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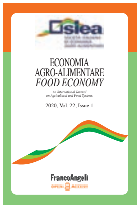

Guest Editorial

Sustainable Management of Water Resources: Agricultural Sector and Environmental Protection

Lucia Briamonte*, Stefania Luzzi Conti*, Raffaella Zucaro*

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Climate change has led to one of the most significant threats of recent decades, creating consequences on both environmental and human systems. According to the 4th Evaluation Report of the Intergovernmental Panel on Climate Change (IPCC), the physical effects of climate change such as rising temperatures, falling rainfall, frequent extreme weather events and limited availability of natural resources have a significant impact on the agricultural sector and its production, strongly influenced by the climate context in which they are produced.

Climate change induces new factors of uncertainty on the prospects of the agricultural sector showing increasingly irregular and unpredictable future conditions with an increase of exceptional events such as floods, periods of intense heat and consequently prolonged drought. The latter is the main responsible for production declines of agricultural production following the reduced availability of water resources.

Water scarcity and quality issues represent, in fact, in the current century, a problem in many parts of the world. They are a serious challenge to future food security and environmental sustainability. At the international level, the awareness of the agricultural vulnerability to climate change is increasing: G20 ministries are trying to tackle the negative impacts and to highlight the rule of the agricultural sector considering water and natural resources management. Ensuring sustainable and resilient agriculture will also allow achieving the objectives declared by the 2030 Agenda for

Sustainable Development and its 17 Sustainable Development Goals (SDGs), that countries adopted in 2015 (United Nations, 2015).

At the European Union level, Green Deal aims to inform, inspire and promote cooperation between people and observe their connections and its impacts: from national, regional and local authorities to businesses, trade unions, civil society organisations, educational institutions, and research reports and innovation, to consumer groups and people (citizens and communities), all should play a role in planning new climate and environment actions and ensure its sustainability (European Council, 2019; von der Leyen, 2019).

At the national level, agro-food production is one of the most important sectors for the national economy, but in the Mediterranean area, agriculture and food production are strongly impacted by scarcity of water and climate change.

Water sustainable management, especially concerning the changed climatic situation that is affecting our country, is a central theme that involves all the sectors and water uses, and mainly the agricultural one. Irrigation practice in Italy is of fundamental importance for agricultural production and the economy of our country.

Problems of water availability arise in areas with low rainfall and high population density, intensive productions or industrial activities. Droughts can occur during any season both in high and low rainfall areas, but the negative impacts of droughts are exacerbated where water resources are not properly managed.

In Italy, increases in the length and frequency of drought periods have been recorded during the last years, especially in northern regions. The reduction in precipitations has clearly affected the aquifers, that showed water retention values close to the historical minimum. In some Italian regions, a decrease of 60-70% of rainfall volumes during winter has been recorded. In addition, as reported by the National Observatory of Water Use, the amount of snow during winter has decreased, subsequently reducing the amount of snowmelt and therefore the overall water reservoirs. Cumulative precipitation values were lower than the typical seasonal average at the national level during the 2018-2019 winter. These factors, added to the growing pressure on agricultural systems, need to be combined with population growth in rural areas.

Therefore, water resources use sustainability and efficiency in the agricultural sector represents a key and important factor in guaranteeing the profitability of our farms and, at the same time, the protection of ecosystems and the territory.

From an economic, environmental and social point of view, it is important to guide the farming systems towards the conservation of resources in order to allow economic sustainability and ensure rural employment in marginal agricultural areas. It needs to encourage the dissemination of new measures and methodologies in line with the objectives above described.

The Research Center for Agricultural Policies and Bioeconomy (CREA-PB) carried out many research activities related to the efficient and sustainable management of water resources, both at the national and international level, as a relevant element for guaranteeing environmental sustainability in the production process, including an increase in production and food security and the conservation of natural resources.

The Research Centre participates in many national coordination tables between agricultural and environmental policy, with attention to the issue of water resources and adaptation to climate change of the agricultural sector. The Research Centre collaborates with different public body and partners in order to support knowledge and innovation sharing for water resources-related policies and to provide scientific and technical support through projects related to water scarcity, sustainable water use and water management in agriculture.

CREA-PB is the responsible body of the SIGRIAN (National Information System for the management of water resources in agriculture), a WEB GIS database containing all the information concerning the use of water in agriculture (equipped areas, irrigated, supply sources, irrigation volumes taken, distributed, returned, costs etc).

Recently, CREA-PB is managing a National database of investment in irrigation and environment (DANIA) with a projects collection (financed and planned) for collective irrigation, complete with technical and financial data useful at different phase (planning and programming, financing, monitoring and evaluation).

CREA also quantified the drought phenomenon using the Reconnaissance Drought Index (RDI) that investigates droughts based on the relationship between precipitation and evapotranspiration. The last elaboration showed that during the 2006-2015 decade, events of agricultural drought were more frequent and severe in the Northern regions than in the South of Italy.

The CREA-PB activities aim to develop analyses and provide support in the processing of sector policies, monitoring their evolution and assessing their effects on the systems. They also aim to analyse the relationship between water and water resources policies, also in relation to the issue of innovation in the use of irrigation resources, all applied in the planning of irrigation investments.

To add new elements, actions and solutions to the water management in agriculture, CREA-PB launched a Call on the topic "*Sustainable management of water resources: agricultural sector and environmental protection*" to contribute to the issue of water resources use in irrigation sector and the problems related to the effects of climate change.

One of the main challenges of the sector is the pursuit of a greater degree of efficiency and sustainability in water irrigation management, in terms of quality protection and management improvement. Since water is a common good and used for different uses, the adoption of strategies and planning of targeted interventions must consider the multiplicity of subjects involved.

To understand if the Call covers most of the important topic related to water management, we need to refer to the Blueprint to Safeguard Europe's Water Resources. It is the EU Commission Communication that analysed the obstacles which hamper action to safeguard Europe's water resources and is based on an extensive evaluation of the water policy. The Blueprint emphasises key themes, which include: improving land use, addressing water pollution, increasing water efficiency and resilience, and improving governance by those involved in managing water resources. Its long-term aim is to ensure the sustainability of all activities that impact on water, thereby securing the availability of good-quality water for sustainable and equitable water use. This goal is already enshrined in the WFD in various ways. The Blueprint aim is to achieve the goal by identifying obstacles and ways to overcome them.

The response to the Call in terms of submitted articles was positive, despite the topic was rather narrow. Therefore, the special issue shows the articles presented at the invitation and selected for this special issue that, as we will see, covers the broad subject of the Call partially. For this reason, in our opinion, many issues remain to be explored.

Specifically, different key elements ranging from efficient water management, policy instruments for irrigation groundwater management, water efficiency in wineries to positive externalities related to irrigation are showed and studied. Finally, a technical note relating to an innovative project of the Tuscan-Emilian Apennines on the river Po was included, which presents new advanced systems designed to guarantee the safeguarding of the area.

The growing urbanisation and industrialisation and the water scarcity condition, also as an important consequence of climate change, requires, as known, continuous attention to the water use in agriculture. This condition entails a more efficient water resource management, with an improvement of water networks and the reuse of wastewater where farmers play a key role. In this direction, the paper "Water management: a way to achieve a more efficient irrigation system" by Siviero, Itimura de Camargo and Masoumi, takes inspiration from the current concern, regarding the water resource management, due to the transport of the water resource in the irrigation area of Arda, located in the province of Piacenza, highlighting the approach proposed by the Piacenza Reclamation Consortium for the water losses reduction in the irrigation network. The project concerns the replacement of the traditional open canal system with a new underground pipe system used only for irrigation, taking into consideration the hydrogeological structure of the area and the aspects related to architectural and technical functional quality.

Another typical point of the management of the common goods concerns the excessive exploitation of groundwater for irrigation purposes. The paper “Policy instruments for irrigation groundwater management an assessment of farmers’ stated preferences” by Giannoccaro, Sardaro, De Vito, Roselli, de Gennaro has analysed some policy options in order to address this problem through a survey carried out in Puglia on a representative sample of 187 farmers, selected in the main irrigated areas. The main survey result shows farmers’ preference for increasing the supply of wastewater and improving control of rural areas.

The Apulian region is also the protagonist in the paper “The technical efficiency of Apulian vineyards with different supply systems of the irrigation water” by Sardaro and La Sala, aimed at measuring and comparing the technical efficiency of the wineries located in northern Apulia and characterised by three different water supply irrigation systems: 1) groundwater use through private wells; 2) irrigation water use through collective water networks; 3) irrigation water use through private wells and collective water networks. The aim is to understand if and how different irrigation water supply systems interact with the use and management of inputs, providing useful information to policy makers in order to develop adequate policy strategies focused on the preservation of environmental resources, as well as its positive externalities. The Apulian area is characterised by a significant need for water resource for irrigation, however, presenting high inefficiency levels of the collective water networks that force most of the regional farms to use groundwater, with a consequent deterioration of the resource quality, but also of the soil and crops characteristics. In order to promote sustainable supply methods for water irrigation, it is necessary to know the effects that current water supply systems have on the economic performance of farms.

The document authored by Zambotti “Saving water, protecting the environment: A new model for agriculture in Val di Non”, illustrates the rules used for agriculture and the environmental protection in the province of Trento, also presenting the complex ongoing research aimed at finding a new balance between the quality preservation of the watercourses in Val di Non and the growing water demand for local agricultural production. The need to provide an adequate water supply for agriculture conflicts with the need to guarantee minimum flow levels in local waterways, as well as to maintain an adequate quality of running water. The proposed solution focuses on the need to connect existing irrigation infrastructures. Thus, it aims at building an integrated irrigation system that covers the entire Val di Non and includes irrigation networks, basins and pumping stations, with the involvement of several stakeholders who provide specialised agricultural services, ranging from plant protection and pest management to insurance against the risk of spring frost, to job protection, processing, storage and marketing of products. In this context, with the support of local research centres, irrigation cooperatives and the administration of the Autonomous Province of Trento, an innovative model of economic efficiency is going to be built.

Finally, the latest paper "On positive externalities from irrigated agriculture and their policy implications: an overview" by Natali and Branca, provides an overview of the direct, indirect and potential benefits of water use in agriculture by identifying and evaluating the positive social, environmental and ecological effects related to the irrigation practice from an economic point of view, observed and attributed to five categories of contributions: 1) irrigation return flows for the recharge of groundwater; 2) biodiversity and wildlife habitats; 3) aesthetic and cultural values of the landscape; 4) recycling and conservation of nutrients; 5) improvement of health, nutrition and living conditions.

The special issue ends with the description by Paglione and Bertozzi, of an innovative project, the Burana Land-Reclamation Board which operates on a district of approximately 250,000 hectares between the Secchia Panaro and Samoggia rivers, coinciding with the water catchment area of the Panaro river and Burana-Po di Volano, from Tuscan-Emilian Apennines in the Po. Its main activities concern the conservation and safeguarding of the land, with particular attention to water resources and their use, ensuring the water drainage from the urban centres and agricultural areas and also water supply in the whole area to ensure the irrigation service and to cope drought. The project was deemed worthy of attention as a joint example of innovation and sustainability that, through the use of innovative and environmentally friendly techniques, improve the management of water resources.

Compared to the European Commission project, the issues addressed with this work respond to most of the key themes, as shown in the following table.

Land Use and Ecological Status	**Chemical Status and Pollution**	**Water Efficiency**	**EU Waters Vulnerability**	**Crosscutting Solutions**
	X	X		X
	X	X	X	X
		X		
		X		X
X		X	X	X

Other topics, albeit important and related to the sustainability and the efficiency of irrigation water management, like water policy, water pricing and the integration between agricultural and water policy and management are not included in the works presented to the Call.

Finally, we want to thank the referees for the effort made in reviewing the works; we are extremely grateful to the work they put into maintaining the quality of published papers. Moreover, we want to thank our colleagues Veronica Manganiello, Marianna Ferrigno, Silvia Baralla, Romina Lorenzetti, Myriam Ruberto, Giulia Benati and Arianna Quaglieri for helping us to ensure the consistency of contributions.

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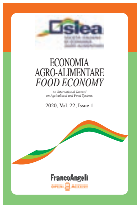

Water management: A way to achieve a more efficient irrigation system

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Abstract

The pressure of growing urbanization, industrialization and water scarcity resulting from climate change imposes limitations on the amount of water allocated to agriculture. There will need to be an increase in food production of almost 50% by 2030. This will be an enormous challenge, requiring a significant increase in irrigable land area in the forthcoming years. It is necessary to improve water 2 systems based on the knowledge that high efficiency can be achieved with less water only by the adoption of more effective water-management plans, especially in agriculture, which is the major consumer of this precious resource. Water management in agriculture has a dual task: improving both water networks and how treated wastewater is used and re-used. Farmer participation in water administration will play a key role in agricultural production growth. The paper highlights current concern regarding the management of water supply for irrigation from the River Arda in Piacenza province, Italy. The approach proposed by the Consorzio di Bonifica di Piacenza for the reduction of water loss in the irrigation network is the replacement of the traditional system of open canals with a new underground pipe system, to be available only for irrigation, in such a way that the hydrogeological structure of the territory would not

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be altered. The project's technical and economic feasibility depend on architectural quality and technical functionality. During the project phase tools and methods were also considered, seeking to involve techniques, materials and equipment that would make the pipe system less invasive and more affordable, efficient and manageable, not only regarding the final results, but also the project's development and construction stages, as well as its post-construction ordinary maintenance.

Introduction

Water is the most important resource in life, it is essential for food production, for our daily activities, for industrial purposes, for the health care, energy, and so. The disproportion between human water needs and water availability around the globe shows the importance of the conscious and efficient water management (Alcamo *et al.*, 1997). Another aggravating factor apart the unbalance water demand/availability is the climate change where the temperature and precipitation increase significantly, but, Alcamo *et al.* (1997) emphasizes that these changes have negative effects when it comes to water vulnerability, since higher temperatures leads to higher evapotranspiration rates, higher water use for agriculture and lower runoff, whereas higher precipitation leads to lower agricultural water use and higher runoff.

According to Chaves and Oliveira (2004), nearly 70% of the available water in the world is employed in agriculture and 40% of the world's food is produced in irrigated soil. Therefore, investing time and research in water management for agriculture is a matter of public interest not only for food producers but also for stakeholders, government institutions, citizens, etc. Mastrorilli and Zucaro (2016) express that: "the rational and efficient management of water is aimed for agriculture in order to preserve and perpetuate uses in the non-agriculture sectors", such as commercial goods, energy and industrial production, transportation, environmental and domestic purposes and so.

The need of sustainable approaches for water management in agricultural activities is increasing by the day. In agronomy, the sustainable water use implies the production without waste and with low impact on the environment. From the economical perspective, the sustainable use is the ability to continuously extract the resource for an indefinite period of time. Therefore, with good practices and scientific knowledge available it is possible to intensify the irrigated crops without neglecting sustainability principles (Mastrorilli and Zucaro, 2019). In addition, it is not possible to ignore the fact that agronomic practices are deeply involved in a wide range of issues related to the use of water, according to Mastrorilli and Zucaro (2016): "from the interception of rain to the protection of water; from the control of the excess water to crop water supply; from the determination of the crop water requirements to reduction in the wastage of water; from the efficiency of water used by crops to landscape conservations […]".

This paper presents one of the projects selected by the National Program of Rural Development 2014-2020 (PSRN, 2017), that was developed aiming to attend and surpass the needs of a highly consolidated agricultural area, searching to implement different techniques and approaches in order to follow the current trend of efficiency and sustainable use of water for irrigation purposes.

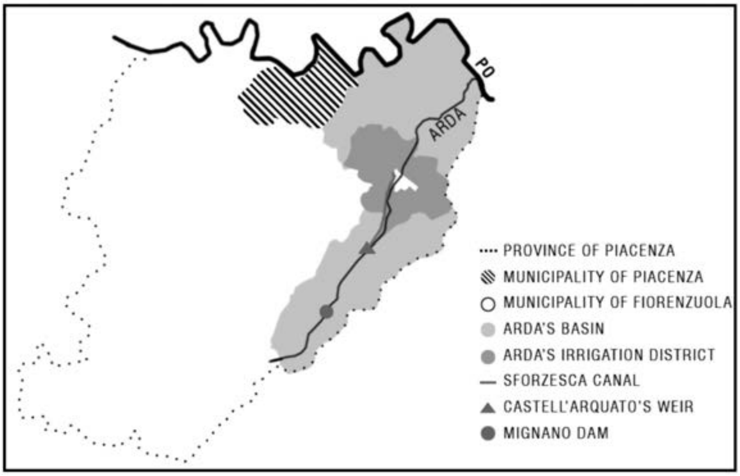
1. Contextualization

The studies and development of this project takes place in Piacenza, a city in the north of Italy, most specifically in the region of the Arda basin, which is very important for the city, not only as a natural resource but also as an economic feature, since it feeds the irrigation system in a vast area of agricultural fields. The Arda river flows through a valley with the same name, and it is an affluent of the Po river, the longest and most important river in Italy (Fig. 1). Arda's irrigation district is in the east flatland of Piacenza, between Lat. 44°55'-44°59' N, and Long. 9°49'-10° E. According to Köppen's climate map, Piacenza is located in a subcontinental temperate zone (the annual average temperature is between 10 °C and 14,4 °C). In Piacenza, the annual average temperature is 12,2 °C, being the hottest month July with an average temperature of 22,9 °C. The precipitation data shows that the total annual rainfall is about 850-900 mm in Piacenza's flatland area. July is the month with lower annual rain index, with 45 mm distributed in 4,5 days of rain. October is the month with highest annual precipitation, with 107 mm over 7,8 days of rain.

This area counts with a highly consolidated scheme for the caption and distribution of water, made by the Mignano dam, which was constructed between 1919-1934 and the final security test was in 2018, the Arda river (about 11 km long) and the Castell'Arquato weir (Fig. 2), from where the main adduction canals branch off, both on the right and left side of Arda river, and feed the irrigation districts.

Figure 1 - Context of the area

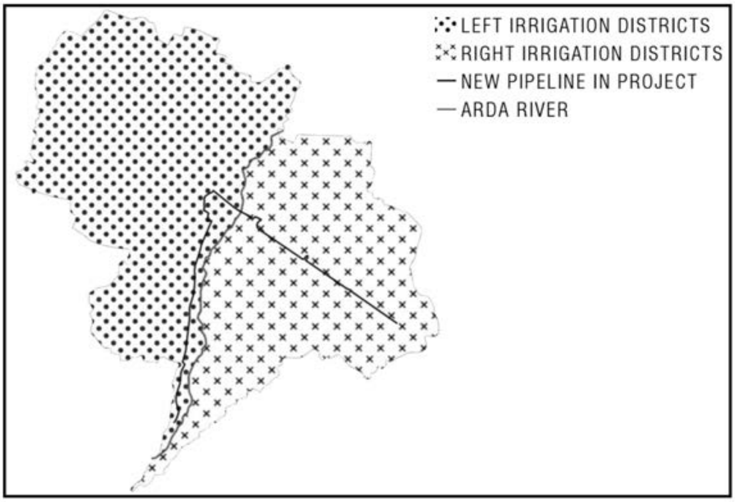
Figure 2 - Context of the water system



The secondary and tertiary distribution networks ramify from the right and left main canals. The territory surface is 15.392 hectares and this irrigation structure supplies approximately 55.9% of Arda's area, generally in the period between April and September. For organizational reasons the area was subdivided into four different irrigation districts, two on the right side of Arda river, two on the left side, all with similar territorial extension. The right bank of the Arda river corresponds to an area of 7.291 hectares, where 50.4% is irrigated land, the left one is 7.811 hectares, in which 61.1% is contemplated by the irrigation system. Arda's irrigation scheme also counts with a remote-control system that allows the management, the constant measurement and archiving of water volume withdraws from Castell'Arquato's weir in selected periods of time (CBPC, 2017).

At present, Arda's right and left main canals provide water for a total of 8445.97 hectares of the territory, the network of canals is about 354,7 km long, of which 44.85% are open alluvial canals and 55.15% are enclosed underground canals. The Sforzesca is the main water canal of the left side of the river, it is valuable for its mixed function of rainwater drainage and water distribution for irrigation. It also has a historical value for the territory, since it was traced over the 'Rivo Sforzesco', which was excavated between the XIV and XV centuries for irrigation and grinding uses, although the second one is no longer carried out. For that reason, the Sforzesca is considered an element of historical interest and care for Piacenza's region. It is 12.203,08 m long and is fully open with the natural bottom, with a trapezoidal

Figure 3 - Irrigation districts and new pipeline



section that varies dimensions from 1,00 to 2,50 m on the bottom, 4,00 to 5,50 m on the top and height of about 1,50 m with both sides inclined 45° (CBPC, 2017).

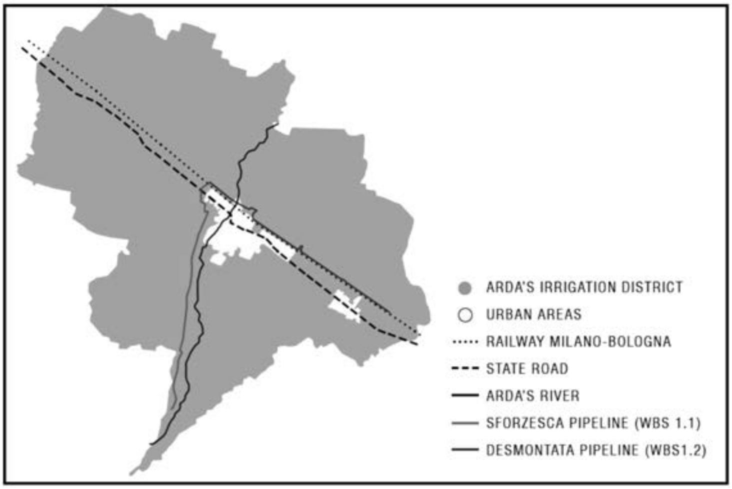
In this context, the aim of this article is to review several issues of Arda's irrigation network. The most critical one is the long distance between the intake structure (the Castell'Arquato weir) and the two main distribution canals, the Sforzesca canal on the left side and the main canal on the right side, causing considerable water losses on the way, mainly made by infiltration in the bottom of the water canals and, in a smaller scale, by evaporation. This makes the system less efficient and can be considered as unsustainable, as the potential of the natural resource is not being fully used and also generates a higher economic loss. Another substantial concern is the mixed function of the canals, being used as distributors of water and collectors of the rainwater, which can create complicated situations as overflow during the rain or irrigation periods (CBPC, 2017).

2. Materials and Methods

As a response to the demands and needs of the territory, the Consorzio di Bonifica di Piacenza decided to develop a project that would offer solutions and manage the presented issues of Arda's region, with the improvement of the adduction and distribution systems, seeking to implement modern and sustainable techniques and achieve, as a result, the main goal: Saving water by reducing the loss during the transportation of the resource due to infiltration. During the project phase, several aspects were examined, aspects like hydrology, geomorphology, social and environmental, among others, in the attempt to achieve a project with relatively low impact, post-built maintenance and cost, disturbance during the construction phase, and so. The first compromise made by the team was to keep the gravity character of the existing system, as an environmental and economical approach, by using the natural topography to transport the water by gravity there would not be energy consumption for pumping it.

Considering the dimension and the linear aspect of the project (20 km long pipe system, approximately), it was decided to divide it into four distinct parts called WBS (work break-down structure), to facilitate the phase of the project programming, and execution. Still in the project phase, after the conclusion of the definitive project, the team inserted every linear and punctual elements of the WBS into the Consorzio's geodatabase with PostGIS, so that the pipeline (linear) and reinforced concrete structures (punctual) are all georeferenced and easily traceable. In addition, the team developed the project with a BIM software (Building Information Modelling), also with the aim of facilitating the construction phase, post-built maintenance and life cycle assessment of the final work. The most relevant WBS for the purposes of this article are WBS 1, i.e. adduction pipes (Fig. 4) and WBS 4 (wastewater recovery).

Figure 4 - Arda's irrigation scheme and the new adduction pipeline

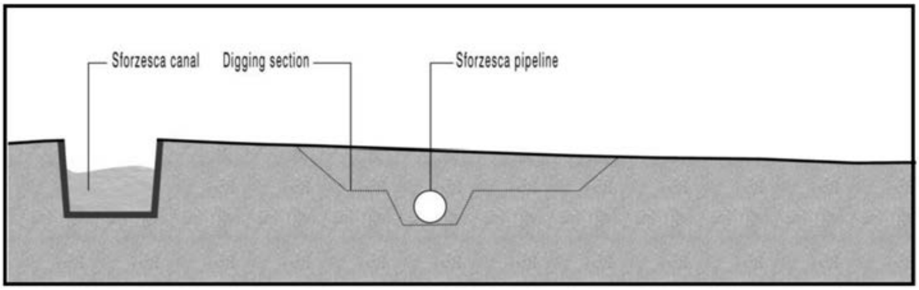


Thus, in the scope of the caption of water, the project intends to 're-functionalize' the intake network to the service of the irrigated lands. The chosen alternative was to introduce new adduction pipes running alongside the Sforzesca canal, ensuring the water volume that arrives in determinate irrigation districts (CBPC, 2017).

This phase, that is designated to be WBS 1.1, includes several actions, being the central one to make adjustments in the existing irrigation network of the Sforzesca canal, such as implementing enclosed underground pipes to distribute water for irrigation ends and keeping the Sforzesca to be rainwater collector only, without modifying its form and function (Fig. 5). This approach also guarantees the protection and care of Sforzesca's aspects as a historical element with significant importance to Piacenza's rural landscape.

Basically, the work begins near the municipality of Castell'Arquato, where the main pipe collects water from the Sforzesca canal, throughout a system of existing floodgates, and channeling it into a tank made of reinforced concrete, to be cast on site. From the tank, which is the starting point of the WBS, the pipe runs alongside the existing canal for 9.814 km, until the intersection with the railway that connects Milan to Bologna (Desmontata location).

Figure 5 - Sforzesca pipeline positioned alongside the Sforzesca canal



The pipes were dimensioned in order to deliver the necessary volume of water to the districts of both sides of Arda, even though the main pipe is located in the left bank of the river (Fig. 4). As a result, the piping system initiates with a diameter of DN1200 mm and drops to DN1000 mm as the Sforzesca pipe goes forward. In this first section (WBS 1.1), considering that is the one with higher pressure and volume of water, the chosen material was GRP (glass reinforced plastic.), for its reduced weight, high resistance to corrosion, convenience to be cut and managed on-site, high mechanical and chemical resistance, long durability, and so on (Sintecnica Engineering *et al.*, 2016).

The WBS 1.2, also known as Desmontata, begins after the intersection with the railway MI-BO. The Desmontata runs alongside the railway in west-east direction for a distance of 10,201 km, from the Desmontata location (Fiorenzuola) until Alseno railway station (Alseno). The diameter of the pipe decreases progressively as the WBS goes forward, growing down from DN1000, DN800, and DN600 until DN500. The ductile cast iron was the material chosen for the WBS 1.2, this type of cast iron has a great resistance/ weight relation, lower cost, operational simplicity of preparation and application, offers high resistance to traction, impact, natural corrosion, oxidation, and abrasion, other than having compression, tensile and fatigue strength (Bartolomeo, 2005-2006).

The project of both pipe systems counts with the implementation of reinforced concrete structures to host the hydraulic systems (such as hydraulic valves like a butterfly, ball, flow, and so on) and to serve as inspection wells. These structures were divided into four typologies and categorized in four varieties of structure (M-Manufatti) and six varieties of hydraulic equipment, in order to facilitate management during the construction and, later, the maintenance of the finalized project. Other than the technical equipment, there are also the interferences along the pipes, such as the intersection of roads (AS-Attraversamenti Stradali), some small watercourses (AC-Attraversamenti Corsi d'Acqua) and the railway (AF-Attraversamento Ferroviario). In critical points where the pipeline crosses tangential roads or the railway, it was decided to use a trenchless (no-dig) technique with micro tunneling. The micro tunneling technology is an economical way to install tubes under infrastructures such as roads, railways, rivers and so. It has a very low environmental impact, a reduced consumption of local materials for the filling of the excavations and also a lower number of necessary excavations, it is required less time to the execution (including preparation and restoration time), for the time saving it becomes more economical (it can reach half of the cost of traditional open-cut techniques.), it is less invasive during the construction phase (socially and ecologically) for the reduced generation of noise and air pollution, among other benefits.

Figure 6 – Reinforced concrete structure that hosts hydraulic equipment (Revit MEP – BIM. Simulation)

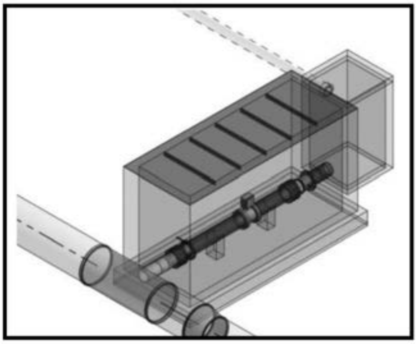
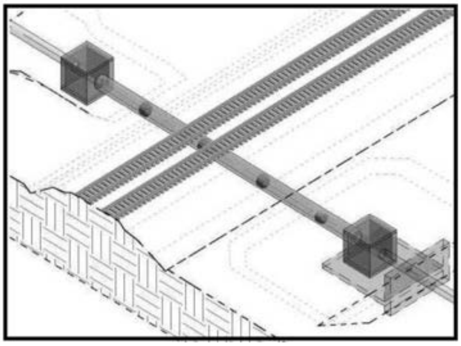
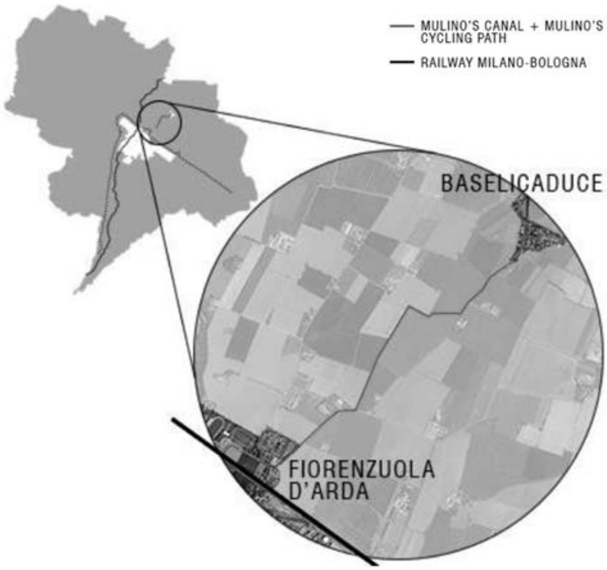


Figure 7 - Intersection of the GRP pipeline with the railway MI-BO, in WBS 1.1 (Revit MEP - BIM. Simulation)



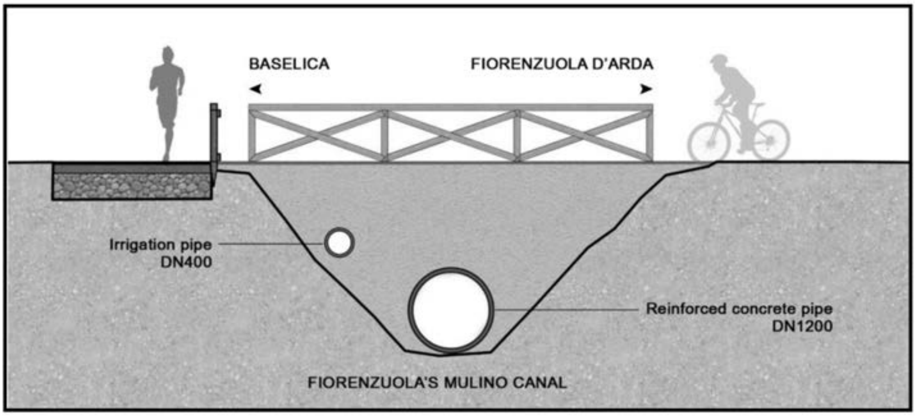
Finally, the wastewater recovery was nominated WBS 4. This section of the project predicts investments for the use of treated wastewater for irrigation, instead of collecting the resource from superficial or underground sources. The proposed actions in this phase include the recovery of wastewater taken from the urban treatment station in Fiorenzuola d'Arda. This section was divided into 2 branches: WBS 4.1, which is related to the wastewater intake structures located in Fiorenzuola's treatment station, and WBS 4.2 corresponds to the construction of the new pipeline 'Mulino di Fiorenzuola'. Therefore, the main goals of the WBS 4 are the water consumption systematization through the installation of a withdrawal measurement system and the piping of Fiorenzuola's Mulino canal, for the reduction of the losses of the water reused for irrigation purposes. At last, this intervention will take place particularly in the lower right of Fiorenzuola, through the introduction of a new pipeline on Mulino di Fiorenzuola canal, of diameter DN400 made in PVC, 1.550 m long, as a substitute of the current open canal (CBPC, 2017).

