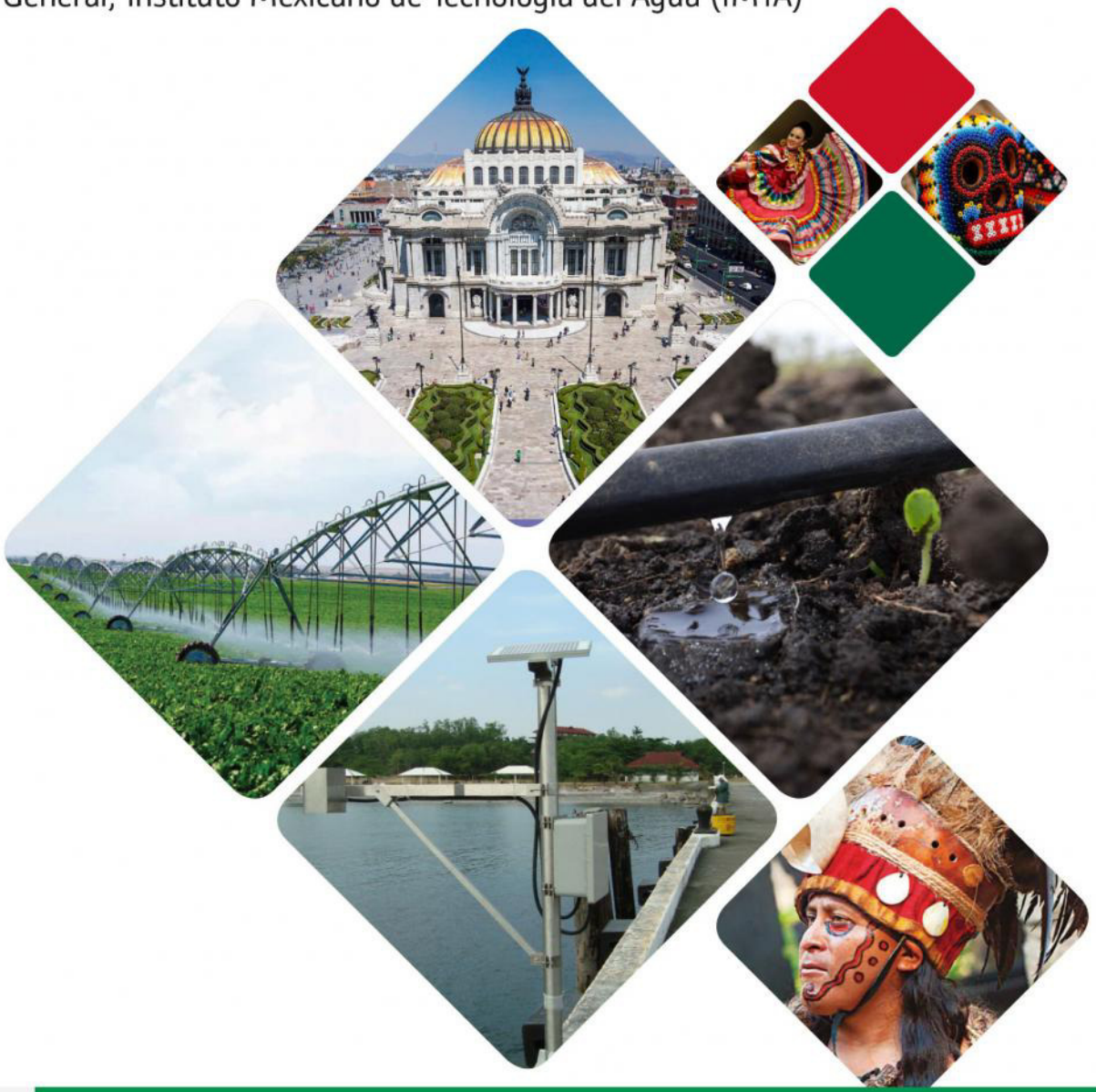
23rd International Congress on Irrigation and Drainage

8-14 October 2017, Mexico City, Mexico

10th N D Gulhati Memorial Lecture for
International Cooperation in Irrigation and Drainage on

Reforms in the Administration of Irrigation Systems: Mexican Experiences

Dr. Felipe Ignacio Arreguín Cortés
Director General, Instituto Mexicano de Tecnología del Agua (IMTA)



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INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE
COMMISSION INTERNATIONALE DES IRRIGATIONS ET DU DRAINAGE

Dr. Felipe Ignacio Arreguín Cortés

Director General, Instituto Mexicano de Tecnología del Agua (IMTA)

Felipe Arreguín has a Ph.D. degree in Hydraulics and a Master's degree in Engineering from de National Autonomous University of Mexico (UNAM). He is currently the Director General of the Mexican Institute of Water Technology (IMTA). He is a Level-II Researcher of the National Researchers System and has been visiting Professor at the Morelos Campus of UNAM's Graduate Engineering Studies Department for more than thirty years.

Dr. Felipe was Deputy Director General for Technical Affairs at the National Water Commission from 2002 to June 2015. He was elected as President by the 30th Board of Directors of the Mexican Hydraulics Association, and is presently Vice-President of the Civil Engineers Association of Mexico and Member of the Pan American Academy of Engineering.

He is the author of more than 240 publications in national and international technical journals and has attended more than 200 conferences in Mexico and other countries. Dr. Felipe has received numerous prizes and awards for his outstanding achievements in the water sector as a researcher, academician, and public servant.

10th N.D. Gulhati Memorial Lecture

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"Reforms in the Administration of Irrigation Systems: Mexican Experiences"

Dr. Felipe Ignacio Arreguín Cortés
Director General, Mexican Institute of Water Technology /
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Presented at:

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ICID•CIID

INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

Jeremiah R.D. Lengoasa
Deputy Secretary-General, WMO

THE N.D. GULHATI MEMORIAL LECTURE
for International Cooperation in Irrigation and Drainage

Preserving the memory of the visionary Water Resource Engineer, ICID, in collaboration with Gulhati Trust has been organizing the 'N.D. Gulhati Memorial Lecture for International Cooperation in Irrigation and Drainage' at the time of its triennial Congresses. The memorial lecture aims at encouraging exchange of significant global developments relevant to irrigation and drainage engineering including all allied aspects like environment, sociology, economics etc. and fostering and enhancing international cooperation to meet ICID objectives. The lecture is delivered by an invited eminent person in a field related to ICID's mission. An honorarium of US $ 1000 is presented to the invited distinguished Lecturer as a token of appreciation.

