9 Water Use for Agriculture in Mexico

Enrique Palacios Vélez and Enrique Mejia Saez

9.1 Introduction[1]

According to *Water Statistics in Mexico* (CONAGUA, 2008), 77 per cent of water is used for agricultural purposes although distribution across Mexico is poor. But knowledge of the spatial and time distribution of water used for irrigation purposes in Mexico is inadequate. Measurement of underground and surface water extraction for agricultural use is deficient at best, non-existent in most cases. The most trustworthy measurements are taken from irrigation districts, but the figures for water withdrawals in small irrigation units are unknown; estimates are taken from unreliable reports of irrigated surfaces reported by SAGARPA.[2] Because of the lack of measurement systems, groundwater extraction is estimated, often using questionable calculations.

The postgraduate *College of Agricultural Science* (COLPOS) has undertaken various research projects for the *National Water Commission* (CONAGUA) to estimate water use for irrigation across the country through various methods including the use of satellite images, electricity bills for pumping, sampling in irrigation areas, and volume measurements in different states throughout the country. This chapter summarizes some of the values obtained and the methodologies used for surface and groundwater measurements in each state.

Among the most important studies by COLPOS is one which estimates groundwater volumes used for irrigation in the aquifers of the Coast of Hermosillo and Janos, undertaken for the Directorate of Hydro-agricultural Infrastructure with the goal of estimating the water used for irrigation, based on remote sensing techniques and on-site sampling. More recently, in the Executive Project for Irrigation District 017 in the Comarca Lagunera, the research team used satellite images (SPOT, Landsat) to show the significant difference between water use for irrigation according to reported levels of concession permits for agriculture, and the actual volumes extracted. This documented the under-reporting in official SAGARPA reports. According to the results of these studies, the water extracted by irrigation districts is similar in magnitude to the volumes extracted by irrigation units, the difference lying in the extraction of groundwaters. Total water extraction for agricultural use was 60.7 km^3 in 2006, of which 20.1 km^3 came from groundwaters and 40.6 km^3 from surface waters.

9.2 Background

Despite the importance of water extraction measurements for controlling water use for each economic sector, it is possible that most of the water extracted from various sources is not measured. The sector that uses most water in Mexico is agriculture. Measurement of surface water extraction from dams and currents is acceptable, although there are no precise measurements of water extraction from deep wells, only estimates. Also, most small irrigation units are unmeasured, both in terms of surface and groundwater, so consumption is estimated according to the reports of irrigated surfaces.

Water extraction measurements at the urban-municipal level are also estimates; unfortunately they lack reliable information and tend to be inconsistent. Generally, there are no overall measures of water extraction in Mexico, and source metering is deficient, as the methods deployed are outdated and have been technically unreliable since the 1980's.

In 1997, the *National Water Commission* (CONAGUA) commissioned the postgraduate *College in Agricultural Science* (COLPOS) to evaluate the dimensions of irrigated surfaces and volumes of water used from the Pesquería River in the state of Nuevo León. Since the dimensions of the surfaces being irri-

1 Keywords: Water consumption, water measurements, water sources, irrigated areas.

2 SAGARPA is the Mexican Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food.

Ú. Oswald Spring (ed.), *Water Resources in Mexico: Scarcity, Degradation, Stress, Conflicts, Management, and Policy*, Hexagon Series on Human and Environmental Security and Peace 7, DOI 10.1007/978-3-642-05432-7_9,

gated with water from this river and the Ayancual Creek were unknown, the research team made a photo-mosaic of the region, as well as measurements of applied irrigation areas. Images from the satellite LANDAST 7 were also used together with software developed by the *Mexican Institute of Water Technology* (IMTA) in order to verify cultivated surfaces using the *normalized difference vegetation index* (NDVI).

In 1999 a thesis was produced (Bolaños, 2000) with the participation of the *International Irrigation Management Institute* (IIMI) and COLPOS. The aim was to evaluate the volume of water use and irrigation surfaces in the high basin of the Lerma River, using four images from Landsat 7. Through a survey of irrigation areas, measurements were undertaken on the main crops produced in that region. Images were treated using IDRISI software for the Microsoft DOS operating system.

Also in 1999, COLPOS undertook a study for CONAGUA to assess the volumes of water extracted in the aquifers of Janos and the Coast of Hermosillo, by applying remote sensing techniques using Landsat 7 images, and measurements of the irrigation areas for the crops of that region. Subsequently, the Directorate of Hydro-agricultural Infrastructure at CONAGUA entered into an agreement with COLPOS to evaluate the irrigated areas and especially small irrigation units across the country.

Since 1985 the General Directorate of Water Administration of the Ministry of Agriculture and Hydraulic Resources has been experimenting with a method of assessing the volumes of water pumped from deep wells through measurements of electricity consumption and the electromechanical efficiency of the pumping equipment. They defined different zones according to average efficiency extraction values in m^3/kWh. Employing this same method and based on energy consumption tariff 9M, reports from the *Federal Electricity Commission* (CFE), the *Coordination of Efficient Water and Energy Use* (CUEAE-SDGIH) evaluated groundwater extraction volumes in every state of Mexico in 1992. They published a manual for evaluating pumping equipment for deep wells, describing methodologies and extraction indexes for every state (CONAGUA, 1994). The methodology deployed in this study was used to estimate the irrigated surfaces and the volumes of water extracted in the *Annual Agricultural Report 2004–2005* for all irrigation units based on research by COLPOS for CONAGUA.

9.3 Objectives

This chapter will estimate the volumes of water extracted for agricultural irrigation from both surface and underground sources through pumping from deep wells in each state of Mexico. Given that there are not enough adequate measurements of these extractions, the study uses indirect methods to obtain the necessary data that are then compared with official data from CONAGUA to assess the methodological validity. Water use trends can also be evaluated by comparing available statistics from CONAGUA and SAGARPA. For this, estimates of extractions were calculated for the period 1998–2007. Based on this analysis, the authors propose actions for improving controls over water used for irrigation to reduce negative impacts on the environment, the economy, and all users of water in agriculture.

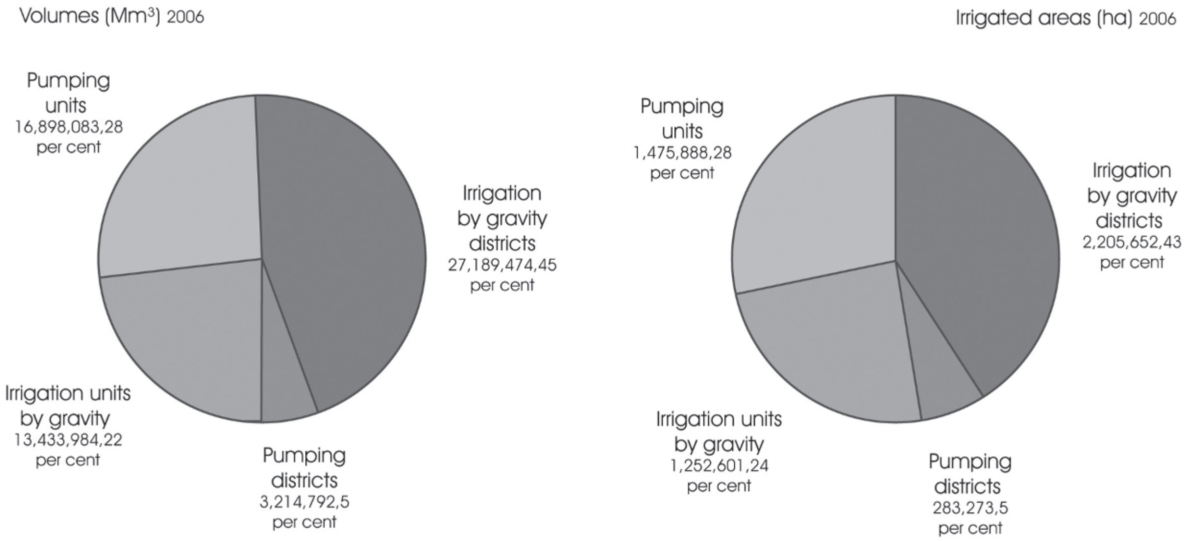
9.4 Methodology

For assessing the volumes of water used for irrigation in each state, both for irrigation districts and irrigation units, it is important to consider various hypotheses of mixed reliability that may offer an acceptable estimate. Two hypotheses are fundamental: 1) the statistics on irrigated areas by SAGARPA and CONAGUA are generally reliable, although they are questionable in many specific cases; 2) the average irrigation surfaces at the state level are representative of the average volume used per hectare for the main crops and thus are taken to estimate average volumes used per crop, which is also very controversial.

