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Can Irrigation Technologies Save Water in Closed Basins? The effects of Drip Irrigation on Water Resources in the Guadalquivir River Basin (Spain)

David Sampedro-Sánchez

University of Seville, Department of Human Geography, Seville, Spain; sampedro@us.es

ABSTRACT: Numerous institutions and governments have opted to increase irrigation efficiency to tackle water problems, especially water scarcity. The purpose of this research is to analyse the effects that the introduction of new irrigation technologies has in closed basins with high water reuse and where most of the water is used for agriculture. We analyse the evolution in the water supply, the irrigated area and the crops in three irrigation communities in different sections of the Guadalquivir River Basin. The results are compared with irrigation areas where traditional irrigation systems are still in use as control groups. The new irrigation systems have triggered a wide range of responses in the irrigated areas, including increases in the size of the irrigated areas, the introduction of crops with greater water requirements, and the production of two harvests per year. Such intensification features have been enabled by the exploitation of resources that previously returned to the system. The analysis of the water balances shows that appropriate measures need to be implemented to reduce rather than increase pressure on resources, most prominently including a revision of water rights and devoting the savings to improving the quality of water ecosystems and/or to urban supply.

KEYWORDS: Irrigation efficiency, closed basins, drip irrigation adoption, water conservation, rebound effect, water rights, Guadalquivir, Spain

INTRODUCTION

The overexploitation of essential resources and global warming are the two main issues propelling the current global environmental emergency. Despite progress being made in the generation and viability of other energy sources to overcome the exhaustion of natural resources such as hydrocarbons, the only option that exists in the case of water is desalination. This explains why, at a time when global water demand continues to grow and the quality of water resources is deteriorating, the main water-related measure endorsed by economic (high-tech irrigation companies and national agricultural organisations) and institutional stakeholders (the United Nations High-Level Panel on Water and national governments such as Morocco and Spain) is an increase in efficiency. Since the end of the 1990s, many national and international organisations have pursued policies for increased irrigation efficiency to address water problems, especially water scarcity (Venot et al., 2014).

Water policy in Spain (from the late 19th to the late 20th century) used to be based on public investments to generate water resources that would respond to the demands of productive sectors, especially for irrigation. The response to the gradual increase in water supply was an increase in consumption. This dynamic led to the collapse of the existing policy, which was unable to respond to the water problems, especially water scarcity during periods of drought. As a result, most of the basins in the south and the east of Spain are closed since, as Seckler (1996: 6) indicates, "most of the primary supply is diverted to meet demand and an increasingly large percentage of drainage water is captured and reused".

As in the case of other basins in Spain, given the inability to continue generating resources a clear commitment was made to improving efficiency in the Guadalquivir Basin. The negative effects of the 1991-1995 drought intensified the debate about water in Spain, especially concerning the need to 'rationalise' water use in agriculture. At the same time, Spanish agriculture was going through a crisis brought about simultaneously by the negative consequences and new opportunities arising from Spain's entry in the European Economic Community (1986). In this context, national and regional administrations made investments and were given public grants for the replacement of traditional irrigation networks with pressurised systems, which were assumed to help reduce losses while enabling the automatic and flexible application of water. This set of public actions is called irrigation modernisation in Spain. Modernisation in Spain is understood as an instrument for rural development rather than a water-saving policy. In this regard, Berbel and Gutierrez-Martin (2017: 13) state:

> For Spain, this measure was a huge gamble to solve the deficit (understood as the difference between agricultural water demand and water resources) and to simultaneously achieve competitive and profitable agriculture by improving the efficiency of irrigation water use.

The approval of the first modernisation plans also saw the first debates around the ability to generate savings by changing the irrigation technologies, especially regarding the consequences of a reduction in the recoverable flows and the use that the saved water would be put to (Sumpsi Viñas et al., 1998; Sampedro-Sánchez, 2020).

The two main national plans were the National Irrigation Plan-Horizon 2008 (MAPA, 2002) and the Shock Plan for Irrigation Modernisation (Ministry of the Presidency, 2006). The National Irrigation Plan was developed between 2002 and 2008 and comprised three programs. The main objective was the "improvement and modernisation of traditional irrigations systems", specifically meaning the modernisation of over 1.1M ha of irrigated land by the end of 2008. This process would include lining old canals, replacing the irrigation system, and creating storage facilities. Second, 'consolidated irrigation' guaranteed water supply in areas that had unreliable irrigation resources. Third, new irrigation areas were created (López-Gunn et al., 2012: 86). Global funding for the Plan was €5024 M and a target of modernising over 1.3M ha was set. With respect to water savings, the Plan estimated that the change in infrastructure would create a saving of 2751 million m^3 (Mm^3), of which 47% would be allocated to irrigation areas that did not have enough resources to cover the water needs of their crops or where supply was not always possible. However, the Plan estimated that the planned increase to the irrigated area would generate a 7% rise in water use and a 2% increase in water consumption (412 Mm^3) (MAPA, 2002: 459).

A slower roll-out than envisaged and a new spell of drought gave rise to the Shock Plan for Irrigation Modernisation (López-Gunn et al., 2012: 86). The funding for this Plan was €2344 M to cover over 866,000898 ha of irrigated land. The goal was to create 1162 Mm^3 water saving in Spanish irrigation. The estimate for the Guadalquivir Basin was 204 Mm^3 (Ministry of the Presidency, 2006: 9849). Savings estimates were made based on the reduction in gross water supplied at the farm level. In theory, the saved volumes could not be used to increase the irrigated area, although they could be used to increase or guarantee supply. In short, the saved water could still be used for agriculture.

The Andalusian Regional Government had previously sanctioned the 1995 Andalusian Irrigation Plan,[1] which considered improved irrigation efficiency a key mechanism for adapting and modernising farms. The initial forecasts were exceeded; by 2010, over 352,000 ha had been modernised with a saving of 434 Mm^3/year (CAP, 2011: 23).

In the last ten years, replacing traditional irrigation networks and the associated projected water savings have become key issues in the implementation of river basin management plans in Spain (Berbel

[1] The irrigated surface area in the Guadalquivir basin amounts to 76% of all irrigation in the Andalusian region.

et al., 2019), albeit with a smaller investment and a smaller affected surface area due to the high number of previously modernised irrigation systems and the reduction in public investment as a result of the 2008 financial crisis.

In sum, the water administrations in Spain have identified the reduction in the water supplied to the irrigated areas from the reservoirs as water savings. However, some plans have factored the reduction in recoverable flows into their calculations of savings. A great deal of these water savings has been used to expand the irrigated area or to expand and guarantee the supply to irrigable areas.

It is necessary to adopt a water accounting terminology framework to correctly understand the effects of the change in irrigation technologies. According to Perry (2011) and Perry and Steduto (2017: 7), the used water goes into one or more of the following categories:

1. Consumptive use (evaporation and transpiration), comprising:
    a. Beneficial consumption (crop transpiration)
    b. Non-beneficial consumption (evaporation from free water surfaces and wet soil; weed transpiration)
2. Non-consumptive use, comprising:
    c. Recoverable flows (returning to a river or aquifer for potential reuse)
    d. Non-recoverable flows (flowing to the sea or some other economically unviable sink)
3. Change in storage, including any flows to or from aquifers, in-system tanks, reservoirs, etc.

In large basins such as the Guadalquivir, where there is a high proportion of recoverable flows, if there is no increase in consumption per area unit, the balance between the non-abstracted water and the fall in return flows should be very similar. Therefore, provided that there are no variations in consumption, no significant real savings would be generated. Instead, the water resources would be redistributed (the water saved by reducing gross supply is kept in storage facilities). Real savings only occur when the water consumed would otherwise be irremediably lost (non-recoverable flows); in other cases, this cannot happen when there is an increase in the consumed amount (Huffaker, 2008; Ward and Pulido-Velázquez, 2008a; Dagnino and Ward, 2012; Pfeiffer and Lin, 2014). Burt et al. (1997: 441) summarised it thus: "water availability for other uses can only be increased by decreasing consumption".

