Sustainable Drainage Estates, London

(Delivered as part of LIFE+ Climate Proofing Social Housing Landscapes and Thames Water Twenty4twenty programme)

SuDS used

- *Large- and small-scale biodiverse green roofs*
- *Rain gardens*
- *SuDS tree pit*
- *Stony basins*
- *Permeable paving*
- *Composite decking*
- *Schotterrasen*
- *Pebble or vegetated channels draining to shallow basins*
- *Vertical rain garden*
- *Green walls*

Benefits

Environmental improvements across the three estates:

- *Approximately 4100m^2 of impermeable surface diverted from draining directly into the sewer – from*

Engagement & social benefits:

- *430 residents have been engaged in the project via consultation events, door knocking, Green Doctor visits and food growing clubs;*

the 12 month period between June 2015 and June 2016 this was approximately 1.3 million litres.

- *Approximately 4600m² of estate land improved.*
- *During the initial monitoring period for Life+ 100% of the rainfall that fell within the catchment areas of the installed measures was diverted away from the sewer and managed in the landscape.*
- *Thames Water Twenty4twenty programme has achieved a net reduction of volumes and flow rates of storm water into the combined sewer network when compared to Greenfield run off rates using retrofitted SuDs devices.*
- *Green roofs (Life+) absorbed an average of 84.15% of rainfall landing on them (a conservative estimate) during the initial October 2015 to June 2016 monitoring period.*
- *81% of residents agree or strongly agree that the quality of the green spaces has improved significantly; and*
- *58% of residents report that they use the green spaces more often since the works were completed.*

Employment & training:

- *15-20 Groundwork London 'Green Team' trainees achieved City & Guilds Level 1 in Practical Horticulture Skills. See section 6 for details.*

Training courses have been run for Council maintenance contractors and senior managers, with training modules in place for future roll-out.

1. Location

This project has been delivered across three housing estates in the London Borough of Hammersmith & Fulham: Richard Knight House (SW6), Queen Caroline Estate (W6) and Cheesemans Terrace (W14).

2. Description

Programme context

Improvements to the three estates have been developed with the support of two separate programmes; Life+ European funding and Thames Water twenty4Twenty funding, both of which support the implementation of retrofit SuDs to meet a series of environmental goals. In both instances there is a clear desire to see designs that are replicable and can be used in a wider context. These two programmes were also supported through additional match funding made available through the Greater London Authority and London Borough of Hammersmith & Fulham.

Life+ funding for the project aimed to deliver packages of low-cost retrofitted climate change adaptation measures across three housing estates in the London Borough of Hammersmith & Fulham in order to reduce these communities' vulnerability to climate change.

Thames Water's Twenty4Twenty programme aims to reduce flood risk pressures from the combined sewer network by diverting stormwater from impermeable surfaces, in this instance using a network of swales and rain gardens to achieve infiltration or greatly reduced flow rates and volumes of water from entering the network.

Character description

Prior to the project's implementation, open spaces across the three estates were often unused and lacking in energy or connection to the homes around them. There were circuitous paths through the estates which were separated from large expanses of disused grass and paved drying areas by rows and rows of loop-top fencing. Site visits identified clear opportunities and needs for transforming the public spaces on the estates. The challenge of persuading estate residents of the value of undertaking landscape improvements to address the slightly abstract and distant threats of climate change and localised flash flooding was also apparent.

However, the local community engaged with these wider issues and supported implementation from the outset, with regular events held on the estate to involve residents young and old in the development of the designs. It demonstrated that retrofit projects provide fantastic opportunities to engage existing communities in large scale issues, providing both improved open spaces and empowering communities to respond to the threats they are facing.

The project has focussed on green infrastructure-based approaches to dealing with the effects of storm water and increasing communities' resilience to climate change whilst also delivering multiple other benefits including improvements in biodiversity, visual amenity, play provision, local food production and air quality. This project was innovative in demonstrating how known green infrastructure techniques, with their many benefits, can be retrofitted on a large scale into existing social housing estates. This approach will be vital for increasing resilience to climate change, as focussing on new build alone will not deliver the scale or speed of change required.

3. Main SuDS components used

Many small-scale interventions have been integrated within wider landscape improvements, including informal play features and revitalised community garden spaces incorporating ornamental and fruit trees and raised planters, with the aim of reducing pressure on the existing surface water drainage networks across the estates. A summary of these small-scale interventions are as follows:

Queen Caroline Estate:

- 142m^2 of biodiverse green roofs installed as source control on bins stores and pram sheds.
- Unused hard landscaping areas replaced with permeable landscape features including rain gardens, stony basins, permeable paving, composite decking and 'schotterrasen' (Austrian gravel lawns).
- Pebble or vegetated channels diverting run-off from downpipes to shallow basins/rain gardens and swales planted with wildflowers.
- Vertical rain garden irrigated by water collected from building roofs which is fed into raised planters containing climbing plants.

Richard Knight House:

- A 172m^2 extensive biodiverse green roof installed as source control.
- 66m^2 of extensive biodiverse green roofs installed on bin stores and pram sheds, draining directly to adjacent paving.
- Conversion of a 20m^2 strip of unused space into a combined rain garden and SuDS tree pit.

