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Potential use of water saved with technification of gravity irrigation in non-agricultural sectors

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ABSTRACT
Objective: To analyze conceptually the potential use of water that the technification of gravity irrigation allows in saving and generating alternatives of use according to the extrapolation of volumes, both in the agricultural sector or outside of it.
Design/methodology/approach: The Modernized Gravity Irrigation Program (RIGRAT) will be evaluated, by measuring the volumes of irrigation used in the Irrigation Districts (ID) 075 Río Fuerte, 076 Valle del Carrizo, and 063 Guasave, Sinaloa, during the 2015-2018 agricultural cycles. The measured and statistical data are integrated for the analysis of volumes saved by the program and its national statistical projection.
Results: The volume saved in the ID 075 was 2,401.02 thousand m^3 (2.4 hm^3) in 6,114.5 ha under technification of the RIGRAT program. The volume of water saved on that surface represents 10% of the water used by the industrial sector of Sinaloa. It is inferred that the modernization of the ID 075 Río Fuerte in the planted area of 289,780 ha, would imply a saving of 40% of the water that can be used in urban areas of Sinaloa. In the same agricultural sector, it would be possible to save a volume of 187 thousand m^3, which represents 6.4% of the water used by the irrigation district at plot level.
Limitations on study/implications: Current regulations do not allow the transfer of water volume in its different uses, with the aim of optimizing the value of water.
Findings/conclusions: With actions implemented in the RIGRAT program, water saving is achieved at the farm level and there would be a great impact, since agriculture is the main consumer of water and there could be volumes saved to be used in other sectors.

Keywords: Efficiency, irrigation sheet, water use, modernization.

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INTRODUCTION

Irrigated agriculture consumes globally 69% of the useful water available (Martínez *et al.*, 2021). The use of technology to elevate the efficiency of water in the agricultural sector acquires increasingly more relevance, with actions in the various stages of their cycle. The proposals contemplate implementation of techniques and policies directed at increasing their efficiency and obtaining resource savings and the possibilities regarding the task with this new volume available.

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Water distribution in the different sectors has diverse implications; there are ways of saving water before its use, that is, reducing the application of water by increasing the efficiency of the processes involved, in the conduction, storage, distribution and consumptive use (Chávez and Fuentes, 2019; Chávez *et al.*, 2020). Another way is after its use, through recovery, with actions such as capture, drainage or treatment for reuse (de Anda and Shear, 2021). China is the country with the highest percentage of water reuse. The United States occupies the first place in treated residual water, with 7.6 million m^3/day (Jiménez and Takashi, 2008).

Administratively, in Mexico, the use and management of agricultural water is distributed through the so-called basin agencies, local management offices and other steering organizations; however, it is in practice where the greatest challenge happens. Specifically, the agricultural sector has a historical backwardness with efficient water management, because it uses 77% of the water for crop production (CONAGUA, 2013), quite above public (12.2%), industrial (4.2%) and energy-generation (4.9%) uses. Most of the water demand is for consumptive uses, with the sources of water being superficial (61.3%) and the remainder (38.7%) that originates from underground sources. From these sources, 263,551 million cubic meters (hm^3) have been licensed, with 65,155 hm^3 corresponding to the agricultural sector, understood to be basically for irrigation (SEMARNAT, 2018). The water sources for irrigation in Mexico are basically storage dams; one of the main inconveniences for irrigation planning in Mexico has to do with the variability in the volume of storage; thus, for one year it can have only 200 hm^3, and the next reach 2,000 hm^3. Facing this variability, the challenges are diverse: 1) how to operate an irrigation zone with this uncertainty, 2) how to project the crop mosaic in this irrigation zone, 3) what to do with the water when an average of 1,165 hm^3 was projected and in the dam there are 2,000 hm^3.

Concerning the non-consumptive use, or alternative uses for water, for example for the generation of electricity, 133,000 hm^3 have been used in a specific period. Regardless of whether this value is high or low, the substantial fact is that it is an alternative form of water use, and that it can be counted again in other uses. The relative scarcity of water in Mexico for urban (domestic) use is reaching critical dimensions, because of the continuous and accelerated population growth, and consequently the need for food in urban zones (Cummings and Nercissiantz, 1992).

