Urban Forestry & Urban Greening 104 (2025) 128661

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

# How well does the 3–30–300 rule mitigate urban flooding?

Gianni Vesuviano [a,*], Alice Fitch [b], Danial Owen [b], David Fletcher [b], Laurence Jones [b]

[a] *UK Centre for Ecology & Hydrology, Maclean Building, Benson Lane, Crowmarsh Gifford, Wallingford OX10 8BB, United Kingdom*
[b] *UK Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor LL57 2UW, United Kingdom*

ARTICLE INFO

*Keywords:*
3–30–300
Nature-based solutions
Urban flooding
Runoff
Sustainable drainage system
Green infrastructure

ABSTRACT

The 3–30–300 rule is a new guideline for urban forestry and urban greening, which is rapidly gaining interest among city planners, international organizations and NGOs. However, the ecosystem service benefits of this new guideline have not been quantified and there has been no research to date on how implementing the 3–30–300 rule may mitigate urban flooding. In this study, we use a gridded implementation of the rational method, with flow attenuation included (ANaRM model), to assess the reduction in runoff that can be achieved by implementing urban land-use change to achieve 3–30–300 targets in three European cities of contrasting size and population: Aarhus Municipality (Denmark), Grad Velika Gorica (Croatia) and Paris Region (France). We find that the creation of new green spaces and tree cover can greatly reduce peak pluvial surface runoff rate at-site, and maintain peak flow reductions of several percent in sub-catchments of several square kilometres, including reductions of over 10 % in some sub-catchments of over 20 $km^2$ in Paris. The specific interventions required to meet aspects of the 3–30–300 rule vary between study areas, and the larger the interventions, the greater the peak runoff rate reduction that can be achieved. This study highlights the importance of linking research with policy in order to quantify the benefits of urban green infrastructure targets and show the real benefits of implementing nature-based solutions.

## 1. Introduction

The 3–30–300 rule (Konijnendijk, 2021; Konijnendijk, 2023) states that every citizen should be able to see three trees (of a decent size) from their home, have at least 30 % tree canopy cover in their neighbourhood and live no more than 300 m from the nearest park or green space (of at least one hectare). While every urban area has its own context, hence its own optimal solution, 3–30–300 was proposed as an objective and easy-to-understand target that can start to be implemented immediately, without the financial or time cost of developing a bespoke optimal solution (IUCN, 2021). A number of cities, international organizations and NGOs have explicitly adopted 3–30–300 targets (Future Woodlands Scotland, 2021; Nature Canada, 2022; Nordic Council of Ministers, 2022; UNECE, 2021), and by setting objective targets, have potentially accelerated provision of fair and equitable access to greenspace, helping to meet target 11.7 of the United Nations Sustainable Development Goals (SDGs) sooner (Tate et al., 2024). This is important, given the impending arrival of the 2030 deadline set for this target (Arora and Mishra, 2019) and the low provision of, and access to, open public spaces reported in the most recent (2023) edition of the Sustainable Development Goals Report (United Nations, 2023).

There have been many studies on the benefits of urban forestry and urban greening, focusing on the effects of visible street trees, tree canopy cover and access to greenspace on mental and physical health (Elsadek et al., 2020; Pérez-del-Pulgar et al., 2021), air quality (Grylls and van Reeuwijk, 2022; Riondato et al., 2020; Jones et al., 2019), cooling (Iungman et al., 2023; Li et al., 2023), noise (Dzhambov, Dimitrova, 2014; Fletcher et al., 2022), and social issues (Garrett et al., 2023; Ryan et al., 2023; Ulmer et al., 2016). Wolf et al. (2020) and O'Brien et al. (2022) conducted detailed reviews of these and other benefits. However, few studies have assessed the benefits of meeting 3–30–300 targets specifically (e.g. Nieuwenhuijsen et al., 2022; Nordic Council of Ministers, 2024), due to the recency of the concept. Furthermore, no studies have been published (to our knowledge) evaluating the effects that achieving 3–30–300 could have on reducing urban flooding, despite the roles that some nature-based solutions (NBS), low-impact development (LID), or sustainable drainage system (SuDS) devices, such as street trees, rain gardens and detention basins, could have in achieving

---

[*] Corresponding author.
*E-mail addresses:* giaves@ceh.ac.uk (G. Vesuviano), afitch@ceh.ac.uk (A. Fitch), danowe@ceh.ac.uk (D. Owen), dfletcher@ceh.ac.uk (D. Fletcher), lj@ceh.ac.uk (L. Jones).

https://doi.org/10.1016/j.ufug.2024.128661
Received 17 July 2024; Received in revised form 19 November 2024; Accepted 27 December 2024

3–30–300 targets. Studies explicitly measuring the current status of areas with respect to the targets defined in the 3–30–300 rule have found that a minority of the residents assessed live in places that meet all three aspects: for example, 37.3 % of people sampled across Florida (Koeser et al., 2023), 12 % in Toronto, Canada (Ling, 2021) and just 4.7 % in Barcelona, Spain, using a surrogate measure for tree canopy cover (Nieuwenhuijsen et al., 2022). However, comparisons are complicated by the different methods used to account for tree visibility, such as surveys (Koeser et al., 2023), estimates from photographs and satellite images (Ling, 2021) and distance-from-building (Nieuwenhuijsen et al., 2022; Owen et al., 2024a). Studies of Turin, Italy (Battisti et al., 2024) and the Barranco district of Lima, Peru (Manyahuillca et al., 2024) found that zero residents in either study area lived in a sub-district with at least 30 % tree canopy cover (a requirement of meeting 3–30–300), but that visibility of trees and access to greenspace even varied widely between the neighbourhoods of Turin, ranging from 2.2 $km^2$ to 15.5 $km^2$ each, and sub-districts of Barranco, each around 0.1–0.2 $km^2$. A Europe-wide study of 978 cities in 31 countries, considering the “300” aspect of the rule only, estimated that only 38 % of urban Europeans live within 300 m of a green space (Pereira Barboza et al., 2021). Space in urban areas is often limited, meaning that there are clear advantages to extracting multiple benefits from every green intervention (Hansen and Pauleit, 2014; Tate et al., 2024; Wang and Banzhaf, 2018; Jones et al., 2022a). This creates a clear need to understand and quantify the multiple benefits of potential interventions: Suppakittpaisarn et al. (2017) review 55 peer-reviewed articles on the human health benefits of green infrastructure and green stormwater infrastructure specifically, concluding that little research had focused on the latter. A more recent evidence synthesis by Jones et al. (2022b) indicated that different types of parks could have high and very high potentials for a variety of ecosystem services, but a medium potential for water flow management.

Given the widespread international interest in 3–30–300, there is a need to better quantify the potential effects on urban flooding of implementing this rule specifically. This study evaluates the potential reductions in urban flooding that can be achieved by applying the 3–30–300 rule in three contrasting case study areas: Aarhus (Denmark), Velika Gorica (Croatia) and Paris (France). First, we describe the study areas in their current state and show the land cover changes required to bring them to a hypothetical 3–30–300 state using the methodology described in detail by Owen et al. (2024a). Next, we describe the Adapted Nature-based-solutions Rational Method (ANaRM: Miller et al. 2023). This is a simple tool that combines a grid-based rational method approach with flow routing, accumulation and attenuation by water bodies, and allows comparison of different high-resolution land-cover scenarios. Using ANaRM, we present the estimated reductions in peak flows achieved by changing land-use from the current to the 3–30–300 scenario in all case study areas. Finally, we discuss the mitigation of urban flooding that can be achieved in the three study areas by implementation of the 3–30–300 rule, as well as the potential for meeting the rule in each study area, and present the conclusions drawn from the study.

## 2. Study areas and data

This study focuses on three European urban areas of contrasting sizes and populations: Aarhus, Velika Gorica and Paris. Two land-use scenarios are created for each area: “current”, representing land-use circa 2015–2020, and “3–30–300”, representing a land-use arrangement that follows the 3–30–300 rule. The land-use/land cover layers for all six scenarios are available online (Owen et al., 2024b). Results and discussion in each study area focus on a set of catchments ranging in area from thousands of square metres to tens of square kilometres.

### 2.1. Aarhus

Aarhus municipality is located midway on the east coast of the Jutland peninsula, Denmark. On 01 January 2023, it had an area of 468.1 $km^2$ (Statistics Denmark, 2024a) and population of 361,544, of which 290,598 lived in the city of Aarhus (Statistics Denmark, 2024b). The municipality is built around and near a system of tunnel valleys leading to Aarhus Bay, most notably the Aarhus Ådal (river valley). Each valley is a separate hydrological watershed. Elevation in the study area ranges from zero to approximately 132 m above sea level.

The study area coincides with the municipality. It contains several lakes, the largest being the connected Brabrand Sø and Årselv Engsø (1.53 $km^2$ and 1.00 $km^2$), through which the Aarhus River passes, and the Egå Engsø (1.15 $km^2$). Table 1 shows the land-use classes in the study area for both the current situation (Fig. 1a) and one following the 3–30–300 rule (Fig. 1b).

Current land-use consists of an urban core expanding outwards from Aarhus Port, surrounded by lower-density suburbs, giving way to agriculture (Fig. 1a). The main interventions required to meet the 3–30–300 rule in Aarhus were an increase in street trees and accessible greenspace in the urban core (Midtbyen), additional greenspace at targeted suburban locations (e.g. Tranbjerg, Tilst, Sabro), and an increase in publicly accessible greenspace near to villages and small towns in the outer agricultural areas (e.g. Beder-Malling, Harlev, Solbjerg) (Fig. 1b and c).

While the current scenario’s provision of publicly accessible and nearby greenspace is such that only 2.6 % of the study area needed conversion to greenspace to meet the 3–30–300 rule, much of the new greenspace was created on agricultural land. However, agriculture remained by far the predominant land-use in the study area. While significant tree planting was required in the urban core, it was also required throughout the suburbs and surrounds of Aarhus, although with an uneven distribution. Tree cover was not greatly increased between the current and 3–30–300 scenarios and the new trees were sparsely distributed, as visibility of trees was a bigger problem than neighbourhood canopy cover in Aarhus.

### 2.2. Velika Gorica

Velika Gorica municipality is located in central Croatia, south of and bordering the capital, Zagreb. On 31 August 2021, it had an area of 326.6 $km^2$ and population of 61,075, with the Velika Gorica urban area accounting for 36.9 $km^2$ and 30,036 people (Croatian Bureau of Statistics, 2022). The municipality is sited on a flat and fertile plain of the Sava River with little variation in elevation.

The study area includes 41.89 $km^2$, centred on the Velika Gorica urban area. The only major water body is Jezero Čiče (Čiče Lake), a flooded gravel pit with an area of 0.96 $km^2$. Table 2 shows the land-use classes in the study area for both the current situation (Fig. 2a) and one following the 3–30–300 rule (Fig. 2b).

