Barking Riverside Green Roof Experiment: Phase 2

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Cover photo: Freight containers with experimental wetland green roof systems on top, Barking Riverside, London, UK © Stuart Connop

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1. Background

1.1 TURAS

Transitioning Towards Urban Resilience and Sustainability (TURAS) is an FP7 funded European-wide research and development programme. The "TURAS" project aims to bring together urban communities, researchers, local authorities and SMEs to research, develop, demonstrate and disseminate transition strategies and scenarios to enable European cities and their rural interfaces to build vitally-needed resilience in the face of significant sustainability challenges (Collier *et al*. 2013). To ensure maximum impact, the TURAS project developed an innovative twinning approach bringing together decision makers in local authorities with SMEs and academics to ensure meaningful results and real change are implemented over the duration of the project. Eleven local authorities or local development agencies are involved as partners in the project orientating research and development from the outset towards the priority sustainability and resilience challenges facing their cities. Nine leading academic research institutions and six SMEs are working with these cities helping them to reduce their urban ecological footprint through proposing new visions, feasibility strategies, spatial scenarios and guidance tools to help cities address these challenges. The specific challenges addressed in TURAS include: climate change adaptation and mitigation; natural resource shortage and unprecedented urban growth.

Over the five year duration of the project, the feasibility of these new approaches are being tested in selected case study neighbourhoods. The impact of these new approaches will be measured and results compared between participating cities before a final set of strategies and tools is developed for demonstration, dissemination and exploitation in other European cities. This report represents a dissemination tool from Work Package 2 (WP2) of TURAS - Greening Public and Private Urban Infrastructure. The aim of WP2 is to develop new visions, feasibility strategies, spatial scenarios and guidance tools to enhance the biodiversity and ecosystem service benefits of urban green infrastructure. This report represents an overview of the establishment of a green roof design research experiment carried out as part of TURAS to investigate the effect of green roof hydrology on the roof's value in terms of supporting regionally important biodiversity and associated ecosystem services.

1.2 Urban Green Infrastructure

"*Green Infrastructure (GI) is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas*" (Naumann *et al*. 2011)

We live in an increasingly urbanised world where more than half the population already live in urban areas (United Nations 2012), and in England over 80% of people now live in towns and cities (UK National Ecosystems Assessment 2012). Built upon old models of high-density living and economic development, towns and cities suffer numerous environmental impacts associated with the loss of biodiversity (White 2002; Grimm *et al*. 2008; Pickett *et al*. 2011; Cook-Patton & Bauerle, 2012):

- cities represent major consumers of energy;
- urban heat island effect leads to problems with air quality, energy use and ambient temperatures;
- large expanses of impervious surfaces result in rapid rainwater run-off and overloading of storm drains and increases the tendency of rivers to overtop their banks and flood surrounding land (Environment Agency 2002; Villareal *et al*. 2004; Mentens *et al*. 2006);
- quality and quantity of water held in the soil immediately beneath the hard surfaces is reduced;
- surface seepage to re-charge groundwater aquifers is reduced;
- effective desert conditions are created for wildlife squeezed between urban expansion and agricultural intensification;
- significantly reduced possibilities for contact with nature resulting in a reduction in the health and well-being of communities (English Nature 2003, Fuller & Irvine 2010).

The incorporation of green infrastructure into cities can help alleviate these problems and contribute to the provision of ecosystem services. A number of studies have researched the environmental and associated economic benefits that urban green infrastructure can provide, including stormwater amelioration and pollution uptake (Mann 2000; Mentens *et al*. 2006; Schroll *et al*. 2011; Nagase & Dunnett 2012), urban heat island mitigation and energy conservation (Ernst and Weigerding 1985; Von Stülpnagel *et al*. 1990; Takakura *et al*. 2000; Bass *et al*. 2002; ; Niachou *et al*. 2001 Wong *et al*. 2003; Alexandri & Jones 2008; Bowler *et al*. 2010; Castleton *et al*. 2010; Lundholm *et al*. 2010), and a resource for urban biodiversity (Pickett *et al*. 2001; English Nature 2003; Grant *et al*. 2003; Baumann 2006; Brenneisen 2006; Köhler 2006; Schrader & Böning 2006; Schochat *et al*. 2006; Cadenasso *et al*. 2007; Kadas 2007; Hunter & Hunter 2008; Tonietto *et al*. 2011). These functions form an essential component of delivering sustainable development and their value is likely to become even more pertinent with the predicted future challenges posed by climate change.

1.3 Design with regional context

Green infrastructure in the built environment has traditionally been designed with limited consideration for biodiversity or regional context. Instead, a blend of horticultural fascination with exotic species, ease of maintenance, accessibility and an innate desire to control nature have led to aesthetic appeal and amenity value being the key drivers for urban greenspace design (Eisenberg 1998). Even selection of species suited to local climates has been limited with artificial irrigation and heavy management of urban landscapes common place.

Given the increasing recognition that the natural environment can provide goods and services of benefit to humans and the planet ('ecosystem services'), the European Commission and the UK Government are now advocating well-planned green infrastructure that provides opportunities to protect and enhance biodiversity (UK National Ecosystem Assessment 2011; Defra 2011; HM Government 2011; Town and Country Planning Association and The Wildlife Trusts 2012; Secretariat of the Convention on Biological Diversity 2012; European Commission 2013). In response to this, there is a need to develop and monitor 'novel', biodiversity-focused designs for green infrastructure at roof, wall and ground-level, and investigate its contribution to urban biodiversity. The key first step to maximising the resilience and sustainability in such a process is ensuring that design is based on regional context both in terms of being current climate and climate adaptation resilient and relevant to regional biodiversity, specifically that of national and international conservation value. Taking such an approach not only maximises the biodiversity and associated ecosystem service benefits, but also facilitates more sustainable urban green infrastructure management with reduced requirements for fossil fuel use, artificial irrigation, and fertilizer and pesticide input.

2. Green roofs

2.1 Background

Roof tops in cities represent a significant unused space. Adding green (intentionally vegetated) roofs to buildings can provide environmental and economic benefits without reducing space available for development at ground level. The practice of adding vegetation to the roofs of buildings dates back centuries and the Nordic tradition of covering roofs with turf continues to the present (Grant 2006b). In more recent times, the term 'green roof' has been adopted and refers to a building roof which has been deliberately vegetated, typically with a commercially manufactured system comprising growing medium and plants.