In the presence of constant climate variations, and the need to sustain crop production, the possibility to improve the stability in storage volumes is suggested, through the constant improvement in the use of water directly by the crops (Unver *et al.*, 2017; Nikolaou *et al.*, 2020). That is, reducing the use of agricultural water at the farm level, through the technification of irrigation, which at the government level was the national program, Modernized Gravity Irrigation Program (*Riego por Gravedad Tecnificado*, RIGRAT).

Mexico has nearly 6.5 million hectares of irrigation, with more than 90% being gravity irrigation in its different modalities, versus about 600,000 ha with pressurized irrigation. To carry out this process there are administratively 13 basin agencies and 23 local management offices, supported by 85 irrigation districts, 23 districts of technified rainfed conditions and irrigation units. As a whole, it is a licensed surface which represents the agricultural surface in Mexico, responsible for supplying harvests to the country.

Other sources such as the National Water Plan (*Plan Nacional Hídrico*, PNH, 2008) and CONAGUA, define that irrigated agriculture in Mexico is developed within a great diversity of conditions of climate, soil, technological levels, and sociocultural factors. Mexico has nearly 6.5 million hectares with irrigation infrastructure that represent 25% of the cultivated surface and from which 50% of the production value is obtained. Of the total irrigation surface, 91% is superficial irrigation and the remainder, 560,000 ha, represents pressurized irrigation systems. However, presently they have reached the limit of the agricultural frontier in the irrigation surface due to lack of water, reason why it is necessary to increase the productivity of irrigation water and to optimize the way of cultivating the largest surface with the minimum amount of water.

With the creation of the National Water Commission (*Comisión Nacional del Agua*, CONAGUA) in 1989, and the enactment of the new National Waters Law in 1992 and its regulations, the transference of the administration of the irrigation districts to users began, supported by a partial rehabilitation program of the infrastructure that is licensed to the Irrigation Users' Civil Associations (*Asociaciones Civiles de Usuarios de Riego*, ACUR) constituted into Irrigation Modules. By 2011 more than 99% of the total surface of the irrigation districts had been transferred to the ACURs. The RIGRAT involves these agencies directly with the primordial purpose of saving water. Each module has a specific amount of water licensed, which is given by the Irrigation District. The volume of water is managed by the module, and it is its main source of income, since it is an input in the production process.

The approach consisted in implementing technification of gravity irrigation in three main aspects: training, design and measurement. Activities were carried out for training and technical assistance with technicians and users of irrigation in design, trace and application of irrigation; the leveling of lands that implies a greater uniformity of irrigation and, therefore, contributes to reducing the volume of water applied; the agronomic and hydraulic design of irrigation, its trace and controlled application to the farm; the forecast of irrigation in real time, which means adjusting the irrigation programs according to rainfall, evaporation, temperature, and crop development; the monitoring and evaluation of irrigation, to guarantee that irrigation is applied according to program, valuing its efficiencies and impacts. The objective of this study was to analyze conceptually the potential use of water that technification of gravity irrigation can achieve and the alternatives of use according to the extrapolation of volumes, both in the agricultural sector or outside of it.

MATERIALS AND METHODS

The field work was carried out in the state of Sinaloa during the agricultural years 2016-2018. Sinaloa is the state with largest surface devoted to agricultural production; form the point of view of water use, it is organized into 8 Irrigation Districts (IDs) as shown in Table 1. The main crops are corn, bean and vegetables, using an average sheet of 113 cm, considering the surface requires a distributed volume approximately of 8,743 million m^3, to attain sowing annually a surface in the order of 800,000 ha.

Table 1. Characteristics of the Irrigation Districts that operate in Sinaloa, Mexico (CONAGUA, 2007-2012).