N.D. Gulhati Memorial International Lectures held so far:

	Mr. Jeremiah R.D. Lengoasa Deputy Secretary-General World Meteorological Organization, Switzerland Delivered the ninth lecture in 2014 at Gwangju, Korea on **"Climate Variability and Change: Impacts on Water Availability"**
	Dr. Charles M. Burt Professor of Irrigation and Chairman of the Irrigation Training and Research Center (ITRC), USA Delivered the eighth lecture in 2011 at Tehran, Iran on **"The Irrigation Sector Shift from Construction to Modernization: What is Required for Success?"**
	Prof. Dr. Chandra A. Madramootoo Dean, Agricultural and Environmental Sciences McGill Unviersity, Canada Delivered the seventh lecture in 2008 at Lahore, Pakistan on **"Irrigation in Context of Today's Global Food Crisis"**
	Er. Albert J. Clemmens Founding Member and Director American Academy of Water Resources Engineers, USA Delivered the sixth lecture in 2005 at Beijing, China on **"A Process-Based Approach to Improving the Performance of Irrigated Agriculture"**
	Dr. Marvin E. Jensen National Program Leader Water Management and Salinity Research Agricultural Research Service, USDA, USA Delivered the fifth lecture in 1993 at The Hague, Netherlands on "**The Impacts of Irrigation and Drainage on the Environment"**

	Late W.R. Rangeley OBE Independent Consultant Water Resources Development, World Bank, UK Delivered the fourth lecture in 1990 at Rio de Janeiro, Brazil on "**Irrigation at a Crossroads"**
	Late Adriaan Volker Professor Extra-Ordinarius in Hydrology Delft University of Technology, The Netherlands Delivered the third lecture in 1987 at Casablanca, Morocco on **"Role of Failures and Negative Secondary effects in the Development of Irrigation, Drainage and Flood Control"**
	Late K.K. Framji Chief Engineer and Joint Secretary Ministry of Irrigation and Power Government of India Delivered the second lecture in 1984 at Fort Collins, USA on **"Past and Likely Future Developments in Irrigation and Drainage and Flood Control Measures in Developing Countries"**
	Prof. Dr. M. Holy Dean of Civil Engineering Prague Technical University, Czechoslovakia Delivered the first lecture in 1981 at Grenoble, France on **"Irrigation Systems and their Role in the Food Crisis"**
Prize winning papers of Young Professionals	
	Er. R. Rajkumar Lecturer, Civil Engineering Centre for Water Resouces Anna University, India Winner of the Second N.D. Gulhati International Award in 1999 for the Best Paper contributed to an ICID Congress titled at Granada, Spain on **"Controlled Water Saving Method for Paddy Cultivation - A Case Study"**
	Ms. Margreet Z. Zwarteveen Gender Specialist, IWMI, Sri Lanka Winner of the First N.D. Gulhati International Award in 1996 for the Best Paper contributed to an ICID Congress titled **"A Plot of One's Own: Gender Relations and Irrigated Land Allocation Policies in Burkina Faso"**

Er. N.D. Gulhati
A Visionary Water Resources Engineer

(1904-1978)

Er. Niranjan Das Gulhati, popularly known as N.D. Gulhati, a visionary, was one of the forces behind India's march towards food self-sufficiency through Green Revolution. As the Chief of the Natural Resources Division in the Planning Commission, Government of India, he laid its foundation by initiating proposals relating to the development of irrigation and power, soil conservation and mineral development in the First Five-Year Plan. The notable positions he held in Government of India service includes Secretary, Central Board of Irrigation and Power (CBIP) from August 1945 to March 1949; Chief Engineer and Joint Secretary in 1953 and Additional Secretary to Government of India in 1958. While serving on these positions, he championed the cause of irrigation and drainage at national and global level.

As the Chief Representative of Government of India on the Indus Water Negotiations under the aegis of International Bank for Reconstruction and Development (IBRD), he played a key role in the successful conclusion of the historical Indus Water Treaty between India and Pakistan in 1960 (ratified in 1961). He represented India in many international engineering conferences and made immense contributions to India's agricultural, water and power sectors.

In recognition of his ''distinguished services of a high order'', Er. Gulhati was bestowed with one of India's highest civilian honours "PADMA BHUSHAN" by the President of India in 1961.

Late N.D. Gulhati dedicated his entire professional life to the development of irrigation engineering and conceived and implemented the concept of an 'International Commission' for ensuring international cooperation on advancing the world knowledge in the fields of irrigation, drainage, flood management and river training by pioneering the idea of setting up an International Commission to the Government of India in 1946. The Commission was set up in the year 1950 and Er. Gulhati was befittingly selected as its first Secretary General to lead its operations in its budding period. Later he led the Commission from the forefront holding positions of Vice President (1957-1960), and President (1960-1963) of ICID.

President Honoraire Gulhati was a globally renowned Water Resources Consultant, whose services were utilized by many State Governments in India and global organizations like IBRD (1963), International Development Association (1963-1973), and United Nations (ESCAP) in 1969.

Born on 15 November 1904 in Lahore, Pakistan, Er Gulhati completed his technical education from the Thomson Civil Engineering College, Roorkee in 1926 (later University of Roorkee and now IIT Roorkee) where he achieved honours. He was appointed to the Indian Service of Engineers in October 1927 and posted to the Irrigation Branch of the Public Works Department, Punjab. Er N.D. Gulhati passed away in December 1978.

Er. Gulhati was amongst the foremost supporters of ICID and did everything possible to promote the objects of ICID. His mature leadership, dynamic personality and diplomatic and adroit handling of all matters won him universal respect and endearment with all the members of the ICID fraternity. As the architect of the “International Commission” who laid a strong foundation for Commission’s growth during its nascent years, Er. Gulhati has been aptly called the ‘Father’ of ICID.

10th N.D. Gulhati Memorial Lecture for International Cooperation in Irrigation and Drainage

Reforms in the Administration of Irrigation Systems: Mexican Experiences

Felipe Ignacio Arreguín Cortés*

ABSTRACT

A brief description is presented of the process and impact of the transfer of the infrastructure, management, and operation of Irrigation Districts in Mexico from the State to farmers. It begins with an overview of the present and future conditions of the hydro-agricultural sector in the country, and goes on to discuss the social background and the legal framework under which the transfer process was planned and carried out, highlighting the participation and the organizational framework adopted by the users, which not only remains in force, but has been consolidated, giving rise to a social organization that constitutes an example nationwide. It also underscores the linkage that has been established between different government agencies and user associations for the sustainable development of the hydro-agricultural sector, which has given rise to a series of programs aimed at the modernization and conservation of hydraulic infrastructure and to the efficient use and management of water at the on-farm level, all of this with the ultimate aim of increasing agricultural production per unit area and the volume of water used in this important sector. In addition, a series of major challenges, problems, and opportunities that need to be addressed in order to meet the current and growing food demand prevailing in the country are discussed, as is the importance of the role of technological research and development institutions within this frame of reference. In closing, a reflection is given on the importance of the legal framework on water and its impact on the agricultural sector, highlighting the need to have a General Water Law that is applicable both to the three tiers of government that exist in Mexico and to society at large; an action currently in progress.

