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Transformations Accompanying a Shift from Surface to Drip Irrigation in the Cànyoles Watershed, Valencia, Spain

Saioa Sese-Minguez

Water Resources Management Group, Wageningen University, Wageningen, The Netherlands; saioa.sese@gmail.com

Harm Boesveld

Water Resources Management Group, Wageningen University, Wageningen, The Netherlands; harm.boesveld@wur.nl

Sabina Asins-Velis

Department of Environmental Planning, Centro de Investigaciones sobre Desertificación-CIDE, Universitat de València, Valencia, Spain; sabina.asins@uv.es

Saskia van der Kooij

Water Resources Management Group, Wageningen University, Wageningen, The Netherlands; saskia.vanderkooij@gmail.nl

Jerry Maroulis

Soil Physics and Land Management, Wageningen University, Wageningen, The Netherlands; and International Centre for Applied Climate Science, University of Southern Queensland, Toowoomba, Queensland, Australia; jerry.maroulis@wur.nl

ABSTRACT: Drip irrigation is widely promoted in Spain to increase agricultural production and to save water. In the Cànyoles watershed, Valencia, we analysed the consequences of change from surface irrigation to drip irrigation over the past 25 years. There were a number of transformations resulting from, or accelerated by, this change including the 1) intensification of well construction causing a redistribution in access to groundwater, water shortages and a lowering of the groundwater table; 2) expansion of irrigation into former rain-dependent uphill areas resulting in increased water use; 3) shift to higher- value monoculture fruit crops, but with associated higher crop water requirements; 4) increased electrical energy consumption and higher costs due to groundwater pumping; and 5) loss of cultural heritage as wells have replaced traditional surface irrigation infrastructure that originated in the Middle Ages. Consequently, the authors argue that transitioning from surface irrigation to drip irrigation should critically look beyond the obvious short-term benefits that are intended by the introduction of the technology, and consider possible unforeseen side effects, that may have serious long-term impacts on the environment and the community.

KEYWORDS: Drip irrigation, water saving, energy consumption, agricultural land use/expansion, cultural heritage loss, Cànyoles watershed, Spain

INTRODUCTION

Utilisation of drip irrigation in agriculture is high on the agenda of many governments and development organisations around the world as a promising tool to save water, improve agricultural productivity, reduce labour and labour costs and help tackle rural poverty. Consequently, there is widespread support and major financial commitment for embracing drip irrigation technology both in the West and in developing countries (World Bank, 2006; EEA, 2009; OECD, 2010a).

The enthusiasm of policy-makers and donor organisations promoting drip irrigation centres on its capacity to use water efficiently. However, the concept of irrigation efficiency is hotly debated due to the vagaries of the term and because efficiency is both scale- and context-dependent (Seckler, 1996; Perry et al., 2009; Lankford, 2012; van Halsema and Vincent, 2012; van der Kooij et al., 2013). Furthermore, the research literature highlights the importance of the perspective of different actors involved in the design and implementation of drip irrigation projects (Knox et al., 2012; Friedlander et al., 2013; Venot et al., 2014).

What drip irrigation does, is tightly linked with the environment in which it interacts, as agricultural policies, geographical settings, irrigation culture, and the users of a technology, all shape what drip irrigation can and will achieve. This notion stems from a socio-technical approach to technology which refutes that the working of a technology is intrinsic to the technology – in other words, that the working of a technology is similar in all contexts (Law, 1992; Jansen and Vellema, 2011). Rather, we approach technology as both hardware and software, and consider that its use-environment matters to how it will perform (van der Kooij, 2016). While drip irrigation can be a very efficient irrigation technology in experimental stations, what it actually does in a farmer's field depends on the farmer, his/her aims and goals, the policies that facilitate or restrict specific outcomes, and a local history of irrigating that guides irrigation practices. For example, Benouniche et al. (2014) describe how drip irrigation efficiency largely depends on the attitude of the farmer, rather than on the technology alone.

In this study, we present a case study of the Canyoles watershed over 25 years, where drip irrigation, linked to current trends and supporting policies, has accelerated or co-shaped changes not normally associated with the transition to drip irrigation. The study will show how an irrigation technology, aimed at increasing irrigation efficiencies, can actually stimulate several other peripheral side effects.

IRRIGATION IN SPAIN: HISTORY AND RECENT POLICY TRENDS

How drip irrigation was introduced and used in Spain is closely linked to both its hydraulic history and current and former policies. The historical character of water use in Spain led Swyngedouw (1999) to proclaim: "The socio-natural production of Spanish society… can be illustrated by excavating the central role of water politics and engineering in Spain's modernisation process" (p. 444). Thus, Spanish hydraulic history and how it shaped current policies, which ultimately influenced the introduction and nature of drip irrigation, will be explored.

Historical context of irrigation in Spain

Spain is a water-scarce country, with total renewable freshwater resources per capita ranking among the lowest in the world, yet it also has among the highest rates of water abstraction per capita (OECD, 2010b) and the highest rate of water abstraction from both groundwater and surface water in the European Union (EUROSTAT, 2016). During the 20th century, water scarcity in Spain was discursively used in hydraulic policy, because irrigation was seen as the main driver of economic growth; a supply-driven hydraulic mission focused on bringing as much land under irrigation as possible. Within this discourse, a common view of a "permanent drought" was highlighted, stressing the need not to "lose a drop of water to the sea" (Lopez-Gunn, 2009: 373).

At the end of the 18th century, irrigated agriculture occupied 1 million ha (Mha), but the area devoted to irrigation increased slowly, reaching only 1.23 Mha in 1904. However, between 1950 and 1970, under the Franco regime, the area devoted to surface irrigation doubled to 2.38 Mha (Gil Olcina, 1999). This period is characterised by the 'hydraulic paradigm'; a state-led modernisation project of the Spanish water sector in which technocratic approaches dominated (López-Gunn, 2009; Sanchis-Ibor et al., 2011). Even after the Franco regime, the hydraulic paradigm remained entrenched, as a powerful network of engineers and other beneficiaries of large water projects continued irrigation expansion well into the last quarter of the 20th century (López-Gunn, 2009; Sanchis-Ibor et al., 2011), so that by 1990, 3.15 Mha were irrigated (Morales Gil, 1999). At the end of that decade the Spanish government, being aware that irrigation was the most relevant sector in terms of water consumption, stressed the need for rehabilitation and modernisation of irrigation networks and emphasised both a new model of water policy and the integration of the different public administrations involved in water management (MMA, 2000).