In both cases, the study area is dominated by grass and agricultural land (Fig. 2). The main change required to follow the 3–30–300 rule was a conversion of private agricultural land to publicly accessible greenspace at the edges of the urban area, but some conversion of buildings and mineral surfaces to greenspace (grass land-use) also happened

**Table 1**
Current and 3-30-300 scenario land-use in Aarhus study area.

| Class | Current (%) | 3–30-300 (%) | Change (%) |
|---|---|---|---|
| Building | 5.5 % | 5.3 % | −0.2 % |
| Mineral surface | 10.0 % | 9.6 % | −0.4 % |
| Artificial grass | 0.0 % | 0.0 % | 0.0 % |
| Grass | 17.9 % | 21.1 % | 3.1 % |
| Shrub | 1.8 % | 1.8 % | 0.0 % |
| Tree | 12.4 % | 12.7 % | 0.3 % |
| Undergrowth | 1.2 % | 1.2 % | 0.0 % |
| Agriculture | 47.4 % | 44.7 % | −2.7 % |
| Bare Soil | 2.1 % | 1.9 % | −0.2 % |
| Lake | 1.4 % | 1.4 % | 0.0 % |
| River | 0.1 % | 0.1 % | 0.0 % |
| Total | 100.0 % | 100.0 % | 0.0 % |

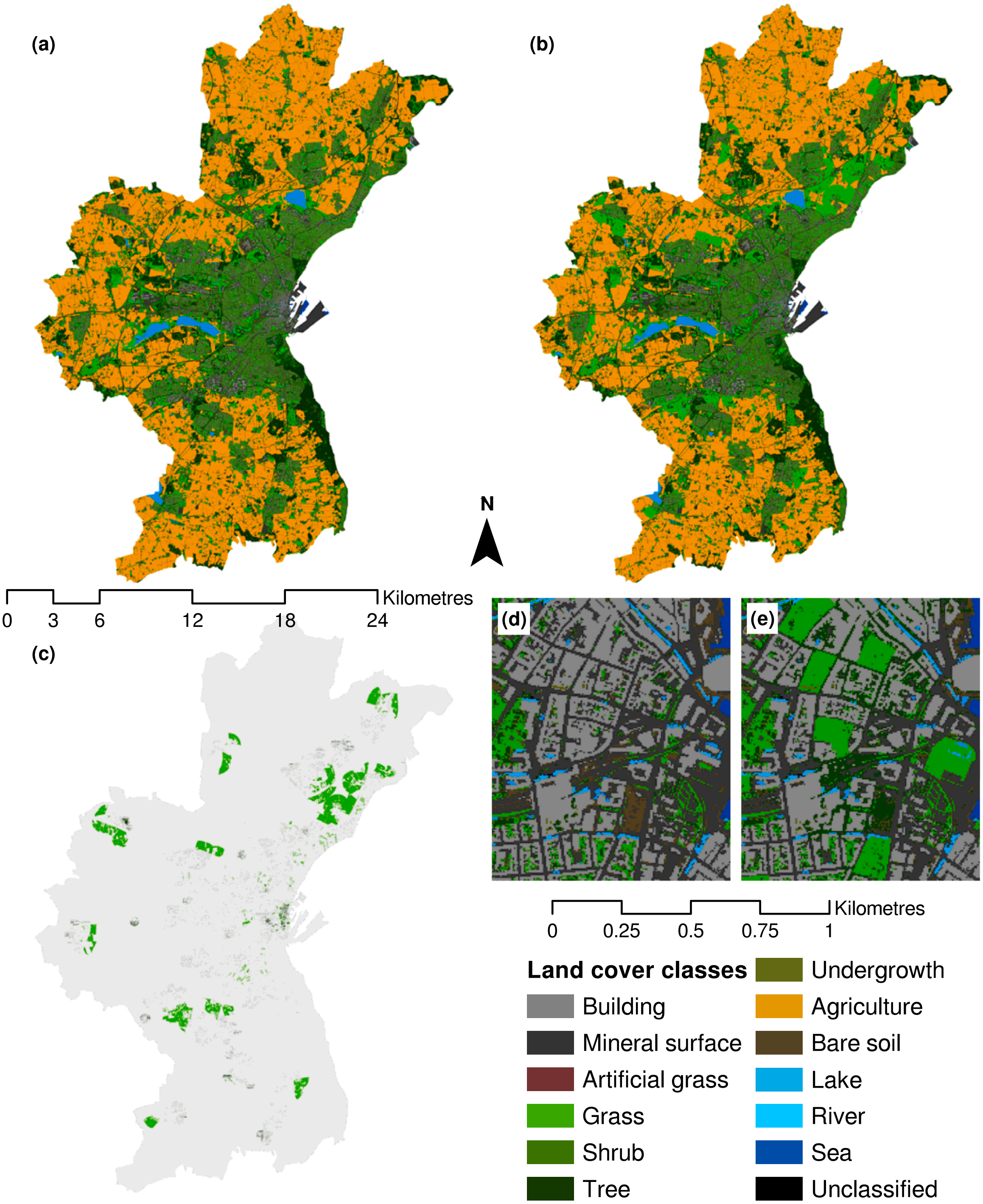

**Fig. 1.** Aarhus study area: current land-use scenario (a), 3–30–300 land-use scenario (b), conversions to grass and tree land-use between the two scenarios (c), close-up of the Aarhus port area for the current (d) and 3–30–300 land-use scenario (e).

within the urban area (Fig. 2c). Very little increase in tree cover was required to meet the 3–30–300 rule, indicating that almost all residents already had sight of at least three trees from their home and all neighbourhoods were already at or near 30 % canopy cover.

### 2.3. Paris

Paris is the capital of France. In 2020, the Paris department/commune had a population of 2,145,906 and area of 105.4 km$^2$, while the Paris urban area had a population of 10,856,407 and area of 2846.0 km$^2$ (Insee, 2024). The urban area is built on relatively flat land around the River Seine and, towards the south-west, the River Marne. Elevation in the study area ranges from approximately 26 m above sea level at the banks of the Seine in Rueil-Malmaison to 181 m above sea level in Le Chesnay-Rocquencourt.

The study area consists of the Paris department/commune and its three surrounding departments: Hauts-de-Seine, Seine-Saint-Denis and Val-de-Marne, plus a 300-metre buffer zone, totalling 913.1 km$^2$. A buffer zone is included in the Paris study area so that the 3–30–300 rule can be met fully at the very edges of the departments surrounding Paris: greenspace outside of the departments may fulfil part of the requirements for dwellings within the department. The 2020 population of

**Table 2**
Current and 3–30-300 scenario land-use in Velika Gorica study area.

| Class | Original (%) | 3–30-300 (%) | Change (%) |
|---|---|---|---|
| Building | 4.9 % | 4.2 % | −0.7 % |
| Mineral surface | 12.3 % | 11.4 % | −0.9 % |
| Artificial grass | 0.0 % | 0.0 % | 0.0 % |
| Grass | 34.5 % | 39.5 % | 5.0 % |
| Shrub | 1.7 % | 1.7 % | 0.0 % |
| Tree | 11.1 % | 11.1 % | 0.1 % |
| Agriculture | 30.9 % | 27.4 % | −3.4 % |
| Bare Soil | 2.1 % | 2.0 % | −0.1 % |
| Lake | 2.5 % | 2.5 % | 0.0 % |
| Total | 100.0 % | 100.0 % | 0.0 % |

the municipality and three departments, excluding the study area's buffer zone, was 6,835,513 (Insee, 2024). Table 3 shows the land-use classes in the study area for both the current situation (Fig. 3a) and one following the 3–30–300 rule (Fig. 3b).

Current land-use is highly urbanized, with almost half of the study area being building or mineral surface (Fig. 3a). Urban concentration is highest in Paris department/commune and remains high in the surrounding departments. Implementation of the 3–30–300 scenario required a more than 20 % reduction in building and mineral surface land-use, to be replaced by publicly accessible greenspace distributed throughout the whole study area (Fig. 3b). A much smaller amount of agricultural land and bare soil was also converted to greenspace in the

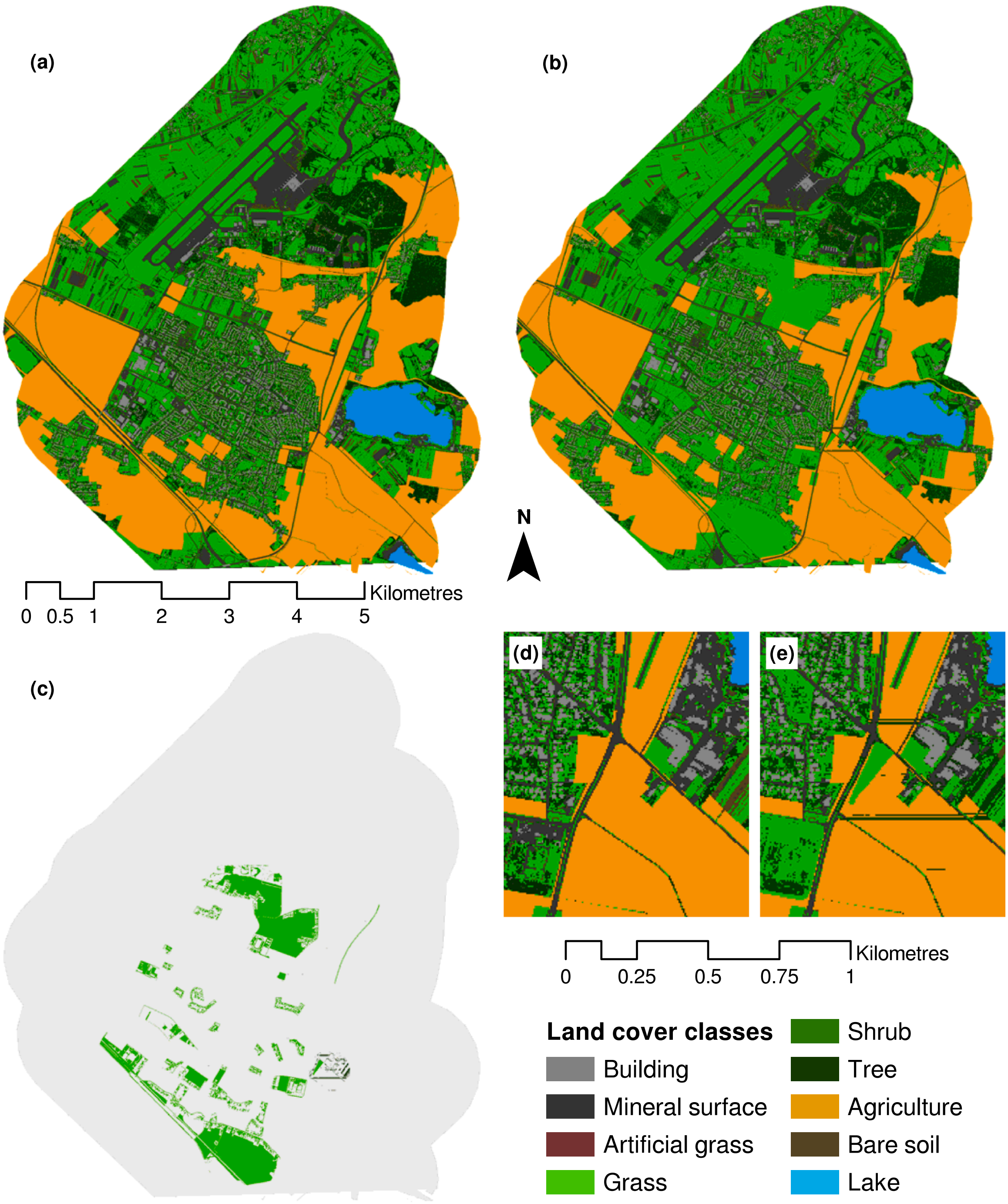

**Fig. 2.** Velika Gorica study area: current land-use scenario (a), 3–30–300 land-use scenario (b), conversions to grass and tree land-use between the two scenarios (c), close-up of the area south-west of Jezero Čiče for the current (d) and 3–30–300 land-use scenario (e).

