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Water attenuation performance of the Museum of London green roof

TURAS TRANSITIONING TOWARDS URBAN RESILIENCE AND SUSTAINABILITY

Water attenuation performance of the Museum of London green roof

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Published by the University of East London

4-6 University Way

Docklands

London

E16 2RD

Cover photo: Biodiverse green roofs installed at the Museum of London © Stuart Connop

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Printed in Great Britain at the University of East London, Docklands, London

Connop, S., Clough, J, Borland, T. and Newport, D.. 2015. Water attenuation performance of the Museum of London green roof. London: University of East London.

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1. Introduction

Global warming induced climate change is predicted to cause an increase in the frequency and intensity of rainfall events (Atkins et al. 1999, DOE 1996, UKCIP 2001). This brings new challenges for fluvial and pluvial storm water management. In urban areas, old and new technologies are being combined to generate sustainable urban drainage systems (SuDs) and water sensitive design in order to mitigate storm water runoff and reduce the occurrence of flooding.

One such technology is the use of green roofs as source control for storm water (Mander and Teemusk 2007). Implementation of green roofs in urban areas is becoming increasingly popular in the United Kingdom and globally. London has its own green roof policy and guidance (Mayor of London 2008), and aspirations in terms of increasing urban green infrastructure, particularly green roofs in the highest density urban areas (Mayor of London 2014).

Green roofs can provide many benefits in urban areas in addition to storm water attenuation. An increasing body of research has demonstrated that green roofs can increase the lifespan of roof construction materials including water proofing, reduce a building's energy consumption, reduce the Urban Heat Island Effect (UHIE), increase biodiversity, improve air and water quality and provide sound insulation (Takakura et al. 1998; Wong et al. 2003; Mentens et al. 2006; Lundholm et al. 2010; European Union 2011; Nagase & Dunnett 2012; Speak et al. 2012; TCPA 2012).

2. Project background

At over 1,500 km² and with an estimated 8 million residents, London is one of the world's major cities. Built on old models for high density living, London suffers from numerous environmental problems. Climate change is exacerbating many of these problems, the impact of which are predicted to become increasingly severe over the next 100 years.

An example of the environmental problems linked to urbanisation and climate change in London is the storm water induced flooding, particularly in areas dominated by hard impervious surfaces. Due to the limited capacity of London's existing combined sewerage system and the increased intensity of storm events, stormwater management drainage systems can become overloaded. This results in them backing up and causing localised storm water flooding issues and causing combined sewage overflow events where the combined sewerage system is overwhelmed and forced to overflow into the River Thames and its tributaries (DEFRA 2015).

There is a regional plan to create a new sewerage system to cope with the increasing demand put on the combined sewerage system - the Thames Tideway Tunnel (Tideway 2015). Whilst this solution is designed to solve much of the current storm water overloading issues, there is still a need to investigate the potential that small scale Sustainable Urban Drainage System (SUDS) interventions can make to localised surface water flooding problems and regional reductions in storm water entering the combined sewerage system. Such investigation is even more important when the additional ecosystem service benefits that green infrastructure can provide to local communities when installed as SUDS is taken into consideration (Woods Ballard et al. 2015).

Part of a potential SUDS management train solution to this problem is the incorporation of green roofs on new build developments and the identification of opportunities for retrofitting green roofs on existing buildings to intercept storm events and reduce the occurrence of flooding. Green roofs are known to alleviate storm water flooding issues by significantly reducing both peak flow rates and total runoff volume of rainwater from the roofs compared to a comparable conventional grey roof. They do this by storing rainwater in the substrate, drainage layer and vegetation components of the green roof and by releasing the stored rainwater back into the atmosphere through evapotranspiration.

To assess the potential for green roofs to mitigate these problems, a knowledge exchange research programme was established between the Greater London Authority (GLA) Drain London scheme and the Museum of London. A series of green roofs were installed at the Museum to showcase the potential for green roof implementation at a centre for public dissemination for London history, culture and London's future. The knowledge exchange programme comprised the monitoring of one of these green roofs on the museum. The green roof was installed next to a control area to enable assessment of its efficacy in comparison to the existing grey roof systems. Due to the unusual nature of the monitoring required, the Sustainability Research Institute (SRI) of the University of East London was commissioned by the Museum of London to monitor the rainfall runoff from the green and control roofs to compare the relative performances of the green and conventional grey roofs.

The following report details the findings of the study period (June 2014 to May 2015):

3. Project description

As part of a sustainability initiative at the Museum of London, London Wall (N51:31:05; W0:05:47), a series of green roofs were installed across the Museum's roof during a programme of waterproofing renewal. Supported by the Greater London Authority's Drain London programme, this install included a range of roofs from biodiverse systems with topographical interest to wildflower and sedum mat systems. The complexity of roof systems at the Museum of London meant that a variety of green roofs could be installed in terms of scale, levels, shading and aspect, thus creating an important urban resource for a range of biodiversity supported by the green roof habitat complexity.

As part of this programme Bauder were commissioned to design and install an extensive green roof at the northwest corner of the Museum of London roof system. The roof area was divided in half by an impermeable barrier feature of the roof creating two separate hydrological units. This area provided an ideal location to enable rainfall run off measurements to compare the performance of the newly installed green roof with an existing control roof.

Figure 1 shows a plan of the roof area in which the monitoring was proposed to take place and Figure 2 shows an image of the area before green roof installation.

The green roof was installed in 2011 and allowed to establish before monitoring began in 2014. Figure 3 shows an image of the green roof at the time the monitoring was initiated. The green roof area (including a gravel margin) was 64.22 m^2. The control roof area was 42.18 m^2.

The green roof was designed following German FLL green roof design guidelines. It comprised of a geotextile filter and root barrier to protect the roof waterproof membrane, a 20 mm depth drainage layer, a 60 mm substrate layer, and a 28 mm sedum vegetation mat with an additional integral moisture retention fleece (Figure 4).