- Small linear rain garden planted with SuDs wildflower turf to correct an area prone to significant water pooling.

Cheesemans Terrace:

- Rain gardens with underlying infiltration trench taking water from paving and a section of the estate road.
- Rain gardens and shallow meadow-filled basins to take water diverted from adjacent car parking areas via simple dished channels.
- Aggregate-filled cellular permeable paving used for vehicular access to bin stores.
- Extensive green roofs added to pram sheds.
- Small meadow-filled basin in play area with associated informal play features.

4. How it works

Queen Caroline Estate

Queen Caroline Estate is located in the Hammersmith Broadway ward of Hammersmith and Fulham. The Estate is made up of 16 residential blocks ranging in size from one to ten storeys, located across an area of 2.5 hectares. Many of the residential blocks have pitched roofs that drain to external downpipes. The Estate has an open structure with fairly large areas of open space between the residential blocks. The combination of external downpipes and relatively large open spaces at ground-level provided the opportunity to introduce a variety of ground-level sustainable drainage features.

In addition to the main blocks, there are also numerous flat roofed single storey ancillary buildings, including pram sheds, bin stores and garages. 142m^2 of extensive biodiverse green roofs were installed on bin stores and pram sheds. These buildings have flat or shallow-domed concrete slab roofs and drain via downpipes to the adjacent paving. The roofs were planted with wildflower seeds and plugs. The green roofs are monitored to assess their capacity to attenuate rainfall, and so far they have demonstrated almost total attenuation of rainfall from short but fairly intense rainfall events.

Prior to the works the Estate had several large and unused paved areas. Sections of these hard landscape areas have been replaced with permeable landscape features including rain gardens, stony basins, permeable paving, composite decking and 'schotterrasen' (Austrian gravel lawn). These features drain both the adjacent areas of hard-standing and sections of the roofs of adjacent buildings.

The 'stony basins' combine an outer skirt of permeable resin bound aggregate and planting beds with a central area of loose aggregate and planting. The use of stony basins reflects the Council's requirement to minimise increases in soft landscape to avoid significant changes to maintenance. The basins are approximately 30% soft landscape and 70% hard landscape. Their design was developed through consultation with residents, who were concerned that larger loose aggregate might be used as a weapon, and by maintenance contractors, who were concerned that loose aggregate near path edges might be easily transferred to grass areas where it would interfere with grass cutting.

In soft landscape areas run-off has been diverted from downpipes via pebble or vegetated channels to shallow basins/rain gardens planted with wildflowers. The basins and adjacent landscaping include informal play features such as bridges, mounds, stepping logs, balance beams and boulders, as well as raised planters for food growing. The result is an active community space that combines food growing and play with significant water management, biodiversity, and visual amenity benefits.

Simple but significant changes to the layout of the open spaces have been incorporated within the design. The Estate has multiple entrance points and is freely accessible to the public. Many of the routes through the Estate are heavily used, connecting the riverside areas to the south with Hammersmith town centre to the north. Prior to the works these main pedestrian routes were circuitous; skirting around areas of green space fenced off from the public with loop-top fencing. The design has stripped out large sections of the loop-top fencing and introduced new diagonal paths that better connect the Estate with surrounding areas. The new paths have created a series of new spaces which connect seperate features that now work as one sustainable drainage management chain.

A vertical rain garden has been built on the end façade of Mary House, combining sections of plug-planted green wall system with climbing plants. Both are irrigated from water collected from the roof of Mary House. Existing downpipes are diverted into a series of narrow stacked tanks which drip-irrigate the plug planted section of the wall. The overflows from the tanks and the plug planted section of the wall feed into a raised planter at the base of the wall which is planted with climbing plants. Any remaining overflow from the system drains to the adjacent rain garden.

Richard Knight House

Richard Knight House is one of three 3-4 storey blocks of flats in the Parsons Green and Walham Ward of Hammersmith & Fulham. The small estate is nestled in an area of Victorian terraced housing, having been constructed on an old World War II bomb site. The three blocks of flats all have flat roofs and are separated by small areas of amenity turf framed by rows of pram sheds and bin stores.

Various climate change adaptation features were integrated within the housing estate landscape using a combination of roof space, pavement, car park and soft landscaped areas. To minimise costs the fundamental layout of the Estate has not been altered, but instead many pockets of unused space were brought back into active community use.

A 172m^2 extensive biodiverse green roof was installed on the flat roof of Richard Knight House. The roof drains via four gullies that connect to internal downpipes. The difficulty of intercepting downpipes and managing water at ground-level was one of the main factors behind the choice of a green roof. The roof is laid out on a grid. Different sections of the grid have different substrate depths (80-120mm) and were planted using different techniques (seeds only, plugs only and a mix of seeds and plugs). A proprietary absorbent fibre layer was also installed within the substrate in some sections of the grid. The relative performance of the different sections of the green roof is being monitored to provide data that will be made available to support the design of future projects. One of the major limiting factors on retrofitting green roofs is the additional loading, so small gains in substrate depth may open up many more opportunities for greening.