**Table 3**
Current and 3–30-300 scenario land-use in Paris study area.

| Class | Original (%) | 3–30-300 (%) | Change (%) |
|---|---|---|---|
| Building | 18.0 % | 14.2 % | −3.8 % |
| Mineral surface | 28.4 % | 22.6 % | −5.7 % |
| Grass | 17.6 % | 27.3 % | 9.7 % |
| Shrub | 7.0 % | 7.0 % | 0.0 % |
| Tree | 24.4 % | 24.8 % | 0.4 % |
| Agriculture | 2.3 % | 1.8 % | −0.5 % |
| Bare Soil | 0.7 % | 0.5 % | −0.1 % |
| Lake | 0.4 % | 0.4 % | 0.0 % |
| River | 1.4 % | 1.4 % | 0.0 % |
| Total | 100.0 % | 100.0 % | 0.0 % |

more distant suburbs of the study area. It is noted that several existing publicly accessible greenspaces in Paris are smaller than one hectare, so did not qualify under the 3–30–300 rule.

Many new street trees were required to fulfil the visibility and canopy requirements, mainly within the municipality, on the right bank of the Seine (1st-4th, 8th-12th and 17th-20th arrondissements), where trees were added along much of the length of most streets. Additional tree cover was also required in a few specific suburban areas, and in more rural areas where residential blocks are adjacent to (tree-less) agricultural fields. Suburban and rural trees added for the 3–30–300 scenario were usually clustered, suggesting that canopy cover rather than visibility was the main tree-related concern in the departments surrounding Paris department/commune.

### 2.4. Land cover and elevation data

Each study area defines its “current” scenario from different land cover and elevation data sources. Land cover for Aarhus was based on Knopp et al. (2023), corresponding to land-use in 2015. Land cover for Velika Gorica was based on Knopp (2022), corresponding to land-use in 2016/17. Both were aggregated from sub-metre to 5-metre resolution.

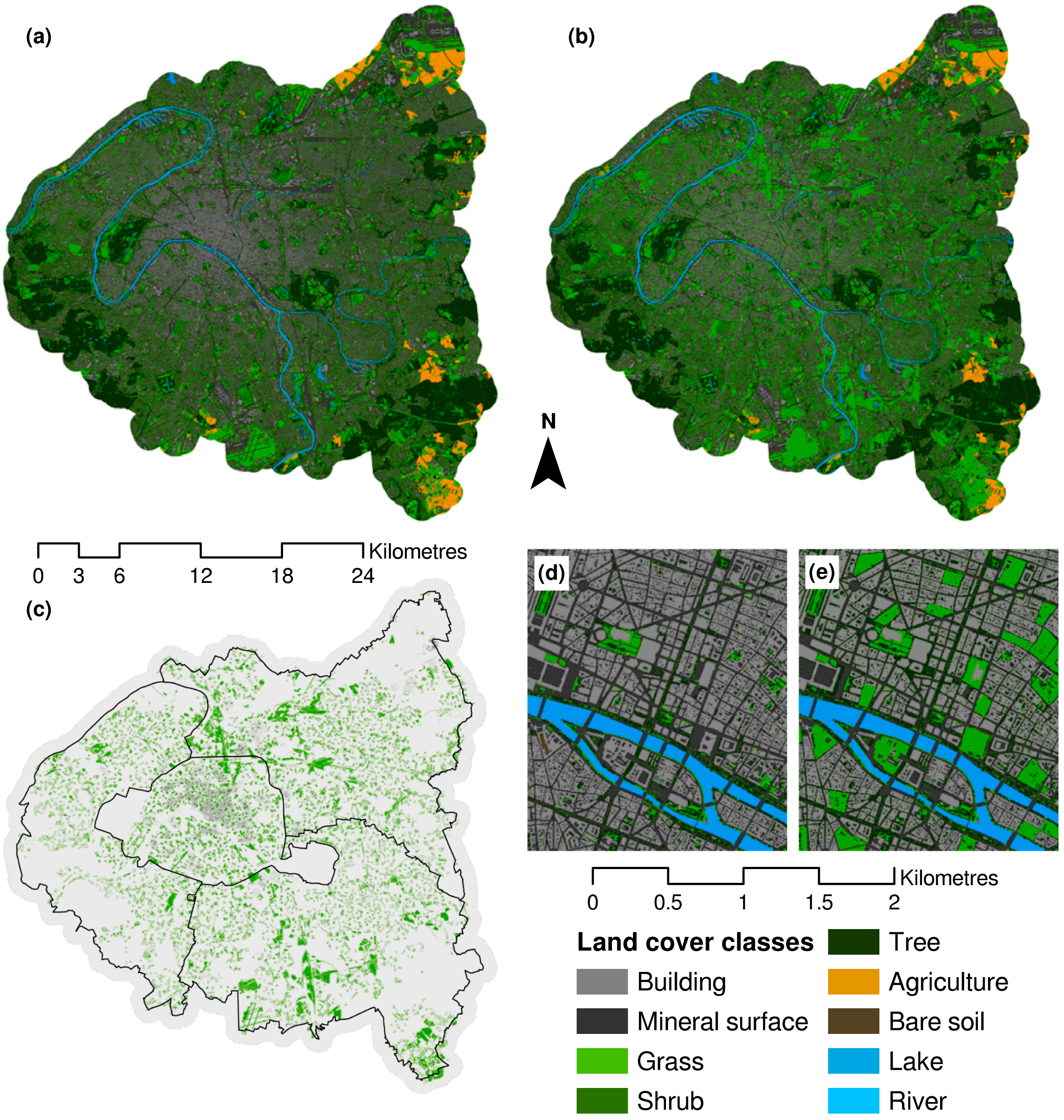

**Fig. 3.** Paris study area: current land-use scenario (a), 3–30–300 land-use scenario (b), conversions to grass and tree land-use between the two scenarios (c), close-up centred on the Île de la Cité for the current (d) and 3–30–300 land-use scenario (e). Paris, Hauts-de-Seine, Seine-Saint-Denis and Val-de-Marne departments are shown as black outlines on (c), while the study area is shown in light grey.

Land cover for Paris was produced from several datasets: MOS+ 2017–81 and Densibati (L'institut Paris Region, 2017), Copernicus Small Woody Features 2018 (European Environment Agency, 2023), Copernicus Urban Atlas Street Tree Layer 2018 (European Environment Agency, 2021), Vegetation Height 2015 (Apur, 2022), and Cadastre vert - Masses vertes (Green land register - Green masses) for Hauts-de-Seine only (Département des Hauts-de-Seine, 2012). Hence, current scenario land-use in Paris corresponds generally to 2017, with additional information from 2012 to 2018 included. The various land cover datasets for Paris were initially vector data, but the combined product was sampled to a 5-metre resolution raster for this study. The 81 MOS+ land-use classes were combined and simplified outside of and prior to this study for use in related projects.

Land cover for the three study areas incorporated different classes according to the data available for each city. Appendix A presents these land cover classes and the standardized categories used for hydrological modelling in this study. In Aarhus and Paris, some water belonged to a general "water" class, while most belonged to either the "lake" or "river" class. All "water" was reassigned to either "lake" or "river" as appropriate for this study, as modelled flow attenuation in ANaRM depends on "lake" only. Reclassification was not required in Velika Gorica.

### 2.5. 3–30–300 scenario generation

This study applied one rule set to generate the "3–30–300" land-use scenario from the current scenario in each study area, which were applied in the following order:

1. every residential building is within 300 m of a contiguous area of publicly accessible greenspace of at least one hectare.
2. every residential building has two pixels of "tree" land cover within 30 m.
3. Blue/green (i.e. "tree", "shrub", "undergrowth", "grass", "river", "lake" and "sea") total at least 30 % land cover in every neighbourhood.

This rule set is described in detail by Owen et al. (2024a), which uses the same land-use scenarios as this study. In brief, residential buildings not meeting rule 1 were identified and overlain with a square grid measuring 212 metres (300 m on the diagonal), then the least-populated block (area enclosed by roads) larger than 1 hectare in each 212 m grid cell was converted to grass (existing blue/green cells were not converted). Next, 30-metre buffers were placed around every residential building and the number of tree pixels in each buffer counted. Where this was less than two, extra tree pixels were placed, prioritizing locations lying within multiple buffers. Finally, a 300-metre buffer was placed around every block, and the total percentage cover of blue/green land uses was calculated in that buffer. Where this was less than 30 %, additional trees were placed, prioritizing locations lying within multiple buffers.

Each of the scenarios studied here is only one of the many possible ways of arranging land-use to meet or exceed the 3–30–300 rule. Owen et al. (2024a) configured the rules to minimize the number of residents impacted and the total land-use change, within the constraint of full automation of the rule set in a GIS at city-scale. Because of this constraint, more land is converted to new public greenspace than is necessary to meet the minimum requirement. All new public greenspaces were initially set as completely grass, with individual pixels later converted to trees if required to meet the "3" or "30" aspects of the 3–30–300 rule. Owen et al. (2024a) considered the "fully grass" approximation to closely represent the initial state of new public greenspace. Defining each "neighbourhood" as the 300-metre buffer around each residential block led to many overlapping neighbourhoods that did not relate to administrative boundaries. However, there is no clear, agreed consistent definition of a "neighbourhood" in general, and this definition did generate consistently sized neighbourhoods, with the "30" aspect met for every block. Overall, other scenarios using different rule sets may achieve 3–30–300 goals with fewer, differently positioned green areas, more trees, shrubs and/or undergrowth, or a completely different spatial arrangement of land-use, all of which would have different effects on runoff.

Due to the differing sizes and densities of urban areas, it may be more difficult to achieve 3–30–300 in some cities (e.g. Paris) than others (e.g. Velika Gorica). It may also be more difficult to achieve 3–30–300 in certain areas of a city than others, as the current distance from the rule, hence the amount of land-use change required to meet it, can vary widely from neighbourhood to neighbourhood (e.g. Battisti et al., 2024; Manyahuillca et al., 2024). However, the reason that the 3–30–300 rule specifies "neighbourhoods" is to ensure that each area of a city independently has sufficient tree cover and access to greenspace so that the benefits are realized for every resident. This is specified explicitly by e.g. UNECE (2021) and Nature Canada (2022).

