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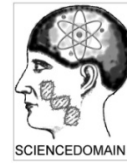
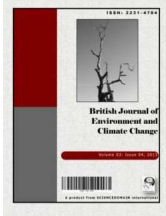
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How Does Your Garden Flow? The Impact of Domestic Front Gardens on Urban Flooding

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: To quantify rainwater runoff from domestic front gardens as a consequence of increased impervious surface area and climate change impacts, thus allowing the runoff contribution from both newly and previously covered front gardens to be assessed in terms of the overall urban flood burden.

Study Design: Numerical simulation of the runoff from a typical front garden in response to simulated rainfall events for four UK cities (Edinburgh, Manchester, London, and Exeter).

Methodology: A typical front garden was simulated with varying areas of impermeable surface area (0%, 10%, 25%, 50%, 75%, and 100%) to represent observed trends in garden paving. Storm events representing current design and projected future rainfall intensities were applied to each of the four cities. The resultant runoff volumes were then quantified.

Results: Runoff is shown to be directly proportional to both the impermeable surface area and the rainfall intensity. Areas of impermeable paving can generate substantial volumes of runoff during a storm event which can contribute to localized flooding or add to the urban flood burden. Increased rainfall intensities and frequencies due to climate change are likely to increase runoff further.

Conclusion: Domestic front gardens play a vital role in managing surface water runoff in towns and cities. Growing trends of paving over front gardens put this role in jeopardy, while increasing rainfall intensities due to climate change make this role increasingly important. The quantification of domestic front garden runoff provides a mechanism for facilitating the protection, and enhancement, of this important asset in terms of water and urban flood management.

Keywords: Climate change; urbanisation; domestic gardens; impermeable surface; flooding.

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1. INTRODUCTION

Domestic gardens make up a significant proportion of our towns and cities. Recent studies in the UK have shown that they can contribute between 22%-36% of the total urban area [1,2] and up to 63% of urban green space [3]. Like all urban green space, domestic gardens provide a valuable asset in terms of ecosystem services and help define the urban environment [4,5]. While there remains a lack of information on the specific contributions of domestic gardens, urban green space more generally is known to contribute, for example, towards biodiversity [6]; air quality [7]; energy conservation [8]; the urban microclimate [9]; health and wellbeing [10], and flood prevention [11,12]. The extents of these benefits rely, not only on the expanse of the urban green space, but also on the type and form of vegetation it contains [13].

However, the traditional front garden, characterized by flowerbeds and lawn, is being lost to the growing trend of replacing them with hard paving to provide off-street parking or low-maintenance gardens [14], see Fig. 1.



Fig. 1. Several front gardens completely covered with impermeable surfacing to provide off-street parking in a street in London (Street View ©2015 Google)

Whilst this may seem insignificant in terms of the size and scale of a single front garden, collectively this can represent large areas of towns and cities being covered with impermeable surfaces. A study of the London borough of Ealing found that two-thirds of front gardens are at least 50% covered with impermeable surfacing and 25% are completely covered [15]. Across the whole of London, it is estimated that the total area of impermeable surfacing in front gardens totals an area of 32 km² [16]. A study of residential areas of Edinburgh found that 56% of front gardens had been completely covered with impermeable surfacing [17]. At the regional level,

a study by the Royal Horticultural Society [18] showed that a significant proportion of front gardens are at least three-quarters covered with impermeable surfacing: North East England (47%), Scotland (31%), and South-West England (30%), Eastern England (30%), East Midlands (25%), North-West England (25%), Yorkshire/Hull (24%), South East England (23%), West Midlands (21%), Wales (19%), and London (14%).

Paving over front gardens with impervious surfacing not only adds to the problem of urban densification, it also increases the risk of surface water flooding by increasing rainwater runoff potential from properties during storm events. Whilst traditional vegetated gardens would help to control surface water flows through evapotranspiration, interception, and infiltration, paved gardens increase flood vulnerability by increasing runoff volumes, reducing runoff times, increasing pollutant loading, and increasing peak flows being directed to an already struggling urban drainage system.

