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METHODS, TOOLS AND BEST PRACTICES

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The cover image shows a sea glacier ice that melts away.

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Renaturalising lands as an adaptation strategy

Towards an integrated water-based design approach

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Abstract

The effects of soil sealing on the hydrological cycle and water resource exploitation are critical issues for the sustainable development of urbanised areas, where uncontrolled growth has led to deep changes in the hydrological balance regime. In a climate change scenario, the expected increase of rainfall results in hydrogeological and contamination issues, with severe impacts on the fragility of many territories such as small mountain cities. In this framework, renaturalising lands using Nature-based solutions can help to restore the original ecosystemic functions and to improve urban quality. To this end, this study proposes a multidisciplinary and transcalar water-based design approach, applied to the case study of the Comano Terme area in Trentino (Italy). Combining landscape design and hydraulic constructions, sustainable urban drainage devices were integrated into a slow mobility system and open-air public spaces to increase rainfall-runoff infiltration and storage. The hydrological model simulations showed how it is possible to treat part of the rainfall-runoff where it is produced, thus reducing and delaying the runoff quantities delivered to the stormwater system up to the receptor bodies. The proposed solutions merge with the existing environment and infrastructures, reconnecting the territory and enhancing its identity, while increasing urban resilience and providing social benefits.

Keywords

Nature-based solutions (NBSs); Green and blue infrastructure (GBI); Sustainable urban water management; Climate change adaptation; Low impact development (LID).

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1. Renaturalising urban areas in a climate change adaptation scenario

Land take and consumption, and the consequent soil sealing are critical issues that are directly connected to the urbanisation phenomenon (Jobstmann et al., 2011). This phenomenon was observed from the 1850s and it is expected to increase in the next decades (UN, 2019), becoming an urgent challenge to cities' sustainable development.

The uncontrolled growth of urban areas, without the implementation of adequate measures for mitigating and adapting to the anthropic impact, has been the cause of the increase in climate-altering greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2001) and of substantial changes in the hydrological cycle (Gibelli et al., 2015). The combination of these trends contributes to climate change and to the loss of ecosystemic functions and services (Intergovernmental Panel on Climate Change, 2022). It has been underlined that cities play a vital role in addressing climate change (Salata & Yiannakou, 2016) and the use of Nature-based solutions (NBSs) in urban water management is recognised to drive adaptive design strategies. The necessity of integrating these strategies with the built environment has been emphasised by Pelorosso et al. (2013) taking into account both their environmental and social benefits (Cohen-Shacham et al., 2016; Frantzeskaki, 2019). As suggested by the International Union for Conservation of Nature (IUCN), NBSs can address a variety of societal challenges:

- restoring the water-related services of nature can help against water scarcity and stresses, that are acquiring increasing relevance in a climate change scenario;
- protecting wild genetic resources, managing wild plants and providing irrigation water with NBSs can help in pursuing food security;
- enhancing the ecosystems, climate and biodiversity quality for the human health, wellbeing and social cohesion by increasing the green spaces, particularly in urban areas;
- offering sustainable solutions for the regulatory function to climate disasters in term of cost-effectiveness compared to the traditional solutions;
- mitigating and adapting climate change through multifunctional and multiscale strategies.

In this framework, this contribution aims at developing a transcalar and multidisciplinary approach focused on the water resource for the renaturalisation of an urbanised and marginal territory, proposing NBSs to restore the original ecosystemic services and functions. The intent is to restore the permeable capacity of the lands before the anthropic intervention by contributing to the ecological valorisation of landscape common resources and development of urban areas.

The case study site is a mountain valley located in Trentino (northern Italy) that includes the Municipalities of Comano Terme and Stenico and is characterised by a network of small towns and cities located along the main transportation axes. In the last century, these urban areas showed similar dynamics to bigger Italian cities, such as the increase in land take and soil sealing (Munafò, 2021), followed by pressures on the urban water drainage systems and hydrogeological hazards. River Sarca, which flows along the valley, has been strongly exploited for hydropower production since the 1950s (Lappi, 2008). The increase in rainfall, together with sudden and intense flow releases from the upstream dam of Ponte Pià (Ufficio Dighe of Trento Autonomous Province, n.d.), causes floods in urban areas, worsened by soil sealing (Gibelli et al., 2015). Furthermore, this fragile territory is characterised by the presence of many, yet disconnected, water resources, such as thermal and mineral springs, streams, and water collectors. Within this context, the experimental study described in this contribution proposes an integrated approach that combines landscape design and hydraulic constructions strategies to increase urban resilience through sustainable urban water management. The approach adopted is based on the context analysis, which aims at understanding the local social, environmental, and economic dynamics, thus the identity of the territory: a land strongly intertwined with the double role of water as a resource (due to the hydropower and wellness production) and as a threat (due to the environmental degradation and hydrogeological hazard). This paper will focus on the design of a sustainable territorial fluvial park based on a slow mobility system that reconnects the territory and increases the environmental urban quality: the modelling and implementation of nature-based sustainable urban drainage devices have been proposed with an integrated approach for the requalification of the areas, providing social, economic, and environmental benefits, that were evaluated with a hydrological model.

2. Water as a resource and a threat: NBSs in urban areas

Water has historically been a fundamental resource for human society in a variety of different forms and shapes. Since the beginning of civilization, villages, cities, and urban areas grew along watercourses and rivers. Rivers constituted a source of irrigation and drinking water. In those urban areas where water streams were absent, infrastructure (such as the Roman aqueducts) were built to gain access to the water resource. Thermal and mineral springs have been a pole of attraction as well, giving origin to thermal and wellness centres. Furthermore, throughout human history, rainfall and the hydrological cycle governed many human dynamics such as drought and flood-related migrations.

Humans' relationship with water has always been controversial, although this theme acquires particular importance in the context of climate change and its effects. In the last century, the terms that characterise the hydrological balance in urban areas have been deeply modified with respect to those of the natural environment with a strong reduction of the infiltration capacity (shallow and deep infiltration) in favour of an increase in the surface runoff (Gibelli et al., 2015). This effect, combined with the expected increase in the frequency and intensity of rainfall (Intergovernmental Panel on Climate Change, 2022), entails hydrogeological instability (EU, 2007), contamination (Pelorosso et al., 2013), and pressures on different parts of urban areas' drainage systems. Moreover, the decreased infiltration and evapotranspiration quantities are directly related to phenomena such as Urban Heat Island (Gerundo, 2018) and reduced ecosystemic quality (Pelorosso et al., 2013). Water, which has been recognised as a vital resource for human society (Pimentel et al., 1997), is now more and more related to negative phenomena, with direct consequences on human health, security (Gallozzi et al., 2020), and economy (Pelorosso et al., 2013). This appears clearly in the 2020 Periodical Report on the climate risks (CNR IRPI, 2020) that underlines the exponential increasing of damages from 1970 to 2020 with significant social and economic impacts: in 2020, 636 Italian towns were affected by floods or landslides that caused fatalities, while from 1970 and 2019 a total of 3,785 lethal floods or landslides were registered in Italy (Bianchi & Salvati, 2021). In the framework of the mitigation and adaptation to climate change, projects involving NBSs started to be proposed, opposed to traditional grey infrastructure (Frantzeskaki, 2019; Frantzeskaki et al., 2022) such as concrete structures, which are effective, yet mono-functional and rigid (Voskamp & Van de Ven, 2015). The true benefits of NBSs are their multipotentiality: they also play a role in creating new green urban commons that instigate a sense of place and belonging in communities and a new relationship between people and nature (Frantzeskaki, 2019; Frantzeskaki et al. 2022). Furthermore, Bianconi et al. (2018) have underlined the role of NBSs in urban regeneration, in particular their balancing action on environmental and ecological instability, their mending action on torn urban fabrics, and their ability to define public spaces. Franteskaki et al. (2019) highlighted the necessity of analysing social and health benefits, as well as their interaction with the environmental effects of NBSs in order to support their diffusion, governance, and financing.

2.1 NBSs, GBI and GI: an overview on the multiple definitions

The definition of NBSs, as well as those of Green and Blue Infrastructure (hereafter GBI) and Green Infrastructure (hereafter GI) have not been uniquely defined. According to Cohen-Shacham et al. (2016), the original definition of NBSs derives from the IUCN, that defines NBSs as "Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". The European Commission (EC), on the other hand, adopts a broader definition of NBSs, defined as "Living solutions inspired by, continuously supported by and using Nature designed to address various societal challenges in a resource efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits". The two definitions both focus on addressing societal challenges through the ecosystemic services that they can provide, but while the IUCN definition emphasises the efficient management or restoration of ecosystems, the EC definition, focuses on the direct use of nature and on the inspiration and support that it can provide (Cohen-Shacham et al., 2016; Frantzeskaki et al., 2022).

The European Environment Agency (EEA et al., 2021) provides a comprehensive interpretation of NBSs, defining them as "actions that work with and enhance nature to restore and protect ecosystems and to help society adapt to the impacts of climate change and slow further warming while providing multiple additional benefits (environmental, social and economic)", therefore classifying them among climate change adaptation and mitigation strategies. A planning tool based on the ecosystem approach for the adaptation and mitigation of climate change is GI (Yiannakou & Salata, 2017). Lafortezza and Sanesi (2019) proposed a standardised applicative framework for NBSs using the structure of the DPSIR (Diving force-Pressure-State-Impact-Response) model. This model is focused on addressing climate change, proposing NBSs concrete 'responses'. These responses are envisioned to lead to sustainable urbanization, which can regulate some of the 'driving forces' and reduce the pressures on urban areas, while interacting at the same time with the ecosystemic services (Lafortezza & Sanesi, 2019).

