ISSN 1831-9424

European Commission

JRC SCIENCE FOR POLICY REPORT

Nature-based solutions for agricultural water management

Characteristics and enabling factors for a broader adoption

Pistocchi, A. (editor)

2022

Joint Research Centre

EUR 31351 EN

Contact information
Name: Alberto Pistocchi
Address: via E.Fermi 2749 – 21100 Ispra, Italy
Email: alberto.pistocchi@ec.europa.eu
Tel.: +39-0332-78-3658

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC131465

EUR 31351 EN

PDF ISBN 978-92-76-60487-7 ISSN 1831-9424 doi:10.2760/343927 KJ-NA-31-351-EN-N

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Pistocchi, A. (ed.), *Nature-based solutions for agricultural water management — Characteristics and enabling factors for a broader adoption*, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/343927, JRC131465.

Contents

Abstract

Nature-based solutions (NBS) may be cost-effective in addressing water management issues in agriculture, while delivering other benefits such as biodiversity, recreational opportunities, climate adaptation. Treatment wetlands enable the removal of excess nutrients from manure in areas with limitations to fertilizers application. Reed beds may be a cheap and operationally simple option for the treatment of sludge before application to agricultural land. When treating domestic wastewater sludge with little runoff and industrial contributions, likely to contain low levels of metals and other persistent contaminants, the long retention time of reed beds ensures degradation of the less persistent chemicals, hence potentially a sludge of good chemical quality that could be a valuable soil conditioner. These solutions may be often financially self-sustainable.

Buffer strips and ponds are effective ways to control diffuse pollution. Their broad implementation may be cost-effective in reducing nutrient and pesticide loads to the receiving water bodies. However, they require public investments or anyway payments to farmers, as they represent net costs for them. Similarly, while ponds to store water for irrigation may be sustainable investments for farmers, their design oriented to support biodiversity entails extra costs that should be compensated in order to make them feasible. Similar considerations apply to in-stream retention measures such as two-stage design of drainage channels.

In some cases, there can be opportunities to restore valuable ecosystems while improving water management, although usually measures at the scale of the catchment require public support to trigger the investments needed to deliver the full benefits. An example of this is the restoration of lake Karla in Greece as a multi-purpose reservoir. Finally, in other cases it may be possible to obtain significant benefits with relatively simple management changes, entailing limited costs, as suggested by the example of blocking the drainage of headwater streams in the Kyll river basin in Germany.

The implementation of NBS requires an assessment of costs and benefits in comparison with their “grey” alternatives, and the definition of appropriate “business models” to secure their broad uptake and sustainable operation.

Acknowledgements

This Science for policy report was prepared to summarize the key outcomes of the Project "Nature-based solutions for climate change adaptation and water pollution in agricultural regions (NB SOLUTIONS)" supported by Administrative Arrangement N °34027704/2018/789016/Aa/Env.C.1 between DG Environment (DG ENV) and DG Joint Research Centre (JRC) (JRC Contract Number 35003). The content of this report is based upon, and includes text from consultants' reports, procured by the JRC during the project. Specific references to the original reports are provided at the appropriate points in this report. The respective authors are gratefully acknowledged. JRC colleague Bruna Grizzetti and an anonymous reviewer provided very useful comments that helped improve this contribution.

Authors

This report was prepared by A.Pistocchi (JRC) on the basis of content provided by the experts listed below.

1) Case study Kastelir (HR): Anja Potokar, Urša Brodnik, Alenka Mubi Zalaznik, Tea Erjavec, Gregor Plestenjak, Martin Vrhovšek, Alenka Fajs, Ivan Kolev, Cveta Dimitrova, Carlos A. Arias, Pedro Carvalho
2) Case study Mojkovac (ME): Anja Potokar, Alenka Mubi Zalaznik, Tea Erjavec, Ursa Brodnik, Gregor Plestenjak, Martin Vrhovšek, Ivan Kolev, Cveta Dimitrova, Carlos A. Arias
3) Case study San Rocco di Piegara (IT): Giulio Conte, Riccardo Bresciani, Anacleto Rizzo, Alessandro de Carli, Leonardo Borsacchi
4) Case study Kyll river, German Middle Mountains (DE): Yurena Lorenzo, Jos de Bijl, Maarten Waterloo, Anouk Gevaert, Rob Nieuwkamer, Lena Vitzthum, Olaf de Haan
5) Case study Ritobäcken (FI): Kaisa Västilä, Sari Väisänen, Jari Koskiaho, Virpi Lehtoranta, Krister Karttunen, Mikko Kuussaari, Juha Järvelä, Kauko Koikkalainen
6) Case study Lamone (IT): Andrea Staccione, Davide Broccoli, Paolo Mazzoli, Stefano Bagli, Jaroslav Mysiak
7) Case study lake Karla (EL): Yiannis Panagopoulos, Elias Dimitriou
8) Case study Venice lagoon (IT): Giulio Conte, Riccardo Bresciani, Anacleto Rizzo, Alessandro de Carli, Leonardo Borsacchi, Bruno Boz
9) Case study Latina (IT): Giulio Conte, Riccardo Bresciani, Anacleto Rizzo, Alessandro de Carli, Leonardo Borsacchi, Stefano Magaudda, Flavio Camerata
10) Research Synthesis: Giulio Conte, Riccardo Bresciani, Nicola Martinuzzi, Anacleto Rizzo, Andrea Nardini.

The report reuses parts of reports or papers provided by the above experts (see citations), under a Creative Commons license.

Executive summary

Policy context

The European Union (EU) aims at protecting biodiversity and ecosystems while ensuring sustainability of agriculture. Nature-based solutions (NBS) may be effective instruments to achieve the first goal while enabling effective management of resources for agricultural production. Among others, the EU Biodiversity Strategy for 2030 indicates NBS as important implementation tools.

In order to support the identification and planning of appropriate NBS for water management in agriculture, we have examined the characteristics of selected types of NBS in real cases of application across EU, considering technical performances, costs and benefits, along with the management and financial conditions that make their implementation possible and desirable.

Key conclusions

NBS are often an effective option, preferable to their « grey » alternatives because of the additional benefits they deliver, while not entailing excessive costs. While the technical aspects of NBS are relatively well known, their implementation requires particular attention in order to ensure they may deliver as many benefits as possible. In particular, it is important to secure regular funding for their implementation and management, and to define an appropriate "business model" clarifying who does what, who pays for what and to whom.

Main findings

Treatment wetlands enable cost-effective treatment of excess manure from intensive animal farms and stabilization of sludge before application on agricultural land. Usually these NBS can be a good investment for the operators of the facilities, compared to "grey" alternative solutions.

Buffer strips and ponds, as well as enhanced in-stream retention with two-stage channel design, can be cost-effective in removing nutrients and other pollutants while helping regulate water flows (floods and low flows). They are a net cost for farmers, or anyway they are more expensive than less ecologically-informed alternatives. Therefore their implementation requires funding, which may come from the public budget (including payments under the European Common Agricultural Policy, CAP) and/or from payments for benefits by well-identified local stakeholders. Similar considerations apply to water storage ponds for irrigation, entailing extra costs if they have to provide ecological functions in addition. Implementation of these measures by individual farmers may reduce costs but could not always ensure optimal performances, while their "centralized" implementation by a technical authority could ensure more uniform and effective design and management.

In some cases, such as the restoration of the Karla lake in Greece, a centralized design and management was indispensable as no single group of stakeholders could make the investments required. However, once implemented, the measure proved to deliver benefits exceeding the investment, including in terms of supporting biodiversity.

In other cases, relatively small changes in management, with limited investments, could deliver substantial benefits, as in the case of blocking headwater streams in the Kyll river basin in Germany, thus enhancing water retention.

Related and future JRC work

The report provides a base of evidence supporting the promotion of NBS in water management for agriculture. The JRC conducts policy scenario analyses on water quantity and quality, that may be informed in the future by the considerations presented here.

Quick guide

Chapter 2 illustrates the characteristics of the various NBS considered in this work, while Chapter 3 discusses the quantification of costs, benefits and identification of enabling conditions and hurdles to the implementation of NBS for water management in agriculture.

1 Introduction

Nature-based solutions (NBS) are increasingly regarded as an effective way to address water management and adaptation to climate change in different contexts, alongside more traditional technical measures.

The European Union is committed to develop nature-based solutions, and supports various initiatives in this direction including research and innovation projects: *"Nature-based solutions are innovations inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. They bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services."([1])*

NBS are identified as one key tool for the implementation of measures in the context of the EU Biodiversity Strategy for 2030 ([2]), whose "Pillar Three" (enabling transformative change) includes the objective to "*unlock at least €20 billion a year for nature and ensure that a significant proportion of the 30% of the EU budget dedicated to climate action is invested in biodiversity and nature-based solutions.*"

Nature-based solutions are supported in many different contexts, by very different actors in the world. Examples:

1. The World Bank : *"Nature-based solutions are actions to protect, sustainably manage, or restore natural ecosystems, that address societal challenges such as climate change, human health, food and water security, and disaster risk reduction effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. For example, a common problem is the flooding in coastal areas that occurs as a result of storm surges and coastal erosion. This challenge, traditionally tackled with manmade (grey) infrastructure such as sea walls or dikes, coastal flooding, can also be addressed by actions that take advantage of ecosystem services such as tree planting."* ([3])
2. The International Union for the Conservation of Nature *(IUCN): "Nature-based solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature. Nature-based solutions address societal challenges through the protection, sustainable management and restoration of both natural and modified ecosystems, benefiting both biodiversity and human well-being. Nature-based solutions are underpinned by benefits that flow from healthy ecosystems. They target major challenges like climate change, disaster risk reduction, food and water security, biodiversity loss and human health, and are critical to sustainable economic development."* ([4])

The EU has supported many research and demonstration projects on NBS, showing evidence that investing in these measures may effectively deliver on biodiversity, climate and other policy objectives ([5]). An area of particular interest for the development of NBS is the implementation of the Water Framework Directive 60/2000/EC and the Floods Directive 60/2007/EC ([6]).

In the agricultural sector, certain natural or managed landscape elements, such as vegetated buffer strips, marshes, wetlands, ponds, represent nature-based solutions, as they may be effective means to retain water and enhance the natural attenuation of pollution; at the same time, these elements may deliver benefits beyond water management, particularly as shelters for biodiversity, amenity and recreational opportunities, micro-climate enhancement etc.

Water retention through nature-based solutions may effectively help cope with reduced water availability due to the hydrological consequences of climatic change. Hence NBS can be considered for inclusion in programmes

[1] https://rea.ec.europa.eu/funding-and-grants/horizon-europe-cluster-6-food-bioeconomy-natural-resources-agriculture-and-environment/nature-based-solutions_en
[2] https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en#documents
[3] https://www.worldbank.org/en/news/feature/2022/05/19/what-you-need-to-know-about-nature-based-solutions-to-climate-change
[4] https://www.iucn.org/our-work/nature-based-solutions
[5] https://op.europa.eu/en/publication-detail/-/publication/d7e8f4d4-c577-11ea-b3a4-01aa75ed71a1
[6] https://op.europa.eu/fr/publication-detail/-/publication/d6efaeeb-d530-11ea-adf7-01aa75ed71a1/language-en/format-PDF/source-143389333

of river basin management measures and in the programmes of the Common Agricultural Policy (CAP), and implemented through various investment programmes.

The IUCN has proposed a “global standard” for the design and verification of NBS ([7]). These solutions require careful planning, design and management in order to deploy the benefits they are intended to provide, particularly in terms of nature protection.

In this report, we limit our scope to analysing the characteristics of specific solutions, without consideration of their broader implications. Our considerations do not support the recommendation to adopt the types of NBS we address in this report, without a careful analysis of the context. For instance, we discuss how ponds intended for the storage of irrigation water may help create habitat, improve ecological connections and consequently support biodiversity. However, the fact of collecting water to support irrigation may not be in itself a sustainable measure in many cases. In a similar way, a wetland may be good for the treatment of manure, but intensive livestock production may not be appropriate in itself in a given context.

In order to better understand the technical, socioeconomic and ecological conditions enabling or hampering the development of NBS as a mainstream agricultural water management option in various context of the European Union (EU), we developed a set of 9 case studies. These provide a homogeneous base of evidence about the practical feasibility, effectiveness and limitations of NBS to address a variety of issues. The case studies, together with the broad literature and other examples already known in Europe and elsewhere, were used in a research synthesis exercise with the goal of identifying criteria for the assessment of costs, effectiveness and benefits of NBS for agricultural water management at the EU scale (see Pistocchi, 2022). The research synthesis has led to the definition of:

- relationships between each solution’s dimensional parameters (e.g. area, volume), landscape and climate (e.g. topography, temperature) and effectiveness (e.g. nutrient retention);
- relationships between each solution’s dimensional parameters (e.g. area, volume), and region-specific implementation costs;
- A valuation of the direct and indirect benefits through value transfer approaches.

In this project, we considered three case studies for each of the following broad categories of NBS:

A. **Constructed wetlands** or other solutions exploiting natural processes under human control, with well-identified input flows and required effluent standards, **for the treatment of manure-derived wastewater and sludge** before application as fertilizer.

B. **Landscape elements addressing diffuse sources of pollution** due to fertilizers and/or pesticides (and associated metals); unlike the previous category, in this case the landscape elements are “passive” (i.e. the natural processes they support are not man-managed) and treat input flows which are not precisely identified a priori, depending on the landscape, climate and fertilizer/pesticide application on the fields. Examples of such elements include buffer strips along water bodies.

C. **Landscape elements addressing water retention** to sustain water availability during dry periods, also as a means to cope with climate-induced water scarcity, and to adapt to climate change. Examples of such elements include ponds and small lakes in agricultural areas, or marshes like those traditionally built for the treatment of hemp and other fibres in parts of Southern Europe.

The pilot case studies focused each on one existing NBS, and address, with reference to their specific context and instance, the following general questions:

- How can NBS help mitigate hydrological events at farm to catchment scale?
- How can they contribute to mitigate agricultural water pollution (nutrients, pesticides, sediments, and other contaminants)?
- What are the costs and cost drivers of NBS?
- What are the benefits they deploy?

[7] https://portals.iucn.org/library/node/49070

- What are the technical, capacity, governance, management and financial constraints hampering their take-up?

Hence, each case study addressed the direct and indirect benefits (recreation, landscape improvement and value of land, flood protection, biodiversity, etc.); the investment, operation and maintenance costs of the examined NBS and their generalization (e.g. per hectare of landscape element, or per m^3 of treated water/waste); the bottlenecks for implementation and barriers to innovation (financing, funding, capacity, culture and behaviour, competing interests, governance etc.), how these were successfully addressed in the case, and where they may be anticipated to be more limiting. Finally, it identified a "business model" that could be proposed for broader implementation of the type of NBS in point, and qualitative and quantitative criteria to judge the applicability of the NBS case to the whole EU.

The outcomes of the case studies and the research synthesis enabled a definition of indicators for the mapping of the most favourable areas for the implementation of different types of NBS, based on technical, ecological and economic criteria, further described in detail in a companion Technical Report (Pistocchi, 2022). The resulting maps of favourability for the implementation of nature-based solutions will support model-based analyses of policy scenarios and enable quantifying the overall benefits, as well as the investment requirements, for these types of solutions in agriculture. Understanding of the costs, effectiveness and benefits of NBS support, in particular, the steering and evaluation of programmes of measures under the Water Framework Directive (WFD) 60/2000/EC, as well as the implementation of the Strategic plans of the new Common Agricultural Policy (CAP)([8]). The case study reports, research synthesis report and criteria for EU-scale mapping of favourability to NBS are accessible through the JRC Water Portal ([9]).

In this report, we build on the case studies to draw policy recommendations, particularly on creating the conditions for the uptake of nature-based solutions (NBS) through appropriate business models, securing of funding and payments for the services provided by NBS. In Chapter 2 we discuss how various NBS can help address water management problems, while Chapter 3 focuses more specifically on the socioeconomic conditions for the uptake of NBS as a mainstream solution. In the conclusions (Chapter 4) we summarize the most important messages for policy makers that we could derive from the experience of this project.

[8] https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans_en
[9] https://water.jrc.ec.europa.eu/

2 Nature-based solutions (NBS) for agricultural water management

2.1 Treatment wetlands

Treatment wetlands (TW) are a well-established NBS for wastewater and sludge, particularly for the treatment of domestic effluents in small agglomerations or for the polishing of secondary wastewater treatment plant effluents. They are typically designed as free-surface water ponds or tanks, or tanks filled with gravel ("beds") through which water may percolate and flow either horizontally or vertically (Pistocchi et al., 2020) according to one of the generic schemes shown in **Figure 1**. Usually TW are characterized by a lower operational cost compared to conventional wastewater treatment technologies, particularly because of lower energy use, and usually do not require highly specialized personnel for their routine operation (Pistocchi et al., 2020). Horizontal and vertical flow TW can be combined in order to enhance the treatment performance, which may be further enhanced by additional interventions such as forced aeration. In this case, though, they become more energy-demanding and complex to operate. A distinctive feature of TW is the presence of vegetation (most often reeds) which, on the one side, is moved by wind and contributes to the aeration of the pond or the porous medium of the filling and, on the other, may play a role in enhancing treatment by taking up nutrients and contaminants. The removal of contaminants results anyway from the complex interaction of microorganisms and plants within the TW ecosystem. Because of the presence of vegetation and the possibility to build TW in earth through soil excavation and embankment, with limited or no use of concrete, these NBS may appear as quasi-natural wetlands, which is attractive from a landscape-architectural point of view. The wetland ecosystem may also provide support to biodiversity. TW usually entail use of plastic or other "grey" material for piping and lining, but usually to a much lesser extent than conventional treatment options. Additional details on the design and management of TW can be found in Dotro et al., 2017, and Langergraber et al., 2020.