Recognizing the implications of this incremental land change on urban flood risk, planning regulations covering garden paving have changed recently in the UK. In England and Wales, planning permission is now required for the installation of paving of more than 5m² unless permeable paving is used or the runoff is directed to a permeable area [19,20], while in Scotland, planning permission is required for the installation of any area of impermeable paving [21]. Whilst these changes aim to reduce further loss of front gardens to impermeable cover, they do not address those that have already been lost. Furthermore, given that domestic front gardens constitute such a significant component of the urban environment, and that so many of them have already been covered over, understanding the role of these spaces on the overall urban flood risk is becoming increasingly important, particularly given that rainfall intensities are likely to increase in the future due to the impacts of climate change.

While a growing number of studies have begun to assess flood risk at the urban scale, none have attempted to quantify the runoff from the individual front garden and its contribution to the collective urban drainage burden. It is at this level that information is needed in order to better inform homeowners, developers, policy makers, and legislators about the contribution of these spaces to urban flood risk and to enhance

resistance and resilience to future floods. This research aims to investigate the potential impact of paved front gardens on flood risk under both current and future rainfall scenarios. A surface drainage model is used to assess runoff sensitivity to impermeable cover for a typical front garden located in four study cities in the UK (Edinburgh, Manchester, London and Exeter). The impact of climate change is assessed by applying projected change factors derived from future climate scenarios to current design rainfall intensities for each location.

2. METHODOLOGY

2.1 Study Cities

Four cities were selected for the study: Edinburgh, Manchester, London, and Exeter as they are distributed widely across the UK and vary in size, location, and climate, see Table 1. Design rainfall intensities were selected from the relevant British Standard [22] to represent current rainfall conditions for each city based on recommended return periods of 1 in 5 and 1 in 50 year events with a duration of 5 min.

To represent future climate change scenarios, the design rainfall intensities were multiplied by change factors derived by the UK Climate

Projections 2009 (UKCP09) which provide estimates of future climate change for the UK across three greenhouse gas emission scenarios (Low, Medium, High) for different decadal time periods [27]. UKCP09 takes account of climate projection uncertainties by presenting the data as probabilistic estimates of future climate based on the strength of current evidence. A *10% probability* indicates a change which is *very likely to be exceeded*, a *50% probability* (known as the central estimate) indicates a change which is *just as likely to be exceeded as not*, and a *90% probability* indicates a change which is *very unlikely to be exceeded*. For this study, the 50% probability was selected for the Low and High emissions scenarios to give a central estimate of change over the range of emissions scenarios. The 90% probability was also used, but for the High emissions scenario only, to represent the upper level of future rainfall change. Analysis was carried out for the 2050s and 2080s to give mid- to long-term comparisons with current conditions. Table 2 shows the rainfall change factors for each of the four cities for the selected climate change scenarios. The projected changes in rainfall, based on that of mean winter precipitation, can be seen to increase from north to south with Edinburgh having the smallest, yet still considerable, changes and Exeter having the largest.

Table 1. Characteristics of the four study cities

City	Area (km ²) ¹	Domestic garden area (%) ²	Domestic garden area (km ²)	Front garden area (km ²)	Annual rainfall (mm) ³	Design rainfall intensity (mm/h) ⁴	
						1 in 5 year	1 in 50 year
Edinburgh	264	11	29	10	670	58	86
Manchester	116	18	21	7	810	72	130
Greater London	1571	20	314	105	610	86	144
Exeter	48	16	8	3	760	72	130

¹Administrative boundary of each city [23]; ²Ratio of domestic gardens to urban area: Edinburgh [24], Manchester [25], London [16]. No data of garden area was available for Exeter, so an average of the other cities was taken.

³Annual rainfall statistics for each city [26]; ⁴Design rainfall intensities for the 1 in 5 year and 1 in 50 year event [22]

Table 2. Change in mean winter precipitation for selected time periods, emissions scenarios, and probability levels (adapted from UKCP09)

Time period	Scenario		Change in mean winter precipitation (%)			
	Emission scenario	Probability level	Edinburgh	Manchester	London	Exeter
2050	Low	50%	+6	+8	+12	+12
	High	50%	+10	+13	+16	+18
	High	90%	+20	+27	+35	+41
2080	Low	50%	+11	+15	+16	+19
	High	50%	+19	+26	+26	+31
	High	90%	+36	+50	+58	+73

2.2 Typical Front Garden

Studies of gardens in UK cities have found the average garden size to be between 151-155 m², and that front gardens are, generally, half the size of rear gardens [28,29]. In this study, a garden size of 150 m² is assumed, giving a typical front garden size of 50 m². Different areas of impermeable surfacing were applied to the typical front garden based on the extent of garden paving already observed to have occurred in the UK, as discussed in Section 1. The impermeable areas studied were: 0%, 10%, 25%, 50%, 75%, and 100%.