Irrigation district		**Number Users**	**Irrigated area (ha)**	**Vol. Dist. Thousand m^3**	**Lb (cm)**	**Sown area (ha)**	**Harvested area (ha)**
Numbre	**Name**						
10	Culiacán	18,797	195,549	2,160,688	110	237,481	204,213
63	Guasave	14,607	107,448	1,367,025	127	135,545	115,140
74	Mocorito	5,518	41,578	463,065	111	49,300	40,022
75	Rio Fuerte	21,075	215,536	2,930,397	136	289,780	264,251
76	El Carrizo	8,830	66,191	726,685	109	79,711	65,434
108	Elota	2,531	20,381	225,976	110	20,381	19,086
109	El Dorado	8,769	61,808	849,505	136	67,020	62,621
111	Baluarte	627	2,595	20,134	79	2,933	2,840
Total		80,753	711,087	8,743,475	113	882,150	773,607

Addressing the surface sown, the analysis of water saving is detailed in the Irrigation Districts 075 Río Fuerte, 062 Guasave, and 076 Valle del Carrizo, and projections are made for the rest of the state. The analysis of irrigation district 075 Río Fuerte was conducted in 6000 ha, in which the technification activities were implemented. During the period when the project was developed, activities were carried out in five main axes:

i. Training and technical assistance to users on basic aspects of design, trace and application of irrigation;
ii. Leveling of lands to favor a greater uniformity of irrigation and reduction of the volume of water applied;
iii. Controlled application of water in the farm; through plot capacity systems, from the control points or hydrants to the plot, with the aim of estimating application and inter-plot efficiencies;
iv. Forecast of irrigation, to adjust the irrigation programs initially elaborated; this is where the tensiometer is used, through continuous sampling, the irrigation calendar is adjusted in function of the moisture content of the soil;
v. The evaluation of plot irrigation to guarantee that water is applied according the crop's demand in interval irrigation.

The estimation of irrigation sheets, efficiencies and calendar follows standardized procedures (Allen *et al.*, 1998; Ojeda and Flores, 2015). From the information gathered in the field and agricultural statistics, for the purpose of this study, results were organized to estimate indicators with which to establish the volumes used and with them to estimate the volume saved by stage (plot, district and dam) and in function of the amount, to conduct the similarity of use in other sectors.

One way of conceiving the implementation of the project is presented in Figure 1.

The process of technification is relatively clear; at the plot level, there are water-distribution systems where plot irrigation efficiencies are officially reported that fluctuate at 38%. This value implies a volumetric investment with a high percentage of diverse losses,

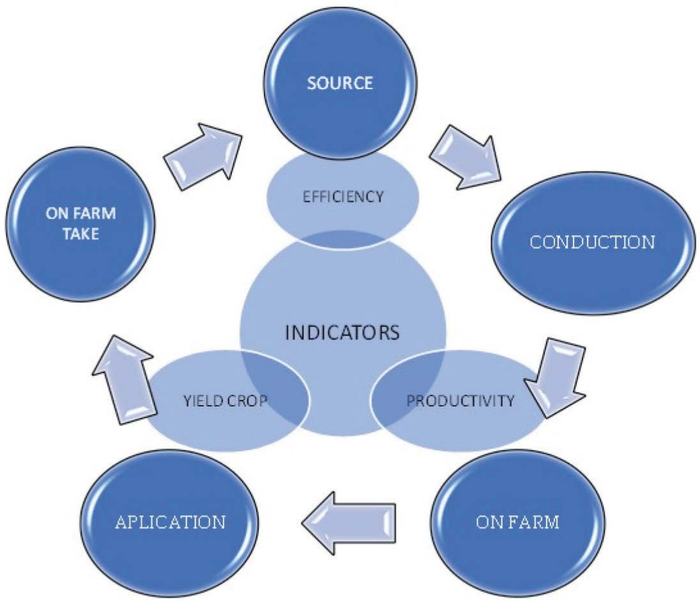

Figure 1. Indicators of efficiency, productivity and yield to measure water savings derived from technification of gravity irrigation.

which is why the increase of this efficiency increased with technification. An increase in the efficiency of plot irrigation implies a reduction in the water volume that has to come out of the source, that is, from the dam in most cases.

RESULTS AND DISCUSSION

The measurements in the control points and the general monitoring of activities for irrigation technification can be summarized in Table 2. The surface established is where the monitoring of the crops was carried out to estimate the volumes saved during agricultural cycles. For the surface established, the water volumes used are shown; at the farm level it was considered global plot efficiency, and from this there is an estimation upstream based on the efficiencies considered by CONAGUA in the different points from the source to the point of delivery to the module.