As many studies underlined, there is no universally accepted definition of GI. Definitions depend on the spatial scale, context and stakeholders (Salata & Yiannakou, 2016; Beauchamp & Adamowski, 2013). The EC (EC, 2013) refers to GI as a "strategically planned network of high-quality natural, semi-natural and cultivated areas designed and managed to deliver a wide range of ecosystem services and protect biodiversity in urban and peri-urban settings".

Natural England (2009) considers GI "a strategically planned and delivered network of green spaces and environmental features". Water elements are directly referenced by the Landscape Institute (2009) definition, adopted by Salata and Yannakou in their studies along with the Natural England one (Yiannakou & Salata, 2017; Salata & Yiannakou, 2020). The Landscape Institute (2009) considers GI as "the network of green spaces and other natural elements such as rivers and lakes that are interspersed between and connect villages, towns and cities".

As Beauchamp and Adamowski (2013) and Hansen and Pauleit (2014) underlined, even if not ubiquitously present in GI definition, the GI concept includes water and the water system.

Closely related to the concept of GI, GBI serves as an umbrella notion as well (Ghofrani, 2017), with a direct reference to water and water systems in the word "blue". GBI was defined by Ghofrani et al. (2017) as "an interconnected network of natural and designed landscape components, including water bodies and green and open spaces, which provide multiple functions such as: (i) water storage for irrigation and industry use, (ii) flood control, (iii) wetland areas for wildlife habitat or water purification, and many others". Perini & Sabbion (2016) provide a second definition of GBI, emphasising their role in urban resilience, referring to GBI as "strategies targeted to increase urban resilience to climate change, improving the coping, adaptive and mitigation capacities within cities". This concept was taken up also by Codemo et al. (2018) that link the role to GBI in urban resilience and sustainability to the ecosystemic services.

In conclusion, in this paper we will refer to NBSs as an umbrella term that, according to Cohen-Shacham et al. (2016), includes a series of actions inspired by, supported by or copied from nature to address societal challenges (effectively and adaptively), simultaneously providing human well-being and biodiversity benefits. Therefore, GBI were considered just a part of the NBSs that can include GI, meaning those infrastructures in which water is present as an operating element (i.e. filtration, evaporation, etc.). On the other hand, we understand GBI as infrastructure in which water is explicitly present to control the runoff (i.e., storage basins).

2.2 Sustainable water management in urban areas

The European Commission (EC, 2000) and the United Nations (UN, 2015) recognised the need to protect the water resource and aquatic ecosystems, to promote a sustainable water use and to reduce pollution, aiming to mitigate the effects of floods and droughts. In this context, water management in urban areas is currently mainly addressed with "end of the pipe" solutions that deal with floods, storms, water scarcity and pollution with downstream strategies. For instance, higher peak flows following the increased soil sealing and rainfall quantities were managed by intervening on the infrastructure's dimensions (Gibelli et al., 2015). Gibelli et al. (2015) also emphasised the need for an integrated, transcalar, and diffuse urban water management, acknowledging its role (in addition to soil sealing) in cities' and territories' vulnerability (Fig.1).

		MINIMIZING THE PROBABILITY	MINIMIZING THE EFFECTS	STIMULATING RESILIENCE
PUBLIC	SUB-CATCHMENT S	Give space to the river, from regulated to natural rivers	Lamination ponds and local widenings	Green and blue infrastructure systems
	CITY C	Greening cities, increasing infiltration areas	Build artefacts that can be submerged (urban furnishing, areas, materials)	Create alternatives (e.g. streets), dedicated insurances, reconnecting small hydrographic networks and devices for a fast disposal of flood water
	NEIGHBORHOOD Q	Water resistant buildings (materials)	Rain gardens, infiltration areas	Pumps
PRIVATE	BUILDING E	Green roofs, barrels	Adaptive building design	Pumps

Fig.1 Actions proposed in the transcalar and multidisciplinary approach for a sustainable urban water management

Towards a more resilient urban water management, the use of NBSs, intended in this specific context to refer to a series of measures and strategies to control pollution and runoff quantities (Venturini et al., 2021; Pelorosso et al., 2013), has started to spread. We underline that NBSs (term most used in Europe) and LID (term most used in North America), as well as other acronyms (i.e., SUDS – Sustainable Urban Drainage Systems, etc.) can be used with the same meaning to represent sustainable strategies to preserve the natural landscape by reducing the influence of human activities on surface runoff (Qiu et al., 2019; Fletcher et al., 2015). Henceforth, we will specifically refer to bioretention cells, rain gardens, green roofs, permeable pavements, infiltration trenches, rain barrels, roof disconnections, detention ponds, and vegetative swales as LID practices, as done by the United States Environmental Protection Agency (EPA, 2019). Each practice can store runoff and allow the evaporation of stored water (except for rain barrels), whereas the infiltration capacity is increased in vegetative swales, bioretention cells, rain gardens, permeable pavement systems, and infiltration trenches (EPA, 2019). As visualised in Fig.2, LID practices offer multiple (ecological, aesthetical, and social) benefits (Pelorosso et al., 2013), maximising at the same time opportunities connected to landscape and urban quality, such as fruition, biodiversity, and microclimate (Gibelli et al., 2015).

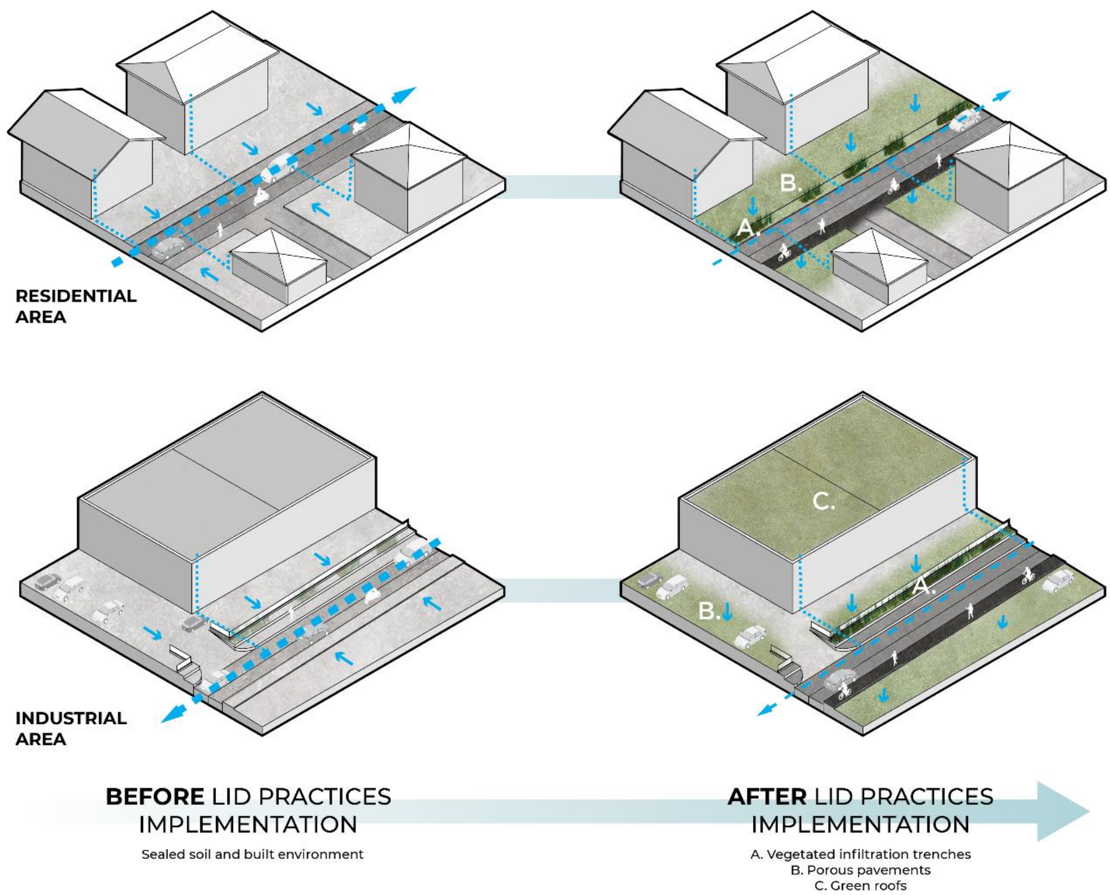

Fig.2 Implementation of LID practices in an urban portion of the study area of Comano Terme

3. Renaturalising the Comano Terme Valley: towards an interdisciplinary and transcalar water-based design approach

The Comano Terme valley is located in the Comunità delle Giudicarie at the feet of the Geopark "Adamello Brenta Nature Park". The area has been intertwined with water resources since the Roman Age when the curative properties of the thermal water were first discovered. Since then, the ancient spring has been a medical centre of attraction for the inhabitants of the valley (Cenedella, 1847). In more recent times, medical tourism has started to increase, as the Terme di Comano consortium company and wellness centre were built (Azienda Consorziale Terme di Comano, 2019). In addition to the thermal vocation, the area has a strong relationship with the Sarca River, along which rose settlements such as Ponte Arche.

The growth of these urbanised areas occurred especially in the last century, after the construction of the main infrastructural road with Trento. River Sarca springs from the Adamello-Presanella mountains in the Rendena valley (770 m a.s.l.) and flows, after 75 km, into the Garda Lake. The river has been exploited since the middle of the XX century for hydropower production, through a complex network of power plants, artificial basins, and penstocks (Zolezzi et al., 2015). Ponte Pià dam, located upstream of the study area, was built in 1956 and gives rise to the Ponte Pià artificial basin (Lappi, 2008), which retains $4x10^6$ m^3 of water and deviates it

from the river to the Santa Massenza power plant, thus releasing the subtracted water many kilometres downstream and reducing the ecological quality of the river (Zolezzi et al., 2015).
The anthropic intervention of the last century has had a critical impact on the valley. The hydropower exploitation of the territory, together with the continuing urbanisation and the land taken out during rural-urban transformation, has caused hydrogeological instability and floods, as shown in the hydrogeological hazard maps elaborated by the Trento Autonomous Province (Fig.3).