In addition to the green roof on Richard Knight House, 66m^2 of extensive biodiverse green roofs have been installed on bin stores and pram sheds. These are visible at ground-level and from the adjacent properties, contributing significantly to the attractiveness of the space. The bin stores and pram sheds have flat concrete slab roofs with no parapet and drain directly to the adjacent paving. A new waterproof liner was applied to the concrete roofs and a pebble-filled gabion edge was used to create a retaining structure for the green roof substrate. The roofs were planted with wildflower seeds and plugs.

A 20m^2 strip of unused space within the Richard Knight House car park was converted to a combined rain garden and SuDS tree pit. The rain garden and tree pit are underlain with a structural soil. The

features drain adjacent hard surfacing within the housing estate, as well as taking water from the roofs of two adjacent private Victorian properties, giving a total catchment area of approx. 180m^2. The feature has an underdrain which connects via a flow control chamber back to the sewer. The flow control chamber limits the speed at which water can drain to the sewer, allowing water to back up to the designed water limit. At the water limit the water overtops a weir in the chamber and flows to the sewer unimpeded. The system has the capacity to manage a 1 in 50 year storm event.

Outside the entrance to Richard Knight House, a small linear rain garden was created in the adjacent grass area. Prior to the works, the entrance to the block was prone to significant water pooling which obstructed access to the block and caused particular problems for one resident who uses a walking frame. This lowcost measure contributes only slightly to the reduction of surface water run-off to the sewer, but has led to a significant improvement in residents' experience of the space. The shallow depression is planted with SuDS wildflower turf which brings colour, interest and wildlife benefits.

The measures described above have been integrated within a re-vitalised community garden space which includes new ornamental trees, espalier fruit trees and raised planters for food growing.

Cheesemans Terrace

Cheesemans Terrace is located in the North End ward of Hammersmith and Fulham. The Estate is densely developed, consisting of 12 blocks of flats with a total of 317 properties within an area of just over 2 hectares. The blocks are positioned around three small courtyard spaces which provide the only areas of public open space. Large car parking areas dominate the northern boundary of the Estate, separated from each other with slivers of amenity grass and planting beds with scattered trees. The blocks of flats and car parks are accessed via a single estate road (Sun Road) that loops through the Estate.

The majority of the blocks are 5 storeys and have a tiered construction and surface water drainage design. The main building roofs are flat and drain directly to the sewer via internally located downpipes. Unfortunately roof access restrictions were identified in the scoping stage of the project which ruled out the introduction of extensive green roofs. A number of the properties have private balconies which drain in turn to communal balconies below. These communal balconies then drain via externally located downpipes to the paving at street level.

During the feasibility stage of the project it became clear that in many cases it would be difficult to route surface water from the balconies, paved areas and estate roads into the existing soft landscaped areas in the courtyards. The courtyards are located to the rear of the properties away from the estate roads, and the private gardens to the rear of most ground floor properties obstructed easy access to the external downpipes. It was clear that any new retrofit SuDS elements would need to be incorporated in existing paved pedestrian areas or in the small strips of land between and around the estate's car parks. Interventions were focussed on three key areas – Sun Road, Orchard Square and the Northern Car Parks.

At the eastern end of Sun Road a wide paved area bounded one of the larger residential blocks. The paved area had three small raised beds immediately adjacent to the highway, which were separated by three driveways providing access to the garages of ground floor properties. The project maintained this arrangement, but the three raised beds were enlarged and sunken to form three rain gardens. Existing falls meant that surface water from the driveways, paving, and the communal balconies that drained onto the paving could all be diverted easily at surface level into the rain gardens. However, the fall on the adjacent section of Sun Road meant that surface water drained away from the rain gardens to the far side of the estate road. Here, the water either drained to a single highway gully or pooled extensively onto an area of slumped paving outside the entrance to the community centre – creating a major obstacle for residents in periods of heavy rain. The decision

was taken to intercept the water with two new gullies, which were then connected via pipes back across the road into an aggregate filled infiltration trench which ran beneath the three rain gardens and the driveways that separated them. This significantly increased the catchment area draining to the combined rain gardens and infiltration trench. The system has an overflow which connects to the sewer via a control chamber.

At Orchard Square, surface water was diverted from a range of sources, including the roof of the adjacent building's entrance block, the roofs of a row of pram sheds, a small car park, vehicular access to some bin stores, and paths. Water from the entrance block, pram sheds and car park was directed into a small rain garden created by converting a narrow strip of amenity grass that separated the parking bays from an adjacent footpath. To increase capacity, this rain garden was connected via a dropped section of kerb to a shallow meadow filled basin in a larger area of amenity grass outside the entrance to the blocks. The combined system had an overflow which connected via a flow control chamber back to the sewer. Associated interventions included the conversion of the vehicular bin store access from concrete hardstanding to an aggregate filled cellular permeable paving, and the introduction of a small meadow filled basin in the adjacent play area. The latter takes very little surface water, but was introduced to engage residents in the scheme.

In the Northern Car Parks very simple alterations were made to intercept surface water. Where the existing falls allowed, a series of new dished concrete channels were introduced to collect and convey surface water from the parking bays into small rain gardens and shallow meadow filled basins, created by dropping the soil levels and re-planting existing planting beds or areas of amenity grass. Due to the relatively small catchment areas, the rain gardens and shallow basins have capacity to manage fairly significant storm events (1 in 100 year). Should capacity be exceeded water is routed over the surface back to the gullies in the adjacent estate road.