Here we focus on the application of TW for two purposes of direct relevance for agricultural water management: the treatment of manure derived from intensive livestock farming, and the stabilization of domestic wastewater sludge.

2.1.1 Manure management

Intensive livestock farms usually produce manure with a quantity of nutrients, particularly nitrogen, exceeding the capacity of agricultural land to receive them as fertilizers and the limits set by the Nitrates Directive ([10]) and related legislation. While spreading manure as fertilizer is by far the cheapest option, in many cases the manure volume and nitrogen content must be drastically reduced before land application. This can be achieved by separation of the solid and liquid phases of manure. The liquid phase may require a treatment process comparable to that of domestic wastewater, in order to remove pollutants before it can be released to the environment. As an example of a relatively large, intensive livestock farm that implemented this approach for the management of manure, we consider the case study of San Rocco di Piegara near Verona, in the northern Italian region of Veneto ([11]). This consists of a pig farm located in a quite isolated and barely visible hilly position, about 3 km away from the town and about 600 m from the closest household. The facility has a maximum capacity of 7848 animals, but it currently hosts 3145. Due to the limited land available where to spread manure, the company needed to minimize manure excess that required transport for application at another site (fields near the village of Magnacavallo, about 80 km away, where the company owns another pig farm), hence entailing costs and causing impacts. In order to minimize manure, until 2013 the liquid fraction was treated with a conventional technological solution (an activated sludge process followed by a membrane stage, designed to comply with emission limit values for discharge into surface waters according to Italian law). Later on, the regional Environmental Protection Agency (ARPAV) imposed to comply with more stringent standards (emission limit values for discharge on soil). Complying with the new standards would have implied excessive costs, especially operational expenditure (OPEX).

[10] Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources
[11] This section builds upon, and reuses text from the case study report by Borsacchi et al., 2021a.

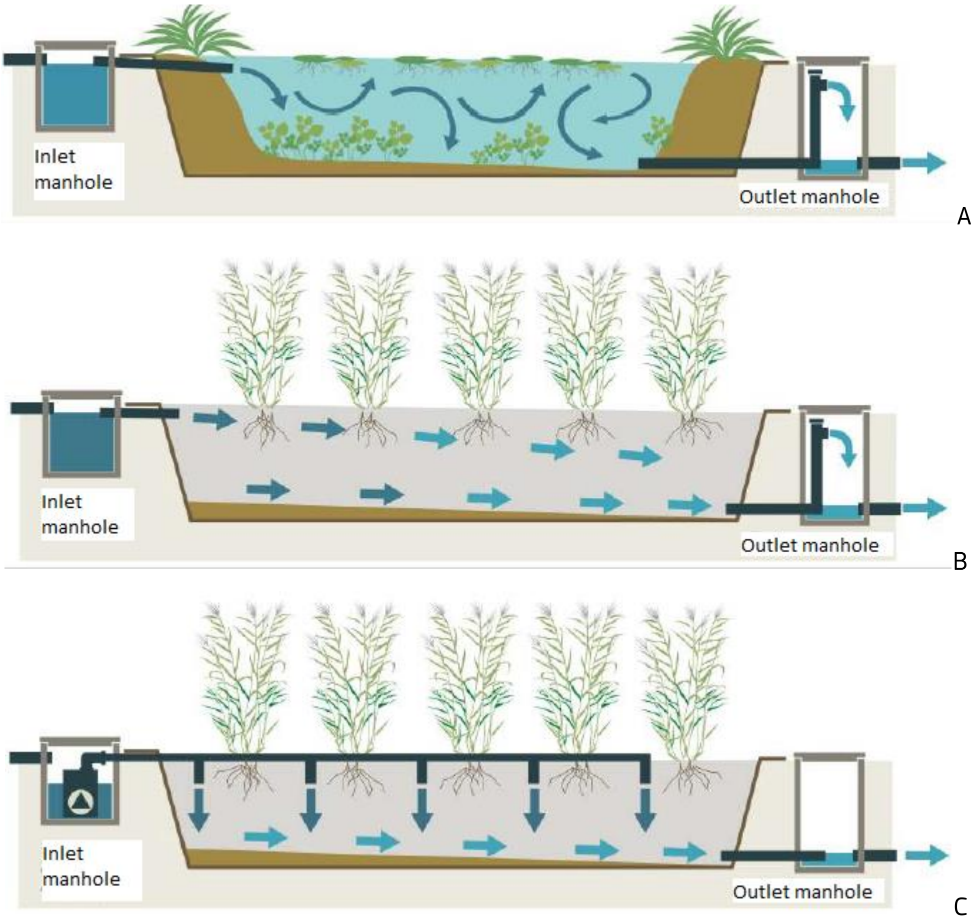

Figure 1. Cross-sections of constructed wetlands with free surface (A), subsurface horizontal (B), and vertical (C) flow. Source: original artwork by IRIDRA srl, in Pistocchi et al., 2020.

In response, the company decided to adopt a nature-based treatment system which, thanks to lower OPEX, could make the re-opening of the farm financially sustainable. The Rural Development plan of the Veneto region funded a pilot project from which the full scale system was developed. Due to limited available space, the chosen solution was a "hybrid" solution consisting of an aerated treatment wetland (TW) plus a membrane filtration stage (reverse osmosis, RO) final polishing stage. The TW consists of 5 beds occupying about 2000 m^2 within the perimeter of the pig farm, and make use of the Forced Bed Aeration (FBA^{TM}) technology (**Figure 2**). The beds are aerated for about 22 hours per day, while they are left in anoxic conditions for about 2 hours, thus achieving a satisfactory level of nitrification and denitrification. Both aeration of TW and RO require energy and electromechanical equipment, and are controlled remotely through a Supervisory Control And Data Acquisition (SCADA) system. While the TW showed relatively high mass removal efficiencies on average (73% for total nitrogen and 80% for total phosphorus), the concentrations in the effluents were still far above the emission limit values for discharge on soil, the reason for the RO polishing stage. **Figure 3** shows the flow diagram of manure management at the San Rocco di Piegara site.

The design adopted in the case study is justified by a number of case-specific considerations. In principle, the polishing of effluents in order to meet the required discharge standards could be performed using other TW such as free surface wetlands. TW could be optimized in order to reduce greenhouse gas emissions (particularly nitrous oxide, having a much higher global warming potential than CO_2) by enhancing denitrification or by adding a treatment stage of ammonia stripping upstream of the TW. The latter is particularly attractive as it may achieve a significant reduction of nitrous oxide emissions, while allowing the recovery of stripped ammonia by precipitating it as an ammonium sulphate fertilizer. The wider the swath of land available to implement TW, the lesser the need of complementary "hybrid" processes, entailing equipment and energy use, because it is possible to establish "passive" natural treatment processes with less energy input. On the contrary, when land availability is a strong limiting factor, TW may struggle in comparison with more compact technological alternatives. In the case of San Rocco di Piegara, though, a comparison of various alternative designs entailing a significant contribution of TW were always significantly less expensive than a conventional wastewater treatment process, mainly due to the lower operational costs. Solutions using a TW also for the polishing of effluents could reduce operational costs by almost a half, but would entail about a doubling of the costs of land acquisition, so a decision will necessarily depend on the trade-offs on a case by case basis.

Figure 2. A view of the treatment wetland in San Rocco di Piegara in the hilly landscape of the region.

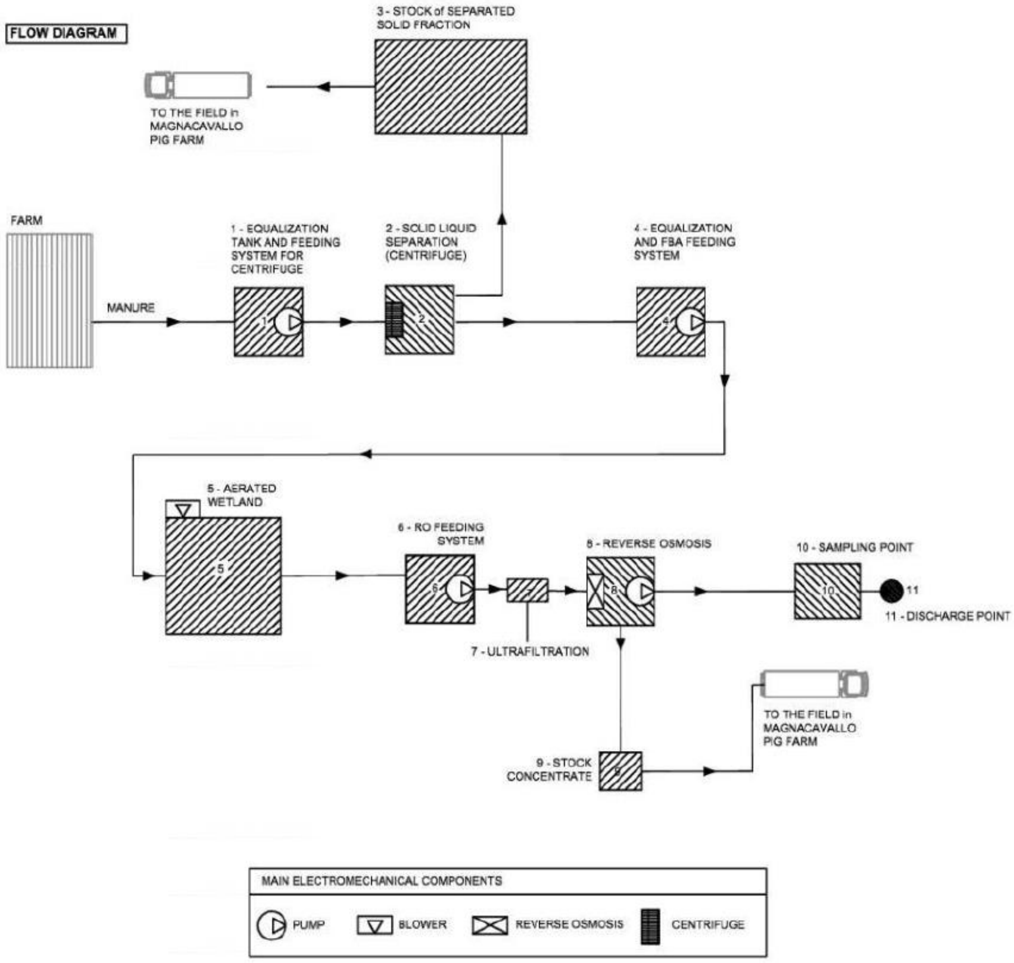

Figure 3. Flow diagram of manure management in the case study of San Rocco di Piegara.

2.1.2 Sewage sludge stabilization

Sewage sludge resulting from domestic wastewater treatment must undergo stabilization to control pathogens, offensive odour and putrefaction before it is used as a soil conditioner or fertilizer in agriculture. Stabilization may entail chemical treatment, aerobic or anaerobic digestion in specifically designed process stages within a wastewater treatment plant. These processes require appropriate technological equipment and energy, although anaerobic digestion allows recovering methane and could be energy-neutral or even energy-positive. Chemical treatment is quite flexible and scalable, but may not be suited for sludge intended for use in agriculture, because of the alteration of the sludge's chemical composition, resulting in lower fertilizing value and altered pH, possibly incompatible with soil application. Usually, aerobic sludge stabilization is cost-effectively implemented at plants with a capacity of about ten to a few tens of thousands population equivalents (PE), and anaerobic digestion at larger plants. At smaller plants (a few thousand PE or less), though, both options may prove disproportionately expensive. In these cases, TW configured as reed beds could enable aerobic sludge stabilization in a very cost-effective way, while delivering other advantages over the abovementioned "conventional" processes. In this type of solutions, the sludge of the wastewater treatment process is discharged directly on a gravel bed populated with reeds, on which it undergoes dewatering by natural drainage, and aerobic stabilization. The process requires little or no energy, while the sludge is left on the reed bed for a long time (a few to several years), resulting in a compost that can be eventually excavated and potentially used on agricultural soils.

As examples of plants where sludge is stabilized using reed bed TW solutions, we consider the case studies of Kastelir in Croatia and Mojkovac in Montenegro ([12]).

In the Croatian village of Kastelir near the Istrian Adriatic coast, the Municipality began to build a sewage network with the establishment of a wastewater treatment plant (WWTP) along with a reed beds (RBs) for sludge treatment in 2010. The WWTP is a TW that includes a filtration planted bed (FB) for the retention of suspended solids and others coarse particles not retained in the primary stage, treatment beds (TB) where intensive degradation of organic matter takes place, and a polishing bed (PB) to further improve effluent quality, particularly with regard to pathogens. It was designed for 1.900 population equivalents (PE). More than the half of households are intended for tourism and their occupation is seasonal. Since the construction in 2015 the WWTP is operating below design capacity, with a remaining extent of 8 km of sewerage system still to be constructed. After completion of the sewerage system, WWTP Kastelir will operate at full capacity. The treatment process in Kastelir consists of a primary treatment (Imhoff tank), followed by biological treatment using TW that meet the final effluent discharge standards for secondary treatment. The sludge from primary treatment undergoes homogenization and eventually drying and stabilization on a reed bed (**Figure 4**). In a first phase, the primary sludge generated in the Kastelir WWTP was extracted and transported on trucks to a larger WWTP in the region. Since the RBs were implemented, in 2016, the primary sludge is simply discharged to the RB on site, with minimal use of energy for pumping. The RBs are designed to receive sludge for a lifetime of a few decades. Every ten years approximately, the stabilized sludge can be excavated and potentially used in agriculture. Reeds and other plants growing on the bed can be simply let grow, thus creating a relatively stable habitat for birds and other organisms, or could be periodically harvested, yielding biomass that could be used in various ways.

Figure 4. Aerial picture of the Kastelir WWTP, with indication of the treatment stages.

In 2004 the town of Mojkovac, Montenegro, was equipped with a conventional biological wastewater treatment plant with an installed capacity of 5.200 PE. Until the construction of RBs in 2016, the generated excess sludge from the secondary clarifier was mainly stored on the WWTP site, and at risk of being flooded by the nearby Tara River during high-flow events. The sludge was meant to undergo thickening and dewatering through a filter press, but the latter was never in operation due to its high operational costs. The municipality had no

[12] This section builds upon, and reuses text from the case study reports by Potokar et al., 2020a (for the Mojkovac case study), and Potokar et al., 2020b (for the Kastelir case study). The reports contain information on other reed bed cases in other European countries as well, for benchmarking.

sustainable option to manage the accumulating sludge because of the constraints on the local landfill, and lack of an incineration plant in the entire country of Montenegro. Limited financial resources and sludge disposal problems were the key drivers for the adoption of a RBs solution (

Figure 5). This allowed a seamless integration of sludge stabilization in the WWTP process, enabling a much safer and cheaper operation. Although operated in a different climate and treating secondary instead of primary sludge, the Mojkovac RB yield sludge with similar properties and quality as in Kastelir, suggesting this can be a broadly applicable solution for small plants.

Figure 5. Aerial picture of Mojkovac WWTP before (left) and after RBs installation (right), from Google Maps™.

The long retention time of the sludge stabilization process enables the degradation of (virtually) all contaminants that are non-persistent, hence it may lead to a higher quality of the sludge for agricultural application. At the same time, the stabilized sludge preserves a sufficient content of nutrients and dry matter to make it useful as a soil conditioner. This solution is much less expensive than conventional alternatives, and is particularly suited for WWTPs receiving only domestic waters. In this case, the metals and persistent chemicals often associated with urban runoff and industrial discharges may be present in significantly lower concentrations, and the sludge should be inherently suitable for agricultural use. Small plants may be often found in rural areas, where this solution may offer a good way to transform the sludge into a desirable input for agriculture.

This solution entails minimal energy and chemicals input. Although in both our examples the RBs are built in concrete tanks, the beds could be implemented in a trench excavated in earth and water-proofed with e.g. a high-density polyethylene sheet (as in the case of the Dellach am Drautal plant, Austria[13]: see **Figure 6**) or, in principle, even with clay, embedding limited greenhouse gas emissions if compared with concrete and steel infrastructure.

[13] The case of Dellach is further described as a benchmark in the Mojkovac case study report: Potokar et al., 2021a.

Figure 6. Reed beds in the Austrian WWTP of Dellach am Drautal in May 2015 – beginning of vegetation season.

2.2 Buffer strips and wetlands for diffuse pollution control

Control of pollution due to excess nutrients from agricultural fields, as well as other contaminants such as pesticides and suspended sediments, can be achieved through a series of diffuse elements, including buffer strips, vegetated drainage ditches and free surface wetland ponds, intercepting runoff before it is discharged to the receiving water bodies. This type of interventions becomes particularly effective when implemented systematically over a catchment, thus intercepting a significant percentage of the total runoff thereby produced.

Free water surface wetlands and vegetated drainage ditches operate the removal of nutrients and sediments by providing conditions for the settling of suspended solids, nutrient uptake by the aquatic vegetation, and denitrification by microorganisms in a complex ecosystem reproducing the conditions of natural wetlands. Buffer strips operate on the same principle, but through the uptake of nutrients by plant roots, entrapment of sediments and denitrification in soils. Buffer strips may be designed to intercept surface flow, subsurface flow or groundwater flow.