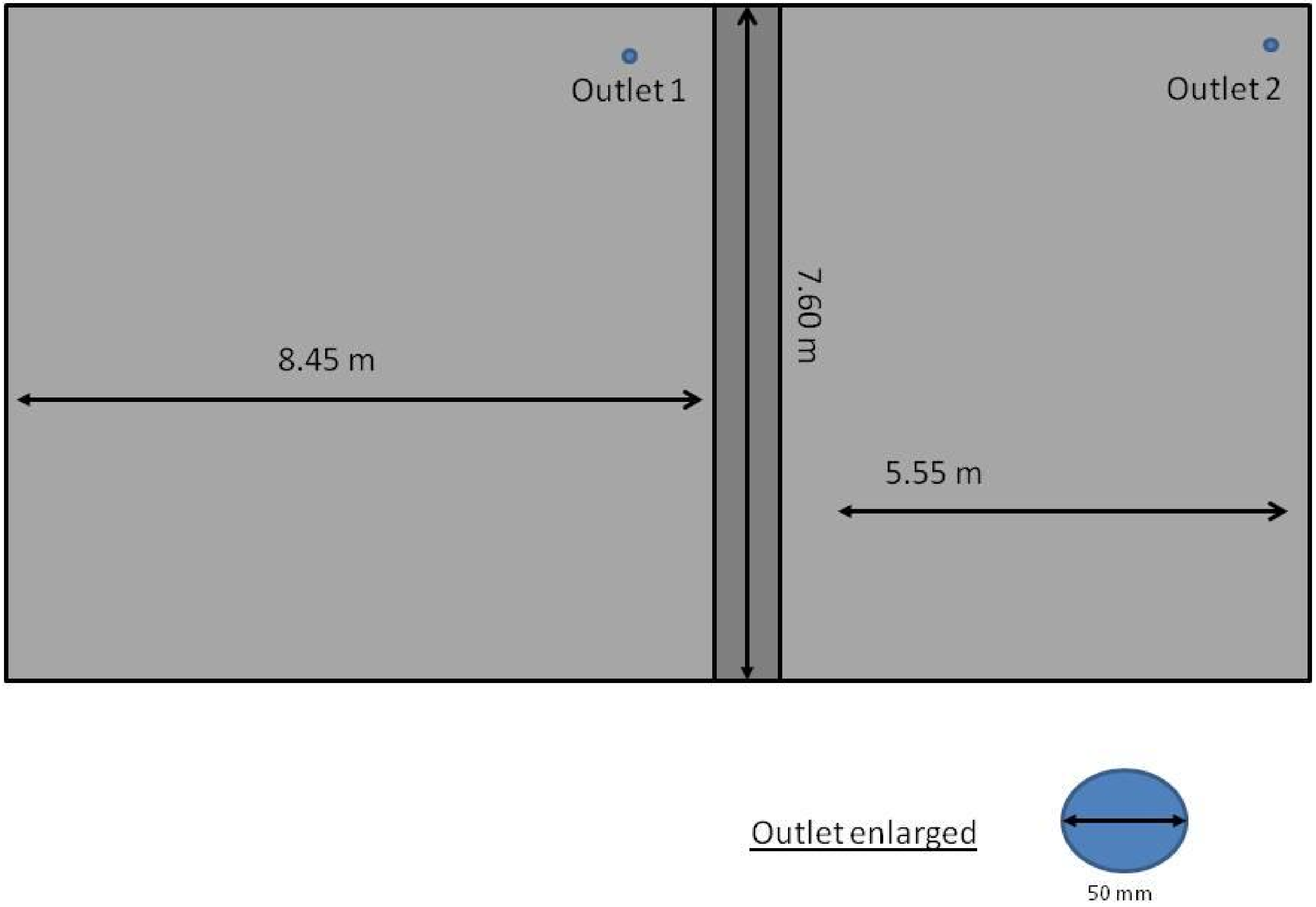


Figure 1. Plan of the roof area where the green roof to be monitored was installed at the Museum of London.

Figure 2. Area of the Museum of London roof to be greened.

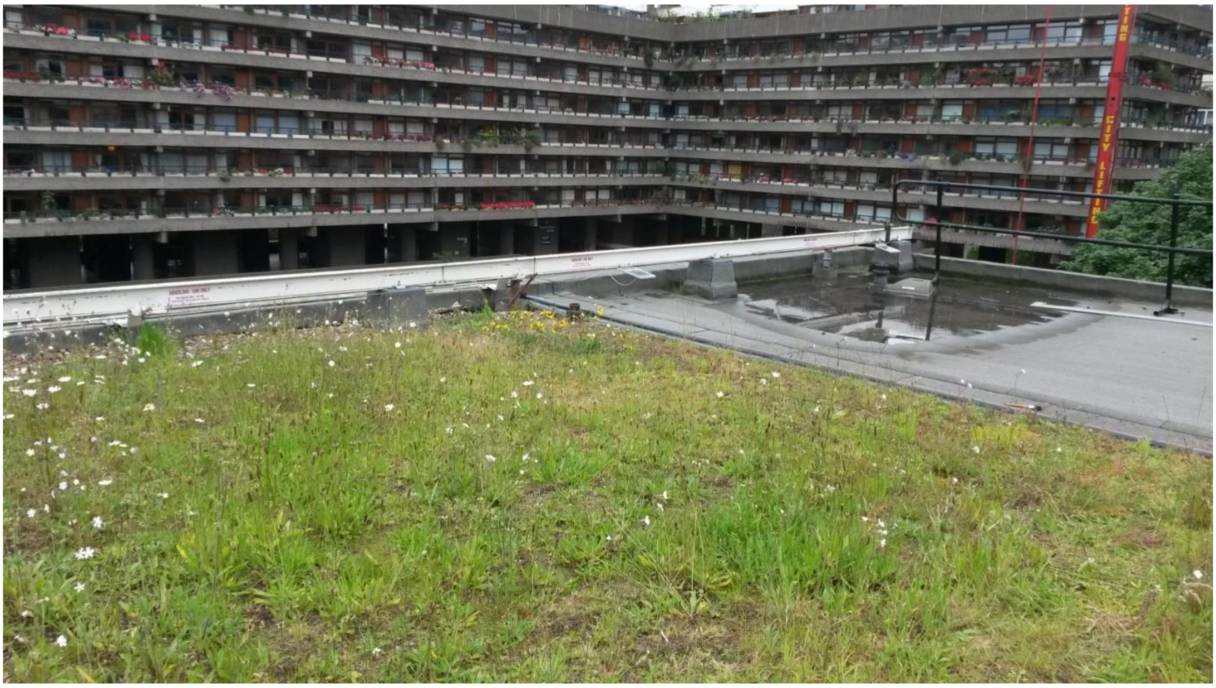


Figure 3. Installed green roof on the northwest corner of the Museum of London roof.

