Landscapes of drought. Future scenarios between agriculture and land aptitudes

SECONDA SERIE
01
2023

RI•VISTA
Research for Landscape Architecture

RI•VISTA
Research for Landscape Architecture
Digital semi-annual scientific journal
University of Florence
second series

Anno XXI n.1/2023
Registrazione Tribunale di Firenze
n. 5307 del 10.11.2003

ISSN 1724-6768

CONTATTI
Ri-Vista. Ricerche per la progettazione del paesaggio on-line: https://oaj.fupress.net/index.php/ri-vista
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In copertina: "More London", Londra 2010. Foto di Fabio Di Carlo.

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Università degli Studi di Firenze

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DIDA Dipartimento di Architettura
Università degli Studi di Firenze
via della Mattonaia, 8
50121 Firenze

Published by
Firenze University Press
Università degli Studi di Firenze
Via Cittadella 7 - 50144 Firenze, Italy
www.fupress.com

Sommario

Landscapes of drought. Future scenarios between agriculture and land aptitudes

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Abstract

The impact of climate change on agriculture and the future rural landscape is strictly related to the need to improve resilience to water stress. In this context, the main problems are the increase in droughts and the intensification of rainfall events. The objective of the research project, carried out in the territory of the Reclamation Consortium of Ferrara, is to manage them through a consistent selection of less productive agricultural areas and their transformation into new habitats capable of storing water and releasing it during drought periods. To identify the project are-as, a method was developed based on the analysis of soil productivity through the processing of satellite images. The proposed system, capable of meeting up to 38-80% of water needs by 2040, is both a tool to support current adaptation policies and a long-term vision towards new spatial configurations of the rural landscape.

L'impatto dei cambiamenti climatici sull'agricoltura e sul futuro dei paesaggi rurali è strettamente legato alla capacità di adattamento allo stress idrico. In questo contesto, aumento della siccità e intensificazione degli eventi piovosi sono i principali fenomeni da fronteggiare. L'obiettivo della ricerca, svolta nel territorio del Consorzio di Bonifica di Ferrara, è stato quello di gestirli attraverso una selezione coerente delle aree agricole meno produttive e la loro trasformazione in habitat capaci di accumulare acqua e rilasciarla durante i periodi di siccità. Per identificare le aree di progetto, è stato messo a punto un metodo basato sull'analisi della produttività dei suoli attraverso l'elaborazione di immagini satellitari. Il sistema proposto, in grado di soddisfare fino al 38-80% del fabbisogno idrico entro il 2040, è sia uno strumento a supporto delle attuali politiche di adattamento che una visione a lungo termine verso nuove configurazioni spaziali del paesaggio rurale.

Keywords

Rural landscape, Agriculture, Drought, Satellite Imagery, Scenario design.

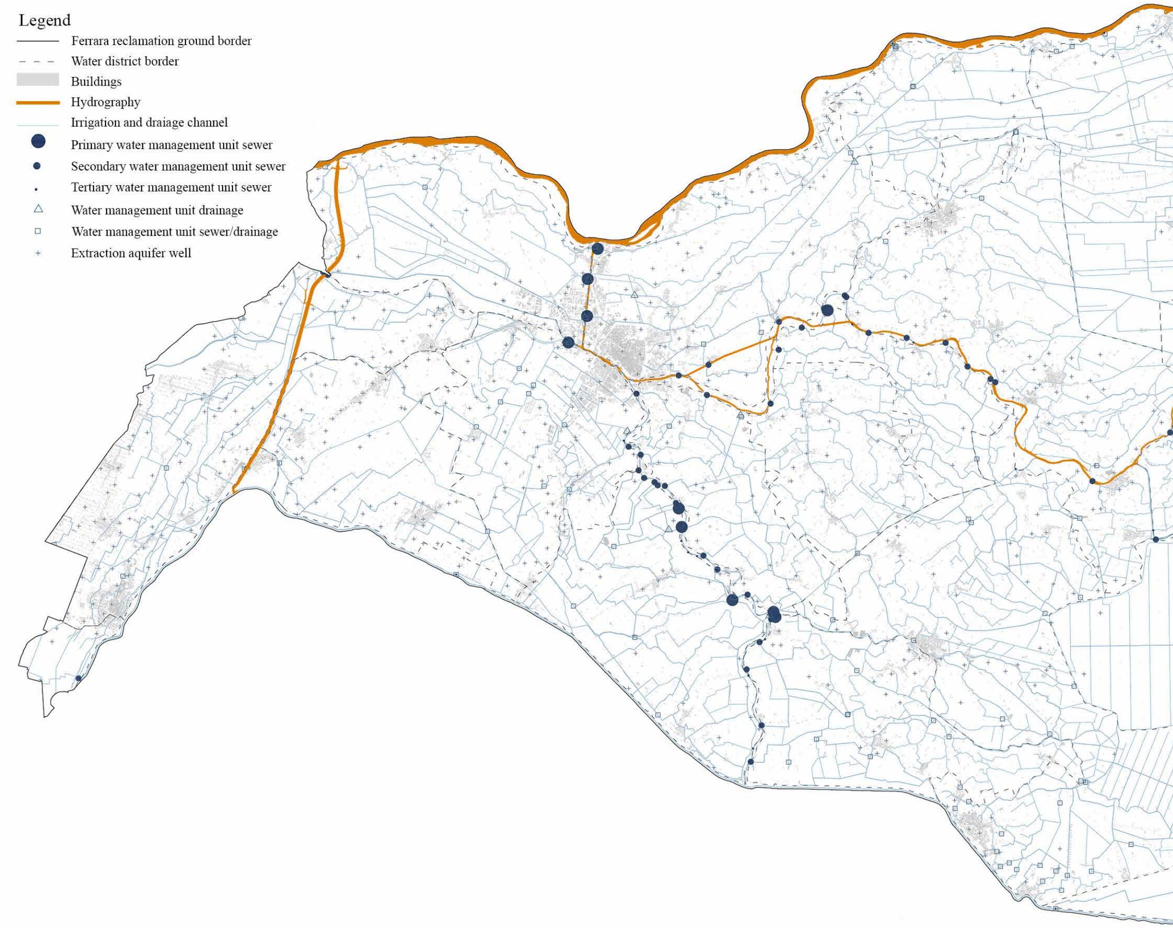
Paesaggio rurale, agricoltura, siccità, immagini satellitari, progettazione per scenari.

