UEL University of East London

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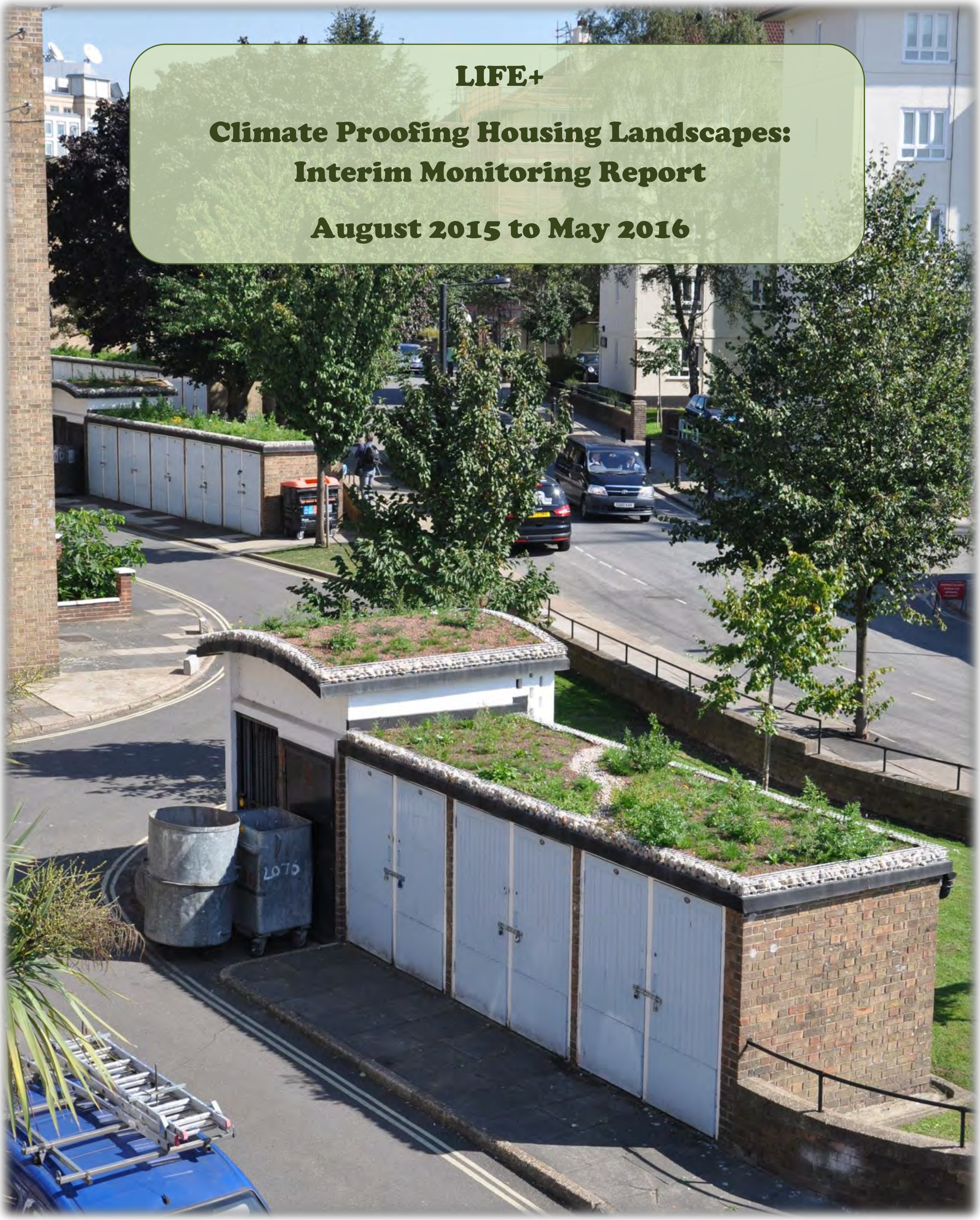
LIFE+

Climate Proofing Housing Landscapes: Interim Monitoring Report

August 2015 to May 2016



LIFE+ Climate Proofing Housing Landscapes: Interim Monitoring Report - August 2015 to May 2016

Authors: Connop, S. and Clough, J.

Corresponding author: Stuart Connop (s.p.connop@uel.ac.uk)

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1. Background

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 thermal stress, air quality and energy use;
- 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. 2011; 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.

Despite this emerging understanding of the benefits that green infrastructure can provide in high-density urban settings, a series of barriers remain in the way of urban green infrastructure up-scaling and broad roll-out (Connop et al. 2016). Central to these barriers is detailed understanding of the costs and benefits of a green infrastructure approach to urban planning. If innovative small-scale green infrastructure demonstrators are to be up-scaled and rolled out across our urban landscapes at a scale large enough to effect real change for biodiversity and our urban communities, it is vital that good practice and ecosystems service provision is captured, quantified and shared.

Groundwork London, in partnership with Hammersmith & Fulham Council, has been working with local residents to design and implement climate change adaptation measures on three housing estates, making them more resilient and adapted for the future. Interventions have comprised a series of green infrastructure and engineered interventions to:

- manage stormwater, create urban comfort zones
- support biodiversity
- provide opportunities for grow-your-own initiatives
- make the public realm spaces within the estates more attractive and functional for local residents (Figure 1).

In order to ensure that lessons are learned from this process so that similar schemes can be roll out across London and globally, it was vital that the benefits derived from these interventions were quantified. As part of this process, the University of East London's Sustainability Research Institute were commissioned to carry out a programme of retrofitted monitoring to assess the biodiversity, water attenuation and thermal benefits of the green infrastructure interventions.

This report details the monitoring methods adopted, monitoring equipment installed and the results of the various monitoring methodologies adopted during the initial monitoring period (August 2015 to May 2016).

Figure 1. Green infrastructure retrofit at Queen Caroline Estate, London Borough of Hammersmith & Fulham. Raised planters, permeable pathways, ornamental planting, pollinator-friendly swales and detention basins.

2. Monitoring methods

2.1 Monitoring equipment installed (to date)

The first level of monitoring equipment installed was a series of time-lapse cameras. These were positioned so that they faced a selection of the key ground level SuDS features (swales and rain gardens) installed at Queen Caroline Estate and Richard Knight House. The cameras were programmed to take a fixed-point photo every 15 minutes. In so doing they captured the performance of the SuDS components during rain events. They were also in-situ to capture a chronological record of the development of the vegetation within each of the SuDS component seasonally and as they matured following initial planting. The cameras included a night vision function to ensure that performance during rain events at night could also be monitored. The cameras have been labelled FPC1 to FPC5. Figures 2 to 5 show the locations of the fixed point cameras at Queen Caroline Estate.

Figure 2. Location of fixed-point camera at Richard Knight House, London Borough of Hammersmith & Fulham. Yellow stars represent the location of the fixed point cameras FPC1 to FPC4.

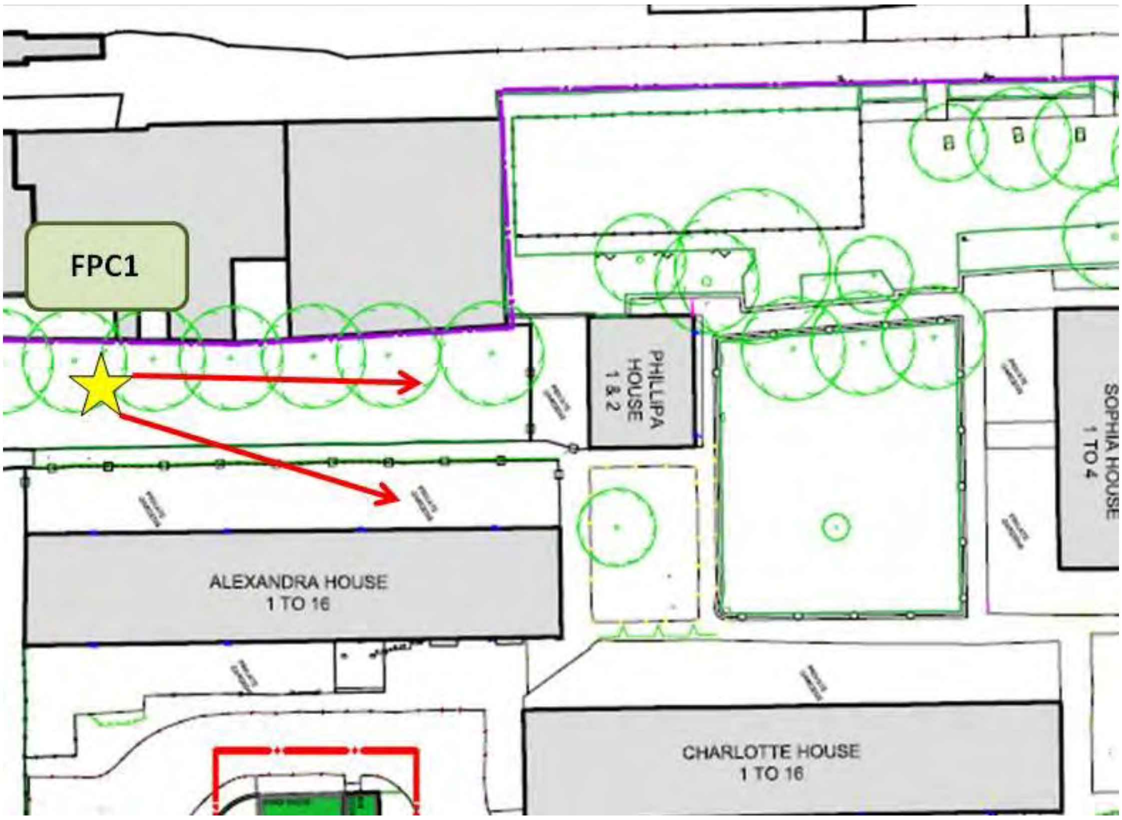


Figure 3. Location of fixed-point camera (FPC) 1 at Queen Caroline Estate, London Borough of Hammersmith & Fulham. Yellow stars represent location of camera and red arrows represent direction of field of view.

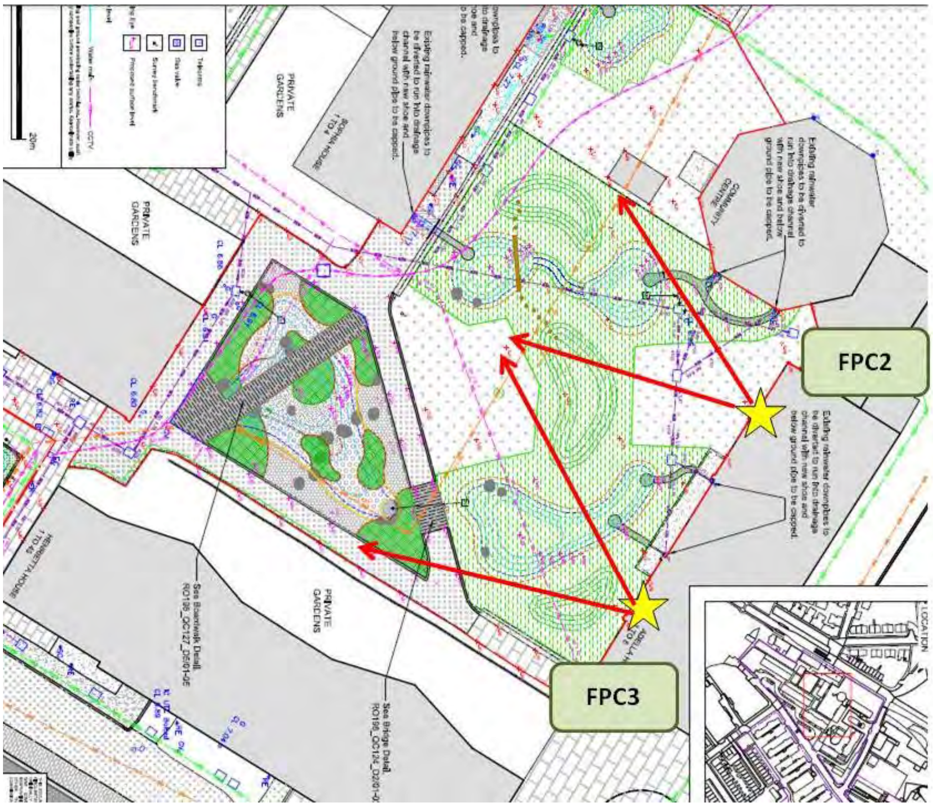


Figure 4. Location of fixed-point cameras (FPC) 2 & 3 at Queen Caroline Estate, London Borough of Hammersmith & Fulham. Yellow stars represent location of camera and red arrows represent direction of field of view.

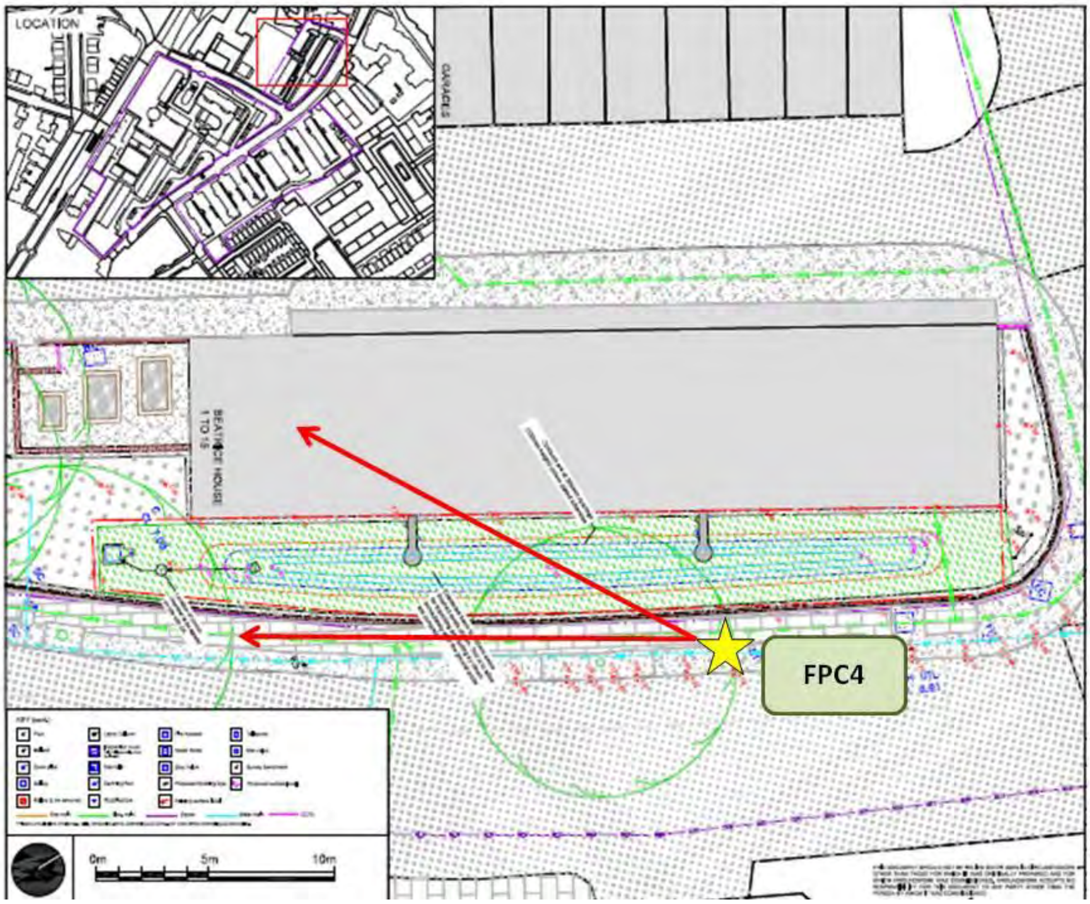
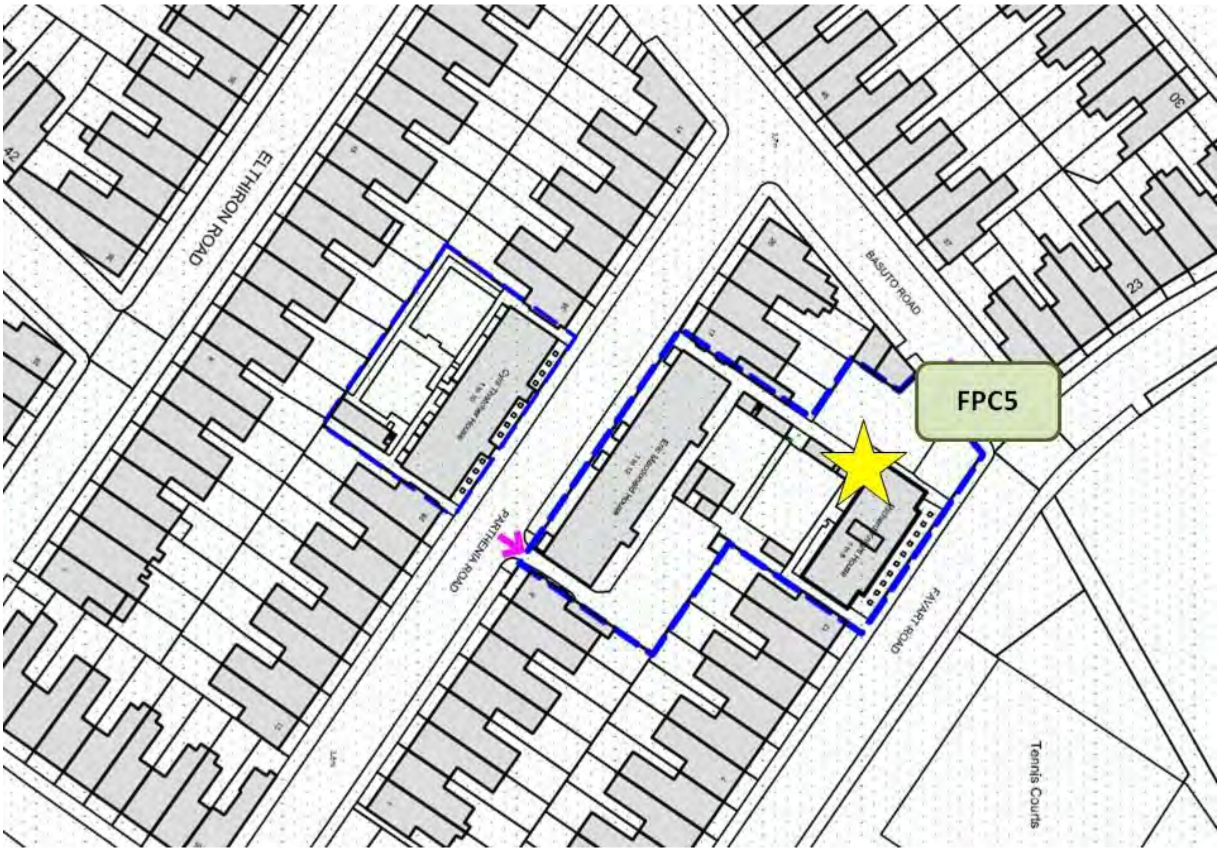


Figure 5. Location of fixed-point camera (FPC) 4 at Queen Caroline Estate, London Borough of Hammersmith & Fulham. Yellow stars represent location of camera and red arrows represent direction of field of view.

Cameras were fixed to the most suitable available location to capture individual selected SuDS components within their field of view. This included fixing them to buildings or trees. Cameras were fixed at height and were orientated so that they were pointing down towards the ground. Where possible cameras were orientated so as to avoid the field of view pointing towards residences. Figure 6 shows the location of the fixed point cameras and the direction of the field of view at Richard Knight House.

Images showing the field of view of each fixed-point camera are included in Figures 7 to 12.

i)



ii)

Figure 6. Location of fixed-point camera at Richard Knight House, London Borough of Hammersmith & Fulham. i) Yellow stars represent location of camera ii) Red arrows represent direction of field of view.

Figure 7. Field of view of fixed-point camera (FPC1) at the rear of Alexandra House, Queen Caroline Estate, London Borough of Hammersmith & Fulham. Field of view orientated to capture the lower end of the swale to monitor infiltration rates and storage capacity exceedance.

Figure 8. Field of view of fixed-point camera (FPC2) at the rear of Adella House, Queen Caroline Estate, London Borough of Hammersmith & Fulham. Field of view orientated to capture the lower basin to monitor infiltration rates and storage capacity exceedance.

Figure 9. Field of view of fixed-point camera (FPC3) at the rear of Adella House, Queen Caroline Estate, London Borough of Hammersmith & Fulham. Field of view orientated to capture two basins to monitor infiltration rates and storage capacity exceedance.

Figure 10. Field of view of fixed-point camera (FPC4) in front of Beatrice House, Queen Caroline Estate, London Borough of Hammersmith & Fulham. Field of view orientated to capture the swale whole to monitor infiltration rates and storage capacity exceedance.

Figure 11. Second field of view of fixed-point camera (FPC4) in front of Beatrice House, Queen Caroline Estate, London Borough of Hammersmith & Fulham. Camera position had to be moved approximately 2 months into monitoring due to a tree removal order being posted on the original vantage point. Field of view orientated to capture the lower end of the swale to monitor infiltration rates and storage capacity exceedance.

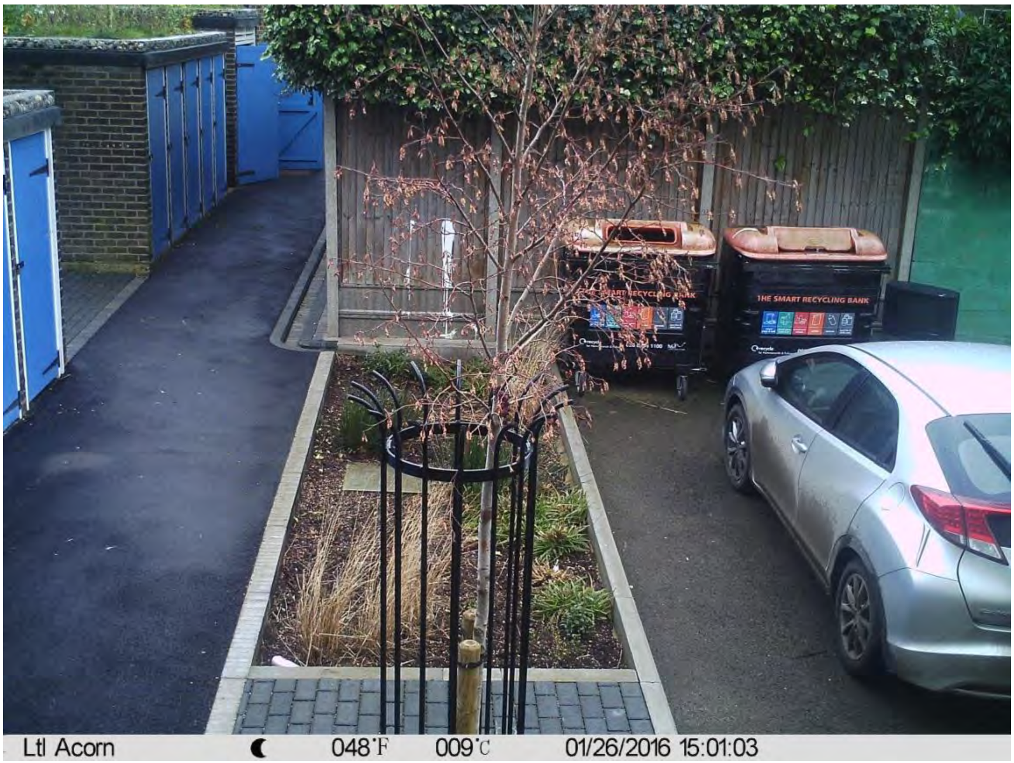


Figure 12. Field of view of fixed-point camera (FPC5) at rear of Richard Knight House, London Borough of Hammersmith & Fulham. Field of view orientated to capture the rain garden to monitor infiltration rates and storage capacity exceedance.

In addition to the fixed-point cameras, two Vantage Vue weather stations were installed to monitor the environmental conditions at Queen Caroline Estate and Richard Knight House. The weather stations were installed primarily to capture data on the timings and size of rain events occurring at the sites in order for comparative analyses to be made with the fixed-point photo monitoring and other equipment monitoring. The weather stations were also installed to capture data on additional environmental variables associated with the performance of urban green infrastructure components retrofitted across the sites including, temperature, wind direction, wind speed and humidity. Locations of weather stations are shown in Figure 13.

i)

ii)

Figure 13. Location of weather stations at i) Queen Caroline Estate (WS1) and ii) Richard Knight House (WS2), London Borough of Hammersmith & Fulham.

An example of the data generated by the Queen Caroline Estate weather station is presented as Figure 14.

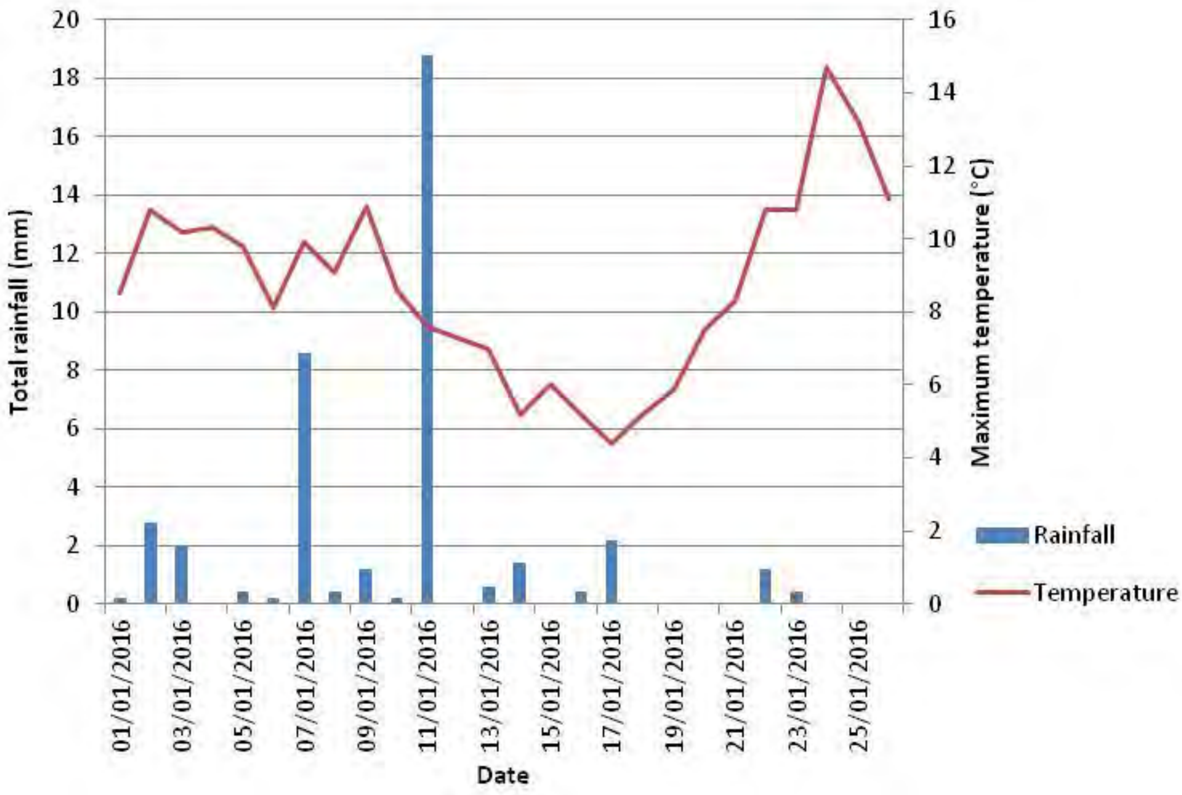


Figure 14. Weather station data from Queen Caroline Estate, London Borough of Hammersmith & Fulham, for January 2016. Largest rain event during this period was 18.8 mm on the 11th and had a maximum rate of 57.6 mm/hr.

A series of flowmeters and a pressure sensor have also been installed at Queen Caroline Estate to monitor the fine performance of a selection of the retrofitted green infrastructure components. This included a series of 3001 LT Leveloggers installed into bespoke calibrated v-notch weir controlled release boxes with direct read cables to enable data download (Figure 15) and an additional pressure sensor level logger buried to measure the depth of water and infiltration times in a water retention feature (Figure 16). Of these, three level loggers with v-notches were installed at the base of downpipes on three of the pram shed roofs retrofitted with small-scale green roofs (Figure 17). The other two Levelloggers with v-notch weirs were installed on the downpipes taking water from Beatrice House and feeding it into the neighbouring swale (Figure 18). The final pressure sensor was buried in the base of this swale to measure the volume of water accumulating from the Beatrice House roof and the time for any accumulating water to infiltrate following large rain events (Figure 18). An additional barologger was installed at UEL to act as an atmospheric pressure control.

Figure 15. V-notch and levelogger installed at Beatrice House, Queen Caroline Estate, London Borough of Hammersmith & Fulham.

Figure 16. Pressure sensor buried beneath swale behind Beatrice House, Queen Caroline Estate, London Borough of Hammersmith & Fulham.

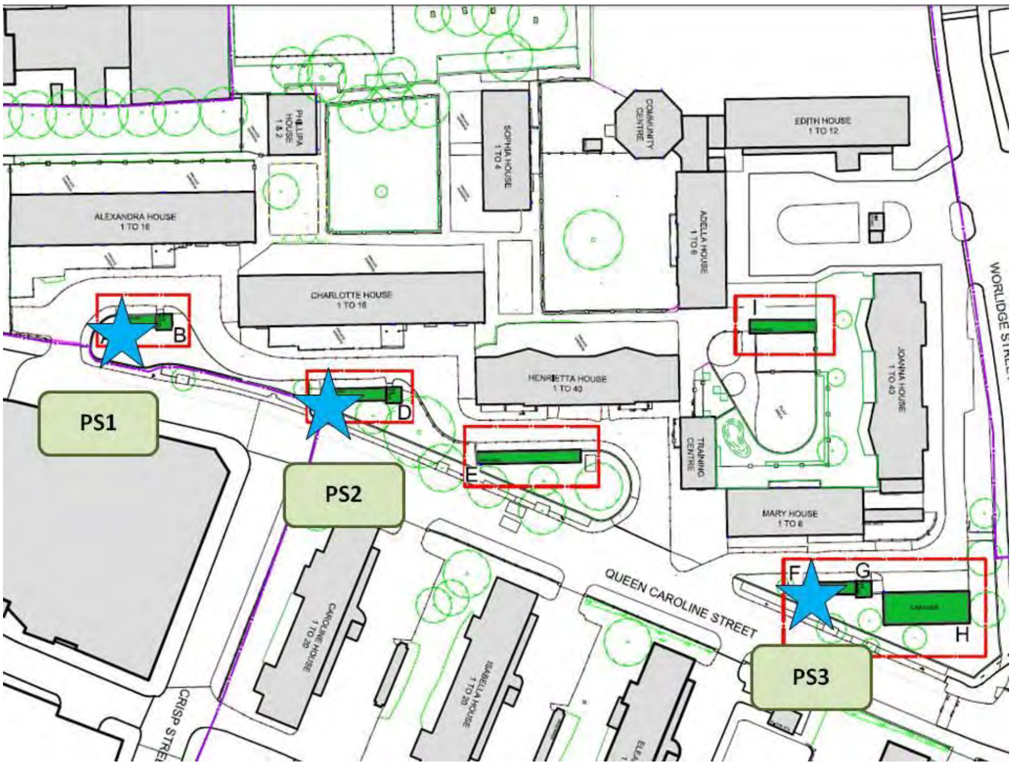


Figure 17. Location of Leveloggers and v-notch weirs on the downpipes of three pram shed roofs at Queen Caroline Estate, London Borough of Hammersmith & Fulham. PS1 - Alexandra House; PS2 - Charlotte House; PS3 - Mary House.

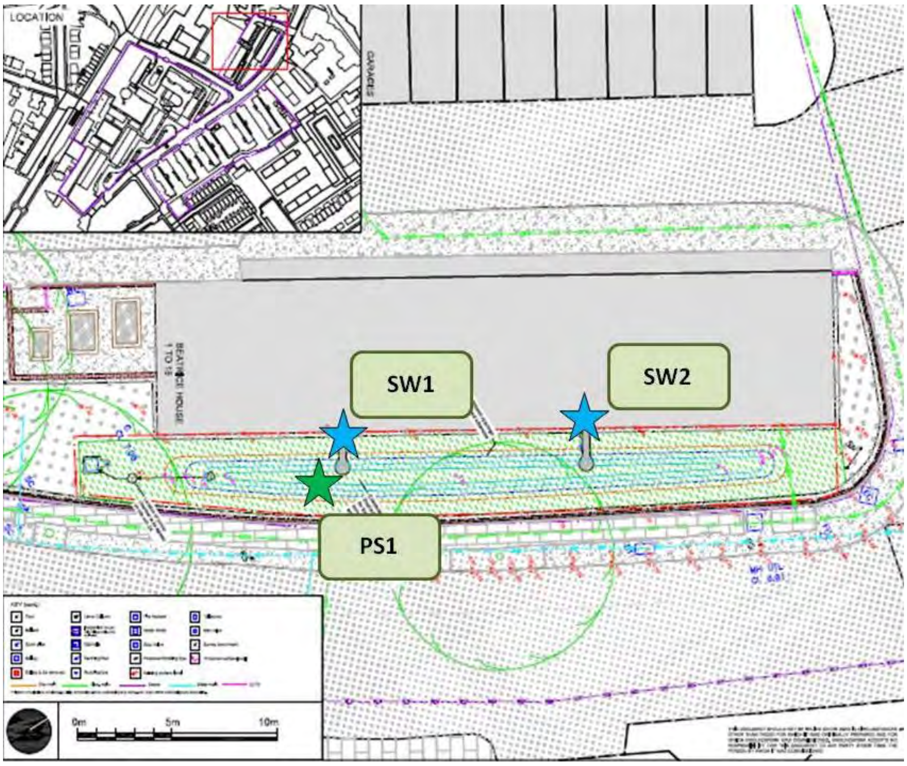


Figure 18. Location of Leveloggers and v-notch weirs (blue stars) and buried levelogger (green star) on the downpipes and in the swale of Beatrice House at Queen Caroline Estate, London Borough of Hammersmith & Fulham.