During the 20th century, the expansion of irrigation was seen as an indicator of economic prosperity. However, in the last decades of the 20th century, the focus on irrigation broadened beyond economic considerations, as the social importance of the irrigation sector received increasing attention. Irrigation is an integral component of the Spanish agriculture sector, contributing 60% of total agricultural produce and 80% of total farm exports (López-Gunn et al., 2012b). At the same time, irrigated agriculture fixes the population of villages, increases the income of farmers (Camacho Poyato, 2005) and creates more employment per hectare (Berbel and Gutiérrez, 2004; Gómez Limon and Picazo Tadeo, 2012). An even broader perspective on irrigation highlights issues such as territoriality, identity of the Spanish provinces and an appreciation of the Mediterranean landscape, which challenge the technocratic approach of developing more and more irrigation projects (López-Gunn, 2009).

Recent developments in the irrigation paradigm

Modernisation of irrigation has to fulfil the goals of the European Union (EU) Water Framework Directive (EU, 2000), especially through improving irrigation efficiency. This is important as irrigated agriculture is the largest consumer of water (68%) in Spain (MARM, 2010). Besides high water consumption and low water resource availability in Spain, climate change is expected to further reduce water availability (Millán et al., 2005; EEA, 2010; Fuentes, 2011). Consequently, finding sustainable solutions to water scarcity is of paramount importance for the agriculture sector. Inspired by the EU Water Framework Directive (EU, 2000) and facilitated by EU Regional Development Funds, the Spanish government launched a number of key policy initiatives including the National Hydrological Plan (BOE, 2001), resulting in 32.6% of the budget being directed towards specific irrigation modernisation plans (Rico Amorós, 2010), such as the National Irrigation Plan (2000-2008) (BOE, 2002), the Emergency Plan for the Modernisation of Irrigation (2006-2008) (Plan de Choque de Regadíos) (BOE, 2006) and the National Plan of Water Reuse (2009-2015) (BOE, 2007a). The Plans' main objective of saving 3000 Mm^3 water/year (Lecina et al., 2010) by increasing plot level efficiency, targeted the reduction of traditional gravity-fed irrigation systems and a commensurate increase in sprinkler and drip irrigation systems.

With the support of EU policies providing subsidies, modernisation plans facilitated the change from surface irrigation to drip irrigation. This modernisation has impacted 1.5 Mha, with the area under drip irrigation growing by >450% between 1989 and 2007 (Gómez-Limón, 2010; López-Gunn et al., 2012b), and expansion continuing unabated as a further 19.3% was added between 2007 and 2015. Currently, drip irrigation systems account for 49.3% (1.79 Mha) of the total irrigated area, while the remainder comprises traditional gravity-fed (26.9%) and sprinkler (15.4%) systems (MARM, 2007; MAAMA, 2016).

The modernisation of drip irrigation projects focused on reducing water usage within the agriculture sector (Maestu and Gómez, 2010; González-Gómez et al., 2012; Moren-Abat and Rodríguez-Roldán, 2012). On average, at the national level, farmers use 3239 m^3/ha with drip *versus* 6252 m^3/ha by surface irrigation (INE, 2012). Therefore, in principle, this change to drip irrigation could be seen as very positive. However, the area of irrigated lands expanded from 3.3 Mha in 2005 to 3.6 Mha in 2015 (MAAMA, 2016), an increase of 9.34% in 10 years. The EU subsidy legislation clearly highlights that irrigation modernisation must be realised within the footprint of existing irrigated areas, without expanding the surface area of irrigation (Cabezas, 2012; López-Gunn et al., 2012b). This principle was also included in the National Strategy for Sustainable Modernisation of Irrigation-horizon 2015: "the modernisation process, in no case, will be an occasion for an increase of the irrigation surface" (MARM, 2010: 4). Despite these intentions, the area of irrigated land expanded and led to increased water use. For example, the volume of water devoted to irrigation in the agricultural sector increased by 4.1% in 2014 compared to 2013 (INE, 2016), due to both the increase in irrigated agricultural area by 64,666 ha, and the fact that 2014 was also a year of drought (MAAMA, 2016). Moreover, in Spain, drip irrigation is also being applied to traditionally rain-fed dependent crops, such as vineyards (37.8% of its total area) or olive-trees (28.7% of its total area) (MAAMA, 2016). It is also important to consider that, in some areas, these new projects are favouring an intensive-commercial irrigated agricultural model that sometimes reveals negative environmental impacts. For example, Almería and Murcia in SE Spain are experiencing great pressure on water supply, contamination of aquifers, residues recycling, etc. (Tolón and Lastra, 2010; Caballero Pedraza et al., 2015).

METHODOLOGY

To explore the longer-term consequences of the transformation from surface irrigation to drip irrigation, we selected a small Spanish watershed as our case site, where the shift from surface irrigation to drip irrigation started in the 1990s. The study area was also selected because irrigation has been practised there for centuries (Viciana, 1564; Glick, 1970, 2007; Guinot, 1991, 2008; Polop and Cano, 2003), and thus the effects of changing from surface irrigation to drip irrigation would be more clearly identified than in newly developed areas. It is also important to note that a top-down approach was used to introduce the change, without any farmer training and no consideration of any possible side effects. This analysis includes four municipalities within a small watershed of eastern Spain (Figure 1) and builds upon the literature from other areas of Spain, focused on irrigation modernisation projects in the Ebro, Tajo and Guadalquivir River catchments.

A case study research methodology was used to investigate what can happen to a region when it transitions from surface irrigation to drip irrigation over a 25-year period. Rather than focusing on the correlation between drip irrigation and water saving, we explored the broader effects of the large-scale introduction of drip irrigation by analysing policy documents, interviewing key stakeholders and making field observations. The core of the study involves semi-structured interviews of farmers (n=19), presidents (4) and secretaries (4) of the local Water Users Associations (WUAs), agricultural councillors (2), irrigation system controllers (3), officials of the basin administration *Confederación Hidrográfica del Júcar* (CHJ) (3), technicians of the Department of Agriculture, Environment, Climatic Change and Rural Development (CAPA) (2) and Institute of Geology and Mining (IGME) (2), town hall administrators (2), and academics from Valencia University (3).

