2nd SWITCH Scientific Meeting
Dan Panorama Hotel, Tel-Aviv, Israel
25 - 29 November 2007

Inaugural green roof research in Birmingham, UK: configuration and preliminary results

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Abstract

In the last two years the city of Birmingham has witnessed the first steps in the development of a network of green roofs that are designed to mimic brownfield habitat (brown roofs) and compensate for its loss during redevelopment. As part of the SWITCH programme, a test array has been established at the University of Birmingham (UoB) that has undergone extensive monitoring since May 2007. This research is testing the potential of brown roof mesocosms, constructed from different mixtures of recycled aggregate, as habitat for brownfield plant and animal species, whilst fulfilling important roles in the sustainable management of urban water. In addition to this site, two, part SWITCH-funded (in association with landfill tax funding from SITA trust), demonstration brown roofs on the International Convention Centre (ICC) and Birmingham Volunteer Studies Council (BVSC) buildings were completed in August 2007. These roofs build on the design concepts used in the UoB design, but their large scale will allow the investigation of the importance of additional habitat resources, and provide an opportunity for the general public to see and appreciate 'real' brown roofs in action. This document describes: (1) the construction, monitoring and development of these brown roofs in their initial establishment phase, (2) reports the initial findings of the UoB research on the effect of substrate type on vegetation development, run-off quality and storm-water attenuation, and (3) describes the initial steps taken to enable the public and practitioners to gain first-hand experience of the make-up and benefits of green roofs.

Keywords: Biodiversity roofs, brownfield, brown roof, green water, habitat loss mitigation, novel habitat, sustainable development, urban ecology, urban stormwater management, vegetated roof.

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1 Introduction

Extensive green roofs can benefit the individual by insulating buildings (Barrio, 1998; Kumar and Kaushik, 2005) and increasing the lifespan of roof waterproof membranes (Ngan, 2004; Wong et al., 2003), so that their life cycle cost can be lower than conventional roofs (Wong *et al.*, 2003). However, green roofs have much wider environmental benefits, potentially including: (1) an improvement in air quality (Ngan, 2004; Rosenfeld et al., 1998), (2) a reduction of the urban heat island effect (Bass and Krayenhoff, 2002; Onmura et al., 2001), (3) a reduction of storm water runoff intensity (Bengtsson et al., 2005; Carter and Jackson, in press; Mentens et al., 2006), (4) an improvement of run-off water quality (Köhler et al., 2002; Steusloff, 1998), and (5) the creation of new habitat for wildlife (Brenneisen, 2003; Kadas, 2002); such that their life cycle environmental benefits are considerable (Kosareo and Ries, 2007; Saiz et al., 2006).

The main motivation for this research is ecological, with the aim of replicating brownfield (demolition site) habitat as far as possible in the form of ‘brown roofs’, but it also concurrently investigates the effect of brown roofs on run-off quantity and quality. The improved understanding of the scope and magnitude of any trade-offs between habitat quality and hydrochemical performance will enable future planners to better develop brown roof systems to balance these requirements. We primarily investigate the suitability of different recycled aggregates, but recognise that habitats on roofs will always differ from habitats on the ground due to both differences in weather conditions (e.g. Figure 1) and height barriers to species dispersal, and these factors are investigated in the wider scope of our research. Our research is in an early phase, and as the development of ecological communities takes some time this report focuses on (a) methodological elements, such as the construction and monitoring of the study roofs; (b) early results, such as the effect of substrate type on storm-water attenuation and run-off quality, and (c) the steps taken to disseminate our knowledge to the public and practitioners. This paper follows on from (Bates et al., 2007), where more extensive and complementary details of the project rationale and design can be found.

2 Brown roof construction and monitoring

Experience from ecological surveys of brownfield sites (e.g. Donovan et al., 2005; Small et al., 2003), and exploratory green roof research in the UK and Switzerland (Brenneisen, 2003; Gedge, 2003; Ngan, 2004), suggest that using low nutrient growing substrates and maximizing the range of microhabitats will increase the diversity of species using brown roofs. All of the Birmingham brown roofs utilize these design guidelines, although the small size of mesocosms necessary for experimental replication in the UoB test array prohibited the use of multiple microhabitats. The BVSC and ICC brown roofs lack experimental replication, but their large size allowed the inclusion of a wide range of microhabitats. These two research threads are thus mutually beneficial.