2.2 Additional monitoring undertaken (to date)

In addition to the equipment installed across Queen Caroline Estate and Richard Knight House, other monitoring approaches have been adopted to quantify the benefits that have been provided by the green infrastructure retrofit. This has included thermal monitoring, targeted biodiversity monitoring and photographic monitoring.

Thermal monitoring - this has been carried out using a FLIR B335 thermal imaging camera. Thermal images of key aspects of the green infrastructure retrofit have been captured on particularly hot days and particularly cold days since the monitoring programme was initiated in summer 2015. Visits with the thermal camera were carried out on the 10th July, 12th August, 27th August, 10th September and 25th September 2015 and on the 21st January 2016. Maximum temperatures during the thermal photography on each of these days respectively were 26°C, 24°C, 20°C, 21°C, 17°C and 4°C). Features targeted for thermal imaging included:

- pram shed roofs with retrofitted small-scale green roofs and pram shed roofs with no green roofs;
- Richard Knight House green roof experimental treatment plots, areas of the Richard Knight House roof that were not greened and neighbouring buildings;
- ground level SuDS features including rain gardens, basins and swales;
- the external wall of the building that has been identified for the creation of a vertical rain garden (Figure 19) plus control walls on neighbouring buildings with similar construction and aspect.

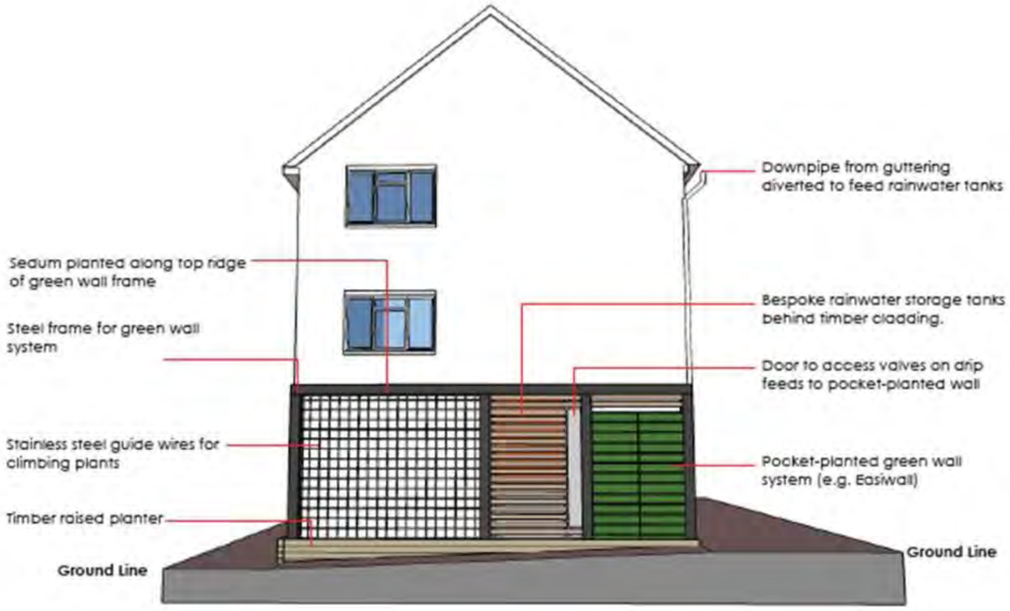
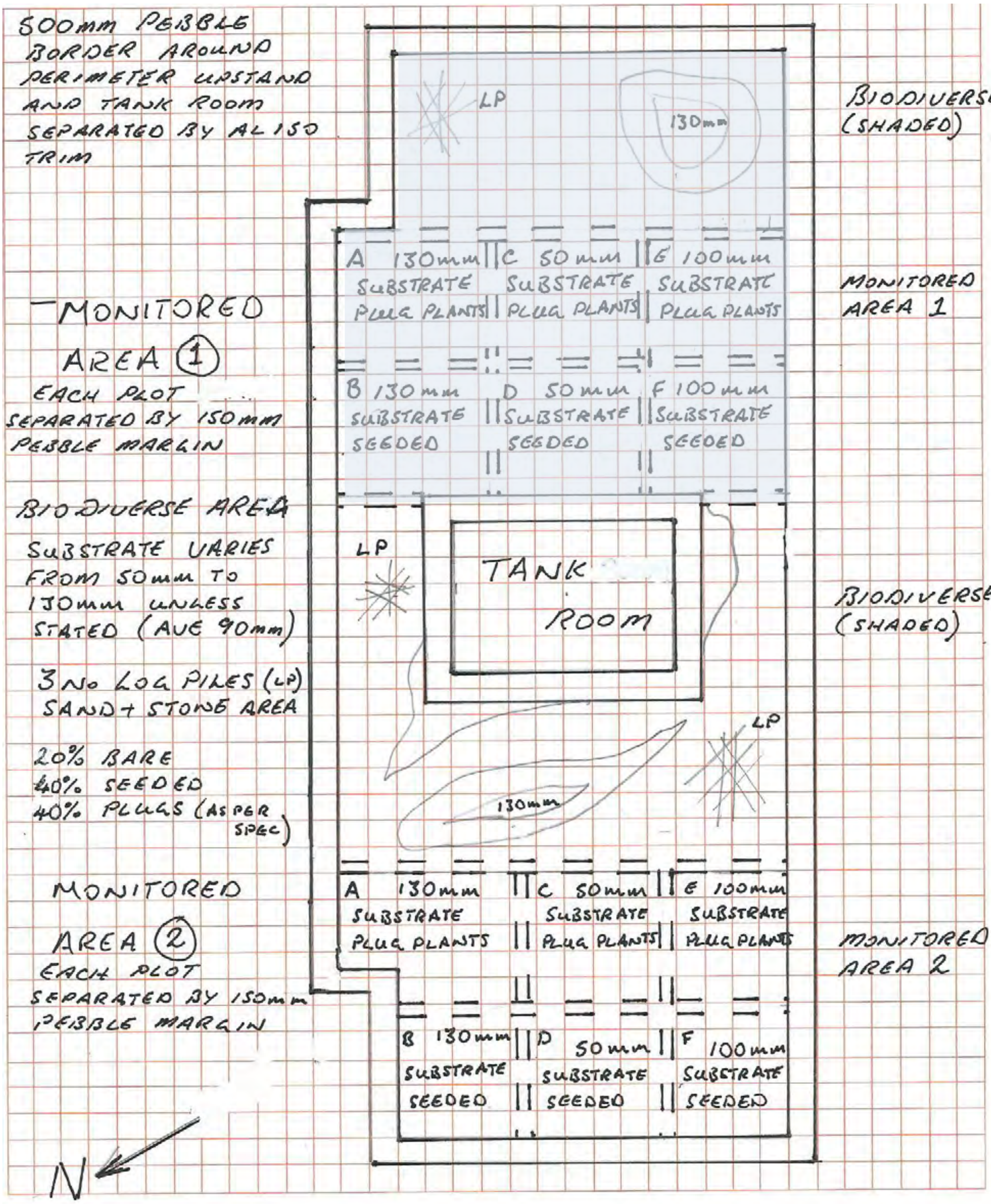


Figure 19. Artist's impression of the vertical rain garden being installed at Mary House, Queen Caroline's Estate, London Borough of Hammersmith & Fulham.

Biodiversity monitoring - this comprised of a series of vegetation surveys to assess the colonisation of various green roof components. Vegetation surveys were carried out three times, in early summer, mid-summer and late summer, to capture development throughout the growing season. Two types of survey were carried out:

- *Inventory survey* - this comprised a walk over survey recording every floral species observed on the roof in order to make a list of all herbaceous species. This method was adopted for the Cheesman Terrace green roof because of the relatively small size of the roof enabling a comprehensive assessment to be made and also because of the novel method for seeding the roof adopted (hay spreading was used on this roof to help colonisation).
- *Quadrat survey* - 50 cm x 50 cm quadrats divided into 100 sub-units were used for floral surveys on the Richard Knight House experimental green roof plots. The experimental plots were created during construction by dividing the roof into 12 experimental areas. Within these areas the depth of substrate, type of planting and the underlying water storage membranes were manipulated (Figure 20). A stratified random methodology was used to place 3 quadrats within each of these experimental areas (one quadrat randomly placed in the bottom right hand corner, one towards the middle and one towards the top left of each experimental plot when looking from the northwest end of the roof). Floral surveys comprised recording each floral species within each quadrat and the number of the 100 sub-units within which each floral species occurred.

Photographic monitoring - this comprised taking photos whilst on site of interesting species and features on retrofitted green infrastructure components. Particular focus was placed on those features that were not accessible/visible to local residents (e.g. Richard Knight House green roof). The photos were taken to create an archive of the development of the biodiversity associated with the project and the development of the individual green infrastructure retrofit elements as they develop and mature.



= Aquaten water retention membrane

Figure 20. Layout of experimental green roof on Richard Knight House, London Borough of Hammersmith and Fulham.

3. Summary of results to date

3.1 Fixed-point photo monitoring

The largest rain event recorded by the Henrietta House weather station following the implementation of the fixed-point cameras and weather stations was 18.2 mm on the 11th of January 2016. The pattern of this rainfall is represented in Figure 21.

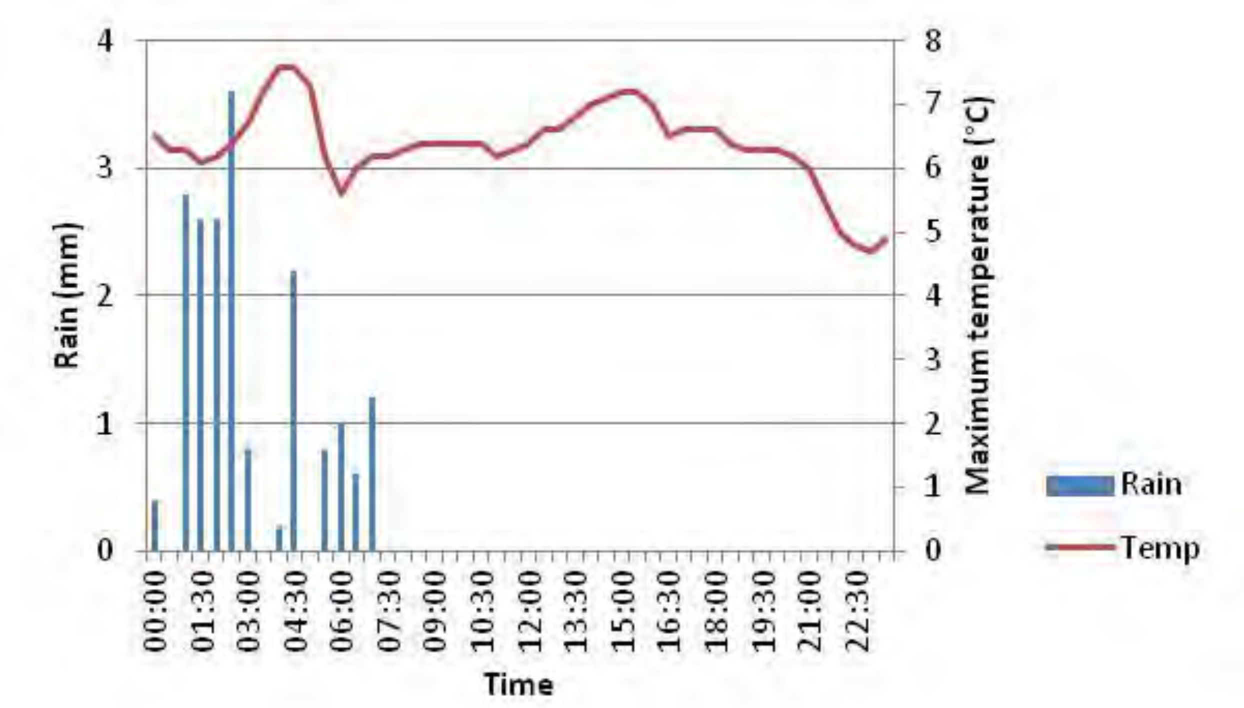


Figure 21. Rain event on the 11th January 2016 at Henrietta House, Queen Caroline Estate, London Borough of Hammersmith and Fulham. Bars represent the total rainfall every 30 minutes

The highest volume and intensity of rainfall during this event fell between 01:00 and 03:30, with the highest rain volume of 6.2 mm in an hour and the highest rain rate recorded as 57.6 mm/hr. To put this event in context, the Met Office classifies rain (other than showers) as 'slight', 'moderate' or 'heavy' for rates of accumulation less than 0.5 mmhr-1, 0.5 to 4 mmhr-1 and greater than 4 mm-hr respectively. Showers are classified as 'slight', 'moderate', 'heavy', or 'violent' for rates of accumulation of about 0 to 2 mm h–1, 2 to 10 mm h–1, 10 to 50 mm h–1, or greater than 50 mm h–1, respectively (Met Office 2007).

Despite the majority of this rain event occurring at night, the time-lapse cameras recorded the performance of the SuDS features during this rain event.

Beatrice House swale (FPC4) performance during 18.2 mm rain event on 11th January 2016

A complete collection of the images from the Beatrice swale during the heaviest rain event recorded since the monitoring equipment was installed (from 01:00 to 03:15 on the 11th January 2016) are presented in Appendix A. They demonstrate that the swale was able to retain and attenuate all of the rainfall that fell directly onto the area and that which was diverted from the roofs of Beatrice House. The images also demonstrate that at around 02:05 there was obvious standing water within the swale, but that this had reduced again by the time of the next image at 02:20 indicating that the swale was releasing water by infiltration and/or conveyance (Figure 22).

i)

ii)

Figure 22. Time-lapse camera images from Beatrice House swale (FPC4). Images show i) evidence of swale filling during period of highest rain intensity 2am to 2:30am on 11/01/2016 [3.6 mm of rain at maximum intensity of 57.6 mm/hr] and ii) evidence of infiltration/conveyance by the time of the next time-lapse photo (~15 minutes later).

Alexandra House swale (FPC1) performance during 18.2 mm rain event on 11th January 2016

Images showing the performance of the Alexandra House swale for the same rain event are presented in Appendix A2. The swale was designed to take stormwater from the surrounding ground level permeable and hardstanding areas and from the roof of the neighbouring Alexandra House. Whilst the fixed point photos showed evidence of the intensity of the rain event in relation to pooling on the ground, there was no evidence of any substantial filling of the swale. This was the case even during the most intense period of rainfall (Figure 23). This indicated that the swale was performing as expected for this rain event. It is important to note at this point, however, that lack of maintenance of the guttering on Alexandra House might mean that not all of the rain falling on the areas of the roof that should be diverted to the swale is actually reaching the swale.

Figure 23. Time-lapse camera images from Alexandra House swale (FPC1). Image shows no evidence of swale filling excessively during period of highest rain intensity 2am to 2:30am on 11/01/2016 [3.6 mm of rain at maximum intensity of 57.6 mm/hr].

Community Hall and Sofia House grass basins (FPC2) performance during 18.2 mm rain event on 11th January 2016

Images showing the performance of the Community Hall and Sofia House grass basins for the same rain event are presented in Appendix A3. The basins were designed to take stormwater from the surrounding ground level permeable and hardstanding areas and from the roof of the neighbouring Community Hall and Sophia House. Whilst the fixed point photos showed evidence of the intensity of the rain event in relation to pooling on the ground, there was no evidence of any substantial filling of the basins. This was the case even during the most intense period of rainfall (Figure 24). This indicated that the basins were performing as expected for this rain event.

Figure 24. Time-lapse camera images from Community Hall and Sophia House basins (FPC2). Image shows no evidence of basins filling excessively during period of highest rain intensity 2am to 2:30am on 11/01/2016 [3.6 mm of rain at maximum intensity of 57.6 mm/hr].

Adella House grass basin and Adella House stoney basin (FPC3) performance during 18.2 mm rain event on 11th January 2016

Images showing the performance of the Adella House grass basin and Adella House stoney basin for the same rain event are presented in Appendix A4. The basins were designed to take stormwater from the surrounding ground level permeable and hardstanding areas and from the roof of Adella House. Whilst the fixed point photos showed evidence of the intensity of the rain event in relation to pooling on the ground, there was no evidence of any substantial filling of the basins. This was the case even during the most intense period of rainfall (Figure 25). This indicated that the basins were performing as expected for this rain event. It is important to note at this point, however, that lack of maintenance of the guttering on Adella House might mean that not all of the rain falling on the areas of the roof that should be diverted to the basins is actually reaching the basins.

Figure 25. Time-lapse camera images from Adella House grass basin and Adella House stoney basin (FPC3). Image shows no evidence of basins filling excessively during period of highest rain intensity 2am to 2:30am on 11/01/2016 [3.6 mm of rain at maximum intensity of 57.6 mm/hr].

The largest rain event recorded by the Richard Knight House weather station following the implementation of the fixed-point cameras and weather stations was 11.6 mm on the 11th of January 2016. The pattern of this rainfall is represented in Figure 26.

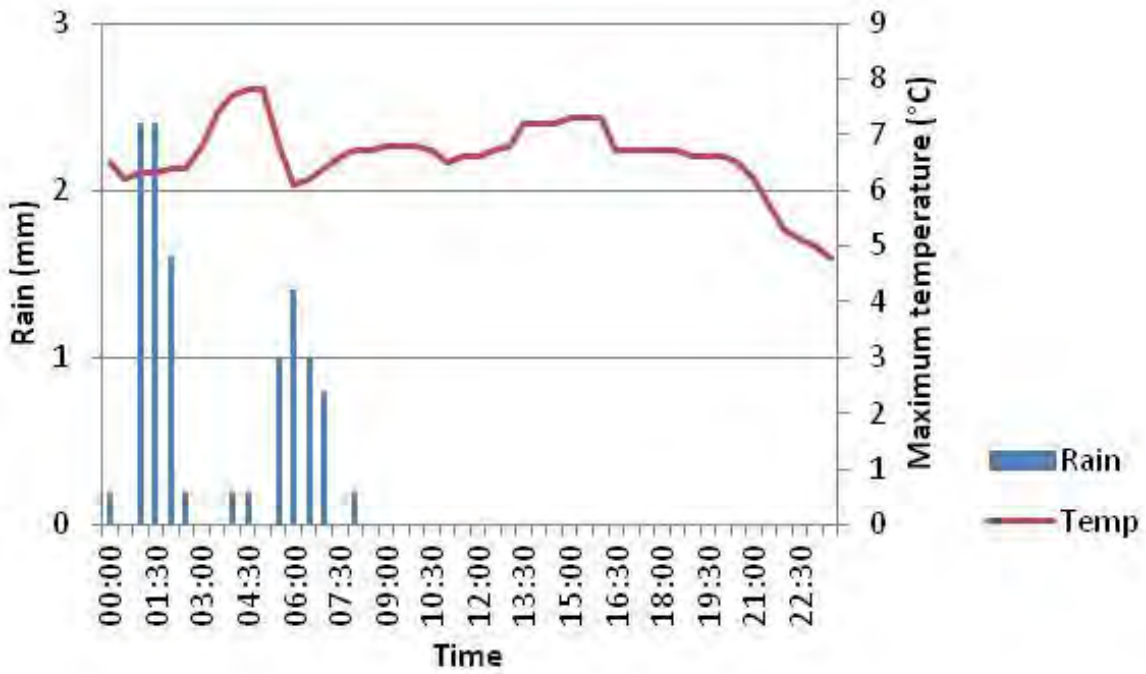


Figure 26. Rain event on the 11th January 2016 at Richard Knight House, London Borough of Hammersmith and Fulham. Bars represent the total rainfall every 30 minutes.

The highest volume and intensity of rainfall during this event fell between 01:00 and 02:30, with the highest rain volume of 4.8 mm in an hour and the highest rain rate recorded as 29.8 mm/hr. To put this event in context, the Met Office classifies rain (other than showers) as 'slight', 'moderate' or 'heavy' for rates of accumulation less than 0.5 mmhr-1, 0.5 to 4 mmhr-1 and greater than 4 mm-hr respectively. Showers are classified as ‘slight’, ‘moderate’, ‘heavy’, or ‘violent’ for rates of accumulation of about 0 to 2 mm h–1, 2 to 10 mm h–1, 10 to 50 mm h–1, or greater than 50 mm h–1, respectively (Met Office 2007).

Despite the majority of this rain event occurring at night, the time lapse cameras recorded the performance of the SuDS features during this rain event.

Richard Knight House rain garden (FPC5) performance during 11.6 mm rain event on 11th January 2016

Images showing the performance of the Richard Knight House rain garden for the rain event on 11th January 2016 are presented in Appendix A5. The basins were designed to take stormwater from the ground level permeable and hardstanding areas surrounding the rain garden, from the green roofs on the pram sheds and from the roof of a neighbouring house. Whilst the fixed point photos showed evidence of the intensity of the rain event in relation to pooling on the ground, there was no evidence of any substantial filling of the basins. This was the case even during the most intense period of rainfall (Figure 27). This indicated that the basins were performing as expected for this rain event.

Figure 27. Time-lapse camera images from Richard Knight House rain garden (FPC5). Image shows no evidence of rain garden filling excessively during period of highest rain intensity 1:30am to 2:00am on 11/01/2016 [2.4 mm of rain at maximum intensity of 29.8 mm/hr].

3.2 Other notable rain events or photography monitoring images for rainfall attenuation:

Richard Knight House on the 28th October 2015

On the 28th October 2015 a 12 mm rain event occurred at Richard Knight House. The pattern of this rainfall event is represented in Figure 28. Whilst the time lapse-cameras were installed at the time of the rain event, they were not taking images every 15 minutes so a comprehensive catalogue of images during the rain event was not captured. Nevertheless, two images were captured, one during and one after the peak rainfall during this event (Figure 29).

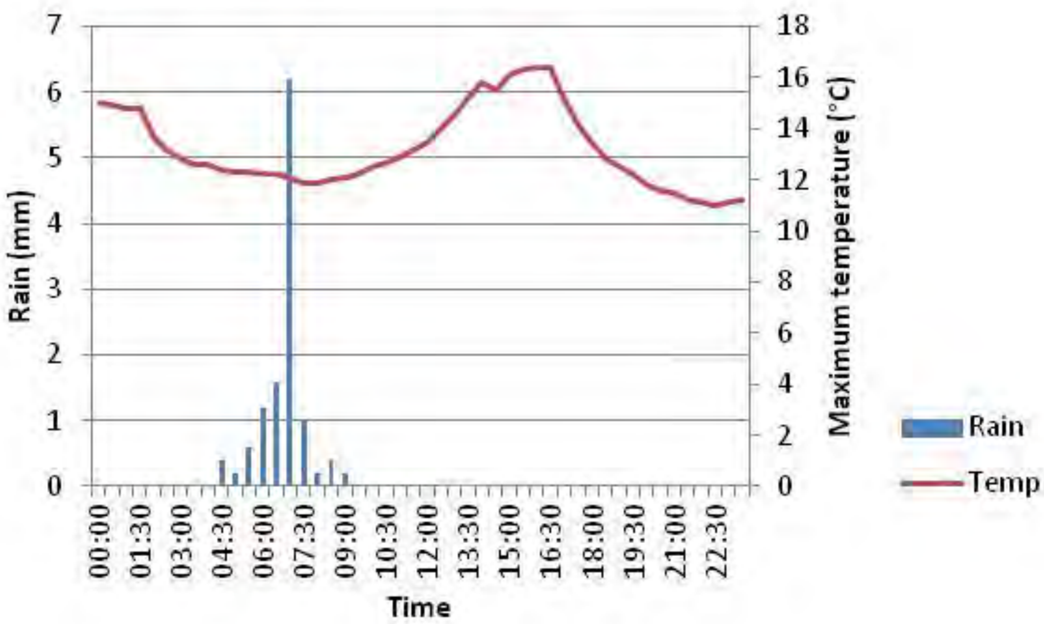


Figure 28. Rain event on the 28th October 2015 at Richard Knight House, London Borough of Hammersmith and Fulham. Bars represent the total rainfall every 30 minutes.

The highest volume and intensity of rainfall during this event fell between 06:00 and 07:00, with the highest rain volume of 6.2 mm in half an hour and the highest rain rate recorded as 32.4 mm/hr. To put this event in context, the Met Office classifies rain (other than showers) as 'slight', 'moderate' or 'heavy' for rates of accumulation less than 0.5 mmhr-1, 0.5 to 4 mmhr-1 and greater than 4 mm-hr respectively. Showers are classified as ‘slight’, ‘moderate’, ‘heavy’, or ‘violent’ for rates of accumulation of about 0 to 2 mm h–1, 2 to 10 mm h–1, 10 to 50 mm h–1, or greater than 50 mm h–1, respectively (Met Office 2007).

Despite this intense and substantial nature of the rainfall over a short period, the time-lapse camera images revealed no evidence of excessive filling of the Richard Knight House rain garden (Figure 29).

Figure 29. Time-lapse camera images from Richard Knight House rain garden (FPC5). Images show i) rain garden during the period of rain building up to the highest rain intensity and ii) following the period of highest intensity.

Henrietta House on the 28th October 2015

On the 7th January 2016 an 8.5 mm rain event occurred at Henrietta House. The pattern of this rainfall event is represented in Figure 30. Whilst the time lapse-cameras were installed at the time of the rain event, they were not taking images every 15 minutes so a comprehensive catalogue of images during the rain event was not captured. Nevertheless, pairs of images were captured across Queen Caroline Estate, during and after the peak rainfall during this event.

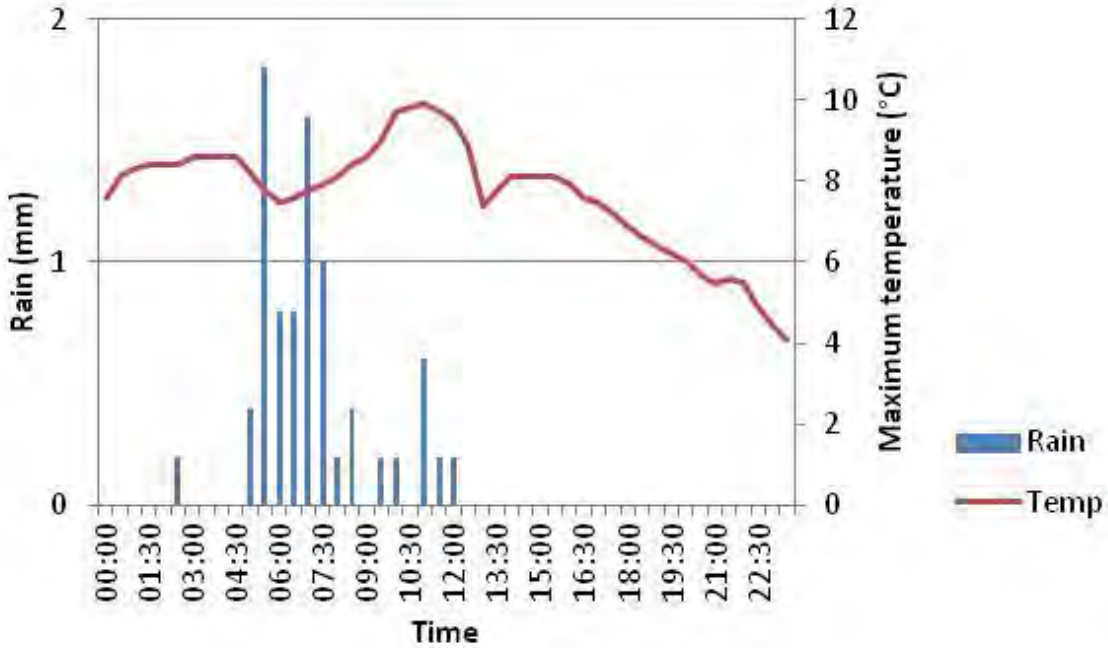


Figure 30. Rain event on the 28th October 2015 at Henrietta House, London Borough of Hammersmith and Fulham. Bars represent the total rainfall every 30 minutes.

The highest volume and intensity of rainfall during this event fell between 05:00 and 12:00, with the highest rain volume of 2.6 mm in half an hour and the highest rain rate recorded as 7.6 mm/hr. To put this event in context, the Met Office classifies rain (other than showers) as 'slight', 'moderate' or 'heavy' for rates of accumulation less than 0.5 mmhr-1, 0.5 to 4 mmhr-1 and greater than 4 mm-hr respectively. Showers are classified as ‘slight’, ‘moderate’, ‘heavy’, or ‘violent’ for rates of accumulation of about 0 to 2 mm h–1, 2 to 10 mm h–1, 10 to 50 mm h–1, or greater than 50 mm h–1, respectively (Met Office 2007).

Selected fixed point photos for this rain event from Queen Caroline Estate are displayed in Figures 31 to 34.

i) 

ii) 

Figure 31. Time-lapse camera images from Beatrice House swale (FPC4). Images show no sign of excessive pooling in the swale i) following the period of intense rainfall or ii) towards the end of the rain event during daylight.

i) 

ii) 

Figure 32. Time-lapse camera images from Adella House basin (FPC2). Images show no sign of excessive pooling in the basin i) following the period of intense rainfall or ii) towards the end of the rain event during daylight.

i)

ii)

Figure 33. Time-lapse camera images from Adella House basin (FPC3). Images show no sign of excessive pooling in the basin i) following the period of intense rainfall or ii) towards the end of the rain event during daylight.

Figure 34. Time-lapse camera images from Alexandra House swale (FPC1). Images show no sign of excessive pooling in the swale i) following the period of intense rainfall or ii) towards the end of the rain event during daylight.

Queen Caroline Estate and Richard Knight House on the 24th August 2015

Prior to the initiation of the time-lapse camera and weather station monitoring on the site, monitoring visits were made to carry out vegetation surveys, thermal surveys and scoping surveys. During these visits, photos were taken of the various SuDS features. One such visit occurred on the 24th August 2015 when approximately 12.2 mm of rain fell in Hammersmith (World Weather Online 2016).

Figures 35 to 48 represent a selection of images from this day demonstrating how the SuDS components on site were functioning and, in contrast, how other hard-standing areas were not functioning well. With the exception of the Richard Knight House rain garden, Community Hall basin and the Beatrice House swale, none of the SuDS features observed demonstrated any evidence of pooling during this rain event.

In the Richard Knight House rain garden there was a small amount of pooling observed at the point where the channel bringing water from surrounding roofs and the ground-level hardstanding entered the rain garden. However, there was no evidence that this pooling was persisting and, with no evidence of pooling further down the rain garden, it appeared that the rain entering the rain garden was infiltrating as designed. There was also no evidence of rain entering the Richard Knight House control flow chamber from the rain garden under-drain for this rain event.

In the Community Hall basin there was evidence of substantial pooling during the heaviest rainfall period of this rain event. However, the pooling was not observed reaching the height of the overflow. It is proposed that rain simulation of a 1 in 100 year rain event is performed to assess the volume of this retention basin compared to the original design to ensure that it was profiled correctly.

In the Beatrice swale, there was some evidence of pooling water towards the centre of the swale during the period of heaviest rainfall. The pooling did not, however, increase above the height of the vegetation at the base of the swale. There was also no evidence of pooling near to the swale overflow.

3.3 Overall conclusions from photographic monitoring of ground-level SuDS features

The photographic data from the fixed-point cameras and the site visits indicated that all SuDS features were able to retain and attenuate the largest rain events that have occurred on site since monitoring began.

Figure 35. Images from hard standing areas around Richard Knight House during a heavy rain event on the 24th August 2015.

Figure 36. Water being channelled from roof level to the rain garden at Richard Knight House during a heavy rain event on the 24th August 2015.

Figure 37. Water being channelled from ground-level hard standing to a swale at Richard Knight House during a heavy rain event on the 24th August 2015.

Figure 38. Water from roof level and ground-level hard standing being channelled into the rain garden at Richard Knight House during a heavy rain event on the 24th August 2015.

i)

ii)

Figure 39. i) Water pooling at the entrance to the rain garden at Richard Knight House during a heavy rain event on the 24th August 2015. ii) The majority of the rain garden showing no pooling due to infiltration

Figure 40. Images from hard standing areas around Queen Caroline Estate during a heavy rain event on the 24th August 2015.