1. Climatological and Water Conditions of Mexico

Mexico has a land area of 1,964 million km2. In the north, it borders with the United States and in the South with Guatemala and Belize; to the east and the west, it borders the Atlantic Ocean and the Pacific Ocean, respectively, with a total of 10,000 km of coastline. It is located

* Director-General, Instituto Mexicano de Tecnología del Agua (IMTA), Mexico.

within the strip of the great deserts of the world, as are Algeria, Libya, Egypt, and Saudi Arabia (Figure 1).

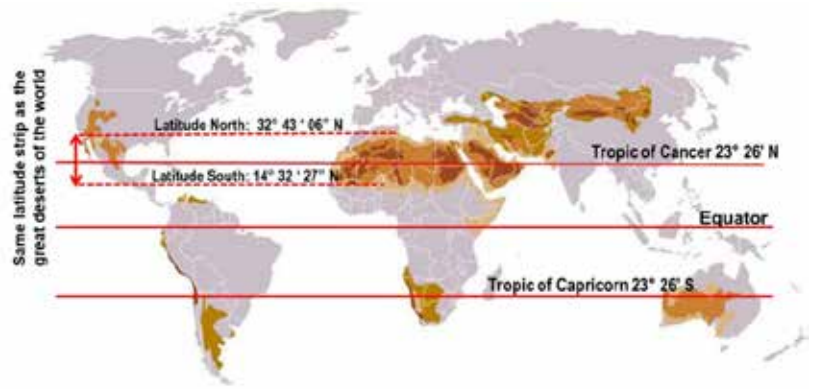

Figure 1. Mexico's vulnerability due to its geographical location

Due to its geographical location, Mexico is naturally exposed to a dry climate and recurrent droughts (Figure 2). The effects of these conditions are magnified in the north central part of the country, with the occurrence of severe and extreme droughts (National Water Commission, 2017). Given this condition, within these areas, agricultural production is subject to the availability or creation of water supply sources for irrigation purposes.

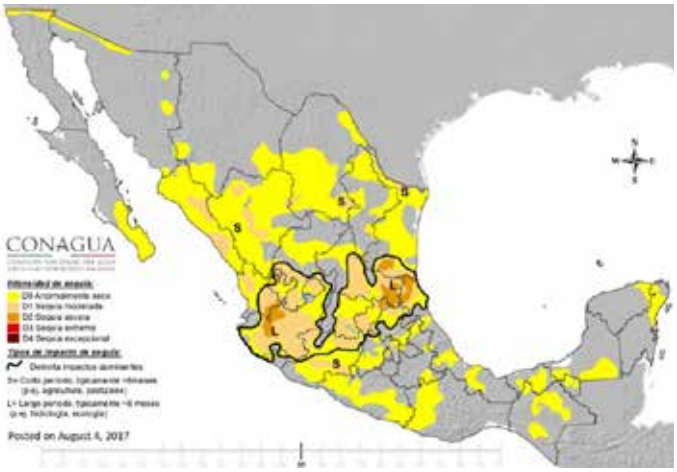

Figure 2. Mexico's drought monitor. Conditions as of July 31, 2017

This location notwithstanding, due to its coastline borders and the consequent presence of meteorological and climatological phenomena at different scales, Mexico has an average annual precipitation (1981-2010) of 740 mm (Figure 3), equivalent to 1,449 km3 (CONAGUA, 22016. "Atlas del agua en México 2016"). Adding to these factors the national orography, which includes two great mountain ranges and several plains, the country displays a great variety of climates, and within its extensive territory precipitations range from 50 mm/year in the north, to more than 4,000 mm/year in the south. In addition, it should be noted that

precipitation is not uniformly distributed throughout the year, with peak values recorded in the months of July to September and the lowest between February and March, when demand for irrigation water is the highest.

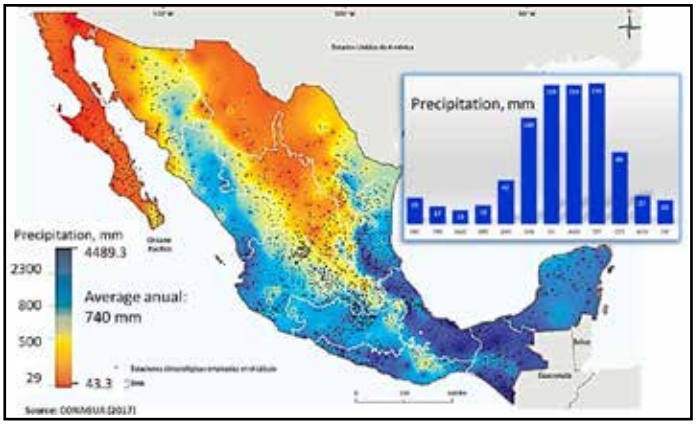

Figure 3. Normal Annual precipitation in Mexico. Average 1981-2010

Within this framework of reference, it's important to note that each year tropical cyclones transport large amounts of moisture from the oceans to the continental zone, and that through precipitation they contribute to the natural replenishment of surface- and groundwater sources (Figure 4). However, it is also necessary to note that they are the cause of significant damages, due to flooding in population centers and in agricultural production areas that are vulnerable and exposed.

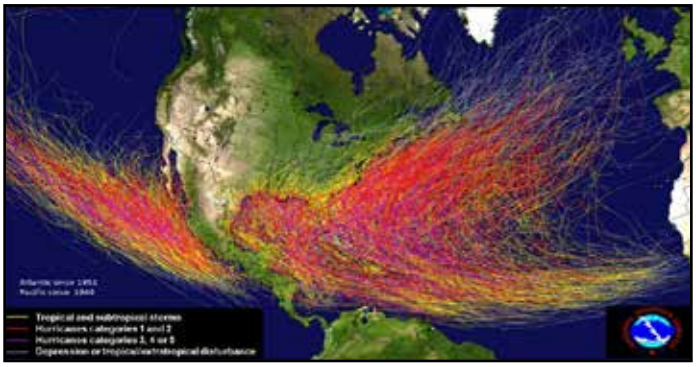

Figure 4. Historic Hurricane trackse 1981-2010

In this respect, it is estimated that 162,000 km2 of the national territory are susceptible to flooding for a probability of a 40-year return period. While this represents less than 10% of the national territory, the socioeconomic impact has become very high as it affects large agricultural and urban areas, mainly due to their vulnerability and resilience.