Received: *May 2023* / Accepted: *July 2023* | DOI: 10.36253/rv-14112

The management of unproductive agricultural areas in the territory of the Reclamation Consortium of Ferrara

Agriculture and rural landscape are the cause and effect of a symbiotic process (Pasini, 2018) whose balance is essentially based on the abundance or scarcity of water resources. Reclaimed lowlands are shaped to dynamically manage both these conditions through infrastructures that ensure safety (drainage) and productivity (irrigation) at the same time. In the last few decades, the detrimental impact of climate change on the frequency and intensity of atmospheric precipitations is threatening the agricultural sector, accelerating soil degradation phenomena (Mahato, 2014). At the same time, the optimization of satellite-based information could represent soon a game-changer for agriculture providing a suite of real-time decision support systems (Diak, 1998) enabling, for example, the assessment of water resources or soil productivity (Jung et al., 2021). Although the processing of high-resolution data remains a challenging task when applied to large-scale case studies, such promising tool need to be tested since, as in the present research, it can outline alternative paths to a more resilient management of the rural landscape.

The project presented in the following pages was developed on the jurisdiction of the Reclamation Consortium of Ferrara (RCF) whose landscape can be described as a performing hybrid between nature and technology where water drainage and lifting operations are supported by a widespread hydraulic infrastructure (Fig. 1) that gives the perception of a stable and safe territory while, as a matter of fact, it hides a very delicate artificiality. The network of canals stretching across the plain has dictated, over the centuries, the rules of human settlement on the area, leading to a progressive detachment from pre-existent landforms deeply characterised by the presence of water. The different density, rhythm and articulation of the landscape patterns reflect the way and periods in which reclamation works have been made. The increasing vastness and recurrence of farming plots, their spatial arrangement and shape, clearly show how the modern mechanization has almost completely obliterated those subtle variations in morphology and soil texture that especially in lowland contexts are essential for biodiversity and landscape variety. Nowadays, with a few notable exceptions (like the Comacchio Valleys), the landscape of water within the Ferrara plain coincides almost entirely with a freestanding hydraulic infrastructure superimposed to the territory (Fig. 2). Nevertheless, beneath this mesh traces of less rigid and repetitive patterns – composed by palaeodunes, ancient shorelines, lev-



ees and infilling channels – are still detectable and can represent the implicit driver to re-establish more sustainable relationships with water, both in functional, ecological, and cultural terms.
Such opportunity is even more significant if we analyse the paradoxical circumstances that have turned the present ultra-efficient drainage (and defensive) system into an unintended wastage device. In fact, the RCF moves every year 235.670.000 m^3 of water for irrigation purposes and 349.100.000 m^3 for drainage. These numbers indicate that a significant amount of water would already be available to compensate for drought if it were not, as is currently the case, immediately discharged into the sea. Nowadays, only a few areas are dedicated to water storage, and most of them are connected to the drainage network but not to the irrigation one. The challenge for the future is to gradually improve similar systems to respond to changing climate conditions and compensate for periods of water stress (Fig. 3).
In this context, the research question was straightforward: can we address increasing seasonal water shortages and flooding events by 'giving up', and transforming, low-productive croplands? Before even discussing this hypothesis, it is worth mentioning that there is an internal debate within

Fig. 1 – The Reclamation Consortium of Ferrara and its hydraulic infrastructure (elaboration by the Authors).

many consortia concerning the convenience – or not – of decommissioning hydraulic systems in proven under-productive and highly sunken districts. Although an increasing number of studies endorse this option (Di Giulio et al., 2017; Greiving and Puntub, 2018) and propose progressive retreating strategies from these areas, the common counterpoint opposes this approach, arguing that it would betray the mission of reclamation consortia and the efforts made by previous generations to conquer these lands for farming. Thus, what may seem like, at first sight, as a technical issue turns into a cultural and political matter that requires the establishment of more articulated strategies and forward-looking visions.

Landscape-oriented approaches have already proven in many contexts how it is possible to design in the terrain of water by relying on instability rather than on elusive, perhaps even detrimental, expectations of fixity (Rijke et al., 2012; Mathur and Da Cunha, 2014; Rossano, 2015). Following this concept, the present research depicts a path towards a different arrangement of the rural landscape in response to ongoing mutations in water availability while merging productivity instances with the safeguard of ecosystem services. The goal of the work was to

Fig. 2 – The network of canals stretching across the Consortium territory coupled with aerial views showing the traces of ancient canals and paleodunes (photos and elaborations by the Authors).

Fig. 3 – Picture from the Po riverbed during a severe drought event in 2022 (photo courtesy: ©Paolo Panni).

provide the Consortium, by the means of both quantitative-qualitative outputs, with an instrument capable of supporting decision-making processes, as well as political and social negotiations with other authorities and stakeholders. Specifically, the research aims at demonstrating how it is possible to enhance resilience towards prolonged drought periods by selectively transforming low-productive agricultural areas into new performative habitats capable of storing water during flood events and releasing it when necessary. To accomplish this, the project develops an intervention methodology that is based on the analysis soils' productivity (Agus et al., 2015). Using satellite imagery processing, suitable (low productive) areas to be transformed in water reservoirs, infiltration forests or aquifer recharge spots are identified and designed according to their pedological and topographical features. In this way, 'land aptitude', becoming a driver for landscape evolution has informed planning strategies and design solutions at different scales.

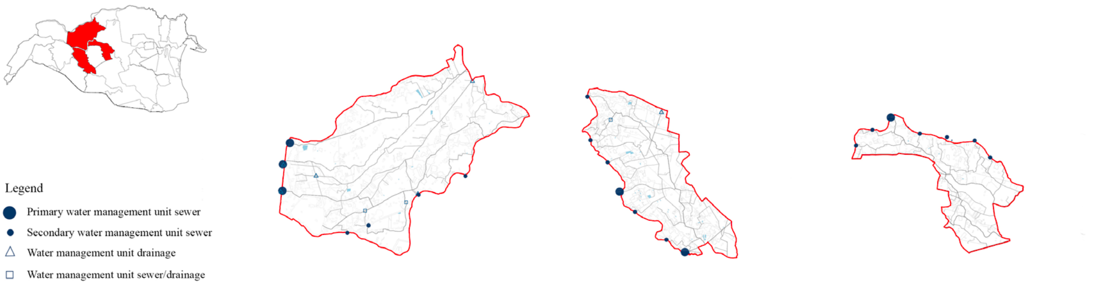
Scenarios' evaluation

In the RCF area, the water requirements to counteract periods of prolonged drought that will affect agriculture have been calculated according to 4 different scenarios at 2100, representing equally plausible future frameworks (Burt and Van Der Heijden, 2003; Emanueli and Lobosco, 2018) which, on long-term horizon, can happen within a range of controlled uncertainty. To quantify the amount of water needed in each scenario to fill the gap with current consumptions, two main field of variables have been set and intertwined: the water deficit for irrigation related to climate change forecasts; and the water savings rate depending on agricultural technique advancement.

