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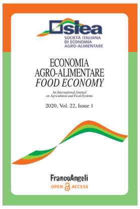

Water management: A way to achieve a more efficient irrigation system

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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.

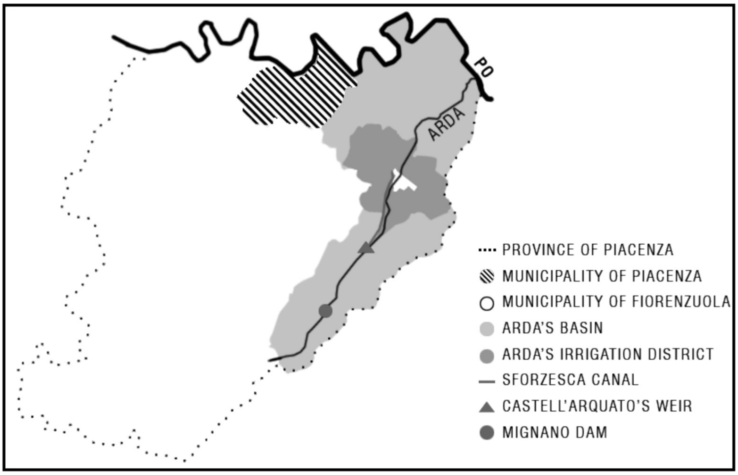
1. Contextualization

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

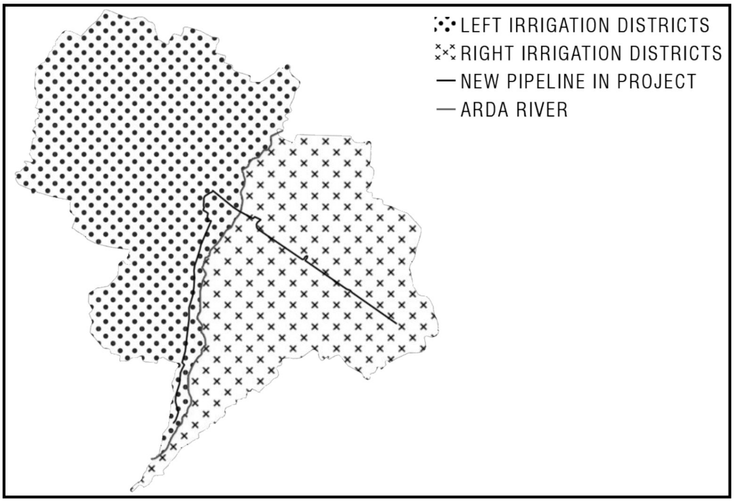
Figure 2 - Context of the water system



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).

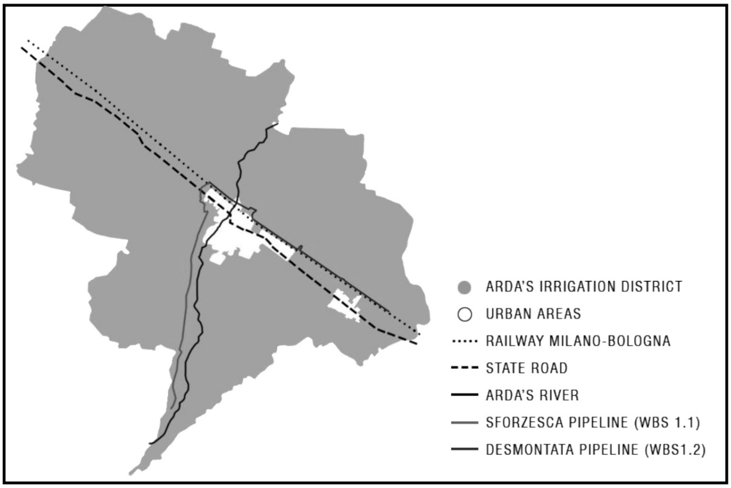
In this context, the aim of this article is to review several issues of Arda's irrigation network. The most critical one is the long distance between the intake structure (the Castell'Arquato weir) and the two main distribution canals, the Sforzesca canal on the left side and the main canal on the right 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

