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The potential of different NBS policies to provide water flow regulation. A scenario-based assessment based on SWMM.

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Abstract
Pluvial flooding is a growing concern in cities, exacerbated by climate change and rapid urbanisation. To address this issue, contemporary flood risk management focuses on urban resilience and the role of Nature-Based Solutions (NBS) in providing Water Flow Regulation (WFR). Using the Storm Water Management Model, this study explores the effectiveness of different NBS policies in a densely built municipality, Cormano (Italy). The research identifies green roofs and permeable pavements as key NBS options and assesses their performance under various rainfall conditions. Six policy scenarios are examined, ranging from 'direct' public policies, where the government directly implements NBS, to 'enabling' policies incentivising private stakeholders to adopt NBS. Results indicate that the 'enabling' policy yields the most significant WFR improvements in the case study. The study underscores the need for multifaceted, integrated, performance based NBS strategies. It emphasises the importance of 'enabling' policy instruments, i.e. incentives for private retrofitting, in promoting NBS adoption.

Keywords
Stormwater management; Nature-Based Solution; Flood Risk; Urban policies; Ecosystem services.

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Introduction

Pluvial flood poses a significant and escalating risk to cities that require attention (Jha et al., 2012; Rosenzweig et al., 2018). Pluvial floods occur when rainfall cannot be absorbed into the land and instead flows over the surface, traversing through urban areas before reaching drainage systems or watercourses (Butler and Davies, 2011). This type of flood is prevalent in urban settings where soil sealing prevents rapid rainfall absorption (Falconer et al., 2009; Paul and Meyer, 2008). Pluvial floods often arise from localised summer storms or weather conditions associated with extensive low-pressure systems. Typically, the intensity of the rain overwhelms drainage systems, causing water to flow over the land and accumulate in lower-lying areas (Ashley et al., 2005). Various studies attribute the rising pluvial flood risk to a combination of factors, among which climate change and urbanisation rates are the most impacting (Azizi et al., 2022).

Contemporary flood risk management (FRM) aims to reduce the vulnerability of risk-prone communities, recognising that floods cannot be prevented (Schelfaut et al., 2011). It consists of a paramount shift from traditional approaches that strive to eliminate the hazard through hard-engineering structural interventions (Bignami et al., 2019). Moreover, this new FRM philosophy introduces the concept of urban resilience as a new paradigm, supporting the integration of risk management into urban planning (Hammond et al., 2015; Wilby and Keenan, 2012). It recognises the role of ecosystems in supporting urban resilience through the supply of supporting, regulating and cultural ecosystem services (ES) (Chan et al., 2018; Sutton-Grier et al., 2015), promoting the implementation of soft-engineering measures, such as green roofs and rain gardens. Specifically, FRM highlights the potentiality of these interventions to reduce urban runoff through the ES of water flow regulation (WFR) (Eckart et al., 2017), presenting an effective tool to provide stormwater source control (Woods Ballard et al., 2015).

Several terms have been used to describe this new paradigm worldwide (Fletcher et al., 2015). In Europe, Green Infrastructure (GI) and Nature-Based Solutions (NBS) are widely accepted planning tools to provide water flow regulation and to reach broader sustainability goals (Hansen and Pauleit, 2014; Lennon and Scott, 2014). Specifically, the European Commission defines GI as 'a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services' (EC, 2013), while NBS are 'solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience' (EC, 2015). In particular, the NBS concept has gained attention recently due to European-financed research (EC, 2020, 2022). Nonetheless, the literature has used the terms ambiguously, labelling different types of measures adopting nature-inspired processes as 'NBS' (Eggermont et al., 2015). This research considers 'NBS' those soft-engineering interventions that aim to reintroduce natural hydrological processes into the urban environment (such as evapotranspiration, storage, and infiltration) while providing a broader spectrum of ecosystem services (EC, 2021).

Therefore, NBS implementation has the potential to support FRM while providing wider benefits to the urban system, thus improving its overall resilience. Nonetheless, the literature has found major technical, economic, and institutional barriers hindering a more comprehensive implementation of NBS in contemporary cities (Eckart et al., 2017; Seddon et al., 2020). Specifically, challenges remain in measuring NBS effectiveness, and the identification of context-specific indicators and metrics is still a topic of research (Christiansen and Martinez, 2018). This uncertainty impacts the amount of investment in NBS, with stakeholders still sceptical about the cost-effectiveness of these solutions (McVittie et al., 2018). Furthermore, the lack of clear and supportive policies has fostered inaction and supported a scattered NBS implementation that cannot ensure city-wide benefits (Davies and Lafortezza, 2019). In this sense, planners could play a fundamental role in prioritising the integration of NBS interventions into urban adaptation strategies and policy instruments addressing climate-related hazards (Hansen et al., 2017; Novotny et al., 2010).

To achieve this target, different scholars have advocated for a paradigm shift towards Performance-based Planning (PBP) (Cortinovis and Geneletti, 2020; Frew et al., 2016). PBP refers to the draft of planning instruments where results-based measurements are used to obtain desired performances at strategic and operational levels (Baker et al., 2006). It differs from the conforming nature of the traditional land use planning model, where strict zoning regulations require urban transformation to comply with the quantitative and morphological planning standard without assessing the suitability of a particular function or the benefits provided (Ronchi et al., 2019). PBP has already been proposed with FRM (Pappalardo and La Rosa, 2020), and different studies have shown the potentiality of integrating performance assessment into the planning processes to provide evidence-based solutions (Pappalardo et al., 2017; Salata et al., 2021). In recent years, an interesting development of academic research has consisted of applying modelling software to assess the performance of different NBS implementation scenarios under different futures (Chui et al., 2016; Li et al., 2018; Mei et al., 2018). Nonetheless, most of this research focused on the performance assessment of individual interventions and did not consider the broader planning framework in which these measures are implemented.

Specifically, little attention has been given to modelling as an informative tool to support decision-makers while deciding which policy to adopt to support NBS implementation. The planning practice demands diverse governance approaches contingent upon contextual factors related to the targeted transformation space (Bulkeley and Kern, 2006; Stead, 2021). Crucial aspects such as land ownership and the nature of the transformation—whether it involves retrofitting or new development/re-development—significantly influence the choice of a specific policy for enforcing NBS integration. Broadly, two overarching categories of municipality-led public policies emerge: 'direct' policies involving public provision and 'enabling' policies encompassing incentives (EC, 2022). This division outlines two fundamental typologies of NBS governance. The first involves direct planning, design, and construction of NBS in the public realm, while the second revolves around indirect facilitation and quality regulation of NBS development in private spaces. During the decision-making process, public authorities may grapple with the choice between these approaches, especially when policy implementation carries a fiscal burden for the municipality. How the decision-making process can be better informed is an aspect often absent in the existing literature focused on NBS performance for runoff regulation, creating a gap for further studies (Chui et al., 2016; Hassani et al., 2023; Mei et al., 2018).

This research thus proposes a PBP methodology in which modelling is utilised to inform decision-makers about the effectiveness of 'direct' or 'enabling' NBS policy scenarios through a WFR-based assessment (Fig. 1). Two indices are proposed as proxies to assess NBS's WFR ability. These indices, better presented in Section Two, illustrate NBS runoff reduction capabilities, an indicator usually applied to assess WFR in the literature (Mei et al., 2018; Pappalardo et al., 2017). The methodology is tested in the dense urban context of Cormano municipality (Milan Metropolitan area) in the Northern part of Italy. Specifically, Section Two presents the case study, the hydrological-hydraulic modelling, NBS policy scenarios definition, and the method to define WFR assessment indices. Section Three describes the results obtained, which are discussed in Section Four. Finally, Section Five illustrates the principal outcomes of this research.