## 3. Hydrological model

This study uses the ANaRM (Adapted Nature-based-solutions Rational Method) model, described fully by Miller et al. (2023) and implemented in the R programming language (R Core Team, 2023). It is intended for rapid comparisons of different land-use scenarios and ease-of-use without requiring high hydrological or programming knowledge. ANaRM is underpinned by the Rational Method (HRL, 1981), which links peak discharge to catchment area, land cover and mean rainfall intensity. However, unlike other rational method-based models, ANaRM accumulates runoff along hydrological flow paths, and attenuates runoff downstream of water bodies according to the size of the water body and distance downstream. Input data for ANaRM consist of a digital elevation model (DEM), land cover map with a specific category for water bodies (for attenuation purposes), runoff coefficient for each land cover type and rainfall intensity. The model's land cover classes and spatial resolution are defined by the input data, so land cover categories can be created and parameterized for specific urban features, for example, to denote impermeable surfaces under a tree canopy. In this study, we use a 5-metre DEM and 5-metre land cover map for all cities, with land-use classes aggregated as shown in Appendix A. Using these data, peak discharge, $Q_P$ ($m^3/s$), for a grid cell is:

$$Q_P = 0.278 \times 1.3 \times C_V \times i \times A \times FARL^{3.445} \quad (1)$$

Where 0.278 is a conversion factor between $m^3/s$ and $mm/hr \cdot km^2$, 1.3 is the fixed value recommended by HRL (1981) for a dimensionless routing coefficient, $C_V$ is the mean runoff coefficient of the land upstream of the grid cell, determined by the DEM, $i$ (mm/hr) is the rainfall intensity, $A$ ($km^2$) is the area of land upstream of the grid cell and $FARL$ is the "Flood Attenuation by Reservoirs and Lakes" index defined by Bayliss (1999).

The rational method's performance relies on the selection of an appropriate runoff coefficient for the catchment. In the case of a gridded implementation, performance relies on the selection of an appropriate runoff coefficient for each grid cell. In each scenario, each grid cell is assigned a land cover type, and all cells of the same type are given the same runoff coefficient. Appropriate runoff coefficients for each land cover type are presented in Appendix B and are broadly equivalent to the top of the ranges presented by Linsley et al. (1992).

The rational method is typically used in small catchments with short concentration times (HRL, 1981), but in practice has been recommended in guidance for use in catchments up to 250 $km^2$ (Pilgrim, 1987). The reason that the rational method is typically not used in larger catchments is because it does not model flow attenuation. However, the ANaRM implementation of the rational method does model flow attenuation through water bodies (i.e. lakes). Furthermore, ANaRM has been verified in a 74 $km^2$ catchment in Birmingham, UK (Miller et al., 2023), against the UK regulator-approved methods WINFAP (Kjeldsen et al., 2008; Wallingford HydroSolutions, 2021) and ReFH2 (Kjeldsen et al., 2013; Wallingford HydroSolutions, 2019), both of which model increasing attenuation with increasing catchment area or flow path length, and one of which (WINFAP) also models flow attenuation through water bodies. To avoid applying ANaRM outside its intended and verified range, we do not present results for any watersheds larger than 50 km$^2$, or for flows in the Aarhus, Sava, Seine and Marne rivers.

The rational method provides a "snapshot" of peak flow, given a constant rainfall rate. Due to the construction of the rational method, peak flows scale linearly with rainfall rate; this is generally unrealistic when considered over too wide a range of peak rainfall rates. This linear scaling means that the percentage changes in runoff between two scenarios are constant if both are given the same peak rainfall rate. In this study, a nominal constant rainfall rate of 10 mm/hour was used throughout. While this does correspond to different rainfall rarities both between and within the three study areas, this study focuses on percentage changes, which are unaffected by the choice of peak rainfall rate. Previous validation of the ANaRM model (Miller et al., 2023) used a constant rainfall rate of 3.54 mm/hr, equivalent to the mean hourly rainfall rate of a 12.5-hour, 10-year return period event in the study catchment. The percentage changes in runoff reported in this study are therefore suggested as indicative for similarly rare rainfall events (i.e. 10-year return period or 10 % annual exceedance probability), independently of the nominal rainfall rate used in this study.

## 4. Results

Fig. 4, Fig. 5 and Fig. 6 show modelled peak runoff rate reduction across the Aarhus, Velika Gorica and Paris study areas respectively, while Table 4 reports peak runoff rate reduction and upstream catchment area at selected points.

Several commonalities and differences can be observed by comparing the three study areas. The maximum percentage peak runoff rate reduction achieved in each study area was 73–75 %, in places where an effectively impermeable land-use class was transformed to trees. However, the most common large areas showing noticeable peak runoff rate reduction were those corresponding to the locations of new greenspace (grass). In all three study areas, much more land was converted to grass than to trees, therefore the total flood mitigation effect of

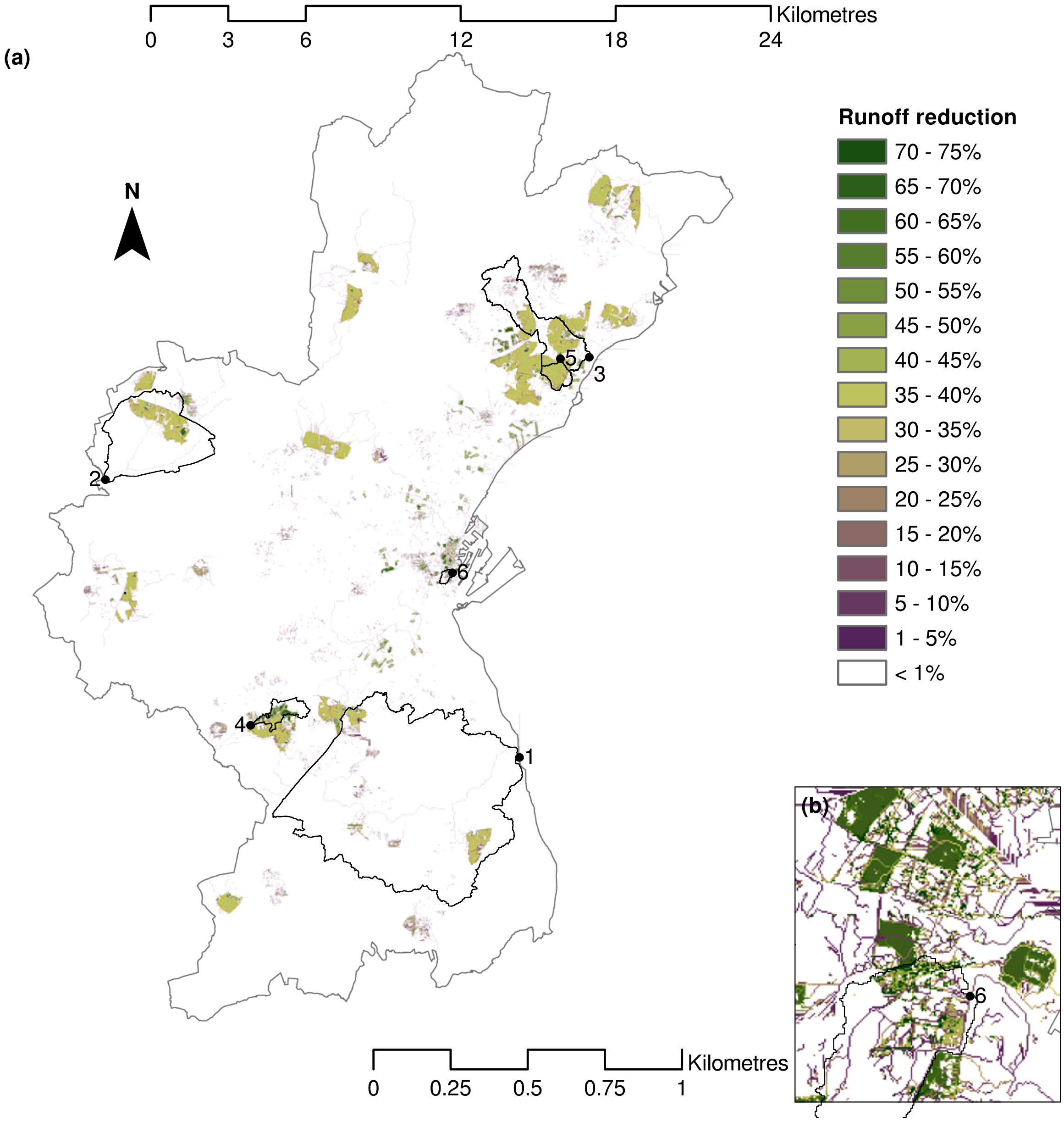

**Fig. 4.** Percentage peak runoff rate reduction across Aarhus study area (a) and port area (b) corresponding to sub-plots (d) and (e) on Fig. 1.