The implementation of activities destined to technification of irrigation allows decreasing the irrigation sheet applied in the participating irrigation plots. With this modernization an increase in efficiency is achieved, in function of the surface. The goal would be to

Table 2. Average yield of crops per irrigation district (CONAGUA, 2013).

Irrigation district Name	Sown area (ha)	Watersheet irrigation					Saved Volume (source) (Thousand of m^3)	Saved watersheet (cm)
		Req. (cm)	Farm (cm)	Module (cm)	DR (cm)	Source (cm)		
063 Guasave	10,102.58	48.2	86.7	114.6	127.3	148.2	5,051.07	5.0
075 Río Fuerte	6,114.50	43.0	103.9	139.2	162.7	171.3	3,960.05	6.5
076 Valle del Carrizo	6,037.87	38.2	65.0	80.2	93.0	102.8	2,808.09	4.7
Three districts	**22,254.95**	**44.0**	**85.6**	**111.3**	**126.8**	**141.5**	**11,819.21**	**5.3**

attain a recovered volume of approximately 3,470 Mm^3, which implies an increase in the efficiency of application of 13%. In this sense, in a cycle is observed the three districts of northern Sinaloa, savings at the farm level in the order of 7000 cubic meters, Table 3.

Water saving is possible through technification of irrigation; the volume saved is stored in the works of the dams, which leaves open the possibility of their use, in the agricultural sector and outside of it. Among the possibilities suggested there was a water bank, the reconversion of crops, and the expansion of the agricultural frontier; however, water savings and its use outside the agricultural sector is of the greatest relevance without there actually being a framework for its distribution; virtual water, ecological water, alternative energies, and non-consumptive used, are the challenges in the study of water.

In the irrigation district 076 Valle del Carrizo, there were 5 modules where monitoring of irrigation was carried out in the same number of ha (5000). At the beginning of the cycle, this module had a water productivity of 0.68 kilograms per cubic meter, and it was using average irrigation sheets of 105.18 cm, which gives a water yield of 2.58 pesos for each cubic meter of water. With the implementation of the program, water productivity was estimated in 1.03 kilograms per each cubic meter and the sheets in the case of the grains of 64 cm and 70 cm combined with vegetables, with which substantial water saving is inferred.

In the fall-winter cycle, 922 plots were attended to, with 799 beneficiaries distributed in the 7,017.27 ha that are dealt with in 6 irrigation modules, from irrigation districts 075 Río Fuerte and 076 Valle del Carrizo. In these plots, the irrigation sheets that originally exceeded 100 cm, and which currently fluctuate around 80 cm on average, have been achieved for all the crops with plot efficiencies above 42 % (Figure 2).

The indicators that allow evaluating the effectivity of irrigation or measuring the impact of technification of irrigation, which include the five main activities mentioned, are exposed in Figure 2. The estimation of these indices contribute accurate and timely information about the volumes used in the farm, measured and contributed, which together with the yields allows estimating the productivity of water. With the volumes measured and estimated in each control point, the efficiencies are estimated and as consequence the water volumes saved from the fact of adopting an irrigation design, an irrigation trace, and a technique in its application. The water volumes are available, and addressing the water quality conditions (Asit *et al.*, 2006 and Asit *et al.*, 2009), there will be the possibility of direct use in the public sector, which has an effect at the domestic level and is contingent on the distance from cities, among other variables.

Table 3. Results of the technification of gravity irrigation in three irrigation districts (RIGRAT, 2016, 2017).

Irrigation district Name	Watersheet irrigation		Used Volume		Saved Volume	
	Farm (cm)	Source (cm)	Source Thousand m^3	Farm Thousand m^3	Source Thousand m^3	Farm Thousand m^3
063 Guasave	86.7	148.2	149,695.8	87,605.8	5,051.1	2,956.0
075 Río Fuerte	103.9	171.3	104,738.6	63,558.8	3,960.1	2,403.1
076 El Carrizo	65.0	102.8	62,046.9	39,269.6	2,808.1	1,777.2
Three districts	85.6	141.5	314,858.9	190,434.2	11,819.2	7,148.5