Green roofs are generally characterised into two types, ‘intensive’ and ‘extensive’. Intensive roofs tend to have deeper substrates (>200 mm) which can support shrubs and trees and generally they have the appearance of ‘roof gardens’ and typically they require significant management and maintenance in terms of irrigation and fossil fuel use. Extensive green roofs typically have a shallower substrate layer (<150 mm), support low-growing, drought-tolerant plants and require low maintenance.

For reasons of cost, weight and maintenance, extensive green roofs are the most commonly adopted green roof format. A standard extensive green roof construction consists of: (1) a waterproofing and root resistant barrier; (2) a drainage layer which also acts as a water reservoir; (3) a filter membrane to prevent sediment blocking the drainage layer; (4) a growing medium (substrate); and (5) a vegetation layer (Figure 1).

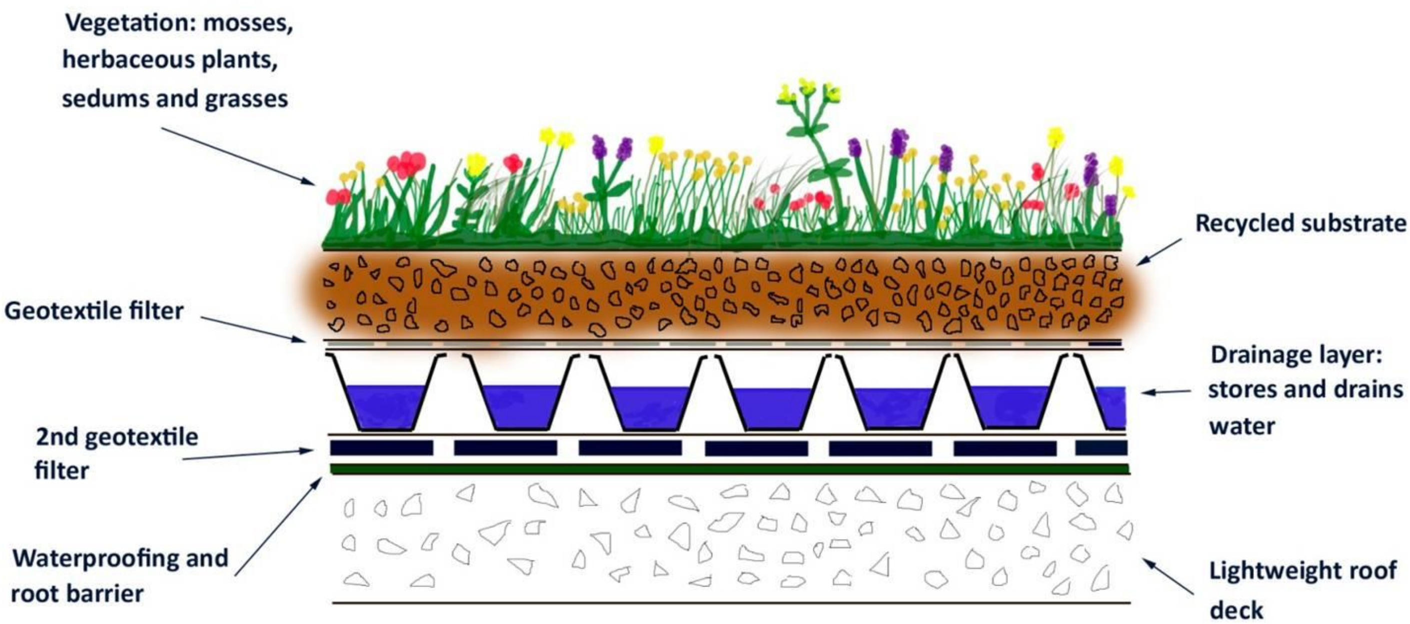

Figure 1. Typical extensive green roof design

Mirroring the pattern of ground level urban greenspace design, to date, the majority of green roof installations in London, across Europe and beyond are ‘off-the-shelf’ industry standard designs. Typically these feature shallow-substrate sedum-dominated extensive systems designed predominantly for aesthetics and stormwater attenuation (Dunnett and Kingsbury 2004; Snodgrass and Snodgrass 2006; Grant 2006a). Sedums are generally selected due to their drought-resistance enabling them to be tolerant of free draining SuDs system rooftop conditions and thus maintain a year-round perceived aesthetic. This focus on a narrow vegetation group means that the number and type of species in these systems is limited compared to the natural ecological communities green roofs are designed to mimic. The resulting lack of plant diversity and habitat structure means that these systems offer restricted biodiversity and associated ecosystem service benefits (Kadas 2007; Gedge *et al*. 2012; Cook-Patton & Bauerle 2012).

2.2 Designing for biodiversity

Research on alternative green roof systems which have used deeper substrates, undulating topography, and a variety of vegetation ('biodiverse' roofs), has shown that even modest modifications to the 'standard' green roof design can result in a wider variety of species utilising a roof (Brenneisen 2006; Köhler 2006; Gong 2007; Kadas 2007; Baumann & Kasten 2010; Tonietto *et al*. 2010). Key to the success of these studies was the technique of incorporating biomimicry into the design of green roofs by incorporating habitat features typical of regionally important habitats for nature conservation.

The majority of these studies have focused on recreating habitat features which mimic the exposed and arid characteristics of brownfield (post-industrial) sites. In intensively managed urban and rural environments, brownfield sites often represent some of the only remaining fragments of 'wildspace' in the landscape. Typically comprising a blend of friable substrates and pockets of contamination, many brownfield sites provide open flower-rich resources with no management intervention. The unmanaged nature of the sites lends itself to being able to support many warmth-loving species at the edge of their range including biodiversity of national and international conservation value.

This value has been recognised internationally (Harvey 2000; Harabiš *et al.* 2013). Such is the importance of the habitat in otherwise heavily managed urban and rural landscapes that, in the UK, the habitat typical of the highest quality brownfield sites has been characterised and recently been included in the new list of UK Biodiversity Action Plan (BAP) priority habitats (Riding *et al*. 2010) as Open Mosaic Habitats on Previously Developed Land.

The value of brownfield sites lies in the complexity of microhabitats within the wider mosaic, which support species throughout their lifecycles (Bodsworth *et al*. 2005). In much of the literature describing wildlife-rich brownfield sites, ephemeral pools/standing water, seasonal wet areas or inundation communities are described as essential components of the brownfield mosaic (Bodsworth *et al*. 2005; Buglife 2009; Riding *et al*. 2010). This habitat mosaic is something that should be aspired to through biomimicry in green roof design. Green roofs are typically stressed exposed environments that lend themselves well to the creation of open flower-rich environments with bare areas and also, potentially, ephemeral wet areas.