Figure 41. Beatrice House swale during a heavy rain event on the 24th August 2015. Images show i) water from Beatrice House roof being channelled into the swale; ii) pooling at the base of the swale; iii) no pooling around the outlet indicating all rainfall stored and infiltrated.

i) 

ii) 

iii) 

Figure 42. Alexandra House swale during a heavy rain event on the 24th August 2015. Images show i) water from Alexandra House roof being channelled into the swale; ii) no pooling at the end of the swale; iii) no pooling around the inlet to the swale.

i)

ii)

iii)

iv)

Figure 43. Community Hall basin during a heavy rain event on the 24th August 2015. Images show i) water from Community Hall roof being intercepted before entering the storm drains; ii) intercepted rainwater being diverted into basin; iii) pooling in the basin; iv) pooling approaching the depth of the overflow.

i)

ii)

iii)

iv)

Figure 44. Sophia House basin during a heavy rain event on the 24th August 2015. Images show i) water from Sophia House roof being intercepted before entering the storm drains; ii) intercepted rainwater being diverted into basin; iii) & iv) no evidence of pooling in the basin.

i)

ii)

iii)

Figure 45. Adella House grass basin during a heavy rain event on the 24th August 2015. Images show i) water from Adella House roof being diverted into basin; ii) no evidence of pooling in basin; iii) no evidence of standing water near overflow.

i)

ii)

iii)

Figure 46. Adella House stoney basin during a heavy rain event on the 24th August 2015. Images show i) water from hard standing areas running into basin; ii) & iii) no evidence of pooling in basin.

i)

ii)

iii)

iv)

Figure 47. Phillipa House basin during a heavy rain event on the 24th August 2015. Images show i) rain from Phillipa House Roof being intercepted before entering the stormdrain system; ii) rain being channelled into Phillipa House basin; iii) no evidence of pooling near basin overflow; iii) no evidence of pooling in basin.

i)

ii)

Figure 48. Pram shed green roofs at Queen Caroline Estate during a heavy rain event on the 24th August 2015. Images show i) low runoff volumes from the roof into the surrounding gutter; ii) little runoff from downpipes to ground level storm drain system.

3.4 Thermal monitoring

Thermal camera images taken using a FLIR B335 thermal imaging camera were analysed using FLIR Quickreport 1.2© software to assess temperature differences between green infrastructure retrofit features, pre-existing green infrastructure features and hardstanding areas across Queen Caroline Estate, Cheeseman Terrace, and Richard Knight House and surrounding areas.

Results for the hottest days that site visits were made with the thermal imaging camera are presented below in Figures 49 to 62. The hottest days when at site were the 10th July, 12th August, 27th August, 10th September and 25th September 2015. Maximum temperatures during the thermal photography on each of these days respectively were 26°C, 24°C, 20°C, 21°C, and 17°C.

Images were also analysed for the coldest day that site was visited on the 21st January 2016 when the temperature was 4°C.

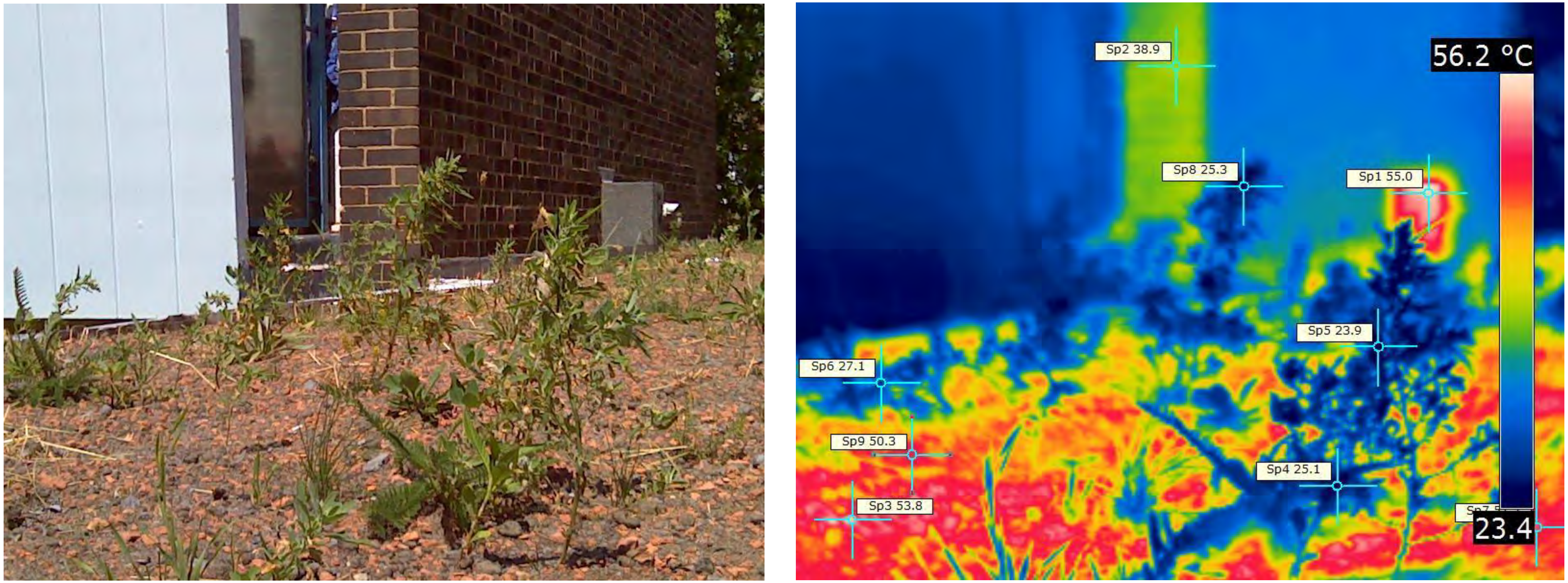


Figure 49. Photo and infrared image of Cheeseman Terrace green roof on the 10th July 2015. Infrared image reveals a temperature difference of 29.8°C between the hottest and coolest areas within the field of view. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Hottest temperatures (>50°C) were associated with metal outlet covers and some areas of bare substrate on the green roof, areas of brickwork and bare areas of substrate were also recorded as substantially hotter than the maximum daily temperature recorded by a nearby weather station (38.9°C and 42.2°C respectively). Coolest temperatures were associated with vegetated areas of the roof with temperatures from 23.9°C to 27.1°C). Vegetation cover of the roof was sparse as the images were taken shortly after roof installation. It would be expected that greater cooling benefits would be achieved once the vegetation cover was more comprehensive.

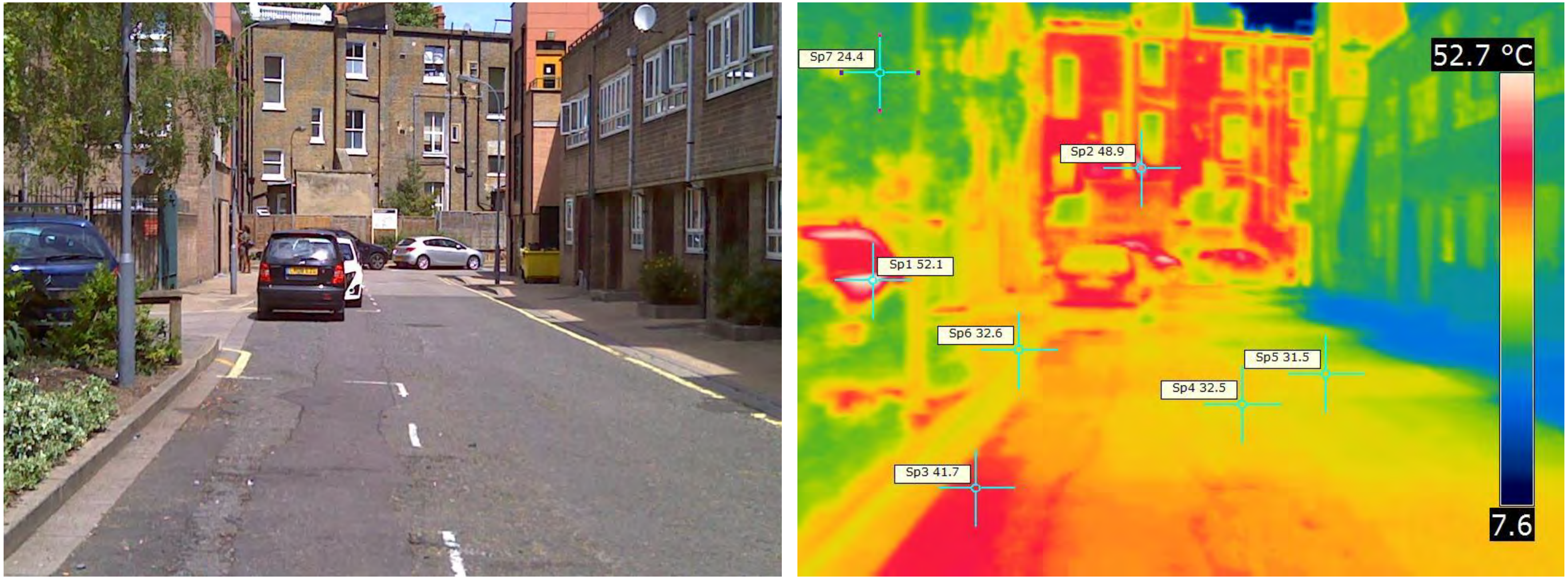


Figure 50. Photo and infrared image of the street next to the Cheeseman Terrace green roof on the 10th July 2015. Infrared image reveals a temperature difference of 45.1°C between the hottest and coolest areas within the field of view. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Hottest temperatures (>40°C) were associated with cars, sections of building exposed to direct sunlight and tarmac areas of the road. Other areas of the road were recorded as 31°C to 33°C. Coolest areas of 24.4°C were associated with trees. These coolest temperatures corresponded to those associated with the vegetation on the neighbouring green roof.

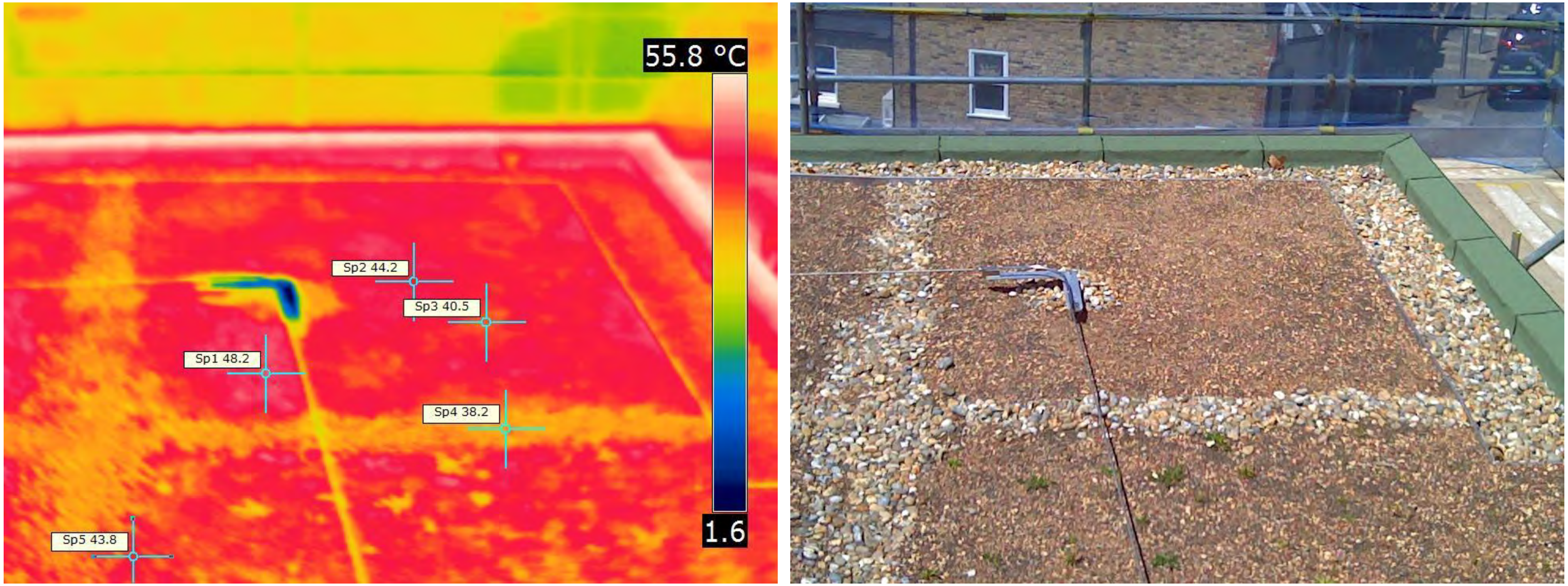


Figure 51. Photo and infrared image of experimental sections of the Richard Knight House green roof on the 10th July 2015. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 38.2°C to 48.2°C associated with the unvegetated areas of the green roof substrate. A prolonged dry period following planting of the newly constructed roof led to poor colonisation in the first few month. This impacted the roofs ability to provide urban cooling. Nevertheless, it would still be expected to provide thermal insulation for the building beneath.

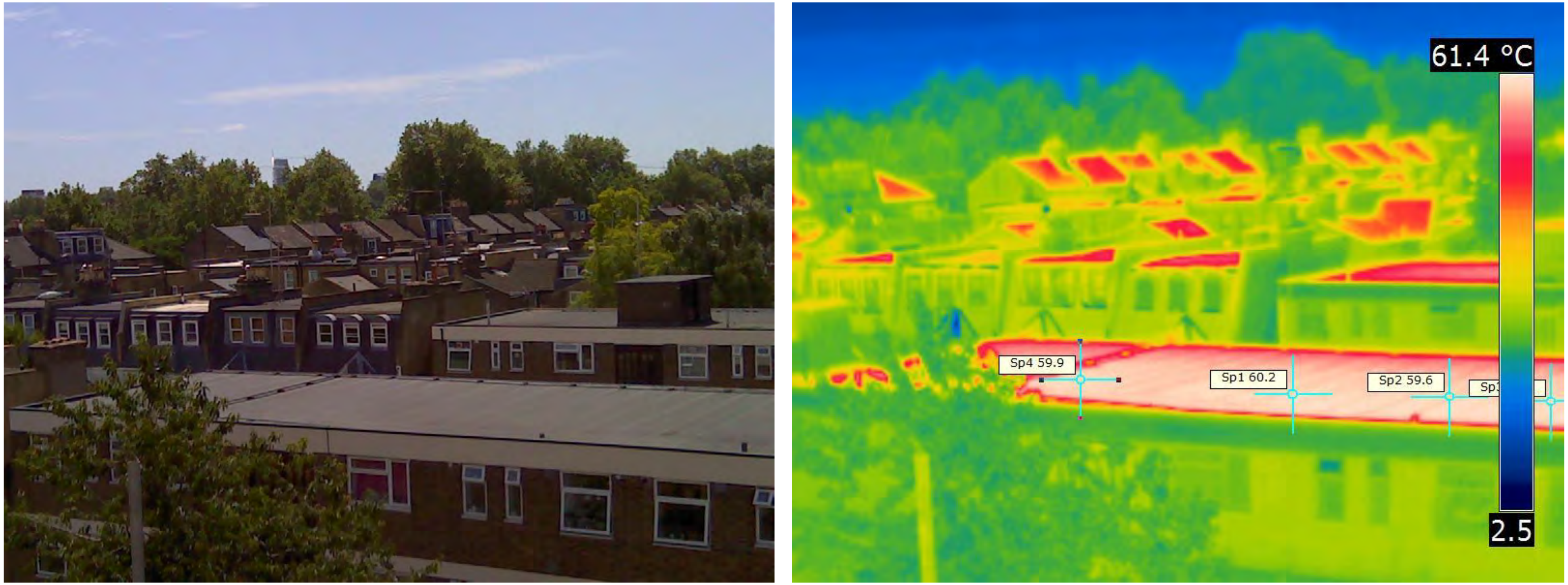


Figure 52. Photo and infrared image of a neighbouring roof to the Richard Knight House green roof on the 10th July 2015. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. The roof was selected as being the closest in design to the Richard Knight House roof prior to the green roof retrofit. Infrared imaging reveals temperatures from 59.6°C to 60.2°C associated with the flat roof waterproofing membrane. These temperatures were 12°C to 20°C degrees higher than those recorded on the unvegetated green roof substrate on Richard Knight House at the same time.

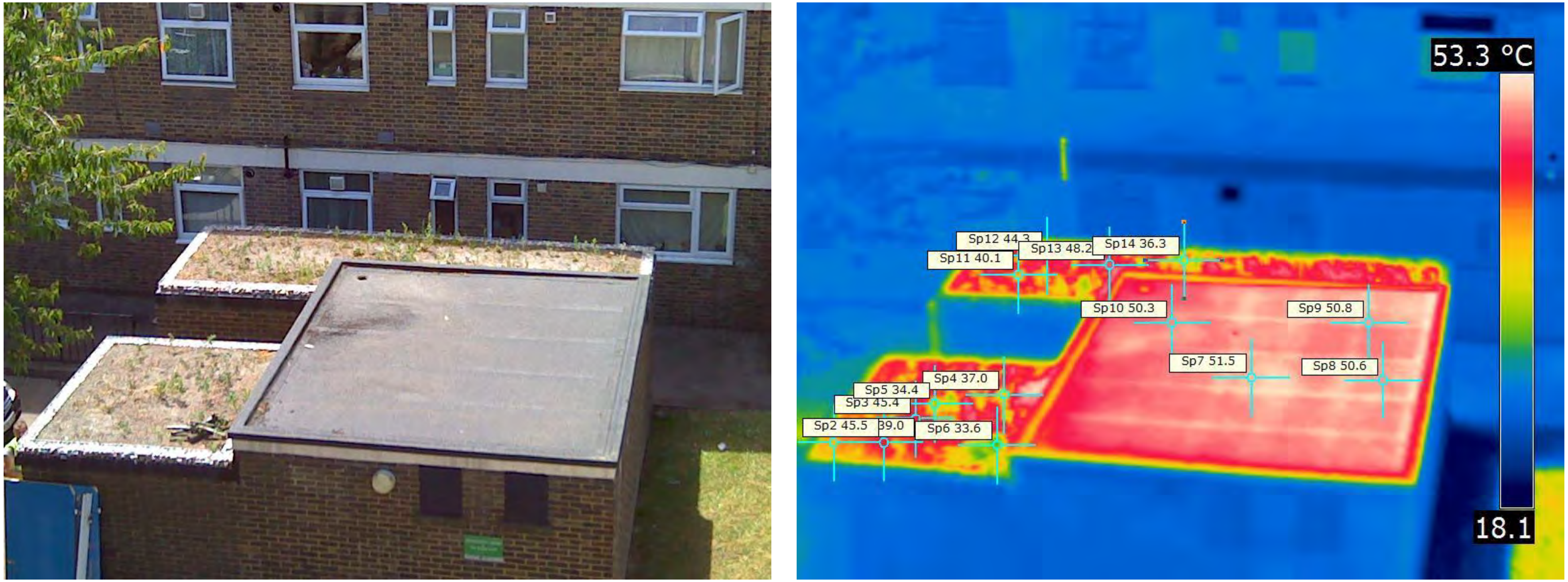


Figure 53. Photo and infrared image of pram shed roofs at Richard Knight House 10th July 2015. Image showing the difference in temperatures between the green roof retrofitted pram shed roofs and the bare roof. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 50.3°C to 51.5°C on the bare flat roof and temperatures of 33.6°C to 48.2°C on the green roofs. Lowest temperatures on the green roof were associated with vegetated areas and deadwood pile areas. Due to images being taken soon after roof installation vegetation was sparse. Highest temperatures on the green roofs were associated with bare substrate areas that were not yet colonised.

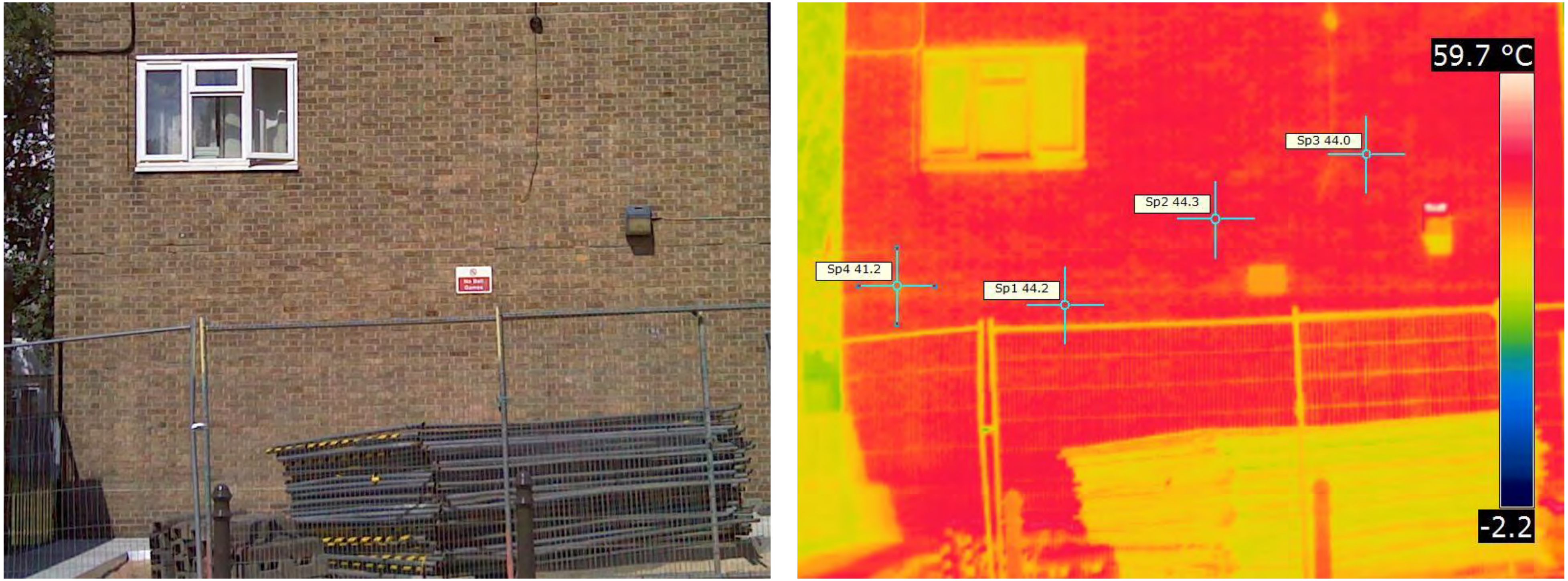


Figure 54. Photo and infrared image of wall of Mary House, Queen Caroline Estate, 10th July 2015. Image showing the location planned for the vertical rain garden SuDS intervention. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 41.2°C to 44.3°C on the bare brick of the wall. Neighbouring walls were also photographed with the infrared camera to find a control wall with similar thermal signature for monitoring after the installation of the vertical green wall.

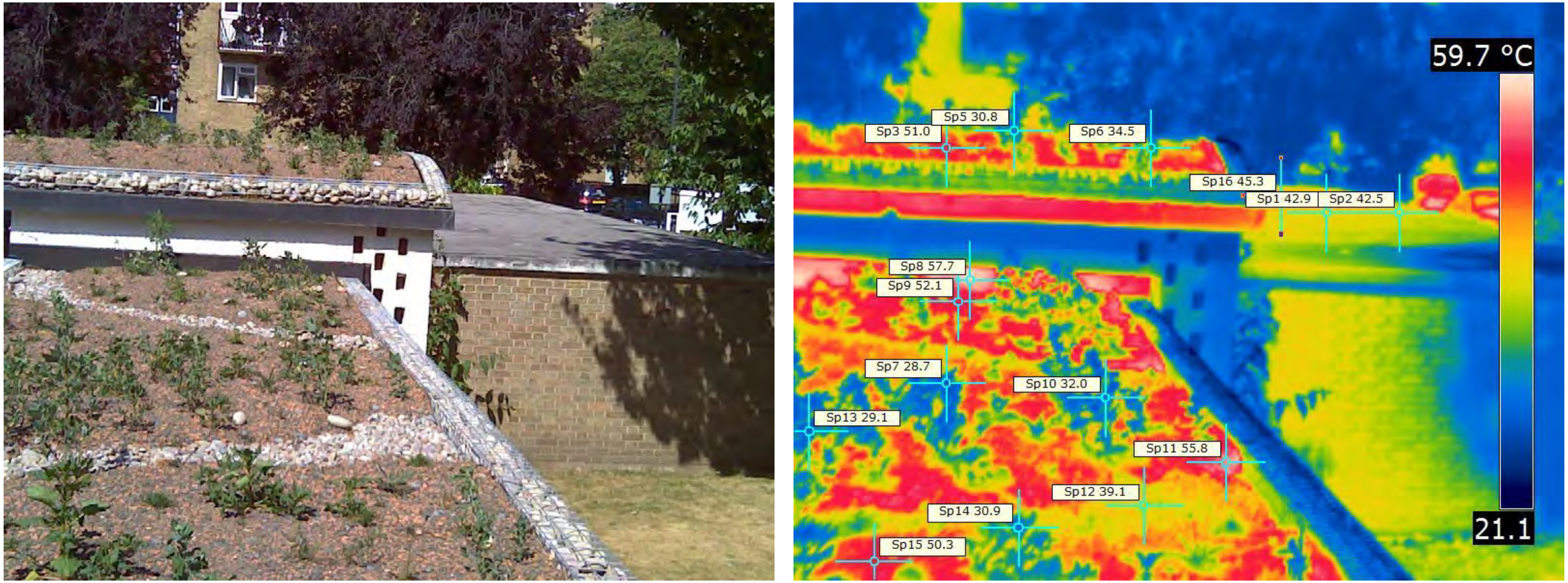


Figure 55. Photo and infrared image of pram shed roofs at Queen Caroline Estate 10th July 2015. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Image showing the difference in temperatures between the green roof retrofitted pram shed roofs and the bare roof. Infrared imaging reveals temperatures from 42.5°C to 45.3°C on the bare flat roof and temperatures of 28.7°C to 57.7°C on the green roofs. Lowest temperatures on the green roof were associated with vegetated areas, highest temperatures were associated with bare substrate areas that were not yet colonised. Images were taken soon after green roof installation so vegetation was still sparse. [N.B. other images of only the bare roof recorded temperatures of 48.9 on areas hidden from the field of view of the above image].

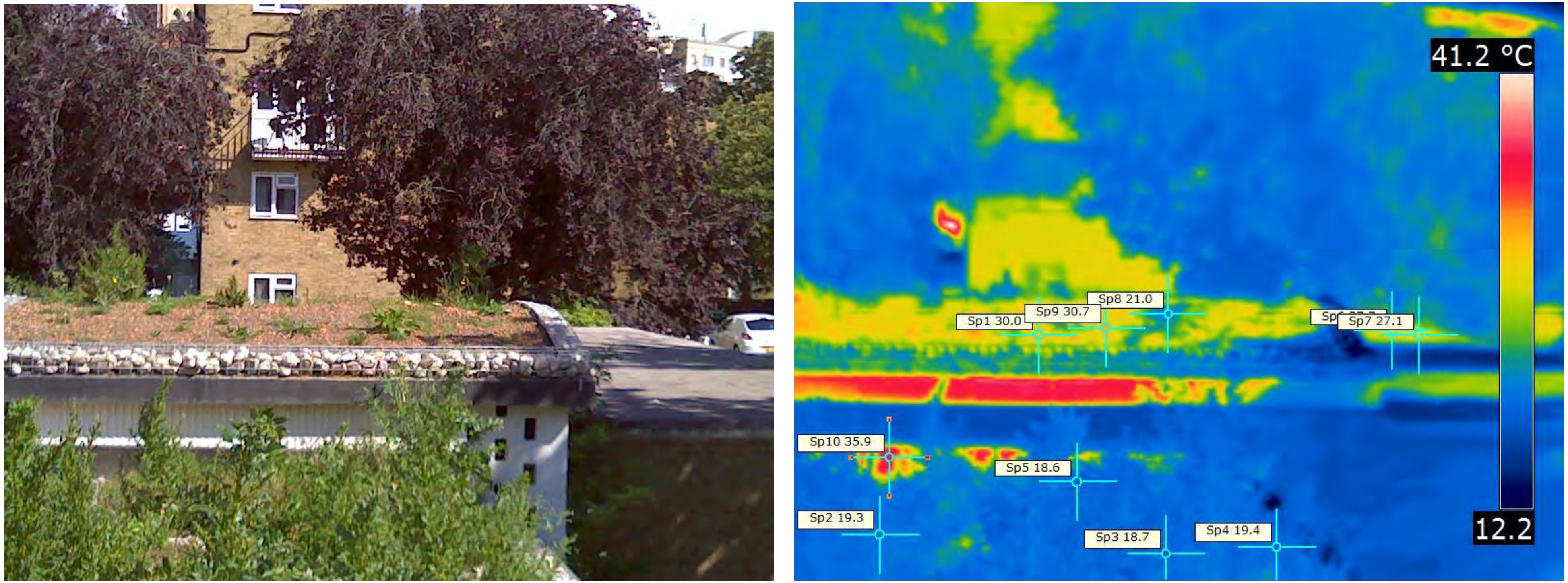


Figure 56. Photo and infrared image of pram shed roofs at Queen Caroline Estate 10th September 2015. Image showing the difference in temperatures between the green roof retrofitted pram shed roofs and the bare roof. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 27.1°C to 27.9°C on the bare flat roof and temperatures of 18.6°C to 35.9°C on the green roofs. Lowest temperatures on the green roof were associated with vegetated areas, highest temperatures were associated with bare substrate areas that were not yet colonised. Images were taken after green roof vegetation had time to colonise. As such much more substantial areas of the green roofs recorded cooler temperatures than on previous visits.

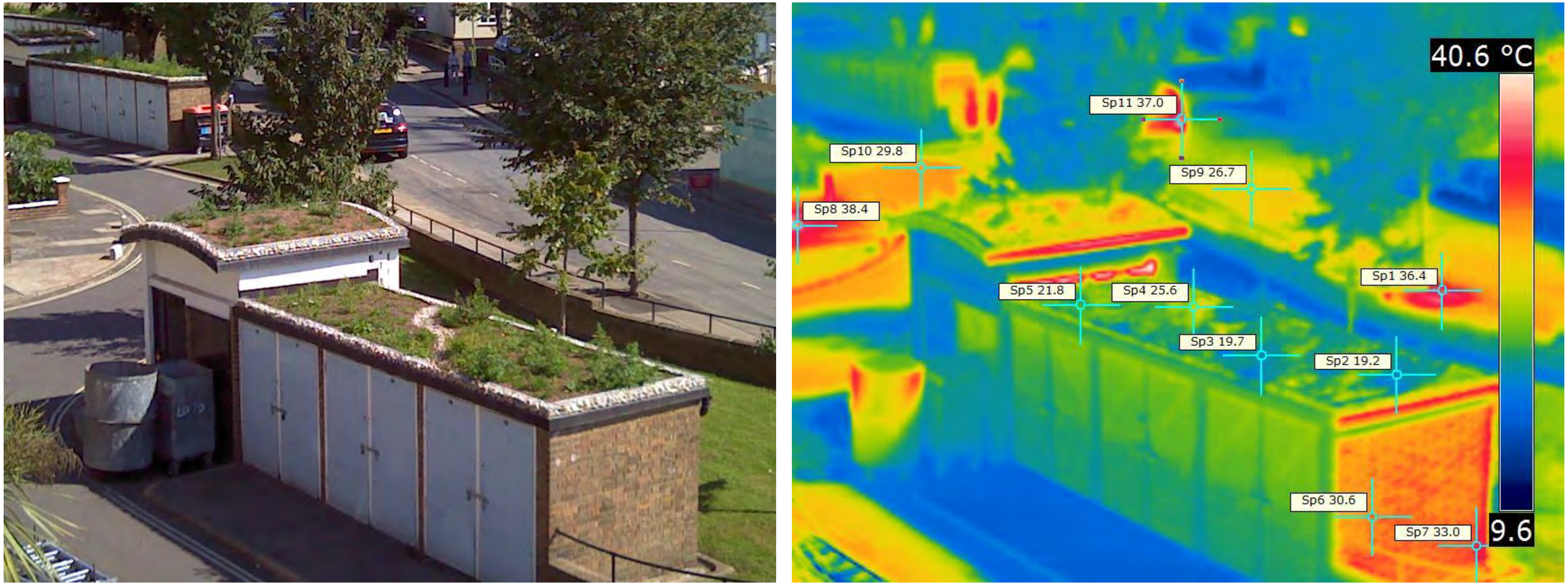


Figure 57. Photo and infrared image of pram shed roofs at Queen Caroline Estate 10th September 2015. Image showing the difference in temperatures between the green roof retrofitted pram shed roofs and the surrounding hard infrastructure. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 19.2°C to 25.6°C on the green roof and temperatures of 26.7°C to 38.4°C on the surrounding roads and walls. Lowest temperatures on the green roof were associated with vegetated areas, highest temperatures were associated with barer substrate areas. Images were taken after green roof vegetation had time to colonise. As such, much more substantial areas of the green roofs recorded cooler temperatures than on previous visits.

