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MODFaBe – Modelling individual farmers behaviours in Coupled Human Natural Systems under changing climate and society

Project no. 832464

Case study: The Muzza system characterization and management

Deliverable 2.3 (D2.3)

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Content of this report	The report characterizes the Muzza Bassa Lodigiana irrigation district from a multifunctional and management perspective. The report includes: (i) an overview of the Muzza system location and extension, hydrogeological and hydraulic nature, and multifunctional water use, and (ii) the management role of the Muzza Bassa Lodigiana Reclamation Consortium. Data could be used in any WP.
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Andrea Castelletti	Review	May. 14, 2021
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1. Introduction

This Deliverable (D2.3) "Case study: The Muzza system characterization and management" is part of Work Package 2 (WP2) "Climate change constraints affecting the Muzza system". The main objective of this work package is to provide a synthesis of the main climate change impacts and risks affecting agricultural activity in the Muzza system by addressing the gap between water scarcity and water demand scenarios and exploring its affection in the water-energy-food nexus. Consequently, D2.3 aims to characterize the Muzza system by describing this socio-ecological system from socioeconomic and environmental perspectives, while deepening on the main issues conditioning the present and the future of irrigation, water management, and climate change nexus.

The report is a useful consultation tool for framing the case study of the project. Due to its descriptive nature, the report is an attribute for all the work packages. Consequently, it sets a special attribute for WP3 ("Vulnerability to climate-change-related risks at farm level") and associated tasks 3.1 and 3.2 which will identify main geographical and socioeconomic factors explaining farm vulnerability in terms of climate change. Moreover, the report will also benefit WP4 ("Key behavioural rules from individual farmer' perception and key stakeholders' decision") and associated tasks 4.1 and 4.2 focused on data collection about climate change perception from Muzza system managers and farmers. In addition, D2.3 will also set the baseline for WP5 ("Behavioural models of individual farmers and key stakeholders using artificial intelligence and machine learning technique") by checking the relevance of the geographical context when identifying new utilities functions and multiobjective problems in the DistriLake model. Finally, the report will be used in WP6 ("Interventions") to elucidate which actions can be promoted by decision-makers to harmonize farmers' behaviour and socio-ecological complexity.

As a state-of-the-art report mainly based on technical documents, it can be used for consultation by utility managers and operators, local government officials and planners, public interest groups, and end-users, like farmers. Starting with an overview of the project (Section 2), the report is structured in two parts:

- Part I: overview of the Muzza system location and extension, hydrogeological and hydraulic nature, and multifunctional water use.
- Part II: (ii) the management role of the Muzza Bassa Lodigiana Reclamation Consortium.

2. MODFABE project overview

Worldwide water consumption continues to grow, and it is estimated that by the year 2030, more than 160% of the total water volume worldwide will be needed to satisfy global water requirements (Azhoni *et al.* 2018). Moreover, with available water resources diminishing in quantity and quality and increases in the range of water uses in competing sectors, water scarcity has become a critical issue (Fitton *et al.* 2019). Agriculture is the sector most affected by water scarcity as it accounts for 70% of global freshwater withdrawals and more than 90% of the consumption (including non- conventional water resources) (Ricart & Rico 2019). Consequently, irrigation systems are under pressure to produce more food with lower supplies of water (Levidow *et al.* 2014).

Climate change impacts such as high temperature, reduced rainfall, and increased frequency of extreme weather events will add new threats to irrigation systems and will compound existing human pressures through changes to hydrological processes and socio-ecosystem interactions (Reid *et al.* 2019). The mismatch between water supply and water demand in different temporal and geographical scales and according to different climate change scenarios calls for new approaches (Chen *et al.* 2018). Decision-makers need information on how climate change impacts affect water resources for all sectors, particularly agriculture, especially in the most drought-prone, water scarcity or surplus, and water competing users (Hunink *et al*. 2019).

Climate change and water resources management represent two necessarily interdisciplinary topics, in which natural and social sciences must be integrated (Escribano-Francés *et al*. 2017). In the last decades, the shift to address the integrated management of water resources from a technocratic ''top-down'' to a more integrated ''bottom-up'' and participatory approach was motivated by the awareness that water challenges are complex, requiring integrated solutions and a socially legitimated planning process (Fritsch & Benson 2019). That is, assuming water flows as physical, social, political, and symbolic matters, it is necessary to entwining these domains in specific configurations in which water users, managers, and decision-makers could be directly involved (Ricart 2020).

Social learning is considered an important issue in achieving this goal of improving water management and decision-making processes (Johannessen *et al.* 2019). It refers to processes that involve active deliberation and engagement by end-users, managers, and key stakeholders with confronted water demands, which can lead to a new understanding or shared meaning to (1) increase adaptive capacity, (2) build trust and collaborative problem solving, and (3) ensure better co-working between stakeholders, who differently understand features of socio-environmental issues in climate change scenarios (Eriksson *et al.* 2019). The social perception of climate change is fundamental for two important reasons: first, because it constitutes a key component of the socio-political context within which policy-makers exercise their decisions in socio-ecological systems. The second reason is more direct: the process of mitigation and adaptation to climate change requires behaviour transformation and attitude change from those who each day make individual and participate in collective choices that have a huge impact on the planet climate balance (Antronico *et al.* 2020).

Water supply and demand nexus was generally overlooked in the modelling literature by mostly focusing on understanding the natural processes only while assuming one or a few scenarios of human actions generally treated as fixed boundary conditions (Giuliani *et al.* 2016). However, this unilateral perspective might no longer be appropriate if social-learning must be achieved, and a paradigm shift is required to put humans in the modelling loop (Wada *et al.* 2017). Modelling techniques have been recognized, also in social sciences, as effective computational techniques to simulate social influence processes in Coupled Human-Nature Systems (CHNS) from interactions within a community of individual agents (van Bruggen *et al.* 2019). Consequently, modelling human behaviour can be used as a safe laboratory for policy experimentation, testing the effectiveness of strategies and policy measures on climate change by learning from human experience. Furthermore, modelling frameworks must find ways to glue the anthropogenic sphere with the hydrological systems such that the feedback between human activities and hydrological cycles can be addressed internally. Agent-Based Models (ABM) can accomplish this task by considering each agent as an active decision-maker who lives in the common environment and interacts within (Kremmydas *et al.* 2018). By modelling agents individually, the full effect of attribute and behaviour diversity of agents, which together give rise to the behaviour of a system, can be observed. The application of an ABM ensures not only the feedback between social (farmers' agents) and physical (water resources) environments but also the social network based on agents' interactions.

How farmers perceive climate change uncertainties, potential impacts, and risks is important because (Gardezi & Arbuckle 2020): 1) Local experience can be shared and compared and this would be useful to identify common patterns and individual strategies (to be transferred to policy-makers), and 2) assess the perception and effectiveness of climate change responses is the first step towards adaptation. Farmers are key constituents in the social-learning process of understanding both climate change impacts on food and water systems and how best to mitigate and adapt to these impacts (Soubry *et al.* 2020). Farmers develop their activity supporting the complexity of interrelated nature and human systems characterized by political, economic, institutional, cultural, and biophysical conditions (Abid *et al.* 2016). Accordingly, personal experience, local knowledge, and social-learning exchange between farmers and managers may help to promote mutual understanding and to reduce agricultural systems vulnerability. Besides, this could override political barriers to action on climate change and promote an integrated response to a shared problem (Marquart-Pyatt *et al.* 2014): How to ensure food and water security while addressing climate change impacts and risk management in a CHNS?

Modelling human behaviour, however, is rather a non-trivial task: human behaviour is well recognized as a complex non-linear, multi-variate process due to the high heterogeneity and uncertainties in human cognition and decision-making processes. The MODFABE project aims to increase the robustness of decision-making processes in CHNS by modelling farmers' perception and adaptation capacity to climate change. Departing from an existing very basic behavioural model (DistriLake) applied to the management of water supply and demand in the Lake Como to balance shoreline floods and irrigation deficit downstream (Li 2016), the MODFABE project aims to integrate observational data (farmers' perception) into the simulation model to increase the rationality of farmers' interventions in the decision-making processes considering multiple competing purposes and a multiobjective context. The updated behaviour model will contribute to characterize the water supply and demand side of the Muzza system – and its irrigation district as a case study– as one of the largest agricultural areas in northern Italy. MODFABE will offer "what-if" decision support functions to investigate new utility functions, optimization problems, and risk reduction options in the demonstration case study. This local context is a test to the understanding of the driving-factors affecting farmers' perception regarding climate change impacts and how their adaptation capacity affects the management of the CHNS. Results could be used to reformulate policy recommendations to better respond to climate change by considering the preferences shift toward a new equilibrium in decision-making processes to reduce the frequency of unsatisfactory system states (Mason *et al.* 2018).

A twofold question in today's climate change adaptation research will be addressed:

- Could behaviour modelling help farmers to promote actions and anticipate decisions to better adapt to climate change and become less vulnerable?

- Could social-learning from farmers' climate change adaptation capacity provide new social scenarios able to increase model robustness when addressing decision-making processes?

Both questions endeavour to connect climate change adaptation, a macro-level issue, with the behaviour and social learning from farmers and key stakeholders, a micro-level issue. The project also considers a systemic (water resources supply and demand) and stakeholder-centred (farmers, managers, and decision-makers) approach and seeks to collaboratively frame the issue of climate change by co-producing solution-oriented knowledge at the local scale from farmers' feedback. Results could be used to inform managers and decision-makers about the effectiveness of different types of interventions and to reformulate policies to better respond to climate change by considering the preferences shift toward a new equilibrium in decision-making processes to reduce the frequency of unsatisfactory system states (Mason *et al.* 2018). Furthermore, MODFABE will contribute to strengthening the role of farmers' perception of climate change impacts, actions, and barriers when planning interventions by highlighting the nexus between climate services and modelling. Consequently, managers and decision-makers will be empowered to perform climate perception proofs and adaptive policies to increase the robustness of the management of CHNS.

3. The Muzza Bassa Lodigiana irrigation district

Key messages

- ✓ *The Muzza district extends over more than 700 km^2 and 69 municipalities of the provinces of Lodi, Milan, and Cremona.*
- ✓ *The hydrographic system is characterized by a very dense irrigation-hydraulic network which develops for a total of about 3,600 km.*
- ✓ *The Muzza canal face with multiple functions: irrigation and industrial supply, energy production, recreation and tourism, navigation, environment, and flood control.*

3.1 Location and extension

The Muzza Bassa Lodigiana irrigation district is located in the Lombardy region, connected to the Lake Como regulation system and the Po River basin (Figure 1), the widest river basin in Italy by covering an area of about 71,000 km^2). Furthermore, the Po river is also the longest one with 652 km from its source in the Cottian Alps to its mouth in the Adriatic Sea, and the one with the highest discharge (yearly average of 1,540 m^3/s, Vezzoli *et al.* 2015).