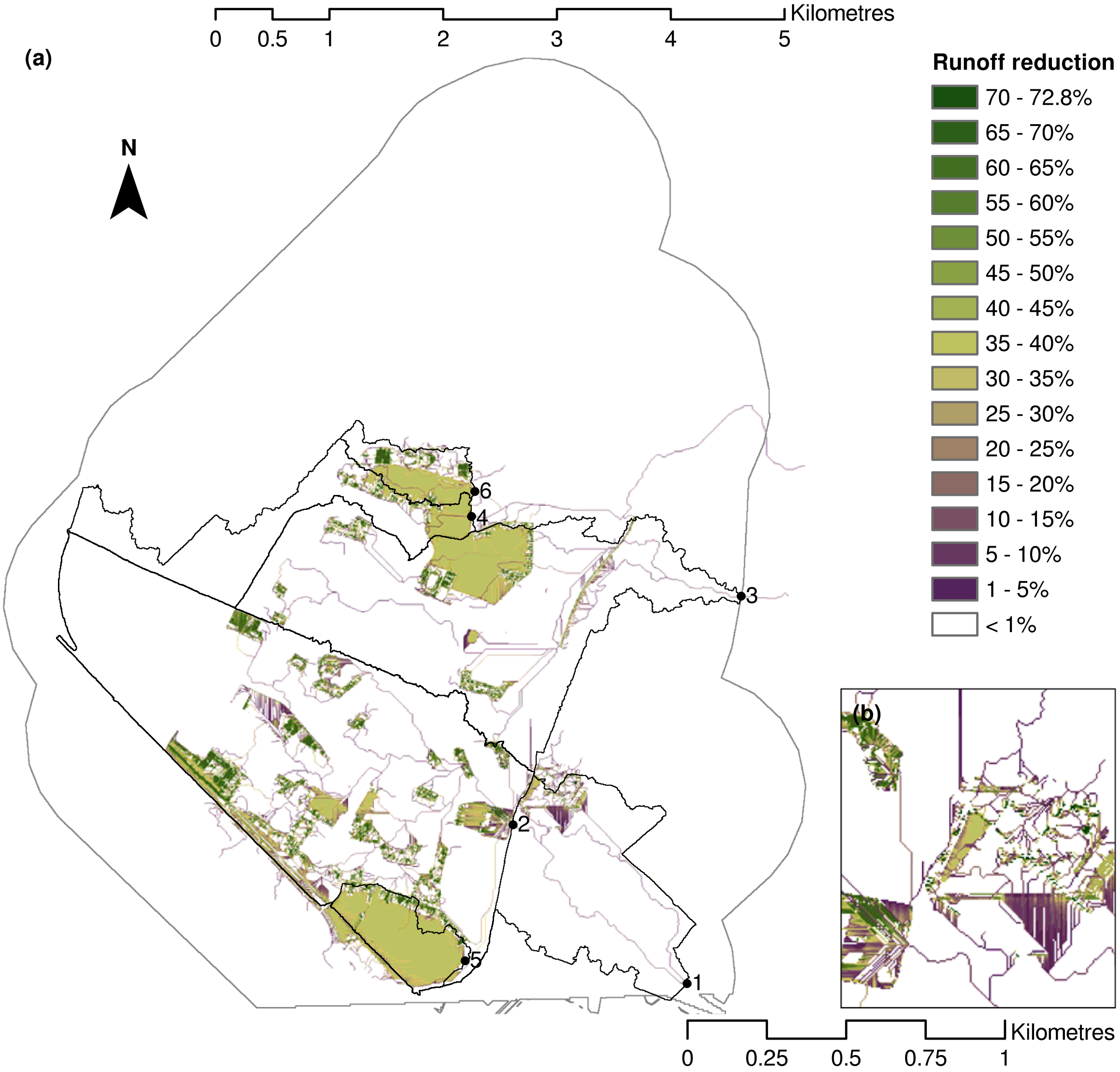

**Fig. 5.** Percentage peak runoff rate reduction over Velika Gorica study area (a) and area south-west of Jezero Čiče (b) corresponding to sub-plots (d) and (e) on Fig. 2.

new greenspace was often greater than that of tree planting. In Aarhus and Velika Gorica, new greenspace was most frequently sited on agricultural land, while in Paris, it was most frequently sited on built land. Hence, the effects of new greenspace on runoff were higher in Paris than in Aarhus or Velika Gorica. Within most parcels of changed land-use in any study area, there were thin pathways of lesser peak runoff rate reduction. These corresponded to flow paths starting outside and topographically above the parcel, flowing through the parcel, and accumulating flow from both the parcel, where land-use was changed, and land upstream of the parcel, where land was either mostly or entirely unchanged. Despite peak runoff rate reduction diminishing further away from land-use interventions, some effect was still noticeable a long way downstream of the interventions, shown as purple lines on Figs. 4–6. In Aarhus and Velika Gorica, the rate of runoff from catchments of several square kilometres could still be several percent lower under the 3–30–300 scenario than the current scenario, while in Paris, reductions of over 10 % were present even for catchments of over 20 or 30 km$^2$ (Table 4).

## 5. Discussion

### 5.1. Effects of implementing 3–30-300 on runoff

The effects on runoff of implementing 3–30–300 were greatest at the locations where the land-use changes took place, but decreased as catchment size increased and land-use interventions became a smaller part of the catchment. This was found in a previous study using the ANaRM model in Birmingham, UK (Miller et al., 2023) and agrees with both a systematic review by Baker et al. (2021), which found little evidence of urban forestry having large-scale effects on hydrology, and Hutchins et al., 2021, which states that the effects of nature-based solutions on flooding may be negligible unless they occupy a significant portion of the total contributing area. Hence, it can be suggested that the provision of new greenspace and street trees could reduce pluvial flooding at the locations of these interventions, but would have diminishing effects at greater distances. However, the “300” aspect of the 3–30–300 rule means that any newly created greenspace would be in the places most distant from existing large greenspaces, and hence would lead to relatively large reductions in pluvial runoff and localized flooding.

The greater peak runoff rate reductions seen in larger catchments in

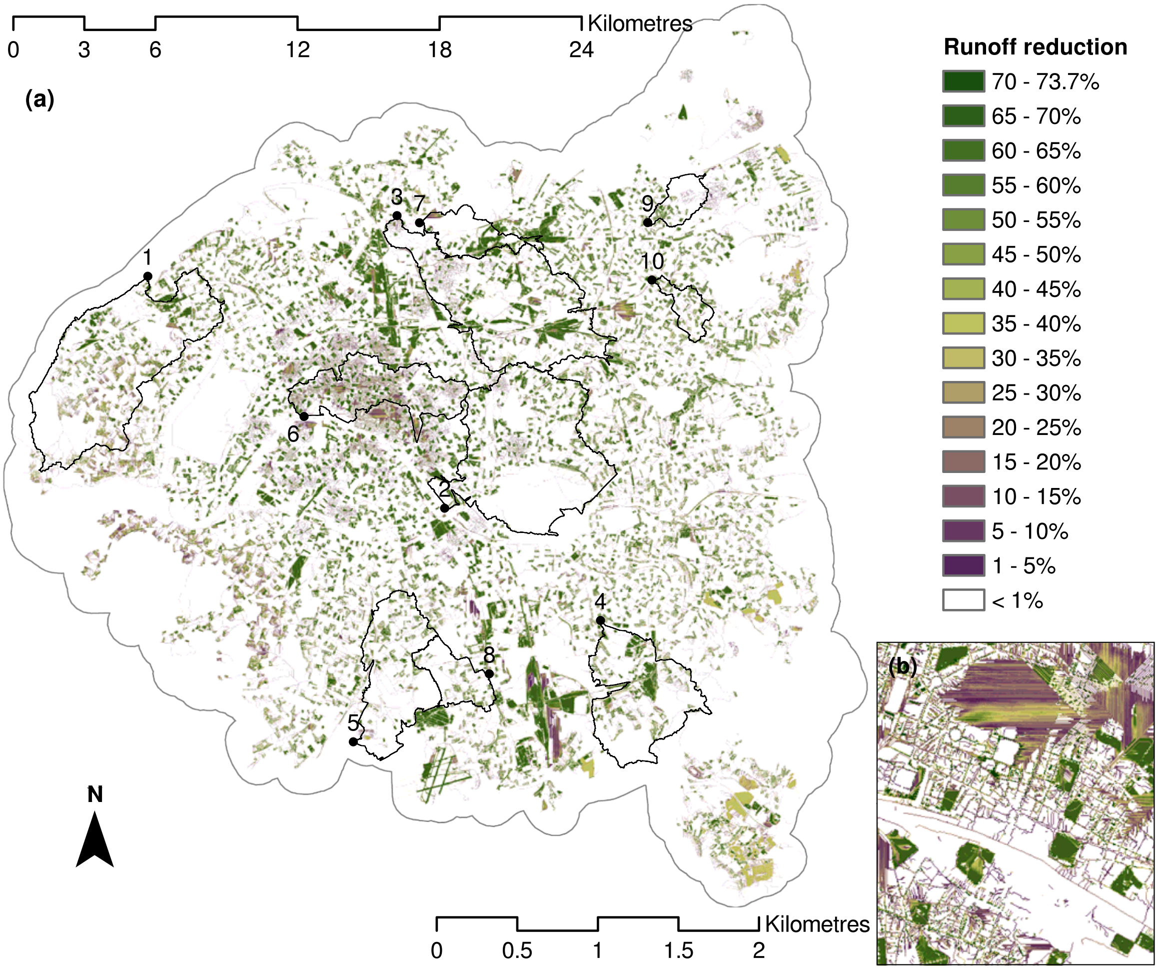

**Fig. 6.** Percentage peak runoff rate reduction over Paris study area (a) and area around Île de la Cité (b) corresponding to sub-plots (d) and (e) on Fig. 3.

Paris were due to the greater fraction of land-use change (i.e. the interventions occupied a larger portion of the contributing area) when compared to the other two study areas, and the higher initial runoff coefficients of the changed land (primarily built land in Paris, primarily agricultural land in Aarhus and Velika Gorica). Hence, implementing 3–30–300 has the greatest effect on urban flood mitigation in the neighbourhoods that are currently the furthest away from meeting 3–30–300 targets. Implementing 3–30–300 in some suburban areas may have a limited effect on flood mitigation, particularly in neighbourhoods that already have large publicly accessible greenspaces, as there may be little change required to meet the rule. However, those neighbourhoods are already likely to have less pluvial flooding, relative to neighbourhoods further away from meeting the rule. It is noted that the 3–30–300 rule is intended to apply separately to each neighbourhood of a city, with trees and adequately sized greenspace provided in targeted locations (UNECE, 2021; Nature Canada, 2022). Hence, as well as improving equity of access to greenspace and visibility of trees, implementation of 3–30–300 may act to “equalize” flood risk across neighbourhoods *and* reduce total city-wide flood risk.

### *5.2. Land-use conversion and spatial arrangement*

Conversion to trees, on a per-square-metre basis, reduces runoff by more than conversion to grass, as trees can intercept rainfall as well as promote infiltration (Dowtin et al., 2023). However, much less land must be converted to trees in order to meet the “3” and “30” aspects than to grass in order to meet the “300” aspect in these scenarios.

The method of 3–30–300 scenario generation used in this study minimized increases in tree cover but not greenspace (grass), due to the differing requirements for the three components of the rule (Owen et al. 2024a). Because the 3–30–300 rule only sets minimum standards for greenspace and urban tree cover, different feasible scenarios may provide more peak runoff rate reduction in more areas. However, additional peak runoff rate reduction is generally achieved through additional land-use conversion, which may extend the urban footprint if some existing buildings are removed and replaced elsewhere. The rule set in this study explicitly minimized the number of residents affected, but care must still be taken to design any necessary replacement developments in a way that minimizes disturbance to nature. Conversely, new development creates an opportunity to implement 3–30–300 *and* sufficient flood management, as well as any other benefits, from the start.

In order to meet the “300” aspect, built/agricultural land parcels larger than 1 hectare were converted to grass only, which was considered to approximate the initial state of a new park without mature trees. However, the 3–30–300 rules themselves do not require that the “300” aspect be met solely by grass – it may also be met by provision of a suitably sized forest, or a combination of grass and tree planting, either of which would likely provide greater flood mitigation than grass alone (Rahman et al., 2023). The presence of trees would also contribute towards the “3” and “30” aspects of the 3–30–300 rule.