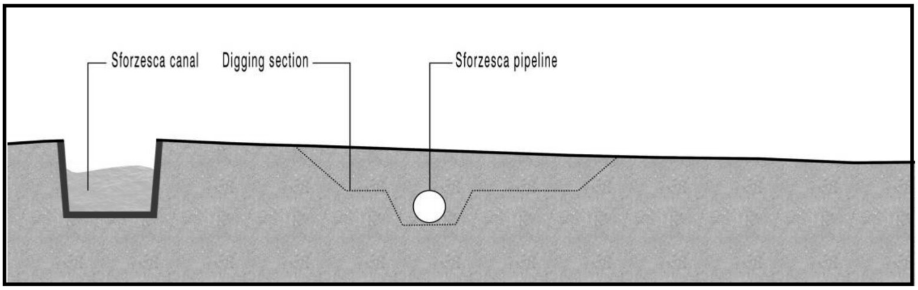


Thus, in the scope of the caption of water, the project intends to 're-functionalize' the intake network to the service of the irrigated lands. The chosen alternative was to introduce new adduction pipes running alongside the Sforzesca canal, ensuring the water volume that arrives in determinate irrigation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

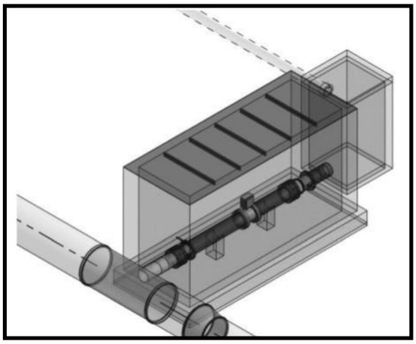
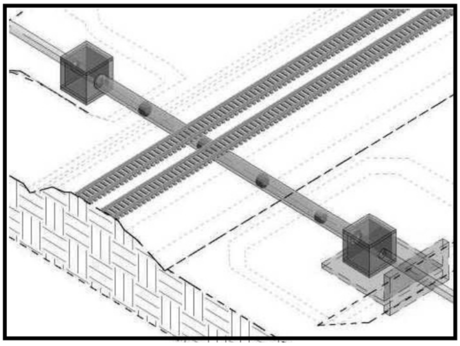
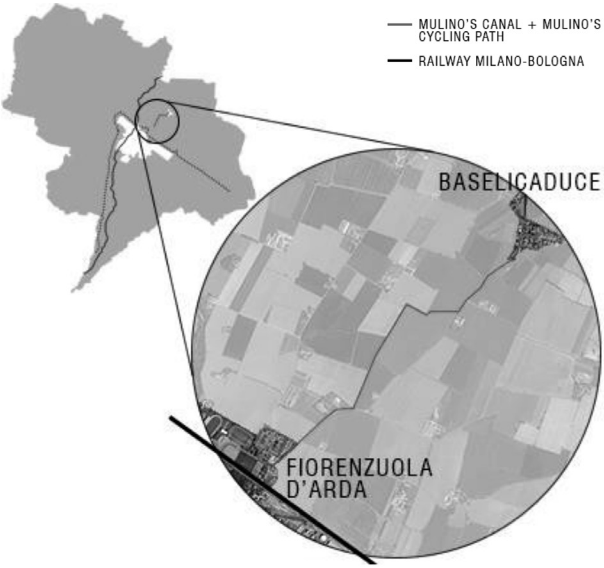


Figure 7 - Intersection of the GRP pipeline with the railway MI-BO, in WBS 1.1 (Revit MEP - BIM. Simulation)



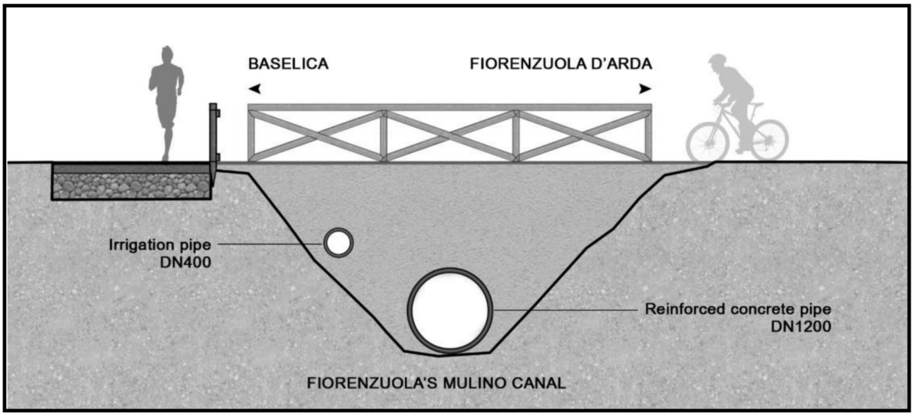
Finally, the wastewater recovery was nominated WBS 4. This section of the project predicts investments for the use of treated wastewater for irrigation, instead of collecting the resource from superficial or underground sources. The proposed actions in this phase include the recovery of wastewater taken 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