The Muzza district extends southward from Cassano d'Adda and it has well defined hydrogeological borders, represented by the Adda, Po, and Lambro rivers (respectively east, south, and west) while to the north it borders with first stretch of the Muzza canal, that coincides with the pre-existent *Addetta* stream, a natural branch of the Adda river.

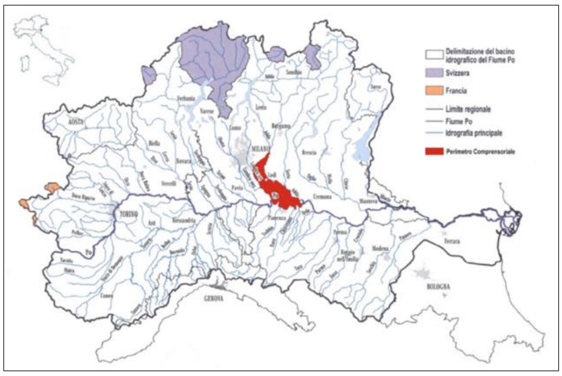

Figure 1. The Muzza district located in the middle of the Po River basin. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2008)*

The district extends over a land area of 726.90 km^2 (Figure 2), distributed between 69 municipalities, of which 53 in the province of Lodi (661.10 km^2), 13 in the province of Milan (62.49 km^2), and 3 in the province of Cremona (3.31 km^2) (Masseroni *et al*. 2016).

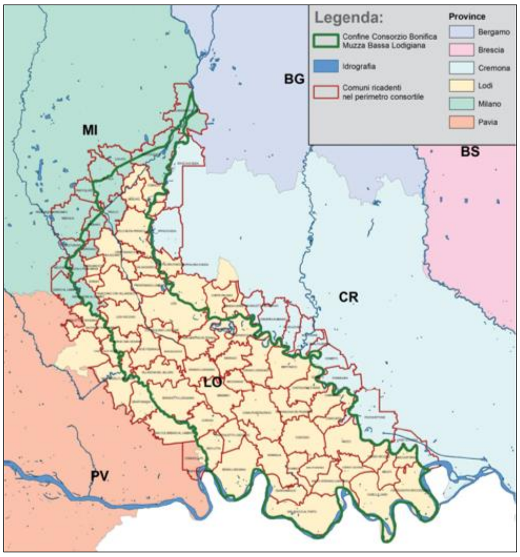

Figure 2. Muzza district limits managed by the Consortium. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

At the end of 2020, a population of 333,217 individuals gravitated to the Consortium area: 210,137 (Lodi), 101,899 (Milano), and 21,181 (Cremona) (ISTAT, 2020).

3.2 Hydrogeological and hydraulic characteristics

From the hydrogeological point of view, the draining effect exerted by the border rivers is evident, but also the presence of an underground aquifer structure which has a main direction of flow north-west/south-east passing parallel to the Lambro and Adda rivers, with the Po basin as its final receiver. As far as the main aquifer is concerned, it has permeability values which are influenced from the lithostratigraphic characteristics of alluvial deposits (Figure 3).

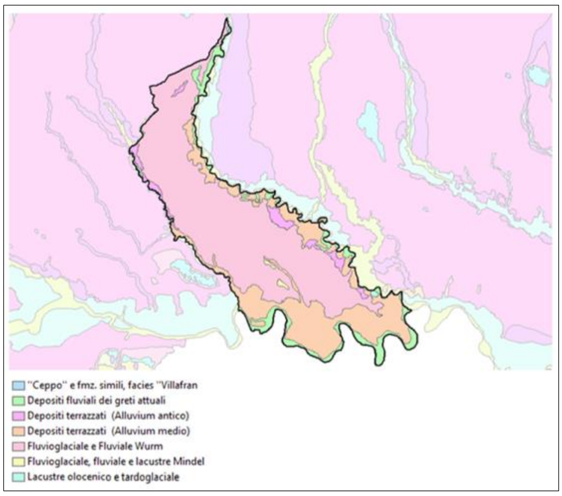

Figure 3. Geological map of the irrigation district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

Gravelly and gravelly-sandy lithotypes have good to medium permeability values as the finer grain sizes increase and they are present almost everywhere but mainly along the areas adjacent to the Adda River (Figure 4). On the other hand, the sandy, sandy-silty, silty-clayey, and clayey deposits, which are the most frequent throughout the whole area, have a medium to low permeability as the clay component increases.

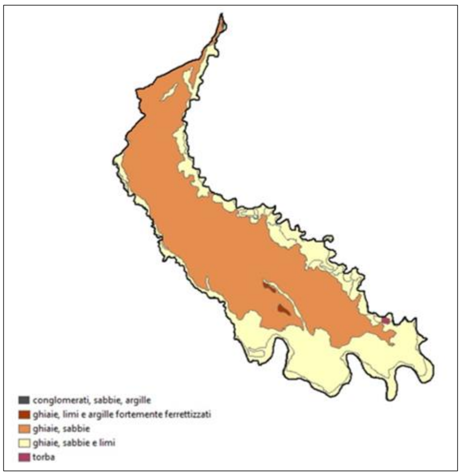

Figure 4. Lithological map of the irrigation district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

The hydrogeological characteristics of the irrigation district can be schematically represented by a top aquifer, highly pervious, included within the upper fluvio-glacial sediments, and an underlying aquifer, with lower hydraulic conductivity, lying on impervious substrata of Quaternary marine sediments. Groundwater dynamics are strongly conditioned by the large recharge fluxes, due to the percolation of irrigation water both from the fields and from the canal network. The piezometric surface is characterised by a divide in direction north-west/south-east, approximately along the Muzza canal, which constitutes an important source of recharge for the aquifer (Facchi *et al*. 2004). The soil textures range from moderately coarse (loamy sand) to coarse (sand) in the northern part and along the Adda River, from medium (loamy) to moderately coarse in the central area and from moderately fine (sandy clay loam, silty clay loam, silty clay) to medium in the southern part.

Based on elevations differences, the hydrological system can be divided into two parts (Figure 5): upstream or upper part (Muzza) and downstream or lower part (Bassa Lodigiana).

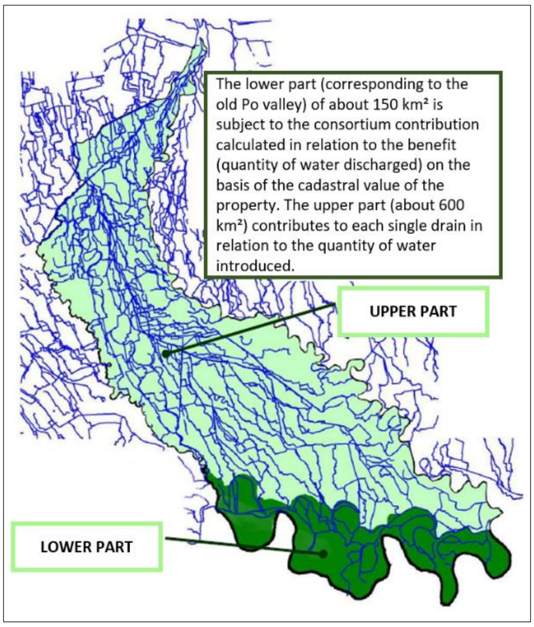

Figure 5. Upper part (reclamation) and lower part (soil protection) of the Muzza system. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2008)*

The two parts are strictly interconnected and duly organized in six territorial units (Figure 6) with an appreciable homogeneity considering origin, composition and soils behaviour, degree of urbanization, slope, as well as crop status and irrigation systems.

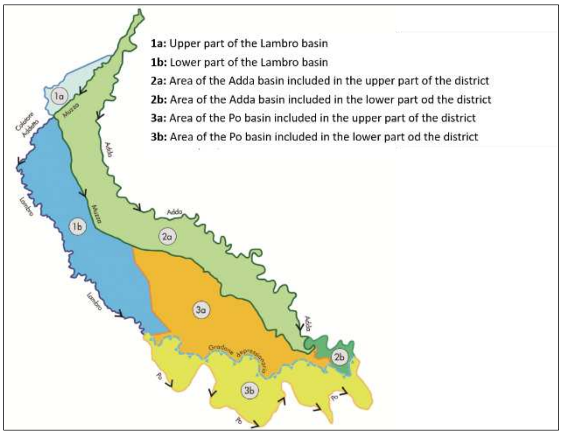

Figure 6. Subdivision of the Muzza district in six main basins. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

The hydrographic system is characterized by a very dense irrigation-hydraulic network which, excluding the farm and inter-farm branches, develops for a total of about 3,600 km. The upper part is irrigated by the Muzza canal which, departing from Cassano d'Adda, extends for about 40 km and distributes water to 36 mouths of as many primary open earth branches. These primary branches, subsequently and downstream of their intake, give rise to numerous secondary canals (about 400) which make up the operational network of the irrigation system (Figure 7). Overall the irrigation network includes 410 km of primary canals and almost 4,000 km of secondary canals.

The Lake Como, with an area of 145.9 km^2 and 22.5 km^3 in volume, is the main reservoir on the Adda River, situated north of the Muzza district.

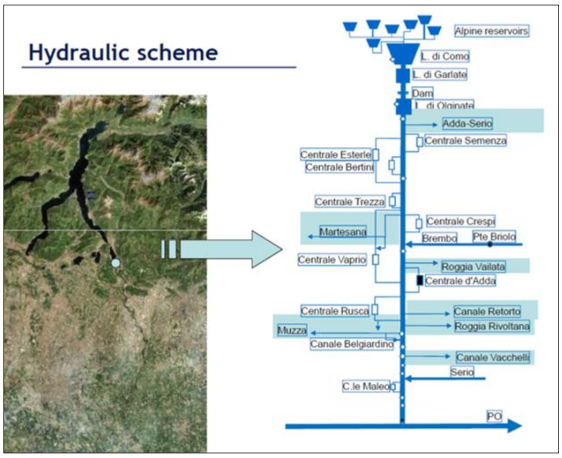

Figure 7. Hydraulic scheme of the Adda and Muzza systems. *Source: Gandolfi (2010)*

The surface drainage and discharge system of the upper area is based on the same network used for irrigation, which in fact performs a mixed-type function (irrigation-hydraulic). The artificial and natural drains do not underpin their own territory but act as a regulator or discharge point for floods (rare in consideration of the water density of the territory). The lower part is considered the natural and perennial site of marshes enlivened by frequent floods since ancient times. The land elevation is lower than in the upper plateau by about 10 m, varying on average from 39 m to 50 m m.a.s.l. several meters below the ordinary flood level of the Po, Adda, and Lambro rivers. The irrigation of this area takes place mostly by pumping water from the Adda and Po rivers or by reusing the return waters from the irrigated areas of the plateau, collected by a system of collectors which, crossing the lower territory transversely, acts as gutters. Furthermore, drainage takes place with an articulated branching of reclamation canals with delivery to the main collector confluent in the Po at Castelnuovo (close to the Adda mouth) (Figure 8).