The maximum and minimum values of the first variable were inferred from IPCC projections (Hoegh-Guldberg et al., 2018), by considering the trend of weather variations expected for the emission scenarios corresponding respectively to the Representative Concentration Pathway (RCP) 2.6 and 8.5. In order to quantify their impact on water availability, both the increasing number of consecutive drought days per year (37 in RCP 2.6; 54 in RCP 8.5) and the increasing number of extreme precipitation days per year (30 in RCP 2.6; 38 in RCP 8.5) have been used for calculating the prospective water deficit in each one of the 28 water districts composing the Consortium. It is important to underline that water deficit is correlated not only to drought, but also indirectly to the periods of intense precipitations which, concentrating a share of the annual rainfall in a short span of time, don't allow to maximize their use for irrigation since the most of this water is drained as soon as possible to the sea.

The second variable, concerning the advancements of agricultural techniques, has been tied to the potential diffusion of precision agriculture (PA), an integrated information and production-based system which can optimize the water supply up to a level strictly dependent on future land use polices (Deffontaines et al., 1995), partly beyond the control of the Consortium. The research hypothesis is that the related percentage of water savings may vary between two extremes: a 5% value, corresponding to a prospective context (named TA) in which traditional agriculture parcelling is still predominant and water savings are just related to crop-tailored irrigation scheduling protocols driven by geo-referenced remote sensing systems (Doron, 2017); and a 30% value corresponding to a prospective context (named PA) in which precision agriculture for water use optimization is fully implemented not only in technological, but also in practical terms, especially with respect to the arrangement of different crops according to inter- and intra-field characteristics rather than following land ownership and boundaries (Stafford, 2015).

Once set these variables, four different long-term scenarios were generated by their interaction. Each



1	District name:	EST BOICELLI	PRIMARO CAMPOCIECO	VOLANO CAMPOCIECO
2	Area:	12.680 ha	6.076 ha	4.264 ha
3	Water management sewer units:	9	8	9
4	Water management drainage units:	7	2	0
5	Current consumption:	4.120.000 m^3	2.350.000 m^3	3.300.000 m^3
6	Current discard:	12.230.000 m^3	4.930.000 m^3	6.450.000 m^3
7	Requirement TA 2.6:	450.000 m^3	260.000 m^3	360.000 m^3
8	Requirement TA 8.5:	680.000 m^3	390.000 m^3	540.000 m^3
9	Requirement PA 2.6:	320.000^4 m^3	180.000 m^3	250.000 m^3
10	Requirement PA 8.5:	470.000 m^3	270.000 m^3	380.000 m^3

Fig. 4 – Three of the 28 water districts composing the Consortium area and their relative data (elaboration by the Authors).

scenario features a specific amount of water storage needed for ensuring the current agricultural productivity rates under specific climatic and technological conditions forecasted at 2100. While giving an overall idea of the challenging issues ahead, these total volumes are more significant if analysed by their specific components. Data collected for each of the 28 water districts in the Consortium area (following the table in Fig. 4) allowed for an evaluation of the extent to which currently dispersed water (item 6) could theoretically fill the gap with respect to the different drought scenarios (items 7 to 10). This data enabled a first infrastructure-based assessment of the areas that could potentially be transformed from agricultural to water storage landscape.

Land-aptitude classification

To understand where and to what extent storage operations could be developed, an additional assessment concerning the pedological attitudes of the cultivated land was made by the means of remote sensing techniques (Di Gennaro et al., 2018). This assessment involved extrapolating crop yield potential from historical data series of the Normalized Difference Vegetation Index (NDVI) obtained from the AgroSat platform.

Such process allowed to render a good approximation of the agricultural un-productivity into a GIS-based cartography composed by those areas with a potential yield ranging from 0% to 30%, extrapolated from the main three colour gradient map describing: productive soil (60%-100%), medium productive soil (10%-50%), unproductive soil (0%-10%). In this way, a first operational-prescriptive criterium for possible water storage localizations and size has been set up and further characterised through metadata related to soil permeability, Lidar derived topography and surface aquifers depth. The overlapping of this set of information allowed to build a 'land aptitude' map (Fig. 5) providing the framework for the next strategic choices.

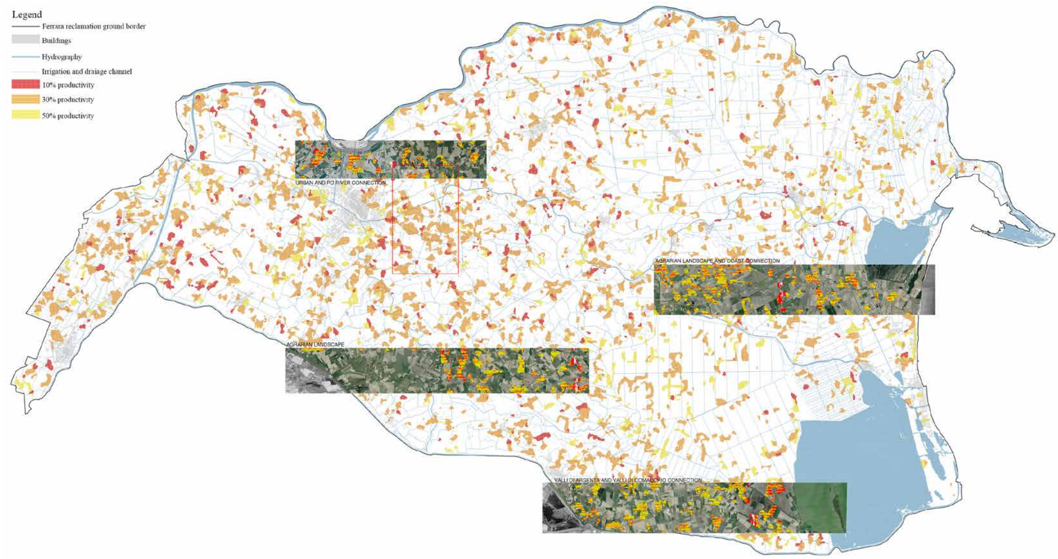


Fig. 5 – The 'land aptitude' map providing the framework for the next strategic choices. Red areas are more suitable to be converted from farming to wetlands (elaboration by the Authors).

