# Chapter 5
# Water Resources Inventory and Implications of Irrigation Modernization

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**Abstract** This chapter presents the effects on water resources created by the introduction of an irrigation modernization policy. The impact caused by the increase of irrigation coverage tends to have negative effects on water stocks because of its technological characteristics and productive practices in the primary sector.

**Keywords** Water resources · Irrigation challenges

## 5.1 Water Resources Inventory and Infrastructure

For management and preservation purposes, since 1997 the country has been divided into 13 Hydrological-Administrative Regions (HAR), which are formed by grouping hydrographic basins. A basin is the basic unit for water resources management, but its limits consider municipalities to facilitate the integration of socioeconomic information (Conagua 2011a).

In Mexico, there is a marked contrast between population living in a given HAR, production value, and renewable water resources. HRA XIII, Mexico Valley Waters, contains almost 20 % of the total population; it contributes a little more, 2 out of every 10 pesos of the national GDP, and it is located in a region with less than 1 % of renewable water resources (Fig. 5.1).

Every year, Mexico receives approximately 1,489 billion cubic meters ($km^3$) in the form of precipitation. It is estimated that 73.1 % of this volume evaporates and returns to the atmosphere; 22.1 % runs off rivers and streams, and the remaining 4.8 % naturally filters through the subsoil and recharges the aquifers. Considering water exports and imports with neighboring countries and incidental recharge, annually the country has 460 $km^3$ of renewable fresh water.[1]

[1]Maximum quantity of water that can feasibly be used every year in a region; it is the quantity of water that is renewed by rainfall and the water that comes from other regions or countries (imports). It is calculated as the mean natural annual internal surface runoff, plus the total annual recharge of aquifers, plus water imports from other regions or countries, minus the water exports to other regions or countries. In the case of Mexico, the mean values are calculated from studies carried out in each region (Conagua 2011c).



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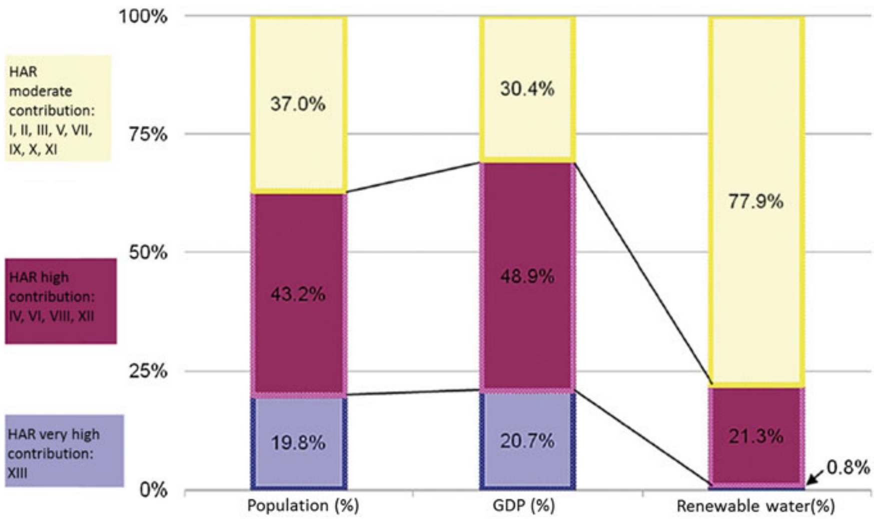


**Fig. 5.1** Contrast in contribution to population, regional gross domestic product and renewable water availability, 2009. *Source* Conagua 2010a *Note* Hydrological-Administrative Regions: I Baja California Peninsula; II Northwest; III Northern Pacific; IV Balsas; V Southern Pacific; VI Rio Bravo; VII Central Basins of the North; VIII Lerma-Santiago-Pacific; IX Northern Gulf; X Central Gulf; XI Southern Border; XII Yucatan Peninsula; XIII Waters of the Valley of Mexico

According to Conagua (2011c), national precipitation is around 760 mm per year; renewable water in the country is just over 460 million cubic hectometers. In 2009, water availability per capita was 4,262 $m^3$/inhabitant/year (Fig. 5.2).