Numerous studies prove the relationship between evapotranspiration (biomass production) and the irrigation system (Ward and Pulido-Velázquez, 2008a; Lecina et al., 2010; Perry and Steduto, 2017; Grafton et al., 2018). Perry et al. (2009: 1519) state, "efficient irrigation systems result in substantial consumptive use, as 85% or more of the diversions go to crop evapotranspiration". Relatedly, studies such as Playán and Mateos (2006) foresee an increase in beneficial consumption after the irrigation system has been replaced, even if the irrigated surface area remains stable. Lecina et al. (2010), who analyse the changes in the irrigated area in Riegos del Alto Aragón (Ebro River Basin, Spain) induced by the replacement of surface irrigation by a sprinkler system, conclude that the increase in consumption results from non-beneficial consumption and, when the irrigation conditions are improved, primarily from beneficial consumption. However, based on the results of their model, Berbel and Mateos (2014) emphasise that if the whole plot has been uniformly irrigated with no water deficit before the shift from surface to drip irrigation, and if the crops remain the same, then evaporation per area unit will not increase significantly. However, the authors conclude that if drip irrigation adoption improves on the previous conditions, beneficial consumption will increase.

In addition, drip irrigation turns water into a more productive input since its application is more uniform and continuous in time. This enables production to be increased and, if there are no measures in place to prevent this, a switch to higher-value crops (with higher water consumption) or a further expansion of the irrigated area (Gutierrez-Martin and Gomez Gomez, 2011; Gómez and Pérez-Blanco, 2014). Developing this idea, Perry and Steduto (2017: 35) state that hi-tech drip irrigation adoption gives farmers greater incentives to obtain more water, making it an even more valuable input and pumping more affordable. The persistence of the 'rebound effect' (Jevons paradox or effect) is an indisputable fact; it has repeatedly been confirmed that any efficiency savings made in an expanding economy are systematically redeployed to new consumption of physical resources. This rule seems to apply to irrigation:

> Given the increases in efficiency, the consumption of water after modernisation can increase, even if abstraction decreases. In these cases, the overall pressure on water resources would actually increase after modernisation (European Commission, 2015: 78).

Increased beneficial consumption is more evident when:

- There is an increase in the number of plants per area unit, especially in the case of tree crops such as citrus fruits and olives.
- Crops with greater water requirements are introduced. In this sense, Pfeiffer and Lin (2014) attribute the 2.5% increase in water abstraction from the High Plains aquifer (Kansas) as much to the introduction of crops with higher water requirements as to the interest in increasing crop yield.
- Two harvests are generated per year thanks to the creation of water storage pools in the irrigation areas. This infrastructure is necessary to pressurise the networks in irrigation areas supplied with surface water and enables the irrigation period to be extended.
- The irrigated area is expanded. This phenomenon has been described in Scheierling et al. (2006) and Ward and Pulido-Velázquez (2008b), who predicted both crop switching and the expansion of the area. The consequences of improved irrigation efficiency in the Gállego River irrigation basin (Spain) (Graveline et al., 2014) include a 2% drop in overall water abstraction and a 4% expansion of the irrigated area, albeit without extensions beyond the boundaries of the irrigable area.

Relatedly, after an extensive literature review, Perry and Steduto (2017: 34) concluded:

> In cases where the water accounting was well documented, there were important examples of water consumption increasing as farmers were able to expand the area irrigated per unit of water delivered to the farm (thus increasing consumption and reducing return flows), and/or where evapotranspiration increased along with biomass formation.

In both cases, this would raise the farm's economic profitability. So, the increase in water consumption is closely linked to the farmer's economic decisions.

Moreover, at least in the case of Spain, when there is a switch from systems that distribute water by gravity to pressurised networks, the new systems make water application more expensive. As Sanchis-Ibor et al. (2017) show in the case of the Spanish Mediterranean coast irrigation communities, this cost increase can often put the viability of farms at risk, forcing irrigators to raise their holdings' profitability. According to calculations made by Alarcón (2017: 111), the cost of irrigating one hectare in Spain, including investments and energy costs, increased by an average of €762 per year after the adoption of drip irrigation. To compensate for this increase, this researcher calculated that "post-drip irrigation adoption profit needs to be increased by between 64% and 71%".

The Guadalquivir River Basin is a closed basin. According to the current Water Plan, the agricultural sector consumed 3357 Mm^3/year in 2015, which amounts to 88% of total water consumption. Such a high volume results from the existence of over 856,000 ha of irrigated land; 62% of this area is irrigated with surface water and receives 75% of the water supplied for agriculture (MAGRAMA, 2015: 65). This is possible thanks to a powerful reservoir system that enables the storage of 8115 Mm^3 (CHG, 2020: 16).

However, the amount of stored water varies from one year to the next due to the typically irregular rainfall in the Mediterranean climate. All the communities analysed in this paper irrigate with surface water. The irrigated area cannot be expanded without authorisation from the Basin Authority, and irrigation rights limit the volume of water used. The Guadalquivir Basin Management Plans set an amount of water for each type of crop, although these provisions do not imply any reduction in water rights. However, due to annual variations in rainfall, every year the Basin Authority specifies the volumes to be supplied to the irrigable areas based on the availability of water resources.

During the 1997-2008 period, from the beginning of the Andalusian Irrigation Plan (1996) to the end of the Shock Plan for Irrigation Modernisation (2008), water supplied to agriculture in Andalusia grew by 2%. The reason for this was that the size of the irrigated area grew by 36% during the same period. However, water use per hectare fell by 25%, due to the large area that was modernised (43% of the 1997 irrigated area) and the strong expansion of olive trees (a crop with low water requirements). During this same period, the evolution in intensely modernised irrigation (over 80% of the irrigable area changed its irrigation system) presented differences with respect to all irrigation in Andalusia. Supplies only fell by 0.6% while the irrigated area grew by 9%. This increase in the surface area in combination with the increase in net demand per hectare due to crop switching produced a 17% increase in water consumption (Corominas and Cuevas, 2017: 284). Based on the results for intensely irrigated areas, Corominas and Cuevas (2017: 283) estimate that modernisation has generated a net water savings of 12% at the basin level.

An analysis of the data in the Guadalquivir Basin Management Plans (GBMP) in 2009-2014 and 2015-2021 shows that this trend continued between 2008 and 2015, although at a slower rate (MAGRAMA, 2013a: 113, 2015: 58):

- Net demand per hectare increased by 5.5% (from 3033 m^3/ha to 3200 m^3/ha). In the GBMPs, net demand (water consumed) is calculated based on the area occupied by each crop and the water allocated per crop (m^3/ha) in the Basin Management Plan. Gross demand is the result of dividing net demand by the efficiency[2] of the irrigation system (MAGRAMA, 2013a: 111).
- The difference between gross and net demand, which corresponds to return flows or non-beneficial consumption (MAGRAMA, 2013a: 111), fell by 312 Mm^3/year. It should be remembered that recoverable flows are systematically used from upstream to downstream in the Guadalquivir Basin, except in the last section of the estuary (MAGRAMA, 2013a: 83).
- The irrigated area grew by 1.1% (9632 ha).

These changes are related to the adoption of high-tech irrigation systems. The GBMPs allow an increase in the irrigated area based on water savings. Specifically, Art. 16 of the current Plan, passed by Royal Decree 1/2016 (MAGRAMA, 2016: 3693), spells out the situation in which 'water savings' – i.e.; reductions in gross withdrawals derived from water allocations defined in the Plan for each crop (net demand) and the irrigation coefficients – can be used to increase the irrigated area:

- The Basin Authority can allocate up to 45% of the savings to increase the size of the irrigated area in any part of the Guadalquivir Basin.
- To drive a reduction in demand, irrigators in modernisation projects that entail 'water savings' can retain a further 45% of the saved water from the remaining savings for use in the new extension to the irrigated area.[3] In return, their water rights must be updated.

[2] Surface irrigation efficiency: 0.70; sprinkler irrigation efficiency: 0.75; drip irrigation efficiency: 0.86.

[3] Several farmers' organizations objected to this measure in the recent public consultation process for the new Guadalquivir Basin Management Plan (2022-2027). Agricultural organisations argue that this system is being used by large investment

- The remaining (a minimum of 10%) is not reallocated and is presumed to be staying in the river system.

