# The sustainable management of surface water at the building scale: preliminary results of case studies in the UK and Spain

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## ABSTRACT

This paper reviews the devices suitable for building scale application and then outlines three case studies, two from Coventry, UK and one from Valencia, Spain. The first assesses the potential to retrofit an extensive green roof to the Frederick Lanchester Library, Coventry University. Costings are given, the structural strength of the building is investigated and various benefits of its installation, including potential to sequester and store carbon, are assessed. The second reports part of the AQUAVAL Project, Spain, whereby an extensive green roof was retrofitted to half of a school roof and porous concrete retrofitted to a pavement. Preliminary monitoring results show expected benefits, including attenuation of the storm peak and increased time to peak. The third case study using WinDes® software compared a conventionally drained new-build housing estate with a Sustainable Drainage Systems train of porous paving, bioretention and swales. Stormwater volume was reduced by ~20% and peak flow by >250 L $s^{-1}$. Addition of extensive green roofs to all buildings increased these differences and delayed return to baseflow conditions reflecting water stored in the management train components.


**Key words** | attenuation of the storm peak, carbon sequestration and storage, green roof, management train, SUDS

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## INTRODUCTION

### Legislation in Spain, and England and Wales

Various European-wide Directives including the Water Framework Directive (EU Directive 2000/60/EC) have had wide-ranging impacts on water resource and flood management strategies which are beyond the remit of this paper (*cf.* Castro-Fresno *et al.* 2013). However, policies specific to Spain as well as England and Wales have recently influenced surface water management strategies in those countries, emphasising the need for a more sustainable approach. In England and Wales, schedule 3 of the Flood and Water Management Act (FWMA), 2010, (www.legislation.gov.uk/ukpga/2010/29/schedule/3) encourages the use of Sustainable Drainage Systems (SUDS) to manage surface water in new build and redevelopments. These drainage systems have to be approved against a set of National Standards by a SUDS Approving Body (SAB) before construction is allowed to begin. Connection to the foul sewer is unchanged, but the automatic right of connection to a storm sewer will cease. Through the SABs, Local Authorities will have the responsibility of adoption and maintenance (Defra 2010). The recommended drainage hierarchy is as follows:

1. Excess water should be discharged into the ground.
2. Or it can be discharged to a surface water body.
3. If neither of 1 or 2 above are suitable, then SAB approval will have to be sought for discharge to a surface water sewer.
4. In the event that scenarios 1–3 are not possible, then discharge to a combined sewer will have to be considered (Defra 2011).

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In the case of Spain, due to a relative lack of specific legislation to control Combined Sewer Overflows and limit resultant contamination, the Spanish Royal Decree 1290/2012 (www.boe.es/diario_boe/txt.php?id=BOE-A-2012-11779) was enacted encouraging the use of best practices and highlighting the importance of identifying landuse and land surface type in managing river basins effectively (Castro-Fresno *et al.* 2013). The Spanish Royal Decree 233/2013 (www.boe.es/diario_boe/txt.php?id=BOE-A-2013-3780) promotes reduction of drinking water use, the sustainable management of urban runoff and the use of green roofs. It does this by funding new build projects as well as urban regeneration and renewal; this plan is valid for 4 years, followed by review of progress.

### Sustainable drainage in context

The SUDS approach encourages infiltration into the ground, storage of water and conveyance of stormwater through the catchment. The main function is to slow water down, thus attenuating the storm peak and reducing the incidences of flooding in areas prone to excess stormwater overflow (Charlesworth & Warwick 2012). At the same time as water is slowed, it is treated such that water quality is improved by the settling or trapping of polluted particulates, biodegradation of hydrocarbons and the systemic uptake of soluble contaminants where vegetated devices are utilized (Charlesworth *et al.* 2003).

There are many studies of the reasons for flooding in urban areas (e.g. Charlesworth & Warwick 2012) including sealing of urban surfaces, the Urban Heat Island Effect (UHIE) and the wider effects of global climate change, so these will not be discussed here. There are also reviews of SUDS devices, their flexibility and multiple benefits including positive impacts on perceptions of human health, reduction in energy use as well as mitigating and adapting to changes brought about by climate change (e.g. Fresno *et al.* 2005; Charlesworth 2010).