The rivers and streams of Mexico constitute a hydrographic network of 6,33,000 km; 50 main rivers stand out, through which 87 % of the surface runoff flows. Two-thirds of the surface runoff belongs to seven rivers: Grijalva-Usumacinta, Papaloapan, Coatzacoalcos, Balsas, Panuco, Santiago, and Tonala. The surface area of their watersheds represents 22 % of the surface of Mexico (Conagua 2011c: 27).

In Mexico, evaluation of water quality is carried out using three indicators: biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). In 2009, it was determined that 21 basins were classified as heavily polluted in one, two, or all three of these indicators. According to BOD, 13 % of surface waters is polluted; 31 % according to COD; and 7.5 % according to TSS.

As for groundwater, which is divided into 633 aquifers (Conagua 2012), it represents almost 37 % of the total volume allocated for offstream uses. From the 1970s, the number of overexploited aquifers has increased considerably, from 32 aquifers in 1975, 80 in 1985, to 105 in 2010. From these overdrafted aquifers, 54 % of groundwater is extracted for all uses, which has caused 32 aquifers to suffer the phenomenon of saltwater intrusion and/or soil salinization and brackish groundwater (Conagua 2011c: 35).

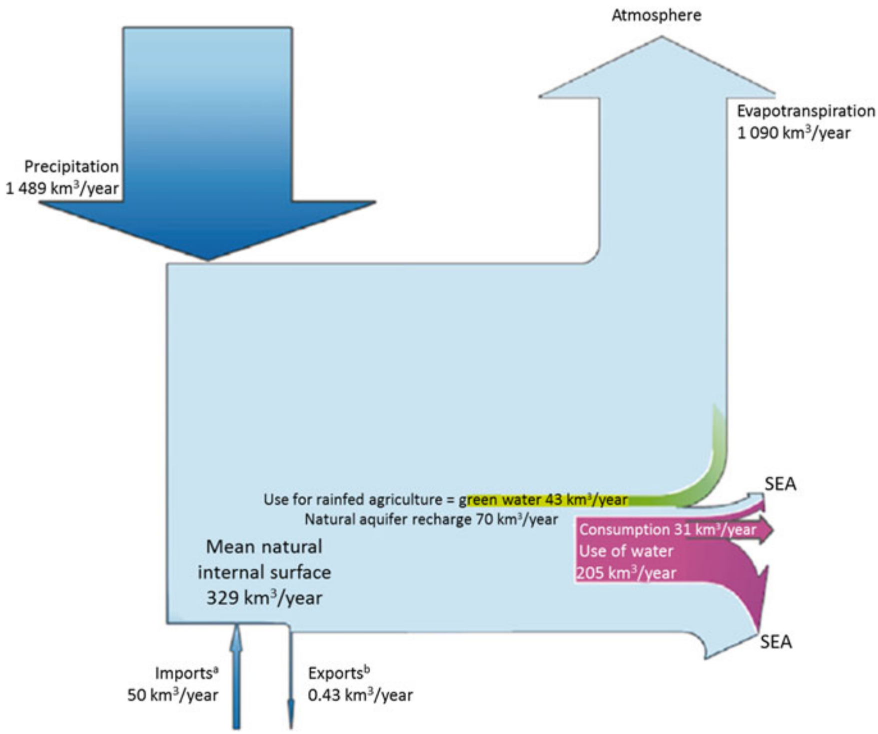


**Fig. 5.2** Mean annual values of the components of the hydrologic cycle in Mexico (km$^3$). *Source* Conagua 2011c. *Note* The mean annual precipitation refers to the period 1971–2000. The remaining values are averages reported for 2009. The natural aquifer recharge reported in the figure, plus 9 km$^3$ of incidental recharge, constitute the total mean recharge

Water volume classification for offstream uses has four main groups: agriculture, public supply, self-supplying industry, and electricity generation. As shown in Fig. 5.3, the greatest water allocation is that corresponding to agricultural activities (61.8 km$^3$), followed by public supply (11.4 km$^3$), electricity (4.1 km$^3$), and self-supplying industry (3.3 km$^3$). It should be noted that 63 % of the water used in Mexico for offstream uses comes from surface water sources (rivers, streams, and lakes), whereas the remaining 37 % comes from groundwater sources (aquifers). In the period 2001–2009, surface water allocation grew by 15 %, while underground water increased by 21 %.