A joint study by COLPOS and CONAGUA of Irrigation District 017 Comarca Lagunera recorded that water consumption in areas with official irrigation permits was underestimated by at least 10 per cent (Bolaños et al., 2008), which severely questions the reliability of available agricultural statistics. It also showed that irrigation areas for different crops varied considerably for this irrigation district in their actual surface; usually their size was under-reported, and consequently more water was used. For groundwater extraction with deep wells, the base hypothesis is also questionable, as is the claim that it is possible to measure mean water volumes according to average kilowatts pumped using information from CFE. CONAGUA had previously scrutinized this hypothesis.

The methods proposed in this chapter for estimating water extraction volumes for agricultural irrigation deal with irrigated crops using wells. They rely on a

Figure 9.1: Distribution of irrigated areas and volume for each water source. **Source:** The authors.



proposal in a study by Cueae for CONAGUA in 1994 based on electricity consumption statistics for each state, provided in CFE reports with some adjustments as outlined below. By dividing the estimated values from this method by the irrigated surfaces (reported by SAGARPA), the average irrigation surfaces may be approximated. The average irrigated areas estimated may be compared with the measurements derived from actual surveys done by COLPOS.

CONAGUA annually supplies agricultural and hydrometric statistics at the district and state level for irrigation districts. Thus, the surfaces can be estimated, and if this information is compared with SAGARPA reports, it becomes relatively trustworthy. If the surface reported by irrigation districts is deducted from the total irrigated surface as reported by SAGARPA, one may calculate the surface of small irrigation units. But it is necessary to make adjustments to official data. For 2006, CONAGUA reported that in Baja California in Irrigation District 014 Colorado River, 197,247 hectares were irrigated, while according to SAGARPA the surface was 180,849 hectares. This difference for Irrigation District 014 reflects the fact that it includes a municipality from Sonora. Therefore, it is necessary to deduct the average irrigated surface in the municipality of San Luis Río Colorado from the total.

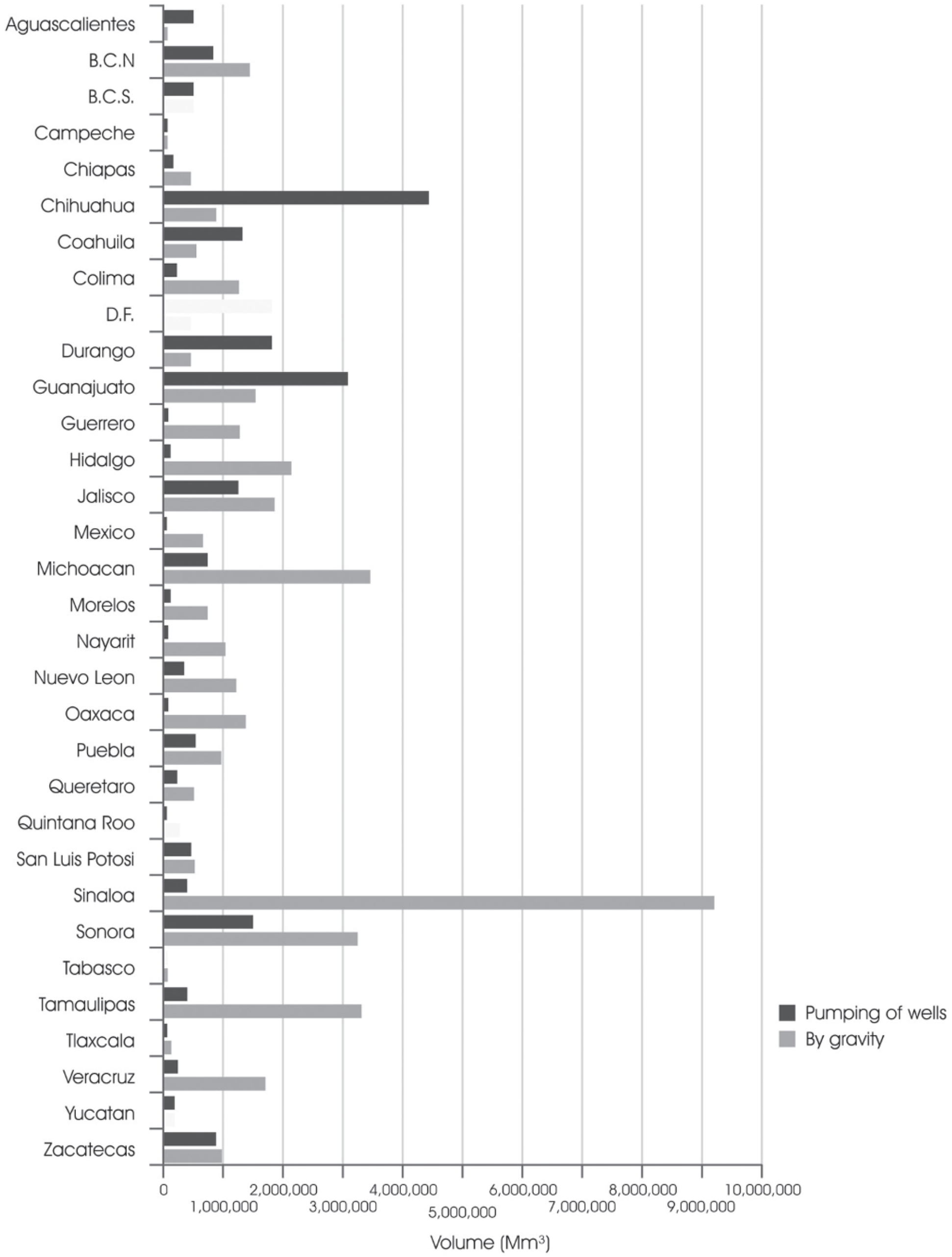
For CFE's electricity consumption reports, consumption was previously subdivided into high and low voltage. The latter corresponded to small wells for livestock and pressurized pumping systems. But part of the reported energy use corresponds to the pumping of flowing water, so a percentage must be deducted from the total to obtain proper consumption estimates for deep wells. In the original CFE reports approximately five per cent of the energy used was low voltage, and two per cent of high voltage was used for pumping from sources other than deep wells; and so the estimates were adjusted. Also, productivity indexes were adjusted to water volumes per kWh; they were usually reduced due to observed falling pumping levels.

9.5 Results and Discussion

The results obtained with these methods for water use in the agricultural sector for 2006 are shown in figures 9.1(a) and 9.1(b), displaying the distribution of volume and irrigated areas according to irrigation districts and units, at the national and state level (figure 9.2). The actual figures for each state are detailed in table 9.1. The total values of surface and groundwater extraction are congruent with CONAGUA's official statistics for 2007; approximately 40 km^3 relied on surface waters and 20 km^3 on groundwaters.

In the year 2006, the irrigated surfaces in districts and units are similar. They tend to be greater in irrigation units which have increased during the past 25 years, whereas surfaces in irrigation districts have declined (see below). Also, the total volumes of water used are similar, perhaps greater in irrigation districts, but the composition according to water source differs. Thus, while 56 per cent of water used in irrigation units comes from underground pumping, this fig-

Figure 9.2: Volumes of water extracted for irrigation according to source in each state according to the source (m3) for 2006. **Source:** The authors.