CASE STUDY AREA: THE CÀNYOLES WATERSHED

Characteristics of the study area

The Cànyoles watershed in the Comarca La Costera, Valencian Community, Spain includes the villages of La Font de la Figuera, Moixent, Vallada and Montesa (Figure 1), and was the focus of this research. This is largely because this was one of the first watersheds where drip irrigation was introduced and thus the impact of irrigation changes over the past 25 years may be more readily evident.

The study area is located 60 km west of the Mediterranean Sea (Fig. 1), experiencing a typical Mediterranean climate (CSa) (AEMET and Instituto de Meteorología, 2011), with dry, high temperatures during summer, and cooler temperatures in winter with irregular and occasional torrential rain mainly in spring and autumn. According to Papadakis agro-climatic classification, the study area experiences a *Subtropical Mediterranean* climate which is favourable for cereal crops (wheat and barley), vineyards and, if irrigated, citrus, especially orange trees (MAPA, 1990). Despite an average annual precipitation (2000-2014) of 553 mm and a potential evapotranspiration of 750-900 mm, the real evapotranspiration is 450-500 mm, which is largely due to the scarcity of summer precipitation (Pérez Cueva, 2003).

The geology of the area is a Quaternary plain in La Font de la Figuera with sediments of the Tertiary and Quaternary periods evident until the boundary of Montesa. The lithology affects water infiltration and geohydrology. Lowlands are usually laid in impermeable marls and are not very suitable for drilling of wells. In some cases, calcareous loams and limestone are found, which are permeable. Normally, the highest water discharges were obtained from wells drilled next to mountain ranges which are composed of limestone from the Cretaceous (IGME, 1976).

The predominant soil type in the historical *huertas* (orchards) is Luvic Calcisol (CAPA, 2001). These soils are characterised by low structural stability due to their low clay and organic matter content in the overlying horizons. Calcisols reach their full productive capacity only when irrigated (IUSS Working Group WRB, 2007). On mountain slopes, soils are classified as Petric Calcisols (CAPA, 2001). These soils have a higher water retention capacity and higher structural stability in comparison to the Luvic Calcisols.

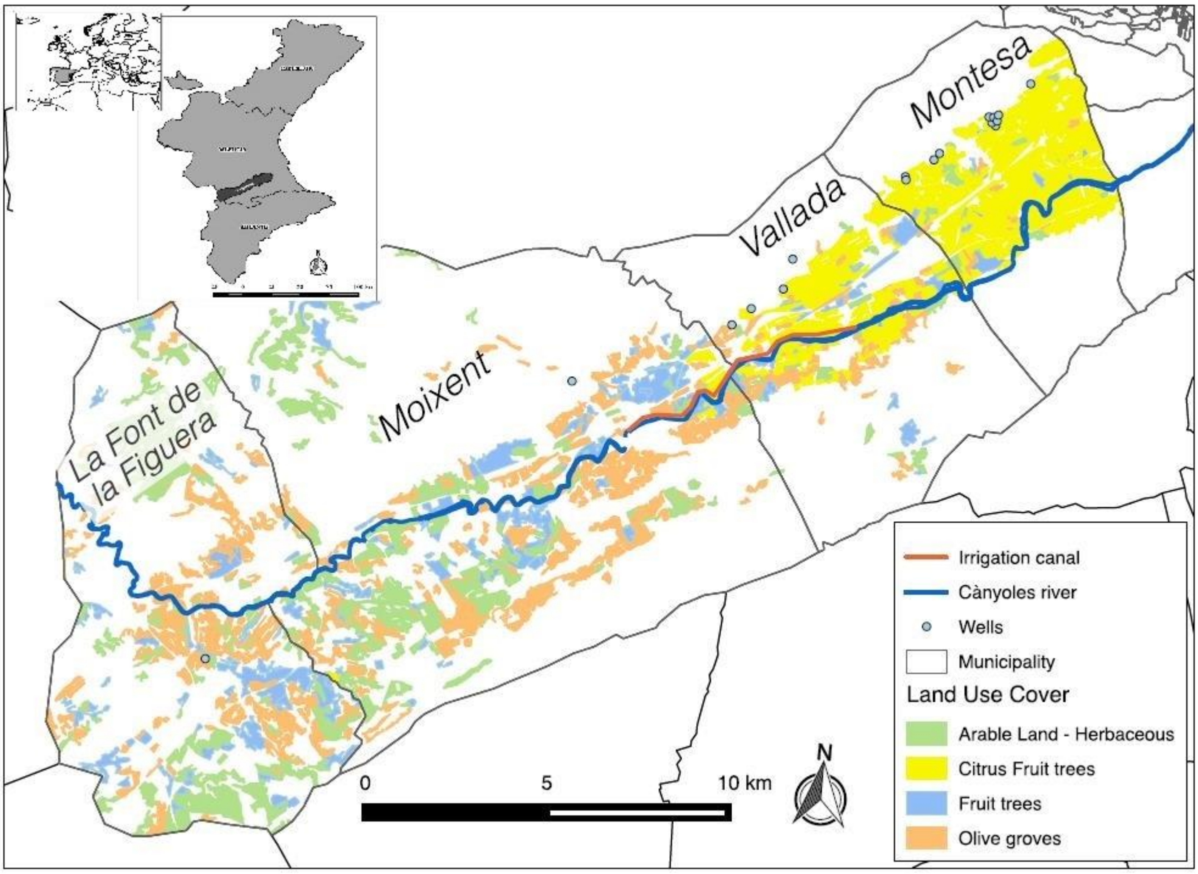
The ephemeral Cànyoles River rises at 840 masl near La Font de la Figuera (Figure 1), and then descends through an incised valley to the village of Canals, before merging with the Albaida River at 80 masl. Its length is 60 km with an average gradient of 0.76º (Mezcua, 2000). Water flow in the Cànyoles River has been so low that, historically, it was considered a *rambla* of Montesa (seasonal stream of Montesa) rather than a river. But when the river floods after torrential rains, coupled with steep valley slopes, the water flows to the Cànyoles River very swiftly, reaching peak discharge in a short timeframe. Apart from the Cànyoles River, there are other temporary watercourses known as *ramblas* and *barrancos* that intermittently discharge water during wet periods.