In 2009, hydropower plants (instream use) employed 136.1 km$^3$ of water to generate 26.4 TWh, which represents 11.3 % of the electricity produced in Mexico. These plants have an installed capacity of 11,383 MW, or 22 % of the country's total. At national level, the stress exerted on hydric[2] resources is moderate;

[2]Percentage of water used for offstream uses as compared to the renewable water resources. Indicator of the water stress in any given country.

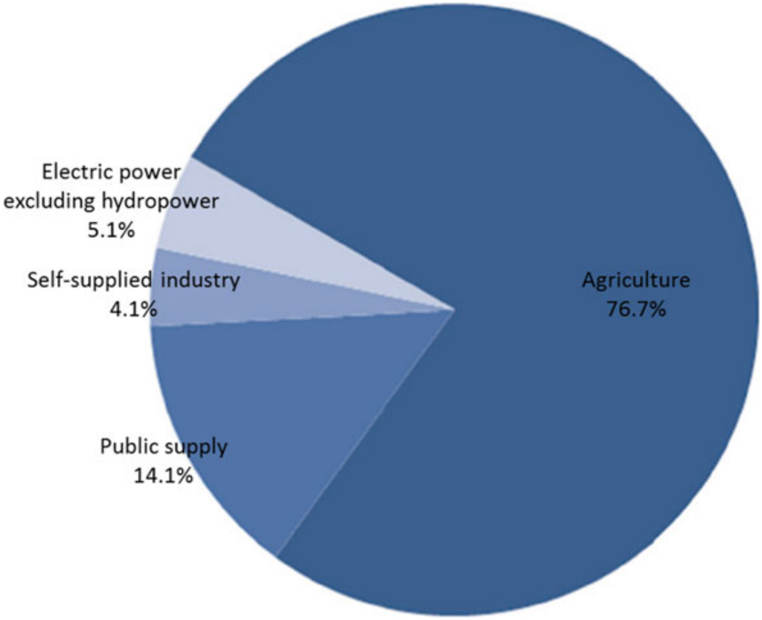


**Fig. 5.3** Allocation volume distribution for offstream uses, 2009. *Source* Conagua (2009)

however, XIII Waters of the Valley of Mexico HAR is under high stress; seven HAR (Baja California Peninsula, Northwest, North Pacific, Balsas, Bravo River, North Central Basins, and Lerma-Santiago-Pacific) are under a strong degree of stress; Northern Gulf region is under low stress and four HAR (South Pacific, Central Gulf, South Border, and Yucatan Peninsula) have no stress.

Among the hydraulic infrastructure available within the country to provide the water required for the various national users, the following stands out: 4,462 dams and water retention berms; 6.50 million hectares with irrigation; 2.9 million hectares with technified rainfed infrastructure; 631 treatment purification plants in operation; 2,029 municipal wastewater treatment plants in operation (Conagua 2011c: 58).

National drinking water coverage is about 90 %, being higher in urban zones (95 %) than in rural areas (70 %). These values have increased since 1990, which were 89.4 and 51.2 %, respectively. National sanitation coverage is about 85 %, composed of 94.5 % coverage in urban areas and 57 % in rural zones; in 1990, the sanitation coverage was 79 and 18.1 %, respectively (Fig. 5.4). The greatest backlogs under both headings are in the regions Southern Pacific, Northern Gulf, Central Gulf, and Southern Border (Conagua 2011c: 68), where water is more abundant.

Urban zones annually discharge 7.49 km$^3$ of wastewater (municipal wastewater discharge); 6.59 km$^3$ (88 %) are collected in the public sewerage and 2.78 km$^3$