2.1 The UoB brown roof test array

Design and construction

The UoB test array is on the 5-floor Watson building on the main UoB campus, Birmingham, UK (52´´27´01.54´´N, 1´´55´43.41´´W), and was completed on 12/3/2007. The layout of the treatment replicates was designed to as far as possible evenly distribute small-scale environmental variation (e.g. localised shading) between treatments (Figure 2). The substrate in each mesocosm is 10cm deep and was seeded with the same seed mix and at the same density (~1.6g per m^2). There are five replicates of seven different substrate treatments, namely: (1) crushed demolition aggregate (mainly concrete and brick, but also ceramics, sand, etc.) with a sterilised loam mulch, (2) crushed demolition aggregate with a compost rich sterilised loam mulch, (3) crushed demolition aggregate with no mulch, (4) crushed brick aggregate with a sterilised loam mulch, (5) solid municipal waste incinerator bottom ash (glass, ceramics, concrete, fused material, etc) with a sterilised loam mulch, (6) a 1:1 mix of crushed brick aggregate with crushed demolition aggregate with a sterilised loam mulch, and (7) a 1:1 mix of solid municipal waste incinerator bottom ash with crushed demolition aggregate with a sterilised loam mulch.

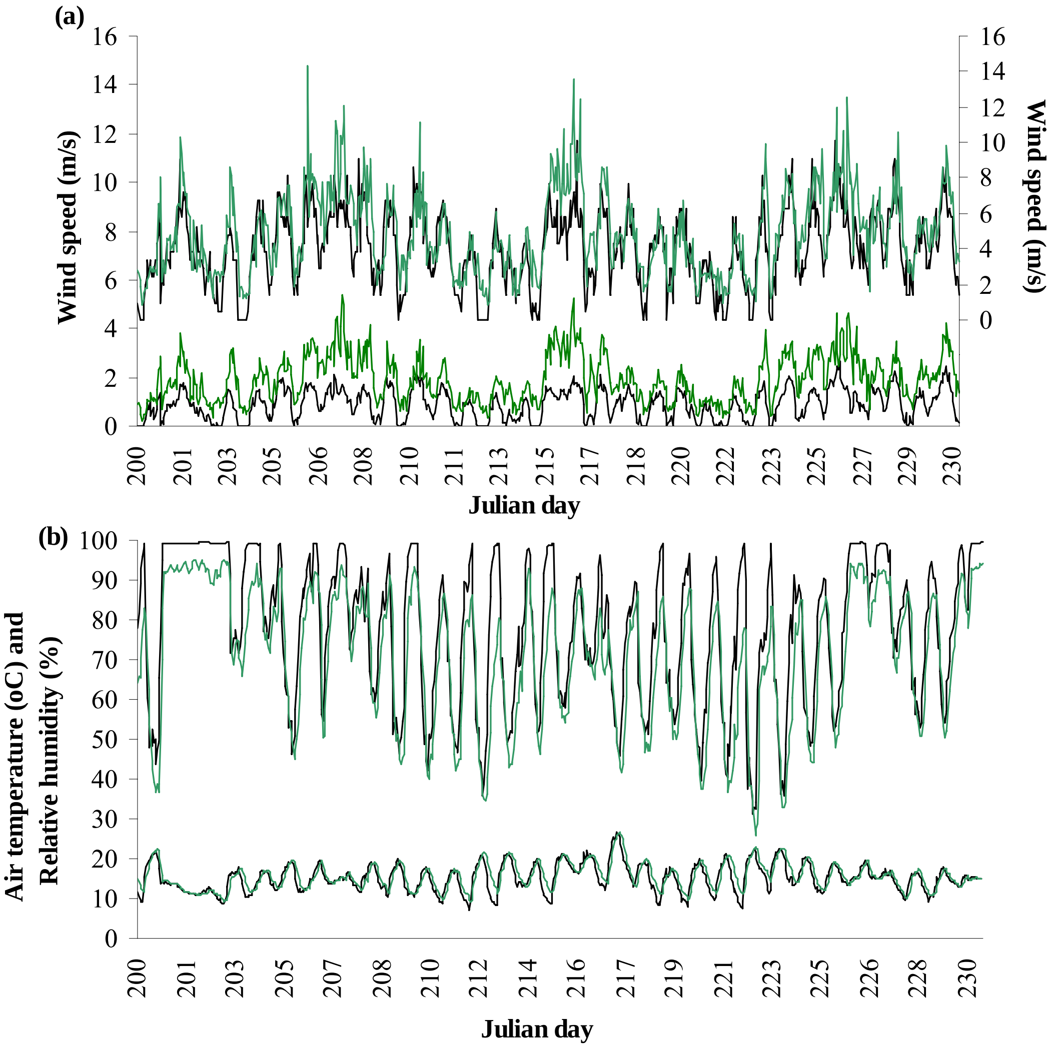

Figure 1: Example data showing the difference between local weather variables at Birmingham University Winterbourne weather station sited on the ground (dark lines), and the weather variables on the green roof research facility roof (lighter lines). Sub-figure (a) shows hourly maximum (top, right-hand axis), and mean (bottom, left-hand axis) wind speed. Sub-figure (b) shows mean hourly relative humidity (top), and air temperature (bottom).

