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SWITCH Green Roof Project: Rationale and Experimental design

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Introduction

Sustainable Water management Improves Tomorrow's Cities' Health (SWITCH)

Global population growth and increasing per capita demand for water resources have caused huge unsustainable negative social, environmental and economic impacts around the world (Micklin 1988; Bulloch and Darwish 1993; Nilsson and Berggren 2000; Tockner and Stanford 2002). These problems are likely to intensify in the future due to concomitant increases in population size, per capita water demand, and the intensity of climate change, with precipitation and hydrological regimes typically becoming more unpredictable and extreme (IPPC 2001; Chiew and McMahon 2002; Hulme *et al.* 2002; Pilling and Jones 2002; Christensen and Christensen 2003). Of particular concern are urban areas, where high population density and extreme environmental modification make sustainable water management particularly challenging (Ellis and Marsalek 1997; White and Howe 2004). These challenges can only increase in the future as urban land area and population increase (c.f. UNFPA 1996; UN 2002). There is therefore, an urgent need for a paradigm shift in urban water management (UWM), which converts current retrospective, fragmented, problem driven approaches to proactive, holistic, sustainability driven approaches (Ellis and Marsalek 1997; White and Howe 2004; House of Lords 2006; SWITCH-Annex 1 2006). It is with this eventual aim in mind that the Sustainable Water management Improves Tomorrow's Cities' Health (SWITCH) project has been developed.

SWITCH is a research driven action orientated project, which has as its main objective: "The development, application and demonstration of a range of tested scientific, technological and socio-economic solutions and approaches that contribute to

the achievement of sustainable and effective UWM schemes in 'The City of the future'" (SWITCH-Annex 1 2006). It brings together 32 partners to develop robust and flexible interactive urban water systems and services across nine cities, which can then be adjusted and conveyed to the geographical and ecological settings of other cities via vertical and horizontal exchange of information through learning alliances. In this way it aims to provide criteria and guiding principles to help cities convert to sustainable UWM practices, with a view to providing high quality water services for all in a way that does not unduly compromise environmental and ecological processes.

What are green roofs?

Green roofs is a broad term for roofs of buildings that have plants growing on them. They are of two main types: (1) intensive green roofs, which are usually heavily landscaped 'gardens' that usually require additional structural support, heavy management and considerable expenditure, and (2) extensive green roofs, which have a shallow substrate layer, can be installed on most low-angle roofs, require minimal management and are relatively inexpensive. The application of green roofs over large urban areas is only really practical using extensive designs and these are the focus of this research. It is important to stress that the design and construction of extensive green roofs varies widely and depends on any number of variables, such as: the preference of the buildings owners, alternatives provided by construction companies, the local availability of materials, the main aim of the construction work, and the spatial location of the roof. Plate 1 illustrates a range of extensive green roof experimental plots in a demonstration facility at the Technical University Burgdorf, Switzerland, but only shows a small number of design possibilities.

Generalising about the construction of extensive green roofs is difficult, but state of the art construction methods typically rely on a five layered system (Figure 1): (1) a root resistant underlay to prevent root damage; (2) a drainage layer, which varies in its construction between manufacturers, and may or may not also act as a water reservoir, storing water for plant use; (3) a filter layer, which prevents fine sediments from being washed away; (4) a sediment or 'soil' layer which varies widely in material and depth, and is usually composed of a mix of inorganic material with some organic matter; and (5) a surface vegetation layer that can be seeded, plug-planted, or turfed with either plant varieties chosen for their high ground coverage or biodiversity potential, or that can be left to colonise naturally (e.g. Sustainable Eastside 2003; Emilsson and Rolf 2005; Monterusso *et al.* 2005).

Plate 1 A selection of extensive green roof types, which vary in the substrate type, substrate depth, and planting regime (photograph Rossa Donovan).
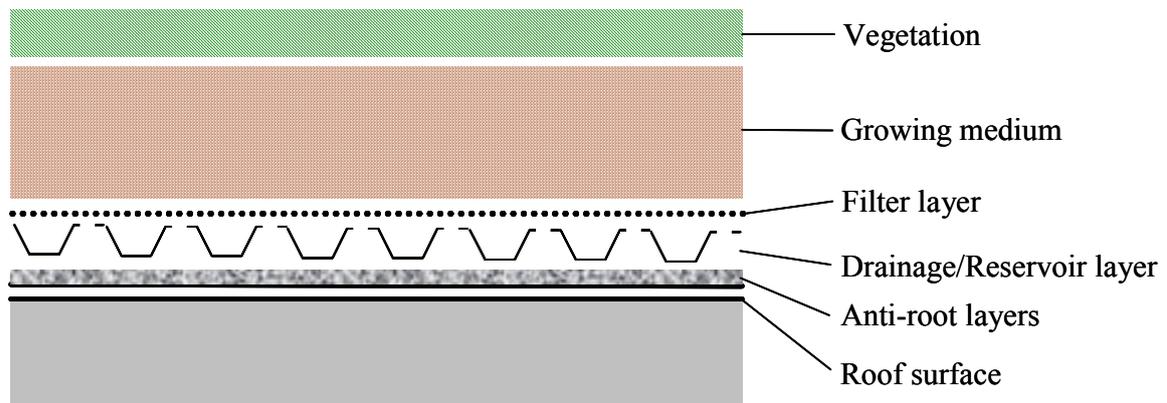
Figure 1 Schematic diagram of a state of the art green roof system

Old demolition and post-industrial sites, often known as brownfields, typically provide important centres of biodiversity not only locally within an urban area but also across regional and sometimes national scales (e.g. Gilbert 1984; Shepherd 1994; Lott and Daws 1995; Spalding and Haes 1995; Eversham *et al.* 1996; Gibson 1998; Small *et al.* 2003, 2006; Woodward *et al.* 2003; Donovan *et al.* 2005; Angold *et al.* 2006). They provide habitat for a diversity of rare species, which were mainly formerly associated with steppe like grassland and later nutrient poor farmland, but are now selected against in intensively managed 'improved' agricultural landscapes (Wilson 1992; Eversham *et al.* 1996; Rich and Woodruff 1996; Andersen 2000). As such, they are now increasingly viewed as habitats deserving conservation protection, both to conserve the habitat itself and to safeguard wider urban biodiversity and habitat connectivity (Harrison and Davies 2002; Donovan *et al.* 2005). At present, the extent of brownfields in the UK is an estimated 66,000 ha and is growing at a rate of 7 ha per day (Thornton and Nathanail 2005). Nonetheless, brownfield communities are under considerable development pressure in many cities (Harrison and Davies 2002), and this pressure can only increase, as their redevelopment is considered a key element of sustainable regeneration, is

currently enshrined in several UK development policies, and can be subject to several

funding initiatives and tax breaks (Pediaditi *et al.* 2005; Thorton and Nathanail 2005).

However, if sustainability in its absolute sense is the goal, redevelopment should

compensate for the habitat destroyed by recreating brownfield habitat of a type as close

as possible to that lost (Donovan *et al.*, 2005). These factors have made brownfield

habitat recreation one of the main aims of ecologically orientated extensive green roof

development.

Ecological surveys of brownfield sites (Gibson 1998; Small *et al.* 2003; Donovan

et al. 2005), experience from habitat creation and restoration (Gilbert and Anderson

1998; Sackville Hamilton 2001; Bischoff *et al.* 2006), and exploratory green roof

research in several countries (e.g. Brenneisen 2003; Gedge 2003; Ngan 2004), have

produced a number of useful design criterion for recreating brownfield habitat and

maximising biodiversity using extensive green roofs. These are to: (a) use low nutrient

substrate layers, to prevent dominance by a few highly competitive species; (b) maximise

the range of microhabitats, from open bare ground to areas heavily vegetated with ruderal

species by controlling substrate type and depth; and (c) allow natural colonisation, or use

seed with a local provenance in order to preserve genetic diversity and to possibly (c.f.

Wilkinson 2001; Bischoff *et al.* 2006) increase plant adaptation to local environmental

conditions. Due to their nature, extensive green roofs that fulfil these criteria are

sometimes termed brown, or eco-roofs (e.g. Plate 2) and it is this type of roof that is the

main focus of this research. There remain important questions however, about how

closely brown roofs replicate brownfield habitats and can be used to support species

associated with these habitats (Grant *et al.* 2003), particularly in relation to the effect of

height and the drainage layer on brown roof ecological communities. The microclimate differs between roofs and the ground and will typically have higher wind speeds, lower maximum air temperatures, and higher minimum air temperatures, which can potentially strongly influence community composition (James Hitchmough pers comm.). The drainage layer at the bottom of roof substrates can potentially cause the development of a perched water table on flat roofs, increasing the field capacity (amount of water remaining in a free drained soil) in relation to the situation with the same substrate on some brownfield sites (c.f. Handreck and Black 2005). Perhaps more importantly however, the height of roofs may act as a substantial barrier to the colonisation and transfer of individuals and propagules between nearby habitat patches, which may preclude their application as stepping stones in integrated habitat networks (Grant *et al.* 2003; c.f. Kim 2003).

Plate 2 An extensive brown/eco-roof in Basel Switzerland (photograph Rossa Donovan)

What are the benefits of green roofs?

Broad benefits

The installation of extensive green roofs increases the construction cost of new buildings and can represent a significant monetary investment when retro-fitted. However, the life cycle costs of using extensive green roofs can be lower than conventional roofs, even in countries (e.g. UK, Singapore) where low uptake has meant that economies of scale do not yet exist (e.g. Wong *et al.* 2003), and the life cycle environmental benefits of using green roofs are significant (Saiz *et al.* 2006; Kosareo and Ries in press). Advantages include: (1) reductions in the need for air conditioning and heating through their effect on a buildings thermal performance (Barrio 1998; Eumorfopoulou and Aravantinos 1998; Niachou *et al.* 2001; Onmura *et al.* 2001; Takakura *et al.* 2000; Liu 2002; Kumar and Kaushik 2005; Lazzarin *et al.* 2005; Saiz *et al.* 2006); (2) reductions in atmospheric carbon dioxide through the uptake by plants and lower levels of release; (3) an improvement in air quality through the binding of dust, filtering of air pollution, increased levels of oxygen and humidity, and reduced ozone concentrations due to city temperature reductions (McMarlin 1997; Rosenfeld *et al.* 1998; Grant *et al.* 2003; Ngan 2004; c.f. Wolverton and Wolverton 1993; Orwell *et al.* 2004); (4) a reduction in the urban heat island effect through increased humidity and alteration of the specific heat capacity of roof surfaces (Onmura *et al.* 2001; Bass and Kryenhoff 2002; c.f. Rosenfeld *et al.* 1998; Takakura *et al.* 2000; Akbari *et al.* 2001; Dimoudi and Nikolopoulou 2003); (5) protection of roof waterproof membranes by (a) moderating temperature and thus reducing expansion and shrinkage damage, (b) providing protection from mechanical damage caused by human traffic and hail, and (c) providing protection

from ultra-violet radiation (Liu 2002; Wong *et al.* 2003); (6) the attenuation of outside noise from rainwater, hail, and airplanes; (7) aesthetic and amenity value, which can potentially enhance emotional wellbeing (c.f. Ulrich 1984; Relf and Lohr 2003) and raise property value (Ngan 2004); (8) the enhancement of a company's environmental image (e.g. Ford Motor Company, Dearborn, Michigan; and Barclays Bank, Canary Wharf, London); and (9) the sustainable re-use of 'waste' aggregates, reducing landfill pressure, and material transport costs (Grant *et al.* 2003), which are currently associated with financial incentives in the UK due to the landfill tax and aggregates levy. Some of these potential advantages have been the subject of careful academic investigation (advantages 1, 3 and 4) others, however, are yet to be rigorously tested.