Therefore, hydrologically-speaking, the Cànyoles watershed is a semiarid catchment, with an average annual discharge of 0.5 m^3/s, and a runoff coefficient of 0.05 (only 5% of precipitation generates surface runoff). The lack of runoff is also partly due to the limestone lithology of the Cànyoles watershed which significantly affects all major water pathways throughout the catchment. Cerdà (1996) found that surface runoff is severely impeded by soils with high infiltration rates formed on limestones in the Cànyoles watershed. Unfortunately, karst springs in the area that once flowed freely have been significantly exploited by agricultural intensification resulting in reduced aquifer levels and consequently in reduced flows that have major implications for the natural and socioeconomic environments of the Cànyoles River Watershed.

Irrigation infrastructure in the Cànyoles Watershed

The initial transition to drip irrigation within the Valencian Community occurred in the area of Montesa, initiated by Decree 47/1987 of the Regional Government of Valencia (GV, 1987). This decree defined the legal framework for introducing different water saving technologies in collectively managed irrigation systems. The *Conselleria d'Agricultura, Pesca, Alimentació i Aigua* selected Montesa as the drip irrigation pilot area, given that in 1990, local initiatives had already been implemented using a similar system to drip technologies (called BIAFRO) to irrigate strawberries. In addition, there was a close relationship between the village of Montesa and the head of the *Conselleria* at that time, which in 1995 resulted in the approval of the Plan of Water Use for Irrigation in the *Comunidad General de Regantes de Montesa* (Valencia) of the Regional Government of Valencia. Thus, the village of Montesa

Figure 1. Comarca La Costera with the Cànyoles River Watershed (Valencian Community, Spain).



became one of the pilot areas of irrigation modernisation in Valencia, which rapidly spread throughout neighbouring villages. Currently, the total cultivated area in the four municipalities comprises 4804 ha of rain-fed-cultivars and 3523 ha of irrigated fields, owned by approximately 3000 smallholders. Farmers are linked to 13 Water Users Associations (WUAs) and three Agrarian Transformation Societies (Sociedades Agrarias de Transformación) that operate 16 big wells with reservoirs at the mountain slopes (Figure 1) to extract and manage the water for drip irrigation (Antequera and Hermosilla, 2003; CAPA, 2014).

There is a long tradition of irrigation in this area which has been practised for many centuries. The Muslims introduced surface irrigation in the 11th and 12th centuries and constructed irrigation infrastructure specifically for crop production (Hermosilla, 2003). The ancient surface irrigation system has sourced water from the Cànyoles River since the Islamic (Pelejero, 2013). Documentation dating back to 1313 refers to practices undertaken by their ancestors: "they have and possess the water that flows through the river crossing Moixent, Vallada and Montesa, and this water has been used for irrigation by them and their ancestors, and they used to irrigate their lands of Vallada and Montesa" (Pelejero, 2013: 13). Intakes from the river guided water by gravity via canals to the irrigated fields. But from the beginning of the 14th century, the waning of the flow of the Cànyoles River was widely reported as a result of farmers of Moixent expanding their irrigated lands, thereby significantly impacting the available water supply for the Montesa and Vallada orchards. Moreover, in medieval Vallada, farmers canalised water from mountain springs to a pool in order to irrigate other orchards not adjacent to the river. However, the Cànyoles River with its ephemeral flow regime resulted in water scarcity which caused numerous conflicts among farmers between the 14th and 19th centuries (Pelejero, 2013).

Currently, two distinct irrigation systems are in use within the study area:

1. *Ancient surface irrigation*: Some are still functioning in an area of Moixent and Vallada, and consist of well-maintained concrete canals (*acequias*, through gravity). In Moixent, these *acequias* irrigate altogether 29 ha using water from springs and 359 ha using water from the River Cànyoles and other minor sources (WUA Rinconada Nueva). In Vallada, surface irrigation is used only in 25 ha, but in the total study area, surface irrigation is used in 413 ha (11.7% of the total irrigated area); and

2. *Recently introduced drip irrigation*: These areas can be further divided into two distinct regions:

   a) *Fields in the proximity of the Cànyoles River:* The irrigated fields located close to the Cànyoles River, that once used ancient surface irrigation infrastructure, but were abandoned, have since been converted to drip irrigation systems fed by wells. In Moixent and Vallada, 230 ha and 325 ha, respectively, have been transformed into drip irrigation, while in Font de la Figuera and Montesa, 265 ha and 920 ha, respectively, have been transformed from traditional surface irrigation to drip irrigation. All these areas – a total of 1740 ha in the study area (49.4% of the total irrigated area) have not resulted in expansion of irrigation land, because they had already been irrigated before drip irrigation technology was introduced; and

   b) *Sloping upland fields:* Once historically devoted to rain-fed crops, these fields now use drip irrigation that results in the expansion of irrigation land. In these areas, water is pumped from wells into open air water reservoirs at elevated locations on mountain slopes which form the main supply for the drip irrigation system. Water is then piped to hydrants from where it is channeled through pipes to individual irrigation stations. From these points, farmers can control water usage, with filtering and fertigation. Out of a total area of 1371 ha (38.9% of the total irrigated area), Moixent has 58 ha transformed from rain-fed to drip irrigation; Vallada, 594 ha; Font de la Figuera, 100 ha and Montesa, 619 ha (Antequera and Hermosilla, 2003; Sese, 2012; CAPA, 2014).

The role of WUAs

Drip irrigation infrastructure was constructed in a collective way and initiated by the local WUAs (defined as a group of owners, usually farmers, within an irrigation area) and thereby representing the basic unit for irrigation management.