With an increasing body of evidence to suggest that green roofs are able to support broad biodiversity if designed appropriately (Brenneisen 2006; Köhler 2006; Gong 2007; Kadas 2007; Baumann & Kasten 2010; Tonietto *et al*. 2010) and increasing recognition that rich biodiversity in cities can have enormous potential to mitigate the effects of climate change making them more sustainable and resilient (Secretariat of the Convention on Biological Diversity 2012) why are the majority of green roofs still incorporating industrial standard sedum systems rather than biomimicry of regional habitat of conservation value?

The simple answer appears to be that green roofs are installed predominantly as Sustainable Urban Drainage Systems designed to manage rainfall runoff from roofs, particularly when included in a development that involves moving from a greenfield or brownfield to hard landscaped state. Under such a scenario little consideration is given to whether a green roof has value for supporting regional biodiversity and rather an assumption of the intrinsic attributes of green roofs to support biodiversity is relied upon (Simmons *et al*. 2008). This can mean that substantial biodiversity benefits can be missed. But, is there an ecosystem service 'cost' associated with shifting away from green roofs designed for SuDs towards more biodiverse systems designed based on regional habitat characteristics?

A Knowledge Transfer Partnership was established in London between Barking Riverside Ltd, the London Borough of Barking and Dagenham, Livingroofs.org, the University of East London and the Institute for Sustainability to design a protocol for investigating this question and to act as a blueprint for use throughout the TURAS partnership and beyond to promote the use of biomimicry of regional habitat of conservation value in the design of green roofs to maximise urban biodiversity.

3 Case study example – Barking Riverside Knowledge Transfer Partnership

3.1 The London context

In its new National Planning Policy Framework (NPPF), the UK coalition government recommends that development be channelled towards urban areas and encourages the 'recycling of derelict and other urban land' (DCLG 2012). Derelict, previously developed land is commonly termed 'brownfield' land. In recent times, there has been recognition that a number of urban brownfield sites support distinctive and unique wildlife assemblages of significant conservation value (Gilbert 1989; Eversham *et al*. 1996, Gibson 1998; Harvey 2000; Eyre *et al*, 2003; Roberts *et al*. 2006). These sites contain an open mosaic of successional habitats which provide a dynamic and heterogeneous landscape, often of greater biodiversity value than intensively managed green spaces such as parks and agricultural land (Gibson 1998; Chipchase & Frith 2002; Roberts *et al*. 2006; Lorimer 2008; Buglife 2009). Consequently, if redevelopment of brownfield land is to be environmentally sustainable, the ecologically valuable features of these sites must be incorporated into landscape design both at ground and roof level through the provision of innovative brownfield landscaping, and biodiverse green walls and green roofs (Connop *et al*. 2011).

Given that urban intensification is a key principle of planning policy in England, and brownfield land is under the greatest pressure to fulfil this target, there is a need to find innovative green infrastructure solutions that can: (a) be incorporated into high-density urban areas; and (b) benefit brownfield communities of conservation value. Incorporating vegetated (green) roofs and walls, and 'wildlife friendly' soft landscaping into new and existing urban developments provides an opportunity for the government to meet its commitments to GI and sustainable development (DCLG 2012; HM Government 2011).

3.2 Barking Riverside

Barking Riverside in the London Borough of Barking and Dagenham, East London represents an example of just such a site. The Barking Riverside site was a 443 acre brownfield site situated in the south of the borough sandwiched between a major trunk road that is heavily used for freight traffic and a heavily industrialised but strategically important employment area. The site was identified for its potential for the creation of a new sustainable community comprising:

- 10,800 new units;
- 1 district centre;
- 3 schools;
- 25,000 new residents planned over the 20 year build.

In addition to the enormous potential of the site for development in relation to the National Planning Policy Framework, the planning process also recognised the value of the greenfield state of the site in terms of local ecosystem service provision. This included its value as accessible greenspace for health & well-being, pluvial and fluvial stormwater management and significant biodiversity value including numerous rare and protected species (such as water voles, grass snakes, bumblebees and numerous birds).

In recognition of this ecosystem service value, the planning consent set out a number of conditions to ensure sustainability was interwoven in all aspects of the development. This included:

- the development of sustainable public transport infrastructure;
- the conservation of the site's valuable biodiversity;
- the retention of 40% of the site as green space;
- the development of a comprehensive Sustainable Urban Drainage Systems (SuDs) master plan including the use of green roofs on 40% of the properties combined with swales, rain gardens, balancing ponds and the existing creek network.

As part of the process of ensuring that sustainability was at the core of the design of the Barking Riverside development, a Knowledge Transfer Partnership has been established at Barking Riverside between Barking Riverside Ltd, the London Borough of Barking and Dagenham, Livingroofs.org, the University of East London and the Institute for Sustainability to investigate how green infrastructure design can increase the sustainability and resilience of the Barking Riverside development as part of the TURAS FP7 programme.

It is hoped that the work that is carried out by TURAS at Barking Riverside will provide practical pointers as to how the new and very diverse community can be established while being able to accommodate the very real challenges of living alongside industry and supporting sustainable and resilient biodiverse green infrastructure.

3.3 The Barking Riverside green roof experiment

As part of the Knowledge Transfer Partnership at Barking Riverside, a green roof experiment was set up to investigate how green roof design effects ecosystem service performance with a particular view of looking at whether there is any ecosystem service 'cost' in terms of moving from traditional sedum-based industrial standard green roof systems to more biodiverse systems that utilize biomimicry of the existing valuable brownfield site conditions in their design (Figure 2). A Knowledge Transfer Report detailing the findings of this initial investigation was published as TURAS Milestone 9 (Connop *et al*. 2013). Results indicated that, rather than there being an ecosystem service 'cost' to moving from industry standard sedum systems to biodiverse green roofs, biodiverse green roofs performed equivalent to or more effectively than corresponding sedum systems for water attenuation, thermal insulation and floral diversity.