According to the Guadalquivir Basin Authority Planning Office[4] (GBAPO), the first step that the Basin Authority takes to calculate the savings obtained after irrigation modernisation (which implies a change in the irrigation coefficient) is to analyse how the crops and their water requirements evolve based on the water supplies for crops provided for in the Plan. The allocations have been quite controversial,[5] especially due to the low theoretical allocations (2150 m^3/ha) provided for 'intensive olive growing' (a higher number of trees per hectare than traditional olive growing). If crops with greater water entitlements in the GBMP are replaced by 'intensive olive growing', consumption will theoretically be reduced. However, the interviewed stakeholders agree with some of the agricultural organisations in stating that the amount of water really applied to these crops is greater than the amount provided for in the GBMP. Second, it compares the evolution of supplies pre- and post-drip irrigation adoption. However, in most irrigated areas, the supplied volumes had already fallen before the adoption of drip irrigation, and the Basin Authority also uses a very long time series. Water supplies had diminished even in some irrigation communities with gravity irrigation systems. This process occurred because excessive amounts of water had been allocated to most of the irrigable areas in the past. The GBAPO estimates that the measure to grant 45% of saved water to irrigators has generated 26 Mm^3 of savings. These savings have enabled the irrigated area to be expanded by 10,000 ha.

In the Guadalquivir Basin, where the decrease in surface water supplies translates to a similar reduction in recoverable flows, an increase in the irrigated area or water consumption per hectare causes decreases in the water available downstream. The reduction in recoverable flows affects the quantity and quality of the water masses (surface water or groundwater), and this impact has not been sufficiently assessed. In the Guadalquivir Basin, groundwater plays a major role in supplying the population, especially during droughts. The reduction in return flows to the aquifers is affecting numerous springs on which ecosystems and high natural value agricultural landscapes depend. Also, the reduction in the water levels of the aquifers results in lower availability for other users and reduced resilience of the irrigated land in drought periods.

As a consequence, any measures to prevent or halt consumption intensification have enormous relevance. Art. 65 of the Spanish Water Law allows for water rights to be revised when the water resources that crops require can be met with a smaller volume of water or by using a system that contributes to water savings (MMA, 2001). Based on this article in Spanish Water Law, Art. 33 of Royal Decree 335/2013 concerning the GBMP (2009-2015) made it compulsory to revise water rights and adapt them to the new circumstances post modernisation (MAGRAMA, 2013b). The GBMP (2015-2021) laid down a maximum gross value per hectare (water use) of 4500 m^3/ha/year for drip irrigation systems and 5000 m^3/ha/year for other systems in the newly irrigated areas (MAGRAMA, 2016: 3693).

Modernisation can have positive effects on management if specific measures are taken to implement a reduction in water rights and prevent saved water from being applied to intensifying or extending

groups to expand the irrigated area with crops that require a very intensive plantation framework. https://www.coagandalucia.com/2021/12/21/coag-andalucia-denuncia-el-expolio-del-agua-en-la-cuenca-del-guadalquivir/ (accessed on 3rd May 2022).

[4] Information collected from the *Water concessions in the Guadalquivir Basin* talk at the STEER project workshop on "The modernisation of irrigation, water consumption and the concession regime in the Guadalquivir", organised by the University of Kassel (Germany) and held on February 24, 2020, at Pablo de Olavide University (Seville).

[5] In the public consultation process for the Guadalquivir Basin Management Plan (2015-2021), the main irrigators' organisation in Andalusia (FERAGUA) requested an increase in the allocations for olive trees, almond trees, strawberries, and alfalfa. Based on scientific research, the irrigators argued that the allocations are below these crops' water requirements. https://feragua.com/lavozdelregadio/2015/07/15/la-confederacion-rectifica-las-dotaciones-para-el-olivar-y-el-almendro-previstas-en-el-plan-hidrologico-del-guadalquivir/ (accessed on 3rd May 2022).

irrigated areas. Otherwise, even though the supplied volume decreases, if consumption is intensified, pressure on water ecosystems rises. Experience has repeatedly shown that, in addition to efficiency, limiting and reducing the scale of physical production are necessary conditions for progress towards reducing the consumption of materials and energy (Schneider et al., 2010: 512 and 517).

This article analyses the changes caused by drip irrigation adoption in three irrigated areas in the Guadalquivir Basin to ascertain whether pressure on water resources has fallen or risen. The aim is to contribute to the debate on the effects of introducing more efficient technologies in closed basins where there is a high degree of reuse and to suggest measures that should be adopted to prevent any unwanted effects.

The following section describes this paper's sources and methods. The third section presents the evolution of the selected parameters in communities with drip irrigation systems and gravity irrigation systems. Finally, there is a discussion as to whether this evolution has contributed to generating water savings in the case studies or, on the contrary, to intensifying consumption.

SOURCES AND METHODS

The evolution of the supplied volumes and, since there are no data available for consumption, the evolution of the irrigated area and cropping patterns have been analysed in three case studies. This analysis has been performed using the sources specified in Table 1. The evolution of the net demand, which is assessed using the theoretical crop consumption proposed by the plans, has been considered in this analysis.

Table 1. Main data sources.

Public reports and statistics generated by agricultural and water administrations	Highlighting the following: Inventories of the Andalusian Irrigation Areas (Regional Agricultural Department), from which data on modernised irrigation land and crops have been obtained for 1997-2008, and the Hydrological and Campaign Reports (Basin Authority), from which information has been obtained about the volumes supplied, irrigated land, and mean rainfall between 2009 and 2019.
Public reports and statistics generated by the various government administrations	Data provided by the Basin Authority upon request: volumes supplied, irrigated land in main irrigable areas for a broad time series (from 1995-1996 to 2016-2017), and land occupied by main crops (from 2013 to 2017).
Data generated by the irrigation communities	Information on new irrigation infrastructure, internal water sharing, the evolution of crop types, and plots that produce two harvests per year, etc.
Information generated by spatial analysis	Based on public data from a variety of government administrations, especially SIGPAC (Andalusian Regional Government Agricultural Plots Information System).
Interviews and fieldwork	Nineteen interviews were given to a total of 20 stakeholders working in public institutions (Regional Agricultural Department and local governments) irrigation management (irrigation communities), major agricultural companies, and associations in the region.