Given that the functioning of most WUAs in the area are similar, we therefore will only present the example of the *Comunidad General de Regantes de Montesa*. Constituted in 1906 under the name of *Villa de Montesa*, this WUA possessed historical water rights of the Cànyoles River and utilised the old canal systems and the Montesa Dam for irrigation purposes. In 1991, this WUA joined two other WUAs in Montesa in order to change from surface irrigation systems to drip irrigation systems. The regional government provided half of the total budget for the initial investment. The WUA constructed reservoirs, installed pumps and provided the required pipes for the drip systems. Water is distributed by turns (Antequera and Hermosilla, 2003), with two employees (*motoristas)* being responsible for the maintenance, management of any failures (breakdowns) and reading of water meters.

The oldest WUA is 'Hortes Velles i Noves' in Moixent and obtained its written rules in 1865 but was already receiving water rights from the feudal lord of Moixent since 1303. The other 11 WUAs in the study area were created between 1966 and 2001 (Antequera and Hermosilla, 2003). All WUAs have to be registered with their respective Hydrographic Confederation and are part of FENACORE (National Federation of Water Users Communities of Spain). The collective management of water through WUAs is considered in the Water Law of 1986. The WUA is managed by a president, secretary, some members (usually from three to five) and a treasurer. They call a General Assembly at least once a year where all *comuneros* (users or irrigators) of the association have the right to vote (Sese, 2012).

TRANSFORMATIONS IN THE CÀNYOLES WATERSHED OVER THE PAST 25 YEARS

Since the early 1990s, the introduction and expansion of drip irrigation have transformed the Cànyoles Watershed in several ways: 1) intensification in digging water wells as an additional source of water; 2) shift in water sources and the use of drip irrigation have enabled the expansion of irrigated areas; 3) changing cropping patterns in the region; 4) increased energy demand; and 5) the neglect and loss of cultural heritage. Although these transformations are strongly linked to the introduction of drip irrigation they cannot be solely attributed to drip irrigation as they also relate to broader changes in Spanish agriculture and society.

Transformation 1: Intensification in digging wells

An important change in water sources took place in 1965, when the National Institute of Agrarian Reform and Development of the Ministry of Agriculture drilled the first well in Vallada. It searched for water for domestic use and found larger volumes of water which were also used to irrigate its crops. From the 1990s onward, irrigated areas expanded rapidly when permits to construct new wells were obtained from the *Confederación Hidrográfica del Júcar*, which provided farmers with permits to dig wells (through WUAs, in a collective way), but they were obligated to instal and use drip irrigation. The WUAs in Vallada received a 40% subsidy from the *Conselleria d'Agricultura, Pesca, Alimentació i Aigua* for the installation of drip irrigation. Two WUAs, which were active, operated two wells and the third WUA, which was active, operated two wells, each well at a depth of 120-150 m.

The administration, convinced of the water saving properties of drip irrigation, set the introduction of drip irrigation as a condition for groundwater exploitation. At that time, the EU Water Framework Directive was not enacted, so the introduction of drip irrigation and the extension of irrigated fields associated with the change in water source was considered an improvement for farmers' economy, as irrigated agriculture increases productivity and allowed the introduction of new varieties of cash crops. Also, the area irrigated by the ephemeral Cànyoles River could not be extended due to the low quantity and reliability of available water.

In Montesa, only one of the WUAs still takes some water from the river. All other WUAs pump groundwater from wells and directly deliver water at the required operating pressure to run the drip system. Farmers of the WUA El Reixach take water from a well of 140-170 m depth using two pumps. Further upstream, the groundwater depth increases and wells reach a depth of 408 m. In La Font de la Figuera, at the origin of the River Cànyoles, river water is an unreliable water source. Consequently, the primary water source for irrigation is groundwater from a deep well. However, the WUAs in this village experienced water shortages and lowering of the groundwater table. Given the water scarcity, surface irrigation has changed to drip irrigation and original rain-fed fields were changed to drip in the first half of the 1990s with farmers receiving a 40% subsidy on drip installation costs.

Currently, according to legislation "the process of irrigation modernisation will never be an occasion to increase the irrigated area" (MARM, 2010: 18). Nevertheless, the *Confederación Hidrográfica del Júcar* provided concessions for all new well construction and expansion of irrigated area on the basis of sustainable water availability:

> Within the limits of the Júcar watershed, we give the permit to open wells or to increase their capacity depending on the level of the groundwater table, which is restricted depending on the area. We study the volume of water they want to extract and determine whether there is overexploitation. If there is

> overexploitation we refuse the permit (Official of water concessions and wells, Confederación Hidrográfica del Júcar, personal communication) (Sese, 2012).

These permits include changes from surface irrigation to drip irrigation and the expansion of drip irrigation to rain-fed areas.

In the 1960s, drip irrigation was not the catalyst for the shift in water sources, but since the 1990s, the promotion of drip techniques favoured the opening of wells. Farmers also took advantage of this technique to change from rain-fed to drip irrigation, allowing the expansion of irrigation into areas with steeper slopes. Concessions were given despite the administration knowing about the expansion of irrigated areas (1,371 ha in the study area). This policy of giving groundwater concessions was also followed in other regions of Spain (WWF/Adena, 2015). Thus, surface water resources have been largely replaced by groundwater sources leading to a transformation in the hydrological situation of the study area, a trend closely linked to the introduction and stimulation of drip irrigation.

Currently, altogether 3110 ha are irrigated using groundwater, equivalent to 88.2% of the total irrigated area of the study area.