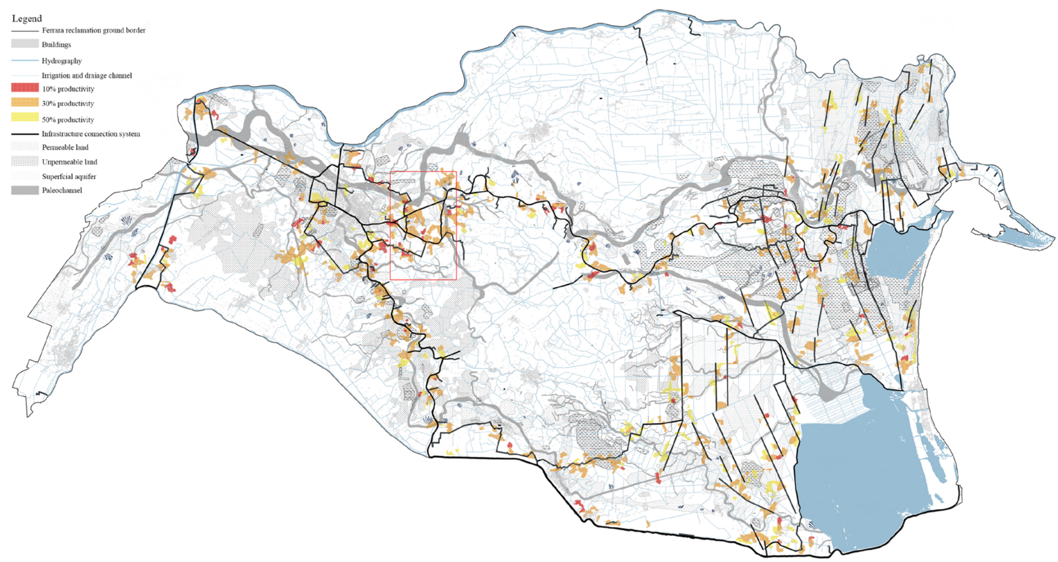


Fig. 6– The proposed 2040 strategic scenario representing the spatial transformation of unproductive agricultural areas into water storage devices (elaboration by the Authors).

In order to set an intermediate resilient landscape capable to counteract drought related issues with respect to a shorter time horizon, the georeferenced dataset has been filtered following two main strategic priorities: creating new environmental corridors and defending croplands from the increasing saltwater intrusion from the coast. With this aims a series of consecutive GIS-based operations were employed to select only those neighbouring unproductive areas located on the shortest path connecting existing 'natural' habitats and those positioned at the boundary of the current mixing zone of the salt wedge's influence area parallel to the coast.
Thanks to this multilayer interpolation, it was possible to identify the backbone of a perspective green-blue territorial infrastructure whose starting points of implementation are represented by unproductive areas and the space in-between them is where the Consortium can gradually plan a land use changing in the long run, by taking advantage, for example, of less space-consuming farming practices related to precision agriculture. The proposed 2040 strategic scenario (Fig. 6) depicts a punctual but diffuse network of potential landscape transformations against flood risk and in favour of water supply. Their highest concentration is along two rivers ('Po di Volano' and 'Po di Primaro') and nearby the paleo dunes systems featuring the eastern sector of the Consortium. By crossing the whole territory from east to west, such prospective infrastructure intersects different contexts providing a plethora of situations which have been the subject of further in-depth investigations aimed at quantifying the average storage capacity of each sample intervention to be projected over the whole network.

Multi-scale design proof

Therefore, the last step consisted in developing specific projects on two different scales exemplifying the hypothetical phases for implementing the program firstly on a medium-term and then on a long-term time horizon. These proposals were meant to supply both quantitative and qualitative information for assessing the overall impact of the strategy. In particular, the 3 local interventions designed on low-productive areas allowed to extrapolate parametric values for calculating the total reservoir capacity of the system in the prospected 2040 strategic scenario. Finally, how such type of actions may evolve into more complex and performing landscapes has been investigated by outlining two large-scale programs for the long run. Some preliminary strategic guidelines have been established, considering the state of the water infrastructure, the possibility of contracting with the Consortium's landowners and the economic feasibility of works. They consisted in:

- locating the interventions at the beginning point of major irrigation systems, next to the water intake points from channels to leverage existing equipment and serve the entire network during emergencies;
- developing on highly unproductive sectors, instead of large water reservoirs, multi-composed storage and infiltration devices, better responsive to the NDVI-based characterization and to soil's texture and structure variations (permeability), also more adaptive to the current land division and less expensive;
- combining such systems, within a 100-meter buffer zone parallel to the main channels, with Forested Infiltration Areas (FIA), phytoremediation ponds, cover crops, perennial grasses or native vegetations more apt to tolerate the so-called 'microlaminazione' technique, namely a widespread-low-depth version of retarding basins, which allows the gravitational percolation of water, taking advantage of very low slopes (around 3‰) of fields;
- incentivizing precision-automatized agriculture in the nearby productive areas through coopera-