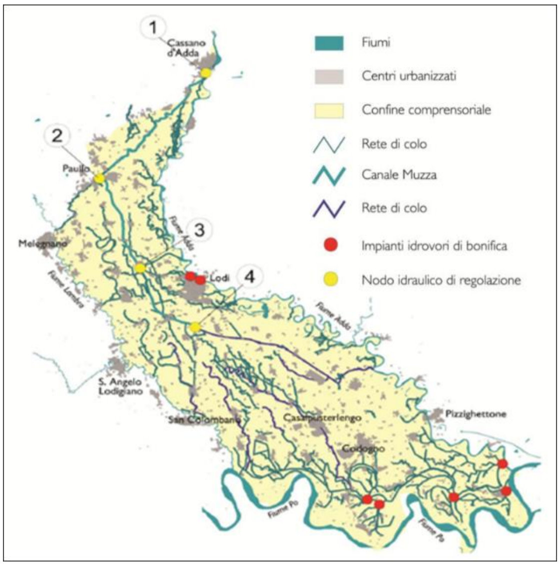

Figure 8. The Muzza drainage system. *Source: Anas SpA (2011)*

Individual processes explaining the hydrological cycle and inflow-outflow dynamic in the Muzza district are showed in Figure 9, where the block diagram represents forms of water storage, while the lines that connect them are the individual processes of water transfer from one to another.

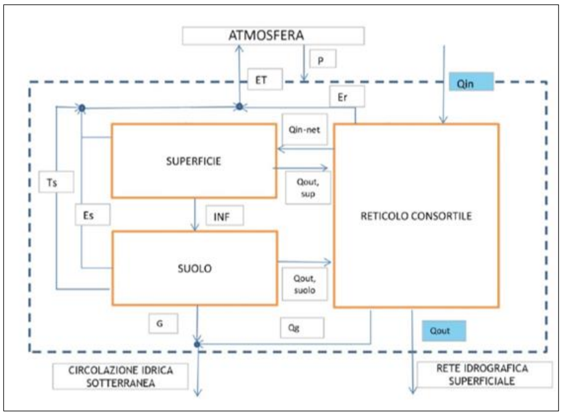

Figure 9. Scheme of the inflows-outflows transformation model in the Muzza system. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

The main characteristic of the above scheme is that each block corresponds to a certain volume in the physical space. The control volume identified consists of the soil layer between the surface and the lower limit of influence of the root systems of plants and crops. The dotted outline delimits the part of the hydrological cycle consisting in the transformation of inflows operated within the area. The basin diagram shown simplifies the processes that occur in the hydrological cycle: the tanks of the same type are brought together in the same block and similar water transfer processes are also concentrated in a single line per block.

The block representing the soil of the basin contains the volume *Vr* of water stored as moisture in the soil, while precipitation *P* is largely concentrated in the block that represents the surface of the basin (including the vegetation cover) and, to a small extent, directly in the Consortium canal network. The three volumetric blocks (surface, soil, and Consortium network) are the site of evaporative processes (indicated as E_s for soil and surface and E_r for the network) through which water returns to the atmosphere. They, together with the plant transpiration, T_s, represent the evapotranspiration flux leaving the system. The Consortium network block feeds the surface of the basin with the flows distributed for irrigation. The gross flow rates entering the network (Q_{in}) suffer seepage losses (Q_g) along the canals, that are totally unlined. The net flow distributed to the irrigated area (Q_{in-net}) is the fundamental term for the water balance of crops (Figure 10). The block representing the land surface feeds the infiltration, *INF*, and the surface runoff, Q_{out}. Finally, the water exchange between the soil and the aquifer together with the term Q_g feeds the underground water circulation.

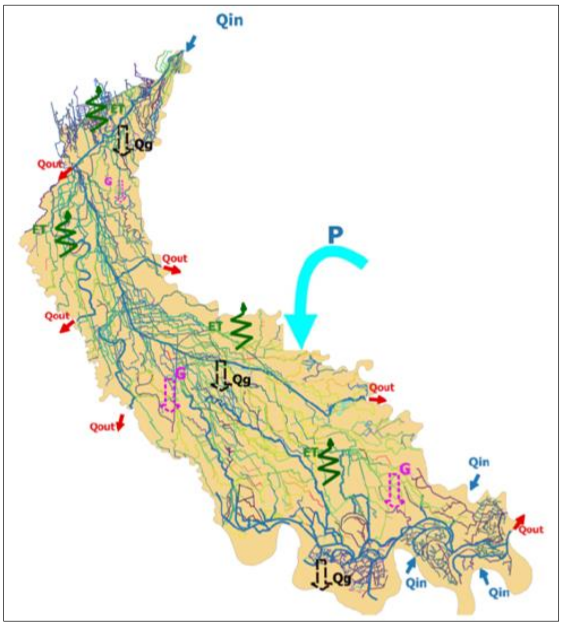

Figure 10. Individual processes that make up the inflow-outflow cycle in the Muzza district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

3.3 Weather characteristics

The climate of the Po River basin is strongly influenced by the orography; the Alps protect the area from cold winds from north Europe while the Apennines limit the mitigation action of the sea.

3.3.1 Temperature

Temperature's trend does not differ from what is generally recorded at a global level. In fact, the comparison, both in the medium and in the short term, shows in every season a generalized increase in temperature even >1°C. The Muzza district is characterised by a high average annual temperature, 10 °C to 15 °C, similar values are recorded also in Alpine Valley and close to the lakes (Vezzoli *et al.* 2015). Higher temperature value in the northern part of the district than in the southern one has been observed in the last seven years. Figure 11 presents the average minimum and maximum temperature values recorded in the seven stations inside or close to the Muzza district during the period 2006-2017.

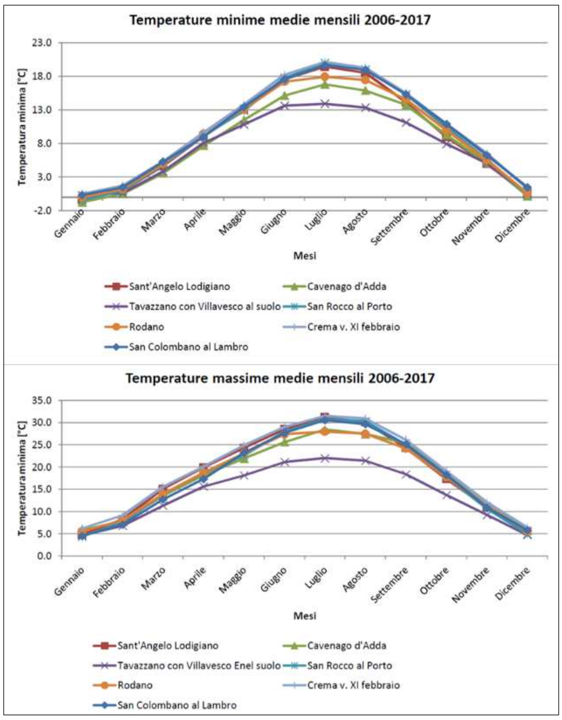

Figure 11. Average minimum and maximum temperature values (2006-2017). *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

3.3.2 Rainfall

Precipitation distribution affecting the area is more complex than temperature; the alpine basins of Oglio, Adda and Ticino rivers, effluents of the North Italy lakes, receive the maximum precipitation in summer and the minimum in winter, while precipitation, in the remaining areas of Po River basin, is characterised by two maxima, in spring and autumn, and two minima, in summer and winter.

The rain distribution (2006-2017) records generally higher values in the northern part of the area, where the average annual rainfall depth is about 800 mm, while going down towards the Po River it decreases by over 100 mm, with values around 700 mm (Figure 12).

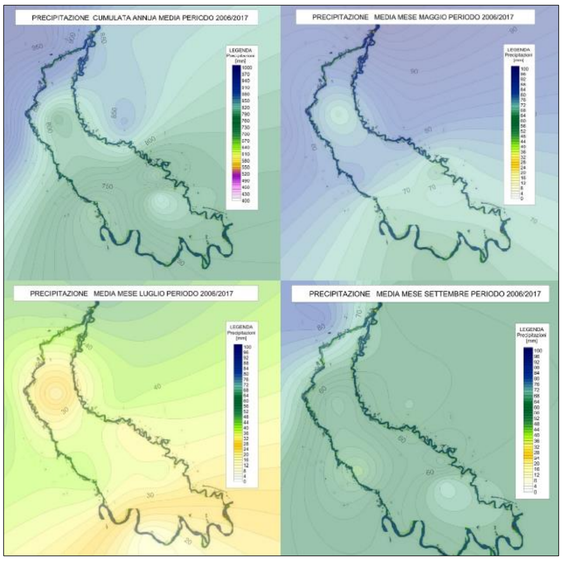

Figure 12. Seasonal isohyet graphs relating to the period 2006-2017. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

3.4 Water use multifunctionality

The original logic of hydraulic reclamation carried out in the district has long changed since when the two main historical objectives, the fight against malaria and the economic need to colonize new lands, gradually lost their meaning, already in the first half of the 20th century. However, the concept of an integrated activity and role of the Consortium in water resources and land management has been confirmed and consolidated as a territorial service, enriching and evolving with it through irrigation and land management while guarantee soil protection (Consorzio di Bonifica Muzza Bassa Lodigiana 2004).

While the irrigation use is seasonal, the water is derived from the river Adda to the Muzza canal all year around to face with multiple other functions: industrial use, energy production, recreation and tourism, environment, and drainage (Ricart 2014) (Figure 13).