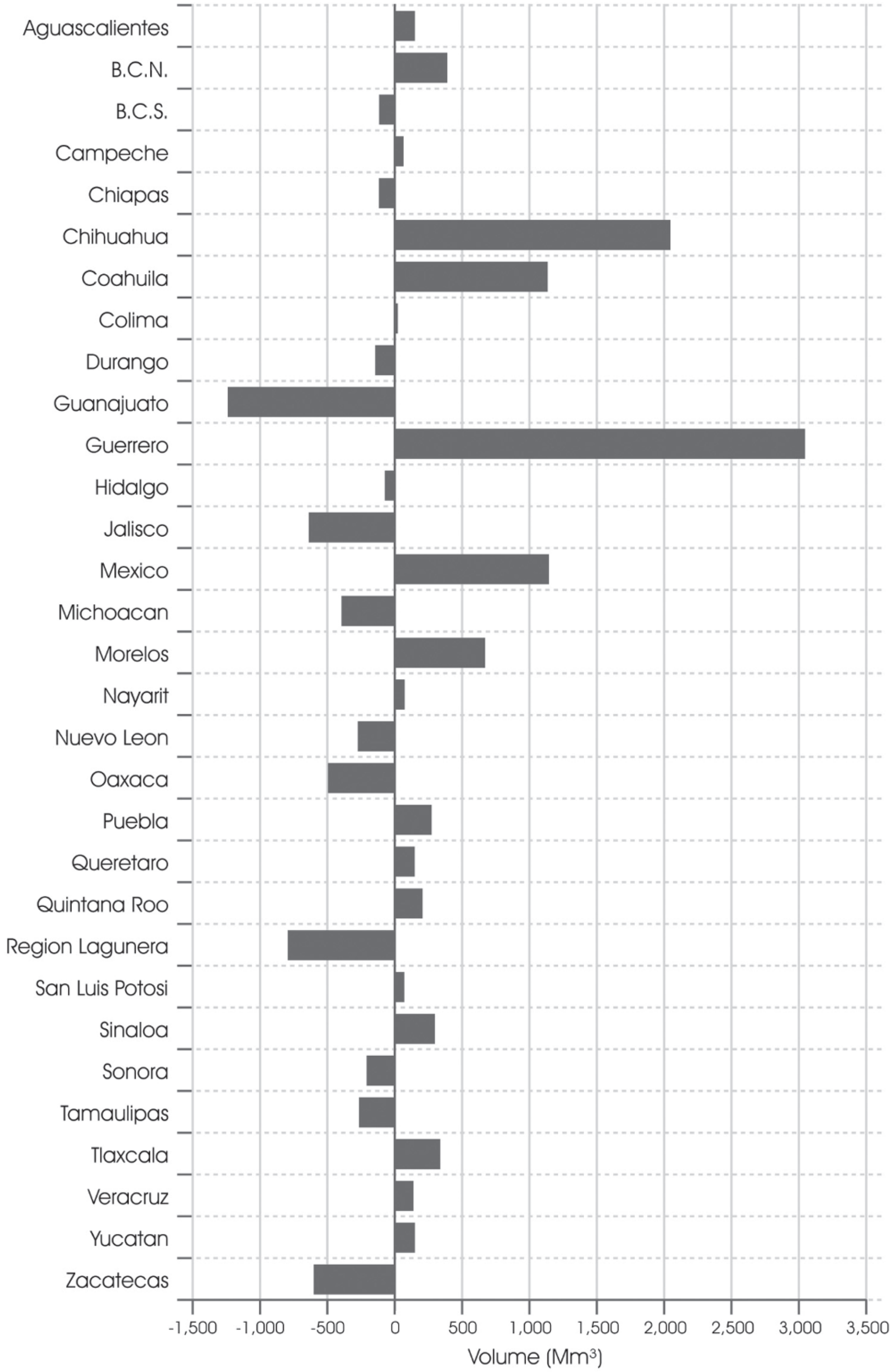


ure amounts to only 11 per cent for irrigation districts, where surface water predominates.

Based on official permits up to the year 2007, as reported by CONAGUA for each state, the volumes of water may be compared with the values obtained in this study. Figure 9.3 points to discrepancies in several states, as there is no complete record of extracted volumes due to a lack of measurements of both surface and groundwaters. However, the total differences are minimal except for some states, e.g. Durango.

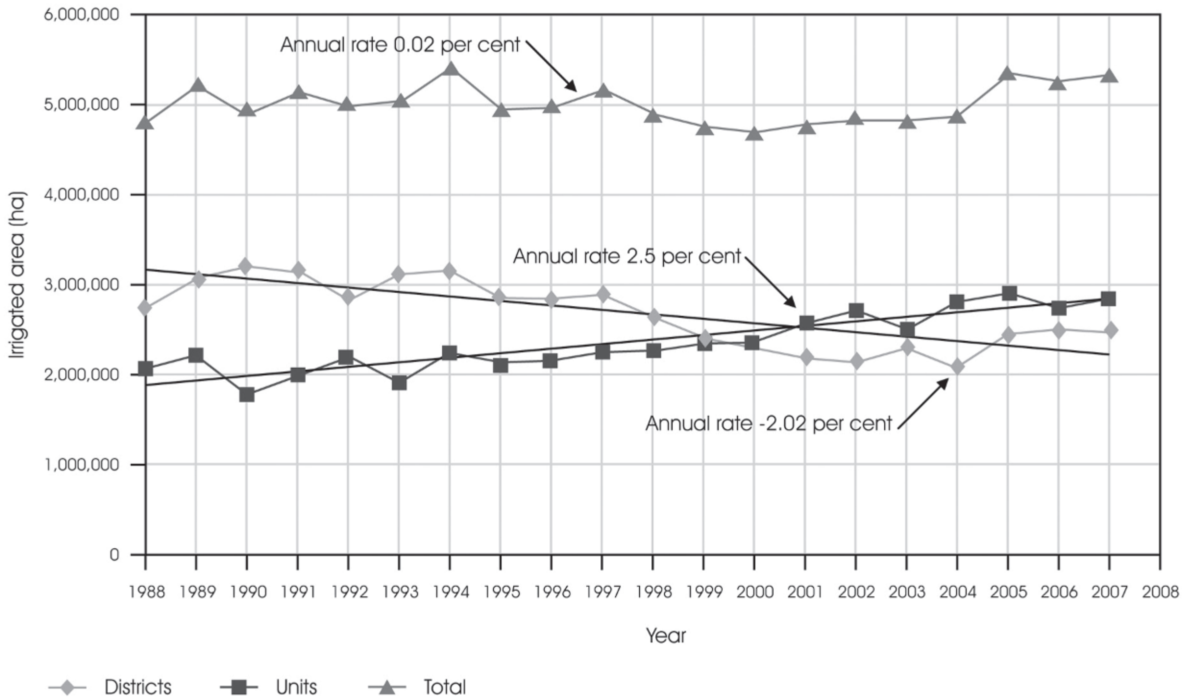
Comparing groundwater extraction for each state in 1992 (CONAGUA, 1994) with data for 2006, the authors observed an important increase in many states, such as Chihuahua, where the energy use for agriculture doubled, and for Durango and Jalisco, where it tripled. Major increases were recorded in Baja California Sur, Mexico, Querétaro, Sonora and Tlaxcala (figure 9.3).

Figure 9.3: Changes in volumes of groundwater extraction between 1992 and 2006. **Source:** The authors.



Following a similar procedure, irrigated surfaces in irrigation districts and small units were calculated, as well as water volumes from surface and underground sources for the past twenty years. The mean average growth rate per annum for each subsector was included. Thus, in figure 9.4 variations in irrigation areas may be observed at the district and small unit level between 1988 and 2007.

Figure 9.4: Variation of irrigated areas according to Irrigation Districts and Irrigation Units in Mexico (1998-2007). **Source:** The authors.