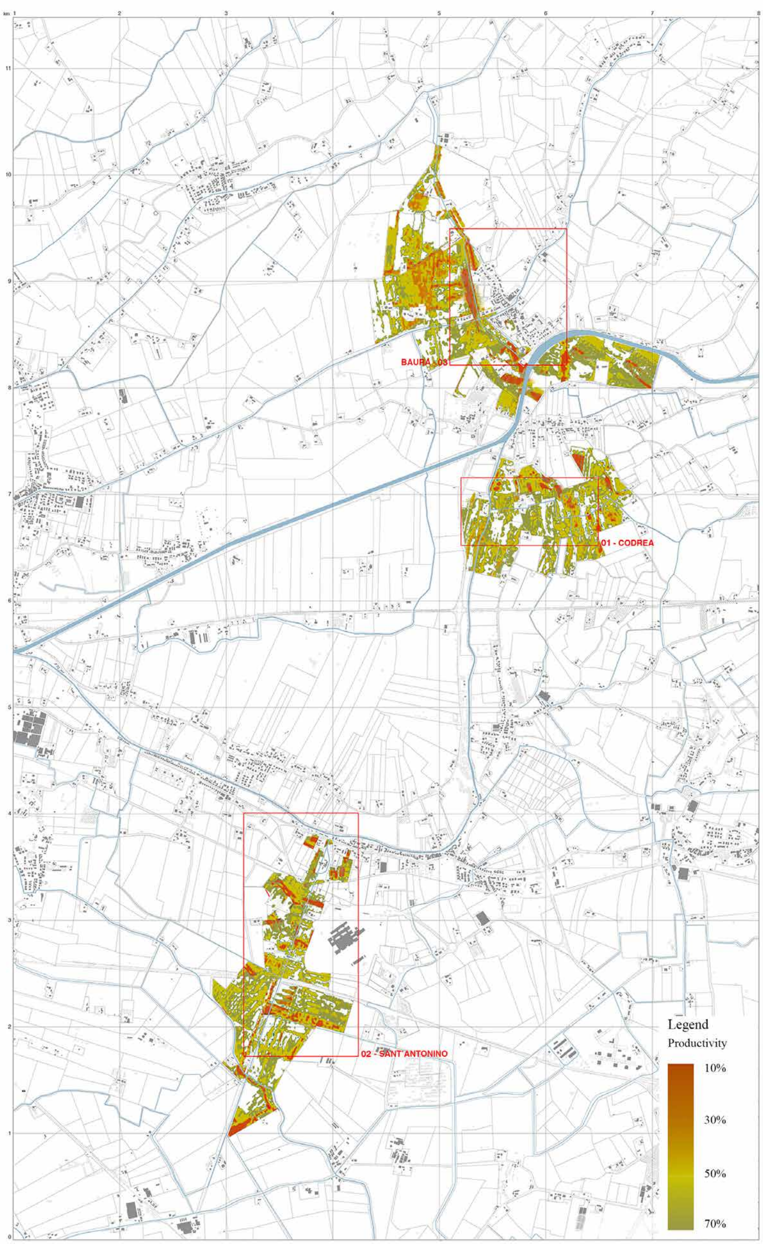
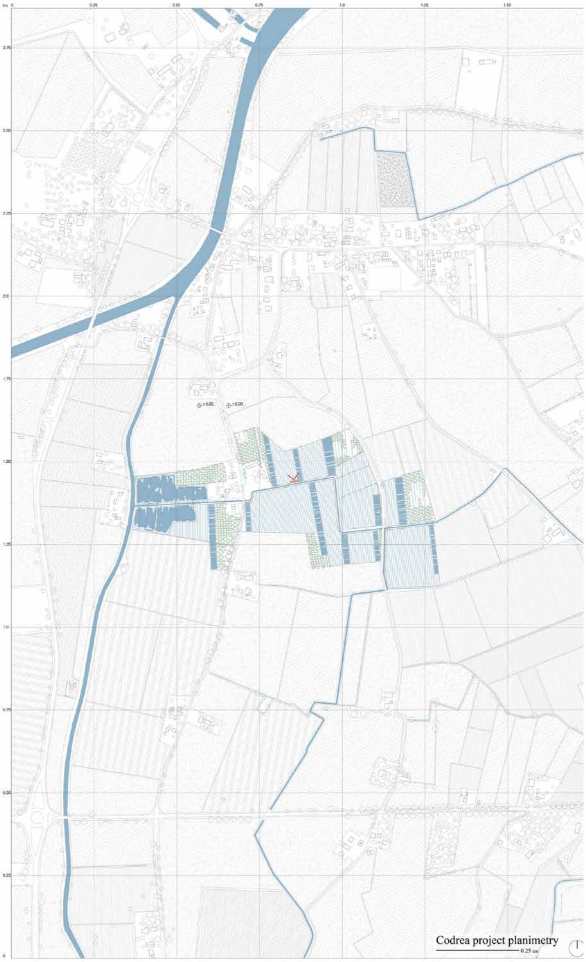


Fig. 7 – Localization of the three local case studies with their respective 'land aptitude' analyses (elaboration by the Authors).

tion agreements between landowners to develop and monitor pilot experiences on a wider range of farm types and sizes;

- integrating water management interventions with site-specific programs addressed to improve the public spaces quality of rural settlements, the accessibility to landscape amenities and the reconnection of fragmented habitats.

Upon these general criteria, three local interventions were developed along the Po di Volano River's area (Fig. 7), one of the main trajectories identified through the scenario transfer operation.



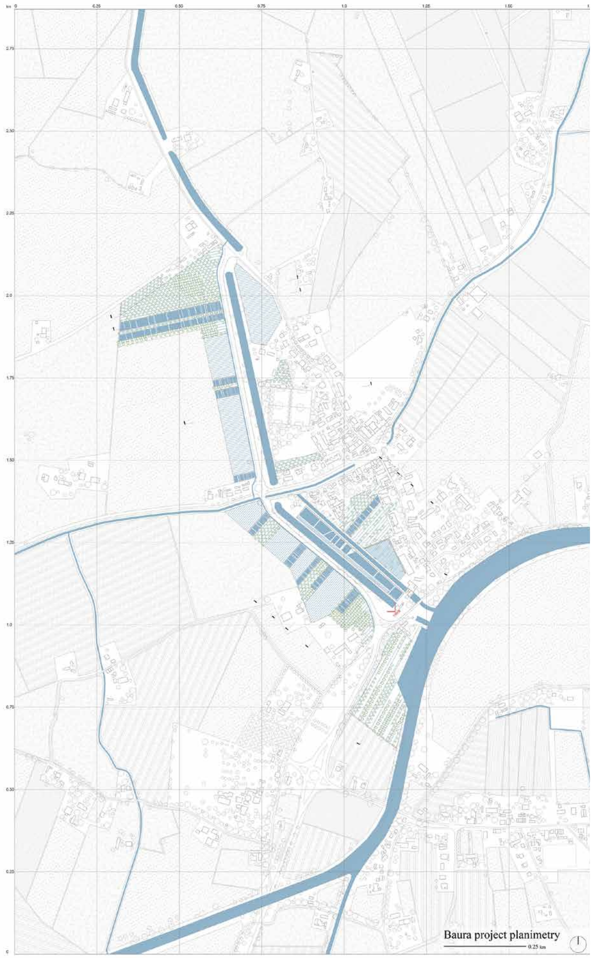


Fig. 8 – The Codrea case study. Note the large storage tank adjacent to the river, from which linear water depot, microlamination and forested areas of infiltration branch off (elaboration by the Authors).

Fig. 9 – The Sant'Antonino case study. The water management systems are integrated in a park next to the Cona Hospital where wetlands and collective spaces hybridize with each other (elaboration by the Authors).