With respect to its population, Mexico is an increasingly urbanized country. In 2015, there were 119.5 million inhabitants (INEGI, 2015), 75% living in urban areas and the rest in rural

areas, Therefore, as in most developing countries, the population engaged in agricultural and livestock activities is becoming increasingly less. Moreover, 77% of the population demanding water and food resides in the north and central part of the country, where only 33% of water resources are found (Figure 5). This generates a lot of pressure on water resources, with the consequent overexploitation of watersheds and aquifers.

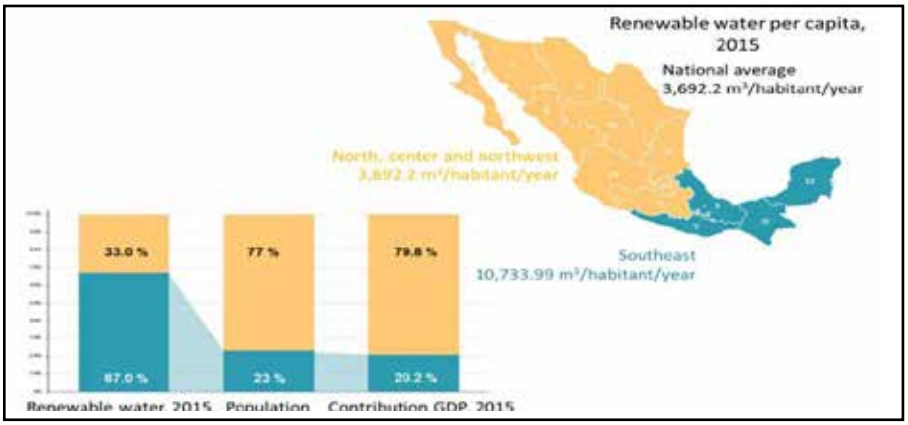

Figure 5. Regional contrast between renewable water and development

Regarding political organization in water issues, Mexico has a set of institutions to carry out, in conjunction with users, the distribution and management of water, as well as the development, maintenance, and management of hydro-agricultural infrastructure. In this context, the Federal Government has the Secretariat of Environment and Natural Resources; the Secretariat of Agriculture, Livestock, Rural Development, and Fisheries; the National Water Commission, the Mexican Institute of Water Technology, the Secretariat of Energy, and the Federal Electricity Commission, among others (Figure 6).

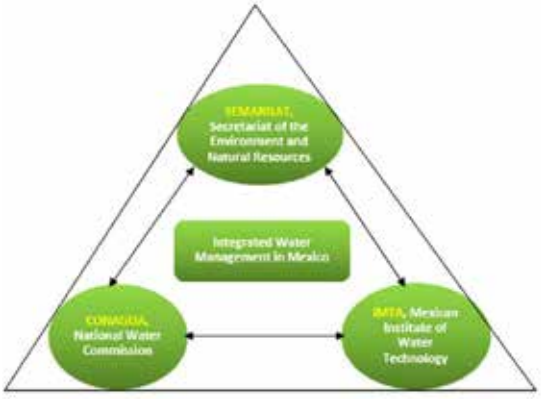

Figure 6. Institutions to distribute, organize and manage the water resources in Mexico

In order to perform an adequate management of available water resources, taking into account the hydrography and the political division, Mexico has been divided into 13 Hydrological-Administrative Regions (Figure 7), which in turn encompass 37 hydrological regions and 728 river basins. (CONAGUA, 2016 “Atlas del agua en México”).

Figure 7. Hydrological/ Administrative regions

2. Hydro-agricultural Organization and Legislation

As regards the legal and normative aspect, the current legislation has its origins in the Constitution of 1857, from which came a series of laws and regulations to manage and regulate the administrative and economic operation of water resources (Box 1). These instruments, including the Political Constitution itself, have been reformed and improved on a number of occasions. The present Constitution, which originated in 1917, is the basis of a set of general, national, and local laws in which water is considered as an asset that is owned by the nation and its use in the hydro-agriculture sector has the highest social priority (COLMEX, 2017). Both the Constitution and the laws that emanate from it are subject to a process of revision, updating, and continuous improvement. For example, the legislature is currently tasked with drafting a new law, the "General Water Law", which will regulate the actions of the three tiers of government (federal, state, and municipal), and will incorporate, among other aspects, the human right to water and food.

Water laws and regulations	Year
Political Constitution of the United Mexican States	1857
Federal Jurisdiction Water Utilization Act	1910
Political Constitution of the United Mexican States (articles 27 and 115)	1917
Federal Public Water Utilization Act	1917
Irrigation with Federal Waters Act	1926
Land and Water Allocation and Restitution Act, regulatory of Article 27 of the 1917 Constitution	1927
National Property Water Act	1934
Irrigation Act	1946
Federal Water Law and Bylaws	1974
National Water Law and Bylaws	1992
General Water Law (in process)	----

Box 1. Water Laws and Regulations

Regarding the management of the hydro-agricultural sector, Mexico has a long history of organization and legislation, which is reflected in the evolution and the level of importance given to the various federal agencies that have governed the use of water resources and their application in agricultural production (Box 2). For example, in 1891, the Secretariat of Promotion was created, which evolved into becoming, in 1989, the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food and the National Water Commission, two great institutions under which the Federal Government serves the national hydro-agricultural sector. (CONAGUA, 2009 "Semblanza histórica del agua en México).

Federal Institutions in charge of the Hydro-agricultural sector	Years
Secretariat of Promotion	1891 - 1917
Secretariat of Agriculture and Promotion	1917 - 1926
National Irrigation Commission	1926 - 1946
Secretariat of Hydraulic Resources	1947 - 1976
Secretariat of Agriculture and Hydraulic Resources	1977 - 1989
National Water Commission/Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food	1989 - 2017

Box 2. Federal Institutions in the hydro-agricultural sector

3. Irrigation Infrastructure

The national agricultural land surface is about 22 million hectares, of which 15.5 million hectares correspond to rainfed areas and 6.5 million to irrigation areas (Figure 8). It is interesting to note that the agricultural frontier of Mexico is of the order of 32 million hectares, which means that virtually 70% of the area with agricultural potential is in production, leaving 30% for expansion; that is, 10 million hectares, so there is an important strategic reserve for food security. (Hinojosa, 2016).