The total irrigated surface area did not grow as much during the past twenty years since the foundation of CONAGUA, despite the large number of public works that were carried out, including storage and dams, pumping plants and deep wells. Irrigated surfaces in irrigation districts have declined, even if the contrary has occurred in small irrigation units. The reduction in irrigated surfaces in irrigation districts, despite the increase in the total number of irrigation districts, is due to the fact that surface water used for irrigation in small units has come from the supply sources of the districts, as has been documented in some regions by COLPOS studies.

The variation in water volumes used for irrigation over two decades, both for surface and underground sources, is illustrated in figure 9.5. Surface water use slightly declined, whereas for groundwater a major increase occurred during the same period, due to increased numbers of wells and over-exploitation of aquifers. Energy consumption for agriculture has notably increased in this period.

The use of electricity for irrigation has steadily increased since 1962 based on CFE data. Between 1962 and 1989 energy consumption increased annually by an estimated 9.79 per cent. But from 1990 energy tariffs increased considerably, and this had an impact on consumption. Since 1993 tariffs have been adjusted and consumption has moderately increased. From 1988 to 2007, energy use increased by 1.22 per cent annually. Also, the number of users has increased more rapidly than consumption; thus, during the first stage from 1962 to 1989 the average annual growth rate of users was 10.76 per cent, whereas in the second period from 1988 to 2007 it was 2.43 per cent, almost double the rate of consumption. Figure 9.6 shows the variations in consumption (MWh) and number of users.

As can be seen for the past few years, energy consumption has stabilized at 7.5 million megawatts per hour even though the number of users has increased, indicating a decrease in the average consumption per user. This could have two causes; the first, possibly a more efficient use of electric energy due to activities by CONAGUA to improve efficiency of electromechanical equipment; and the second, a part of the consumption was for low pressure pumping, for example drip irrigation (figure 9.5).

Also, the apparent diminution of irrigated areas in organized districts during the past twenty years is worrying, especially as the number of irrigation districts has increased. However, CONAGUA's annual reports show a diminution in irrigated areas in most states. In figure 9.7 the average growth variations of irrigated surfaces for each state are shown graphically and ap-

Figure 9.5: Variation in volumes of water used for irrigation according to source. **Source**: The authors.

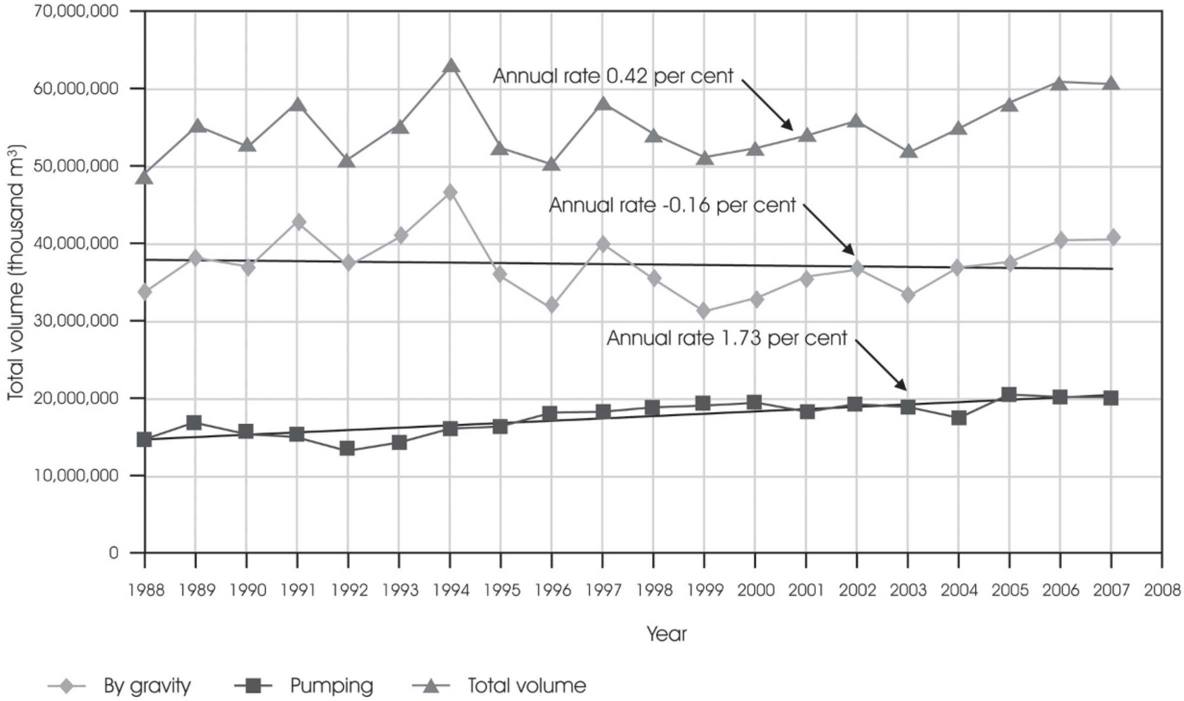
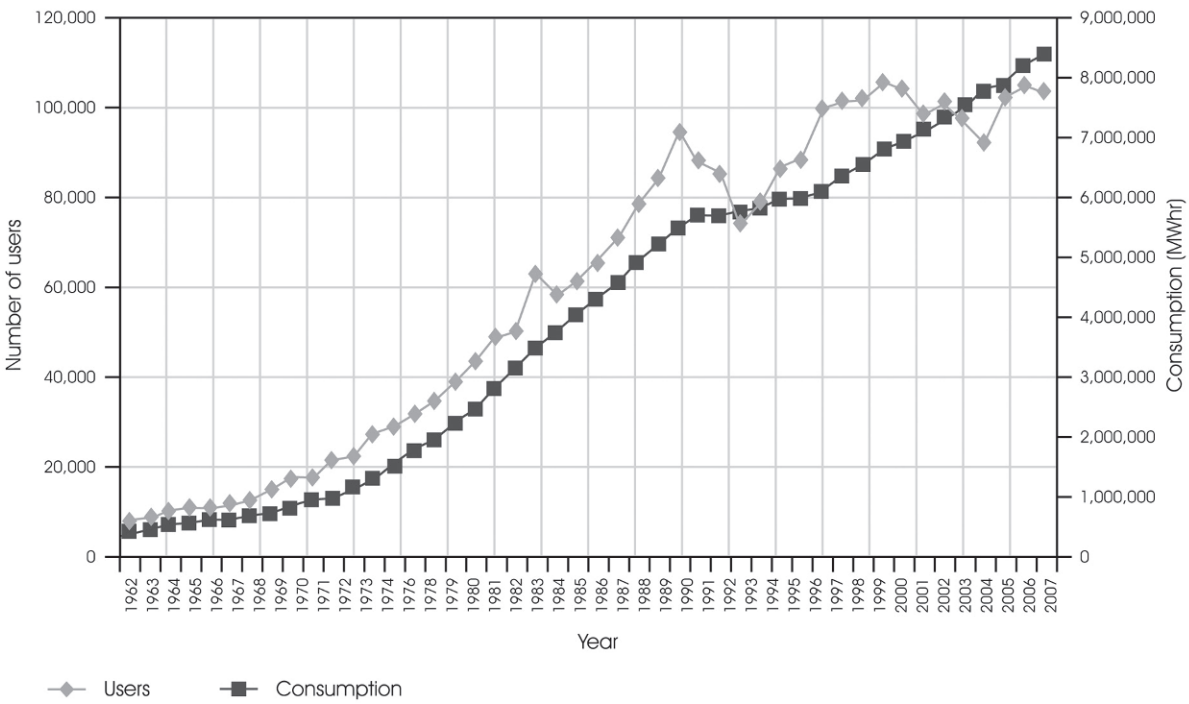