Figure 8 - Fiorenzuola's Mulino canal



As an additional intervention to the works in WBS 4, with a partnership between the Consorzio and the municipality of Fiorenzuola d'Arda, it was proposed a new cycling/pedestrian path along the Mulino canal, in order to improve the landscape/citizen relationship and to enhance connectivity and mobility in that area.

Figure 9 - Section of Mulino canal and cycling/pedestrian path

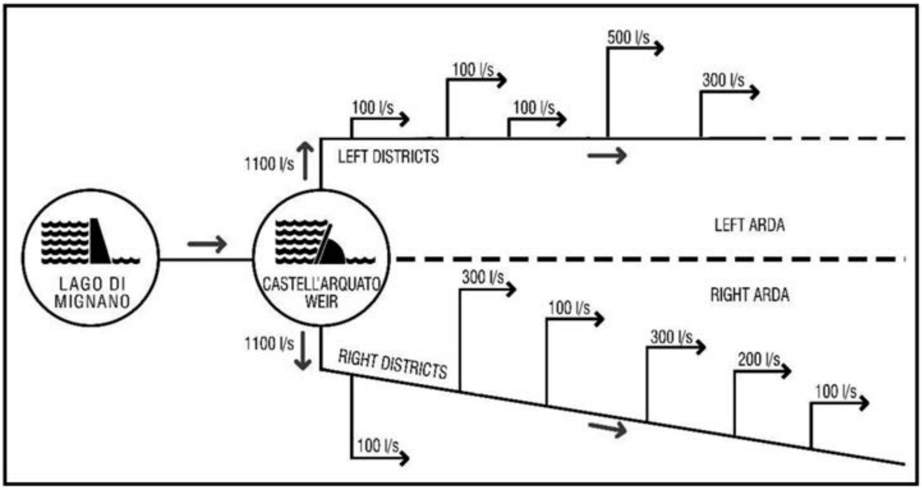


3. Results

The improvement of Arda's system is defined by an expression named 'Potential hydraulic saving', which is determined by the relationship between the volume of water saved after the intervention and the volume derived from the irrigation system's source. The main aspects considered to define the potential hydraulic savings are the territorial framework, the definition of the irrigation scheme, the reconstruction of the fluvial outflow and water volumes, the project synthesis, the projection of the water losses by leak and the data and result analysis (CBPC, 2017).

The total territorial surface covers about 15.392,6 ha of Piacenza's province, of which 13.433,84 ha is supplied by the irrigation system. The total length of the network is 354,7 km and the main canalization is about 21,1 km. The irrigation scheme, in numbers, is made by one dam (Mignano), one river (Arda), one weir (Castell'Arquato), two main adduction canals of about 23 km, secondary and tertiary distribution system of about 384,5 km in length (Fig. 10). The distribution system consists in open-air canals in soil and concrete and in pipelines made of PVC, concrete and steel materials. As mentioned, the existing remote-control system makes it possible to register the volume of water taken from the Castell'Arquato weir, from both right and left main canals (CBPC, 2017).

Figure 10 - Irrigation system



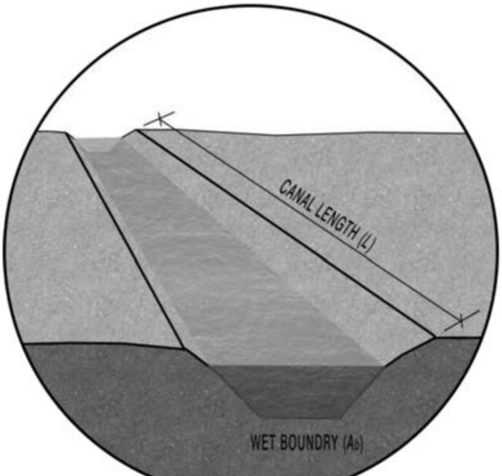
The water loss of a canal depends on the type of material that it is made, its length and how this distribution network is managed.

In order to calculate the water loss by the leak of the system, it was considered the average irrigation season, keeping as the base the data from the last 7 years (2010 to 2016). The parameters that are more relevant for the losses by the leak in the canals are the length of the open-air canal, the wet perimeter of the canal's hydraulic section, the coefficient of water loss (which depends on the soil structure).

In this case, the **length** (*L*) of the canals was found with the support of the software PostGIS. The **wet boundary** (*Ab*) refers to the perimeter of the canal's hydraulic section in contact with the water, and it was obtained from the water levels data measured by the remote-control system, corresponding to the average flow rate transit reported on Fig. 10.

Lastly, the coefficient of **hydraulic loss** (*C*) refers to the daily loss of water by square meter of wet area, in other words, the relation between the water volume leaked in the terrain and the unitary wet surface of the canal, calculated on the daily basis. The wet surface of a canal is the result of the calculation: wet boundary times the length of the canal (Fig. 11).

Figure 11 - Wet Surface



This coefficient of hydraulic loss was evaluated using the guidance values of the daily loss by square meter of wet area, as reported in the following table:

Table 1 - Water loss in l/m²/d based on the soil typology

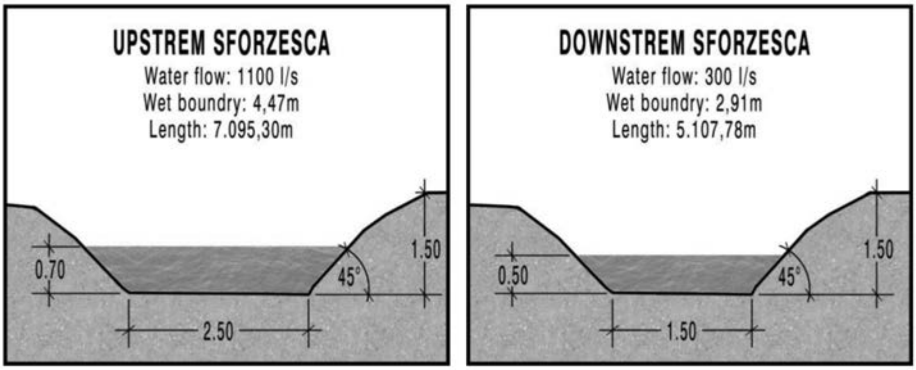
Soil Typology	New Canals	Old Canals
Clay – Silty (impermeable)	76	107
Clay – Sandy alternated with clay – silty	152	228
Clay – Sandy	228	305
Sand – Clayey	305	457
Sandy	457	533
Sandy and gravel	609	762
Gravel	762	914
Gravel (very permeable)	914	1.829

The soil types were taken from the soil map of Emilia-Romagna region (Carta dei Suoli – catalogo dei tipi di suoli).

To keep into account the different typologies of the soil of the terrain along the course of the canals, it was evaluated an average loss coefficient, based on the length of the section that would correspond to every terrain typology (weighted average). Thus, the water loss of the canals (in cubic meters), was calculated with the formula $P = L \times Cb \times C \times d$, where ***L*** is the canal's length (m), ***Cb*** is the canal's wet boundary (m), ***C*** is the daily loss coefficient of the wet area (l/m²/d) and ***d*** is the irrigation period defined in days. On average, the irrigation period starts half of June until half of September (approximately 92 days). The reference for this calculation was the Selection Call "Reg. (UE) 1305/2013, Misura 4, Sottomisura 4.3, Tipologia di Operazione 4.3.1" (PSRN, 2017). This document provided the guidelines for the calculations of the project regarding investments for irrigation infrastructures.

For this paper, the left bank of the Arda river was taken as an example of how the calculations were made and how the project team arrived to the numbers of the result. The Sforzesca canal has a length of about 12.203,08 meters and is completely open. To calculate the water losses, the Sforzesca is divided into two parts according to its geometry, its average inclination and the water flow in transit (as it decreases from upstream to downstream). The 'Upstream Sforzesca' is about 7.095,30 meters long, with a trapezoidal section represented in Fig. 12. The average water flow in this part of the canal is about 1100 l/s, equal to the flow derived from the Castell'Arquato weir to the service of Arda's Left districts. Therefore, the **wet boundary** (*Ab*) is equal to 4,47 m. The 'Downstream Sforzesca' is 5.107,78 meters long, with a trapezoidal section with measures also indicated on Fig. 12. The average water flow of this part of the canal is about 300 l/s. Therefore, the wet boundary of this section is equal to 2,19 m.

Figure 12 - Calculation example – Sforzesca Canal



The daily loss coefficients were identified for each canal, obtained from the Regional Soil Map:

Table 2 - Coefficient of daily loss – Arda's Left Riverbank

	C (l/m²/d)
Upstream Sforzesca Canal	160
Downstream Sforzesca Canal	147

The following table represents the data employed to define the water losses during the analyzed irrigation season:

Table 3 - Water loss in l/m²/d based on the soil typology – Arda's Left Riverbank

	Upstream Sforzesca Canal	**Downstream Sforzesca Canal**
Length (m)	7.095,30	5.107,48
Cb – Wet Boundry (m)	4,47	2,91
C – Daily Loss Coefficient (m³/m²/d)	0,160	0,147
Surface (m²)	31.715,99	14.863,64
Daily Losses (m³/d)	5075	2185
Average Days in Irrigation Period (d)	92	92
Average Losses in Irrigation Season (m³)	466.900	201.020
Total Water Loss (m³)		**667.920**

This calculation method was repeated in several parts of Arda's irrigation canals in order to obtain the data needed for the development of the project.

Since the project foresees new underground pipelines, the hypothetical efficiency of the new system is equal 100%, not considering the water losses made by the aging of the pipelines over time. Since the prediction of the water loss of the new system is zero, the resource saving comparing the exiting one is equal to the actual water losses. In the case of Sforzesca canal, **667.920 m³**.

Finally, the percentage of water saving in Arda's left bank was calculated as the relationship between the potential hydraulic saving and the collected water volume, therefore it will be equal to 667.920/2.896.349=**23.06%**.

Table 4 - Expected Water Saving – Arda's Left Riverbank

Withdrawal Volume (m³)	Losses (m³) Current State	Losses (m³) Project State	Water Saving (%)
2.896.349	667.920	0	23,06

4. Data analysis and results

The percentage of water-saving achieved with the conclusion of the project would be equal to 26.12%, as calculated in Tab. 5. This table summarizes the comparison between the current status and the project status. The values were calculated as explained in Tab. 3, applying the formula in both riverbanks.

Table 5 - Project water loss reduction

Arda irrigation district	Current water loss (mc)	Water loss (mc)	Project water saving (mc)
Left Arda riverbank	667.920	0	667.920
Right Arda riverbank	1.126.576	524.990	601.586
Total Arda	**1.794.496**	**524.990**	**1.269.506**

Combining the result obtained for the left and right bank of Arda, in order to evaluate the expected average of water savings potential with the realization of the entire project, it is obtained:

Table 6 - Project potential water saving

Arda irrigation district	Withdrawal Volume (mc)	Water saving (mc)	Project water saving (%)
Left Arda riverbank	2.896.349	667.920	23,06%
Right Arda riverbank	1.964.405	601.586	30,62%
Total Arda	**4.860.754**	**1.269.506**	**26,12%**

Conclusions

The Arda region is very important in the area of the province of Piacenza (Italy), economically, for its strong agriculture, environmentally, for its natural resources and socially for the importance it has in the lives of local people and producers.

Over the years Arda's area would show new needs and demands regarding irrigation, some adjustments and updates were necessary for keeping up with the advances of agriculture.

After several studies and data analysis of the area and the irrigation and drainage systems, the Consorzio di Bonifica di Piacenza reached the conclusion that it was time to develop a project that would solve the concerns related to Arda.

The objective was clear: save water destined for irrigation, from the moment it was collected to the moment it arrives in the agricultural fields, a considerable amount of water is lost, generating economic and environmental losses. To achieve this goal, several aspects were considered: the existing irrigation system, the characteristics of the territory and the impact on the surroundings during construction and post-construction.

Therefore, the first step of the project was to divide the 22 km pipeline into 4 different parts called WBS, of those 4, the ones that were relevant to this article were WBS 1, which is related to the creation of a main pipeline for caption of water, and WBS 4, which refers to the pipes that would be added to implement the wastewater usage in the irrigation system. The main action in WBS 1 is the creation of a PRFV pipeline system (Sforzesca) to serve only for irrigation purposes, whilst the existing Sforzesca canal is left for rainwater drainage only, since, nowadays, it has a double function, and the prolongation of this pipeline until the Stazione di Alseno (in ductile cast iron), in order to supply water for the irrigation districts of both sides of Arda, lower and higher altitudes. The WBS 4 is much less complex for its scale, it proposes an underground PVC piping alongside Fiorenzuola's Mulino canal, to enhance the usage of wastewater collected from Fiorenzuola's treatment station in the agricultural activities of Arda's Area.

This project was thought to improve the irrigation system with minimal disturbance possible, using techniques as micro-tunneling, underground pipeline, cast on-site reinforced concrete and so. As a cost, these approaches make the execution of the construction phase and management of the post-built much more feasible, in the social sphere, the agricultural fields practically won't lose productive area, and in environmental aspects the underground pipelines also would affect the landscape to the minimal, as well as the micro-tunneling in the construction phase.

In conclusion, the new project would avoid the loss of water during transportation from Arda to the agricultural fields. The presented results show that, in fact, an intervention was needed by the studies of the collected data of the area during the irrigation periods of the past few years. It is confirmed that there is a considerable loss of water during these periods and the implementation of the project will offer an improvement of about 26%.

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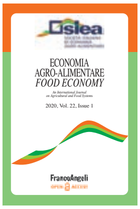

Politiche di gestione della risorsa idrica sotterranea a fini irrigui. Analisi delle preferenze degli agricoltori

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Abstract

Policy instruments for irrigation groundwater management. An assessment of farmers' stated preferences

The overexploitation of groundwater for irrigation purposes is a general problem affecting the management of common resources. The objective of this study was to analyze some of the policy options when facing this issue. A choice experiment was performed in order to elicit farmers' stated preferences for four policy instruments, namely i) implementation of a compulsory measurement system of groundwater extraction; ii) improved monitoring of rural areas in order to limit illegal access to groundwater; iii) reforming the groundwater tax system; iv) increasing the supply of reclaimed wastewater for irrigation. A survey was conducted in the Puglia region on a representative sample of 187 farmers, selected in the main hot-spot irrigated areas. A Random Parameter Logit Model was estimated using two covariates (i.e. size of irrigable farmland and farmers' awareness of groundwater shortage). Findings highlighted the farmers' preference for increasing the supply of water for irrigation (i.e. wastewater supply). Among the measures aiming to handle groundwater demand for irrigation, the respondents positively valued the enhancement of rural area monitoring to prevent illegal

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access, but they rejected a compulsory groundwater metering system. Finally, the methodological approach proved to be an effective tool to improve policy design, making the decision-making process more participatory.

1. Introduzione

L'irrigazione nell'agricoltura del XXI secolo è diventata un fattore di produzione che caratterizza in misura crescente numerosi sistemi colturali. Infatti, nell'ultimo censimento generale dell'agricoltura (ISTAT, 2010), per la prima volta è stato rilevato un insieme di variabili strutturali in relazione alla pratica irrigua. In Italia, l'importanza dell'irrigazione è da ricondurre anche all'andamento delle precipitazioni piovose concentrato nel periodo autunno-invernale con una media annuale di piovosità di 942 mm, fra le più alte dei paesi del bacino del Mediterraneo.

In generale, la disponibilità di risorsa idrica nel Paese è abbondante, sebbene sussistano grandi differenze territoriali. La risorsa idrica disponibile deriva dall'ampio reticolo fluviale, dalle numerose sorgenti naturali e da una abbondante riserva sotterranea. Ciononostante, il territorio nazionale si caratterizza per la complessità della struttura idrologica, nella quale molte aree sono classificate a rischio. Negli ultimi anni, inoltre, l'aumento dei periodi di siccità ha messo in evidenza la vulnerabilità dell'agricoltura ai cambiamenti climatici, in particolare per i sistemi colturali irrigui. Per questi ultimi, gli impatti economici derivati dall'interruzione del servizio irriguo sono particolarmente rilevanti (Giannoccaro *et al.*, 2019; Dono & Mazzapicchio, 2010; Massarutto & Carli, 2009).

In Italia, grazie all'abbondante disponibilità idrica, il ricorso all'irrigazione è molto diffuso, anche se con una diversità territoriale che ricalca la disponibilità naturale della risorsa. Secondo i dati disponibili sulla rete rurale nazionale (RRN) la Valle d'Aosta è la regione italiana con la percentuale più alta di aziende che ricorrono all'irrigazione, mentre la Puglia e la Calabria sono le regioni con la percentuale più bassa. In termini di superficie irrigata, l'Italia è al secondo posto tra i Paesi dell'Unione Europea con una SAU irrigata pari a 2,4 milioni di ettari (ISTAT, 2010) seconda solo alla Spagna dove si contano circa 3 milioni di ettari.

L'approvvigionamento irriguo in Italia avviene da fonti superficiali (fiumi, laghi e sorgenti) ovvero da acquiferi sotterranei. I dati dell'ultimo censimento dell'agricoltura (ISTAT, 2010) riportano una netta prevalenza delle fonti superficiali, mentre circa il 35% dell'approvvigionamento idrico utilizzato a fini irrigui proviene da fonti sotterranee.

Tuttavia, rispetto al quadro nazionale, la regione Puglia si caratterizza per la netta prevalenza dell'approvvigionamento idrico sotterraneo, caso probabilmente unico in Italia. Infine, mentre il dibattito sull'incremento della disponibilità di fonti non convenzionali (riuso irriguo delle acque reflue affinate oppure dissalazione) è cresciuto enormemente negli ultimi anni, l'effettivo utilizzo ai fini irrigui di tali fonti non convenzionali è ancora sporadico e limitato, in maniera omogenea su tutto il territorio nazionale.

A differenza di quanto è avvenuto per i grandi progetti di mobilizzazione delle risorse idriche superficiali, dove l'erogazione del servizio idrico è sottoposta a un sistema di turnazione o controllo volumetrico (si pensi ai Consorzi di Bonifica e Irrigazione)[1], lo sfruttamento delle risorse idriche sotterranee risulta di difficile gestione. Ciò è dovuto al fatto che il prelievo da fonte sotterranea avviene, pressoché ovunque, su iniziativa di un ampio numero di piccoli utilizzatori (sia pubblici che privati), attraverso un servizio in auto-approvvigionamento direttamente all'interno dell'azienda o nelle sue prossimità, determinando una situazione che rende il monitoraggio e la regolamentazione particolarmente difficile. Inoltre, l'utilizzo delle risorse idriche sotterranee avviene grazie a tecnologie sempre più semplici e a basso costo, con costi d'investimento sostenuti dall'utilizzatore finale, piuttosto che dall'operatore pubblico. È opportuno ricordare che nello sfruttamento delle risorse a uso irriguo in auto-approvvigionamento, tutti i costi per la ricerca, captazione, distribuzione della risorsa sono di natura privata, sostenuti interamente dagli agricoltori.

La scienza economica inserisce le risorse idriche sotterranee nella categoria dei "beni comuni" (Zucaro, 2014). Per tali beni una corretta definizione dei diritti di accesso e uso della risorsa in grado di garantire l'escludibilità è difficile e costosa. L'escludibilità è la possibilità fisica, tecnica, ma anche economica e giuridica, di impedire a qualcuno il godimento di un bene. Per le risorse idriche sotterranee l'escludibilità è limitata. Sebbene sia possibile definire dei diritti di accesso alla risorsa (per esempio un sistema di concessioni), è altamente costoso applicare un sistema di monitoraggio, controllo e sanzionatorio efficace. Nella fattispecie, l'accesso alla risorsa idrica sotterranea in Italia è regolamentato da un sistema di concessione d'uso. Tuttavia, la numerosità delle utenze agricole, sparse su un territorio vasto, rendono il controllo dell'accesso e dell'uso della risorsa molto costoso (Ursitti *et al.*, 2018). Ai problemi di costo, si aggiungono quelli derivanti dalla presenza di asimmetria informativa tra principale (controllore) e agente (controllato) (Viaggi *et al.*, 2010), ossia i problemi conseguenti a comportamenti opportunistici (*free-riding*) connessi alla gestione delle

1. In Italia, ricoprono un ruolo predominante i Consorzi di Bonifica e Irrigazione. L'ANBI (Associazione Nazionale Bonifica e Irrigazione) è l'associazione nazionale di afferenza dei Consorzi di Bonifica e Irrigazione, e rappresenta in termini di copertura territoriale, utenti serviti e volumi distribuiti il primo operatore nazionale di servizio irriguo (Zucaro INEA, 2011).

risorse comuni. È il tipico caso di coloro i quali pur non osservando un comportamento conforme alla normativa traggono beneficio dall'uso della risorsa (è il caso degli accessi abusivi alla falda).

Ma il problema più grave relativo a questa tipologia di beni è quello di un eccessivo sfruttamento delle risorse idriche sotterranee, noto come la "tragedia dei beni comuni" (Hardin, 1968). Questo fenomeno si determina quando gli utenti, perseguendo i propri interessi, ignorano gli effetti delle loro azioni sulla risorsa e su altri utenti. Infatti, nel caso specifico, quando una falda è sfruttata da un ampio numero di soggetti indipendenti, ciascun utilizzatore non è incentivato a conservare la risorsa, poiché non è certo che i risparmi individuali siano di personale ed esclusivo beneficio, potendo essere sfruttati anche da altri utilizzatori[2] (Giannoccaro *et al.*, 2017). Pertanto, si può anche affermare che ogni singolo utente qualora fosse consapevole delle conseguenze della sua azione sul sovra-sfruttamento della risorsa, non sarà disposto a ridurre il suo prelievo senza la certezza che il risparmio ottenuto sia a suo esclusivo vantaggio. La natura economica di un bene collettivo condiziona le modalità di gestione, le politiche e le misure atte a garantirne la sostenibilità nel lungo periodo.

Considerata la specificità delle risorse idriche a uso irriguo di origine sotterranea, questa ricerca si pone l'obiettivo di analizzare le politiche di gestione della risorsa idrica sotterranea a fini irrigui. L'analisi è condotta attraverso un esperimento di scelta su un campione di agricoltori della regione Puglia. Nello specifico l'analisi delle preferenze degli agricoltori rappresenta un elemento conoscitivo rilevante nella valutazione delle politiche di settore. Questo tipo di approccio è essenziale nel processo programmatorio perché consente agli attori coinvolti di partecipare in modo trasparente alla formulazione delle politiche e rende maggiormente consapevoli i decisori pubblici delle scelte che devono operare.

Coerentemente con quanto previsto dagli aggiornamenti normativi nazionali (Decreto MIPAAF del 31 luglio 2015) e regionali (Regolamento n. 2 del 28 febbraio 2017 della Regione Puglia e Deliberazione della Giunta Regionale n. 976 del 20 giugno 2017) le politiche analizzate rispondono alla necessità di individuare misure di gestione della domanda irrigua. Per la gestione della domanda irrigua sono state analizzate: i) politica dei prezzi, veicolata attraverso l'incremento dei canoni di uso della risorsa idrica sotterranea; ii) politica del comando e controllo, implementata attraverso la misurazione volumetrica della risorsa sotterranea a uso irriguo e iii) politica del comando e controllo della conformità legale dell'accesso alla risorsa. Alle politiche di gestione della domanda si integra l'incremento dell'offerta di risorsa non convenzionale, al fine di evitare il sovra-sfruttamento della

2. In conseguenza della difficoltà e onerosità di una corretta definizione dei diritti di accesso e uso della risorsa in grado di garantire l'escludibilità.

falda e garantire la sostenibilità dei prelievi nel futuro: iv) incremento dell'offerta di risorsa non convenzionale valutando il potenziale utilizzo a fini irrigui dei reflui urbani affinati.

La scelta dell'agricoltura irrigua pugliese quale caso studio è motivata dalla sua specificità rispetto al contesto nazionale. Ciononostante, sia la metodologia adottata che le politiche analizzate possono trovare riscontro anche in altri contesti irrigui nei quali il servizio irriguo è in auto-approvvigionamento da fonte sotterranea. D'altronde la necessità di quantificazione dei volumi irrigui indicata nel decreto MIPAAF (2015) è comune a tutte le Regioni e Provincie Autonome così come il principio del recupero dei costi della risorsa in ottemperanza a quanto stabilito dalla Direttiva Quadro sulle Acque (60/2000 UE).

2. La gestione delle risorse idriche sotterranee

Per le acque sotterranee i diritti di proprietà sono usualmente dello Stato, il quale può rilasciare delle concessioni temporanee per il loro utilizzo a fini privati[3]. Lo Stato, attraverso le sue amministrazioni, può esercitare un ruolo diretto nella tutela quantitativa e qualitativa della risorsa, attraverso strumenti quali il controllo del numero di concessioni (accesso alla risorsa) e dell'entità degli emungimenti (uso della risorsa).

In Italia, il governo e la tutela dei corpi idrici sotterranei avvengono attraverso un modello di "controllo centralizzato" per il quale è definita un'autorità con poteri coercitivi a cui affidare le competenze di assegnazione, controllo, prescrizione e sanzione delle infrazioni (nella fattispecie le Regioni). Poca attenzione è stata posta finora sul costo della creazione e mantenimento di tale agenzia, oltre che sui costi e la mole d'informazioni necessarie per stabilire sanzioni adeguate, e sulle difficoltà nel controllo del livello di effettiva conformità alla legge da parte degli utenti. Un sistema di tipo concessorio, portato alle sue estreme conseguenze, può determinare situazioni distorte in merito alla possibilità di esercitare il diritto di accesso alla risorsa. Infatti, chi già possiede una concessione si trova in una posizione privilegiata rispetto a chi non ha ancora avuto modo di usufruire di tale diritto. Inoltre, forme troppo elaborate di controllo, in situazioni di elevata diffusione dei "punti da osservare" su un territorio vasto e con scarso personale a disposizione per una concreta procedura di verifica da parte della Pubblica Amministrazione, rischiano di essere poco efficaci, oppure vincolati a complicati e costosi sistemi di verifica (Ursitti *et al.*, 2018).

3. La proprietà formale è pubblica e pertanto il rapporto che viene a crearsi tra il privato e la P.A. è di tipo concessorio. Il diritto all'uso dell'acqua non è incluso nel diritto di proprietà del suolo che è sovrastante la falda acquifera.

L'articolo 9 della Direttiva Quadro Acque (60/2000) prevede l'individuazione di idonee politiche dei prezzi dell'acqua che incentivino un uso razionale della risorsa idrica, nonché un adeguato contributo al recupero dei costi dei servizi idrici a carico dei vari settori di impiego, tra cui l'agricoltura (Zucaro, 2014). Se è possibile affermare che nello sfruttamento delle risorse in auto-approvvigionamento, tutti i costi sono di natura privata e sostenuti interamente dagli utilizzatori (es. la ricerca, captazione, distribuzione della risorsa), in condizioni di sovra-sfruttamento si avranno dei costi ambientali (impatti sugli eco-sistemi connessi) e un costo legato alla minore disponibilità di risorsa (nel caso degli acquiferi costieri comporta una minore disponibilità della risorsa di buona qualità).

Una delle opzioni di politica utilizzabile in questi casi è quella della applicazione di tariffe e/o tasse. In Europa, l'applicazione di tali strumenti di policy alle acque sotterranee è molto diversificato (Berbel *et al.*, 2019). In generale, mentre alcuni Stati Membri come Portogallo e Francia hanno recentemente introdotto sistemi di *pricing* per l'uso delle risorse sotterranee a fini irrigui, altri, come la Germania, hanno eliminato ogni tributo attribuendo scarsa efficacia agli strumenti economici nella gestione della domanda idrica a fini irrigui. Nel caso della Spagna, invece, non sono mai state implementate politiche di *pricing* per le acque sotterrane. Come già detto, l'accesso alla risorsa idrica in Italia è regolamentato da un sistema di concessione d'uso. Oltre ai costi d'istruttoria per la richiesta di autorizzazione alla ricerca e della successiva pratica di rilascio della concessione di derivazione e/o emungimento per l'utilizzazione (concessione d'uso), l'utenza è gravata di un canone d'uso della risorsa stabilito dal Regio Decreto (T.U. 1775/1933 Art.35.) e successivamente dalle leggi regionali emanate a partire dal 1994.

Infine, la sostenibilità degli acquiferi sotterranei dipende anche dall'incremento di offerta di risorsa idrica da fonti non convenzionali. In Italia, l'attenzione per il riuso in agricoltura delle acque reflue affinate è aumentata fortemente, sia in ambito scientifico che nel dibattito politico. Gli studi sul potenziale di risorsa disponibile per l'agricoltura in Europa (Pistocchi *et al.*, 2018) e anche in Puglia (Arborea *et al.*, 2017; Giannoccaro *et al.*, 2019) stimano che il volume potenziale della risorsa economicamente conveniente sia pari a circa il 10% della domanda irrigua attuale.

3. Materiali e Metodi

3.1. *L'area di studio: il servizio idrico irriguo in Puglia*

La regione Puglia si estende per circa 20.000 km^2 ed è caratterizzata da una forte vocazione agricola. Con 63.909 aziende irrigue, pari al 23,5% del totale delle aziende censite e una superficie irrigata che ammonta a 238.545

ettari (ISTAT, 2010), l'irrigazione svolge un ruolo di primaria importanza per il settore agricolo pugliese. Un altro dato rilevante ai fini della comprensione delle potenzialità dell'agricoltura irrigua è l'insieme di aziende e superfici definite irrigabili[4]. In Puglia sono state censite al 2010 ben 87.463 aziende con superficie irrigabile e una superficie interessata di 374.534 ha. La discrepanza tra le superfici agricole effettivamente irrigate e quelle irrigabili (in media il 64% della superficie irrigabile è effettivamente irrigata) evidenzia la scarsità strutturale della disponibilità di risorsa idrica per l'irrigazione.

La specializzazione tecnico-economica dell'intera agricoltura regionale si riflette anche sul comparto irriguo. L'olivo, infatti, è la coltura irrigata più diffusa, seguita dalla vite, rispettivamente per un'estensione di 81.700 e 63.000 ettari. Queste due colture rappresentano il 61% della superficie irrigata pugliese. Al terzo posto troviamo gli ortaggi in pieno campo (pomodoro da industria, finocchio, broccolo, spinacio, sedano, carota, carciofo, asparago e vari tipi di insalata) che raggiungono circa 47 mila ettari. Queste tre tipologie colturali rappresentano complessivamente più dell'80% della superficie irrigata. La restante superficie è coltivata a fruttiferi (pesco, albicocco, ciliegio e agrumi).

Una peculiarità del comparto irriguo pugliese riguarda le colture ortive intercalari a ciclo breve (patata, lattuga, cavolo, cavolo broccolo, finocchio, ecc.), realizzate in successione sullo stesso appezzamento nel corso dell'anno. Queste coltivazioni sono rese possibili dalla disponibilità di risorsa irrigua e dal clima temperato. Alle colture intercalari si aggiungono le consociazioni di tipo arboreo-ortivo, in cui le colture ortive a ciclo breve sono praticate in consociazione con colture arboree.