Since 80% of the buildings required in England and Wales by 2040 are already in existence (Charlesworth & Warwick 2012), the focus for flood resilience and mitigation needs to be on retrofitting these measures to buildings which are currently standing; however, retrofit is still perceived as being difficult and expensive. A UK Environment Agency (2007) report highlights Permeable Paving Systems (PPS) in particular as having both 'net financial benefits for property owners as well as overall net economic benefits', furthermore stating that PPS 'costs less on a lifecycle basis than traditional surfaces' and citing ease of replacing block pavers and monetary savings due to obviating the need to pay a water company to deal with surface water if it is disposed of onsite.

The following section reviews devices specifically suitable for utilisation at the building scale, considering the efficient use of surface water including secondary use and efficient surface water disposal, as well as their suitability for retrofit. Case studies are then given to address the following three aims:

1. To illustrate the efficacy of the SUDS approach at various scales, from a single building to a new housing estate.
2. To illustrate the various benefits of SUDS retrofit at the single building scale.
3. To show the utility of monitoring demonstration sites.

## SUSTAINABLE DRAINAGE AT THE BUILDING SCALE

Charlesworth & Warwick (2012) proposed the 'Bull's Eye' approach to designing SUDS for cities in which the urban centre included patches of suitable devices such as PPS, green walls and roofs, rain gardens, rainwater harvesting, pocket parks, road traffic islands and grass verges, most of which would be suitable for retrofitting, or new build, at the individual building scale. It is possible to use larger devices such as ponds and wetlands further out from the centre in the suburbs and then to design management trains around the urban periphery, none of which are suitable in an area of dense construction such as a city centre.

At the single building scale, however, it would be expected that rainwater would be disposed of onsite and that therefore the majority of management would be focused on source control such as green roofs, porous paving, rain gardens and rainwater harvesting. In the event that surface water runoff was to occur, swales could be utilised for conveyance, if appropriate for the site.

## EFFICIENCY OF SUDS DEVICES AT THE SMALL SCALE

SUDS has multiple benefits and is flexible, its efficiency can therefore be measured using several indicator roles. The main three are encapsulated in the 'SUDS triangle': water quantity reduction, water quality improvements and the provision of amenity and biodiversity benefits. There has been much research undertaken on the first two of these, and the benefits are clear (e.g. Blanc *et al*. 2012), however, whilst some research has been carried out on increased biodiversity (e.g. Brenneisen 2006) and also amenity provision (e.g. Apostolaki *et al*. 2006), difficulties quantifying the latter have led to this area being researched much less. Reflecting other areas in which SUDS provide benefits, the SUDS 'rocket' proposed by Charlesworth & Warwick (2012), includes human health benefits, energy use reductions, mitigation of the UHIE as well as Carbon Sequestration and Storage (CSS) capability. Table 1 shows the efficiency of a variety of SUDS devices which could be used at the small, individual building scale with respect to a variety of measures.

All three case studies make use of green roofs, which, in terms of rainwater quantity benefits, will both retain water and also evapotranspire it into the overlying atmosphere, attenuating the storm peak. The volume of water able to be stored is highly dependent on antecedent conditions, i.e. the amount of water already present which is itself dependent on the depth and type of growing medium, type of drainage layer, vegetation used and regional weather (Stovin *et al*. 2012). In fact, Stovin *et al*. (2012) state that 'inter-event processes are complex' although over 50% cumulative annual rainfall retention by an experimental green roof was achieved. In general, providing the rainfall event does not exceed 5 mm, green roofs can prevent runoff, and in summer, can potentially retain up to 80% of incident rainfall which falls to a maximum of 35% in winter due to lowered evapotranspiration activity of the plants in winter (see Stovin *et al*. (2007) and references therein). The following case studies begin with a theoretical consideration of the retrofit of a green roof to an existing building, sited on Coventry University campus, and its potential benefits taking account of both stormwater attenuation and CSS. The second case study illustrates the success of such a green roof retrofit as well as rainwater harvesting to a school in Spain, and the third case study models the storm attenuation benefits of a SUDS management train to a larger area of regeneration in Coventry.