As with Queen Caroline, opportunities were also taken to introduce extensive green roofs on pram sheds where structures were assessed to have capacity for additional greening loads.

5. Specific project details

The original LIFE+ project and subsequent work through Thames Water's Twenty4twenty programme have been instrumental in drawing attention to the possibilities for retrofitted SuDS, tackling some of the actual and perceived barriers to uptake, and demonstrating the potential benefits of the large-scale roll out of retrofit solutions. Requirements of developers brought to bear through the planning system will deliver steady incremental increases in the number of SuDS measures implemented. However, as noted in the London Sustainable Drainage Action Plan (GLA, 2015), new development typically only affects about 0.5% of urban land per annum. Clearly, relying on new build alone will not achieve the step change in implementation required.

Retrofit projects such as this provide fantastic opportunities to engage communities in the issues, providing both improved open spaces and empowering communities to respond to the threats they are facing. The project's focus on low-cost interventions integrated within wider landscape improvements has been central to this. This approach led the team away from more expensive engineered hard landscape and below ground measures, towards less expensive, small scale, at surface, near building interventions. Consequently, the project has delivered many small green infrastructure focussed interventions across the estates, spreading out the impact and bringing colour, interest and wildlife to everyone's front door.

The project has been delivered by a large and diverse team of professionals. Groundwork London's Landscape Architect team were responsible for all stages of the works and provided continuity through site survey & analysis, feasibility assessment, design and delivery. However, a number of other professionals provided significant input to the project in the areas of community engagement, engineering support, and the provision of specialist design advice.

The support and partnership working of staff within the London Borough of Hammersmith & Fulham was central to the success of the project. Staff from the Council's Housing and Flood Risk Management teams, and their external management and maintenance contractors were central to the successful design and delivery of the schemes, from initial survey and analysis through to maintenance of the completed works.

Design review meetings, held at each design stage, were attended by the Council's maintenance contractors. These meetings provided the opportunity for the maintenance contractors to ask questions and voice concerns. The designs were adapted on a number of occasions in response to the input received (e.g. stony basin design).

The residents were engaged in the project from the outset, with regular events held on the estates to involve residents young and old in the development of the designs. Residents have also been engaged through Green Doctor visits which offer free installation of a range of simple energy and water efficiency measures in their homes; through the development of Community Adaptation Plans for each of the estates; and through the establishment of food growing groups.

There was also a great deal of support and input from other organisations during the development of the project, including the Greater London Authority, the Environment Agency and Thames Water, who provided strategic and technical support to the design and project team when required.

6. Maintenance & operation

Following Practical Completion, Groundwork London's Green Teams* maintained the spaces for a period of 12 months. The Green Teams were responsible for most of the soft landscape installation, so this period provided them the opportunity to ensure that the planting was well established before handing responsibility back to the Council's maintenance contractors. The 12 month period also provided an opportunity for Groundwork to develop and deliver training courses for the Council's maintenance contractors. These courses were based at Queen Caroline Estate and provided an excellent opportunity for the Green Team to pass on the learning from their initial 12 months maintaining the sites.

From the start of the project the Council made it clear that net increases in maintenance were to be avoided, or as minimal as possible. With this in mind, the green roofs have been designed to minimise maintenance after initial establishment, and increases in planted areas at ground-level have been restricted, for instance through the use of stony basins. The small increases in planted area have been off-set by reducing the maintenance requirements of other soft-landscaped areas, for instance by reducing the mowing regime for some grass areas by replacing standard mown amenity turf with wildflower turf that only requires cutting 2-3 times a year.

By engaging residents in their open spaces through the informal play features, better access and the establishment of food growing groups, residents were also encouraged to support the long-term management and maintenance of the spaces.

**** Green Teams:*** Green Teams are Groundwork London waged horticultural training programmes that enable trainees to gain horticultural skills and qualifications and ultimately get back into work. Participants work on real grounds maintenance jobs from the off, gaining valuable on-the-job experience. The programmes are employer led, which ensures that we equip our trainees with the skills and qualifications companies want for their employees. Over the 26-week programme,

participants can gain a Level 1 City & Guilds Certificate in Practical Horticulture Skills, and also benefit from 1-2-1 advice from a dedicated employment advisor to help them prepare for job applications and interviews.

7. Monitoring and evaluation

The environmental, social and environmental benefits of the scheme are being evaluated to provide a body of quantitative and qualitative data which will be made available to support other green infrastructure projects and the implementation of retrofit SuDs.

The University of East London's Sustainability Research Institute (SRI) were commissioned to carry out a programme of retrofitted monitoring to assess the biodiversity, water attenuation and thermal benefits of the green infrastructure interventions. Monitoring comprised a diverse range of technological (and more manual) methods to capture the environmental (ecosystem service) benefits. This included:

- Using of time-lapse cameras to monitor the performance of ground-level SuDS basins and rain gardens.
- Installing flow meters and pressure sensors to monitor run off from green and grey roofs and infiltration rates in swales and rain gardens.
- Simulating storm events to assess how the SuDS features would perform under the extreme rainfall conditions for which they were designed.
- Thermal imaging to quantify the difference in temperature between greened surfaces and grey (hard infrastructure) surfaces.
- Thermal monitoring to investigate any reduction in heat stress associated with proximity to the green wall.
- Undertaking biodiversity surveys to quantify floral diversity on green roofs.
- Installing weather stations to monitor weather patterns on site.