While large greenspaces are required to meet the “300” aspect of 3–30–300, Yang & Lee (2021) and Forman (2022) also demonstrate that many smaller parks can have a greater total effect on overland flow reduction than fewer larger parks of the same total area, while Thomas et al. (2020) show a similar effect for woodland fragmentation on the

**Table 4**

Percentage peak runoff rate reduction for catchments within Aarhus, Velika Gorica and Paris study areas.

| Catchment | Area ($km^2$) | New grass ($km^2$) | New trees ($km^2$) | Peak runoff rate reduction (%) |
|---|---|---|---|---|
| Aarhus 1 | 48.2 | 0.93 | 0.17 | 1.1 |
| Aarhus 2 | 10.3 | 1.40 | 0.012 | 6.1 |
| Aarhus 3 | 6.75 | 2.28 | 0.032 | 14.3 |
| Aarhus 4 | 1.16 | 0.44 | 0.00015 | 26.1 |
| Aarhus 5 | 0.85 | 0.66 | 0.0011 | 29.7 |
| Aarhus 6 | 0.18 | 0.0016 | 0.033 | 11.3 |
| Velika Gorica 1 | 9.78 | 1.17 | 0.026 | 7.5 |
| Velika Gorica 2 | 7.67 | 1.16 | 0.0019 | 9.2 |
| Velika Gorica 3 | 4.75 | 0.51 | 0.00035 | 5.5 |
| Velika Gorica 4 | 1.38 | 0.15 | 0 | 5.8 |
| Velika Gorica 5 | 0.59 | 0.51 | 0 | 35.2 |
| Velika Gorica 6 | 0.44 | 0.21 | 0 | 24.1 |
| Paris 1 | 33.7 | 3.60 | 0.0067 | 10.4 |
| Paris 2 | 33.5 | 3.42 | 0.11 | 9.8 |
| Paris 3 | 29.5 | 4.93 | 0.16 | 13.8 |
| Paris 4 | 17.9 | 2.34 | 0.00080 | 13.2 |
| Paris 5 | 15.6 | 1.24 | 0.013 | 6.9 |
| Paris 6 | 13.4 | 1.65 | 1.13 | 15.4 |
| Paris 7 | 5.55 | 1.15 | 0.0016 | 18.5 |
| Paris 8 | 5.47 | 0.46 | 0.00058 | 8.1 |
| Paris 9 | 3.29 | 0.27 | 0.013 | 7.7 |
| Paris 10 | 2.92 | 0.44 | 0.00058 | 13.1 |

hydrological benefits of ecosystem services in rural settings. Hence, the clustering of greenspace into large areas encouraged by the “300” aspect may not be optimal for urban flood mitigation; greater effects may be achieved with more dispersed spatial arrangements.

The presence of “thin pathways” of peak runoff rate reduction show that conversion to green or blue land uses upstream of an urban area can reduce runoff rates downstream of the converted area, allowing more capacity to accept runoff from unconverted urban areas.

Paris, and potentially other cities not studied here, contains many small parks of under one hectare, which do not strictly qualify under the “300” rule. A stricter interpretation of the 3–30–300 rule would require larger greenspaces, increasing the flood mitigation potential of those that are expanded, but would also discount non-qualifying (too-small) greenspaces, allowing their removal and reducing or eliminating their flood mitigation potential. Strict interpretation of the 3–30–300 rule could therefore have mixed effects on urban flood mitigation, and just meeting the rule may not be the most efficient way to reduce urban flooding per unit area greened. While it is possible for small parks to provide physical and mental health benefits (Ekkel and de Vries, 2017), it is important to quantify this relative to larger greenspaces.

### *5.3. Relationship to sustainable drainage systems*

In addition to the optimal spatial arrangement of green spaces differing between meeting 3–30–300 and mitigating urban flooding, many sustainable drainage system (SuDS) components are not optimal for meeting 3–30–300. For example, swales, filter strips, trenches, rain gardens, and soakaways are too small to contribute to the “300” aspect and lack the trees required to contribute to the “3” aspect. Permeable paving, geocellular storage and flow control structures do not contribute to meeting 3–30–300 at all. Infiltration basins, if large enough, can contribute to the “300” aspect and mitigate urban flooding by accumulating surface water from surrounding areas. However, they must infiltrate the accumulated water rapidly, as they are not fully accessible greenspaces whenever there is standing water (although with careful design a degree of accessibility can be retained even when full of accumulated water).

Green roofs are one option to add permeable surfaces to urban areas without removing buildings, and roofs designed for recreation and aesthetic value often require thicker substrate layers with more organic content, resulting in high capacities for water storage and outflow attenuation (Yio et al., 2013). However, making a green roof a publicly accessible greenspace adds cost, weight and maintenance requirements to the design (Shafique et al., 2018), and few buildings have a physical footprint large enough to provide a greenspace of the one-hectare minimum size stated in the rule. It is noted that Paris already has a few vegetated rooftops larger than one hectare in area: for example, the Jardin Atlantique, above the tracks and platforms of Montparnasse railway station, has an area of 3.4 ha, while the Coulée verte René-Dumont has an area of 6.5 ha (Jim, 2017). However, the Coulée verte René-Dumont also has a length of 4.7 kilometres, illustrating how few opportunities there are to build rooftop parks over multiple hectares. This study did not consider the potential to provide new accessible greenspaces of one hectare or larger via green roofs, due to the perceived limited opportunity to do so. It should also be noted that the original definition of the 3–30–300 rule has a stated focus on urban trees.

Ponds and wetlands can provide considerable water storage and fluvial flow attenuation, but the 3–30–300 rule traditionally focuses on canopy cover when calculating the “30” aspect. However, Konijnendijk (2023) does suggest that other vegetation be included in certain circumstances, like high-density or arid cities. The multiple ecosystem service benefits of ponds and wetlands (Carter, 2015; Ekkel & de Vries, 2017; Pedersen et al., 2019) suggest that it may be legitimate to extend the “30” aspect to include them. Ponds and wetlands then become a land-use that is beneficial for 3–30–300 and urban flood mitigation.

### *5.4. Practical applications for urban planning*

Challenges in implementing the 3–30–300 rule vary between the three case studies. Practical implementation of the “300” aspect in full in Paris is unlikely to be possible, due to the requirement for 88.7 $km^2$ of new greenspace, the land for which is mostly obtained by converting 86.8 $km^2$ of the current 423 $km^2$ of buildings and mineral surface. In contrast, only 0.66 $km^2$ of buildings and mineral surface are converted in Velika Gorica, and there is an abundance of unbuilt land around the existing urban area into which new urbanization could be placed, although at the expense of nearby agricultural land. Similarly, just 2.82 $km^2$ of impermeable land were converted in the Aarhus study area. The 3–30–300 scenarios in this study were designed to minimize the number of affected residents, but removal of any building implies the probable construction of replacement floorspace, which may extend the urban footprint. In all three case studies, agricultural land is most at risk from this. From both a 3–30–300 and urban flood mitigation perspective, forests and publicly accessible greenspace are preferable to agricultural land. However, agricultural land often provides other benefits, and may be publicly accessible in certain cases, helping to achieve the “300” aspect without conversion. It is important that this be considered when implementing 3–30–300 over an urban area and its surrounds. Inclusion of mature trees where agricultural and residential areas meet can also help to achieve the “3” aspect without land-use change on either side.

Tree cover was increased by only 1.55 $km^2$ in Aarhus and 0.03 $km^2$ in Velika Gorica. New trees were sparsely distributed, indicating that neighbourhoods were generally at 30 % green/blue coverage, but three mature trees were not always visible from every home. In Paris, an additional 3.67 $km^2$ of trees were required, mainly within the municipality on the right bank of the Seine (1st-4th, 8th-12th and 17th-20th arrondissements), where trees were added along much of the length of most streets. Additional tree cover was also required in a few specific suburban areas, and in more rural areas where residential blocks border agricultural fields. Trees added in suburban and rural areas were usually clustered, suggesting that neighbourhood green/blue coverage was lacking in the lower-density departments surrounding Paris municipality, as well as the high-density centre.

### 5.5. Study limitations

This study is the first to quantify urban flood mitigation resulting from application of the 3–30–300 rule. Here, we discuss limitations of this study.

The three case study areas considered here represent diverse urban typologies, from large- to small-scale, heavy to light urbanization. However, all three share a temperate, no-dry-season climate, so the findings from this study may be less applicable to urban areas in other climates. Similar modelling in arid and tropical climate zones would be a useful avenue for further work.

The grass-only representation of new parks in the 3–30–300 scenarios in this study will not represent their long-term flood mitigation potential in many cases – newly planted trees within parks would be expected to mitigate increasing flood risk as they grow, suggesting that potential urban flood mitigation is underestimated. Due to a lack of information otherwise, all agricultural land was assumed inaccessible to the public. Given the correct information, it is likely that less conversion away from agricultural land would be required to meet the “300” aspect in all case studies.

ANaRM estimates the flow attenuation downstream of water bodies, but not the lesser attenuation of flow that would be expected in a river or a long overland flow path, again suggesting that the model outputs presented here may underestimate the urban flood mitigation provided. However, the potential for underestimating attenuation in large rivers is somewhat countered by the pre-existing recommendation that ANaRM only be used for catchments up to tens of square kilometres.

Infiltration and detention basins were discussed previously as a primarily runoff-reducing intervention that could also fulfil the “300” aspect of 3–30–300. ANaRM can implement these basins through modification of both the land cover scenario and DEM. As this study did not consider modification of the DEM, it could not model these basins. In order to design basins that become usable as public greenspace soon after the end of a storm, infiltration and/or hydraulic models are required, to determine the total volume directed to the basin and the rate at which water is infiltrated and/or released.

## 6. Conclusions

The 3–30–300 rule was proposed in 2021 as an objective and easy-to-understand target for urban forestry and urban greening, and rapidly adopted by a number of cities, international organizations and NGOs. However, due to the recency of the rule, there is limited research on the benefits to urban areas of meeting the 3–30–300 rule. This study is the first to assess the effects of implementing 3–30–300 on peak runoff rate reduction, considering three urban areas in Europe of contrasting sizes and populations: Aarhus (Denmark), Velika Gorica (Croatia) and Paris (France). The ANaRM gridded hydrological model was used to assess runoff under two land-use scenarios in each urban area, all at 5-metre resolution: “current”, representing measured land-use in the mid- to late-2010s, and “3–30–300”, representing one arrangement of greenspace and tree cover that meets the 3–30–300 rule.

The main hydrological benefits provided by implementation of the 3–30–300 rule were found in the areas where new greenspace and tree cover are implemented, with greater than 70 % peak runoff rate reduction at the locations where built land is converted to tree cover. This implies that the interventions required to meet 3–30–300 are most effective at reducing pluvial flooding. It is notable that the “300” requirement of the rule prioritizes locating new greenspace in neighbourhoods poorly served by large greenspaces. Hence, implementation of 3–30–300 generally reduces pluvial runoff most in the neighbourhoods with the highest existing runoff coefficients and serves to “equalize” urban flood impacts across neighbourhoods. While the effects of land-use change on peak runoff rate reduction were lessened by distance, peak runoff rate reductions of several percent were still possible within sub-catchments of several square kilometres, implying a reduction in river flows. However, the total conversion to greenspace and increased tree cover required to meet the 3–30–300 criteria was too small to have a greater effect than this at city-scale in the three cities studied here. The 3–30–300 rule was not developed foremost to mitigate urban flooding. Hence, other interventions may reduce urban flooding more efficiently, albeit potentially at a cost to other ecosystem service benefits. However, large greenspaces can both meet the “300” aspect of the rule and provide large-scale urban flood mitigation if they are designed to accumulate water from their surroundings and either infiltrate it or release it at an attenuated rate that is still sufficient to clear it for public use soon after the end of a storm event.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This work was undertaken as part of the REGREEN project (https://regreen-project.eu), which received funding from the European Union’s Horizon 2020 research and innovation funding programme (grant agreement ID 821016). Authors also acknowledge funding under the UK RECLAIM Network Plus project (EP/W034034/1), funded by UK Research and Innovation (UKRI): Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC), and Arts and Humanities Research Council (AHRC).