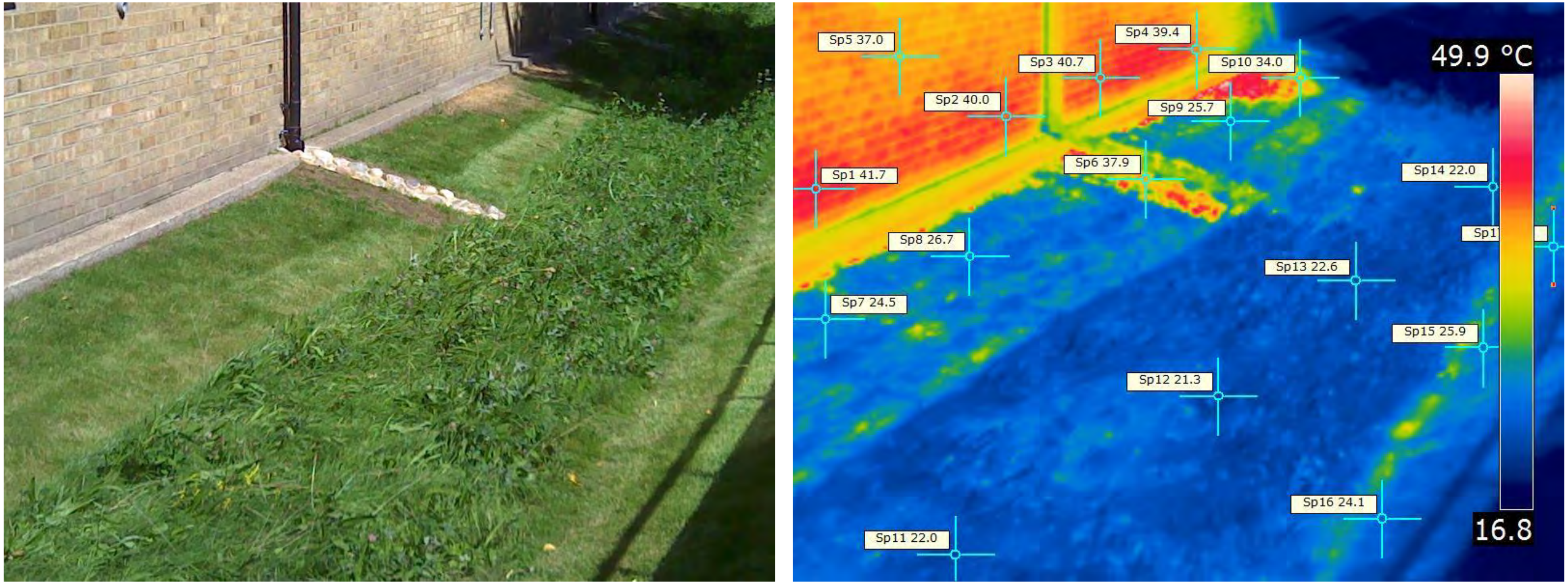


Figure 58. Photo and infrared image of Beatrice House swale at Queen Caroline Estate, 10th September 2015. Image showing the difference in temperatures between the walls of Beatrice House, the amenity grass area surrounding the swale and the taller vegetation within the swale. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 21.3°C to 22.6°C in the swale, 24.1°C to 34.0°C on the amenity grass areas surrounding the swale and temperatures of 37.0°C to 41.7°C on the surrounding walls. This imagine indicates that the taller vegetation areas associated with the swale planting provided the greatest benefit in terms of urban cooling.

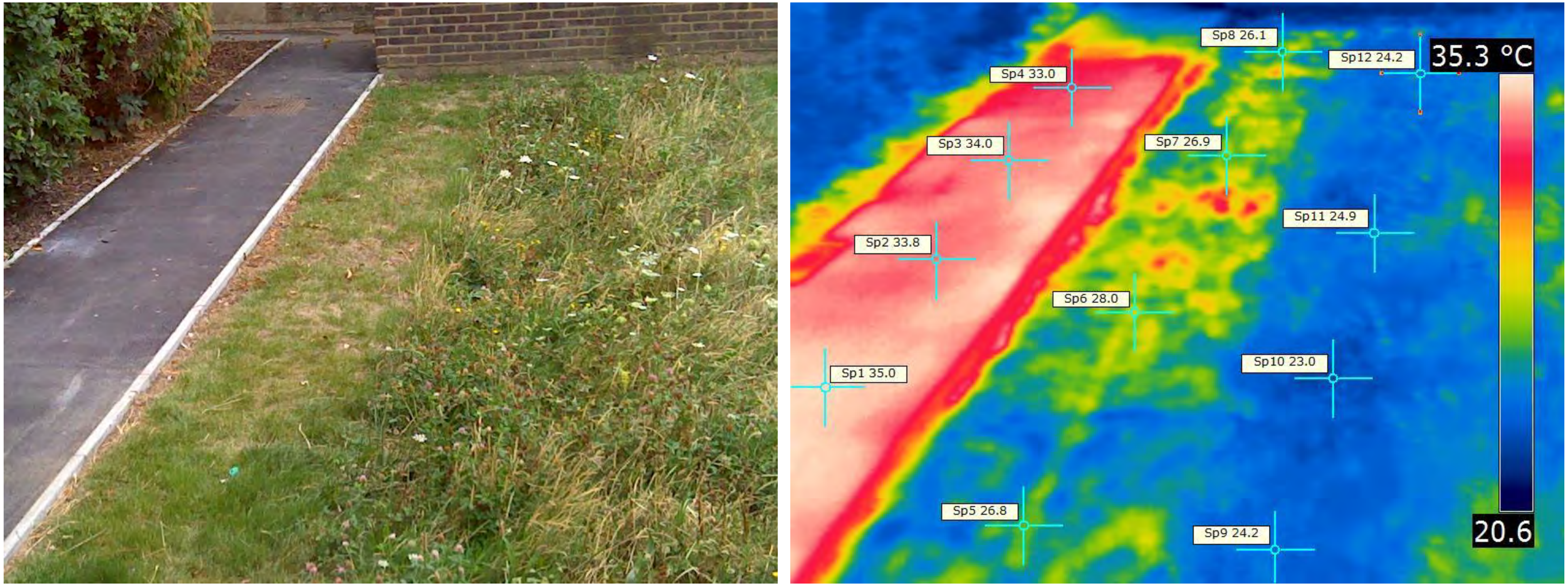


Figure 59. Photo and infrared image of Richard Knight House swale, 12th August 2015. Image showing the difference in temperatures between the pathways around Richard Knight House, the amenity grass area surrounding the swale and the taller vegetation within the swale. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 23.0°C to 24.9°C in the swale, 26.1°C to 28°C on the amenity grass areas surrounding the swale and temperatures of 33.0°C to 35.0°C on the neighbouring path. This imagine indicates that the taller vegetation areas associated with the swale planting provided the greatest benefit in terms of urban cooling.

Figure 60. Photo and infrared image of Alexandra House swale Queen Caroline Estate, 12th August 2015. Image showing the difference in temperatures between the amenity grass area surrounding the swale, the taller vegetation within the swale and the hard surfaces around the swale. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 22.6°C to 23.0°C in the swale, 25.9°C to 32.3°C on the amenity grass areas surrounding the swale, temperatures of 32.2°C and 32.4°C on the neighbouring path, and temperatures of 28.0°C to 29.9°C on the wall of the building behind. This imagine indicates that the taller vegetation areas associated with the swale planting provided the greatest benefit in terms of urban cooling.

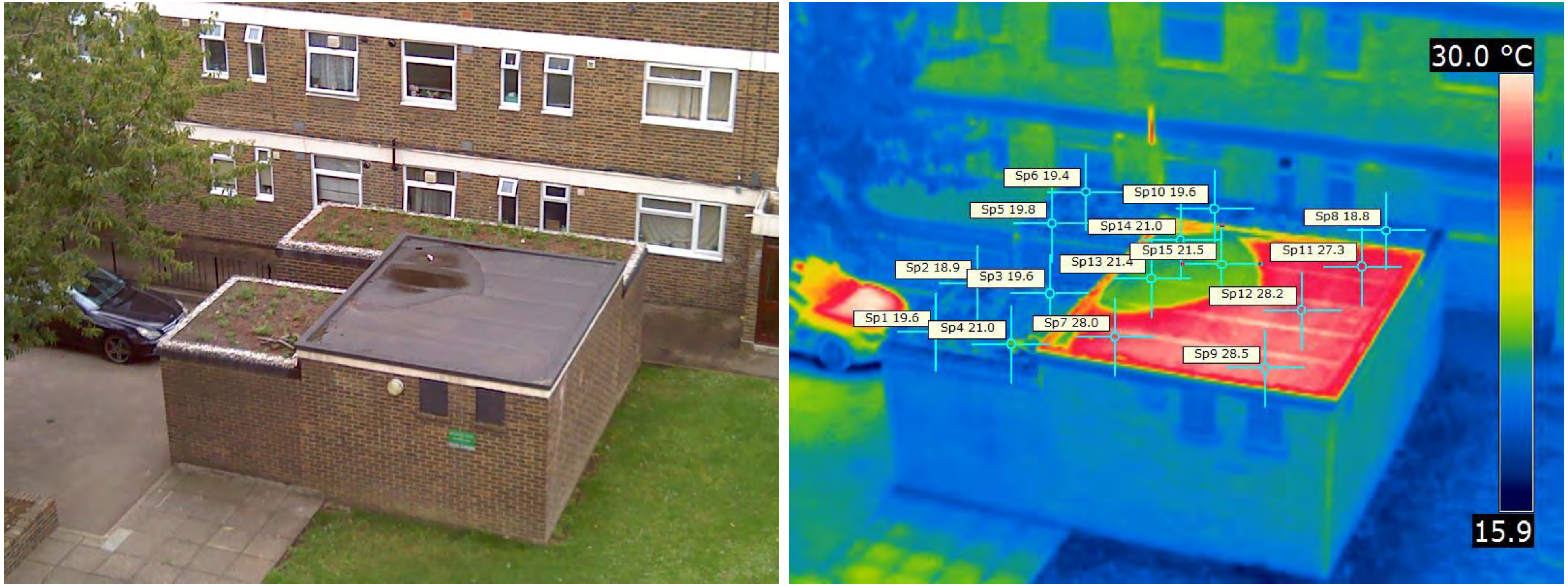


Figure 61. Photo and infrared image of Pram shed roofs at Richard Knight House 27th August 2015. Image showing the difference in temperatures between the green roof areas and the flat roof area. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 18.9°C to 21.0°C on one of the greened roof areas and 18.8°C to 19.8°C on the other. Temperatures on the bare roof area of the pram sheds was higher with temperatures of 27.3°C to 28.5°C on the bare area with temperatures reaching as high as 21.5°C even where there was evidence of pooled rain. This imagine indicates that green roof areas provided the greatest benefit in terms of urban cooling.

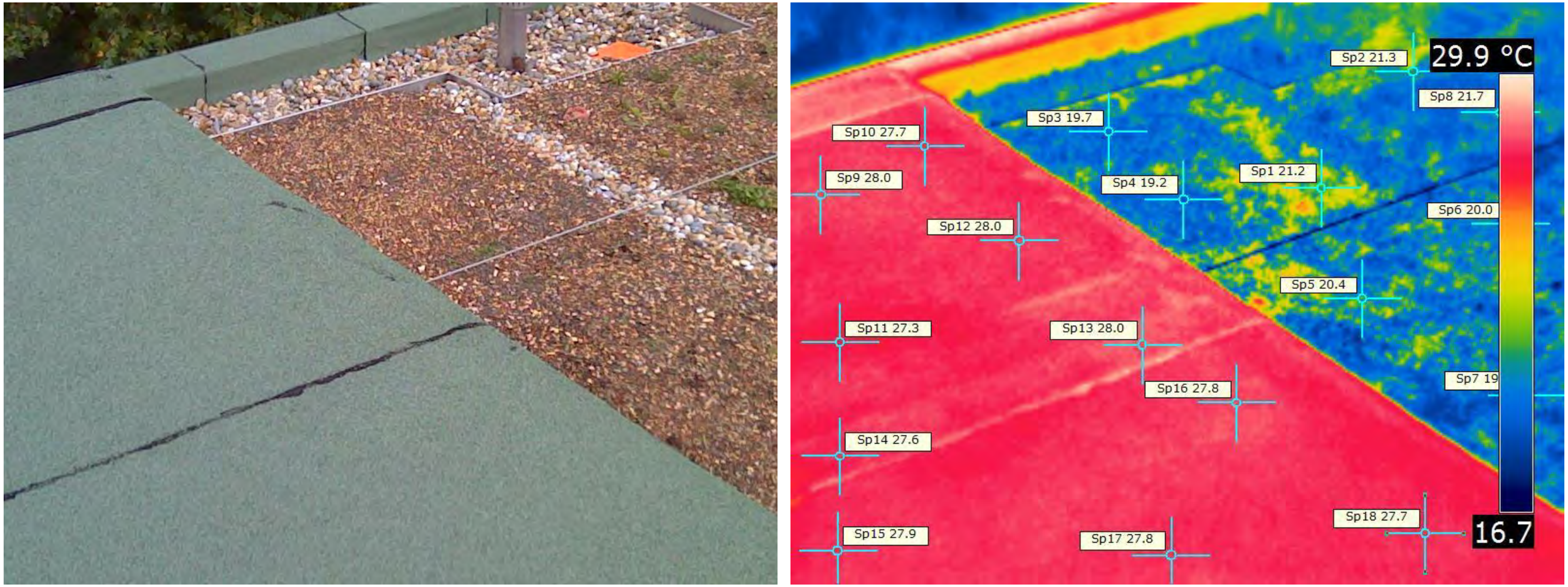


Figure 62. Photo and infrared image of green roof and bare roof at Richard Knight House 27th August 2015. Image showing the difference in temperatures between the green roof areas and the flat roof area. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 19.2°C to 21.7°C on one of the greened roof experimental areas. Temperatures on the bare roof area of the Richard Knight House roof (raised central roof area) were higher with temperatures of 27.3°C to 28.0°C. This imagine indicates that green roof areas provided the greatest benefit in terms of urban cooling.

Richard Knight House experimental plots

Thermal images were also taken of each of the experimental plots on the Richard Knight House green roof. This was carried out to assess whether there were consistent differences in the thermal performance in relation to the experimental design of each plot. Results for the 10th July, 27th August and 25th September 2015 are presented in Table 1.

Table 1. Average temperatures recorded on the green roof experimental plots of Richard Knight House. Temperatures calculated using a FLIR B335 thermal imaging camera. Images were analysed using FLIR QuickReport 1.2 software. Ten spots were placed on the image of each green roof testplot using stratified randomisation. An average of the temperature within each of these test spots was calculated.

	Experimental design of area			10/07/2015		27/08/2015		25/09/2015	
Expt. area	**Substrate depth (mm)**	**Planting**	**Aquaten**	**Average temp (°C)**	**S.E.**	**Average temp (°C)**	**S.E.**	**Average temp (°C)**	**S.E.**
1	100	Plug	No	41.37	0.50	16.01	0.18	14.18	0.15
2	50	Plug	No	41.94	0.79	17.47	0.22	14.53	0.13
3	130	Plug	No	43.48	0.68	17.76	0.23	14.80	0.09
4	100	Seed	No	38.86	0.74	16.53	0.22	14.66	0.17
5	50	Seed	No	38.84	1.20	17.08	0.12	14.47	0.17
6	130	Seed	No	40.95	0.68	18.04	0.22	15.10	0.10
7	100	Seed	Yes	45.82	0.62	16.84	0.23	15.68	0.16
8	50	Seed	Yes	46.77	0.52	18.61	0.50	17.33	0.18
9	130	Seed	Yes	45.32	0.45	19.08	0.14	15.99	0.20
10	100	Plug	Yes	43.01	0.67	17.62	0.21	15.89	0.19
11	50	Plug	Yes	45.56	1.10	18.61	0.42	15.77	0.26
12	130	Plug	Yes	43.56	0.60	19.51	0.39	15.71	0.17

A Kruskal-Wallace non-parametric test was carried out on the data to assess whether there was a significant difference between the temperatures recorded across the test plots. Non-parametric testing was used due to the low sample number (n=10). For all three thermal imaging dates (the 10th July, 27th August and 25th September) a significant difference was found between the test plots ($p<0.001$).

Following the positive results for significance obtained by the Kruskal-Wallace test, Mann-Whitney U exact tests were performed to identify where significant thermal differences were recorded.

Selected Mann-Whitney results from the thermal images taken on the 10th July 2015, 27th August and 25th September are presented in Tables 2 to 4.

Table 2. Mann-Whitney U exact test on the difference between thermal properties of the experimental green roof plots on Richard Knight House, 10th July 2015. Significance levels are given for those comparisons that were significant in relation to a p <0.05 significance level. For non-significant comparisons N/S is listed. The direction of significance is also presented.

Test	**Significance**	**Warmest roof experiment**
Aquaten vs no Aquaten	**p < 0.001**	Aquaten
No Aquaten plug planted vs no Aquaten seeded	**p = 0.001**	Seeded
Aquaten plug planted vs Aquaten seeded	**p = 0.001**	Seeded
50 mm substrate vs 100 mm substrate	N/S	N/A
50 mm substrate vs 130 mm substrate	N/S	N/A
100 mm substrate vs 130 mm substrate	N/S	N/A

Results from 10th July indicated that the Aquaten plots were significantly warmer than the non-Aquaten plots. Due to the design of the experiment, there is no way of knowing whether this is due to the Aquaten membranes or the position of all of the Aquaten plots on the southern end of the roof. If it is due to the Aquaten, however, this may be due to the membrane wicking moisture from the substrate and therefore there being less evaporative cooling from the substrate with Aquaten at its base. The July 10th data also indicated that plug planted plots were significantly cooler than the seeded plots. This indicated that, as would be expected, initially plug planting is a more effective technique for promoting urban cooling after green roof construction. This was presumably due to the more mature perfomance of the above and below ground vegetation following plug planting. It will be interesting to observe whether this pattern continues as the vegetation develops.

Table 3. Mann-Whitney U exact test on the difference between thermal properties of the experimental green roof plots on Richard Knight House, 27th August 2015. Significance levels are given for those comparisons that were significant in relation to a $p < 0.05$ significance level. For non-significant comparisons N/S is listed. The direction of significance is also presented.

Test	Significance	Warmest roof experiment
Aquaten vs no Aquaten	**p < 0.001**	Aquaten
No Aquaten plug planted vs no Aquaten seeded	N/S	N/A
Aquaten plug planted vs Aquaten seeded	N/S	N/A
50 mm substrate vs 100 mm substrate	**p < 0.001**	100 mm
50 mm substrate vs 130 mm substrate	**p < 0.001**	130 mm
100 mm substrate vs 130 mm substrate	**p = 0.001**	130 mm

In contrast to the July survey, there was no significant difference between the plug planted and seeded results. This may have been due to the colonisation that was now occurring on the seeded plots. The Aquaten half of the roof was again significantly warmer than the non-Aquaten half. There were also significant differences recorded between the plots of different depths with the deeper substrates recording the highest average temperatures.

Table 4. Mann-Whitney U exact test on the difference between thermal properties of the experimental green roof plots on Richard Knight House, 25th September 2015. Significance levels are given for those comparisons that were significant in relation to a $p < 0.05$ significance level. For non-significant comparisons N/S is listed. The direction of significance is also presented.

Test	Significance	Warmest roof experiment
Aquaten vs no Aquaten	**p < 0.001**	Aquaten
No Aquaten plug planted vs no Aquaten seeded	**N/S**	N/A
Aquaten plug planted vs Aquaten seeded	**p = 0.013**	seeded
50 mm substrate vs 100 mm substrate	**N/S**	N/A
50 mm substrate vs 130 mm substrate	**N/S**	N/A
100 mm substrate vs 130 mm substrate	**N/S**	N/A

Results from the 25th September recorded no significant difference between the substrate depths or the plug planted versus seeded plots on the non-Aquaten side of the roof. Significant difference was again found between all Aquaten plots compared to non-Aquaten plots, with Aquaten plots again with higher average temperature. There was also a significant difference between the plug-planted and seeded plots on the Aquaten plots.

Thermal imaging during periods of cold weather

In addition to the images taken on hot sunny days, images were also taken on the coldest day that site was visited on the 21st January 2016 when the temperature was 4°C.

Results for green components and bare roof comparisons are presented in Figures 63 to 66. Results for the green roof experimental plots on Richard Knight House are presented in Table 5.

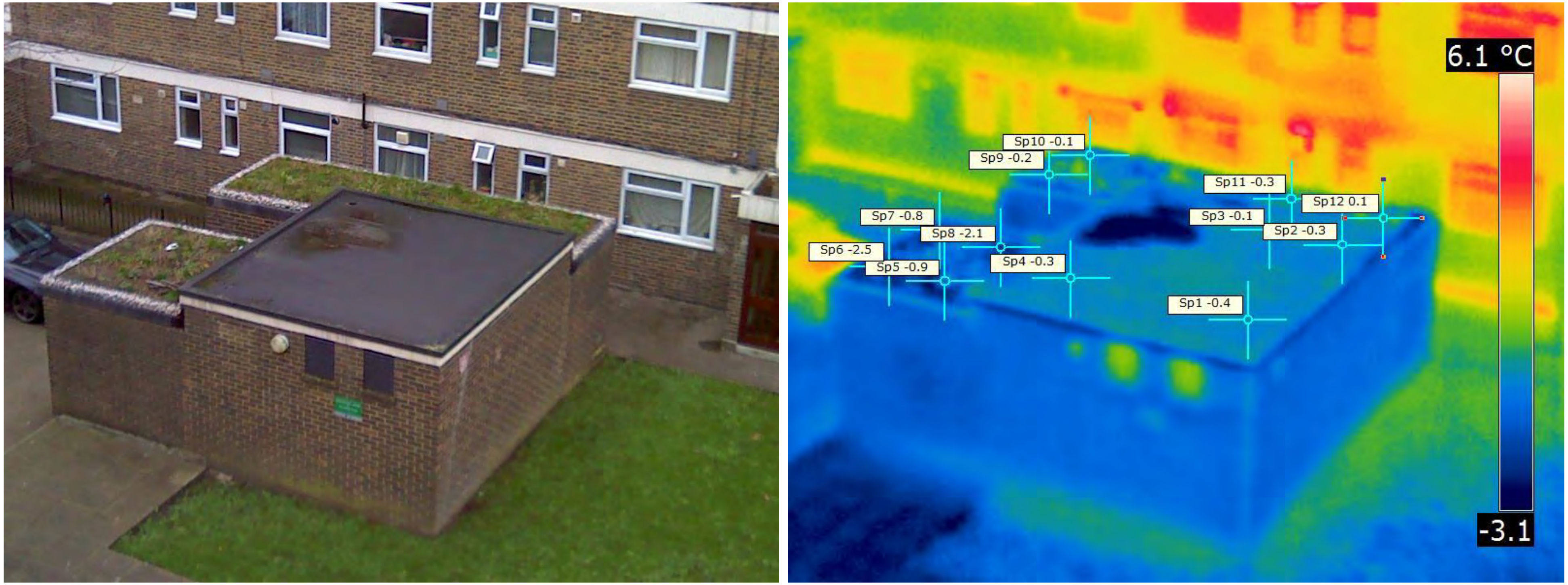


Figure 63. Photo and infrared image of pram shed roofs at Richard Knight House, 21st January 2016. Image showing the difference in temperatures between the green roof areas and the flat roof area. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from -2.5°C to 0.1°C on the green roof areas. Temperatures on the bare roof area were similar with temperatures of -0.4°C to -0.1°C. With no internal source of heat within the buildings, green roofs appeared to have little effect on winter temperatures.

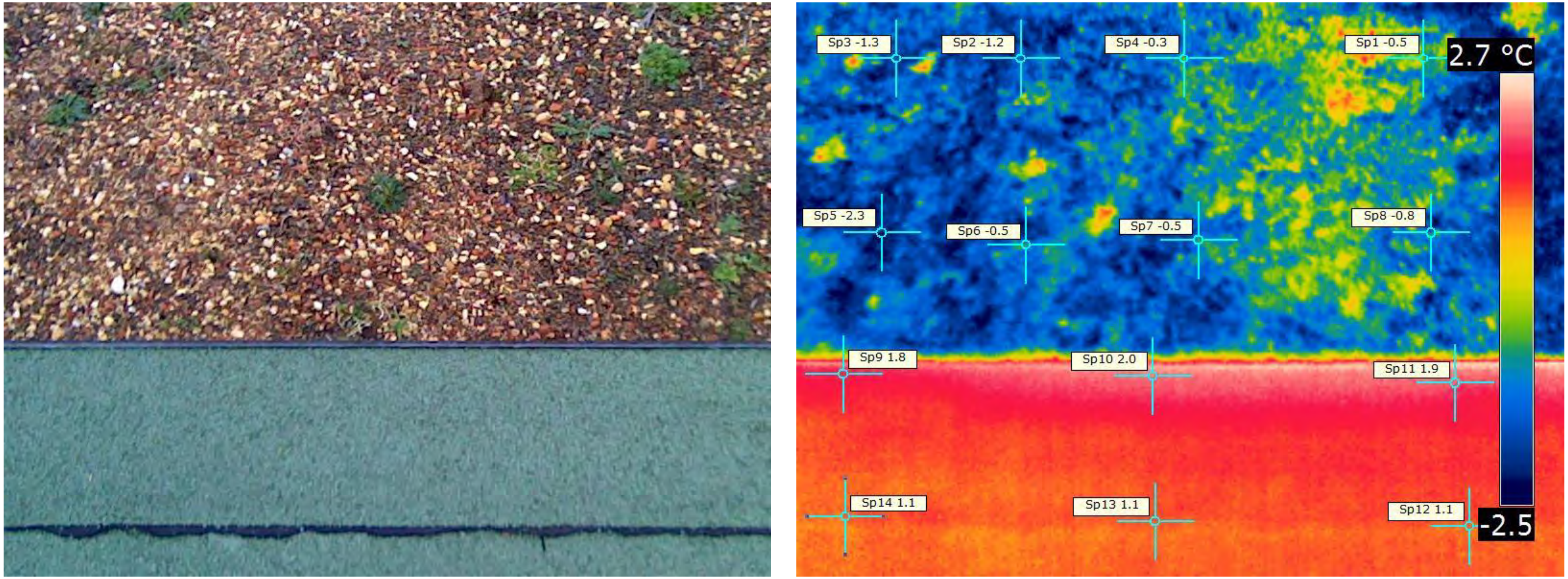


Figure 64. Photo and infrared image of bare roof and green roof at Richard Knight House, 21st January 2016. Image showing the difference in temperatures between the green roof areas and the flat roof area. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from -2.3°C to -0.3°C on the green roof area. Temperatures on the bare roof area were higher with temperatures of 1.1°C to 2.0°C. Bare roof temperatures were warmer, but with no additional monitoring, it impossible to assess whether this is due to the roofing felt being heated by sun or whether it is due to heating loss from within the building.

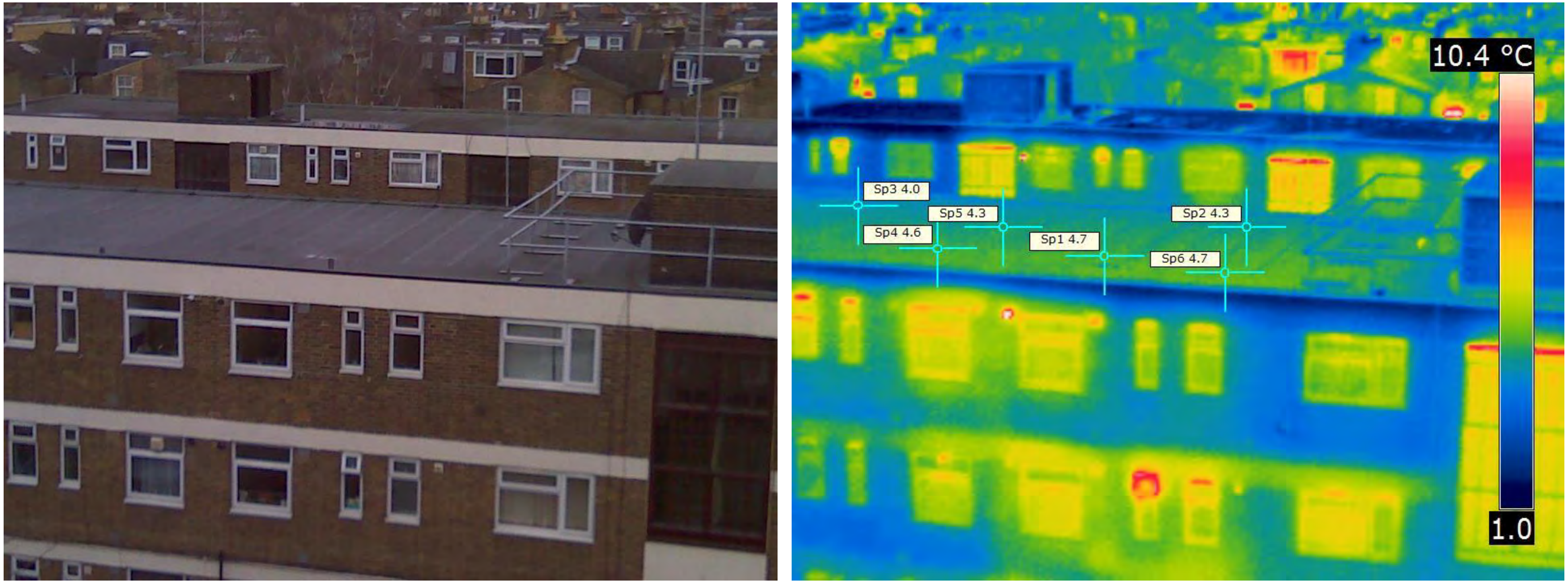


Figure 65. Photo and infrared image of bare roof on building neighbouring Richard Knight House, 21st January 2016. Image showing the temperatures on the flat roof area of a neighbouring building with similar construction to Richard Knight House. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 4.0°C to 4.7°C on the bare roof area. These temperatures were substantially higher than those on the green roof area of Richard Knight House (-2.3°C to -0.3°C from previous Figure). Again, it impossible to definitively assess whether this is due to the roofing felt being heated by the sun or whether it is due to heating loss from within the building but as these values are higher than the flat roof area in the previous Figure (which had no internal heating), it seems likely that at least some of this temperature difference is related to heat loss from rooms immediately below the roof.

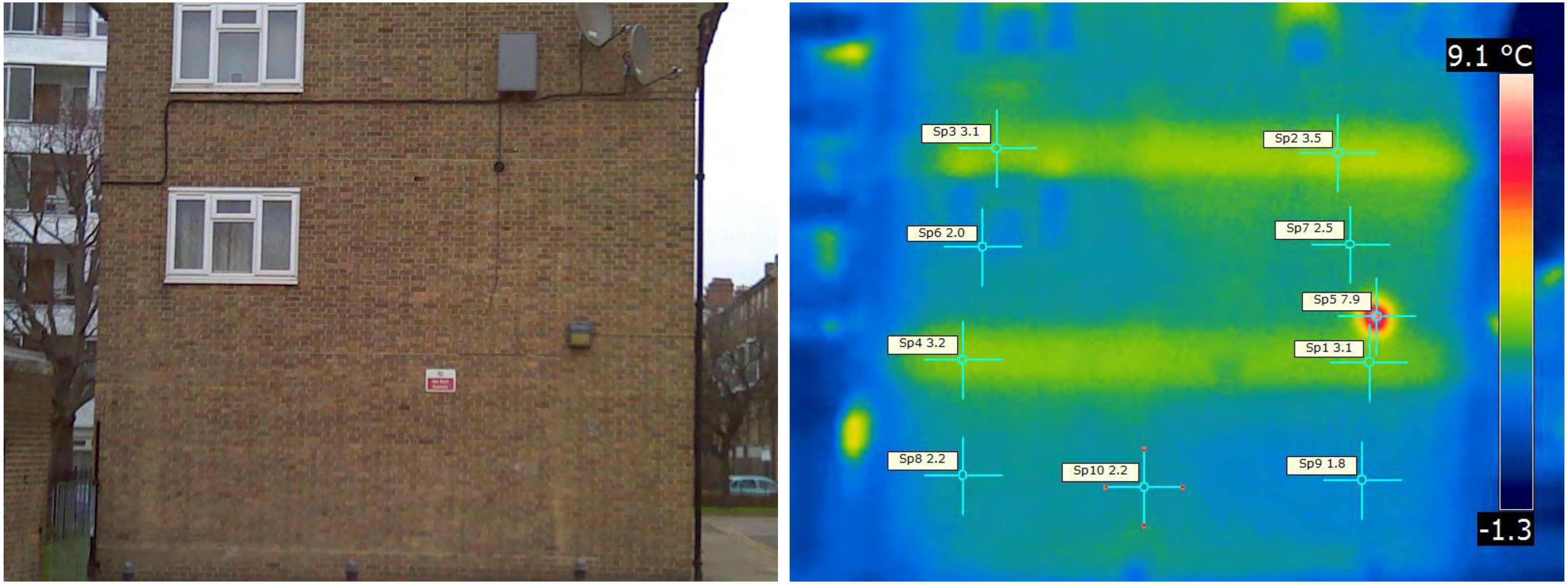


Figure 66. Photo and infrared image of wall area where vertical rain garden is planned to be installed at Queen Caroline Estate, 21st January 2016. Image showing the temperatures on the external wall of Mary House. A FLIR QuickReport spotmeter was used to identify individual temperatures within the field of view. Infrared imaging reveals temperatures from 1.8°C to 3.5°C on the bare wall and a temperature of 7.9°C on an external light. Thermal imaging pictures were also made of similar walls on neighbouring buildings to get an assessment of their value as control walls for comparison following the installation of the vertical rain garden at Mary House.

Table 5. Average temperatures recorded on the green roof experimental plots of Richard Knight House, 21st January 2016. Temperatures calculated using a FLIR B335 thermal imaging camera. Images were analysed using FLIR QuickReport 1.2 software. Ten spots were placed on the image of each green roof testplot using stratified randomisation. An average of the temperature within each of these test spots was calculated.

	Experimental design of area				
Expt. area	**Substrate depth (mm)**	**Planting**	**Aquaten**	**Average temp (°C)**	**S.E.**
1	100	Plug	No	-0.10	0.28
2	50	Plug	No	0.79	0.24
3	130	Plug	No	0.75	0.13
4	100	Seed	No	-0.88	0.19
5	50	Seed	No	-0.09	0.13
6	130	Seed	No	0.41	0.20
7	100	Seed	Yes	-0.01	0.17
8	50	Seed	Yes	0.24	0.18
9	130	Seed	Yes	-0.91	0.15
10	100	Plug	Yes	0.39	0.22
11	50	Plug	Yes	-0.04	0.13
12	130	Plug	Yes	0.09	0.15

A Kruskal-Wallace non-parametric test was carried out on the data to assess whether there was a significant difference between the temperatures recorded across the test plots. Non-parametric testing was used due to the low sample number (n=10). A significant difference was found between the temperature of the test plots on the 21st July 2016 ($p<0.001$).