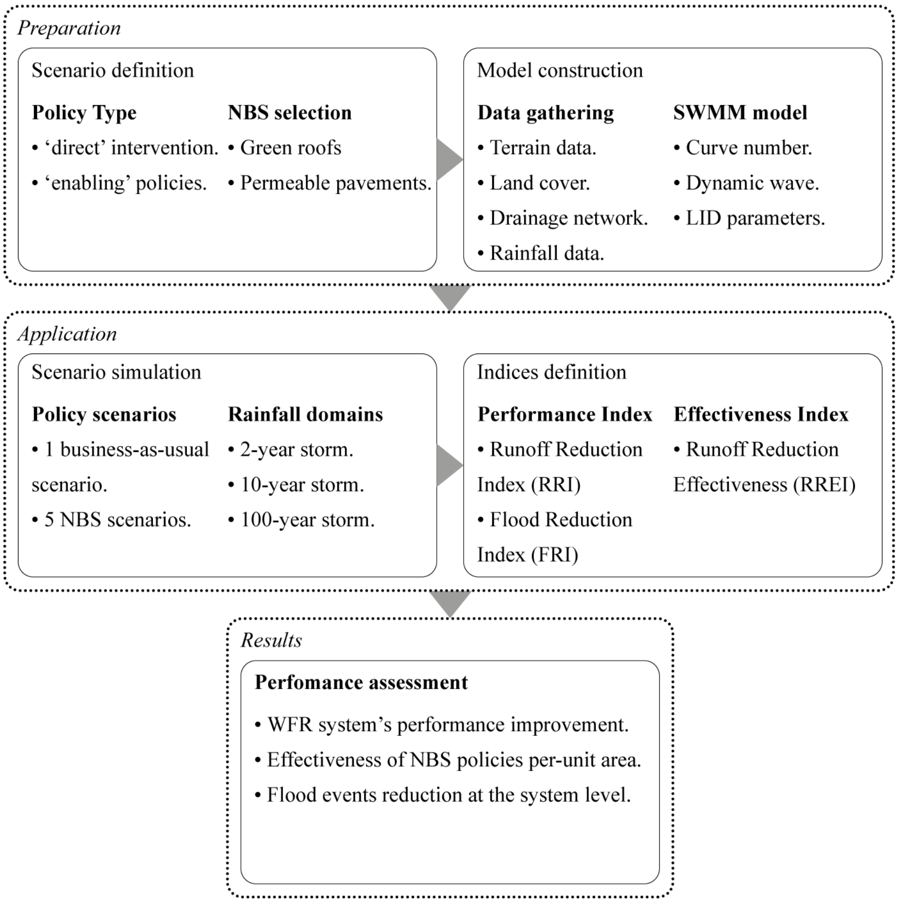

Fig. 1: *Research framework (author own elaboration).*

Materials and methods: case study

The case study consists of the city of Cormano, a small municipality in the north of Milan (Italy), characterised by high levels of soil sealing (49%). The city covers an area of about 448 ha and is part of the Seveso drainage basin (Fig. 2). The Seveso drainage basin extends from the Pallanza Mount in the Province of Varese (Northern Lombardy, Italy) to Milan. Despite its secondary importance in the Italian fluvial landscape, it is one of the most renowned rivers for its propensity to flood and cause damage to the Milanese northern neighbourhood (Becciu et al., 2018). FRM strategies have been deployed since the Romans' time, highlighting the complicated long relationships between humans and the river (Frontori, 2016), and critical structural interventions were deployed after World War II, exemplified by the construction of the "Canale Scolmatore Nord Ovest", a diverging channel initiated in 1954 that sought to deviate excessive water flows towards Ticino River (ADBPO, 2017).

Nevertheless, the urban expansion that characterized the Milanese northern region in the final decades of the 20th century led to an escalation in soil sealing rates and alterations in hydrological processes. This process resulted in higher downstream flow rates that rendered deployed structural solutions increasingly ineffective in mitigating the escalating challenges posed by these changing hydrological conditions. Consequently, downstream areas, especially within the municipality of Milan, faced a pronounced upswing in flooding events, necessitating the exploration of novel approaches to tackle this issue.

Notably, a 2004 study conducted by ADBPO (the Po Basin Authority) emphasized the imperative for municipalities in the southern Seveso basin—among which Cormano—to enhance their drainage systems for reducing stormwater volumes discharged into Seveso during extreme weather events (ADBPO, 2017). The Strategic Project of the Seveso Sub-basin (2017) recommended a series of interventions consisting on de-sealing measures in urban public spaces, focusing on large parking lots (ERSAF, 2017).

Given the need for improved drainage capabilities and a prevailing 'direct' approach, omitting more 'enabling' solutions, the municipality of Cormano, presents an ideal case study for applying the proposed methodology.