Tuttavia, la disponibilità del servizio idrico ai fini irrigui è geograficamente differenziata e fortemente frammentata con notevoli differenze sia nella tipologia di approvvigionamento della risorsa, che nel costo per l'utenza. In particolare, due sono gli elementi che contraddistinguono il servizio idrico irriguo, come definite dal decreto MIPAAF del 31 luglio 2015: i) la distribuzione di tipo collettiva, caratterizzata da reti di distribuzione gestite da Enti irrigui, e ii) l'auto-approvvigionamento da fonti superficiali e/o sotterranee, caratterizzato da prelievi irrigui diretti, effettuati autonomamente dai singoli utenti mediante pozzi e/o prese dirette.

Rientrano nella distribuzione collettiva, le reti consortili gestite dai Consorzi di Bonifica e Irrigazione (Capitanata, Gargano, Stornara e Tara, Terre d'Apulia e Ugento Lì Foggi), le cui fonti di approvvigionamento sono sia superficiali (fiumi, laghi e dighe) che sotterranee. Alle reti consortili,

4. Superficie massima potenzialmente irrigabile nel corso dell'annata agraria di riferimento in base alla capacità degli impianti tecnici e alla quantità di acqua disponibile in condizioni di normalità.

si aggiungono le reti di distribuzione dell'ARIF (Agenzia Regionale per le attività Irrigue e Forestali) e le reti comunali di distribuzione delle acque approvvigionate dagli impianti di affinamento terziario per il riuso irriguo. In tabella 1 è riportato il dettaglio dell'organizzazione del servizio idrico pugliese in funzione della fonte di approvvigionamento.

Tab. 1 - Fonti idriche di approvvigionamento e organizzazione del servizio idrico; Fonte: nostre elaborazioni da AdBP (2015a)

Fonte idrica di approvvigionamento	**Organizzazione del servizio idrico**	
	Distribuzione collettiva	**Auto-approvvigionamento**
Superficiale (fiumi, laghi e sorgenti)	Consorzi di Bonifica di Capitanata, Stornara e Tara, Terre d'Apulia, Gargano, Ugento lì Foggi	Circa 1500 patiche censite nelle aree di amministrazione dei Consorzi di Capitanata, Gargano e Stornara e Tara. Quasi la totalità interessano la provincia di Foggia
Falda sotterranea	Consorzio di Bonifica di Ugento lì Foggi, Terre d'Apulia, Arneo, ARIF, rete comunale Fasano-Forcatelle	Utenze individuali con autorizzazione all'uso irriguo
Non convenzionale (in uso) (acque reflue affinate)	Consorzio di Bonifica Ugento lì Foggi, Fasano-Forcatelle e Ostuni	

Nel caso della distribuzione collettiva, sebbene più del 90% del territorio regionale ricada nelle aree amministrative degli enti irrigui, le aree attrezzate e in esercizio per l'irrigazione rappresentano meno del 13% del territorio, limitando drasticamente l'offerta del servizio irriguo collettivo.

Il servizio in auto-approvvigionamento da fonte sotterranea, invece, rappresenta la componente più importante dell'irrigazione pugliese (più del 60% del volume mediamente usato per l'irrigazione). Tuttavia, non mancano approvvigionamenti diretti da corsi d'acqua superficiale. Infine, è presente, anche se in misura molto limitata, l'approvvigionamento da fonti non convenzionali mediante l'uso di acque reflue affinate.

I pozzi per il prelievo in auto-approvvigionamento sono distribuiti su tutto il territorio regionale con una densità variabile in funzione di una serie di fattori incentivanti (assenza di reti collettive, inefficienza del servizio idrico collettivo, costo o facilità di trivellazione). Nelle aree in cui le acque sotterranee sono la principale fonte di acqua dolce, le portate di prelievo superano le portate di ricarica naturale causando il continuo assorbimento della falda freatica, l'esaurimento dei pozzi, un aumento dei costi di emungimento e una grave intrusione di acqua marina negli acquiferi costieri (PTA Regione Puglia, 2015).

3.2. *Disegno dell'indagine*

L'analisi delle preferenze degli agricoltori pugliesi relativamente alle politiche di gestione della risorsa idrica sotterranea destinata a scopi irrigui è stata condotta attraverso gli esperimenti di scelta (ES), uno dei metodi delle preferenze espresse. Agli operatori del settore primario è stato somministrato un questionario d'indagine che consta di tre sezioni. La prima ha consentito di raccogliere informazioni circa i caratteri strutturali e le pratiche agricole aziendali, con particolare riferimento agli aspetti quali-quantitativi della risorsa idrica utilizzata (qualità dell'acqua irrigua, volumi adoperati, periodi di somministrazione, tipo di emungimento, ecc.). La seconda sezione, invece, ha consentito di investigare le preferenze nei confronti di una serie di misure relative alla gestione delle acque sotterranee al fine di preservarne la qualità e la disponibilità, attuali e future. Infine, la terza sezione ha reso possibile la raccolta delle caratteristiche sociodemografiche degli intervistati.

Gli elementi teorici alla base degli ES risiedono nella *conjoint analysis* e nella teoria delle scelte discrete (Louviere & Woodworth, 1983; Train, 2009). Il metodo in prima battuta prevede l'individuazione di una serie di plausibili scenari ipotetici (alternative), ricavati da realistiche combinazioni di attributi e rispettivi livelli. Le alternative vengono quindi raggruppate in set di scelta, che vengono infine somministrati ai rispondenti in modo che questi ultimi, per ciascun set, possano scegliere l'alternativa più gradita, ossia quella in grado di generare la maggiore utilità relativa (Hensher, Rose & Greene, 2015).

Lo studio muove dalla constatazione che l'attuale livello di prelievo delle acque sotterranee non è sostenibile, essendo già evidenti i fenomeni di salinizzazione della falda negli acquiferi costieri, e che sono già manifeste le problematiche quantitative per gli acquiferi freatici (PTA Regione Puglia, 2015).

Pertanto, l'obiettivo dello studio consiste nella valutazione dei benefici associati ad alcune possibili politiche di intervento in materia di risorsa irrigua attraverso l'analisi delle preferenze degli agricoltori regionali, per una più oculata gestione della risorsa irrigua.

Attraverso due *focus group*, che hanno coinvolto sia agricoltori che tecnici ed esperti, sono state ricavate informazioni utili al fine di definire gli scenari ipotetici degli ES. Nello specifico, sono state considerate le seguenti misure di gestione (Tab. 2):

- misurazione dei volumi idrici prelevati da ciascuna utenza;
- aumento delle attività di sorveglianza e controllo sull'intero territorio regionale al fine di limitare l'accesso illegale alle acque sotterranee;
- riordino del canone di concessione d'uso in vigore;
- aumento della fornitura di acque reflue urbane affinate a fini irrigui.

Tab. 2 - Attributi e livelli utilizzati per la definizione degli scenari ipotetici

Attributi	**Livelli**
Misurazione volumetrica consumi irrigui	No, Sì
Aumento del controllo e della sorveglianza sul territorio	No, Sì
Canone d'uso della risorsa irrigua in auto-approvvigionamento (€/ettaro/anno)	11, 16, 21, 26, 31, 36
Aumento dell'offerta di acque reflue per uso irriguo	No, Sì

La scala del canone d'uso della risorsa irrigua è stata costruita partendo da un valore minimo pari a circa 11 €/ettaro/anno, corrispondente a quello medio attualmente sostenuto dagli agricoltori, fino ad un valore massimo più che triplicato (36 €/ettaro/anno).

Al fine di ridurre il numero di alternative generate da tutte le possibili combinazioni di attributi e livelli, è stato effettuato un disegno sperimentale *D-optimal*, opportunamente vincolato al fine di evitare combinazioni dominate. In particolare, 12 profili sono stati generati dalle 48 alternative possibili ($2^3 \times 6^1$), oltre allo *status quo*. Quest'ultimo scenario non prevede l'implementazione di alcuna misura considerata, fatta eccezione per l'applicazione del valore massimo del canone, pari a 36 €/ettaro/anno. La scelta di associare il valore massimo del canone in assenza delle altre misure di gestione discende dalla necessità di ottemperare al principio di recupero del costo pieno per il servizio idrico. L'Italia e le Regioni, si sono impegnate a implementare misure adeguate di *pricing* capaci di recuperare tutti i costi, in linea con le prescrizioni delle norme in materia di condizionalità ex-ante del PSRN e PSR (Zucaro, 2014). Pertanto, in assenza delle altre misure ipotizzate, è verosimile attendersi un costo maggiore, soprattutto ambientale, e quindi un canone più elevato.

Quindi, sono stati costruiti quattro set di scelta, ognuno costituito da quattro alternative. In figura 1 è rappresentato un esempio di cartellino somministrato durante l'indagine agli agricoltori.

Fig. 1 - Esempio di set di scelta utilizzato nell'indagine

Alternativa A	**Alternativa B**	**Alternativa C**	**Alternativa D (Status quo – Aumento canone)**
Installazione misuratori **Sì**	Installazione misuratori **No**	Installazione misuratori **Sì**	Installazione misuratori **No**
Potenziamento offerta acque reflue **Sì**	Potenziamento offerta acque reflue **Sì**	Potenziamento offerta acque reflue **No**	Potenziamento offerta acque reflue **No**
Aumento controllo e sorveglianza **Sì**	Aumento controllo e sorveglianza **Sì**	Aumento controllo e sorveglianza **No**	Aumento controllo e sorveglianza **No**
Canone **11 €/ettaro/anno**	Canone **16 €/ettaro/anno**	Canone **26 €/ettaro/anno**	Canone **36 €/ettaro/anno**
□	□	□	□

Il questionario è stato pretestato su un campione casuale di 12 soggetti al fine di individuare, e quindi correggere, eventuali incoerenze interne e/o scarsa comprensibilità delle domande e degli scenari prospettati. In base a tale disegno dell'indagine sono state programmate 200 interviste *face-to-face* ad agricoltori regionali della durata di circa 45 minuti. La somministrazione è stata effettuata in 5 aree *hot-spot* (Tavoliere centro meridionale, Murgia e litorale barese, Arco ionico tarantino, litorale brindisino e Salento sud-occidentale) ad aziende opportunamente individuate mediante un piano di campionamento con l'intento di rappresentare le specificità dell'agricoltura irrigua pugliese. L'indagine campionaria si è svolta in un periodo di 4 mesi, tra novembre 2018 e febbraio 2019, ed è stata condotta da 5 intervistatori (uno per ciascuna delle aree hot-spot) preventivamente addestrati presso centri di assistenza agricola e studi professionali agronomici.

3.3. *Il modello econometrico*

Le basi teoriche degli ES risiedono nello schema concettuale di Lancaster (1966), secondo cui l'utilità che gli operatori agricoli traggano da una specifica politica è il risultato delle utilità derivati dalle singole caratteristiche della politica stessa. Pertanto, è possibile ipotizzare che i rispondenti scelgano uno specifico scenario in relazione alle singole caratteristiche che lo compongono. Inoltre, secondo la *Random Utility Theory* alla base dei modelli di utilità stocastica (Thurstone, 1927), gli agricoltori esprimono le loro preferenze individuali al fine di massimizzare l'utilità sotto il vincolo del profitto d'impresa. Pertanto, le scelte sono connesse alla soluzione di un problema di massimizzazione dell'utilità ottenibile da un set di alternative disponibili. In tal caso, considerando un individuo n che sceglie l'alternativa in grado di garantire la maggiore utilità tra le *J* alternative possibili ad una determinata occasione di scelta *t*, la funzione di utilità è data dalla seguente espressione (Train, 2009):

$$U_{njt} = V_{njt} + e_{njt}, \quad n = 1, \dots, N; j = 1, \dots, J;, t = 1, \dots, T \tag{1}$$

dove V_{njt} è la componente deterministica, mentre e_{njt} è quella casuale, indipendentemente ed identicamente Gumbel distribuita (IID). Dato un set finito di *J* alternative, il rispondente n effettua una serie di confronti a coppia tra le stesse, così da individuare l'alternativa che massimizza la sua utilità. In particolare, sarà preferita l'alternativa *i* alla *j* se $U_{nit} > U_{njt}$, $\forall j \neq i$. Data la natura stocastica della funzione di utilità, il problema di massimizzazione può essere risolto in termini probabilistici. Pertanto, considerando un set di *J* alternative, la probabilità che un soggetto *n* scelga l'alternativa *i* è data da:

$$P_{nit} = Prob\left[(V_{nit} + \varepsilon_{nit}) > \left(V_{njt} + \varepsilon_{njt}\right)\right] > 0, \forall j \neq i, \forall J \tag{2}$$

la cui stima può essere effettuata mediante un modello a scelta discreta implementato attraverso un esperimento di scelta (McFadden, 1986). Assumendo una funzione di utilità lineare nei parametri per la componente deterministica, l'espressione (1) può essere riformulata come:

$$U_{njt} = \beta_n x_{njt} + \varepsilon_{njt}, \quad n = 1, \dots, N; j = 1, \dots, J;, t = 1, \dots, T \tag{3}$$

dove β_n è un vettore di $K \times 1$ parametri da stimare e inerenti all'utilità, corrispondenti a *K* caratteristiche di scelta, mentre x_{njt} è il vettore $K \times 1$ delle caratteristiche di scelta riguardanti l'alternativa *j* in corrispondenza dell'occasione di scelta *t* effettuata dall'individuo *n*. In genere, i rispondenti possono presentare atteggiamenti simili in presenza di diversi set di scelta, determinando fenomeni di correlazione e dunque la violazione dell'assunzione di indipendenza delle alternative irrilevanti (IIA). L'espressione (3), invece, prevede l'introduzione di un vettore di parametri β_n specifici per gli intervistati e che seguono una distribuzione $g(\beta|\theta)$, il cui vettore θ indica media e varianza. Tale specificazione consente di rilassare la suddetta assunzione e di formulare il random parameter logit model (RPLM) così da catturare l'eterogeneità relativa a fattori non osservati, ma comuni a gruppi di rispondenti ed in grado di influenzare le scelte. La probabilità che un soggetto *n* scelga l'alternativa *i* all'occasione di scelta *t* è calcolata come (Train, 2009):

$$P_{nit} = \int \frac{\exp(V_{nit})}{\sum_j \exp(V_{njt)})} f(\beta) d(\beta) \tag{4}$$

dove la distribuzione $f(\cdot)$ dei parametri casuali β è specificata dal ricercatore. Poiché le estrazioni di Halton (1960) sono una efficiente alternativa a quelle casuali (Bhat, 2003), è stato adoperato il metodo di Halton a 1000 estrazioni. Inoltre, è stata utilizzata una distribuzione triangolare per la forma funzionale delle funzioni di densità dei parametri (Greene & Hensher, 2003). Avendo misurato uno degli attributi in termini monetari (prezzo), il tasso marginale di sostituzione derivante dal rapporto delle utilità tra ciascun attributo non monetario ed il prezzo rappresenta la stima della disponibilità a pagare (WTP), *ceteris paribus* (Louviere *et al.*, 2000; Carson & Louviere, 2010), pertanto:

$$WTP_k = -\frac{\beta_k}{\beta_p} \quad (5)$$

dove WTP_k è la disponibilità a pagare per l'attributo k, b_k è il coefficiente stimato dell'attributo k e b_p è il coefficiente stimato per l'attributo relativo al prezzo. Gli intervalli di confidenza al 95% sono stati calcolati mediante il metodo proposto da Krinsky & Robb (1986), la WTP è stata stimata mediante il delta method ed i risultati del modello sono stati ottenuti mediante il software NLOGIT 5.

4. Risultati

4.1. *Caratterizzazione del campione*

L'indagine campionaria è stata condotta su tutta la regione Puglia e ha consentito la raccolta di 187 osservazioni valide. Nel campione ci sono aziende che hanno accesso alla risorsa idrica soltanto in auto-approvvigionamento da falda sotterranea e aziende che possono contare sia sull'auto-approvvigionamento che sul servizio irriguo collettivo.

Gli intervistati, responsabili della gestione aziendale, hanno un'età media di 51 anni e un livello d'istruzione medio (in prevalenza con diploma di scuola superiore). Circa il 79% delle aziende rilevate sono ditte individuali, di cui: più della metà sono condotte con salariati (53%); segue la conduzione diretta del coltivatore con l'ausilio di manodopera familiare (45%). Soltanto il 2% delle aziende intervistate sono condotte mediante il ricorso a conto terzi. Per il 72% degli agricoltori intervistati, l'agricoltura rappresenta l'unica fonte di reddito.

Il campione di aziende analizzato coltiva complessivamente una SAU irrigata pari a 4.028 ha (Tab. 3). L'indagine campionaria ha riguardato prevalentemente aziende di medio-grandi dimensioni poiché come risulta evidente dal dato regionale (Tab. 3) sono quelle che gestiscono la maggior parte della superficie irrigata. Difatti, poco meno del 15% delle aziende in Puglia gestisce circa il 60% della superficie irrigata con una superficie media aziendale maggiore di 10 ha irrigui.

Tab. 3 - Superfici e aziende irrigue per classi di SAU irrigata

	Campione*				Puglia**			
Classi di SAU irrigata	**Aziende**		**SAU irrigata**		**Aziende**		**SAU irrigata**	
[ha]	*N.*	*%*	*[ha]*	*[%]*	*N.*	*%*	*[ha]*	*[%]*
0,00-4,99	43	22,99	89,49	2,22	46.965	73,49	56.891,66	23,85
5,00-9,99	39	20,86	280,44	6,96	7.831	12,25	36.427,80	15,27
10,00-19,99	38	20,32	546,27	13,56	4.827	7,55	42.370,90	17,76
20,00-49,99	47	25,13	1.365,55	33,90	3.158	4,94	51.293,35	21,50
>49,99	20	10,70	1.746,29	43,35	1.128	1,77	51.562,00	21,62
Totale	**187**	**100**	**4.028,00**	**100**	**63.909**	**100**	**238.545,71**	**100**

* *Fonte*: Indagine diretta
** *Fonte*: ISTAT (2010)

Il riparto irriguo è costituito in prevalenza dalle colture permanenti (principalmente vite e olivo) che rappresentano rispettivamente il 27% e il 26% della superficie irrigata (Tab. 4); seguono le orticole in pieno campo che occupano una superficie pari a circa il 21% di quella irrigata, gli agrumi e i fruttiferi che complessivamente occupano circa il 14% della superficie irrigata. Il confronto con il dato censuario (ISTAT, 2010) mette in evidenza che la ripartizione delle superfici irrigate per coltura rispecchia la distribuzione regionale. Tuttavia, un discostamento significativo si riscontra per l'olivo che è sotto rappresentato a vantaggio delle superfici coltivate ad agrumi.

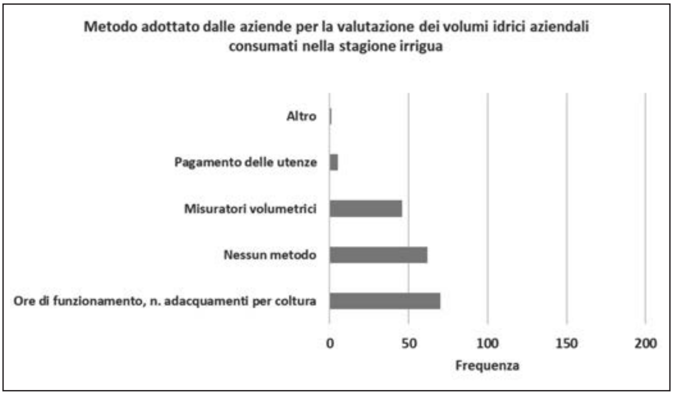
Tab. 4 - Rappresentatività del campione

Variabili strutturali:	**Campione***		**Puglia****	
Superficie irrigata [ha]	4.028,00		238.545,71	
Aziende irrigue [N.]	187		63.909	
• *Aziende con autoapprovvigionamento*	*153*		*n.d.*	
• *Aziende con autoapprovvigionamento e servizio collettivo*	*34*		*n.d.*	
Volume irriguo medio unitario [m^3/ha][1]	1.842,00		2.600,00	
SAU irrigata aziende agricole (media) [ha]	21,54		3,73	
	Campione*		**Puglia****	
SAU delle colture irrigate:	**[ha]**	**%**	**[ha]**	**%**
Oliveto	1.057,34	26,25	81.737,33	34,26
Vigneto	1.104,01	27,41	63.088,32	26,45
Ortive in pieno campo	862,05	21,40	46.925,35	19,67
Fruttiferi	244,52	6,07	12.230,90	5,13
Agrumi	310,17	7,70	7.948,54	3,33
Altre colture	449,91	11,17	26.615,28	11,16
Totale	**4.028,00**	**100**	**238.545,72**	**100,00**

* *Fonte*: Indagine diretta
** *Fonte*: Censimento ISTAT (2010)
[1] Il dato è riferito alle sole 122 aziende che hanno restituito il volume irriguo del 2017

Il 65% del campione ha fornito l'indicazione dei volumi irrigui stagionali per la stagione irrigua 2017, riportando complessivamente un volume totale di circa 4,2 Mm^3. Il volume unitario risulta essere di 1.842,0 m^3/ha/anno, lievemente inferiore alla media regionale riportata per la stagione irrigua 2009/10 nel censimento generale (ISTAT, 2010). La misurazione volumetrica è presente solo in una percentuale minoritaria del campione (25% delle osservazioni), mentre la modalità più frequente di contabilità irrigua in azienda è di tipo indiretto (40% delle osservazioni); essa avviene attraverso il conteggio delle ore di funzionamento dell'impianto irriguo ovvero attraverso il conteggio degli adacquamenti medi stagionali (Fig. 2).

Fig. 2 - Metodo utilizzato per la valutazione dei volumi irrigui aziendali



Più generalizzata invece è la contabilità economica per l'irrigazione. I costi operativi del servizio in auto-approvvigionamento così come dichiarati dagli agricoltori, riportano una media di circa 371 €/ha, corrispondenti a 0,26 €/m^3. La profondità media di presa dal pozzo è pari a circa 128 m mentre la potenza media delle pompe installate di circa 18 CV.

Tab. 5 - Costo di emungimento, Potenza delle pompe installate e Profondità del pozzo dichiarati dagli agricoltori

Variabile	**Media**	**Dev. Standard**
Costo emungimento [€/m^3]	0,26	0,18
Costo emungimento [€/ha]	371,59	288,21
Potenza pompa installata [CV]	18,60	19,11
Profondità del pozzo [m]	128,44	105,54

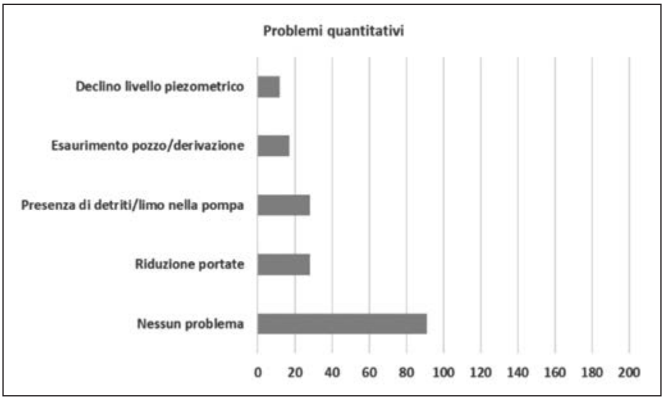
Fonte: Indagine diretta

Con riferimento ai problemi qualitativi legati alla salinità (Fig. 3 - in grigio scuro) il 75% delle aziende intervistate ha dichiarato di non aver mai sperimentato problemi legati ad essa. Coloro che hanno già sperimentato le conseguenze dell'incremento di salinità, indicano in maniera quasi paritaria i problemi legati alla riduzione delle rese ovvero i problemi del peggioramento della qualità del prodotto edibile. Invece, per quel che riguarda i problemi qualitativi legati all'inquinamento (Fig. 3 - in grigio chiaro) delle acque destinate a scopi irrigui, il 94% delle aziende censite non ha mai sperimentato problemi.

Fig. 3 - Incidenza dei problemi qualitativi nell'utilizzo della risorsa idrica ai fini irrigui sperimentati dalle aziende campionate

Le criticità maggiori si riscontrano, invece, per i problemi quantitativi sperimentati dalle aziende (Fig. 4). Infatti, circa la metà del campione ha già sperimentato problemi quantitativi legati all'utilizzo di acque irrigue. In particolare, circa il 30% delle aziende ha sperimentato problemi legati alla riduzione delle portate e alla presenza di detriti nelle pompe. Il 10% ha sperimentato problemi dovuti all'esaurimento del pozzo e solo il 6% delle aziende ha avvertito problemi legati al declino del livello piezometrico.

Fig. 4 - Risultati dell'analisi dei dati relativi al tipo di problemi quantitativi legati all'utilizzo della risorsa idrica ai fini irrigui sperimentati dalle aziende campionate



4.2. *Risultati del modello*

I dati raccolti con l'indagine campionaria hanno consentito la valutazione delle preferenze degli agricoltori nei confronti delle quattro politiche di gestione delle acque sotterranee proposte nell'ES. In particolare, sulla base delle variabili definite in tabella 6, è stato stimato il modello Random Parameter Logit (RPLM) (Tab. 7).

Il modello stimato è statisticamente significativo (Chi^2 pari a 945,70, p-value inferiore 0,01) e mostra un buon adattamento ai dati (McFadden Pseudo-R2 pari 0,45). Il coefficiente stimato della variabile monetaria CANONE_ACQUA è negativo e statisticamente significativo. Il segno negativo del coefficiente conferma che, a parità di altre condizioni, ad un aumento del canone d'uso dell'acqua è associata una diminuzione dell'utilità dei rispondenti, e implica una minore probabilità di scelta. Anche il coefficiente della variabile Alternative Specific Costant (ASC) è negativo e statisticamente significativo, confermando la bontà dell'esperimento di scelta proposto ovvero un buon livello di accettazione da parte degli intervistati delle alternative proposte diverse dall'alternativa 4 presente in ciascun cartellino (canone massimo).

I coefficienti medi stimati per le altre variabili del modello consentono una valutazione delle preferenze degli agricoltori per le politiche di gestione della risorsa irrigua. In particolare, il coefficiente della variabile ACQUE_REFLUE, concernente l'aumento dell'offerta di acque reflue per uso irriguo, è statisticamente significativo ed ha un valore positivo e più alto rispetto a tutte le altre politiche di gestione considerate. Questo risultato indica l'interesse degli agricoltori per questa fonte di approvvigionamento, che, pertanto, può essere considerata una risorsa utile ad incrementare la disponibilità di acqua per finalità irrigue. I risultati ottenuti in questa ricerca differiscono da quelli di alcune ricerche condotte in precedenza nell'area di studio (Saliba *et al.*, 2018) nelle quali sebbene l'accettabilità degli agricoltori per l'utilizzo delle acque reflue affinate sia alta, in effetti la loro disponibilità a pagare è sempre inferiore al valore della tariffa per il servizio idrico convenzionale. La maggiore diponibilità a pagare rilevata in questo studio potrebbe essere ricondotta al disegno sperimentale il quale contempla l'interazione dell'incremento dell'offerta di acque reflue affinate con altre misure di gestione della domanda.

Anche per la variabile CONTROLLO_TERRITORIO, riguardante l'aumento del controllo degli accessi alla risorsa e della sorveglianza nelle aree rurali, il coefficiente stimato è positivo e statisticamente significativo. Questi risultati sono in linea con quanto riscontrato in un'area di produzione di uva da tavola nella provincia di Bari da Sardaro *et al.* (2018).

Per quanto riguarda la variabile MISURAZIONE, invece, il coefficiente stimato è negativo e statisticamente significativo. Ciò implica che gli agricoltori

Tab. 6 - Variabili utilizzate nel modello

Variabile	**Descrizione**
Politiche di gestione	
MISURAZIONE	1 sistema obbligatorio di misurazione dei prelievi idrici, 0 altrimenti
ACQUE_REFLUE	1 aumento dell'offerta di acque reflue, 0 altrimenti
CONTROLLO_TERRITORIO	1 aumento del controllo e della sorveglianza nelle aree rurali, 0 altrimenti
CANONE_ACQUA	canone pagato dagli agricoltori per l'uso dell'acqua prelevata dal sottosuolo (€/ettaro/anno)
Covariate	
SAU_IRRIGABILE	Superficie Agricola Utilizzata irrigabile (ettari)
PROBLEMI_QUANTITÀ	1 se gli agricoltori hanno sperimentato in passato problemi di disponibilità di acqua per finalità irrigue, 0 altrimenti

*Tab. 7 - Risultati della stima del modello RPL con le covariate; Nota: ***, **, * ⇒ Significatività del 1%, 5%, 10%*

	Coefficiente (errore standard)	**Dev. standard (errore standard)**
Parametri casuali		
MISURAZIONE	–0,42458*** (0,15164)	0,06849 (1,12613)
ACQUE_REFLUE	2,21683*** (0,57880)	31,5043*** (4,66053)
CONTROLLO_TERRITORIO	1,34807*** (0,41762)	7,30880*** (1,70053)
CANONE_ACQUA	–,09435*** (0,01860)	1,85101*** (0,22929)
Parametri non casuali		
ASC	–1,21628** (0,47549)	–

N. di osservazioni: 748 (187 rispondenti)

Funzione di verosimiglianza logaritmica: -569,65

Chi^2: 945,70

Significatività: < 0,0001

McFadden Pseudo-R^2: 0,45

intervistati hanno una sostanziale avversione alla predisposizione di un sistema di misurazione puntuale dei prelievi idrici.

I valori medi dei coefficienti stimati, se interpretati unitamente ai valori di deviazione standard, indicano che le preferenze degli intervistati sono piuttosto omogenee nel caso della variabile MISURAZIONE, mentre vi è una elevata eterogeneità per quanto concerne le variabili CONTROLLO_TERRITORIO e soprattutto per la variabile ACQUE_REFLUE.

L'eterogeneità delle preferenze dei rispondenti per le diverse politiche di gestione è in parte spiegata dalle covariate utilizzate nel modello stimato. In Tabella 8 sono riportati gli effetti delle variabili SAU_IRRIGABILE e PROBLEMI_QUANTITÀ sui coefficienti medi stimati delle diverse politiche di gestione. Entrambe le covariate hanno effetti negativi sul coefficiente della variabile MISURAZIONE e sul coefficiente della variabile CONTROLLO_TERRITORIO, mentre hanno effetti positivi sul coefficiente della variabile ACQUE_REFLUE e sul coefficiente della variabile CANONE_ACQUA. Gli effetti stimati indicano che all'aumentare della superficie irrigabile dell'azienda agricola si riduce l'apprezzamento del rispondente per un sistema obbligatorio di misurazione dei prelievi idrici e si riduce la preferenza per l'aumento del controllo e della sorveglianza nelle aree rurali. Viceversa, all'aumentare della superficie irrigabile aumenta l'utilità dei rispondenti associata ad un aumento dell'offerta di acque reflue e vi è una maggiore disponibilità a pagare un canone d'uso dell'acqua prelevata dal sottosuolo.

Per quanto riguarda la variabile PROBLEMI_QUANTITÀ, gli effetti stimati mostrano che gli agricoltori che hanno sperimentato in passato problemi di disponibilità di acqua per finalità irrigue sono meno propensi ad accettare un sistema obbligatorio di misurazione dei prelievi idrici e mostrano un minore

*Tab. 8 - Eterogeneità dei coefficienti (Politiche di gestione: Covariate); Nota: ***, **, * ⇒ Significatività del 1%, 5%, 10%. In parentesi sono riportati gli errori standard*

	Covariate	
Politiche di gestione	**SAU_IRRIGABILE**	**PROBLEMI_QUANTITÀ**
MISURAZIONE	–0,00312**	–0,42470**
	(0,00129)	(0,16589)
ACQUE_REFLUE	0,03422***	7,19357***
	(0,01145)	(1,77814)
CONTROLLO_TERRITORIO	–0,00495**	–2,57651***
	(0,00220)	(0,66492
CANONE_ACQUA	0,00320***	0,48451***
	(0,00084)	(0,11937)

apprezzamento per un aumento del controllo e della sorveglianza nelle aree rurali. Questi agricoltori riconoscono, invece, una maggiore utilità all'aumento dell'offerta di acque reflue e mostrano una maggiore disponibilità a pagare un canone d'uso dell'acqua prelevata dal sottosuolo.