### Case study 1: Coventry University Library

The Frederick Lanchester Library (for location see Figure 1), built in 2000, was designed for 1,200 students and staff and occupies approximately 10,000 $m^2$ (Noon 2008). It makes maximum use of natural light as well as innovative lighting technology and along with natural ventilation, energy consumption is significantly reduced compared to traditional air conditioned buildings (see Figure 2(a)).

However, it was planned, designed and built before the FWMA (2010) and thus does not include SUDS devices. The roof of the building offers opportunities to retrofit an extensive green roof. As Figure 2(b) shows, the roof is square in plan, 50 × 50 m, includes space for the light towers and has access pathways (not drawn for clarity) between which are stones to a depth of 7–8 cm (see Figures 3(a) and 3(b)). These stones are angular or rounded, and vary in weight from less than 7 g to over 130 g, an estimated load to the roof of around 123 kg $m^{-2}$.

The aim of this case study was to show the advantages of retrofitting an extensive sedum roof (with a pre-grown sedum blanket over an 8 cm thick layer of extensive soil substrate) onto the Frederick Lanchester Library, replacing the stones between the access pathways. Although further checks will have to be carried out at a later stage, it is envisaged that structural strength of the building is not a problem for the retrofitting, as the typical saturated weight of the proposed extensive substrate (96 kg $m^{-2}$) is lower than the one currently posed by the existing stone layer.

However, unless it can show advantages to the university, the cost would preclude its installation (estimations from the Bauder Group are of around £180 per $m^2$, i.e. £234,000 for the 1,300 $m^2$ proposed to be retrofitted). As set out above, energy usage for a building of its size is low, therefore the advantage of a green roof in reducing energy use is less relevant in this case. Since this is an extensive roof, there will not be access to it, therefore positive, direct

**Table 1** | Benefits of SUDS devices (from Dickie *et al*. (2010) and Woods-Ballard *et al*. (2007))

| | SUDS | What | Why | Where | Flood risk management benefits | Water quality management benefits | Amenity and biodiversity benefits | Climate change mitigation benefits | Landtake | Capital cost | Maintenance cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Green roofs |  | The partial or complete coverage of a roof with vegetation or another growing medium. | Controls runoff close to source, stores it and filters out pollutants. Can provide other benefits. | Private in curtilage (source control). | θ θ | θ θ | θ θ θ | θ θ θ | NONE | £ £ £ | £ £ |
| Water butts |  | Small, off-line storage devices designed to capture and store runoff for use in garden or other domestic. | Reduces potable water use. | Private in curtilage (source control). | θ θ θ | θ θ | θ | θ | £ | £ | £ |
| Rainwater harvesting |  | Water collection system from impermeable surfaces for non-potable water use. | Reduces potable water use. | Private in curtilage (source control). | θ θ θ | θ θ | θ | θ | £ | £ £ £ | £ £ |
| Permeable pavements |  | Porous surfaces to replaces traditional hard (impermeable) that allow water to infiltrate. | Water is stored and released gradually during which water quality is also improved. Can be used in permeable and impermeable ground conditions by incorporating some form of outflow and overflow component. | Private in curtilage (source control), car parks and some roads. | θ θ θ | θ θ θ | θ | θ | £ | £ £ | £ |

(*continued*)