Benefits related to the SWITCH project objectives

Extensive green roofs can potentially fulfil several features highlighted by the SWITCH project objectives as essential for the development of sustainable UWM. Firstly, extensive green roofs can reduce storm water runoff intensity by delaying, retaining and returning water to the atmosphere via evapotranspiration (Köhler *et al.* 2002; Monterusso *et al.* 2004; Bengtsson 2005; Bengtsson *et al.* 2005; Kidd 2005, VanWoert 2005; Villarreal and Bengtsson 2005; Mentens *et al.* 2006; Carter and Jackson in press; Carter and Rasmussen in press). They can therefore reduce pressure on the urban drainage infrastructure, and reduce the incidence of flooding and fluvial erosion, thereby having considerable potential for utilization within Sustainable (Urban) Drainage System's (SUDS) or stormwater Best Management Practices (BMPs) (Carter and Jackson in press; c.f. White and Howe 2004; Ellis and Marsalek 1997). Secondly, extensive green roofs can potentially improve ecological conditions in urban streams by reducing the

influx (e.g. from combined sewer overflows) and re-suspension of pollutants during heavy rainfall and high flow events, reducing the level of hydrological disturbance (Carter and Jackson in press; c.f. White and Howe 2004; Walsh *et al.* 2005a, b; Lawler *et al.* 2006; Robson *et al.* in press), and by storing or removing pollutants from precipitation as the water travels through the sediment (Köhler *et al.* 2002). The latter can be due to high pH taking metals out of suspension, or the uptake of nutrients by plants (Aziz and Smith 1992; Johnston and Newton 1993; Steusloff 1998), although recent evidence suggests that extensive fertilised sedum-moss roofs can in some instances increase the level of contaminants in runoff (Berndtsson *et al.* 2006). Thirdly, green roof water through-flow could potentially be harvested for non-potable uses such as toilet flushing, cleaning, and garden watering (Saiz *et al.* 2006; c.f. Hochstrat *et al.* 2006; House of Lords 2006).

Extensive green roofs can potentially be used to address all three of these SWITCH project objectives and should not compromise the environment, but rather have favourable effects on the communities of urban streams and rivers. Moreover, the installation of extensive green roofs should actually enhance a city's natural environment by creating new habitat, particularly when a brown roof design is used. Extensive green roofs have successfully been installed in a large number of countries with widely differing climates (e.g. Köhler *et al.* 2002; Onmura *et al.* 2002; Gedge 2003; Grant *et al.* 2003; Ngan 2004; Emilsson and Rolf 2005; Kumar and Kaushik 2005), so the method is likely to be robust and flexible and has large global potential. Although it must be appreciated that findings from one climatic region cannot easily be extrapolated to different climatic regions (Mentens *et al.* 2006; James Hitchmough pers comm.).

Are the SWITCH benefits mutually attainable?

The largest green roof reductions in storm water run-off are achieved through the use of large sediment depth and/or vegetation ground cover (Emilsson and Rolf 2005; Kidd 2005; Mentens *et al.* 2006). The maintenance of high vegetation cover typically requires the use of specialist xerophilic plants such as species of *Sedum*, and a fertile soil. High soil fertility can lead to nitrate leaching, which can compromise through-flow water quality (Ngan 2004), whilst continuous coverage of *Sedum* compromises roof biodiversity (Kadas 2002). Green roof designs that maximise reductions in storm water run-off may not permit sufficient through-flow of water to allow viable use for toilet flushing and garden watering. So the potential SWITCH benefits of extensive green roofs do trade-off against each other to some degree. It is hoped that a brown roof design can combine high biodiversity value with sufficient reductions in storm water run-off, whilst still supplying enough water, of sufficient quality, for viable water use in certain applications.

Aims and objectives

This investigation has three distinct, but interrelated broad research aims: (1) to examine how closely brown roofs mirror the conditions on brownfield sites, particularly in relation to the differing propensity for colonisation between these two habitat types; (2) to investigate the effect of substrate type on the ecology and hydrochemistry of brown roofs to determine which substrate can be used to best fulfil storm water interception, water re-use and biodiversity objectives; (3) to transfer the findings of the project to encourage the uptake of the best-practise in green roof design, as identified by this research.

Objectives and research questions

The project objectives and research questions have been sub-divided into four themes, (a) the effect of height and roof type on coloniser availability, (b) the sustainable management and re-use of storm water, (c) the ecological enhancement effects of green roofs, and (d) the knowledge transfer of new understanding and techniques to the Birmingham Learning Alliance.

The effect of height and roof type on coloniser availability

1. To measure the relative fallout/rain of plant seeds at multiple ground sites and roofs of various types and character.

2. To assess the viability of the collected seeds for colonisation and establishment on brown roofs.

3. To measure the relative availability of indicator groups of invertebrate colonisers on the same ground sites and roofs.

4. Does the height of brown roofs mean that they are too isolated from other similar habitats to be naturally colonised by plants and invertebrates, and can they therefore act as stepping stones between brownfield habitats?

Sustainable management and re-use of storm water

5. To measure the quantity of local precipitation, 'traditional' roof run-off, and green roof through-flow to calculate the amount of precipitation intercepted, stored and lost through evapotranspiration by brown roofs.

6. To measure the chemical quality of local precipitation, 'traditional' roof run-off, and brown roof through-flow, to determine the effect of brown roofs on water quality.

7. How do different substrate types, different amounts and types of vegetation cover, the 'age' of green roofs, and local climatic conditions affect the quantity and quality of brown roof through flow?

8. Can brown roofs be used as a useful tool for the management of storm water quantity and quality?

9. Can the through-flow of brown roofs form a viable source of water for domestic use, and if so, what is it most suitable for (e.g. toilet flushing, gardening, drinking)?

Ecological enhancement

10. To measure the changing diversity of a number of ecological indicator groups and investigate the influence of substrate type on ecological diversity.

11. To measure the changing ecological functional resource diversity on brown roofs (e.g. vegetation cover, nectar sources, etc) and investigate the influence of substrate type on functional resource diversity.

12. Can brown roofs with natural colonisation be used to mitigate for the loss of brownfield habitat, or is the use of substrates sourced from local brownfields, or seeding of brown roofs necessary to achieve this?

Knowledge transfer

13. To transfer knowledge both independently and via the Birmingham learning alliance to water utility managers, urban planners, consultancies, the general public, and academics and their students to illustrate the ecological, hydrological, social and economic value of green roofs for sustainable urban living.

Methods

The city of Birmingham, site and roof description

Birmingham is one of the nine demonstration cities in the SWITCH project and in terms of the SWITCH global change indicators is characterised by: (a) changing rainfall patterns, (b) limited water scarcity, (c) limited population growth, and (d) limited urbanisation and industrialisation. In addition the city has a: (e) high per capita income, (f) high water sector development, and (g) a moderate, maritime climate. Birmingham city itself has a population of one million but is part of a much larger conurbation.

The city largely developed in the 18th and 19th centuries as an industrial centre in Britain's industrial revolution, but over the last fifty years industry has declined substantially. The resultant industrial derelict buildings and brown-field sites have become home to diverse urban ecological communities at a variety of stages of succession (Angold *et al.* 2006; Small *et al.* 2003). However current regeneration projects (e.g. Eastside Porter and Hunt 2005) are rapidly developing derelict and brown-field sites to the detriment of Birmingham's biodiversity resource. The Nature Conservation Strategy for Birmingham (Birmingham City Council 1997) aspires to sustainably manage the city's biodiversity resources, aiming to keep the amount of brownfield habitat constant, and to allow all people close access to natural open spaces. The construction of brown roofs in the city can help achieve those aims if (a) brown roofs are shown to be a reasonable replacement for brownfield habitat, and (b) people are able to enjoy brown roof habitat, either through direct access, or by other exposure to them (e.g. seeing them through their windows).

The Nature Conservation Strategy for Birmingham also aims to link isolated wildlife habitats using wildlife corridors and wildlife stepping stones (c.f. Dawson 1994). Such initiatives are only likely to be successful where corridors and stepping stones are of a similar habitat type to the isolated habitat patches (Dawson 1994; Fernández-juricic 2000; Angold *et al.* 2006), therefore brown roofs may act as stepping stones between communities of brownfield and other disturbed early successional habitat patches. However, it is possible that the dispersal abilities of many species associated with disturbed habitats are so good, that they are capable of colonising new habitat patches regardless of the degree of connectivity between patches of habitat, and that only species with intermediate dispersal abilities could benefit from brown roof stepping stones (c.f. Gilpin 1980; Dawson 1994; Small *et al.* 2006). Good evidence supporting the concept that enhancing levels of habitat connectivity increase the dispersal of individuals between habitats is generally lacking (Dawson 1994), so the whole concept may be erroneous.

The two brown roof outdoor laboratories will be situated on The University of Birmingham's main Edgbaston campus. A phase-1 habitat survey of the campus has recently been completed and digitised. This allows the testing of the effects of a number of landscape parameters on colonisation characteristics. Two buildings have been selected for the installation of the two brown roof field laboratories: (1) the Watson building (Plate 3), and (2) the north wing of the Arts building (Plate 4). Each building is 4-5 stories high and has sufficient edge protection to allow safe sampling.

Plate 3 The roof of the Watson building (photograph Adam Bates)

Plate 4 The roof of the north wing of the Arts building (photograph Adam Bates)

Experimental design

The experimental design has two higher un-replicated treatments 'seeded' and 'un-seeded' (Figure 2). These higher treatments also act as two experimental blocks, within which there are six lower substrate treatments (a-f). Within each block there are five replicate substrate treatment mesocosms (i-v). The lower treatment mesocosms are arranged in a latin square type layout in order to minimise unwanted spatially directional environmental variations across the blocks (Figure 2).
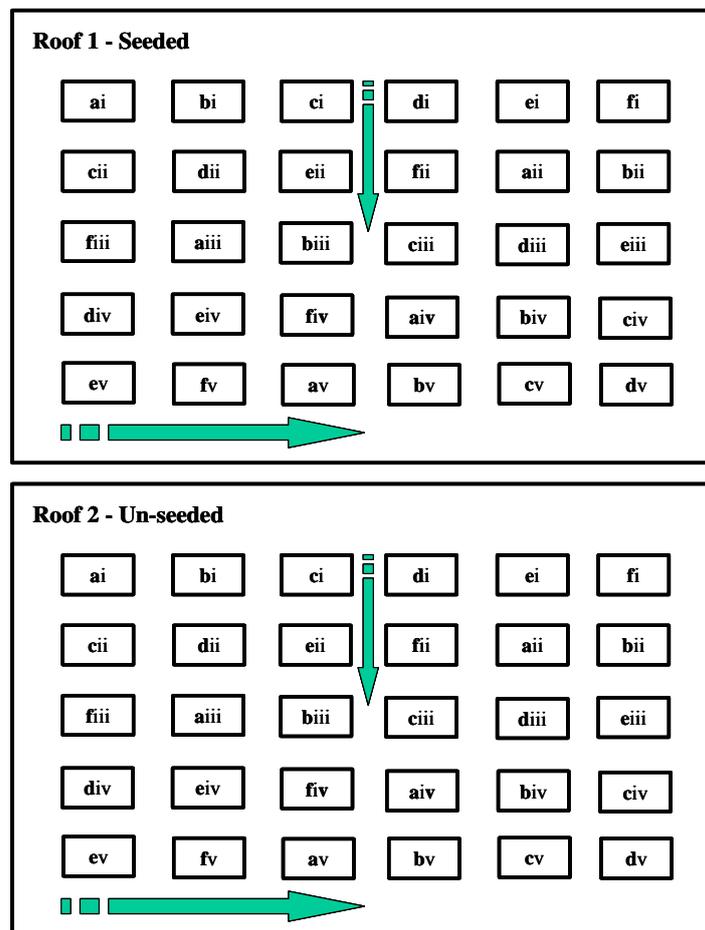
Figure 2 The experimental design (the exact distribution of mesocosms will likely vary from that shown). The letters a-f represent sediment treatments, the arrows represent possible broad directional environmental gradients and 'edge' to 'centre' gradients.

Individual mesocosms will be spatially separated in order to minimise as far as possible the transfer of individuals and propagules between mesocosms, but will not be so far apart that small-scale environmental variation is likely to become very important. On the seeded roof block, a mixture of seeds that are known to do well on brown roofs (Dusty Gedge and Emorsgate wild seed company pers comm.), mainly made up of species associated with brownfield sites in Birmingham (Appendix 1) will be spread on the trays at a density of 1 g m^{-2}, with the seed mixed with dry sand to help ensure an even distribution. Grasses have been avoided in this mix, as they tend to outperform and competitively exclude forb species on aggregate substrates and therefore lead to low diversity (Hitchmough *et al.* 2001). Cross-colonisation between mesocosms is a possibility, but their spatial separation will mean that this can only be achieved through active, or inactive 'flight', rather than cursorial movements. To date, as far as the authors are aware, all ecological investigations of green roof substrate effects have used no, or very little separation (short vertical wooden boards), to separate experimental plots. The degree of spatial separation in this experiment is therefore a considerable improvement on the other designs.