## Appendix A. Land cover classes in data provided for study areas, and standardized land cover classes

| Aarhus | Velika Gorica | Paris | Standardized |
|---|---|---|---|
| | Building | Building | Building |
| Building: lowest rise | | | Building |
| Building: low rise | | | Building |
| Building: mid rise | | | Building |
| Building: high rise | | | Building |
| Building: highest rise | | | Building |
| | | Built parcel | Building |
| Mineral surface | Mineral surface | Mineral surface | Mineral surface |
| Artificial grass | Artificial grass | | Artificial grass |
| Grass | Grass | Grass | Grass |
| | Shrub | Shrub | Shrub |
| Shrub round | | Shrub round | Shrub |
| Shrub linear | | Shrub linear | Shrub |
| Evergreen | Evergreen | Evergreen | Tree |

(*continued on next page*)

(*continued*)

| Aarhus | Velika Gorica | Paris | Standardized |
|---|---|---|---|
| Deciduous | Deciduous | Deciduous | Tree |
| Undergrowth | | | Undergrowth |
| | Agriculture | Agriculture | Agriculture |
| Agriculture: intensive, temporary crop | | | Agriculture |
| Agriculture: intensive, permanent crop | | | Agriculture |
| Agriculture: extensive | | | Agriculture |
| Bare soil | Bare soil | Bare soil | Bare soil |
| Water | | Water | Lake or River |
| Lake | Lake | Lake | Lake |
| River | River | River | River |
| Sea | | | Sea |
| Unclassified | | Unclassified | Unclassified |

## Appendix B. Runoff coefficients for land cover classes in study areas

| Class | Runoff coefficient |
|---|---|
| Building | 0.95 |
| Mineral surface | 0.92 |
| Artificial grass | 0.70 |
| Grass | 0.35 |
| Shrub | 0.35 |
| Tree | 0.25 |
| Undergrowth | 0.30 |
| Agriculture | 0.55 |
| Bare Soil | 0.45 |
| Lake | 1.00 |
| River | 1.00 |
| (Unclassified) | 1.00 |

## References

Apur (2022). Vegetation Height 2015. Apur (Atelier Parisien d'Urbanisme), Paris. https://opendata.apur.org/datasets/Apur::hauteur-vegetation-2015/about.

Arora, N.K., Mishra, I., 2019. United nations sustainable development goals 2030 and environmental sustainability: race against time. Environ. Sustain. 2 (4), 339–342. https://doi.org/10.1007/s42398-019-00092-y.

Baker, H.J., Hutchins, M.G., Miller, J.D., 2021. How robust is the evidence for beneficial hydrological effects of urban tree planting? Hydrol. Sci. J. 66 (8), 1306–1320. https://doi.org/10.1080/02626667.2021.1922692.

Battisti, L., Giacco, G., Moraca, M., Pettenati, G., Dansero, E., Larcher, F., 2024. Spatializing urban forests as nature-based solutions: a methodological proposal. Cities 144, 104629. https://doi.org/10.1016/j.cities.2023.104629.

Bayliss, A.C., 1999. Catchment Descriptors. Flood Estimation Handbook volume 5. Institute of Hydrology, Wallingford.

Carter, M., 2015. Wetlands and Health: How do Urban Wetlands Contribute to Community Wellbeing? In: Finlayson, C., Horwitz, P., Weinstein, P. (Eds.), Wetlands and Human Health. Wetlands: Ecology, Conservation and Management, 5 Springer, Dordrecht. https://doi.org/10.1007/978-94-017-9609-5_8.

Croatian Bureau of Statistics (2022). Population by Age and Sex, by Settlements, 2021 Census. Census of Population, Households and Dwellings in 2021. Croatian Bureau of Statistics, Zagreb. https://podaci.dzs.hr/media/rqybclnx/popis_2021-stanovnistvo_po_naseljima.xlsx.

Département des Hauts-de-Seine (2012) Cadastre vert - Masses vertes (Green land register - Green masses). Département des Hauts-de-Seine, Nanterre. https://opendata.hauts-de-seine.fr/explore/dataset/cadastre-vert-masses-vertes.

Dowtin, A.L., Cregg, B.C., Nowak, D.J., Levia, D.F., 2023. Towards optimized runoff reduction by urban tree cover: a review of key physical tree traits, site conditions, and management strategies. Landsc. Urban Plan. 239, 104849. https://doi.org/10.1016/j.landurbplan.2023.104849.

Dzhambov, A.M., Dimitrova, D.D., 2014. Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: a systematic review. Noise Health 16 (70), 157–165. https://doi.org/10.4103/1463-1741.134916.

Ekkel, E.D., de Vries, S., 2017. Nearby green space and health: evaluating accessibility metrics. Landsc. Urban Plan. 157, 214–220. https://doi.org/10.1016/j.landurbplan.2016.06.008.

Elsadek, M., Liu, B., Xie, J., 2020. Window view and relaxation: viewing green space from a high-rise estate improves urban dwellers' wellbeing. Urban For. Urban Green. 55, 126846. https://doi.org/10.1016/j.ufug.2020.126846.

European Environment Agency, 2021. Urban Atlas Street Tree Layer 2018 (vector), Europe, 6-yearly, Feb. 2021. European Environment Agency, Copenhagen. 〈https://sdi.eea.europa.eu/catalogue/copernicus/api/records/205691b3-7ae9-41dd-abf1-1fbf60d72c8c〉.

European Environment Agency, 2023. Small Woody Features 2018 (vector), Europe, 3-yearly, May 2023. European Environment Agency, Copenhagen. 〈https://sdi.eea.europa.eu/catalogue/srv/api/records/7fd9d32e-8c2f-42b2-b959-c8e12b843821〉.

Fletcher, D.H., Garrett, J.K., Thomas, A., Fitch, A., Cryle, P., Shilton, S., Jones, L., 2022. Location, location, location: modelling of noise mitigation by urban woodland shows the benefit of targeted tree planting in cities. Sustainability 14 (12), 7079. https://doi.org/10.3390/su14127079.

Forman, R.T.T., 2022. Values of large-versus-small urban greenspaces and their arrangement. *Why cities need large parks.* Routledge, New York.

Future Woodlands Scotland, 2021. Invitation to Tender: The Development of a £ 10m Urban Forestry Fund for Scotland. Future, Woodlands Scotland, Edinburgh. 〈https://www.futurewoodlands.org.uk/wp-content/uploads/2022/05/Future-Woodlands-Scotland-Urban-Forestry-Fund-ITT-May-2022.pdf〉.

Garrett, J.K., Rowney, F.M., White, M.P., Lovell, R., Fry, R.J., Akbari, A., Geary, R., Lyons, R.A., Mizen, A., Nieuwenhuijsen, M., Parker, C., Song, J., Stratton, G., Thompson, D.A., Watkins, A., White, J., Williams, S.A., Rodgers, S.E., Wheeler, B.W., 2023. Visiting nature is associated with lower socioeconomic inequalities in well-being in Wales. Sci. Rep. 13 (1), 9684. https://doi.org/10.1038/s41598-023-35427-7.

Grylls, T., van Reeuwijk, M., 2022. How trees affect urban air quality: it depends on the source. Atmos. Environ. 290, 1–14. https://doi.org/10.1016/j.atmosenv.2022.119275.

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 (4), 516–529. https://doi.org/10.1007/s13280-014-0510-2.

HRL, 1981. The Wallingford Procedure for design and analysis of urban storm drainage. Volume 4: The Modified Rational Method. Hydraulics Research Limited, Wallingford. 〈https://eprints.hrwallingford.com/37/2/Volume4_Modified_Rational_Method.pdf〉.

Hutchins, M.G., Fletcher, D., Hagen-Zanker, A., Jia, H., Jones, L., Li, H., Loiselle, S., Miller, J., Reis, S., Seifert-Dähnn, I., Wilde, V., Xu, C.Y., Yang, D., Yu, J., Yu, S.,

2021. Why scale is vital to plan optimal nature-based solutions for resilient cities. Environ. Res. Lett. 16 (4), 044008. https://doi.org/10.1088/1748-9326/abd9f4.

Insee (2024). Comparateur de territoires (Territory comparator). Institut national de la statistique et des études économiques, Montrouge. https://www.insee.fr/fr/statistiques/1405599?geo=UU2020-00851+DEP-75+DEP-92+DEP-93+DEP-94.

IUCN (2021). Promoting health and wellbeing through urban forests – Introducing the 3-30-300 rule. International Union for Conservation of Nature, Gland. https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/.

Iungman, T., Cirach, M., Marando, F., Pereira Barboza, E., Khomenko, S., Masselot, P., Quijal-Zamorano, M., Mueller, N., Gasparrini, A., Urquiza, J., Heris, M., Thondoo, M., Nieuwenhuijsen, M., 2023. Cooling cities through urban green infrastructure: a health impact assessment of European cities. Lancet 401 (10376), 577–589. https://doi.org/10.1016/S0140-6736(22)02585-5.

Jim, C.Y., 2017. Green roof evolution through exemplars: germinal prototypes to modern variants. Sustain. Cities Soc. 35, 69–82. https://doi.org/10.1016/j.scs.2017.08.001.

Jones, L., Vieno, M., Carnell, E., Cryle, P., Holland, M., Nemitz, E., Morton, D., Hall, J., Mills, G., Dickie, I., Reis, S., 2019. Urban natural capital accounts: developing a novel approach to quantify air pollution removal by vegetation. J. Environ. Econ. Policy 8 (4), 413–428. https://doi.org/10.1080/21606544.2019.1597772.

Jones, L., Reis, S., Hutchins, M., Miller, J., He, B., Seifert-Dähnn, I., Xu, C.-Y., Hagen-Zanker, A., Yu, J., Lin, T., Jia, H., Loiselle, S., Russel, D., Sabel, C.E., Fletcher, D., Fitch, A., Inostroza, L., 2022a. Airsheds, watersheds and more – the flows that drive intra-extra-urban connections, and their implications for nature-based solutions (NBS). Nat. Based Solut. 2, 100040. https://doi.org/10.1016/j.nbsj.2022.100040.

Jones, L., Anderson, S., Læssøe, J., Banzhaf, E., Jensen, A., Bird, D.N., Miller, J., Hutchins, M.G., Yang, J., Garrett, J., Taylor, T., Wheeler, B.W., Lovell, R., Fletcher, D., Qu, Y., Vieno, M., Zandersen, M., 2022b. A typology for urban Green Infrastructure to guide multifunctional planning of nature-based solutions. Nat.-Based Solut. 2, 100041. https://doi.org/10.1016/j.nbsj.2022.100041.