**Table 1** | continued

| | SUDS | What | Why | Where | Flood risk management benefits | Water quality management benefits | Amenity and biodiversity benefits | Climate change mitigation benefits | Landtake | Capital cost | Maintenance cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bioretention |  | Depressions backfilled with a mixture of sand/soil, planted with vegetation. Water enters through a vegetated surface, trickling via a filter layer to a perforated pipe at the base. | Stores water, releases it gradually. Some water quality improvement provided by the filter layer. | Private in curtilage SuDS (source control, open spaces, next to roads and car parking). | θ θ θ | θ θ θ | θ θ θ | θ θ θ | £ £ £ | £ | £ £ |
| Rain garden |  | Vegetated area into which runoff is drained, attenuated and/or stored. Water infiltrates and taken up by plants. | Stores runoff, filters out pollutants, recharge groundwater. | Next to roads, in residential developments and throughout urban areas. | θ θ θ | θ θ θ | θ θ θ | θ θ θ | £ £ | £ | £ |
| Swales |  | Shallow vegetated ditches, swales can run parallel to hard surfaces, allowing runoff to trickle down the sides into the base. Water conveyed in a controlled manner to another SuDS device or to the receiving watercourse. | Treats and attenuates runoff. Can be used in permeable or impermeable ground conditions (the latter if underdrained). | Open space, next to roads and car parks. | θ θ θ | θ θ θ | θ θ θ | θ θ | £ £ £ | £ | £ £ |

*Key*: θ Low contribution £ Low cost
θ θ Medium contribution £ £ Medium cost
θ θ θ High contribution £ £ £ High cost

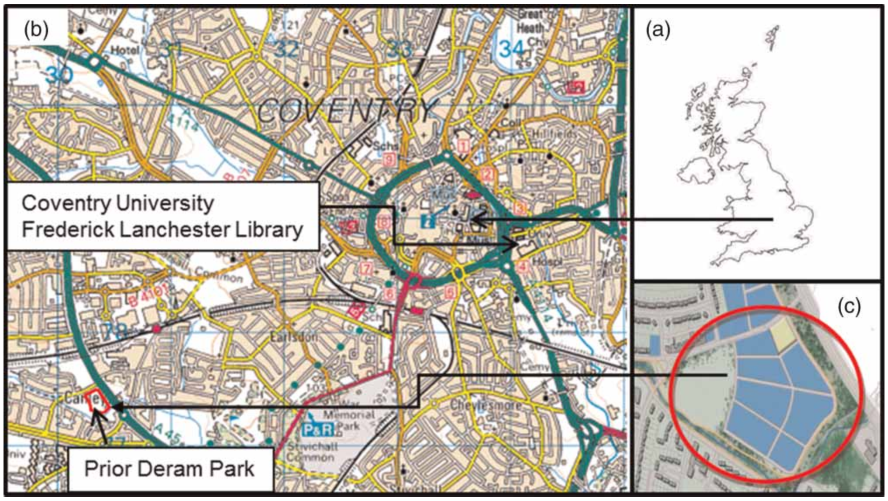


**Figure 1** | The locations of: (a) Coventry; (b) Frederick Lanchester Library and Prior Deram Park. (c) A map of Prior Deram Park with the 250 house area highlighted.