In order to take this research further, a second green roof experiment was planned at Barking Riverside to investigate how green roof design effects the biodiversity supported. This second investigation (Phase 2) involves assessing whether, by changing some of the design principles of green roofs, it is possible to broaden the scope of flora and fauna the roofs are able to support. This remit was carried out specifically in relation to the diversity of conservation priority species found on good quality Thames Corridor brownfield sites such as the Barking Riverside site.

Figure2. Installed green roof test bays at Barking Riverside Offices.

The following report details the rationale behind the Phase 2 green roof experiment at Barking Riverside and the design and installation of the experiment.

3.4 Rationale behind the Barking Riverside Phase 2 experiment

Since the value of biodiversity and its fundamental role in underpinning ecosystems and ecosystem services is becoming increasingly recognised (UK National Ecosystem Assessment, 2012), it is important that the biodiversity potential of current urban GI applications such as green roofs, green walls and soft landscaping is being fully realised.

Following on from the success of the Barking Riverside Phase 1 green roof experiment (Connop *et al*. 2013) it was decided that further experimentation would be beneficial to understand the link between green roof design and the biodiversity supported. One of the conclusions from the Phase 1 work was that the scale of the experimental plots (approx. 2 m x 1.30 m) was potentially too small to accurately capture a measure of the variation in biodiversity between plots, particularly the fauna. It was decided that it was necessary to scale up the size of the green roof experimental plots and increase the spacing between them to enable them to be treated as separate ecological units for the study of floral and faunal development and colonisation.

By scaling up and physically dividing the test plots by more than the low divide used in the Phase 1 experiment, it would be possible to conclude with a greater level of confidence that organisms recorded on each test plot were there because of the specific environmental conditions on the plot rather than merely being present due to the location of the subplot within a larger green roof mosaic to which organisms might be attracted.

With these conclusions in mind, it was decided that a Phase 2 green roof experiment would be established at Barking Riverside as part of the TURAS EU FP7 research programme to further investigate how green roofs installed across the site could maximise their benefits in relation to supporting the diverse and valuable biodiversity found on the brownfield site prior to development.

It was also decided that further investigation would include assessment of the range of brownfield open mosaic habitats that can be created on green roofs. The value of brownfield sites is the complexity of microhabitats within the wider mosaic, which provide species throughout their lifecycles (Bodsworth *et al*. 2005). In addition to dry wildfower-rich grasslands, this includes ephemeral pools/standing water, seasonal wet areas or inundation communities are described as essential components of the brownfield mosaic (Bodsworth *et al*. 2005; Buglife, 2009; Riding *et al*. 2010). Since green roofs are often used as mitigation for brownfield habitat loss, including at Barking Riverside, ideally green roof designs should incorporate these habitat features, otherwise they are failing to provide adequate mitigation for the loss of the brownfield mosaic. The Phase 2 study was designed to address this gap, by designing green roofs with a wetland component and investigating whether increasing the water gradient on a green roof can augment the biodiversity benefits afforded by current ‘xeric’ green roof design.

In addition to brownfield mitigation, further experimentation with green roof design has been recommended in a number of studies, particularly altering green roof designs to facilitate greater moisture retention, thus enabling the existence of a less drought-tolerant flora and fauna (Grant *et al*. 2003; Mentens *et al*. 2006; Olly *et al*. 2011; Cook-Patton & Bauerle 2012). Designing a green roof which detains water for longer would also contribute to ecosystem services and climate change mitigation, for instance by increasing the volume of stormwater held on the roof and thus reducing the rate of runoff (Mentens *et al*. 2006) and increasing evapotranspiration and thus contributing to urban cooling.

It was decided that the Barking Riverside Phase 2 green roof experiment would attempt to address these gaps in knowledge by designing and monitoring novel green roofs with the aim of providing opportunities for biodiversity that are not currently being delivered by standard green roof designs. The main focus of the research is to construct a series of experimental green roof test platforms at the Barking Riverside Development site and manipulate the water retention capacity of the platforms.

3.5 Phase 2 experimental design

The experimental design for the Phase 2 experiment comprises three treatments. All roofs were constructed following biodiverse green roof design principles, featuring a blend of extensive green roof aggregates with topographical profiling. The drainage outlets of the roofs were then manipulated so that rate of drainage and volume of drainage would be different across the three treatments. To achieve this, the drainage outlet was designed to sit at three different heights in relation to the base at of the green roof:

i) *Treatment 1* - a conventional green roof with drainage outlet at the base of the roof;

ii) *Treatment 2* - a green roof with a 40 mm raised drainage outlet to slow the rate of drainage and ensure that the base of the substrate is saturated following rain events;

iii) *Treatment 3* - a green roof with an 80 mm raised drainage outlet to temporarily pool water in hollows between the higher areas of the topographically profiled substrates.

Figures 3 & 4 represent plans for the design of the three experimental treatments.

Each roof would then be seeded with a seed mix comprising a blend of typical dry green roof species and additional species associated with a gradient of wetter conditions. The study would then monitor the performance of the seeded vegetation and colonisation by flora and targeted fauna.

Each treatment was replicated on three of the test roofs. In total, nine test platforms were designed and installed on the roofs on a series of containers located at the Barking Riverside development offices (51:31:12N, 0:07:09E). Each green roof was 6 m x 3 m. The layout of each green roof treatment was randomised across the test platforms to reduce any effect of position within the test set-up on green roof performance. Construction on the test platforms began in March 2013 and was completed in November 2013.

With the green roof experiment now in place, the specific questions that will be answered by the Phase 2 research programme are:

- Can altering the hydrological dynamic of green roofs provide habitat for regional and national biodiversity?
- How does this design compare to a standard, commercial green roof design in terms of the biodiversity recorded during the study?