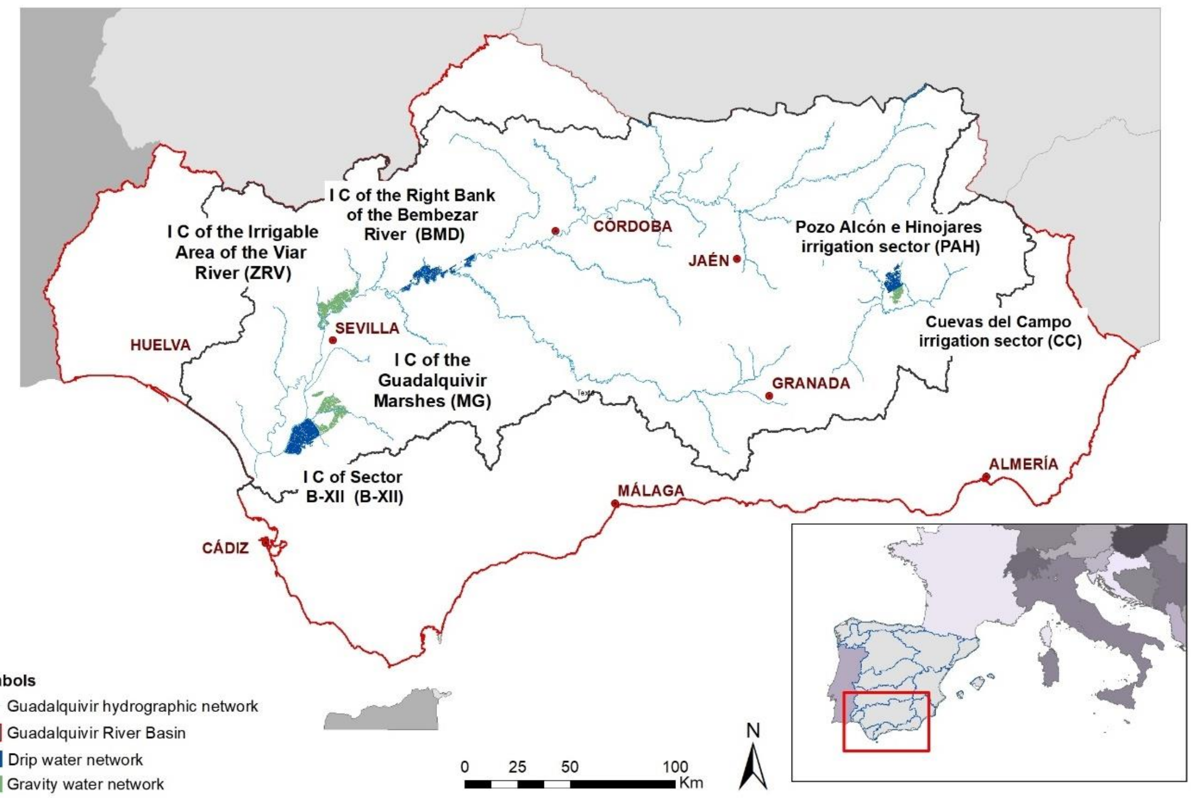
Prepared by author

In each of the cases, water consumption is compared between one community that has adopted drip irrigation and another that has continued to use its original irrigation system. The areas with gravity irrigation systems acted as a control group. The documentary, bibliographical, and statistical analysis was complemented by a spatial analysis when no disaggregated data were available on the required scale. The results have been complemented and enriched by fieldwork and interviews with 19 major institutional, social, and economic agents in the study area. The main purpose was to dig deeper into the irrigators' interest in making new investments, as this is a key element that determines the outcomes of drip irrigation adoption. The majority of the interviews (semi-structured and a half-hour long) were carried out between September 2015 and January 2016.

The following criteria were set for selecting the case studies: first, three irrigation communities were selected in different sections of the basin. This enabled different responses to be observed while at the same time offering an overview of the different irrigation types in the basin (Figure 1).

In the upper section, an irrigated area was selected in the Alto Guadiana Menor region, between the district of Cazorla (Jaen province) and the high plateau of Granada. This is an irrigable area with plots at different heights where mostly olive trees are grown. The second case is in the plains between the provinces of Cordoba and Seville, specifically in the Bembezar irrigable area. These are very productive lands with no crop restrictions. The last case is in the last river sector, in the marshland reclaimed in the second half of the 20th century. This land has a high clay and salt content, which prevents the introduction of tree crops.

Figure 1. Location of the study areas.



Source: Inventory and Characterisation of Irrigation in Andalusia (Third edition). Spatial Reference Data, Institute of Statistics and Cartography of Andalusia. Prepared by author

Second, we selected an irrigation community (IC) in each section that had adopted the drip system close to another irrigation community with a gravity system and similar physical, agronomic, and socioeconomic features to enable a comparative analysis and identify the changes caused by the switch in irrigation systems. In the case study in the upper part of the basin, the Pozo Alcón, Hinojares and Cuevas del Campo IC itself presented this opportunity, as the Pozo Alcón e Hinojares (PAH) sector had changed its irrigation system while the Cuevas del Campo (CC) sector still used the traditional system. In the middle-lower area, the changes brought about by drip irrigation adoption in the IC of the Right Bank of the Bembezar River (BMD) can be contrasted with the evolution of the IC of the Irrigable Area of the Viar River (ZRV), where the new irrigation system did not come into operation until 2016. Finally, in the last section of the basin, the changes in the IC of Sector B-XII (B-XII) can be compared to the IC of the Guadalquivir Marshes (MG), which still uses gravity irrigation.

The third selection criterion singles out two cases (PAH and BMD) where the water supply depends on only one or two reservoirs and one case (B-XII) where supply comes from a large system of 17 interconnected reservoirs. There is a greater guarantee that the unused volumes in PAH and BMD are turned into reserves for the following year.

The last criterion is related to the higher costs of applying water after drip irrigation adoption, which is directly linked to electricity. To examine this criterion, an irrigation community (PAH) was chosen because its network is pressurised by gravity alone, at no cost. Electricity is used to power the system in the other selected modernised communities.

RESULTS

The first subsection shows the evolution of water use in the modernised and non-modernised irrigation communities in all three cases. The second subsection analyses the evolution of the irrigated area and cropping patterns.

Reduction in water released from reservoirs

The change in irrigation infrastructure has led to a reduction in the water volumes released from reservoirs in the three areas where irrigation has been pressurised (Table 2). Except for MG, water use has also fallen in the non-pressurised areas during the same period, albeit to a lesser extent.

Table 2. Change in water use.

	Period analysed		Irrigation communities	
	Pre-modernisation	Post-modernisation	Drip irrigation system	Gravity irrigation system
Upper basin	2009-2010	2011-2017	PAH -39.4%	CC -15.1%
Middle-lower basin	1996-2003	2008-2015	BMD -25%	ZRV -21%
Lower basin	2001-2003	2015-2017	B-XII -10%	MG +2%

Source: Guadalquivir River Basin Authority and Pozo Alcón, Hinojares and Cuevas del Campo Irrigation Community. Prepared by author

The data used in the upper basin case study are taken from the Pozo Alcón, Hinojares and Cuevas del Campo IC, as the figures generated by the Basin Authority correspond to the community as a whole. The supplies have been reduced in both sectors, despite the pre-drip irrigation adoption period being more humid (requiring less irrigation) and shorter (two years compared to the six years of the postpressurisation period). However, there is a greater reduction (by 24.33%) in the area with drip irrigation. This sizeable difference can mainly be explained by decreases in the following: seepage from canals, runoff to drains from excess irrigation (recoverable flows), and to a lesser extent, evaporation from wet soil at the farm level and weed transpiration (non-beneficial consumption). The Pozo Alcón, Hinojares and Cuevas del Campo IC reports indicate that 'losses' (leaks) in the pressurised sector (PAH) have fallen from 30% to 5%, whereas in the non-pressurised sector (CC) they continue to stand at 30%. The reduction in supply to the non-pressurised area remains a product of fluctuations in the water supply caused by irregular rainfall. During the post-drip irrigation adoption period, water availability in the reservoir that supplies this irrigable area was 24% lower than it was in the period before the change to the system.

In the middle-lower area of the basin, there was a 25% decrease in water use in BMD after pressurised irrigation adoption. The reduction in ZRV was 21% during the same period. According to information collected during the fieldwork, the reduction in the gravity irrigation community can basically be explained by the restoration of, and improvements to, the main water conveyance canal. So, both are explained by the reduction in leaks from canals. However, this reduction may be affecting other users. There are some irrigated areas close to BMD that use groundwater, and some of the agents interviewed in this case study stated that in conjunction with the reductions produced upstream, the reduction in recoverable flows from canal seepage has led to a decrease in available groundwater.

In B-XII (in the lower section of the basin), a comparison between the last five available campaigns (from 2011-2012 to 2016-2017) and the five that preceded the opening of the regulation-irrigation reservoir (from 1997-1998 to 2002-2003) shows an 18% reduction in water use. The periods used must be reduced to three campaigns in each case (2001-2003 and 2015-2017) for these results to be compared to the control community, as the MG Irrigation Community was only set up in 2000. Whereas use in MG has risen by 2%, in B-XII it has fallen by 10%. As Table 3 shows, the reduction in water use is related to a fall in water availability from the basin's main reservoirs. The new irrigation system makes it possible to meet the water needs of crops with lower supplies from reservoirs, which explains the 12% difference.

Table 3. Water available in the Main Reservoir System and actual supply to irrigation communities in the lower section of the basin.