Mexico has 86 Irrigation Districts (IDs) and more than 40,000 Irrigation Units (IUs) distributed throughout the national territory (CONAGUA, 2016, "www/siga.cna.gob.mx/ Mapoteca/ Regiones Hidrológicas"). Fifty percent of the national agricultural production is harvested on irrigated land, producing 2.4 times more, per unit area, than in rainfed areas.

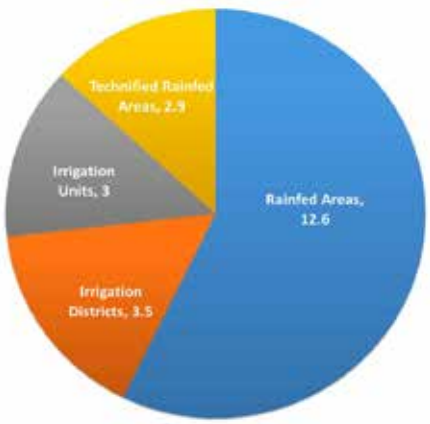

Figure 8. Irrigated areas in Mexico

After the Revolution of 1810, Mexico established as a political priority the development of irrigation infrastructure (Figure 9), which was enhanced, as of 1926, with the construction of large storage dams, reaching growth rates of 100,000 ha/year between 1946 and 1989. (Ramos V. C.O. 2017, "Seguridad hídrica en la producción de alimentos", CICM). It is important to note here that in order to meet the food demand in Mexico by 2050, with an estimated population of 150 million inhabitants, coupled with a significant increase in the consumption of calories, it is foreseeable that the growth should be adjusted to the order of 40,000 ha/ year.

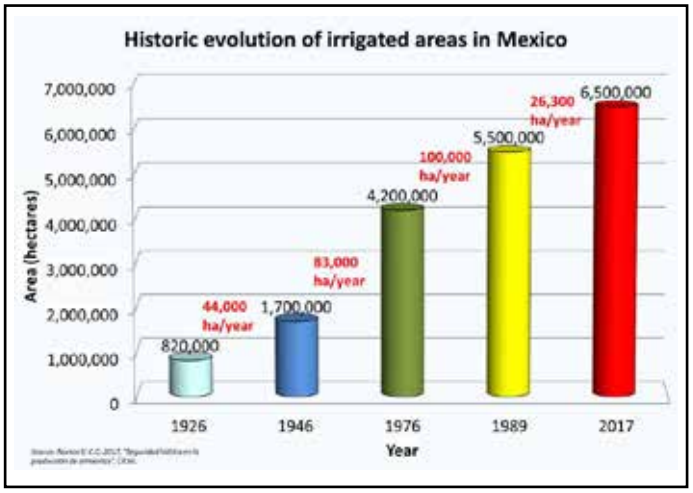

Figure 9. Evolution of irrigated areas

Irrigation units, also known as “small-scale irrigation”, are run by 960,000 users. For agricultural production, they use an average of 35,000 hm3/year of irrigation water, and their average water productivity is estimated at 2.29 kg/m3 (CONAGUA, 2016, “Estadísticas agrícolas de las unidades de riego”).

For their part, the 86 Irrigation Districts, also known as “large-scale irrigation” zones, are managed by 557,381 users, accredited as irrigators. For agricultural production, an average of 30,000 hm3/year are used, and their average water productivity is of the order of 1.69 kg/m3 (CONAGUA, 2016, ““Estadísticas agrícolas de los distritos de riego”).

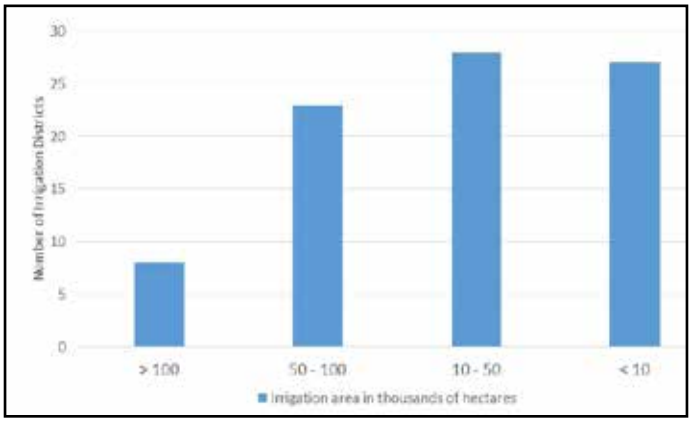

Figure 10. Dimension of irrigation districts in Mexico

At the global level, in terms of availability of hydro-agricultural infrastructure, Mexico ranks seventh. As part of this infrastructure (Figure 16), for example, Irrigation Districts have 139 storage dams and 345 diversion dams, 664 pumping plants, 2,760 deep wells, 50,069 km of canals, 31,164 km of drains and 70,156 km of roads (CONAGUA, 2015, “Inventario de obras de infraestructura de distritos de riego”).

As already mentioned, all of this infrastructure began to be constructed more than a hundred years ago; an example of this is the “La Boquilla” dam, which dates back to 1910 (Figure 17). This multipurpose dam, located in the north of the country, in the state of Chihuahua, generates electricity and covers the water needs of 75,200 agricultural hectares in ID 005 “Delicias” (CONAGUA, 2016, “Características de la presa La boquilla””, DR 005 Delicias Chihuahua).

Irrigation Districts are quite diverse in terms of size (Figure 10), so that, depending on the availability of soil and water, there are relatively small irrigation districts, with surface areas around 10,000 hectares, to very large districts exceeding 100,000 hectares. Among the latter are ID 014, Valle de Mexicali, in Baja California, and ID 075, Valle del Fuerte, in Sinaloa (CONAGUA, 2015, “Inventario de obras de infraestructura de distritos de riego”).

4. Irrigation District Transfer

Among the major transformations and reforms promoted in the hydro-agricultural sector in Mexico, the “transfer of irrigation districts to users” stands out (Box 3). This transfer began in 1988, and has represented a fundamental change in the administration, distribution and delivery of water at the on-farm level. The initiative is supported by the Federal Water Law of 1974 and its consolidation is fully based on the National Water Law of 1992. Thus, the administration and operation of the districts, except for supply sources and headworks, become responsibility of the users (Trava, 1996).

Year	Beginning of the process of transferring irrigation districts to users
1988	The administration, operation, and conservation of irrigation districts and their infrastructure depended on the Federal Government and were executed by the Secretariat of Hydraulic Resources.
1989	The National Water Commission (CONAGUA) is created.
1990	CONAGUA plans the delivery of the hydro-agricultural infrastructure to the users in order to lead them to financial self-sufficiency and enhance water and land productivity.
1992	Transfer of irrigation districts to users begins: • Their training and organization is enhanced • The regulations for the creation of irrigation modules and limited responsibility societies, with their rights and obligations, are established.