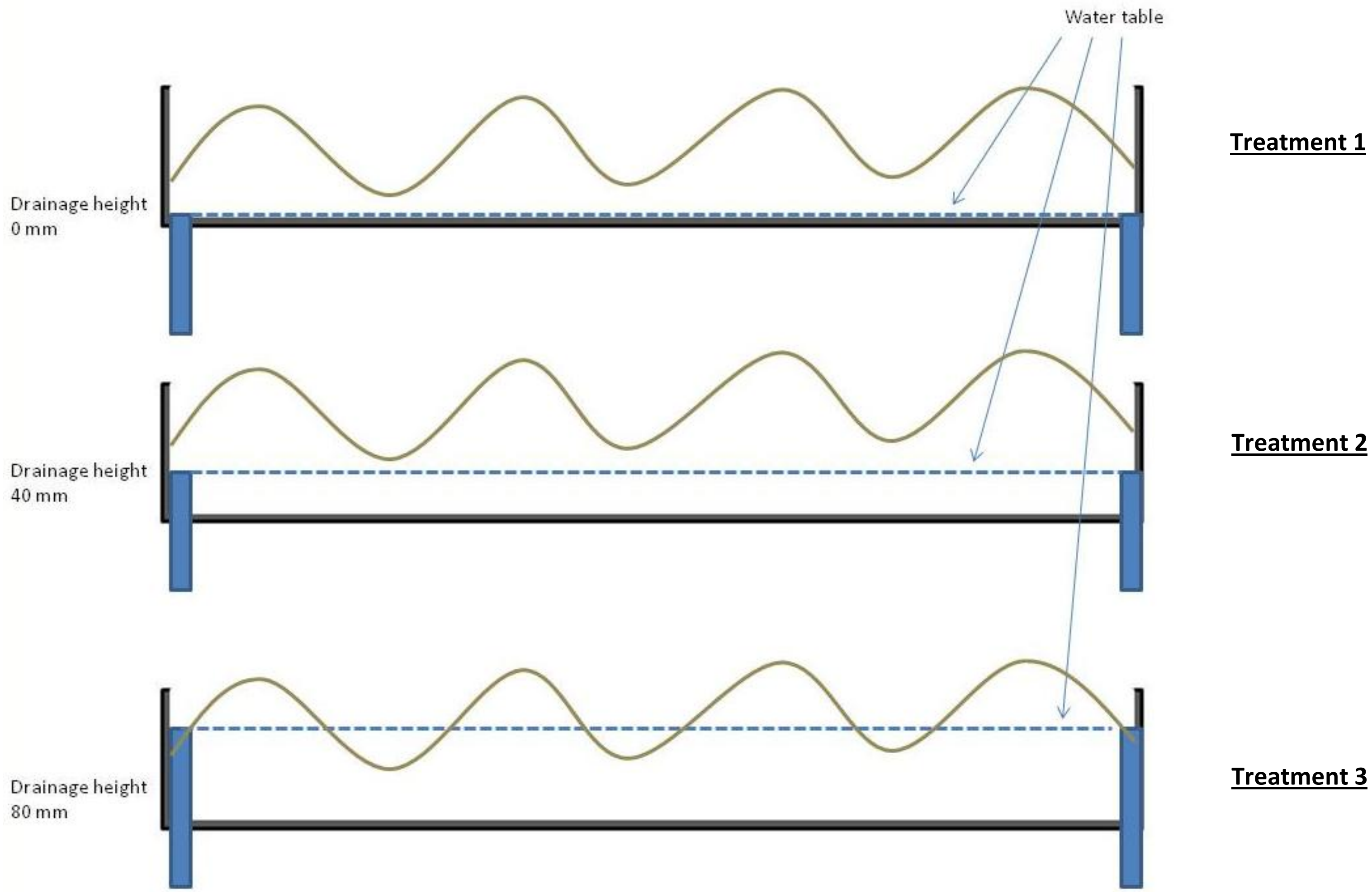

Figure3. Profile of the three Phase 2 green roof experimental treatments at Barking Riverside, East London. Plan shows the height of the drainage outlets in relation to the green roof substrate topographical profile.

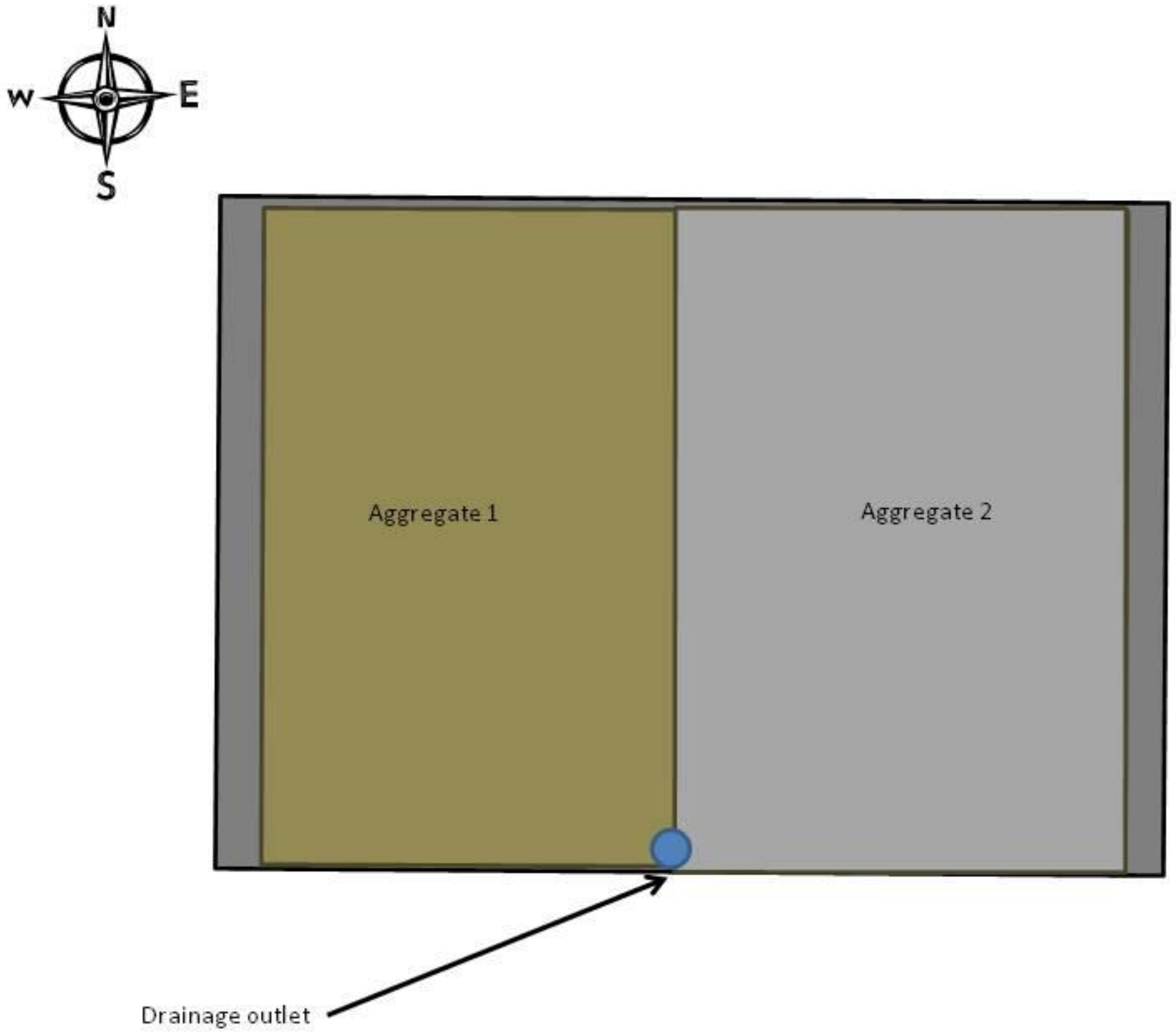

Figure4. Layout of the two aggregates blended for the Phase 2 green roof experimental treatments at Barking Riverside, East London. Orientation of the aggregates will be varied between treatments to reduce effects of location on results.