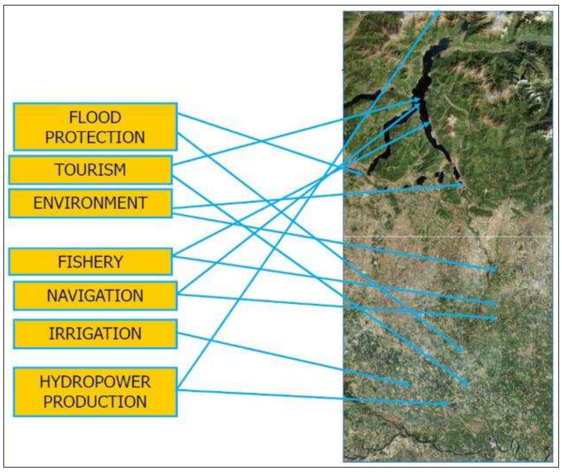

Figure 13. Water related functions developed in the Muzza system. *Source: Gandolfi (2010)*

Consequently, nowadays the aforementioned water network and lifting systems are aimed at the following uses:

- irrigation exercised in a utilised agricultural area (UAA, SAU in italian) of approximately 568 Km^2;
- hydraulic reclamation on approximately 73,000 hectares; 7,000 of which are underpinned by five pumping plants equipped with a total of 18 electro-mechanical units with a maximum discharge potential of 22.4 m^3/s, collected with a primary drainage network that extends for 200 km;
- flood protection with hydraulic nodes located on the territory which are fundamental for the regulation of flood inflows to safeguard important urban centres;
- production of hydroelectric energy of approximately 73.2 million KWh with eight plants (four on the Muzza canal, two on the Belgiardino spillway, one on the Sillaro drain ditch, and one on the Muzza drain ditch);
- industrial use for the thermoelectric cooling of the A2A power plant in Cassano d'Adda and the EP Production plant in Tavazzano;
- intensive fish production with water supply up to about 9 m^3/s for eel and sturgeon breeding plants;
- collection, regulation, conveyance, and disposal through the irrigation and reclamation network of the pluvial inflows coming from the urban drainage of almost all the residential and production centres located in the territory;
- water distribution, planned and controlled, to numerous wetlands adjacent to rivers, in particular the Adda River, whose areas of environmental value depend, from the hydraulic aspect, exclusively on the supply of water from the Consortium water network;
- design and execution of environmental interventions for recreational purposes.

3.4.1 Land use and flood protection

Considering the information contained in the 2015 DUSAF project (regional database), about 67% of the district is occupied by arable land and crops (Figure 14); while the remaining 33% is occupied by buildings (about 13.65% of the total area of the Consortium), grasslands, bushes, uncultivated green areas, parks, and gardens (13%), water courses (2.23%), rice fields and meadows (1,78%), woods, vegetation, and degraded areas (less than 1% each one).

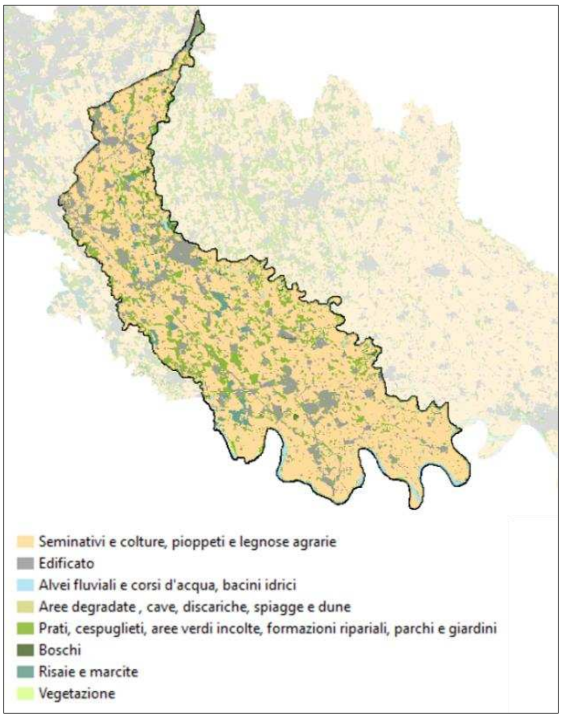

Figure 14. Land use in the Muzza system (2015). *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

When severe weather-climatic events occur, one of the main functions of the flood protection system is to maintain the lower territory in conditions of safety and normality. This gives rise to a direct benefit on the real estate of the area, in fact, interrupting the operation of the protection system would progressively cause the return of the lower territory to its original situation, compromising the general safety and liveability.

3.4.2 Agriculture and livestock

Agricultural activity and irrigation are certainly the oldest uses of water resources, being already practiced by the Romans who settled in the area of present-day Muzzano, south of Paullo about 200 years B.C., while in the lower part of the district the irrigation practice is more recent, in any case prior to the reclamation function.

A picture of local agricultural activity and its relevance can be traced through the data of the Italian National Institute of Statistics (ISTAT) and more specifically data from censuses on agriculture. According to the last census carried out in 2010, there were 1,267 farms in the referenced municipalities. Irrigated surface is 648.65 km^2 (88% of the total district area) of which 614.70 km^2 (94,70%) is irrigated by the Adda River, including 'direct or first water use' (84%) and wastewater or runoff water (16%) (Consorzio di Bonifica Muzza Bassa Lodigiana, 2004). About 600 Km^2 (92,5%) are irrigated by surface water.

As mentioned before, the upper part of the district is irrigated by the Muzza canal which branches off from the Adda River in Cassano d'Adda and extends for about 40 km through secondary canals, which in turn give rise to a capillary distribution network which extends for more than 4,000 km (Ricart & Gandolfi 2017). The irrigation of the lower territory takes place mostly by pumping from the Adda and Po rivers or by reusing the return flows of the plateau recovered by means of special systems placed along the general drainage collector which, crossing the lower territory transversely, acts as a gutter. The irrigation practice is carried out through 12 pumping systems, which have 21 lifting groups with an installed power of about 1,200 KW and a flow rate of 7.98 m^3/s. The distribution network extends for about 200 km.

Maize (60-74% of the surface) and temporary grasslands (20 % of the surface) are the major cultivated crops, with minor crops including rice, soybean, wheat, tomato, and barley (Li *et al.* 2017). However, in the last decade, the dominance of maize was reduced until representing the 57% of the total area, while meadows (almost 17%) and other uses (almost 12%) have gained more significance (Table 1 and Figure 15) (Bocchiola *et al.* 2013; Consorzio di Bonifica Muzza Bassa Lodigiana, 2018).

Table 1. Main irrigated crops in the Muzza system

Crop type	Surface (km^2)	Dominance (%)
Maize (sweet, chopped, grain)	326.342	57.48
Industrial and vegetables	21.234	3.74
Meadows	96.234	16.95
Winter cereals	43.547	7.67
Rice	13.228	2.33
Other	67.165	11.83
TOTAL	**567.751**	**100**

Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)

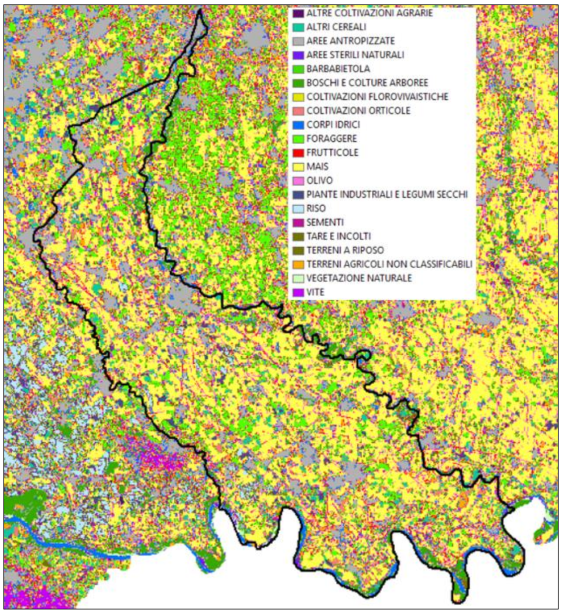

Figure 15. Agricultural land use in the Muzza system (2012). *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018).*

The irrigation method is predominantly surface irrigation (90%), followed by sprinkler irrigation (Figure 16). In the upper part of the district, the predominant technique is that of surface or flood irrigation with turn-based delivery, while in the lower part distribution is carried out after pumping and delivery on demand.

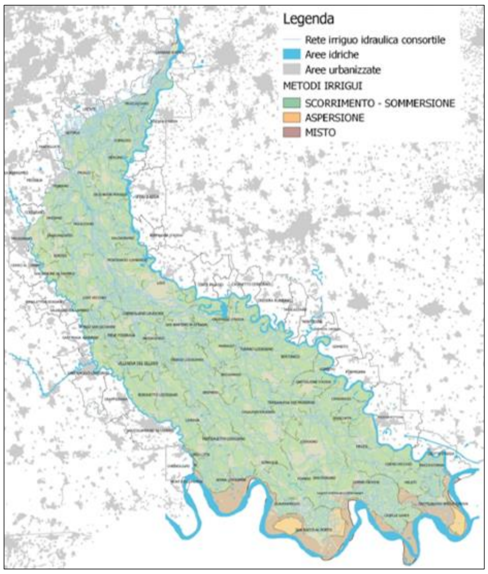

Figure 16. Irrigation techniques: Territorial distribution based on the field supply. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

However, going into the specifics, different water delivery techniques can be distinguished, which are set out below:

- *By temporary cyclical or turn-based surface irrigation*, by far the most used system belonging to the classic summer harvests (maize, weeds, and meadows). It consists in making a certain height of water (from 5 to 15 cm) until it reaches the opposite edge along which there is a collection ditch for the pouring waters to runoff from the ground, not being infiltrated deeply. The water flow depends on the nature of the soil, the type of cultivation, and in particular the slope of the particle, generally between 0.01 and 0.03%.
- *By continuous seasonal flow surface irrigation*, a historical system, today very limited, typical of '*jemale*' or winter fodder crops (the marching meadows) consisting of running, continuously (except for the moment of cutting) starting from an edge along the entire esplanade of the field, a certain height of water (from 3 to 5 cm) until reaching the opposite edge along which there is a collection ditch for the pouring water. The continuous water flow,

aimed at preserving the crop from the cold, depends on the nature of the soil and the slope of the particle which in some cases is very accentuated up to values between 0.2 and 0.5% (the meadows positioned on the coasts or on the slopes overlooking the river valleys).