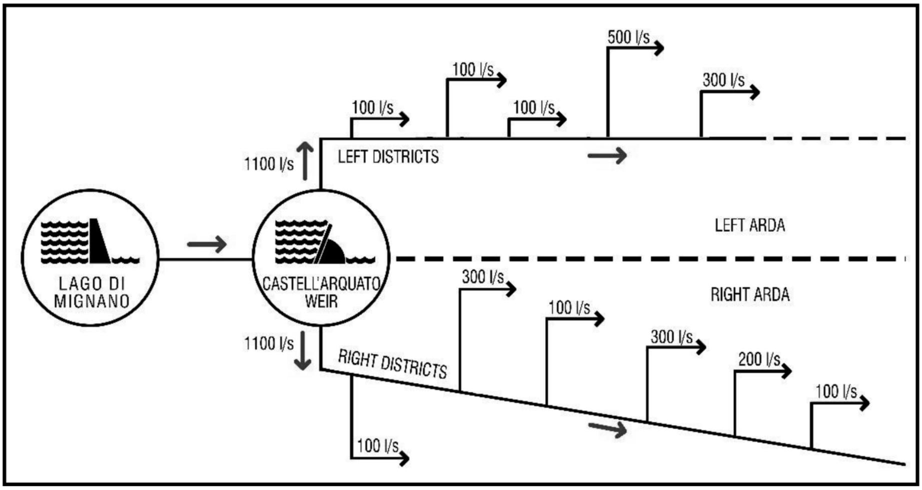


3. Results

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



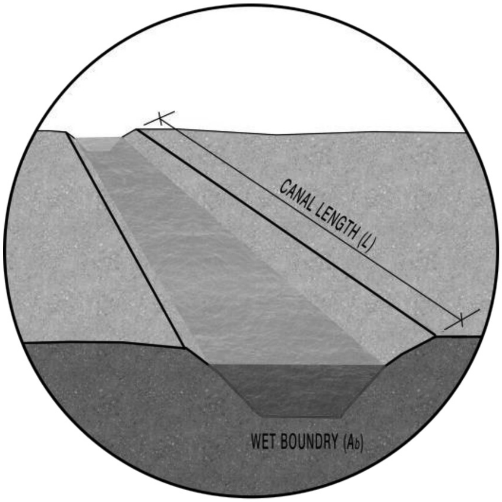
The water loss of a canal depends on the type of material that it is made, its length and how this distribution network is managed.

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

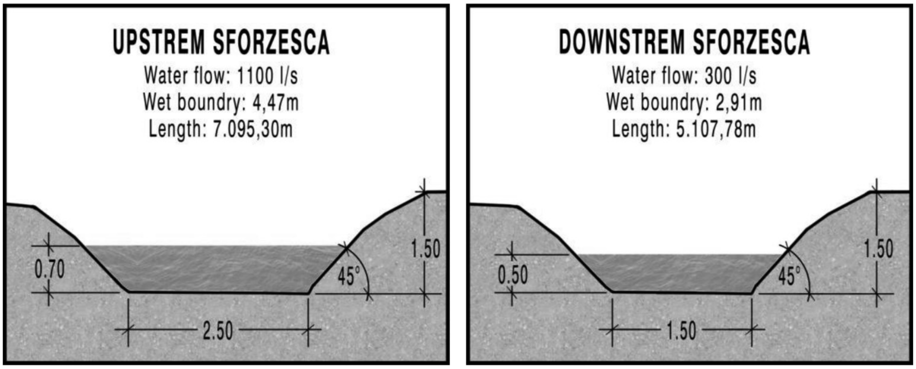
Soil Typology	**New Canals**	**Old Canals**
Clay – Silty (impermeable)	76	107
Clay – Sandy alternated with clay – silty	152	228
Clay – Sandy	228	305
Sand – Clayey	305	457
Sandy	457	533
Sandy and gravel	609	762
Gravel	762	914
Gravel (very permeable)	914	1.829

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 $\boldsymbol{L}$ is the canal's length (m), $\boldsymbol{Cb}$ is the canal's wet boundary (m), $\boldsymbol{C}$ is the daily loss coefficient of the wet area (l/m²/d) and $\boldsymbol{d}$ 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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