Following the positive results for significance obtained by the Kruskal-Wallace test, Mann-Whitney U exact tests were performed to identify where significant thermal differences were recorded.

Selected Mann-Whitney results from the thermal images taken on the 21st January 2016 are presented in Table 6.

Table 6. Mann-Whitney U exact test on the difference between thermal properties of the experimental green roof plots on Richard Knight House, 21st January 2016. Significance levels are given for those comparisons that were significant in relation to a p <0.05 significance level. For non-significant comparisons N/S is listed. The direction of significance is also presented.

Test	Significance	Warmest roof experiment
Aquaten vs no Aquaten	N/S	N/A
No Aquaten plug planted vs no Aquaten seeded	**p = 0.002**	Seeded
Aquaten plug planted vs Aquaten seeded	**p = 0.04**	Plug planted
50 mm substrate vs 100 mm substrate	**p = 0.016**	50 mm
50 mm substrate vs 130 mm substrate	N/S	N/A
100 mm substrate vs 130 mm substrate	N/S	N/A

Results from Mann-Whitney U exact tests were fairly inconclusive for the thermal images taken on the 21st January 2016. No significant difference was recorded between the Aquaten and Non-Aquaten halves of the roof. There was also no significant difference between the 50 mm and 130 mm substrate depths, nor the 100 mm and the 130 mm substrate depths. There were significant differences recorded between the plug planted and seeded plots, but the direction of significance was opposite on the Aquaten and non-Aquaten halfs of the roof. The other interesting difference was between the 50 mm substrate depths and the 100 mm substrate depths. 50 mm substrate plots were significantly warmer than 100 mm substrates. This may have been indicative of reduced thermal insulation provided to the building by the shallower substrate depth. However, due to the non-randomised arrangement of the plots, it could also be an artefact of the 50 mm plots being in the centre of the roof or in relation to vegetation performance.

3.5 Biodiversity monitoring

Floral surveys were carried out on the Cheeseman Terrace green roof and the Richard Knight House green roof experimental plots. The Cheeseman Terrace survey comprised an inventory list of all species colonising the roof. This method was adopted for two reasons. Firstly because a novel haying technique developed in Switzerland was used to create the green roof and encourage colonisation of the roof so it is possible that interesting species associated with the hay might appear on this roof compared to the other green roofs. Secondly, because the roof had no edge protection and no mansafe cable so appropriate working at heights safety protocols could not be adopted for accessing the roof for the long durations necessary for carrying out more comprehensive quadrat surveys.

Surveys were carried out at Cheeseman Terrace on the 10th July, 12th August and the 25th September 2015. Results of these surveys are presented in Table 7.

Table 7. Floral inventory surveys on the Cheeseman Terrace green roof, summer 2015

Species	Common name	10th July	12th August	25th September
Achillea millefolium	Yarrow	x	x	x
Agrostis stolonifera	Bentgrass	x	x	x
Centaurea nigra	Knapweed	x	x	x
Chenopodium album	Fat hen	x	x	x
Clinopodium vulgare	wild basil	x		x
Dianthus maritima	Thrift		x	x
Festuca sp.	Fescue grass	x	x	x
Galium verum	Lady's bedstraw		x	
Geranium spp	Geranium spp.			x
Leucanthemum vulgare	Oxeye daisy		x	x
Lotus corniculatus	Birdsfoot trefoil	x		x
Malva sylvestris	Common mallow		x	x
Oxybasis rubra	Red goosefoot	x	x	
Persicaria maculosa	Redshank	x	x	x
Plantago lanceolata	Narrowleaf plantain	x	x	x
Sanguisorba minor	Salad burnet			x
Scorzoneroides autumnalis	Autumn hawkbit	x	x	x
Senecio vulgaris	Groundsel	x	x	x
Silene dioica	Red campion		x	
Silene latifolia	White campion	x	x	x
Sonchus oleraceus	Smooth sowthistle		x	
Urtica dioica	Common nettle			
Viola tricolor	Wild pansy			x
Totals		**13**	**17**	**18**

Floral diversity on the roofs increased with time following the creation of the roof. It will be interesting to investigate whether this pattern continues into the 2016 growing season. Whilst the roofs had a diversity of wildflower species, these were all fairly typical London green roof species and, as yet, there is no evidence of unusual species occurring following the haying treatment.

Surveys were also carried out at Richard Knight House on 10th July, 27th August and the 25th September 2015. Surveys here comprised of 50 cm x 50 cm quadrat surveys. Three quadrats were placed in each of the green roof experimental plots (Figure 20), using a stratified random methodology. The quadrats were divided into 100 sub-units. The presence of each vegetation species present within the quadrat as a whole was recorded within each of the sub-units (i.e. a species present in all sub-units within the quadrat would score a total abundance of 100). Where possible, plants were identified to species. Presence of new shoots that were as yet unidentifiable to genus or species were also recorded, as was the presence of bare ground within each sub-unit.

10th July 2015 survey

For the first survey carried out, no species were recorded on the seeded plots (1 to 3 and 7 to 9) other than new shoots and bare areas. Bare areas were recorded as 100 for all quadrats on the seeded areas. Sub-units with seedlings ranged from 0 to 22 on the seeded plots on the non-Aquaten area of the roof and from 0 to 4 on the Aquaten area of the roof. For both the Aquaten and non-Aquaten halves of the roof. Average new shoot counts were highest on the middle plots 2 and 8 (Figures 67 and 68), these are the plots with the shallowest substrate (50 mm). Low colonisation rates during this survey were due to it being carried out not long after roof installation and during a period of sustained drought. Due to these environmental conditions, occasional irrigation of the roof was carried out. Watering more towards the middle of the roof, combined with a drying effect at the edge of the roofs may explain the greater abundance of new shoots in the central shallow plots of plots 2 and 8. Nevertheless, average new shoot abundance followed the same pattern on the Aquaten and non-Aquaten halves of the roof for the seeded plots: 50 mm > 100 mm > 130 mm.

Similarly to the seeded plots, bare areas were recorded in all of the sub-units of all of the plug-planted quadrats. Again this represented the early colonisation state of the green roof plots and the dry weather conditions. All of these plots should have been similarly plug planted, and none were seeded. This was reflected in the results for new shoots, with an abundance of 2 sub-units within a quadrat being the highest recorded and the majority of quadrats containing no new shoots. This was a substantially lower colonisation rate than the seeded plots.

The prolonged period of dry weather had a detrimental impact on many of the plug plants. Despite this, several plug plants persisted within the plots. This included a campion species, a hawkbit species, chive, kidney vetch, lady's bedstraw, thrift and wild carrot. Table 8 presents the average abundance of these plug plants and the new shoots across the plug planted experimental plots.

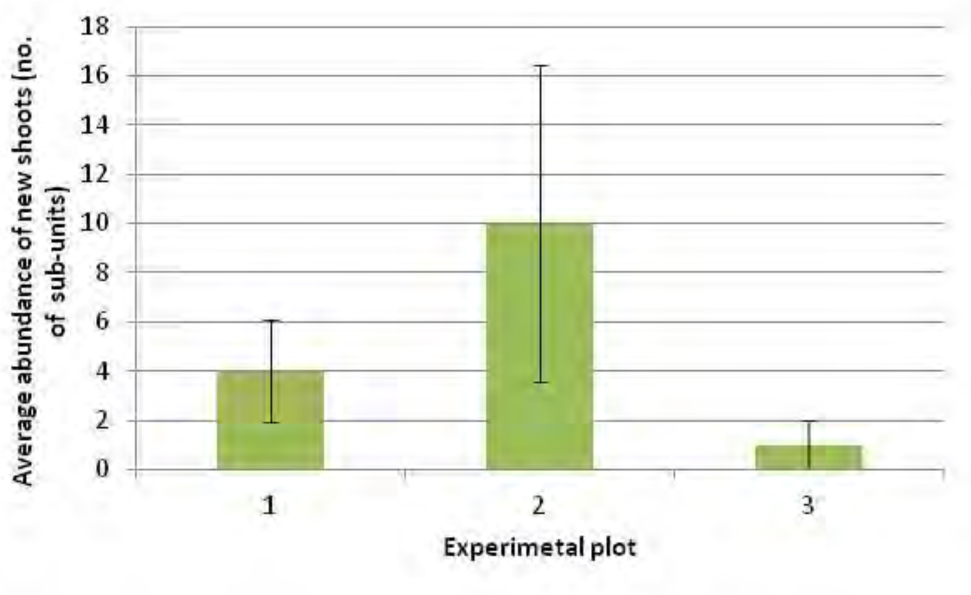


Figure 67. Average count of new shoots on the seeded experimental green roof plots1 to 3 on Richard Knight House, 10th July 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 1 - 100 mm substrate depth, no Aquaten; Plot 2 - 50 mm substrate depth, no Aquaten; Plot 3 - 130 mm substrate depth, no Aquaten. Error bars represent standard error of the mean.

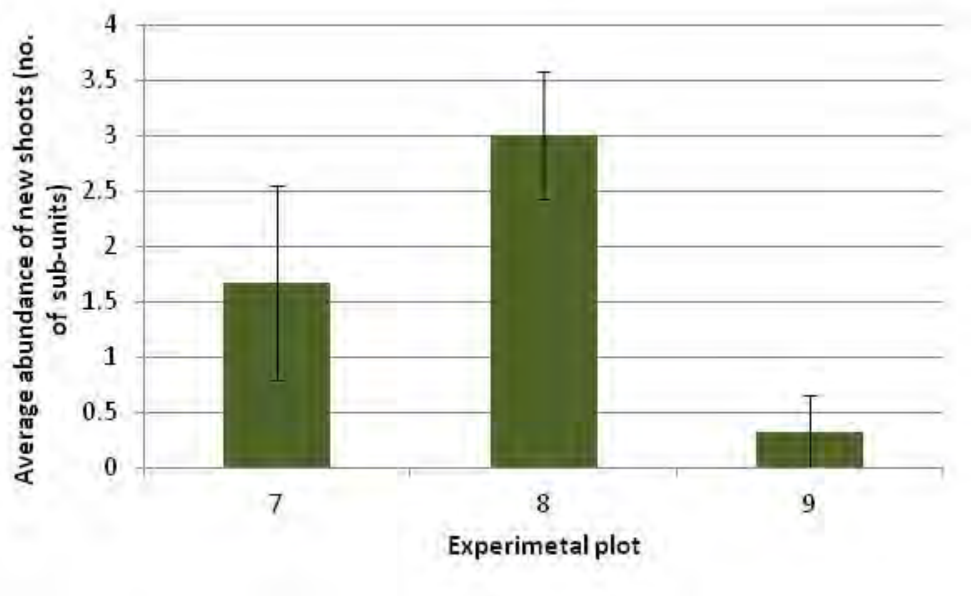


Figure 68. Average count of new shoots on the seeded experimental green roof plots 7 to 9 on Richard Knight House, 10th July 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 7 - 100 mm substrate depth, Aquaten; Plot 8 - 50 mm substrate depth, Aquaten; Plot 9 - 130 mm substrate depth, Aquaten. Error bars represent standard error of the mean.

Table 8. Average sub-unit abundance counts for plug planted experimental green roof plots at Richard Knight House, 10th July 2015. Abundance averages are taken from presence/absence surveys using three quadrats each with 100 sub-units. Coloured cells represent the experimental plot with the highest average abundance for each floral species from the three plots (purple for non-Aquaten plots, red for Aquaten plots).

	Plots					
	Non-Aquaten			Aquaten		
Species	**100 mm**	**50 mm**	**130 mm**	**100 mm**	**50 mm**	**130 mm**
Campion	1.67	1.67	5.33	2.00	1.00	2.33
Chive	2.00	1.00	1.00	0.00	0.33	1.33
Hawkbit spp	0.00	0.00	0.00	1.33	0.00	2.33
Kidney vetch	0.00	3.33	5.00	0.00	0.00	0.00
Lady's bedstraw	1.33	0.00	2.67	3.33	0.67	4.00
Thrift	1.67	0.67	4.33	2.00	2.00	0.67
Wild carrot	0.33	4.67	0.00	2.00	1.33	3.33
New shoots	0.33	1.00	0.33	0.00	0.00	0.67

For the plug planted plots, the deepest substrate depth plots (130 mm depth) recorded the highest average abundance for the majority of plant species. For the Aquaten plots, the only exception to this was thrift. For the non-Aquaten plots the exceptions were chive, wild carrot and new shoots. This provided some evidence for the importance of substrate depth in plug plant colonisation.

27th August 2015 survey

Due to the prolonged drought spell the plug plants originally planted on the experimental plots had all failed. As such, the plots were replanted between the first surveys and the second surveys carried out at Richard Knight House. This meant that results of the second surveys were not a direct comparison of colonisation success since the previous survey. Instead, plug plant records had to be viewed as an new study.

Despite a longer duration since the roof was installed bare areas were still recorded in all subunits of all quadrats surveys on the roof. This was representative of the still sparse nature of the colonising, seeded and planted vegetation. There were, however, substantially larger counts of new shoots on the seeded experimental plots during the second survey than during the first (Figures 69 and 70).

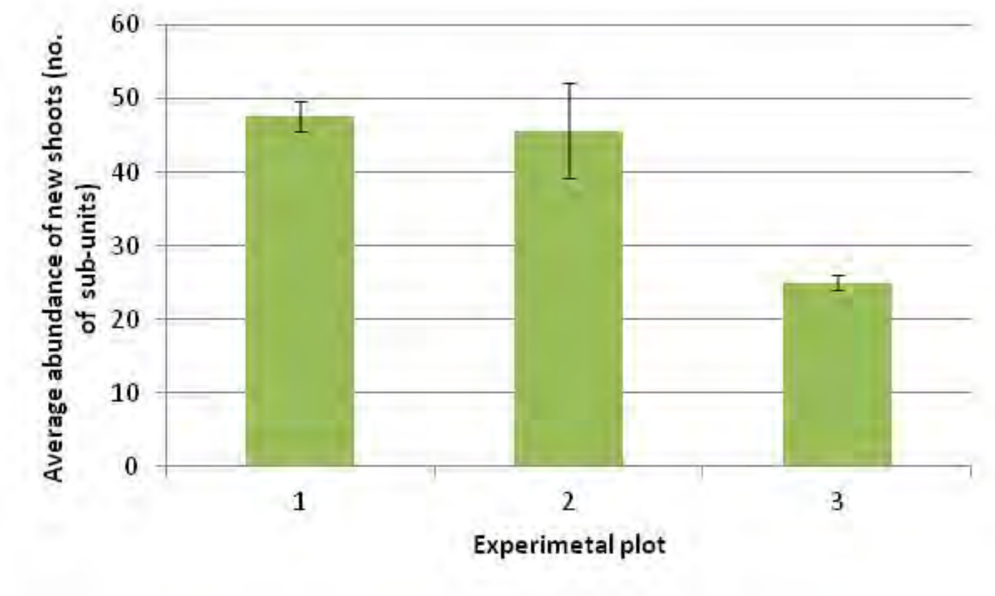


Figure 69. Average count of new shoots on the seeded experimental green roof plots1 to 3 on Richard Knight House, 27th August 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 1 - 100 mm substrate depth, no Aquaten; Plot 2 - 50 mm substrate depth, no Aquaten; Plot 3 - 130 mm substrate depth, no Aquaten. Error bars represent standard error of the mean.

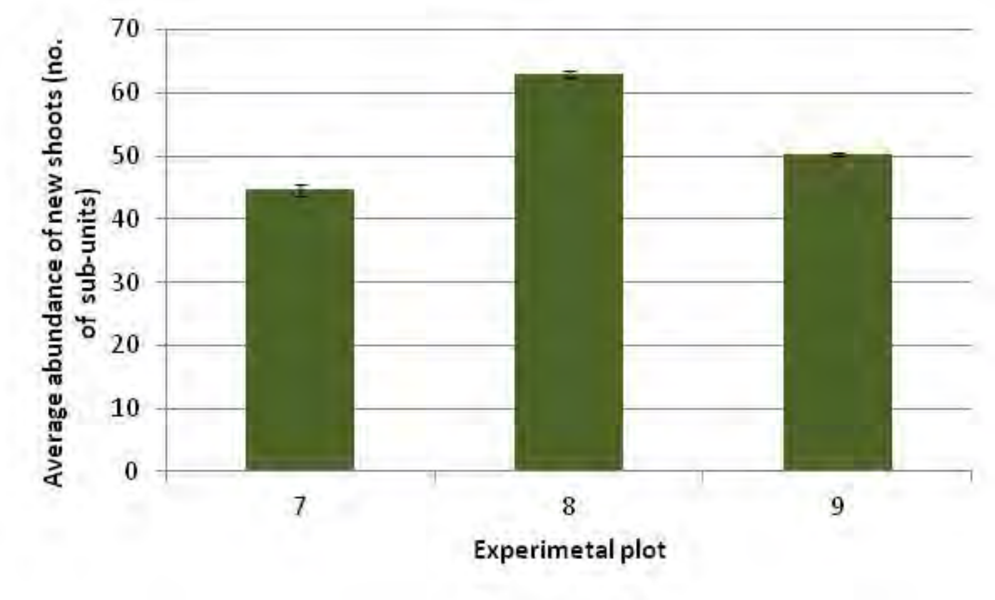


Figure 70. Average count of new shoots on the seeded experimental green roof plots 7 to 9 on Richard Knight House, 27th August 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 7 - 100 mm substrate depth, Aquaten; Plot 8 - 50 mm substrate depth, Aquaten; Plot 9 - 130 mm substrate depth, Aquaten. Error bars represent standard error of the mean.

Similarly to the previous survey, the shallowest substrate plots (2 and 8) were performing well and the deepest substrate plots (3 & 9) were performing less well in terms of new shoot colonisation. However the pattern of hierarchy observed during the first survey (50 mm > 100 mm > 130 mm) was no longer apparent, with the 100 mm substrate the best performing of the non-Aquaten plots and the worst performing of the Aquaten plots. This indicates a level of randomness in the colonisation of the roofs and a problem with the single replicate plot design of the experiment as this randomness could be related to position of the plot on the roof.

In addition to the new shoots, several identifiable species had colonised the seeded plots. This included a *Conyza spp*, *Hirschfeldia incana*, *Leucanthemum vulgare*, a *Muscari spp*, a *Silene spp*, and *Daucus carota*. Distribution of these was relatively even across the Aquaten and non-Aquaten seeded plots.

In terms of the plug planted plots, new shoot colonisation was substantially lower on the plug-planted plots than the seeded. The highest number recorded being 4 sub-units on one of the 100 mm experiment plots.

Following the re-plug planting of the plots, the total number of species recorded on the plug-planted plots was substantially higher than recorded during the previous survey. Average abundance of each species on the plug-planted plots was calculated (Table 9). In contrast to the previous survey results, there appeared to be no pattern in terms of this abundance in relation to the substrate depth of the experimental plots with no plot dominating the abundance of the majority of species recorded. This may reflect the recent replanting and thus the short amount of time for the environmental conditions on each plot to impact the development of the planted vegetation.

Table 9. Average sub-unit abundance counts for plug planted experimental green roof plots at Richard Knight House, 27th August 2015. Abundance averages are taken from presence/absence surveys using three quadrats each with 100 sub-units. Coloured cells represent the experimental plot with the highest average abundance for each floral species from the three plots (purple for non-Aquaten plots, red for Aquaten plots).

	Experimental plot					
	Non-Aquaten			**Aquaten**		
Species	**4**	**5**	**6**	**10**	**11**	**12**
Agrimonia eupatoria	3.33	1.33	0.00	0.00	1.00	0.00
Allium schoenoprasum	0.33	2.67	1.67	0.00	0.00	1.33
Linaria vulgaris	3.00	0.00	2.00	0.00	0.00	0.00
Epilobium spp	0.33	0.00	0.00	0.00	0.00	0.00
Knautia arvensis	2.33	3.67	16.00	7.00	6.00	5.33
Galium verum	6.00	1.33	4.33	3.67	1.00	3.67
Hawkbit spp	0.00	0.00	0.00	1.33	0.00	1.00
Anthyllis vulneraria	0.00	1.67	10.33	0.00	0.00	0.00
Lotus corniculatus	0.00	14.00	0.00	0.00	0.00	0.00
Malva sylvestris	0.00	2.00	0.00	2.67	0.00	0.00
Origanum majorana	0.00	0.00	0.00	3.67	9.67	3.67
New shoots	2.67	0.00	0.00	0.00	0.00	0.00
Sanguisorba minor	1.33	0.00	0.00	0.00	0.00	5.00
Sedum acre	4.33	0.00	0.00	0.00	0.00	3.33
Sedum rupestre	7.00	6.33	4.00	0.00	1.00	4.00
Sedum sexangulare	0.00	0.00	0.00	0.00	5.67	0.00
Silene dioica	0.00	5.00	7.33	3.33	0.00	0.00
Silene latifolia	6.00	0.00	0.00	0.00	0.00	1.67
Dianthus maritima	1.67	0.00	9.67	2.67	0.33	1.00
Daucus carota	0.00	2.33	0.00	0.67	1.67	0.67

25th September 2015 survey

The final survey was carried out a substantial length of time following the replugging of the experimental plots. Artificial irrigation of the roofs had also ceased at this point so it is likely that the results of the final survey would be more representative of the effects of the plot design on the vegetation development.

For the first time, not all of the quadrats recorded 100 for the abundance of bare ground. Average bare ground abundances were 100, 96.7, 100, 96.3 100 and 99.3 respectively for the seeded plots 1, 2, 3, 7, 8, 9. Again, no pattern of cover with substrate depth was apparent from this data. Abundance of new shoots had also increased with greater levels of colonisation (Figures 71 and 72). Similarly to the previous survey, there was no specific pattern in relation to substrate depth but the hierarchies were the same as the previous survey: 100 mm > 50 mm > 130 mm for the non-Aquaten plots and 50 mm > 130 mm > 100 mm for the Aquaten plots.

In addition, 24 species were recorded on the seeded plots. This was an increase of 18 since the previous survey and provided further evidence of the gradual colonisation of the green roof plots. These species comprised chive (*Allium schoenoprasum*), common amaranth (*Amaranthus retroflexus*), kidney vetch (*Anthyllis vulneraria*), fern grass (*Catapodium rigidum*), wild carrot (*Daucus carota*), Thrift (*Dianthus maritima*), marsh bedstraw (*Galium palustre*), dove's-foot crane's-bill (*Geranium molle*), hoary mustard (*Hirschfeldia incana*), oxeye daisy (*Leucanthemum vulgare*), toadflax spp (*Linaria spp*), perennial ryegrass (*Lolium perenne*), birdsfoot trefoil (*Lotus corniculatus*), common poppy (*Papaver rhoeas*), meadow clary (*Salvia pratensis*), goldmoss stonecrop (*Sedum acre*), white stonecrop (*Sedum album*), reflexed stonecrop (*Sedum rupestre*), tasteless stonecrop (*Sedum sexangulare*), common sowthistle (*Sonchus oleraceus*), woundswort spp (*Stachys spp*), clover spp (*Trifolium spp*), Grass spp and Muscari spp.

Of these floral species, the species that were fairly ubiquitous across the survey area were studied in greater detail to assess whether there were any obvious affinities to particular experimental designs:

Fern grass - was substantially more abundant on the Aquaten seeded plots than the non-Aquaten. On the non Aquaten plots it was only found in substantial numbers on the deepest substrate (130 mm) indicating that available water might have been a limiting factor on this species' distribution on the plots

Muscari spp - was more abundant on the corresponding non-Aquaten plots than the Aquaten plots. The species was also more abundant on the shallower substrate plots than the deepest.

Sedum acre - showed no real pattern in relation to Aquaten and substrate depth.

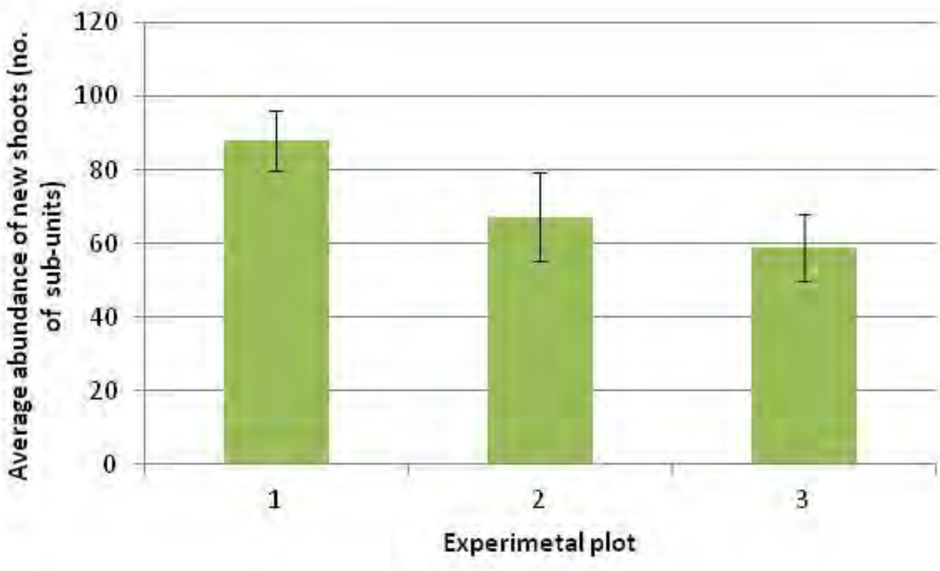


Figure 71. Average count of new shoots on the seeded experimental green roof plots1 to 3 on Richard Knight House, 25th September 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 1 - 100 mm substrate depth, no Aquaten; Plot 2 - 50 mm substrate depth, no Aquaten; Plot 3 - 130 mm substrate depth, no Aquaten. Error bars represent standard error of the mean.

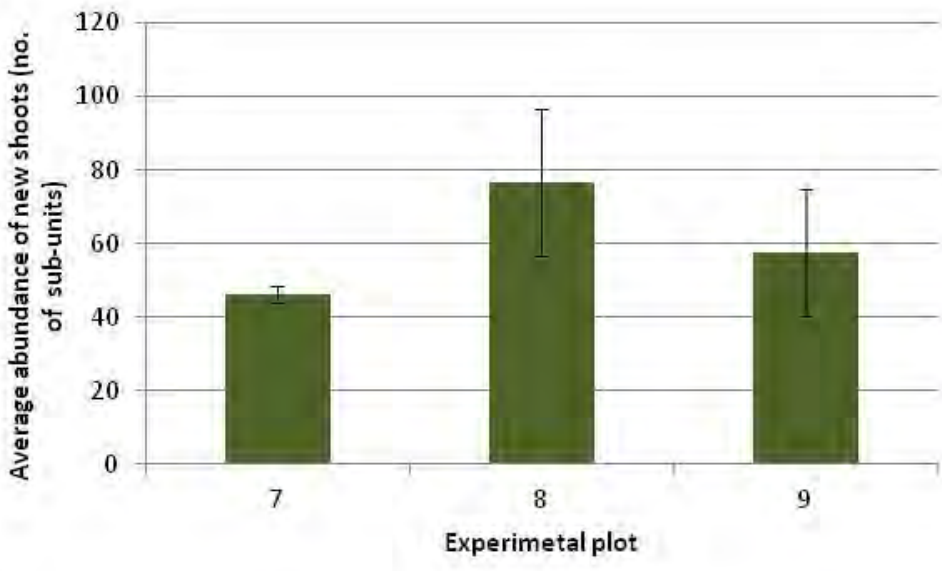


Figure 72. Average count of new shoots on the seeded experimental green roof plots 7 to 9 on Richard Knight House, 25th September 2015. Averages were taken from three quadrats on each experimental plots. Counts created by recording the number of the sub-units within which new shoots were recorded. Plot 7 - 100 mm substrate depth, Aquaten; Plot 8 - 50 mm substrate depth, Aquaten; Plot 9 - 130 mm substrate depth, Aquaten. Error bars represent standard error of the mean.

Wild carrot - was generally more abundant on the corresponding non-Aquaten plots than the Aquaten plots. The species was also more abundant on the shallower substrate plots than the deepest.

Surveys on the plug planted plots also recorded quadrats with bare ground abundance less than 100 for the first time. Average bare ground abundances were 100, 97.7, 97, 99.3, 99.3 and 98.7 respectively for plots 4, 5, 6, 10, 11, 12. This followed a general pattern of the lowest bare ground areas corresponding with the deepest substrate depth (130 mm). No similar pattern was present for the 100 mm and 50 mm depths however.

In terms of new shoots colonising, numbers remained extremely low compared to the seeded areas. An average abundance 5.7 on plot 10 (100 mm, Aquaten) was the highest recorded on the plots. There was no obvious pattern in relation to substrate depth nor in relation to presence of Aquaten. Results for new shoots again indicated the success of seeding in terms of encouraging green roof colonisation.

Overall species diversity on the plug planted plots was 23 species. This was an increase of 3 species compared to the previous survey, again indicating that the roofs were colonising and becoming more diverse with time since the initial planting. Average abundance of each species was calculated (Table 10). In contrast to the first survey results, but similarly to the second survey, there appeared to be no pattern in terms of this abundance in relation to the substrate depth of the experimental plots with no plot dominating the abundance of the majority of species recorded. It might be possible that certain species have preferences for certain green roof experimental designs (e.g. the prevalence of sedum on the 100 mm non-aquaten substrate), but such patterns would be expected to become more obvious over time as the influence of colonisation and environmental conditions impact the vegetation development to a greater extent than initial planting. It would thus be interesting to monitor the vegetation development of the roofs over longer time periods to assess this.

Table 10. Average sub-unit abundance counts for plug planted experimental green roof plots at Richard Knight House, 25th September 2015. Abundance averages are taken from presence/absence surveys using three quadrats each with 100 sub-units. Coloured cells represent the experimental plot with the highest average abundance for each floral species from the three plots (purple for non-Aquaten plots, red for Aqauten plots).

	Quadrat					
	Non-Aquaten			Aquaten		
Species	**4**	**5**	**6**	**10**	**11**	**12**
Allium schoenoprasum	0.00	0.00	2.67	0.00	1.00	1.33
Anthyllis vulneraria	0.00	10.67	10.00	0.00	0.00	0.00
Catapodium rigidum	1.00	0.00	0.00	0.33	0.00	0.00
Daucus carota	0.00	6.67	0.00	1.33	0.00	0.33
Dianthus maritima	2.67	0.00	2.33	2.33	1.00	0.33
Epilobium spp	1.33	0.00	0.00	0.00	0.00	0.00
Galium palustre	0.00	0.00	1.33	0.00	0.00	0.00
Galium verum	6.33	0.00	6.00	7.33	0.00	9.00
Knautia arvensis	6.33	0.00	20.67	3.00	9.00	5.67
Lotus corniculatus	0.00	13.33	0.00	0.67	0.00	0.67
Malva sylvestris	0.67	2.33	0.00	0.00	0.00	0.00
Myostis spp	1.67	0.33	1.67	1.33	2.33	0.00
New shoots	2.00	2.33	3.00	5.67	2.33	3.00
Origanum majorana	0.00	0.00	0.00	1.33	3.33	2.00
Reseda lutea	0.00	0.00	0.00	0.00	0.00	1.67
Salad burnet	0.00	0.00	0.00	0.00	0.00	3.67
Scorzoneroides autumnalis	0.00	0.00	0.00	2.67	0.00	1.00
Sedum acre	0.67	0.33	0.00	0.00	0.00	0.00
Sedum album	2.33	0.00	1.00	0.00	1.67	6.33
Sedum rupestre	8.00	5.33	0.67	0.00	5.33	2.67
Sedum sexangulare	0.00	0.00	0.00	0.00	1.67	0.00
Sedum spurium	2.33	0.67	1.33	0.00	0.00	0.00
Silene dioca	2.67	0.67	3.00	0.00	0.00	0.00
Silene latifolia	1.33	1.67	0.00	1.00	2.00	0.67

3.6 Photographic monitoring

In addition to the specific vegetation monitoring of the retrofitted green infrastructure, addition photos were taken to capture the development of the vegetation and wildlife visiting the sites. Below are a small selection of these images (Figures 73 and 74):

Figure 73. Images from green infrastructure retrofit project in Hammersmith. Clockwise from top left: common carder bee on clover in a SuDS swale; hoverfly on yellow composite flower on Cheeseman Terrace green roof; honey bee in Richard Knight House rain garden; and campion flowers on pram shed roof.

Figure 74. Images from green infrastructure retrofit project in Hammersmith. Clockwise from top left: cornflower in SuDS swale; pram shed green roof in full bloom; fungi growing on pram shed roof; solitary bee on thrift on a pram shed roof; red-tailed bumblebee on birdsfoot trefoil in a SuDS swale; and a poppy on the Richard Knight House green roof.

3. 7 Flowmeter rainfall runoff monitoring

At the time of preparing this interim report, monitoring of the flowmeter had been continuous from December 2015 to May 2016. Data monitoring had been carried out on three pram shed roofs (Alexandra, Charlotte and Mary), two roof downpipes (Beatrice House left and right sides), a pressure sensor in the Beatrice House swale, and a barrologger located at the University of East London Docklands campus.

A graph of a sample of the raw data generated by one of these gauges is presented in Figure 75.