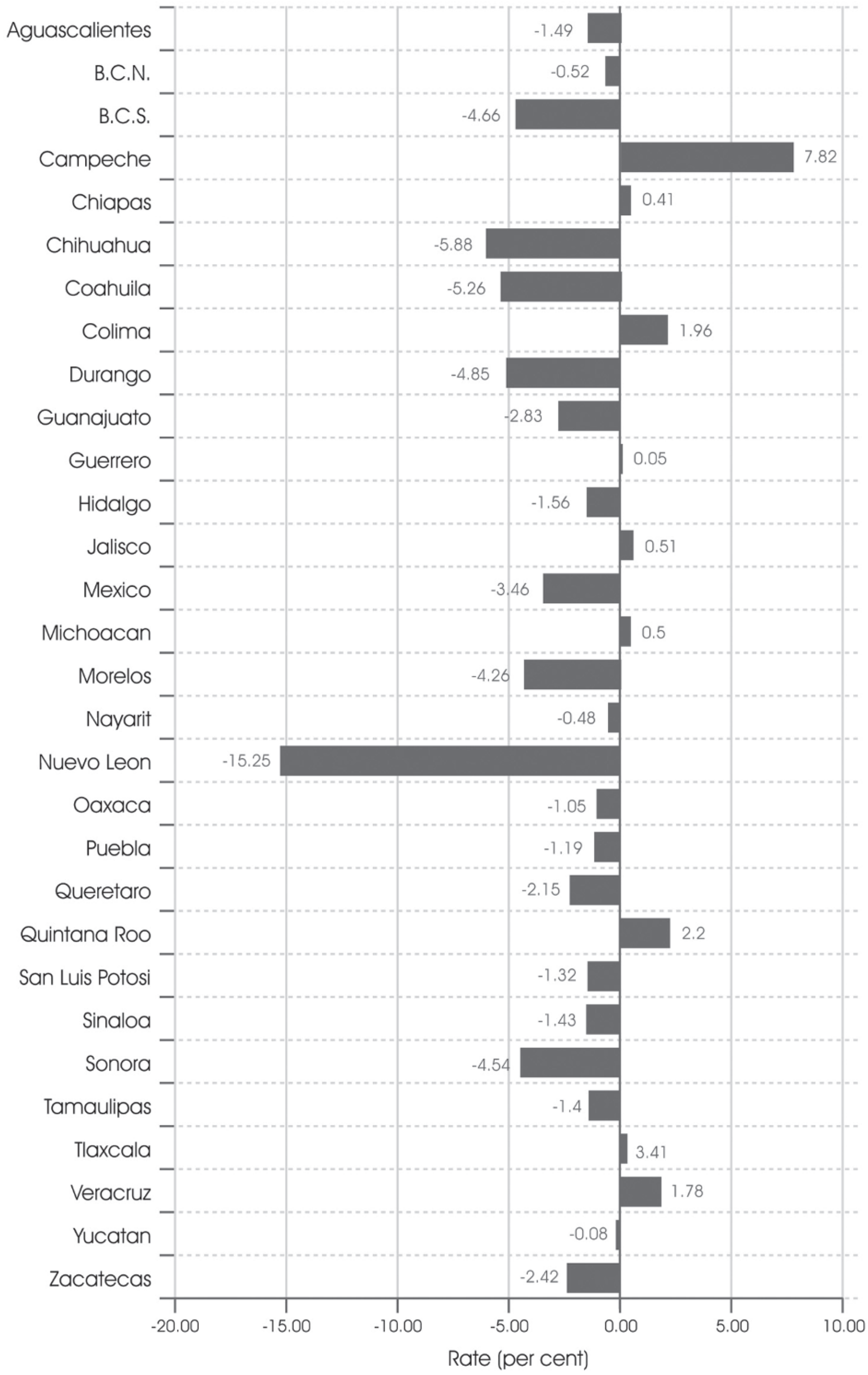
Figure 9.6: Variations in energy consumption (MWh) and number of users in the agricultural sector, 1962- 2007. **Source**: The authors.



pear to be negative, except in Campeche, where the irrigation district by pumping source became a small irrigation unit.

However, there has been an increase in small irrigation units, as well as a rise in users of surface water and groundwater, which has compensated the former

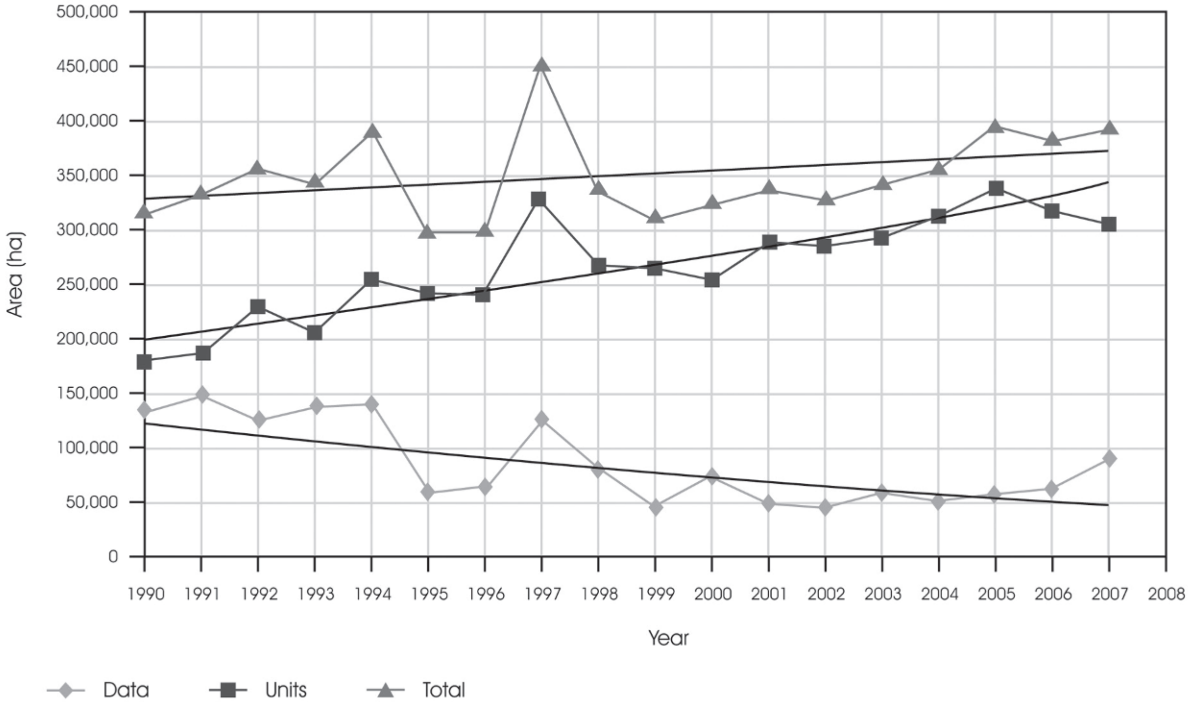
Figure 9.7: Average growth variation of irrigation areas contrasted with irrigation districts for each state. **Source**: The authors.



trend in irrigation districts. This means that water previously used for irrigation in districts is currently being used for micro-irrigation, and that groundwater extraction by deep wells has increased.

An important example of this is the state of Chihuahua, where the surface irrigated in districts has considerably decreased (figure 9.7), with an annual variation rate of -5.88 per cent, but the rise of overall

Figure 9.8: Variation of irrigation areas in the State of Chihuahua. **Source**: The authors.



irrigated surface of the state is positive (0.7 per cent annually). This is caused by water use in irrigation units, especially with wells, which have increased by 3 per cent per annum, implying an increase in energy consumption and in groundwater extraction. To illustrate this specific example, figure 9.8 shows how irrigated surfaces have varied in the state of Chihuahua, a case where irrigation has shifted from the irrigation districts to smaller irrigation units.

From a legal, environmental and economic perspective, an important problem is the building of an irrigation infrastructure without thoroughly evaluating its impact. This affects users by undermining their rights, the environment if works negatively impact on regions, and the economy as investments might have negative productivity.