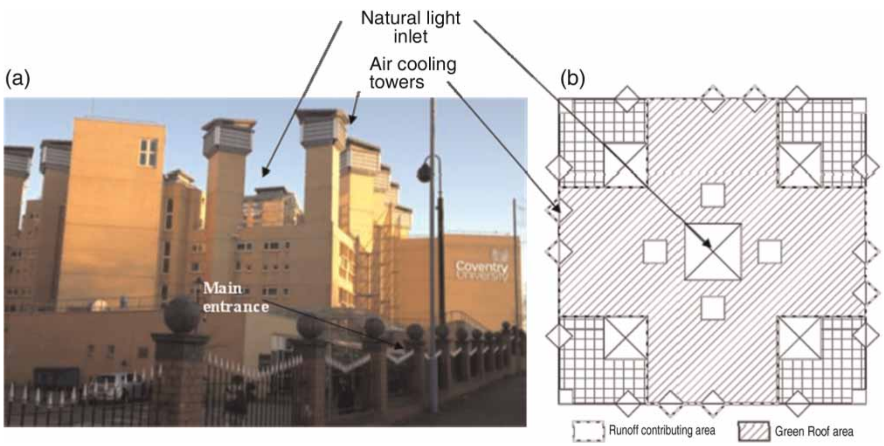


**Figure 2** | (a) The Frederick Lanchester Library, Coventry University, Coventry. (b) Plan of the roof.

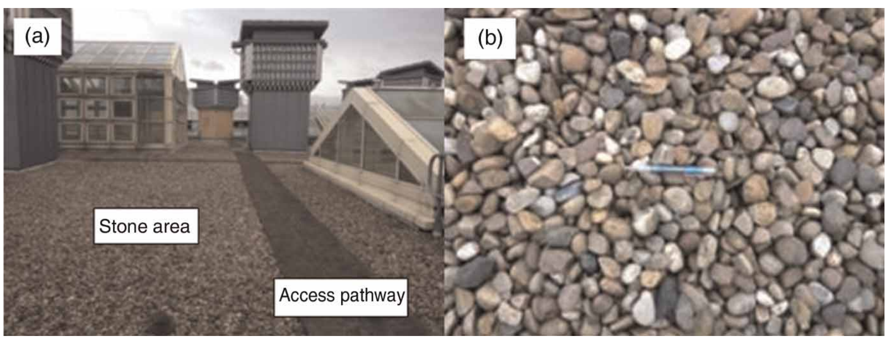


**Figure 3** | (a) View of the Frederick Lanchester Library roof. (b) Close up of stones.

human health impacts or amenity are, similarly, irrelevant. This therefore leaves the remaining two sides of the SUDS triangle: water quality and quantity and from the 'rocket', CSS and mitigation of the UHIE. Of those four benefits, reduction of carbon is probably presently of most interest.

Coventry University's 2011 Environmental Policy was to reduce carbon by 500 tonnes pa; it was awarded Silver in the EcoCampus Environment Management System during 2011. There are very few studies of green roofs estimating their CSS capabilities (Charlesworth 2010); Getter *et al.* (2009) conducted a study of an extensive green roof (6 cm thick soil layer) in the USA, finding the whole roof (above-ground biomass, below-ground biomass and substrate) sequestered 375 $gCm^{-2}$ over a 2-year period. Using this figure, it is estimated that replacing 1,300 $m^2$ of the existing stone roof could sequester 487 kgC over a similar time frame to the Getter *et al.* (2009) study. Hence, greening the library roof could go towards addressing some of the university's carbon reduction target.

Estimates by the manufacturer of the proposed green roof (Bauder pers. comm.) were that it could *potentially* store more than 25 L water $m^{-2}$. However, the attenuation benefits of the green roof took account of the data reviewed above, in which a rainfall event of up to 5 mm did not produce runoff. The calculations of storm peak attenuation were undertaken using Win*Des*®, a commercially available urban stormwater model (www.microdrainage.co.uk) that incorporates several SUDS devices at source, site and regional level. Results in Table 2 indicate peak flow reduction of between 78 and 98% of existing roof runoff could be expected, with time to peak delayed from 9 to 57 min.

## Case study 2: Gozalbes Vera Public School, Xàtiva (Valencia, Spain)

This case study is part of the AQUAVAL project (see www.aquavalproject.eu) and is based in Valencia, Spain, specifically the towns of Xàtiva and Benaguasil. The main aim of this part of the project is to show the value of SUDS demonstration sites, their design, construction and monitoring. These alternative solutions to traditional sewer systems are being monitored (for both water quality and quantity) for a year and it is expected that they will provide proof of concept in the field. Further details explaining site choice and community involvement can be found in Casal-Campos *et al.* (2012).

One of the demonstration sites is at Gozalbes Vera Public School, located in the centre of Xàtiva (see Figure 4). This site was chosen for two main reasons: firstly, its ability to raise the awareness of SUDS to pupils from an early age and secondly, because the Xàtiva combined sewer system is overloaded and interventions such as SUDS have the potential to reduce peak flows, hence contributing to reducing the frequency of local flooding and also incidences associated with CSO overflows (Castro-Fresno *et al.* 2013).