Ulteriori valutazioni emergono se si analizzano le relazioni tra le diverse politiche di gestione della risorsa irrigua considerate (Tabella 9). In particolare, vi è una correlazione significativa e sempre positiva tra ACQUE_REFLUE e le politiche di gestione della domanda, nella fattispecie il controllo degli accessi, la misurazione puntuale dei prelievi e la politica di riordino dei canoni d'uso. Vi è invece una correlazione significativa e negativa tra le politiche di gestione della domanda.

*Tab. 9 - Matrice di correlazione tra i coefficienti del modello RPL stimato; Nota: ***, **, * ⇒ Significatività del 1%, 5%, 10%*

	MISURAZIONE	**ACQUE_ REFLUE**	**CONTROLLO_ TERRITORIO**	**CANONE_ ACQUA**
MISURAZIONE	–			
ACQUE_REFLUE	0,13**	–		
CONTROLLO_TERRITORIO	–0,19***	13,75***	–	
CANONE_ACQUA	–0,03***	14,93***	–12,68***	–

Una valutazione quantitativa dell'importanza di ciascuna delle politiche di gestione analizzate è fornita dalla stima della Willingness To Pay (WTP) per ciascun degli attributi considerati (Tabella 10). Il valore medio più alto della WTP è associato all'attributo ACQUE_REFLUE, seguito dall'attributo CONTROLLO_TERRITORIO, mentre l'attributo MISURAZIONE mostra una WTP negativa. I valori stimati per ciascuna politica rappresentano il valore del beneficio economico che gli intervistati traggono da ciascuna delle misure analizzate. Questi risultati confermano che vi è, in media, un buon apprezzamento degli agricoltori intervistati per il controllo degli accessi alla risorsa e l'aumento dell'offerta di acque reflue affinate. Allo stesso tempo, i risultati del modello segnalano una generale e significativa perdita economica in conseguenza della misurazione sistematica dei prelievi idrici in auto-approvvigionamento da falda.

*Tab. 10 - Disponibilità a pagare per le politiche di gestione (€/ettaro/anno); Nota: ***, **, * ⇒ Significatività del 1%, 5%, 10%*

	WTP (errore standard)
MISURAZIONE	–4,50005*** (1,18734)
ACQUE_REFLUE	23,49581*** (3,02781)
CONTROLLO_TERRITORIO	14,28797** (5,87982)

5. Conclusioni

In questa ricerca è stato condotto un esperimento di scelta su un campione di aziende irrigue della regione Puglia. L'indagine aveva l'obiettivo di elicitare le preferenze degli agricoltori pugliesi per alcune politiche di intervento volte a migliorare lo stato degli acquiferi sotterranei e rendere l'emungimento irriguo sostenibile nel lungo termine. Le politiche analizzate fanno riferimento alle misure che l'amministrazione Regionale ha avviato negli ultimi anni finalizzate all'incremento della risorsa idrica non convenzionale insieme alle iniziative in fase di implementazione per la gestione della domanda.

Dall'analisi del campione emerge una situazione abbastanza diffusa di problematicità, soprattutto di carattere quantitativo, dello sfruttamento della falda sotterranea. Meno diffusa è la consapevolezza del peggioramento qualitativo della risorsa irrigua da fonte sotterranea, specificatamente in termini di incremento di salinità. Come hanno fatto notare Giannoccaro *et al.* (2017), sebbene in Puglia sia in atto un processo antropico di salinizzazione della falda, tale processo avviene ad una velocità e con una progressione molto graduali, da rendere impercettibili agli agricoltori le sue conseguenze.

Le preferenze degli agricoltori riguardo le politiche analizzate mostrano una chiara preferenza per le misure di incremento dell'offerta di risorsa a uso irriguo, nello specifico della risorsa proveniente dall'affinamento dei reflui urbani. Tra le misure di contenimento della domanda, l'unica misura alla quale gli intervistati associano un beneficio economico è il controllo degli accessi alla risorsa, insieme a una maggiore sorveglianza sul territorio. Tuttavia, l'analisi econometrica ha evidenziato un'ampia eterogeneità delle preferenze all'interno del campione intervistato, in particolare per queste ultime due politiche. In dettaglio, le aziende con una maggiore superficie irrigabile preferiscono molto di più l'incremento dell'offerta di risorsa non convenzionale piuttosto che il controllo sul territorio degli accessi alla risorsa. Le stesse preferenze sono espresse da coloro che hanno già sperimentato le conseguenze in termini quantitativi del sovra-sfruttamento degli acquiferi. Al contrario, le preferenze degli agricoltori campionati sono omogenee riguardo al rifiuto della misurazione puntuale e sistematica degli emungimenti.

In generale, l'accettabilità dei reflui urbani affinati per l'irrigazione in Puglia è risultata molto buona anche in altri studi condotti in precedenza. Tuttavia, la disponibilità a pagare da parte degli agricoltori per le acque reflue è risultata essere minore rispetto a quella per le risorse irrigue convenzionali (Saliba *et al.*, 2018). In questa indagine, invece, emerge un beneficio associato dagli agricoltori all'incremento di risorsa non convenzionale insieme alla disponibilità a pagare un supplemento rispetto al canone d'uso attualmente in vigore. Questo risultato è riconducibile all'interazione tra le politiche esaminate. Infatti, l'analisi della matrice di correlazione delle politiche ha messo in evidenza la relazione diretta tra le politiche di gestione della domanda e l'incremento dell'offerta di acque reflue affinate. Da ciò si evince l'importanza dell'approccio multiplo nelle politiche di settore, dove finora gli interventi spot e le soluzioni dominanti hanno spesso contraddistinto l'intervento pubblico.

Inoltre, sebbene l'approccio metodologico basato sull'analisi delle preferenze espresse prenda in considerazione solo il punto di vista dell'agricoltore, esso si è dimostrato uno strumento valido in chiave programmatoria. Infatti, è in grado di facilitare l'ingegnerizzazione delle politiche di settore, garantendo una maggiore efficacia e accettabilità delle stesse, rendendo il processo decisionale più partecipato. Infine, proprio con l'intento di rendere il processo decisionale maggiormente partecipativo, le prospettive future di questo lavoro si pongono come obiettivo ultimo il coinvolgimento degli altri attori interessati al problema del sovra-sfruttamento della risorsa sotterranea.

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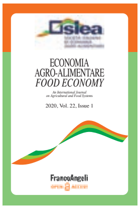

The technical efficiency of the Apulian winegrowing farms with different irrigation water supply systems

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Abstract

Apulia has a considerable demand of irrigation water, however high inefficiency levels of the collective water networks force most of the regional farms to use groundwater, with a consequent worsening of its quality, as well as of soil and crops characteristics. Therefore, the use of sustainable supply methods for irrigation water is desirable both through improvements of the collective networks and by appropriate economic tools. However, making the correct choices in these matters requires knowledge concerning the effects of the present water supply systems on the economic performance of farms.
The objective of this study is to measure and compare the technical efficiency of winegrowing farms in northern Apulia that use different supply systems for irrigation water: groundwater from private wells, irrigation water from collective networks, and irrigation water from both private wells and collective networks. The results enable to understand if and how different supply systems of irrigation water affect the management of productive factors and inputs. These findings also provide useful information for appropriate policies aimed at preserving groundwater and its externalities, as well as at improving the economic performance of Apulian farms.

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Introduction

The use of irrigation water involves both private (production factor) and public (landscape, hydraulic safety, economic supply chain, etc.) goods, therefore this resource can be considered a mixed good (Zucaro, 2014). Assessment of its economic value in the absence of suitable market mechanisms for regulating its demand and supply is a crucial element for the efficient allocation of this resource. Furthermore, its economic value allows the quantification of indicators aimed at highlighting its scarcity, granting efficient user rights, and estimating tariffs in line with the use and the contribution capacity of users (Berbel *et al*., 2019). Directive 2000/60/EC, i.e. the framework that fixes the fundamental principles for the protection and management of surface, transitional and underground water, highlights the need for member states to implement measures ensuring good qualitative and quantitative conditions of water. Member states should adopt economic instruments aimed at recovering the costs of water services in line with the "polluter pays" principle; these costs include environmental and resource costs related to damage or negative repercussions for the aquatic environment. In particular, the EU directive highlights the need for a pricing policy to guarantee the following conditions: recognition of the correct price for all water uses and services, which takes account of their real economic cost; reduction in the demand for water and decrease in environmental impacts; more efficient allocation of water resources, with positive effects on use and pollution. In this way, it is possible to contribute to the sustainability of water use in the various sectors, and, in particular, to environmental (qualitative and quantitative protection of ecosystems), social (fair sharing and accessibility for all users), economic and financial (rationalization of the management processes to obtain an efficient, effective and economic use) sustainability.

The Apulian irrigation sector is structurally weak, and this situation is exacerbated by the region's low annual rainfall and small hydrographic network, which cause a limited availability of water for the primary sector. The region has a utilized agricultural area (UAA) of over 1.28 million hectares, equal to 10% of the Italian total, of which over 238,000 ha are irrigated (18.6%) using over 655 million cubic meters of water. Overall, Apulia is Italy's fifth most important agricultural region in terms of both irrigated surface area and irrigation volumes used (ISTAT, 2010). The Province of Foggia accounts for a third of the region's irrigated area and a third of its water demand; the crops accounting for the largest irrigated areas are vegetables (38%) and grapes (26%). Irrigation water is mainly supplied by the collective networks managed by irrigation bodies, irrigation consortia and the Regional government (on average 21%), which take water from springs and reservoirs, or else by private wells (on average 68%), which use groundwater and are managed by single or associated farmers. Within this framework, five irrigation consortia play an important role, managing more than 90% of the regional territory, although their equipped area amounts on average to just 11.5% of the managed area, while the actual irrigated area is 4.6% of the equipped area (Distretto Idrografico dell'Appennino meridionale, 2010; ANBI, 2009). Furthermore, the water supplied by these consortia is just 31% of the total water used (655 Mm^3/year) and 23% of estimated needs, i.e. 874 Mm^3/year (Nino and Vanino, 2009). Therefore, the private farm wells make it possible to overcome these shortfalls, especially where the collective irrigation networks are absent, deactivated or not fully efficient (Fabiani, 2009), meaning that private farm wells are the main source of irrigation water for the region's agricultural sector. However, their overuse can lead to the progressive salinization of groundwater, with negative consequences on soil and crops and the related problem of desertification.

It is necessary to create favourable conditions to reduce the use of groundwater and increase the use of irrigation water from collective networks, in addition to promoting irrigation practices based on water-saving and reduction of the overall demand for water. In order to achieve these objectives, the regional collective networks require interventions for their enhancement, expansion and modernization, and against unauthorized withdrawals (ANBI, 2009). Implementation of these measures requires significant changes in regional water policy, but its importance for Apulian agriculture means that these changes could generate significant effects on management of production factors, on production function and on the technical efficiency of farms. This creates a need for studies assessing the economic impacts of changes in the availability of irrigation water from different sources, considering the general situation of water scarcity or allocative decisions unable to meet current needs. Knowledge of these aspects can help decision makers to formulate adequate water supply strategies for Apulian farms, in order to minimize the negative impacts on economic performance that at present characterize the region's agriculture (Petrillo and Sardaro, 2014; Acciani and Sardaro, 2014).

The aim of the work is to measure the technical efficiency of winegrowing farms in northern Apulia that use different irrigation water supply systems. The results highlight the extent to which different sources of irrigation water influence the management of production factors and inputs. This may suggest more efficient management strategies to farmers, and may provide decision makers with useful information for the formulation of policies to preserve both groundwater and the economic performance of farms.

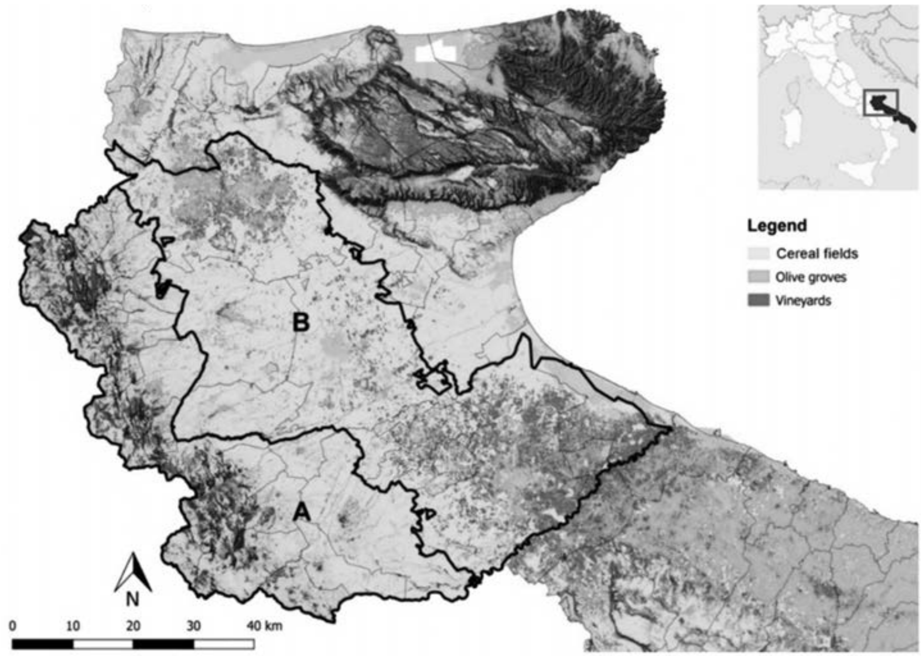
1. Materials and methods

1.1. *The study areas*

According to the classification of the 2014-2020 Rural Development Policy (based on the OECD method and reassessed through the National Strategic Plan for Rural Development), the regional municipal territories are classified into four types of area: rural areas with specialized intensive agriculture, intermediate rural areas, rural areas with overall development problems, and urban poles. This classification allows the territorialisation of rural development interventions in relation to the needs of each type of area, with their significant differences in terms of land characteristics, labour force, crops, technology and management of production factors. This study concerns rural areas with specialized intensive agriculture and rural areas with overall development problems (Figure 1), both in northern Apulia. The first area (A) includes 28 municipalities, has a UAA of 124,000 hectares, and coincides with the hilly territory of the province of Foggia, where the main crops are cereals (mainly durum wheat) (89% of the UAA), olives (4%) and grapes (3%) (Censimento nazionale sull'agricoltura, 2010). The second area (B) includes 13 municipalities, has a UAA of 211,000 hectares, and is mainly a flat territory corresponding to the Tavoliere plain in the Province of Foggia. Cereal crops account for 53% of the UAA, followed by olive groves (11%) and vineyards (14%). In general, Area A crops are managed using semi-extensive cultivation systems, i.e. based on a modest use of production factors and inputs (fertilizers, pesticides, irrigation water, etc.). On the contrary, farmers in Area B operate high-intensity production systems, i.e. based on a considerable use of factors and inputs.

The study focuses on the production of wine grapes using two different production systems, depending on the type of rural area. In particular, Area A uses the semi-extensive espalier production system, based on medium-low yields (9-16 t/hectare), local varieties, moderate use of inputs, and production of wines with the Protected Designation of Origin (PDO) or Protected Geographical Indication (PGI) marks. On the other hand, Area B mainly uses the intensive tendone production system, based on high yields (up to four/five times more compared to the semi-extensive system) obtained using more productive grape varieties, and requiring high levels of inputs; the grapes are mainly used to produce table wine.

Figure 1 - The study areas



Source: our elaboration through data from the Territorial Information System of the Apulia Region.

1.2. *The economic data*

Between October 2017 and December 2018, a survey form was used to collect economic data for the period 2014-2018 from 118 winegrowing farms in Area A and 126 in Area B. The cultivated varieties were Montepulciano, Uva di Troia, Bombino Bianco and Pampanuto for Area A, and Sangiovese, Lambrusco, Trebbiano and Garganega for Area B.

The survey form and variables for efficiency analysis were based on the economic balance, as defined by Serpieri (1929) and formalized by De Benedictis and Cosentino (1979). This approach compares the value of the final production with the related costs, so allowing the assessment of the income from the farm, the understanding of the economic mechanism generating income, and the investigation of how income is allocated among the subjects involved in the farm management (Idda *et al*., 2010).

Therefore, concerning the estimation of production function, output consists of the value of wine grapes produced, while the inputs are farm area, machinery value, number of working days, input quantities, and year

(Table 1). Based on the literature for this sector (Lawson *et al.*, 2004; Bozoğlu and Ceyhan, 2007; Sardaro *et al.*, 2018; Hansson and Öhlmér, 2008; Rahman, 2003; Tzouvelekas *et al.*, 2001; Tan *et al.*, 2010; Sardaro *et al.*, 2019) and on the specific characteristics of this study, we also considered some variables intended to explain the farm inefficiency. The input variables used for the production function are inversely related to technical inefficiency, and the age of the farmer negatively affects technical innovation, so as to be directly related to inefficiency. Access to credit increases farm's ability to spend money, encouraging technical innovations and making it possible to buy production factors and inputs, with positive effects on reducing inefficiency. The number of plots farmed indicates the level of land fragmentation and is directly related to travel and surveillance costs, and thus to inefficiency. The terrain slope has a negative influence on mechanized operations and the farm's technological level, and is thus also directly related to inefficiency. Finally, another variable is the water supply system, i.e. private farm wells, collective networks or a combination of both. Concerning this last aspect, it should be noted that the use of private wells often allows more flexible irrigation, in terms of watering frequency and volumes used. However, the use of private wells also entails various costs concerning: drilling of the well and its progressive depreciation during its technological life, which lasts an average of 25 years in the study areas; installation of electric pump; ordinary and extraordinary maintenance; use of irrigation water, which in Apulia requires paying for a five-year permit. Furthermore, and particularly in Apulia, the environmental impacts of overusing groundwater can cause wells to dry up and/or lead to the salinization of aquifers. Conversely, collective networks are less flexible because farmers must respect organized shifts for water use and also have to pay both a fixed fee for the ordinary maintenance of the network and a variable fee related to consumption. In addition, the collective networks may have problems concerning malfunctioning or leaks, illegal water withdrawals, and periods of low supply during dry years, meaning a consequent decrease in the water availability. Depending on crop and farming system, these aspects could affect farm efficiency.

The variables used in the production and efficiency functions were obtained via the survey form used during direct inspections of farms, except for the terrain slope, which was taken from the Territorial Information System of the Apulia Region (www.sit.puglia.it/). The monetary variables were inflation-adjusted.

Table 1 - Economic and efficiency variables

Variables		U.M.	Expected sign
Output			
Production	P	€/ha	
Inputs			
Farm area	L	ha	+
Machineries value	M	€/ha	+
Labour days	LD	N./ha	+
Fertilizers	Fe	kg/ha	+
Pesticides	Pe	kg/ha	+
Irrigation water	IW	m^3/ha	+
Year	Y	0-1	+/–
Determinants of the technical efficiency			
Farm area	L	ha	–
Machineries value	M	€/ha	–
Labour days	LD	N./ha	–
Fertilizers	Fe	kg/ha	–
Pesticides	Pe	kg/ha	–
Irrigation water	IW	m^3/ha	–
Farmer age	Age	Years	+
Dummy = 1: Credit access during the period 2014-2018	Credit	0-1	–
Number of plots	Plots	N.	+
Average land slope	Slope	%	+
Dummy = 1: groundwater through private well	Well	0-1	+/–
Dummy = 1: irrigation water through collective network	Network	0-1	+/–
Dummy = 1: irrigation water through well and collective network	Well/Network	0-1	+/–

Source: authors' elaborations through data from direct survey.

1.3. *The economic model*

The methodological approach concerns the production stochastic frontier (PSF) model applied to panel data (Aigner *et al.*, 1977; Meeusen and van den Broeck, 1977; Coelli, 1996; Coelli *et al.*, 1998; Kumbhakar *et al.*, 1989), which allows estimation of the technical efficiency (TE) related to different irrigation water supply systems in the winegrowing farms of northern Apulia. In particular, TE is defined as the farm's aptitude to achieve the maximum output through specific input levels (Ali and Flinn, 1989). In this study, TE is output-oriented (Farrell, 1957), i.e. the ratio between the obtained output and the maximum possible output. In formal terms, the PSF can be expressed as:

$$P_{it} = f\left(x_{it};\beta\right) + v_{it} - u_{it} \tag{1}$$

where: P is the production obtained by the farm i in the year t (i = 1,2, …, N and t = 1,2, … T), x is the vector of production factors and inputs, and β is the J×1 vector of the production function parameters. Concerning error, it can be decomposed into two terms, i.e the symmetric v_{it}, which includes any measurement error or other factors beyond the farm control, and u_{it}, i.e. a non-negative asymmetric term relating to farm inefficiency. The first term is assumed independently and identically distributed (iid) with mean equal to zero and constant variance, so that $N(0, \sigma_v^2)$, while the second terms is also iid, but with half-normal distribution, so that $N^+(0, \sigma_u^2)$. The estimate of maximum likelihood (MLE) enables calculation of the vector of the parameters β, as well as the variance parameters, that is:

$$\begin{aligned} &\sigma^2 = \sigma_v^2 + \sigma_u^2 \\ &and \\ &\gamma = \sigma_u^2 / \sigma^2 \end{aligned} \tag{2}$$

where γ is between zero (no technical inefficiency effect on the output variation) and one (the output variation is solely generated by the technical inefficiency) (Battese and Coelli, 1995). Hence, the level of TE for each farm can be calculated, according to Jondrow *et al.* (1982), as:

$$TE_{it} = \frac{P_{it}}{P^*} = \exp\left(-u_{it}\right) \tag{3}$$

where P^* is the output on the frontier. TE is between zero (no TE) and one (full TE) so that a value lower than one indicates that the present technological structure of the farm is inefficient, thus it is able to increase output without any variation of input. Finally, the inefficiency term u_{it} is defined as:

$$u_{it} = \delta_0 + \sum_m \delta_m z_{mit} + \omega_{it} \tag{4}$$

where z is the vector relating to the determinants of inefficiency, δ is the vector of the parameters to estimate, and ω is the unobservable random error that is assumed independently distributed with positive half-normal distribution, zero mean and variance σ^2. Noteworthy is the nonlinear relationship between $E(u_i)$ and the z variables, so that the slope coefficients are not marginal effects. Instead, these can be calculated as:

$$\frac{\partial E(u_i)}{\partial z_m} \tag{5}$$

Assuming a translog production function (Christensen *et al.*, 1973), which is more flexible than a Cobb-Douglas function about the constant elasticity of production and the unit elasticity of substitution (Wilson *et al.*, 1998), the PSF is defined as:

$$\ln P_{it} = \beta_0 + \sum_j \beta_j \ln x_{ijt} + \frac{1}{2}\sum_j \sum_k \beta_{jk} \ln x_{ijt} \ln x_{ikt} + d_t + v_{it} - u_{it} \tag{6}$$

where, in addition to the previously defined components, d_t is the dummy variable referred to each year in which a variation of the production function could occur.

In order to integrate both the unobserved heterogeneity of farm production and the variation of inefficiency over time within the PSF model, Greene (2004, 2005) proposed the "True Random Effect" (TRE) model, which adds a stochastic iid term related to the farm i, namely w_i, so that:

$$\ln P_{it} = w_i + f\left(\ln x_{it}; \beta\right) + v_{it} - u_{it} \tag{7}$$

where the error component is defined as in the equation (1) and the parameters are estimated with the simulation of the maximum likelihood proposed by Greene (2005). The inefficiency term u_{it} is calculated so that $E\,[-u_{it} \mid w_i + \varepsilon_{it}]$, while the technical efficiency is assessed as in the equation (3).

The parameters of the production function and the inefficiency determinants were estimated simultaneously through the maximum likelihood (MLE) method according to Battese and Coelli (1993), and the analysis was carried out through FRONTIER 4.1 (Coelli 1996).

The fitting of the model was tested through the statistics γ (as previously defined), σ^2, which indicates the inefficiency of the farm output, and γ^* (Coelli *et al.*, 1998), which measures the differences between the inefficiency of the sampled farms and the inefficiency on the frontier. In addition, a number of hypotheses relating to some restrictions of the full models were verified:

i) H_0: $\beta_{ij} = 0$ (the translog function can be reduced to a Cobb-Douglas function);
ii) H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_m$ (there are no determinants of technical inefficiency, so the sampled farms are fully efficient);
iii) H_0: δ_1; δ_2; δ_3; δ_4; δ_5; δ_6; δ_7; δ_8; δ_9; δ_{10}; δ_{11}; δ_{12}; δ_{13}; δ_{14}; δ_{15}; $\delta_{16} = 0$ (No effect on technical inefficiency by each determinant considered).

Checking used the Generalized likelihood-ratio test, which allowed the comparison between the implemented models and the restricted models based on the aforesaid hypotheses. The related statistic index is defined as:

$$-2\left[\ln L(H_0) - \ln L(H_1)\right] \tag{8}$$

where $L(H_0)$ and $L(H_1)$ are the likelihood values concerning the implemented model and the restricted models, respectively. The λ statistic can be approximated to a χ^2 distribution, with a number of degrees of freedom equal to the parameters affected by the restriction. Finally, the elasticity of production was calculated through the following equation:

$$\varepsilon_j = \frac{\partial \ln(P)}{\partial \ln(x_j)} = \beta_j + \sum_k \beta_{jk} \ln x_k \tag{9}$$

2. Results and discussions

2.1. *Characteristics of the sampled farms*

The descriptive statistics confirmed the differences between the two study areas relating to the outputs, the inputs and the inefficiency variables (Table 2). In particular, the farms in Area B had a higher income, mainly due to higher yields. The more intensive cultivation system required a use of inputs that was 19% to 47% higher than in Area A. Concerning the variables used to explain technical inefficiency, the vineyards in Area B were managed by younger farmers, who used more forms of credit in the period 2014-2018; these farms were smaller, more fragmented, located in flat areas and with greater access to private wells or mixed supply systems (both wells and collective networks). All differences in the considered variables between the two areas were at least 5% significant using the t-test (continuous variables) and the chi-square test (categorical variables).

Table 2 - Characteristics of the sampled farms, per study area (average values of the period 2014-2018)

Variables	Use of the variable[a]	U.M.	Winegrowing farms in area A (n = 118)				Winegrowing farms in area B (n = 126)				t-test
			Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	
P (.000 €)	O	€/ha	4.75	9.33	6.21	4.10	7.05	12.38	10.72	8.24	***
L	I/In	ha	1.18	22.82	5.39	11.63	0.88	18.54	4.71	9.06	**
M (.000 €)	I/In	€/ha	4.74	9.92	5.59	7.81	5.67	11.38	7.60	9.15	***
LD	I/In	N./ha	32.94	43.81	39.27	27.68	38.17	56.88	48.53	52.75	***
Fe	I/In	kg/ha	147.35	393.42	272.07	260.93	355.02	640.75	419.54	357.04	***
Pe	I/In	kg/ha	4.67	11.28	7.83	7.54	12.85	17.96	14.72	16.28	***
IW	I/In	m^3/ha	792.03	2,672.60	1,378.53	1,962.17	1,482.09	3,181.80	2,397.25	2,285.64	***
Y	I	0-1	0	1	0.50	0.71	0	1	0.50	0.71	–
Age	In	Years	18	64	49.33	35.21	18	62	46.95	37.04	**
Credit	In	0-1	0	1	0.28	0.14	0	1	0.47	0.39	***
Plots	In	N.	1	5	2.80	1.56	1	6	3.65	3.84	***
Slope	In	%	2.36	7.87	5.16	3.58	0	2.52	1.38	0.19	***
Well	In	0-1	0	1	0.11	0.17	0	1	0.53	0.58	***
Network	In	0-1	0	1	0.76	0.67	0	1	0.21	0.33	***
No irrigation	In	0-1	0	1	0.04	0.04	0	1	0.05	0.04	**
Well/ Network	In	0-1	0	1	0.09	0.12	0	1	0.21	0.36	***

[*] Sign. 10%; ** Sign. 5%; *** Sign. 1%.
[a] O = output variable of the production function; I = input variable of the production function; In = variable of the technical inefficiency.

Source: authors' elaborations through data from direct survey.

2.2. *The production frontier and technical efficiency*

The hypotheses relating to the restrictions of the models showed that (Table 3) i) the translog production function was the best functional form; ii) the use of determinants aimed at explaining technical inefficiency provided a sound analysis; iii) the determinants concerning farm inputs, farmer's age, credit access, land characteristics, and types of water supply were able to explain the technical inefficiency of the sampled farms. The only exception concerned the terrain slope of the farms in Area B, which had small values and standard deviation (Table 1), hence a scarce impact on technical inefficiency.

Table 3 - Hypotheses tests for some restriction of the PSF model

Restrictions	Area A				Area B			
	λ	d.f.	$\chi^2_{0.95}$*	Decision on H_0	λ	d.f.	$\chi^2_{0.95}$*	Decision on H_0
i) H_0: $\beta_{ij} = 0$	79.17	21	32.08	Rejected	85.02	21	32.08	Rejected
ii) H_0: $\gamma = \delta_0 = \delta_1 = \ldots = \delta_m$	41.05	16	25.69	Rejected	48.19	16	25.69	Rejected
iii) H_0: $\delta_1; \delta_2; \delta_3; \delta_4; \delta_5; \delta_6; \delta_7; \delta_8; \delta_9; \delta_{10}; \delta_{11}; \delta_{12}; \delta_{13}; \delta_{14}; \delta_{15}; \delta_{16} = 0$	$11.76 < \lambda < 18.42$	1	2.71	Rejected	$13.26 < \lambda < 22.70$	1	2.71	Rejected, except for the land slope (λ=1.63)

* Critic values from Kodde and Palm (1986).

Source: authors' elaborations through data from direct survey.

Concerning the final models (Table 4), the variance parameters σ^2 and γ were significantly different from zero, indicating how technical inefficiency in Areas A and B affected output. In particular, parameter γ was close to one, suggesting that the outcome variations were mainly caused by changes in inefficiency, or, in other terms, that the differences in technical inefficiency among farms were important in explaining the output variation of the winegrowing farms in the study areas. Furthermore, γ^*, which best measures the effect of inefficiency on the total output variance, highlighted that 71% of the difference between the output of farms in Area A and the output assessed on the frontier was due to farm inefficiency. The same indicator for Area B was equal to 50%, also confirming the importance of technical inefficiency in influencing output of the intensive vineyards.

Since the output and the regressors were quantified in logarithmic form, the first-order coefficients were interpretable as elasticities of output. Thus, the results of the production frontier in both the areas confirmed that output is positively influenced by the considered factors and inputs. In particular, irrigation water generated the most decisive impact on output in both the areas, with an elasticity in Area B over double that of Area A, so that a 1% increase in the quantity of irrigation water generated an output increase of 0.78% and 1.72%, respectively in Areas A and B. These findings were due to the Mediterranean climate, the surface and underground hydrographic systems, and the characteristics of soil in Apulia, which created a higher demand for water to irrigate specific crops, such as grapes, tomatoes, etc., whose growth and harvest phases are in summer. In general, the incidence of the considered factors and inputs on output was significantly lower in Area A, where winegrowing mainly focused on grape quality. The sole exception was the labour factor, which had a greater impact due to the presence of obsolete and less varied machinery for cultivation practices. Furthermore, the quadratic forms of some factors and inputs showed that their excessive use reduced output in both areas. These factors/inputs were fertilizers, pesticides and irrigation water for Area A, and labour and pesticides for Area B. On the other hand, a significant increase in irrigation water in Area B helped to generate more output, due to the intensive cultivation system's ability to produce very high yields.