	2001	2002	2003	Average 2001-2003	2015	2016	2017	Average 2015-2017	Difference
Water available (Mm^3)	5668	5251	5675	5531	6558	5115	4271	4973	-10%
Supplies to B-XII (Mm^3)	98	110	77	95	94	82	79	85	-10%
Supplies to MG (Mm^3)	86	92	85	88	97	88	86	92	2%

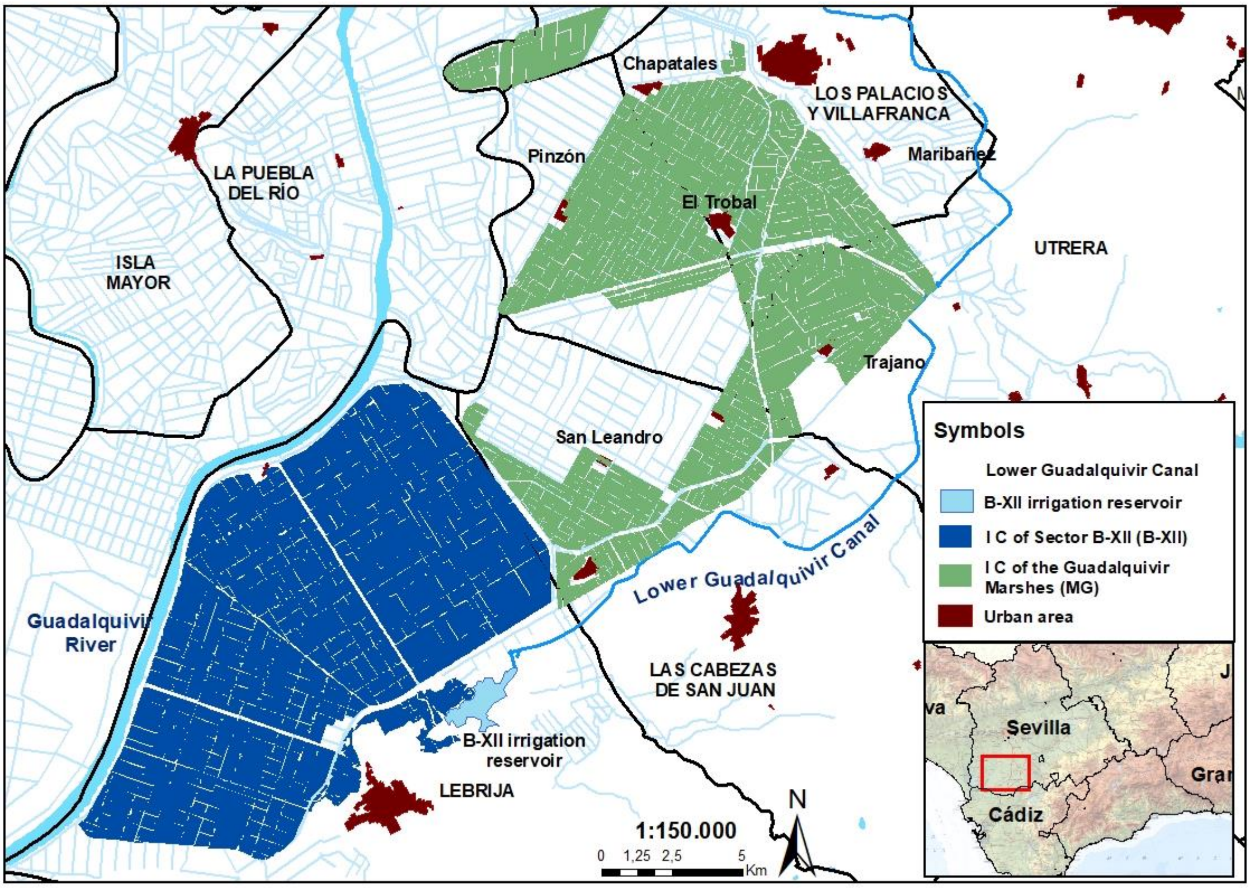
Source: Guadalquivir River Basin Authority. Prepared by author

However, to identify the total amount of water used in B-XII, we would have to compute the total water volume pumped from the B-XII irrigation reservoir (see Figures 2 and 3). Apart from the volumes allocated to B-XII, this irrigation reservoir receives large flows of excess water from other irrigable areas (the irrigation reservoir lies at the end of the Lower Guadalquivir canal, which supplies over 50,000 ha) and from natural runoff. These waters are available to irrigators in B-XII, especially in autumn and winter, but are not counted as supply by the Basin Authority.

Figure 2. B-XII irrigation reservoir.

Source: Photograph taken by author in March 2017

Figure 3. Study area in the last section of the Guadalquivir Basin.



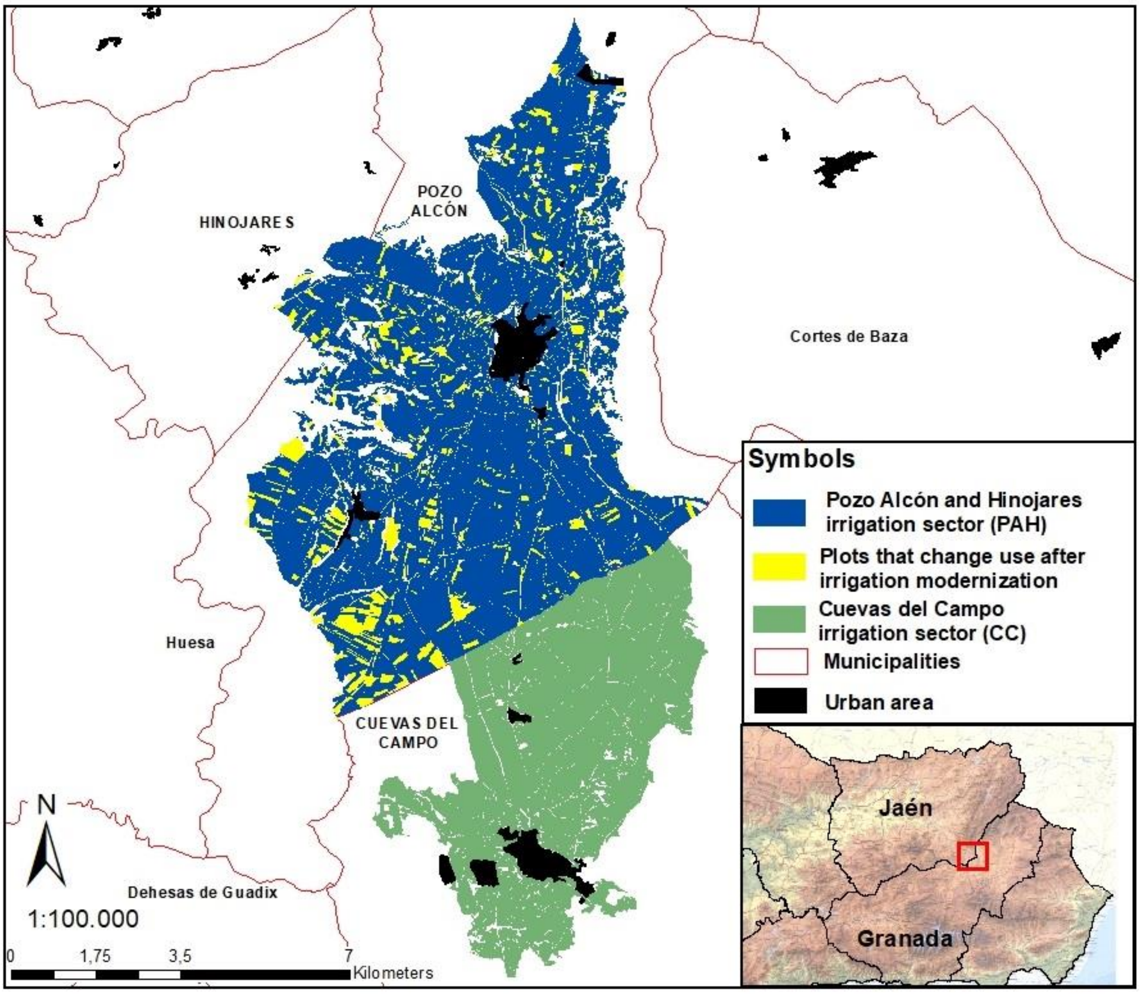
Source: Inventory and Characterisation of Irrigation in Andalusia (Third edition). Spatial Reference Data, Institute of Statistics and Cartography of Andalusia. Prepared by author.

Increase in irrigated area, crop intensification and changes

The irrigated area has increased in the three pressurised communities, albeit to a different extent, and crop intensification and changes have occurred.