Here we refer to two real cases of application of this type of solutions in Italy, one in the catchment of the Venice Lagoon (Northern Italy), and the other in the province of Latina(Central Italy). The former is representative of a continental, the latter of a Mediterranean climate ([14]).

The first case study([15]) is an area in the catchment of the Venice Lagoon including two sub-basins (Marzenego and Dese-Zero), for a total surface of 37.785 hectares. The entire area is managed by the *Consorzio di Bonifica Acque Risorgive*: a public body in charge of managing the water and preventing floods. Part of the area has been reclaimed through the centuries from original wetlands and swamps, and kept dry by mechanical drainage.

To protect the Venice Lagoon from eutrophication, since 1973 several national and regional laws have established a special regulatory framework in the area, involving different administrative bodies (State, Region, Province, Municipalities). The most recent Regional Strategic Master Plan, approved in the year 2000, sets quantitative objectives for the removal of pollutants, particularly nitrogen (the limiting factor controlling eutrophication in the Venice lagoon) from point and diffuse sources. The removal target set by the Strategic Master Plan is 3000 tons per year for nitrogen for the whole region, including point and diffuse pollution sources. This reduction is expected to come mainly from the upgrading of urban and industrial wastewater treatment plants, the treatment of animal manure and the reduction of nitrogen load at source through better farming

[14] This section builds upon, and reuses text from the case study reports by Borsacchi et al., 2021b, and Borsacchi et al., 2021c.
[15] See Borsacchi et al., 2021b.

practices. Still 300 tons per year (10% of the target) are to be removed through riverbed and floodplain restoration, wetlands and buffer strips distributed along the capillary drainage network of the catchment. The *Consorzio di Bonifica Acque Risorgive* (managing 40% of the lagoon catchment) alone has set a removal target of 150 tons of total nitrogen per year. To this end, since the year 2000, the Consorzio has implemented 23 interventions, exploiting financial resources provided by the government and allocated by the Regione Veneto – including in-stream and off-stream wetlands, buffer strips, and woody buffer areas – covering a cumulative area of approximately 252 hectares. In the following, we describe four representative nature-based solutions implemented.

As an example of in-line wetland, the Rusteghin pond receives water from a drainage canal. It was designed to create a tortuous flow in order to increase the residence time and improve the natural processes of nutrient removal. Due to its characteristics, the wetland can also provide buffer volume to mitigate floods (**Figure 7**).

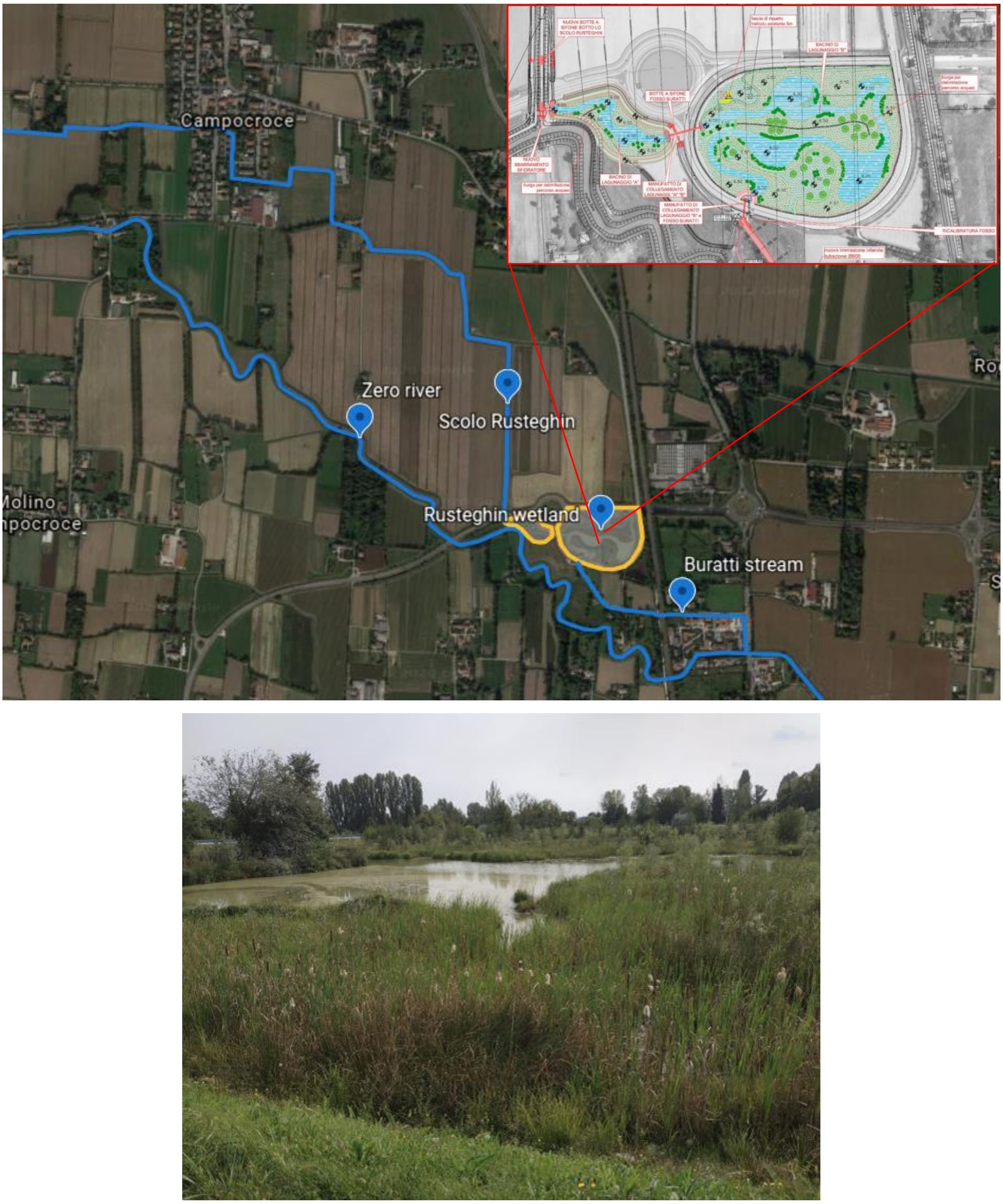

Figure 7. Above: plan view of the Rusteghin wetland and its location in the catchment. Below: a view of the wetland.

Salzano is instead an example of an off-line wetland implemented in a former clay quarry, of which it covers about 30%. This wetland is located between two water bodies: the Marzenego river and the Rio Roviego. Part of the flow of the Marzengo river is withdrawn to feed the wetland and it takes 6 days to pass through the wetland and then flows into the Rio Roviego.the flow is ensured by gravity alone, with limited electromechanical control of the inflow (**Figure 8**).

The Scandolara stream has been equipped with an 11 m wide buffer strip (**Figure** 9 and **Figure 10**) constructed in 2007 to remove the nitrogen of the sub-surface flows to a the adjacent cultivated areas, as part of a wider river restoration project. The buffer is formed by two rows of trees planted within the higher portion of the bank (see Figure 9), while the inner part of the buffer strip, between the river and the tree rows, is covered by spontaneous vegetation (Figure 10). The site includes an experimental section with dedicated monitoring.

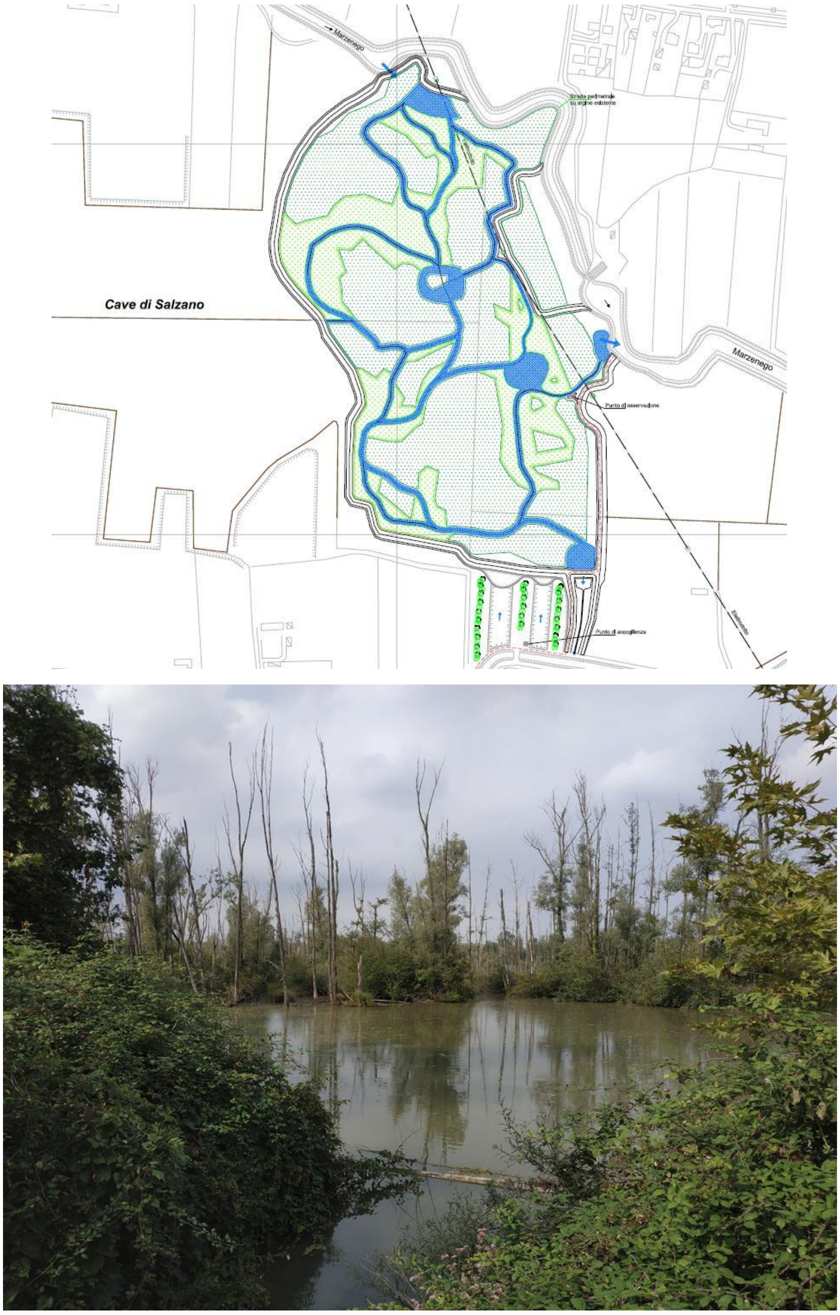

Figure 8. Above: plan view of the Salzano wetland, built within the Salzano quarry: wood area (dark green dots); vegetated free water surface (FWS) area (light green dots); open water FWS area in blue. Below: a view of the wetland.

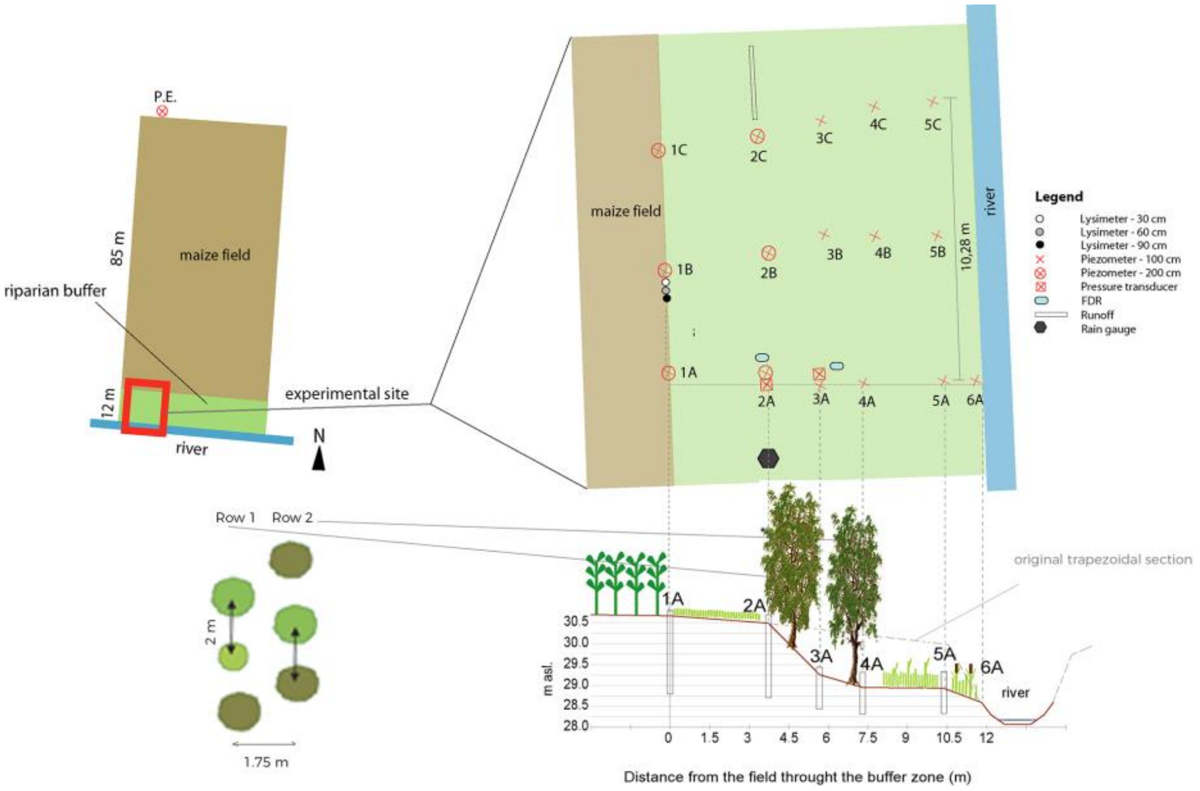

Figure 9. Illustrative design of the Scandolara buffer strip.

Figure 10. General and detailed views of the Scandolara buffer strip 3 years after the restoration project.

The NICOLAS site([16]),located in the area of the village of Mogliano Veneto consists of a 30 ha sub-irrigated and afforested buffer area. It was designed to manage the water flow pumped from the nearby Zero River through a system of ditches. Ridges and furrows facilitate subsurface water flow from the inlet point to the parallel drainage ditches located at lower elevations. **Figure 11** shows the evolution of the site during the first years of the project. The buffer strip includes a wooded area on the side of the Zero river. Five pumps distribute the water from the Zero river to 30 drainage channels, where water is accumulated and then allowed to seep through the soil. Finally, water reaches the main drainage channel and then it is discharged back to the Zero river (**Figure 12**). Even if it is a peculiar buffer strip, treating the water abstracted by a polluted river instead of the runoff or the sub-surface flows draining from cultivated areas, it is representative of buffer strips for irrigation ditches.

Figure 11. Sequence of images depicting the evolution of the NICOLAS riparian buffer site.

[16] The site was named NICOLAS after the European Research Project "Nitrogen Control by Landscape Structures in Agricultural Environment" (NICOLAS: 1997-2000) which aimed at designing and monitoring buffer strips throughout Europe.

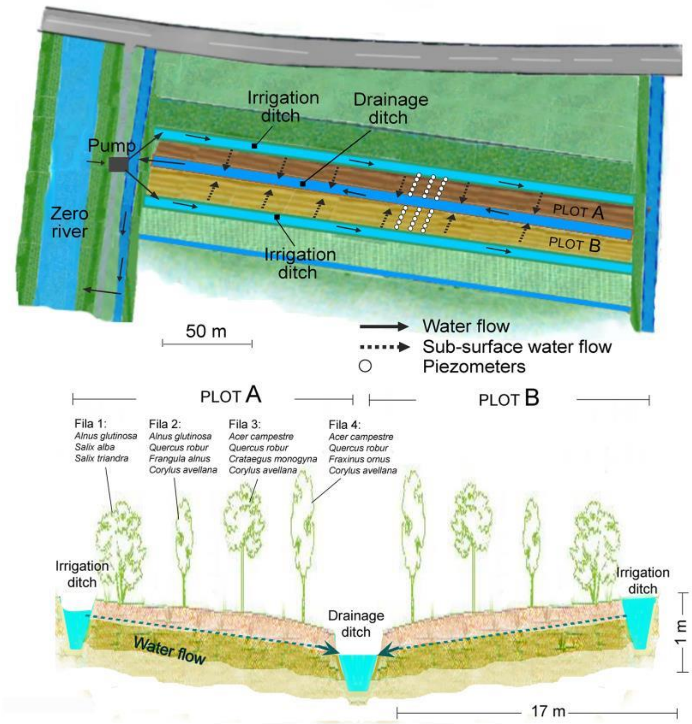

Figure 12. Plan (above) and section (below) of the 30 m wide experimental sub-site within the NICOLAS site: each plot is watered through an irrigation ditch carrying water from the Zero river. Soil setting allows a difference in elevation among the irrigation ditches (INPUT) and the drainage ditch (OUTPUT), resulting in a subsurface flow of water running through the wooded buffer strips (modified from Gumiero et al., 2011).

The removal capacity of the four nature-based solutions is quite variable and depends on the specific design and on the pollutant load (see **Table 1**). The Rusteghin wetland shows the lower performance in Total Nitrogen (TN) removal as percentage of the incoming load, but it has by far the best performance in terms of nitrogen removal capacity per unit of area occupied.

Table 1. Total nitrogen (TN) removal performance of the four solutions in the Venice Lagoon catchment case study.