The interaction terms highlighted the importance of the relationships between factors/inputs and grape quality in Area A, and between factors/inputs and yields in Area B. In Area B there was a notably positive effect of each interaction term including irrigation water on output. The highest coefficient concerned joint use of irrigation water and fertilizers (0.37), although this interaction caused the greatest output reduction in Area A. This finding further confirms the opposing characteristics of the two cultivation systems in the investigated areas, and highlights the crucial role of irrigation water in combination with specific inputs, i.e. fertilizers, in affecting production.

Concerning inefficiency analysis (Table 4, Table 5), Area A farms achieved an efficiency of 73% with their current technology. Based on the output-oriented approach used in this study, these farms can achieve a 27% increase in output by using the current factors and inputs in a more efficient way. On the other hand, Area B farms are more efficient (86%), and can increase their output by 14% using their current technology. Specifically, technical inefficiency in Area A can be reduced by an increase in land area in order to exploit returns to scale, and by an increase in the value of machinery, both in terms of modernization and diversification of equipment. Inefficiency in Area A can also be reduced by increasing the number of working days, which is a problem in the semi-extensive area for the high age of farmers and the lack of generational turnover. In addition, the use of fertilizers, pesticides and irrigation water should be increased and improved without compromising grape quality (sugar content, total acidity, residues from fertilizers and pesticides, etc.). There is also a need for the average age of farmers (generational turnover) to come down, which would favour the implementation of innovative management strategies, while easier credit access would enable investments in innovations, such as innovative cultivation practices mainly related to mechanization to reduce the inefficiencies due to the terrain slope. Similar trends also affected Area B farms, although with some differences. These include the irrelevance of farmer age, which is on average lower compared to the area A; the importance of the number of plots, positively related to technical inefficiency since strongly connected to organizational and managerial difficulties (increased surveillance time and travel costs, need for different cultivation strategies according to the soil and climatic characteristics of each plot, etc.); the terrain slope, which was not analysed due to the restrictions imposed on the model.

The considered water supply systems generated different impacts in the two areas (Table 5). In particular, the collective network was the only system able to reduce inefficiency in Area A, while in Area B all the systems considered contributed to this result. The most efficient source was private well, followed by the simultaneous presence of well and collective network, and lastly by the network alone. However, as water use increased, the efficiency of the three water sources was similar in the two areas. In particular, the greatest efficiency was achieved with the use of well, followed by the combination of well and collective network, while the presence of collective network alone increased inefficiency in both areas. In any case, well and mixed supply system were more effective in reducing inefficiency in Area B, while the collective network increased inefficiency more in Area A.

Overall, irrigation water was the most important input for winegrowing farms in both areas (highest coefficients in the PSF model); if combined with fertilizers, it allowed a significant increase in output in Area B, but a decrease in Area A. Moreover, the supply systems of this resource strongly affected efficiency, which was greater in presence of wells in Area B, and also in Area A as the quantity of water used increased. Conversely, the collective network was the most efficient supply system in Area A only during years of sufficient rainfall, but was always the least efficient system in Area B.

Table 4 - Estimate of the PSF and TE parameters

Variables	**Param.**	**Area A**			**Area B**			**Sig. z-test**
		Coeff.	**S.E.**		**Coeff.**	**S.E.**		
PSF model								
Constant	β_0	0.379	0.113	***	0.231	0.060	***	°°
ln(L)	β_1	0.661	0.230	**	1.147	0.242	***	°°°
ln(M)	β_2	0.452	0.143	***	0.910	0.256	***	°°°
ln(LD)	β_3	0.318	0.071	***	0.481	0.145	***	°°
ln(Fe)	β_4	0.536	0.092	***	1.495	0.257	***	°°°
ln(Pe)	β_5	0.502	0.181	**	0.513	0.189	**	
ln(IW)	β_6	0.781	0.165	***	1.725	0.249	***	°°°
ln(Y)	β_7	0.439	0.152	**	0.208	0.087	**	°°°
$[\ln(L)]^2$	β_{11}	0.060	0.025	**	0.101	0.027	***	°°°
$[\ln(M)]^2$	β_{22}	0.050	0.019	**	0.073	0.019	***	°°
$[\ln(LD)]^2$	β_{33}	0.032	0.007	***	–0.048	0.013	***	°°
$[\ln(Fe)]^2$	β_{44}	–0.084	0.020	***	0.156	0.037	***	°°°
$[\ln(Pe)]^2$	β_{55}	–0.055	0.009	***	–0.079	0.021	***	°°
$[\ln(IW)]^2$	β_{66}	–0.151	0.041	***	0.291	0.080	***	°°°
$[\ln(Y)]^2$	β_{77}	0.018	0.007	**	0.006	0.001	***	°°°
ln(L) × ln(M)	β_{12}	0.063	0.052		0.185	0.052	***	°°°
ln(L) × ln(LD)	β_{13}	–0.051	0.019	**	0.026	0.025		°°°
ln(L) × ln(Fe)	β_{14}	–0.027	0.011	**	0.278	0.064	***	°°°
ln(L) × ln(Pe)	β_{15}	–0.050	0.045		0.059	0.044		
ln(L) × ln(IW)	β_{16}	–0.076	0.059		0.094	0.025	***	°°°
ln(L) × ln(Y)	β_{17}	–0.018	0.015		–0.023	0.016		°°
ln(M) × ln(LD)	β_{23}	0.062	0.025	**	–0.056	0.016	***	°
ln(M) × ln(Fe)	β_{24}	0.047	0.018	**	0.178	0.048	***	°°°
ln(M) × ln(Pe)	β_{25}	–0.039	0.032		0.065	0.039		°°°
ln(M) × ln(IW)	β_{26}	0.028	0.011	**	0.113	0.029	***	°°°
ln(M) × ln(Y)	β_{27}	0.024	0.009	**	0.059	0.020	***	°°°
ln(LD) × ln(Fe)	β_{34}	0.069	0.016	***	0.041	0.018	**	°°
ln(LD) × ln(Pe)	β_{35}	0.031	0.025		–0.022	0.013		°°
ln(LD) × ln(IW)	β_{36}	0.078	0.015	***	0.119	0.028	***	°°°
ln(LD) × ln(Y)	β_{37}	0.020	0.014		0.013	0.009		°°
ln(Fe) × ln(Pe)	β_{45}	0.044	0.017	**	0.085	0.034	**	°°°
ln(Fe) × ln(IW)	β_{46}	–0.107	0.029	***	0.369	0.090	***	°°°
ln(Fe) × ln(Y)	β_{47}	0.024	0.020		0.051	0.033		°°°

Table 4 - continued

Variables	Param.	Area A			Area B			Sig. z-test
ln(Pe) × ln(IW)	β_{56}	–0.083	0.055		0.117	0.028	***	°°
ln(Pe) × ln(Y)	β_{57}	0.015	0.010		0.034	0.021		°°°
Inefficiency model								
Constant	δ_0	0.325	0.068	***	0.142	0.035	***	°°°
L	δ_1	–0.327	–0.149	**	–0.601	0.178	***	°°°
M	δ_2	–0.268	0.107	**	–0.533	0.124	***	°°°
LD	δ_3	–0.671	0.137	***	–0.264	0.098	**	°°°
Fe	δ_4	–0.320	0.120	**	–0.716	0.185	***	°°°
Pe	δ_5	–0.055	0.023	**	–0.051	0.020	**	
IW	δ_6	–0.163	0.038	***	–0.858	0.177	***	°°°
Age	δ_7	0.022	0.009	**	0.062	0.044		°°°
Credit	δ_8	–0.039	0.012	***	–0.044	0.017	**	°
Plots	δ_9	0.083	0.068		0.057	0.013	***	°°
Slope	δ_{10}	0.095	0.022	***	–	–		–
Well	δ_{11}	0.467	0.336		–0.835	0.233	***	°°°
Network	δ_{12}	–0.771	0.173	***	–0.324	0.102	***	°°°
Well/Network	δ_{13}	0.149	0.134		–0.776	0.211	***	°°°
Well × IW	δ_{14}	–0.635	0.135	***	–1.472	0.308	***	°°°
Network × IW	δ_{15}	0.403	0.165	**	0.272	0.084	***	°°°
Well/Network × IW	δ_{16}	–0.588	0.154	***	–0.941	0.166	***	°°°
Variance parameters								
σ_u^2		0.159			0.101			
σ_v^2		0.024			0.036			
$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.183	0.044	***	0.137	0.035	***	
$\gamma = \sigma_u^2 / \sigma^2$		0.869	0.153	***	0.737	0.175	***	
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\pi/(\pi-2)\right]$		0.706			0.505			
Log-likelihood		–248.77			–295.30			
Farms		118			126			
Obs.		572			615			
Technical efficiency								
Mean		0.724			0.859			
Min.		0.431			0.654			

Table 4 - continued

Variables	Param.	Area A	Area B	Sig. z-test
Max.		0.985	0.992	
S.D.		0.284	0.315	

***: sign. 1%; **: sign. 5%; *: sign. 10%.

°°°: sign. 1%; °°: sign. 5%; °: sign. 10% from the z-test $\left(Z = b_1 - b_2 / \sqrt{SE_{b_1}^2 + SE_{b_2}^2}\right)$

Source: authors' elaborations through data from direct survey.

Table 5 - Marginal effects of the exogenous factors

Determinants of inefficiency		Marginal effect on $E(u_i)$			
		Area A		Area B	
L	δ_1	–0.232	**	–0.451	***
M	δ_2	–0.201	**	–0.378	***
LD	δ_3	–0.476	***	–0.187	**
Fe	δ_4	–0.227	**	–0.551	***
Pe	δ_5	–0.036	**	–0.038	**
IW	δ_6	–0.098	***	–0.704	***
Age	δ_7	0.016	**	0.047	
Credit	δ_8	–0.029	***	–0.031	**
Plots	δ_9	0.064		0.044	***
Slope	δ_{10}	0.072	***	–	
Well	δ_{11}	0.304		–0.710	***
Network	δ_{12}	–0.609	***	–0.224	***
Well/Network	δ_{13}	0.106		–0.629	***
Well × IW	δ_{14}	–0.495	***	–1.178	***
Network × IW	δ_{15}	0.282	**	0.182	***
Well/Network × IW	δ_{16}	–0.429	***	–0.772	***

Source: authors' elaborations through data from direct survey.

Finally, regarding the elasticities of production (Table 6), the estimates indicated that the most important inputs in Area A were labour and machinery, so that an increase in output can be obtained mostly by levering on these factors. In particular, ceteris paribus, a 1% increase in annual days of work and in machinery value generated a 0.37% and 0.28% increase in output, respectively. Therefore, Area A winegrowing was rather elastic regarding these factors, thus allowing farmers to achieve significant improvements in management performance. Irrigation water, however, was characterized by an elasticity of production of 17%, thus affecting output to the extent to which this input can contribute to maintaining grape quality. On the other hand, in Area B, land and irrigation water mainly affected economic performance so that, ceteris paribus, a 1% increase in these factors gave a 0.33% and 0.30% rise in output, respectively. The elasticity of production for irrigation water in Area B was 47% greater than for Area A, thus providing a further impact measure of this input on income in the considered areas. Finally, the returns to scale showed that farms in Area A and Area B can increase their production by an average of 26% and 17% respectively by efficient use of their available resources.

Table 6 - Elasticity and returns to scale

Inputs	**Area A**		**Area B**	
	Elasticity	**S.D.**	**Elasticity**	**S.D.**
L	0.201	0.192	0.328	0.297
M	0.283	0.214	0.171	0.174
LD	0.369	0.281	0.134	0.136
Fe	0.142	0.101	0.176	0.124
Pe	0.095	0.115	0.052	0.038
IW	0.167	0.137	0.305	0.295
Returns to scale	**1.257**	**0.936**	**1.166**	**1.200**

Source: authors' elaborations through data from direct survey.

2.3. *The irrigation system of the Capitanata Consortium*

The inefficiency results concerning the use of irrigation water by winegrowing farms in northern Apulia highlighted the weaknesses of the current water management in a wide share of the administrative area of the Capitanata Consortium. The analysis indicated the great importance of private wells, despite the serious environmental problems caused by exploitation of groundwater. Its use is almost free (except for a small fixed fee paid every five years), and allows farmers to meet rapidly the water demand of their crops in summer. On the other hand, irrigation water from the collective network is more expensive (a fixed fee for ordinary network maintenance in addition to approximately 0.40 € m^{-3} for the water use) though water demand is not always satisfied.

The inefficiency related to the irrigation water management can be enhanced through the findings of recent studies concerning the Capitanata Consortium or the region as a whole. In particular, Giannoccaro *et al.* (2019) investigated the economic impacts of reduced irrigation water availability over 16 years in the Capitanata Consortium. The results showed that in comparison with years of sufficient rainfall, dry years caused an economic loss of 30% in terms of gross product reduction and increased irrigation costs, suggesting the need for a broader drought management plan to minimize the economic impacts of irrigation water shortages. Benedetti *et al.* (2019) measured the technical efficiency of several irrigated crops and production techniques using a stochastic frontier production method, in order to develop efficient management options to reduce water consumption and waste in the Capitanata Consortium. The results highlighted that processing tomato was the most efficient crop production system, that organic farms had lower efficiency levels than conventional ones, and that a fertigation system was able to increase technical efficiency. Finally, Arborea *et al.* (2017) carried out an economic analysis of the costs and benefits of wastewater treatment and reuse by focusing on wastewater project plants in Apulia. In particular, the study focused on the use of wastewater by newly irrigated farms and already irrigated farms, which could use wastewater as an alternative to groundwater. The results showed that urban wastewater could increase regional irrigation water availability by an additional 10% of overall demand. In addition, while treatment costs depended on effluent quality and plant size, the benefits were stable. These outcomes highlighted the divergent trends between the demand and supply of irrigation water in the Capitanata Consortium, and indicated the need to provide a suitable water management plan to meet the demand for irrigation water, including the use of supplementary resources, i.e. wastewater. Indeed, the collective network of the Capitanata Consortium, included in the Southern Apennines Hydrographic District, currently has the second largest irrigation network in Italy (4,000 km) after the Padano District in northern Italy (over 11,000 km). The Consortium is subject to frequent water supply crises, which are not always caused by the extreme climatic events (drought) typical of the Mediterranean area. Water deficits are often due to the structural and technological obsolescence of the collective network, which cause the loss of significant volumes of water, and to poor network maintenance. Other factors are inadequate storage systems, poor water quality due to illegal dumping, and unauthorized withdrawals (Zucaro *et al.*, 2011). In addition, the irrigated area of the district amounts to 47% of the equipped area (against a national average of 71%) and to 4% of the administrative area, while the equipped area is 8% of the administrative area. Therefore, irrigation water from private wells, which is often uncontrolled and unauthorized, is the sole resource for ensuring constant satisfaction of the yearly water demand, although its use can cause irreversible environmental damage, such as lowering the piezometric level of the aquifer, seawater intrusion into coastal aquifers, and a general deterioration in soil quality. A further problem related to the management of water in the study areas is that many users do not actually pay for the water they consume, and this generates critical issues in planning water use. However, one positive aspect concerns the diffusion of high-efficiency irrigation systems, such as localized irrigation (48%) and sprinkler irrigation (44%), also because of environmental objectives promoted by the EU and by national policies. In this regard, water demand has increased in recent decades (also due to climate change), thus creating notable supply problems for different water uses in the civil, industrial and agricultural sectors. Thus, planning of water supply has been based on a territorial and intersectoral perspective, giving priority to civil and agricultural uses, also in compliance with environmental objectives (Zucaro *et al.*, 2011). Consequently, there has been a reduction in the irrigated UAA, and expansion of this area is now possible only if more efficient irrigation systems are planned. The problems concerning management of the collective networks in the study areas can be summarized by the relationship between annual contribution in the respective district and the related equipped area. This ratio is equal to about 105 €/hectare in the Southern Apennine District and to about 50 €/hectare in the Padano District, whose network is 2.75 times larger (Zucaro *et al.*, 2011). Although these values are not fully comparable, since the two districts have additional and different services besides the management of irrigation water, the significant discrepancy can still be used to consider the economic consequences of the structural and management inefficiencies of the collective irrigation networks in the study areas.

These aspects summarize the dynamics that compel farmers to use groundwater from private wells rather than irrigation water from collective networks. However, a correct water policy should focus on the preservation of groundwater via a partial or total ban on farmers using this resource, and should provide for interventions to make the collective networks more effective and efficient. The use of private wells ensures a higher level of farm efficiency, but this could be greatly reduced by restrictions on the use of groundwater. If this reduction is not adequately compensated by a suitable improvement in the collective networks, which this study has shown to be highly inefficient, the winegrowing sector could suffer significant damage. Obviously, similar trends could affect other crops with considerable water requirements in summer, including, peaches, nectarines, tomatoes and melons.

The setting of a water management policy able to promote a decreasing use of private wells together with enhanced efficiency of the collective networks is crucial. In addition, there is a need to promote efficient irrigation practices and systems for water saving. The advantages would benefit not only the agricultural sector, but the entire community, since irrigation provided by collective networks has multifunctional characteristics, especially in the study areas. In particular, it is based on reservoirs, i.e. infrastructures for irrigation that have also acquired environmental and recreational functions over the years, generating externalities that are more or less compensated (Sardaro *et al.*, 2018). These are related to aquifer recharge, the conservation of biodiversity and protected migratory species, the preservation of irrigation agroecosystems and the historical agricultural landscape, the creation of wetlands, the management of supply chains based on irrigated crops, and general improvements in production quality.

3. Conclusions

The study investigated important management aspects in the light of Directive 2000/60/EC, related to the formulation of policies to improve the qualitative and quantitative conditions of groundwater, to increase the efficiency of the collective irrigation networks and to strengthen the related positive externalities, and to improve the economic performances of regional winegrowing farms. Analysis of technical inefficiency enables understanding of the mechanisms by which output is obtained through the management and interaction of the production factors and inputs. Focusing on different water supply systems makes it possible to classify them in terms of technical inefficiency and to understand their impacts on farm output. Consequently, farmers can be informed and directed towards more sustainable approaches, while policy makers can be supported in formulation of suitable water management policies that also take account of their effects on farms' economic performance.

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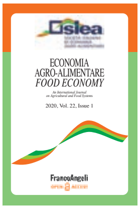

Un nuovo modello per l'agricoltura in Valle di Non, fra risparmio idrico e tutela ambientale

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Abstract

Saving water, protecting the environment: A new model for agriculture in Val di Non

The southern slopes of the Alps are facing a changing climate. This is acutely perceived in areas ideally suited to high-quality agriculture, such as the Val di Non, in the northern Italian Province of Trento. Here agriculture has been constantly improving in technology and management. Drip irrigation now covers 100% of fruit tree cultivation, notably apple and cherry representing 90% of the over 8,000 hectares of farmed land. Cooperative management of resources, both in irrigation and land management, underpins and strengthens the agricultural sector in the Province of Trento. The Province's primary legislative control over agriculture and environmental protection maximizes the legislator's closeness to the interests and needs of agricultural producers and economic actors. This article illustrates the norms regulating agriculture and environmental protection in the Province of Trento. Secondly, it presents the ongoing complex research aimed at striking a new balance between environmental concerns (namely, the preservation of the quality of water streams in Val di Non) and growing demand for water for local agricultural production. The need to provide adequate water supply for agriculture conflicts with

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the necessity to guarantee minimum flow levels in local water streams, as provided for by law (environmental flow), as well as to preserve adequate quality of flowing water. The article proposes to connect existing irrigation infrastructure – irrigation networks, reservoirs and pumping stations. Itanalyzesa range of issues – parasite management; insurance against spring frost; labor protection; processing and marketing of produce. It connects with local research centers – the University of Trento for climatological research, the Mach Foundation for agronomic research and the Kessler Foundation for the application of new technologies to data harvesting and management.

Lista degli acronimi utilizzati nel testo

C.M.F. o CMF o CI	Consorzio di Miglioramento Fondiario e Consorzi Irrigui di Miglioramento Fondiario
Consorzio	Consorzio di Miglioramento Fondiario 2° Grado "Consorzio Val di Non"
Consorzio Tovel	Consorzio di Miglioramento Fondiario 2° Grado "Val di Tovel"
DCF	Disponibilità di capitale futuro
DGP	Deliberazione della Giunta Provinciale di Trento
DMV	Deflusso minimo vitale
FBk	Fondazione Bruno Kessler – Centro di ricerche
Ha o ha	ettaro
IASMA	Istituto Agrario di San Michele all'Adige – Centro di ricerche
L.P. o LP	Legge della Provincia Autonoma di Trento
MWh	megawattora
PAT o P.A.T.	Provincia Autonoma di Trento
PGUAP	Piano Generale di Utilizzazione delle Acque Pubbliche della PAT
PSR	Programma di Sviluppo Rurale della Provincia Autonoma di Trento
PSRN	Programma di Sviluppo Rurale Nazionale
PTA	Piano di Tutela della Acque della Provincia Autonoma di Trento
SUAP	Servizio Utilizzazione della Acque Pubbliche della PAT
VIA	Valutazione di impatto ambientale

Premesse e contenuti

Gli impatti delle attività agricole sulle componenti ambientali, acqua, aria, suolo, paesaggio, sono argomento di studio soprattutto quando le modificazioni climatiche diventano di dominio e interesse pubblico. Le distorsioni climatiche si manifestano anche in aree, come il versante meridionale delle Alpi, che fino a qualche decennio fa ne parevano immuni. Questo scritto affronta il tema della risorsa idrica irrigua in una zona, in cui l'agricoltura ha rilevante importanza sociale ed economica. Si tratta della Valle di Non in Trentino, dove la coltura specializzata della mela è elemento peculiare del territorio. Qui, l'irrigazione ha permesso la trasformazione agricola dalle colture estensive in quelle specializzate di oggi. Data l'espansione della frutticoltura, la gestione della risorsa idrica è diventata una necessità e un obbligo, ma il percorso per garantire la sopravvivenza del settore deve affrontare adesso le sfide più impegnative, le quali non si limitano al solo risparmio dell'acqua, ma richiedono una prospettiva di sistema, come cercherò d'illustrare.

Intendo iniziare con un breve excursus delle politiche agricole e ambientali della Provincia Autonoma di Trento (PAT) nell'uso e protezione della risorsa idrica, per concentrarmi poi sulla situazione della Valle di Non. Il tema si pose in evidenza fin nell'ultima decade del secolo scorso[1], ma fu riconosciuto da tutti con la crisi anomala del 2003. Per iniziativa della PAT e, in valle, del Consorzio M.F. di 2° Grado Val di Tovel (Consorzio Tovel), furono avviati allora studi mirati a conoscere il fabbisogno idrico delle colture[2] e valutare le risorse disponibili per l'irrigazione[3]. Con il primo Piano di Sviluppo Rurale (PSR) e ancor più con le norme in materia di tutela dell'acqua, dal 2011 oggetto degli studi è diventato l'intero bacino del Noce (valli di Non e di Sole). Intendo nel seguito fare il punto della situazione, per proiettare poi la questione nella programmazione.

1. Politiche agricole e ambientali in provincia di Trento

Godendo la PAT di prerogative autonome in tema di agricoltura e tutela ambientale, essa legifera direttamente sui due argomenti. In campo agricolo il PSR[4] è lo strumento programmatico settennale, che vuole armonizzare lo

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2. Si veda la nota 8.

3. Zambotti, A. (a cura di), *Indagini e studi per la ricerca d'acqua per conto del CMF 2° Grado Val di Tovel*, 2003-2014.

4. PSR, Ver. 5.1 del Fondo Europeo Agricolo per lo Sviluppo Rurale (FEASAR), approvato dalla Commissione Europea il 27 settembre 2018.

sviluppo trentino con le politiche comunitarie e con i fabbisogni del territorio. Esso mira così a «*valorizzare la vocazione produttiva del Trentino… – promuovere l'uso sostenibile ed efficiente delle risorse… – garantire lo sviluppo del territorio mantenendone il presidio…*»[5].

Il PSR opera in sinergia ed integrazione del Programma di Sviluppo Rurale Nazionale (PSRN). Entrambi gli strumenti sostengono le azioni di sviluppo agricolo con bandi di finanziamento, che sono orientati a più tipologie d'intervento e verso il livello nazionale o provinciale secondo la grandezza dell'opera. Ad esempio, la competenza provinciale in materia d'invasi si ferma a 250.000 m^3 di capacità, quella del programma nazionale opera per invasi di volume maggiore. Le tipologie d'intervento sono articolate in priorità, da attuare con appropriate misure, cui sono dedicate le risorse economiche. Gli obiettivi del PSR sono: innovazione, competitività e redditività in agricoltura, filiera delle produzioni, preservazione, ripristino e valorizzazione degli ecosistemi, uso efficiente delle risorse, economia con basse emissioni di carbonio e sostegno allo sviluppo sociale ed economico delle zone rurali. Benché numerose, le sue misure non rispondono a tutti i casi, vuoi per la specificità del problema o le sue dimensioni, vuoi per la temporalità della programmazione, vuoi ancora per ragioni di disponibilità finanziaria. Nei casi in cui il PSR non sia applicabile, PAT può intervenire con i sostegni previsti dalla L.P. 4 del 28 marzo 2003 e s.m.i.

Parlando, invece, di utilizzo di acque pubbliche, la materia è regolata in provincia di Trento dal Piano generale di utilizzazione delle acque pubbliche (PGUAP)[6]. Nello specifico, il compito di tutela ambientale è demandato al Piano di Tutela delle Acque (PTA), approvato una prima volta con la delibera GP n. 3233 del 30 dicembre 2004 e rinnovato ora con la 233 del 16 febbraio 2015.

2. Studio generale per l'integrazione delle risorse idriche in Val di Non

Inquadramento

Gli studi e i progetti degli anni novanta e primi duemila fecero comprendere con sempre maggior consapevolezza che l'acqua in Valle di Non, oltre ad essere un problema di quantità di risorsa, è specialmente una questione di gestione. Entrambi i fattori non coinvolgono, si badi bene, solamente il mondo agricolo, ma riguardano l'intera società: il consumo idrico civile è molto elevato a causa di dislocazione sul territorio, numerosità e dimensioni contenute dei nuclei abitati, ognuno dei quali utilizza e gestisce un proprio acquedotto potabile. In quest'uso ci sono molti margini di

5. Si veda: www.psr.provincia.tn.it.
6. In vigore da 8 giugno 2006 (Gazzetta Ufficiale n. 119 del 24 maggio 2006).

miglioramento, che necessitano di decisioni programmatiche consapevoli e ferme, a livello provinciale e locale.

Volendo limitarci al problema irriguo, l'elevata domanda d'acqua in valle è acuita dall'estensione delle colture del melo e più recentemente del ciliegio, le quali, con l'aumentare delle temperature medie, hanno raggiunto e oltrepassato orma i 1000 metri di quota. Lo sviluppo generalizzato della pratica irrigua, avviata secoli or sono (oggi interessa quasi tutti gli 8000 e più ettari coltivati), è giustificata dalle caratteristiche intrinseche del territorio: ridotta piovosità (600-800 mm/anno), regime idrologico e morfologia del territorio. La piovosità, poi, si concentra nei mesi primaverili e autunnali, mentre l'estate vede calare di molto le portate fluenti nei torrenti, specialmente quando i bacini imbriferi hanno ridotta estensione e ancor più dove le captazioni giacciono nelle parti più alte del corso d'acqua. L'assenza di gruppi montuosi elevati priva l'area delle riserve dei ghiacciai, mentre i versanti terrazzati, su cui sono disposte le aree coltivate, scaricano rapidamente le acque piovane nel fondovalle, dove il torrente Noce e i suoi affluenti scorrono in forre profonde con alvei a quote costantemente inferiori rispetto a quella dei terreni agricoli. Nel contempo, alcuni fattori hanno favorito il successo agricolo della valle, spingendo così ancor più la domanda d'acqua: clima mite, esposizione e orientamento ideali, suolo fertile e lavorabile. Questi elementi naturali, sposati con l'operosità degli abitanti e l'attitudine a cooperare in molte azioni (dall'irrigazione, alla preparazione dei prodotti anticrittogamici, alla conservazione, lavorazione e commercializzazione della frutta) attutiscono gli effetti negativi della frammentazione catastale e della ridotta dimensione dell'azienda agricola familiare.

La limitatezza di risorsa idrica e il progredire delle tecniche agronomiche hanno spinto i Consorzi Irrigui e di Miglioramento Fondiario (CMF ad aggiornare costantemente i sistemi irrigui, grazie anche al sostegno pubblico della PAT. Dagli anni '50, in cui s'irrigava a scorrimento, gli impianti distributivi sono stati sostituiti più volte per obsolescenza. Dall'ultimo decennio del secolo scorso la goccia copre il 100% delle colture arboree (circa il 90% delle colture), mentre la distribuzione a pioggia a bassa intensità è presente ancora nelle zone più elevate, dove permangono le coltivazioni erbacee per la zootecnia. Ridotte sono le aree dotate di impianti per la difesa antibrina attraverso l'aspersione a pioggia, perché al momento della fioritura primaverile lo scioglimento delle nevi sulle montagne non ingrossa a sufficienza le portate dei torrenti. Con il ricorrere di condizioni atmosferiche che portano correnti fredde, il problema delle gelate su vasta scala va ad aggiungersi a quello delle brinate, imputabile all'inversione termica.

Con l'adozione dell'irrigazione a goccia gran parte dei CI da qualche anno riusciva a soddisfare il fabbisogno idrico delle colture; il ricorrere di situazioni locali di carenza era superato senza danni irreparabili per il sistema. Con l'entrata in vigore delle norme sull'obbligo di rilasciare negli alvei la portata di salvaguardia (o deflusso minimo vitale – DMV) prima di attivare la derivazione, la valle s'è ritrovata ancora una volta fragile in relazione alla disponibilità idrica.

Così, la combinazione del clima in modificazione con lo sfruttamento elevato della risorsa e l'alta qualità delle produzioni voluta dal mercato sono fattori che spingono a cercare un nuovo equilibrio. Ciò a maggior ragione in un'area di montagna, dov'è indispensabile che l'alta qualità sia sostenibile per l'ambiente, ma anche per mantenere in vita le piccole aziende agricole. Mentre nelle aree di pianura il bilancio aziendale può fare affidamento anche sulla quantità di produzione e il basso impiego di manodopera, nell'agricoltura di montagna la qualità della produzione, e quindi il prezzo del prodotto venduto, è fondamentale per dare un ricavo sufficiente a compensare il lavoro della famiglia coltivatrice.

Il lavoro che vado a presentare ha tracciato un percorso per la ricerca di un nuovo modello d'equilibrio, il quale, benché non ancora consolidato nelle soluzioni tecniche, lo è di certo nella diagnosi e negli obiettivi.

Il percorso dell'analisi generale – Alternativa 1ª gravità

Un primo lavoro importante relativo alle esigenze idriche per l'irrigazione in Trentino si deve al dott. Giambattista Toller, responsabile dell'Unità Operativa Agrometeorologica e Clima dell'Istituto Agrario di San Michele all'Adige (IASMA)[7], mentre un prezioso aggiornamento sullo stato dell'agricoltura trentina fu pubblicato, alcuni anni dopo, dal Dipartimento Agricoltura e Alimentazione della PAT[8]. Questo conteneva l'esame delle risorse idriche impiegate in agricoltura (fabbisogni e concessioni) e indagava gli effetti, sulla quantità e qualità delle acque, dei nutrienti e fitofarmaci impiegati nelle pratiche colturali. Data la rilevanza della questione irrigua e ambientale proprio in Valle di Non, il modello utilizzato per misurare gli effetti fu applicato al bacino del Noce.