2.3 Garden Runoff Model

The runoff generated from the typical front garden was simulated using a previously developed property-level drainage model [30]. The model is capable of simulating the flow conditions of the entire property drainage system (including roof, surface, and local drainage) however, only the surface drainage module was used in this study to calculate the runoff of rainwater from front gardens. The surface drainage module assesses rainwater runoff by using a simple volumetric approach based on the area drained, surface type (permeable/impermeable), and rainfall intensity. The basic effect of permeable surfaces is calculated using the Horton infiltration approach [31], which calculates the quantity of rainwater at each time step that infiltrates into the soil rather than running off onto the street:

$$f_t = f_c + (f_o - f_c)e^{-kt} \quad (1)$$

where f_t is the infiltration rate at time t , f_o is the initial (maximum) infiltration rate; f_c is the final infiltration rate; and k is a constant based on soil type. Runoff volume from impermeable surfaces, R_i , is calculated from the effective impermeable area, A_i , and the rainfall intensity, i :

$$R_i = A_i \times i \quad (2)$$

The runoff volume from permeable surfaces, R_p , is calculated as the resultant rainfall volume that exceeds the infiltration rate of the permeable surface at each time step, such that:

$$R_p = (A_p \times i) - f_t \quad (3)$$

where A_p is the effective permeable area. Total runoff, R_T , from the front garden is the sum of the

resultant runoff from both the impermeable and permeable surfaces:

$$R_T = R_i + R_p \quad (4)$$

The model was used to simulate the runoff from the typical front garden in each of the four study cities, under current and future rainfall intensities, and for each of the areas of impermeable cover.

2.4 Assumptions and Limitations

The influence of vegetation on the interception and storage of rainwater were out with the limits of this study, which instead focuses on the infiltration characteristics of the soil. A coarse, well-drained soil with a high infiltration rate was assumed for all permeable surfaces; areas with finer soils, such as clay, could experience higher runoff rates due their significantly lower infiltration rates. Antecedent moisture conditions of the soil were not considered; saturated soils would produce higher runoff rates, as would compacted soils. Evapotranspiration or soil moisture variations across the surface were not taken into account, however, neither of these factors are particularly significant during critical urban rainfall events, which typically last minutes rather than hours. Finally, all runoff was assumed to flow away from the garden and not to any adjacent permeable surface, therefore, assuming maximum runoff conditions.

3. RESULTS AND DISCUSSION

3.1 Current Runoff

In each of the four study cities, the typical front garden with no impermeable paving was found to produce no runoff in response to both the 1 in 5 year and 1 in 50 year events. The addition of even small areas of impermeable paving was found to generate rainfall runoff, see Fig. 2. The typical front garden in London generated higher runoff volumes than those in the other three cities due to the higher design rainfall intensities applicable to the south-east (see Table 1). Manchester and Exeter (both located in the west) have the same design rainfall intensities and so typical front gardens in those two cities produce runoff volumes of the same amount. Interestingly, the current 1 in 5 year event in London is equivalent to the 1 in 50 year event in Edinburgh.

As would be expected, the runoff volume is directly proportional to the area of impermeable

cover and rainfall intensity. Taking London as an example, a typical front garden which has 50% impermeable cover generates a runoff volume of 0.297 m³ (49.5% runoff) during a 1 in 50 year event, while this increases to 0.595 m³ (99.2% runoff) for a garden with 100% impermeable cover. Across each city, the collective runoff from front gardens can be estimated by extrapolating the runoff volumes in Fig. 2 with the cumulative area of front gardens in each city. Accounting for the front gardens with at least

three-quarters impermeable cover only [18] (between 75%-100% covered), the total runoff from these gardens is estimated at between: 16-22,000 m³ in Edinburgh; 14-19,000 m³ in Manchester; 132-176,000 m³ in London; and 6-9,000 m³ in Exeter during the 1 in 50 year design event. While the runoff volume for London is very large due to the size and scale of the city, the contribution to surface runoff from front gardens in each city is substantial.