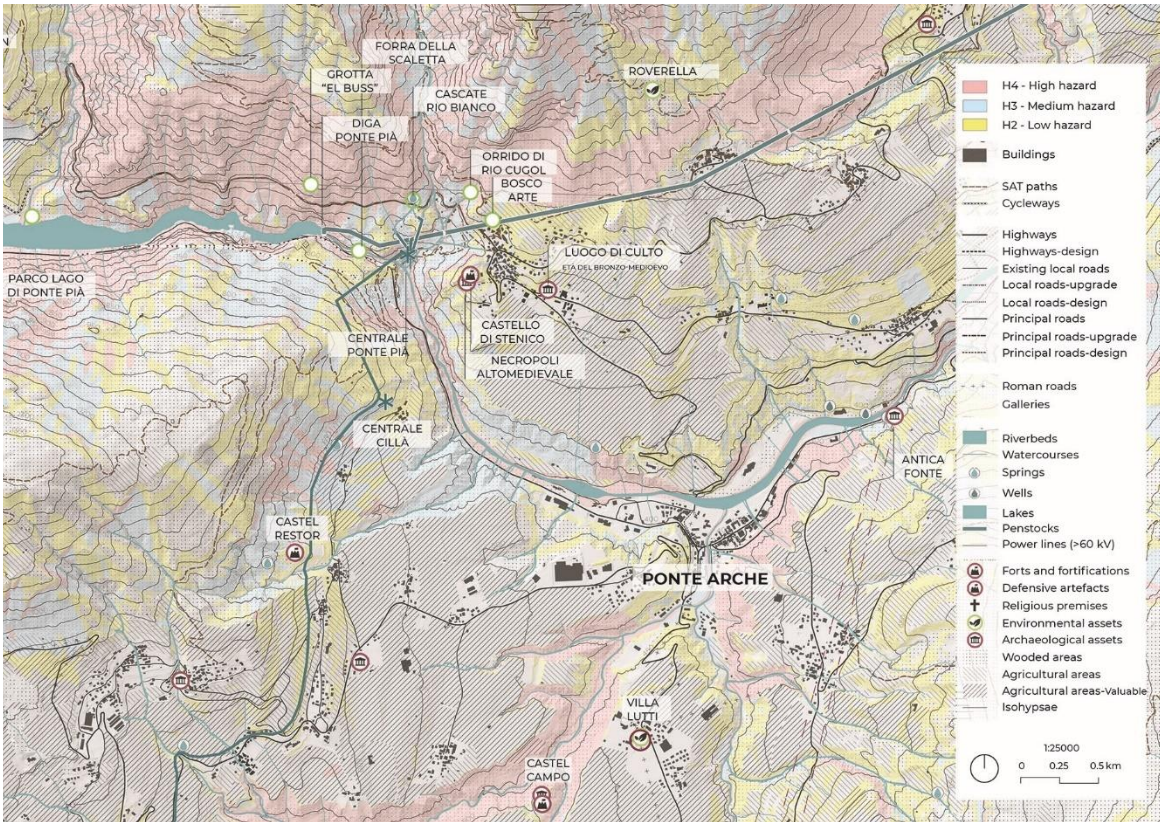

Fig.3 Planimetric visualisation of the Comano Terme valley, overlayed with the hydrogeological hazard map

Data (Ufficio Dighe of Trento Autonomous Province, n.d.) show that the sudden flow releases from the Ponte Pià dam that follow intense precipitation events, result in floods and in certain areas of Ponte Arche, where the fluvial hazard has been determined as high. It has been calculated that 60% of Ponte Arche's urban area is impervious, causing reduced evapotranspiration and infiltration losses, and favouring the increase of the surface runoff collected by the urban drainage system and delivered to the fluvial receptors (Sarca River and Duina Stream).
From a cultural point of view, many thermal and hydropower artefacts such as the Ancient thermal spring and the Ponte Pià power plant are marginal and don't intersect with tourists' main routes and social fluxes, which are mainly linked to the Terme di Comano wellness centre. In particular, the Ancient thermal spring is nowadays partially located under the main road and therefore inaccessible, except through a small private hypogeum corridor situated in the wellness centre.
The main challenges to be addressed in the Comano Terme valley urban areas were defined (Fig.4), recognizing the role of cities in climate change adaptation and the urgency of a shift towards more resilient urbanised lands.
The aim of the case study is the recovery of the natural hydrological cycle in urban areas, as well as their relationship with the water resource.
On a broader scale, it aims to propose strategic interventions for the management of critical issues such as the ecological degradation of the Sarca River and the marginality of many cultural and natural resources.

Having emphasised the multiple benefits NBSs, they were proposed as a strategic design framework and designed with the additional intent of valorising and enhancing the thermal and hydropower identity of the valley, reconnecting marginal and peripheral resources with the main connection and touristic routes.

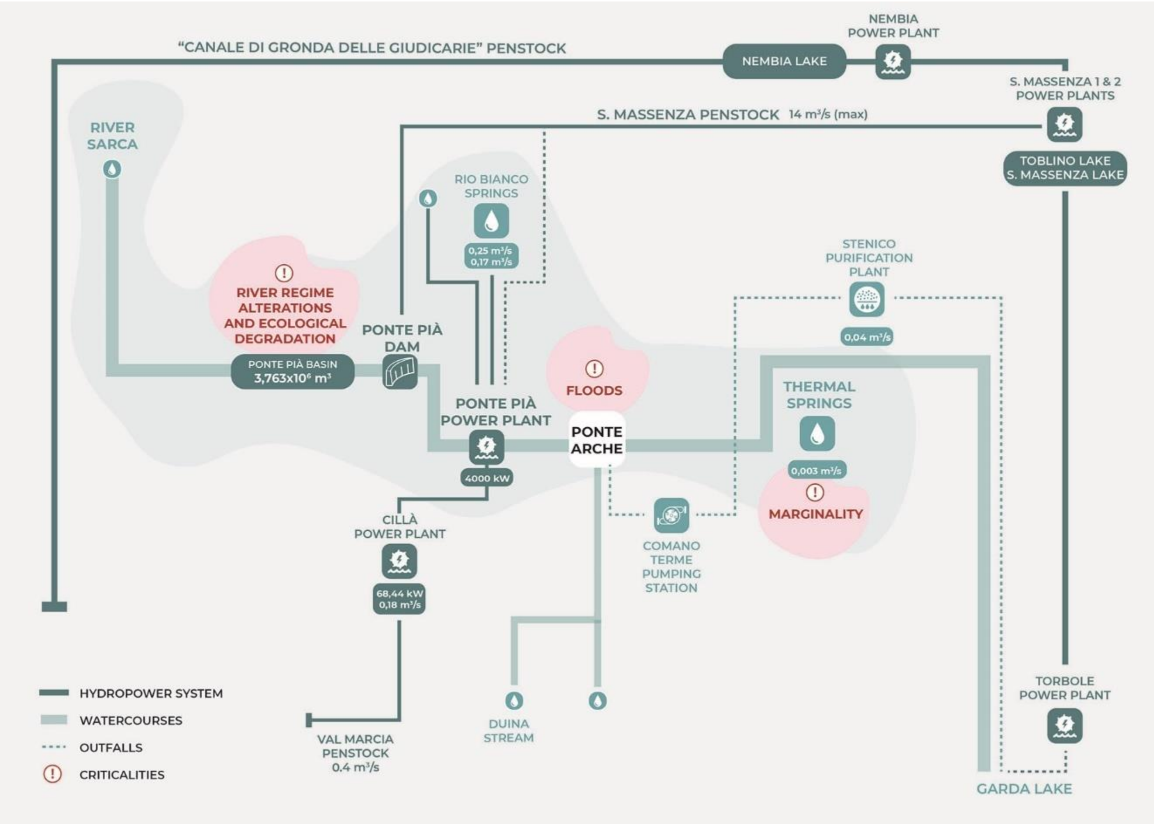

Fig.4 Conceptual visualisation of Comano Terme valley's water system and its criticalities