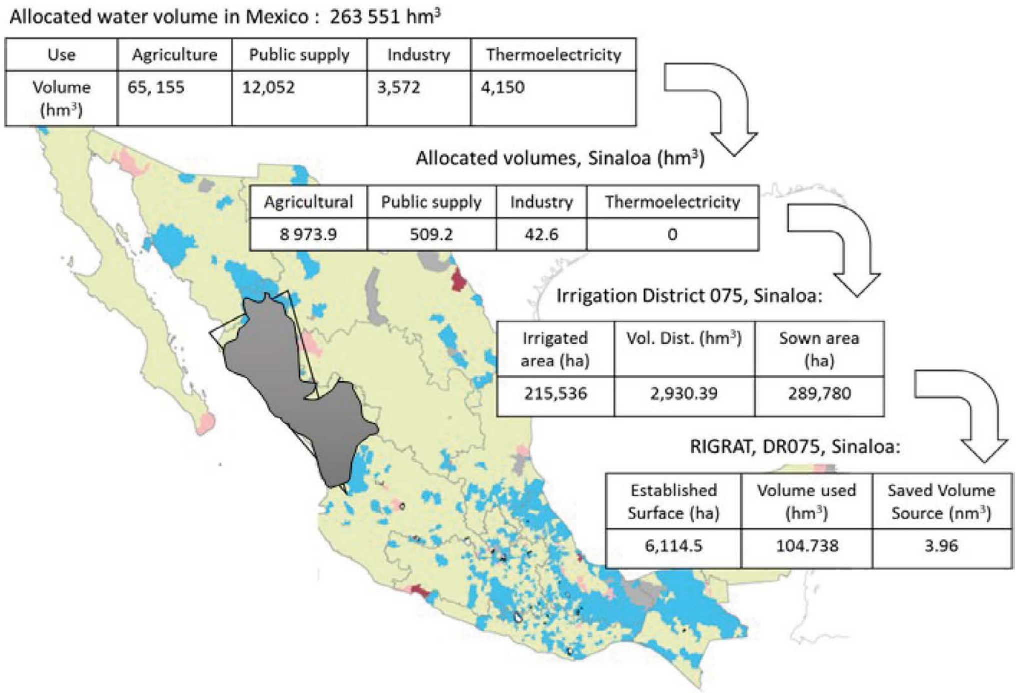

Figure 2. Volume of water saved and uses in the ID 075, Río Fuerte.

The use and management of water in general has different contexts, although the basic aspect is that there is water, which under the technification scheme is achievable; the next step will be to involve the authorities and the citizens to consider the nature of the national good whether from the environmental, social or economic point of view (Carabias and Landa, 2005). In Mexico, with the advances in matters of water and specifically related to the free trade agreement, NAFTA, which liberates the transit of virtual water, problems persist of criteria standardization, among which the price difference stands out (Cummings & Nercissiantz, 1992) which can derive into a water crisis similar to the cross-border crisis, affecting the production of crops.

The agricultural sector is one of the most affected by climate change (Ringler *et al.*, 2010) which is why the implementation of actions directed at saving water must go through improving water productivity (Kijne *et al.*, 2003); however, the management and availability of the volume saved is still pending, which is why the regulating institution is the one in charge of quantification and management of the resource (OECD, 2013).

The technological implications for this activity are clear: a) having gauging structures available at the farm to determine the volumes delivered, b) land levelling with the purpose of irrigation, c) irrigation programming based on soil and climate variables, d) calculation of the irrigation requirement per crop and for the crop mosaic; these actions were implemented in each of the participating farms of the program.

CONCLUSIONS

The volumes saved at the dam level are presented, estimated according to the methodology established. The dam is presently maintained from this volume saved.

Among the alternatives initially suggested, there is increase in the surface sown and as consequence increase in the harvest. There is the possibility of double planting or double cultivation. However, the use of this volume in other sectors, such as the energetic and a new ecological concept, directed at the recharge of aquifers and the stratification of the environment, is unclear. The strategies for development and conservation of the water resource in the agricultural sector should go through aspects of water optimization, addressing the productive uses. Selecting technologies that can be appropriated by the producer, based on the understanding of the process by the user. Managing the irrigation system and sensitizing the producer by addressing the problem of water use beyond the farm, giving an added value to the use of water saved, which is not used due to the increase in efficiency, and of reuse, recovered after irrigation.

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