Nel 2012 il Consorzio Tovel depositò presso il Servizio Utilizzazione delle Acque Pubbliche (SUAP) domanda per derivare dal torrente Rabbies in val di Rabbi la portata di 350 l/sec. Lo scopo del progetto era consentire di superare i momenti in cui le derivazioni sul torrente Tresenica, in Val di Non, non fossero sufficienti per dare la priorità al DMV sul torrente (secondo PGUAP) e soddisfare il fabbisogno irriguo. L'esigenza era motivata dal valore molto elevato del coefficiente di rilascio adottato (da 5,0 a 7,0 l/(sec*km^2 di bacino imbrifero sotteso). Il progetto proponeva di potenziare l'acquedotto

7. Toller, G., *I fabbisogni di acqua irrigua nel Trentino.* IASMA, febbraio 2002.

8. Marcazzan, G. (a cura di), *Monitoraggio degli Indicatori del PSR. Dipartimento Agricoltura e Alimentazione*, dicembre 2011.

irriguo preesistente dal Rabbies in uso al Consorzio Acquario di M.F. di Cles, associato nel Consorzio Tovel: la portata di 100 l/sec veniva aumentata a beneficio dei circa 2.000 ettari del Consorzio Tovel. Per l'ottenimento del nuovo titolo, nel 2014, il proponente avviò il procedimento di valutazione ambientale con la procedura di prefattibilità ambientale (screening) presso la PAT. La relazione[9] di screening documenta lo stato critico del Consorzio Tovel a causa dell'entità del rilascio e dimostrava come valori di rilascio meno gravosi [2,0 o 4,0 l/(sec*km^2)] ne mitigassero l'effetto. Lo studio s'interroga poi sulla possibilità di soddisfare esigenze anche di altri territori in Valle di Non, non meno in crisi di quello all'esame, e si proponeva come opera strategica nel contesto della valle. Nel rimandare il giudizio ambientale alla procedura di VIA, la Commissione di valutazione esprimeva l'esigenza che fosse approfondito e analizzato "*il profilo strategico dell'opera nel contesto infrastrutturale irriguo della valle*"[10]. Le Fig. 1 e 2 riportano le zone e il DMV da PGUAP.

Fig. 1 - Zonizzazione del bacino del Noce

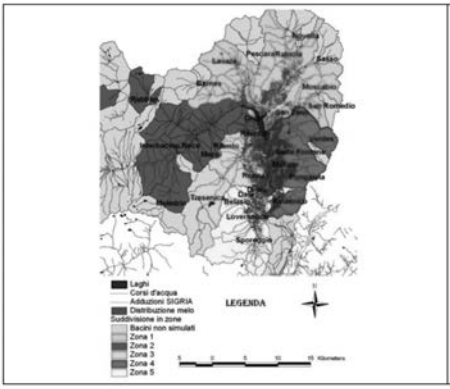
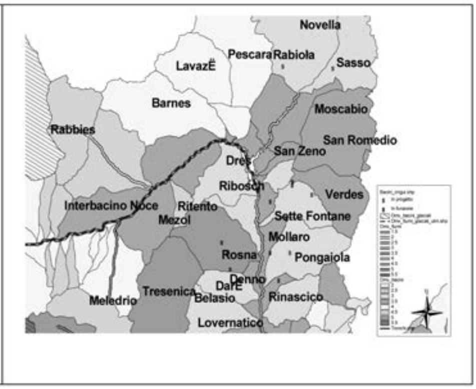


Fig. 2 - Indici del DMV previsti dal PGUAP



Il Dipartimento Territorio, Agricoltura, Ambiente e Foreste provinciale avviò subito una fase di verifica per esaminare l'interesse non solo per la valle, ma per tutta l'agricoltura trentina. Ne fece seguito un lavoro[11], in cui il territorio

9. Studio Tre, Società d'Ingegneria: Relazione generale alla procedura di Verifica ambientale (SCR-2014-27), pp. 2 e 3, 2014.

10. PAT Servizio Autorizzazioni e Valutazioni Ambientali – Determinazione del Dirigente n. 44,9 ottobre 2014.

11. Marcazzan, G., Zambotti, A., *Verifica di ipotesi progettuali per una gestione integrata degli attingimenti a scopo irriguo nel bacino del Noce*, febbraio 2015.

di riferimento diventava tutta la valle. I dati d'ingresso dell'analisi sono: disponibilità di una derivazione esterna per alimentare un nuovo acquedotto irriguo a gravità, interconnessione sul territorio agricolo di reti, invasi di regolazione, pompaggi di soccorso dai laghi (Santa Giustina e Mollaro), gestione integrata delle strutture irrigue in valle.

Il modello matematico sonda le disponibilità idriche per l'irrigazione nelle diverse zone del territorio applicate al nuovo schema interconnesso. Il calcolo considera agente il DMV da PGUAP e prevede che la gestione sia coordinata da un soggetto avente «*facoltà di utilizzare l'insieme delle risorse idriche in concessione nell'ambito del bacino, mediante una visione uniforme sul territorio, indipendentemente dalla titolarità e dalla localizzazione della singola risorsa*» (vedi nota 11). L'interconnessione determina il fatto che l'acqua erogata negli impianti irrigui non sia solo la portata proveniente dall'esterno (è applicata per moduli crescenti da 100 a 400 l/sec), ma anche quella fornita dai titoli attivi in valle, ridotti del deflusso di salvaguardia ambientale. Anche gli invasi presenti sul territorio contribuiscono alla gestione: tutti gli apporti agiscono in modo che le fasce altimetriche a quote superiori integrano le esigenze di quelle più in basso. Il risultato si riassume in: deficit annullato con portata esterna di 400 l/sec (100+300), mentre rimane un margine di 645.000 m^3 (Tab. 1).

Tab. 1 - Deficit massimo irriguo per l'apporto dal Rabbiés con DMV *da* PGUAP

Q derivata sul Rabbiés (l/s)	**Deficit annuo sul Rabbiés (%)**	**Deficit max. irriguo (%) e (periodo)**	**Deficit max. nelle zone 3+4 [m^3]**	**Fascia di quota inizio deficit (m. s.l.m.)**
100 l/s	–	–	–2.060.000	540-570
100+100 l/s	0	0 (aprile)	–1.010.000	485-515
100+200 l/s	–0.2	–3.8 (aprile)	–150.000	320-350
100+300 l/s	–1.8	–22.02 (aprile)	**+645.000**	–
100+400 l/s	–1.9	–24.7 (aprile)	**+1.200.000**	–

La verifica degli impatti sulle derivazioni in atto sul Rabbiés dimostra che non ne è compromessa l'efficienza (col. 2) in Tab. 1. Per stimare, poi, l'impatto dell'entità del rilascio, il modello è stato riapplicato con DMV ridotto a 2,0 l/(sec*km^2), deducendo l'evidenza secondo cui con Q=200 l/sec (100+100) il margine passa a 880.000 m^3 senza effetti diversi sulle altre derivazioni dal Rabbies (Tab. 1bis).

*Tab. 1bis - Deficit massimo irriguo per l'apporto dal Rabbiés con DMV 2,0 l/(sec*km²)*

Q derivata sul Rabbiés (l/s)	**Deficit (%) annuo sui prelievi irrigui dal Rabbiés**	**Deficit max. irriguo (%) e (periodo)**	**Deficit max.(*) (m^3) nelle zone 3+4 – DMV di 2 l/(s*km²)**
100	-	-	–170.000
100+100	0	0 (aprile)	**+880.000**
100+200	–0.2	–3.8 (aprile)	**+1.740.000**
100+300	–1.8	–22.02 (aprile)	**–**
100+400	–1.9	–24.7 (aprile)	**–**

Alternativa 2ª pompaggio

Oltre la soluzione a gravità, lo studio esamina anche una seconda alternativa: che per coprire il fabbisogno si utilizzino solo pompaggi dai laghi di fondovalle e che si costruisca lo stesso schema idraulico del caso precedente. Gli aspetti pro e contro si vedono in Tab. 2.

Tab. 2 - Elementi di giudizio delle alternative

Caratteristica	**A. 1: sistema a gravità**	**A. 2: pompaggi dai laghi**
Tipo di sistema idraulico	A gravità	Sollevamento meccanico
Prelievo dell'acqua	Fuori valle	In valle
Impatto diretto su	Corso d'acqua	Bacini idroelettrici artificiali
Comunità civili coinvolte	Val di Sole e Val di Non	Val di Non
Sinergie d'investimenti	Molte[1]	Nessuna
Sicurezza del servizio	Garantita	Possibili disservizi
Continuità del servizio	Garantita	Fuori servizio per manutenzione
Funzionamento	Continuo	Non del tutto certo
Manutenzione ordinaria	Normale	Onerosa per via dei pompaggi
Manutenzione straordinaria di	Componenti idraulici statici	Componenti idraulici anche in movimento ed elettrici
Anno di sostituzione	20° e 40° componenti idraulici	7°, 22°, 37° e 52° pompaggi attuali 15°, 30°, 45° stazioni nuove

Tab. 2 - segue

Caratteristica	**A. 1: sistema a gravità**	**A. 2: pompaggi dai laghi**
Fabbisogno energetico	Come lo stato attuale	Elevato
Produzione energetica	14.700 MWh /anno	Nessuna
Difesa antibrina[2]	600 ha con 12 l/(sec*ha), 1.450 con 5,0 l/(sec.*ha)	Limitato dalla fattibilità (impianto)

Note: 1) acquedotto potabile di Cles, metanizzazione dell'alta val di Sole, pista ciclabile Cles-Mostizzolo, produzione energetica, capacità di fornire acque per servizio antibrina; 2) l'utilizzo antibrina richiede sempre investimenti aggiuntivi per potenziare le stazioni di pompaggio, sostituire le reti con tubazioni di maggior diametro e costruire l'impianto a pioggia in campo.

Le tabelle 3 e 4 raccolgono i dati della verifica economico-finanziaria, calcolata con il metodo DCF (disponibilità di capitale futuro). I dati d'ingresso adottati sono:

- vita utile dell'opera 60 anni
- attualizzazione degli investimenti futuri 1,0%
- tasso d'interesse del danaro 2,50%
- alternativa 1: sostituzione componenti idraulici (non la dorsale) al 20° e 40° anno
- alternativa 2: sostituzione dei pompaggi attuali al 7°, 22°, 37° e 52° anno
- alternativa 2: sostituzione dei pompaggi nuovi al 15°, 30°, 45° anno

Tab. 3 - Costi e benefici prodotti dall'investimento

Componente di costo	**Derivazione esterna**	**Pompaggi dai laghi**
Investimenti	**Euro**	**Euro**
opere generali e idrauliche	45.895.695,00	25.248.000,00
elettromeccaniche	1.921.905,00	883.000,00
stazioni di sollevamento	1.500.000,00	7.236.000,00
invasi	17.240.000,00	17.240.000,00
TOTALE INVESTIMETI	66.263.000,00	49.724.000,00
Costi annui		
diretti	545.459,00	1.423.290,00
indiretti	4.438.200,00	4.438.200,00
COSTI ANNUI DI GESTIONE	4.983.659,00	5.861.490,00
Benefici diretti	19.118.000,00	19.118.000,00

Tab. 4 - Confronto economico-finanziario delle alternative

Componente economico	Note	Alternativa	
		1 – Rabbies	2 – Pompaggi
Investimento iniziale (€)		66.363.000,00	49.724.000,00
Investimento in 60 anni (€)	valore attuale	89.931.505,00	106.135.640,00
	valore corrente	100.703.800,00	124.890.800,00
Investimento iniziale (€/ha)		9.720,00	7.282,00
Investimento totale (€/ha)		14.748,00	18.291,00
Ritorno investimento (anni)		6	5

Aggiornamento delle alternative

Fece seguito una fase interlocutoria fra Servizi provinciali e Consorzi Irrigui allo scopo di condividere le problematiche ambientali, i compiti delegati ai Consorzi e le criticità prevedibili, data la necessità di raggiungere rapidamente i traguardi del PTA sulla qualità dei corsi d'acqua in coerenza con PTA e Direttiva Quadro Acque. Nel 2017 si raggiunse un primo risultato importante: con il supporto della Federazione provinciale dei Consorzi irrigui e di Miglioramento Fondiario fu costituito un nuovo soggetto, il Consorzio di Miglioramento Fondiario di 2° Grado "Consorzio Val di Non" (nel seguito "Consorzio"), cui aderirono 51 dei 60 Consorzi irrigui della valle. Con esso la Provincia ha già sottoscritto un protocollo d'intesa[12], che porterà a progettare e costruire le opere previste nel programma e gestire il sistema irriguo. Il Consorzio coordina anche gli associati, affinché, sotto le indicazioni del regolatore idraulico nominato allo scopo, sia attivato il DMV. È stato definito un periodo di 10 anni, ritenuto necessario per costruire il nuovo sistema, in cui l'acqua sarà gestita in modo da permettere ai Consorzi di irrigare e, nel contempo, sia attuato al massimo livello possibile il rilascio di tutela. Si devono ottenere da subito miglioramenti ambientali senza compromettere il sistema produttivo. Successivamente, realizzate le opere, le derivazioni irrigue dovranno rilasciare le portate di salvaguardia programmate. I Consorzi Irrigui associati hanno già costruito i dispositivi di limitazione e regolazione presso le opere di presa, con cui è possibile già ora modulare il rilascio in base allo stato idrologico del rio e al fabbisogno irriguo.

Nel maggio 2018[13] il Consorzio presentò alla Provincia il programma degli investimenti, aggiornato poi nel 2019[14]. Con gli aggiornamenti fu

12. PAT; Consorzio Valle di Non: Protocollo d'intesa – Deliberazione GP 1558-2018-1.

13. Lorenzi, R., Lotti, P., Vivari, F., Zambotti, A. (a cura di), *Relazione sul programma degli investimenti*, Consorzio Valle di Non, 2018.

14. Lotti, P., Vivari, F., Zambotti, A. (a cura di), *Relazione integrativa Rev.04*, Consorzio Valle di Non, 2019.

proposto di spostare il soccorso dal Rabbies al torrente Noce di Peio, corso d'acqua più ricco del Rabbies, e il Consorzio depositò domanda per la relativa derivazione. Con l'occasione alcuni altri temi divennero argomento d'analisi:

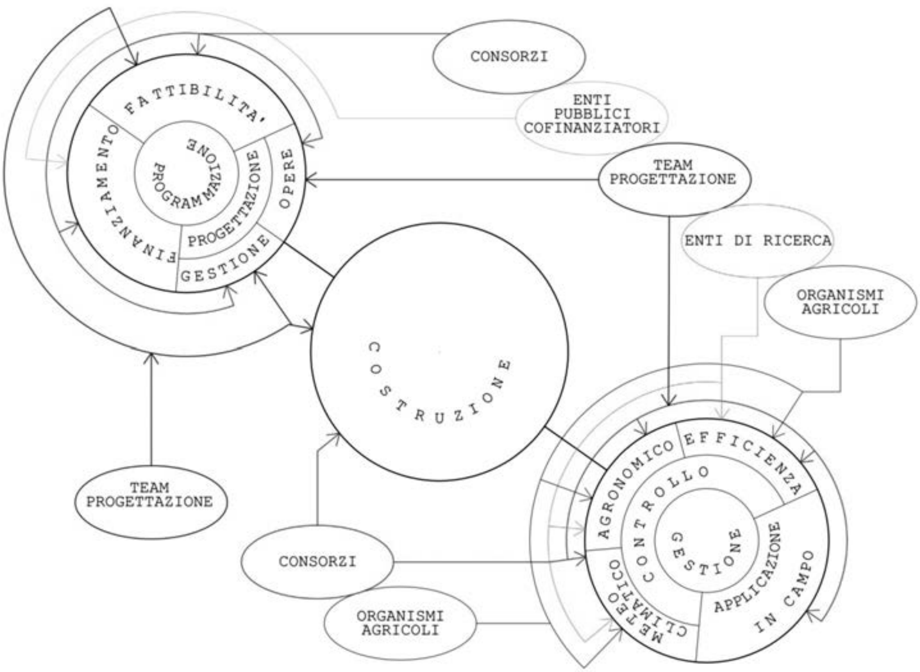
- sinergie con altre esigenze del territorio [vedi Nota 1 di Tab. 1];
- sfruttamento energetico della condotta irrigua da Peio;
- utilizzo per l'irrigazione antibrina;
- aggiornamento dell'investimento previsto: € 84.915.000,00;
- spese annue di gestione € 1.892.000,00.

Nel frattempo fu avanzata anche una terza ipotesi di lavoro. Essa ipotizza la costruzione di una diga in c.a. nell'invaso di Santa Giustina, in modo da enuclearne una porzione dal suo grande catino (180 milioni di m^3). Il setto consentirebbe di mantenere costante il livello di regolazione a monte, mentre a valle continuerebbe l'oscillazione odierna, dipendendo esso dalle portate degli immissari e dal programma energetico del gestore dell'impianto di Taio. Il dislivello fra le due linee sarebbe in grado di generare energia nelle macchine idrauliche disposte nel setto. Il maggior beneficio della soluzione sta nell'alternativa pompaggi, perché questi preleverebbero l'acqua alla quota di massima regolazione odierna del lago, quota che resterebbe invariata durante la stagione. Inoltre, l'energia prodotta (nell'ordine di 50.000 MWh/anno) compenserebbe quella consumata dai pompaggi della rete irrigua per il servizio di irrigazione antisiccitaria e antibrina e potrebbe coprire altri consumi energetici del comparto agricolo (impianti di refrigerazione). L'ipotesi, però, è rimasta allo stato embrionale, perché le difficoltà normative e l'incertezza circa la disponibilità del sito nell'invaso di Santa Giustina, nonché il costo molto elevato, ne fanno temere la fattibilità.

3. Modello di attuazione del programma

Da quanto riportato sopra sinteticamente appare come gli studi abbiano ormai esaminato il problema in tutte le dimensioni. Consorzio e Provincia devono assumere ora le decisioni programmatiche prima di passare alla fase operativa. L'attuazione del progetto è incardinata sull'agricoltura del territorio, che ha il punto di forza nella capacità dei suoi operatori alla collaborazione, ma non solo. Si tratta di argomento su cui molti soggetti hanno possibilità di fornire utili contributi: il flusso di tali contributi è schematizzato nella seguente Figura 3.

Fig. 3 - Diagramma di flusso per i contributi d'idee e processo di attuazione del progetto



Vero è che la rilevanza del comparto e la preoccupazione per il suo sviluppo equilibrato sono dimostrati, se ce ne fosse bisogno, dall'interesse di cui gode il tema acqua in Valle di Non. Su di esso ovviamente le idee non sono univoche, anche perché non tutto il territorio si trova allo stesso livello di partenza in relazione al fabbisogno e alle disponibilità idriche. Sono argomenti di cui non ragionano solo gli addetti ai lavori oppure i Consorzi Irrigui. Si può certamente condividere il fatto che tutti i portatori d'interesse della filiera frutticola e del comparto agroalimentare abbiano interesse diretto a ché l'agricoltura in Valle di Non sia forte e capace di svilupparsi armonicamente. Solo così, infatti, sarà assicurata la continuità produttiva di qualità, il mercato rimarrà legato al marchio e il sistema economico sarà efficiente e in grado di dare soddisfazione alle oltre 5000 famiglie diretto-coltivatrici. Per questa ragione, il Consorzio ha in atto un processo di monitoraggio e consultazione con tutti gli organismi agricoli interessati.

A questo modello di coinvolgimento sono chiamati in particolare i centri di ricerca che da sempre operano sui problemi agricoli in Trentino, ovvero l'Università degli studi di Trento, la Fondazione Edmund Mach con l'istituto IASMA e la Fondazione Bruno Kessler (FBk). I relativi contributi scientifici spaziano in differenti campi della materia: cambiamenti climatici e meteorologia presso l'Università, agronomia in tutti i suoi argomenti presso IASMA e tecniche di efficientamento, mediante densificazione e trattamento dei dati rilevabili in campo per la gestione dell'irrigazione, presso la Fondazione Kessler.

Con questo processo Consorzio e Provincia danno attuazione ad un modello di lavoro che, coinvolgendo insieme ai progettisti più attori con competenze differenti, conduca ad una progettualità e programmazione ad ampio raggio, facendo proprie metodologie che è più usuale trovare in campo industriale, laddove si parla di "Industria 4.0". La sfida delle criticità climatiche richiede un approccio multidisciplinare, che è, per l'appunto, il nuovo modello che si vuole implementare e che è sintetizzato nel diagramma di flusso.

4. Conclusione

Ritengo, per concludere, utili alcune considerazioni riepilogative:

1. L'attività svolta negli anni ha sviscerato la problematica in attesa della decisione sulle alternative (sistema a gravità oppure a pompaggio). Dopo la preferenza accordata alla prima dal Consorzio, l'attesa decisione della PAT è dovuta in forza della competenza provinciale in materia di acque pubbliche ed è indispensabile per contemperare interessi anche contrastanti espressi dal territorio.
2. Consorzio e PAT devono trovare le risorse per finanziare gli investimenti e determinare la quota a carico degli agricoltori. Solo così le assemblee dei Consorzi di 1° grado approveranno l'iniziativa: l'incertezza sui costi può sviare da un giudizio sereno i votanti, timorosi per la sostenibilità finanziaria dell'opera nelle proprie aziende.
3. I contributi d'idee attesi dai centri di ricerca e dagli altri organismi agricoli non riguardano solo il tema acqua, quanto piuttosto il sistema agricolo nel suo complesso. La situazione climatica in arrivo spinge l'agricoltura trentina verso un modello più consono al metodo di lavoro dell'Industria.
4. Stante l'annosa ricerca svolta con metodi scientifici, non è giustificato il procrastinarsi delle scelte, che comunque nelle fasi a venire potranno fornire utili contributi provenienti dai centri di ricerca. Il calendario iniziale è già oggi in ritardo: il decennio previsto va già oltre il 2027, data entro cui tutti i corsi d'acqua del Trentino dovranno trovarsi in "*qualità buona*", per soddisfare i parametri della Direttiva Quadro Acque.
5. La convinzione che la convivenza fra agricoltura e ambiente sia indispensabile e migliorabile è maturata negli agricoltori. Sono da biasimare scorciatoie che ipotizzino modifiche normative; perfino eventuali dilazioni

non sono nell'interesse dell'agricoltura. L'urgenza è dimostrata dal fatto che il Consorzio ha ottenuto di poter applicare gradualmente il DMV nel periodo transitorio, proprio perché s'è impegnato nella ricerca di una soluzione risolutiva, che consenta il miglioramento qualitativo delle acque. Lo spostare in avanti le decisioni non rimuove il problema e le sue ragioni.

6. La nuova organizzazione non dovrà stravolgere l'attuale organizzazione dell'irrigazione, incentrata sull'azione dei Consorzi Irrigui di 1° grado. In essi continua la tradizione secolare preunitaria del Trentino, che vede molte persone impegnarsi gratuitamente per la comunità. Il valore sociale di questo patrimonio deve essere conservato anche quando la modernizzazione tecnologica porti verso nuove strade e nuovi modi di lavorare. Solo così potrà avere successo il programma collaborativo descritto; diversamente si sprecherà una grande occasione. La sfida che si presenta ora è quella di costruire l'organizzazione in grado di conferire maggiori capacità decisionali al Consorzio generale senza sminuire l'azione del Consorzio locale di 1° grado.

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Il dott. Lorenzo Cattani, Direttore della Federazione provinciale dei Consorzi irrigui e di miglioramento fondiario di Trento mi ha stimolato a scrivere questo contributo; lo ringrazio per l'opportunità e i suggerimenti preziosi.

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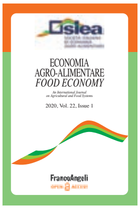

On positive externalities from irrigated agriculture and their policy implications: An overview

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Abstract

Water has important economic values, mainly in the agricultural sector. Beside enhancing agricultural output and crop diversification, irrigation generates positive externalities which have been little emphasized by the literature. The purpose of this review is to investigate the direct, indirect and potential benefits of water use in agriculture by taking an additional step towards the identification and economic evaluation of the observed positive, social, environmental and ecological effects of irrigation. Five categories of contributions are examined: irrigation returns flows for groundwater recharge; biodiversity and wildlife habitat; landscape aesthetic and cultural values; nutrient recycling and retention; and improved health, nutrition and living conditions. Knowing the economic value of such positive externalities would help to get the right policy incentives for better water use and increased water savings in a context of growing water scarcity.

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Introduction

Water is one of the most essential natural resources. It plays a main role in life's birth and evolution of all living species and ecosystems of the planet. Water utility does not cease with the fulfilment of its environmental and biological functions. Indeed, main civilizations started their development nearby rivers or water basins, becoming able to address their needs and provisions by using water resources to develop primary activities (FAO, 2011). The importance of water resources for human life has been formally underlined by the UN (2010) that have declared access to safe water as an essential human right. Water has also been recognized with the state of economic good (ICWE, 1992) which makes it suitable to be treated as any other private good (Perry *et al.*, 1997) or considered as a social good that has to be kept outside the process of market pricing (Van der Zaag & Savenije, 2006).

Nowadays, water is directly or indirectly at the core of each basic human need and is daily used in many different sectors of the economy (FAO, 2011). The agricultural sector is by far the main user of global water resources. The quantity of water consumed by agriculture covers 70% of total freshwater consumption (WWAP, 2017). However, because of climate change, the availability of water resources is destined to be reduced (FAO, 2012). Furthermore, world's population is projected to reach 9.7 billion in 2050 (UN, 2019) requiring increases in food production (Alexandratos & Bruinsma, 2012). Agriculture is the economic sector mostly affected by water scarcity (FAO, 2012) which refers to the limited amount of supply of a good or resource with respect to its demand. Since water demanded by other sectors is increasing more rapidly than that demanded by agricultural sector (FAO, 2011), it becomes increasingly important to find alternative and sustainable water management methods in agriculture (Mastrorilli & Zucaro, 2016).

Water used in agriculture is conveyed through rainfalls and precipitations (rainfed agriculture) or through irrigation techniques (irrigated agriculture). This paper specifically refers to irrigated agriculture. The primary benefit of irrigation is the increase in agricultural production. Indeed, irrigated agriculture is more productive than rainfed cropping. It accounts for 40% of total global agricultural output with only 20% of cultivated lands being irrigated (Turral *et al.*, 2011). Therefore, irrigation development is among the key actions to be undertaken in order to adequately satisfy food demand.

There is a wide debate about the existence of negative externalities of irrigation practices (Singh, 2016), but their positive externalities are much less researched and documented. This paper tries to fill this literature gap. It conducts a review to highlight the benefits of irrigation in the form of positive environmental externalities. The presence of such externalities does not automatically imply a net positive outcome for the environment as negative effects could outbalance the positive ones. Our discussion on the positive externalities from irrigation is biased since the balance between positive and negative effects is not considered. Further research is needed to assess such balance and the effects on the overall society's welfare.

The purpose of this paper is to investigate about the positive externalities of irrigation and make a step towards the complete identification and classification of such positive effects on society's welfare. The paper is structured as follows. Section 1 illustrates the conceptual framework. The methodology adopted for the review is described in section 2. Section 3 summarizes and discusses the main evidences emerging from the literature review. Conclusions are reported in the final section.

1. Irrigation externalities and ecosystem services: a conceptual framework

Irrigation has profound interactions with natural and productive ecosystems and can generate externalities, i.e. variations in the welfare level of other individuals without monetary compensations (Buchanan & Stubblebine, 1962).

The presence of externalities indicates that there are consequences of production or consumption activities which are not included in their economic values. Externalities consist of the environmental and social costs or benefits of economic activities which do not participate to the market price formation of a certain good and fall back to other subjects that are not directly included in the consumption or production activities (Turner *et al.*, 1994). Policies like command and control, taxes, cap and trade mechanisms should be implemented to internalize such costs and benefits in the price of goods. The existence of externalities makes resources allocation inefficient (Turner *et al.*, 1994) and is a cause of market failure. Economic efficiency is achieved when the net benefits deriving from resource use are maximized (Tietenberg and Lewis, 2012) and the maximum level of social wellness is reached. This corresponds to Pareto optimality, i.e. a situation when there is no resource reallocation capable to increase the utility level of society's members (Hein, 2010).

When the efficiency level is sub-optimal the value of production may be improved through a different allocation of inputs and resources involved in the production process (Wichelns, 2002). Inefficiency sources include market failures and property rights misspecification. Markets usually reach efficiency for private goods. Public goods and common-pool resources as water or other natural resources are managed with more difficulties. When resources are non-regulated and their property rights are not defined, the free-riding problem can cause excessive resource use and depletion. Open access resources face economic inefficiencies more frequently than the regulated ones: they are often overexploited by free riders, i.e. users which take advantage of them without paying the corresponding price (Hardin, 1968).

Negative externalities are linked to pollution and represent a cost for the entire society as they negatively affect its welfare levels. On the opposite, positive externalities are associated with an increase of social welfare and represent a benefit for the society that is not incorporated into producers' revenues (Turner *et al*., 1994).

Positive environmental externalities coming from water use in agriculture are often in the form of enhanced ecosystem services. They are defined as an entire set of processes, conditions and ecological functions that natural ecosystems largely develop providing benefits to the environment and other living species (Daily *et al*., 1997). They may be given an economic value (Costanza *et al*., 1997). However, human interaction with natural ecosystems may positively or negatively affect the environment and cause modifications to the natural cycle.

Ecosystem services supply many vital functions that are often interconnected. Identification and evaluation of such functions may be useful to set up systems of economic incentives (Payment for Environmental Services, PES) to generate ecosystem functions at a larger scale. Including the real value of those services and benefits in the price of commodities would create a compensation system for their providers, many of them are farmers and land stewards, improving overall economic efficiency (Branca *et al*., 2011).

The provision of ecosystem services related to agriculture has already been documented (Zhang *et al*., 2007; Gordon *et al*., 2010; Power, 2010) but there is still a lack of debate regarding positive ecosystem services specifically generated by the irrigation practices. Indeed, externalities coming from irrigation water use in agriculture are often associated with negative effects such as pollution, waterlogging or salinization that may directly contribute to land degradation (van Schilfgaarde, 1994; Hussain, 2007; Singh, 2016; Singh, 2018). However, irrigation generates positive externalities as well. They are considered in this work.

2. Methodology

This review has been undertaken through a Google Scholar and Scopus online search engines research. The Food and Agricultural Organization library focused on agricultural studies (AGRIS) was also consulted. The initial keywords used were combinations of the following terms: "positive externalities", "ecosystem services", "irrigation", "benefits", "water resources". After an initial collection and selection of resulting papers, five different categories of contributions were defined, namely: groundwater recharge, increase of biodiversity, landscape aesthetics, nutrients retention and positive impacts on human health and nutrition.

According to this classification, further investigation using the same online libraries and digital archives was undertaken.

Research has been primarily conducted in English. However, a few results in Spanish and Italian languages were also collected, due to their relevance and pertinence to the main topic. To be selected for the review, studies had to include: a discussion on the observed positive social, environmental and ecologic consequences coming from irrigation in agricultural areas in at least one of the categories identified above. Quantitative analysis and evaluations were preferred. However, a small number of qualitative studies, reviews and discussions were also considered. Most of the studies selected and cited in this review have been published in peer-reviewed journals. Additionally, the reference list of each of the selected articles was used to expand the search and potentially include additional insights, with the aim to provide a more comprehensive review about the topic.

Studies reviewed have been divided in five different categories of contributions, in order to better classify and discuss their implication. Such benefits include:

1. Irrigation returns flows for groundwater recharge
2. Biodiversity and wildlife habitat
3. Landscape aesthetics and cultural values
4. Nutrient recycling and retention
5. Improved health, nutrition and living conditions

Table 1 includes a list of the studies considered for the review.