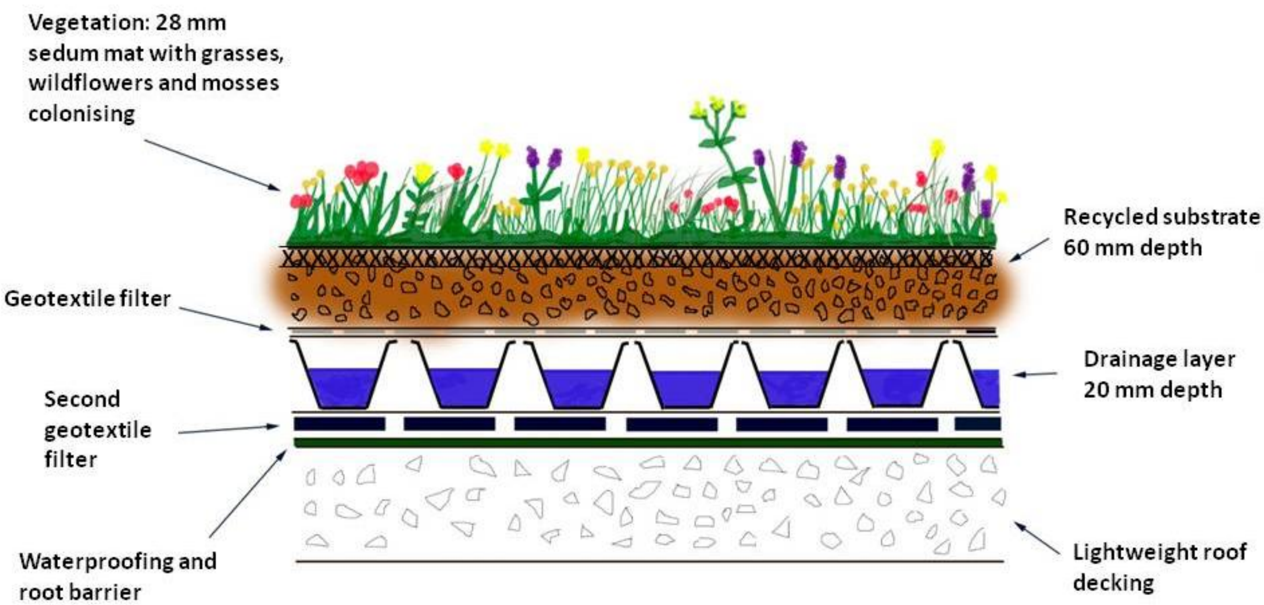


Figure 4. Plan of Museum of London green roof profile.

In order to monitor the water attenuation performance of the green and control roofs it was necessary to quantify the volume and rate of rain falling onto the roof and the volume and rate of rainfall runoff entering the storm drain system of the Museum. In order to capture the rainfall falling on the roof a Vantage weather station was attached to the roof edge protection railings. The weather station provided data on rainfall volume and maximum rate during 30 minute periods. It also recorded additional prevailing weather patterns on the roof such as temperature and wind speed and direction. The weather station transmitted data to a desktop datalogger within the Museum to record continuous weather data for the entire monitoring period.

The storm drain system of the Museum was internal to the building. As such it was difficult to access the downpipes to install in-line flow metres or tipping buckets at the bottom of downpipes as has been done on similar projects, both due to access issues and insurance issues related to the Museum's collections. This meant that monitoring had to be carried out at roof level at the entrance to the storm drain downpipes. At the time of the initiation of the green roof monitoring programme no off-the-shelf monitoring solution existed, so a prototype system had to be employed.

Prototype gauges

At the time of the initiation of this monitoring programme, the University of East London's Sustainability Research Institute (SRI) were developing in-line rainfall runoff gauges for installation in the downpipes of green roofs to monitor coarse rainfall runoff patterns at a London Underground depot. Due to logistical issues related to the depot, it was not possible to access the roof downpipes or utilise the depot's power supplies. As such, it was necessary for the SRI to develop an entirely novel gauge that could be inserted into the top of downpipes draining the green and control roof areas. It was also necessary to develop a solar panel system to provide power to these gauges for long periods of continuous active monitoring with long spells between site visits.

To meet the project specifications, prototype V-notch capacitance sensor monitoring devices were developed, tested and calibrated in the laboratory and then installed in the opening of downpipes of each green and control roof respectively (Figure 5). The v-notch systems limited the rate of flow from the roof gutter systems. The gauges were calibrated so that they could detect changes in the height of the water in the gutter systems and this could be converted to a flow rate of rain water leaving each roof.

Figure 5. V-notch capacitance sensor monitoring device in-situ on the London Underground depot at Ruislip, London.

Although several reliability issues were identified during the 18 months of monitoring on the London Underground depot, numerous rain events were captured and comparative analysis of the water attenuation performance of the green and grey roofs was possible (Connop et al. 2015). Due to the potential benefit of these gauges for projects where only roof level monitoring is possible, a phase 2 prototype v-notch system was developed for the Museum of London. The phase 2 design aimed to reduce some of the reliability issues that had affected the London Underground project.

Two V-notch capacitance sensors were installed at the opening of the downpipes of the green and control roofs on the Museum roof in May 2014 (Figure 6). In addition to the two v-notch rainfall runoff gauges, barriers were installed across the divided sections of the roof to ensure that the only rainfall runoff being measured came from the hydrological catchments of the green and grey roof areas (Figure 7).

For the purpose of presenting results within this report, the devices will be numbered 1 and 2. These numbers refer to rainfall runoff gauges monitoring the following roofs:

1 - Green roof;

2 - Control grey roof.

Figure 6. V-notch capacitance sensor monitoring device. (Top) V-notch installation; (Bottom) Capacitance sensor stilling tube attached to v-notch.

Figure 7. Barrier dividing the green roof catchment from the control roof catchment.

