minutes, which were developed by the IBWC to address issues regarding the implementation of the Treaty (IBWC, 1944). Groundwater hasn’t been addressed by any U.S.-Mexico water agreements and may become an important element to climate change adaptation (Carter, Ribando Seelke, & Sheed, 2015).

Minutes have been developed since the completion of the agreement to address changing water conditions within the terms of the Treaty. A demonstrative example of collaboration is Minute 319: Water Conservation and Environmental Protection. The Minute was designed to provide pulse flows and base flow for the restoration of the Colorado River Delta. This Minute required a lot of effort and cooperation of scientific experts from universities and environmental and government agencies from both countries (IBWC, 2012). Conjunctive actions are a key element for an effective application of adaptation strategies across the border.

Theoretical framework

A bottom-up approach with an IWRM framework is suggested to address the challenges that climate change imposes on water resources in Mexico. A bottom-up approach means that stakeholders provide feedback for water resources planning at the local level, and authorities are in charge of putting together the feedback of many stakeholder groups from different local regions into a comprehensive basin-wide plan (Loucks, Van Beek, Stedinger, Dijkman, & Villars, 2005). An IWRM framework is a process recommended as a way to manage all water sources (river, lagoons aquifer, spring, recycled water, etc.) and all water demands to meet urban, industrial, agriculture, and environmental needs while maximizing economic and social welfare, and the sustainability of ecosystems. This framework must be flexible, adaptable and responsive to needs at the local, regional and basin level. Shared vision planning is also recommended as a way to show the needs of other competing users during the planning and execution process. This can help to achieve water security in a sustainable manner.

IWRM covers a portfolio of strategies that incorporates different disciplines to holistically manage water resources for improving water supply reliability while protecting the environmental integrity of the basin (Table 2). California has implemented actions from a comprehensive water portfolio and many experiences from California can be used to help Mexico to improve water supply reliability and prevent some of the environmental problems expected to be exacerbated with future climate change.

Table 2 Integrated Water Resources Management Portfolio

Objectives	Activities/Strategies
Reduce water demands	Improve agricultural and urban water use efficiency with a constraint on water right extractions, change to crops with less water demand, reduction in cropping area.
Improve operational efficiencies and transfers	System's reoperations, build or modify infrastructure, and stablish water transfers.
Increase water supply	Conjunctive management of surface and groundwater, desalination, recycled water, increased groundwater recharge.
Improve water quality	Drinking water treatment and distribution, groundwater remediation, pollution prevention, waste water treatment, urban runoff management.
Responsible planning and management of resources (stewardship)	Economic incentives, ecosystem restoration, coordinated land use planning and water resources management, educational and recreational activities.
Improve flood management	Design resilient flood protection systems, integrated water supply and flood protection management, forecast informed reservoir operations.
Increase support and integration activities to reduce uncertainty	Regional water planning, improve data and tools, develop research and sciences.

Some strategies have proven to be successful, and others need more time before having results or further research for its application. Successful strategies include reservoir re-operations, groundwater banking, use of recycled water, conjunctive use of surface water and groundwater, coordinated water extractions for frost protection, and so on. For instance, in Pajaro Valley, the Pajaro Valley Water Management Agency implemented a groundwater management plan that considered water conservation, expansion and new infrastructure, as well as tier water prices. These strategies were proposed, discussed, analyzed and approved in a decision making process that followed a bottom up approach (PVWMA, 2013). The decision making process ended with a planning document that specified funding, implementation, and strategies for reducing sea water intrusion, many of these strategies are now under execution. Specifically, the implementation of the water conservation strategy has reduced groundwater overdraft. In contrast, some projects developed in California are controversial for their environmental implications, such as the State Water Project (SWP) and the Central Valley Project (CVP). The SWP moves water from water abundant regions (the Feather River of the Sierra Nevada) to water scarce regions (the west side of the San Joaquin Valley, the central coast and southern of California). This project is controversial because it has affected the aquatic ecosystem of the Sacramento-San Joaquin Delta by reversing the flows when water is moved from the Sacramento to Southern California through pumps and aqueducts. In addition, it made dependent southern California of water from the north, and more vulnerable to droughts happening in the north part of California. The SWP has also created a sentiment of resentment between people of the north who sees “their” water moved to the south, and people from southern California defending and securing “their” water resources in the north.