Box 3. Process of transferring irrigation districts in Mexico

The transfer of Irrigation Districts drives a series of processes that give rise to a productive reconversion in Mexico (Figure 11). This reconversion was initially conducted by the former Secretariat of Hydraulic Resources in 1988 and was consolidated in 2010, already under the responsibility of the National Water Commission, securing the transfer to the users, including not only the physical infrastructure, but also the responsibilities for the operation, conduction, distribution, and delivery of water for irrigation.

Thus, the main objective of the water reform in terms of water resources management in irrigation districts is achieved by transferring the hydraulic infrastructure and its integrated management to the users, which implies for them taking on the responsibility of making an efficient and sustainable use of water resources (Trava, 1996).

As part of the process of transfer of irrigation districts, the creation of the so-called Irrigation Modules (IMs) was conceived as a central figure for the administration and social organization

Figure 11. Productive reconversion process in Mexico

of users. At the same time, integrating several modules, other administrative entities, known as Limited Responsibility Societies (SRLs) were created (Trava, 1996).

Irrigation district transfer process is described as follows:

- Creation of irrigation modules and limited responsibility societies (SRL's)
  - Integrated by users representing small property and ejidos
- Irrigation modules manage, operate and maintain the hydro-agricultural infrastructures assigned to them
  - Irrigation modules contribute 50% of the investments for rehabilitation and modernization, which are complemented with 50% of federal support
  - Each irrigation module receives a volume of water according to their surface area and to the annual availability in the storage source

The transfer of the 86 irrigation districts involved the creation of 474 irrigation modules and 16 LRSs in order to manage an area of 3,495,085 hectares. These administrative structures are made up of 557,381 irrigation users. The area per module varies between 5,000 and 15,000 ha. Small owners are 139,345 in number compared to the 418,036 ejidatories (communal land holders).

Each irrigation module is managed by a board of directors that is periodically renewed, and which usually consists of a president, a supervisory council and three major areas: administration, operations, and conservation. For the implementation of these structures, the State supported the modules with technical and administrative training (Figure 12). These

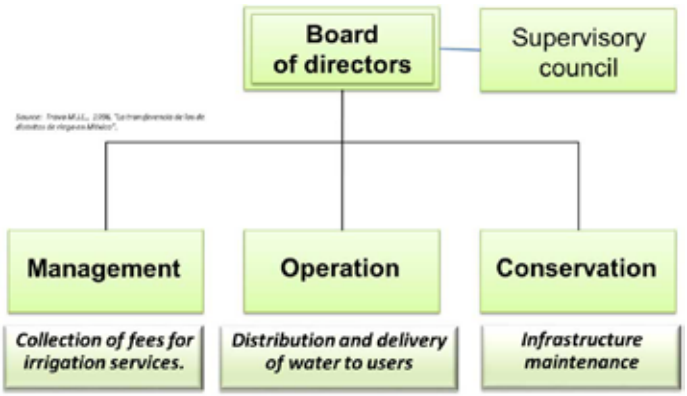

Figure 12. Organization chart of an Irrigation module

support mechanisms for strengthening the modules have had continuity and, in a certain way, have allowed to consolidate the organization of users (Trava, 1996).

It is important here to reiterate that the State, through the National Water Commission, maintains the control and management of the headworks in the irrigation districts, that is, of the supply sources (Figure 13). Thus, dams and other bodies of water, as well as the series of wells, are managed and operated by the National Water Commission (Trava, 1996).

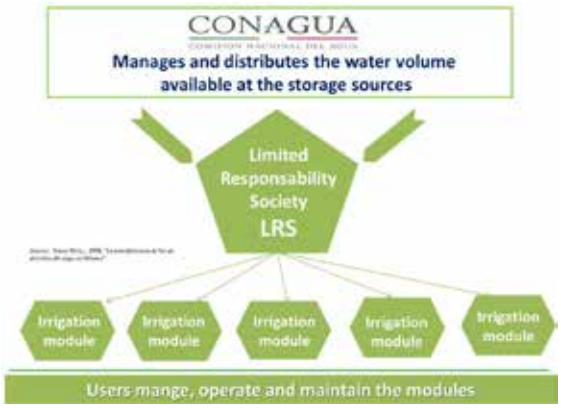

Figure 13. State of the National Water Commission

This form of management has made it possible to organize both small and large irrigation districts in the country. For instance, in Irrigation District 075, Valle del Fuerte, the National Water Commission is responsible for operating and managing the water available at the Miguel Hidalgo and Luis Donaldo Colosio dams ("Huites"), which constitute one of the largest hydraulic systems in the country and one of the main sources of water for agriculture in Mexico (CONAGUA, 2010).

5. Irrigation District Development Programs

n order to enhance the technical and administrative management of Irrigation Districts, the State, together with the users developed the "Master Plans for Irrigation Districts" (Figure 14). These plans consider and prioritize the needs of economic investment and the technical actions to be taken in each irrigation zone, based on a diagnosis that includes an analysis of the current situation and the pending problems, as well as a ranking of alternative solutions. The impact of investments and actions is evaluated through a set of social, technical, and economic indicators within a framework of action aimed at the sustainability of Irrigation Districts.

Among the actions that the Mexican Government has prioritized through institutions such as the National Water Commission, together with the users, a series of programs have been promoted for the rehabilitation, modernization, and technification of irrigation districts; the efficient use of water and energy; the reimbursement of payments for block water supply; the technification of gravity irrigation; the recovery of saline soils with on-farm drainage; and the training of users on water resources management and agriculture (D.O.F., 2016).

Figure 14. Development of infrastructure requirements in irrigation areas

Hydro-agricultural infrastructure support programs include the followings:

- Rehabilitation, modernization and technification of irrigation districts,
- Equipment provision for irrigation districts,
- Efficient use of water and energy,
- Reimbursement of payments for block water supply,
- Technification of gravity irrigation,
- Recovery of saline soils with on-farm drainage, and
- Training of users on management.

Therefore, through the Modernization and Rehabilitation Program for Irrigated Areas, the State contributes up to 50% of the investments for high- and low-pressure irrigation systems, as well as for the technification of gravity irrigation through:

- Executive projects of collective networks (low- and high- pressure) and of irrigation systems, such as multigate, spray and micro-spray systems; and
- Technification of gravity irrigation by means of furrow alignment, land leveling, and the measurement, delivery and fee collection of the water volume provided to the user in order to increase the efficiency of water use at the on-farm level.