NBS	TN removal [%]	TN removal [g m^{-2} y^{-1}]
Rusteghin wetland	23	94.58
Salzano wetland	41.5	20.5
Scandolara buffer strip	39	22.5
Nicolas buffer strip	50	6

The second case study([17]) on the application of nature-based solutions for diffuse pollution control is located in the province of Latina in the *Agro Pontino* area, once one of the largest European wilderness areas with 80,000 hectares of woods and wetlands lying from the *Albani* hills (south east of Rome) to the Mount Circeo on the Thyrrenian coast. The landscape of the area as of today is the result of a heavy landscape transformation caused by the “Great Land Reclamation” of the 1920s. This transformation is continuing to this day, adding an intense industrial (1960s and 1970s) and later residential (1990s-2000) development to the environmental pressures due to crop and livestock farming. These changes caused progressive pollution of surface and groundwater and a growing artificiality of the landscape, with important losses in terms of ecosystem services. The water quality of most of the artificial and natural watercourses of the area is considered "poor" or "bad", according to the parameters established by the Water Framework Directive (WFD) 2000/60/EC.

[17] See Borsacchi et al., 2021c.

In this context the *Life+ REWETLAND* project, coordinated by the Province of Latina, aimed at promoting NBS to control diffuse pollution and improving the quality of waters. The project led to the drafting of an *Integrated Environmental Restoration Program (ERP) of the Pontine Plain*, which identifies several NBS typologies that should be promoted on an area of about 700 km^2, entailing a network of 220 km of drainage canals. Besides acting at large scale by developing the ERP, the *Life+ REWETLAND* project implemented four pilot projects aimed at demonstrating the effectiveness of constructed wetlands and buffer strips to control diffuse pollution.

The area of Villa Fogliano covers a total surface of 5 ha (around 2 ha of wetlands) along the right bank of the Allacciante Canal. It is characterized by three basins (A, B and C) organized as shown in **Figure 13**.

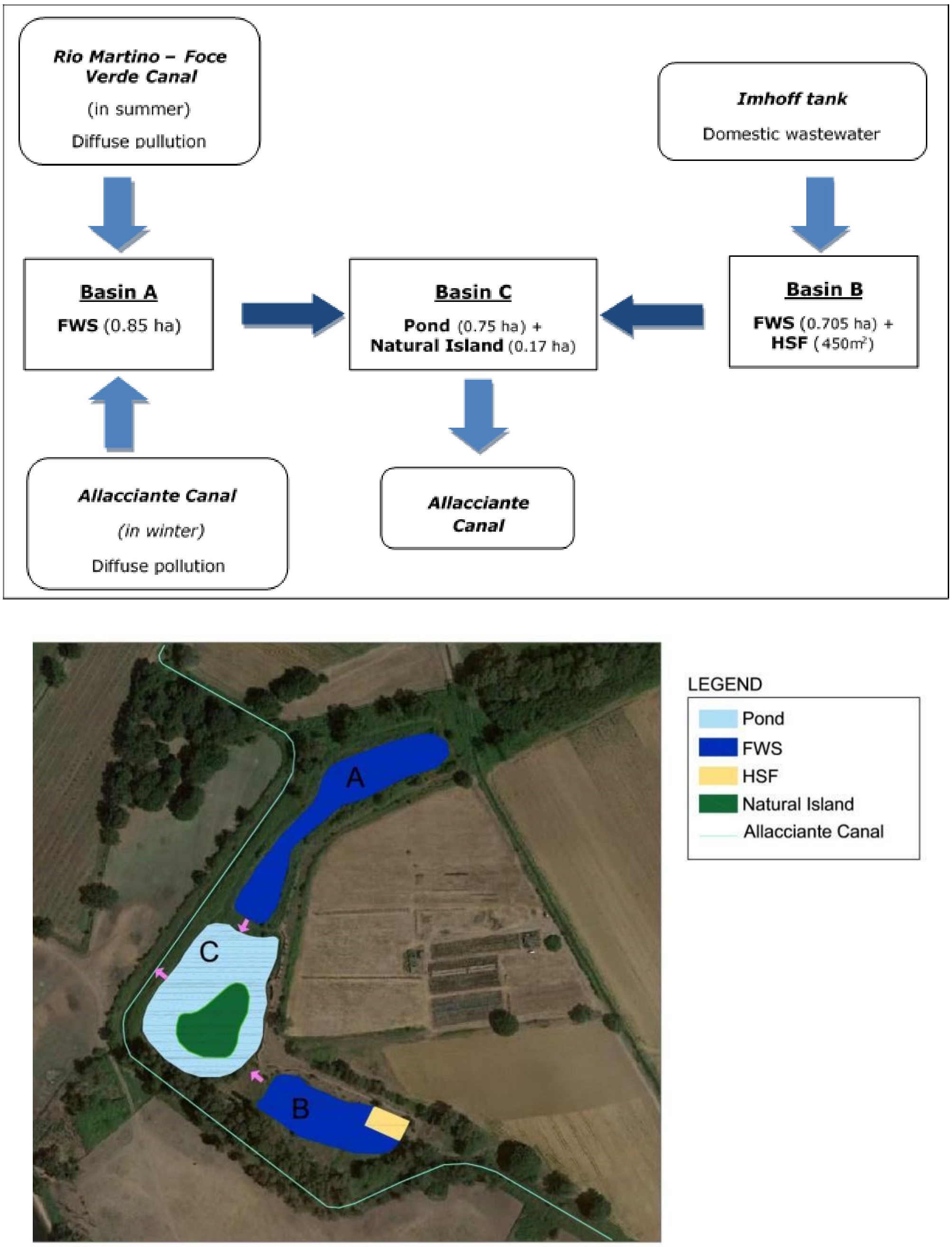

Figure 13. Functional scheme of the Villa Fogliano Constructed wetlands

Basin A (**Figure 14**) covers an area of 0.85 ha, with a depth of 0.8 m. In this area, a surface flow system (FWS) treats the outflow from the Rio Martino – Foce Verde Canal (in summer) and from the Allacciante Canal (in winter). The discharge from basin A to basin C takes place by means of a pipe of 400 mm in diameter. Basin B (**Figure 15**) has an area equal to 0.75 ha and a depth of 0.80 m. This wetland system includes a small (450 m^2) horizontal sub-surface system (HSF) for the secondary treatment of the waste water of the Villa Fogliano village and a surface flow system (FWS) of 0.71 ha for the tertiary treatment of the waste water. The primary waste water treatment is performed upstream by means of an Imhoff tank. The sub-surface system is made up of a rectangular basin (W= 18 M; L= 25 m), with a depth of 0.8 m and a bottom slope equal to 2%. The bottom of the reservoir is covered with a 10 cm layer of sand and a bentonite geosynthetic barrier of 6 mm (dry). The system has a gravel layer of 60 cm. The inlet and outlet of the tank are characterized by larger cobbles. The type of aquatic plants used are: *Phgramites australis, Typha latifolia L.* and *Iris pseudacorus L.*Basin C (**Figure 16**) has a rounded shape, covering a surface of 0.52 ha. In the centre there is an island of about 0.17 ha. It receives the outflow coming from basin A and basin C. The surface waters are conveyed into the Allacciante Canal by means of a 250 mm diameter pipe.

Figure 14. Basin A (Source: LIFE+ REWETLAND)

Figure 15. Basin B (Source: LIFE+ REWETLAND)

Figure 16. Basin C (Source: LIFE+ REWETLAND)

The wetland in the Linear Park of Marina di Latina is a hybrid constructed wetland system: the 1st stage is formed by a horizontal subsurface flow (HF) constructed wetland, with 2 beds in parallel; the 2nd stage by 2 free water surface (FWS) basins in series. Overall, the constructed wetland system covers an area of about 0.4 ha. The functional scheme of the system is shown in **Figure 17**, while **Figure 18** and **Figure 19** show details of the HF and FWS basins, respectively.

Figure 17. Functional scheme of the Linear Park of Marina di Latina

Figure 18. A view of the HF basins in the Linear Park of Marina di Latina (Source: LIFE+ REWETLAND)

Figure 19. A view of the FWS basins in the Linear Park of Marina di Latina (Source: LIFE+ REWETLAND)

The wetland is fed by the water coming from the Colmata Canal through a completely underground system, characterized by a pair of submerged pumps; after the treatment, the water is discharged into the Mastro Pietro Canal, by means of a pumping system. The second and third basins are FWSs, which cover an area of approximately 0.1 ha each. They are characterized by a double crossed layer of non-woven of 200 g/m^2, a waterproof clay layer with $k<10^{-7}$ cm/s and thickness equal to 10 cm. They have a free flowing water level of 40 cm. The original design of both free-water systems envisaged to introduce in the wetlands floating macrophytes (water Hyacinth: *Eichornia crassipes; Lemna minor*), but then they were excluded and the basins were spontaneously colonized by local vegetation (emergent and floating).

In the same context, two Buffer strips (BS) were also implemented (**Figure 20**). The first BS was implemented along the left bank of the Spaccasassi Ditch (Astura Allacciante Canal), in the stretch between the confluence with the Bottagone Ditch and the confluence with the Acqua Alta Canal. The buffer was 6 metres wide and included both trees (willows – *Salix spp*.) and shrubs (dogwood – *Cornus sanguinea* – and hawthorn – *Crataegus monogyna*). The buffer strip was designed and implemented with a slope of about 5%. The second buffer strip was implemented along the Selcella Canal downstream of the Forecellata pumping station, with the same structure as the first one, but with a slope of about 25%. Besides the buffer strip, to enhance the self-purification capacity of the Selcella canal, both emergent macrophites (*Phragmites australis*) and submerged hydrophytes *(Polygonum amphibium, Potamogeton crispus*) were planted in the canal section, to increase the roughness of the flow and therefore the retention time of the system.

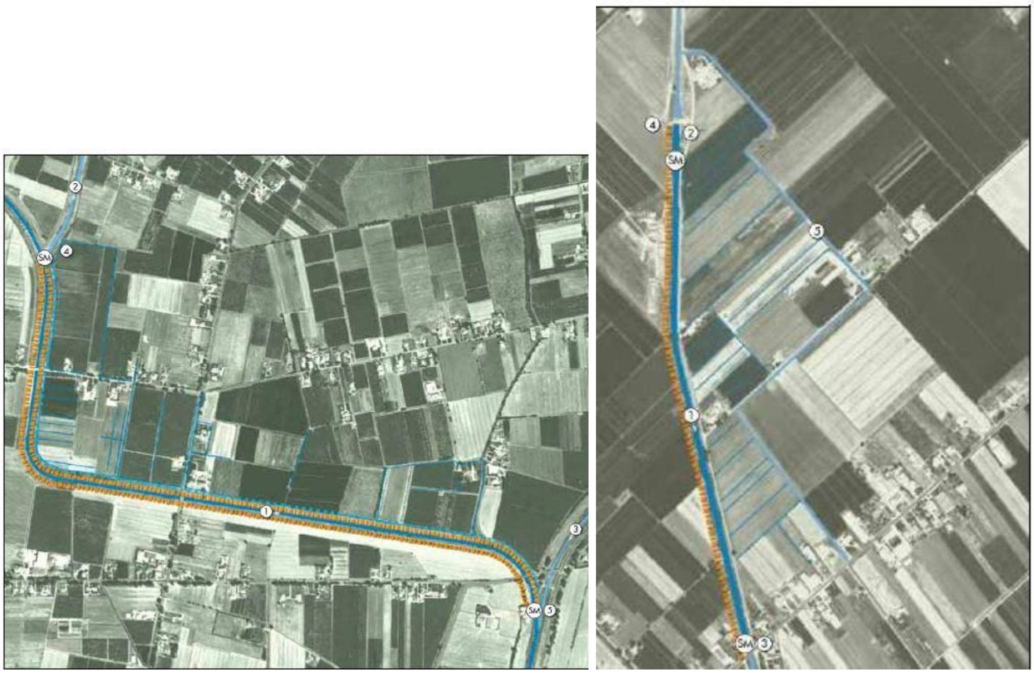

Figure 20. Buffer Strip of the Allacciante Astura Canal (left) and self-purification enhancement of the Selcella Canal (right). It is apparent that the agricultural context is highly artificialized, and the buffer strips could have added landscape elements now almost completely lacking, with a potential for supporting biodiversity.

Both buffer strips were implemented without reshaping the canal section. This technical solution is acceptable for BSs along small ditches or streams whose outflow in case of floods does not cause damages. When this is not the case, the presence of vegetation, hence the higher roughness of the section and consequently lower water velocity, could locally increase the flood risks. In order to solve the problem, in other areas (e.g. the Consorzio Acque Risorgive near Venice) BSs are implemented by widening the canal section, hence preserving the required conveyance for floods, while allowing vegetation to grow. In 2017 and 2018 the area of Agro Pontino was affected by important floods causing several damages to the local agricultural activity. After the floods, the local farmers protested against the Consorzio di Bonifica Agro Pontino, blaming it for not taking care of the vegetation along the canals and thus not fulfilling its task of ensuring the maintenance of the water network. In response, the Consorzio di Bonifica Agro Pontino cut down most of the trees, bushes and aquatic vegetation along the canals (**Figure 21**), hence the NBS project failed. In the absence of adequate monitoring data, the pollutant removal capacity of the NBS in the Latina case study could only be estimated through a modelling exercise, suggesting for the wetlands ranges of removal rates between 2 and 20 g m^{-2} y^{-2} for nitrogen, between 0.,2 and 1.1 g m^{-2} y^{-2} for phosphorus, and between 0.1 and 4 g m^{-2} y^{-2} for pesticides (Glyphosate).

It was also estimated that the buffer strips could have had a better performance, although the estimation is affected by high uncertainty, with a removal rate of 28.8 g m^{-2} y^{-2} for nitrogen, 1,1 g m^{-2} y^{-2} for phosphorus and 0.2 g m^{-2} y^{-2} for pesticides (Glyphosate). Obviously, the failure of the project due to lack of coordination of the design objectives undermined the achievement of these performances.

Figure 21. Above: The banks of the Allacciante Astura canal: the buffer strips have almost completely disappeared. Below: The right banks of the Selcella canal (left in the picture): only the shrubs of the original buffer strip are still visible (picture taken in January 2020)

2.3 Enhanced in-stream retention

Another NBS to enhance the retention of pollutants and the buffering of high flows in streams is the two-stage channel (TSC) design. This has been proposed as an alternative to conventional dredging to mitigate the adverse environmental impacts of conventional drainage canal design (including a morphology not supportive of aquatic ecosystems and a tendency to siltation), and was examined in detail in Västilä et al., 2021 ([18]). Two-stage (compound) channels consist of constructed floodplains on one or both sides of the existing main channel (**Figure *22***). TSCs are a nature-based solution since their design mimics the natural geometry of lowland streams that have a rather small main channel with adjacent frequently flooded floodplains. The TSC design aims at optimising the transport of both water and sediment, and thus at prolonging the life cycle of the channel by decreasing the frequency for maintenance. The more natural-like geometry and flow conditions in the low-flow channel together with the new floodplain habitat are expected to contribute to enhanced ecological functioning and improved biodiversity. In conventionally dredged channels, the channel bed silts up and overgrows more easily, causing a greater need for dredging, whereas the low-flow channel of well-functioning TSCs is self-cleansing. The reduced need for maintenance is explained by the fact that TSCs mimic natural conditions in terms of natural sedimentation and flooding processes. Properly designed TSC geometry functions hydraulically at low, medium and high flow conditions, providing both sufficient flood capacity and higher water levels at low flows.

In only a few studies available, TSCs have shown to provide water quality benefits because of the retention of suspended sediment and phosphorus on the floodplain, and enhanced removal of nitrogen. The retention and removal of nutrients and suspended sediment improves the water quality in the channel itself but also decreases the loads to downstream water courses. The limited evidence available also suggests that TSCs likely have positive effects on biodiversity.

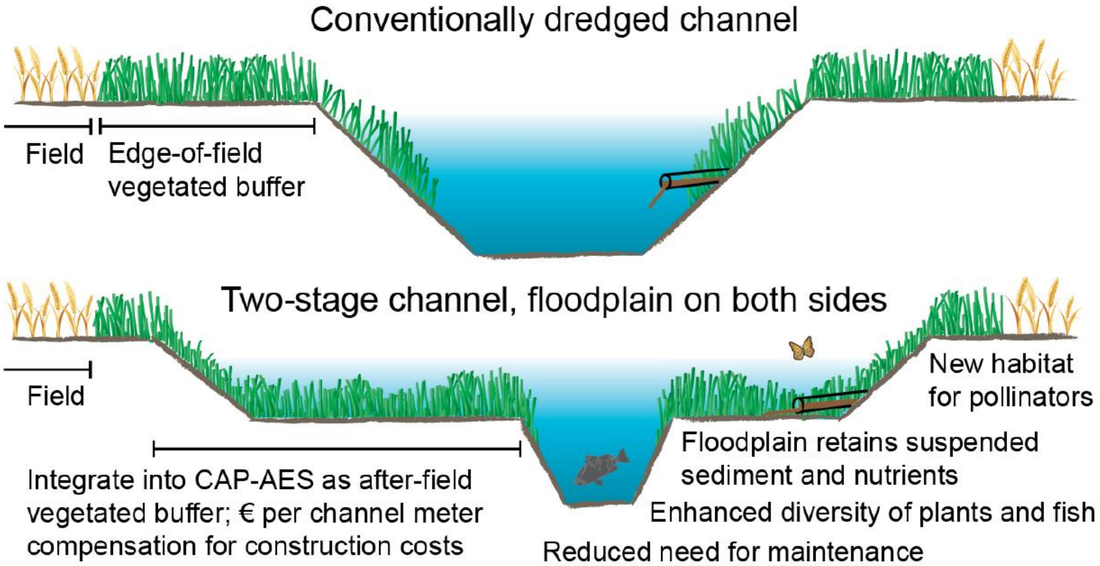

Figure 22. Characteristics of TSC design. From Västilä et al., 2021. CAP-AES means Agri-Envronmental Schemes under the Common Agricultural Policy of the EU.