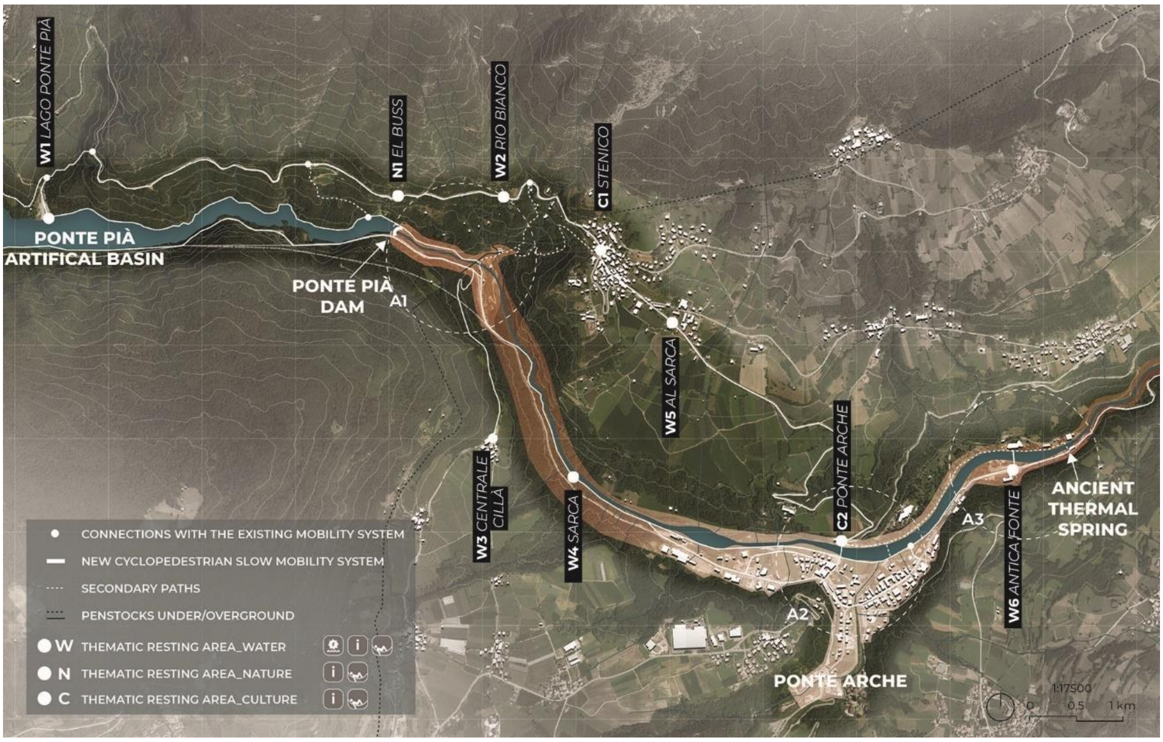

Fig.5 Visualisation of the new territorial system that was designed for the Comano Terme valley

The new territorial system (Fig.5) develops along the Sarca River, the physical and functional axis of the territory, thus becoming the main path of the design phase, which consists of four fundamental and interconnected elements:

- a slow sustainable mobility system stretching along the river, with resting areas and electric bike charging points where the paths intersect cultural and natural points;
- a river restoration project for the Sarca River, that proposes the artificial release of sediments in the riverbed downstream the Ponte Pià dam, in order to recover endangered fluvial habitats;
- two new thematic parks (thermal and energetic) in the Ponte Pià area and at the Ancient spring, that reconnect these areas to the system, allowing users' access these marginal resources;
- a hydrological cycle restoration pilot project in Ponte Arche urban centre (accurately described in the next chapter).

Each intervention was designed to address a specific criticality as well as to positively impact on the main water system of the territory.

3.1 Analysis of the urban area and its drainage system

Ponte Arche's urban area occupies 33.12 hectares with 60% (19.83 hectares) impervious surfaces such as streets, paved accesses and parking lots, and roofs (Fig. 6c). The built environment is characterised by commercial and residential buildings with sloped roofs, and the productive area is located on the western side of the town. The main attraction points are not interconnected by slow mobility, as pedestrian and cycle paths are fragmented and do not allow users for a comfortable fruition of the urban space. The existing paths also lack greenery and shade, and often, a proper separation from road traffic does not exist.

The precipitation runoff is managed by a separated and terraced drainage system[1] (Fig. 6a), which consists of concrete, gres, PVC, and PE circular conduits, with diameters spanning from 16 cm to 150 cm. The systems' outflow is delivered in the Sarca River and the Duina Stream, which are disconnected from the main social routes and fluxes of the urban area by a buffer area of greenfields.

3.2 Sustainable urban drainage system in Ponte Arche: a pilot project

The hydrological cycle restoration project in Ponte Arche proposes a pilot implementation of LID practices (permeable pavements, green roofs, green infiltration systems, and detention ponds) in the urban area. The main aim is to recover the natural hydrological cycle with soil desealing actions that renaturalise the urban area, increasing rainfall infiltration and storage while reducing the surface runoff, in comparison to the current situation. Recovering the natural hydrological cycle means reducing and delaying the peak water discharge in the river, as well as reducing the rainfall runoff routed by the urban drainage system. The project intends to be a first experimental leading case that aims to stimulate further implementations in the other urban areas of the valley. This section will present an approach that proposes the systematic implementation of the LID practices in Ponte Arche that can be seen as divided into the following steps: analysis of the urban area and its drainage system; model development; simulation and evaluation of the existing drainage system; LID practices design and implementation; evaluation of the designed drainage system (presented also in the results and discussion chapter).

3.3 Urban drainage model development

The first step in the model development has centred around the calculation of the diameters of 23 conduits located mainly near the systems' outfalls. The intensity–duration–frequency (IDF) curves were determined for

[1] The urban drainage system survey was kindly provided by Ing. Riccadonna and the Municipality of Comano Terme.

different return periods, by analysing the maximum annual rainfall depths of short duration rainfall showers (15, 30, 45, and 60 minutes) retrieved from the closest meteorological gauging station of Tione di Trento (https://www.meteotrentino.it) between 1930 and 2002. The computed IDF curves used in the design/verification phase consider a return period, T_R, of 10 years for which the rainfall intensity (j, mm/hr) is: j (T_R=10 years) =$24.849t^{0.42-1}$. Starting from this power law function representing j, we assumed that the precipitation that fall on the Ponte Arche area are constant (in space and time) and can be represented through a synthetic rectangular hyetograph characterised by a particular time of precipitation (t_p). We analysed the behaviour of the stormwater system considering different t_p and we observed that the maximum water discharges that reach the stormwater pipes occurs for t_p=5 min (in the majority of the pipes) and t_p=10 min. Consequently, we used these two different times of precipitation for design purposes (as reported in Tab.1).

Synthetic rectangular hyetograph for 5- and 10-minutes durations

Duration [min]	Precipitation intensity j [mm/h]
5	153.31
10	94.18

Tab.1 The synthetic rectangular hyetograph used for the design of the conduits

A design hydrograph and in particular the peak value Q_{max} were therefore computed by simulating, through the software SWMM (Storm Water Management Model, Rossmann et al., 2015) a dynamic rainfall-runoff model with the rectangular 5 minutes hyetograph in input and the Green-Ampt method for calculating the infiltration losses. The project was set up using the open-source software Giswater (Giswater, n.d.) and QGIS (QGIS, 2022). The former allowed:

- the selection of some input parameters of the urban drainage system: the reference system, the units, the pipe material (i.e., information on Manning roughness coefficient), and the conduit shape (i.e., section geometries);
- the introduction of the precipitation time series with all the possible scenarios under investigation (for the design phase 5- and 10-minutes hyetographs obtained from IDF curves with T_R=10 years);
- the method selected for quantifying the infiltration losses (Green Ampt);
- all the other options (i.e., date and time steps) to setup the mathematical model used to simulate the surface runoff and its routing along the network systems until the outfalls.

The Giswater software (https://www.giswater.org/) automatically builds a QGIS project (https://qgis.org/en/site/) where, along with the Digital Terrain Model (DTM) file and the Technical Map of Trento Autonomous Province, it is possible to delineate the layout of the drainage system (Fig.6a) where:

- the sectors correspond to the area of the drainage network associated to a particular outfall to the fluvial receptor;
- the nodes represent the starting and ending points of each pipe (i.e., the inlet for the water, the junctions among different pipes, or the outfall to the fluvial receptors) characterised by a planimetric position and by the ground elevation. In our simulations, we set the surcharge depth of the nodes equal to zero, by assuming that during rainfall events nodes can't pond.
- the conduits represent the links that connect the different nodes and are characterised mainly by alength, a slope, a roughness coefficient, and a particular depth from the ground surfaces (related to the node elevation). To prevent the operation under pressure of the pipes, the alignment of the water depth was ensured;
- the sub-catchments afferent to each node (Fig.6b) were then delineated by using the Thiessen polygon method with each sub-catchment characterised by a slope (calculated from the DTM, represented in Fig.6d), a percentage of impervious and pervious surfaces (calculated from the orthophoto, represented in Fig.6c), an area, a length (perimeter/2), the Manning coefficients for permeable and impermeable

area and the width (W=area/average maximum overflow length). For the evaluation of W, we approximated the average maximum overflow length as half of the sub-catchment perimeter (this approximation can be assumed valid when the shape of the sub-catchments is close to rectangular shape). Furthermore, we set the parameters required by SWMM to characterise the infiltration losses through the Green-Ampt method. We assume that each sub-catchment was characterised by the same type of soil composed mostly by sand; therefore, in-line with the United States Department of Agriculture (USDA) soil texture classification (Maidment, 1992) we set: the ratio between volume of air and volume of voids: SM_{Dmax}=0.342, the saturated hydraulic conductivity: K_{sat}=235.6 mm/hr and the suction head at the wetting front: ψ_f=49.5 mm.