GWL and EPG have also undertaken modelling of the As Built devices delivered under the Twenty4Twenty programme to demonstrate their performance of the As Built devices against a theoretical Greenfield rate.

8. Benefits and achievements

The monitoring and evaluation activities are ongoing. However, the impact of the project is clear, with 4100m^2 of impermeable surface diverted from draining directly to the sewer, and approx. 4500m^2 of the estate land improved. During the initial monitoring period for the first 3,000m2, 100% of the rainfall that fell within the catchment areas of the installed measures was diverted away from the sewer and managed in the landscape; and the green roofs absorbed an average of 84.15% of rainfall landing on them (a conservative estimate).

The SRI recently completed data analysis from the second year of monitoring (full results available online: http://roar.uel.ac.uk/7001/). Results from the second year of survey demonstrated that the retrofitted green measures continue to perform a range of valuable services to residents and the borough. Highlights of the monitoring included:

- The combined SuDS features diverting approximately 1,220,900 litres of rain water away from the combined sewer system (June 2015 to 2016).
- An average of approximately 80% of rainfall being absorbed by the small-scale green roof.
- A swale capturing, storing and infiltrating a 1 in 100 year simulated rain event even during the winter period when the ground would be expected to be more saturated.
- A total of 57 species of wildflower and grasses on a single green roof.
- An approximate 40% reduction in temperature on a green roof compared to a control roof on a hot summer day.

The benefits of the project have not only come from the performance of the installed measures, but also from engaging the local community in the wider issues and involving them in implementation. 430 residents were engaged during the project via consultation events, door knocking, Green Doctor visits and food growing clubs. 81% of residents agreed or strongly agreed that the quality of the green spaces improved significantly; and 58% of residents reported that they use the green spaces more often since the works were completed.

Young unemployed people from the borough were also engaged in the delivery of the soft landscape works on each of the estates as part of the LIFE+ Green Teams. Green Teams provide structured programmes that enable young unemployed people to learn new skills, gain qualifications and enhance their employment prospects whilst delivering valuable environmental improvements in neighbourhoods. 15-20 Green Team trainees achieved City & Guilds Level 1 in Practical Horticulture Skills, and training courses were run for Council maintenance contractors and senior managers.

For works delivered under the Twenty 4 Twenty programme, a different approach was used to assess the performance of the project. Nine separate sub-catchments were assessed against theoretical/modelled Greenfield performance, by measuring reductions to peak flow rates and volumetric reductions to the Combined Sewer network. These have been modelled against four storm events; 1 in 1, 1 in 5, 1 in 10 and 1 in 30, for volume and flow rate, and show at which storm event full infiltration is achieved. In addition modelled flow rate performance showed where devices are still fully infiltrating to a 1 in 100 + 40% storm event.

Simulated test storm events indicate that the devices are out-performing initial expectations, and as a minimum to some original specifications. Simulations undertaken during 2016 at Sun Road rain garden, Cheesemans Terrace, show the rain gardens were still fully infiltrating at minimum 1 in 5 storm event, despite having been designed to a 1 in 2 storm event – with no trace of overflow water discharging into the combined sewer. The performance of the nine catchments have been shown below in table A.

Performance Measure	**Performance Summary**
1. ***Volume performance across the combined catchments*** *(total volume to combined sewer for solution and theoretical Greenfield)*	Reduction of 5.363m3 @ 1 in 1 yr rainfall event Reduction of 8.813m3 @ 1 in 30 yr rainfall event. *Reduction in volume from the modelled Greenfield to As Built 1 in 30 year event*
2. *Full **infiltration performance** at modelled storm events*	Full infiltration achieved at 9 individual sub-catchment: 5 no catchment at minimum 1 in 100yr+ 40% 2 no catchment at minimum 1 in 30 yr

	2 no catchment at minimum 1 in 5 yr
3. ***Peak flow performance across the combined catchment*** *(peak flow rate to combined sewer for solution and theoretical Greenfield)*	Modelled and As Built peak flow rate into the combined sewer network. **<u>1 in 1</u>** Greenfield outflow at 1 in 1: 0.299 litres per second (lps) Brownfield outflow at 1 in 1: 20.72 lps As built outflow at 1 in 1: 0 lps **<u>1 in 30</u>** Greenfield at 1 in 30: 0.737 lps Brownfield at 1 in 30: 57.90 lps As built outflow at 1 in 30: 0.7 lps

Table A: performance of the As Built devices against a theoretical Greenfield rate

9. Lessons learnt

The project is unique, both in its scale and the scope of its outputs, in promoting the widespread retrofit of low-cost climate change adaptation measures in the urban landscape. It is hoped that the project will inspire a step change in the retrofitting of green infrastructure solutions to tackle both the threats posed by climate change, and the many other environmental, social and economic challenges facing society today.

Lessons before/during construction phase:

Services:

Full topographic surveys were undertaken along with below ground radar surveys to try and locate existing services as well as consulting all existing plans that were available. Inevitably, despite these surveys, not all services were picked up and in some instances they were found to be on a slightly different alignment or at a different depth to that recorded. We would recommend some well-placed intrusive site investigation to establish to the extent of services in key areas, where this is feasible.