This school has been retrofitted with three types of SUDS:

1. A 475 $m^2$ extensive green roof (Figure 5(a)), with an enriched light soil layer, including fragments of brick to aid drainage, 10 cm thick (see Figure 5(b) for detailed structure) and planted with seven species of *Sedum* (see Table 3) which will retain the first 5 mm of rain (based on estimations in Stovin *et al.* (2012)).

**Table 2** | Expected peak flow reduction and delay benefits from retrofitting the green roof. Where '100 + 20%CC' = indicates taking climate change into account in calculations

| | Stone roof | | | Green roof | | |
|---|---|---|---|---|---|---|
| Return period (years) | Critical storm | Max. runoff (Ls) | Time to peak (min) | Critical storm | Max. runoff (L/s) | Time to peak (min) |
| 1 | 15 min Summer | 23.9 | 9 | 15 min Summer | 0.5 | 57 |
| 2 | 15 min Summer | 30.8 | 9 | 15 min Summer | 2.2 | 33 |
| 5 | 15 min Summer | 39.8 | 9 | 15 min Summer | 4.4 | 24 |
| 30 | 15 min Summer | 58.5 | 9 | 30 min Winter | 13.0 | 22 |
| 100 | 15 min Summer | 75.8 | 9 | 30 min Winter | 17.1 | 21 |
| 100 + 20%CC | 15 min Summer | 91 | 9 | 30 min Summer | 18.8 | 20 |