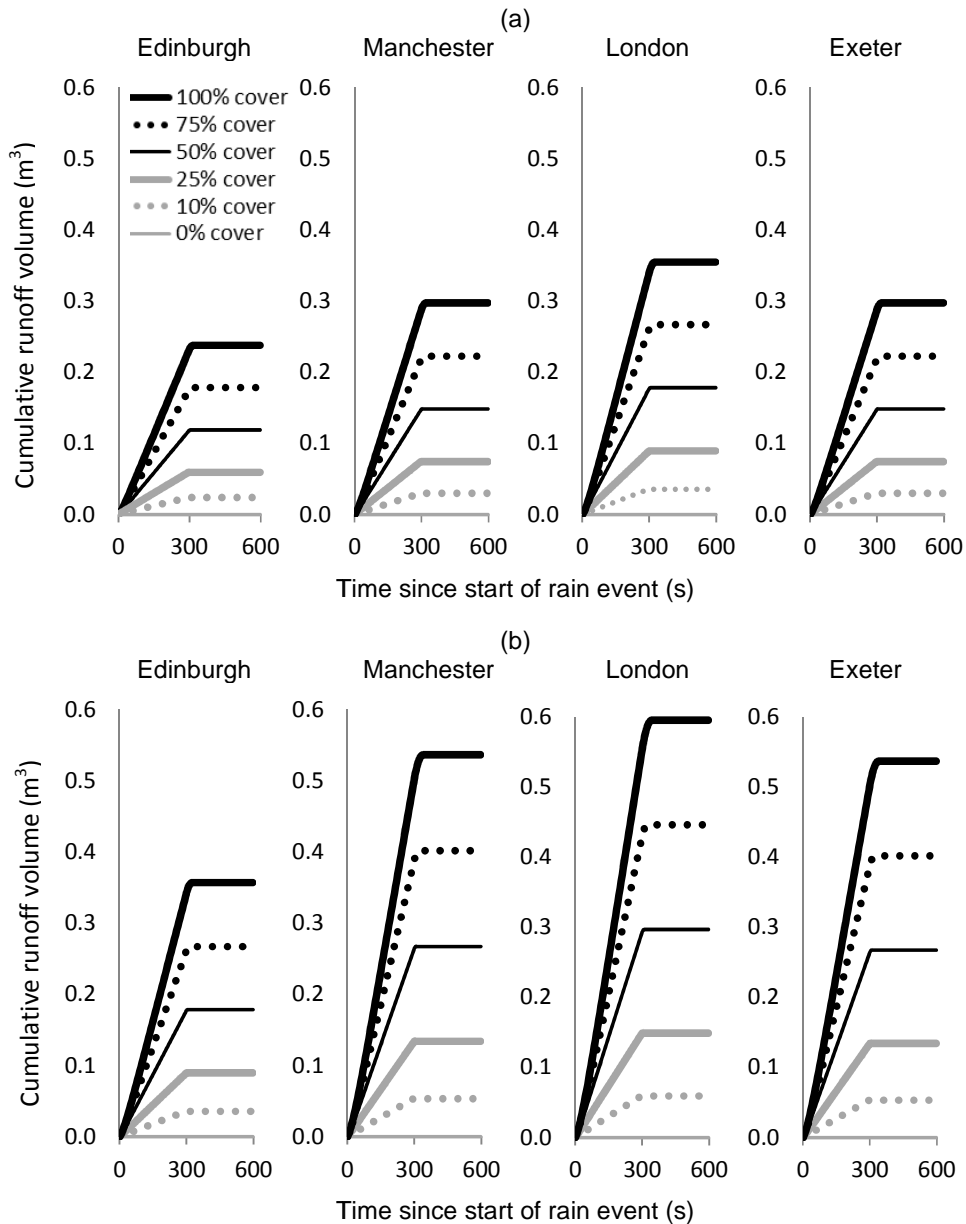


Fig. 2. Variation in cumulative runoff volume with impermeable coverage for rainfall return periods of: (a) 1 in 5 years, and (b) 1 in 50 years

3.2 Future Runoff

Figs. 3 and 4 show the total runoff modelled for each impermeable garden area for the 2050s and 2080s, respectively, based on the projected

rainfall change factors in Table 2. As would be expected, the increased rainfall intensities projected to occur due to climate change have the effect of increasing runoff from the typical front garden in each city.