The most significant effect of drip irrigation adoption in the upper basin is a 12% increase in the irrigated area, which rose from 6259 ha to 7031 ha. Depending on whether the source is the Pozo Alcón, Hinojares and Cuevas del Campo IC or the Institute of Statistics and Cartography of Andalusia (ISCA), respectively, either 82% or 86% of the new irrigated area is in the sector that changed its irrigation infrastructure. In 2020, the Water Authority[6] renewed the water rights and expanded the irrigable area to 8353 ha. When expansion due to modernisation is completed,[7] the irrigated area will have increased by 33% (from 6259 ha to 8353 ha). With respect to crops, the most significant change was the spread of annual spring-summer crops (basically, vegetables), which increased from 25 ha to 855 ha (equivalent to a 12% increase in the irrigated area) (Figure 4).

Figure 4. Changes in use after drip irrigation adoption.



Source: Inventory and Characterisation of Irrigation in Andalusia (Third edition). Spatial Reference Data, Institute of Statistics and Cartography of Andalusia. Prepared by author.

[6] Resolution M-3369/2012 of 21st August 2020. https://bit.ly/3z2ErqB (accessed on 3rd May 2021).

[7] In April 2022, the works began. https://bit.ly/3PYJ3V5 (accessed on 20th April 2022).

In the middle-basin, the most noticeable effect of drip irrigation adoption in BMD has been the change in crop type. From the time that the new infrastructure came into operation, between 2004 and 2007 to 2013, the main changes were an increase in the surface area devoted to citrus fruits (2879 ha) and a decrease in cotton (-2358 ha). Maize decreased between 2013 and 2017, while forage, vegetables, and fruit trees all continued to expand. The increase in vegetables (30%), especially onions (77%), stands out. These are crops that can often be grown before the spring-summer crops. So, two harvests are produced per year on the same land. A slight increase in the irrigated area can be observed (4.4%) as a result of the consolidation of some areas (537 ha) that had previously only been watered in years with abundant water reserves. The current GBMP envisages the continued expansion of the irrigated area by up to 12,722 ha, which will amount to a total increase of 6.8% since drip irrigation adoption began. These changes have incurred a rise in water consumption, a phenomenon that will be discussed in the following section.

In ZRV, the new system began operation in 2016. The last stage before the shift was characterised by a decrease in maize due to the drop in market price[8] in 2013. This sharp fall occurred after the crop changes had been made in BMD following three years of rising prices. However, the crops that replaced maize changed both before and after drip irrigation adoption in ZRV. During the three campaigns before the drip system was implemented (2013-2015), the crops with an increased presence were: wheat (+80%), vegetables (+32%), cotton (+18%) and olives (+16%). In 2017, with the new system in operation, apart from the decrease in maize (-38%), wheat (-77%) and olives (-43%) also shrank and were replaced by vegetables (+82%), cotton (+14%) and fruit trees (+5%). As in the other areas studied, after drip irrigation adoption, the winter cereals were replaced by vegetables or fruit trees, which have greater water requirements.

In the lower section of the basin, the 2003 Common Agricultural Policy (CAP) reform affected the majority of crops in the two analysed communities (sugar beet and cotton). In B-XII, the CAP reform coincided with the inauguration of the new infrastructure. The pressurised and the non-pressurised communities have evolved differently due to the pressurised community' opportunity to adopt a drip irrigation system and, above all, their year-round access to water. In the pressurised community, the surface area vacated by sugar beet has been devoted to vegetable crops and, to a lesser extent, cotton. It is precisely this expansion of horticultural crops, especially tomatoes (which in 2017 made up 25% of the irrigated area) that is the main difference from MG. This growth is a product of the high yields achieved with drip irrigation systems. A second notable phenomenon that can be highlighted is the expansion of vegetable crops in autumn-winter driven by the guarantee of their successful cultivation thanks to it being possible to irrigate them outside the official period authorised by the Basin Authority (see Figure 5), as the construction of the irrigation reservoir has enabled winter irrigation (see Figure 2).

On occasion, these vegetables are grown on plots that are later cropped again in spring-summer. In 2015, double harvests occurred on 148 ha, according to the B-XII Irrigation Community. In the non-pressurised community, after an initial increase, vegetables have lost ground to sugar beet and alfalfa.

With respect to the surface area, the 2013 Water Plan envisaged the irrigation of a further 700 ha in the vicinity of B-XII (Los Yesos area), "with no increase in resources, based on savings brought about by modernisation". From 2016 on, approximately 260 ha of 'extraordinary irrigation' (temporary irrigation rights) have gradually been authorised. In March 2021, the Government of Spain extended irrigation to another 590 ha, increasing the area with rights to irrigation to 15,085 ha (3% increase post-drip irrigation adoption) (MITECO, 2021). For this, 89.95 Mm^3 were granted, 2.95 Mm^3 of which were for the new 590 ha (5000 m^3/ha/year) and 87 Mm^3 for the previous 14,495 ha (6000 m^3/ha/year).

[8] According to the Price and Market Observatory of the Junta de Andalucía, maize had an ex-warehouse price of 250 €/Mg in June 2013. However, by October of the same year, it had fallen to 157 €/Mg. It did not reach the price of 250 €/Mg again until May 2021.

Figure 5. Autumn-winter vegetables in B-XII.

Source: Photograph taken by author in March 2017

Discussion

Is water being saved?

In the following discussion, we examine whether the evolution of the parameters analysed in the case study translates into net water savings or, on the contrary, into greater pressure on water resources. It should be remembered that although the increase in efficiency in the conveyance and application of water enables a reduction in the volumes released from reservoirs, in basins such as the Guadalquivir Basin, where there is a high degree of reuse, these reductions cannot all be considered savings. If some of this non-supplied water (volumes 'saved' as a result of reducing allocations) are made available to the irrigators, as is the case in this basin, the irrigators will use them to expand the size of the irrigated area and/or intensify consumption. In this case, drip irrigation adoption will have resulted in an increase in the pressure on (i.e. depletion of) water resources.

Table 4. Potential water consumption considering expansion and change in cropping patterns.

	Period analysed		Irrigation communities	
	Pre-modernisation	Post-modernisation	Drip irrigation system	Gravity irrigation system
Upper basin	2010	2017	PAH +12%	CC 0%
Middle-lower basin	2003	2015	BMD +8%	ZRV +1%
Lower basin	2003	2017	B-XII +1%	MG -3%

Source: Guadalquivir River Basin Authority. Prepared by author.

In the upper part of the basin, the reduction in water withdrawals has been much greater in the pressurised sector (-24%, taking the non-modernised area as a reference) than the increase in the irrigation system's efficiency and the resulting reduction in seepage from canals (recoverable flows). With regard to consumption, the irrigated area has increased by 12% (722 ha). Considering that all the new irrigated plots are occupied by olive trees (a crop with low water requirements) when the amounts set out in the GBMP are applied, this expansion equates to a 12% increase in water requirements and, by implication, water consumption. A recent extension of irrigation to another 2077 ha has been authorised, which corresponds to a 33% growth since drip irrigation adoption began. In fact, the recent authorisation to expand the irrigated area is linked to the forthcoming project to pressurise the sector that still uses the traditional system (CC).