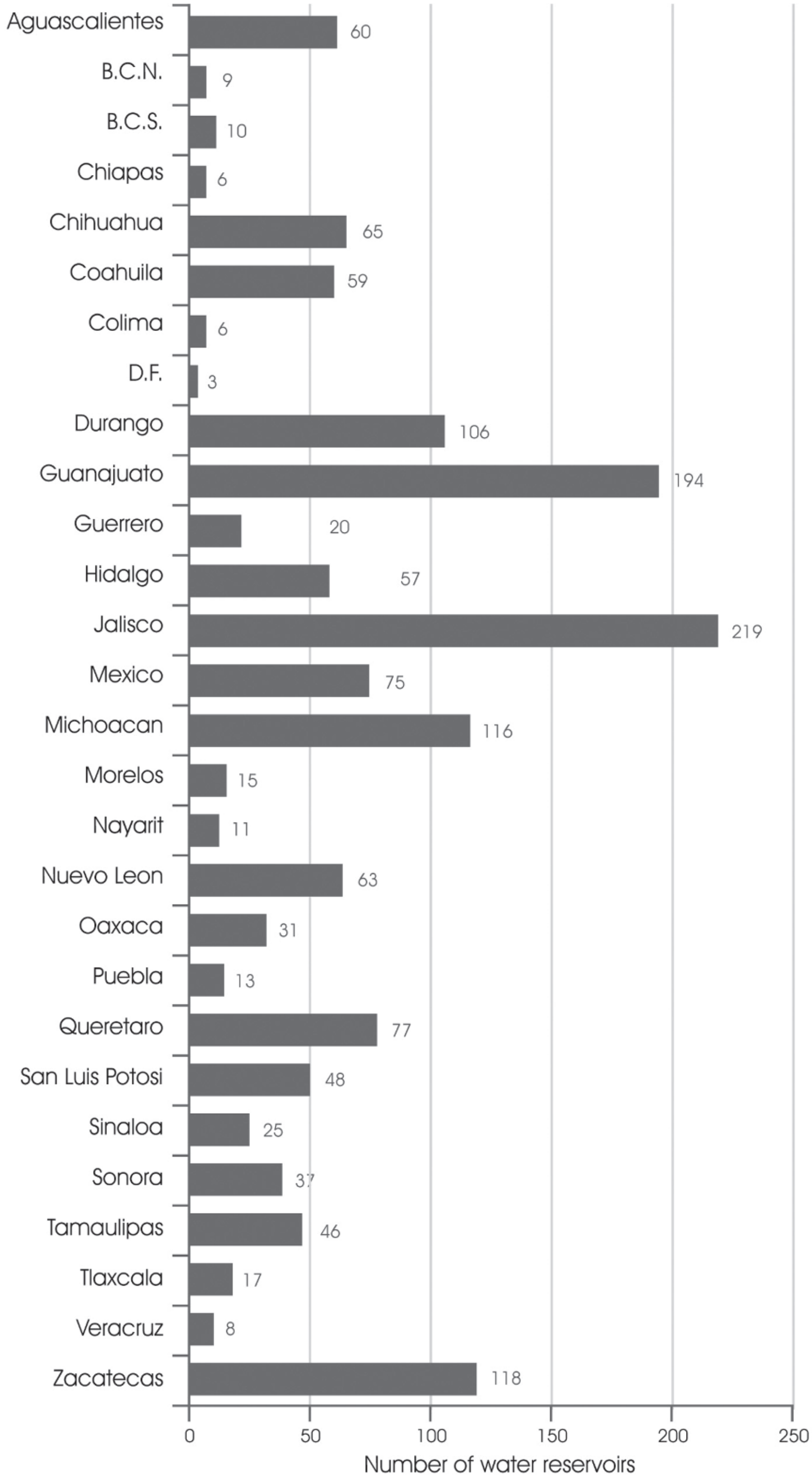
A well known example is the construction of the dam El Molinito in the River Sonora, upstream from the dam Abelardo Rodríguez, and close to the city of Hermosillo. This dam stopped the waters from arriving at Rodríguez dam, which operated as one of the prime water sources for the city and as a thermal regulator, given that water evaporation in the dam positively impacted on the high summer temperatures. With the construction of the new dam, water flows in the aquifer of the Coast of Hermosillo were significantly reduced, and agriculture in the region of the high basin was favoured, further reducing surface and underground run-off downstream.

These types of problems became generalized due to a lack of thorough studies on the environmental impact of irrigation works. COLPOS undertook various studies in the River La Laja basin in Guanajuato where the negative impacts of irrigation infrastrucutre and well drilling in the high basin were demonstrated (Palacios, 2004). During the last twenty-five years the construction of new water infrastructure has affected the water users and the environment, generating conflicts between regions and producing reduced irrigation surfaces in many areas of the country.

According to CONAGUA reports, during the past twenty years infrastructure was built for up to 20 thousand hm^3, but the present study shows that the overall irrigated surface remained constant, with 5 million hectares being cultivated annually on average (variations are mainly due to weather conditions). The problem has been the construction of too many dams, with water contention walls and dykes generating water losses due to evaporation and to upriver dams curtailing flows downstream. Thus, works that benefit small irrigation units have reduced water sources for irrigation districts.

According to CONAGUA's database, Mexico has more than 15,000 reservoirs with a capacity of more than 0.5 hm^3, with an overall total capacity estimated

Figure 9.9: Number of dams with a capacity of over 0.5 hm^3 by state. **Source**: The authors.



at over 150,000 cubic hectometres; this includes important dams used for hydroelectric generation, but the proportion is much higher for smaller dams used for irrigation. Some states have more than a hundred (figure 9.9).

Besides dams, there are also a high number of levees and irrigation channels with different capacities; they are mainly used for irrigation and livestock. SAGARPA, through its programme of micro-basins, has supported the building of these levees and irrigation channels, which keep run-off waters from reaching dams. For example, in Guanajuato, besides the 194 dams registered by CONAGUA, there are 830 levees and irrigation channels in the various municipalities of the state.

So far there is no agreement between SAGARPA and CONAGUA on guidelines for authorizing the construction of levees and irrigation channels. CONAGUA itself builds new water dams upriver in the same streams where there are other dams, affecting the rights of users of irrigation districts and small irrigation units.

It is worrying that many hydraulic works built by CONAGUA lack adequate environmental impact studies. Often, they have only assessed their most apparent benefits, neglecting any broad negative impact or environmental externalities. Another worrying fact is that CONAGUA provides faulty reports on irrigation surfaces to international institutions such as FAO, based on areas that according to CONAGUA are suitable for irrigation but are not actually irrigated. Thus, according to National Water Statistics 2008, the irrigated surface in Mexico is reported as 6.46 million hectares. Such an area has never been irrigated; the maximum surface that has been irrigated, including primary and secondary crops, has been 5.41 million hectares in 1994. This means one million hectares less than what is reported. Furthermore, the area suitable for irrigation is estimated by experts at less than 5 million hectares, despite new irrigation works being inaugurated every year.

In a study undertaken by COLPOS and CONAGUA (1998) on the surface that could be suitable for irrigation within irrigation districts – based on data directly provided by the personnel responsible for operations in the districts – the figure for the area having sufficient water was estimated at 3.1 million hectares. Thus, the annual water availability in some irrigation districts did not enable all available infrastructures to operate.

It would possible to increase the irrigated surfaces if it were possible to enhance water use efficiency, for which it would not be necessary to create more irrigation districts or units, but rather to make better use of the available infrastructure. Generally, water use efficiency is considered to be low, although it would be important to undertake more detailed studies on the real efficiency of water use.