4. Results

The prototype gauges were calibrated and installed in May 2014 to provide continuous runoff rate data. The gauges were in-situ on the roofs until June 2015. Data for numerous rain events was obtained and the results are presented below. In addition to the rain gauges, the weather station installed at the depot captured a continuous record of rain events:

Weather station data

The Vantage weather station was positioned on the edge protection of the control roof approximately 5 metres from the number 2 runoff gauge. As such, the weather station data provided an accurate representation of the prevailing weather conditions experienced on the monitored roofs. Figure 8 represents an example of the weather station data for the June 2014 monitoring period.

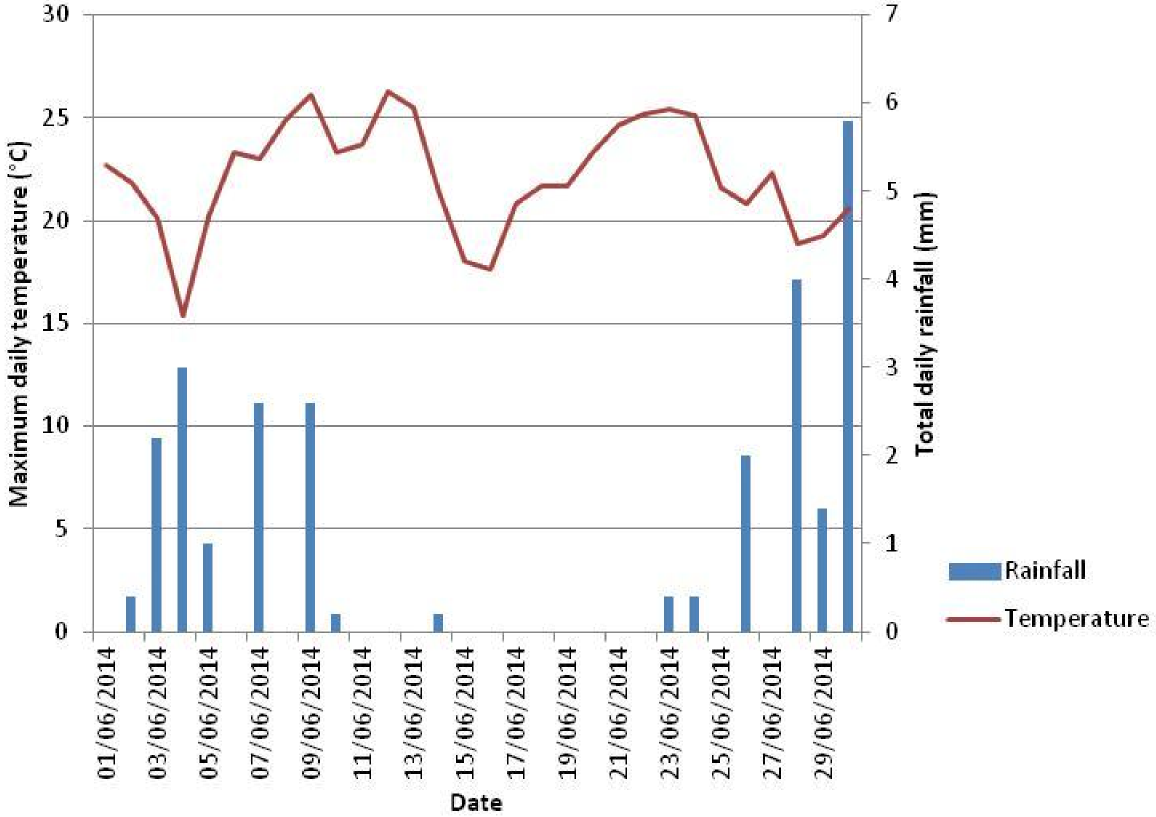


Figure 8. **Weather station data from the Museum of London.** Data generated by Vantage Vue weather station and data logger for the period June 2014.

For each rain event during the survey period, the weather station was able to provide information on the duration, maximum intensity and volume of the event. This data is presented for each of the rain events detailed below.

4.1 Rain gauge data

In developed catchments typical of urbanized areas, swathes of hard impermeable surfaces cause large volumes of rainwater to rapidly transfer into storm drain systems following major rain events. This can lead to surface water flooding. Such incidences are becoming increasingly common in large cities where intense rain events can cause significant social and economic disruption. This can be exacerbated further during spells of very hot dry weather when ground level green infrastructure can becoming extremely dry and compacted and thus perform hydrologically like hard surfaces rather than soft catchments (Figure 9). Climate change predictions indicate that such weather patterns will become more frequent in future and the impacts of these will be severe. Such impacts were reported in Central London during the green roof monitoring period including periods of very heavy rain on the 28th July 2014 (ITV 2014), with 43 mm of rain falling in a two hour period, and the 10th

August 2014 (nw3weather.co.uk) with 23.3 mm of rain falling in a one hour period at a maximum rate of 90 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).

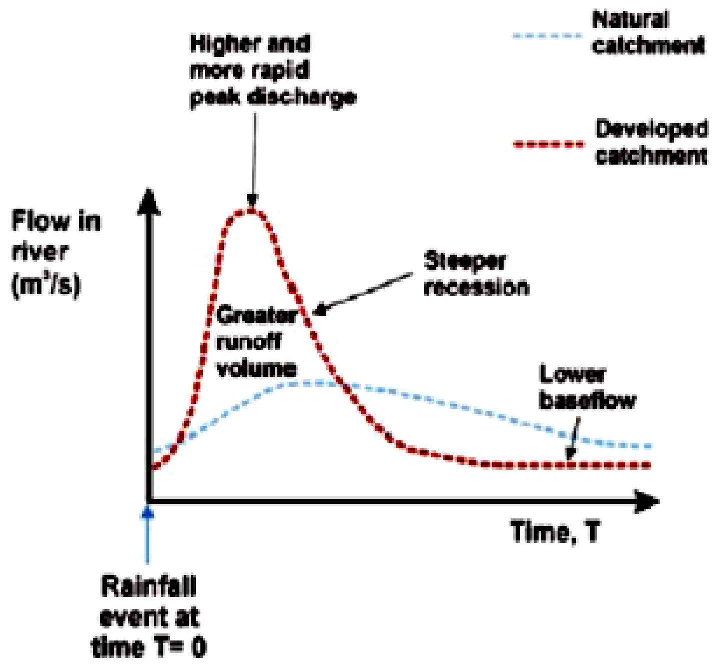


Figure 9. **Natural and developed catchment hydrograph.** Hydrograph demonstrating the differences in peak flow, run off rates and run off volumes between developed catchments (with large areas of hard surfaces) and natural catchments (green infrastructure) (Woods Ballard et al 2007).