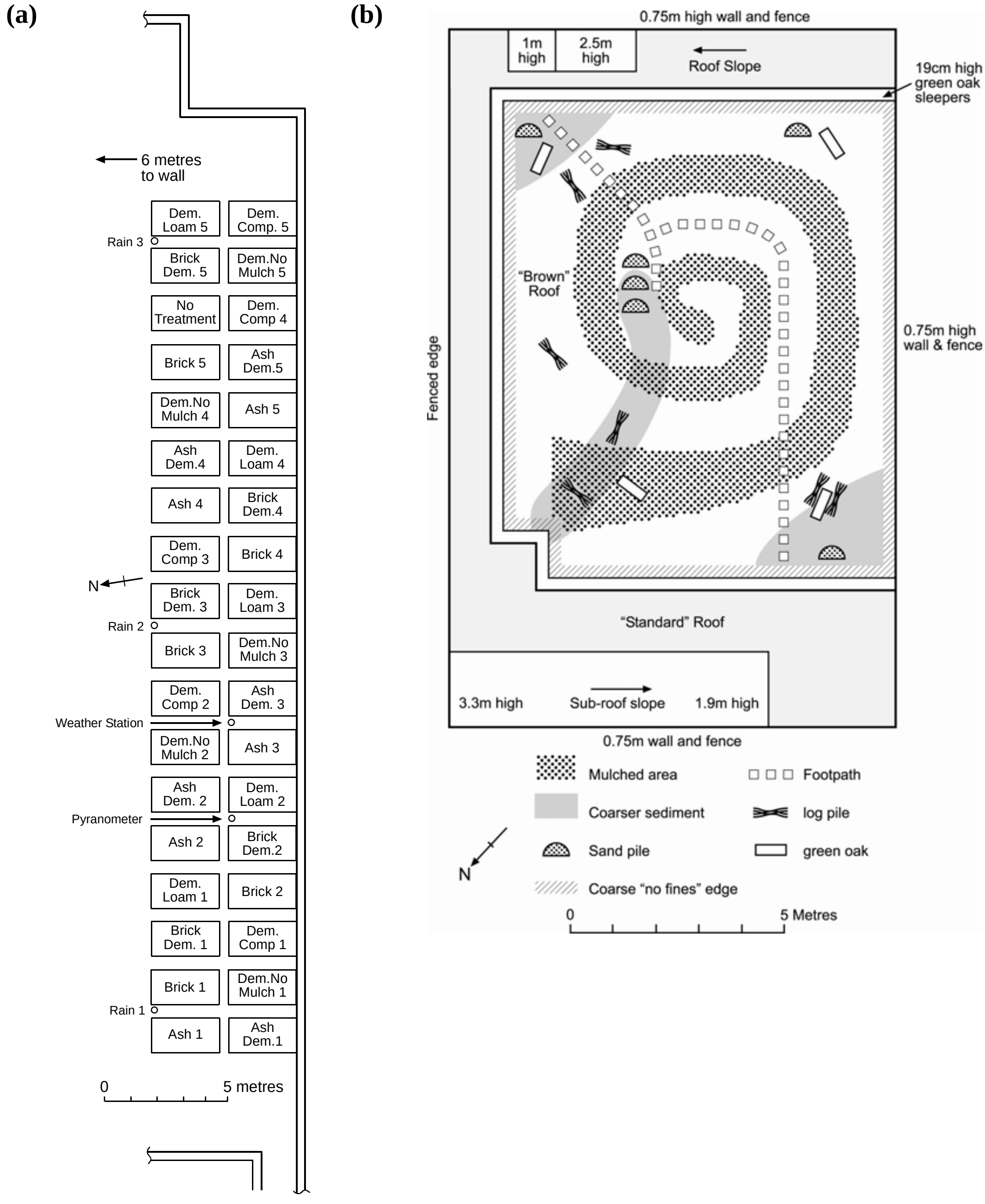

Figure 2: The design of: (a) the Birmingham University green roof experimental facility (treatment codes are: Dem. Loam = demolition aggregate with a loam mulch, Dem. No mulch = demolition aggregate with no mulch, Dem. Comp. = demolition aggregate with a compost mulch, Ash = incinerator bottom ash with a loam mulch, Brick = crushed brick with a loam mulch, Brick Dem. = 1:1 crushed brick demolition aggregate mix with a loam mulch, and Ash Dem. = 1:1 incinerator bottom ash demolition aggregate mix with a loam mulch); and (b) the BVSC brown roof.