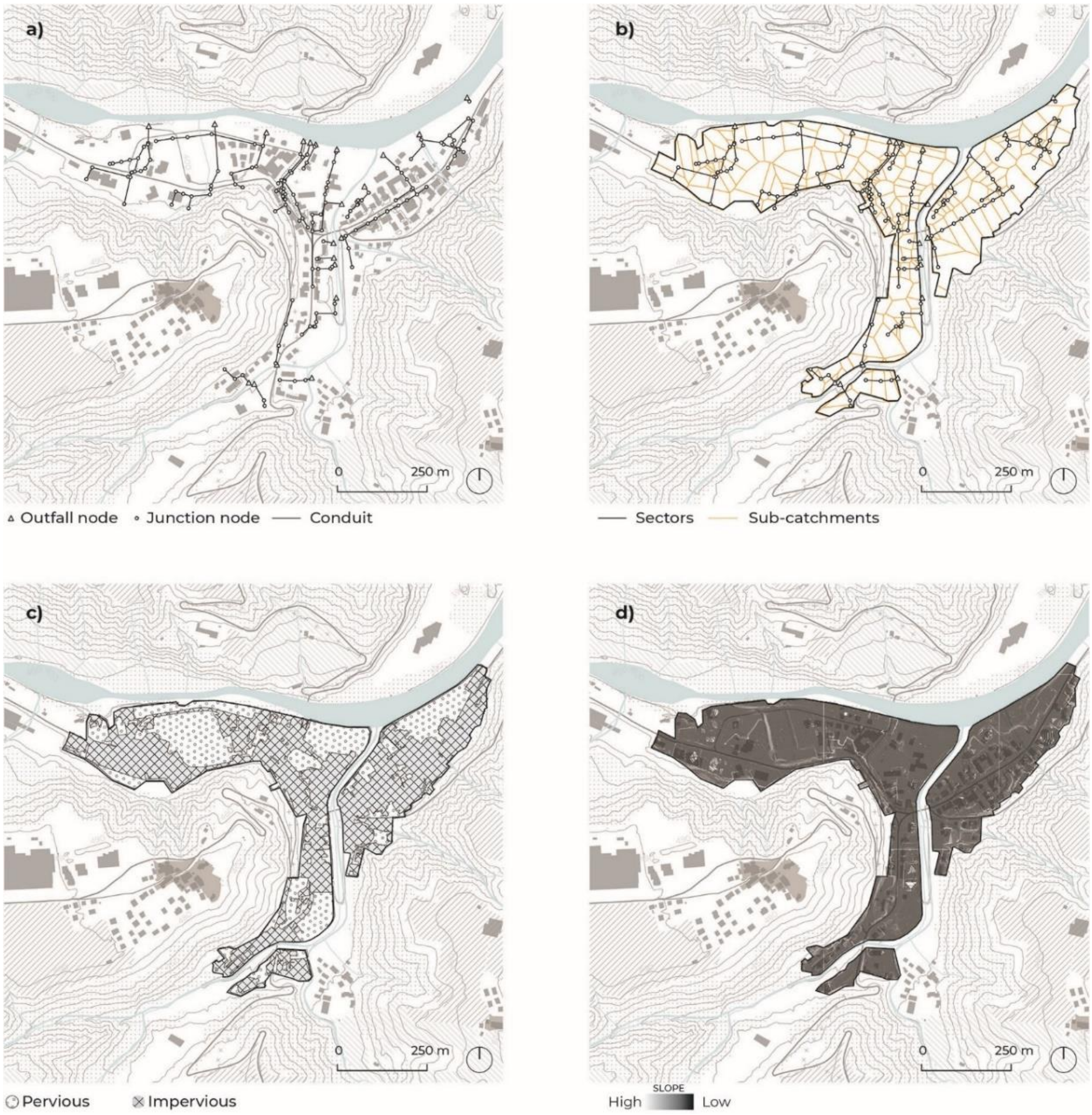

Fig.6 Urban water drainage system of Ponte Arche: (a) conduits, nodes, and outfalls, (b) sectors and sub-catchments, (c) pervious and impervious areas, (d) slope

All these procedures allow Giswater to create the SWMM input file through which was then possible to evaluate the peak water discharge (Q_{max}) to be used to obtain the unknown diameters of the pipes by using the Chezy formulation parameterised according to Gauckler-Strickler expression after the selection of a certain filling degree (G=0.75 a typical value selected for pipes with circular section in stormwater systems). The calculated diameters were then compared to those commercially available in order to select the diameter immediately higher and proceed with the self-cleaning and velocity checks.

3.4 Simulation and evaluation of the existing drainage system

The urban drainage system self-cleaning criterion (1) was verified if:

$$\tau = \gamma \cdot R_H \cdot i_f > 2\ Pa \tag{1}$$

where τ is the shear stress [Pa], R_H is the hydraulic radius [m], γ is the specific weight of water [N/m^3] and i_f is the slope of the pipe.

The hydraulic radius R_H (2) is defined and was calculated as follows:

$$R_H = \frac{A}{P} = \frac{D_i}{4}\left(1 - \frac{sin\theta}{\theta}\right) \tag{2}$$

where A is the wetted area [m^2], P [m] is the wetted perimeter of the cross-section, D_i is the commercial diameter of the conduit and θ [rad] is the angle calculated according to the filling degree $\theta = 2 \cdot acos(1-2G)$.

To evaluate the system's functionality (over-pressure of the conduits) during a rain event, SWMM reports were analysed. Moreover, to check the performance of the stormwater system under different rainfall conditions, we performed SWMM simulation for other two scenario: the first one considers a return period lower (T_R=5 years) to simulate more frequent events and short-term rainfall for generating the IDF curves; a second one considers a real event registered in the study area in October 2020.

Synthetic rectangular hyetograph (T_R=5 years)

Duration [min]	Return period T_R [years]	Precipitation intensity [mm/h]
5	5	87.39

Tab.2 The synthetic rectangular hyetograph used for verifying the urban drainage system

Data in the above table (Tab. 2) represent a simulation scenario obtained considering the IDF curves of short-term rainfall (1, 3, 6, 12, 24 hours) for a return period of 5 years: $j(T_R=5\ years)=21.435t^{0.43-1}$.

The simulation showed that there were 10 pipes working under pressure, yet the system was considered verified as this condition persisted for a short period of time and the implementation of sustainable drainage techniques will be proposed, improving the overall performance of the drainage system. The simulation allowed us to compute the percentage of infiltration in the soil, which is equal to 36% of the total precipitation. In pre-urbanised conditions, this quantity is usually about 50% (Gibelli et al., 2015). LID practices were then proposed in order to decrease the 33.12 hectares of impervious surface, which correspond to 60% of the urban area, thus aiming to increase the infiltration volume. The percentages of impervious surface that were assigned to each sub-catchment range from 0% for completely permeable areas (i.e., a sub-catchment completely included in a greenfield) to 90%, assumed as the maximum impervious percentage observed in the study area.

3.5 LID practices design and implementation

The location of the LID practices was chosen according to multiple factors: the current and future land use (retrieved from the Piano Regolatore Generale of the Municipality of Comano Terme), the existing connections towards the other urban centres, the impervious surface location, and the position of the 10 most critical conduits which were identified in the first simulation.

The strategy for the LID practices implementation involves the insertion of several LID techniques in the same sub-catchment, in order to manage different portions of the surface runoff produced in the sub-basin, providing an incremented infiltration and storage capacity of the urban area. The impervious surfaces to be desealed were chosen among public and commercial areas and private and public parking lots. The LID practices were chosen according to the benefits that they can provide and to the urban morphology (infrastructural and built environment): porous pavements, that provide storage and infiltration benefits were implemented in the many parking lots and residual paved areas of Ponte Arche, allowing pedestrian and car traffic; vegetated infiltration trenches, that increase runoff storage, were placed along the roads of the urban centre to separate, visually and physically, pedestrians' and cars' paths, therefore improving air and environmental quality and noise control, as well as the citizens' psychological and physical comfort; green roofs, which benefit runoff storage as well as thermo-hygrometric comfort, were implemented according to the roofs area's slope and availability; detention ponds, which not only increase rainfall infiltration, storage and lamination, thus reducing its pollution level, but are also an opportunity to create new recreational areas. The greenfield that separate the urban centre from the Sarca River serve this purpose and were therefore chosen for the detention ponds location (Fig.7).

The prevalent LID practices that were implemented are porous pavements (5.14 hectares), due to the high availability of impervious parking lots and residual areas. On the other hand, the predominance of pitched roofs makes the implementation of green roofs difficult: only 0.89 hectares of impervious area were greened. Due to the intrinsic linear and non-extensive nature of infiltration trenches, they occupy an area of only 0.26 hectares.

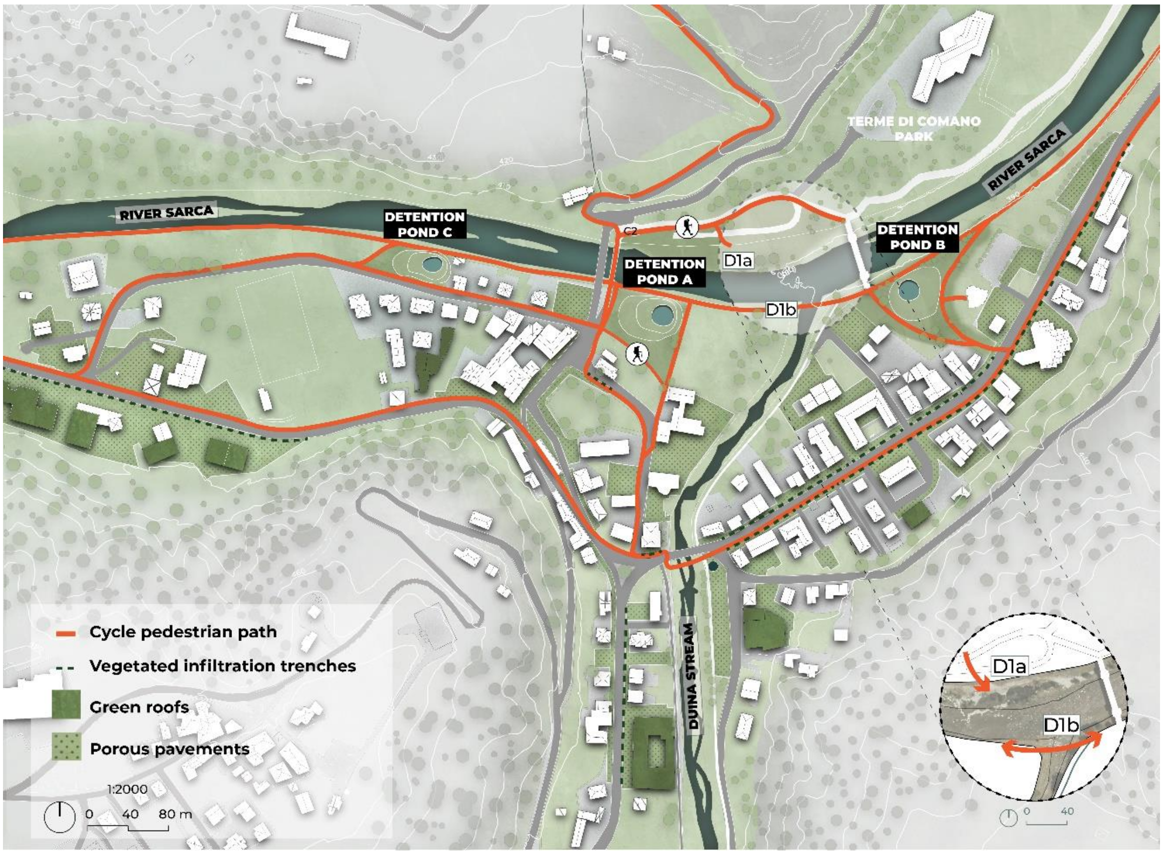

Fig.7 Masterplan of the LID practices implementation in Ponte Arche and the new connections