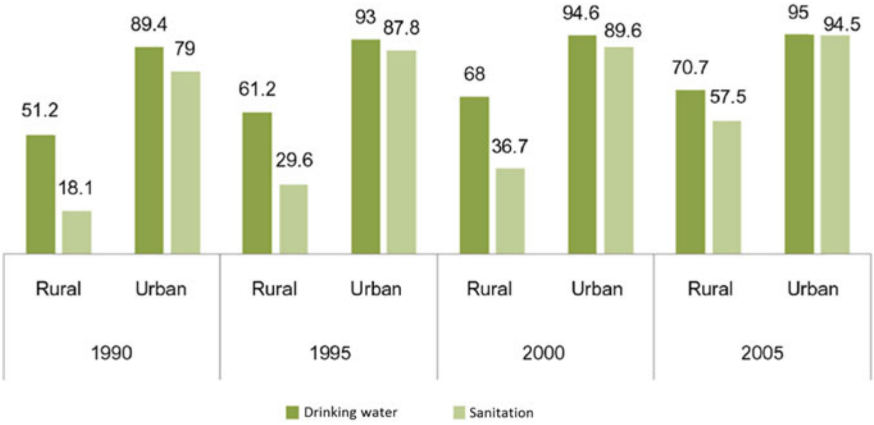


**Fig. 5.4** Evolution in the rural and urban populations with drinking water and sanitation coverage in Mexico. *Source* Conagua (2011d)

(37 %) are treated. The industrial wastewater discharge is about 6 km$^3$/year and only 1.16 km$^3$ (19 %) are treated.

## 5.2 Irrigation Systems

In Mexico, the area with infrastructure that allows irrigation is approximately 6.5 million hectares (Mha), of which 3.5 Mha corresponds to 85 irrigation districts (Table 5.1 and Fig. 5.5) and the remaining 3 Mha to more than 39,000 irrigation units for rural development (Urderales in Spanish). Information from Conagua (2010b) notes that in the agricultural year 2008–2009, the irrigated area in the irrigation districts was 2.6 Mha (Table 5.1), similar to the historical mean of 2.5 Mha. Sinaloa, Sonora, Tamaulipas, Baja California, and Michoacan accounted for 71.1 % of the irrigated surface (Fig. 5.5).

The DR and the Urderales were designed according to the prevailing technology in the 1940s; however, even today, in 88 % of the irrigated surface of the DR water is employed by gravity, usually flooding the furrows (Fig. 5.6).

Gravity irrigation has a low total efficiency (driving efficiency plus application efficiency) in water use, between 10 and 49 %. 12 % of the irrigated area is technified with pressurized multi-floodgate, sprinkler, drip, and streak systems, with an overall average efficiency in water use between 56 and 80 % (Table 5.2).

Irrigation by sprinkler, drip, and **streak** are relatively new techniques that require a greater initial investment and a more intensive management than gravity irrigation, but they imply an important increase in the efficiency of water use, estimated in 130 % with respect to gravity irrigation.

**Table 5.1** Surface irrigation use in irrigation districts by hydrological-administrative region

| HAR | Name | DR No. | Area (ha) | | Allocation volume ($m^3/s$) | Irrigated area (ha) | | Pumping wells | Flows |
|---|---|---|---|---|---|---|---|---|---|
| | | | Total | Irrigated | | Gravity dams | Bypass | | |
| I | Baja California Peninsula | 2 | 246,906 | 226,041 | 86.711 | 0 | 129,064 | 96,977 | 0 |
| II | Northwest | 7 | 502,281 | 391,473 | 124.973 | 315,273 | 0 | 76,200 | 0 |
| III | Northern Pacific | 9 | 7,89,034 | 755,451 | 311.118 | 725,933 | 27,563 | 1,813 | 142 |
| IV | Balsas | 9 | 225,511 | 151,325 | 77.623 | 73,923 | 77,402 | 0 | 0 |
| V | Southern Pacific | 5 | 75,389 | 28,460 | 17.079 | 22,990 | 5,470 | 0 | 0 |
| VI | Rio Bravo | 12 | 554,597 | 368,433 | 103.409 | 349,229 | 13,505 | 5,699 | 0 |
| VII | Central Basins of the North | 1 | 1,16,577 | 69,820 | 32.463 | 69,820 | 0 | 0 | 0 |
| VIII | Lerma-Santiago-Pacific | 14 | 4,99,237 | 318,291 | 131.329 | 168,633 | 64,989 | 58,296 | 26,373 |
| IX | Northern Gulf | 13 | 2,65,594 | 135,960 | 48.221 | 86,955 | 27,757 | 0 | 21,248 |
| X | Central Gulf | 2 | 43,508 | 31,248 | 25.246 | 0 | 31,248 | 0 | 0 |
| XI | Southern Border | 4 | 36,399 | 25,970 | 11.219 | 5,152 | 20,445 | 373 | 0 |
| XII | Yucatan Peninsula | 2 | 36,871 | 10,051 | 2.095 | 0 | 0 | 10,051 | 0 |
| XIII | Waters of Valley of Mexico | 5 | 1,04,998 | 79,611 | 50.16 | 22,351 | 54,884 | 0 | 2,376 |
| Total | Mexican Republic | 85 | 3,496,902 | 2,592,134 | 1,021.65 | 1,840,259 | 4,52,327 | 249,409 | 50,139 |