The sediment size distribution inevitably varied somewhat between the aggregate treatments (Figure 3a). The Ash and Brick treatments in particular had less fine sediment than the Demolition aggregate treatments, but all treatments were characterised by a bimodal distribution of sands and pebbles/cobbles.

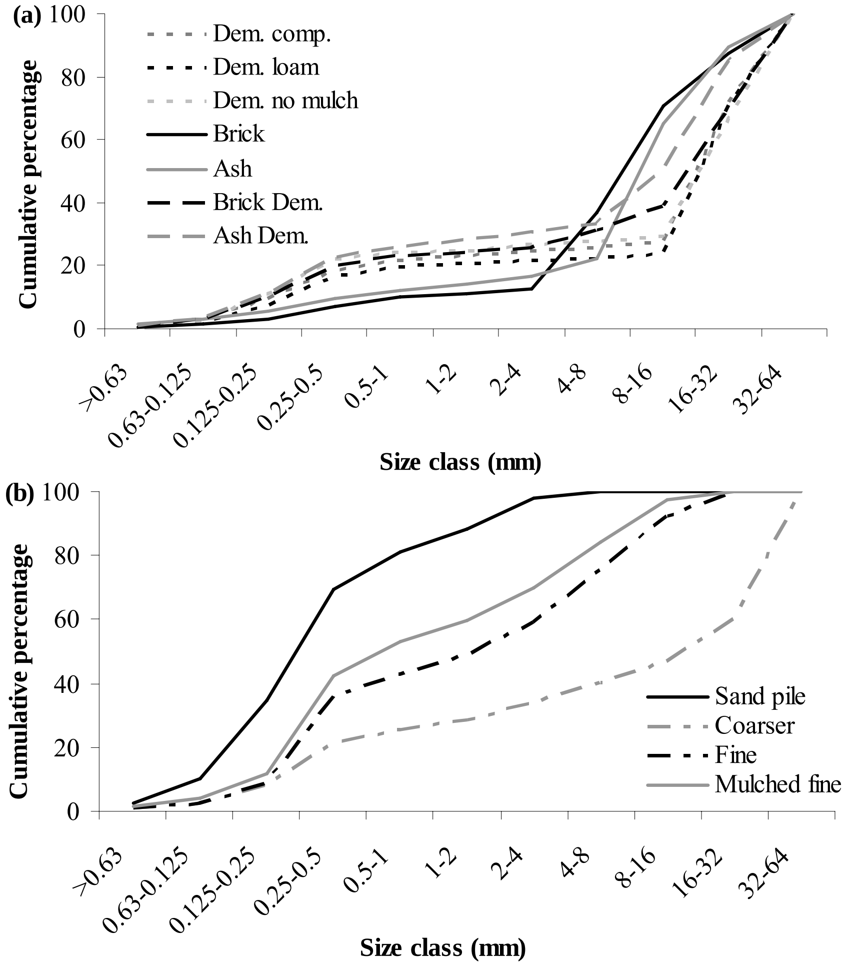

Figure 3: Cumulative percentage size distribution of sediment on (a) the University of Birmingham (mean, N = 5) and (b) the BVSC (bulked samples) brown roofs.