Statistical analysis

Data from the seeded and un-seeded blocks will be analysed separately. One-way ANOVA's will be performed using substrate type as the treatment, with data transformations where it is necessary to homogenise variance and move towards statistical normality.

Mesocosm design

The overall design of all mesocosms will be the same, the only factor that will vary between treatments is the substrate composition. Mesocosms will consist of a plywood deck (2.44 x 1.22m) with timber curbs at all sides and a 50mm outlet in one corner. Two bitumen waterproof layers, the upper being root resistant, will be fixed to the plywood deck, above which will sit a composite drainage-reservoir board and fleece layer. The waterproof layers will be wrapped around the timber curbs. The drainage-reservoir board will allow free drainage of the substrate and will provide a temporary store of water. The fleece layer will limit the amount of fine sediment that washes through the mesocosms. The mesocosms will be installed with a 2° slope along their long axis. Roof blocks will be placed on protection boards that will extend 1m beyond the experimental area to protect the roofs from foot traffic during sampling.

Bengtsson (2005) has shown that altering the size of experimental green roof plots does not alter the hydrological response of the plots as the response is controlled by vertical, rather than horizontal flow characteristics. Brown roof biodiversity experiments in London (Kadas pers comm.) have sampled large numbers of invertebrates from small experimental plots. Therefore the relatively small size of the experimental mesocosms was considered sufficient for the purposes of the investigation.

The sediment layer will be composed of on average 10cm of inorganic substrate, with a 1cm mulch of either sterilised loam or IKO extensive soil mix in all treatments (see below). Each tray will include one 20cm mound of inorganic substrate at the up-slope end as a biodiversity enhancement measure. The six treatments will be: (1) 40mm down crushed demolition aggregate (mainly concrete and brick, but also ceramics, sand, etc.) with a sterilised loam mulch, (2) 40mm down crushed demolition aggregate with an

IKO extensive soil mix mulch (3) 40mm down solid municipal waste incinerator bottom

ash (glass, ceramics, concrete, fused material, etc) with a sterilised loam mulch, (4) 3:1

crushed demolition aggregate : conditioned pulverised fuel ash mix with a sterilised loam

mulch, (5) 1:1 crushed demolition aggregate : asphalt shavings mix with a sterilised loam

mulch, (6) 1:1 crushed demolition waste : solid municipal waste incinerator bottom ash

mix with a sterilised loam mulch. The substrate production processes do not necessarily

preclude the colonisation by plant or invertebrate propagules, but substrates will be used

soon after their production to minimise the chance of propagule contamination as much

as possible, and few seeds are typically contained in such aggregates (Hitchmough *et al.*

2001). The tray design is illustrated in Figure 3.

Naturally colonising, or seeded vegetation
10mm mulch
Average 100mm deep aggregate mix
Permanite filter layer
Permanite drainage/reservoir board
Permanite Superflex T-O Anti-root slate finish®
Permanite superbase underlay®
Plywood tray
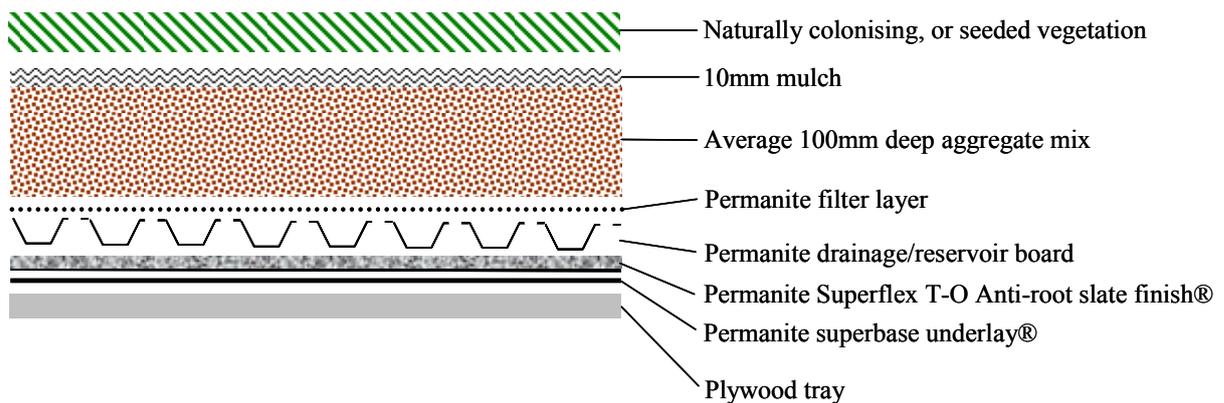
Figure 3 Brown roof tray design used in this investigation

Monitoring

The project objectives require concurrent monitoring of multiple ecological,

hydro-meteorological, water quality, and 'soil' conditions over the whole period of

investigation. However the temporal distribution and resolution of this monitoring will

vary because of likely differences in the rate of development of the different variables.

The temporal distribution of sampling is currently provisional, and will depend very much on the rate of development and changing meteorological conditions.

Ecological

Target taxonomic study groups and identification precision

Changing biodiversity and ecological community composition on the experimental units will be assessed using a number of taxonomical groups chosen for their community function, ease of sampling and identification, and microhabitat dependencies. Sampling and identification of all species will not be possible due to the large range of sampling methods, requirements for diverse taxonomical expertise, and potential damage to the developing biological communities.

The target study groups and level of identification are: (1) carabid beetles (Coleoptera, Carabidae), identified to species; (2) other beetles (Coleoptera) identified to species in most instances; (3) spiders identified to species in most instances; (4) wasps, identified to species where possible; (5) bees, identified to species; (6) butterflies, identified to species; (7) birds, identified to species; and (8) plants, identified to species where possible. Carabid beetles are strongly dependent on sediment microclimate and structure, so are good indicators of substrate conditions and have variable active flight capabilities (Thiele 1977). Spiders can be indicative of substrate conditions if they are ground dwelling, but can also be indicative of plant structural conditions if they are orb weaving. They are not capable of active flight, but are dependent on passive 'flight' by ballooning on air currents (Bristowe 1958). Other beetle species range markedly in their microhabitat and dispersal capabilities and are indicative of substrate conditions, and plant structure and species. Many species of bees and wasps are dependent on open

friable substrate for nesting and shelter, and are therefore often associated with brownfield sites (Falk 1991; O'Toole and Raw 1991) and could be favoured by brown roofs (Grant *et al.* 2003). Some species, particularly the social species, are strong fliers, but flight ability typically decreases strongly with body size (Gathmann and Tscharntke 2002). Adult and larval bees and many wasps require nectar and pollen for food (Potts *et al.* 2003), and in most geographical regions bees are the principle pollinator group (Michener 2000). Similarly, adult butterflies require nectar for food, often from specific plants, and the larvae of many species are often associated with a specific host plant (Howarth 1973). Birds travel widely looking for food and are good indicators of the type and range of food resources available on the mesocosms. Plants are the most important functional group, largely determining the habitat structure and ecological resource availability (e.g. nectar and pollen foodstuffs).

The chosen taxonomic study groups thus comprise species with wide ranging dispersal abilities, which are likely to act as indicators of several ecological habitat characteristics. They also occupy several levels in the food chain and occupy many different feeding niches, including general and specialist phytophages (plant eaters), for example, granivores (seed eaters), nectar feeders, pollen feeders; detritivores (detritus eaters); scavengers; generalists; parasites; and predators. They should therefore provide a good representation of the biodiversity and ecological community composition of the mesocosms.

Sampling methods

Due to the limited spatial extent of the study mesocosms and the need to limit interference with successional trajectories as far as possible, sampling methods have been

designed to minimise physical damage to the habitats and the removal of organisms. Where possible therefore, organisms will be identified *in situ*, with only a few samples taken for identification purposes.

Sampling will take place every two weeks between April and September, and less frequently during the winter. The sequence of sampling will be rotated in order to avoid bias due to the diurnal rhythms of the various study groups. Ecological sampling will comprise four elements: (1) vegetation surveys, (2) non-fatal pitfall trapping, (3) bird surveys, and (4) 'general' entomological surveys. Digital photographs of the mesocosms will also be taken as a visual record of their development.

Vegetation surveys will comprise both floristic, and structural components, which will encompass the entire area of each tray. Given the relative small size of the mesocosms, and the recommended quadrat sizes for the expected communities, smaller samples are not appropriate (c.f. Kent and Coker 1996). Floristic surveys will involve the identification of all vascular plants, except the graminoids, to species or taxonomic group using appropriate floristic keys and identification guides (e.g. Clapham *et al.* 1985; Stace and Thompson 1997; Rose and O'Reilly 2006). Voucher specimens and digital colour photographs will be taken in cases when identification proves difficult and the opinion of botanical experts sought. The cover abundance of taxa will be estimated on the Domin-Krajina scale. This semi-quantitative measure involves the rapid visual estimation of abundance at low density, or cover at higher density, and although subject to some degree of error is likely to provide a good summary of the coverage of different taxa (c.f. Smartt *et al.* 1976).

Vegetation structural surveys will comprise three main elements: (a) analysis of stratification, (b) analysis of the cover-abundance of different structural elements, and (c) analysis of the richness of nectar, pollen and seed resources. The approximate average and maximum height of ground, field and scrub layers (when present) will be measured to provide a summary of vegetation stratification. The Domin-Krajina scale will be used to estimate the cover abundance of bare ground, forbs, graminoids, lichens and mosses, flowering plants, plants in seed, and woody plants. The richness and abundance of nectar, pollen and seed resources will be determined simply by summing the number of species in seed or flower, and estimating the cover abundance of plants in seed and flower. Plant pollinator and plant granivore interactions are clearly complex and dependent on a variety of factors, such as the amount of nectar and pollen, nectar concentration, flower morphology, seed abundance, seed size, and seed shape (e.g. O'Toole and Raw 1991; Honek *et al.* 2003; Potts *et al.* 2003). However, the abundance and diversity of flowering plants have been shown to be strongly positively correlated with the diversity and abundance of pollinators (Banaszak 1996; Steffan-Dewenter and Tscharntke 1997; Potts *et al.* 2003, 2004), and granivores are known to be adapted to eating seeds of certain species (Honek *et al.* 2003), so they are likely to provide reasonable summary measures of the diversity of nectar and seed resources. The vegetation survey record sheet that will be used is shown in Appendix 2.

Non-fatal pitfall trapping would be used to sample ground-active beetles and spiders. Species that could be identified using a hand lens could then be released unharmed, thereby limiting the damage to the ecological communities. A modified trap (Bates *et al.* 2005), which helps prevent within-trap predation by separating captured

individuals by size, would be employed with damp sediment in the bottom to prevent the desiccation of captured individuals (Figure 4). Two traps would be used per tray and opened for 24-hours at the time of sampling.
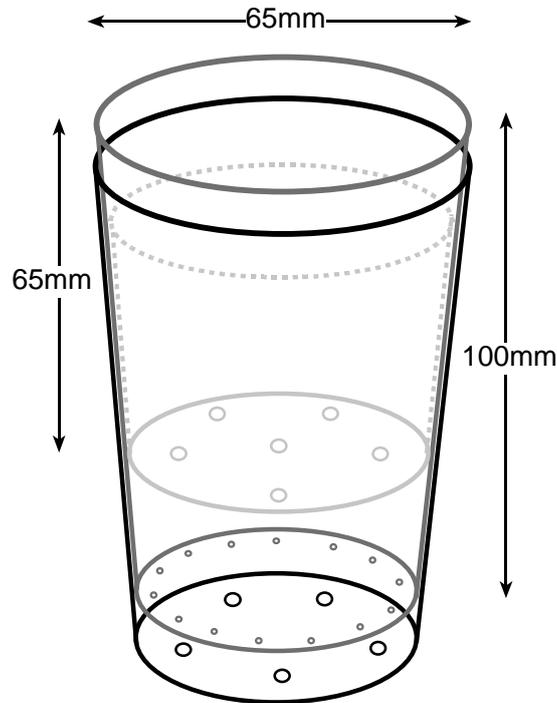
Figure 4 Design of the modified pitfall trap. The two outer section of the trap are 0.2L clear plastic cups, the innermost section is a 0.3L clear plastic cup with the upper part removed. Holes (3mm) in the bottom of the innermost and outermost sections allow small arthropods and water to pass through respectively. Pin-sized holes in the middle section allow the drainage of water, but not the passage of small arthropods. Damp sediment in the lower section reduces mortality due to desiccation.