TSC were investigated in more detail in the Ritobäcken catchment and other complementary sites in Finland (**Figure 23**). The sites are representative of Finnish clay-silt agricultural areas, with surface or sub-surface drained agricultural fields comprising 11.7% of the 10.3 km^2 Ritobäcken catchment area. The remaining non-agricultural catchment is comprised of forests and heaths, partly drained by open ditches, and rock (80.5%); constructed area (4.9%); water areas (2.9%); and wetlands and fens (0.1%).

[18] The paper by Västilä et al., 2021, was prepared on the basis of a report prepared for this project. The reader is referred to the paper for any further detail.

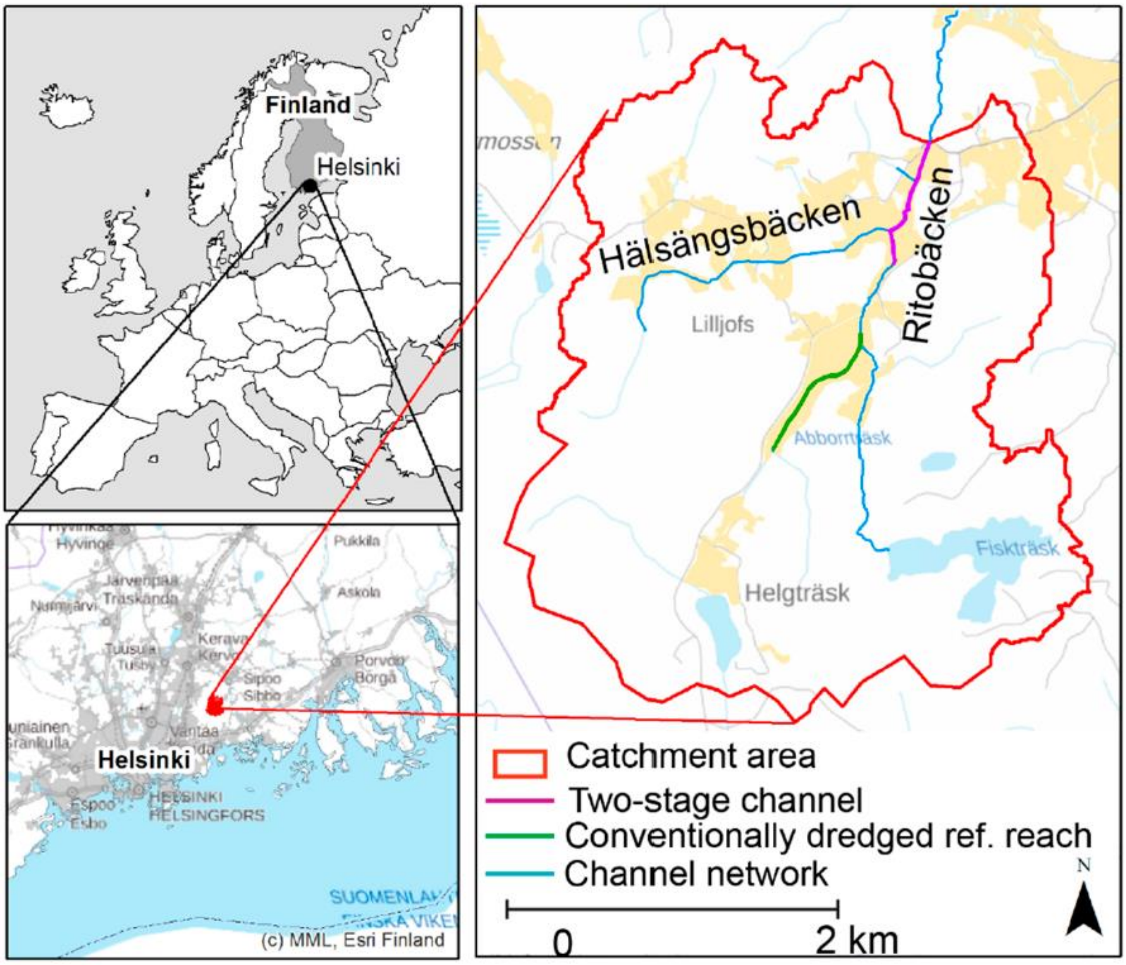

Figure 23. The Ritobäcken study area. Source: Västilä et al., 2021.

In the case study, the TSC design (see example in **Figure 24**) showed larger plant biodiversity than conventional dredging, and improved riparian and instream habitat quality, as evidenced by a greater species richness of fish and higher percentages of gravel-spawning fish than in conventional ditches, in line with the understanding that connectivity to floodplains is an important driver for fish and macroinvertebrate communities. The floodplain retention of suspended sediments (SS) and phosphorus (P) averaged 15,000 kg SS/y/km and 17 kg P/y/km respectively, with the retention efficiency of 13.6% for SS and 16.3% for P per km of TSC length. Because of the re-suspension of sediment from the bed of the low-flow channel, the total net retention considering the entire cross-sectional area was lower at 2400 kg SS/y/km and 4.3 kg P/y/km, with the retention efficiency of 2.1% for SS and 3.5% for P per km of TSC length. The re-suspension rate from the low-flow channel is expected to decrease significantly over time, as the loose deposits originating after the last conventional dredging have been flushed away. Thus, over a longer time span, the net retention percentages of SS and P are expected to increase in comparison to the first 2–2.5 years after floodplain excavation. Assuming that the re-suspension from the main channel reduces to half results in medium-term P retention of ~12 kg or 10% per km of TSC length.

Figure 24. example of a TSC in the case study.

The observed differences in plant species richness between the bank and floodplain, as well as between the banks and the conventionally dredged area, were statistically significant, but the differences between the floodplains and the conventionally dredged areas were not. The TSC appeared to be beneficial to herbs favouring moist or wet conditions. Richness in both the floodplain and bank could be due to the proximity of the wider and more uniform flooded section, i.e., the man-made floodplain: some species 'creep' up the bank. Conversely, in the conventionally dredged channel, the vegetated area extends to the water level in the ditch, yet wetland species were few. All study channels had some species that were not recorded elsewhere, but the number of species that were recorded in the banks or the floodplains or in both was distinctly higher in the TSC than in the reference channels. In Ritobäcken, 41% of the species were common to the conventionally dredged and two-stage bank and floodplain, 40% of the species were recorded only from floodplain and/or banks while only 8% of the species were unique to the conventionally dredged channel. Shannon's diversity index, calculated based on frequency and cover, indicated a rather high diversity for all Ritobäcken sections, but the lowest diversity for the conventionally dredged channels.

The TSC design is widely applicable to small and medium-sized ditches, brooks, and streams particularly under Boreal and Continental climates requiring efficient drainage and flow conveyance. Based on the investigations under Northern European and Midwestern United States conditions, TSCs appeared to be well suited to lowland and mildly sloping areas with clayey to sandy soils. The TSC design is particularly favourable for channels having high biodiversity values or where conventionally dredged channels are unstable or require frequent clean-outs. Protected species such as Unio crassus and Salmo trutta likely suffer from conventional dredging and could be better preserved with TSC design. Based on the literature survey, we expect measurable benefits if TSCs cover a minimum of ~10–20% of the stream reach length.

Climate change increases the need for efficient drainage, flow conveyance, and new methods for controlling agricultural loading since the amount of precipitation and the leaching of suspended soils and nutrients from fields is expected to rise in the Boreal zone. The need to maintain the agricultural channel network in Central and Eastern Europe is extensive, with thousands of kilometres of channels in need of maintenance in Finland alone. TSC are after-field vegetated buffers capable of treating both the local lateral runoff and the loading from the upstream areas. Their implementation likely provides water quality improvements in sub-surface drained areas where the drain flows bypass the edge-of-field buffers. Northern and Central Europe have plenty of potential sites for implementation of TSCs, as around 80% of the field area has sub-surface drainage.

2.4 Water retention

Nature-based solutions for the collection and storage or retention of water can provide benefits in terms of water harvesting, flood mitigation or a combination of the two. Each aspect depends strictly on the volume available for these purposes. Depending on how the storage volumes are implemented, they may associate their hydrological function to an ecological, as well as a socioeconomic function. Here we consider three strategies for water retention solutions that have a catchment-scale relevance: small farm-scale reservoirs in the form of ponds; large reservoirs; and restoration of the retention capacity of soils.

2.4.1 Ponds

A first way to store water is through an ensemble of relatively small ponds, distributed over a catchment, each designed to store water for irrigation. As a representative example of an agricultural catchment where ponds are implemented for water harvesting, we consider the case study of the Lamone river catchment. The case study is presented in details in Staccione et al., 2021 ([19]). The catchment is located within the Po River Basin District on the border between the Regions of Emilia-Romagna and Tuscany (Italy). It originates in the Apennines and flows northeast, reaching the Adriatic Sea north of Ravenna. The basin area is 530 km2. Agricultural land covers more than 47% of the river catchment. The area is important for the production of kiwi and other fruits, grapes and olives, as well as arable crops. Kiwi production is a key compart of the agricultural sector in the Romagna area, and the upstream part of the basin hosts 700 ha of this crop, producing on average 25 tonnes per ha yearly. The river has a torrential regime with marked seasonal variability. The flow rate peaks in spring and in autumn, and low flows occur in summer and winter. Water availability, i.e. the withdrawable water volume in the river, is ca. 100 Mm^3 from November to May, whereas only 15 Mm^3 from June to October. The total amount of abstraction permits (including domestic, industrial and irrigation uses) is around 31 Mm^3/year, of which 13 Mm^3/year is used for irrigation in the dry summer season. The high abstraction in summer causes water scarcity. Therefore, water retention ponds are recommended to satisfy agricultural water demand and maintain ecological flow. Water retention ponds are built mostly by excavation. Soil characteristics make it possible to use the deeper clay layer as a bottom impermeable component, while the excavated gravel is sold to partially cover costs. Additional construction elements include pumping systems to collect water from the river and to irrigate crops from the ponds. While no weirs are present, a common practice is to install removable pump hoses. The existing ponds are designed to maximize water storage volume with low land requirements and no regard for ecosystem functions. However, retention ponds can be designed for improving ecological performance by creating buffer vegetation, designing gentler side slopes, and building floating islands that serve as refuges for wildlife and aquatic fauna (**Figure 25**).

[19] The paper by Staccione et al., 2021, was prepared on the basis of a report prepared for this project. The reader is referred to the paper for any further detail.

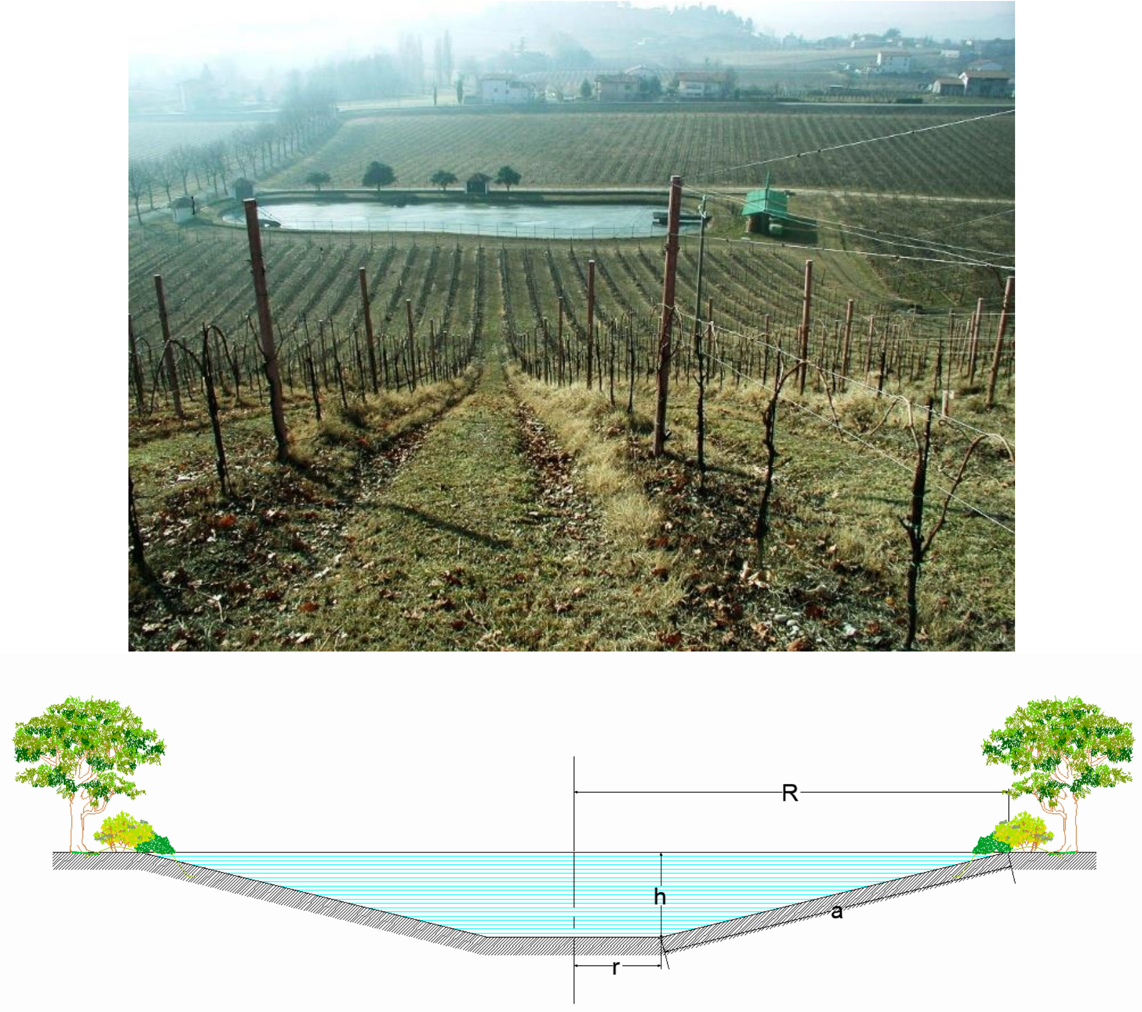

Figure 25. Above: example of a pond for the storage of water used for irrigation in the Lamone catchment. Below: example cross section of a pond designed with milder-sloped shores to enhance the provision of habitat.

This case study allowed a quantification of the ecological and hydrological effects of a system of additional ponds on both the water balance and ecological connectivity based on the use of suitable sites for the construction of new ponds. Using a landscape connectivity index it is possible to estimate the ecological importance of each potential site as a node of the ecological network. The additional water storage volume obtained by implementation of ponds at sites that show an importance for connectivity and ecological functionality helps improve water availability and river flow regime, while costs and benefits are identified and quantified as far as possible. A precondition for ponds to have an ecological function is their multifunctional design. This entails additional costs compared to conventional ponds in the area: while a traditional pond requires an investment of about 12 Euro/m^3, an ecologically designed pond requires an additional investment of about 2 Euro/m^3 (17% higher) and causes a potential loss of agricultural production that was estimated in 3 to 5 cents of Euro per m^3 of pond and year. These costs can be compensated by the additional benefits, for which payment mechanisms can be defined.

2.4.2 Large reservoirs

Rather than through a multitude of small reservoirs, water may be stored in a single, large reservoir. While large reservoirs are usually associated with the idea of building dams on streams, large storage volumes could be obtained from the restoration of valuable lake/wetland ecosystems, to serve highly diversified purposes. Here we consider more in detail an example of large storage volume obtained by rewetting the Karla lake in Central

Greece, an important natural lake that was drained in the recent past to reclaim land for agriculture, as presented in detail in Panagopoulos and Dimitriou, 2020 ([20]).

The case study focuses on a NBS at the water scarce eastern part of the agricultural Pinios river basin (~10,800 km^2) in Central Greece, the newly created Karla reservoir within the Karla basin, in Thessaly (Central Greece: **Figure 26**). Thessaly is the most important agricultural region in the country, characterized by water scarcity adversely affecting agriculture and resulting in irrigation cutbacks, overexploitation of groundwater and significant losses of crop. The main irrigated (and subsidized) crop is cotton, which, despite the water shortage threat, remains the engine of the local agricultural economy. The Pinios basin is characterized by cold and wet winters but hot and dry summers. The Lake Karla basin suffers more from water scarcity than any other area within Pinios basin, with an average annual precipitation of 560 mm. Agriculture is by far the main water consumer representing 90-95% of the annual water demand in the Pinios basin, with irrigated land covering half of the total cultivated area (400,000 ha). Cotton is the main crop, with high water demands (5,000 m^3/ha water per growth cycle), followed by maize and alfalfa. Wheat occupies an area almost equal to cotton's while not irrigated. Irrigation water abstracted mostly from massively depleted groundwater sources, has grown more expensive due to the need of deep pumping, and has caused saline water intrusion in the eastern coastal areas. Energy is by far the largest cost item for farmers, usually paying very little for water itself.