Monitoring

A suite of physical variables are logged every five minutes from the UoB mesocosms, namely: rainfall, wind speed and direction, air temperature, relative humidity, solar radiation, substrate temperature at the surface and 5cm down in Brick 2 and Dem. loam 2, soil moisture in Brick 2 and Dem. loam 2, and bulked run-off from the five Brick and the five Dem. loam treatments (Figure 2a). The run-off is measured using small v-notch weirs that have been calibrated in situ using known flows from a constant head tank. The weather variables measured are not only of interest for their ecological effects, but also affect the rate of evapotranspiration, and therefore the amount of run-off from the plots (e.g. Figure 1).

Observations, sweep-netting and pitfall trapping are all used sparingly in order to study the development of invertebrate assemblages on the plots, without compromising the development of those assemblages (e.g. over-trapping before establishment). Changes in plant species abundance and structural composition are estimated on the Domin-Krajina cover abundance scale, and the total vegetation cover is estimated from digital photographs taken above the plots using image analysis software.

Three replicate manual samples of water from each treatment, and rainfall at the time of sampling (Figure 2a), are taken periodically at least 30 minutes after the initiation of run-off from the plots. A range of parameters are measured from filtered water samples, namely: pH, electrical conductivity, alkalinity (as $CaCO_3$), chloride, bromide, nitrite, nitrate, phosphate, sulphate, B, Al, Si, Mn, Fe, Ti, V, Cr, Cu, Zn, As, Se, Cd, Sb, Ba, Pb, Ni, Sr, Na, Ca, Mg and K.

2.2 SWITCH and SITA funded brown roof demonstration projects

The BVSC and ICC brown roofs were mainly funded by SITA Trust from the Landfill Communities Fund and partly funded by SWITCH demonstration project funds. They were completed in August 2007 and were mainly constructed using recycled demolition aggregate and aggregate already on site. Two more SITA/SWITCH demonstration brown roofs are planned for the future. The two roofs include a variety of microhabitats such as areas of finer sediment, areas of coarser sediment, areas that have been mulched, areas without mulch, varying depths of substrate, piles of pure sand for invertebrate nest sites, large stones, log piles, and willow hurdles (e.g. Figure 2b). The sediment on the BVSC roof is finer than that in the UoB mesocosms (Figure 3b), but the ICC roof is much more similar. Both have been seeded with the same seed mix used at the UoB. Monitoring is currently being established, but will wherever possible follow the regime used on the UoB test array, with modifications due to the size and nature of the habitat (e.g. use by birds will be studied, sampling will be stratified by microhabitat).

3 Preliminary research findings

3.1 Vegetation development

Vegetation cover has remained below 25% on all plots in the first growing season, so it has remained structurally similar to the earliest stages of succession on a brownfield site. Around half of the seeded species successfully germinated in the first spring and the plots quickly became dominated by annual species, such as *Papaver dubium* L. (long-headed poppy), *P. rhoeas* L. (common poppy), and *Centaurea cyanus* L. (cornflower), which mostly successfully flowered and seeded (Figure 4). Perennial species, such as *Sedum acre* L. (biting stonecrop), and *Silene vulgaris* (Moench) Garcke (bladder campion) have generally slowly developed on the Demolition compost, Demolition loam and Ash demolition mix plots, whilst remaining fairly static in their coverage after initial germination on the other plots. Few perennial species have flowered and seeded in the first growing season. Some taxa, such as mosses and *Verbascum Thapsus* L. (great mullein) have only really begun to develop with the onset of autumn.