Bird survey techniques are adapted from those of Brenneisen (2003) and would involve sitting out of sight close to each experimental block identifying bird species with the aid of binoculars and bird keys where necessary. The best time of the day for general bird surveys is dawn, as this is the time when bird territorial displays and song are most common (Bibby *et al.* 2000). However, the aim of this survey is to detect the utilization of green roof resources by birds, rather than to detect their presence in the area of the

green roof mesocosms. Therefore, observations will be made over three one-hour periods in mid-morning, mid-afternoon and early evening and notes taken on which mesocosms are used by each bird and their activity at the time. It will not be possible to determine the actual numbers of visiting birds during observation periods, because of the difficulty in determining re-visits from individuals. Therefore, data will be expressed in terms of the number of visits, rather than number of visiting individuals. Appendix 3 illustrates the bird recording sheet that will be used.

General invertebrate surveys would mainly be aimed at bees, wasps and orb weaving spiders and will involve general observations, combined with limited sweep netting. Species will either be identified *in situ* when feasible, captured and identified, or captured and removed for later identification. Additional notes will be made about the activity of bees and wasps (e.g. using burrow, visiting flowers, etc.), so that foraging and nesting activity can be distinguished.

Hydrological and Meteorological

To adequately quantify and understand the hydrological process within the roof trays it is necessary to measure the inputs and outputs from the system over time. The climate is clearly a key control as this determines the amount of water entering the system as well as influencing evaporative losses, soil moisture content and temperature. Local microclimates are common in the proximity of buildings as the mesoclimate is influenced by site aspect, elevation and roof form. In order to accurately measure the microclimate variables, a fully logged weather station will be installed on the roof to monitor air temperature, rainfall, wind speed, wind direction, relative humidity, and direct and indirect solar radiation.

Water falling on the roof tray will percolate through the substrate. That which is not retained by the substrate or lost due to evapotranspiration will leave mesocosms via the 50mm diameter drain situated in the base. To more accurately quantify the volume of through-flow, the discharge from three mesocosms with the same substrate treatment will be combined and channeled through a 'V-notch' weir. The depth of the water behind the weir will be measured using an ultrasonic transducer, the output from which will be used to calculate the water flow. The apparatus will be semi-mobile insofar as it will be possible to move the monitoring hardware between trays containing different substrates until an adequate dataset for each treatment has been gathered.

Soil moisture and temperature probes will also be installed at various depths within the substrate. By comparing inflows and outflows, the hydrological properties of the substrates and the influences upon flow and water balances will be investigated. Both the transducers of the weather station and the roof trays will be continuously monitored and recorded by datalogger.

Soil moisture probe

Flow meter

Temperature (surface and at depth)

logger
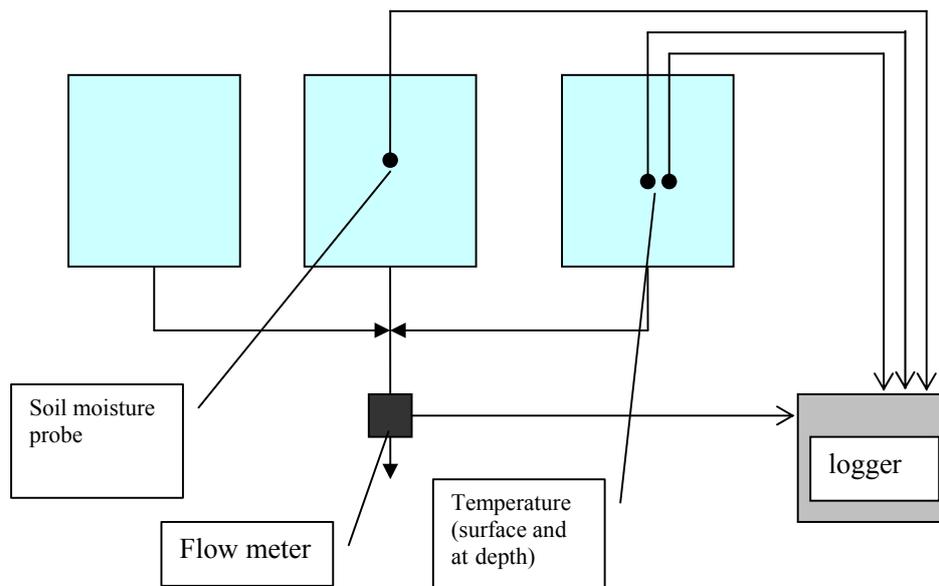
Figure 5 A schematic diagram of the mesocosm monitoring network.

Water quality

The water quality of through-flow from the brown roofs is of importance for both the possible effects on surface or groundwater quality, and for the potential viability of harvesting it for sub-potable household use such as toilet flushing, car washing, and garden watering. The likely required water quality for sub-potable household use is higher than that for release into surface or groundwater in most cases so the water quality monitoring will be mainly aimed at detecting failure of suitability for household re-use. However, the negative effects of certain substances (e.g. sulphate and phosphate) are most apparent in aquatic habitats, so in some cases water quality monitoring was extended to substances not covered by drinking water quality standards. Other measured variables, such as pH, conductivity and alkalinity, are useful in the interpretation of the through-flow water quality.

At present there is no national or EU legislation defining the required water quality standards for using sub-potable water in households (Hochstrat *et al.* 2006; House of Lords 2006). However, pets and children can potentially drink from toilets, and there is a genuine risk of misconnecting harvested water to the mains (House of Lords 2006). The water can be treated (e.g. disinfected and filtered), but each level of treatment will increase its cost and therefore decrease the financial viability of using the harvested water. Furthermore, the general public are often somewhat reticent about using harvested water in the home (Baggett 2006). Therefore, harvested water should ideally be of high quality in order to minimise potential health risks, be financially viable, and convince the general public that the water is safe to use.

The national (and EU) Water Supply (Water Quality) regulations (2000) for potable water were used to produce a preliminary list of water quality standards (Appendix 4), out of which several substances were selected, which our preliminary knowledge of rainfall and aggregate chemistry suggested might be of concern. Pulverised fuel ash (PFA), for example, can have very high levels of trace metals sorbed to particle surfaces (e.g. Mo, Se, As, Cr, Zn, Cd, Pb, Ni, Ti and Hg), and elevated levels of calcium ions, sulphate, boron, molybdenum, arsenic and selenium, can, depending on pH, leach from PFA (Theis and Wirth 1977; Cherkauer 1980; Le Seur Spencer and Drake 1987; Lee and Spears 1995). Municipal incinerator bottom ash can leach a variety of metals (e.g. As, Ba, Be, Cd, Cr, Cu, Hg, Mo, Pb, Sr and Zn) when the pH is very high before it begins to weather (mainly through carbonation), and also under low pH conditions (Buchholz and Landsberger 1995; Johnson *et al.* 1995; Meima and Comans 1999; Meima *et al.* 2002). Calcium and magnesium can leach from Portland cement concrete aggregate (Dollimore *et al.* 2001) and sulphate often leaches from brick and concrete aggregate (David Coleman pers comm.). *Escherichia coli* concentrations are also known to sometimes (e.g. the BedZED extensive sedum green roof) be high from green roof through-flow (Peter Wright pers. comm.). Green roof through-flow often has high concentrations of nitrate and phosphate, particularly when composts or fertilisers are used (Ngan 2004; Ed Snodgrass pers comm.). In addition, bituminous roof waterproofing has been shown to elevate pH, conductivity and the concentration of calcium, potassium, magnesium, silicon and chloride relative to rainfall in Birmingham (Jane Harris unpublished data).

Through-flow water quality will be compared with the water quality of three rainfall samples per roof collected during the same storm event. Rainfall will be collected from sloping $1m^2$ plastic sheets that decant into collecting vessels in order to collect sufficient rainfall for all analyses. Sealable containers will be positioned to catch through-flow from three replicate mesocosms of each substrate treatment at the onset of rainfall events before any through-flow is generated and then removed at the end of the rainfall event to give an integrated water sample for that rainfall event. The number of rainfall events studied will depend upon the frequency of events and the consistency of results.

The collection, preparation and storage of the water samples will follow the recommendations of Eaton *et al.* (2005) wherever possible. As soon as possible on site the conductivity and pH of samples will be measured with the appropriate meters and the turbidity determined using a Nova 60 Spectroquant$^®$ photometer. The volume of samples will be measured and the samples (or sub-samples, depending on sample volume) filtered on pre-weighed 0.45μm cellulose nitrate filters (acid-washed for metal analysis) as soon as possible to remove any suspended sediments and to allow later determination of the concentration of suspended sediments. Total alkalinity will be determined using sulphuric acid (H_2SO_4) titration with phenolphthalein and methyl purple indicator solutions using a HACH digital titrator (model 16900-01). The concentration of nitrate (NO_3-N), ammonium (NH_4-N), sulphate (SO_4), phosphate (PO_4-P) and chloride (Cl) anions will be determined using a Nova 60 Spectroquant$^®$ photometer using the appropriate photometric test kits.

Sub-samples will be collected in acid-washed polypropylene or linear polythene sample bottles and acidified with Aristar nitric acid to a 2% solution (~pH 2), to keep

metals in solution, and refrigerated until later (<6 months) analysis. These samples will be analysed using an Agilent 7500 series inductively coupled plasma mass spectrometer (ICPMS) using an ASX-520 autosampler for a range of metals. Initial semi-quantitative analyses on water samples will be run to identify elements in high relative concentration and these elements will be focused on in later element-specific analyses. These element specific analyses will at least include analysis of the concentrations of aluminium, arsenic, copper, molybdenum, iron, lead and cadmium.

The enzyme substrate Colitag^{TM} test will be used to test for the presence or absence of coliform bacteria and, more specifically, *Escherichia coli*, in 100ml samples of through-flow. This method relies on the detection of β-glucuronidase and β-D-galactosidase, which are characteristic of *E. coli* and coliform groups respectively. Samples will be refrigerated as quickly as possible and processed within 24 hours (see Appendix 5 for details). A test for the presence or absence of coliform bacteria and *E. coli* is a sufficient microbiological quality assessment because the national water quality regulations dictate that no coliform bacteria or *E. coli* should be present in potable water (Eaton *et al.* 2005), and the method is at least as efficient as the membrane filter and multiple-fermentation-tube methods at detecting the presence of coliform bacteria and *E. coli* (Clark and El-Shaarawi 1993).

'Soil' conditions

The changing conditions within the soil are of fundamental importance for the development of plants, the water quality of through-flow, the water storage capacity, and to a lesser extent, the development of invertebrate assemblages. The soil water content is seen as a key variable for extensive green roof plant communities because of the

relatively thin depth of soils and the increased level of evapotranspiration due to enhanced wind speeds. For healthy plant growth the concentration of water in soils should be high enough to be easily available to roots, but not so high that roots cannot get enough oxygen for respiration (Handreck and Black 2005). The ability of a soil to hold water is dependent on a range of factors including the amount of organic matter and the particle size distribution (Rowell 1994). Bengtsson (2005) and Bengtsson *et al.* (2005) showed that runoff is not generated until the roof substrate has reached field capacity and that the amount of runoff storage corresponds with the conditions at the permanent wilting point.

Schrader and Bőning (2006) have shown that in extensive sedum green roofs the total soil nitrogen and percentage organic matter increase with roof age, and pH declines with roof age. The availability of nutrients, such as nitrogen, is another key determinant of plant growth and the water quality of through-flow. Both the ash based and demolition waste based substrates are likely to develop into alkaline soils, but pH may fall over time due to the leaching of carbonate and bicarbonate and the addition of sulphuric and nitric acid from acid rain (Darlington 1981; Handreck and Black 2005). Changing pH is of particular importance because it controls the availability of many heavy metals (e.g. Theis and Wirth 1977; Buchholz and Landsberger 1995; Steusloff 1998).