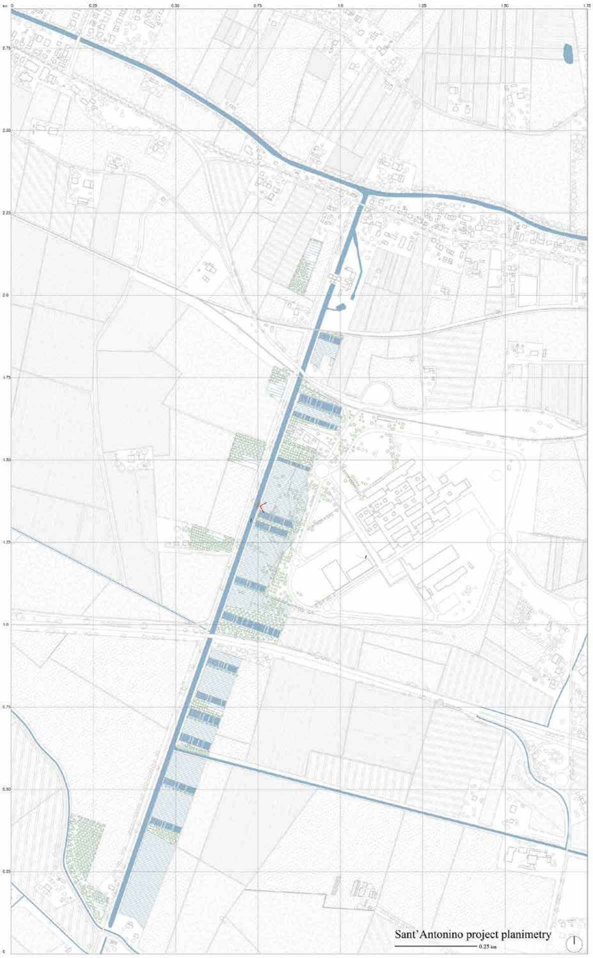


Fig. 10 – The Baura case study. Water purification systems are arranged on the left side of the canals, while on the opposite side a floodable square blurs urban and agricultural patterns (elaboration by the Authors).

The Codrea case study (Fig. 8) is carried out on a rural area in the countryside of Ferrara involving the croplands along an irrigation canal branching off from the Po di Volano River. Here, the soil productivity is taken into account for identifying the most suitable areas to be devoted to water storage and infiltration (i.e. aquifer recharge). At the same time, the ground topography and the soil composition inform the choice of the different landscape devices addressed to those functions. In fact, the project area can be distinguished in two portions. The higher and most impermeable one at the mouth of the canal, corresponding to the Po di Volano paleo river, houses an extensive phytoremediation. From here, without pumps but using gravity, the water is then diverted towards the lower part whose spatial articulation is determined by a sequence of water deposit bands sized to meet the storage needs while being adaptable both to the structure of private properties and soil productivity. Each band integrates an aquifer recharge section at the end which is meant to be activated in case of water overload: made of ponds and drainage wells, it is hydraulically connected with neighbouring areas. These last ones, keeping their productivity function, are converted into infiltration groves (also for shading the water basins contrasting evaporation) and hydrophilic crops in order to work as micro-lamination areas during extreme rain events.

The unusual feature of the Sant'Antonino site is the presence of an outsized building serving the city in a rural area: the Sant'Anna Hospital with its huge car parking stands beside an important drainage channel flowing toward the Po di Volano River. In this application (Fig. 9), the water storage system, developed according to the same above-mentioned principles, has also the aim of cleaning the water runoff from the hospital district before it reaches the canal. By this way, the right side of the watercourse, instead of an unproductive 'terrain vague', becomes a linear floodable park providing the health facility

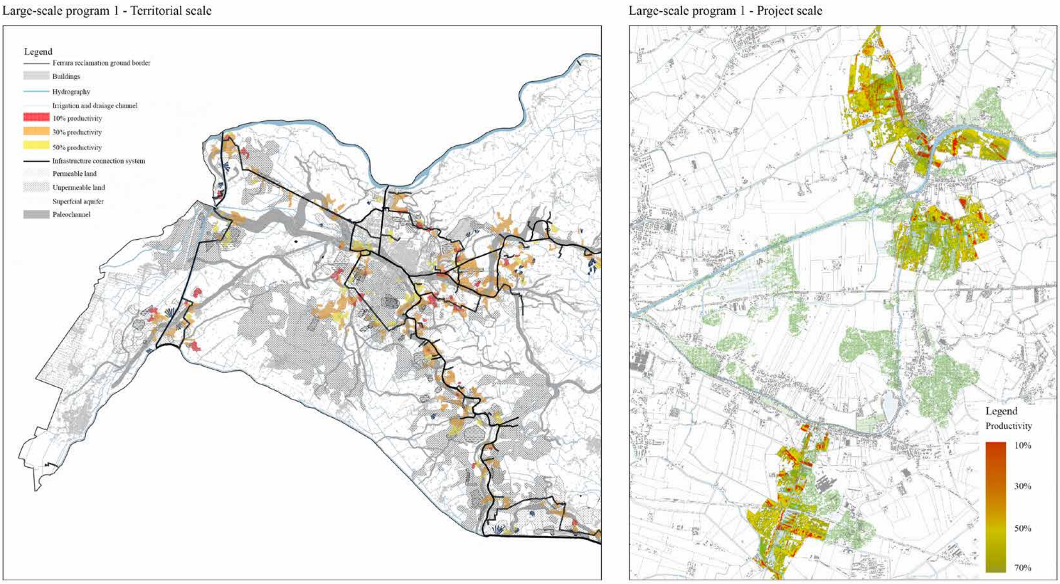


Fig. 11 – The western large-scale program concerns a new unitary ecosystem of wetlands that shapes a green-blue belt around the city of Ferrara; on the right, a zoom of the masterplan connecting the local interventions proposed (elaboration by the Authors).

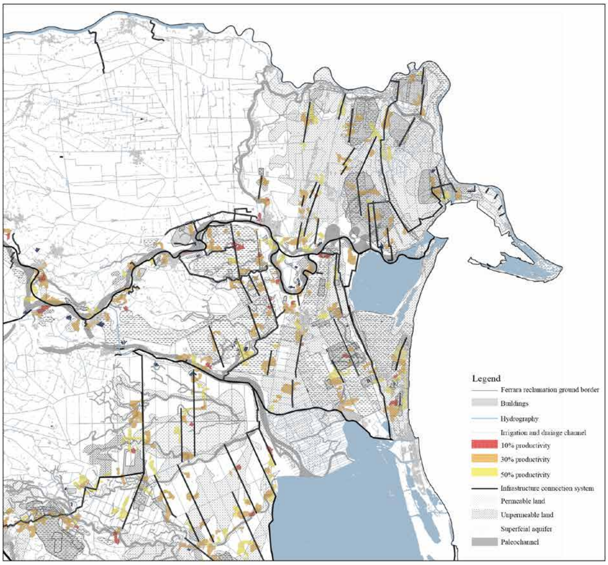
with a space for outdoor activities and with a green-blue infrastructure capable of mitigating the parking heat island during the summer thanks to the water's evaporation pushed in that direction by the prevailing winds.