With regards to upgrading the machinery for the conservation of hydro-agricultural infrastructure, support is provided for the acquisition of various pieces of equipment, among which stand out brushcutters, backhoes, leveling tools, tractors and long arms. Thus, the users are in better conditions for carrying out maintenance and rehabilitation works in canals, drains, and roads within irrigation zones (D.O.F., 2016).

Upgrading of machinery for the conservation of hydro-agricultural infrastructure results in:

- Decrease in the cost of conservation work on hydro-agricultural infrastructure and
- Selection of machinery according to the characteristics of the infrastructure

Due to its impact on the operation, special attention has been given to the integrated control of aquatic weeds, such as lily, algae and tulle, which obstruct water flow in both main canals and in the secondary network, which is why programs and actions for biological control have been promoted and supported by using neochetina and grass carp, as well as for mechanical control, i.e. by direct extraction of aquatic weeds.

Due to the exploitation of agricultural land in soils with a certain degree of salinity, combined with the effects of evapotranspiration and the application of irrigation, among other factors, in no less than 600,000 ha there have been salinity problems and elevated water tables, the

control of which requires soil washing and the installation of on-farm drainage.

Remote sensors such as satellite imagery, electronic sensors, and soil and crop sampling are used to identify soils with salinity and drainage problems and have facilitated the following:

- The system irrigation are calibrated and statistical models are obtained.
- Soil salinity maps in large areas of irrigated agricultural land are obtained.
- The analysis includes estimation of crop yields and impact of salinity on the economics of the irrigation zone.

In order to address this problem, the Program for the Rehabilitation of Solis with Salinity and Poor Drainage Problems was implemented at the national level. Thus, to date, on-farm drainage has been installed in more than 100,000 ha, with production capacity being restored and even increased.

In order to increase productivity per land area unit and cubic meter of water used for irrigation, the Program for the Technification on Irrigation Districts and Units was established. With this program, which involves investments shared at 50% between the Federal Government and the users, to date, irrigation systems have been installed or improved in more than 850,000 hectares.

Technification in Irrigation districts and units include the followings:

- Irrigation systems with frontal advance, hose reel, and central pivot
- Spray and micro-spray irrigation
- Drip irrigation and localized irrigation
- Greenhouses, moldboards, tunnels, and shade mesh
- Technification of gravity irrigation

Upon considering the process described, there is a natural interest in knowing what have been the achievements and positive impacts of the reforms promoted by the Federal Government through the transfer of irrigation districts to the users. In this regard, it should be recognized that very positive changes have been generated in the legal field, which have been reflected in the National Water Law, which regulates Article 27 of the Political Constitution of the United Mexican States. These instruments have made it possible to consolidate and formalize the transfer of Irrigation Districts. On the other hand, mechanisms have been established to promote and capitalize investments shared between the State and the users in favor of improvements in the technification of agricultural land and, consequently, in the hydro-agricultural productivity within the 3.5 million hectares under their responsibility. In this same regard, the knowledge and skills for the technical and administrative organization of users have increased, which give them a greater level of competitiveness in international markets, an aspect that is enhanced by the increase in production in the 850,000 ha where irrigation systems have been modernized.

Achievements and impact of irrigated agriculture can be summarized as follows:

1. **Legal**
   - Laws and regulation on national waters
   - Transfer of irrigation districts to users
2. **Construction and technification in irrigated agriculture**
   - Hydro-agricul infrastructure in 6.5 million ha
   - Federal support programs for hydro-agricultural infrastructre

3. Transfer of science and technologyto the Mexican countryside

- Irrigation technification in 850,000 ha
- Increase in agricultural production
- Permanent training for irrigation users

The positive effects and impacts of these reforms (Figure 15) are visible and quantified in a tangible way through the evidence associated with the construction of new dams to increase water availability for irrigation purposes; the construction and lining of canals to increase their conduction efficiency; the opening and piping of drains to drive surplus flow outside the irrigation areas, to lower elevated water levels, and to control salinity; the installation of wells and pumping plants to aid irrigation; and the transfer of irrigation technology itself, such as the Program for the Technification of Gravity Irrigation from which 200,000 ha have been benefited.

Figure 15. Positive effects and impacts of the reforms

Due to the need to have a series of indicators that reflect the progress of the reforms and especially the transfer of Irrigation Districts to the users, the Federal Government, through the National Water Commission, implemented the Annual Agricultural Statistics in irrigation districts and units, as well as in technified rainfed districts (Box 4). These documents contain data on the production in each of the irrigation zones and their evolution over time, as well as statistics on irrigated and harvested land, and the volumes of water used by each crop and by irrigation district, among other parameters of interest (CONAGUA, 2015 “Estadísticas agrícolas de los distritos de riego, año 2013-2014”).

Statistical report on agricultural production:

- Statistical concentration on agricultural production
- Analysis of agricultural production
- Agricultural Statistics by irrigation zone
- Agricultural Statistics by crop
- Statistical summaries on agricultural production

Statistical reports on physical irrigated areas water volumes distributed in irrigation districts:

- Statistical concentration on irrigated areas and distributed volumes
- Analysis of physical irrigated areas and distributed volumes
- Physical irrigated areas and volumes distributed by irrigation zone
- Statistical summaries on physical irrigated areas and distributed volumes

Box: 4. Hydro-Agriculture Statistics

From the agricultural statistics of irrigation zones, the evolution of water productivity, expressed in kg/m3, is derived. It can be observed how this productivity has been increasing, from 1.1 kg/m3 in 1990 to 1.83 kg/m3 in 2014 (Figure 16). These results constitute one of the best evidences of the benefits derived from the reforms to irrigated agriculture in Mexico (CONAGUA, 2015 "Estadísticas agrícolas de los distritos de riego, año 1990 al 2015").

Figure 16. Evolution of water productivity in kg/m^3

It should be noted that the government institutions that oversee agriculture and irrigation in Mexico continue to provide ongoing training for users, with the aim of bringing them up to date and optimizing their integrated management of irrigation agriculture (Figure 17). To that end, priority has been given to the following topics: irrigation and drainage, operation, administration, and conservation.

6. Challenges for the Irrigation Sector

One of the main challenges for the irrigation sector in the short, medium and long terms is water and food security for the Mexican population. Among the elements that justify its prioritization are the negative effects associated with climate change, as well as the need to increase agricultural productivity and the opening of new irrigation zones in the south south-east of

Figure 17. Training in irrigation zones

Mexico, and the urgent need to optimize the sustainable use of available water resources, and to promote governance and governance within the hydro-agricultural sector. To this end, it is necessary to create a "General Water Law" that includes the human rights to water and food with a high degree of priority, under a joint and inextricable approach.