Policy responses and challenges

At a national level, important laws have been developed to protect and restore water resources in Mexico. Such is the case of the General Law of Ecological Balance and Environmental Protection (LGEEPA, 2012) and the National Water Law (LAN, 2016) stablished in 1988 and 1992 respectively. For climate change, the General Law for Climate Change (LGCC, 2015) stablished in 2012 provides the framework for policies related to this issue. Other programs are developed at the beginning of each government administration, the National Water Program, the National Development Plan, and the National Infrastructure Program (CONAGUA, 2014; PND, 2013; PNI, 2014).

However, there are challenges associated with the legal and institutional framework described above. First, there is a lack of execution and enforcement of the regulations mentioned above: it exists but there is almost no enforcement in its application. Second, there is a lack of continuity in of such policies, at the beginning of each presidential term, a series of plans are developed, and then, dismantled or redesigned all over again in the next presidential term. Thus there is a lack of long term planning as each administration last six years.

In terms of research, there are highly qualified scientist doing research in climate change and water resources, however, there is still a need for more applied research that can solve on the ground problems. In addition, there is no bridge between science (scientist) and policy design (decision makers). Scientific projects may be funded but developed in vacuum without decision maker’s feedback, and vice versa. Decisions are not made based on scientific results frequently funded and encouraged by policy makers themselves. This is a chronic and systematic problem that has delayed or prevented the selection and implementation of scientific-supported solutions.

Some of the challenges of the suggested bottom-up approach, is the selection of a diverse group of stakeholders that represent the different interests in the basin, which ultimately requires transparency in the selection process and a selection system that is based in the merits of each individual. The proposed system does not work in political environments that are biased by individual or institutional interest.

Scientific/historical background: What do we know?

Climate Change and Agriculture in Mexico

In Mexico, agriculture represents around 3% of GDP and employs around 13% of the total working population (INEGI, 2016a, 2016b). 37.5% of the total population lives in the rural sector, those localities with up to 15,000 inhabitants. In Mexico, irrigated agriculture accounts for 77% of the fresh water use. Irrigated agriculture represents only 25.9% of the total agricultural area and generates 56.8% of the total commercial value of agricultural commodities.

Yields per hectare on irrigated agriculture are up to 3.3 times higher than those from rainfed agriculture (CONAGUA, 2015).

Agriculture in Mexico is largely heterogeneous. In one hand, there is a vast majority of small-scale agricultural producers (66% of total agricultural producers with less than 5 ha) farming (staples) for self-consumption and marginally participating in the market for agricultural commodities. These producers are highly sensitive to climate uncertainty as they mostly rely on rainfall as their primary water source, particularly in the South and Southeast regions of Mexico. On the other hand, large-scale producers form the bulk of irrigated agriculture, and are located in the drier areas of central and northern Mexico. These farmers have easier access to credit, insurance and new technologies and their production decisions respond primarily to domestic and international market demands (only 6% of total agricultural producers). The rest are middle-scale producers transitioning towards higher levels of productivity (Monterroso Rivas et al., 2015).

Both types of producers are expected to experience the effects of climate change differently. Mendelsohn, Arellano-Gonzalez, and Christensen (2010) estimate that by 2100, agricultural land values in rural Mexico will decrease by roughly 50% under three different climate change scenarios. In all scenarios, the authors find that climate change will be more detrimental to irrigated farms than to rainfed farms. Also, raising temperatures will be more harmful to irrigated farms while precipitation decreases will be more damaging to rainfed farms. Galindo, Reyes, and Alatorre (2015) show similar findings. Their study reports that an increase of 2.5° Celsius and a simultaneous reduction in precipitation of 10% causes net revenue average losses ranging from 36% to 55% and 14% to 25% for irrigated and rainfed farms respectively. Regardless of the farm type, climate change effects are expected to be detrimental for agriculture in Mexico and thus, an increase in rural poverty levels is expected. Lopez-Feldman (2013), employing two climate change models, estimated that by 2100 rural poverty levels in Mexico might increase from currently 45% up to 54% under the most severe climate change scenario. He also found that poverty impacts will be differentiated by region. In the South-Southeast, poverty is expected to reach levels above 70%, while in the Northwest, were most of the entrepreneurial agriculture is located, poverty levels are practically unaffected continuing to be around 20%.