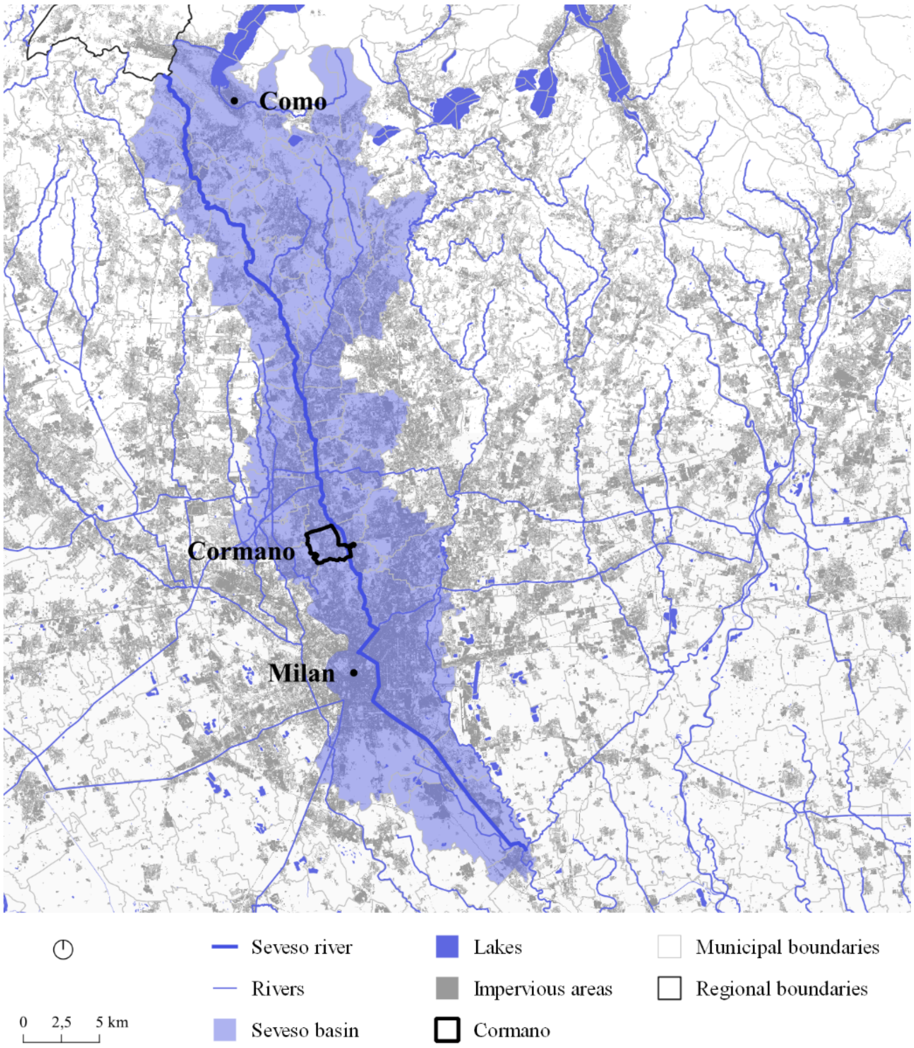

Fig. 2: *Cormano in the Seveso basin (author own elaboration).*

Hydrological model

The study utilises the US EPA Storm Water Management Model (SWMM) (Rossman, 2015) to assess the WFR provided by selected NBS. SWMM comprises a dynamic rainfall-runoff module and a hydraulic module tailored for piped systems, primarily simulating runoff quantity and quality within urban areas. The SWMM model has gained extensive use in assessing the impact of stormwater management, whether based on conventional drainage systems (Zoppou, 2001) or sustainable designs (Mei et al., 2018; Zhang and Chui, 2018). Indeed, the current version (5.2.4) features a Low Impact Development (LID) control module, enabling the explicit modelling of NBS hydrologic performance. SWMM provides alternatives for computing hydrological processes. This study adopts the Curve Number equation to estimate infiltration losses (USDA, 1989). Dynamic wave theory was used for the flow routing computation.

SWMM-based simulation requires four main physical components: sub-catchments, conduits, junctions, and outlets (Fig. 3). Sub-catchments are the fundamental unit of the hydrological model. The literature provides several alternative methodologies to perform their identification (Ji and Qiuwen, 2015; Shen and Zhang, 2014). This study delineates sub-catchments from the Urban Atlas Land Cover/Land Use 2018 high resolution database, provided by the Copernicus Land Monitoring Service (available at https://land.copernicus.eu/en). The Urban Atlas is a comprehensive land cover/land use database offering detailed and high-resolution information about land cover/land use types within urban areas. With its fine spatial resolution, the Urban Atlas is particularly valuable for urban-scale analyses, providing a detailed and accurate portrayal of land cover characteristics essential for studies related to urban planning (Annerstedt van den Bosch et al., 2016; Kabisch et al., 2016; Wüstemann et al., 2017). The analysis specifically choses this dataset for its high resolution, enabling to delineate the municipality into hydrologically homogeneous land use areas. With a minimum mapping unit of 0.25 hectares for urban classes, the dataset accurately captures the structure of urban blocks while categorizing each block based on its predominant land use (e.g., residential, industrial, etc.). In addition, its European-scale availability ensures the reproducibility of our proposed methodology.
Each land cover/land use polygon is treated as an individual sub-catchment, assigned a unique identification number, and further defined by incorporating the identification number of the nearest drainage junction. To simplify the modelling process, the nearest drainage junction is determined based on its proximity to the centroid of the respective sub-catchment. Furthermore, for each sub-catchment, the necessary geometric properties for the modelling phase are computed: area, flow length and width, percentage of impervious surface cover, and average slope. Specifically, the analysis employs the Copernicus high resolution layer "Imperviousness Density" (available at https://land.copernicus.eu/en) and the Lombardy Region 5x5-meter grid Digital Terrain Model (available at https://www.geoportale.regione.lombardia.it/) to compute the percentage of impervious surface cover and average slope, respectively. Finally, each sub-catchment is assigned the Curve Number (USDA, 1989) to estimate infiltration losses. Conduits, junctions, and outlets are the fundamental components of the drainage infrastructure. The study manually reconstructed the layout and the main hydraulic parameters, recovering the information directly from the municipal plan for underground utilities, available at https://www.multiplan.servizirl.it.

As mentioned before, the SWMM version used in this study provides a LID control module capable of simulating the hydrological responses of NBS. Within the SWMM model, NBS is represented through a composite of vertical layers, each defined by properties like thickness, void volume, hydraulic conductivity, and underdrain characteristics, all on a per-unit-area basis. NBS can be strategically placed within selected sub-catchments at user-defined sizes or areal coverage. This study specifically highlights Green Roofs (GR) and Permeable Pavement (PP) as the NBS to be evaluated in their implementation. The rationale behind this selection is rooted in the core objective of the study, which revolves around source control, and is aligned with the characteristics of the urban context being examined. Indeed, within the context of the Cormano municipality, characterized by high-density built-up areas and vast sealed parking spaces, GR and PP stand out as the most practical and effective source-control features. The vertical layers' characteristics are drawn from the literature (Madrazo-Uribeetxebarria et al., 2022; Randall et al., 2020). The site selection process is explained in the next paragraph.

Finally, the analysis considers 2-year, 10-year, and 100-year precipitation events. This choice is motivated by the necessity to assess NBS performances in three rainfall domains of urban FRM: medium intensity-medium frequency event, requiring technical optimisation (10-year event), high intensity-low frequency events, involving spatial planning (100-year event), and low intensity-low frequency, concerning day-to-day uses (2-year event) (Fratini et al., 2012). According to ARPA's Hydrological Information System (https://idro.arpalombardia.it/it/#/it), the 2-year, 10-year, and 100-year precipitations in Cormano present a storm intensity of 29 mm/h, 47 mm/h, and 70 mm/h, respectively. The rainfall duration is assumed to be 60 min, and the hyetograph is rectangular, with 5-minute time steps.

All the essential information was organised and analysed using QGIS 3.28.10 and then converted to SWMM.inp format. Specifically, this study deploys the "Generate SWMM inp" plugin to perform the conversion; technical details can be found in Schilling & Tränckner (2022).

Fig. 3: *SWMM Model (author own elaboration).*

NBS policy scenarios

This study identifies GR and PP as the two NBS to be assessed in their implementation. As previously discussed, these two NBS are considered the most practical source-control measures, particularly in light of high-density built-up areas and extensive sealed parking spaces. Numerous studies have affirmed their efficacy in mitigating stormwater runoff in urban environments (Brattebo and Booth, 2003; Eckart et al., 2017; Stovin, 2010). Moreover, PP has been proposed by the Strategic Project of the Seveso Sub-basin (2017) as a primary measure to alleviate stormwater runoff pressure on the drainage system, representing a purely 'direct' policy response to address the issue. In an effort to enhance informed decision-making, this study positions GR as an NBS that can easily be built in public and private areas. GR serves as a focal point for an alternative 'enabling' policy, providing alternative scenarios and insightful comparisons to evaluate the effectiveness of the initial policy.

The site selection of the NBS is determined based on land use-land cover characteristics and the public-private property of land. The Geo-Topographic Database and the spatial delineation of public services, provided by the Lombardy Region (https://www.geoportale.regione.lombardia.it/), are the informative bases for the NBS site selection. A more detailed selection process, involving the manual exclusion of sloped roofs that are not suitable for hosting green roofs, was carried out through orthophoto interpretation.