For what concerns a possible LID practices incremental implementation, public surfaces were considered immediately exploitable, whereas private or commercial areas were considered potentially available, foreseeing a public administration intervention or the direct involvement and initiative of the citizens. Therefore, simulations were conducted with all the identified surfaces converted to LID practices, but also in smaller sections, to test the effect of their implementation in an incremental way. The incremental process is strongly dependent on the specificities of the urban area and could start, as a first option, from porous pavements and vegetated infiltration trenches, as they are mainly located in public areas.

The identified areas can be desealed in smaller sections while playing a demonstrative role, fostering interest and raising awareness on the climate change adaptation and mitigation through NBSs. While green roofs are relatively easy to implement, the flat roofs of the city are predominantly private, requiring an additional effort for their implementation, thus delaying the timing.

A second option would be to implement LID practices in sectors, thus in a limited number of sub-catchments at first, expanding later to the whole urban area.

Concerning the detention ponds implementation, in both incremental options the process could start from detention pond B, which it is located in a public park, and would therefore generate urban regeneration for citizens health and wellbeing. Detention pond A and C could then follow as they are located in private unused areas and would require public intervention or incentives for their realisation. Public incentives for the implementation of the LID practices seem realistic as there is a raising public and private conscience on flood risk and disaster risk reduction.

After defining the LID areas, the percentages of impervious area (%impervious) (3) and length (W) (4) of the sub-catchments were recalculated considering the new pervious LID areas (A_{LID}), the decreased impervious areas (A_{IMP}) and the total areas (A_{TOT}), and the model was updated.

$$\%impervious = \frac{A_{IMP} - A_{LID}}{A_{TOT} - A_{LID}} \tag{3}$$

$$W_{LID} = \frac{A_{TOT} - A_{LID}}{A_{TOT}} W_{iniziale} \tag{4}$$

The LID practices were then implemented into SWMM by assigning to each of them, stratigraphies that were chosen according to available literature data:

- Porous pavements (Tab.3), according to Zhang and Guo (2014) were modelled with a surface layer, a pavement layer, and a storage layer;
- Green roofs (Tab.4) were implemented with a surface layer, a soil layer, and a drain according to Zheng et al. (2018) and Wu et al. (2017);
- Vegetated infiltration trenches (Tab.5) were modelled with a surface layer, a soil layer, a storage layer, and a drain (Zheng et al., 2018).

Porous pavements

Stratigraphy	Thickness [mm]	SWMM Model	Thickness [mm]	Parameters
Vegetation	-	Surface	-	Manning n 0.015
Concrete blocks	100	Pavement	10	Void ratio 0.16; permeability 254 mm/h
Rubble + gravel	10 + 35	Storage	450	Void ratio 0.5; conductivity 3.3 mm/h
Soil	-	Soil	-	-

Tab.3 Porous pavements’ stratigraphy and the stratigraphy implemented into the SWMM model

Green roofs

Stratigraphy	Thickness [mm]	SWMM Model	Thickness [mm]	Parameters
Vegetation	75	Surface	75	Vegetation volume fraction 0.15; Manning n 0.24
Substrate	150	Soil	150	Porosity 0.5; field capacity 0.4; wilting point 0.1; conductivity mm/hr; suction head 100 mm
Filter	1	-	-	-
Drain + Waterproofing	75 + 1	Drain	75	Void fraction 0.5; Manning n 0.1
Building	-	Building	-	-

Tab.4 Green roofs' stratigraphy and the stratigraphy implemented into the SWMM model

Vegetated infiltration trenches

Stratigraphy	Thickness [mm]	SWMM Model	Thickness [mm]	Parameters
Vegetation + Retention zone + Mulch	75 + 150 + 150	Surface	150	Vegetation volume fraction 0.7, Manning n 0.41
Soil + Filter fabric	600 + 1	Soil	600	Porosity 0.42; field Capacity 0.19; wilting Point 0.089; conductivity 10 mm/hr; conductivity slope 3; suction head 100 mm
Rockfill	400	Storage	400	Void ratio 0.4; seepage rate 0.5 mm/hr
Perforated pipe	-	Drain	-	Void fraction 0.5; Manning n 0.1
Building	-	Building	-	Flow exponent 0.5

Tab.5 Vegetated infiltration trenches' stratigraphy and the stratigraphy implemented into the SWMM model

The detention ponds that were designed and implemented in the model consist of a cylindrical water storage volume equipped with bottom drains and an overflow, designed and dimensioned according to the precipitation data. The optimal location for the detention ponds is the greenfield situated between the urban area and the Sarca River, right before the outfall nodes of the urban drainage system: in this position, they can collect the runoff produced by the urban centre. The design of the detention ponds involves the calculation of the Water Quality Control Volume (WQCV), defined as the critical volume necessary for the removal of pollutants. The WQCV (the watershed[2] multiplied by the total area) was calculated considering a drainage time of 40 hours, a rainfall duration of 15 minutes, a return time of 15 years, and 60% imperviousness of the urban area. The obtained volume was then adapted to the characteristics of the urban centre with the coefficient d_6 (the average precipitation depth calculated as the precipitation height multiplied by %infiltration – 1) that considers the infiltration percentage of the urban area and rainfall, obtaining the $WQCV_0$ (5) with the following expression (Tab.6):

[2] Precipitation height expressed in inches, function of the drainage time and the impervious percentage of the sub-catchment

$$WQCV_0 = d_6 \frac{WQCV}{0.43} \tag{5}$$

Detention ponds' design parameters

Rainfall	Infiltration [%]	d_6 [mm]	WQCV [m^3]	$WQCV_0$ [m^3]
T_R=15 years, rain duration 15 minutes	0.36	9.67	2019	1788

Tab.6 Design parameters and results that were considered in the WQCV and $WQCV_0$ design

Three detention ponds (A, B, C) were designed to manage the $WQCV_0$ that was calculated and the results of the simulation of a precipitation event (5 minutes duration and 5 years return time) were used for the design of the system outlets. The maximum depth (2 metres) of the detention ponds was set according to the altimetric position of the river and the outfall pipes, thus allowing us, having determined the $WQCV_0$, to obtain the ponds' radiuses. Given the geometric dimensions, the maximum water depth for a precipitation with a return period of 5 years was calculated (Fig.8 and Tab.7).

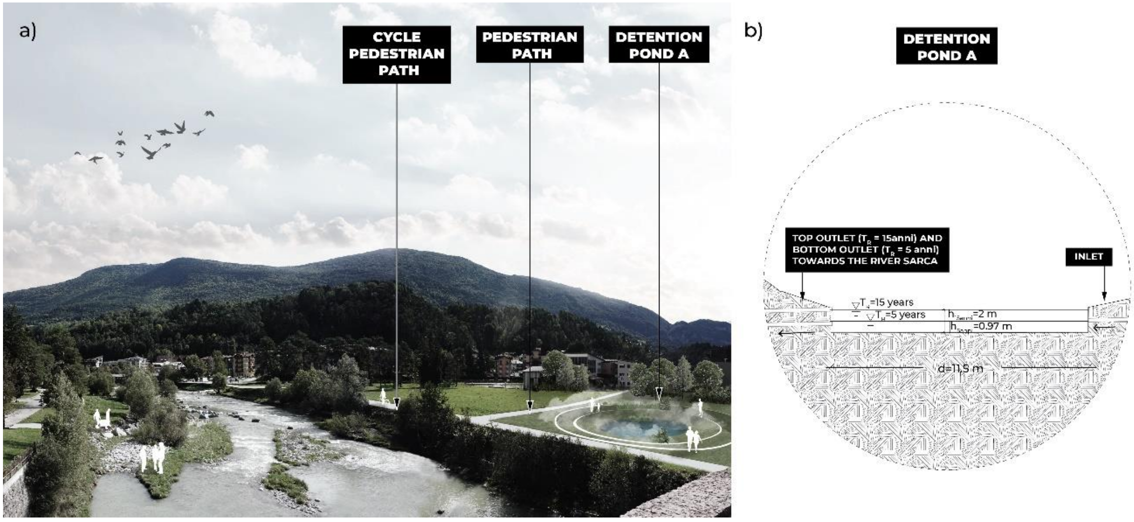

Fig.8 Detention pond A: (a) visualisation of its implementation in the urban area and (b) section

Detention ponds' geometric parameters

	Detention Pond A	Detention Pond B	Detention Pond C
$WQCV_0$ (T_R=15 years) [m^3]	790.0	500.0	500.0
Calculated (T_R=5 years) volume [m^3]	53.4	134.9	225.9
Depth (T_R=15 years) [m]	2	2	2
Calculated radius	11.21	8.92	8.92
Calculated (T_R=5 years) depth [m]	0.14	0.54	0.90
Orifice diameter [m]	0.1	0.2	0.25
Overflow bxh [m^2]	1x0.5	1x0.5	1x0.5

Tab.7 Volume ($WQCV_0$) and dimensions of the three detention ponds (A, B, and C)

Finally, the urban drainage system was tested using the data of a real meteoric event (the precipitation event that caused a flood in Ponte Arche in October 2020).