Table 1 – Reference list by category

Category	**Reference**	**Journal**
Irrigation return flows and groundwater recharge	Maréchal *et al.*, 2003	n/a (conference paper)
	Causapé *et al.*, 2004	Agricultural Water Management
	Aizaki *et al.*, 2006	Paddy Water Environments
	Kendy & Bredehoeft, 2006	Water Resources Research
	Silva-Hidalgo *et al.*, 2008	n/a (conference paper)
	Jiménez-Martínez, 2009	Journal of Hydrology
	Kim *et al.*, 2009	Agricultural Water Management
	Lu *et al.*, 2010	National Groundwater Association
	Poch-Massegú *et al.*, 2014	Agricultural Water Management
	Zucaro, 2014	n/a (Research report INEA)
	Ebrahimi et al, 2016	Water Resource Management
	Séraphin *et al.*, 2016	Journal of Hydrology

Table 1 - continued

Category	Reference	Journal
Biodiversity and wildlife habitat	Katano *et al.*, 2003	Environmental Biology of Fishes
	Renault & Montginoul, 2003	Agricultural Water Management
	Bambaradeniya *et al.*, 2004	Biodiversity and Conservation
	Mazerolle, 2004	Landscape Ecology
	Sánchez-Zapata *et al.*, 2005	Biodiversity and Conservation
	Abellán *et al.*, 2006	Journal of Arid Environments
	Aizaki *et al.*, 2006	Paddy Water Environments
	Davies *et al.*, 2008	Agriculture, Ecosystems & Environment
	González-Estébaneza *et al.* 2010	Agriculture, Ecosystems & Environment
	Sebastián-González *et al.*, 2010	European Journal of Wildlife Research
	García Sánchez, 2011	Estudios Avanzados
	Maltchik *et al.*, 2011	Revista de Biología Tropical
	Aspe Gille & Jacque, 2016	Regional Environmental Change
	Choe *et al.*, 2016	Entomological Research
	Herring *et al.*, 2019	Agriculture, Ecosystems & Environment
Landscape aesthetic and cultural values	Sayadi *et al.*, 2005	Ecological Economics
	Aizaki *et al.*, 2006	Paddy Water Environments
	Gil Meseguer, 2006	Papeles de Geografia
	Sayadi *et al.*, 2009	Land Use Policy
	Zekri *et al.*, 2012	Journal of Agricultural Research
	Thiene & Tsur, 2013	Journal of Agricultural Economics
	Zucaro, 2014	n/a (Research report INEA)
	Sánchez-Sánchez *et al.*, 2016	n/a (book chapter)
	Vivithkeyoonvong & Jourdain, 2016	International Journal of Biodiversity Science, Ecosystem Services & Management
	Tekken *et al.*, 2017	Ecosystem Services
	Jourdain & Vivithkeyoonvong, 2017	Agricultural Economics

Table 1 - continued

Category	Reference	Journal
Nutrient recycling and retention	Follett, 2001	Soil & Tillage Research
	Feng *et al.*, 2004	Agricultural Water Management
	Hitomi *et al.*, 2006	Water Science and Technology
	Gillabel *et al.*, 2007	Soil Science Society of America Journal
	Herzon & Helenius, 2008	Biological Conservation
	Wu *et al.*, 2008	Soil Science Society of America Journal
	Battacharyya *et al.*, 2013	Agronomy Journal
	Trost *et al.*, 2013	Agronomy for Sustainable Development
	Olsson *et al.*, 2014	Applied Energy
	Dollinger *et al.*, 2015	Agronomy for Sustainable Development
	Törnqvist *et al.*, 2015	PLoS ONE
Improved health, nutrition and living conditions	Lipton, 2001	Proceedings of the Nutrition Society
	Renault & Montginoul, 2003	Agricultural Water Management
	Hussain & Hanjra, 2004	Irrigation & Drainage
	Smith, 2004	International journal of Water Resources Development
	Hussain, 2007	Irrigation & Drainage
	Tesfaye *et al.*, 2008	Irrigation & Drainage Systems
	Rahman & Parvin, 2009	Journal of Water Resource and Protection
	Burney *et al.*, 2010	Proceedings of the National Academy of Sciences
	Namara *et al.*, 2010	Agricultural Water Management
	Namara *et al.*, 2011	n/a (Research report IWMI)
	Aseyehegn *et al.*, 2012	Journal of Agricultural Sciences
	Burney & Naylor, 2012	World Development
	Domènech & Ringler, 2013	n/a (IFPRI Discussion Paper)
	Dinesh Kumar *et al.*, 2014	International Journal of Water Resources Development

3. Positive externalities of water use in agriculture

This section summarizes and discusses review findings and the resulting evidence regarding positive externalities of irrigation.

3.1. *Return flows for groundwater recharge*

Groundwater surface recharge usually depends on percolation from rainfall precipitations or irrigation practices in agricultural areas. Agricultural uptakes reduce groundwater levels, but deep percolation through irrigation return flows partially compensates the withdrawals. When irrigation processes are adequately managed, irrigation return flows can be consistent and help maintain groundwater levels in a sustainable way. Plants and soil only absorb a small quantity of water, but the rest is subject to natural and physical transformations through which it returns to natural ecosystems. Remaining water continues to flow and eventually starts infiltrating underground towards rivers (horizontal percolation) or groundwater aquifers (vertical percolation). Water not consumed by crops in the fields, and not evaporated directly from the surface or through plants (evapotranspiration), will flow to stream and drainage canals, until it percolates toward groundwater reservoirs. In arid and semi-arid areas irrigation is the primary source of water distribution for cultivated crops. Water return flows generate an important service for the environment and the community particularly during the dry season (Marechal *et al.*, 2003). Such water reserves provide valuable services for the entire society by covering fundamental functions for the well-being of the environment because they help to prevent land subsidence caused by the excessive groundwater withdrawal (Galloway & Burbey, 2011). Managing and preserving groundwater reservoirs is crucial for the sustainability of the environment and under the right conditions could provide a regulating ecosystem service (MEA, 2005).

Ebrahim *et al.* (2016) point out that recharge models often account only for recharges coming from rainfalls, or do not distinguish between rainfall and irrigation return flows. However, in many basins, irrigation return flows represent a consistent source of groundwater recharge. The quantification of irrigation-driven recharges is therefore crucial to guarantee an adequate management of groundwater resources and allow evaluating the real value of water use in agriculture. To quantify such effects, evidence about separated rainfalls from irrigation return flows is needed. Their study was conducted the Mosian aquifer of Western Iran. Results show that 15% and 10% of irrigation water and rainfalls water respectively reached back the aquifer, proving that irrigation can contribute to the water balance of the area. Also, Lu *et al.* (2010) distinguish between irrigation and rainfall return flows. They look at five different agricultural areas (piedmont, alluvial and lacustrine, coastal plains) situated in the Hebei plain of China. Water used in agriculture resulted to be a consistent contributor to aquifer recharge since groundwater from irrigation accounted for about 27-49% of the total recharged amount. Studies quantifying the percentage contribution of irrigation to groundwater reservoirs were carried also in Korean paddy fields (Kim *et al.*, 2009), where the estimated average irrigation return flows from 1998 to 2001 was 25.7% of the annual irrigation amount; and in Mexico (Florido river basin), where this value reached 30% (Silva-Hidalgo *et al.*, 2008). The rate of return of water resources may vary depending on the crop types, depending on the rates of transpiration and percolation (Ali-Askari & Shayannejad, 2015).

Evidence from case studies in the Mediterranean areas also exists. In the Campo de Cartagena in South-Eastern Spain, irrigation is simultaneously a cause of freshwater withdrawals and an important source of aquifer recharge. Infiltrations from fields covered by melon and lettuce crops showed different rates of recharge, confirming that return flows may also depend on the crop types (Jiménez-Martínez *et al.*, 2009). However, despite the consistent levels of irrigation return flows in various fields in different agriculture areas of Spain (Poch-Massegú *et al.*, 2014), nitrate concentration has also increased. Causapé *et al.* (2004) suggest that irrigation management is fundamental to control the amount of fertilizers in return flows: careful and flexible irrigation management together with improved fertilization practices is crucial to contain negative effects of nutrient leaching and percolation. Consistent groundwater contributions were highlighted also in Southern France (Crau basin), where irrigation channels used for cultivations make irrigation activity to be the main contributor of the underlying groundwater aquifer (Séraphin *et al.*, 2016).

An interesting perspective is given by Kendy & Bredehoeft (2006). Their study suggests a possible existence of a trade-off between irrigation technical efficiency and groundwater recharge. Technical efficiency concerns the capacity to obtain a maximum output from a given set of inputs (output-oriented measures) or to use a minimal input mix to generate the same level of output (input-oriented measures) (Kijne *et al.*, 2003). This is linked to physical water productivity defined as the ratio between outputs and inputs, where the output is identified with farmers' yield and the input with the amount of water used to obtain such yield. Water productivity represents the "net return for a unit of water used" and is achievable by raising production keeping the same amount of water or maintaining the same volume of production after a decrease of water inflows (Molden *et al.*, 2010). Water used for irrigation is an input in agricultural production. On-farm efficiency depends on how irrigation is managed and varies by crop type (Benedetti *et al.*, 2019; Laureti *et al.*, 2020). Kendy & Bredehoeft (2006) found that water savings coming from an increase in water use efficiency may happen at the expense of reducing or eliminating irrigation return flows that mainly contribute to groundwater recharges. A simple increase in irrigation efficiency is associated with a lower amount of water withdrawals which should compensate the missing return flows from agriculture. However, if farmers decide to increase the cultivated areas, freshwater withdrawals may increase as well, leaving few or no space for deep aquifers recharge. Moreover, downstream users of return flows such as living species of the surrounding aquatic ecosystem would not be able to survive without them.

Scarce attention has been put to measuring the economic impact of groundwater recharges. Aizaki *et al.* (2006) estimate the economic value of groundwater recharge in a case study in Japan, by using a contingent valuation method. In the study, they asked to Japanese responding households to report their willingness to pay for different services provided by agriculture. They resulted to be willing to pay 4.63$ per household (in 2003) in order to maintain groundwater recharges in place. In Italy, a similar experiment has been conducted to assess the willingness to pay for the positive externalities coming from irrigation. Groundwater aquifer recharge externalities were valued and a sample of interviewed Italian citizens asserted to be willing to pay 1.65$ per household each month (in 2014) in addition to their water bill consumption (Zucaro, 2014).

3.2. *Biodiversity and wildlife habitat*

Through irrigation systems, water is conveyed towards agricultural lands which become more productive. Ecosystem services associated to landscape changes and to the interaction between water and crops are generated (García Sánchez, 2011). They are relevant for many living species, altering the biodiversity level of the flora and fauna surrounding agricultural crops. Indeed, biodiversity in irrigated lands is maintained, improved or even enhanced through agricultural water management.

Strong evidence relating water and increased biodiversity in irrigated agroecosystems is found in the irrigated rice fields of Asia. Studies prove that water used in such fields create environmental benefits by providing a living habitat to plants and animals. Bambaradeniya *et al.* (2004) consider irrigated rice fields as temporary wetland ecosystems and report that the number of living species and organisms found in irrigated rice fields of Sri-Lanka is extremely high, consisting of about five hundred different species, including invertebrates, vertebrate, macro- and micro-phytes. Most importantly, fifteen new species were recorded for the first time in the irrigated fields. Authors claim that traditional irrigated rice field ecosystems may contribute to the achievement of high biodiversity levels and are among the most sustainable forms of agriculture. Similarly, in reviewing the positive externalities of rice-based irrigation in Sri Lanka, Renault & Montginoul (2003) highlight that water effectively consumed by crops only accounts for a small part of the total amount of water available for irrigation, and most of its uses are related to the provisions of positive externalities such as the perennial vegetation growth besides rice plants. Perennial vegetation consumes part of the water destined to rice fields and plays an important role for the local community because it is used to feed cattle and is fundamental to balance high temperatures in tropical areas. In many cases, perennial vegetation provides additional sources of food as well as medicinal plants, wood and other raw materials. Rice fields in Japan have also been proved to host a high level of fish diversity: as plankton and aquatic invertebrates usually develop in irrigation water, fish may eat them and continue to grow, moving throughout irrigation ditches especially when they are connected to rice crops (Katano *et al.*, 2003). In some cases, fish may also be used as food source by the local communities (Renault & Montginoul, 2003).

The connection between rice field irrigation and increased biodiversity have also been documented in other parts of the world. For example, Maltchik *et al.* (2011) found that in Southern Brazil around 160 living species were hosted in irrigation channels. Herring *et al.* (2019) linked rice field irrigation to the presence of water birds in Australia. Choe *et al.* (2016) found that irrigation channels and ponds are an effective way to enhance biodiversity in Korean paddy fields. Davies *et al.* (2008) compared five different European locations observing a significant contribution to biodiversity from agricultural water ponds and ditches.

Evidence regarding the association between irrigation and increased biodiversity is found also in the Mediterranean area. Indeed, the crucial importance of irrigation is noticeable in arid and semi-arid regions where rainfall is scarce. Under these conditions, every single aspect concerning irrigation is fundamental to help plants growing in a hostile environment. Consequently, new species of plants and trees rise in the newly created wet areas benefiting of a more favorable climate conditions (Gil Meseguer, 2006). In Southern Spain, water irrigation flows in arid agricultural areas had many positive effects in terms of plants variability and diversification (García Sánchez, 2011). Irrigated agriculture fields in the semi-arid Mediterranean landscape represent functional habitats for many different species of water birds (Sánchez-Zapata *et al.*, 2005; Sebastián-González *et al.*, 2010) and other living species such as invertebrates and amphibian (Abellán *et al.*, 2006). González-Estébaneza *et al.* (2010) have also found that irrigated farmlands provide more favourable conditions for butterflies which are considered a good environmental indicator of biodiversity mostly being very sensitive to air pollution and climate shocks. Butterfly diversity was expected to decrease due to agriculture intensification, but irrigation has been effective in reversing this trend. They conclude that, since water and rainfall shortages are common in the Mediterranean area during the dry season, irrigation constitutes a way to maintain green vegetation along cultivated crops, which positively affects butterflies' living conditions.

Irrigation may introduce infrastructures and technologies in natural landscapes and ecosystems altering water natural cycles and diverting the resource toward farmed areas. However, in some cases infrastructures built for water distribution could increase ecosystems' protection. For example, channels and ditches used for water transportation can connect different water basins creating a hydrological network which offers a safe passage from one place to another to some aquatic species (Mazerolle, 2004; Aspe, Gille & Jacque, 2014).

Limited evidence about the economic implications of such outcomes can be found in the literature. Aizaki *et al.* (2006) estimate that the willingness to pay for the environmental conservation function of rice fields and for the wildlife protection service provided in Japan in 2003 was approximately equal to 5.90$ per household. However, there is no clear definition of what the category "environmental conservation" includes or excludes. Further economic evaluation is needed to better assess the positive externalities of irrigation in terms of biodiversity maintenance, diversification and increase.

3.3. *Landscape aesthetics and cultural values*

Irrigation is one of the main responsible of the changes in agricultural landscapes, which are often enjoyed by individuals and families for outdoor activities or recreational purposes (MEA, 2005). For instance, in the Mediterranean area, agriculture often implies the establishment of terraces, canals or ditches for water conveyance. This has helped farmers in managing fields also in places with irregular morphology due to the presence of hills and mountains; and helped creating suggestive landscapes. In Southern Spain there are traditional irrigated lands called Huertas that have been shaped by agricultural activities and especially from irrigation practices. Gil Meseguer (2006) and Sánchez-Sánchez *et al.* (2016) both provide an interesting historical description of the area. They specifically ascribe the landscape evolution of the agricultural views of Murcia's region to water used in irrigation. Huertas sometimes incorporate archaeological sites and ancient ruins from roman's age that once were used to convey water. Albeit despite having been replaced by modern irrigation infrastructure, they continue to be important as a part of the historical capital of the region. Similar values may be found in completely different areas. For example, Tekken *et al.* (2017) have conducted a qualitative assessment of farmers' perception of rice cultivations in Vietnam and the Philippines, confirming that the cultural identity and the heritage value of rice cultivations is a crucial feature of rice production.

Cultural or aesthetic ecosystem services provided by the implementation of irrigation practices should be considered when evaluating water use in agriculture (MEA, 2005). To understand the relevance of the provision of landscapes aesthetic and cultural services, their economic value must be estimated. Since there is no market of landscape provision, some evaluation methods are available, e.g. the contingent valuation method. Individuals may be willing to pay for the provision and preservation of ecosystem services provided by irrigated agriculture and their willingness to pay (WTP) can be quantitatively estimated trough surveys (Spangenberg & Settele, 2010). For example, Sayadi *et al.* (2005; 2009) have highlighted that the provision of landscape amenities produced by farmers in Southern Spain can contribute to revise agriculture's role in the society in addition to the economic function of producing food. They proved that irrigated landscapes provide more beauty and aesthetic values than drylands. Through a survey conducted in 2002, they estimated people's WTP to enjoy the landscape features existing in the area by showing pictures to a sample of interviewed persons asking their WTP to pay for enjoying that view. Some of those landscapes were irrigated. Individuals have decided to assign a higher value to enjoy the view of irrigated farmlands (between 28$ and 31$), because they judged them more aesthetically pleasing (Sayadi *et al.*, 2009). A similar pattern can be found in Italy: the WTP for a typical irrigated agricultural landscape was estimated at 9.5$ per month for each household (in 2014) in addition to their bill for water consumption (Zucaro, 2014). Landscape provision was the most valued positive attribute among those that irrigated landscapes can provide to society.

Similar studies have been conducted in other geographical areas. For example, Zekri *et al.* (2012) find that the role of desert oases in Oman is to provide a positive amenity value beside being a source of food to residents. In their study, 64% of the visitors (mostly foreign visitors that entered the oasis in 2008) declared that they would have been willing to pay $8.6 per visit (per group) to enjoy the scenic view of the oasis. Even if revenues coming from the touristic activity would only represent 6% of farmers' incomes, a wise use of such earnings could be done, such as maintaining the irrigation infrastructures. Aizaki *et al.* (2006) estimated that the WTP for landscape provision and recreation services coming from rice cultivations in a case study of Japan is approximately equal to 3.61$ and 2.66$ per household (in 2003).

The WTP for rural landscape provision also depends on the respondents' social status. When they are given a choice to decide whether to contribute for the preservation or the intensification of such ecosystem services, lower income respondents confirm their willingness to pay only for essential services while upper income respondents are more willing to declare that they would also contribute to non-essential services (Vivithkeyoonvong & Jourdain, 2017). The WTP for mitigating droughts in rice cultivation in Thailand has been estimated to be 4.8$ per household per year (in 2013), while the WTP for environmental, recreational and aesthetic rural landscape functions was oscillating between 20$ and 25$ per household per year (in 2013). Results also depended on socioeconomic characteristics of respondents (Jourdain & Vivithkeyoonvong, 2017).

Thiene & Tsur (2013) confirm that the market equilibrium and the social equilibrium differ when externalities are detected. Northern Italy (Vicenza province) farm landscape values range 9,197-57,664 \$/ha for vineyards and 10,204-63,980 \$/ha for orchards. Afterwards, such values are used to calculate the WTP for amenity services generated by the agricultural landscape, which represents the social demand for water. It is computed by dividing the WTP per hectare by the quantity of water used by crop and is expressed in terms of $\$/m^3$. For vineyards cultivations it varies between 10 and 64 $\$/m^3$, while for orchards it resulted between 5 $\$/m^3$ and 32 $\$/m^3$. The difference is explained by the different minimum water requirements of the different crops.

3.4. *Nutrient recycling and retention*

Irrigation helps soil nutrient retention, i.e. conservation and recycling of land and crops' nutrients and pollutants attenuation. Functioning irrigation systems provide regulating ecosystem services due to the set of channels and ditches used to convey water resources (MEA, 2005). Besides offering safe habitats for aquatic living species, they contribute to nutrient and sediment retention recycling or temporary nutrients storage. In reviewing potential ecosystem services originating from irrigation ditches, Herzon & Helenius (2008) and Dollinger *et al.* (2015) have found that adequate management of ditches vegetation can increase recirculation and recycle of soluble nutrients such as phosphorus and nitrogen. Such flows are also useful to help mitigating the amount of pollutants, sometimes leading almost to their complete removal. Well-maintained wildlife and vegetation that spontaneously grows inside the channels and ditches destined to convey water flows can effectively drain and retain plants nutrients and pollutants, reducing their excessive accumulation and associated negative environmental effects. Using recycled water to irrigate fields may reduce the overall amount of water and fertilizers used in agriculture.

Evidence regarding nutrient retention has been found in Japanese rice fields. Paddy areas performs well in removing nitrogen and phosphorus through recycling irrigation water systems, proving that nutrient retention ability may successfully be employed in those crops where there is a recycling irrigation system managing water inflows and outflows (Feng *et al.*, 2004; Hitomi *et al.* 2006; Törnqvist *et al.*, 2015).

Irrigation practices fall within the agricultural management practices which positively affect soil conservation and enhance soil carbon content, mitigating the amount of CO_2 emissions in the atmosphere (Olsson *et al.*, 2014). Follet (2001) highlights that large-scale cultivations and intensive agricultural practices have led to the erosion of soil carbon content. He finds that the efficient water use in agriculture increases soil carbon content and balances the losses caused by intensive farming. Additional evidence regarding the increase in soil organic and inorganic carbon content is documented by Gillabel *et al.* (2007) and Wu *et al.* (2008) which compare carbon storage processes in irrigated and dryland crops. Their results confirm that carbon sequestration in irrigated lands is higher than in drylands. More recently, Trost *et al.* (2013) show that irrigation generates positive impacts in carbon storage particularly in arid and semiarid areas, while its benefits are not very significant in humid areas. Positive effects on carbon storage potential due to irrigation practices have been highlighted in diverse geographical areas and confronting a variety of different crops such as rice and wheat (Battacharyya *et al.*, 2013) or in grasslands (Olsson *et al.*, 2014).

Irrigation might help establishing and maintaining good soil conditions. Further research on irrigation potential in nutrient recirculation and recycling is needed to completely evaluate them from an ecological and economic perspective. If nutrient cycles become more efficient due to irrigation practices, farmers will decide to reduce the amount of fertilizers used generating positive externalities in terms of reduced fertilizers' production, water pollution, and greenhouse gas emissions.

3.5. *Improved health, nutrition and living conditions*

The link between irrigation and improved human living conditions is particularly evident in developing countries which rely on agriculture as their main source of income. In these countries, farm households find challenges in securing enough food availability due to erratic rainfalls and increasing water scarcity, recently worsened by climate change (FAO, 2016). However, enhancing agricultural production may improve living standards especially in the poorest countries (Smith, 2004) and irrigation plays a crucial role.

Irrigation has both direct and indirect effects on poverty. Direct effects mainly consist in the increase of farmers' income due to enhanced crops' productivity: irrigation makes water supply more reliable and allows for higher food production levels and for the diversification of cultivated crops (Turral *et al.*, 2011). This is particularly important during the dry season, when water resources are less available or during weather extreme events such as droughts and floods (Hussain & Hanjra, 2004; Burney & Naylor, 2012). There is evidence that water may improve life conditions increasing nutritional intakes and health conditions both in the African and Asian continents (Smith, 2004; Hussain & Hanjra, 2004; Tesfaye *et al.*, 2008; Rahman & Parvin, 2009; Burney *et al.*, 2010; Namara *et al.*, 2011; Aseyehegn *et al.*, 2012).

Besides enhancing agricultural yields, water management in agriculture is associated with the provision of positive side effects. Namara *et al.* (2010) and Doménech & Ringler (2013) highlight that direct irrigation benefits provide secondary effects related to food nutrition. Households have direct access to a larger variety of food products, including fruits and vegetables, ensuring a more balanced diet with a net improvement in the amount and variety of micronutrients and calories intakes (Lipton, 2001, Hussain & Hanjra, 2004).

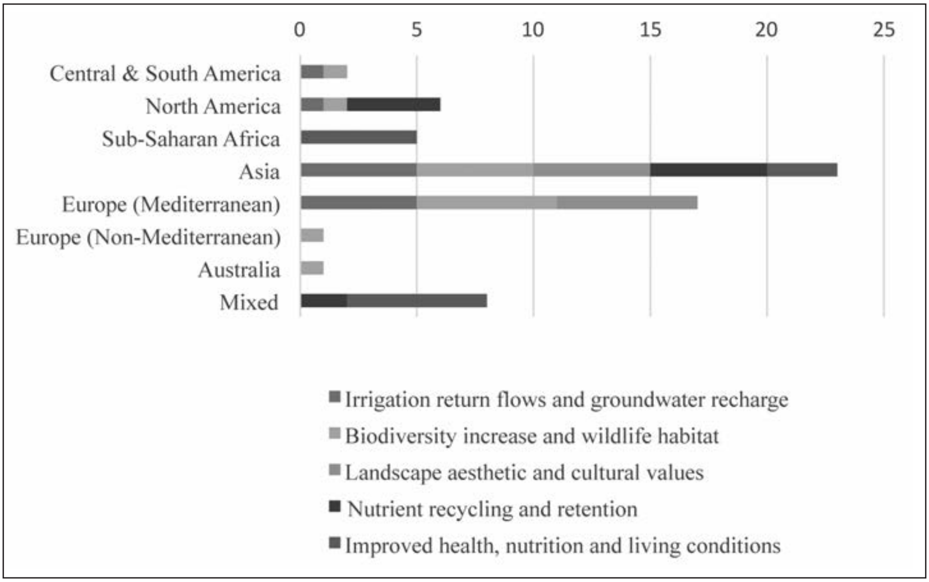
Further benefits coming from irrigation may derive from the multifunctionality of water resources conveyed by irrigation infrastructures and systems. Poor rural households could take advantage of increased water supply by using it for additionally purposes other than irrigating crops (Hussain, 2007; Dinesh-Kumar, 2014). In some cases, they may even use water flows as a mean of transportation (Renault & Montginoul, 2003).

3.6. *Some geographical considerations*

A geographical assessment of the evidence reviewed is helpful for making additional considerations on the distributional patterns of positive externalities resulting from water used for irrigation. Figure 1 reports the geographical origin of the case studies by sub-areas. The studies reviewed refer to different areas: North America, Central and South America, Asia, Europe (especially from the Mediterranean area) or sub-Saharan Africa. Results comparison is difficult due to diverging agro-ecologies and socio-economic conditions.

As concerns the Mediterranean area, documentation available refers to the following categories: groundwater recharge from irrigation return flows, biodiversity increase, and landscape aesthetics. Most references are based on case studies in Spain. However, a relatively smaller number of contributions relates to France and Italy. This indicates that further research should be conducted to assess whether the results from the case studies in Spain can

Figure 1 - Geographical distribution of case-studies considered in this review



be extended to similar contexts in the Mediterranean area. Also, additional data about nutrients retention, storage and recycle due to irrigation are needed for this region. In Asia, comprehensive case studies are available including all benefits categories examined in this review. In sub-Saharan Africa a few studies are available, accounting only for the contributions to health, nutrition and food security category.

Results reported in this review refer to a range of various climate conditions and geographical areas, which may represent a limit of the work. However, despite such differences, there is evidence of at least one of the irrigation benefits in each geographical area, suggesting that agriculture could claim to generate such positive externalities in a global context.

4. Conclusions

Irrigation is necessary to guarantee crop production in dry areas and obtain higher and more stable yields. Food demand is expected to increase due to population growth. Considering the high competition for water resources combined with the increasing water scarcity also due to climate change, serious concerns regarding the availability of water resources in the future arise. To get the right policy incentives for improved water use and increased water savings, total economic value of water should be estimated. The value of the ecosystem services generated by irrigation must be included in the computation. Such services are positive externalities which are often underestimated because of assessment difficulties due to the numerous variables involved and data scarcity. In most cases, economic values can only be approximated by analysing how people perceive them and by estimating the willingness to pay for their preservation.

This paper has described the results of a literature review about the known evidence about such positive externalities and their value. Information available has been classified considering the following categories: 1) groundwater recharges through irrigation return flows; 2) increase of biodiversity trough wildlife habitation and vegetation growth in agricultural areas; 3) landscape aesthetic value where the creation of suggestive landscapes can generate environmental systems that individuals can enjoy; 4) nutrient and sediment recycling and retention through ditches and other irrigation infrastructures; and 5) impacts on socio-economic conditions such as human nutrition increase and health improvements.

Results show that there is a wide ecological recognition for some of the ecosystem services originating from irrigation. Nutrient retention, groundwater recharges through irrigation return flows and biodiversity conservation have been extensively studied from an environmental perspective. Evidence of economic evaluations is lacking, probably due to the estimation difficulties. Cultural services such as landscape provision have been better analysed from the economic point of view, sometimes considering their strong correlation with non-agricultural sectors of the economy (e.g. tourism). Irrigation indirect effects on nutrition and health have also been largely studied, together with their economic implications.

Knowing the total economic value of water resources would help policy makers introducing the right incentives to enhance water use efficiency and obtain water savings. Through the Dublin Statement on Water, the international community has recognized that "managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources" (ICWE, 1992). Appropriate measures to reward farmers for the positive externalities generated should be introduced. For example, payments for ecosystems services programs can be used to compensate farmers for the positive externalities provided to the society (Branca *et al.*, 2011). In the water pricing approach considered in the European Water Framework Directive (WFD) (EC, 2012) the proper identification and evaluation of the positive externalities of irrigation would be necessary for setting equitable pricing systems.

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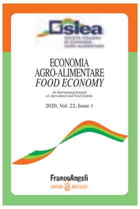

New advanced designed systems to ensure safeguard of the territory and preservation of water resources for irrigation

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Abstract

The Burana Land-Reclamation Board is an interregional water board operating in three regions and five provinces. The Burana Land-Reclamation Board operates over a land area of about 250,000 hectares between the Rivers Secchia, Panaro and Samoggia, which forms the drainage basin of the River Panaro and part of the Burana-Po di Volano, from the Tuscan-Emilian Apennines to the River Po. Its main tasks are the conservation and safeguarding of the territory, with particular attention to water resources and how they are used, ensuring rainwater drainage from urban centres, avoiding flooding but ensuring water supply for crop irrigation in the summer to combat drought. Since the last century the Burana Land-Reclamation Board has been using innovative techniques in the planning of water management schemes designed to achieve the above aims, improving the management of water resources while keeping a constant eye on protection of the environment.

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Introduction

Directive 2000/60/EC – Water Framework Directive (WFD) establishes a framework for the Community action in the field of water, pursuing ambitious objectives, namely: preventing qualitative and quantitative deterioration, improving water status and ensuring sustainable use, based on the long-term protection of the available water resources.

Coherently to these objectives, in 2000 the European Parliament established a framework for Community action in the field of water policy: The Directive 2000/60/EC. In the first article of the Directive we can read: *"The purpose of this Directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which:*

(a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;

(b) promotes sustainable water use based on a long-term protection of available water resources;

…

(e) contributes to mitigating the effects of floods and droughts".

The European Union identifies among its goals a smart, sustainable and inclusive growth, that can be pursued through the use of structural monetary funds, coordinated by the Common Strategic Framework (CSF): a general guideline document that the member states have taken into account relied on for the 2014-2020s planning activities.

Within this program the European legislation aims to promotes the competitiveness of the agricultural sector, as strictly linked to the protection and development of rural areas, as well as the improvement of competitiveness for holdings in agriculture, agri-food, forestry, fisheries and aquaculture.

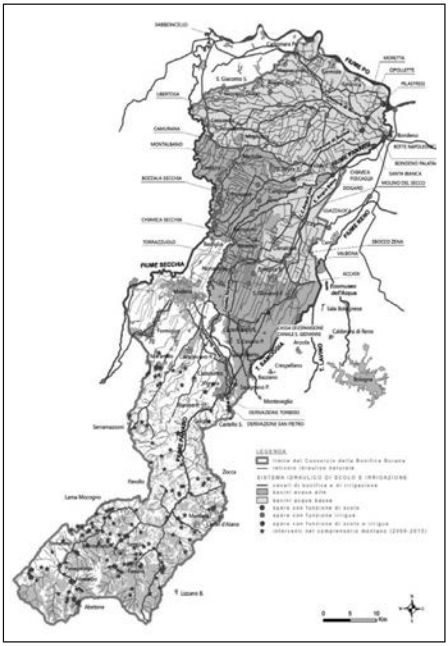
These tasks are carried on based on the importance of environmental sustainability, adaptation and mitigation of climate change, animal well-being quality production, innovation and job security.