Information on the efficiency of water-carrying devices such as pipes or ducts exists, but it is not very reliable. Water supply is not measured when it arrives at the irrigation fields. Looking at the variation patterns in data reported by CONAGUA on water-carrying efficiency in irrigation districts (figure 9.10) in the period between 1985 and 2005, it is difficult to identify possible causes. It is assumed that data are more reliable after 1990 when estimates were made by CONAGUA; but even then there is a significant increase from 1990 up to 1996, with a decline in 1997 and 1998, rising again in 1998 and falling again from 1999 onwards. Perhaps this is due to under-reporting by organizations of water users, called also 'administrative losses'.

If we analyse losses in terms of water-carrying efficiency in each irrigation district, there are some that do not have significant reductions, for example Irrigation District 014 Colorado River and Irrigation District 038 Mayo River. They have negative variations of up to 10 per cent, indicating that a part of these losses are indeed administrative losses.

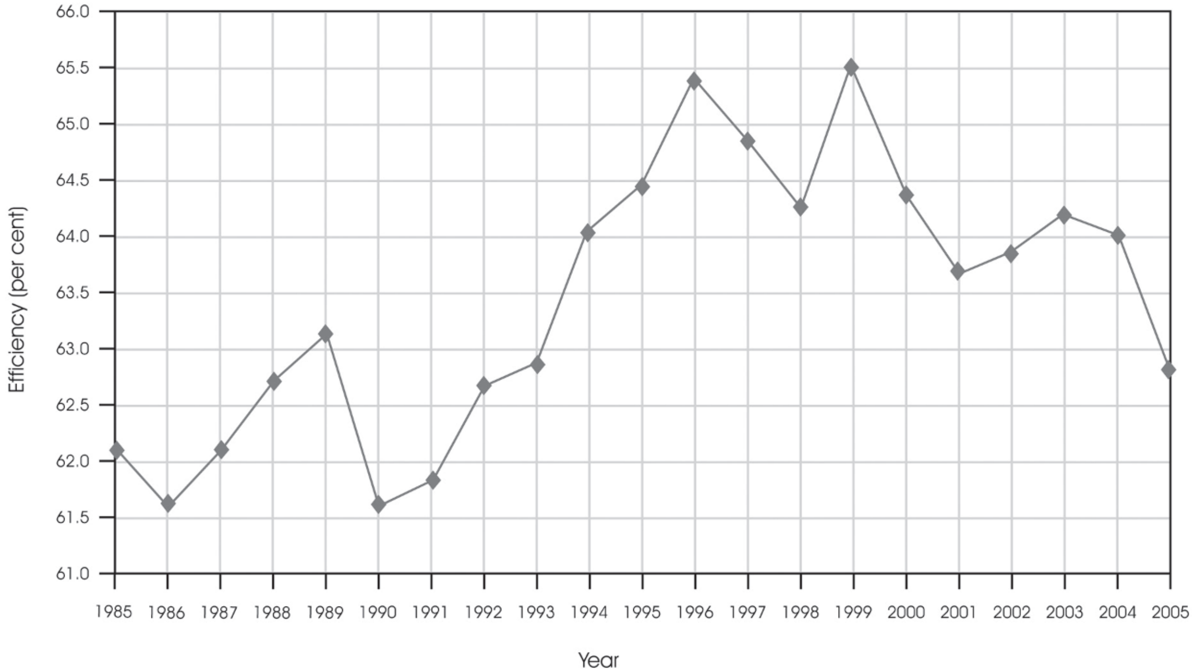
Also, we must consider irrigation districts in the inner part of Mexico, where the water is not really lost, because the run-off can be used downstream, and it recharges aquifers via infiltration. As for losses due to mismanagement in the actual irrigation fields, there is not enough information to make a reliable assessment. However, in some irrigation districts a considerable volume of water is lost due to poor irrigation practices. However, in many cases this trend is reversing because farmers are realizing that with efficient use of water they not only save water but also achieve greater productivity.

Improvement in water management focused on the distribution networks and on actual irrigation methods is a way of increasing irrigation areas without heavy investment. However, this requires the implementation of improved techniques, including efficient structures in the distribution network, levelling lands, and applying the most efficient irrigation methods.

9.6 Conclusions and Recommendations

Estimates of water use for agriculture in Mexico rely on methods used by CONAGUA. They show that irrigation areas in irrigation districts have been reduced

Figure 9.10: Conveyance efficiency reported by irrigation districts. **Source:** The authors.



at the same time as areas irrigated in small units have increased. These trends have allowed the overall irrigated surface to remain constant for the past two decades, with only minor variations caused mainly by weather conditions, as there is less surface water available in dry years.

Available annual surface water volumes have also decreased, which has led to an increase in groundwater use, especially through deep well pumping. Thus, many of the most important aquifers in the centre and north of Mexico have been over-exploited. Diminishing surface waters are not only caused by climate conditions, they are also related to evaporation in irrigation infrastructure and to the decreased runoff either because water is used in the upstream basin or because part of the waters used for irrigation is destined for other purposes.

Here, it is pertinent to note that water from wells used for irrigation has certain advantages over surface water, for example time and space, because farmers can make use of it when crops need it. This is not always possible with surface water, especially in irrigation districts where water availability is limited, either because water is insufficient or because water-carrying networks are inadequate to meet demand on time. Besides, some localized irrigation methods cannot be properly maintained in most irrigation districts.

Given energy tariffs subsidized by CFE, it is still possible for agricultural producers to irrigate the least profitable crops without economic losses; this policy produces an over-use of groundwater, and this is why pumping water has become more popular.

Currently there is not enough control over the distribution, efficiency, and use of water. The National Water Law has important limitations, including lacking a definition of what water rights are. Users of water for irrigation often lack legal security over the water volumes allowed by official permits. In other countries, water rights are clearly defined as the volume of virtual water estimated according to mean water availability in basins (statistically defined as a 50 per cent probability, not as an arithmetical measure), and every year water authorities estimate mean availability in order to fix greater or lower volumes to match official user permits.

Increasing irrigation areas without having enough available water poses a threat to all water users who currently have a right over that water and who see water availability decreasing. This situation is already present in many over-exploited basins, and it constitutes one of the causes of the decline of surface water for agricultural irrigation.

It is important to measure water properly when it is distributed, not only in agriculture, but in every sector, in order to make a fair allocation of water resources, and to ensure that the National Water Law is obeyed. Besides, it is important to provide water to users by volume so that they can save water for example from one agricultural cycle to the next. This would ensure efficiency and at the same time boost productivity. A strictly regulated market of water rights would also be an alternative.

Despite all factors that have been addressed in this chapter, irrigation agriculture has a great potential. While water use efficiency is currently low, it could be enhanced by using appropriate practices. Agricultural productivity could be doubled with the water and infrastructure currently available. Technology exists to improve crop productivity significantly, increasing the production of foods and raw materials. Unfortunately, this technology has not been accessible to most users in the agricultural sector, which is why the government, together with user organizations, technological centres and universities, disseminates this knowledge. A minor investment in these terms would be greatly beneficial to water users and to the entire country.

References

Bolaños, G.M. (2000), "Estimación de los volúmenes de agua usados en zonas de riego mediante el uso de sensores remotos", Master thesis in hydrology, Montecillo, Colegio de Postgraduados (COLPOS).

Bolaños, G.M., F. Paz, E. Palacios, V.A. Zarco, F. Pascual and A. Cano (2008), "Estimación de superficies regadas usando imágenes de satélite en el distrito de riego número 17, Región Lagunera", Florianopolis, Reunión Red Iberoamericana de Riegos.

CFE [Comisión Federal de Electricidad] (1962–2007), *Anuarios sobre producción y distribución de energía eléctrica en México*, at: <www.cfe.gob.mx>.

COLPOS (1998), *Diagnóstico sobre la situación de los distritos y unidades de riego,* Estudio llevado a cabo para la SDGIH, Montecillo, Colegio de Postgraduados, Programa de Hidrociencias.

__ (1999), *Estimación de las áreas regadas y los volúmenes utilizados en los acuíferos de Janos, Chihuahua y Costa de Hermosillo, Sonora*, Estudio llevado a cabo para la SDGT de la CONAGUA, Hermosillo and Montecillo, Colegio de Postgraduados, Programa de Hidrociencias.