Most species have grown most quickly on the Demolition compost, Demolition loam and Ash demolition plots, and least quickly on the Demolition no mulch and Ash plots. It would seem likely therefore that growth is so far being controlled by the amount of fine sediment and availability of nutrients/organic matter from the mulch. There is also some suggestion of a delay in the growth of plants in the Ash plots (Figure 4), possibly due to a toxicity effect that has reduced over time (see 3.2), but it is too early to make these statements with authority.

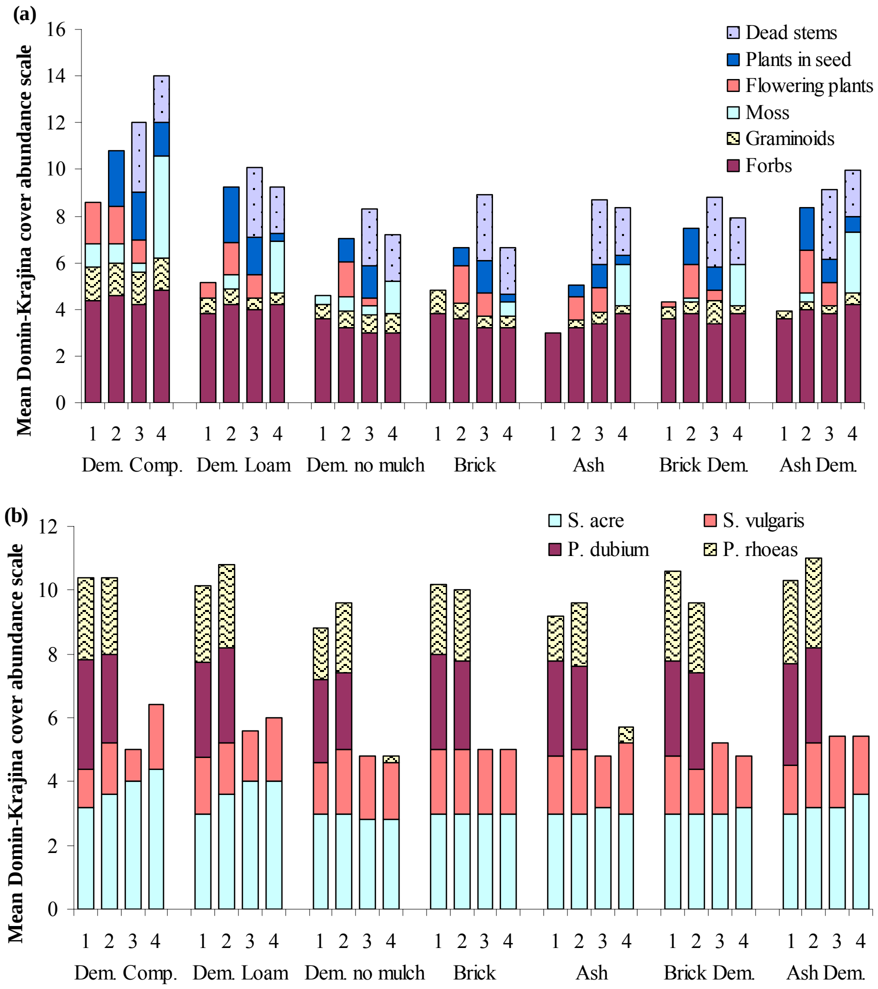

Figure 4: Temporal changes in the Domin-Krajina cover abundance of (a) different plant habitat resources, and (b) selected plant species on the University of Birmingham mesocosms (time period 1 = 21/6/07 to 5/7/07, 2 = 31/7/07 to 3/8/07, 3 = 4/9/07 to 7/9/07, 4 = 15/10/07 to 18/10/07).

3.2 Run-off quality

So far water has been sampled and analyzed, or partly analyzed from two large run-off events. The first was on 11/5/07 shortly after the completion of the UoB test array and was the second time that run-off had been initiated. This water was characterized by high concentrations of many solutes from all the treatments, with Ash clearly displaying the worst water quality (Table 1). The later flush of water on 20/7/07 was of much better quality, so there seems to have been a 'first-flush' effect. Given the pH of the run-off, the concentrations of some elements (e.g. Al) is surprising and we will try to identify whether this is due to adsorbtion onto very fine particulates or organic carbon in future analyses.