Selected chemical and physical characteristics of the soils will be determined. Soil samples will be taken from each mesocosm every five months for physical measures after a two-month bedding in period, and every two months for chemical measures. Following analysis the samples will be returned to the same area from which they were sampled. An undisturbed area of soil will be sampled each time.

Chemical

The pH will be measured in three sub-samples of 5ml of soil in a calcium chloride solution according to the methods in ISO 10390:2005 (Appendix 6). Calcium chloride solution is thought to give the pH reading most close to that in the soil (Handreck and Black 2005) and was therefore chosen over water and potassium chloride. Electrical conductivity will be measured from three 20g sub-samples of soil suspended in 100ml of water according to the methods in BS 7755-3.4:1995 (Appendix 5).

Physical

The sediment size distribution will be determined once after the bedding-in period from three sub-samples by wet sieving, oven drying (105°C) and weighing the sediments for each phi size class division above 2mm. The size distribution of particles <2mm will be determined using a laser particle sizer. The overall (all size fractions) density of soil particles will be determined from three sub-samples by measuring the volume of a known mass of soil particles using a method modified from Rowell (1994), see Appendix 7. The overall (all size fractions) dry bulk density of the soil will be determined from three small areas of the mesocosms using the excavation method, which involves excavating a quantity of soil, drying and weighing it and determining the volume of the excavation by filling it with sand (modified from ISO 11272:1998, Appendix 8). The soil porosity expressed as a volume ratio will be calculated using:

Porosity = 1 – (bulk density/particle density)

The air filled and water filled porosity at the approximate field capacity and permanent wilting point will be measured in three sub-samples of about 10g of soil by measuring the change in mass after heating at 105°C (Appendix 9). Soil samples for the

determination of field capacity will be taken a day after heavy rainfall, when the soil has freely drained, and samples for the determination of permanent wilting point will be taken during prolonged dry periods. Due to the difficulty associated with determining when each of these soil water contents are reached, soil moisture content will also be measured remotely using soil moisture probes and used to help determine when the field capacity and permanent wilting point are reached. The water content measurements will help to ground truth the readings from the moisture probes. The air filled porosity at the approximate field capacity and permanent wilting point will be calculated using:

Air filled porosity = porosity – water content at field capacity

or permanent wilting point

The loss on ignition, which is an approximate measure of organic matter content, will be determined in three oven-dried (105°C) sub-samples of about 10g of soil by measuring the change in mass after heating at 550°C in a muffle furnace (modified from Rowell 1994, Appendix 10).

Variability in coloniser availability

The colonisation of green roofs will generally require the ability to disperse aerially, and the relative colonisation ability will vary markedly between species. Birds, for example, are almost all capable of the flight distance necessary to utilise green roofs, but their behaviour and habitat requirements will dictate whether they utilise green roofs in reality. Many flighted invertebrates will be capable of dispersal to green roofs but this will depend on their behaviour, habitat requirements, flight ability and weather conditions (c.f. Southwood 1962). Furthermore, other species propagules or individuals may disperse to green roofs through: (1) movement by wind, or anemochory, (2) transport by

birds (ornithochory), which can occur through three processes: (a) synzoochory, where a bird disgorges seeds usually after eating the fruit, (b) endozoochory, where a seed passes through the digestive system of a bird, and (c) epizoochory, where a seed is transported on the body of a bird, although this is generally a rare phenomenon (c.f. Van der Pijl 1982), or even (3) transport by ants (myrmecochory), which are known to disperse seeds to walls (Darlington 1981; Gilbert 1992). Invertebrate specialists of early successional (e.g. brownfield sites, exposed riverine sediments, grasslands), and therefore, transient habitats are typically capable of dispersing long distances (Southwood 1962), as are many plant species of similar habitats, mainly through anemochory (Van der Pijl 1982; Fenner 1985; Soons and Heil 2002). Plant species are known to colonise new habitat from long distances surprisingly rapidly (e.g. Bradshaw 1983; Gibson *et al.* 1987), and many species of plant colonise the roofs, walls and gutters of buildings, mainly through anemochory (Ridley 1930; Darlington 1981; Payne 2000). Walls and buildings tend to concentrate airflows and wind blown particles in strong up-draughts, with a large proportion of these particles falling out of suspension at the top where the velocity of the wind slows down (Darlington 1981; Payne 2000). However, it remains to be seen whether pools of dispersers on roofs are comparable with those on the ground. In addition, species whose individuals or propagules can disperse to green roofs are not necessarily capable of establishing and, thus, colonising green roofs. Both the propensity for the target study groups (see 'Green roof substrate effects') to disperse to green roofs and to establish themselves on green roofs will be assessed.

Experimental design

Six ground sites and nine roof sites (1-6 stories) have been selected across the
University of Birmingham campus. Ground sites vary from brownfield sites with bare
ground and ruderal vegetation where there are distinct swards of vegetation to 'rain' into
seed traps, to mown grass, where seeds will have to disperse in from elsewhere. Roofs
vary widely in both their height and character (e.g. type of parapet, area). All sites are
spread over a wide area and vary in their proximity to potential source habitats. At each
site 12 seed traps, 3 window traps and 3 pan traps will be installed and emptied weekly
during the spring, summer and autumn and sampled less frequently in winter. Data will
be analysed by individual months in order to investigate the seasonal variation in
coloniser availability.

Environmental variables

A range of semi-quantitative and quantitative environmental variables will be
measured for each trap on a monthly basis (Table 1). The distance from the nearest sites
that are vegetated or contain ruderal species, and the area of this habitat within 50, 100,
200 and 500m will be measured in ArcView from the phase 1 habitat survey geographical
information system. Distances to roof sites will be the shortest possible distance to the
roof accounting for the building height (ie the hypotenuse calculated using Pythagoras'
theorem). The wind direction will be measured on each visit and used to work out the
predominant wind direction at each site. The cover-abundance of forbs, plants in seed,
and plants in flower within 1m of the trap will be estimated on the Domin-Krajina scale.
The variables that are only relevant to roof sites will be examined using separate
ordinations in order to test their significance. Weather variables will also be measured at

the university ground weather station and will be examined with a view to explaining the

temporal variation in coloniser availability (c.f. Southwood 1962; Forcella 1996).

Table 1 Environmental variables used to characterise trap position

Variable	Variable code	Data type	Scoring method
Roof ground	Rogr	Binary	0 = ground, 1 = roof
Height above ground	Height	Decimal	From building plans
Distance from roof edge	Distedge	Decimal	Measured
Height of parapet (if solid)	Paraheig	Decimal	Measured
Distance from vegetated	Distveg	Decimal	Measured in ArcView
Distance from ruderal	Distrud	Decimal	Measured in ArcView
Distance from vegetated along predominant wind direction	Distvegw	Decimal	Measured in ArcView
Distance from ruderal along predominant wind direction	Distrudw	Decimal	Measured in ArcView
Area of ruderal habitat within 50m	Arrud50	Decimal	Measured in ArcView
Area of ruderal habitat within 100m	Arrud100	Decimal	Measured in ArcView
Area of ruderal habitat within 200m	Arrud200	Decimal	Measured in ArcView
Area of ruderal habitat within 500m	Arrud500	Decimal	Measured in ArcView
Area of vegetated habitat within 50m	Arveg50	Decimal	Measured in ArcView
Area of vegetated habitat within 100m	Arveg100	Decimal	Measured in ArcView
Area of vegetated habitat within 200m	Arveg200	Decimal	Measured in ArcView
Area of vegetated habitat within 500m	Arveg500	Decimal	Measured in ArcView
Maximum height of vegetation within 1m	Vegmaxh	Decimal	Measured
Approximate mean height of vegetation within 1m	Vegmeah	Decimal	Estimated and measured
Cover-abundance of plants in seed within 1m	Inseed	Ordinal	Estimated (Domin-Krajina)
Cover-abundance of forbs within 1m	Forbs	Ordinal	Estimated (Domin-Krajina)
Cover-abundance of plants in flower within 1m	Inflow	Ordinal	Estimated (Domin-Krajina)

Statistical analysis

The number of variables likely to influence the potential coloniser pool (e.g.

habitat type, habitat distribution, predominant wind direction, roof height, etc) is large, so

multivariate ordinations will be used to identify the most important factors using Canoco

for Windows version 4.51 (ter Braak and Šmilauer 1998). Individual traps will be treated

as data points. The monthly variability in coloniser availability will be analysed using

multiple regressions with weather variables, time and average cover of plants in seed and

flower as predictive variables. Where necessary for both types of analysis, data will be

transformed prior to analysis to satisfy assumptions of normality and homogeneity of variance.

Seed dispersal

There are a large number of different types of traps used to measure seed rain, but no kind of trap provides a perfect measure of seed rain, the type of trap that is best is heavily dependent on the aims of the study (Forcella *et al.* 1996; Kollmann and Goetze 1998; Page *et al.* 2002; Chabrerie and Alard 2005). The traps used have been designed to intercept and capture wind-blown seeds and still effectively sample gravity seed rain. Sticky traps were not used because of the danger of damaging seeds whilst removing them, which would interfere with the plant establishment investigation. The design of the trap is shown in Figure 5. The plywood vane on the trap is designed to intercept windblown seeds, the mesh collects seeds, but allows water to drain away. Seeds will be collected on a weekly basis and identified under a dissecting microscope where possible using appropriate keys. Seeds will be classified as filled, partially filled, or empty, and classified as plumed, plane winged, rotating winged, or fruited. Seeds from each trap will be weighed, either individually or collectively depending on their size, and the average weight of each seed type calculated. In instances where the species of seed cannot be identified, several of each seed morphotype will be grown on in a greenhouse until identification is possible.
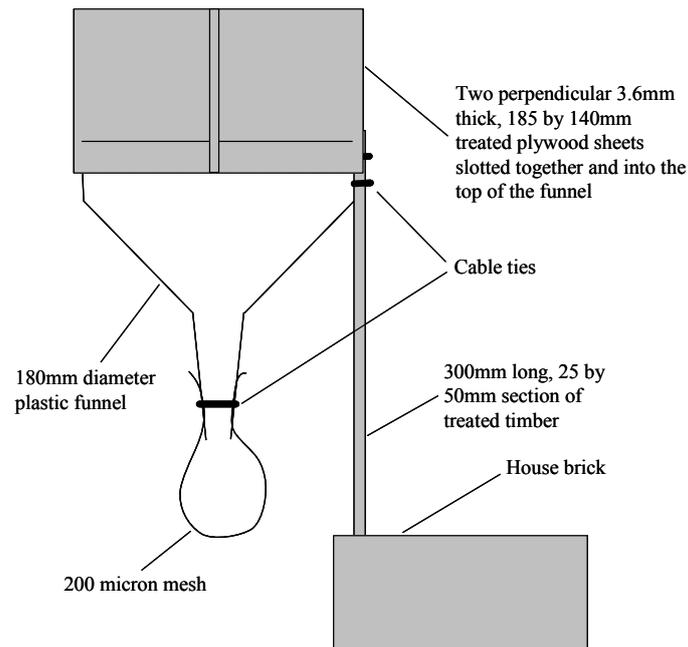
Figure 6 Schematic diagram of the seed trap that will be used in the investigation.

Plant establishment

Germination investigations will be implemented to test the viability of the seeds for establishment on brown roofs. All, or a sub-sample of seeds will be sprinkled on pots containing 100mm depth of 40mm down crushed demolition aggregate with a 1cm sterilised loam mulch (see above). Pots will be watered weekly (or more when necessary) and kept in unlit, unheated greenhouses. Un-seeded pots will be kept in amongst the seeded pots in order to assess the possibility of unwanted seed colonisation within the green house. The upkeep of pots will continue for one year to allow all seeds with all types of annual germination cycle to germinate (c.f. Chabrerie and Alard 2005). Growing conditions will be more favourable for most species in the greenhouses compared to those on real brown roofs because of the higher temperature and more regular water supply. Therefore this investigation will over-estimate seed viability for brown roof colonisation to some degree.