Following the rationale presented before, the study develops six policy scenarios (Tab. 1):

1. Scenario One (S1) serves as the business-as-usual condition, employed as a benchmark to assess NBS policies.

2. Scenarios Two (S2) depict the 'direct' policy proposed by the Strategic Project of the Seveso Sub-basin (2017), involving the implementation of PP in public parking lots.
3. Scenario Three (S3) involves an alternative 'direct' policy, wherein the public administration constructs Green Roofs (GR) on publicly owned buildings.
4. Scenario Four (S4) combines S2 and S3, representing a more extensive public intervention.
5. Scenario Five (S5) presents the 'enabling' policy alternative, assuming the deployment of an economic incentive to enhance private building GR retrofitting. Examples of similar policies have already been approved by city councils worldwide (Carter and Fowler, 2008). Specifically, S5 aligns with the guidelines of the Toronto 'Green Roof Bylaw' (available at https://www.toronto.ca/city-government/planning-development/official-plan-guidelines/green-roofs/green-roof-bylaw/) and envisions the construction of GR on all industrial buildings with a floor area exceeding 2000 sqm.
6. Scenario Six (S6) combines 'direct' and 'enabling' policies to assess the maximum benefits achievable through a comprehensive municipal strategy.

To evaluate the effectiveness of each policy under varying rainfall conditions, the six scenarios have been integrated with three distinct 'rainfall domains,' encompassing precipitation events of 2-year, 10-year, and 100-year magnitudes. The final result stems from this last merge, accounting for 18 policy-rainfall scenarios.

Name	Policy	NBS	Space	HA	%
S1	-	-	-	-	-
S2	D	PP	Public parking lots	2,92	100% of parking lots
S3	D	GR	Public buildings roofs	2,70	95% of public buildings
S4	D	PP + GR	Public parking lots + Public buildings roofs	22,53	Same as S2 and S3
S5	E	GR	Industrial Roofs (> 2000 sqm)	5,62	67% of industrial roofs
S6	M	PP + GR	Public parking lots + Public buildings roofs + Industrial Roofs (> 2000 sqm)	28,15	Same as S2, S3 and S5

Tab 1: *The six NBS scenarios' characteristics.*

(D = 'Direct' policy, E = 'Enabling' policy, M = 'Mixed' policy; PP = Permeable Pavements, GR = Green Roofs).

Indices for WFR assessment

The provision of WFR by the different NBS scenarios is assessed through hydrological performance indices that display the NBS capabilities to provide source-control functions. The source-control perspective requires prioritizing the evaluation of local capacity for direct stormwater management. As a result, the assessment methodology focuses on sub-catchments and their ability to intercept, collect, and infiltrate stormwater loads before they enter the conveyance system, considering the impacts of NBS interventions on this capacity. However, it is crucial to evaluate the effects of stormwater runoff on the performance of the conveyance system to understand the effectiveness of source-control features in alleviating pressures on the drainage infrastructure.

Therefore, the research introduces three synthetic indices that encompass both dimensions.
1. The Runoff Reduction Index (RRI) depicts the cumulative ability of NBS to deliver Water Flow Regulation (WFR) benefits at the urban level.
2. The Runoff Reduction Effectiveness Index (RREI) evaluates the efficiency of a particular NBS scenario (e.g., green roofs) in providing WFR on a per-unit area basis.

3. The Flood Reduction Index (FRI) calculates the decrease in pluvial flooding events attributable to the advantages of NBS policies.

It is crucial to emphasize that these indices are designed as initial-level tools intended to facilitate decision-making in the preliminary planning phases. Consequently, aggregated, aspatial indices have been chosen for their intuitiveness and direct applicability.

To calculate the RRI and the RREI, the analysis utilises the 'Surface Runoff' value (mm), computed by SWMM. This indicator is derived from a mass balance equation that considers the system's rainfall, infiltration, evaporation, and surface runoff. The indicator quantifies the stormwater load that remains untreated locally by sub-catchments, subsequently being discharged into the drainage infrastructure. To calculate the FREI, the analysis utilises the 'Flooding Loss' value (hectacre-m), still computed by SWMM. The indicator is derived from the hydrodynamic modelling of the conveyance system. The indicator quantifies the total volume of stormwater that surpasses the conveyance system's capacity, leading to flooding events.

Formula (1), (2) and (3) are used to calculate the RRI, the RREI, and the FRI. For the different NBS scenarios, the business-as-usual scenario (S1) is used as a benchmark.

(1) $RRI_X = (SR_{S1} - SR_X) \times 100 \,/\, SR_{S1}$

Where SR_{S1} is the surface runoff produced in the S1 (mm) and SR_X is the surface runoff produced by the assessed scenario X (mm). RRI is presented as %.

(2) $RREI_X = (SR_{S1} - SR_X) * Area_{SC} \,/\, Area_{NBS}$

where SR_{S1} is the surface runoff produced in the S1 (mm), SR_X is the surface runoff produced by the assessed scenario X (mm), $Area_{SC}$ is the sub-catchments total extension (sqm), $Area_{NBS}$ is the NBS total extension (sqm). RRI is presented as mm.

(3) $FRI_X = (FRI_{S1} - FRI_X) \times 100 \,/\, FRI_{S1}$

where FRI_{S1} are the flooding losses produced in the S1 (hectare-m) and FRI_X are the flooding losses produced by the assessed scenario X (hectare-m). FRI is presented as %.

RRI and FRI are regarded as performance indices, given their purpose to assess both the direct and indirect effects of WFR provided by NBS policies. In contrast, RREI is categorized as an effectiveness index, focusing on evaluating performances on a per-unit basis.

Results

Assessment of NBS WFR performance: RRI and FRI

Hydrological performances of the 15 NBS scenarios were investigated, and the results of RRI are illustrated in Tab. 2. The table shows runoff reduction of varying magnitude under the different NBS scenarios, reflecting the improved hydrological regime associated with NBS implementation. Indeed, PP and GR decrease the quantity of rain washed away as runoff, reintroducing natural processes such as interception, storage, and infiltration. Nevertheless, Tab. 2 shows that different policies provide different WFR performances according to the properties of the specific NBS employed and the characteristics of the study area. Indeed, it must be noted that different policies are related to different implementation potentials that greatly influence the WFR performances supplied. The analysis assesses S6 as the most performing scenario with an average RRI of 9,9%, followed by S5 with an average RRI of 8,2%. S2, S3, and S4 provide only marginal WFR with RRI values of 0,9%, 0,5%, 1,6% respectively. Considering the performance variation in the three different 'rainfall domains', all scenarios share a similar pattern of performance reduction with higher values for the 2-year events and lower values for the 10-year and 100-year events.

	2y	10y	100y	Mean
S2	0,6%	1,0%	1,0%	0,9%
S3	0,4%	0,8%	0,4%	0,5%
S4	1,4%	1,8%	1,5%	1,6%
S5	9,7%	9,1%	5,7%	8,2%
S6	11,6%	11,0%	7,2%	9,9%

Tab. 2: Runoff Reduction Index (RRI) results.

Consequently, the reduction rate of stormwater runoff provided by NBS decreases the flooding volume caused by drainage system failures, as shown in Table 3. The FRI shares similar patterns with the RRI, identifying S6 as the most-performing scenario with an average value of 12,9%, followed by S4 with an average value of 10,9%. S2, S3, and S4 provide marginal improvement also for the FRI, with values of 1,3%, 0,8%, and 2,1%, respectively. A decrease in performance is still visible with an increase in precipitation intensity. Finally, the FRI presents slightly higher values than the RRI, which could be related to the reduced peak flow provided by NBS implementation.