The key aim of the use of SuDs components, and particularly green infrastructure SuDs components, is to mimic the hydrological runoff patterns more typical of natural catchments where plants and substrates intercept and delay the runoff of rain water to such an extent that peak run off rates are reduced and overall run off volumes are more diffuse over longer time periods (Figure 9). Central to the assessment of the efficacy of such SuDs components is an assessment of their ability to reduce and delay the peak flows leaving the roof system by the downpipes following large rainfall events. As, in doing so, the SuDs components reduce the probability that the existing storm drainage system would get overloaded and back up causing flooding and downtime at the depot.

With these key aims in mind, the prototype rain gauges installed were designed to capture a coarse comparison of patterns of peak flows leaving the green and control roofs following rain events. Due to the necessity of using v-notch systems at the entrance to the downpipes to achieve this, accurate quantification of precise runoff volumes at very low flow rates was not possible. This was due to the reduced accuracy of flow rate quantification at the very bottom of the v-notch range using a capacitance method. Similarly to natural catchments, green roofs can release excess rainwater very slowly over long periods of time following heavy rainfall events, this meant that for the green roof, much of the flow from the roof was within the lowest range of the v-notch gauges where flow rate could not be captured accurately. This lack of accuracy of flow rates at very low flows meant that precise measurements of total volumes flowing from the green roof during an extended period following a single rain event were not reliable within this study.

In addition to this issue related to low flow rates, prolonged pooling of water around the base of the gauges caused additional unforeseen problems. Whilst this was not a significant problem for the green roof gauge due to the small area of pooled water between the green roof and the outlet (see Figure 6), the control roof area pooled a substantial area of water prior to it reaching the outlet point (presumably due to sagging of the roof materials over time (see Figure 3). Raising the height of the outlet using the v-notch exacerbated this effect and it meant that the gauge sat in pooled water for long periods. This affected both the pattern of runoff from the roof and also led to unexpected changes in the baseline level readings (i.e. 0 mL/m^2 flow rate) for the gauges. Nevertheless, the gauges were designed to capture raw capacitance sensor data in addition to processed calibrated data. This meant that it was possible to post-process raw data to ascertain baseline levels (zero flow rate levels) by careful analysis of the raw data recorded by each gauge to identify the baseline at the time of pooling. Whilst this added an additional level of complication preventing the precise measurement of overall volumes at very low flow rates, it would not be expected to substantially affect the results of the gauges during peak flow events when the gauges were operating nearer to their maxima.

Due to these issues related to prolonged low flows, pooling and the focus of the study being on the prevention of storm drain overloading through the performance of the roofs in relation to reducing peak flows, the focus of the analyses within this report is on peak flow events. Results are thus presented for a series of rain events throughout the study period each represented by a graph and data showing:

i) Rainfall timing, intensity and volume;
ii) Differences in peak flow intensity and timing between the control grey roof and the green roof treatment;
iii) Percentage reduction in peak flow for the green roof system compared to the grey roof control.

Whilst it was unfortunate that this study could not also quantify precise total water storage by the green roof, this was a consequence of the set-up of the study site limiting the type of gauge that could be installed.

Data presented below represents relative comparisons of peak flow (maximum flow rate recorded) from grey roof control and green roof. Data is presented in terms of:

- *Relative peak flow reduction (%)* - this represents the reduction in flow rate between the control and green roof at the time of the peak flow from the control roof;
- *Absolute peak flow reduction (%)* - this represents the reduction in peak flow between the control roof and green roof for the peak flow recorded from each roof type for each rain event peak regardless of timing;
- *Delay in peak flow (hrs)* - this represents the delay between the time the peak flow was recorded from the control roof and from the green roof. Delay was recorded in terms of 30 minute periods as this was the format of the data generated by the weather station.

Peaks are separated into the first peak following a substantial rain event then subsequent peaks following soon after the first peak over the course of a 24 hour period. This was done to assess the difference in performance between first flush and subsequent rain events. Data from the green and control roofs has been standardised due to the different catchment areas of the green and control roofs. For some of the rain events presented no data was available for the control roof system due to gauge malfunction or v-notch blockage. When this was the case, this information was detailed in the rain event description. Data has also been divided between summer performance and winter performance due to the substantial effect that seasonality can have on green infrastructure SuDs components. Summer rain events were defined as those recorded from mid-spring to mid-autumn (April to September). Winter rain events were defined as those recorded from mid-autumn to mid-spring (October - March).

All events over 2 mm for which data was available were analysed. The five largest events for summer and winter are presented in the results section. The remaining events are presented in Appendices 1 and 2. All events were analysed to calculate peak reduction ranges and lag times. As the rain gauges logged instantaneously but the weather station data was logged at the end of each half hour period, data for the rain gauges was summed to the same half hour intervals as the weather station data to allow easy comparison.

4.2 Summer rain events

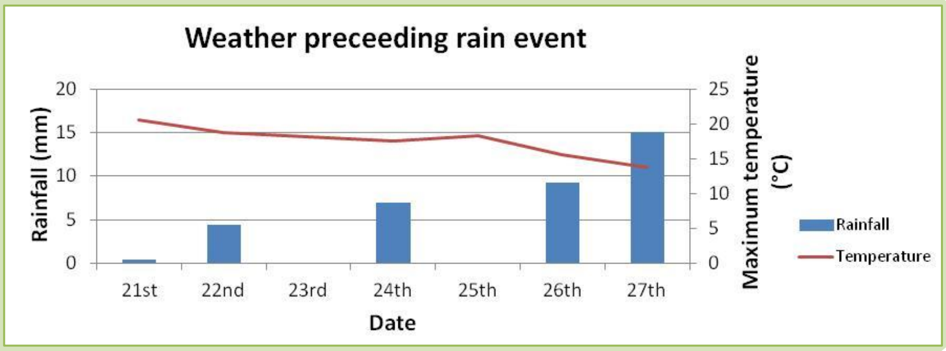
Key to the assessment of green roof performance as SuDs components is their performance under heavy rainfall conditions following periods of hot dry weather. Not only is this the time that green roofs should perform at their maximum potential (as evapotranspiration during the dry spell should ensure that the green roofs are at their maximum storage capacity), as discussed previously, such rain events are increasing in frequency and intensity and are known to cause significant disruption in urban areas due to ground level green infrastructure becoming extremely dry and compacted, leading to flash floods and social-economic impacts. The five largest rain events during the summer survey periods are presented in the below Figures (Figures 10 to 14). Summer events are defined as those occurring between April and September.