CONAGUA (1990–2007), "Estadísticas agrícolas de los distritos de riego" (1990–2007), Hermosillo, Gerencia de Uso Eficiente del Agua y la Energía (SDGIH).

__ (1990–2007), "Superficies Regadas y Volúmenes de Aguas Distribuidos en los Distritos de Riego", Hermosillo, Department of Irrigation Districts (SDGIH).

__ (1994), "Uso Eficiente del Agua y la Energía Eléctrica", Hermosillo, Gerencia de Uso Eficiente del Agua y la Energía (SDGIH).

__ (2006), "Estadísticas Agrícolas de las Unidades de Riego: Año Agrícola 2004–2005", Hermosillo, Gerencia de Uso Eficiente del Agua y la Energía (SDGIH).

__ (2008), "Estadísticas del Agua en México", at: <www.cna.gob.mx>.

Palacios V. E. (2004), "La sobre explotación de las Cuencas Hidrológicas: El caso de la Cuenca del Río Laja, Guanajuato", in Helena Cotler (ed.), *Manejo Integral de Cuencas en México,* Mexico, SEMARNAT, Instituto Nacional de Ecología, pp. 117–131.

SAGARPA (2008), "Sistema de Información Agroalimentaria de Consulta (SIACON) 1988–2007", in *Information System for Food and Fishery*, at: <www.siap.sagarpa.gob.mx>.

Annex 1: Areas and volumes used in irrigation units and districts in 2006. **Source**: The authors.

	District (ha)			Units (ha)			Total area (ha)	Districts hm^3			Units hm^3			Total volume
State	Area	Pumped area	Total area	Area	Pumped area	Total area	Irrigated area	Volume	Pumped volume	Total volume	Volume	Pumped volume	Total volume	Irrigated volume
	Districts)	Districts	Districts	Units (ha)	Units (ha)	Units (ha)	Units +Districts	Districts hm^3	Districts hm^3	Districts hm^3	Units hm^3	Units hm^3	Units hm^3	Units +Districts hm^3
1. Aguascalientes	3,500	3,908	7,408	386	39,774	40,160	47,568	25,271	37,057	62,328	4,036	443,442	447,479	509,807
2 Baja California	100,990	66,049	167,039	3,090	10,719	13,810	180,849	1,390,298	799,775	2,190,073	32,309	6,294	38,603	2,228,676
3 Baja California Sur	0	27,316	27,316	1,520	5,778	7,298	34,614	0	152,693	152,693	12,917	112,060	124,976	277,669
4 Campeche	0	0	0	8,476	7,987	16,464	16,464	0	0	0	68,657	64,698	133,356	133,356
5 Chiapas	23,268	0	23,268	13,833	14,335	28,169	51,437	300,258	0	300,258	155,762	161,417	317,179	617,437
6 Chihuahua	50,420	15,022	65,442	140	319,495	319,635	385,077	880,728	192,276	1,073,004	2,032	4,256,794	4,258,827	5,331,831
7 Coahuila De Zara-goza	37,835	0	37,835	1,359	97,010	98,369	136,204	532,606	0	532,606	15,821	1,309,636	1,325,457	1,858,063
8 Colima	26,762	0	26,762	35,960	14,948	50,908	77,670	744,874	0	744,874	521,744	216,877	738,621	1,483,495
9 Mexico City	0	0	0	2,294	212	2,507	2,507	0	0	0	24,090	3,205	27,296	27,296
10 Durango	36,367	1,468	37,835	3,913	98,666	102,579	140,414	380,292	14,337	394,629	47,352	1,768,041	1,815,393	2,210,022
11 Guanajuato	58,953	44,588	103,541	97,018	269,602	366,619	470,160	568,959	431,456	1,000,415	950,772	2,647,603	3,598,375	4,598,790
12 Guerrero	17,801	0	17,801	59,736	2,908	62,643	80,444	421,608	0	421,608	848,248	37,217	885,465	1,307,073
13 Hidalgo	75,780	0	75,780	50,160	7,526	57,687	133,467	1,391,306	0	1,391,306	737,267	110,622	847,890	2,239,196
14 Jalisco	49,392	0	49,392	78,420	93,084	171,504	220,896	777,009	0	777,009	1,072,872	1,273,488	2,346,359	3,123,368
15 State Of Mexico	16,334	0	16,334	125,190	15,952	141,143	157,477	94,602	0	94,602	543,207	69,217	612,423	707,025
16 Michoacán De Ocampo	153,579	17,092	170,671	148,745	54,410	203,156	373,827	1,924,454	130,351	2,054,805	1,508,102	594,598	2,102,700	4,157,505
17 Morelos	20,449	0	20,449	21,261	4,042	25,303	45,752	467,670	0	467,670	270,018	91,191	361,209	828,879
18 Nayarit	22,060	0	22,060	38,882	1,755	40,637	62,697	415,339	0	415,339	608,604	27,469	636,074	1,051,413
19 Nuevo León	13,247	0	13,247	64,085	21,238	85,323	98,570	235,837	0	235,837	943,041	312,523	1,255,564	1,491,401
20 Oaxaca	24,886	0	24,886	54,208	2,687	56,895	81,781	698,865	0	698,865	677,598	59,564	737,162	1,436,027
21 Puebla	19,553	0	19,553	67,674	56,637	124,311	143,864	234,941	0	234,941	682,383	571,085	1,253,467	1,488,408

	District (ha)			Units (ha)			Total area (ha)	Districts hm^3			Units hm^3			Total volume
State	Area	Pumped area	Total area	Area	Pumped area	Total area	Irrigated area	Volume	Pumped volume	Total volume	Volume	Pumped volume	Total volume	Irrigated volume
	Districts)	Districts	Districts	Units (ha)	Units (ha)	Units (ha)	Units +Districts	Districts hm^3	Districts hm^3	Districts hm^3	Units hm^3	Units hm^3	Units hm^3	Units +Districts hm^3
22 Querétaro De Arteaga	1,000	6,155	7,155	32,187	8,535	40,722	47,877	20,526	34,758	55,284	450,612	170,908	621,520	676,804
23 Quintana Roo	0	2,700	2,700	0	401	401	3,101	0	23,566	23,566	0	3,810	3,810	27,376
24 San Luis Potosí	20,794	0	20,794	38,535	57,056	95,591	116,385	190,924	0	190,924	288,772	427,562	716,334	907,258
25 Sinaloa	702,932	0	702,932	52,028	43,084	95,113	798,045	8,734,461	0	8,734,461	471,128	390,138	861,266	9,595,727
26 Sonora	322,911	91,155	414,066	27,498	57,273	84,771	498,837	3,005,224	1,363,021	4,368,245	216,436	121,261	337,697	4,705,942
27 Tabasco	0	0	0	3,601	1,367	4,968	4,968	0	0	0	30,607	11,624	42,230	42,230
28 Tamaulipas	350,424	0	350,424	74,880	61,743	136,623	487,047	2,857,798	0	2,857,798	432,032	356,233	788,265	3,646,063
29 Tlaxcala	4,030	0	4,030	16,180	7,136	23,316	27,346	22,191	0	22,191	77,982	34,392	112,374	134,565
30 Veracruz-Llave	42,464	0	42,464	63,643	298	63,941	106,405	746,768	0	746,768	941,700	237,920	1,179,620	1,926,388
31 Yucatán	0	7,820	7,820	2,175	26,508	28,683	36,503	0	35,502	35,502	17,618	129,273	146,892	182,394
32 Zacatecas	9,921	0	9,921	65,521	73,721	139,242	149,163	126,665	0	126,665	780,266	877,921	1,658,187	1,784,852
Totals	2,205,652	283,273	2,488,925	1,252,601	1,475,888	2,728,489	5,217,414	27,189,474	3,214,792	30,404,266	13,433,984	16,898,083	30,332,067	60,736,333