	2y	10y	100y	Mean
S2	1,4%	1,3%	1,2%	1,3%
S3	0,9%	1,0%	0,5%	0,8%
S4	2,2%	2,2%	1,7%	2,1%
S5	14,1%	11,7%	6,8%	10,9%
S6	16,2%	13,9%	8,5%	12,9%

Tab. 3: Flood Reduction Index (FRI) results.

Assessment of NBS WFR effectiveness: RREI

To evaluate the effectiveness of each NBS scenario to provide WFR in a per-unit basis, the RREI is proposed. The development of this index stems from the necessity to compare scenarios that implement NBS with different extensions according to space availability. Tab. 1 displays the hectares of NBS deployed in each scenario. S5 and S6 present the higher value for hectares of NBS implemented, equal to 22.5 ha and 28.2 ha, respectively. S2, S3, and S4 present lower values at 2.9 ha, 2.7 ha, and 5.6 ha. The sharp differences in implementation potential thus require weighted indices to understand the effectiveness of different types of NBS to provide WFR that is decoupled from the area of NBS implemented. This approach facilitates a more comprehensive understanding of the WFR potential of various NBS policies, particularly those employing single NBS. It fosters the exploration of alternative scenarios that might exhibit enhanced performance when provided with broader spatial implementation of selected NBS.

RREI derives from the simulation of the hydrological performances of the 15 NBS scenarios. As for Tab. 2, Tab. 4 shows runoff reduction of varying magnitude under the different NBS scenario; however, it presents excellent differences in recognisable patterns. According to the simulated values, S5 is the most effective NBS scenario, with an average runoff reduction of 36 mm per sqm, followed by S2 and S6, with an average runoff reduction of 35 mm per sqm each. S3 is the less effective scenario, with an average value of 21,5 mm per sqm. Considering the effectiveness variation in the three different 'rainfall domains', S2 presents a peculiar rising trend that displays PP's ability to manage high-intensity precipitation effectively. This PP ability concurs with creating the same trend in S4 and S6. On the contrary, S3 and S5 present a rising effectiveness between 2-year and 10-year precipitation events that stabilise or worsen after this threshold. This trend suggests a GR's ability to manage lower-intensity precipitation with higher effectiveness with lower return for heavier storms.

	2y (mm)	10y (mm)	100y (mm)	Mean (mm)
S2	11,62	36,31	57,46	35,13
S3	8,20	29,83	26,58	21,54
S4	14,60	33,20	42,84	30,21
S5	25,14	41,04	41,21	35,80
S6	23,98	39,48	41,55	35,00

Tab. 3: Runoff Reduction Effectiveness Index (RREI) results.

Discussion

Findings on WFR and the importance of mixed public policies

The results show that certain NBS policies effectively provide WFR and, thus, are capable of mitigate flooding events within the study area. Notably, under the 2-year rainfall scenario, scenarios S6 and S5 demonstrate a substantial runoff reduction of 12% and 10%, respectively. These reductions translate to significant flood mitigation, with S6 achieving a 16% reduction and S5 achieving a 14% reduction. However, flood mitigation is only partial for all policy-rainfall scenarios, and the effectiveness of different NBS practices displays diminishing returns under heavier rainfall (Tab. 3). The consistent residual risk, particularly high even in the most favourable scenario, underscores the need for a more comprehensive planning strategy that extends beyond a purely source-control approach. Spatial planning must consider the implementation of integrated networks of NBS aiming to manage stormwater runoff on the surface collectively and in which each component is endowed with a specific function: source control, conveyance, storage, and infiltration (Woods Ballard et al., 2015). Furthermore, green and grey infrastructures must be integrated to provide adequate flood risk management during extreme events. This integrated and comprehensive approach is particularly crucial in high-sealed environments, as Cormano's case study exemplified.

From the standpoint of governance modalities, the results clearly show that in Cormano, 'direct' public policies are far less performing than 'enabling' public policies. Indeed, all three pure 'direct' policy scenarios (S2, S3, S4) underperform the pure 'enabling' policy scenario (S5) by a significant margin, between -8% and -9%. While the results may appear unsurprising given the specific urban morphology of the case study, characterized by a substantial availability of private industrial green roofs in high runoff-producing sub-catchments, the underwhelming performance of 'direct' policies raises questions about the decision-making process that led public authorities to prioritize de-sealing strategies in the Strategic Project of the Seveso Sub-basin (2017). Indeed, the findings underscore the importance for public authorities to diversify their approach, recognizing that relying solely on 'direct' interventions may not be sufficient. Instead, consideration should be given to supporting more 'enabling' public policies to support private initiatives (Barton et al., 2017). In particular, many experiences in different cities worldwide showed that different tools could be used successfully to enhance the adoption of green roofs, ranging from building code requirements to fee discounts or density bonuses (Carter & Fowler, 2008; USEPA, 2010). In the Cormano case study, economic incentives and tax relief emerge as the most pragmatic options, given their efficacy in encouraging private retrofitting for existing buildings. Nevertheless, the implementation of regulations is imperative to ensure the establishment of minimum standards for the construction of NBS (Bengston et al., 2004).

Finally, deploying two index types, one to measure the system performance (RRI and FRI) and one to measure the NBS effectiveness (RREI), allows a discussion on the importance of extensiveness for source control strategies. Indeed, as Fig. 4 shows, even though permeable pavement (S2) is the most effective solution to manage surface runoff under the 100-year rainfall scenario (-54 mm/sqm), industrial green roof (S4) provides far better system performances (-6%) just due to higher deployed area. This outcome advocates for 'quantity' over 'quality' while considering which policy to implement to support source control. Nonetheless, an interesting development in the planning practice could consist of creating spatial-sensitive public policies, crossing the feasibility, effectiveness, and performance of different NBS in smaller municipal units (e.g., neighbourhoods), and thus deploying solutions tailored to the unit's specific characteristics. Site-specific performance indicators are needed to support this transition from city-scale planning policies to local-scale ones (Cortinovis and Geneletti, 2018) and could be an interesting future development of this research.