Agricultural year 2008–2009. *Source* Conagua (2010b)
*HAR* Hydrological-Administrative Region. *2008–2009
*DR* Irrigation District (in Spanish)

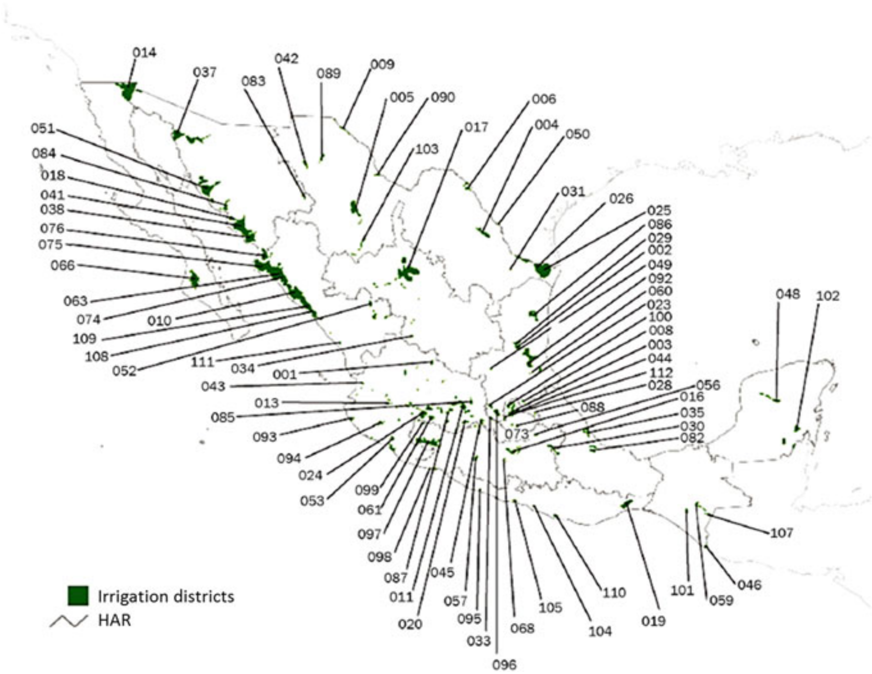


**Fig. 5.5** Irrigation districts, 2009. The numbers indicate the DR no. assigned by Conagua *Source* Conagua (2011c)

The DR of the XII Yucatan Peninsula HAR are the only ones that are completely technified; however, the irrigation surface (only 10,000 ha) is the smallest of the country. In the DR of the rest of the HAR, the technified surface is less than 50 % of the total irrigation area.

The hydro-agricultural programs of the Federal Public Administration, supported by the National Water Commission (Conagua in Spanish), the Secretariat of Environment and Natural Resources (Semarnat in Spanish), and the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (Sagarpa in Spanish), as well as their projects and financial resources, and the modernization and rehabilitation of the irrigation districts, farm development, efficient use of water and electricity, full use of hydro-agricultural infrastructure and technified irrigation programs are important programs designed to increase production based on the most efficient use of water and hydraulic infrastructure.

However, despite the enormous resources at its disposal, public policy to modernize and technify irrigation has not achieved its main goal, which is to save water. Conversely, it has caused unwanted effects by not considering important decision-making factors (CDRRS, PEC 2007–2012).