**Figure 4** | Location of Gozalbes Vera Public School (from Google maps).

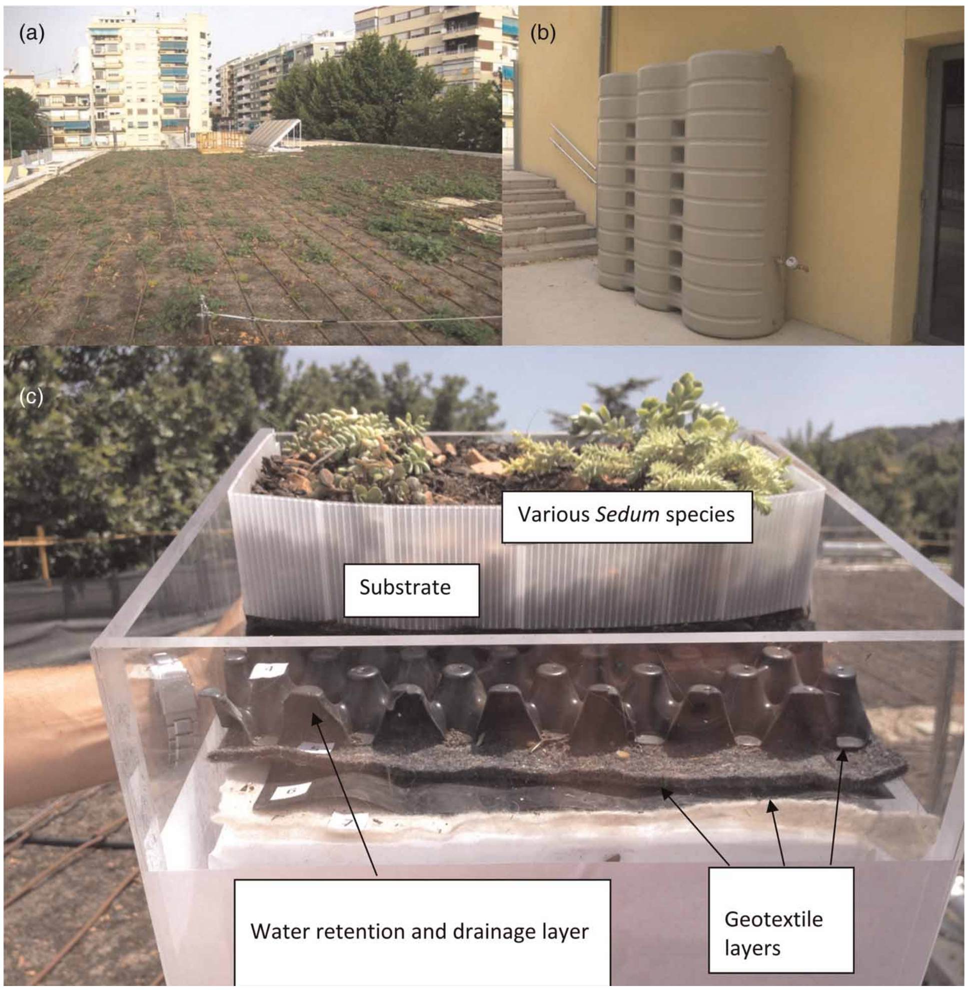


**Figure 5** | Gozalbes Vera Public School SUDS retrofits. (a) Extensive green roof; (b) rainwater tank; (c) structure of the green roof.

**Table 3** | Sedum species and percentage used in the Xativa retrofitted green roof

| % Plants used | Sedum species |
|---|---|
| 10 | *Sedum album* |
| 15 | *Sedum acre* |
| 20 | *Sedum floriferum* |
| 15 | *Sedum spurium* |
| 20 | *Sedum reflexum* |
| 10 | *Sedum sediforme* |
| 10 | *Sedum sexangulare* |

2. A 3,000 litre rainwater tank (Figure 5(c)) to collect water from a section of impermeable roof to use for watering plants on the patio and for cleaning tasks. This is being monitored for the amount of water subsequently used on these tasks.
3. Re-paving the sand playground (370 $m^2$) with 8 cm of porous concrete, covering a 25 cm clean gravel sub-base separated from the underlying soil by a porous geotextile layer. The drainage capacity of the porous concrete was 200–400 L $min^{-1}$ $m^{-2}$ with a minimum cement content of 300 kg $m^{-3}$ (Lafarge pers. comm.).

Due to budget restrictions, only part of the former cobbled roof was retrofitted, which allows comparison, at the same site, of the storm attenuation performance of both the green and cobbled areas. This is being undertaken using a tipping bucket fitted on two downpipes to measure runoff from the roofs; rainfall data was collected at 10 min intervals by the Spanish Agency AEMET, from the local Xàtiva Station. Data are retrieved on a monthly basis, any runoff from the green roof generates an SMS message for samples to be collected for water quality analysis. These real-life measurements can then be used to calibrate models of green roof efficiency in attenuating the storm peak which can then be used to assess larger scale green roof retrofit across the city. Water quality tests are being carried out on runoff from both locations, but monitoring, including that of rainfall amount, is ongoing and is not reported here.

In assessing storm peak attenuation by both retrofitted devices, a return period of 15 years was used in the design models since this is demanded under the Communidad Valenciana's PATRICOVA legislation (Olcina Cantos 2010) for catchments >10 ha. Results indicated that the green roof delays runoff by about 30 min, with a 50% reduction both in peak flow and runoff total volume. Calculations using Win*Des*® (for details see case study 1) of the benefits of the porous concrete indicate that the reduction in peak flow would be around 70% for the rainfall design event. In terms of carbon sequestration, using assumptions from case study 1, the green roof could sequester about 180 kgC over a 2-year period (Getter *et al.* 2009).

## Case study 3: Prior Deram Park, Canley, Coventry

The aim of the third case study was to increase the scale at which these approaches can be utilised, by modelling the impact of a SUDS management train on a 250-house new build estate. Prior Deram Park is part of the Canley Regeneration project and is located to the east of the site, as shown in Figure 1. It is proposed that part of the site remains as open space, providing a children's play area, whilst 250 new houses at 50 houses $ha^{-1}$ will be built on the rest (WSP Environmental Ltd & Coventry City Council 2008). The access road layout has been designed and is shown in Figure 1(c), but the layout for housing has yet to be decided. The housing styles will be mixed, with, for example, 116 three-storey terraced townhouses, 66 set out in two-storey terraces and the remaining 68 semi-detached, and will include private as well as social and affordable housing (Alliance Planning & Coventry City Council 2008).