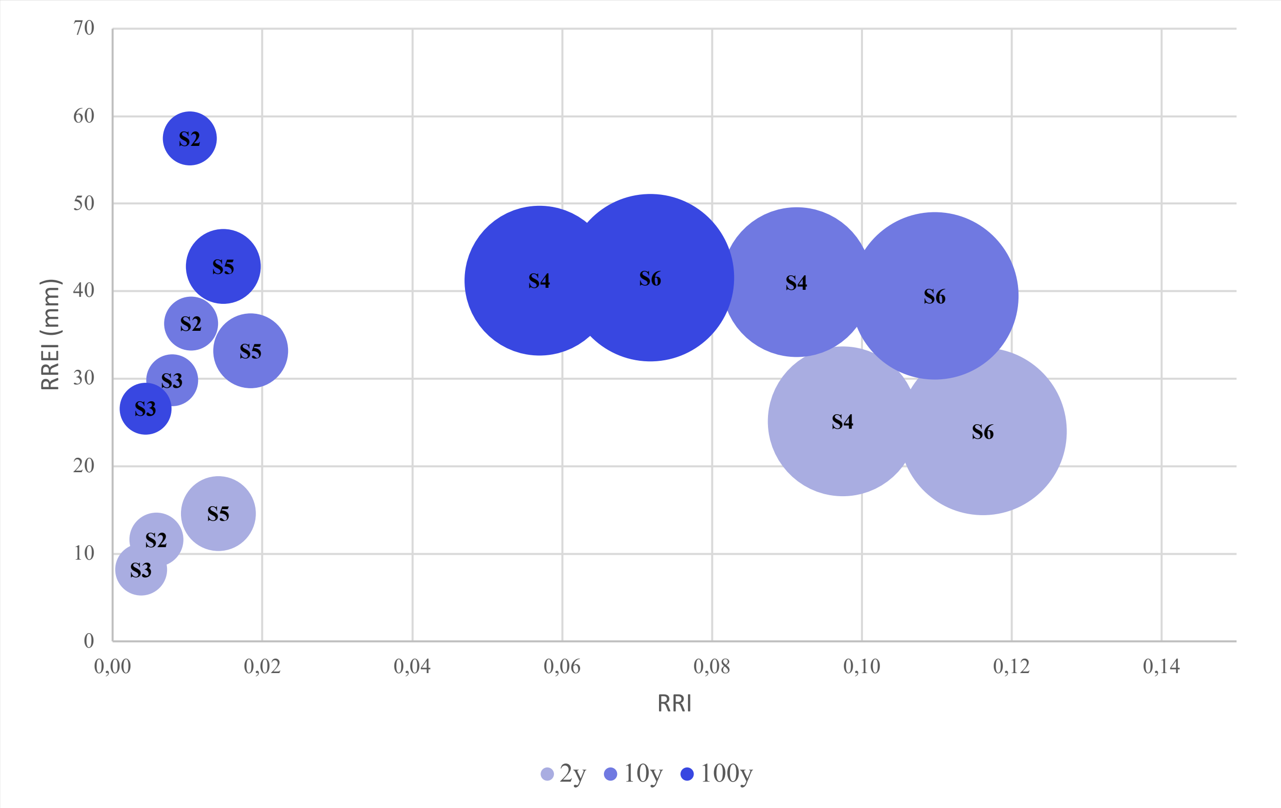

Fig. 4: *RRI-RREI-Area diagram. Bigger circles represent scenarios with a more considerable NBS extension.*

Strengths and limits of modelling to inform public policies

The study employs the SWMM model to assess the effects of different NBS-deploying public policies on urban drainage performances. Few studies have attempted to investigate the hydraulic performances of single NBS trough modelling (Chui et al., 2016; Mei et al., 2018), and fewer have related the implementation of the NBS to specific public policies (Hassani et al., 2023). Nonetheless, applying scenario modelling and simulation during the decision-making process is crucial to systematically explore the multiplicity of possibilities that are presented to planners and policymakers (e.g., policy type, possible measures, rainfall scenarios, etc.), quantify the most critical trade-off between different possibilities, and take more informed decisions (Lempert, 2019). Furthermore, integrating modelling during the participatory phase of the planning process could enhance stakeholders' understanding of the urban system's response to a particular issue and clarify the impacts of proposed solutions to that given issue (Voinov and Bousquet, 2010).

Nonetheless, modelling requires a specific set of data about land uses, terrain and hydrological characteristics that are not always easily accessible and require technical skills to be processed. In this research, input data for the SWMM model are not available in a georeferenced format, demanding a preliminary, time-consuming data construction phase that could severely hinder the integration of simulation in the planning process. Specifically, the input parameters for junction nodes and conduits of the drainage system have to be derived from planning documents. Even though the Cormano utility plan provides this information, this data is not always accessible. Strong collaboration between utility companies and public administration is required to guarantee easy accessibility to this kind of data.

Furthermore, a crucial point concerns the uncertainty of defining the NBS features. Properly representing NBS in SWMM is critical to generating reliable results (Mccutcheon and Wride, 2013). This study utilises input parameters from specialised literature (Madrazo-Uribeetxebarria et al., 2022; Randall et al., 2020) and the SWMM manual (Rossman, 2015). Even though this choice is suboptimal in providing precise quantitative values resulting from the NBS implementation, it was considered sufficient for the aim of this study. Indeed, the analysis seeks to assess the plausible effects of different policy scenarios to inform better decisions in the planning phase and not to evaluate accurately the benefit provided by different NBS designs, which is more useful in a later phase of the implementation process. Furthermore, if the planning process can integrate simulations effectively, NBS-related uncertainties could be improved by onsite validation of modelling results after implementing the first NBS. The availability of field data can facilitate parameter calibration during the modelling phase, consequently enhancing the reliability of results. Whenever it is not possible, expert elicitation is necessary to validate modelling choices (Mccutcheon and Wride, 2013).

Finally, future developments of this study could involve expanding the scope to include additional NBS or integrating other types of evaluations crucial for supporting the decision-making process. For instance, Mei et al. (2018) highlight that GR are effective in providing WFR due to their extensive coverage and favourable technical attributes. However, it is essential to acknowledge that, compared to other NBS, GR may incur relatively higher costs, which can impact the overall cost-benefit performance of this solution. Moreover, considering the comprehensive assessment of NBS performance, including their ability to deliver multiple ES, would provide a holistic understanding of their benefits. This approach would be particularly useful for conducting a cost-benefit or cost-effectiveness analysis, allowing for the evaluation of NBS not only based on their primary proposed benefits, such as water flow regulation, but also considering their multi-functionality and the diverse ES they contribute to.

Conclusion

The paper proposes a performance assessment of the effects of different NBS implementation policies in a highly dense urban catchment, the municipality of Cormano. Specifically, the introduced methodology evaluates the improved capacity of WFR due to different combinations of NBS deployments compared to a business-as-usual scenario. GR and PP are the two NBS measures simulated with different spatial configurations and under different rainfall domains. The hydrologic-hydraulic model selected is SWMM.

Results show that not considering the best-case scenario (i.e., the combination of all policies assessed, S6), enabling policies supporting the implementation of GR on industrial buildings is the most performing scenario. Limited results are reached by implementing direct policies alone, highlighting the need to adopt strategies fostering private stakeholder to retrofit their properties. In this sense, enabling policy instruments such as regulation, incentives, tax relief, and information campaigns could play a central role in raising awareness about the importance of stormwater management and supporting private owners to adopt NBS (Frantzeskaki et al., 2019). These instruments must be examined during the planning phase as valid solutions to complement the more traditional form of direct intervention. The paper advocates modelling and simulations as the most suited tools for making informed decisions.

Nevertheless, substantial efforts in interdisciplinary research are still necessary to provide a PBP framework able to support robust decision-making processes, combining performance assessment with cost-benefits evaluation and accounting for different degrees of uncertainty (Lempert, 2019). Furthermore, to facilitate public participation and foster support from the communities involved, key stakeholders must reach a consensus on the environmental objectives achieved through implementing NBS (Pappalardo et al., 2017). Collaborative activities during the entire planning process (design, implementation, maintenance) could enhance the sustainability, effectiveness, and acceptance of NBS (EC, 2023). This, in turn, will significantly contribute to flood risk management and promote the development of resilient urban systems.

References

ADBPO, 2017. Progetto di Variante al PAI: Torrente Seveso da Lucino alla confluenza nella Martesana in Milano.