- Expect the unexpected when excavating near services as the locations may not be as shown even where service scans have been undertaken. Understand that the scheme may need to be adjusted on the ground.
- The importance of consulting the original SuDS designer to agree how the scheme may be amended to retain the same design intent for all aspects of the design (quality, quantity, amenity and biodiversity).

Establishing planting

Due to wider programming restraints, planting on the green roofs was delayed. This resulted in a greater need for establishment watering, as well as increased risk of the vegetation browning off

during longer periods of drought. It took time and additional discussion to help residents, who were perhaps expecting lots of lush meadow, understand that the roof would bounce back, which they did, as the planting selected was relatively resilient to this pattern of drought.

- Manage residents' expectation with regard to appearance and establishment.
- Plan your construction and planting phase as best as possible to avoid the need for extensive watering during establishment.

Logistical challenges

Throughout much of the construction process there were significant logistical challenges, particularly around the handling and storage of materials on site, and the management of noise from the works, with some residents, e.g. elderly or unwell, more sensitive to the disturbance than others. Access was an issue throughout with difficulties getting materials through narrow passageways, and having storage areas immediately adjacent to people's homes. Careful planning and ongoing liaison with residents was required. Using the right machinery for the narrow estate roads and constrained sites was key, and restricting the use of residents' parking spaces for site access, accommodation and storage required very careful site planning and ongoing discussion between the contractor, contract administrator and residents; representatives. These challenges were mainly overcome by the contractors developing very good on-site working relationships with the residents, and Groundwork communicating with residents by attending Tenants and Residents Association (TRA) meetings, and inviting resident representatives to key meetings before, during and after construction.

Lessons learnt

- The need for careful planning and communication to residents of materials and waste transport routes and storage areas.
- The need for on-going careful and effective communications.
- Key to successful delivery was the good relationship established between the contractors, Groundwork and the estates residents.

Challenges in achieving the right construction through inspections

Soft landscaping

Examples of where 'typical' soft landscape practice may not always be needed include soiling up to the level of adjacent surfaces rather than leaving the soil level 50-75mm lower to support the flow of run-off into the beds, and mulching rain garden beds following planting which risks causing blockages in the overflow pipework if washed off in heavy rain. Throughout the project these issues were rectified and the lessons learnt applied to the next phase of works.

Lessons learnt

- The 'way we usually do it' is not always appropriate for SuDS. With contractors or teams who are inexperienced in building SuDS, much greater care is required in checking that they understand the requirements for the works.

Hard landscaping

During the construction of the combined rain garden, tree pit and trench at Richard Knight House it was not possible to inspect every stage of the build-up (as the feature was small so the works progressed quite quickly). This therefore required part of the construction works to be evidenced through site photographs to have an acceptable degree of certainty that it would deliver the attenuation required. In some cases the photographs were from positions or angles that did not allow a full assessment of the works. It is important to agree/confirm photographic requirements

e.g. location points before the works begin and then to review these as the works progress to ensure that they remain suitable.

To test the functionality of the SuDS, a number of features were subjected to storm simulation events, where a pre-determined quantity of water was released into the SuDS features to replicate the design storm event. In all cases the performance of the features exceeded what was expected.

Lessons learnt

- It is difficult to inspect each stage where a SuDS feature is so small, and reliance has to be put on good site photographs to evidence the construction works. Undertaking a storm simulation was therefore a useful way to check that the scheme coped during a measured storm simulation.

Wider Lessons learned:

Scalability

Across three housing estates in one London Borough the project has diverted over 4000m^2 (0.4ha) of impermeable hard surface away from draining directly to the piped drainage system. There are 99 housing estates across the London Borough of Hammersmith & Fulham, covering 92ha of land. If we were to undertake similar works on these estates, 10ha could theoretically be diverted from housing estates in just one London Borough. If these measures were extended beyond housing estates and into highways, industrial and commercial land etc. there is a huge opportunity for replication across London.

Team working

For all involved in planned or cyclical improvements to housing, highways, public realm and parks land, opportunities exist to retro-fit low-cost climate change adaptation measures. In the hope of disseminating useful lessons from the LIFE+ project, a wide range of associated activities were delivered to support the widespread roll-out of the project's approach. These include:

- Monitoring of the environmental benefits and evaluation of the wider social benefits of the scheme;
- Training modules for decision makers within organisations procuring green infrastructure and maintenance contractors tasked with maintaining completed schemes;
- An implementation guide and layman's guide; and
- Case study material, a project film and 360-degree photographic tours of the estates held on the project website, with links to other organisations promoting best practice in the UK and Europe.

Promotion

Since completion, 100+ visitors have toured the project, including representatives from local authorities and housing associations interested in undertaking similar works, sustainable drainage and green infrastructure professionals from the UK, Europe, and North America, and members of the general public interested in progressing their own local green infrastructure projects.