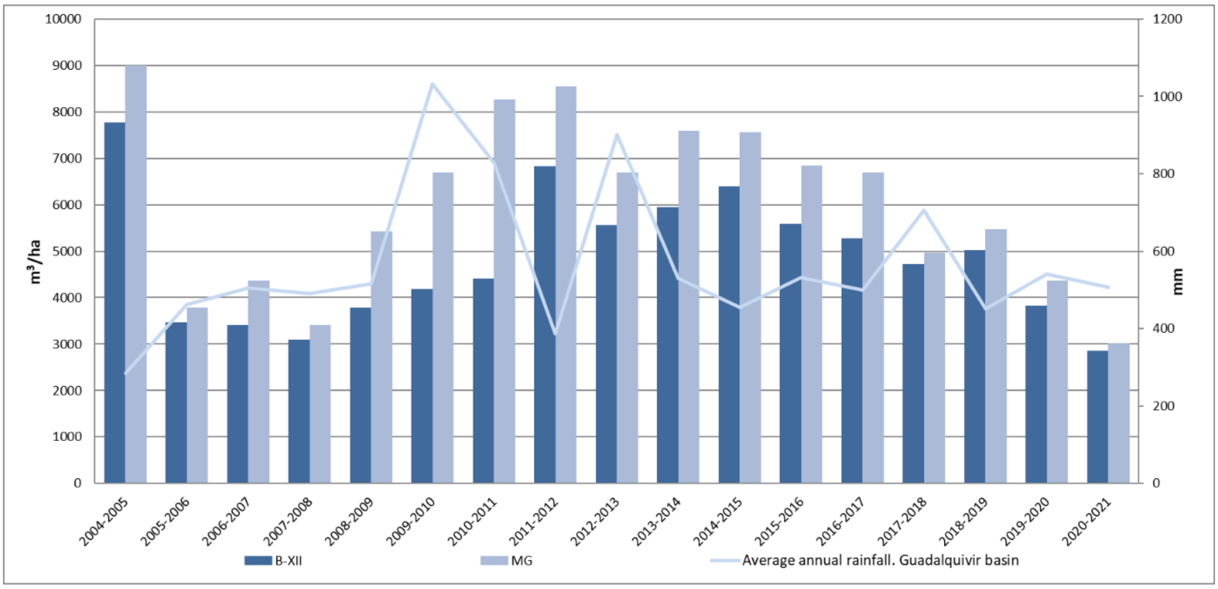
Supplies have been reduced in the two analysed irrigation communities in the middle area of the basin. In the gravity irrigation system community (ZRV), there has been a 21% reduction, basically due to measures taken to restore the main canal. In parallel, supplies have been reduced by slightly more (-25%) in the drip irrigation system community (BMD). This reduction is greater than that detected in Camacho et al. (2017)(-16%, post-drip irrigation adoption period from 2010 to 2011) and similar to that recorded in Fernández et al. (2014: 59)(-22%, post-drip irrigation adoption period from 2010 to 2012). However, it is lower than the figure recorded by Rodríguez-Díaz et al. (2011), where a very steep fall (-40%) is caused by the differences in humidity between the broad pre-drip irrigation adoption period considered (1996-2002) and the only post-drip irrigation adoption campaign analysed (2008-2009). As the authors themselves state, what is most significant is that "most of the decrease in water use corresponds to reductions in recoverable flows and not to water savings as such" (Rodríguez Díaz et al., 2011: 1007).

The analysis of these strong decreases in water use in the initial campaigns after drip irrigation adoption should also consider other phenomena in addition to a reduction in seepage from canals and differences in rainfall. Firstly, there was an increase in the cost of applying the water, exacerbated by the increase in the price of energy after the liberalisation of the electricity market in 2009. Secondly, there was a smaller demand for water for citrus plantations, which were in their initial development stage. In this sense, for Perry and Steduto (2017: 26), the reduction in water use (-21%) indicated by Berbel et al. (2014) in five irrigation districts in the Guadalquivir Basin, including BMD and B-XII, is not clear, given the differences in rainfall (average rainfall in the post-modernisation period was up by over 50%) in the analysed periods in conjunction with the application of amounts below the crops' theoretical requirements.

There was a notable change in the crops in the BMD Irrigation Community after drip irrigation adoption. This change was characterised by the expansion of citrus fruits (142% since 2003), which largely replaced cotton and, to a lesser extent, maize. A greater amount is allocated to citrus fruits in the recent GBMP (5400 m^3/ha/year) than to cotton (4500 m^3/ha/year) and maize (5000 m^3/ha/year). So, applying the volumes envisaged in the GBMP translates into an 8% increase in water requirements and, therefore, an increase in water consumption. In addition to this increase in consumption caused by crop switching, the BMD Irrigation Community saw an increase generated by the irrigation of plots authorised on a yearly basis by the Basin Authority (temporary irrigation rights), which represents a rise of between 4.5 and 6.8% in this community's irrigated area, depending on the campaign. In a comparison of a six-year pre-modernisation period (1996 to 2002) and a two-year post-drip irrigation adoption period (2008 and 2009), Rodríguez Díaz et al. (2011) calculated that the overall increase in water requirements and evapotranspiration was as much as 20% due to crop switching (Rodríguez Díaz et al., 2011: 1004). For the same irrigation community, though using different periods, Fernández et al. (2014: 59) recorded a growth of only 0.3% in total crop water requirements (ETc) caused by the changes to the cropping pattern. Also, Camacho et al. (2017) calculated a 2.8% reduction in ETc for BMD due to the young citrus plantations requiring less water, as commented above. However, both of these studies envisage an increase in ETc due to both the expansion of citrus fruits and the development of the existing plantations. Specifically, Camacho et al. (2017) estimated a 38% increase in ETc during the 2011-2020 period. According to the data supplied by the Basin Authority, citrus trees expanded by 800 ha in this irrigation community between 2011 and 2017. Therefore, they have increased their share of BMD land from 46% to 55%, which confirms the forecasts for the increase in consumption made by Camacho et al. (2017).

In the lower section of the basin, the supplies to the gravity irrigation system community have risen slightly. In contrast, they have fallen from 18% to 10% in B-XII, depending on the post-drip irrigation adoption period considered. This reduction is smaller than that observed by Fernández et al. (2014) (-33%) and Camacho et al. (2017) (-39%) in the same area, but it used different periods. As in the case of BMD, this has two explanations: firstly, the periods analysed in the articles have differences in rainfall, the post-drip adoption period being more humid, and secondly, financial circumstances for farmers changed due to the withdrawal of the special tariff for agriculture in June 2008 and the electricity tariff adjustment in July 2007. As can be observed in Figure 6, there were greater differences in water use between B-XII and the gravity irrigation community in 2010 and 2011. These were very humid years in the Guadalquivir Basin, which meant that rainfall covered a significant amount of the crops' water needs. These years are included in the post-drip irrigation adoption period in Fernández et al. (2014) (2010 to 2012) and Camacho et al. (2017) (2010-2011).

Figure 6. Evolution of supplies to B-XII (drip irrigation system) and MG (gravity irrigation system) irrigation communities.



Source: Guadalquivir River Basin Authority. Prepared by author.

As Figure 6 shows, compared to periods with similar rainfall (around 500 mm), supplies have remained stable and showed an upward trend from the time that the large-scale irrigation modernisation plans that transformed extensive areas of the Guadalquivir were completed (2010). It seems evident that modernisation has tempered the variations in supply caused by the irregularity of the Mediterranean climate.

With respect to the evolution of consumption in B-XII, using the GBMP methodology and volumes, the crop changes have not resulted in any significant increase in water requirements; requirements only increased from 63.15 Mm^3 in 2004 to 63.68 Mm^3 in 2017 (1%, Table 4). This is explained by the fact that all the crops with a greater presence (cotton, sugar beets, and vegetables) receive the same allocations in the current Guadalquivir Plan. However, for Fernández García et al. (2014: 59), the reduction in the land given over to sugar beet in the post-drip adoption period represents a theoretical 11% increase in evapotranspiration as the theoretical requirements for cotton are greater than for sugar beet. In our analysis, consumption has fallen by 3% in the community that continues to use the gravity irrigation system (MG).

In summation, water supplies showed strong reductions during the first years of drip irrigation adoption. After this initial period, supplies tended to stabilize. As a consequence, the differences with non-modernised areas were reduced.

However, water consumption increased after drip irrigation was adopted while water consumption did not vary significantly in the areas using the gravity irrigation system during the same period. An upward trend in consumption in the years since drip irrigation was adopted was cushioned during the system's first years since there was an adaptation period when the increase in the system's operating costs required the 'right' decisions to be made. There were also some other factors that contributed to offsetting the initial rise in consumption: the increase in the price of electricity, the effects of the 2003 CAP reform, and the lower water requirements of tree crops during the initial stages.

Policy implications and debate

The current legal framework allows irrigators to use 45% of 'saved' water volumes to expand their irrigated areas. The Basin Authority can allocate another 45% of the savings to the same purpose elsewhere in the Guadalquivir basin. Behind these measures is the inertia of a Water Authority that continues to consider irrigation as the main beneficiary of water policy and still does not consider that the basin is closed.