- *By prolonged seasonal submersion irrigation*, traditionally belonging to rice cultivation. With this system, the water is introduced onto the countryside appropriately arranged in compartments surrounded with containment embankments about 20-50 cm high, hydraulically connected to each other by special openings made along the profile of the embankments themselves. The amount of water required in the initial phase is very consistent to allow the total submersion of the compartment with a water tie of about 20 cm, to be kept constant throughout the flooding period. Once the submersion is completed, the supply of water is progressively reduced to the values strictly necessary for recharging with slow circulation aimed at maintaining a constant optimal water level. The flooding process is usually repeated twice a season.
- *By mechanical sprinkling*, after the surface irrigation system, the most used in the area (albeit in much smaller proportions). The technique consists in distributing the water through cyclic jets that simulate rain. The system can be fixed or mobile and the administration can take place: for contingent needs related to the season aimed at occasionally helping the growth of a product that is generally irrigated by flow (emergency irrigation) or systematically, almost always when the conditions do not exist for exercising surface irrigation or the farming vocation is partially horticultural in nature. The great majority of the rain systems available in the farms are of the mobile type (generally owned) with sprinkling on a circular or rectangular footprint, essentially distinguishable in the systems with water transport lines consisting of rigid pipes or with pipes that can be rolled up on a special mobile wheel. The surfaces subtended by fixed sprinkler systems (pivots) are increasing quantitatively, in particular in the areas where it is more difficult to shape the fields with slopes suitable for surface irrigation or where water availability is limited.
- *By drip distribution, or micro irrigation*, used in marginal areas mostly experimental also applied to maize crops. It consists in the precise destination of water drops directly or almost directly to the single plant with an articulated network of synthetic material tubes. The system, traditionally applied to the driest areas of the country, allows the undoubted advantage of water saving, although facing substantial investments and equally maintenance and operating costs.

A further relevant element for the characterization of the agricultural sector concerns the presence of livestock farming. Data from the last agricultural census (2010) (Table 2) reflected the dominant role of cattle regarding the number of farms but the leading role of poultry and pig farms considering the number of animals (heads).

Table 2. Livestock farms and heads in the Muzza system

Livestock	Farms	Heads (n° of animals
Cattle	435	97,309
Buffaloes	5	1,185
Equine	70	632
Sheep	2	65
Goat	5	68
Pig	133	333,364
Poultry	17	625,849
Rabbit	7	12,516

Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)

3.4.3 Energy production

The use of water for thermoelectric use is, historically, the first non-agricultural use implemented in the area (Fanfani 2010). The waters of the Muzza canal have been used for the refrigeration cycle of thermoelectric groups since the early fifties, when the company S.T.E.I. (later merged into the E.N.E.L. group) built, along the right bank of the Muzza canal in the municipality of Tavazzano, the first two units of the current plant, with a power of 60 MW each.

Subsequently, starting from the early sixties, in the municipality of Cassano d'Adda, the company A.E.M. proceeded to the construction of a thermoelectric power plant by installing a conventional 75 MW heavy oil group. The cooling waters were drawn along the right bank of the Muzza, just downstream where the canal originates by deriving water from the Adda (Figures 17 and 18).

However, the main pilot experiences applied starting from the 1970s have progressively improved and expanded in current industrial use with the waters of the Muzza canal, for the refrigeration cycle of six large thermoelectric groups: two of the A2A power plant in Cassano d'Adda (Milano) and four of the E.ON of Tavazzano - Montanaso (Lodi).

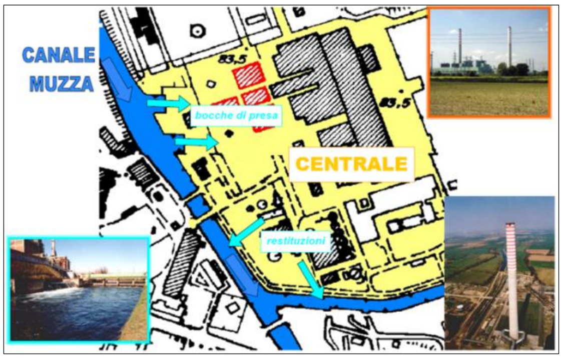

Figure 17. Typical diagram of thermoelectric station on the Muzza canal. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2004)*

Figure 18. Aerial view of the E.ON thermoelectric plant in Tavazzano-Montanaso. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2004)*

There are eight low head hydroelectric plants currently in operation in the Muzza district that use the same water conveyed for irrigation: Cassano d'Adda, Paullo (Figure 19), Bolenzana and Quartiano plants (all of them located on the same Muzza canal), Belgiardino (1 and 2, located in the Belgiardino canal), Biraghina (located in a Muzza drain ditch), and Sillaro 1 (located in the Sillaro drain ditch) (Table 3).

Table 3. Hydroelectric plants operating in the Muzza system

Hydroelectric plant	Municipality	Operating since	Annual production (million kwh)
Cassano 1	Cassano d'Adda	05/2008	13
Paullo	Paullo	01/2005	11.8
Bolenzana	Zelo Buon Persico	01/2002	12.7
Quartiano	Cervignano d'Adda	01/2002	11.7
Belgiardino 1	Montanaso Lombardo	09/2000	14
Belgiardino 2	Montanaso Lombardo	01/2008	6
Biraghina	Terranova dei Passerini	05/2015	2.5
Sillaro 1	Salerano sul Lambro	06/2015	1.5

Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)

Figure 19. Paullo hydroelectric power plant. Source: The authors (2020)

3.4.4 Environment and landscaping

The main environmental peculiarity that characterizes the water network is its marked ecological connotation connected to the presence of water and the naturalness of the waterways. The waterways represent real ecological corridors that develop extensively throughout the area including the constant presence of water, spontaneous or planted vegetation of herbaceous, shrubby and arboreal character, in a continuous interweaving of canals of different sizes and physical characteristics, being stationary sites of natural habitats for the permanence and reproduction of numerous fish and fauna species, including migratory ones. These are environments completely integrated with the rural countryside of Lodi, with which it constitutes a widespread natural continuum typical of the medium and low Po Valley.

The protected areas currently present in the territory amount to three regional parks (South Milan Agricultural Park, North Adda Park, and South Adda Park) (Figure 20), one Local Park of Supra-municipal Interest (PLIS del Brembiolo), and two regional natural reserves (Monticchie and Adda Morta). Overall, these protected areas cover 184.74 km^2 of the district.

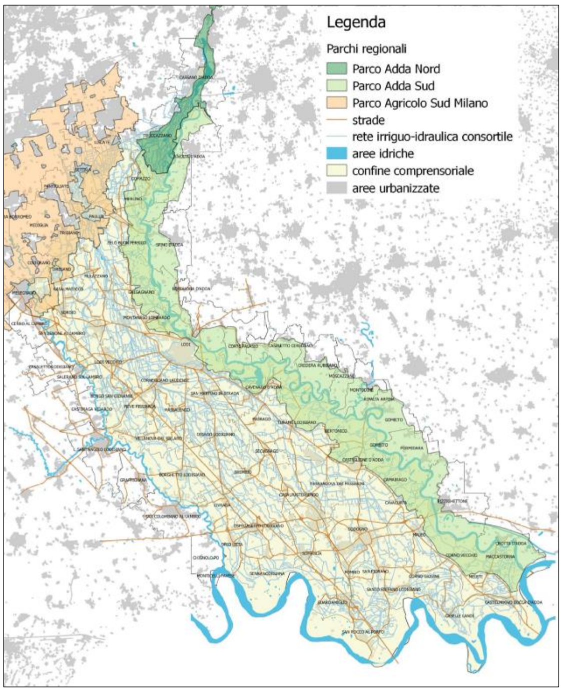

Figure 20. Regional parcs present in the district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

In addition, as shown in Figures 21 and 22, these protected areas are flanked by frequent overlaps with the Natura 2000 Network Sites in or around the district (within 5 km), including 14 Sites of Community Importance and 8 Special Protection Areas.

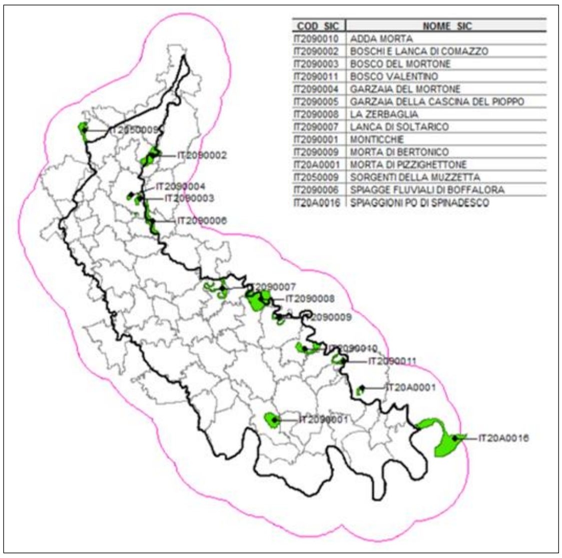

Figure 21. The reclamation area and the Sites of Community Importance in the district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

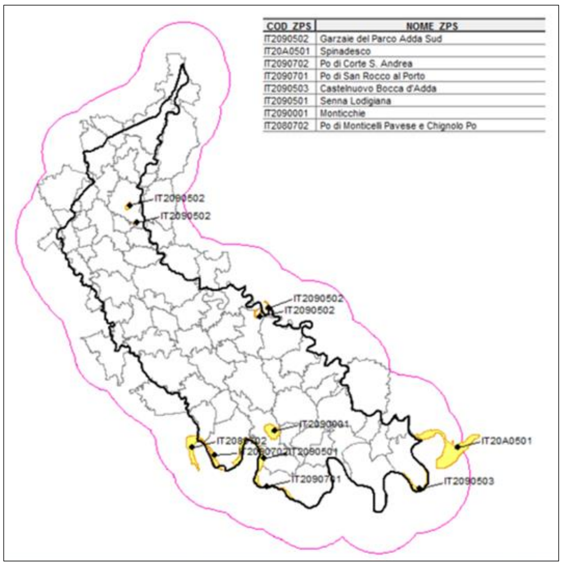

Figure 22. The reclamation area and the Spetial Protection Areas in the district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

With reference to the regional ecological network, the following Figure 23 shows how the Consortium area is affected by Level I elements (dark green) and Level II elements (light green) which partly reflect the previously illustrated protected areas. The ecological corridors follow the course of the main rivers, while there is a widespread presence of passages to be preserved.