3.6 Phase 2 monitoring

The overall goal of the project is to quantitatively evaluate the influence of the innovative green roof designs on biodiversity. The study is designed to quantify differences between the novel green roof treatments and control treatments (0 mm drainage level). As there is no single objective measure of biodiversity, evaluation of the biodiversity recorded during the study will require a multidimensional approach. The sampling techniques will provide data on species richness and evenness, which are the fundamental currency of biodiversity value. The findings will also be evaluated in terms of existing research in this area, and the presence of target species such as UK and London Biodiversity Action Plan Priority Species (BRIG 2007; London Biodiversity Partnership 2007), Species of Principal Importance for Biodiversity in England (Great Britain. NERC Act 2006) and species of conservation value commonly associated with wildlife-rich urban habitats (Gibson 1998; Bodsworth *et al*. 2005; Roberts *et al*. 2006). Whilst the research is primarily focused on maximising the biodiversity potential of green infrastructure, it also aims to recognise that the designs of these components should contribute to urban water sustainability and more generally environmental sustainability through ecosystem service provision.

Green roofs designed to mimic characteristics of wildlife-rich brownfield sites have been shown to support a range of biodiversity including invertebrates, flora and birds (Brenneisen 2006; Kadas 2007; Gedge *et al*. 2012). In order to assess the success of the experimental design, monitoring would be divided into three elements: vegetation/habitat, invertebrates and birds.

Fieldwork to monitor the development of flora will include:

- annual fixed-point stereo photography;
- generation of an annual species list for each roof;
- mapping of habitat niches on each roof;
- fixed-point line transect surveys (encompassing all habitat niches), recording species and sward height along the line transect.

These methods will provide data on vegetative and structural development during the study period, and seasonal/annual variability and spatial data on vegetation and habitat development.

Invertebrate monitoring will comprise:

- fixed-time observational surveys, using a modified version of the bee walk transects used by Banaszak (1980) and Saville *et al*. (1997) recording species easily identifiable on the wing e.g. bumblebees, butterflies and dragonflies ;
- fixed-time sweep net surveys of vegetated areas of the roofs;

- pitfall trapping in key niche areas.

These invertebrate standard sampling methods and protocols will follow those set out in the Natural England guidance document 'Surveying terrestrial and freshwater invertebrates for conservation evaluation' (Drake *et al*. 2007). Using a combination of invertebrate survey techniques would achieve a relatively comprehensive species list, and provide data on species composition, diversity and abundance.

Bird monitoring will follow a modified version of the 'vantage point' survey technique (Gilbert *et al*. 1998), monitoring the roofs from a discrete distance, for a fixed period, using binoculars or other suitable optical equipment. Records will include all birds seen landing on the individual test platforms and their behaviour (i.e. feeding, breeding, resting).

Vegetation and invertebrate surveys will be carried out at repeated, regular intervals during the growing season and peak season for invertebrates (April to October). Bird monitoring will be conducted year round as birds may utilise the roofs as a foraging resource throughout the year. The standardised nature of these survey techniques makes them replicable and comparable every year.

4. Phase 2 construction

The remainder of this document represents a diary of the Phase 2 green roof test platform construction. It is hoped that by cataloguing the progress of the install it would support any future endeavours to replicate green roof experimentation on this scale. Similarly, the report should act as a blueprint for those wanting to develop small-scale green roof systems with wetland habitat features.

4.1 Support for the green roofs

With the increase in scale of the roofs from 2 m x 1.30 m plots to 6 m x 3m, a substantial supporting frame was required. Initial plans for the experiment were that it would be sited on top of temporary classroom buildings at the site of a new school at Barking Riverside. Development of the school was, however, first delayed and then it was determined that the temporary buildings being used would not support the loadings of the experiment. This meant that an alternative location and solution was needed. It was decided that the simplest solution would be to replicate the design of the Phase 1 experiment and use freight containers near to the Barking Riverside offices. Rather than 4 containers for 32 test plots however, a single 20 ft freight container would be required to support each green roof experimental platform.

This meant that nine containers had to be sourced. Due to the substantial increase in the cost of scrap metal since the establishment of the Phase 1 experiment, freight containers were significantly more expensive (from £250 up to around £1500 each). Moreover, due to the planned long duration of the experiment, it would be more expensive to hire the containers than to purchase them. These costs made the project prohibitive as there were insufficient funds in the project budget to purchase the freight containers and build the green roofs. This meant that additional funding had to be sourced before the project could commence. Eventually UEL was able to source funds internally to purchase 9 very old and damaged containers (Figure 5), but this followed significant delays.

Figure 5. One of nine scrap 20 ft freight containers for the Phase 2 green roof experimental treatments at Barking Riverside, East London. It was possible to source old damaged containers at a discounted price as these were not suitable for further use for freight transportation.

4.2 Moving the containers into position

Once the containers had been purchased, the next stage of the process was to get them on site, this required heavy vehicle access to level the land on which the containers were to be placed and then to move the containers into position on top of the levelled area. It was decided that, due to security issues on the site, the only relatively secure area to locate the Phase 2 green roof experiment was near to the Phase 1 experiment next to the Barking Riverside offices (Figure 6).