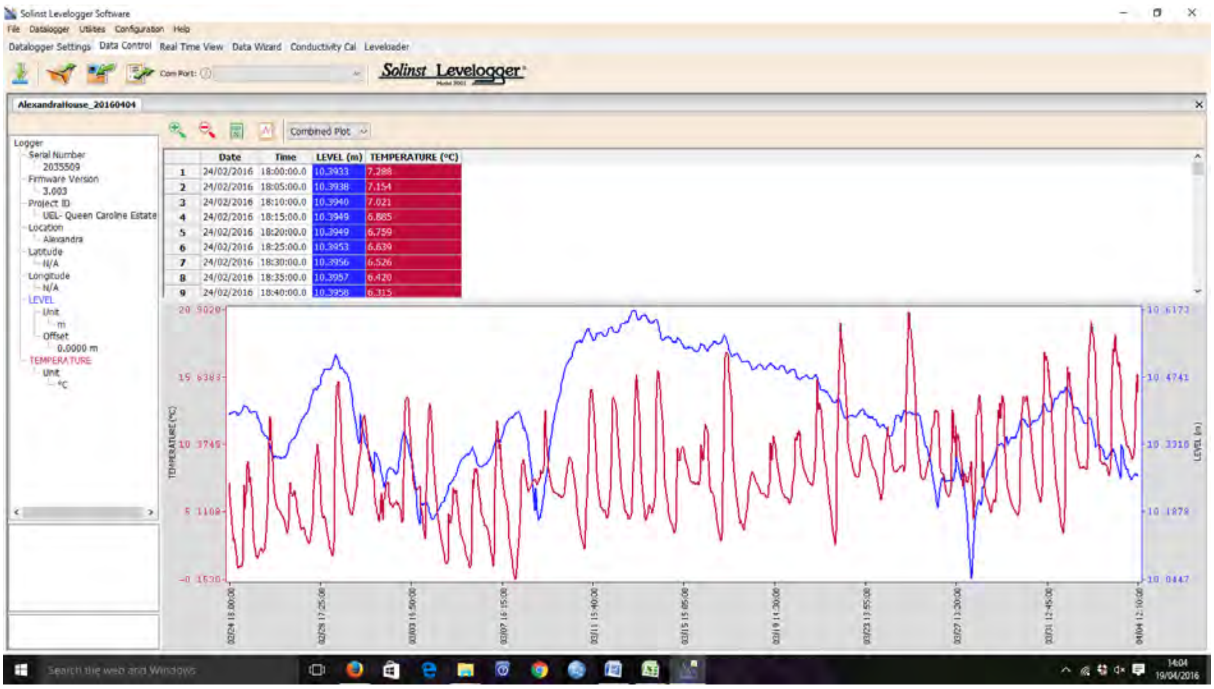


Figure 75. Raw rainfall runoff data collected from Alexandra House pram shed roof in-line flowmeter from the 24th February 2016 to 4th April 2016.

Due to the continuous nature of the monitoring, substantial volumes of data were generated for all rain events. In order to present the most relevant of this data within this report, the five largest rain events during this monitoring period are presented. The largest events were selected as they are those of most interest in terms of causing localised flooding and overloading London's storm drain system.

Details of the five largest rain events are presented in Table 11.

Table 11. Top five largest rain events recorded at Queen Caroline Estate, Hammersmith during the initial monitoring period. Monitoring period was from December 2015 to May 2016. Data comes from a Vantage Vue weather station positioned on Henrietta House at Queen Caroline Estate.

Date	Max temp (°C)	Total rain (mm)	Maximum rain rate (mm/hr)
07/01/2016	9.9	8.6	7.6
11/01/2016	7.6	18.8	57.6
09/03/2016	11.2	9.8	11.6
15/04/2016	14.1	17.6	27.6
11/05/2016	20.2	27.2	45.8

In order to assess the performance of the green roof features, two different analyses were carried out for each of the rain events. The first was an analysis of the proportion of the total rainfall that was attenuated by each of the pram shed roofs. The second was a graphical representation of the timing and intensity of runoff from the green roofs, control roofs and the values from the pressure sensor at the base of Beatrice House swale.

Rain event 07/01/2016

Figure 76 shows the prevailing weather patterns preceding the rain event in the 7th January 2016

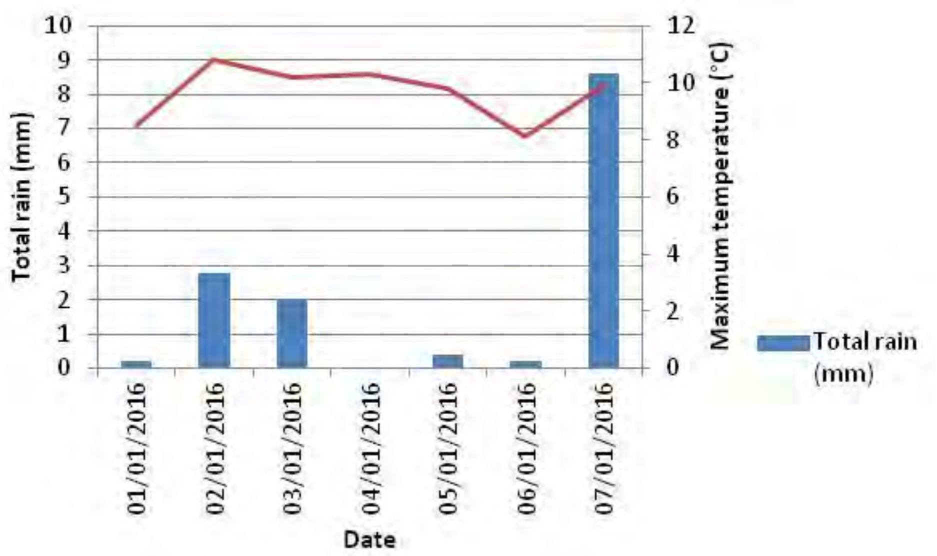


Figure 76. Prevailing weather conditions preceding one of the five largest rain events at Queen Caroline Estate, Hammersmith. Rain event was 8.6 mm on 7th January 2016.

Table 12 presents the attenuation performance of the pramshed roofs during the rain event on the 7th January 2016.

Table 12. Pramshed green roof water attenuation performance during a rain event on the 7th January 2016. Water attenuation calculated as the percentage of the total rainfall that fell on the roof held within the roof rather than being released to storm drains.

Green roof	Total rain (mm)	Catchment area (m)	Volume of rainfall in catchment area (L)	Attenuation (%)
Alexandra	8.6	22	189.2	79.85
Charlotte	8.6	32	275.2	93.16
Mary	8.6	33.25	285.95	92.72
Average				**88.58**

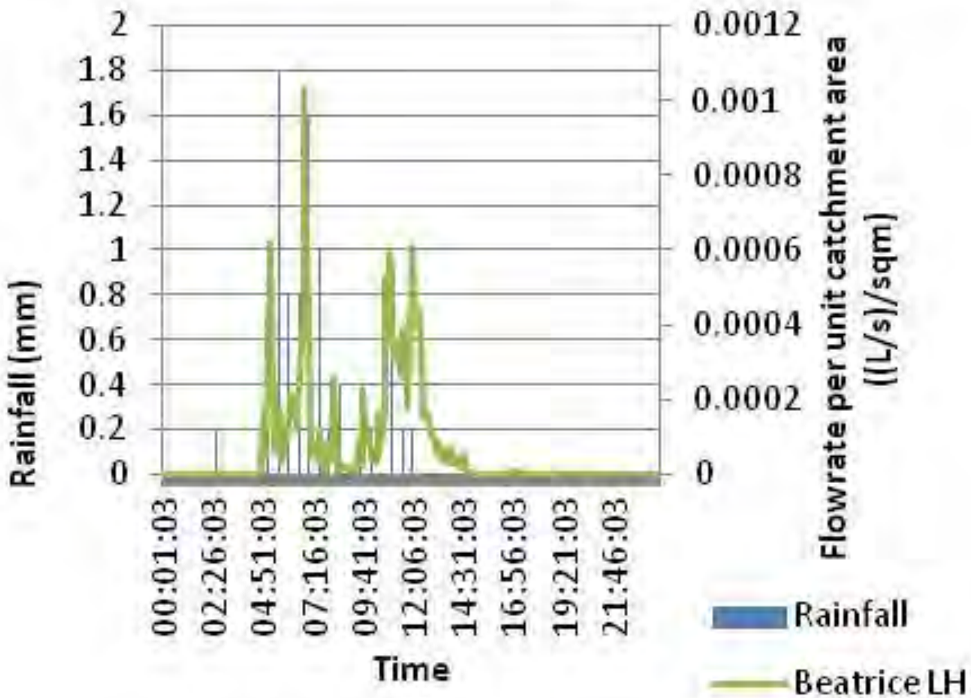
Figure 77 represents the water runoff from (i) and (ii) the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) the three pram shed roofs at Queen Caroline estate, and (vi) the pattern of the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event.

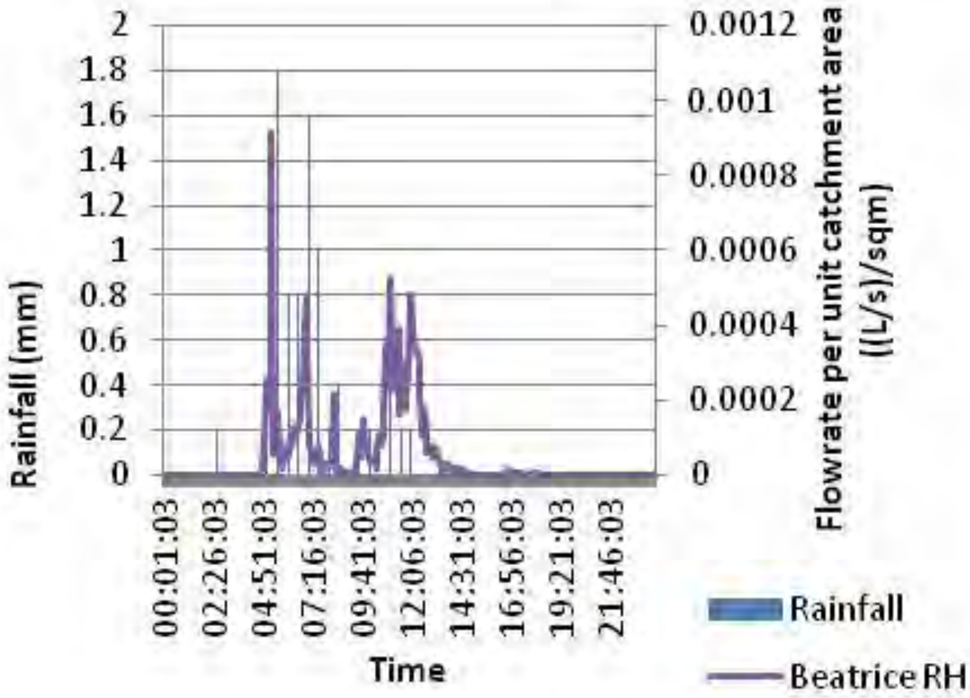
Evidence from the roof runoff monitoring was positive with substantial reductions in the peak flows from the green roofs compared to the control roofs (Table 13.i). Maximum peak flow reduction recorded was 74%. Peak flows were also substantially delayed (Table 13.ii). Reduction and delay in peak flow of storm drain systems is vital in order to avoid system overloading.

Table 13. i) Percentage reduction in peak flow and ii) delay in peak flow from green roofs compared to control roofs for the 8.6 mm rain event on the 7th January 2016 at Queen Caroline Estate, Hammersmith. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area.

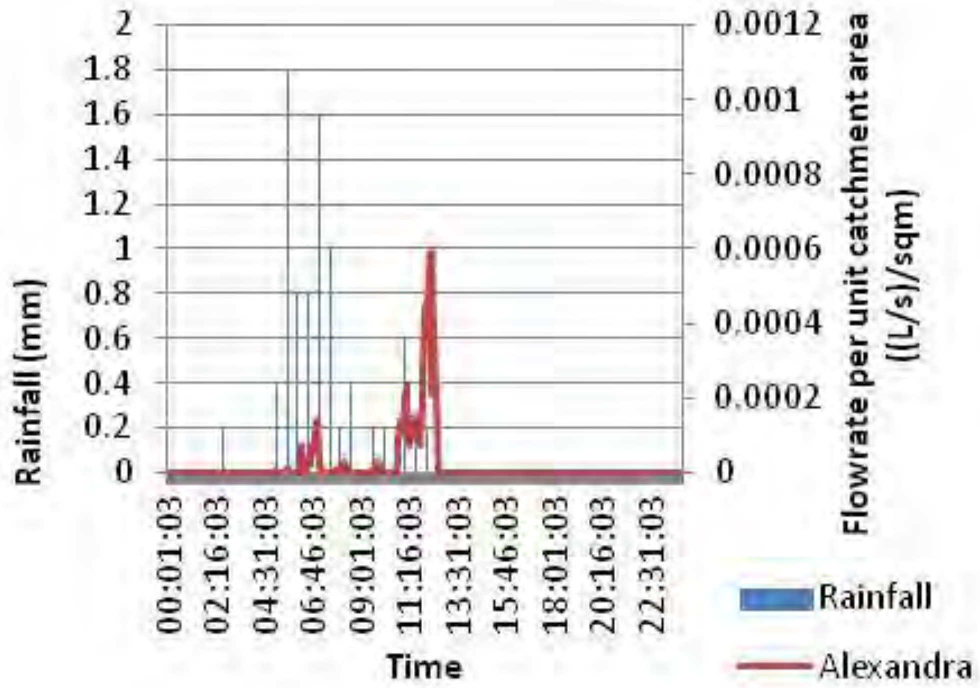
i)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	42.59%	73.83%	73.16%
Beatrice RH	35.36%	70.53%	69.78%

ii)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	05:30:00	04:00:00	04:00:00
Beatrice RH	07:05:00	05:35:00	05:35:00

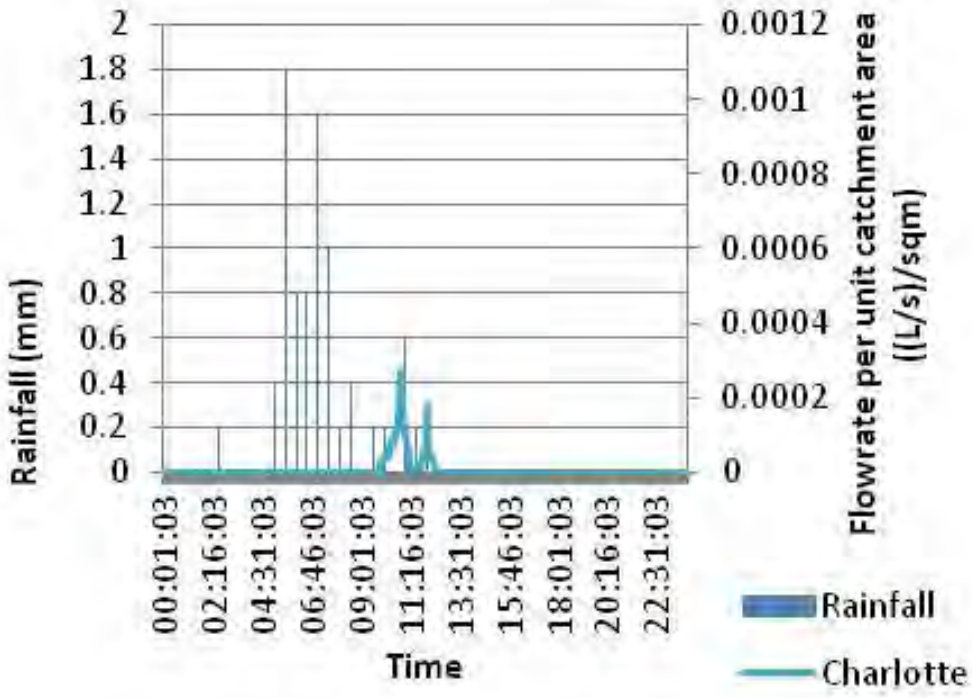

Rainfall (mm)
Flowrate per unit catchment area ((L/s)/sqm)
Time
Rainfall
Beatrice LH


Rainfall (mm)
Flowrate per unit catchment area ((L/s)/sqm)
Time
Rainfall
Beatrice RH

i) **ii)**



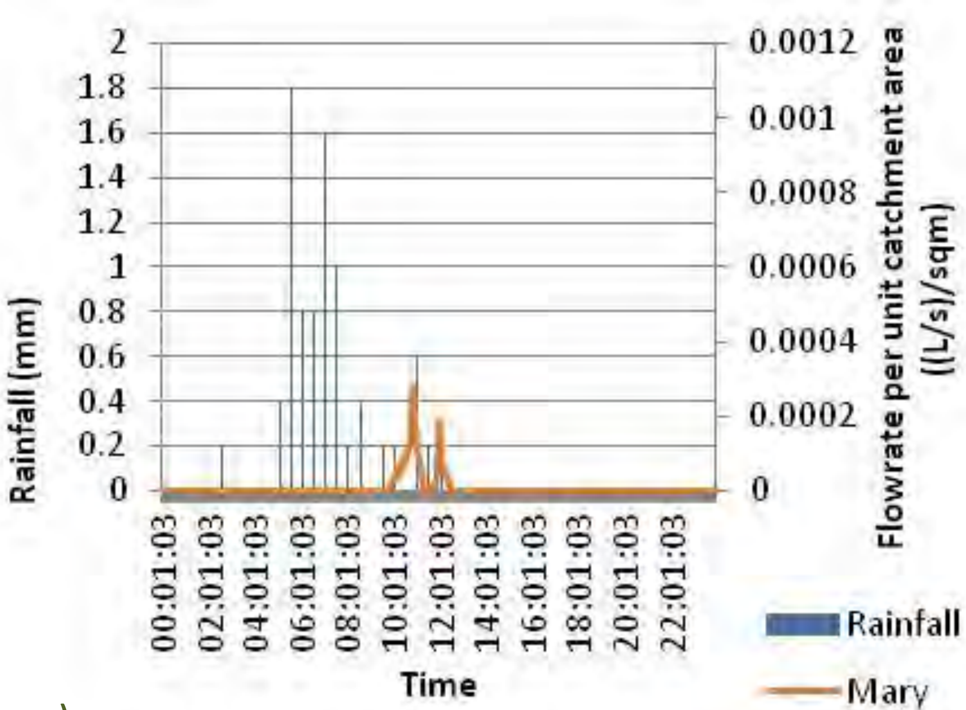
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:16:03
04:31:03
06:46:03
09:01:03
11:16:03
13:31:03
15:46:03
18:01:03
20:16:03
22:31:03
Time
Rainfall
Alexandra



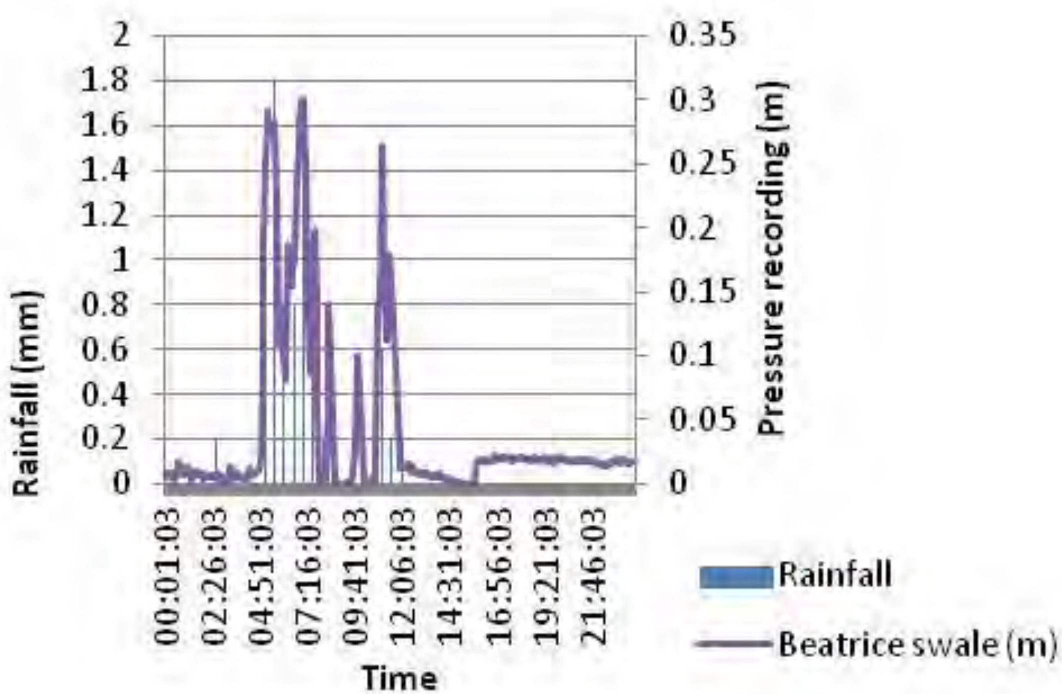
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:16:03
04:31:03
06:46:03
09:01:03
11:16:03
13:31:03
15:46:03
18:01:03
20:16:03
22:31:03
Time
Rainfall
Charlotte

iii)

iv)



v)



vi)

Figure 77. Water attenuation patterns from Queen Caroline Estate, Hammersmith, 7th January 2016. Graphs represent individual storm management infrastructure components: (i) and (ii) represent the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) represent the three pram shed green roofs at Queen Caroline Estate, and (vi) the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event. Roof flow rates were measured using a pressure sensor combined with a v-notch weir. The swale was measured using a pressure sensor beneath the swale. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area. ***N.B. It must be noted that the control roofs were pitched roofs and the catchment areas were based on the aerial view of the roof (i.e. a 2D 'vertical footprint'). Due to the pitch, the direction of rain for the rain event may have affected the volume of water recorded on the control roofs (i.e. the SE -facing pitched roofs would be expected to catch more rain from a SE wind direction rain event than a NE wind rain event). As such, the peak flows from the control roofs were likely to be a conservative estimate for all rain events other than those with wind from a SE direction.***

Data from the pressure sensor in the Beatrice swale (Figure 77 vi) supported the evidence captured by the time-lapse cameras. The pressure sensor captured the swale reacting quickly to rainfall by recording an increase in pressure very quickly following rain (caused by water pooling above the sensor). This increase in pressure was short-lived however, with a reduction in pressure in relatively short periods following the cessation of the rain. This indicated that the swale was effectively conveying and infiltrating the stormwater, rather than the basin holding pooled water over long periods. This is important as it means that stormwater storage volumes are available for the next rain event.

Rain event 11/01/2016

Figure 78 shows the prevailing weather patterns preceding the rain event in the 11th January 2016.

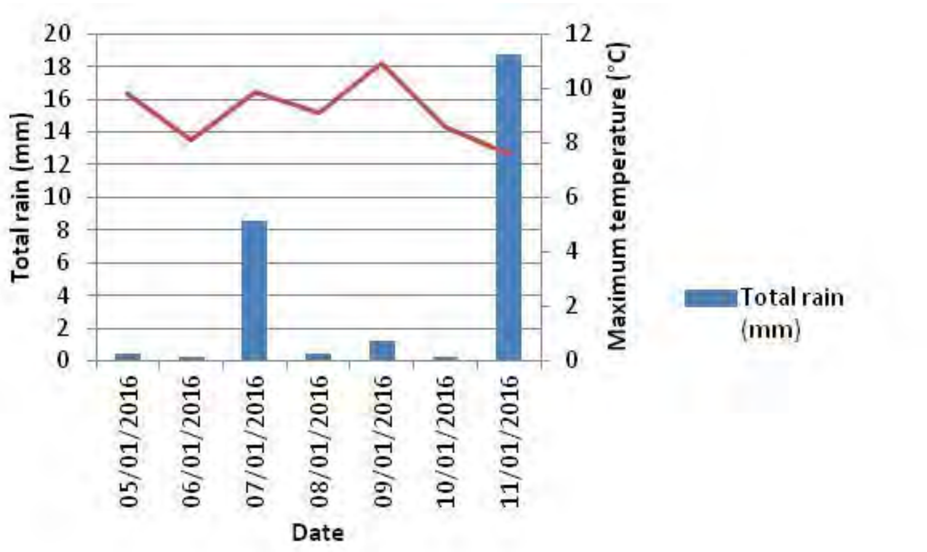


Figure 78. Prevailing weather conditions preceding one of the five largest rain events at Queen Caroline Estate, Hammersmith. Rain event was 18.8 mm on 11th January 2016.

Table 14 presents the attenuation performance of the pramshed roofs during the rain event on the 11th January 2016.

Table 14. Pramshed green roof water attenuation performance during a rain event on the 11th January 2016. Water attenuation calculated as the percentage of the total rainfall that fell on the roof held within the roof rather than being released to storm drains.

Green roof	Total rain (mm)	Catchment area (m)	Volume of rainfall in catchment area (L)	Attenuation (%)
Alexandra	18.8	22	413.6	90.71
Charlotte	18.8	32	601.6	75.67*
Mary	18.8	33.25	625.1	70.24*
Average				**78.87**

**Some evidence that there may have been a slight blockage in the v-notch after the rainfall event potentially lowering the attenuation value*

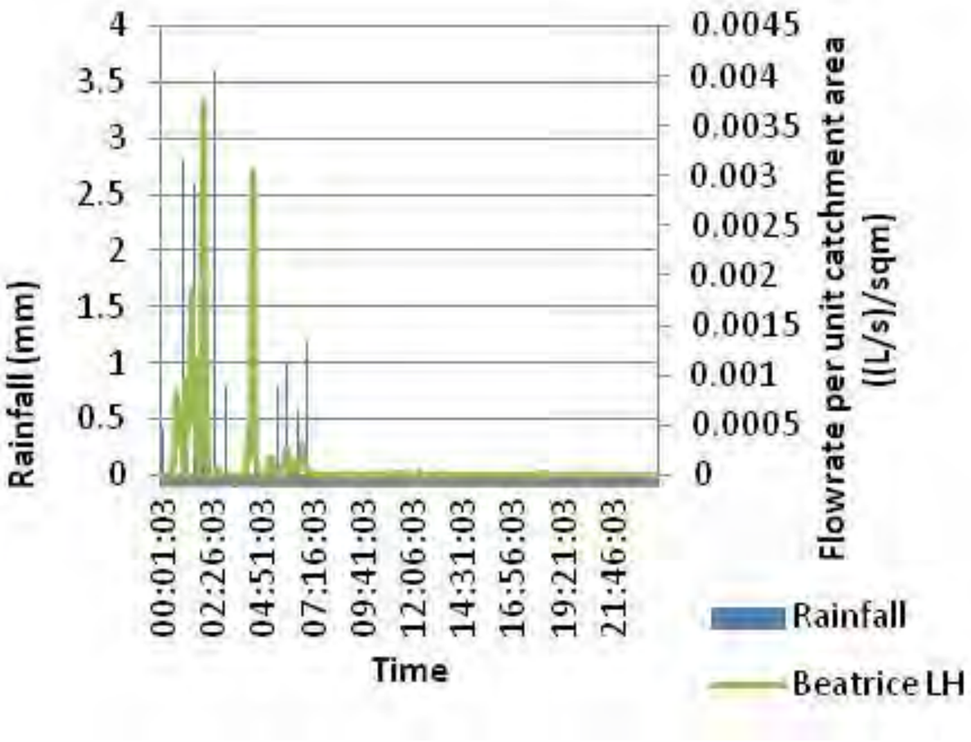
Figure 79 represents the water runoff from (i) and (ii) the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) the three pram shed roofs at Queen Caroline estate, and (vi) the pattern of the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event.

Evidence from the roof runoff monitoring was positive with substantial reductions in the peak flows from the green roofs compared to the control roofs (Table 15.i). Maximum peak flow reduction recorded was 80%. Peak flows also showed some evidence of delay (Table 15.ii). Reduction and delay in peak flow of storm drain systems is vital in order to avoid system overloading.

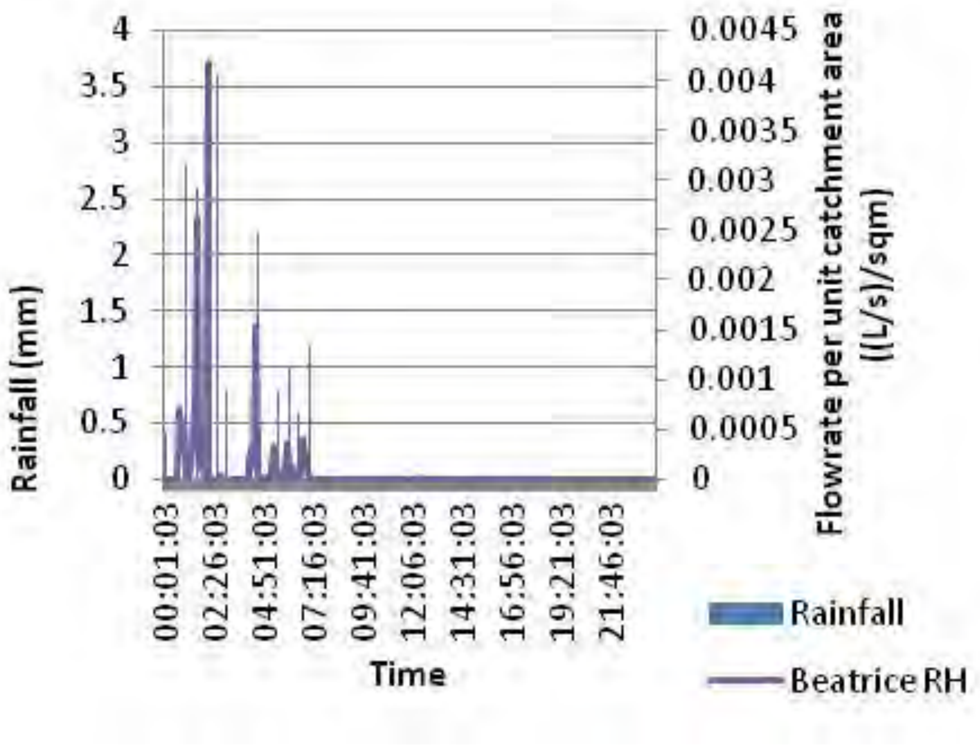
Table 15. i) Percentage reduction in peak flow and ii) delay in peak flow from green roofs compared to control roofs for the 18.8 mm rain event on the 11th January 2016 at Queen Caroline Estate, Hammersmith. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area.

i)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	49.07%	78.10%	53.17%
Beatrice RH	54.44%	80.41%	58.11%

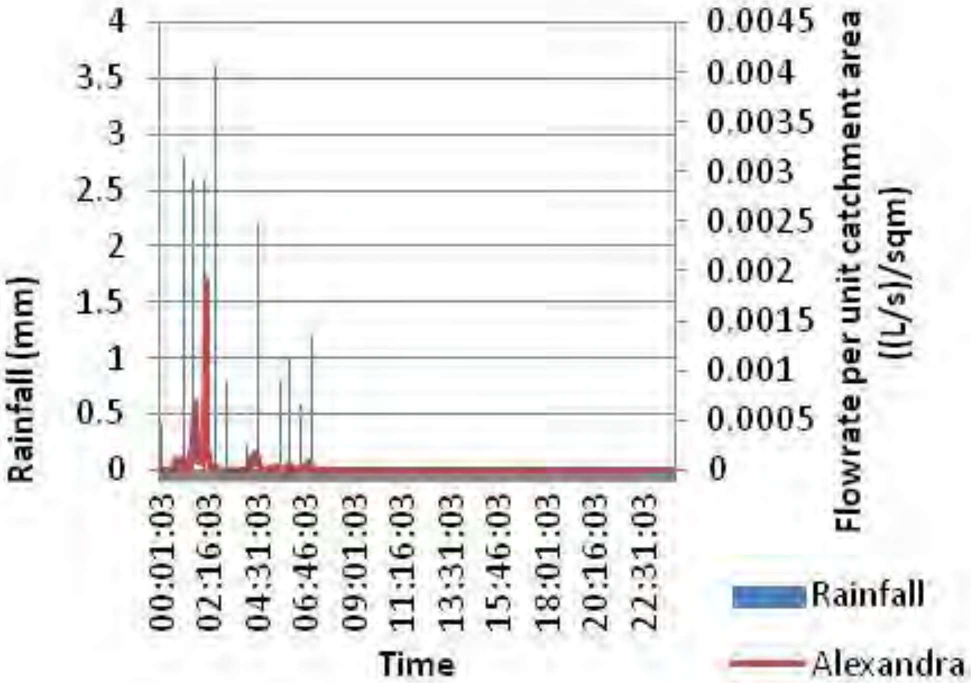
ii)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	00:05:00	02:25:00	00:05:00
Beatrice RH	00:00:00	02:20:00	00:00:00

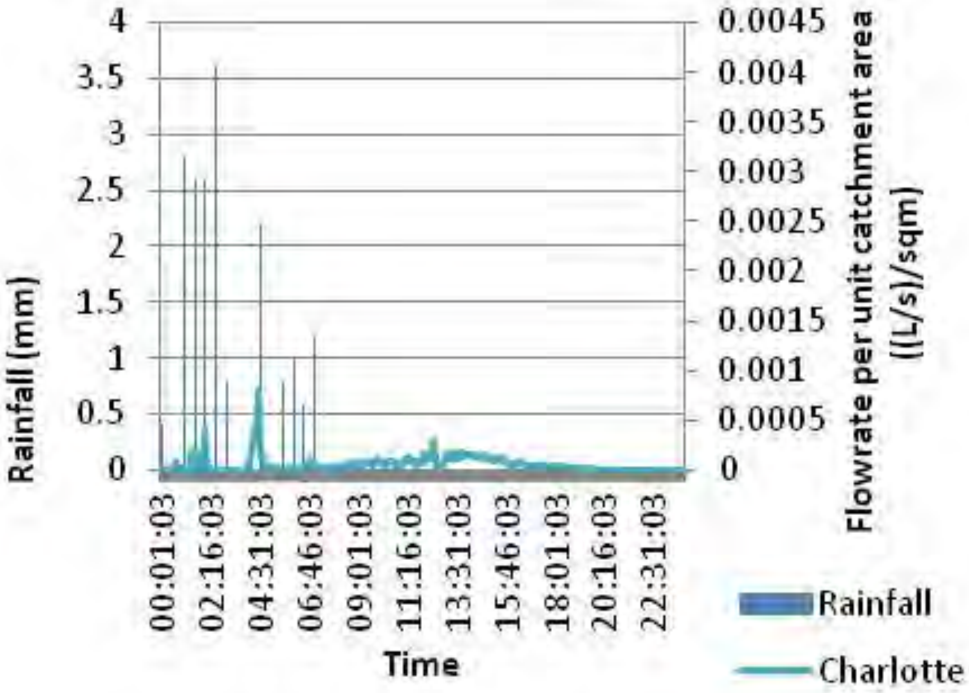

4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:26:03
04:51:03
07:16:03
09:41:03
12:06:03
14:31:03
16:56:03
19:21:03
21:46:03
Time
Rainfall
Beatrice LH

i)