Invertebrate dispersal

The pool of potential invertebrate colonisers at each site will be investigated using pan and window traps. The colour of pan traps strongly influences the species caught (Disney *et al.* 1982; Leong and Thorp 1999; Laubertie *et al.* 2006), so each pan trap will have an area coloured red, yellow, white and blue on the inside. These colours on the outside of traps can potentially attract insects from some distance (Laubertie *et al.* 2006), and insects might be able to perceive them from a greater distance at ground sites. Therefore the outside of traps will be coloured in a non-attracting dark green colour (c.f. Laubertie *et al.* 2006). Pan traps will have 3cm deep saturated NaCl solution and a dash of unscented detergent to preserve captured arthropods and break up surface tension respectively.

Window traps will consist of two perpendicular sheets of clear plastic embedded into concrete in plastic trays (painted dark green on all surfaces to prevent 'attraction'), with a 3cm deep saturated salt and detergent solution to kill and preserve arthropods that fall into the trays after hitting the clear plastic (Figure 6). The concrete will weight the traps down to prevent them being blown by wind and becoming a hazard.

2mm clear styrene sheets (height = 400mm, width = 180mm)

perpendicular styrene sheet (height = 400mm, width = 250mm)

30mm deep saturated NaCl solution with unscented detergent
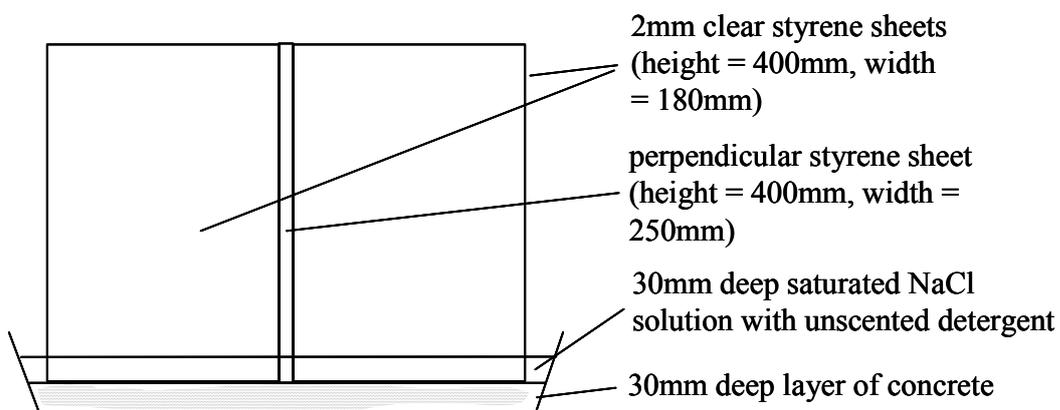
30mm deep layer of concrete

Figure 7 Schematic of the window trap design.

Invertebrate establishment

The species detected in window and pan traps on roofs will be compared with the species sampled from the brown roof mesocosms in order to assess to the difference between those species able to disperse to brown roofs and those species able to colonise brown roofs.

Knowledge transfer

ARUP will provide support for the overall development and coordination of Birmingham's Learning Alliance. The working knowledge gained from the green roof project will be an important contribution to this alliance, and will be transferred via the planned meetings of the Alliance, the Alliance newsletter and through the Web site. Within the wider SWITCH community and the other Learning Alliances, the current plans are to prepare training materials describing the implementation of the roofs and the tools that have been developed as part of the current research to address design issues and materials impacts. In addition the findings will be more widely circulated in the public and academic domains by University of Birmingham researchers through local press releases, journal publications, academic conference presentations, and lectures to university students.

References

Akbari H, Pomerantz M, Taha H. 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy* **70**: 295-310.

Andersen J. 2000. What is the origin of the carabid beetle fauna of dry, anthropogenic habitats in western Europe? *Journal of Biogeography* **27**: 795-806.

Angold PG, Sadler JP, Hill MO, Pullin A, Rushton S, Austin K, Small E, Wood B, Wadsworth R, Sanderson R, Thompson K. 2006. Biodiversity in urban habitat patches. *Science of the Total Environment* **360**: 196-204.

Aziz HA, Smith PG. 1992. The influence of pH and coarse media on manganese precipitation from water. *Water Research* **26**: 853-855.

Baggett S, Jeffrey P, Jefferson B. 2006. Risk perception in participatory planning for water reuse. *Desalination* **187**: 149-158.

Banaszak J. 1996. Ecological bases of conservation of wild bees. 55-62. In Matheson A, Buchmann SL, O'Toole C, Westrich P, Williams IH (eds.) The conservation and biology of bees in temperate habitats. Linnean Society Symposium Series 18. Academic Press, London, UK.

Barrio EPD. 1998. Analysis of the green roofs cooling potential in buildings. *Energy & Buildings* **27**: 179-193.

Bass B, Krayenhoff S. 2002. Mitigating the urban heat island with green roof infrastructure. North American urban heat island summit, Toronto.

Bates AJ, Sadler JP, Fowles AP, Butcher CR. 2005. Spatial dynamics of beetles living on exposed riverine sediments in the Upper River Severn: Method development and preliminary results. *Aquatic Conservation: Marine and Freshwater Ecosystems* **15**: 159-174.

Bengtsson L. 2005. Peak flows from thin sedum-moss roof. *Nordic Hydrology* **36**: 269-280.

Bengtsson L, Grahn L, Olsson J. 2005. Hydrological function of a thin extensive green roof in southern Sweden. *Nordic Hydrology* **36**: 259-268.

Berndtsson JC, Emilsson T, Bengtsson L. 2006. The influence of extensive vegetated roofs on runoff water quality. *Science of the Total Environment* **355**: 48-63.

Bibby CJ, Burgess ND, Hill DA, Mustoe S. 2000. Bird census techniques (2nd Ed.). Academic Press, London.

Birmingham City Council. 1997. Nature Conservation Strategy for Birmingham. Birmingham City Council, Birmingham.

Bischoff A, Vonlanthen B, Steinger T, Müller-Schärer H. 2006. Seed provenance matters – Effects on germination of four plant species used for ecological restoration. *Basic & Applied Ecology* **7**: 347-359.

ter Braak CFJ, Šmilauer P. 1998. *CANOCO reference manual and user's guide to Canoco for Windows: Software for canonical community ordination (version 4).* Microcomputer Power, Ithaca.

Bradshaw AD. 1984. Land restoration of ecosystems. *Journal of Applied Ecology* **20**: 1-17.

Brenneisen S. 2003. The benefits of biodiversity from green roofs – key design consequences. Green roofs for healthy cities – Chicago 2003, conference preceedings.

Bristowe WS. 1958. The world of spiders. Collins.

Buchholz BA, Landsberger S. 1995. Leaching dynamics studies of municipal solid-waste incinerator ash. *Journal of the Air & Waste Management Association* **45**: 579-590.

Bulloch J, Darwish A. 1993. Water wars: coming conflicts in the Middle East. Victor Gollancz, London.

Cain ML, Milligan BG, Strand AE. 2000. Long-distance seed dispersal in plant populations. *American Journal of Botany* **87**: 1217-1227.

Carter T, Jackson CR. In press. Vegetated roofs forstormwater management at multiple spatial scales. *Landscape & Urban Planning*

Carter TL, Rasmussen TC. In press. Evaluation of the hydrologic behavior of green roofs. *Journal of the American Water Resources Association*

Chabrerie O, Alard D. 2005. Comparison of three seed trap types in a chalk grassland: toward a standardised protocol. *Plant Ecology* **176**: 101-112.

Cherkauer DS. 1980. The effect of fly ash disposal on a shallow groundwater system. *Ground Water* **18**: 544-550.

Chiew FHS, McMahon A. 2002. Modelling the impacts of climate change on Australian streamflow. *Hydrological Processes* **16**: 1235-1245.

Christensen J, Christensen O. 2003. Climate modelling: severe summertime flooding in Europe. *Nature* **6925**: 805-806.

Clapman AR, Tutlin TG, Moore DM. 1985. Flora of the British Isles. Cambridge University Press, Cambridge.

Clark JA, El-Shaarawi AH. 1993. Evaluation of commercial presence-absence test kits for detection of total coliforms, *Escherichia coli*, and other indicator bacteria. *Applied & Environmental Microbiology* **59**: 380-388.

Darlington A. 1981. Ecology of walls. Heinemann Educational Books, London.

Dawson D. 1994. Are habitat corridors conduits for animals and plants in a fragmented landscape? A review of the scientific evidence. English Nature Research Report 94, Peterborough.

Dimoudi A, Nikolopoulou M. 2003. Vegetation in the urban environment: microclimatic analysis and benefits. *Energy & Buildings* **35**: 69-76.

Disney RHL, Erzinçlioğlu YZ, Howse DJdeCHD, Unwin DM, Withers P, Woods A. 1982. Collecting methods and the adequacy of attempted fauna surveys, with reference to the Diptera. *Field Studies* **5**: 607-621.

Dollimore D, Lerdkanchanaporn S, Gupta JW, Nippani S. 2001. An examination of recycled Portland cement concrete rich in dolomite and low in calcite obtained from various locations in Ohio. *Thermochimica Acta* **367**: 311-319.

Donovan RG, Sadler JP, Bryson JR. 2005. Urban biodiversity and sustainable development. Engineering Sustainability. **158** (ES2): 105-114.

Eaton AD, Clesceri LS, Rice EW, Greenberg AE (eds.). 2005. Standard methods for the examination of water and wastewater. 21st Edition. American Public Health Association.

Ellis JB, Marsalek J. 1997. Overview of urban drainage: environmental impacts and concerns, means of mitigation and implementation policies. *Journal of Hyraulic Research* **34**: 723-731.

Emilsson T, Rolf K. 2005. Comparison of establishment methods for extensive green roofs in southern Sweden. *Urban Forestry & Greening* **3**: 103-111.

Eumorfopoulou E, Aravantinos D. 1998. The contribution of a planted roof to the thermal protection of buildings in Greece. *Energy & Buildings* **27**: 29-36.

Eversham BC, Roy DB, Telfer MG. 1996. Urban, industrial and other manmade sites as analogues of natural habitats for Carabidae. *Ann. Zool. Fennici* **33**: 149-156.

Falk S. 1991. A review of the scarce and threatened bees, wasps and ants of Great Britain. Research & survey in nature conservation no. 35. NCC, Peterborough.

Fenner M. 1985. Seed ecology. Chapman & Hall, London.

Fernández-Juricic E. 2000. Avifaunal use of wooded streets in an urban landscape. *Conservation Biology* **14**: 513-521.

Forcella F, Peterson DH, Barbour JC. 1996. Timing and measurement of weed seed shed in corn (*Zea mays*). *Weed Technology* **10**: 533-543.

Gathmann A, Tscharntke T. 2002. Foraging ranges of solitary bees. *Journal of Animal Ecology* **71**: 757-764.

Gedge D. 2003. From rubble to redstarts. London Biodiversity Partnership. Unpublished report.

Gibson CWD. 1998. Brownfield Red Data: the values of artificial habitats for uncommon invertebrates. English Nature Report 273, Peterborough.

Gibson CWD, Watt TA, Brown VK. 1987. The use of sheep grazing to recreate species-rich grassland from abandoned arable land. *Biological Conservation* **42**: 165-183.

Gilbert OL. 1989. The ecology of urban habitats. Chapman & Hall, London.

Gilbert O. 1992. The flowering of cities. The natural flora of urban commons. English Nature Peterborough.

Gilbert OL, Anderson P. 1998. Habitat creation and repair. Oxford University Press, Oxford.

Gilpin ME. 1980. The role of stepping-stone islands. *Theoretical Population Biology* **17**: 247-253.

Grant G, Engelback L, Nicholson B, Gedge D, Frith M, Harvey P. 2003. Green roofs: their existing status and potential for conserving biodiversity in urban areas. English Nature Research Report No. 498.

Handreck K, Black N. 2005. Growing media for ornamental plants and turf (third ed.). UNSW Press, Sydney.

Harrison C, Davies G. 2002. Conserving biodiversity that matters: practitioners' perspectives on brownfield development and urban nature conservation in London. *Journal of Environmental Management* **65**: 95-108.

Hitchmough J, Kendle T, Paraskevopoulou AT. 2001. Seedling emergence, survival and initial growth of forbs and grasses native to Britain and central/southern Europe in low productivity urban "waste" substrates. *Urban Ecosystems* **5**: 285-308.