Yunez-Naude and Rojas-Castro (2008) provide results on the importance of water provision and availability for agricultural production. Using a general equilibrium approach, the authors estimate that a 50% reduction in water supply would decrease agricultural production by 9.2%. Irrigated agriculture would suffer the most with a decrease of 17.9% while rainfed agriculture would have a small increase of 2.9%. As expected, regions where agriculture is mainly rainfed would experience the least damages. Virtually the production of every crop cultivated in irrigated areas would decrease with Maize and Beans suffering the largest decreases, 24.3% and 18.9% respectively. Crop production in rainfed areas will slightly increase in response to increased crop prices but the increase would not be enough to offset the losses of irrigated agriculture. As result, imports of agricultural products might increase.

FAO-SAGARPA (2014) estimate that by 2050, 25 states (out of a total of 32) will suffer some degree of profit losses but 11 of them will have losses greater than 50%. By 2099, the number of states with losses higher than 50% increases to 20. This analysis also predicts that over the course of the century, maize and bean production, the two most important staples in Mexico’s diet, will tend to decrease, particularly in the southern and northwest states, the higher producing regions. Grassland will also decrease due to decreases in precipitation thus affecting the production of beef and dairy products. Similarly, the production of wheat and fruits will also decrease.

With lower agricultural incomes and limited adaptation strategies, agricultural households will likely opt out of agriculture. By decreasing agricultural productivity, climate change might create a mass of rural workers seeking to make a living from employment in other sectors. Feng, Krueger, and Oppenheimer (2010) estimate that by 2080, climate change is estimated to induce 1.4 to 6.7 million adult Mexicans (or 2% to 10% of the current population aged 15–65) to migrate as a result of declines in agricultural productivity alone. Hunter, Murray, and Riosmena (2013) showed that in historical sending regions of Mexico’s vulnerability to dry years, significantly increases the likelihood of US migration of at least one member of the household by 40%. Multi-year droughts increase this likelihood by 75%. In contrast, wet years significantly decrease the odds of U.S. migration by 35%. Similarly, Jessoe, Manning, and Taylor (2014) find that extreme heat shocks increase migration domestically from rural to urban areas by as much as 1.4% and internationally to the U.S. by as much as 0.25%. Extreme heat may also decrease local wage and off-farm employment by up to 1.4%.

Climate Change and the Environment in Mexico

Mexico has a great biodiversity as a country, is contains a vast number of ecosystems whose protection is important for the entire world (CONABIO, 2016). Water resources management for environmental purposes was not been recognized as a need until recent years, when environmental degradation has been evident in terms of decreased water quality and loss of ecosystems. There have been individual efforts to improve the environmental condition of rivers, lagoons and estuaries. In the Lerma-Santiago-Pacifico hydrologic region, a comprehensive study was done to determine water allocations for different users while sustain adequate levels in the Chapala lake to prevent it for completely draining (DOF, 2006). These studies ended up in a regulation that establishes the water allocation for every water user in the basin and water quality restrictions for water discharge into the river. In 2012 a binational agreement (Minute 319) was signed to provide environmental flow pulses for restoring habitat in the Colorado Delta (IBWC, 2012). This was an important accomplishment of the Colorado river restoration efforts of both countries. Also in 2012, the federal government developed some guidelines for determining environmental flows throughout the Mexican territory (NMX-AA-159-SCFI-2012). These guidelines are meant to support water resources management at the voluntary basis within each hydrologic region. This is a small first step towards including environmental flows into IWRM.

Climate Change and the Urban Sector in Mexico

Models developed for some areas in Mexico show that despite increasing temperatures and reduced water availability, heavy rains may exceed flooding thresholds, augmenting the risk of lives losses and economic damage (Herrera-Pantoja & Hiscock, 2015).