1. Sustainable management of water

In ancient times the plain was almost entirely marshland. During the centuries, its inhabitants worked hard to reclaim and reshape the land, in order to achieve a better standard of living. Nowadays the threat of water has been transformed into opportunities by the action of all the Land-Reclamation Boards. At present, Emilia-Romagna is considered one of the richest European regions, with a remarkable balance between agriculture and industry. Burana Land-Reclamation Board contributes to the improvement of social, economic and environmental conditions.

The Burana Board is an interregional water board acting on ~~in~~ three regions and five provinces; it operates over a land district of about 250.000 hectares between the rivers Secchia and Panaro, coinciding with the drainage basin of Panaro River, from the Tuscan-Emilian Apennines to Po River. This area is one of the most fertile zone of the whole Po Plain, which is characterised by technologically advanced farming practices and strategic industrial districts. Furthermore, in this district are located several environmentally relevant wetlands and many rare species of plants, birds and animals live here. The water supply of these protected areas is guaranteed by the Board.

Figure 1 - Burana Board's District



Burana's main activities regard the conservation and safeguard of the territory, with particular attention to water resources and their use, ensuring water drainage from urban centres and farming areas and water supply throughout the area under its management to ensure irrigation and to fight drought.

Since the beginning of the century Burana Land-Reclamation Board has planned and designed modern hydraulics works, using innovative techniques, in order to improve water resources management and to be more mindful about ~~of~~ the environment.

In 2009 Burana Land-Reclamation Board received funds from the Ministry of Agricultural, Food and Forestry Policies and built a pilot pressurized irrigation system among agricultural holdings on the Diamante canal, whitin the Protected Designation of Origin (POD) area called *Basse di Vignola*, characterized by a huge production of the typical Vignola-cherries and plums.

Thanks to this micro-irrigation systems farmers use 3.250 m^3/ha/year: compared to the traditional submersion irrigation technique (the consume is more than 8.000 m^3/ha/year), it Burana Board ensures water volume saving of about 60%.

As a matter of fact all of the 13 agricultural holdings involved into the sperimental project and the others, which have joined later, have replaced the traditional surface irrigation system with this innovative and advanced system, in order to save money and increase productions.

Figure 2 - Diamante Plant – pumping station and pipe lines

1.1. *Water efficiency for irrigation – A New innovative project to be carried out*

In 2016-2017 Burana Land-Reclamation Board took part in an european open call to receive funds within the *European Network for Rural Development*.

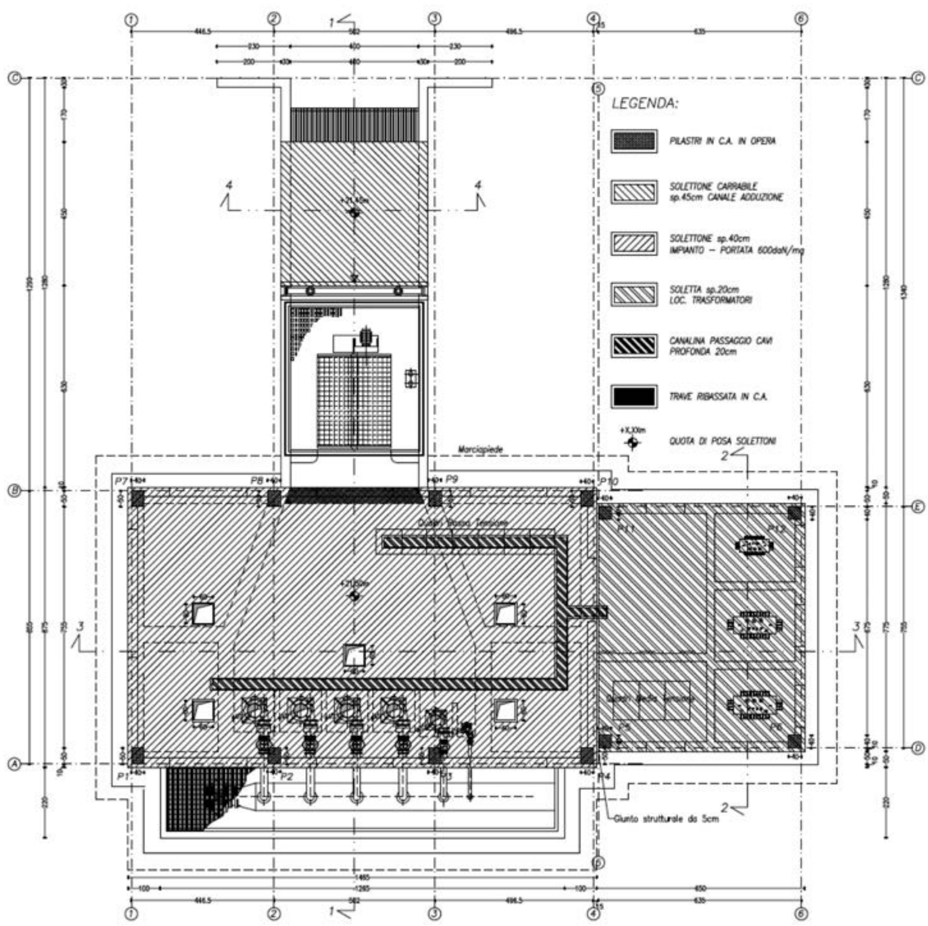
Within Burana's Plain sub-District, consisting of about 70.000 hectars, it was detected an area of about 700 hectars, characterized by a high agronomic value, where are cultivated some of the most precious-crops, such as pears, peaches, vineyards and melons.

The project is a new, innovative and technologically advanced irrigation system that includes the building of a new irrigation plant, to deliver pressurized irrigation water.

The plant is composed of:

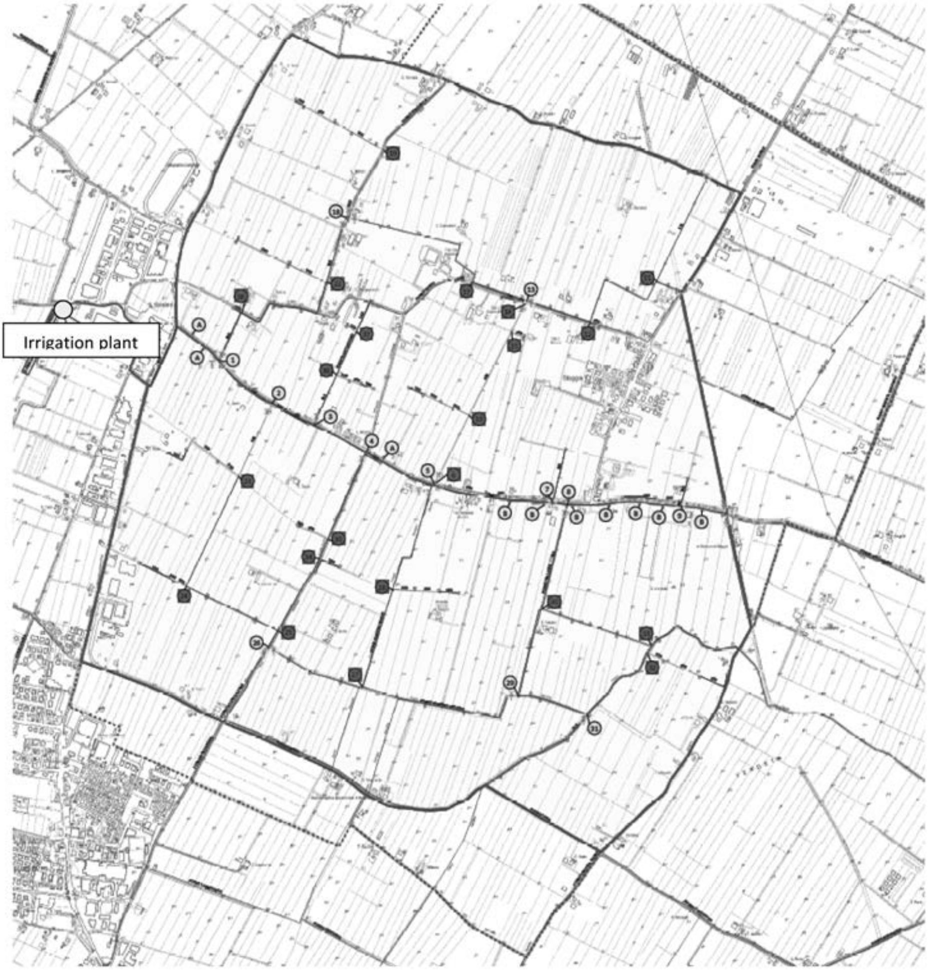
- A pumping station, with a maximum discharge of 700 l/sec. and a pressure of 7,5 bars. There are 6 vertical axes centrifugal pumps: 4 pumps of 175 l/sec., 1 pump of 100 l/sec. to control water stream and 1 pilot pump of 20 l/sec. Energy consumption is about 800 kW in total.

Figure 3 - Staggia Plant – layout pumping station



- An undergorund irrigation network, made of about 26 km of pipes (7.620 meters are made of cast iron and 17.900 meters are made of PVC) with a diameter ranging from 160 mm to 800 mm and 124 irrigation hydrants.

Figure 4 - Staggia Plant – irrigation pipe network



This advanced pressurized irrigation system makes it possible to **save a medium annual water volume amount, needed for irrigation, of about 41%** and about **38.800 kW of energy consumed** by irrigation plants.

In order to quantify water saving it was compared the total water volume per year: in one case it was considered the volume delivered to crops using open channels and in the other case the volume delivered through underground pipe network.

1.2. *Water Balance*

Croops need a volume of water which is lower than the total amount of water Burana Board uplifts from natural rivers, since during delivering activities, due to the losses during the transition through ~~to~~ open channels, a huge amount of water is lost. Below it is shown how to compute water losses, according to some parameters related to this phenomenon, and how to compare data before and after the construction of the new innovative irrigation plant described in par. 2.1.

a) Before Analysis

- **Crops need**: The total amount of water needed per year for all areas is calculated multuplying for each crop its cultivated areas by crops need specific value. Crops' water need data are estimated in partnership with Canale Emiliano Romagnolo Board (CER), in spite of cultivated areas are discovered by AGREA database.

Crops	**Areas (ha)**	**Crops need (m^3/ha/year)**	**Water volume needs for crops (m^3/year)**
Sugar Beet	40,83	1.496	61.085,08
Onion	0,07	2.853	203,79
Watermelon	10,08	2.455	24.747,10
Alfa Alfa	112,36	1.178	132.361,79
Maize	71,78	2.188	157.059,36
Melon	5,57	1.521	8.467,08
Potato	1,55	1.973	3.049,69
Pear	54,16	1.701	92.120,18
Peach	0,55	747	407,35
Soy	12,85	1.343	17.251,20
Grapevine	106,45	1.276	135.825,49
	416,23	**Total**	**632.578,12**

- **Efficiency of irrigation systems**: according to DGR n. 1415/2016 "Guidelines to quantify water volumes for irrigation" (Emilia-Romagna, 2016), depending on the irrigation systems used by agricoltural holdings on the considered area, it is selected an irrigation efficiency index of 0,7.

Parameters	**Water volume needs for crops (m^3/year)**
1 - Crops need	632.578,12
Efficiency index	0,7
2 - Crops need due to efficiency of irrigation systems (1/index)	**903.683,03**

- **Infiltration losses**: to compute infiltration losses, in 2013, Burana Board studied how much water goaes across the ground from canals to underground water. The infiltration coefficient for this area is 0,34 $m^3/m^2/d$ (Raimondi, 2013).

Then, to calculate total water infiltration volume during an irrigation season, it has been considered these additional parameters:

- Open canals lenght which deliver water to the study area;
- Irrigated water level into these canals;
- Irrigation season period.

This table contains all the data described above.

Canal name	**Lenght (m)**	**Hydraulic perimeter (m)**	**Days/ year**	**Coeff. ($m^3/m^2/d$)**	**Water infiltration volume (m^3)**
Fosso 1° ordine – (Gallarana)	3.400	1,0	120	0,34	138.720
Fosso 1° ordine – (Gesso)	3.840	1,0	120	0,34	156.672
Fosso 2° ordine (Scorticacane)	1.270	0,9	100	0,34	38.862
Fosso 2° ordine (Ginepro Nuovo)	1.290	0,9	100	0,34	39.474
Fosso 2° ordine (Ginepro Vecchio)	1.300	0,9	100	0,34	39.780
Fosso 2° ordine – (Valluzze)	815	0,9	100	0,34	24.939
Fosso 2° ordine – (Fanin)	550	0,9	100	0,34	16.830
Fosso 2° ordine – (Bosco)	2.850	0,9	100	0,34	87.210
Fosso 2° ordine – (Forcirola)	2.460	0,9	100	0,34	75.276
Fosso 2° ordine – (S. Antonio)	560	0,9	100	0,34	17.136
Total					**634.899**

- **Evaporation losses**: evaporation losses can be quantified as 1,5% of all water delivered thanks to open canals; this value emerges from the study made by CER in 1993 "L'evaporazione dalla superficie del Canale Emiliano Romagnolo" – Edagricole (Romagnolo, 1994).

So, using all parameters and data described above, in next table it is shown how much water (expressed in cubic metres per year) has to be delivered to the study area.

Parameters	**Water volume (m^3/year)**
1 - Crops need	632.578,12
2 - Crops need due to efficiency of irrigation systems	903.683,03
3 - Infiltration losses	634.899
Total (2+3)	**1.538.582,03**
4 - Evaporation losses (1,5%)	23.078,73
Total volume (2+3+4)	**1.561.660,76**

Comparing total volume with the crops' need, water losses are about 60%.

B) After Analysis

- **Crops' need**: The total water need per year for all areas is calculated moltiplying for each crop its cultivated areas by the crops' need specific value. Crops' need data are estimated in partnership with Canale Emiliano Romagnolo Board (CER), in spite of cultivated areas are discovered by AGREA database.

Crops	**Areas (ha)**	**Crops need (m^3/ha/year)**	**Water volume needs for crops (m^3/year)**
Sugar Beet	40,83	1.496	61.085,08
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Grapevine	106,45	1.276	135.825,49
	416,23	**Total**	**632.578,12**

- **Efficiency of irrigation systems**: according to DGR n. 1415/2016 "Guidelines to quantify water volumes for irrigation" (Emilia-Romagna, 2016), depending on irrigation systems used by agricoltural holdings on the studing area, it is selected an irrigation efficiency index of 0,7.

Parameters	**Water volume (m^3/year)**
Crops need	632 578,12
Efficiency index	0,7
Crops need due to efficiency of irrigation systems (1/index)	**903.683,03**

- **Infiltration losses**: No losses.
- **Evaporation losses**: No losses.

Utilizing all parameters and data mentioned above, in next table it is shown how much water(expressed in cubic metres per year) has to be delivered to the study area. After the construction of the new irrigation plant, the only water loss is due to the efficiency of the agricoultural holdings irrigation systems. e can therefore affirm that the new plant can save the following volume percentage of water:

$$V_{tot\ saved}(\%) = (1 - 903.683{,}03/1.561.660{,}76)\% \approx \mathbf{41\%}$$

Last but not least, if agricoltural holdings decide to improve their irrigation systems with new advanced ones, like microirrigation, then the efficiency index would increase to 0,9, and water saving wil be:

Parameters	**Water volume (m^3/year)**
Crops need	632.578,12
Efficiency index	0,9
Crops need due to efficiency of irrigation systems	**702.864,57**

$$V_{tot\ saved}(\%) = (1 - 702.864{,}57/1.561.660{,}76)\% \approx \mathbf{55\%}$$

2. Climate change and environmental issue related to irrigation

The design and innovation activities led by Burana Board on its infrastructure aim to ensure a the correct management of the water resource for irrigation, and the correct development for a greater competitiveness of the agricultural sector, together with the protection of rural areas, agri-food, forestry, fisheries and aquaculture businesses. These goals are achieved while taking into account criteria such as environmental sustainability, reduction of the effetcts on climate change, quality of production, innovation and job security.

In last fifteen years Burana technicians has had to face five unexpected water crises, with fluctuating climatic conditions characterized by poor railfalls and snowfalls during autumn and winter, very high temperatures and evaporation from soils and vegetation during summer, as well as very low water levels into Po river from June to September.

2.1. *A land affected by drought – an example of ecological and economic losses*

The lack of water resources could create damages on local agricultural activities, above all to tree crops like pears, peaches and vineyards. However, besides the economic damage, drought induces other chain reactions on the environment, which are not immediately quantifiable in monetary terms, but on the long term they will be the cause of a deterioration of the ecosystems first, and human health after.

Drought influences the quality of underground waters too, as a matter of fact in case of a not sufficient volume of rainfalls and melted snow after winter, the recharging of aquifers can be compromised and their hydrological structure modified untill irreversible conditions.

Another phenomenon which must not be overlooked, that is becoming increasingly in recent years, is the drying of the soils surface layer.

The lack of adequate rainfalls during autumn and winter seasons (when we talk about adequate rainfalls we have to think about steady rainfall events, not anomalous meteorological events), followed by a sudden increase in temperatures and evapotranspiration, usually creates strong stress conditions in soils. This could be the cause of a huge lost in organic, chemical and physical properties, the ones that in normal conditions characterize the Po river Valley for being one of the most fertile zone in Europe.

In recent years the water catchment area of the Panaro river has been affected by increasingly drought phenomena, during which Burana was ordered to reduce the volume of water resource which can be drawn, or even to suspend its uplift, in order to guarantee the respect of a condition of minimum outflow into the river;. This was needful to the maintenance of the natural ecological integrity. As a matter of fact nowadays we are observing a dangerous change of the Appennine watercourses hydraulic conditions: they are all becoming torrential courses, featuring very critical flows during flood events and almost dry riverbed during the summer.

One of the agricoltural areas which are most at risk of drought, under Burana Board management, in which during the coming years it could be possible to stop irrigation in case of a lack of water, is located surrounded Nonantola, Ravarino and Sant'Agata towns. In these territories there are crops of high agronomic value, like pears, peaches, vineyards, melons and plums; here are also cultivated lot of precious field crops as sugar beet, alfa alfa, maize and some vegetables, as tomato. In 2017 Burana technicians had to close irrigation for some field crops, in order to avoid more damages to high agronomic crops.

In next table we can find a lot of crops, it is possible to find in an irrigation subdistrict close to Nonantola town; for each crops we can find cultivated area, specific water need for year and total water need for year for all areas.

Crops	**Areas (ha)**	**Crops need (m^3/ha/year)**	**Water volume needs for crops (m^3/year)**
Sugar Beet	140,00	1.620	226.800
Alfa Alfa	700,00	1.320	924.000
Fodder	35,00	1.320	46.200
Maize	215,00	2.470	531.049
Apple	3,00	2.900	8.700
Vegetable	17,00	2.000	34.000
Pear	180,00	2.900	522.000
Peach	1,00	1.490	1.490
Tomato	20,00	2.000	40.000
Soy	77,00	1.781	137.137
Plum	21,00	1.490	31.290
Grapevine	140,00	1.303	182.420
	1.549	**Total**	**2.685.086**

Using these data, it is possible to quantify economic losses caused by drought and a lack of water. At the same time we can compute a productivity index for water use. All the analysis are made for two crops, selected for the following reasons:

- Maize: it is one of the most water-demanding crop and there are a lot of cultivated areas; moreover in case of scarcity, this colture is one of the first deprived of water;

- Tomato: there are not so much areas cultivated with tomatoes, but this is one of the most water-demanding crop and it suffers more than the others the lack of water.

After 2017 drought, Burana technicians, calculated that the profit for maize per year, for a standard irrigation season, is 1.218,46 €/hectars; so into the irrigation subdistrict close to Nonantola town, for 215 hectars of maize, the total profit is more than 260.000 € per year. Therefore, if a reduction of resource for agricolture occours, it could be the cause of hundreds of thousands euros losses on an area of less more than 200 hectars.

After a SIM project meeting at the Ministry of Agricultural, Food and Forestry Policies, we decided to compare profit value, calculated as shown above, with an associated hypotetical profit value simulated using economic water productivity data for maize, calculated by the team of Prof. Ing. Marco Mancini during SIM project researches (Mancini & Menenti, Waterjpi, 2019) (Mancini, SIM, 2019). The index is 0,39 € for each cubic meter delivered to maize (Mancini & Menenti, SIM: Smart Irrigation from Soil Moisture Forecast using Satellite and Hydro Meteo Modelling, report, 2019); consequently moltipliyng this index for total water volume needs for maize (513.049 m^3/year) it can be found that the hypotetical profit is about 210.000 €.

Using the same calculation model for tomatoes, which index is 2,44 €/m^3, total economic losses, in case of resource scarsity, are about 100.000 € for only 20 hectars.

Lastly, after the economic analysis described in this paragraph, it is possible to understand why it will be so important for Burana Board to reshape irrigation systems and to design new advanced irrigation structures; one of this enterprise is the project described in next paragraph.

The enterprise of a new path for water resources from Po River

In order to reduce the increasing risks due to drought into Panaro river Basin, Burana Board has begun a campaign of hydraulic surveys and the evaluation of further water uplifting from the Canale Emiliano Romagnolo (CER). CER takes the resource from Po river close to Ferrara, so it will be possible to uplift it untill Modena, going to rescue Nonantola irrigation sub-district, increasingly hit by the crises due to the lack of water for irrigation.

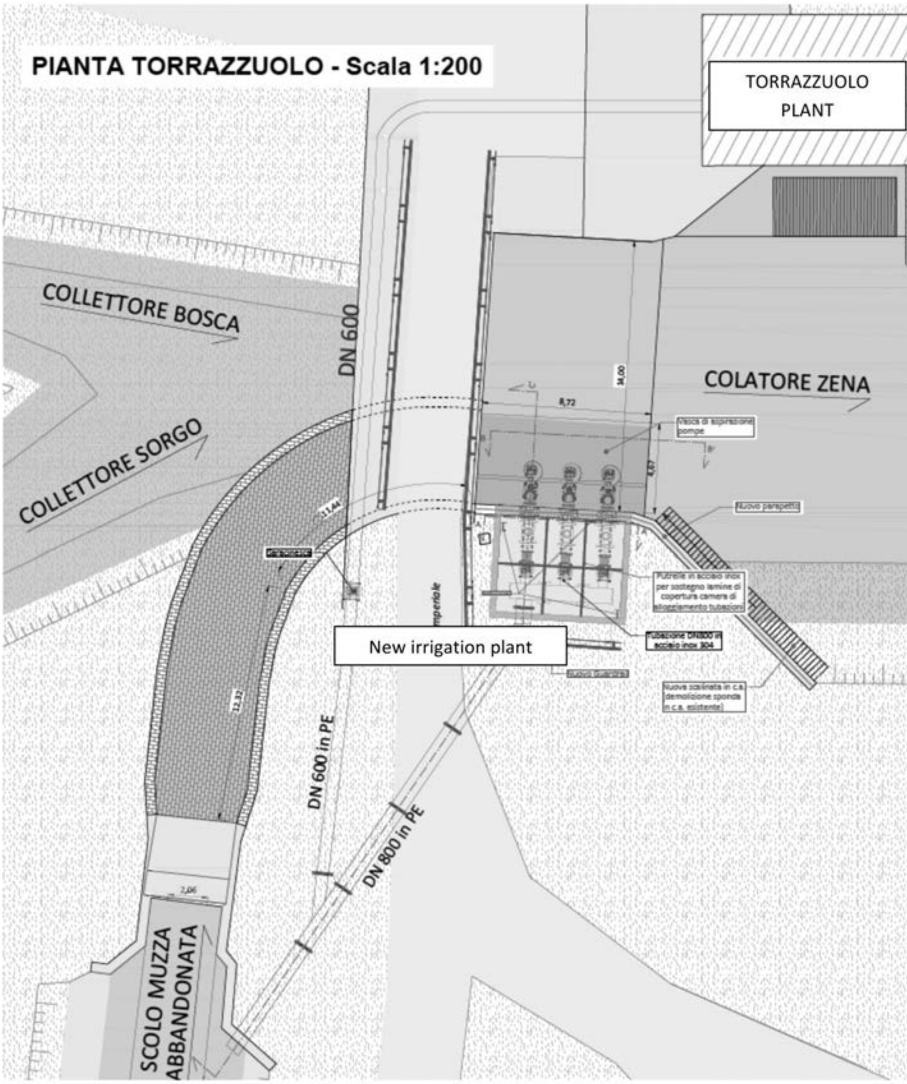
Figure 5 - Project to be carried out to increase water supply into irrigation sub-district called Nonantola

The project is made of several works, thank to Burana Board it can achieve its purposes and perform its duties:

A) Building a new pumping station, called Sussidiario Torrazzuolo

After the check of pumps layout it was clear the impossibility to increase irrigation flow up to Nonantola sub-district using only the old pumping station; therefore Burana's engineers designed this new station equipped with n. 3 pumps with the power of 400 l/s each (2 operating pumps and 1 spare pump). The water is uplifted into a pipe and then discharged into Muzza Abbandonata canal, to starts its journey towards Modena.

Figure 6 - Layout Sussidiario Torrazzuolo Plant



B) Building two new pumping hydraulic works: Redù and Principe

To uplift water from areas lower than others, untill territories close to Modena, it's necessary to build two new hydraulic works (called Redù and Principe) equipped with two pumps of 380 l/s each and two sluice gates to stop downstream and storage water between the hydraulics works designed.

Moreover, thanks to the opportunity of setting sluice gates, it is possible to control the discharge through the hydraulic works; so in case of a low rainfall event, which could be the cause of a not huge flow into canals, Burana thecnicians can store a volume of water, saving it from uncontrolled discharge and storaging into the canal. This makes it possible to reduce consumption of energy too.

Figure 7 - Redù hydraulic pumping work – front view

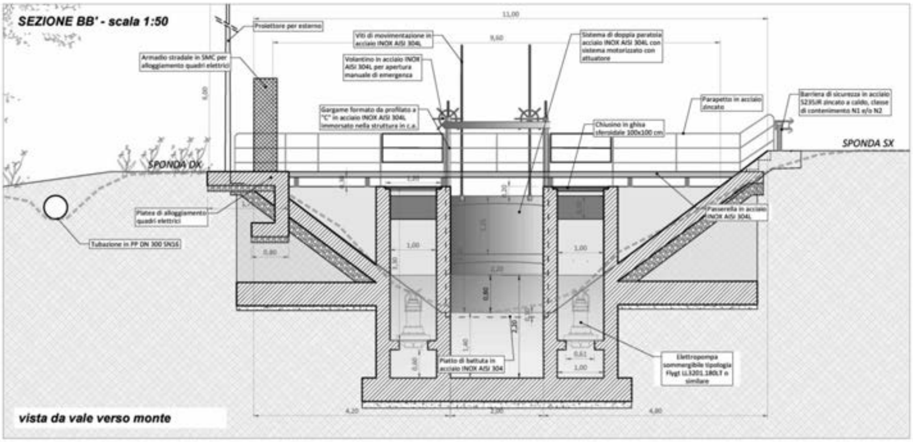
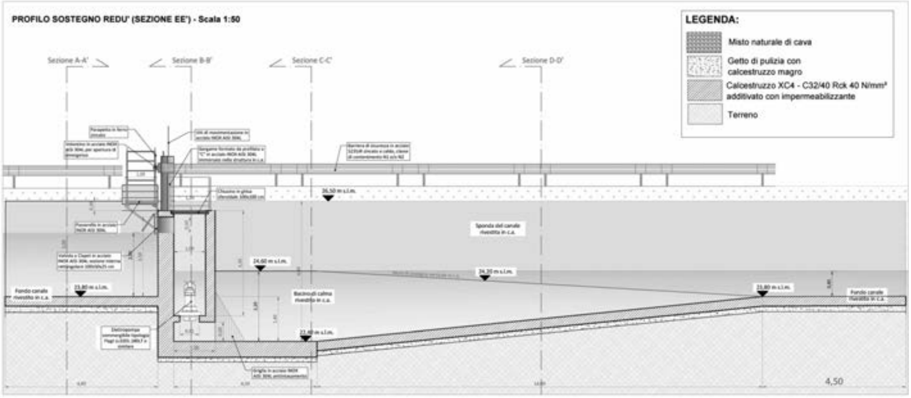


Figure 8 - Redù hydraulic pumping work – side section view



C) Laying PEAD pipe to carry out water from irrigation main canal to irrigation sub-district

At last, in order to make possible the irrigation of Nonantola sub-district, it's being built a PEAD pipe to connect the main irrigation canal, the Gaggio-Panzano, to the first irrigation canal into Nonantola sub-district, called Canaletta A-B; then it will be possible to deliver water resource even in case of a strong drought. To control flow through the pipe, a sluice gate will be put on its entrance, which can be controlled and set by Burana technicians, depending on the irrigation needs.

Figure 9 - Hydraulic connection between Gaggio-Panzano canal and Canaletta A-B canal – layout PEAD pipe

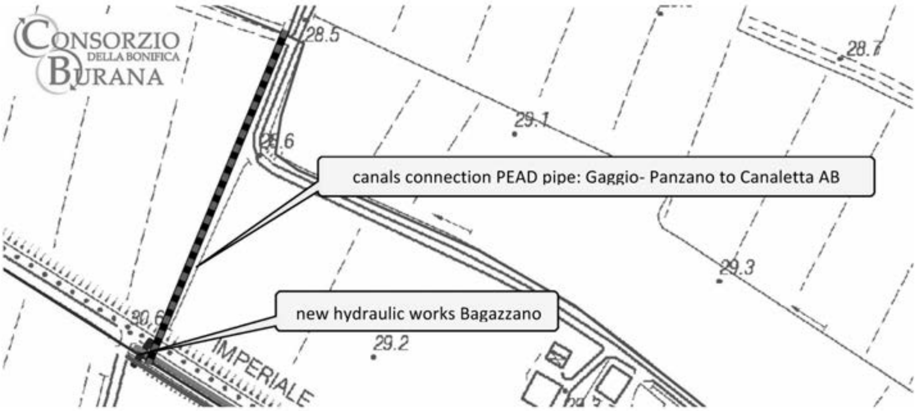
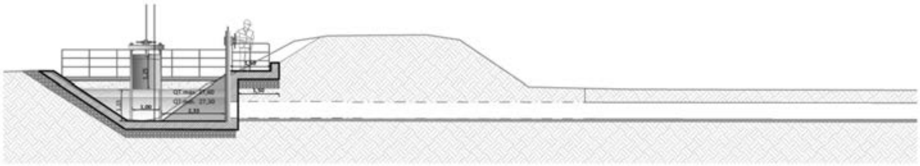


Figure 10 - Hydraulic connection between Gaggio-Panzano canal and Canaletta A-B canal – section view PEAD pipe



3. Conclusion

The projects described in this article, which use modern irrigation technologies and materials, are the clear proof of the reduction of water consumption in irrigation and of the optimization of the surface water resources for "top grade specialization" farms gathered together.

Moreover, thanks to these new works it is possible to provide indirect benefits to the environment, such as: fighting against drought, increasing the value of ecosystems and natural water habitats.

All the projects are repeatable in other territories, so it will be useful to encourage their implementation in the areas that are lacking in available surface water resources and where a huge use of surface water and groundwater can get ecosystem qualitative status worse. Moreover, an improvement in water management systems can be quantified immediately in a financial return of hundreds of thousands euros per year for each agricoltural holdings, as discussed in par. 3.1.

In conclusion, in Chapter 3, we underlined the opportunity to use a part of flood waters, setting sluice gates. In such a way we can storage a volume of water, which is bounded between an hydraulic works and another, transforming the threat of a flood into a resource for agricolture, environment and ecosystems.

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