Challenges for the irrigation sector are as follows:

- Water and food security in the face of climate change
- To increase agricultural productivity in irrigated areas
- Opening of new irrigation zones in southern Mexico
- Sustainable optimization of water resources
- Greater technological transfer to the Mexican countryside
- To promote governance in hydro-agricultural management
- Application and adaption of the National Water Law and its bylaws

The Mexican Institute of Water Technology, through its Irrigation and Drainage Division, plays an important role in the development of the country's hydro-agricultural sector, since it is responsible for carrying out research, developing technology, training human resources, and providing highly specialized technological services in order to contribute to the sustainable development of this important sector. To this end, it has several laboratories and equipment and, especially, highly qualified human resources, which account for more than 30 years of institutional experience.

Functions of the Mexican Institute of Water Technology include:

- Conduct scientific research
- Develop, adapt and transfer technology
- Innovate in the sustainable management of water resources
- Train human resources
- Provide consulting services and dissemination of scientific knowledge at national and international level

In Mexico, it is necessary to analyze, determine, and plan the best sustainable alternatives to the effects of climate change, which look negative for the hydro-agricultural sector, since projections indicate that there will be less availability of and increased demand for water resources for agricultural production. Given this scenario, it will be necessary to adopt and develop better and new technologies and productive practices, with a preventive approach, to adapt the sector to the new conditions that will prevail, and thus avoid, as far as possible, the affectations and even the damages caused by ever increasing extreme events, such as droughts, frosts, and floods, as well as the affectations derived from the gradual, but continuous precipitation decreases and temperatures increases shown by forecasts.

The increase in agricultural production required by Mexico, as in the rest of the world, to meet the demands of future generations, must be achieved through an increase in productivity per land area unit and through an extension of its agricultural frontier. This is expected to be on an 80%/20% ratio, which means that 80% of incremental demand will have to be absorbed through higher productivity per land area unit and the remaining 20% through new agricultural areas. Thus, in order to increase agricultural productivity in the areas currently under irrigation, agriculture using precision irrigation should be promoted, such as greenhouses, while a better and more efficient management of irrigation water should be done. This must be accompanied by an adequate control of pests and diseases, the selective planting of crops, and the installation of more and better irrigation systems, giving priority to collective networks and automated drip, sprinkler and micro-sprinkler systems.

Mexico has a great water potential in its southern and southeastern regions, as precipitation in these areas reaches 2,000 mm/year, and there are large bodies of water and rivers, including the Usumacinta River, one of the most abundant rivers in the world. Adding to this wealth is the availability of large arable areas, estimated at more than 3 million hectares, for the production of forest, fruit, and vegetable species. To exploit these areas in a sustainable manner, it will be necessary to introduce systems to control excess moisture and in other areas to drill wells to harness groundwater for irrigation purposes, and it will even be necessary to develop and design new irrigation infrastructure for diverting and using the water from the multiple and large rivers.

In the context of the sustainable use and management of available water resources, efforts should be made to increase the overall efficiency with which irrigation water from surface sources is managed, distributed, and supplied, with the aim to increase it to values no lower than 50%; and, on the other hand, attention must be paid to controlling and reducing the overexploitation of aquifers. There are now more than 106 overdrafted aquifers, largely due to poor irrigation practices and excessive water withdrawals compared to allocated volumes in the hydro-agricultural sector. This is a complex problem, the solution of which requires both technical interventions and the correct and strict application of the National Water Law and its bylaws, as well as reconsidering electric energy subsidy programs for agricultural wells in over drafted aquifers.

Government agencies are collaborating with research institutions and with users to promote the development, adaptation, transfer, and especially the appropriation of state-of-the-art technology for the benefit of the Mexican countryside. The lines of action include projects oriented towards the measurement of irrigation water, real-time irrigation forecasting, the availability and use of meteorology in irrigation planning, the use of drones in agriculture, irrigation automation, agro-climatological forecasting, studies on the temporal variations of precipitation patterns by regions, and the effects of climate change on agriculture. In all these thematic fields, the Mexican Institute of Water Technology has open lines of research and technology development, and has the personnel and installed capacities to provide highly specialized services in support of addressing and finding solutions to the great challenges posed by the sustainable development of the hydro-agricultural sector.

Finally, and without a doubt, some of the most important challenges are to improve governance and to consolidate the governability of institutions within the hydro-agricultural sector. This requires a broad and permanent participation of users, who are responsible for the administration of hydro-agricultural infrastructure and who should be considered as having voice and vote, from the stating of the problem to the processes of selection and approval of solution alternatives. This does not imply that the institutions responsible for water and land resources will lose leadership; on the contrary, it requires them to maintain a close relationship and collaboration with the users, who are ultimately the beneficiaries of the decisions and actions that are taken and carried out.

7. Enhancement of Irrigation District Modules and Limited Responsibility Societies

Not all the challenges of the sector are technical in nature. In parallel, there are a series of challenges to continue with the enhancement of irrigation organizations (Box 5); they will have to seek integration in order to have a shared vision throughout the hydro-agricultural sector in order to achieve the joint sustainability of irrigation districts, irrigation units, technified rainfed areas and normal rainfed areas. Facing this challenge, among other things, will lead to a model of integrated management and an orderly process in view of the necessary conversion of certain areas from rainfed to irrigated areas, as well as the introduction of changes in

Box 5. Challenges in Irrigation Organizations

Box 6. Challenges of Irrigation Organizations

economic activities, crop patterns and the application of clear and equitable rules for water distribution; all this backed by the promotion of technology adoption.

As a result of these transformations, it can be concluded that, in general terms, users now have a more entrepreneurial mindset and that their priorities are focused on the search for financial and technical self-sufficiency; on increasing hydro-agricultural productivity; on the care, utilization, conservation, and extension of the useful life of the infrastructure under their control; and, of course, on the consolidation of organizations with a business approach that may guarantee the sustainability of the national agricultural sector.

CONCLUSIONS

In summary, with the transfer and reforms that have been implemented, Mexico has the bases for achieving water and food sustainability and security. To this end, as has already been mentioned, priority has been given to social, technical, economic and environmental aspects. It should be noted that these decisions and actions emanate from the guidelines and

mandates established in the Political Constitution and the laws that derive from it, especially the National Water Law and its bylaws. However, we must recognize that, in order to continue making progress on water-related issues and to ensure sustainable development, Mexico requires a General Water Law for ensuring water sustainability and security in the national hydro-agricultural sector; that is, a law applicable to all three tiers of government, to society as a whole and, of course, to all productive sectors, especially the hydro-agricultural sector.

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23ème International des Irrigations et du Drainage

Mexico City, Mexique, 2017

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