The rainfall analyzed was of very good quality (Table 1) most probably because it was sampled after long periods of heavy rain. However, it seems likely that in the early phase of establishment of this type of brown roof the run-off is likely to be of lower quality than that from traditional roofs, a finding supported by (Berndtsson et al., 2006) for extensive *Sedum* roofs. The results are preliminary, but it would seem possible that steps such as: (1) leaving aggregates for a period to leach before they are put onto roofs and (2) ensuring green roof run-off does not drain directly into surface waters might be advisable.

Table 1: Example water quality data (average of three replicates) from mesocosm run-off from an early and later flush (- = data not yet available)

Treatment	Date	pH	Cond. (uS/cm)	Chloride (mg/l)	Nitrate (mg/l)	Sulphate (mg/l)	Al (PPB)	Mn (PPB)	Fe (PPB)	Cu (PPB)	As (PPB)
Rain	11/05/2007	7.7	40.7	2.8	0.5	10.3	65.7	5.4	60.9	7.3	1.9
Dem comp	11/05/2007	8.2	2300.0	117.8	76.5	1484.2	52.9	18.9	2164.3	46.3	13.7
Dem loam	11/05/2007	8.2	2033.3	41.9	61.5	1266.1	43.3	13.9	2033.7	31.5	12.6
Dem no mulch	11/05/2007	8.3	2233.3	69.6	18.8	1568.7	45.1	17.2	2702.3	29.0	8.9
Brick	11/05/2007	8.2	2733.3	31.5	65.2	2203.4	77.4	45.8	3554.0	17.0	26.8
Ash	11/05/2007	8.1	12666.7	4187.7	61.2	3181.7	212.0	84.3	4526.7	118.0	7.4
Brick Dem	11/05/2007	8.2	2733.3	61.2	72.2	2150.0	71.1	23.5	4123.0	22.9	14.1
Ash Dem	11/05/2007	8.1	5000.0	1341.3	65.9	2507.1	96.4	27.1	4043.0	68.2	10.7
Rain	20/07/2007	7.0	40.3	1.0	1.8	3.3	-	-	-	-	-
Dem comp	20/07/2007	8.2	563.3	3.4	0.3	277.8	-	-	-	-	-
Dem loam	20/07/2007	8.2	460.0	3.6	0.6	251.1	-	-	-	-	-
Dem no mulch	20/07/2007	8.3	513.3	5.4	1.1	356.7	-	-	-	-	-
Brick	20/07/2007	8.0	2100.0	2.5	3.7	1865.3	-	-	-	-	-
Ash	20/07/2007	7.9	2133.3	66.2	7.1	2280.1	-	-	-	-	-
Brick Dem	20/07/2007	8.1	1933.3	3.2	3.3	1739.9	-	-	-	-	-
Ash Dem	20/07/2007	8.0	900.0	19.2	0.3	868.5	-	-	-	-	-

3.3 Storm-water attenuation

The Brick and Demolition loam treatments studied have both demonstrated a significant ability to remove and delay the run-off of a significant proportion of rainfall (e.g. Figure 5a). Run-off has not been generated until plots are saturated or close to saturated, therefore many rainfall events have not produced any run-off, depending on their magnitude and the antecedent conditions. So far, the two treatments have behaved very similarly, although the Brick treatment, possibly owing to its larger pore spaces, has out-performed the Demolition aggregate in its ability to delay very heavy rain. Some initial exploratory modelling of the brown roof hydrology has been completed by Rix (2007) with some success (e.g. Figure 5b).

4 Knowledge transfer

A range of methods have already been implemented to transfer knowledge of green and brown roof technology to the public and developers and these will be expanded in the future. In collaboration with Landcare Associates Birmingham we have arranged two green roof based seminars entitled ‘Green roofs and biodiversity seminar’ on 15th November 2006, and ‘Actions to combat climate change and benefit biodiversity in an urban environment’ on 25th July 2007, and have plans to organize similar annual events. These have been well attended by environmental consultants, landscape gardeners, architects and planners, and have both included key-note presentations by green roof experts from other areas of the UK (Dusty Gedge, livingroofs.org in 2006 and Nigel Dunnett, Sheffield University in 2007). The 2007 seminar included visits to the Dunlop Fort *Sedum* matt green roof and the UoB research facility so that delegates could have first-hand experience of some of the different approaches to designing green roofs. The UoB facility was also visited by 30 architects from several firms as part of a green roof tour organized by Groundwork Birmingham and Solihull. The ICC brown roof will not be accessible to the public and the BVSC roof will only be partly accessible. To compensate, images from video cameras are going to be transferred to the foyer of both buildings, where they can be viewed by the many thousands of people who annually use the buildings. These images will be complemented by information boards that explain the advantages of green roofs.