The three detention ponds, as well as the LID practices were integrated with new cycle pedestrian paths and connections in the urban area (Fig.7 and Fig.8), thus increasing urban connectivity and accessibility: a peri-fluvial path and a new connection on the Duina Stream (near detention pond A) were designed in order to create resting and social areas where the urban relationship with the Sarca River was restored, and where users can come in contact with the water resources. Moreover, the urban system is connected to the slow mobility network that was proposed for the whole Comano Terme territory.

4. Results and discussion

The simulations, which were aimed at assessing the benefits of the LID practices on the urban drainage system, evaluate infiltration, storage, runoff, and outflow quantities.

Four different simulations were set to evaluate the effect of each LID practice:

- TEST1_Urban drainage system;
- TEST2_Urban drainage system with the implementation of vegetated infiltration trenches;
- TEST3_Urban drainage system with the implementation of porous pavements;
- TEST4_Urban drainage system with the implementation of green roofs;
- TEST5_Urban drainage system with the implementation of vegetated infiltration trenches, porous pavements, green roofs.

The simulations showed that porous pavements increase infiltration, whereas storage is increased by all three practices (Fig.9).

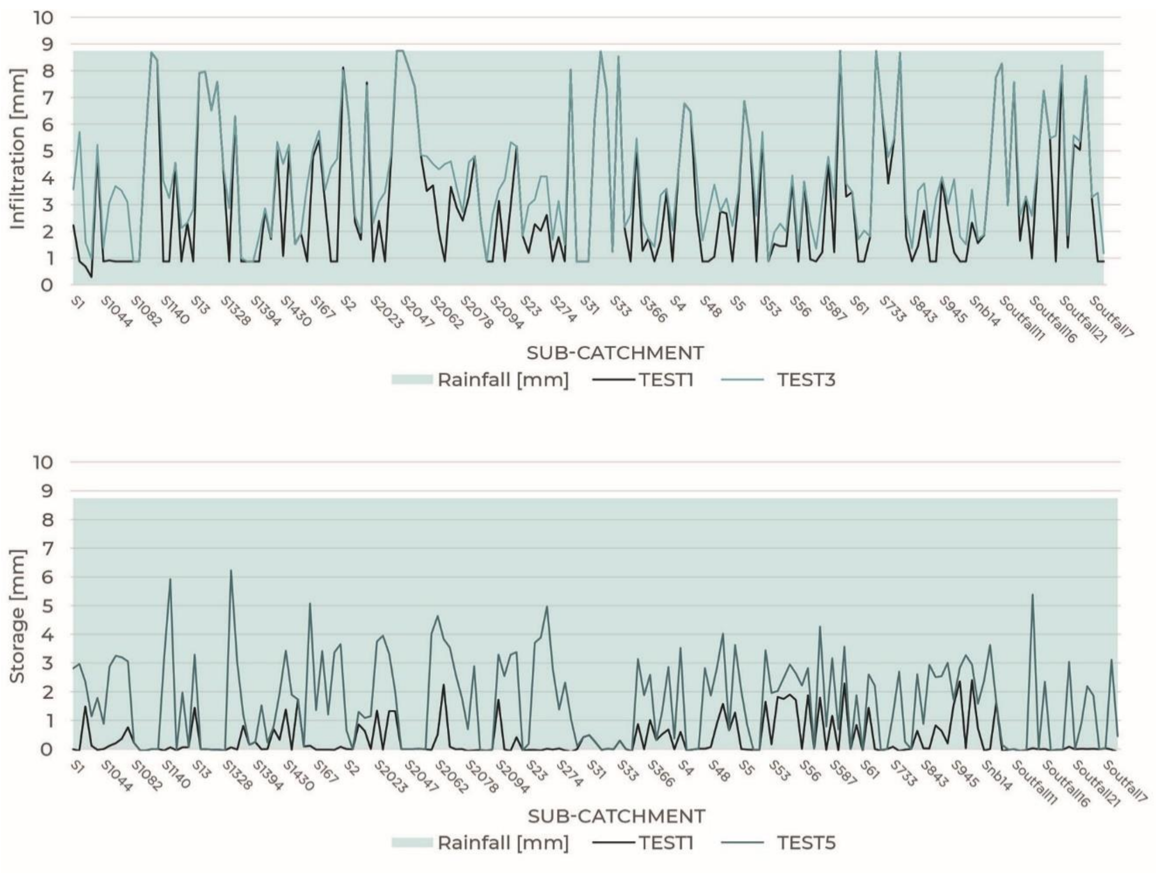

Fig.9 Simulation results: storage and infiltration of the system's sub-catchments

Moreover, runoff flows were evaluated for two portions of the urban area (AREA A and AREA B), to demonstrate the benefits of LID practices when implementing them in steps, foreseeing the incremental implementation of the sustainable drainage per sub-catchment and LID practice, as discussed in Section 3.5. The results showed a reduced peak discharge, as well as a decreased runoff volume (Fig.10).

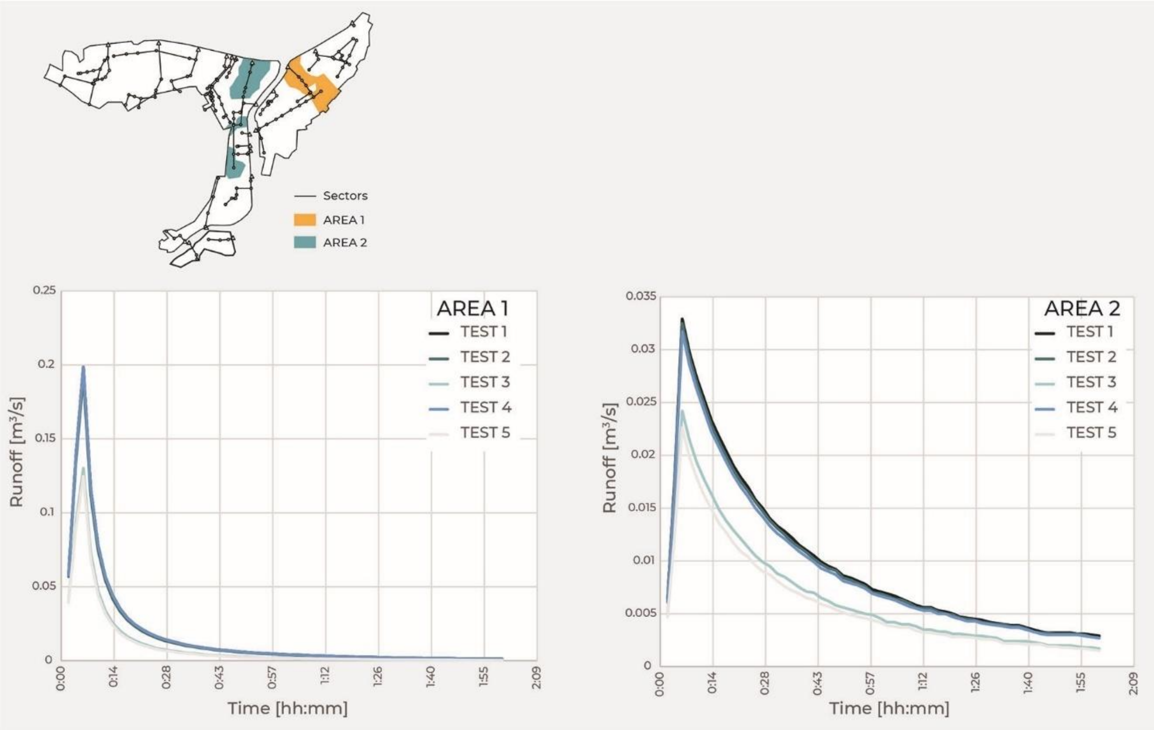

Fig.10 LID practices' effect on the runoff produced by AREA A and AREA B

Two more tests were run to evaluate the effects of LID practices on the outflow and runoff of the whole urban drainage system, keeping into consideration also the detention ponds:

- TEST6_Urban drainage system with the implementation of detention ponds;
- TEST7_Urban drainage system with the implementation of porous pavements, green roofs, vegetated infiltration trenches, and detention ponds.

The comparison between TEST1 and TEST6 demonstrates that detention ponds do not affect the runoff volume (1533,6 m^3), whereas implementing porous pavements, green roofs, and vegetated infiltration systems (TEST5), reduced it to 892.8 m^3, i.e., by 42% (Tab.8).

In the initial situation (TEST1), the collected runoff volume reached 1,549.8 m^3. The implementation of detention ponds reduced the total outflow by 24%, with a total outflow volume of 1,180.8 m^3. Implementing all the LID practices (TEST7) reduces the volume to 612.6 m^3, i.e., by 60% (Tab.8).

In conclusion, while runoff is affected by porous pavements, green roofs, and vegetated infiltration trenches, (as they increase soil permeability, thus the infiltration quantities), detention ponds do not have an effect as they are located at the system's outflows.