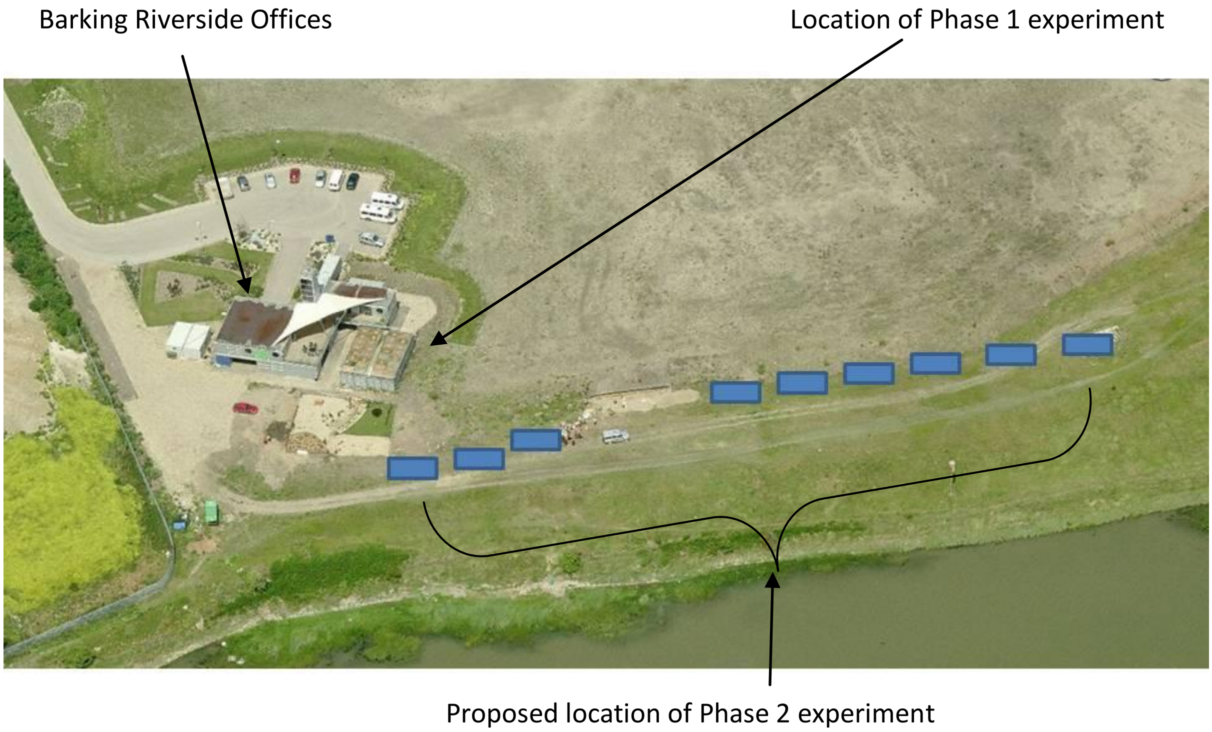

Figure 6. Plan detailing the approximate location of the Phase 2 green roof experimental treatments at Barking Riverside, East London. The area at the rear of the seawall path was selected due to its proximity to the Barking Riverside offices offering some protection.

Due to the delays in sourcing the containers described previously, by the time they were ready for delivery, a long spell of particularly wet and cold weather in the UK made heavy vehicle access to the respective area of the site impossible. This delayed levelling the land and getting the containers onto the site based on original planned timings.

Following a spell of drier weather in Spring 2013, vehicle access to the site was possible and work was able to begin levelling the land (Figure 7).

Figure 7. Construction of a levelled area on which the container bases for the Phase 2 green roof experimental treatments could be sited at Barking Riverside, East London. The area in question was to the rear of the seawall pathway.

On completion of the levelling, containers were moved into position using an excavator (Figure 8). Containers were orientated in an east-west direction along the rear of the seawall. A space of 2 metres was left between each container to provide an 'ecological divide' between each green roof experiment (Figure 9). Due to site restrictions, the containers were aligned in two groups with an approximately 20 m gap in between.

Figure 8. Freight container being moved into position by excavator for the Phase 2 green roof experiment at Barking Riverside, East London.

Figure 9. Five freight containers in place for the Phase 2 green roof experiment at Barking Riverside, East London. Gaps between freight containers are designed to create and 'ecological gap' between green roof experiments (gaps were at least 2 metres wide).

4.3 Construction of green roof frames

Once the containers were sited, there was an additional delay waiting for the contractors to be available to build the green roof frames. This was a knock-on effect from other project delays. Despite all of this, construction began on site prior to the Milestone (MS8) deadline but miscommunication between the installers (who were operating under domestic Health & Safety principles) and the site managers (Bellway Homes - who operate under large scale construction Health & Safety principles) meant that construction was stopped until improved Health & Safety could be guaranteed. This included the provision of permanent edge protection on all nine containers, comprising scaffolding of the value of approximately £6000. Again, the TURAS budget was insufficient to cover this unexpected cost and delays in sourcing funds had knock-on effects on delivery of the MS8. Nevertheless, some funding was sourced and permanent scaffolding erected (Figure 10). This included a substantial subsidy from Metric Scaffold (SE) Ltd. Without Metric's support, the development of this experiment might still be on hold.

Figure 10. Edge protection scaffolding being erected for the Phase 2 green roof experiment at Barking Riverside, East London. The scaffold will remain in place for the duration of the experiment.

The scaffolding provides comprehensive edge protection for the duration of the green roof build and will remain in place throughout the duration of monitoring. It will also provide the added benefit of a platform around the green roof experiment, making it easier for visitors to the Case Study site to view the Phase 2 experiment.

Once the scaffolding was in place, approval was given by the site Health and Safety manager for works to commence. The next step in the production of the experimental green roofs was construction of the wooden frames to provide a base for the green roofs (Figures 11 and 12). Designs were based on the Green Roof Shelter (www.greenroofshelters.co.uk) company's system for installing green roofs on top of freight containers. This method provides a strong stable base with the majority of the loading on the load-bearing edges of the freight containers. Installation was carried out by the Grass Roof Company (www.grassroofcompany.co.uk) with help from UEL staff.

Figure 11. Construction of the wooden bases for the Phase 2 green roof experiment at Barking Riverside, East London. Frames were based on the Green Roof Shelter Company's designs (www.greenroofshelters.co.uk).

Figure 12. Completed wooden bases for the Phase 2 green roof experiment at Barking Riverside, East London. Frames were based on the Green Roof Shelter Company's designs (www.greenroofshelters.co.uk).