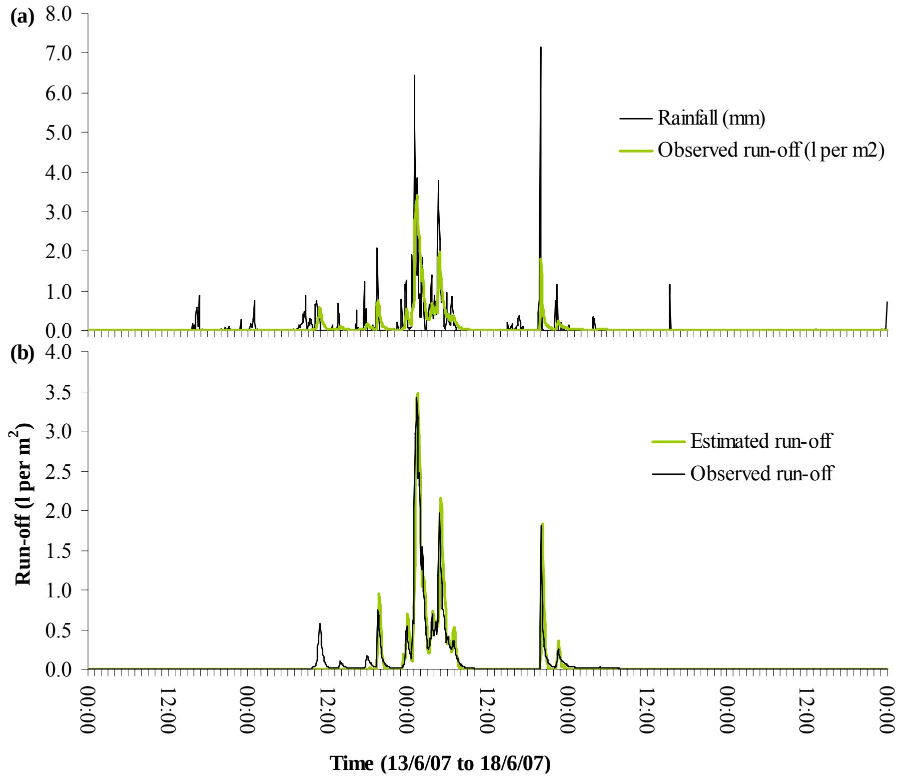

Figure 5: Example hydrometeorological data for the Brick treatment during a period of heavy rainfall, (a) illustrates the observed rainfall and run-off, (b) illustrates the correlation between the observed, and estimated run-off using a two-reservoir model with a built-in bypass from (Rix, 2007).

Acknowledgements

We would like to thank Amy Rix, Rachel White, Véronique Durand, Maria Fernanda Aller, Jane Harris, and Debbie Hurst at the University of Birmingham for helping with the UoB green roof construction and monitoring; IKO/Permanite green roof company, Dusty Gedge and Emorsgate wild seed company for advice on the design of the UoB facility; and all the partners in the Birmingham green roof project, namely Groundwork Birmingham and Solihull, Advantage West Midlands, the East Birmingham North Solihull Regeneration Zone, Birmingham and Black Country Biodiversity Partnership, Birmingham and Black Country Wildlife Trust, Birmingham City Council, Birmingham Environmental Partnership, Birmingham Voluntary Service Council, the Environment Agency, The NEC Group, and the green roof consultancy Livingroofs.org. We especially thank SWITCH for their role in funding the Birmingham University green roof research facility and for part-funding the Birmingham green roofs in partnership with SITA Trust, and to SITA Trust for their funding of the Birmingham green roofs through the Landfill Communities Fund.

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