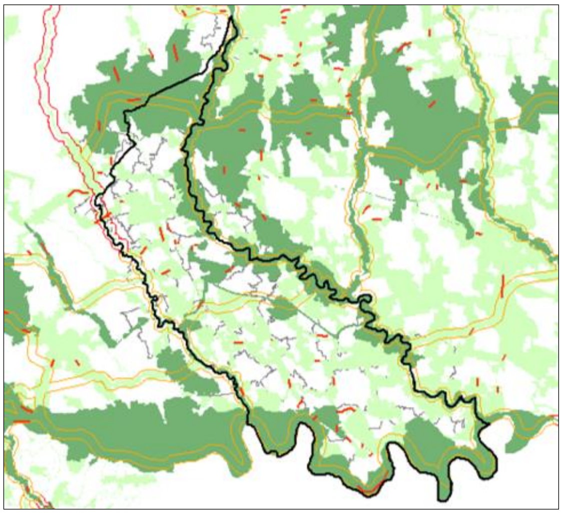

Figure 23. The Regional ecological network affecting the district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

With reference to the elements that make up the Regional Landscape Plan, the district involves the following elements (Figure 24):

- areas of specific protection of the Po River and its area of protection;
- 2 areas of regional identity (*Castelli del lodigiano* and defensive lines of the Adda-Ticino and *Piazza della Vittoria* in Lodi);
- 2 sensitive views (view of the Adda valley in Cassano d'Adda and the bridge over the Po in Piacenza);
- 1 landscape observation point (Landscape of the irrigated plain - Lodigiano);
- 2 geosites (*Adda morta* - Lanca della rotta e Lanca di Soltarico);
- landscape guide tracks (*Sentiero del Po*, *Greenway della Valle dell'Adda*, *Alzaia del Canale Muzza e navigazione sui fiumi Po, Adda e Mincio*) and panoramic roads.

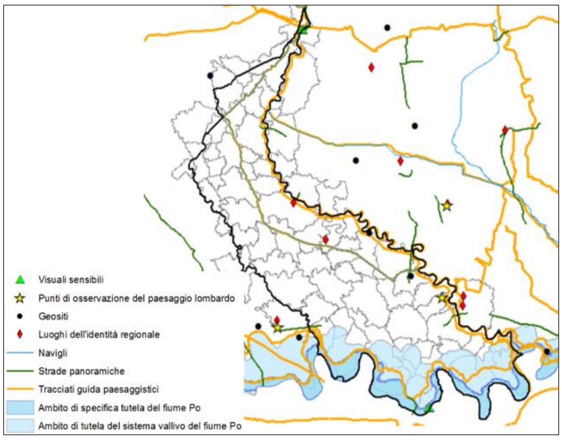

Figure 24. The Regional Landscape Plan affecting the district. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

3.4.5 Recreational and educational use

Recreational use of waterways is a further use of an environmental and non-productive nature connected to the irrigation system. Despite the purely agricultural vocation of the area, paths constitute a green environment of absolute landscape value. Environmental initiatives related to the recreational use of waterways have also determined the ideal conditions for subsequently making many canals accessible.

Consequently, kilometres of waterways have been transformed into recreational spaces by providing technical, historical, and naturalistic information on the area, as well as the positions carried out for the practice of sport fishing. The citizen frequency, especially on holidays, is very high; pedestrians, cyclists, and horse-riding enthusiasts visit the area and stop in the special equipped areas after using some of the 60 km of paths adapted for. Various projects and interventions have followed over the years, both exclusively with respect to functionality, and at the same time as other structural or hydraulic interventions. For example, the "Fishing on the Muzza and the Belgiardino" project, developed by the Consortium in collaboration with the Lombardy Region and the Lodigiana Fishermen Association, for the enhancement of Consortium canals aimed at sport fishing.

Figures 25 contains the network of the environmental paths created over the years, as well as figures 26 and 27 provide images relating to the same paths along the main waterways for recreational activities, and figure 28 shows the sport fishing use.

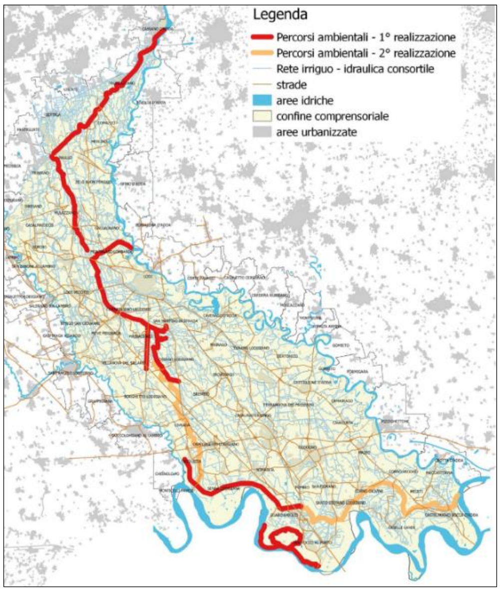

Figure 25. Recreational environmental paths along the Consortium waterways. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

Figure 26. Environmental paths following the Muzza canal, at Cornegliano Laudense. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

Figure 27. Greenways along the canal for recreational use. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2004)*

Figure 28. Sport fishing along the Muzza canal. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2004)*

Regarding educational function, the "Casa dell'Acqua" (water house) (Figure 29) located in Paullo is an educational cultural centre directly managed by the Consortium for dissemination activities on the many issues involving water at a territorial level, in particular the environmental one. On the back of the main building, a perfectly functional hydraulic model was created from the point of view of water supply reproducing the different types of irrigation watering practiced in the area. Through the collaboration with a social cooperative, educational courses are organized for schools, from elementary to high school but also at university level, integrated with thematic outings along the canal or in points of interest on the network, giving students the opportunity to learn hydraulic dynamics which characterizes the Lodi area.

Figure 29. Paullo's water house, main building restructured in 2006. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

One of the main aims of the activities carried out in the water house is to promote the study and historical-hydraulic knowledge of the territory of the South Milan Agricultural Park, suited to agriculture and characterized by a water network of significant territorial and environmental importance. Among the main activities, the water house pursues the following objectives:

- promote initiatives aimed at getting to know the surface hydrographic network of the territory, making use of and enhancing the structures present in the hydraulic node of Paullo;
- organize guided cycle-pedestrian excursions along the towpaths of the Muzza canal to support the use of bicycles as an alternative way of enjoying the area with educational stops and tasting of Park products;
- collaborate in the creation and maintenance of relationships with organizations and associations to allow the exchange of information and technical material, conferences and training courses;
- propose environmental and agro-food education courses aimed at user citizens of all ages.

4. The Muzza Bassa Lodigiana Reclamation Consortium

Key messages

- ✓ *The Consortium is formally operational from 1990 as a public economic entity with an associative character.*
- ✓ *The Consortium has the diversion license for the Muzza canal (110 m^3/s) to serve about 5,000 users.*
- ✓ *Main functions include land reclamation and irrigation, drainage, energy, environmental, landscaping, and recreational activities.*
- ✓ *Main challenges are intense rain events management, irrigation operation, water derivation, management costs, and energy efficiency.*

The *Muzza Bassa Lodigiana Reclamation Consortium* (from now on, the Consortium) was constituted by Decree of the President of the Regional Council of Lombardy region n°21157 in 19/10/1989 under art. 59 of the Regional Decree 13/02/1933 n°215. According to the Regional Law 26/11/1984 n° 59 concerning the reorganization of the Land Reclamation Consortia, the Lombardy Region autonomously classified its plain territory as reclamation, thus excluding only the mountain areas (Figure 30). The Consortium is formally operational from 01/01/1990 as a public economic entity with an associative character. The Consortium is the union of the territories and functionalities of nine already operating consortia: one for reclamation (*Consorzio di Bonifica*), three for land improvement, and five for irrigation (*Organizzazioni di Miglioramento Fondiario ed Irrigue*).

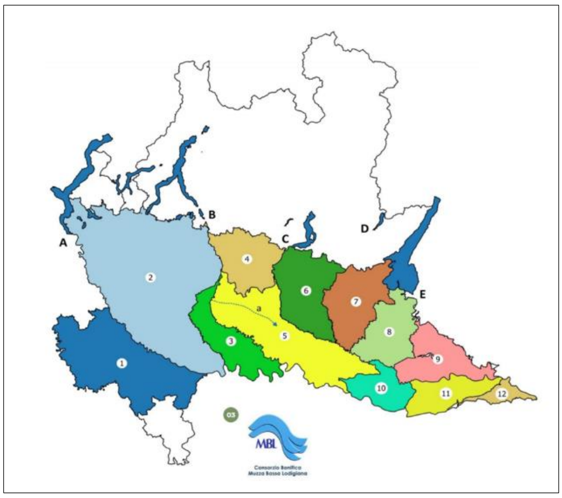

Figure 30. Location of the Muzza district (n°3). *Source: ISIL project (ANBI Lombardia website: https://www.anbilombardia.it/portfolio-items/isil/)*

4.1 Infrastructures

The Muzza system is a typical land reclamation area whose natural origin was characterized by hydraulic risk and hydrogeological instability. Furthermore, the lower part of the area was strongly compromised by water stagnation, marsh, seat uncontrolled river flooding, and landslides. However, the transformation of the place was carried out by constructing the canal network and the related drainage systems to regulate the water coming from the mountain and the control of the outflows from the valley and the water levels emerging (Fanfani 2010).

Water supply and distribution take place with a highly complex structure characterized, as mentioned, by two main peculiarities: the functional conjugation between adduction-distribution and drainage-reuse derivations (Figure 31). The district adduction system can be considered constituted, concerning the Muzza derivation, by the Muzza canal itself and the primary branches off from it, providing for the conveyance of the flows to the peripheral adduction within the district.

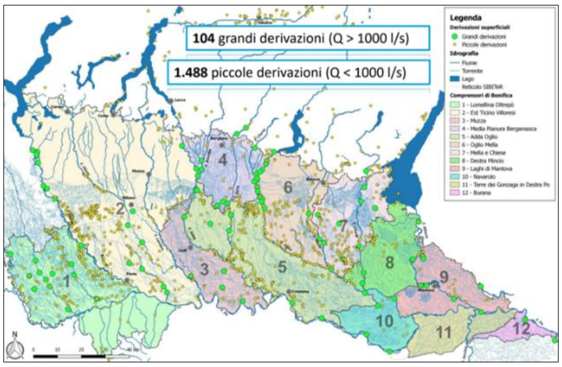

Figure 31. Water distribution systems in the upper Po valley. The Muzza is the n°3. *Source: ANBI Lombardia, ISIL project (2018)*

4.1.1 The Muzza canal

The Muzza canal is the largest irrigation canal by capacity and the first artificial canal built in Northern Italy (Figure 32). With a flow at a total capacity of 110 m^3/s, it is the primary source of irrigation water in the district. The canal is about 40 km long and derives water resources from the Adda River at Cassano d'Adda, and it flows back close to Castiglione d'Adda. The Consortium has the license for diverting 110 m^3/s from the Adda river into the Muzza canal to serve about 5,000 users (Water2Adapt project 2012).