Urban and rural populations, agriculture, and industry are increasing their water use and subsequently augmenting their waste water discharges. When the waste water is discharged to a stream or water body without treatment it compromises the water use for agriculture, fishing, recreation, and drinking. Untreated waste water discharges are common in Mexico, and it’s a consequence of a lack of coordination between water users and authorities (De la Peña et al., 2013). Better waste water management in terms of recollection, conduction, treatment, and discharge is necessary to stop water resources depletion, riparian and aquatic ecosystem degradation, soils contamination, and an overall impact in food security.

Waste water treatment is a crucial factor to improve water security as it not only prevents the contamination of streams, water bodies, and soils, it also reduces the instream and groundwater demands from some industries and agriculture by recycling treated water.

Unanswered questions, research void

Extensive information by HAR is accumulated every year by CONAGUA. The information includes water use by sector, water quality on main rivers and water bodies, infrastructure, storage capacity, water stress, population with access to potable water and sewages, groundwater extractions and aquifers conditions, among others. However, this information is not integrated into a comprehensive analysis to address specific problems and propose a set of solutions for each of the HAR. Thus, there is a need for an IWRM modeling framework that integrates all the individual pieces into a system's dynamic model, which may include hydrologic, water allocation and system's operation, environmental and social model components for every HAR.

Climate change information is accessible for every HAR, however, this information has not been translated into impacts on the ground in terms of: (a) increase in severity and frequency of droughts and change of water availability, (b) shifts in start and ending of rain seasons, (c) modification in agriculture growing seasons, increase/reduction in crop-water needs, (d) increase in magnitude and frequency of large rainfall events and related floods, (e) diminishing water quality due to pattern water cycle alteration, (f) alteration/modification of habitat for ecosystems. Thus, there is a need to evaluate/quantify the impact of climate change through water resources modeling and monitoring, as well as designing adaptive strategies to cope with climate change impacts.

There is a need for designing institutional structures than can cope effectively with climate change impacts. Such institutions must be couple with economic strategies and incentives to mitigate and adapt for changing climate conditions. Lastly, it is necessary to develop educational programs and materials that communicate the basics of climate change, current impacts on water resources, and actions to mitigate these negative effects at local, regional, and national levels.

Thinking ahead: Priorities for future binational research and training initiatives

The longstanding and renowned expertise on IWRC at the UC system can become a key contribution to the UC-Mexico Initiative. Past case applications in California, using large scale hydro-economic models like CALVIN and SWAP, and local applications of groundwater management in Pajaro Valley, surface water management in the Russian River, can be easily adapted to the modelling challenges in the Mexican context. For instance, in the Russian River, currently there are studies exploring the feasibility of Forecast Informed Reservoir Operations (FIRO) for enhancing reservoir storage during the rainy season, while protecting urban settlements from flood events. This type of analysis can be utilized and adapted to reservoir management within the Mexican context. In addition, the UC Davis team can help in the development of strategic planning for each HAR, their involvement in decision making processes in these river basins can help Mexican authorities to implement participatory processes for successful planning and execution of policies. Benefits from this collaboration will provide tools (hydrologic and planning models) in an open and inclusive framework for stakeholders.

Mexican institutions that can benefit from this knowledge and collaboration include CONAGUA, SEMARNAT, SAGARPA, INECC, IMTA, basin councils, irrigation district, state and municipal water agencies, NGOs, among others.

In achieving these goals, a bundled water supply, flood and environmental water management approach should be pursued. However, this bundle should allow for extensive feedback so that each management objectives are evaluated and understood for informed decision to take place. UC Davis experts can provide the know-how experience on these areas, in terms of training and development of the construction of such a tools and processes. Benefits from this system's integration are the understanding of human and hydrologic systems as a whole to avoid fragmented science, management and policy.

Adaptive management strategies, a review and formulation of new policies and regulations, as well as educational programs and incentives are needed at different institutional levels to successfully develop an IWRM framework (Hanak & Lund, 2012). However, adaptation policies need to have particular attention on vulnerable populations, as adapting may come at expense of other aspect as human welfare (Eakin et al., 2016). The continuation of this perspective will set the ground for future research agendas and binational cooperation.

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