4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:26:03
04:51:03
07:16:03
09:41:03
12:06:03
14:31:03
16:56:03
19:21:03
21:46:03
Time
Rainfall
Beatrice RH

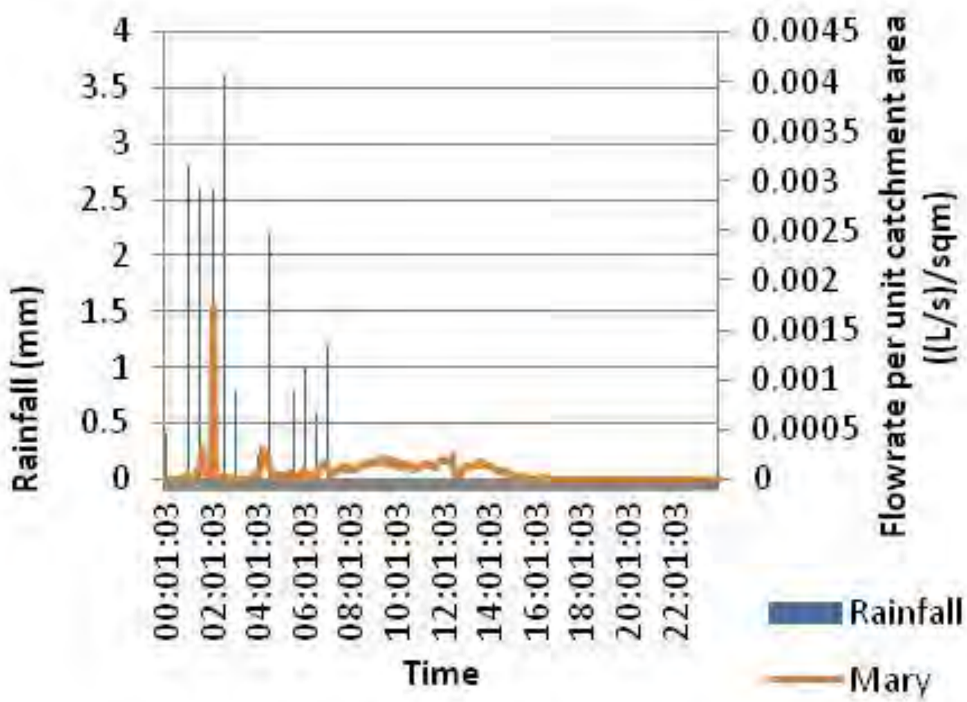
ii)


4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:16:03
04:31:03
06:46:03
09:01:03
11:16:03
13:31:03
15:46:03
18:01:03
20:16:03
22:31:03
Time
Rainfall
Alexandra

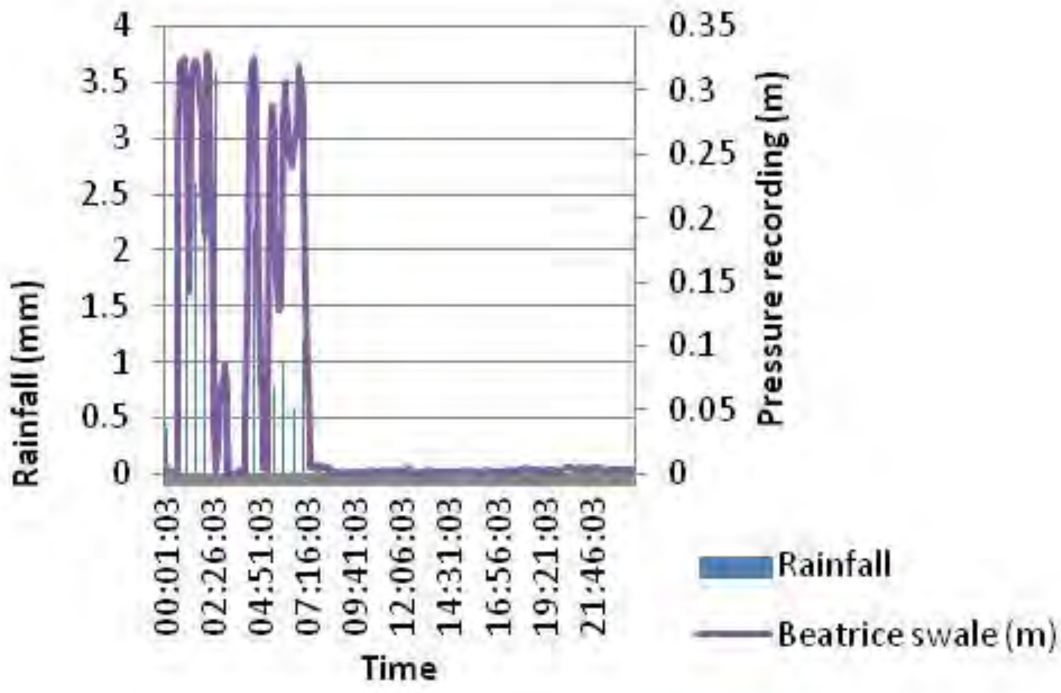

4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:01:03
02:16:03
04:31:03
06:46:03
09:01:03
11:16:03
13:31:03
15:46:03
18:01:03
20:16:03
22:31:03
Time
Rainfall
Charlotte

iii)

iv)



v)



vi)

Figure 79. Water attenuation patterns from Queen Caroline Estate, Hammersmith, 11th January 2016. Graphs represent individual storm management infrastructure components: (i) and (ii) represent the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) represent the three pram shed green roofs at Queen Caroline Estate, and (vi) the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event. Roof flow rates were measured using a pressure sensor combined with a v-notch weir. The swale was measured using a pressure sensor beneath the swale. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area. ***N.B. It must be noted that the control roofs were pitched roofs and the catchment areas were based on the aerial view of the roof (i.e. a 2D 'vertical footprint'). Due to the pitch, the direction of rain for the rain event may have affected the volume of water recorded on the control roofs (i.e. the SE -facing pitched roofs would be expected to catch more rain from a SE wind direction rain event than a NE wind rain event). As such, the peak flows from the control roofs were likely to be a conservative estimate for all rain events other than those with wind from a SE direction.***

Data from the pressure sensor in the Beatrice swale (Figure 79 vi) also supported the evidence captured by the time-lapse cameras. The pressure sensor captured the swale reacting quickly to rainfall by recording an increase in pressure very quickly following rain (caused by water pooling above the sensor). This increase in pressure was short-lived however, with a reduction in pressure in relatively short periods following the cessation of the rain. This indicates that the swale was effectively conveying and infiltrating the stormwater, rather than the basin holding pooled water over long periods.

Rain event 09/03/2016

Figure 80 shows the prevailing weather patterns preceding the rain event in the 9th March 2016.

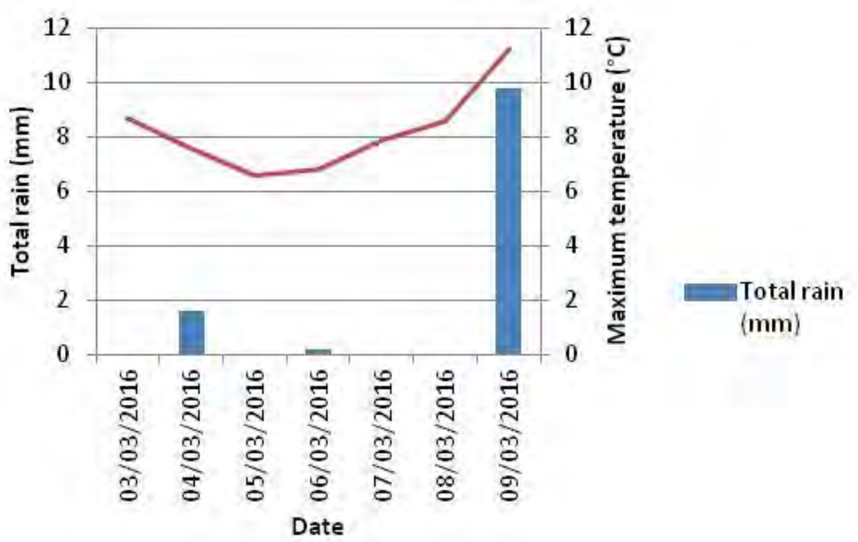


Figure 80. Prevailing weather conditions preceding one of the five largest rain events at Queen Caroline Estate, Hammersmith. Rain event was 9.8 mm on 9th March 2016.

Table 16 presents the attenuation performance of the pramshed roofs during the rain event on the 9th March 2016.

Table 16. Pramshed green roof water attenuation performance during a rain event on the 9th March 2016. Water attenuation calculated as the percentage of the total rainfall that fell on the roof held within the roof rather than being released to storm drains.

Green roof	Total rain (mm)	Catchment area (m)	Volume of rainfall in catchment area (L)	Attenuation (%)
Alexandra	9.8	22	215.6	94.01
Charlotte	9.8	32	313.6	82.97
Mary	9.8	33.25	325.85	87.78
Average				**82.25**

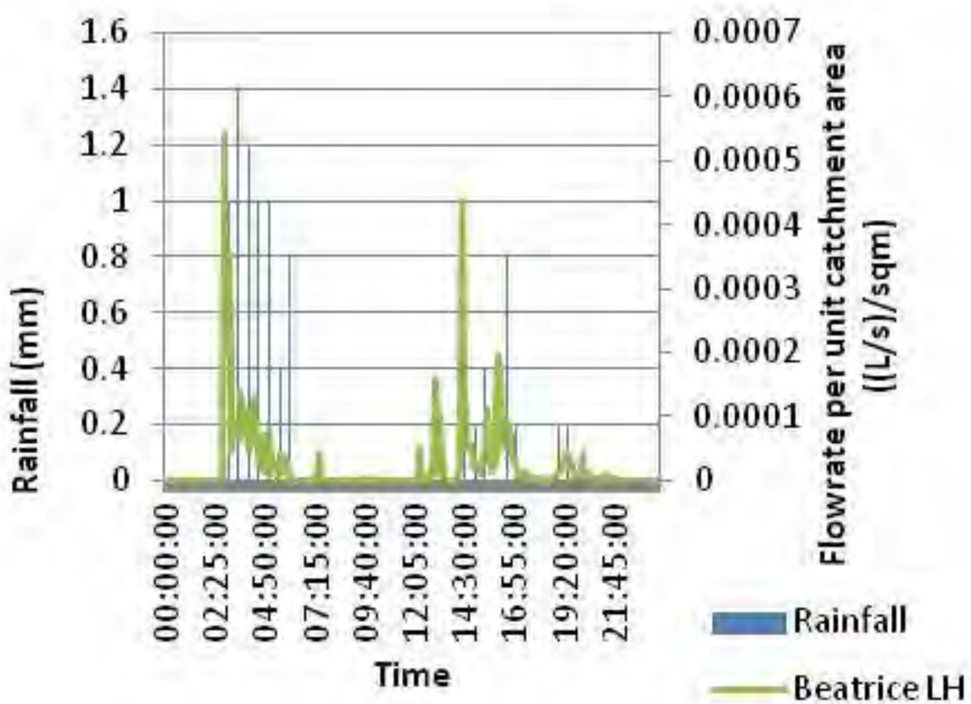
Figure 81 represents the water runoff from (i) and (ii) the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) the three pram shed roofs at Queen Caroline estate, and (vi) the pattern of the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event.

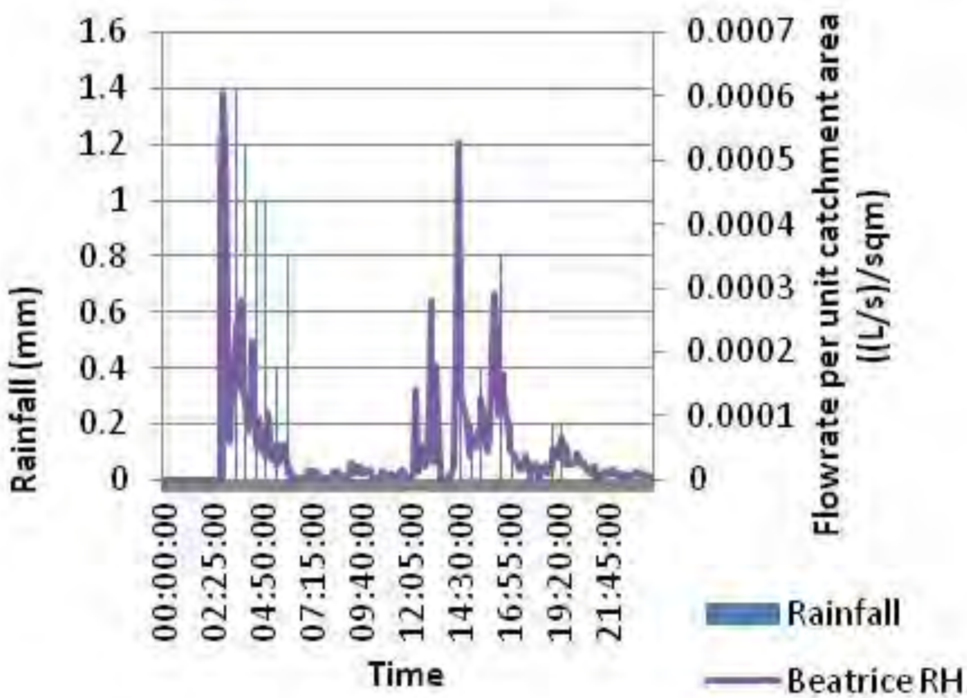
Evidence from the roof runoff monitoring was positive with substantial reductions in the peak flows from the green roofs compared to the control roofs (Table 17.i). Maximum peak flow reduction recorded was 33%. Peak flows also showed substantial evidence of delay with at least 10 hours delay for all green roof peak flows (Table 17.ii). Reduction and delay in peak flow of storm drain systems is vital in order to avoid system overloading.

Table 17. i) Percentage reduction in peak flow and ii) delay in peak flow from green roofs compared to control roofs for the 9.8 mm rain event on the 9th March 2016 at Queen Caroline Estate, Hammersmith. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area.

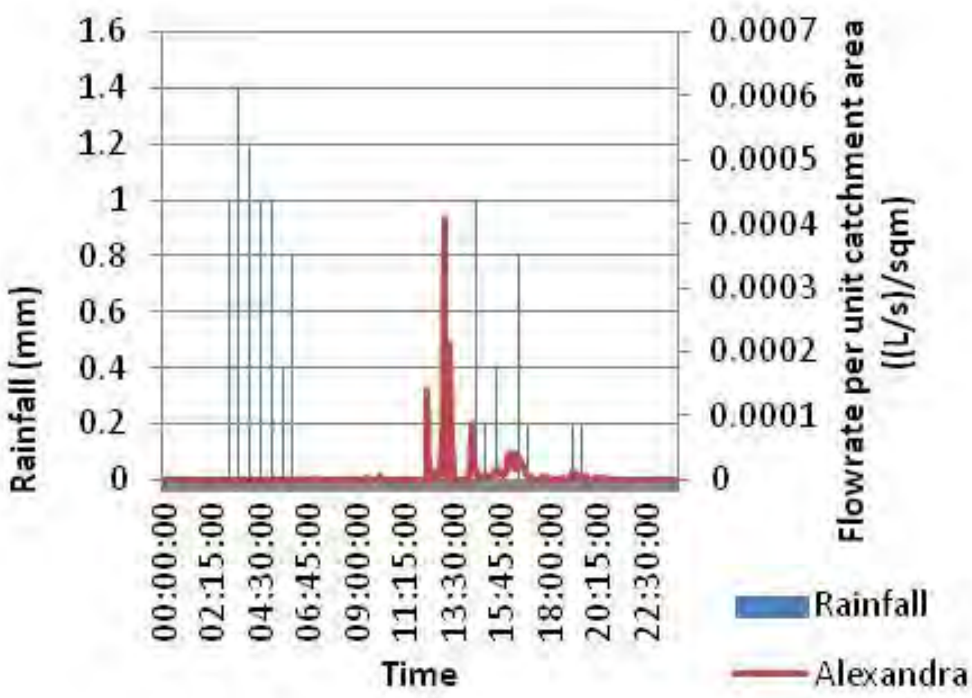
i)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	24.56%	23.36%	12.19%
Beatrice RH	32.78%	31.71%	21.75%

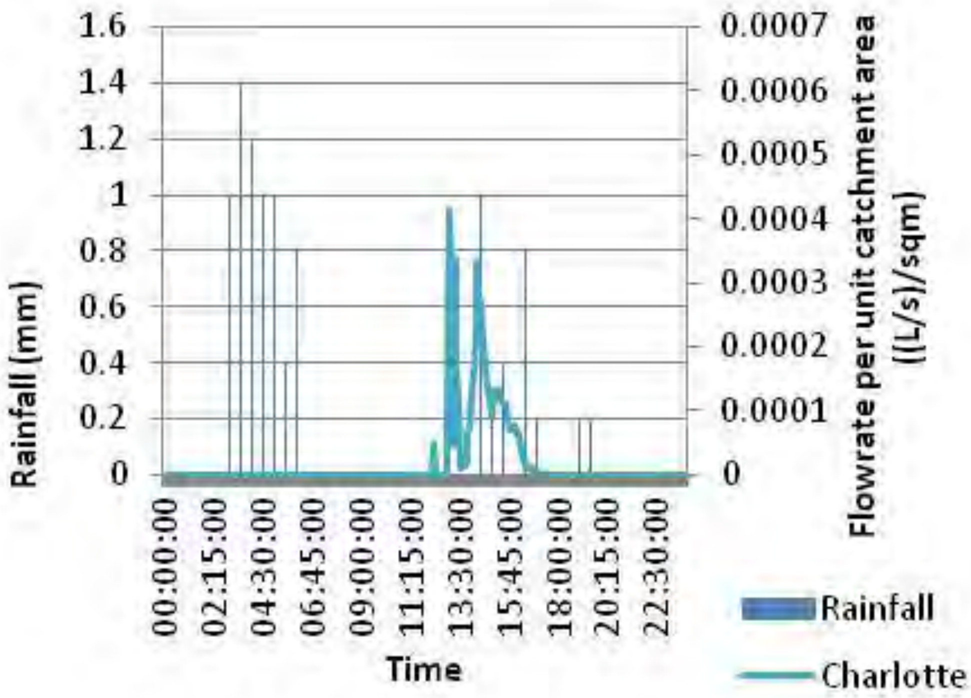
ii)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	10:15:00	10:15:00	10:15:00
Beatrice RH	10:10:00	10:10:00	10:10:00


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:25:00
04:50:00
07:15:00
09:40:00
12:05:00
14:30:00
16:55:00
19:20:00
21:45:00
Time
Rainfall
Beatrice LH


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:25:00
04:50:00
07:15:00
09:40:00
12:05:00
14:30:00
16:55:00
19:20:00
21:45:00
Time
Rainfall
Beatrice RH

i) **ii)**


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Alexandra


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Rainfall (mm)
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Charlotte

iii)

iv)

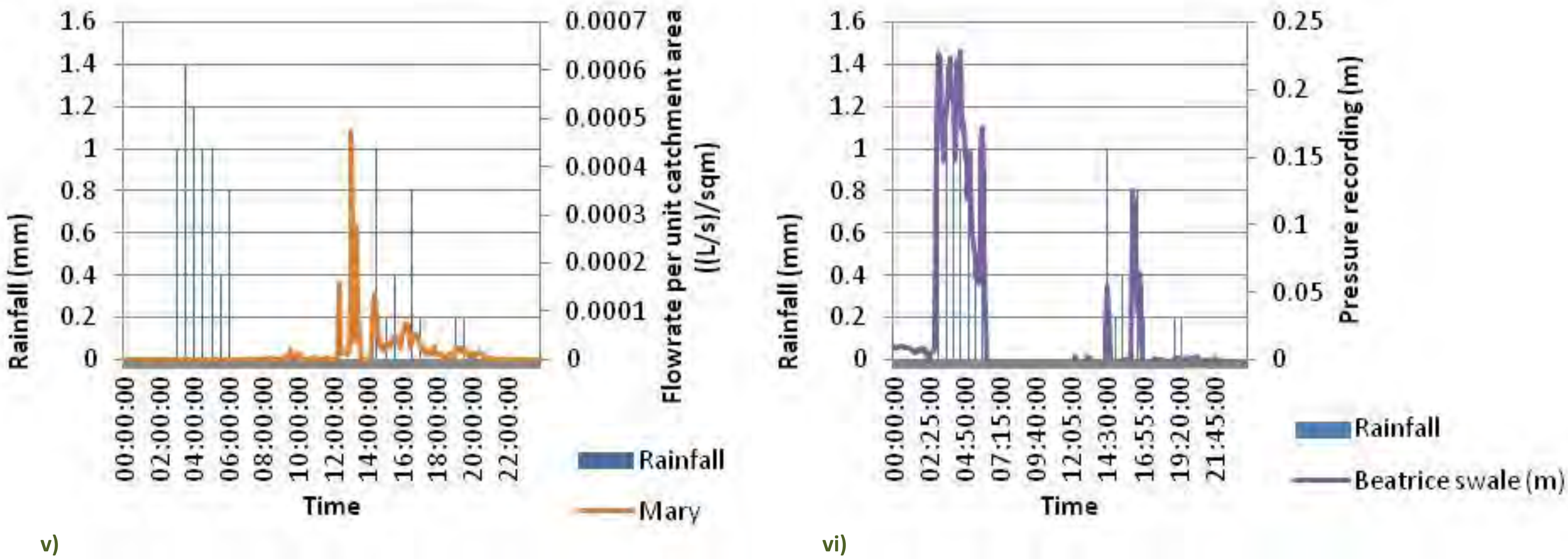


Figure 81. Water attenuation patterns from Queen Caroline Estate, Hammersmith, 9th March 2016. Graphs represent individual storm management infrastructure components: (i) and (ii) represent the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) represent the three pram shed green roofs at Queen Caroline Estate, and (vi) the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event. Roof flow rates were measured using a pressure sensor combined with a v-notch weir. The swale was measured using a pressure sensor beneath the swale. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area. ***N.B. It must be noted that the control roofs were pitched roofs and the catchment areas were based on the aerial view of the roof (i.e. a 2D 'vertical footprint'). Due to the pitch, the direction of rain for the rain event may have affected the volume of water recorded on the control roofs (i.e. the SE -facing pitched roofs would be expected to catch more rain from a SE wind direction rain event than a NE wind rain event). As such, the peak flows from the control roofs were likely to be a conservative estimate for all rain events other than those with wind from a SE direction.***

Data from the pressure sensor in the Beatrice swale (Figure 81 vi) also supported the evidence captured by the time-lapse cameras. The pressure sensor captured the swale reacting quickly to rainfall by recording an increase in pressure very quickly following rain (caused by water pooling above the sensor). This increase in pressure was short-lived however, with a reduction in pressure in relatively short periods following the cessation of the rain. This indicated that the swale was effectively conveying and infiltrating the stormwater, rather than the basin holding pooled water over long periods.

Rain event 15/04/2016

Figure 82 shows the prevailing weather patterns preceding the rain event in the 15th April 2016.

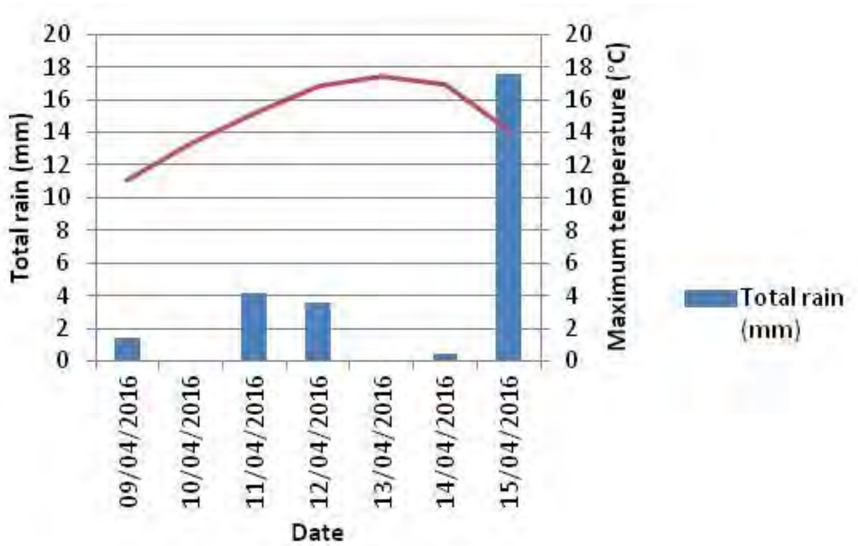


Figure 82. Prevailing weather conditions preceding one of the five largest rain events at Queen Caroline Estate, Hammersmith. Rain event was 17.6 mm on 15th April 2016.

Table 18 presents the attenuation performance of the pramshed roofs during the rain event on the 15th April 2016.

Table 18. Pramshed green roof water attenuation performance during a rain event on the 15th April 2016. Water attenuation calculated as the percentage of the total rainfall that fell on the roof held within the roof rather than being released to storm drains.

Green roof	Total rain (mm)	Catchment area (m)	Volume of rainfall in catchment area (L)	Attenuation (%)
Alexandra	17.6	22	387.2	58.41
Charlotte	17.6	32	563.2	93.20
Mary	17.6	33.25	585.2	70.32
Average				**73.98**

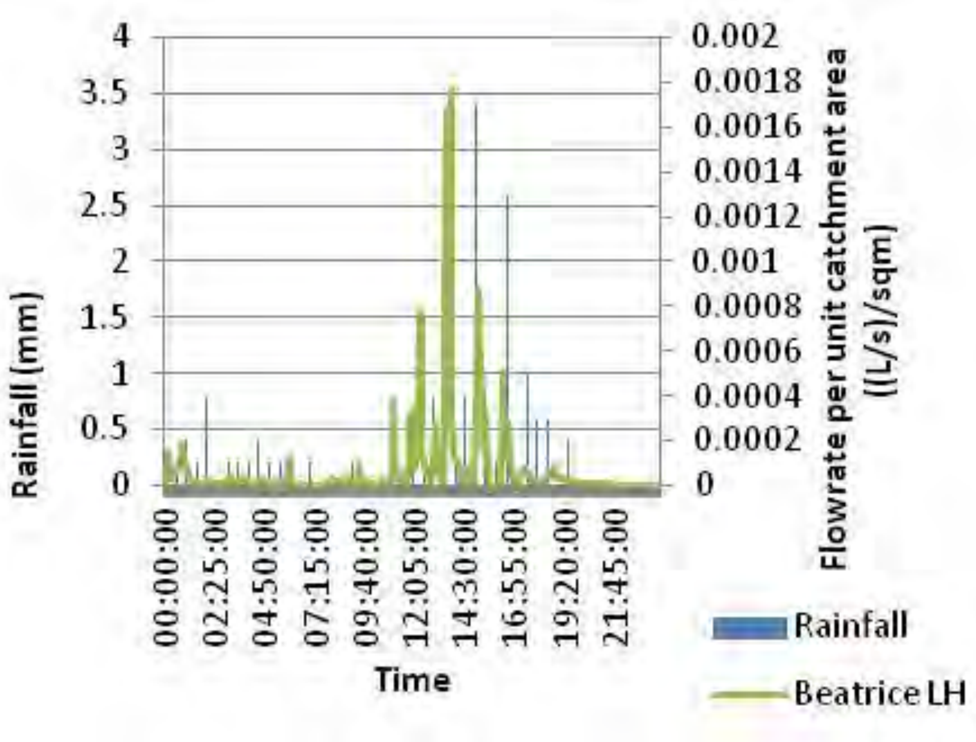
Figure 83 represents the water runoff from (i) and (ii) the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) the three pram shed roofs at Queen Caroline estate, and (vi) the pattern of the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event.

Evidence from the roof runoff monitoring was positive with substantial reductions in the peak flows from the green roofs compared to the control roofs (Table 19.i). Maximum peak flow reduction recorded was 83%. Peak flows also showed substantial evidence of delay (Table 19.ii). Reduction and delay in peak flow of storm drain systems is vital in order to avoid system overloading.