Hochstrat R, Wintgens T, Melin T, Jeffrey P. 2006. Assessing the European wastewater reclamation and reuse potential – a scenario analysis. *Desalination* **188**: 1-8.

Honek A, Martinkova Z, Jarosik V. 2003. Ground beetles (Carabidae) as seed predators. *European Journal of Entomology* **100**: 531-544.

House of Lords. 2006. Science and technology – Eighth report. Science and Technology Committee publications. http://www.publications.parliament.uk/pa/ld200506/ldselect/ldsctech/191/19102.htm

Howarth TG. 1973. South's British butterflies. Frederick Warne & Co. Ltd., London.

Howe HF, Smallwood J. 1982. Ecology of seed dispersal. *Annual Review of Ecology & Systematics* **13**: 201-228.

Hulme M, Jenkins GJ, Lu X, Turnpenny JR, Mitchell TD, Jones RG, Lowe J, Murphy JM, Hassell D, Boorman P, McDonald R, Hill S. 2002. Climate change scenarios for the United Kingdom: the UKCIP02 scientific report. Tyndall Centre for Climate Change Research, Norwich.

IPPC. 2001. Climate change 2001: the scientific basis. Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds.). Working group 1 to the 3rd assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Johnson CA, Brandenberger S, Baccini P. 1995. Acid neutralizing capacity of municipal waste incinerator bottom ash. *Environmental Science & Technology* **29**: 142-147.

Johnston J, Newton J. 1993. Building green, a guide for using plants on roofs, walls and pavements. The London Ecology Unit, London.

Jurado E, Westoby M, Nelson D. 1991. Diaspore weight, dispersal, growth form and perenniality of central Australian Plants. *Journal of Ecology* **79**: 811-828.

Kadas G. 2002. Study of invertebrates on green roofs – how roof design can maximise biodiversity in an urban environment. MSc Conservation thesis, Department of Geography, UCL.

Kent M, Coker P. 1996. Vegetation description and analysis. John Wiley & Sons, Chichester.

Kidd J. 2005. Optimum green roof design for Brisbane. BSc dissertation for the University of Brisbane, Australia.

Kim K-G. 2003. The application of the biosphere reserve concept to urban areas: the case of green rooftops for habitat network in Seoul. Urban Biosphere & Society Conference. Partnership of Cities Conference, Columbia University, New York.

Köhler M, Schmidt M, Grimme FW, Laar M, Gusmäo F. 2002. Urban water retention by greened roofs in temperate and tropical climate. *Technology Resource Management & Development – Scientific Contributions for Sustainable Development* **2**: 151-162.

Köhler M, Schmidt M, Grimme FW, Laar M, de Assunção Paiva VL, Tavares S. 2002. Green roofs in temperate climates and in the hot-humid tropics – far beyond the aesthetics. *Environmental Management & Health* **13**: 382-391.

Köhler M. 2004. In proceedings of the greening rooftops for sustainable communities symposium. Hosted by Green Roofs for Sustainable Cities and the City of Chicago, Chicago 22-24 June 2004.

Kollmann J, Goetze D. 1998. Notes on seed traps in terrestrial plant communities. *Flora* **193**: 31-40.

Kosareo L, Ries R. in press. Comparative life cycle assessment of green roofs. *Building & Environment*

Kumar R, Kaushik SC. 2005. Performance evaluation of green roof and shading for protection of buildings. *Building & Environment* **40**: 1505-1511.

Laubertie EA, Wratten SD, Sedcole JR. 2006. The role of odour and visual cues in the pan-trap catching of hoverflies (Diptera: Syrphidae). *Annals of Applied Biology* **148**: 173-178.

Lawler DM, Petts GE, Foster IDL, Harper S. 2006. Turbidity dynamics during spring storm events in an urban headwater river system: the Upper Tame, West Midlands, UK. *Science of the Total Environment* **360**: 109-126.

Lazzarin RM, Castelloti F, Busato F. 2005. Experimental measurements and numerical modelling of a green roof. *Energy & Buildings* **37**: 1260-1267.

Le Seur Spencer L, Drake LD. 1987. Hydrogeology of an alkaline fly ash landfill in eastern Iowa. *Ground Water* **25**: 519-526.

Lee S, Spears DA. 1995. The long term weathering of PFA and implications for groundwater pollution. *Quarterly Journal of Engineering Geology* **28**: 1-15.

Leong JM, Thorp RW. 1999. Colour-coded sampling: the pan trap colour preferences of oligolectic and nonligolectic bees associated with a vernal pool plant. *Ecological Entomology* **24**: 329-335.

Liu K. 2002. Research quantifies benefits of rooftop gardens. *Construction Innovation* **7**: winter.

Lott DA, Daws JT. 1995. The conservation value of urban demolition sites in Leicester for beetles. *Land Contamination & Reclamation* **3**: 79-81.

McMarlin RM. 1997. Green roofs: not your garden-variety amenity. *Facilities Design & Management* **16**: 32.

Meima JA, Comans RNJ. 1999. The leaching of trace elements from municipal solid waste incinerator bottom ash at different stages of weathering. *Applied Geochemistry* **14**: 159-171.

Meima JA, van der Weijden RD, Eighmy TT, Comans RNJ. 2002. Carbonation processes in municipal solid waste incinerator bottom ash and their effect on the leaching of copper and molybdenum. *Applied Geochemistry* **17**: 1503-1513.

Mentens J, Raes D, Hermy M. 2006. Green roofs as tools for solving the rainwater runoff problem in the urbanized 21st century? *Landscape & Urban Planning* **77**: 217-226.

Michener CD. 2000. The bees of the world. Johns Hopkins University Press, Baltimore, Maryland, USA.

Micklin PP. 1988. Desiccation of the Aral Sea – a water management disaster in the Soviet-Union. *Science* **241**: 1170-1175.

Monterusso MA, Rowe DB, Rugh CL, Russell DK. 2004. Runoff water quantity and quality from green roof systems. *Acta Horticulturae* **639**: 369-376.

Monterusso MA, Rowe DB, Rugh CL. 2005. Establishment and persistence of *Sedum* spp. and native taxa for green roof applications. *HortScience* **40**: 391-396.

Ngan G. 2004. Green roof policies: tools for encouraging sustainable design. Unpublished report.

Niachou A, Papakonstantinou K, Santamouris M, Tsangrassoulis A, Mihalakakou G. 2001. Analysis of the green roof thermal properties and investigation of its energy performance. *Energy & Buildings* **33**: 719-729.

Nilsson C, Berggren K. 2000. Alterations of riparian ecosystems caused by river regulation. *Bioscience* **50**: 783-792.

Onmura S, Matsumoto M, Hokoi S. 2001. Study on evaporative cooling effect of roof lawn gardens. *Energy & Building* **33**: 653-666.

Orwell RL, Wood RL, Tarran J, Torpy F, Burchett MD. 2004. Removal of benzene by the indoor plant/substrate microcosm and implications for air quality. *Water, Air & Soil Pollution* **157**: 193-207.

O'Toole C, Raw A. 1991. Bees of the world. Sterling Publishing, New York, USA.

Page MJ, Newlands L, Eales J. 2002. Effectiveness of three seed-trap designs. *Australian Journal of Botany* **50**: 587-594.

Payne RM. 2000. Flora of roofs. Booklet. Kings Lynn.

Pediaditi K, Wehrmeyer W, Chenoweth J. 2005. Monitoring the sustainability of brownfield redevelopment projects: the Redevelopment Assessment Framework. *Land Contamination & Reclamation* **13**: 173-183.

Pilling CG, Jones JAA. 2002. The impact of future climate change on seasonal discharge, hydrological processes and extreme flows in the Upper Wye experimental catchment, mid-Wales. *Hydrological Processes* **16**: 1201-1213.

Porter L, Hunt D. 2005. Birmingham's Eastside story: making steps towards sustainability? *Local Environment* **10**: 525-542.

Potts SG, Vulliamy B, Dafni A, Ne' eman G, Willmer P. 2003. Linking bees and flowers: How do floral communities structure pollinator communities. *Ecology* **84**: 2628-2642.

Potts SG, Vulliamy B, Roberts S, O'Toole C, Dafni A, Ne'eman G, Willmer PG. 2004. Nectar resource diversity organises flower-visitor community structure. *Entomologica Experimentalis et Applicata* **113**: 103-107.

Relf PD, Lohr VI. 2003. Human issues in horticulture. *HortScience* **38**: 984-993.

Rich TCG, Woodruff ER. 1996. Changes in the vascular plant floras of England and Scotland between 1930-1960 and 1987-1988: the BSBI monitoring scheme. *Biological Conservation* **75**: 217-229.

Ridley HN. 1930. The dispersal of plants throughout the world. Reeve and Co., Ashford.

Robson M, Spence K, Beech L. in press. Stream quality in a small urbanised catchment. *Science of the Total Environment*

Rose F, O'Reilly C. 2006. The wild flower key (Revised Edition) – How to identify wild plants, trees and shrubs in Britain and Ireland. Frederick Warne Books.

Rosenfeld AH, Akbari H, Romm JJ, Pomerantz M. 1998. Cool communities: strategies for heat island mitigation and smog reduction. *Energy & Buildings* **28**: 51-62.

Rowell DL. 1994. Soil science: methods and applications. Longman, Singapore.

Sackville Hamilton NR. 2001. Is local provenance important in habitat creation? A reply. *Journal of Applied Ecology* **38**: 1374-1376.

Saiz S, Kennedy C, Bass B, Pressnail K. 2006. Comparative life cycle assessment of standard and green roofs. *Environmental Science & Technology* **40**: 4312-4316.

Schrader S, Bőning M. 2006. Soil formation on green roofs and its contribution to urban biodiversity with emphasis on collembolans. *Pedobiologia* **50**: 347-356.

Shepherd PA. 1994. A review of plant communities of derelict land in the city of Nottingham, England and their value for nature conservation. *Memorabilia Zoologica* **49**: 129-137.

Small EC, Sadler JP, Telfer MG. 2003. Carabid beetle assemblages on urban derelict sites in Birmingham, UK. *Journal of Insect Conservation* **6**: 233-246.

Small E, Sadler JP, Telfer M. 2006. Do landscape factors affect brownfield carabid assemblages? *Science of the Total Environment* **360**: 205-222.

Smartt PFM, Meacock SE, Lambert JM. 1976. Investigations into the properties of quantitative vegetational data. II. Further data type comparisons. *Journal of Ecology* **64**: 41-78.

Soons MB, Heil GW. 2002. Reduced colonization capacity in fragmented populations of wind-dispersed grassland forbs. *Journal of Ecology* **90**: 1033-1043.

Southwood TRE. 1962. Migration of terrestrial arthropods in relation to habitat. *Biological Reviews* **37**: 171-214.

Spalding A, Haes ECM. 1995. Contaminated land – a resource for wildlife: a review and survey of insects on metalliferous mine sites in Cornwall. *Land Contamination & Reclamation* **3**: 24-29.

Stace CA, Thompson H. 1997. New flora of the British Isles. Cambridge University Press, Cambridge.

Steffan-Dewenter I, Tscharntke T. 1997. Early succession of butterfly and plant communities on set-aside fields. *Oecologia* **109**: 294-302.

Steusloff S. 1998. Input and output of airborne aggressive substances on green roofs in Karlsruhe. 144-148. In Breuste J, Feldmann O, Uhlmann O (eds.) Urban Ecology. Springer-Verlag, Berlin.

Sustainable Eastside. 2003. Green roofs: benefits and cost implications. Eastside Sustainability Advisory Group & Groundwork Birmingham. Unpublished report.

SWITCH-Annex 1. 2006. Sustainable Water management Improves Tomorrow's Cities' Health – Annex 1 "Description of Work". Sixth Framework Programme Priority [1.1.6.3] [Global Change and Ecosystems]. Contract no.: 018530-2

Takakura T, Kitade S, Goto E. 2000. Cooling effect of greenery cover over a building. *Energy & Buildings* **31**: 1-6.

Theis TL, Wirth JL. 1977. Sorptive behaviour of trace metals on fly ash in aqueous systems. *Environmental Science & Technology* **11**: 1096-1100.