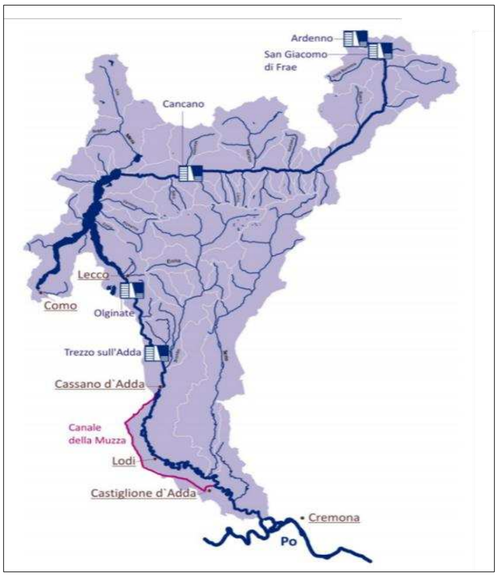

Figure 32. The Adda River basin with the Muzza canal highlighted. *Source: Water2Adapt project (2012)*

A total of 36 secondary canals branch off from the canal, 25 of which can be considered adductors (Figure 33), not directly underpinning inter-estate canals or irrigation funds. In contrast, the other 11 can be regarded as distributing canals, having instead the addresses mentioned as final derivations (Figure 34).

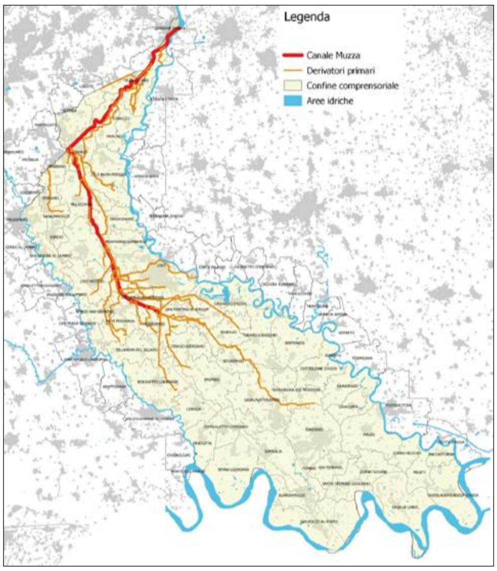

Figure 33. Muzza adduction network. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

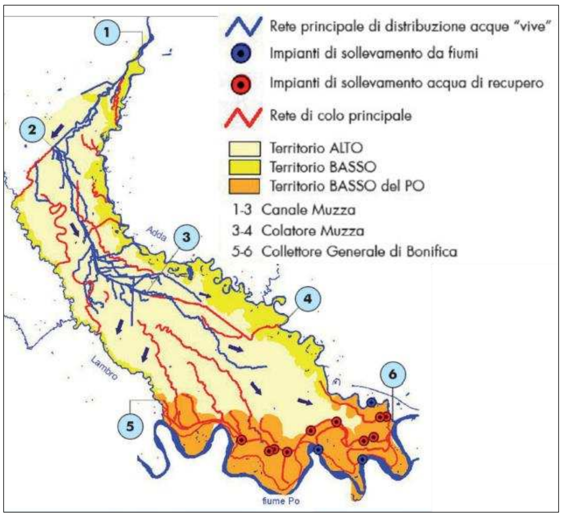

Figure 34. General scheme of water distribution and irrigation dynamics. *Source: Fanfani (2010)*

4.1.2 Wastewater treatment plants

In addition to the achievement of minimum hydraulic conditions to guarantee the summer irrigation outflows during the crop production season, one of the central and fundamental actions of the Consortium is to maintain an environmental system integrated with the territory. In this line, the Consortium gives permission to different wastewater treatment plants to discharge treated wastewaters effluents into specific canals aimed at improving the environmental quality standards of water resources and with it, the biodiversity of the whole hydrological network. In 2013 there were 65 wastewater treatment plants present in the Muzza area, 90% of which characterized by the most varied dimensions in terms of equivalent inhabitants served, deliver the purified water, directly or indirectly, to the Consortium irrigation-hydraulic network (Figure 35).

A first observation relates to the quantitative aspects (volumes or flow rates). The average purified discharge introduced in the system is at least one order of magnitude (factor 10) larger than the irrigation flows (average in the irrigation season). Still, it could be even more significant (up to three magnitudes), referred to as the Muzza canal.

Therefore, in volumetric terms, the contribution from wastewater is configured as a negligible integration of the water supply of the Consortium network. In total average duration, the sum of the discharges from the wastewater treatment plants to the Consortium network, in dry weather, is equal to about 0.85 m^3/s, which compared to the seasonal average, from April to September, of the nominal flow derived from the Muzza canal, it represents 0.87%.

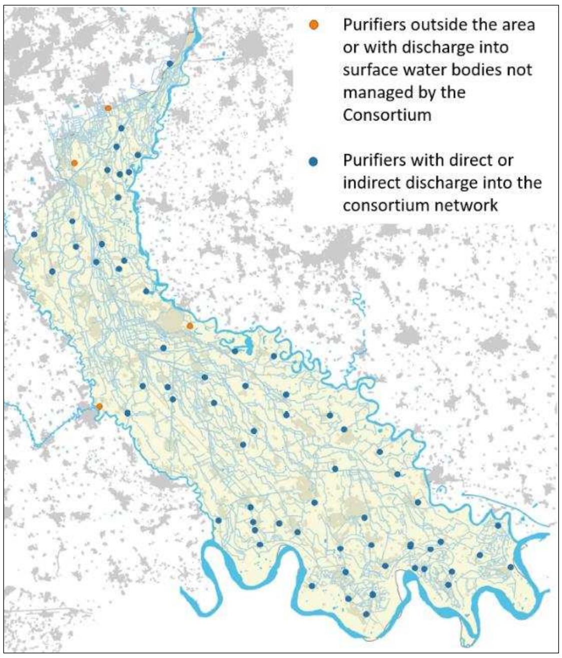

Figure 35. Map of main wastewater treatment plants (purifiers) and their relative location. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

Another aspect to consider is that reclaimed water injections have temporal dynamics utterly different from those of the irrigation system. This temporal context entails achieving both hydrogeological balance (to avoid damage to the riverbed infrastructure) and hydraulic balance, duly managed, regulated, and shifted according to constant and pre-established quantitative, temporal, and organizational criteria, different from the internal distribution among the canals.

Regarding the Muzza district, the treatment plants–irrigation nexus could be defined in terms of opportunities for the treatment plants to count on a receptor network that offers the constant presence of water to satisfy the environmental requirements at the regional, national and European level. Moreover, this circumstance is configured as a service for the direct benefit of the managing bodies of the treatment plants for which some specific agreements have already been developed.

4.2 Functions and management

The Consortium must institutionally provide for the management, maintenance, and execution of public reclamation works in the Muzza district. Furthermore, it is responsible for the water management and the related water network, assuming the land improvement functions, as referred in the Royal Decree n°215, of February 13, 1933, still valid, and in the following national and regional legislations. Moreover, all the other subjects operating in the irrigation sector, and those of water use relating to irrigation and water utilities that are exercised in the reclamation canals and in the waterways that affect the Consortium territory. More recently, through the issuance of the Regional Law June 16, 2003 n°7 'Regulations on reclamation and irrigation' (*Norme in materia di bonifica ed irrigazione*), it was confirmed the public relevance of the irrigation and reclamation activities as essential, permanent tools for the hydraulic safety of the territory. Moreover, it was considered the rational and plural use of water resources, consolidating the principles of the functionality of drainage and irrigation distribution and expanding the competencies of the consortia towards all activities concerning the use of surface water.

Therefore, the main functions include land reclamation but also irrigation and drainage, and new water uses and numerous strategic skills, such as hydroelectric, thermoelectric, aquafarming, environmental, landscaping, and recreational activities:

- ecological and landscape protection actions, sustainable economic enhancement and water rehabilitation;
- actions for the re-naturalization of waterways and phytodepuration by the provisions of article n°6 paragraph n°3 of Legislative Decree on May 11, 1999 n°152;
- prevention and protection actions from natural disasters studies and experimentation;
- design and construction of rural roads, aqueducts, and power lines, and
- design and construction of civil protection and navigation work.

These functions should be internally countersigned according to the Board of Directors who governs the Consortium. It consists of 15 members: 12 members elected by those entitled to vote, a representative of the two principal municipalities whose territory operates the Consortium, a representative of the leading province, and a regional representative. The Board is convened at least six times a year to address and discuss the internal hydraulics and surrounding soil and land management options and challenges.

The owners of the properties located in the district are part of the Consortium. All the direct Consortium members, the aggregated ones (generally for extra agricultural use), and all the water users (direct and indirect) are considered customers. Land and buildings' owners located in the district territory are part of the Consortium by paying a contribution based on the benefit received from the functionality of the surface water network and related works.

4.3 Irrigation water use

4.3.1 Internal organization

At the structural level, irrigation units are considered the agricultural surface subtended by a control structure with continuous flow form which distribution to the individual plots of the unit starts. The irrigation units supplied by the same secondary canal from a sub-district and the sub-districts supplied by the primary canal from the Muzza district. The Consortium is organized in 60 irrigation districts (*distretti*) and 187 units (*comizi*) with related functional attributes and a canals' network. Each farm is directly connected to the hierarchy of the canals. From the largest to the smallest (Figure 36), there is an irrigation district or an underlying unit formed by the sum of the irrigated surfaces by the canal itself to each canal of whatever degree. All users who irrigate with the same canal or the same system are responsible for maintenance and operating costs of canal and all the structures present along the path.