Transformation 2: Expansion of irrigated area

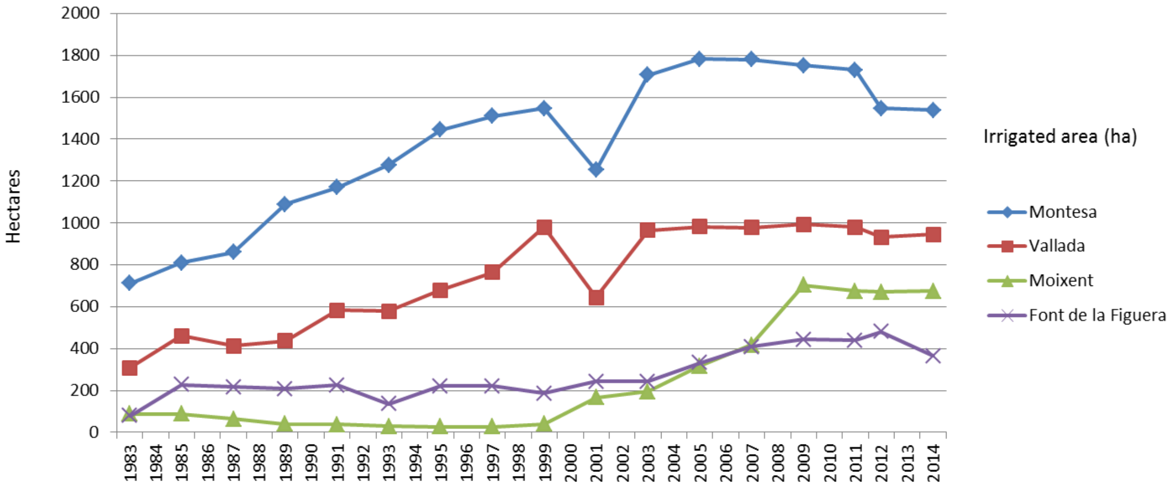
In 1848, irrigated land occupied only 56.8 ha in Moixent, 22.3 ha in Vallada and 4.2 ha in Montesa (Hermosilla, 2003). However, since the 1970s, land devoted to irrigation in the Cànyoles Watershed expanded, with the timing coinciding with the successful drilling of deep wells and the availability of pumps. From the 1990s onward, the surface irrigated areas were transformed to drip irrigation. This change was initially caused by a shift from surface water use towards groundwater use, and is now further accelerated by the move to drip irrigation which allows production even on sloping terrain.

As new wells were dug and drip irrigation introduced, there was an increase in the growth of irrigated areas. Figure 2 shows the long-term expansion of irrigated areas within the four municipalities. In Montesa, farmers started experimenting with drip irrigation in 1990 which was intensified in 1995 with the Plan of Water Use for Irrigation in the *Comunidad General de Regantes de Montesa* (Valencia) Neighbouring villages of Vallada followed suit in the following years. From the late 1990s, the spread of drip irrigation continued in upstream villages of Moixent and Font de la Figuera on the basis of the experiences in Montesa and Vallada. This increase continued especially since 2000, after approval of the EU Water Framework Directive, with rain-fed lands being converted to drip. In some areas, the expansion in irrigated fields occurred above the altitude of the former irrigation canals. Terraces of rain-fed crops in the mountainous parts were irrigated through the installation of water tanks on mountain slopes. On these uphill areas, drip irrigation helped farmers to turn rain-fed land into irrigated land because drip irrigation was feasible on slopes previously not suitable for surface irrigation. Municipalities in the lower part of the study area (Montesa and Vallada) have the largest expansion of irrigated land as they possess sufficient water. The president of WUAs in Montesa, the first area to shift to drip irrigation, explains the situation of the expanded areas:

> The reason that the irrigated area was expanded is that we obtained a permit to increase the capacity of the well and to implement drip irrigation systems, so we can reach other extra areas to irrigate. We experienced expansion overall up the hills to the mountains (President of WUAs, Montesa, personal communication) (Sese, 2012).

In the upper part of the watershed at La Font de la Figuera, the lack of access to water hampered further irrigation expansion. One of the WUAs already had drip systems in place but could not use them as their wells dried up in 2005. A farmer cooperative uses drip irrigation but only as supplemental irrigation to rain-fed agriculture.

Figure 2. The development of irrigated land from 1983 to 2014 in the villages of Montesa, Vallada, Moixent and Font de la Figuera.



Source: Generalitat Valenciana 1983-2014, Superficies de Cultivos por Municipios.

> We can't have more land irrigated than what we have as the available water only covers the fixed hectares, and as, at the moment, the well is dry (Technician support irrigation system from the farmer cooperative, La Font de la Figuera, personal communication) (Sese, 2012).

> At this moment we don't have any water in the well. This happens because they take water from another well to supply the town with water. They started in 1985 and for the first 20 years we all had water but now it does not reach everyone (Secretary and ex-president of the WUAs, La Font de la Figuera, personal communication) (Sese, 2012).

The total expansion of irrigated area in previously rain-fed agricultural land located on the slopes of the mountains is 1371 ha (38.9% of the irrigated area).

Transformation 3: Shifts in crop selection and agricultural production

The Cànyoles Valley is characterised by smallholding farm systems, where each farmer or landowner has small plots of farmland of less than 0.5 ha. The majority of farmers work part-time and often have additional off-farm income (CAPA, 2014).

In traditional surface irrigated plots (*huertas,* situated close to the river and grown for self-consumption), farmers grew a range of vegetable crops such as artichoke, pepper, lettuce, cauliflower and beans. However, in 2014, these vegetables occupied only 44 ha (2%) of the total surface irrigated area. This can be attributed to the introduction of drip irrigation, where there has been a shift to orchards both in the formerly irrigated areas and in those fields previously devoted to rain-fed crops.

During the mid-20th century, Moixent, Vallada and Montesa were dominated by rain-fed vineyards and olive trees in addition to carob and almond trees. Subsequently, vineyards were replaced with apricots and plum trees. With the introduction of drip irrigation since the early 1990s, citrus trees (orange, mandarin and clementine trees) and kaki (persimmon) rapidly expanded, with oranges currently being the most abundant monoculture crop at 70-80% in the villages of Vallada and Montesa, while the remainder consists of olives and summer trees (apricot, plum and peach). The consequence of this shift is that irrigated crops in Montesa represent 93% of the total cultivated area and 68% in

Vallada (CAPA, 2014) (Table 1). In Montesa, citrus represents 76% of the total irrigated produce, which is a significant issue as crop water requirements of an orange crop are higher than for rain-fed crops like olive, almond and carob trees that were historically grown in the area (Allen et al., 1998).

The *Instituto Valenciano de Investigaciones Agrarias* (IVIA) provides monthly drip irrigation advice to farmers in Montesa. Yearly irrigation requirements are estimated at: 5184 m^3/ha/year of bell pepper; 4114 m^3/ha/year of citrus; 2559 m^3/ha/year of almonds; olive trees m^3/ha/year of almonds; and a vineyard of 2053 m^3/ha/year (IVIA, 2016).