Rain event: 27th May 2014

Rain volume: 15 mm

Rain intensity: 19.2 mm/hr

Max temp: 13.7 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	66%	72%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	66%	68%

Delay in peak flow (hrs):

	Peak 1	**Peak2**
Green roof:	0	0.5

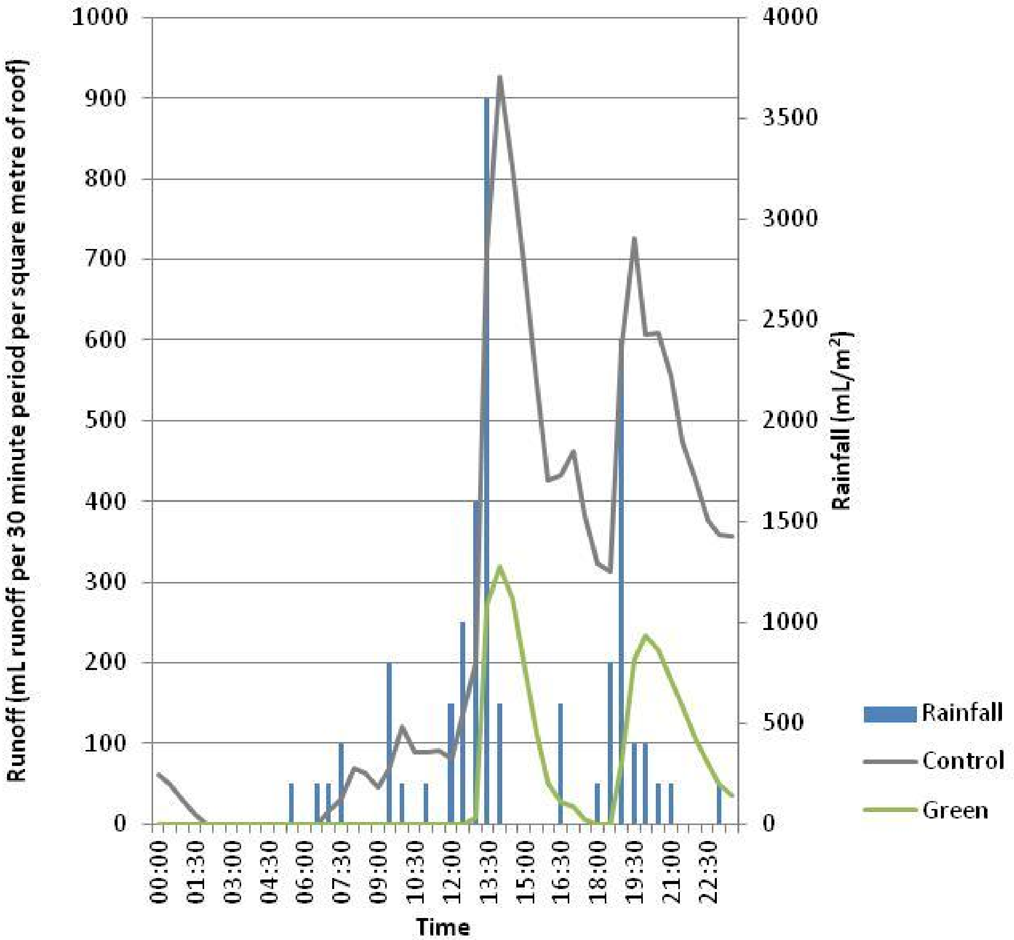


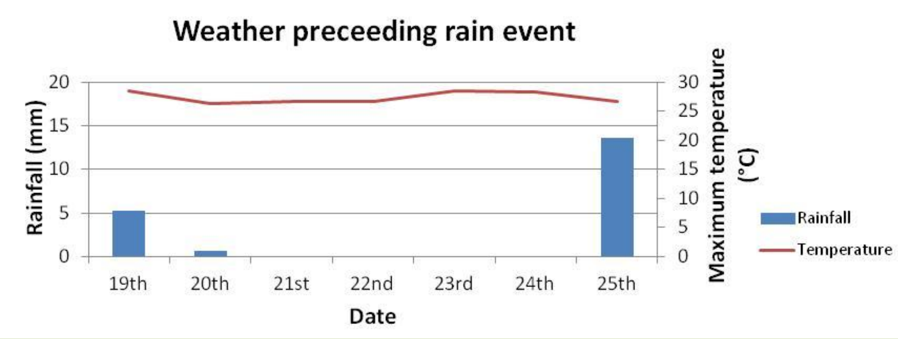
Figure 10. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 27th May 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 25th July 2014

Rain volume: 13.6 mm

Rain intensity: 360 mm/hr

Max temp: 26.6 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	100%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	96 %