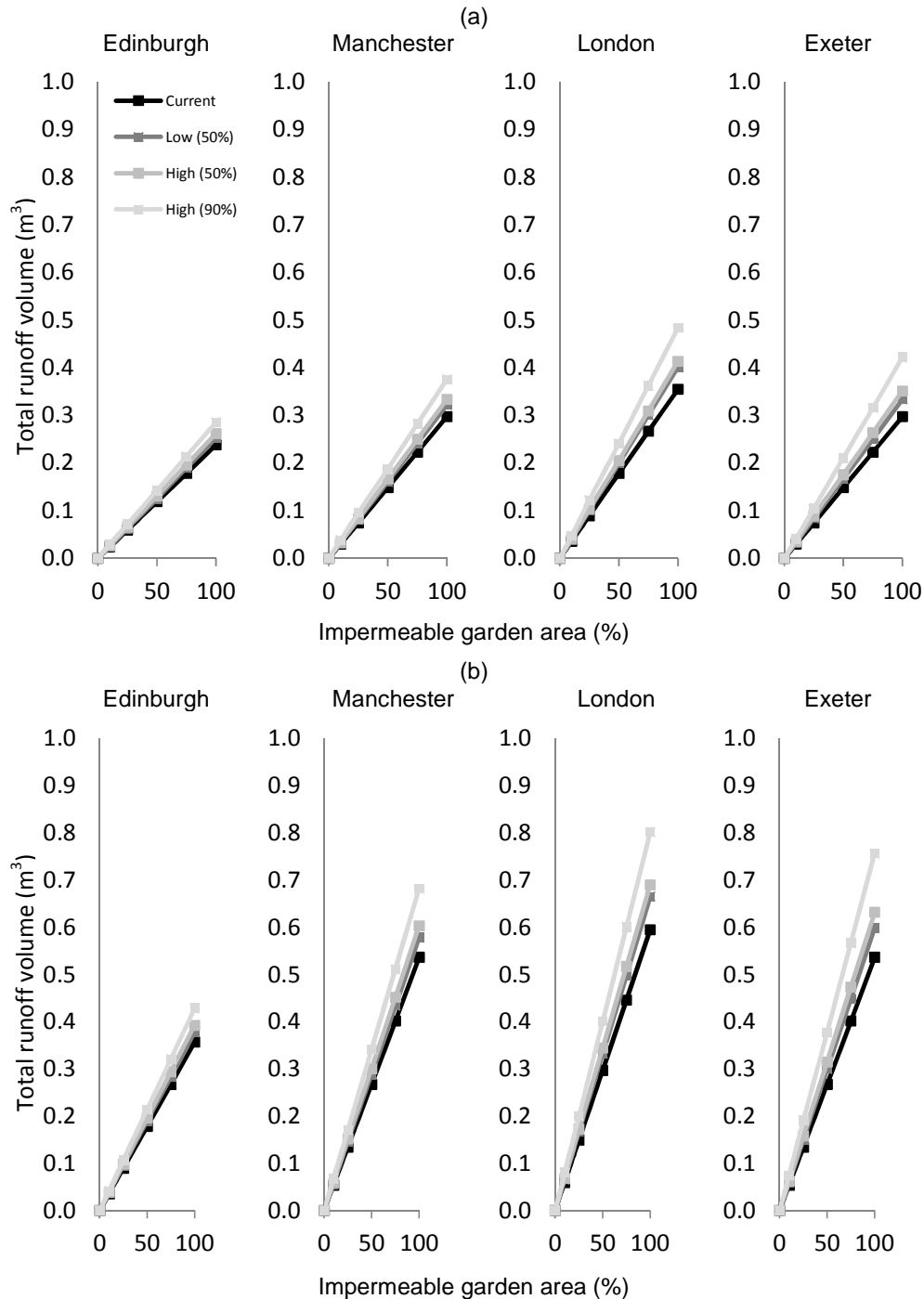


Fig. 3. Variations in total runoff volume with impermeable garden area and future climate scenario for the 2050s, based on (a) 1 in 5 year return period, and (b) 1 in 50 year return period