In parallel, given that irrigators needed to shore up their profits after the adoption of drip irrigation and the increase in production costs, they switched and intensified cropping patterns, and the Basin Authority allowed an expansion of the irrigated area. It should be emphasized again that irrigation modernisation in Spain has been understood as an instrument for rural development and that crop diversification and intensification have been two of the main goals.

Notwithstanding, in the case of the basin's middle and lower sections, the expansion of the irrigated area is the result of decisions made by Basin Authority. On the contrary, the initiative to extend the irrigated area in the upper basin came from the farmers and was based on theoretical rights dating from 1875. In 2020, the Basin Authority renewed the water rights and authorised the expansion of the irrigated area.

Neither the redefinition of water rights in B-XII nor the reduction in per-crop allocations in the recent GBMPs can be considered as measures adopted by the Basin Authority to prevent or reduce this increase in consumption. The 2021 Resolution[9] that granted irrigation rights to B-XII allocated 6000 m^3/ha/year. Despite this amount being 18% less than the gross volumes supplied per hectare during the pre-drip irrigation adoption period (from 1996 to 2003), this cannot be considered water savings. This reduction is equivalent to water use experienced between the pre- and post-drip irrigation adoption periods. The water rights exceed the current per-crop allocations established in the GBMP and the supply average (5017 m^3/ha/year) in the post-drip adoption period (from 2004 to 2017). Contrary to the opinion of some of the interviewed agents, the reduction in the per-crop allocations for olives and almond trees laid down in the recent GBMPs cannot be considered a measure that prevents the intensification of post-modernisation consumption as it affects all the irrigable areas irrespective of the irrigation system used. On the contrary, this reduction in crop allocations, most especially for olive trees, should be understood as a measure that enables the Basin Authority to expand the irrigated area.

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[9] Various circumstances meant that Spanish Water Law could not grant water rights until 2001: https://www.chguadalquivir.es/-/el-miteco-otorga-a-los-regantes-del-sector-b-xii-sevilla-la-concesion-de-riego-e-inscripcion-en-el-registro-de-aguas-de-15-085-hectareas (accessed on 3rd May 2022)

There has been an intense debate around the effects of modernisation in Spain over the past ten years. Some non-profit organisations (WWF[10] and the New Water Culture Foundation,[11] for example) have contributed to the debate by providing evidence of some of the unwanted effects of these processes. These organisations regard irrigation modernisation as an opportunity for agriculture and aquatic ecosystems provided that the necessary measures are taken to prevent any increased pressure on the environment or the disappearance of the cultural landscapes associated with traditional irrigation. In parallel, the irrigators' organisations[12] and other pressure groups (high-tech irrigation companies) have attempted to talk up the positive effects of these policies by emphasising the collective benefits of irrigation modernisation. This debate is still open and must be explored more deeply, especially in view of the public investments into irrigation modernisation foreseen by the Ministry of Agriculture[13] for the 2021-2023 period (€1243 million with a target of 200,000 ha).

This considerable investment in modernisation must be accompanied by a deeper analysis of the effects of this public policy. The subject that requires the deepest and most urgent analysis may well be the effects on environmental flows and aquifers.

Meanwhile, the implications of irrigation modernisation for energy consumption also demand further analysis. In particular, future research should consider the effect of the increased energy consumption on irrigation at the state scale. Energy consumption per hectare increased by a factor of 2.7 from 1950 to 2007 (González-Cebollada, 2015: 462). While in 1995 average consumption was 1173 kWh/ha, in 2007 this had increased to 1560 kWh/ha, due to both the increased use of groundwater and the irrigation modernisation process (Corominas, 2012: 106). In 2010, irrigation agriculture consumed 2.37% of all electricity used in Spain (Corominas, 2010: 226).

Related to the above, from a social perspective, the post-modernisation increase in productivity has not led to an increase in farmers' revenue in most cases. This paradox can be explained to a great extent by the increase in the costs of applying water that comes from energy consumption (Tarjuelo et al., 2015) in Spain. Some of the interviewed agents have even ventured to state that the increased costs and the intensification of production could push the irrigators with the least available capital to give up farming. García-Mollá et al. (2014) and Sanchis-Ibor et al. (2017) have already concluded that some of the farms in the Spanish Mediterranean coast irrigation communities are unviable after the adoption of drip irrigation. This explains why all the stakeholders interviewed for this research stated that increased costs are the negative effects of changing the irrigation systems. Consequently, studies are required to determine whether the adoption of drip irrigation is benefitting capital-intensive agents and operators to the detriment of small- and medium-sized farmers.

CONCLUSIONS

In the modernised areas, drip irrigation adoption has enabled an 18-to-25% reduction in water supply in proportion to the increase in efficiency.

However, despite the Guadalquivir being a basin with high levels of reuse, these reductions in supply have been considered real savings by the Water Authority, whereas they are only 'dry' or gross savings in reality. Similar reductions can be achieved with the implementation of other measures, such as restoring conveyance systems (as was done in ZRV), with no or little increase in water application costs.

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[10] https://wwfes.awsassets.panda.org/downloads/modernizacion_regadios.pdf?39782/Informe-Modernizacin--de-Regados (accessed on 3rd May 2022)

[11] https://fnca.eu/guia-nueva-cultura-del-agua/areas/los-usos-del-agua-en-la-agricultura (accessed on 3rd May 2022)

[12] www.fenacore.org/empresas/fenacoreweb/Boletines/BOLETIN%2050%20Diciembre%202016.pdf (accessed on 3rd May 2022)

[13] https://www.mapa.gob.es/es/prensa/ultimas-noticias/luis-planas-el-gobierno-movilizar%C3%A1-la-cifra-hist%C3%B3rica-de-1.243-millones-de-euros-para-la-modernizaci%C3%B3n-de-regad%C3%ADos-en-el-periodo-2021-2026/tcm:30-582659 (accessed on 3rd May 2022)

In any case, it is important to emphasize that the reduction in recoverable flows translates into reduced aquifer recharge. Despite the importance of groundwater for ecosystems and for supplying the population and a sizeable share of the irrigation sector, it appears that no due consideration has been given to the fate of recoverable flows.

In this context, has exacerbated the pressure on water resources in the three irrigation communities with a drip system as a result of the combination, to differing extents, of the increase in the irrigated area and the changes and intensification of the crops. Drip irrigation adoption drives the expansion of crops with greater market value and greater water requirements, especially fruit and vegetables. Furthermore, the opportunity to temporarily prolong irrigation allows the production of two harvests per year. It is precisely this intensified usage of natural resources, along with the expansion of the irrigated area, that are the main differences observed between the modernised irrigated areas and those that continue to use the traditional irrigation system.

This intensification has not been accompanied by effective measures from the Basin Authority to avoid the impact of the increase in consumption. In particular, the mandatory reduction of water rights, after irrigation modernisation process, set out in the GBMPs. Although the GBMP establishes a maximum gross value per hectare for new irrigation areas (4500 m^3/ha/year for drip irrigation systems), it does not take this into consideration in its revision of water rights for modernised areas.

In synthesis, the increased efficiency of the irrigation systems in the Guadalquivir Basin, which is closed and has a high degree of reuse, has led to an increase in pressure on natural resources (water and soil). The non-supplied volumes, which are largely recoverable, are being used not only to expand the irrigated area but also to introduce crops with greater water requirements and intensify production. This increase in water consumption affects both the quantity and quality of water masses and impacts other users in the basin, especially groundwater users.

To generate real savings and environmental benefits, the non-supplied water cannot be used for agriculture. Non-supplied water can only be described as water savings if consumption by agriculture is stabilised and the non-consumed volumes are made available for improving aquatic ecosystems and/or for urban supply. Thus, Spain is currently facing the same issues that sparked the first irrigation modernisation plans in the mid-90s: the need for an overhaul of water rights and a review of what the non-supplied volumes are used for.

In conclusion, technology alone does not seem to be a good solution unless it is accompanied by measures to prevent or offset the increased consumption associated with intensification, such as a reduction in the irrigated area or an adjustment of water rights based on consumption, not water use.

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