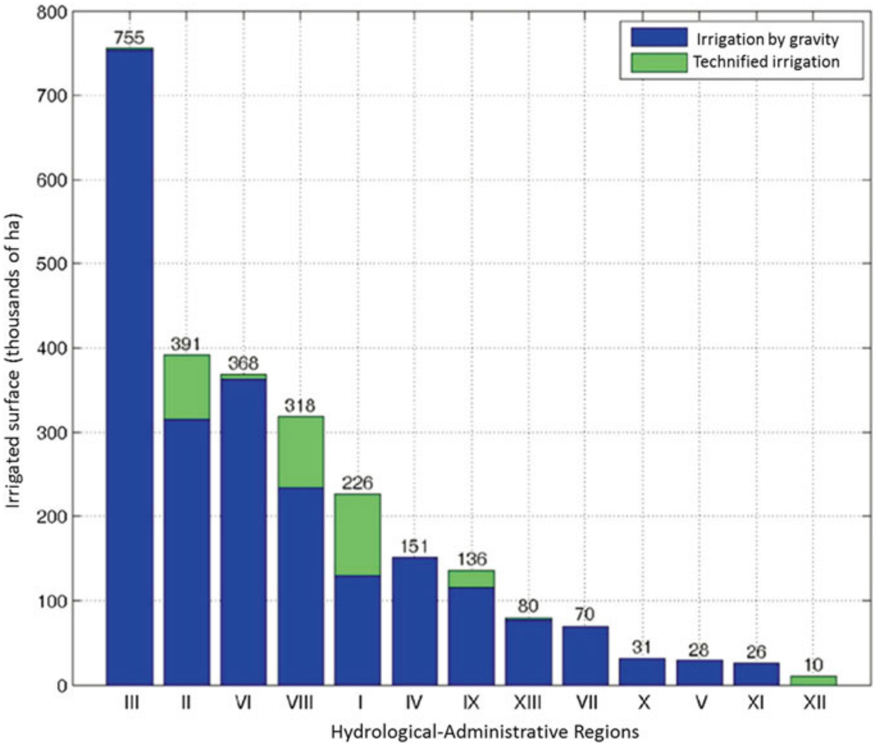


**Fig. 5.6** Surface distribution in the HAR by type of irrigation, 2009. *Source* based on data of Table 5.1

Some of the problems related to irrigation policy are: the lack of irrigation user participation, except for the large hegemonic farmers; the lack of an ecosystem vision, which has not taken into account water bodies requirements; a program offering without having defined a target population; the poor training of the majority of farmers to access more complex technologies; credit shortage for participating in programs that require significant contribution from producers; operation, more formal than functional of the water institutions: Basin Councils and Organizations, Groundwater Technical Councils.

Agricultural water public policies have caused collateral problems, such as the use of an increasing water volume in irrigated areas; aquifer overexploitation because of the electricity subsidy in agricultural pumping; the lower water return due to more efficient irrigation systems (Huffaker 2010) and an increased water pollution because an increase in the use of water corresponds to a higher use of agricultural inputs, fertilizers, and pesticides.

**Table 5.2** Estimated efficiencies for different irrigation systems

| Irrigation system | Efficiencies (%) | | | Average total efficiency increment (%)[a] |
|---|---|---|---|---|
| | Driving | Application | Total | |
| By gravity | 35–70 | 30–70 | oct-49 | |
| By sprinkler | | | | |
| (a) simple | 90–95 | 60–85 | 54–81 | 130 |
| (b) mechanized | | | | |
| 1. wheel line | 90–95 | 67–86 | 59–82 | 140 |
| 2. traveler | 90–95 | 61–75 | 55–72 | 115 |
| 3. frontal advance | 90–95 | 72–89 | 65–85 | 154 |
| 4. center pivot | 90–95 | 73–90 | 66–86 | 158 |
| Micro-irrigation | | | | |
| (a) drip | 90–95 | 85–95 | 77–90 | 183 |
| (b) micro-sprinkler | 90–95 | 83–93 | 75–88 | 176 |
| (c) bubblers | 90–95 | 80–90 | 72–86 | 168 |
| By low pressure | | | | |
| 1. tubing | 90–95 | 30–70 | 27–67 | 60 |
| 2. (a) tubing with gates (d./t) | 90–95 | 35–72 | 32–69 | 70 |
| (b) driv./canal | 35–70 | 35–72 | 13–51 | 9 |
| 3. (a) tubing with gates and intermittent valve (driv. by tube) | 90–95 | 55–85 | 50–81 | 120 |
| (b) driv. by channel | 35–70 | 55–85 | 20–60 | 36 |

[a]With respect to gravity irrigation
*Source* Arana-Muñoz and Monroy

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