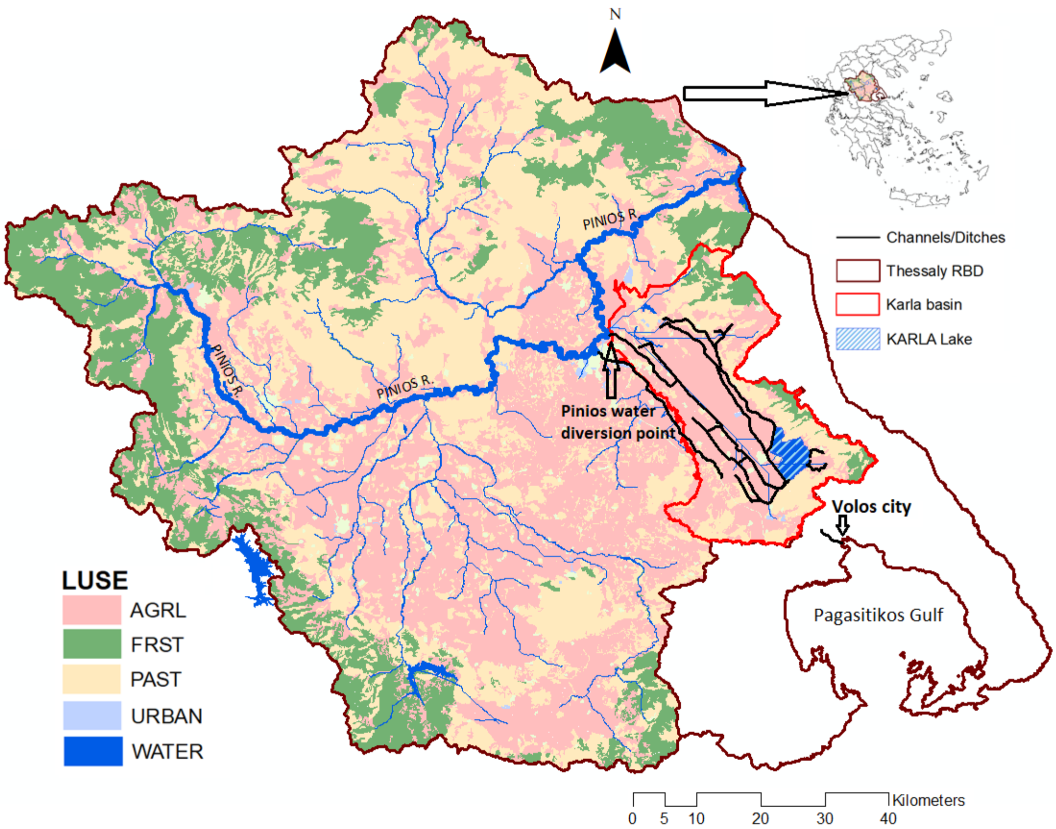

Figure 26. The agricultural Pinios river basin, including Lake Karla basin, and its location in Greece.

In response, the authorities decided to restore the lake. The final restoration decision was taken in 2000 by the Greek government, the costs being partially covered by the European Union's Operational Program 'Environment' (Structural funds) which was approved by the European Commission for the period 2000-2006. The new project is today an artificial reservoir in the same place of the old natural Lake Karla. The new Lake Karla has already been characterized as a vital aquatic ecosystem, being a Natura and Ramsar site, and a functional multi-purpose reservoir which, by harvesting natural winter runoff in the catchment and water diversions from Pinios river,

[20] The paper by Panagopoulos and Dimitriou, 2020, was written on the basis of a report prepared for this project. The reader is referred to the paper for any further detail.

will be able to protect adjacent lowland areas from flooding, irrigate nearby crops during the dry seasons and provide water supply to the nearby city of Volos (see **Figure 27**).

The new reservoir is now situated at the lowest part of the former wetland and is maintained through the construction of two 9 m-high dikes. Through pumping stations, drainage ditches and four rainwater collectors, surface runoff water from the higher elevation zones of the upper basin is diverted into the reservoir. The project also includes the water supply works to Volos, irrigation networks for approximately 90 km^2, flood control works, artificial wetland constructions (three manmade islands and a shallow wetland area of 0.45 km^2 for bird nesting and the reproduction of fish), landscape and ecosystem management, as well as new infrastructure aimed at the development of ecotourism and other recreational activities. According to the lake's water budget assessments, the additional water required annually from the Pinios river during the winter season is around 90 hm^3 including irrigation and drinking water supply to the Volos area, but also the necessary water quantities for continuous water availability in the lake that can ensure its environmental and ecological functions including its capability to recharge the aquifer. The diversion from Pinios is achieved by a network of ditches. The re-constructed Lake Karla has a surface of 38 km^2. It is designed to store water up to a maximum water depth of 4.5-5 m, while a minimum depth of 2-2.5 m is preserved to satisfy ecological criteria as a wetland. The available volume of water that the reservoir can deploy for human use is 100 million m^3.

Figure 27. A panoramic view of Lake Karla from the eastern part of its perimeter including the eastern embankment on the left and two bird nesting islands on the right.

2.4.3 Enhanced soil retention

Besides ponds and reservoirs, an effective way to store water is through retention in soils. A farmer is usually interested in keeping the soil at an appropriate water content in order to balance water and air availability in the root zone. Moreover, excessively wet soils are more difficult to access and cultivate. This has justified extensive artificial drainage of agricultural land throughout Europe, effectively causing a loss of storage capacity in soils that could be in part restored to the benefit of a better regulation of the water cycle. Here we discuss the potential of restoring soil water retention in headwater catchments, with reference to a case study developed in the Kyll river basin upstream of Steinebrück, located in the German Middle Mountains within the Rhine river basin in Germany ([21]).

Most European rivers have been subject to modifications in order to support human activities: meanders were cut off and lateral floodplains narrowed, mainly to improve conditions for navigation, and reclaim land for agriculture and settlements. The Rhine is no exception to this. The negative side-effects of these modifications include quicker discharge of water, leading to higher flood risks, longer periods of drought and the loss of biodiversity. At least as important, but less known, is that the micro-catchments of large rivers have changed dramatically over time as well. Marshy, upstream valley parts used to function as "natural sponges", temporarily storing water from heavy rainfall, before gradually releasing it as small and steady streams. The development of drainage has reduced this function substantially. **Figure 28** shows, as an example, the dramatic change in the drainage of a small tributary of the Rhine in the Netherlands, over the last 170 years. It is important to know that not only rainfall and snow falling in the valley itself was buffered, but also precipitation from the much wider, uphill surroundings. Because of this, a relatively small patch of wetland on the valley floor had a

[21] This section is based on the report by Lorenzo et al., 2021.

much larger regulatory effect. But all across Europe, many of these crucially important wetland areas have been drained. The steady flows of water emerging from them changed into strongly pulsating streams, responding almost immediately to changes in rainfall with higher occurrences of both flooding and droughts, on local, regional and (inter)national scale. This already causes greater risk from floods and droughts, and without action these problems will increase due to climate change resulting in both more erratic and intense precipitation patterns, and thus even larger fluctuations in river discharge.

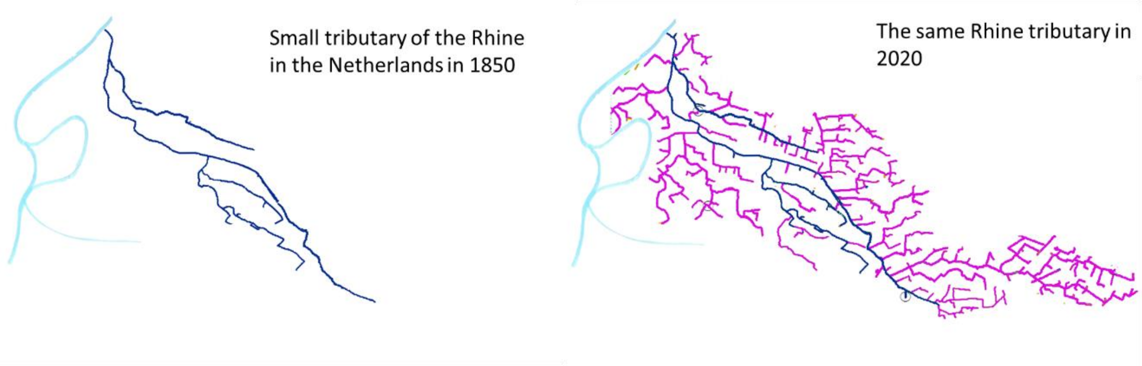

Figure 28. Changes in the drainage network occurred in a Dutch tributary of the Rhine between 1850 and 2020. Left: drainage network in 1850 (blue lines). Right: historical drainage (blue lines) and artificial drainage implemented since 1850 (pink lines)

The intervention needed to remedy this is relatively simple (see **Figure 29**): if in suitable areas existing drainage channels are blocked, a much larger fraction of the precipitation will start infiltrate the soil again and travel downwards as a much slower subsurface flow, while a smaller proportion of the precipitation will travel as a fast overland flow. In the circumstances that precipitation intensity exceeds the infiltration capacity of the soil, overland flow still remains the dominant discharge process. It will however be slowed down by natural vegetation in comparison with the fast-flowing drainage channels. As a result, the simple intervention of blocking drainage canals in relatively small parts of the river basin can be expected to result in an overall reduction of stream velocity and hence a reduction of both flood peaks and droughts.

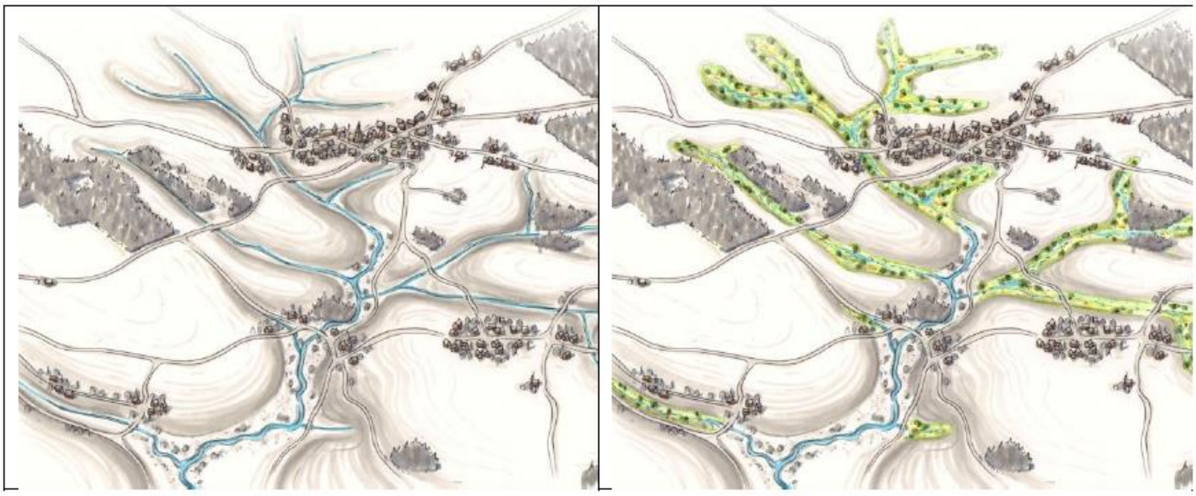

Figure 29. The concept of Natural Water Retention (sponge restoration) in upstream micro-catchment areas. Left: catchment in present conditions, with a high density of drainage. Right: reduction of drainage density through restoration of soil retention in small streams.

Figure 30 shows three parts of the study catchment at different stages of the reclamation process. The effect of this strategy, analysed with a calibrated hydrological model in the case study, appears strong: removal of drainage systems in 6% of the area in a micro-catchment results in a 20-30% lower maximum peak flow emerging from that micro-catchment, whereas low flow (an indicator for drought reduction) increases by 10-30%. When looking at the catchment as a whole, the effects tend to decrease but remain sizable.

The restoration of retention capacity slows down the transport of water and hence allows more time for vegetation and soil to absorb nutrients, so that the concentration and export of nutrients from a catchment is reduced. When water retention areas are restored as natural wetlands, water quality improves even further because inputs from manure and fertilizers is significantly reduced. In the study area, the use of fertilizer and manure is already limited at present so that water quality improvements are largely caused by reduced stream velocity. Reductions in nutrients in the micro catchments in which retention capacity was restored were estimated at 50% for Nitrogen (N) and 65% for Phosphorus (P). Peak levels, which are particularly important for biodiversity since high levels of nutrients contribute to turbidity and the potential occurrence of blue-green algae, are reduced as well. Daily maximum N and P exports show considerable decreases of 28-60% for N and 52-69% for P for the wetland scenario in the project areas.

Figure 30. Representative snapshots of drainage at three successive stages of restoration of the retention capacity of soils: from left to right, a ditch draining excess runoff as quickly as possible; a blocked ditch, and a wetland originated from the blocking of the drainage.

3 Conditions for the uptake of NBS

3.1 What can make NBS a choice

NBS are characterized by having a potentially multifunctional nature, in contrast with their “grey” alternatives. Hence, they should be designed in order to maximize the benefits they may provide, and this may require involving various actors, stakeholders and beneficiaries.

Some NBS, notably treatment wetlands (TW) and storage ponds, are typically implemented by private, relatively small-scale operators for the needs of their activities, and address in the first place a specific goal for which they must provide a cost-effective response, often being cheaper than more “technological” alternatives. These cases present a risk to dismiss benefits other than meeting the primary need (in the examples: waste management or water storage). For instance, TW within an industrial facility may not be managed in view of supporting biodiversity or landscaping the area; ponds designed for water storage may have too steep shores to allow thriving aquatic ecosystems; and so on.

In some cases, operating a NBS with a view to its ecological functions may not necessarily entail significant costs, and in some cases might even reduce the operational expenditure. For instance, while certain reed beds are periodically mowed (this was the case in San Rocco di Piegara, Mojkovac and Kastelir), it has been shown that they may be let grow spontaneously (as in the case of Dellach), thus evolving into a more stable and diversified habitat for amphibians and birds.

In the case of ponds, a more ecological design with milder slopes entails a larger land occupation, which may conflict with the needs of agricultural production as in the case of the Lamone catchment. The two-stage design of drainage ditches is more expensive than traditional design, as shown in the Ritobäcken case study. In this case, it may be necessary to provide additional incentives to the operators. These may consist e.g. of direct funding (as with the EU’s Common Agricultural Policy funds), or indirect incentives such as opportunities for the development of economic activities.

Usually small-scale private NBS offer limited opportunities to attract and involve stakeholders insofar as not directly accessible, hence their uptake depends on the ability of the operators to identify clear direct advantages. At the same time, the public may have an interest in incentivizing NBS because of the cumulative benefits these may provide at the larger scale. For instance, ponds for irrigation in the agriculture-dominated Lamone catchment may become stepping stones or nodes of an ecological network, so that funding the operators to cover the extra cost entailed by a more ecological design could be a cost-effective investment under nature conservation budgets.

Other benefits of NBS may be more local. For instance, the landscaping of a wastewater treatment plant may make a nearby area more attractive for public recreation as in the case of Mojkovac.

When NBS are designed at the scale of a catchment, usually their multifunctional role is more apparent. The buffer strips and wetlands implemented by the Consorzio di Bonifica Acque Risorgive in the catchment of the Venice lagoon provides control of diffuse nutrient pollution along with flood mitigation and biodiversity support, while making the landscape more attractive. The restoration of the Karla lake in Thessaly has been the occasion of an overall rehabilitation of the landscape in a catchment severely affected by the previous artificial drainage. In these cases, it is more frequent that stakeholders are actively engaged because of the recreational activities that can be opened up. In some cases, action on marginal parts of a catchment that retain no apparent value in terms of recreation may be justified on cost-effectiveness grounds, as in the case of the German Middle Mountains. In these cases, it may be possible to create conditions for long-term ecological rehabilitation of the landscape, which may turn into a higher scenic and recreational attractiveness over time.

The examples we have presented in the previous sections suggest that NBS become a choice when they either have an apparently lower cost than their “grey” traditional alternatives, or can be addressed in the context of multiple objectives, hence with multiple budgets supporting the extra costs that would not be covered by a single budget, and thanks to clear additional benefits.

3.2 Quantifying costs

The costs of NBS vary by typology, but can be evaluated as a first approximation using appropriate cost functions. Here we propose a simplified approach to the estimation of the capital expenditure (CAPEX) and operational expenditure (OPEX) of various types of NBS, enabling a quick estimation of costs for planning and programming purposes ([22]). The same formulation is proposed for calculations at the EU scale in a companion technical report (Pistocchi, 2022), with indicative default parameters.

We consider the following types of interventions:

- Subsurface flow treatment wetland (SSF)
- Surface flow treatment wetland (SF)
- Ponds
- Buffer strips
- Vegetated ditches (VD).

For each type of intervention, we propose an expenditure function providing the CAPEX (**Table 2**) and one providing the OPEX (**Table 3**), in Euro (€). The variables used for each type of intervention are indicated in The variables of the OPEX equations are:

— $n_{checking}$ the parametric number of equivalent personnel working hours for annual checking, function of NBS area (h m^{-2} y^{-1});

— $n_{green,reed}$ the parametric number of equivalent personnel working hours for annual reed and green maintenance, function of NBS area (h m^{-2} y^{-1});

— *C1* a corrective coefficient, function of the area;

— *C2* a corrective coefficient of the primary treatments maintenance cost.

Table 4.