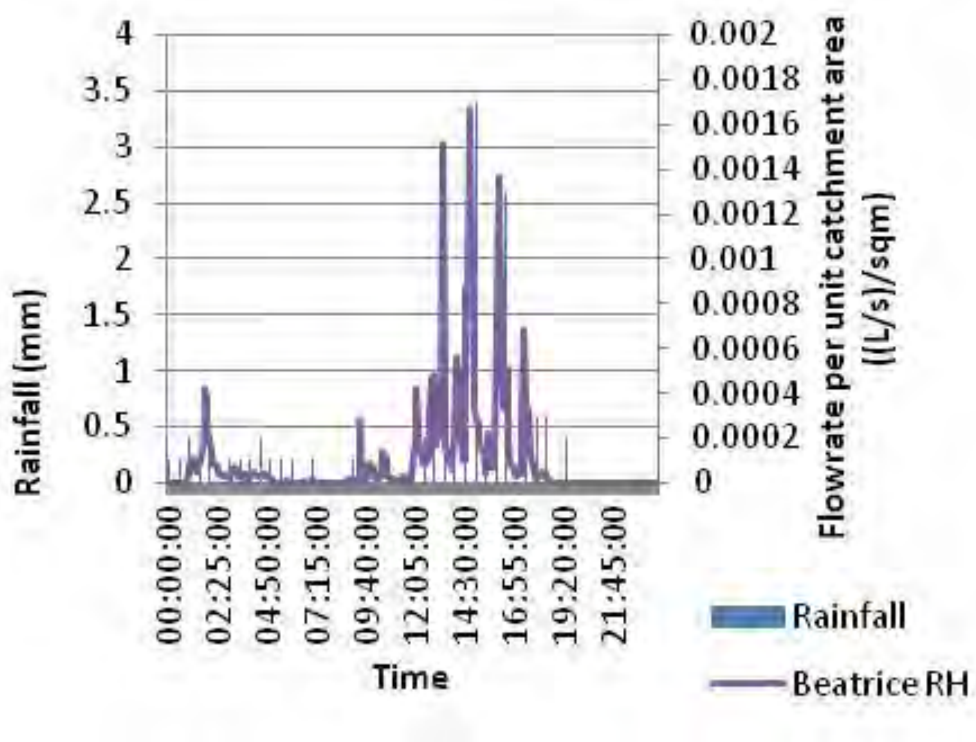
Table 19. i) Percentage reduction in peak flow and ii) delay in peak flow from green roofs compared to control roofs for the 17.6 mm rain event on the 15th April 2016 at Queen Caroline Estate, Hammersmith. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area.

i)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	38.21%	82.79%	62.42%
Beatrice RH	34.34%	81.71%	60.07%

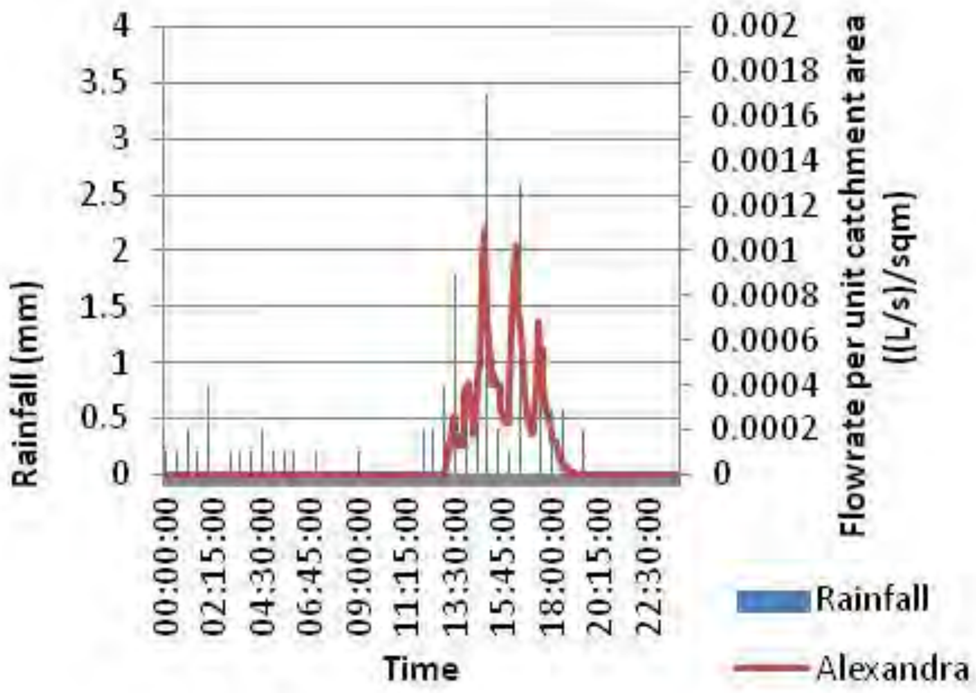
ii)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	01:05:00	01:35:00	01:05:00
Beatrice RH	00:10:00	00:40:00	00:10:00

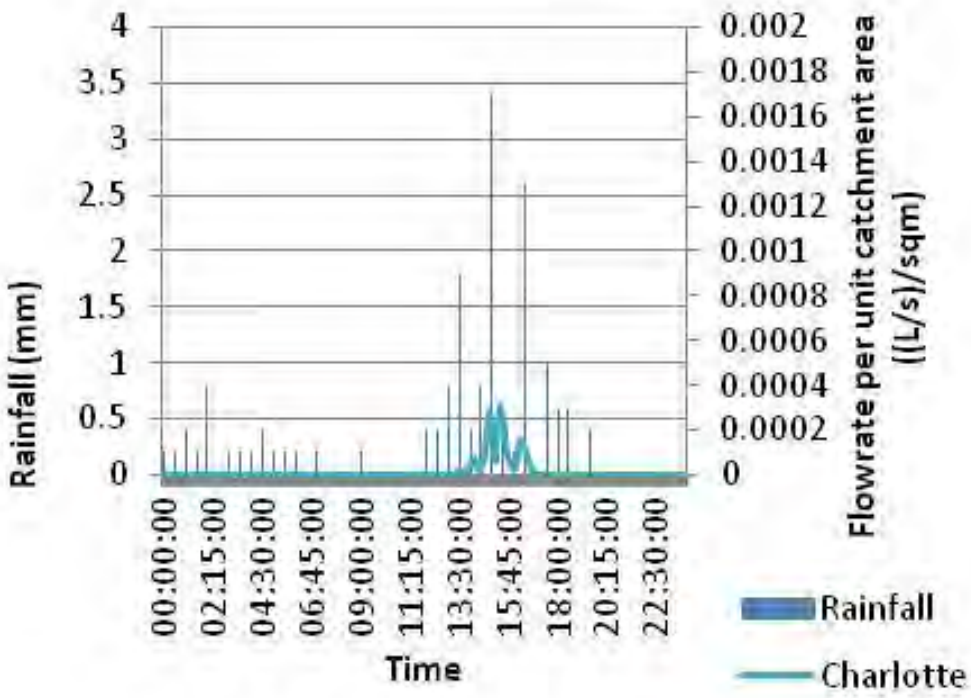

Rainfall (mm)
Flowrate per unit catchment area ((L/s)/sqm)
Time
Rainfall
Beatrice LH

i)


Rainfall (mm)
Flowrate per unit catchment area ((L/s)/sqm)
Time
Rainfall
Beatrice RH

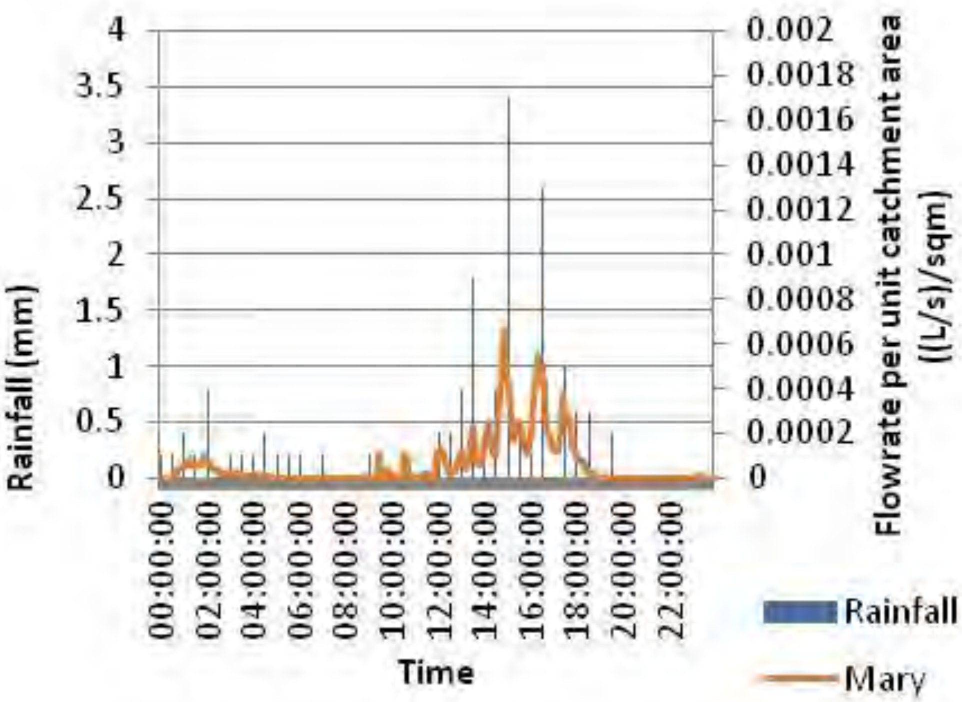
ii)


4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Alexandra

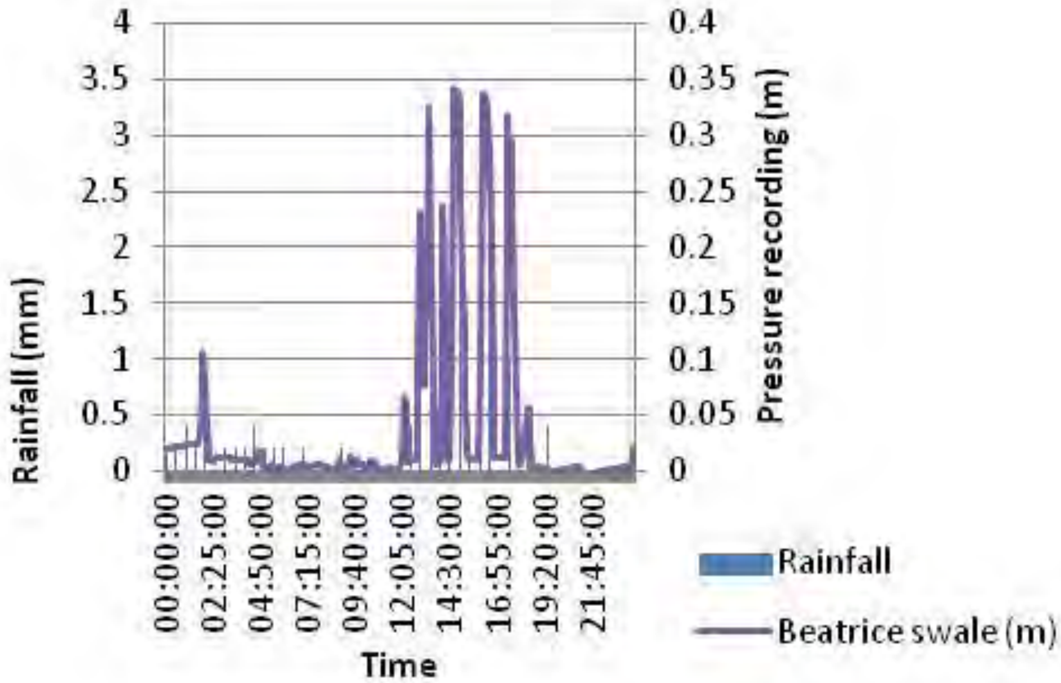

4
3.5
3
2.5
2
1.5
1
0.5
0
Rainfall (mm)
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Charlotte

iii)

iv)



v)



vi)

Figure 83. Water attenuation patterns from Queen Caroline Estate, Hammersmith, 15th April 2016. Graphs represent individual storm management infrastructure components: (i) and (ii) represent the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) represent the three pram shed green roofs at Queen Caroline Estate, and (vi) the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event. Roof flow rates were measured using a pressure sensor combined with a v-notch weir. The swale was measured using a pressure sensor beneath the swale. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area. ***N.B. It must be noted that the control roofs were pitched roofs and the catchment areas were based on the aerial view of the roof (i.e. a 2D 'vertical footprint'). Due to the pitch, the direction of rain for the rain event may have affected the volume of water recorded on the control roofs (i.e. the SE -facing pitched roofs would be expected to catch more rain from a SE wind direction rain event than a NE wind rain event). As such, the peak flows from the control roofs were likely to be a conservative estimate for all rain events other than those with wind from a SE direction.***

Data from the pressure sensor in the Beatrice swale (Figure 83 vi) also supported the evidence captured by the time-lapse cameras. The pressure sensor captured the swale reacting quickly to rainfall by recording an increase in pressure very quickly following rain (caused by water pooling above the sensor). This increase in pressure was short-lived however, with a reduction in pressure in relatively short periods following the cessation of the rain. This indicated that the swale was effectively conveying and infiltrating the stormwater, rather than the basin holding pooled water over long periods.

Rain event 11/05/2016

Figure 84 shows the prevailing weather patterns preceding the rain event in the 11th May 2016.

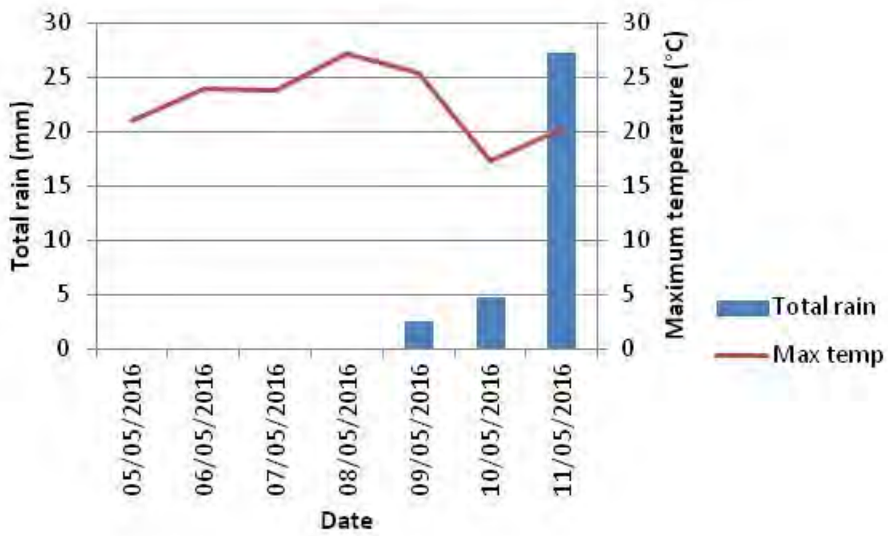


Figure 84. Prevailing weather conditions preceding one of the five largest rain events at Queen Caroline Estate, Hammersmith. Rain event was 27.2 mm on 11th May 2016.

Table 20 presents the attenuation performance of the pramshed roofs during the rain event on the 11th May 2016.

Table 20. Pramshed green roof water attenuation performance during a rain event on the 11th May 2016. Water attenuation calculated as the percentage of the total rainfall that fell on the roof held within the roof rather than being released to storm drains.

Green roof	Total rain (mm)	Catchment area (m)	Volume of rainfall in catchment area (L)	Attenuation (%)
Alexandra	9.8	22	598.4	87.57
Charlotte	9.8	32	870.4	93.29
Mary	9.8	33.25	904.4	92.22
Average				**91.03**

Figure 85 represents the water runoff from (i) and (ii) the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) the three pram shed roofs at Queen Caroline estate, and (vi) the pattern of the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event.

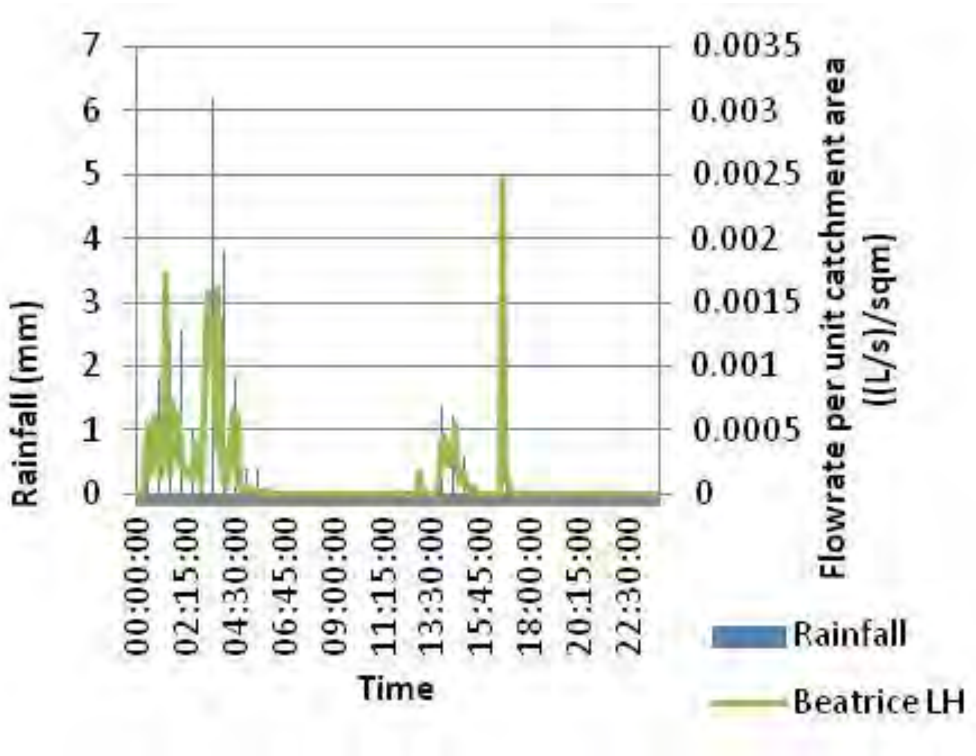
Evidence from the roof runoff monitoring was positive with substantial reductions in the peak flows from the green roofs compared to the control roofs (Table 21.i). Maximum peak flow reduction recorded was 91%. Peak flows also showed substantial evidence of delay (Table 21.ii). Reduction and delay in peak flow of storm drain systems is vital in order to avoid system overloading.

Table 21. i) Percentage reduction in peak flow and ii) delay in peak flow from green roofs compared to control roofs for the 27.2 mm rain event on the 11th May 2016 at Queen Caroline Estate, Hammersmith. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area.

i)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	80.65%	84.38%	89.02%
Beatrice RH	83.85%	86.97%	90.84%

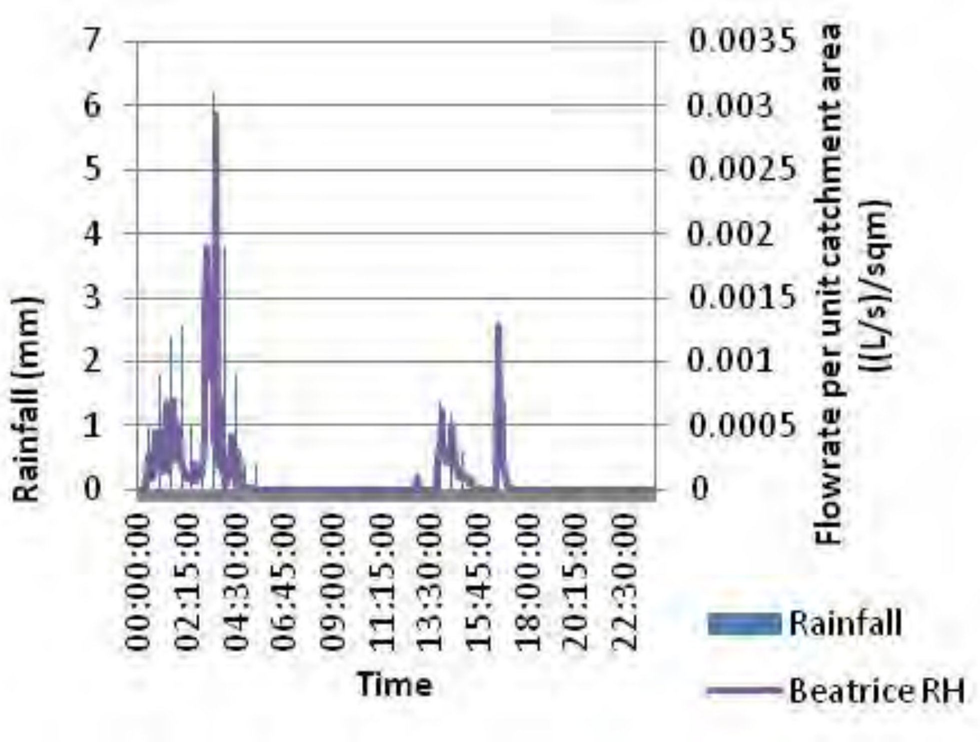
ii)	**Green roofs**		
Control roofs	**Alexandra**	**Charlotte**	**Mary**
Beatrice LH	-02:20:00*	-01:50:00*	-03:45:00*
Beatrice RH	10:55:00	11:15:00	09:20:00

**Values are negative as highest flow from Beatrice LH roof was after the earlier recorded rain event.*



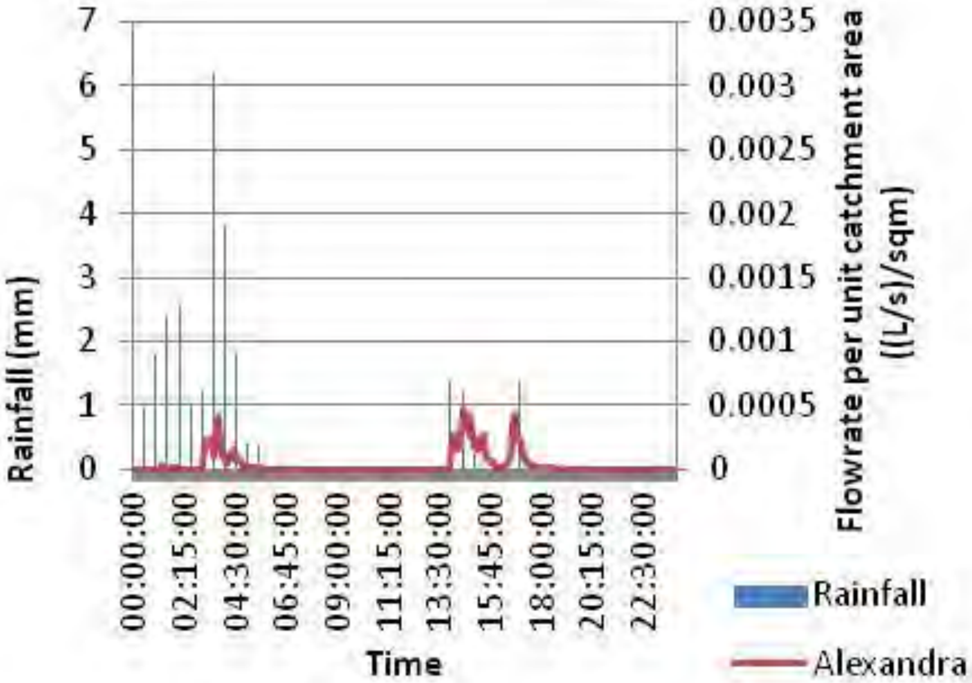
7
6
5
4
3
2
1
0
Rainfall (mm)
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Beatrice LH

i)

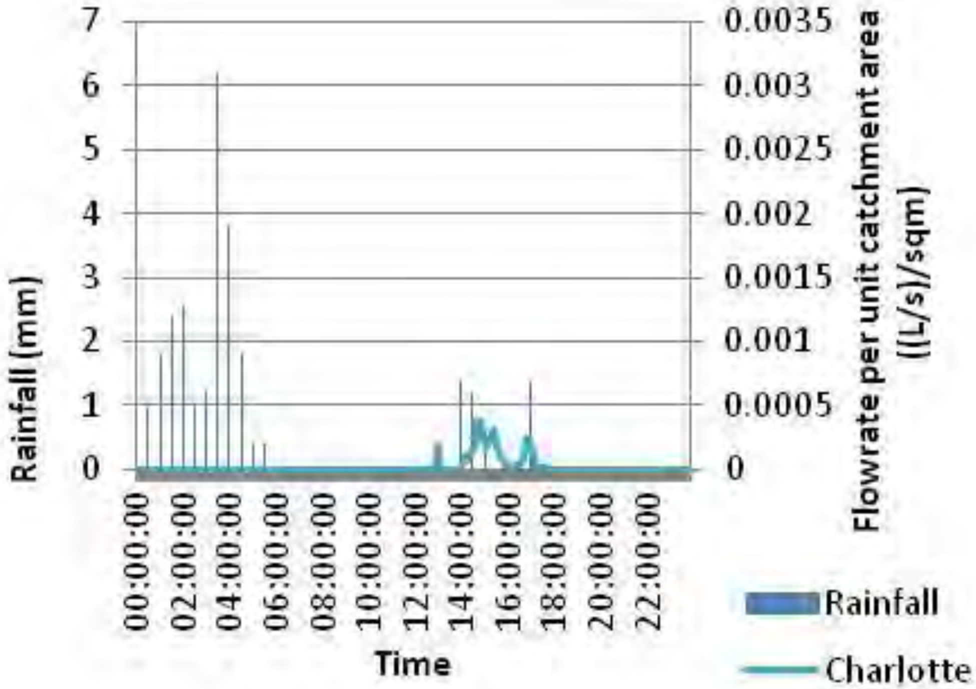


7
6
5
4
3
2
1
0
Rainfall (mm)
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Beatrice RH

ii)



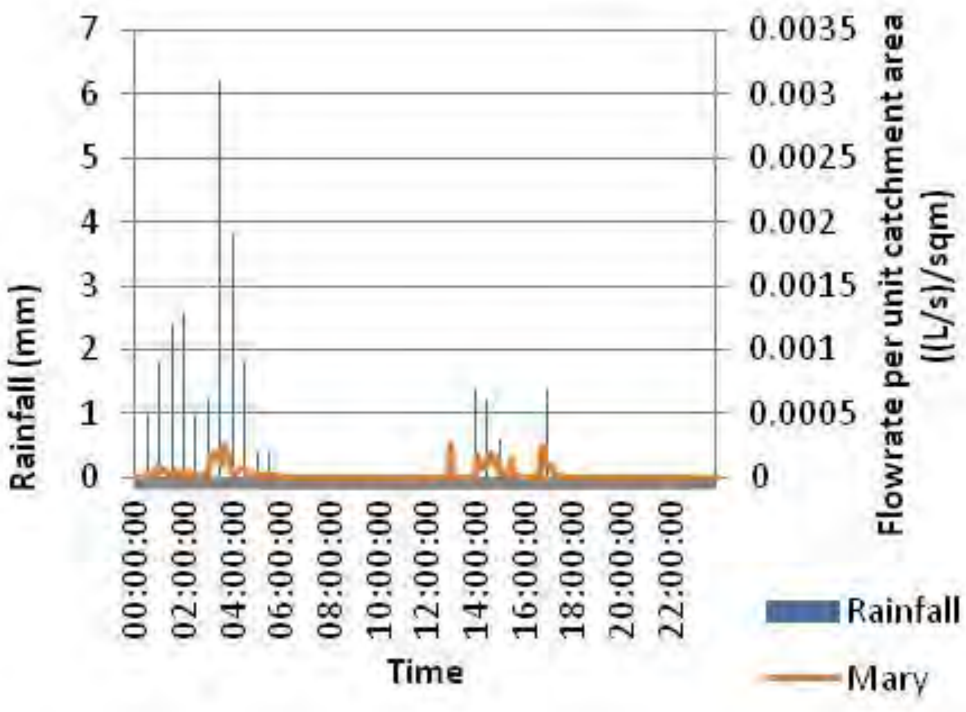
Rainfall (mm)
7
6
5
4
3
2
1
0
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:15:00
04:30:00
06:45:00
09:00:00
11:15:00
13:30:00
15:45:00
18:00:00
20:15:00
22:30:00
Time
Rainfall
Alexandra



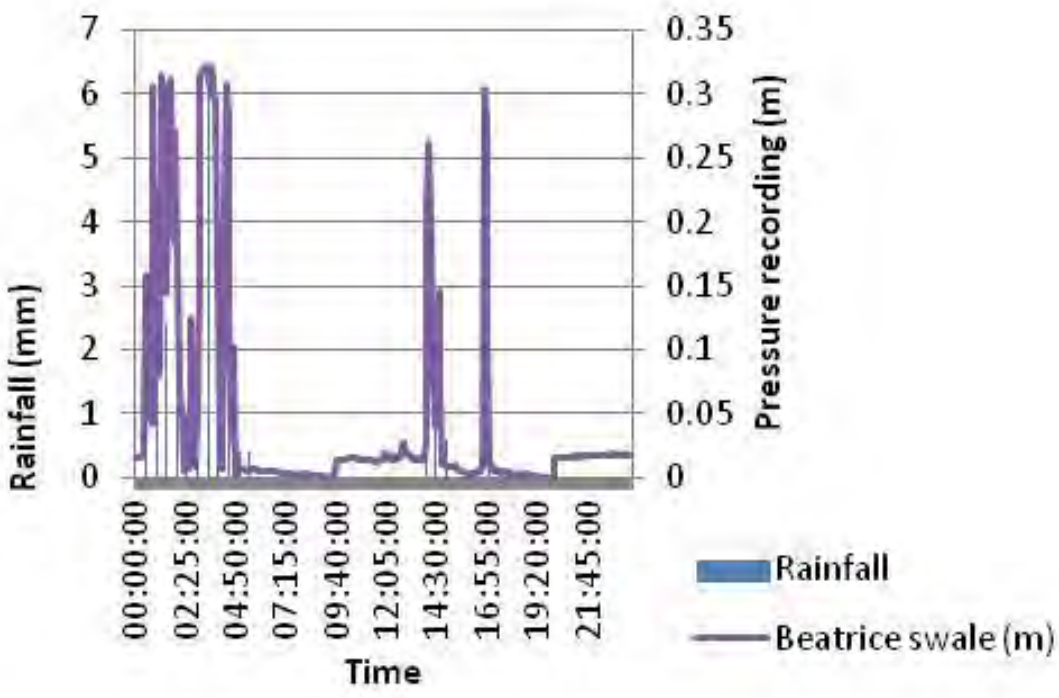
Rainfall (mm)
7
6
5
4
3
2
1
0
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Flowrate per unit catchment area ((L/s)/sqm)
00:00:00
02:00:00
04:00:00
06:00:00
08:00:00
10:00:00
12:00:00
14:00:00
16:00:00
18:00:00
20:00:00
22:00:00
Time
Rainfall
Charlotte

iii)

iv)



v)



vi)

Figure 85. Water attenuation patterns from Queen Caroline Estate, Hammersmith, 11th May 2016. Graphs represent individual storm management infrastructure components: (i) and (ii) represent the two control roof areas on Beatrice House (with no green roof), (iii), (iv) and (v) represent the three pram shed green roofs at Queen Caroline Estate, and (vi) the pressure sensor beneath Beatrice swale compared to rainfall patterns for the same rain event. Roof flow rates were measured using a pressure sensor combined with a v-notch weir. The swale was measured using a pressure sensor beneath the swale. All run off flow rates have been adjusted to a rate per metre square to compensate for difference in catchment area. ***N.B. It must be noted that the control roofs were pitched roofs and the catchment areas were based on the aerial view of the roof (i.e. a 2D 'vertical footprint'). Due to the pitch, the direction of rain for the rain event may have affected the volume of water recorded on the control roofs (i.e. the SE -facing pitched roofs would be expected to catch more rain from a SE wind direction rain event than a NE wind rain event). As such, the peak flows from the control roofs were likely to be a conservative estimate for all rain events other than those with wind from a SE direction.***

Data from the pressure sensor in the Beatrice swale (Figure 85 vi) also supported the evidence captured by the time-lapse cameras. The pressure sensor captured the swale reacting quickly to rainfall by recording an increase in pressure very quickly following rain (caused by water pooling above the sensor). This increase in pressure was short-lived however, with a reduction in pressure in relatively short periods following the cessation of the rain. This indicated that the swale was effectively conveying and infiltrating the stormwater, rather than the basin holding pooled water over long periods.

3. 8 Total volumes attenuated

Based on the data captured from the weather stations, the time-lapse cameras, the v-notch sensors and the pressure sensor, it is possible to calculate an approximate volume of rain that has been diverted from otherwise entering the storm drain system by the interventions installed across the estates during this initial monitoring period. This estimation was carried out by calculating the total rainfall that had fallen on each of the estates during the period 16th October 2015 to 31st May 2016:

- Richard Knight House = 283.2 mm

- Queen Caroline Estate = 245.8 mm

The total catchment areas of the SuDS interventions at each site:

- Richard Knight House = 258.5 m^2 ground level SuDS and 244.5 m^2 of green roofs

- Queen Caroline Estate = 1305.5 m^2 ground level SuDS and 129.75 m^2 of green roofs

Then multiplying the rainfall by the area of the SuDS interventions based on:

- the evidence that the capacity of the ground level SuDS was never exceeded (and they therefore diverted 100% of the rainfall away from the storm drain system);

and

- that green roofs absorbed an average of 84.15% of rainfall landing on them (a conservative estimate based on the average attenuation for the five largest storm events analysed thus far).

This provided a total value of <u>479204 Litres</u> of rainfall retained and thus diverted away from the storm drain system by the interventions during the initial monitoring period.

N.B. it must be noted that this is a rough estimate based on monitoring thus far and several caveats must be attached to this value. Firstly, values for the green roofs were based on the performance during the largest rain events and their performance during smaller events (that made up the majority of the events) would be expected to be better than the 84.15% threshold. Secondly, values for the Richard Knight House green roof used the same retention values as those for the pram shed roofs, although it is likely that the Richard Knight House green roof would have better retention potential (monitoring has not yet been possible due to lack of access to downpipes). The estimate also assumes that all rainfall falling within the catchment areas had been diverted to the SuDS features (and thus that all guttering was functioning correctly).

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Appendix A

A1 *Beatrice House swale performance during 18.2 mm rain event on 11th January 2016*


Ltl Acorn
039°F 004°C
01/11/2016 01:29:03


Ltl Acorn
039°F 004°C
01/11/2016 01:41:38


Ltl Acorn
039°F
004°C
01/11/2016 01:54:12


Ltl Acorn
039°F
004°C
01/11/2016 02:06:46


Ltl Acorn
039°F
004°C
01/11/2016 02:19:20


Ltl Acorn
039°F
004°C
01/11/2016 02:31:55


Ltl Acorn
039°F
004°C
01/11/2016 02:44:29


Ltl Acorn
039°F
004°C
01/11/2016 02:57:04

Ltl Acorn ☽ 039°F 004°C 01/11/2016 03:09:38

Ltl Acorn ☽ 041°F 005°C 01/11/2016 03:22:13

A2 - Alexander House swale (FPC1) performance during 18.2 mm rain event on 11th January 2016


Ltl Acorn
039°F
004°C
01/11/2016 01:30:20


Ltl Acorn
039°F
004°C
01/11/2016 01:43:05


Ltl Acorn
039°F
004°C
01/11/2016 01:55:50


Ltl Acorn
039°F
004°C
01/11/2016 02:08:35


Ltl Acorn
039°F
004°C
01/11/2016 02:21:20


Ltl Acorn
039°F
004°C
01/11/2016 02:34:05


Ltl Acorn
039°F
004°C
01/11/2016 02:46:51


Ltl Acorn
039°F
004°C
01/11/2016 02:59:36


Ltl Acorn
041°F
005°C
01/11/2016 03:12:22


Ltl Acorn
041°F
005°C
01/11/2016 03:25:07

A3 - Community Hall and Sofia House basin (FPC2) performance during 18.2 mm rain event on 11th January 2016


Ltl Acorn
041°F
005°C
01/11/2016 01:27:49


Ltl Acorn
041°F
005°C
01/11/2016 01:40:13


Ltl Acorn
041°F
005°C
01/11/2016 01:52:37


Ltl Acorn
041°F
005°C
01/11/2016 02:05:01


Ltl Acorn
041°F
005°C
01/11/2016 02:17:25


Ltl Acorn
041°F
005°C
01/11/2016 02:29:49


Ltl Acorn
041°F
005°C
01/11/2016 02:42:14


Ltl Acorn
041°F
005°C
01/11/2016 02:54:38


Ltl Acorn
041°F
005°C
01/11/2016 03:07:01


Ltl Acorn
041°F
005°C
01/11/2016 03:19:26

A4 - Adella House grass basin and Adella House stoney basin (FPC3) performance during 18.2 mm rain event on 11th January 2016


Ltl Acorn
042°F
006°C
01/11/2016 01:27:32


Ltl Acorn
042°F
006°C
01/11/2016 01:39:52


Ltl Acorn
042°F
006°C
01/11/2016 01:52:14


Ltl Acorn
042°F
006°C
01/11/2016 02:04:35


Ltl Acorn
041°F
005°C
01/11/2016 02:16:57


Ltl Acorn
041°F
005°C
01/11/2016 02:29:18


Ltl Acorn
041°F
005°C
01/11/2016 02:41:39


Ltl Acorn
041°F
005°C
01/11/2016 02:54:01


Ltl Acorn
042°F
006°C
01/11/2016 03:06:22


Ltl Acorn
042°F
006°C
01/11/2016 03:18:44

A5 *Richard Knight House rain garden performance during 11.6 mm rain event on 11th January 2016*


Ltl Acorn
039°F
004°C
01/11/2016 01:31:13


Ltl Acorn
039°F
004°C
01/11/2016 01:44:06

Ltl Acorn ☽ 039°F 004°C 01/11/2016 01:56:59

Ltl Acorn ☽ 039°F 004°C 01/11/2016 02:09:52


Ltl Acorn
039°F
004°C
01/11/2016 02:22:45


Ltl Acorn
039°F
004°C
01/11/2016 02:35:38