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	-0.5

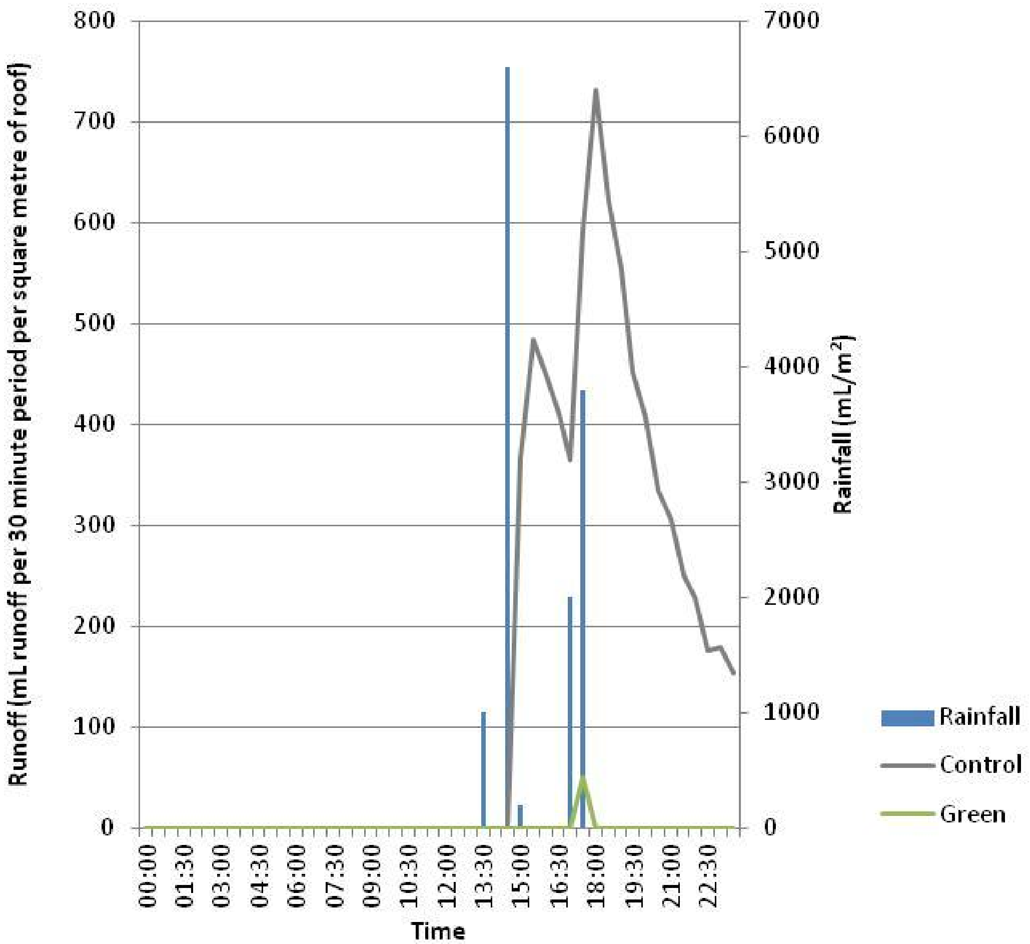


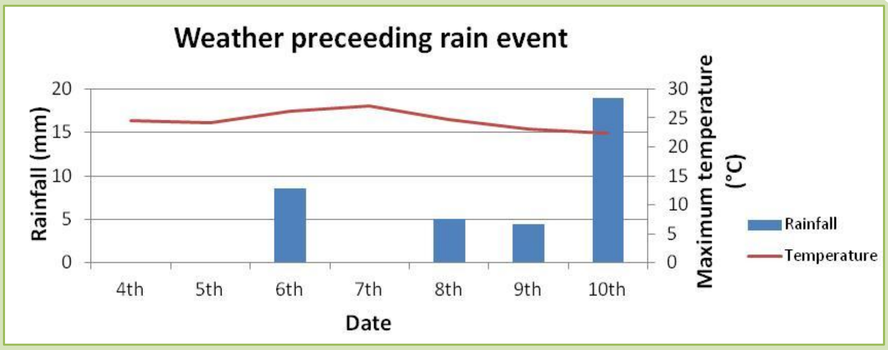
Figure 11. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 25th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 10th August 2014

Rain volume: 19 mm

Rain intensity: 81.2 mm/hr

Max temp: 22.4 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 67% 100%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 67% 100%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: 0 N/A