The Baura case-study (Fig. 10) deals with an intricate hydraulic system composed by three main elements: the Po di Volano River which flows 3 meters above the surrounding lands; an irrigation canal that, branching off from the river, runs along the west side of the village and enters a subsequent one to the north called Canale Naviglio; then, an additional western channel, beside the former one but flowing in the opposite direction, which drains its waters into the river by means of a mechanical lifting system. In this context, the main issue is to manage the risk of flooding during intense precipitations that also cause frequent contaminations of the canals by the village wastewater. To better regulate the levels of the drainage system, the project aims at expanding its retention capacity, slowing down the run-off towards the river by a series of floodable areas placed on either side of the bundle consisting of the two channels. In the strip of land between them, taking advantage of the lower flowing level of drainage waters, a new phytoremediation wetland is created to treat the waters before they reach the irrigation network.

Following a bottom-up approach, the research assumes that local interventions, as the ones described above, might work as milestones for wider transformations. Such perspective was investigated by outlining two strategic masterplans dealing with different environmental issues.

The first large-scale program (Fig. 11) consists in a forward-looking implementation of the previous three case studies embedded in the design of a unitary wetlands' ecosystem forming a green-blue belt around the city of Ferrara. The system connects all the pulverized unproductive areas identified, expanding their retention capacity and acting as an ecological corridor in contrast with the homogeneity of the rural landscape. Its position at the edge of the peri-urban area of the town allows to address

Large-scale program 2 - Territorial scale



Large-scale program 2 - Project scale

Fig. 12 – The eastern large-scale program envisages a striped landscape made of 156 km linear woodlands aimed at protecting farming areas from saltwater intrusion and desertification; on the right, a zoom of the masterplan on a reclamation area next to the coast (elaboration by the Authors).

some land degradation processes that typically affect such porous and transitory contexts where housing and industrial developments extend, often with no foresight, into the rural. So, the masterplan aims to provide a buffer against land consumption by setting up both a physical boundary and an environmental infrastructure capable of preserving the productivity of the leftover farmlands into the urban fringes. Besides that, the implementation of new humid ecosystems is expected to better manage the increasing water run-off, face to more intense rainfalls, that the existing large industrial areas, at the outskirts of the city (such as the petrochemical hub on north-west or the Cona Hospital on the south-east), are going to produce. In this perspective, the constructed wetlands will also operate as a pollution control tool assuring natural cycles of phytoremediation for waters coming both from sealed (urbanised) areas than from intensive farming plots. Also according to this function and the necessity of preventing undue evaporation, most of the system will be featured by the re-creation of floodplain swamp forests that anciently were spread across the territory and now are almost disappeared: composed by various hydrophilic tree species (like oak, alder, willow, elm, maple, ash, white and black poplar), their closed-canopy structure assures shade and especially ideal microclimatic conditions to host a wide range of biotopes depending on soils' texture and morphology. So, along its 55 kilometres extension, the proposed green-blue belt is expected to have significant impacts not only upon agricultural uses and productivity, but also on biodiversity and environmental services through the interconnection of fragmented habitats around the city.

The second large-scale program (Fig. 12) insists on the eastern part of the Consortium where the saltwater intrusion is significantly endangering agriculture through its advance along rivers and into the soil. Extending up to 30 kilometres inland, such process affects the most those reclamation areas located on the back of the ancient paleo dunal cordons outcropping parallel to the coast between Taglio di Po and the Comacchio Valleys. On these lowlands, where the soil salinity level is high already between 50 and 100 cm, it is crucial to infiltrate as much as possible freshwater in order to push down the interface layer with saltwater. With this aim, the masterplan identifies from north to south a discontinuous bundle of agricultural areas in which to develop MAR (Managed Aquifer Recharge) plants (Dillon et al., 2019), transforming water consuming fields into storage and percolation devices. The stripes composing the system are arranged to sort out a pattern of linear woodlands which is supposed to work as a barrier against desertification processes thanks to the combined action of retention and infiltration areas. Indeed, each strip, given its considerable length (up to 10 km), can exploit the different soil textures (mainly sandy, loamy or clayey) determined by the geological formation of the alluvial valley for hosting a series of habitats hydraulically connected and capable of managing storm water outside the drainage network to gradually release it to the ground in unsaturated areas. A key-role in this process can be played by the so-called Forested Infiltration Areas: constructed deep rooting forests with a productive vocation that allow water to permeate faster into the soil, preventing evapotranspiration (Mezzalira et al., 2014). According to the proposed scheme, the future agrarian landscape, instead of the current homogeneous scenery, may evolve into a more various system where farming and crops distribution will follow the ecotone resulting from a new spatial distribution of water resources and ground salinity (Fig. 13).

The strength of an integrated strategy

Through a multi-scalar approach, the research has been addressed to prove at different scales the effectiveness of an integrated strategy that considers both productive expectations and the realistic assessment about those lands which should be directly or not devoted to farming. At the scale of the three exemplar case studies, such program would allow to reach the quantitative results, synthesized in the Table 1. Each intervention is expected to cover approximately 5-7% of the water deficit in the worst-case scenario, while in the best-case scenario, this percentage could increase to 12-15%. Given that the three districts have multiple intake points where similar transformations could be implemented, the goal of storing enough water to fully compensate for prolonged drought periods is highly achievable in the long run, especially considering that each proposed project affects less than 1% of its respective catchment area.

Such hypothesis has been verified by projecting the results obtained from previous calculations to the scale of the entire consortium territory (Tab. 2). The selected low-productive areas which are supposed to be transformed in a medium-term horizon (2040) amount to the 5,4% of the current croplands located among 97 water intake points along the channels network. Referring to the performances analysed in the case studies, the total reservoir capacity of the system is estimated at 33.642.000 m^3 per year, half of which can be directly used for irrigation, while the leftover will be stored underground by infiltration. In this way, almost 10% of the water that the consortium currently moves, instead of being directed to the sea (and wasted), will be kept out of the network, contributing, on the one hand, to improving the performance of the drainage system during extreme rainfalls and, on the other hand, to ensuring a reserve of water for periods of drought. The latter quantity, corresponding to 16.020.000 m^3 per year, represents 38 to 80% of the total projected water demand for each reference scenario in 2100. This means that the proposed system could provide, in just a few years, a valid response to water stress and, above all, lay the foundations for a resilient evolution of the rural landscape.