Annerstedt van den Bosch, M., Mudu, P., Uscila, V., Barrdahl, M., Kulinkina, A., Staatsen, B., Swart, W., Kruize, H., Zurlyte, I., Egorov, A.I., 2016. Development of an urban green space indicator and the public health rationale. Scand J Public Health 44, 159–167. https://doi.org/10.1177/1403494815615444

Ashley, R.M., Balmforth, D.J., Saul, A.J., Blanskby, J.D., 2005. Flooding in the future – predicting climate change, risks and responses in urban areas. Water Science and Technology 52, 265–273. https://doi.org/10.2166/wst.2005.0142

Azizi, K., Diko, S.K., Saija, L., Zamani, M.G., Meier, C.I., 2022. Integrated community-based approaches to urban pluvial flooding research, trends and future directions: A review. Urban Clim 44, 101237. https://doi.org/10.1016/j.uclim.2022.101237

Baker, D.C., Sipe, N.G., Gleeson, B.J., 2006. Performance-Based Planning. J Plan Educ Res 25, 396–409. https://doi.org/10.1177/0739456X05283450

Barton, D.N., Ring, I., Rusch, G.M., 2017. Policy Mixes: Aligning instruments for biodiversity conservation and ecosystem service provision. Environmental Policy and Governance 27, 397–403. https://doi.org/10.1002/eet.1779

Becciu, G., Ghia, M., Mambretti, S., 2018. A century of works on river seveso: From unregulated development to basin reclamation. International Journal of Environmental Impacts: Management, Mitigation and Recovery 1, 461–472. https://doi.org/10.2495/ei-v1-n4-461-472

Bengston, D.N., Fletcher, J.O., Nelson, K.C., 2004. Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. Landsc Urban Plan 69, 271–286. https://doi.org/10.1016/j.landurbplan.2003.08.007

Bignami, D.F., Rosso, R., Sanfilippo, U., 2019. Flood Proofing in Urban Areas, Flood Proofing in Urban Areas. Springer International Publishing. https://doi.org/10.1007/978-3-030-05934-7

Brattebo, B.O., Booth, D.B., 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. Water Res 37, 4369–4376. https://doi.org/10.1016/S0043-1354(03)00410-X

Bulkeley, H., Kern, K., 2006. Local Government and the Governing of Climate Change in Germany and the UK. Urban Studies 43, 2237–2259. https://doi.org/10.1080/00420980600936491

Butler, D., Davies, J.W., 2011. Urban Drainage, 2nd ed. Spon Press, London.

Carter, T., Fowler, L., 2008. Establishing green roof infrastructure through environmental policy instruments. Environ Manage 42, 151–164. https://doi.org/10.1007/s00267-008-9095-5

Chan, F.K.S., Griffiths, J.A., Higgitt, D., Xu, S., Zhu, F., Tang, Y.T., Xu, Y., Thorne, C.R., 2018. "Sponge City" in China—A breakthrough of planning and flood risk management in the urban context. Land use policy 76, 772–778. https://doi.org/10.1016/J.LANDUSEPOL.2018.03.005

Christiansen, L., Martinez, G., 2018. Adaptation metrics: Perspectives on measuring, aggregating and comparing adaptation results, in: Christiansen, L., Martinez, G., Naswa, P. (Eds.), Adaptation Metrics: Perspectives on Measuring, Aggregating and Comparing Adaptation Results. UNEP DTU Partnership, Copenhagen, pp. 7–13.

Chui, T.F.M., Liu, X., Zhan, W., 2016. Assessing cost-effectiveness of specific LID practice designs in response to large storm events. J Hydrol (Amst) 533, 353–364. https://doi.org/10.1016/j.jhydrol.2015.12.011

Cortinovis, C., Geneletti, D., 2020. A performance-based planning approach integrating supply and demand of urban ecosystem services. Landsc Urban Plan 201, 103842. https://doi.org/10.1016/j.landurbplan.2020.103842

Cortinovis, C., Geneletti, D., 2018. Mapping and assessing ecosystem services to support urban planning: A case study on brownfield regeneration in Trento, Italy. One Ecosystem 3. https://doi.org/10.3897/oneeco.3.e25477

Davies, C., Lafortezza, R., 2019. Transitional path to the adoption of nature-based solutions. Land use policy 80, 406–409. https://doi.org/10.1016/j.landusepol.2018.09.020

Eckart, K., McPhee, Z., Bolisetti, T., 2017. Performance and implementation of low impact development - A review. Sci Total Environ 607–608, 413–432. https://doi.org/10.1016/j.scitotenv.2017.06.254

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., Van Ham, C., Weisser, W.W., Le Roux, X., 2015. Nature-based solutions: New influence for environmental management and research in Europe. GAIA - Ecological Perspectives for Science and Society. https://doi.org/10.14512/gaia.24.4.9

ERSAF, 2017. Progetto strategico di sottobacino del torrente Seveso.

European Commission (EC), 2022. Nature-based Solutions and the Challenges of Water: Accelerating the transition to more sustainable cities. Luxembourg.

European Commission (EC), 2020. Nature-based solutions for flood mitigation and coastal resilience: analysis of EU-funded projects. Bruxelles.

European Commission (EC), 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions and Re-Naturing Cities. Publications Office of the European Union, Luxembourg. https://doi.org/https://doi.org/10.2777/765301

European Commission (EC), 2013. Green Infrastructure (GI) — Enhancing Europe's Natural Capital.

European Commission (EC), Directorate-General for Research and Innovation, 2021. Evaluating the Impacts of Nature-based Solutions: A summary for Policy Makers. Luxembourg. https://doi.org/10.2777/2219

European Commission (EC), Directorate-General for Research and Innovation, Naumann, S., Burgos Cuevas, N., Davies, C., Bradley, S., Mahmoud, I.H., Arlati, A., 2023. Harnessing the power of collaboration for nature-based solutions. https://doi.org/10.2777/954370

Falconer, R.H., Cobby, D., Smyth, P., Astle, G., Dent, J., Golding, B., 2009. Pluvial flooding: New approaches in flood warning, mapping and risk management. J Flood Risk Manag 2, 198–208. https://doi.org/10.1111/J.1753-318X.2009.01034.X

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.L., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M., 2015. SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. Urban Water J 12, 525–542. https://doi.org/10.1080/1573062X.2014.916314

Frantzeskaki, N., McPhearson, T., Collier, M.J., Kendal, D., Bulkeley, H., Dumitru, A., Walsh, C., Noble, K., van Wyk, E., Ordóñez, C., Oke, C., Pintér, L., 2019. Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making. Bioscience 69, 455–466. https://doi.org/10.1093/biosci/biz042

Fratini, C.F., Geldof, G.D., Kluck, J., Mikkelsen, P.S., 2012. Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality. Urban Water J 9, 317–331. https://doi.org/10.1080/1573062X.2012.668913

Frew, T., Baker, D., Donehue, P., 2016. Performance based planning in Queensland: A case of unintended plan-making outcomes. Land use policy 50, 239–251. https://doi.org/10.1016/j.landusepol.2015.10.007

Frontori, I., 2016. L'acqua nei sistemi difensivi delle città romane: alcuni casi in Lombardia. Gilgames. Giornale Interdisciplinare di Lettere e Linguistica, Geografia, Arte e Archeologia, Musica e Spettacolo I, 96–113.

Hammond, M.J., Chen, A.S., Djordjević, S., Butler, D., Mark, O., 2015. Urban flood impact assessment: A state-of-the-art review. Urban Water J 12, 14–29. https://doi.org/10.1080/1573062X.2013.857421

Hansen, R., Pauleit, S., 2014. From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for Urban Areas. Ambio 43, 516–529. https://doi.org/10.1007/s13280-014-0510-2

Hansen, R., Rall, E.L., Rolf, W., Pauleit, S., 2017. Urban Green Infrastructure Planning: A Guide for Practitioners.