The last test (TEST8) was run in order to verify detention ponds' capability to store water during a storm event, thus contributing to decreasing the outflow in the Sarca River. TEST8 simulated a real rainfall event, i.e., the precipitation that caused floods in Ponte Arche and along the course of the river during the first days of October 2020 (Fig.11):

- TEST8_Urban drainage system with the implementation of porous pavements, green roofs, vegetated infiltration trenches, and detention ponds with OCTOBER2020 precipitation input.

Systems' surface runoff and outflow in TEST1, TEST5, TEST6 and TEST7

	TEST1	TEST5	TEST6	TEST7
System runoff [m^3]	1533.6	892.8	1533.6	892.8
Decrease in system runoff	-	42%	0%	42%
System outflow [m^3]	1549.8	907.2	1180.8	612.6
Decrease in system outflow	-	41%	24%	60%

Tab.8 Results of TEST1, TEST5, TEST6, and TEST7: system runoff and outflow amounts and their decrease (in percentage) compared to the initial situation (TEST1)

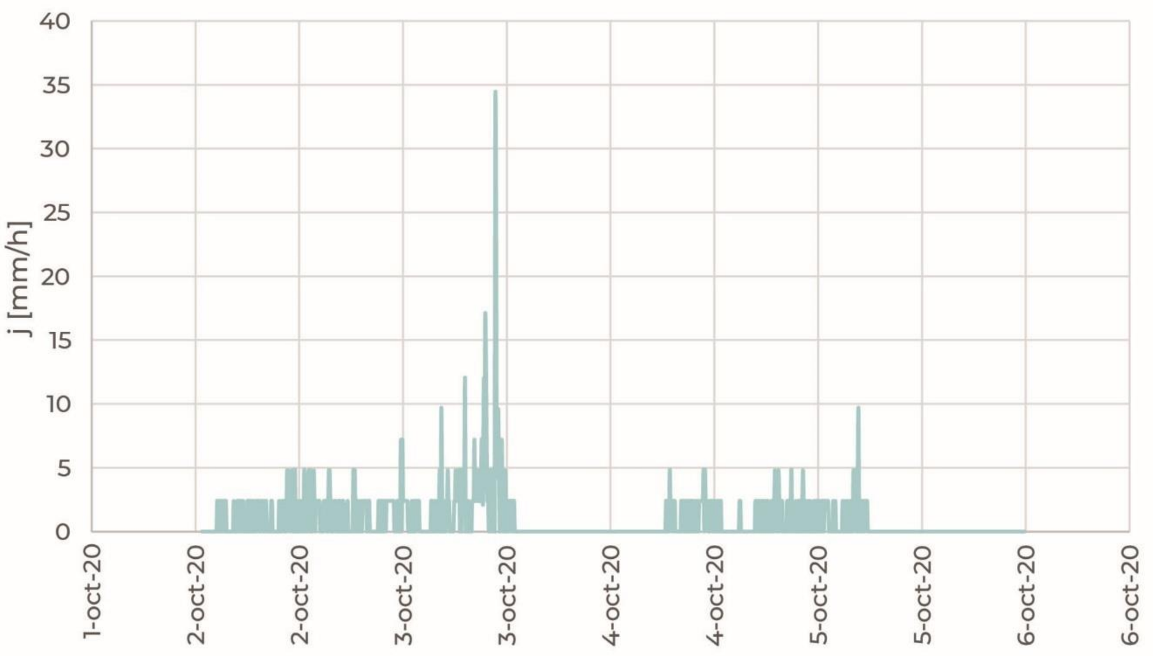

Fig.11 Precipitation event observed in October 2020

Results show that, during that storm event, the three detention ponds would have been able to store approximately 570 m^3, thus decreasing the water volume discharged into the river by the urban area (Tab. 9).

Detention ponds' capacity during TEST8

Detention Pond	A	B	C
Maximum capacity stored (TEST8) [m^3]	145.59	142.69	282.01
Maximum capacity [m^3]	789.57	499.93	499.93

Tab.9 Maximum capacity of the detention ponds and the volume of water managed during the rainfall that was registered in October 2020 (TEST8)

The simulations' results allowed us to quantitatively evaluate the benefits of implementing LID practices with hydrological quantities in a climate change scenario: in particular, their role in decreasing runoff, increasing precipitation storage and infiltration, while decreasing the pressure on receptor bodies. Their hydrological benefits are not limited to Ponte Arche but affect positively the whole water system of the territory and the Sarca River basin, reducing the quantities delivered into the Sarca River and decreasing the flood flows, providing a cost-effective alternative to grey infrastructure. Moreover, renaturalising the urban area provides additional benefits, such as ecological and thermoregulation functions. In this multifunctional and transcalar perspective, the interaction between different disciplines (hydraulic construction and landscape architecture) allowed us to valorise the urban area, as well as its territory: the interventions on Ponte Arche were designed in the bigger context of a fluvial park, that includes the whole cycle pedestrian slow mobility system, the two thematic parks, and the river restoration project. The urban area was connected to the territorial slow mobility system (Fig.5): it intersects the ancient spring of the thermal centre and the Ponte Pià hydropower plant, where the two thematic parks were planned. As shown in Figure 7, the location of the paths in the urban area was chosen accordingly to the services, attraction points and existing paths of Ponte Arche, connecting them with a continuous and identifiable infrastructure. The route intersects the Terme di Comano Park and its bridge, as well as an existing path that runs along Duina Stream. The new cycle pedestrian path stretches along the Sarca River and the main road of Ponte Arche while providing also transversal connections through the recreational areas of the detention ponds. A new bridge is added where the river meets Duina Stream (Fig.7, detail D1b) and new access to the riverbed is opened (Fig.7, detail D1a) to provide a riverbed observation point. The cycle pedestrian path was designed in permeable materials (porous asphalt on a gravel bed) with an average width of 2.50 m, to allow cycle traffic in both directions. This means that space availability was also kept into account during the design phase.

The new path was designed to favour accessibility and recognizability of the territory, and to increase its identity, with expected benefits on the local and regional image, thus favouring sustainable tourism and economy. Accessibility and connectivity were enhanced while providing an alternative to road traffic. Moreover, the LID practices promote users' psychophysical wellness, as well as sociability, citizens' involvement, and cohesion: LID practices, such as detention ponds create new recreational and aggregation points, favouring with the creation of new paths, sport activities and outdoor activities with consequent health benefits. Moreover, sustainable urban drainage interventions stimulate curiosity and environmental awareness in the users.

5. Conclusion

This project was intended as an experimental pilot case and was focused on a small urban centre in a mountain area, in order to study and emphasise the impact of urbanisation on the hydrological cycle. In the NBSs framework, it was observed that a sustainable urban water management along with the desealing of 20% of the urban area (increasing the permeable area from 13.30 to 19.59 hectares), makes it possible to infiltrate and store 42% of the original system runoff and 60% of the original system outflow, while valorising at the same time the urban quality. The role played by the detention ponds is also significative in disaster risk reduction, by reducing the peak rainfall runoff flows delivered to the receptor bodies. If implemented before the October 2020 storm, the designed detention ponds would have been able to store up to 570 m^3 of water. The proposed design approach aims to inspire further renaturalising interventions on the other urban areas of the Comano Terme valley, highlighting the role of NBSs in a climate change adaptation and mitigation framework and their multiple additional societal benefits (reduction of water stresses, promotion of human health, wellbeing and social cohesion, and climate change related disasters mitigation), towards more sustainable and resilient lands and cities: the territory and the urban centre are ecologically recovered, citizens and users are given a greener, more inclusive city while the territorial resources are valorised and protected, thus generating interest and economic benefits.

The multidisciplinary and transcalar water-based design approach aims to show the advantages of intervening on different levels with different disciplines: methodologically the design approach deals with "acupuncture" interventions on the building scale that, when strategically planned, positively impact the whole urban area and merge into the wider system that was designed for the territory. Furthermore, the transcalar design approach allows planning an adaptive and incremental implementation of the interventions, therefore controlling and better managing their economic impacts as well. Further research will need to focus on the quantitative evaluation of the social and economic impacts of the proposal, as well as the monitoring of the environmental indicators and their evolution over time.

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Fig.2: Elaboration by the authors based on De Noia, I. (2021);

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Fig.6: Elaboration by the authors based on De Noia, I. (2021) with data retrieved from: Piano urbanistico of Trento Autonomous Province (agg. 2019), http://www.urbanistica.provincia.tn.it/pianificazione/piano_urbanistico_provinciale/; Technical Map of Trento Autonomous Province (2017), http://www.territorio.provincia.tn.it/portal/server.pt/community/carta_tecnica_provinciale/920/carta_tecnica_provinciale/40052; Piano Regolatore Generale of the Municipality of Comano Terme (2016),

https://www.comune.comanoterme.tn.it/Comune/Documenti/Piani-e-progetti/1-PRG-Comano-Terme-in-vigore Urban drainage system survey kindly provided by Ing. Riccadonna and Municipality of Comano Terme;

Fig.7: Elaboration by the authors based on De Noia, I. (2021) with data retrieved from:
Technical Map of Trento Autonomous Province (2017),
http://www.territorio.provincia.tn.it/portal/server.pt/community/carta_tecnica_provinciale/920/carta_tecnica_provinciale/40052;

Fig.8: Elaboration by the authors based on De Noia, I. (2021);

Fig.9: Elaboration by the authors based on De Noia, I. (2021);

Fig.10: Elaboration by the authors based on De Noia, I. (2021) with data retrieved from:
Urban drainage system survey kindly provided by Ing. Riccadonna and Municipality of Comano Terme;

Fig.11: Elaboration by the authors based on De Noia, I. (2021).

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