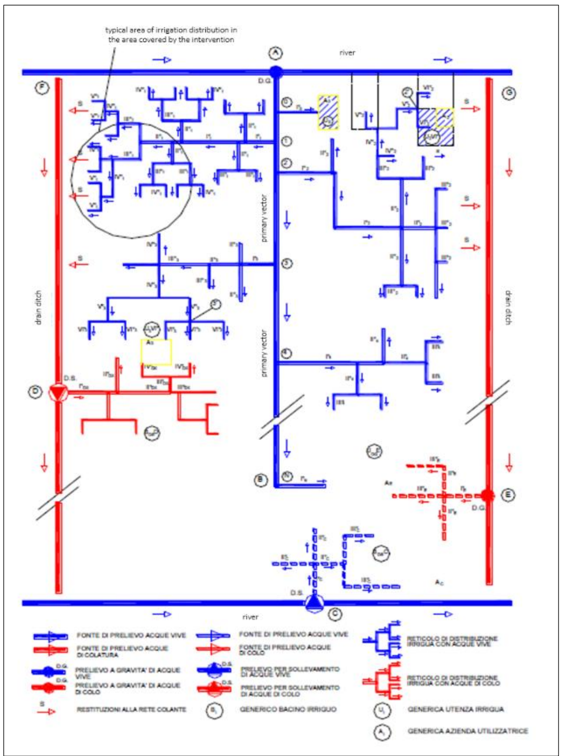

Figure 36. Irrigation water distribution in the Muzza system. *Source: Anas SpA (2011)*

The inertia of water distribution is very high; the waters of Muzza, which directly or indirectly underlie more than 90% of the district territory, need up to 75 hours to reach the irrigation units that lie farthest from the Cassano d'Adda derivation. Figure 37 describes the irrigation network as divided into the sub-districts and the related irrigation units. In the upper part, each unit corresponds to a feeding distributor canal, while in the lower part, characterized by closed irrigation basins, the most appropriate classification has been defined for which the irrigation districts coincide with the units.

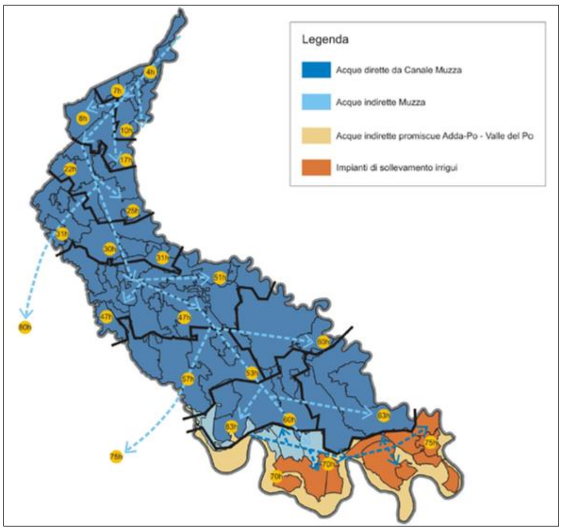

Figure 37. Irrigation districts and hydraulic inertia in the Muzza. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

4.3.2 Water diversion license

The primary water supply source for the district is the Muzza canal. Their dynamics of derivation are expressed in Table 4 and Figure 38, where the twelve-year average diversion (2006-2017) is represented in the different periods of the year, compared to the diagram of the water license.

Table 4. Water concession and water derived of the Muzza canal (2006/2017)

Period	Licensed flow (m^3/s)	Diverted flow (m^3/s average)	Difference (%)
01/01-10/04	62	51.03	18
11/04-10/05	72	53.10	26
11/05-10/06	82	71.93	12
11/06-20/08	110	89.50	19
21/08-30/09	82	67.75	17
30/10-31/12	62	55.64	10

Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)

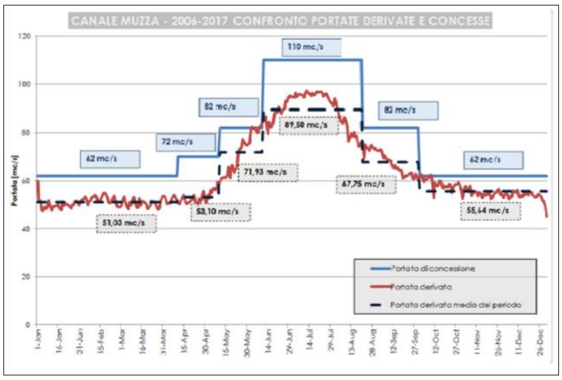

Figure 38. Diagram of licensed water flow and actual water diversion from the Muzza canal. *Source: Consorzio di Bonifica Muzza Bassa Lodigiana (2018)*

The higher diverted flows coincide with the seasonal irrigation period. The derived flow is functional to the multiple activities underlying the Muzza system which, include irrigation flows, the supplies of two thermoelectric plants, aquafarming and hydroelectric plants, as well as all the environmental aspects linked to surface water circulation, such as green strips along the canals, wetlands, and biodiversity, but also the sanitary function when receiving the discharge of the treatment plants in the area.

4.3.3 Procedures for assigning water to users

The Consortium organizes the management of water allocation to users according to different modes:

- *The cyclical turn with associated water rights*, characteristic of the upper part of the district directly or indirectly subtended by the Muzza canal. Each farm has a continuous water right (the nominal endowment) registered in the official roles of the Consortium. The origin of the water right is of very ancient origin, from the early Middle Ages and subsequent eras. The title was transferred with the notarial deeds of sale of the funds; it can be said that since the early years of the last century, the role has remained virtually unchanged. The sum of the individual water flows determines that of the user canal or the underlying irrigation basin. In a particular cyclical time, the administration acts by concentrating known in the jargon as 'irrigation wheel', the total water flow rate of the user canal. The shift of variable duration depends on the farm's equipment and is repeated every 15 days (360 hours). The time can be perpetual (it always has the same development, e.g., starting with the first Sunday of April always at the same time), partially perpetual (starting at the same time now but on different days of the week, e.g., beginning with April 1st at the same time); or variable every year, e.g., starting on April 1st alternately starting at 12:00 or 24:00). In the first case, users who have the time, or most of it, during the night or/and holidays are undoubtedly disadvantaged. In the second and third type, however, cyclically every year, the inconvenience and higher costs are distributed over the whole wheel.

- *The continuous flow of 'jemale' water* from ancient times allowed a continuous independent water distribution to winter meadows. '*Jemale*' irrigation period begins in September and continues until the end of March, is considered the irrigation carried out during the colder months and used for the exclusive cultivation of water meadows. It is continuous, since otherwise, in the winter, it would cool down and be caught by frost for a few hours that the water did not cover the ground flowing over it in a thin veil. Although the practice has decreased considerably, farms still tend to maintain it, even without practising the cultivation of winter meadows. Maintaining the activity serves to generate permanent and constant water flow into the network, which in addition to hydraulic advantages, also gives rise to significant environmental implications (for example, as a spontaneous minimum and ecological flow).

- *Water access fixed by the land surface* is the classic system used in the irrigation basins of the lower part of the district. The water is assigned to the Consortium based on the land surface, which means that the specific equipment of the land within the same basin is the same for all users. The water is assigned upon reservation; the next shift is not carried out until, unless waived, the water 'tour' is completed, that is, the total satisfaction of the farmers' needs, a tour which is exercised in proportion to the company extension. Water, operating, and maintenance costs are applied according to the irrigated area (Euro/ha).

- *The flow rate on the reservation fixed by the time of use*, a typical system applied to irrigation with immediate lifting, which is assigned to the farm, with constant water flow rate, according to the time required. This means that, although the available flow rate is the same within the same basin, the specific endowment of the land may vary according to the respective requests. As in the previous circumstance, the water is assigned upon reservation. Variable costs (water, energy, overtime for personnel) are applied according to the requested time (Euro/hour), while the fixed costs are divided according to the underlying surface (Euro/ha). With a binomial tariff, this system turns out to be the model to follow according to the European Union directives.

4.3.4 Irrigation water costs

The whole territory contributes to the maintenance of the network. On one side, farms and landowners in the upper area (from Cassano d'Adda to the territorial limits of the municipalities that overlook the low-pressure step) contribute according to the water used or discharged, and the contribution is calculated directly on the quantity itself (m^3/s) or based on the extension of the property or the number of resident inhabitants (for sewers). On the other side, farms and landowners of the lower part of the district (from the territorial limits of the municipalities that overlook the low-lying step to the Po River) also contribute based on the amount of water used or discharged, but the contribution is paid differently, namely:

- for those who use water, based on the extension of the property (in this case, the irrigated land);
- for anyone who discharges water, based on the property's asset value or the cadastral income of the surface area for land, the real estate value registered in the land registry for farms and buildings.

Concerning the irrigation service contributions, these are paid regarding 1) summer water (from March to September), 2) *jemale* water (from September to March), and 3) canal operating expenses. Each user for each irrigation canal of the upper area has X summer irrigation hours, which correspond to Y l/s of each canal (the total of l/s of all the irrigation canals form the maximum summer flow that can be derived from the Muzza canal from the Adda River). The summer water contribution is calculated: l/s endowment x rate (in 2018, it was equal to €4.68 l/s), determined each year with a resolution of the Management Board. Furthermore, each user for each irrigation canal of the upper area has X *jemale* or winter irrigation hours, which correspond to Y l/s of each canal (the total of l/s of all the irrigation canals form the maximum *jemale* flow that can be derived from the canal Muzza from the Adda River). The *jemale* water contribution is calculated as the summer water and in 2018 it was equal to €0.85 l/s. Likewise, the contribution for the running costs of the canal network is calculated as a percentage based on the user's summer water supply for that canal.

4.4 Main risks and challenges

According to the Consortium (2018), the hydraulic inputs to the irrigation-hydraulic network have increased considerably in recent years, subjecting it to a commitment that has exceeded its capacity and resilience in many situations. Some risks have been identified:

- Unmanageability of the water flows during extreme rain events, with climate change that tends to exacerbate their severity.

- Irrigation operation interruption when multiple and diversified users require water resources.

- Limited water availability: In the last decade, less than 90% of the licensed value has been diverted, resulting in a deficit in irrigation. The requirement to deliver a flow rate up to a maximum of 4.5 m^3/s to the Addetta drain ditch as a condition for the renewal of the Muzza canal derivation water concession induces an equivalent reduction the flow rate available for the district.

- Irrigation network management costs deriving from the intensely mixed water use, a circumstance that must be constantly monitored and pursued with a view to the economic sustainability of a territorial infrastructure that exercises multifunctionality.

- Operational efficiency and energy saving measures in the lower part of the district, where irrigation takes place exclusively by mechanical pumping, affecting cost containment in an area that is already disadvantaged for altitude and morphology.

- Efficiency and functional flexibility of the irrigation network. Currently is not yet consistent with the multifunctional water needs nor the increase in pluvial stresses in recent decades concerning the widespread urban and productive development of the territory and the consequent waterproofing.

- Interruption of the irrigation operation due to the massive hydraulic inputs entering the Muzza canal from the North-West sector. This requires drastic and sudden adjustments (even to the total closure) of the flow of the Muzza canal to create the necessary hydraulic capacity, with relative heavy consequences on the network and the underlying activities. It was argued that this criticality has two aspects: the first physical, hydraulic, corresponding to the receptive capacity of the input outflows to the Consortium network, the second has a technical-administrative character, relative to the scarce exchange of information with the border bodies competent in hydraulic matters and the consequent lack of knowledge of the genesis of the outflows in input to the district.

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