In fact, the two large-scale masterplans outlined show possible paths for extending the new water

Fig. 13 – The evolution of the future agrarian landscape: from actual conditions to a new symbiotic landscape passing through specific interventions (elaboration by the Authors).

management system far beyond the low-productive areas selected in order to reach more ambitious goals by 2100. The main output of the green-blue belt programme around Ferrara is to provide the Consortium with a vision to share with stakeholders and local authorities to initiate a process of negotiation and promote further in-depth studies to confirm the feasibility of the proposal. The same applies to the second design suggestion concerning the striped landscape made of 156 km linear woodlands aimed at protecting farming areas from saltwater intrusion and desertification. Ultimately, both masterplans represent a forward-looking strategic framework without which even shorter-term implementations risk failing due to a lack of consensus and perspective.

Unproductive soil as a driver for landscape adaptation

The research explored the hypothesis of using unproductive soil as a driver for landscape adaptation to climate change, showing its potential in addressing strategic and design actions to face water stress. Despite its limitations, the research demonstrates how degraded lands can turn into resources for the entire agricultural sector and the rural landscape. Such evidence is strengthened by the two proposed large-scale visions whose deeper objective is to shift the focus from 'flat' data to more 'telling' representations of the long-term opportunities that landscape planning can generate by translating regional policies into site-specific processes of change rather than limited and vague good practices.

In this sense, the conceptual 'attachment to the soil' featuring the research is an attempt to overcome generalisations while detecting spatial patterns where to develop green-blue infrastructures. Such an approach seeks to update some fundamental experiences and reflections on the importance of soil as a crucial determinant for the landscape planning (McHargh, 1969; Secchi, 1986; De Roo and Rauws, 2012; Lobosco, 2020). That is why its precise characterization is a major topic especially for what concerns the availability of high-resolution historical data regarding for example land productivity (Bucci et al., 2019) and drought impacts on water resources (Wilhite et al., 2007). In practice, a similar goal can only be achieved through remote sensing monitoring systems (Prince, 2019) far more sophisticated and exhaustive than those used in this study which just represents a first demo application of its kind in the Italian context.

Although further investigation is undoubtedly needed to refine the results obtained, an unequivocal issue raised by this work is the urgency of a regulatory framework on the payment for ecosystem services (Rodríguez-Robayo and Merino-Perez, 2017) which would represent a key lever for the implementation of ambitious programmes in complex agrarian contexts, as the Italian one, characterised by a high fragmentation of properties and by a considerable morphological diversity. Fortunately, the reclamation Consortia already have an equalisation tool by law that could be adapted for this purpose: the so-called 'Classification and Allocation Plan' identifies different macro-zones of the territory according to the benefits they receive from the consortium operations (drainage and irrigation) and on these bases it allocates the charges to be paid by landowners. So, if improved with new criteria concerning, for example, the value of ecosystem services provided by constructed wetlands or aquifer recharge devices (De Giglio et al., 2018) and if integrated with real-time high-resolution monitoring systems, such instrument will really be able to support a balanced land-use reform based on the intrinsic characteristics of the soils.

As this article has tried to prove besides new tools, also a cultural shift is needed on what is meant by a productive rural landscape especially in view of radical changes that will affect the availability of ba-

Case study - Water district	Water district Area (ha)	Trans-formed Crop-lands (ha)	Percentage of transformed areas over the entire water district	Water district annual consumption (mc)	Retain capacity for irrigation after the project (mc)	Drought requirements quantities for each scenario (mc)			
						TA 2.6	PA 2.6	TA 8.5	PA 8.5
CODREA Volano Campocieco	4.265	38	0,89%	3.300.000	38.465	360.000	250.000	540.000	380.000
					Percentage incidence of the project	**10,68%**	**15,39%**	**7,12%**	**10,12%**
SANT' ANTONINO Primaro Campocieco	6.076	27	0,44%	2.350.000	22.633	260.000	180.000	390.000	270.000
					Percentage incidence of the project	**8,71%**	**12,57%**	**5,80%**	**8,38%**
BAURA Est Boicelli	12.681	24	0,19%	4.120.000	41.296	450.000	320.000	680.000	470.000
					Percentage incidence of the project	**9,18%**	**12,91%**	**6,07%**	**8,79%**

Tab. 1 – Quantitative results of the three local projects (elaboration by the Authors).

Total cultivated area of the Consortium (ha)	Convertible Croplands (ha)	Percentage of convertible areas over the entire Consortium	Amount of water discharged in the sea by the Consor-tium (mc)	Water retain potential of convertible areas (mc)	Percentage of water potentially off the drainage network after the project im-plementation
178.000	9.612	5,40%	349.100.000	33.642.000	9,64%

Retain capacity for irrigation af-ter the project implementation (mc)	Drought requirements quantities for each scenario (mc)			
	TA 2.6	PA 2.6	TA 8.5	PA 8.5
16.020.000	27.470.000	19.980.000	41.210.000	28.840.000
Percentage incidence of the project	**58,32%**	**80,18%**	**38,87%**	**55,55%**

Tab. 2 –Quantitative results of the medium-term program at the scale of the whole Consortium (elaboration by the Authors).

sic resources such as water (Heijman et al., 2019). In fact, cultivated land converted into water management devices or ecological reserves cannot be considered as something detached from the entire agricultural system, since their contribution will be increasingly crucial to ensure lasting and good quality harvests. At the same time, their function as water regulators, biodiversity generators and landscape hotspots will make them one of the main components in achieving a symbiotic relationship between the city and the countryside, which perhaps is precisely the duality to overcome in order to effectively tackle climate change.

In the same perspective, it is equally important to consider 'time' as a key factor for the success of transformations involving complex environmental systems such as those investigated in this research. Today more than ever, it's crucial to set in motion processes that can reform the perception of water landscapes among citizens and decision-makers. This will help them develop a more intimate understanding of habitats that are inherently variable and subject to significant changes in both the short and long term. The persistent notion of rural landscapes as static and unchanging is not only historically inaccurate but also a dangerous anaesthetic to climate awareness. In this regard, landscape design has a crucial role to play in shaping the space where mutations can happen unleashing their full aesthetic and functional potential.

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