4.4 Drainage outlets and waterproofing

Following the completion of the wooden frames, the next stage in the construction process was to waterproof the roof bases. This was done using Hertalan EPDM roof waterproofing membranes. These are a typical membrane used for waterproofing roof decking in preparation for a green roof. The membranes were supplied by Hertalan (www.hertalan.co.uk) in support of the research. We are very grateful for this support which helped to make such a large-scale experiment possible.

Prior to installing the Hertalan membranes, a single drainage outlet was installed at the middle of the south edge of each green roof frame (Figure 13). Hertalan adhesive was then used to stick the EPDM membranes down to the roof frames (Figure 14).

Figure 13. Drainage outlet installed for the Phase 2 green roof experiment at Barking Riverside, East London. A single drainage outlet was installed for each green roof.

Figure 14. Installing the Hertalan EPDM water proofing membrane on the Phase 2 green roof experiment at Barking Riverside, East London. The membranes were supplied by Hertalan (www.hertalan.co.uk) in support of the research.

4.5 Geotextile and substrates

A geotextile was laid on top of the waterproofing membrane. The geotextile was included to act as a barrier to prevent plant roots causing damage to the membrane. It was also utilised to act as a drainage layer at the base of the roof, storing rainwater and releasing it gradually following rain events. On top of the geotextile, two green roof aggregates were installed onto each green roof experimental plot. The substrates used were a standard extensive green roof substrate donated by Shire Green Roof Substrates Ltd (www.greenroofsubstrates.co.uk) and a lytag-based green roof substrate (Hortag) blended with green bin waste. The substrates were added to each green roof test platform in the same volumes and the same pattern (both spatially and topographically) to ensure that each test platform was as identical as possible for experimental purposes (Figures 15 and 16).

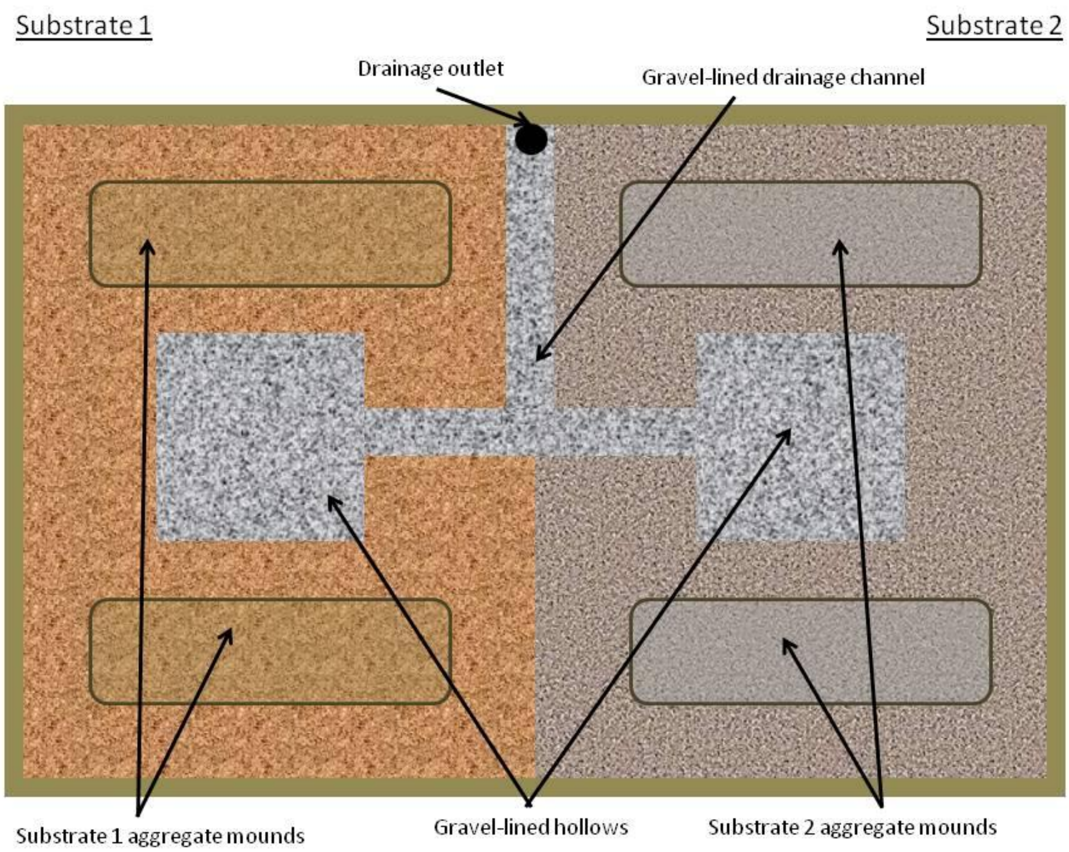

Figure 15. Plan of aggregate installation on the Phase 2 green roof experiment at Barking Riverside, East London. The aggregate volume on all roofs was measured so as to be as identical as possible. Placement of mounds was done using a wooden frame template for reproducibility. The only thing that varied between green roofs was the east-west orientation of the two substrates.

Figure 16. Installation of aggregates on the Phase 2 green roof experiment at Barking Riverside, East London. The aggregate volume on all roofs was measure so as to be as identical as possible. Placement of mounds was done using a wooden frame template for reproducibility. The only thing that varied between green roofs was the east-west orientation of the two substrates.

4.6 Planting

The final stage of the experimental green roof development process was to plant them. A novel seed mix was created that consisted of a typical biodiverse London green roof seed mix. This mix was similar to that used for the Phase 1 experiment which was considered to be representative of the kind of flora found on the Barking Riverside brownfield site prior to development. This typically dry flower-rich grassland seed mix was combined with some additional floral species which represent a range of habitat preferences from those that are tolerant of winter wet conditions to those that are considered to be wetland species. Selected species from these mixes would also be plug planted. The rationale behind the plant selection was that each roof treatment would then be monitored to assess how flora performance varied with the different hydrological regimes.

Following completion of the substrate install the weather turned cold and very wet. It was thus decided that the seeding and plug planting of the roofs would be delayed until early Spring 2014 to try to avoid the plug losses that occurred during the install of the Phase 1 green roof experiment at Barking Riverside.

At the time of writing this report, the experiment was, therefore, up and running at Barking Riverside and awaiting the final seeding early in 2014 (Figure 17) before monitoring could begin throughout the 2014 monitoring season.

Figure 16. Completed construction of the Phase 2 green roof experiment at Barking Riverside, East London. Image shows the layout of all 9 green roof test platform surrounded by edge protection scaffold.

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