In the upstream area of La Font de la Figuera, crop production differs from other areas within the Cànyoles Valley due to limited availability of river water and much lower groundwater levels. Before 1980, farmers predominantly produced cereals as most of the agricultural lands were rain-fed, but during the 1980s, there was a change to vineyards, peach, apricots and vegetable production plus more plant nurseries appeared. There are also cereals, olives and almonds, with apricots to a lesser extent. This area differs from the rest of the watershed as there is no citrus grown because of the higher altitude and colder winter temperatures (Table 1).

Table 1. Area (ha) of crops by municipalities in the Cànyoles Valley (CAPA, 2014).

	La Font de la Figuera		Moixent		Vallada		Montesa	
	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated	Rain-fed	Irrigated
Cereals	513	7	249	1	11	3	1	
Leguminous			7			2		
Potato		1				1		
Sunflower	24		71					
Vegetable		7		4		15		18
Citrus				41		598		1178
Other fruit trees	590	150	185	349	108	158	34	246
Vineyard	700	125	509	115		2		
Olive grove	475	68	916	157	255	144	51	93
Plant nursery	1	7		5	61	19	26	4
Others			3	3	7	2	7	
Total	2303	365	1940	675	442	944	119	1539
%	86	14	74	26	32	68	7	93

The change in productivity from rain-fed to drip-irrigated lands is readily apparent in many parts of the world (Ayars et al., 1999; Soussa, 2010). An example in the Cànyoles Valley revealed considerable increases in the yield of olive trees in a few years:

> My 30 olive trees in production obtained a yield of 700-900 kg every two years. After I installed the drip irrigation system, the production increased markedly to a maximum of 2400 kg per year (farmer, personal communication) (Sese, 2012).

The increased agricultural productivity in the region is due not only to the introduction of drip irrigation, as the farmers themselves stated, but also to other factors including weather, flowering, pollination, climate, fertigation or training of users, which are crucial for the productivity of crops cultivated with drip irrigation (Sese, 2012).

Thus, crop production has shifted to high-value, more water-demanding, monoculture fruit crops. It has led to an increase in agricultural productivity but, at the same time, to higher crop water requirements and water consumption. This trend coincides with the results of a recent study in other areas of Spain, where there has been agricultural intensification, including changes in crops, increases in irrigated area, increases in water consumption (+25% in Bembézar-Guadalquivir; +42% in Riegos del Alto Aragón) and even a double cropping regime (WWF/Adena, 2015), all linked to the introduction of drip irrigation technologies.

Transformation 4: Increase in energy use

Surface irrigation by gravity involves very low energy consumption (García-Mollá et al., 2014). By contrast, drip irrigation requires pressure to operate effectively. Hence, electrical pumps are used to lift the groundwater and create the necessary operating pressure to pump water, which results in higher energy usage. As expansion of irrigated land under drip irrigation continued, there was a commensurate increase in water demand in areas not normally irrigated, resulting in even more water being needed to be pumped and thus more energy being consumed.

While irrigation modernisation in Spain aimed to increase water efficiency, it also contributed to increased energy consumption. This is a major concern for farmers in the research area but has also been reported in other parts of the world (Doukkali and Lejars, 2015; Langarita et al., 2016). Rodríguez-Díaz et al. (2011) estimated that energy consumption has increased from 2.6 to 10%, while the percentage of farmers' income to cover water costs and energy represents around 40% of total water costs. In July 2008, the electricity market in Spain was liberalised and special rates for irrigation disappeared leading to even higher energy costs (BOE, 2007b, 2008; Corominas, 2010), with electrical costs tripling in the last 20 years. Drip irrigation was championed for the sustainable use of water by increasing water efficiency. However, water users were confronted with the unsustainable energy issue that was of great concern to water users and policy-makers alike (Hardy et al., 2012).

All stakeholders in the case study area expressed their concern about energy consumption and energy costs involved in drip irrigation (Sese, 2012. Personal communications).

> *Last September the rates rose 17% and what we pay is a scandal!* (President WUAs, Montesa).

> *The best help would be to decrease electricity costs because we are drowning* (Farmer, Vallada).

> *Electricity costs are the highest cost that we have to face after implementation of drip irrigation* systems (Farmer, Moixent).

Wells and pumps have increased the operational costs of irrigation due to higher energy use, which adds additional pressure on the already low profitability of agriculture in the area.

Transformation 5: Neglect and loss of cultural heritage

Since the Middle Ages, the inhabitants of the Cànyoles watershed have practised irrigation. During the Islamic period, the territorial organisation was structured on the basis of a network of *alquerías* (hamlets). Alquerías integrated rain-fed and irrigated lands with a group of rural houses (Glick, 2007). In the study area, three out of the four villages contain archaeological remains of alquerías: in Montesa: Les Alqueries; in Vallada: Alquería les Solanetes; and in Moixent: Hortes Velles (CULT, 2011).

Christians, after regaining control of the territory in the early 13th century, maintained these traditional irrigation structures due to their efficiency in distributing water. Viciana (1564) described the landscapes and villages of La Costera, highlighting the water wealth and fertile lands of the area. In La Costera, the first written ordinances that regulated the administration in the different canals were dated from the 17th century (Hermosilla, 2003); and in Vallada the corresponding ordinances were dated since 1655 (Pelejero, 2013). It is in the 18th century, owing to population increase and technological improvements, that agricultural areas expanded and new water resources were developed.

Currently, ancient infrastructures related to *alquerías* and *azudes* (weirs), underground and open canals, aquaducts, reservoirs, mills and traditional washing places can still be found. These structures demonstrate how water management has been sustained for centuries and provided a distinctive charm to the Valencian countryside. Despite there being distinct infrastructure related to ancient water management in every village, there is a loss of cultural heritage being experienced in these areas due to their lack of maintenance (Sese, 2012. Personal communications):

> We have a weir in Vallada but it is not maintained. We also have abandoned canals (Secretary WUAs, Vallada).
>
> El Bosquet, which is the oldest reservoir coming from a spring in the whole area, delivered water from the Moorish Canal (Acequia mora). This canal is not preserved and it is partly destroyed. We also have a small aqueduct in disuse and a Muslim tower. These infrastructures should be well maintained at least for the memory of the Moors (President WUA, Moixent).
>
> Cultural heritage is not preserved here; what we had has been transformed so it does not have the same value. The rest – it is not conserved (Farmer, Moixent).