Perceptions of costs

In order to establish the relative cost of delivering retrofit SuDs of this nature, GWL undertook an outline analysis of cost per m2 by comparing these against 15 housing estate improvement projects that Groundwork have undertaken since 2014. Using a general landscape improvement costs per m2

and setting this as '100%' (entrances, paving, soft landscape), the following relative costs were identified:

- Traditional play areas & outdoor gyms: 140%
  (play surfacing & equipment)
- LIFE+ ground-level SuDS: 95%
  (hard & soft landscaped basins, channels, and associated paving)
- LIFE+ green roofs, excluding waterproofing: 120-168%
  (residential block, pram sheds & bin stores)

Whilst these are only intended to provide an outline indication of cost, they seem to suggest cost is not necessarily a significant prohibitor to progress green infrastructure retrofit projects of this type. Many landscape improvement projects can be identified where, with simple adaptations, at no or limited additional cost, climate change adaptation benefits can be delivered alongside core recreation, play or visual amenity improvement.

10. Interaction with local authority

The London Borough Hammersmith & Fulham were a key supporter, funder and partner in the delivery of this work. A project management structure was utilised throughout the scheme, with a high level project board signing off design process and supporting the various project steams where needed, and providing valuable political and corporate support.

Technical support was provided by representatives from the boroughs flood risk officer, planning team, housing team and asset management teams, who coordinated their contribution through various technical design meetings. They gave their, skills and energy to this project and were a vital part of the success of the project and keeping momentum for its delivery.

11. Project details

The works were delivered as a series of small contracts, with works commissioned on an estate-by-estate basis. Green roof works were delivered in advance of the ground-level works. The ground-level works were then split into two parts, with landscape contractors employed to deliver the ground works and hard landscaping, and Groundwork's Green Teams delivering the finished soft landscaping works, i.e. topsoil to finished levels and planting.

Completion dates:

Date of end of rectification/defects of the scheme:

- Richard Knight House: April 2016 (LIFE)
- Queen Caroline Estate: August 2016 (LIFE)
- Cheesemans Terrace (green roofs): April 2016 (LIFE)
- Cheesemans Terrace and Queen Caroline Estate (ground-level works): September 2017 (Twenty4twenty)

Cost:

Budgets

- Richard Knight House: approx. £80k*
- Queen Caroline Estate: approx. £230k*
- Cheesemans Terrace (green roof): approx. £10k*

- Cheesemans Terrace (ground-level works): approx. £110k*

* Capital only - The design team were involved in many of the wider project work packages in addition to design and contract administration (e.g. monitoring, training, media work, project website, dissemination activities etc.).

Extent:

Approx Size of sites:

- Queen Caroline Estate: 2800m^2
- Cheesemans Terrace: 1000m^2
- Richard Knight House: 800m^2

12. Project team

Funders	• Co-financed by the EU LIFE programme. • Thames Water Twenty4twenty programme • London borough Hammersmith and Fulham • Greater London Authority
Clients	• Sharon Schaff, Head of Estate Services, London Borough of Hammersmith & Fulham • Binita Shah, Project Manager, London Borough of Hammersmith & Fulham • George Warren / Jessica Bastock, Flood Risk Manager, London Borough of Hammersmith & Fulham (George Warren now of GLA)
Lead Designers	• Mark Bentley CMLI, Landscape Architect, Groundwork London • Marion Phillips CMLI, Senior Landscape Architect, Groundwork London (until Apr 2015) • Matthew Conlon-Perry, Landscape Architect, Groundwork London
Contractors	• Greatford Garden Services Ltd (groundwork, drainage infrastructure & hard works) • Warwick Landscaping Ltd (groundwork, drainage infrastructure & hard works) • Groundwork Green Teams* (soft works) • Organic Roofs (green roofs – pram sheds & bin stores) • Bauder (green roof – Richard Knight House) • Mitie * Green Teams provide structured programmes that enable young unemployed people to learn new skills, gain qualifications and enhance their employment prospects whilst delivering valuable environmental improvements in neighbourhoods.

Other: Engineering support/design	• Steve Wilson, Technical Director, Environmental Protection Group Ltd (drainage) • John Richards, Project Engineer, Environmental Protection Group Ltd (drainage) • Richard Jackson, Engineering, Design and Analysis (structural assessment of roofs)
Other: Consultancy support / "critical friend" role	• Dusty Gedge, Director, Green Infrastructure Consultancy • Gary Grant, Director, Green Infrastructure Consultancy • Rosie Whicheloe, Ecologist, The Ecology Consultancy Ltd
Other: Community engagement	• Daniel Brittle, Senior Community Project Officer, Groundwork London • Nicola Wheeler, Housing Partnerships Manager, Groundwork London (until December 2015)
Other: Monitoring	• Stuart Connop, Senior Research Fellow, University of East London • Jack Rhodes, Research Assistant, University of East London