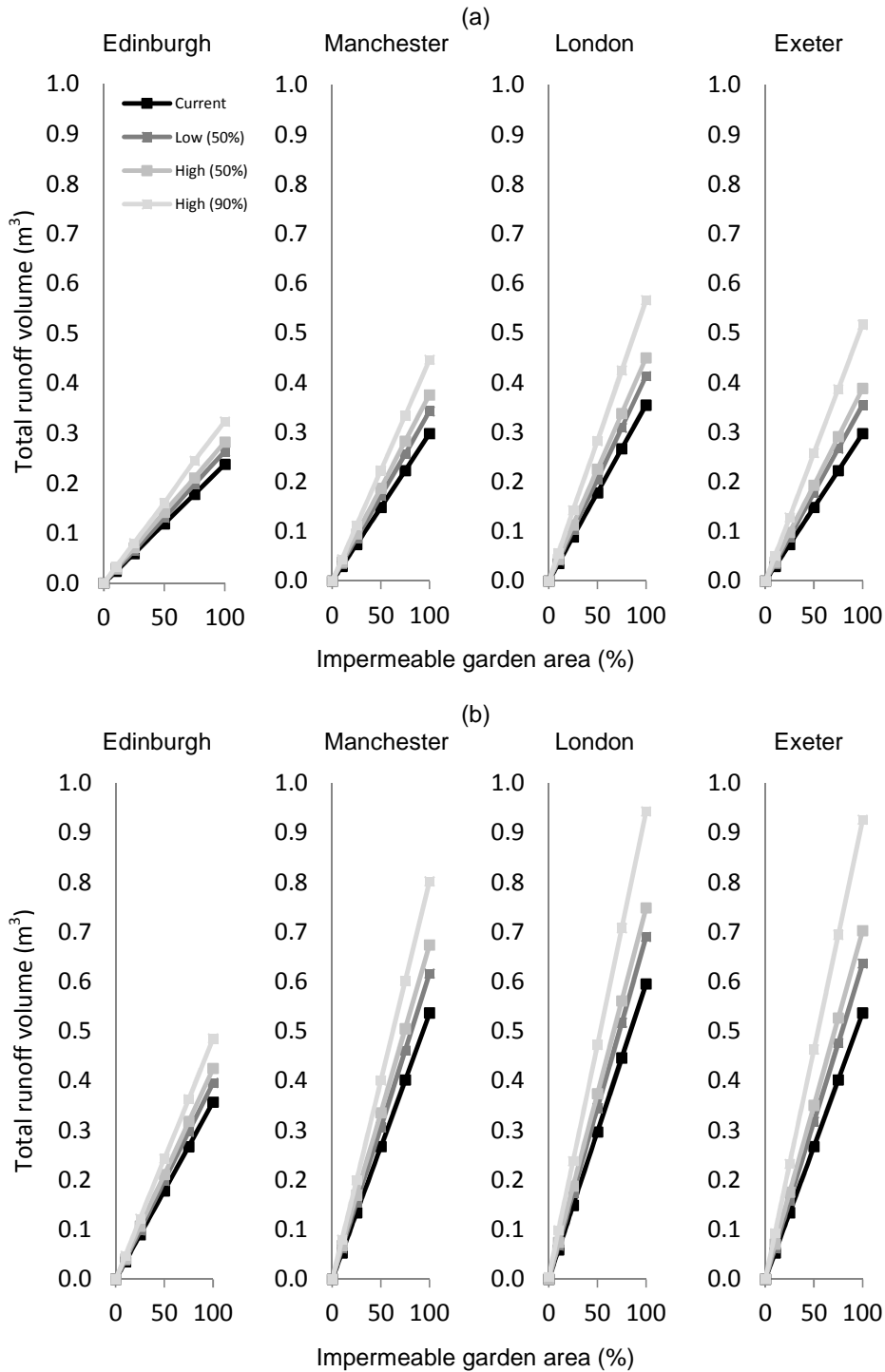


Fig. 4. Variations in total runoff volume with impermeable garden area and future climate scenario for the 2080s, based on (a) 1 in 5 year return period, and (b) 1 in 50 year return period

Edinburgh is expected to see increased rainfall of up to +20% by the 2050s and +36% by the 2080s. Whilst these are the smallest changes for

any of the study cities, they are still significant and could cause the runoff from a typical front garden with 100% impermeable cover to

increase from 0.357 m³ to 0.485 m³ by the 2080s based on the current 1 in 50 year event. Exeter is projected to experience the largest increase in future rainfall; increasing up to +36% by the 2050s and up to +73% by the 2080s. The modelled runoff from paved front gardens in Exeter, therefore, saw the greatest increase of any of the four study cities: for the 100% impermeable front garden, runoff increased from a current 0.537 m³ to 0.756 m³ by the 2050s and further to 0.926 m³ by the 2080s based on the current 1 in 50 year event. Runoff from the same front garden in London would only be slightly higher at 0.943 m³ by the 2080s.