Hassani, M.R., Niksokhan, M.H., Mousavi Janbehsarayi, S.F., Nikoo, M.R., 2023. Multi-objective robust decision-making for LIDs implementation under climatic change. J Hydrol (Amst) 617, 128954. https://doi.org/10.1016/J.JHYDROL.2022.128954

Jha, A.K., Bloch, R., Lamond, J., 2012. Cities and Flooding. The World Bank. https://doi.org/10.1596/978-0-8213-8866-2

Ji, S., Qiuwen, Z., 2015. A GIS-based Subcatchments Division Approach for SWMM. The Open Civil Engineering Journal 9, 515–521. https://doi.org/10.2174/1874149501509010515

Kabisch, N., Strohbach, M., Haase, D., Kronenberg, J., 2016. Urban green space availability in European cities. Ecol Indic 70, 586–596. https://doi.org/10.1016/j.ecolind.2016.02.029

Lempert, R.J., 2019. Robust Decision Making (RDM), in: Decision Making under Deep Uncertainty. Springer International Publishing, Cham, pp. 23–51. https://doi.org/10.1007/978-3-030-05252-2_2

Lennon, M., Scott, M., 2014. Delivering ecosystems services via spatial planning: reviewing the possibilities and implications of a green infrastructure approach. Town Planning Review 85, 563–587. https://doi.org/10.3828/tpr.2014.35

Li, Q., Wang, F., Yu, Y., Huang, Z., Li, M., Guan, Y., 2018. Comprehensive performance evaluation of LID practices for the sponge city construction: A case study in Guangxi, China. https://doi.org/10.1016/j.jenvman.2018.10.024

Madrazo-Uribeetxebarria, E., Garmendia Antín, M., Almandoz Berrondo, J., Andrés-Doménech, I., 2022. Modelling Runoff from Permeable Pavements: A Link to the Curve Number Method. Water (Basel) 15, 160. https://doi.org/10.3390/w15010160

Mccutcheon, M., Wride, D., 2013. Shades of Green: Using SWMM LID Controls to Simulate Green Infrastructure, in: Journal of Water Management Modeling. pp. 246–261. https://doi.org/10.14796/JWMM.R246-15

McVittie, A., Cole, L., Wreford, A., Sgobbi, A., Yordi, B., 2018. Ecosystem-based solutions for disaster risk reduction: Lessons from European applications of ecosystem-based adaptation measures. International Journal of Disaster Risk Reduction 32, 42–54. https://doi.org/10.1016/j.ijdrr.2017.12.014

Mei, C., Liu, J., Wang, H., Yang, Z., Ding, X., Shao, W., 2018. Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed. Science of The Total Environment 639, 1394–1407. https://doi.org/10.1016/J.SCITOTENV.2018.05.199

Novotny, V., Ahern, J., Brown, P., 2010. Water Centric Sustainable Communities. Planning, Retrofitting, and Building the Next Urban Environment. John Wiley & Sons, Hoboken, New Jersey.

Pappalardo, V., La Rosa, D., 2020. Policies for sustainable drainage systems in urban contexts within performance-based planning approaches. Sustain Cities Soc 52, 101830. https://doi.org/10.1016/j.scs.2019.101830

Pappalardo, V., La Rosa, D., Campisano, A., La Greca, P., 2017. The potential of green infrastructure application in urban runoff control for land use planning: A preliminary evaluation from a southern Italy case study. Ecosyst Serv 26, 345–354. https://doi.org/10.1016/j.ecoser.2017.04.015

Paul, M.J., Meyer, J.L., 2008. Streams in the urban landscape, in: Urban Ecology: An International Perspective on the Interaction Between Humans and Nature. Springer US, pp. 207–231. https://doi.org/10.1007/978-0-387-73412-5_12

Randall, M., Støvring, J., Henrichs, M., Bergen Jensen, M., 2020. Comparison of SWMM evaporation and discharge to in-field observations from lined permeable pavements. Urban Water J 491–502. https://doi.org/10.1080/1573062X.2020.1776737

Ronchi, S., Arcidiacono, A., Pogliani, L., 2019. Integrating green infrastructure into spatial planning regulations to improve the performance of urban ecosystems. Insights from an Italian case study. https://doi.org/10.1016/j.scs.2019.101907

Rosenzweig, B.R., McPhillips, L., Chang, H., Cheng, C., Welty, C., Matsler, M., Iwaniec, D., Davidson, C.I., 2018. Pluvial flood risk and opportunities for resilience. Wiley Interdisciplinary Reviews: Water 5. https://doi.org/10.1002/WAT2.1302

Rossman, L.A., 2015. EPA Storm Water Management Model. User's Manual.

Salata, S., Ronchi, S., Giaimo, C., Arcidiacono, A., Pantaloni, G.G., 2021. Performance-Based Planning to Reduce Flooding Vulnerability Insights from the Case of Turin (North-West Italy). https://doi.org/10.3390/su13105697

Schelfaut, K., Pannemans, B., van der Craats, I., Krywkow, J., Mysiak, J., Cools, J., 2011. Bringing flood resilience into practice: the FREEMAN project. Environ Sci Policy 14, 825–833. https://doi.org/10.1016/j.envsci.2011.02.009

Schilling, J., Tränckner, J., 2022. Generate_SWMM_inp: An Open-Source QGIS Plugin to Import and Export Model Input Files for SWMM. Water (Basel) 14, 2262. https://doi.org/10.3390/w14142262

Seddon, N., Chausson, A., Berry, P., Girardin, C.A.J., Smith, A., Turner, B., 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. Philosophical Transactions of the Royal Society B: Biological Sciences. https://doi.org/10.1098/rstb.2019.0120

Shen, J., Zhang, Q., 2014. Parameter Estimation Method for SWMM under the Condition of Incomplete Information Based on GIS and RS. EJGE 20, 6095–6108.

Stead, D., 2021. Conceptualizing the Policy Tools of Spatial Planning. J Plan Lit 36, 297–311. https://doi.org/10.1177/0885412221992283

Stovin, V., 2010. The potential of green roofs to manage urban stormwater. Water and Environment Journal 24, 192–199. https://doi.org/10.1111/j.1747-6593.2009.00174.x

Sutton-Grier, A.E., Wowk, K., Bamford, H., 2015. Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. Environ Sci Policy 51, 137–148. https://doi.org/10.1016/J.ENVSCI.2015.04.006

United States Environmental Protection Agency (USEPA), 2010. Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure.

USDA, 1989. Runoff Curve Number Computations.

Voinov, A., Bousquet, F., 2010. Modelling with stakeholders. Environmental Modelling & Software 25, 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007

Wilby, R.L., Keenan, R., 2012. Adapting to flood risk under climate change. Prog Phys Geogr 36, 348–378. https://doi.org/10.1177/0309133312438908/FORMAT/EPUB

Woods Ballard, B., Wilson, S., Udale-Clarke, H., Illman, S., Ashley, R., Kellagher, R., 2015. The SuDS Manual. London.

Wüstemann, H., Kalisch, D., Kolbe, J., 2017. Access to urban green space and environmental inequalities in Germany. Landsc Urban Plan 164, 124–131. https://doi.org/10.1016/j.landurbplan.2017.04.002

Zhang, K., Chui, T.F.M., 2018. A comprehensive review of spatial allocation of LID-BMP-GI practices: Strategies and optimization tools. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2017.11.281

Zoppou, C., 2001. Review of urban storm water models. Environmental Modelling & Software 16, 195–231. https://doi.org/10.1016/S1364-8152(00)00084-0