Table 2. CAPEX equations

System	CAPEX		
	Equation	c1	c2
SSF	CAPEX=((Cs*V)+(Ce*V)+(Cf*Vf)+(Cw*A))*C1*C2)+(Cl*Al)+(p*WC)	C1=3.7136*Area^(-0.088)	1.4
SF	CAPEX=((Cs*V)+(Ce*V)+(Cw*A))*C1*C2)+(Cl*Al)+(p*WC)	C1=7.46*Area^(-0.102)	1.5
Pond	CAPEX=((Cs*V)+(Ce*V)+(Cw*A))*C1)+(Cl*Al)+(p*WC)	C1=7.819*Area^(-0.189)	-
VD	CAPEX=((Cs*V)+(Ce*V))*C1)+(Cl*Al)+(p*WC)	1.7	-
Buffer	CAPEX= ((Cs*V)+(Ce*V)+n_trees*p_pers*A)+(Cl*A)+(p*WC)	-	-

The variables of the CAPEX equations are:

— *Cs* the parametric cost for the excavation (€/m^3);

— *Ce* the parametric cost for the embankment (€/m^3);

— *Cf* the parametric cost for the filling medium (€/m^3);

— *Cw* the parametric cost for the waterproofing (€/m^2);

— *Cl* the parametric cost for the land acquisition (€/m^2);

— *WC* are the Working cost of the system (€);

— *A* the area (m^2);

— *Al* is the acquisition area (m^2);

— *V* the volume (m^3);

— *Vf* the filling medium volume (m^3);

[22] This section is an extract of section 2.2 of the report by Bresciani et al., 2021.

— *C1* a corrective coefficient, function of the area;

— *C2* a corrective coefficient of the primary treatments cost;

— n_{trees} the parametric number of equivalent personnel working hours for tree planting, function of buffer strip area (h/m^2);

— p_{pers} the parametric cost of personnel (€/h).

— *p* the percentage of the working cost that indicate the technical investigation and consultancy costs, equal to 20% for SSF, SF and Pond, 10% for VD and Buffer;

— *WC* the working cost of the system.

Table 3. OPEX equations

System	OPEX				
	Equation	C1	C2	$n_{checking}$	$n_{green,reed}$
SSF	OPEX=n*p*C1*C2	C1=1.1658*Area^0.0239	1.8	12.016*Area^0.758	0.09
SF	OPEX=n*p*C1*C2	C1=1.0585*Area^0.0461	1.9	12.016*Area^0.758	0.07
Pond	OPEX=n*p*C1	C1=0.332*Area^0.2637	-	12.016*Area^0.758	-
VDD	OPEX=n*p*C1	1.5	-	12.016*Area^0.758	0.01
Buffer	OPEX=n*p*C1	1.6	-	0.01	-

The variables of the OPEX equations are:

— $n_{checking}$ the parametric number of equivalent personnel working hours for annual checking, function of NBS area (h m^{-2} y^{-1});

— $n_{green,reed}$ the parametric number of equivalent personnel working hours for annual reed and green maintenance, function of NBS area (h m^{-2} y^{-1});

— *C1* a corrective coefficient, function of the area;

— *C2* a corrective coefficient of the primary treatments maintenance cost.

Table 4. Variables used in the equations

CAPEX					
	SSF	**SF**	**Pond**	**VD**	**Buffer**
Cs	X	X	X	X	X
Ce	X	X	X	X	X
Cf	X				
Cw	X	X	X		
Cl	X	X	X	X	X
WC	X	X	X	X	X
A	X	X	X		
V	X	X	X	X	X
Vf	X				
Al	X	X	X	X	X
p	X	X	X	X	X
C1	X	X	X	X	
C2	X	X			
OPEX					
	SSF	**SF**	**Pond**	**VD**	**Buffer**

CAPEX					
	SSF	**SF**	**Pond**	**VD**	**Buffer**
$n_{checking}$	X	X	X	X	X
$n_{green,reed}$	X	X		X	
p	X	X	X	X	X
C1	X	X	X	X	X
C2	X	X			

3.3 Valuating benefits

The multiple benefits provided by NBS in the form of ecosystem services can be assessed in the framework of the Common International Classification of Ecosystem Services (CICES) ([23]) as shown in **Table 5**.

Table 5. Indicative list of ecosystem services that NBS may provide.

NBS type	**Benefit (ecosystem service)**	**Ecosystem services CICES classification**	
		Code from CICES V 4.3	**Code from CICES V 5.1**
Treatment wetlands	Water Quality	2.3.4.1	2.2.5.1
	Biodiversity support	2.3.1.2	2.2.2.3
	Climate change mitigation (control of GHG emissions)	2.3.5.1	2.2.6.1
	Nuisance	2.1.2.3	2.1.2.1; 2.1.2.2; 2.1.2.3
	Energy from bioethanol	N/A	1.1.5.3
	Energy from wood production	1.1.1.3	1.1.5.1; 1.1.5.2
Buffer strips, wetlands and vegetated ditches	Water Quality	2.3.4.1	2.2.5.1
	Biodiversity support	2.3.1.2	2.2.2.3
	Landscape amenity, microclimate enhancement, attractiveness	3.1.2.5	3.1.2.4
	Climate change mitigation (control of GHG emissions)	2.3.5.1	2.2.6.1
	Energy from bioethanol	N/A	1.1.5.3
	Energy from wood production	1.1.1.3	1.1.5.1; 1.1.5.2
Ponds for water storage	Flood risk mitigation	2.2.2.2	2.2.1.3
	Droughts mitigation	1.1.2.1; 1.2.2.1	4.2.1.1; 4.2.1.2
	Water Quality	2.3.4.1	2.2.5.1

[23] https://cices.eu/

NBS type	Benefit (ecosystem service)	Ecosystem services CICES classification	
		Code from CICES V 4.3	Code from CICES V 5.1
	Biodiversity Support	2.3.1.2	2.2.2.3
	Landscape, amenity, microclimate enhancement, attractiveness	3.1.2.5	3.1.2.4
	Climate change mitigation	2.3.5.1	2.2.6.1
	Energy from bioethanol	N/A	1.1.5.3
	Energy from wood production	1.1.1.3	1.1.5.1; 1.1.5.2
	Saline intrusion mitigation, Subsidence mitigation	N/A	N/A

Certain benefits, such as removal of pollutants, may be quantified using e.g. shadow prices. Other benefits, such as flood risk mitigation, can be valued with reference to the avoided costs. The valuation of benefits consisting in the provision of goods or services (water, energy biomass, sequestration of CO2 equivalents etc.) may come from market prices. Finally, there is a broad group of benefits for which it is particularly difficult to define a monetary value. These include e.g. biodiversity support, recreation, amenity, landscape improvement, wellbeing and socialization. All these “socio-ecological” benefits may have been quantified in specific studies. For a first valuation, one may decide to transfer the quantified values from the original context to another (value transfer approach).

Table 6 shows quantified values for selected benefits/services in various contexts. The value of ecosystem services for different NBS across Europe can be transferred from the original context to other sites (study sites) as ([24]):

$$VT^{PS}_{NBS,2018,€} = VT^{SS}_{NBS,2018,\$} \cdot \frac{GDP^{PS}_{2018}}{GDP^{SS}_{year\ of\ VT}} \cdot c_{\$\ to\ €,2018}$$

where:

— $VT^{PS}_{NBS,i,2018,€}$ is the value transfer of ecosystem service in the policy site (PS) for the NBS of interest in 2018, expressed in €

— $VT^{SS}_{NBS,2018,\$}$ is the value transfer of ecosystem service in the study site (SS) for the NBS of interest in 2018, expressed in $

— GDP^{PS}_{2018} is the Gross Domestic Product (GDP) per capita based on Purchasing Power Parity (PPP) for the PS country

— $GDP^{SS}_{year\ of\ VT}$ is the GDP per PPP for the SS country

— $c_{\$\ to\ €,2018}$ is Dollar to Euro exchange ratio in 2018, equal to 0.87097 €/$[25]

In the case of TW, and generally any local NBS in isolation, usually “socio-ecological” and other benefits are limited and do not significantly affect an investment decision. This was the case e.g. in San Rocco di Piegara (§ 2.1.1), where the industrial context of an intensive animal farm, the relative abundance of habitat hence limited additional contribution of the NBS, and the lack of demand for a fruition of the site make the side benefits minimal. In these cases, usually a NBS could be preferred to a conventional “grey” solution on the basis of cost-effectiveness, lower energy use and operational simplicity, as well as stability and resilience of natural processes. A benefit of TW could be to buffer the visual impacts and nuisance of treatment plants, when the latter are located in an ecologically, socially or scenically sensitive context. In the case of Mojkovac, for example, described in § 2.1.2, a public recreation area is being implemented right next to the WWTP, with the reed beds

[24] The approach to value transfer presented here was developed, and is illustrated in more detail, in the report by Bresciani et al., 2021.
[25] https://it.exchange-rates.org/Rate/USD/EUR/31-12-2018

used for sludge stabilization screening the view of the plant. “Socio-ecological” benefits, on the contrary, may be very significant when we look at a system of distributed and connected NBS over an area such as a river basin. This is often the rationale for funding individual private NBS by the government, when their costs exceed those of less multifunctional or “grey” alternatives.

A valuation of benefits may be useful mainly when comparing different scenarios, but should be always regarded as highly uncertain and dependent on the context. In most cases, a decision to support the implementation of NBS may be taken merely on the basis of its cost being “reasonable” with regard to the number of beneficiaries and their estimated willingness to pay for the expected benefits. La Notte et al., 2021, for example, discuss the value attributed in various parts of Europe to the “habitat and species maintenance” ecosystem service.

Table 6. Matrix of variable needed for value transfer of ecosystem services provided by NBS

Ecosystem service	Increases (↑) / decreases (↓)	Study site			NBS value transfer (VT step 3)													Unit
		Country	Year ES valuation	GDP per capita (PPP) Year of ES valuation	NBS A wet. SSF	NBS A wet. SF	NBS B wet.	NBS B VDD	NBS B BS-R	NBS B BS-G	NBS B int. BS	NBS C Stor. Pond	NBS C Stor. Pond + wet.	NBS C MAR pond	NBS C MAR pond + wet	NBS C MAR dry pond	NBS C MAR infiltr. Wood	
WATER SUPPLY	↑	Spain	2004	26119.79								4396	4396	4396	4396	4396	4396	$/ha/yr
		Poland	2013	24719.25								807	807	807	807	807	807	$/ha/yr
		Spain	2004	26119.79						5470								$/ha/yr
NATURAL HABITAT and BIODIVERSITY SUPPORT	↑	Spain	2004	26119.79	179	286	321	179										$/ha/yr
		UK	2007	35600.01					29	29	32						29	$/ha/yr
WATER QUALITY	↑	Germany	2001	28380.38	4111	4111	4111	4111					4111		4111			$/ha/yr
		Spain	2004	26119.79	2121	2121	2121	2121					2121		2121			$/ha/yr
		US	1998	32853.68					59	107	107							$/ha/yr
CARBON SEQUESTRATION	↑	US	2008	48382.56	140	140	140	100					140		140			$/ha/yr
		UK	2007	35600.01					1974	1974	1974						1974	$/ha/yr
FLOOD RISK	↑	Denmark	2000	28662.09		83	133	83				133	133	133	133			$/ha/yr
		Spain	2004	26119.79							222							$/ha/yr
Reduce NUISANCE (ODOURS, RUMORS, OBSTACLES TO COMMON FARMING PRACTICES)	↓	Belgium	2008	37883.33	4720	4720	2622	2622				2622	2622	2622	2622			$/house/yr
		Belgium	2008	37883.33														$/house/yr
RECREATION and TOURISM	↑	Spain	2004	26119.79			4003	2224				2224	2224	2224	2224			$/ha/yr
		Denmark	2000	28662.09			5											$/person/visit
		Spain	2007	32438.17			3											$/person/visit
		Spain	2004	26119.79					3901	3901	3901						2167	$/ha/yr
VISUAL IMPACT/AMENITY and AESTHETIC	↑	Spain	2004	26119.79			2252	1408				1408	1408	1408	1408			$/ha/yr
		UK	2007	35600.01						1606							1147	$/ha/yr
AWARENESS/EDUCATION	↑	Greece	2003	23870.16			9											$/person/visit
		Canada	1983	46723.32						10							7	$/person/visit

3.4 Governance and business models

For NBS at the local scale and following mainly an operator's initiative, such as the TW examples discussed in §2.1, the business model is akin to that of any industrial investment: an NBS may enable reducing or avoiding costs, hence increasing the sustainability or profitability of the operation. In the case of reed beds, the simplification of sludge management is significant. Moreover, it is possible to recover the biosolids derived from the excavation of reed beds after several years, with a possible additional revenue ([26]). However, this aspect is normally quite marginal in comparison with the overall advantages of an NBS over traditional "grey" solutions.

For small scale NBS on the operator's initiative, the social, ecological and landscape benefits are usually not a focus of the investor, therefore additional mechanisms should be foreseen in order to support more multifunctional NBS.

When an investment undergoes some kind of environmental assessment and/or requires a discretional permit setting case-specific conditions (for instance, an environmental impact assessment ([27]), an assessment of implications of plans and projects in areas subject to the "Habitats directive" ([28]), a permit under the Industrial Emissions Directive ([29]), or a planning permission procedure), it is possible to prescribe that the NBS take into account these aspects during design and operation. For instance, a reed bed could be approved under conditions of a biodiversity-supporting management of the vegetation, or a pond for water storage could be permitted under conditions of an appropriate design of shores. For the rest, we do not normally expect that these NBS provide ecosystem services worth being paid for by stakeholders or the public. Whenever there is a public interest in the activity for which the NBS is required, public funds may be also available. However, these should not be motivated by the fact of supporting the NBS in itself. As an example, again, ponds for irrigation could be supported by the rural development plans in the name of supporting agriculture in a region, and in that context the extra costs of appropriate landscaping could be factored in, but there would be probably limited scope for financing ponds mainly as a way to support biodiversity.

Unlike for individual, small scale ones, for NBS conceived as a system of interventions distributed all over a territory, such as a catchment, landscape, social and ecological benefits may be entangled and of comparable importance. In these cases, very often there is a primary budget covering initial costs of interventions, but there is scope for a broader involvement of stakeholders. For instance, in the case of the Venice lagoon (§2.2) buffer strips and ponds were initially funded by the government with the goal of reducing nutrient pollution. However, some interventions could in principle qualify also as measures for the management of flood risks, hence receive funding from the respective budgets. Last but not least, the development of recreational trails along these natural elements of the landscape could attract funds also from tourism and nature protection budgets. As a prominent example, in the Salzano wetland (a former clay quarry in which the creation of a wetland developed a diversified aquatic environment able to host a wide biodiversity) was declared Site of Community Importance currently managed by a group of environmental associations named NAPEA (Associazioni per il Presidio e l'Educazione Ambientale). While the current business model of the NBS in the Venice lagoon (**Table 7**) is based on a single line of funding, the area would lend itself to the development of an alternative business model capable of recovering the costs by involving other stakeholders thorough a form of contribution quantified, in the specific case, in approximately 20 to 30 euro per person per year.

The regular availability of funds to cover the costs of NBS is key to their effective deployment, irrespective of the source of funding. The business model implemented in the Venice lagoon is an example of a "centralized governance", with the Drainage Authority "Consorzio di Bonifica delle Acque Risorgive" having appropriate technical capabilities and a capacity to organize, coordinate and optimize a broad set of diffuse interventions.

This is different from the most widespread model, where the construction and maintenance of NBS on private land is funded by subsidizing the farmers directly (what could be called "diffuse governance"). An example of diffuse governance is offered by the Ritobäcken case study (§2.3)([30]), where farmers may receive subsidies to implement two-stage drainage canals bringing various benefits. In spite of the possible long-term benefits for crop growth and income levels, the present, relatively low level of subsidies and the presence of other administrative and practical hurdles make farmers often prefer conventional dredging methods. In this context,

[26] See Potokar et al., 2020a, and Potokar et al., 2020b.
[27] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0092&from=EN
[28] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31992L0043&from=EN
[29] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0075&from=EN
[30] The following text is partly reused from Västilä et al., 2021: https://www.mdpi.com/2071-1050/13/16/9349/htm, under CC-BY license,

beside an appropriate and stable level of subsidies, it would be important to ensure that the public administration is supportive of, and facilitates the uptake of the NBS including by enforcing correct implementation.

Table 7. Business Model of the Venice Lagoon case study. See Borsacchi et al., 2021b, for all details.

Regulatory Framework
The Venice Lagoon Master Plan (VLMP) desings a long-run strategy to improve the environmental status of the Venice Lagoon. Among the planned actions, VLMP identifies NBS as a solutions to address the diffuse pollution issue. The VLMP allocates coherent national funds to implement NBS.

<table>
<tr><th>Key Activities</th><th>Key Resources</th><th>Value Proposition</th><th>Key Partners</th><th>Key Beneficiaries</th></tr>
<tr>
<td rowspan="2">1. Land acquisition; 2. Design and realization of NBS (some of them equipped for recreational and education activity) ; 3. Maintenance of NBS and water quality monitoring; 4. Organization of events and project for environmental education and dissemination by Consorzio Acque Risorgive and other organizations; 5. research on NBS performance and dissemination of results</td>
<td rowspan="2">1. Land available for "collective" benefits (possibly accessible to the public); 2. Special funds through VLMP; 3. Internal technical expertise and skills on nature-based diffuse pollution control solutions, including the design, realization and maintenance.</td>
<td rowspan="2">Environmental
Diffuse pollution prevention to improve the environmental conditions of the Venice Lagoon; improved water quality of the drainage network; support to biodiversity (new aquatic and wooded habitats).