Increased future rainfall intensities will see a dramatic increase in the collective contribution of paved front gardens to the overall surface runoff volume across each of the four study cities. Again, considering only those front gardens which are at least three-quarters paved, the collective runoff by the 2080s is estimated to increase by 6-7,000 m³ in Edinburgh to between 22-29,000 m³, by 7-9,000 m³ in Manchester to 21-28,000 m³, by 77-102,000 m³ in London to 209-278,000 m³, and by 5-6,000 m³ in Exeter to 11-15,000 m³ based on the 1 in 50 year event. It is highly likely that existing urban drainage systems will be inadequate to cope with this level of increased runoff from paved front gardens. With runoff from all impermeable surfaces, including paved front gardens, likely to increase in future, the risk of urban flooding is bound to increase also unless substantial efforts are made to minimize runoff.

With this in mind, it can be seen from Figs. 3 and 4, that each simulated future rainfall event was completely infiltrated by the typical front garden which had no impermeable paving. While this result is based on the garden having coarse and well-drained soil and does not account for antecedent moisture conditions or the effects of garden vegetation on rainfall interception, it clearly emphasizes the role of the domestic garden in helping to control surface water flows in urban areas, which will become increasingly important in the future. In light of this, there is a clear argument for encouraging homeowners to “de-pave” front gardens which are already paved over in order to enhance the overall community resilience to both current and future urban flood risk. However, a recent study of properties in Edinburgh found that just 2% of homeowners were considering removing their impermeable driveway and reinstating a garden [17]. The same study suggests that legislation, education,

and incentivisation schemes are needed to reclaim the front garden.

While planning regulations have recently changed to minimize further loss of front gardens to impermeable cover, these regulations need to be enforced effectively so that impermeable paving of front gardens is stopped. Furthermore, the regulations in England in Wales should be brought in line with those in Scotland which require planning permission for any area of impermeable paving, rather than for areas over 5 m² only. However, no legislation currently exists to target the many gardens across the country that are already covered over.

Educating homeowners about the valuable role that front gardens play in the urban landscape, in terms of biodiversity and environmental enhancement, and providing them with practical advice and guidance on the design and installation of permeable alternatives would help to raise awareness. Some initiatives, such as the Royal Horticultural Society's *Gardens Matter* series [18] and the London Wildlife Trusts' *Living with Rainwater* [32], are already attempting to address this, however, more work is needed. Making homeowners aware of the financial implications of paved gardens could also act as a strong driver for change. There is already evidence that house prices could reduce once the majority of front gardens on a street have been paved over as the streetscape becomes less attractive to prospective buyers [16]. In addition, the increased risk of urban flooding due to additional runoff from paved front gardens, particularly in light of future climate change impacts, could affect household water and sewerage bills.

Incentives for homeowners, such as grants or providing access to free help and advice, could also be used to encourage homeowners to de-pave. Lambeth Council in London provides help in planning de-paving projects as well as tools and compost to carry out the work, however, schemes like this are rare [33]. Financial penalties for paved front gardens, such as increased council tax bills, could also be used as an incentive to de-pave.

4. CONCLUSION

Domestic front gardens make up a significant proportion of the urban environment and as such they play a vital role in the control of surface water by intercepting and infiltrating rainfall.

While the importance of domestic front gardens on flood alleviation is already recognized, until now there has been no measure of the contribution of individual front gardens to both the localized and overall urban flood burden. The aim of this research was to provide quantifiable data of front garden runoff volumes so that homeowners, developers, policy makers, and legislators could be better informed about the contribution of these spaces to urban flood risk.

The quantification of runoff from paved front gardens emphasizes the need for them to be considered as a key component in the overall urban water and flood management strategy. This study has shown that while paved gardens pose a significant risk to urban flooding, those that retain the permeable qualities of the traditional garden could provide a positive asset for surface water management, particularly in light of the challenges posed by climate change, by helping to attenuate and manage surface water runoff in urban environments.

Importantly, this study has demonstrated that runoff from front gardens varies greatly with respect to geographical location (due to differences in localised rainfall intensities and projected climate change impacts) and as such, can help to identify areas most at risk both currently and under future climate scenarios. Since future rainfall is projected to increase across the UK, it will be necessary to reduce runoff from every building, new or existing. Homeowners need to be provided with the relevant information and incentives for retaining or reinstating their front garden for the overall societal benefits that this would achieve in terms of flood resistance and resilience.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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