Thiele HU. 1977. Carabid beetles in their environments: A study on habitat selection by adaptation. Springer-Verlag, Berlin, New York.

Thornton G, Nathanail P. 2005. Are incentives for regenerating UK brownfield sites sustainable? *Land Contamination & Reclamation* **13**: 327-338.

Tockner K, Stanford JA. 2002. Riverine flood plains: present state and future trends. *Environmental Conservation* **29**: 308-330.

Ulrich RS. 1984. View through a window may influence recovery from surgery. *Science* **224**: 420-421.

UN. 2002. World urbanization prospects: the 2001 revision. United Nations, New York.

UNFPA. 1996. Changing places: population, development and the urban future. State of world population 1996, United Nations Population Fund.

Villarreal EL, Bengtsson L. 2005. Response of a *Sedum* green-roof to individual rain events. *Ecological Engineering* **25**: 1-7.

Walsh CJ, Fletcher TD, Ladson AR. 2005a. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. *Journal of the North American Benthological Society* **24**: 690-705.

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan II RP. 2005b. The urban stream syndrome: current knowledge and search for a cure. *Journal of the North American Benthological Society* **24**: 706-723.

White I, Howe J. 2004. The mismanagement of surface water. *Applied Geography* **24**: 261-280.

Wilkinson DM. 2001. Is local provenance important in habitat creation? *Journal of Applied Ecology* **38**: 1371-1373.

Wilson PJ. 1992. Britain's arable weeds. *British Wildlife* **3**: 149-161.

Wolverton BC, Wolverton JD. 1993. Plants and soil micro-organisms-removal of formaldehyde, xylene and ammonia from the indoor environment. *Journal of the Mississippi Academy of Sciences* **38**: 11-15.

Wong NH, Tay SF, Wong R, Ong CL, Sia A. 2003. Life cycle cost analysis of rooftop gardens in Singapore. *Building & Environment* **38**: 499-509.

Woodward JC, Eyre MD, Luff ML. 2003. Beetles (Coleoptera) on brownfield sites in England: an important conservation resource? *Journal of Insect Conservation* **7**: 223-231.

Appendices

Appendix 1 The seed mix chosen for the seeded roof

% Latin name	Common English name	Typical habitat
6 *Agrimonia eupatoria*	Agrimony	Grassy places in fields & hedgerows
6 *Agrostemma githago*	Corn cockle	Cultivated & waste ground
5 *Anthyllis vulneraria*	Kidney vetch	Grassland, dunes, cliff tops, waste ground, usually calcareous
5 *Centaurea cyanus*	Cornflower	Traditionally native to cornfields, now mainly in waste places
5 *Centaurea nigra*	Common knapweed	Grassy places, rough ground & waysides
3 *Daucus carota*	Wild carrot	Grassy & rough ground mostly on chalky soils and near the sea (stunted)
5 *Echium vulgare*	Viper's-bugloss	Open grassy places, cliffs, dunes, shingle, rough ground on light calcareous soils
6 *Knautia arvensis*	Field scabious	Dry grassy places on light soils
5 *Leontodon hispidus*	Rough hawkbit	Basic, often calcareous grassland
4 *Leucanthemum vulgare*	Oxeye daisy	Grassy places, especially rich soils
1 *Linaria vulgaris*	Common toadflax	Rough & waste ground, stony places, banks, open grassland
5 *Lotus corniculatus*	Birdsfoot trefoil	Grassy & harsh places, mainly well-drained soils
2 *Origanum vulgare*	Wild majorum	Dry grassland, hedgebanks & scrub, usually on calcareous soils
2 *Papaver dubium*	Long-headed poppy	Arable ground, roadsides & waste places
4 *Papaver rhoeas*	Common poppy	Arable ground, roadsides & waste places
5 *Plantago media*	Hoary plantain	Neutral & basic grassland
5 *Prunella vulgaris*	Selfheal	Grassland, lawns, wood-clearings, rough ground
5 *Ranunculus bulbosus*	Bulbous buttercup	Dry grassland & fixed dunes
5 *Reseda lutea*	Wild mignonette	Disturbed, waste & arable land esp. calcareous soils
6 *Sanguisorba minor ssp minor*	Salad burnet	Calcareous or neutral grassland
5 *Silene vulgaris*	Bladder campion	Grassy places, open & rough ground
1 *Verbascum thapsus*	Great Mullein	Waste and rough ground, banks & grassy places esp. sandy and chalky soils
4 *Viola tricolor*	Wild pansy	Waste, marginal & cultivated ground

Appendix 2 Vegetation record sheet

Vegetation Survey

Recorder		Tray code	
Date			

Floristic Survey

Taxa cover-abundance (* indicates in flower, ** indicates in seed, PTO for extra space)

Notes

Structural Survey

Stratification

	Present	Ave. height	Max. height
Ground layer		-	-
Field layer			
Scrub layer			

Domin-Krajina cover-abundance scale

+	Solitary, insignificant cover
1	Seldom, insignificant cover
2	<1% cover
3	1-5% cover
4	5-10% cover
5	10-25% cover
6	25-33% cover
7	33-50% cover
8	50-75% cover
9	>75% cover
10	~100% cover

Cover-abundance

Bare ground	
Forbs	
Graminoids	
Lichens & Mosses	
Woody plants	
Flowering plants	
Plants in seed	

Appendix 3 Bird activity record sheet

Bird activity survey

Recorder	
Date	

Block code	
Time	

Species	No. visits (block/mes. code)	Activity (block/mes. code)
Black redstart (*Phoenicurus ochruros*)		
Chaffinch (*Fringilla coelebs*)		
Collared dove (*Streptopelia decaocto*)		
Feral pigeon (*Columba livia*)		
Goldfinch (*Carduelis carduelis*)		
Greenfinch (*Carduelis chloris*)		
House sparrow (*Passer domesticus*)		
Magpie (*Pica pica*)		
Pied Wagtail (*Motacilla alba*)		
Starling (*Sturnus vulgaris*)		
Tree sparrow (*Passer montanus*)		

Notes

Bird activity codes
1 Foraging/feeding
1a Foraging/feeding - arthropods
1b Foraging/feeding - seeds
2 Preening
3 Collecting nesting material
4 Displaying/singing
5 Resting
6 Unknown/other activity

Appendix 4 Drinking water quality standards under: the water supply (water quality) regulations 2000. Prescribed concentrations and values at consumer's taps.

	Conc./value maximum	Units		Conc./value maximum	Units
Microbiological			Lead	25 <2014, 10 >2013	µgPb/l
Coliform bacteria	0	number/100ml	Manganese	50	µgMn/l
Enterococci	0	number/100ml	Mercury	1	µgHg/l
Escherichia coli	0	number/100ml	Nickel	20	µgNi/l
Chemical			Nitrate	50	$mgNO_3/l$
1, 2 dichloroethane	3	µg/l	Nitrite	0.5	$mgNO_2/l$
Acrylamide	0.1	µg/l	Odour	3 at 25°C	Dilution number
Aluminium	200	µgAl/l	PAH's	0.1	µg/l
Ammonium	0.5	$mgNH_4/l$	Selenium	10	µgSe/l
Antimony	5	µgSb/l	Sodium	200	mgNa/l
Arsenic	10	µgAs/l	Taste	3 at 25°C	Dilution number
Benzene	1	µg/l	Tetra- & trichloroethene	10	µg/l
Benzo(a)pyrene	0.01	µg/l	Tetrachloromethane	3	µg/l
Boron	1	mgB/l	Trihalomethanes: total	100	µg/l
Bromate	10	$µgBrO_3/l$	Turbidity	4	NTU
Cadmium	5	µgCd/l	Vinyl chloride	0.5	µg/l
Chromium	50	µgCr/l	**Pesticides**		
Colour	20	mg/l Pt/Co	Aldrin	0.03	µg/l
Copper	2	mgCu/l	Dieldrin	0.03	µg/l
Cyanide	50	µgCN/l	Heptachlor	0.03	µg/l
Epichlorohydrin	0.1	µg/l	Heptachlor epoxide	0.03	µg/l
Flouride	1.5	mgF/l	Other pesticides	0.1	µg/l
Hydrogen ion	6.5-10	pH	Total pesticides	0.5	µg/l
Iron	200	µg/l			

Appendix 5 Colitag[TM] test for the presence or absence of total coliforms and *E. coli*

1. Aseptically add Colitag[TM] to the 100ml water sample and shake.
2. Incubate the solution at 35°C+/-0.5°C for 24+/-2 hours.
3. Observe the solution at 24 hours, if the sample is yellow then coliform bacteria are present and if no yellow colour is observed no coliform bacteria are present.
4. Examine the solution for fluorescence using a long wavelength (366nm) UV lamp. If a bright blue fluorescence is observed, *E. coli* are present and if no fluorescence is observed no *E. coli* are present.

Appendix 6 ISO 10390:2005 determination of soil pH

1. Place a representative 5ml sample of soil (<2mm fraction) into a sealable sample bottle.
2. Add 25ml of 0.01mol/L calcium chloride solution.
3. Shake or mix the suspension for 1 hour using a mechanical shaker or mixer.
4. Seal the bottle and leave for 1-3 hours.
5. Measure the pH to two decimal places using a calibrated glass pH electrode until reading is stable (does not vary by more than 0.2 pH units over a period of 5 seconds).
6. Round up the pH to 1dp.

Appendix 7 BS 7755-3.4:1995 Determination of the specific electrical conductivity of the soil.

1. A representative sample of 20.00g of air-dried soil will be placed in a shaking bottle.
2. 100ml of grade 2 water at a temperature of 20°C (+/- 1°C) will be added to this and the bottle sealed.
3. The bottle will be shaken for 30 min, and the suspension then filtered through a low ash, highly retentive filter paper.
4. The conductivity measurement will then be made on the filtrate using a calibrated conductivity meter at 25°C.
5. A blank will be run with the same method and if the conductivity value is greater than 1mS/m the extraction will be repeated.
6. Results will be noted to 1dp and reported in whole numbers expressed in millisiemens per metre.

Appendix 8 The determination of the overall density of soil particles (modified from Rowell 1994).

1. A representative, approximately 100ml sample of oven-dried soil will be added to a pre-weighed 1000ml beaker.
2. The beaker and sample will be reweighed.
3. About 200ml of water will be added and the beaker boiled gently for 30 minutes.
4. The suspension will be cooled by standing the beaker in running water and then added through a funnel (with the assistance of a wash bottle) to a pre-weighed 1000ml measuring cylinder.
5. Water will be added up to the 1000ml mark and cylinder reweighed.
6. The volume of water in the measuring cylinder = mass of suspension – mass of dry soil (1ml = 1g of water).
7. The volume of soil particles in the measuring cylinder = 1000ml – volume of water in the measuring cylinder.
8. The particle density = mass of dry soil / the volume of the soil particles.

Appendix 9 Determination of overall dry bulk density (modified from ISO 11272:1998)

1. Vegetation will be removed from a small area (~140cm^2) of soil and the soil surface flattened.
2. A hole will be dug into the leveled soil to the filter layer and the excavated soil with be bagged.
3. The hole will be lined with a flexible plastic sheet.
4. Dry, graded sand (500-700 μm) of a known volume will be used to fill the hole from a funnel with a falling height of 5cm until it is level with the surrounding soil surface. The amount of sand used to fill the hole is the volume of the hole.
5. The excavated soil will be dried in an oven at 105°C allowed to cool in a desiccator and weighed. This process will be repeated until the soil reaches a constant mass.

6. The overall dry bulk density = the dry mass of the excavated soil / the volume of the hole.

Appendix 10 Measurement of water content at the approximate field capacity, approximate permanent wilting point and loss on ignition (modified from Rowell 1994).

1. A representative sample of soil will be taken at approximate field capacity or approximate permanent wilting point.
2. About 10g of the soil will be weighed, placed into a weighed crucible and then placed in an oven at 105°C. The samples will be placed in a desiccator while they cool and then weighed. This drying will be repeated until they reach a constant mass.
3. Water content (g H_2O g^{-1}) at approximate field capacity or permanent wilting point = mass of water lost/mass of oven dry soil
4. The samples will then be cooled in a desiccator and reweighed.
5. The samples will then be placed in a muffle furnace at 550°C until they reach a constant mass.
6. The samples will again be cooled in a desiccator and reweighed.