The most important consequence in the Cànyoles Valley is that some canals, used before the shift to drip irrigation, have been abandoned or disused. Only a few old canals are currently in use for surface irrigation, maintained and cleaned by farmers. As for ancient weirs, only one situated in Montesa remains operational. Other infrastructures such as ancient mills, pools and underground canals, like those of Vallada (Pelejero, 2013) are now abandoned. Despite the maintenance of ancient canals and reservoirs elsewhere (Hermosilla, 2010), in this research area there is a non-conservation attitude towards the old irrigation infrastructure from the public administration, highlighting that water heritage is not seen as a priority (Sese, 2012). Farmers, on the other hand, cannot cope with the maintenance costs that would be required to sustain the infrastructure, resulting in the eventual demise of this cultural heritage. In the opinion of the authors, this could be an irreversible loss, while the old infrastructure could have been of cultural value to future generations and for the development of tourism in the region.

DISCUSSION

Farmers, WUAs, municipalities and national and EU policies all facilitated the shift from surface irrigation to drip irrigation, ultimately transforming the agricultural and social character of the Cànyoles watershed. The primary objective of water managers, policy-makers and public administration was to save water and improve agricultural production.

In the research area, traditional surface irrigated land of 1739 ha was transformed into drip irrigation. On these fields there was a change to higher-value crops such as citrus and kaki. At the same time, former rain-fed land of 1371 ha was transformed into drip-irrigated land. On these steeper fields, traditional rain-fed crops like olives, cereals and almonds were replaced by irrigated crops such as citrus and vegetables which have higher crop water requirements. Thus, at the watershed level, there has been a marked expansion of irrigated lands, change of crops grown and increased agricultural production. Perry et al. (2009) argue that when all other conditions remain the same, drip irrigation tends to increase water consumption along with yield, because yield and transpiration are directly related. This combination of change to drip irrigation with expansion of irrigated area and intensification of agriculture all led to more water use at the watershed level. Water saving at the plot level does not explain water consumption at the river basin or watershed level (Seckler, 1996). Research in other river basins in Spain confirms the uncertain relation between irrigation modernisation and water saving at the basin and watershed levels (Cots Rubió, 2011; WWF/Adena, 2015).

Some transformations such as the expansion of irrigated areas and intensified agricultural production have achieved parts of the intended policy objectives (improve agricultural production), but they may also contradict other policy objectives (save water). At the same time it leads to unforeseen effects including the redistribution of access to groundwater, lowering of groundwater tables, increased consumption of energy, increased energy costs, and loss of cultural heritage. Farmers in the upper part of the watershed experience a lowering of the groundwater table and thus need to pump from deeper wells resulting in higher consumption of energy and costs.

Any intervention such as the introduction of drip irrigation will interact with many other elements of the socio-material landscape and, as such, can influence aspects other than the intended ones, which is widely reported in the literature (Ramalingan et al., 2008; López-Gunn at al.; 2012a; Scott et al., 2014; Sanchis-Ibor et al., 2016), and may even contradict existing policy objectives (Boelens and Uiterweer, 2013).

Current legislation for drip irrigation subsidies clearly mentions that a change to drip must be realised in the existing irrigated areas without expanding the irrigated surface area (EC, 2009; MARM, 2010; López-Gunn et al., 2012b). However, expansion of irrigated areas has taken place. Although these expanded areas might enhance agricultural production, there is a clear contradiction with the drip-irrigation policy objective which is saving water without expansion. It is unclear how the *Confederación Hidrográfica del Júcar* made the assessment to provide new well concessions, quantifying availability of water source and the assurance of minimum use for every water activity in the Cànyoles Valley and yet authorised expansion. This discrepancy might be partly explained by the strong influence of the historic Spanish hydraulic mission on past and current policies, whereby major investments are made in increasing the irrigation potential of the country (Lopez-Gunn, 2009: 373).

The expansion of irrigation in other regions in Spain was a consequence of the introduction of drip irrigation. For example, between 1995 and 2005, irrigated areas increased by 60% in the Guadalquivir and Guadalete-Barbate basins (Autonomous Community of Andalucía), due to the extension of drip irrigation, which enlarged from 12.0 to 44.6% of the irrigated surface (Camacho Poyato, 2005); or in La Campana (Ebro), where the area under cultivation increased by 43.7% (WWF/Adena, 2015). The same process has been observed in the southeast of Spain, where traditional rain-fed cultivars such as olive trees and vineyards, have been transformed to drip irrigation to increase their productivity (Morales and Hernándes, 2010).

CONCLUSIONS

While most studies focus purely on the water saving capacity of drip irrigation (or specifically on its impact on fertiliser use, or on soil structure), this study uncovered the interlinked transformations within a system. For the Cànyoles watershed, the shift to drip irrigation resulted in five main transformations: 1) the search for new water sources through the drilling of wells since the mid-1960s; 2) continued unabated expansion of irrigated land; 3) changing cropping patterns and agricultural productivity; 4) increased energy use, and 5) the demise of cultural heritage. The case study provides a recent historical account of the impacts of the transformation to drip irrigation and complements recent studies carried out in other areas of Spain, which suggest that assessing the effects of drip irrigation cannot be based exclusively on the assumption that all other conditions remain the same. Without necessarily attributing all reported impacts to drip irrigation alone, the case shows that the transfer to drip may form part of, or is accompanied with, wider transitions and impacts in agriculture.

Transformations and unintended effects are sometimes directly related to the use of drip irrigation and in other cases, closely related to broader changes in the agriculture sector in Spain where drip irrigation is just one element. Interventions such as drip irrigation appear to work effectively especially in the short term, but may actually have many unforeseen, undesired and possibly irreversible consequences in the longer term. Policy makers and drip irrigation users should look beyond the short-term consequences of drip irrigation and consider possible additional transformations that might impact the long-term sustainability of agricultural communities such as the Cànyoles watershed.

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