13. Site Images and illustrations

Fig 1 Queen Caroline drainage rationale for consultation

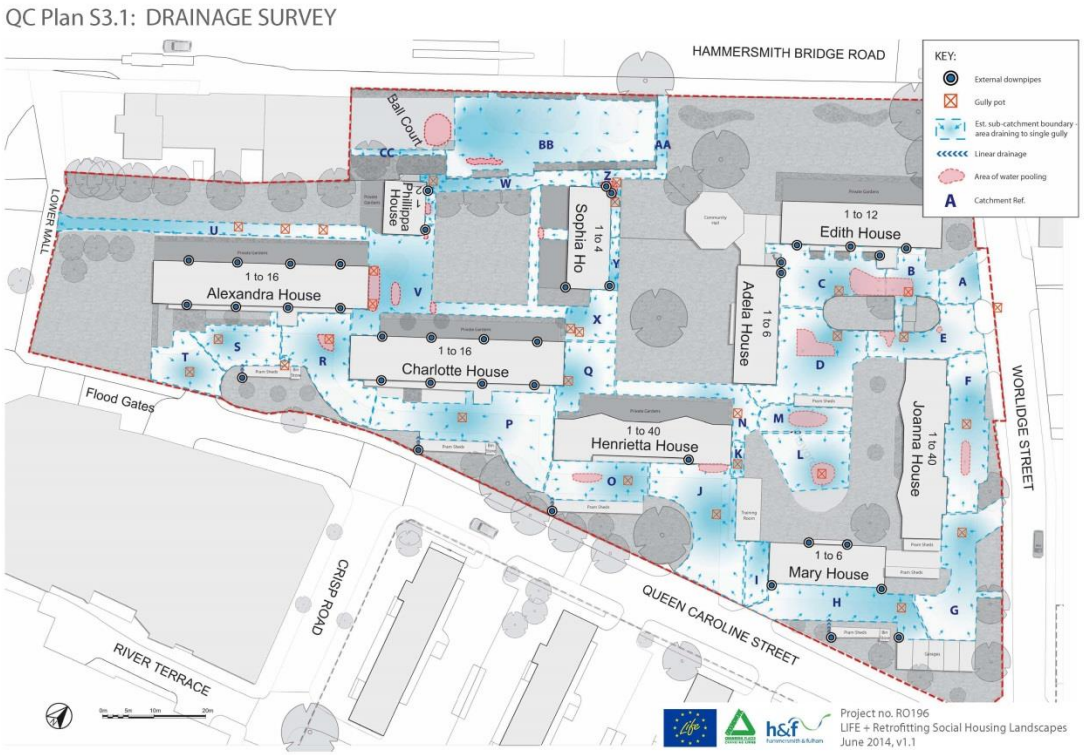

Fig 2 Queen Caroline Site Plans - drainage and flow analysis

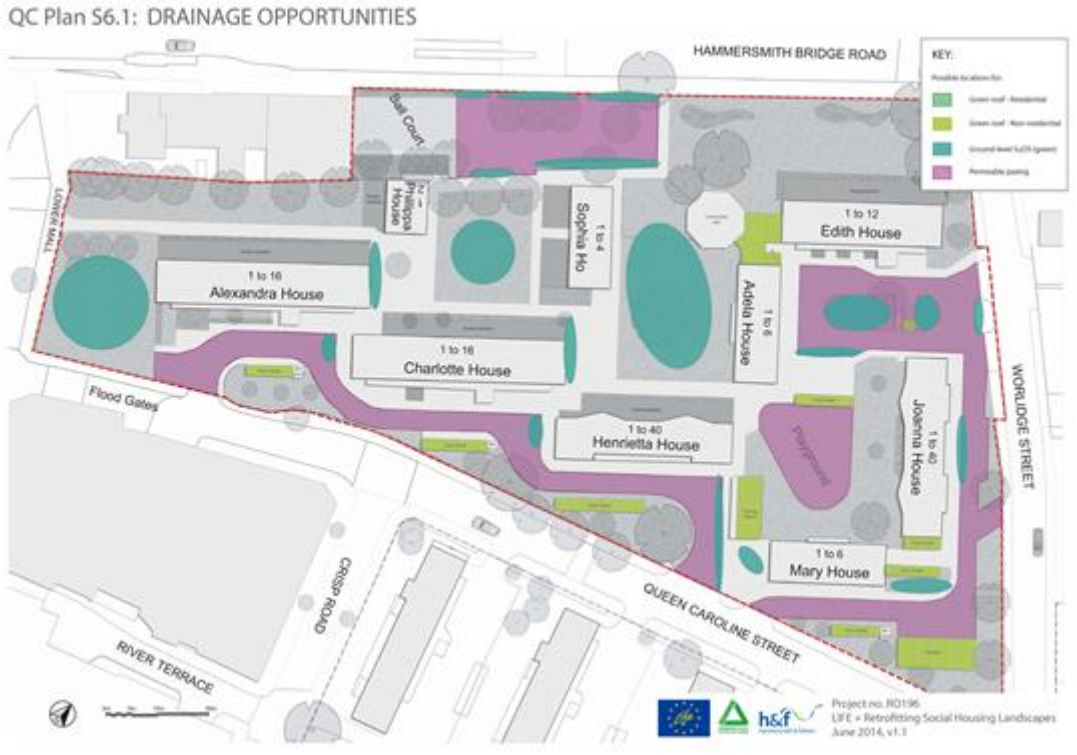

Fig 3 Queen Caroline Site Plans - drainage opportunities

Fig 4 Orchard Square, Cheesemans Terrace, shallow meadow basins with informal play

Fig 5 Queen Caroline Schotterasen gravel garden, adjacent to Adella House, and permeable paving and composite deck

Fig 6 Queen Caroline Swale and pebble channel to down pipes

Fig 7 Sun Road, Cheesemans Terrace, rain gardens

Fig 8 Richard Knight biodiverse extensive green roof