In order to assess the benefits of a SUDS management train to reduce surface water volume at Prior Deram Park, runoff was modelled from a conventional pipe-based drainage system and compared against a SUDS management train with and without green roofs using the modeling software Win*Des*® (see case study 1 for more details) which has in-built SUDS devices and associated performance criteria. Assumptions for climatic data were retrieved from the Flood Estimation Handbook (Institute of Hydrology 1999). Following FWMA guidance (Defra 2011), the pipe-based system should be designed to deal with a one in 30-year storm return period (standard-period average annual rainfall is 688 mm) to prevent flooding on any part of the site. In the current simulation, both pipe-based and SUDS systems were designed for a one in 100-year

30 min winter storm return period and did not include an outflow control so that total outflow volumes could be compared.

The design of the SUDS management train was limited by the underlying clay soil which restricted infiltration, and the fact that part of the site was previously used for landfill (WSP Environmental Ltd & Lockhart Garratt 2008). Therefore, to reduce the possibility of groundwater pollution, infiltration SUDS devices such as PPS would need to be tanked and any runoff conveyed via pipes. Thus tank-based PPS as well as a single bioretention device were utilized for the driveways of each house for source control; swales were used for conveyance where possible and ponds for site control.

The results are shown in Figure 6, which illustrates the benefits of utilising a SUDS management train in comparison with pipe based conventional drainage whereby the peak flow is reduced by 252.7 $Ls^{-1}$, and the time to peak extended by approximately 5 min. Response to rainfall is increased by about 8 min, and rainfall volume to outfall is reduced by approximately 20%. By adding green roofs to all houses to the SUDS train, the time to baseflow was increased by at least 15 min. This is likely to represent stormwater stored in the SUDS devices of the train and also in the green roofs (Berndtsson 2010) which is subsequently released more slowly than by the pipe-based system. As described above, the design flows are larger than that required by Defra (2011) and illustrate how the systems could cope with exceedance flows; the exercise shows the positive impacts of a SUDS management train on surface water management but in reality, flow can be further slowed using weirs and weir plates, or other flow constraining devices.

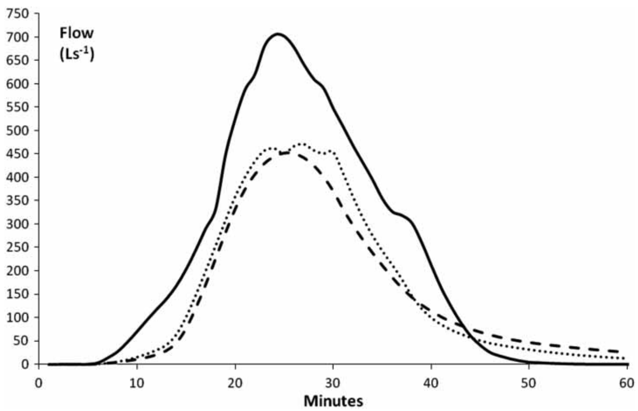


**Figure 6** | Comparison of the impacts of conventional drainage (-), SUDS management train with (--) and without green roofs ( … ) on outflow at Prior Deram Park, Canley, Coventry.

## CONCLUSIONS

The three case studies detailed here show the benefits of retrofitting small scale SUDS devices to buildings mainly by attenuating the storm peak, but also other benefits in terms of carbon sequestration and storage. There is a singular lack of SUDS demonstration sites in England and Spain, and monitoring of those in the AQUAVAL project will generate data to allow calibration of green roof efficiency models which can then be used at greater scales, for instance application of such retrofit approaches city-wide. The case studies also show that these benefits are possible at larger scales, by modelling the impacts on stormwater volume and peak flow by designing a SUDS management train and then adding green roofs. All three projects made use of green roofs as well as other devices, showing that they integrate well into a SUDS management train. In addition to addressing aspects of the SUDS triangle, particularly water quantity issues, green roofs can also mitigate impacts brought about by a changing climate, by absorbing and storing carbon already in the atmosphere, and calculations indicate the extent to which even a single roof can assist in this regard. The case studies presented here, both from Spain and the UK, demonstrate the potential for, and feasibility of, sustainable management of surface water at the building scale.

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