Social
Reduction of the incidence and intensity of flood events in the area; raising citizen awareness on water pollution and environmental issues; attractive recreation areas available for residents and visitors tanks to the aesthetic improvement.

Economic
New jobs created for the design, realization and maintenance of the NBS. Anyway, today this aspect is still negligible. In the future, NBS could improve the attractiveness of the area for business and lead to an increase in property prices and related taxes.

Trade-off
Expropriation challenges; diffusion of invasive species; noise pollution during the implementation phases.</td>
<td>Italian government (main funder), Veneto Region, Consorzio Acque Risorgive, Environmental Association and local NGOs (minor role for Farmers, Municipalities)</td>
<td>Venice Lagoon, local communities, including schools and environmentalNGOs; in a limited way also farmers (flood risk)</td>
</tr>
<tr><td colspan="2">Governance
The regulatory framework, designed by Venice Lagoon Master Plan, allows the Drainage Authority to play a new key role in the model working as an Utility: in addition to traditional irrigation and drainage services, it provides a public utility services, it ensures a service of diffused water pollution remediation. Municipalities and NGO are also involved by managing the ricreation activities in some area and mantaining the related facilities. The governance model could by classified as a "Network government"</td></tr>
</table>

Cost Structure	**Cost Reduction**	**Capturing Value**
NBS O&M costs (5k euro/yr for wetland, 2k euro/yr for buffer strips) are incurred by the Drainage Authority through its budget, without additional contribution of its members. NGO, involved in recreation activities, spends 6K euro/yr to maintain trails, signages, booklets, ...	Volunteer labour by NGOs allows to deliver most of the social benefits included in the value proposition	No direct revenue could be generated by the NBS. Most important indirect values are: diffuse pollution control, flood protection, support to biodiversity, recreation, awareness and education

CAPEX Costs	**Source of Capital Investment**
The total investment is estimated in about 4 milion euro (revaluated in euro 2018): for the 2 wetlands the investment is 3,7 milion (euro 2018), 300.000 euro for buffer streeps	Total capital Investment funded by the Italian Government and managed by the Veneto Region through the Venice Lagoon Master Plan - "Plan for diffuse pollution prevention and restoration of water in the draining basins of the Venice Lagoon", entered into force in 2000.

A system based on the "diffused governance" would probably allow a reduction of parametric costs of NBS (both capital and O&M), thanks to the recourse to the work time of farmers. However, the effectiveness regarding pollutant removal and several other benefits would be highly uncertain. For example, buffer strips need to be designed carefully, in order to obtain significant removal capacity. According to the experience of the technical staff of the Consorzio Acque Risorgive, farmers subsidized to implement buffer strips locate them with a view to minimize their negative effects on agricultural production, rather than to maximize environmental benefits. A system of "centralized governance" can secure the effectiveness of environmental benefits much more than a "diffuse governance" system. Moreover, the approach used by Consorzio Acque Risorgive to acquire to the public property the land where the NBS are constructed guarantees that, in the long term, the areas involved do not change their allocation and can be fully exploited for other, e.g. recreational purposes.

The Consorzi di Bonifica in Italy, and similar organizations in other European countries, are responsible for the management of the secondary hydrographic network in rural areas. Sometimes these organizations have been tasked with a broader management mandate, as in the case of water boards in the Netherlands([31]). In order to mainstream the action of Consorzi di Bonifica as in the Venice Lagoon case study, it would be important to strengthen their mandate and financing mechanisms, and to secure adequately skilled personnel familiar with modern approaches to water management through NBS and other multifunctional solutions. Similar considerations could be valid also in other European contexts.

On the other hand, when the authority in charge of the "centralized governance" is not committed to integrate NBS in their modus operandi, including through the deployment of an adequate technical expertise, the results may be disappointing as shown in the case study in the province of Latina, where buffer strips were

[31] https://dutchwaterauthorities.com/wp-content/uploads/2021/05/The-Dutch-water-authority-model.pdf

implemented without consideration of flood hazards and, eventually, dismantled and abandoned without achieving any benefit.

Certain investments could be funded based on the value of important co-benefits. For instance, the restoration of soil retention capacity analysed in the German Middle Mountains provides a significant benefit in terms of greenhouse gas sequestration and, as such, it might be suitable for investments on a voluntary or, potentially, mandatory emission trading system, such as the EU ETS[32]. To this end, a critical aspect is the certification of the carbon sequestration credits.

A case where a centralized governance model proved indispensable is the Karla lake restoration project (§2.4.2), where large public investments were unavoidable, and multiple benefits may only arise from a multifunctional management of the water body. In that specific case, the value of water for irrigation is high but farmers would not be able to cover the full cost at the current conditions of agricultural production. Other benefits, including the preservation of the ecosystem and support to biodiversity, may amply justify a coverage of the cost gap and, in some cases, bring also monetary revenues (e.g. tourism). However, there is no single stakeholder group capable to initiate and lead such a project in the absence of massive public funding. The centralized governance model is suited where the stakeholders can only pay a (limited) part of the overall costs (**Figure 31**).

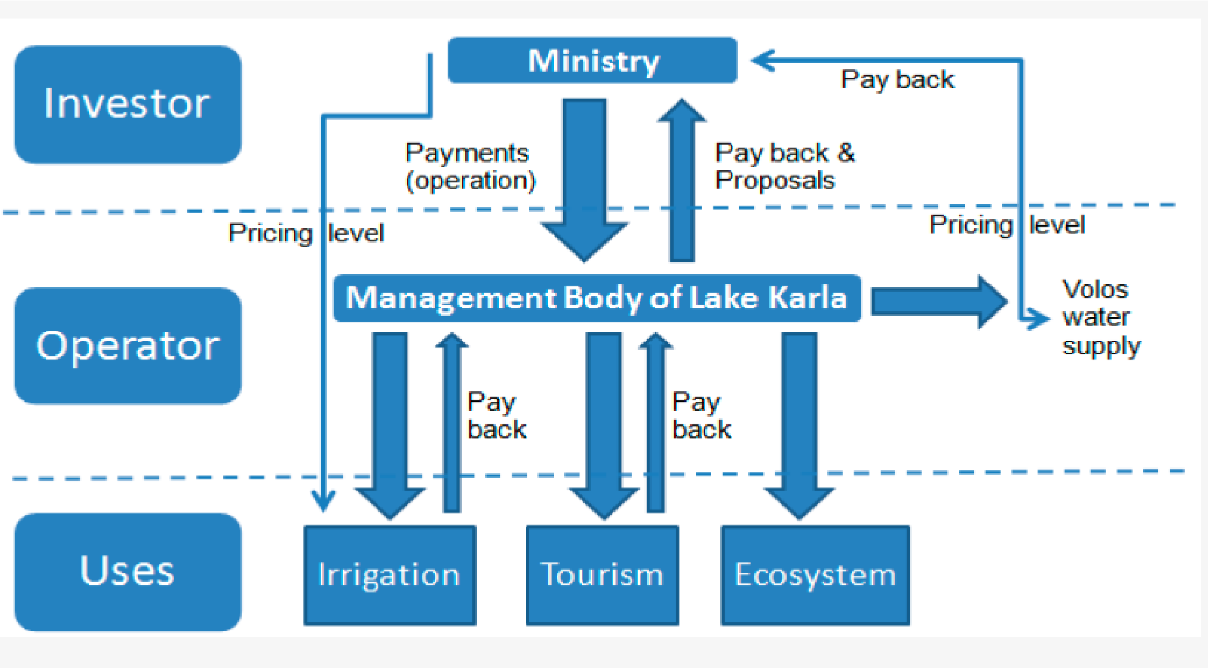

Figure 31. A proposed governance scheme for the operation of the Lake Karla. Se Panagopoulos and Dimitriou, 2020, for all details.

A "mixed governance" model was explored in the case study of the Lamone catchment, where Staccione et al., 2021, examine various possibilities to establish a mechanism of individual farmers paying for their own irrigation ponds, with a "central governance" body ensuring that they receive payments or compensations, in different possible forms including through land swaps and fiscal revenues from urban development, to cover the extra costs for making ponds supportive of nature conservation. Similar considerations are made also in relation to the possibility of urban residents to pay a contribution for the development of NBS suitable for recreation and landscape improvement in the case study of the Venice Lagoon.

[32] https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

4 Conclusions

Nature-based solutions can help address pollution and water availability issues in agriculture. We have examined the following types of well-established NBS that can be readily implemented:

1) Treatment of excess manure and sludge stabilization before application in agriculture;
2) Buffer strips and ponds for the interception and removal of nutrients and other pollutants;
3) Two-stage channels (TSC) for enhanced in-stream retention of water and contaminants;
4) Ponds, lake restoration and enhanced soil retention improving water availability.

These NBS can be effective at addressing a primary need (pollution control or water storage) while delivering a series of additional ecosystem services. In some cases, they can be cheaper than their “grey” alternatives, while in other cases they require extra investments in order to seize their multiple benefits. Although a decision can be often made only with reference to the specific conditions of each case, often the additional benefits may exceed the extra costs. Hence, these NBS can be regarded as a viable, and often preferable option in many situations. As such, they should be applied whenever possible.

In order to enable an extensive implementation of NBS, it is key to define an appropriate “business model”: who does what and who pays for what, to whom. Small scale measures such as treatment wetlands or ponds may be self-sustaining investments as they prove cheaper than alternatives. Buffer strips and ponds for pollution control, as well as TSC, are often a mere cost for farmers and usually require subsidies in order to be implemented by the farmers themselves. In some cases, there may be permitting or approval procedures for NBS (e.g. ponds for water storage). In those cases, the competent authorities may give prescriptions on the way to implement NBS (e.g., require shore slopes of ponds to have a mild slope in order to support biodiversity) in order to maximize their ecological and other functionalities. Such prescriptions may be complementary or alternative to subsidies, depending on the case.

As an alternative, these NBS could be implemented by a technical authority, such as a water board or “Consorzio di bonifica”, on behalf of the farmers that could receive a compensation for the land they lose to implement these solutions. The advantage of this approach is in the possibility for a technical authority to optimize the interventions, while farmers may tend to implement the measures more with a view to minimizing interferences with their activity than to making them work effectively (e.g., placing buffer strips in a way that does not fully intercept the runoff, in order to ease the operation of tractors and other machines). However, it is important that the technical authority have a good understanding of NBS and their application in the context of their core mandate. When NBS are developed occasionally, they may fail to pursue important objectives, hence to become regular practice. In one case, for example, failure to design buffer strips compatible with flood hazards, in addition to being effective for pollution control, led to their dismissal.

In some cases, a “centralized governance” model is indispensable in order to enable investments that may mobilize large benefits, but that could not be supported by a single group of stakeholders. For example, the restoration of the former Karla Lake, subject to a land reclamation project in the years 1960, in the form of a managed reservoir retaining an important ecological function, required governmental support to deliver on municipal and irrigation water supply, flood control and ecosystem services. In other cases, simply changing the management rules may deliver large benefits at relatively low costs, as shown by the example of restoration of headwater swamps in the Kyll river basin, enhancing soil water retention.

In any case, it is important to secure regular funding for the development and management of NBS, in order to have them work over time and become an effective instrument to improve the landscape. Funding may come from the public budget (e.g. Common Agricultural Policy or other funds), when there is a clear general benefit, or from specific payment mechanisms, such as tariffs or taxes, when they benefit local stakeholders (residents, tourists etc.). In some cases, it may be possible to consider compensatory mechanisms, such as use of taxes paid for urban development, in exchange for the services of public interest delivered by NBS.

References

Bresciani, Riccardo, Giulio Conte, Nicola Martinuzzi, Fabio Masi, Andrea Nardini, Anacleto Rizzo. Nature-based solutions for climate change adaptation and water pollution in agricultural regions: services supporting the synthesis and dissemination of results. Final report (deliverable D2), 21 may 2021. Provided as an annex to Pistocchi, 2022 (doi:10.2760/822671).

Borsacchi, Leonardo, Riccardo Bresciani, Giulio Conte, Alessandro de Carli, Fabio Masi, Anacleto Rizzo. Nature-based solutions for climate change adaptation and water pollution in agricultural regions - Lot 2: Treatment of sludge and manure in a continental environment, 2021a. Available at https://water.jrc.ec.europa.eu/nbs.html

Borsacchi, Leonardo, Bruno Boz, Riccardo Bresciani, Giulio Conte, Alessandro de Carli, Fabio Masi, Anacleto Rizzo. Nature-based solutions for climate change adaptation and water pollution in agricultural regions. Lot 5: landscape elements for diffuse pollution control in a continental environment, 2021b. Available at https://water.jrc.ec.europa.eu/nbs.html

Borsacchi, Leonardo, Riccardo Bresciani, Flavio Camerata, Giulio Conte, Alessandro de Carli, Fabio Masi, Stefano Magaudda, Anacleto Rizzo. Nature-based solutions for climate change adaptation and water pollution in agricultural regions. Lot 6: landscape elements for diffuse pollution control in a Mediterranean environment, 2021c. Available at https://water.jrc.ec.europa.eu/nbs.html

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., von Sperling, M., Treatment Wetlands. IWA Publishing, 2017. https://doi.org/10.2166/9781780408774

Gumiero et al., 2011: Gumiero, B., Boz, B., Cornelio, P., & Casella, S. (2011). Shallow groundwater nitrogen and denitrification in a newly afforested, subirrigated riparian buffer. Journal of Applied Ecology, 48(5), 1135-1144.

La Notte A., Ferrini S., Pisani D., Grilli G. Grammatikopoulou I., Badura T., Vallecillo S., Turner K., Maes J., How much do Europeans value biodiversity? A choice experiment exercise to estimate the “habitat and species maintenance” ecosystem service, EUR 30953 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-46351-1, doi:10.2760/927786, JRC127797

Langergraber, G., Dotro, G., Nivala, J., Rizzo, A., Stein, O.R. (eds), Wetland Technology: Practical Information on the Design and Application of Treatment Wetlands. IWA Publishing, 2020. https://doi.org/10.2166/9781789060171

Lorenzo, Yurena, Jos de Bijl, Maarten Waterloo, Anouk Gevaert, Rob Nieuwkamer, Lena Vitzthum, Olaf de Haan. Natural retention in the Rhine catchment as a nature-based solution for flood risks, drought control, biodiversity restoration and climate challenges. Contract Number: 939651-IPR-2020.1st Technical Report, 2021

Panagopoulos, Y.; Dimitriou, E. A Large-Scale Nature-Based Solution in Agriculture for Sustainable Water Management: The Lake Karla Case. *Sustainability* 2020, *12*, 6761. https://doi.org/10.3390/su12176761

Pistocchi, A., Husemann, J., Masi, F., Nanu, C., (eds.) Wastewater treatment in the Danube region: opportunities and challenges. Lessons learnt from a “synthesis centres” exercise. Publications Office of the European Union, Luxembourg, 2022, EUR 30106 EN. ISBN 978-92-76-16429-6, doi 10.2760/220413, PUBSY No. JRC115606

Pistocchi, A.,, Mapping favorability to the implementation of nature-based solutions for agricultural water management in Europe. Constraints, demand, effectiveness and costs. EUR 31331 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-60171-5, doi:10.2760/822671, JRC131469

Potokar, Anja, Alenka Mubi Zalaznik, Tea Erjavec, Ursa Brodnik, Gregor Plestenjak, Martin Vrhovšek, Ivan Kolev, Cveta Dimitrova, Carlos A. Arias. Nature Based Solutions in Agriculture - Lot 1: Treatment of wastewater sludge or manure from livestock in a nordic or alpine environment. 2020a. Available at https://water.jrc.ec.europa.eu/nbs.html

Potokar, Anja, Urša Brodnik, Alenka Mubi Zalaznik, Tea Erjavec, Ursa Brodnik, Gregor Plestenjak, Martin Vrhovšek, Alenka Fajs, Ivan Kolev, Cveta Dimitrova, Carlos A. Arias, Pedro Carvalho. Nature Based Solutions in Agriculture - Lot 3: Treatment of wastewater sludge or manure from livestock in a Mediterranean environment. 2020b. Available at https://water.jrc.ec.europa.eu/nbs.html

Staccione, A., Broccoli, D., Mazzoli, P., Bagli, S., Mysiak, J., Natural water retention ponds for water management in agriculture: A potential scenario in Northern Italy, Journal of Environmental Management, Volume 292, 2021, 112849, https://doi.org/10.1016/j.jenvman.2021.112849.

Västilä, K.; Väisänen, S.; Koskiaho, J.; Lehtoranta, V.; Karttunen, K.; Kuussaari, M.; Järvelä, J.; Koikkalainen, K. Agricultural Water Management Using Two-Stage Channels: Performance and Policy Recommendations Based on Northern European Experiences. *Sustainability* 2021, *13*, 9349. https://doi.org/10.3390/su13169349

List of figures

List of tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

On the phone or in writing

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

— by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

— at the following standard number: +32 22999696,

— via the following form: european-union.europa.eu/contact-eu/write-us_en.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

You can view or order EU publications at op.europa.eu/en/publications. Multiple copies of free publications can be obtained by contacting Europe Direct or your local documentation centre (european-union.europa.eu/contact-eu/meet-us_en).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex (eur-lex.europa.eu).

Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office
of the European Union