Kjeldsen, T.R., Jones, D.A., Bayliss, A.C., 2008. Improving the FEH statistical procedures for flood frequency estimation. Environ. Agency, Bristol. In: 〈https://assets.publishing.service.gov.uk/media/602e5c0f8fa8f54331b080e6/Improving_the_FEH_Statistical_Procedures_for_Flood_Frequency_Estimation_Technical_Report.pdf〉.

Kjeldsen, T.R., Miller, J.D., Packman, J.C., 2013. Modelling design flood hydrographs in catchments with mixed urban and rural land cover. Hydrol. Res. 44 (6), 1040–1057. https://doi.org/10.2166/nh.2013.158.

Knopp, J., 2022. High resolution land cover 2016 Velika Gorica (Version v1) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.7107513.

Knopp, J.M., Levin, G., Banzhaf, E., 2023. Aerial data analysis for integration into a green cadastre – an example from Aarhus, Denmark. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 16, 6545–6555. https://doi.org/10.1109/JSTARS.2023.3289218.

Koeser, A., Hauer, R., Andreu, M., Northrop, R., Clarke, M., Diaz, J., Hilbert, D., Konijnendijk, C., Landry, S., Thompson, G., Zarger, R., 2023. Using 3-30-300 Rule Assess. Urban For. Access Prefer. Fla. https://doi.org/10.20944/preprints202305.1760.v1. *Preprints* 2023051760.

Konijnendijk, C.C., 2021. Promoting health and wellbeing through urban forests – Introducing the 3-30-300 rule. IUCN, Gland.

Konijnendijk, C.C., 2023. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3-30-300 rule. J. For. Res. 34, 821–830. https://doi.org/10.1007/s11676-022-01523-z.

Li, Y., Ren, C., Ho, J.Y.-e, Shi, Y., 2023. Landscape metrics in assessing how the configuration of urban green spaces affects their cooling effect: a systematic review of empirical studies. Landsc. Urban Plan. 239, 104842. https://doi.org/10.1016/j.landurbplan.2023.104842.

Ling, K. (2021). A look at access to green space in Toronto using the 3-30-300 rule for greener cities (Master's thesis). John H. Daniels Faculty of Architecture, Landscape and Design, University of Toronto, Toronto. https://hdl.handle.net/1807/109858.

Linsley, R.K., Franzini, J.B., Freyburg, D.L., Tchobanoglous, G., 1992. Water Resources Engineering (4th Edition). Irwin McGraw-Hill, New York.

L'institut Paris Region (2017). The MOS, in a few words. L'institut Paris Region, Paris. https://en.institutparisregion.fr/paris-region/portraying-paris-region/land-use-map/land-use-mode/the-mos-in-a-few-words/.

Manyahuillca, C.A., Manta, M.I., Negrin Marques, T.H., 2024. 3-30-300 rule: adaptation to a Peruvian coastal desert city. e-88993 Rev. Floresta 54. https://doi.org/10.5380/rf.v54.88993.

Miller, J.D., Vesuviano, G., Wallbank, J.R., Fletcher, D.H., Jones, L., 2023. Hydrological assessment of urban nature-based solutions for urban planning using ecosystem service toolkit applications. Landsc. Urban Plan. 234, 104737. https://doi.org/10.1016/j.landurbplan.2023.104737.

Nature Canada (2022). Canada's Urban Forests: Bringing the Canopy to All. Nature Canada, Ottawa. https://naturecanada.ca/wp-content/uploads/2022/09/Nature-Canada-Report-Tree-Equity.pdf.

Nieuwenhuijsen, M.J., Dadvand, P., Márquez, S., Bartoll, X., Barboza, E.P., Cirach, M., Borrell, C., Zijlema, W.L., 2022. The evaluation of the 3-30-300 green space rule and mental health. Environ. Res. 215, 114387. https://doi.org/10.1016/j.envres.2022.114387.

Nordic Council of Ministers (2022). Nordic Cities: Green, Resilient, Healthy. Nordic Council of Ministers, Copenhagen. https://pub.norden.org/nord2022-018/#.

Nordic Council of Ministers (2024). Yggdrasil – The Living Nordic City. Nordic Council of Ministers, Copenhagen. https://www.norden.org/en/funding-opportunities/yggdrasil-living-nordic-city.

O'Brien, L.E., Urbanek, R.E., Gregory, J.D., 2022. Ecological functions and human benefits of urban forests. Urban For. Urban Green. 75, 127707. https://doi.org/10.1016/j.ufug.2022.127707.

Owen, D., Fitch, A., Fletcher, D., Knopp, J., Levin, G., Farley, K., Banzhaf, E., Zandersen, M., Grandin, G., Jones, L., 2024a. Opportunities and constraints of implementing the 3-30-300 rule for urban greening. Urban For. Urban Green. Press. https://doi.org/10.1016/j.ufug.2024.128393.

Owen, D., Fitch, A., Fletcher, D., Knopp, J., Banzhaf, E., Wu, W., Jones, L., 2024b. 5m land cover for baseline and 3-30-300 scenarios in Paris, Aarhus, and Velika Gorica (Version v1) [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.11067492.

Pedersen, E., Weisner, S.E.B., Johansson, M., 2019. Wetland areas' direct contributions to residents' well-being entitle them to high cultural ecosystem values. Sci. Total Environ. 646, 1315–1326. https://doi.org/10.1016/j.scitotenv.2018.07.236.

Pereira Barboza, E., Cirach, M., Khomenko, S., Iungman, T., Mueller, N., Barrera-Gómez, J., Rojas-Rueda, D., Kondo, M., Nieuwenhuijsen, M., 2021. Green space and mortality in European cities: a health impact assessment study. Lancet Planet. Health 5 (10), e718–e730. https://doi.org/10.1016/S2542-5196(21)00229-1.

Pérez-del-Pulgar, C., Anguelovski, I., Cole, H.V.S., de Bont, J., Connolly, J., Baró, F., Díaz, Y., Fontán-Vela, M., Duarte-Salles, T., Triguero-Mas, M., 2021. The relationship between residential proximity to outdoor play spaces and children's mental and behavioral health: the importance of neighborhood socio-economic characteristics. Environ. Res. 200, 111326. https://doi.org/10.1016/j.envres.2021.111326.

Pilgrim, D.H., 1987. Australian Rainfall and Runoff - A Guide to Flood Estimation. Engineers Australia, Barton, ACT.

R Core Team (2023). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.r-project.org/.

Rahman, M.A., Pawijit, Y., Xu, C., Moser-Reischl, A., Pretzsch, H., Rötzer, T., Pauleit, S., 2023. A comparative analysis of urban forests for storm-water management. Sci. Rep. 13, 1451. https://doi.org/10.1038/s41598-023-28629-6.

Riondato, E., Pilla, F., Sarkar Basu, A., Basu, B., 2020. Investigating the effect of trees on urban quality in Dublin by combining air monitoring with i-Tree Eco model. Sustain. Cities Soc. 61, 102356. https://doi.org/10.1016/j.scs.2020.102356.

Ryan, S.C., Sugg, M.M., Runkle, J.D., 2023. Association between urban greenspace, tree canopy cover and intentional deaths: an exploratory geospatial analysis. Urban For. Urban Green. 86, 128015. https://doi.org/10.1016/j.ufug.2023.128015.

Shafique, M., Kim, R., Rafiq, M., 2018. Green roof benefits, opportunities and challenges – a review. Renew. Sustain. Energy Rev. 90, 757–773. https://doi.org/10.1016/j.rser.2018.04.006.

Statistics Denmark (2024a). ARE207: Area 1. January by region. Statistics Denmark, Copenhagen. https://www.statbank.dk/ARE207.

Statistics Denmark (2024b). BY1: Population 1. January by urban, rural areas, age and sex. Statistics Denmark, Copenhagen. https://www.statbank.dk/BY1.

Suppakittpaisarn, P., Jiang, X., Sullivan, W.C., 2017. Green infrastructure, green stormwater infrastructure and human health: a review. Curr. Landsc. Ecol. Rep. 2, 96–110. https://doi.org/10.1007/s40823-017-0028-y.

Tate, C., Wang, R., Akaraci, S., Burns, C., Garcia, L., Clarke, M., Hunter, R., 2024. The contribution of urban green and blue spaces to the United Nation's sustainable development goals: an evidence gap map. Cities 145, 104706. https://doi.org/10.1016/j.cities.2023.104706.

Thomas, A., Masante, D., Jackson, B., Cosby, B., Emmett, B., Jones, L., 2020. Fragmentation and thresholds in hydrological flow-based ecosystem services. Ecol. Appl. 30 (2), e02046. https://doi.org/10.1002/eap.2046.

Ulmer, J.M., Wolf, K.L., Backman, D.R., Tretheway, R.L., Blain, C.J.A., O'Neil-Dunne, J.P.M., Frank, L.D., 2016. Multiple health benefits of urban tree canopy: the mounting evidence for a green prescription. Health Place 42, 54–62. https://doi.org/10.1016/j.healthplace.2016.08.011.

UNECE (2021). Sustainable Urban and Peri-urban Forestry. An Integrative and Inclusive Nature-Based Solution for Green Recovery and Sustainable, Healthy and Resilient Cities. United Nations Economic Commission for Europe, Geneva. https://unece.org/sites/default/files/2023-03/Urban%20forest%20policy%20brief_final_0.pdf.

United Nations, 2023. The Sustainable Development Goals Report 2023: Special Edition. United Nations Statistics Division, New York. 〈https://unstats.un.org/sdgs/report/2023/〉.

Wallingford HydroSolutions, 2019. ReFH Technical Guide. Wallingford HydroSolutions, Wallingford. 〈https://refhdocs.hydrosolutions.co.uk/The-ReFH2-Model/Introduction/〉.

Wallingford HydroSolutions, 2021. WINFAP Technical Guide. Wallingford HydroSolutions, Wallingford. 〈https://winfapdocs.hydrosolutions.co.uk/Introduction/〉.

Wang, J., Banzhaf, E., 2018. Towards a better understanding of green infrastructure: a critical review. Ecol. Indic. 85, 758–772. https://doi.org/10.1016/j.ecolind.2017.09.018.

Wolf, K.L., Lam, S.T., McKeen, J.K., Richardson, G.R.A., van den Bosch, M., Bardekjian, A.C., 2020. Urban trees and human health: a scoping review. Int. J. Environ. Res. Public Health 17 (12), 4371. https://doi.org/10.3390/ijerph17124371.

Yang, B., Lee, D., 2021. Urban green space arrangement for an optimal landscape planning strategy for runoff reduction. Land 10 (9), 897. https://doi.org/10.3390/land10090897.

Yio, M.H.N., Stovin, V.R., Werdin, J., Vesuviano, G., 2013. Experimental analysis of green roof detention characteristics. Water Sci. Technol. 68 (7), 1477–1486. https://doi.org/10.2166/wst.2013.381.