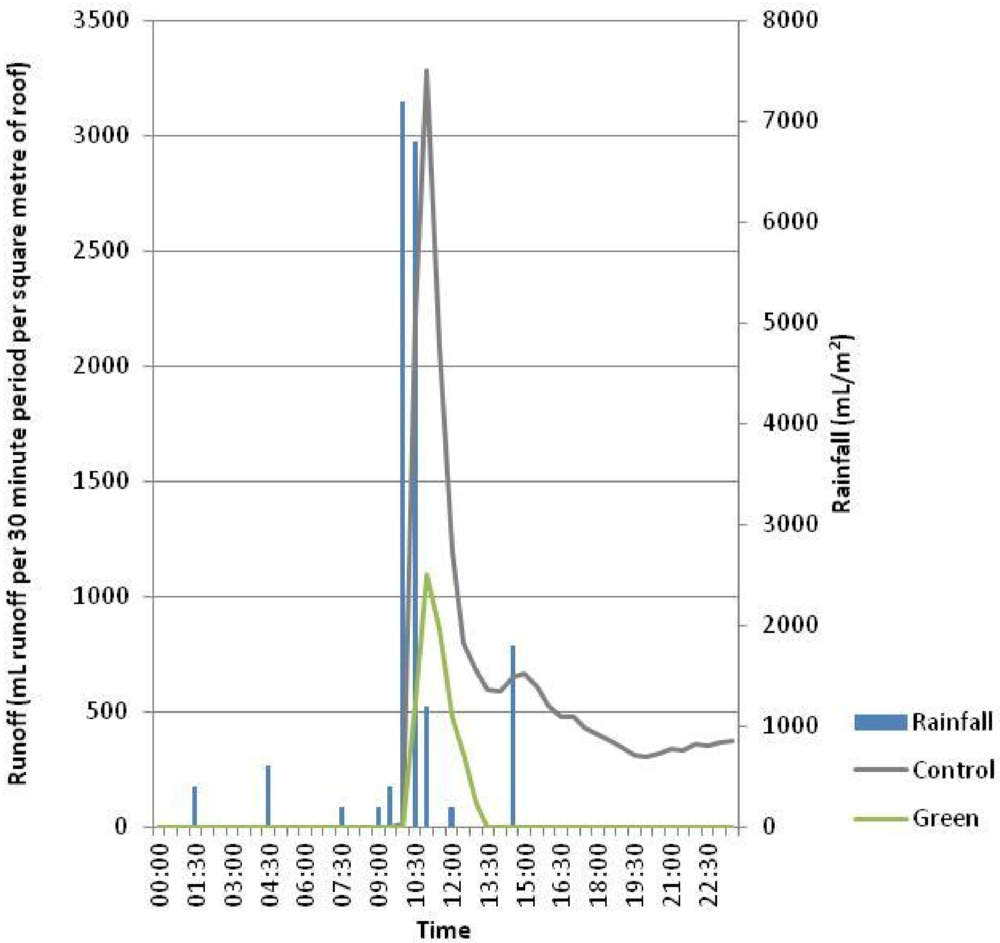


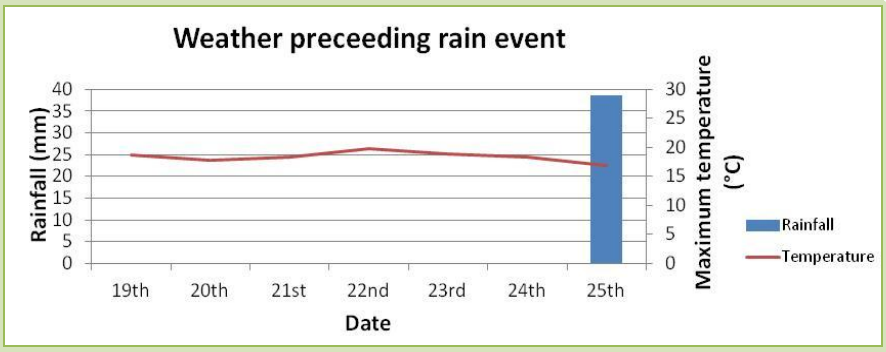
Figure 12. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 10th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 25th August 2014

Rain volume: 38.5 mm

Rain intensity: 36 mm/hr

Max temp: 16.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2 3

Green roof: 100% 60% -3%

Percentage peak flow rate reduction:

Absolute: Peak 1 2 3

Green roof: 100% 55% -7%

Delay in peak flow (hrs):

Peak 1 2 3

Green roof: N/A -0.5 0.5

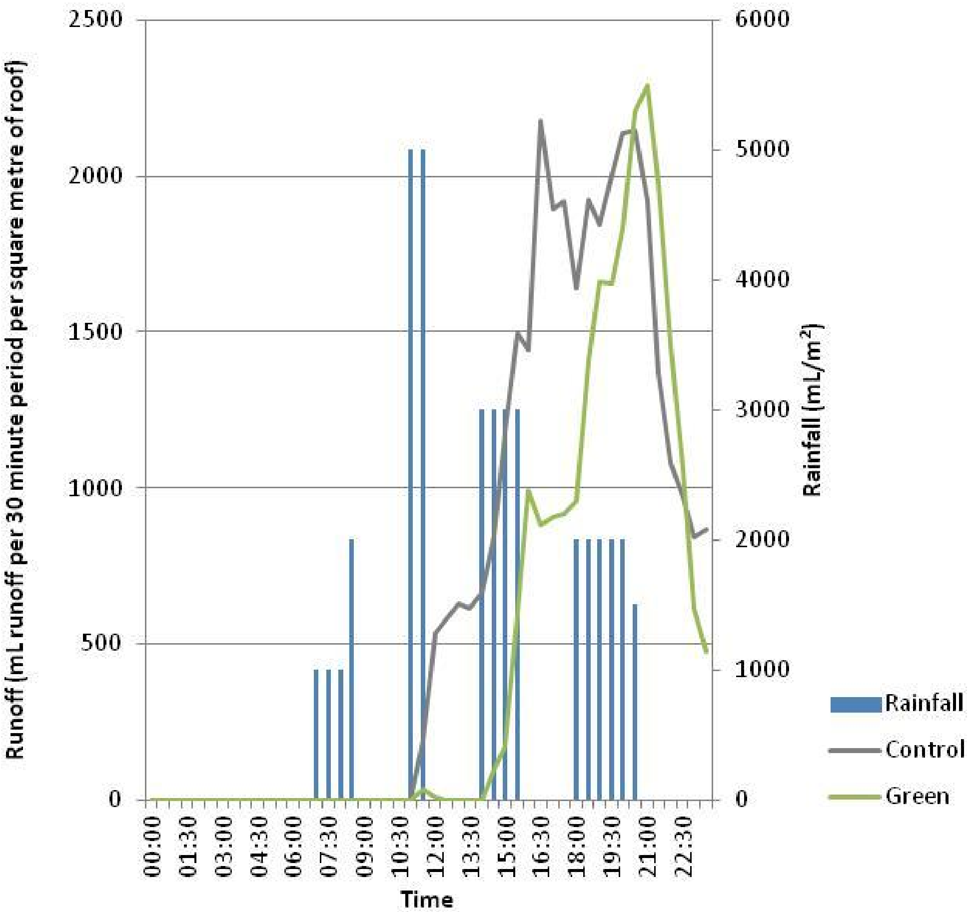


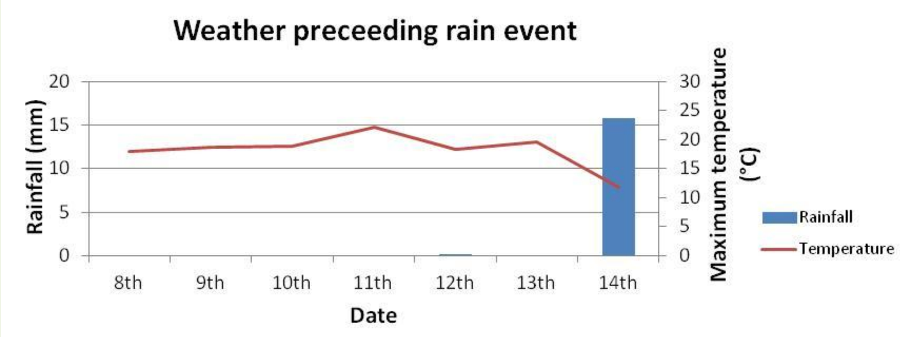
Figure 13. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 25th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. *N.B. weather data based on Hampstead weather station, approx 4.5 miles from Museum of London due to weather station datalogger malfunction.*

Rain event: 14th May 2015

Rain volume: 15.8 mm

Rain intensity: 14.4 mm/hr

Max temp: 11.7 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	0 %	0 %

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	0 %	0 %

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	N/A

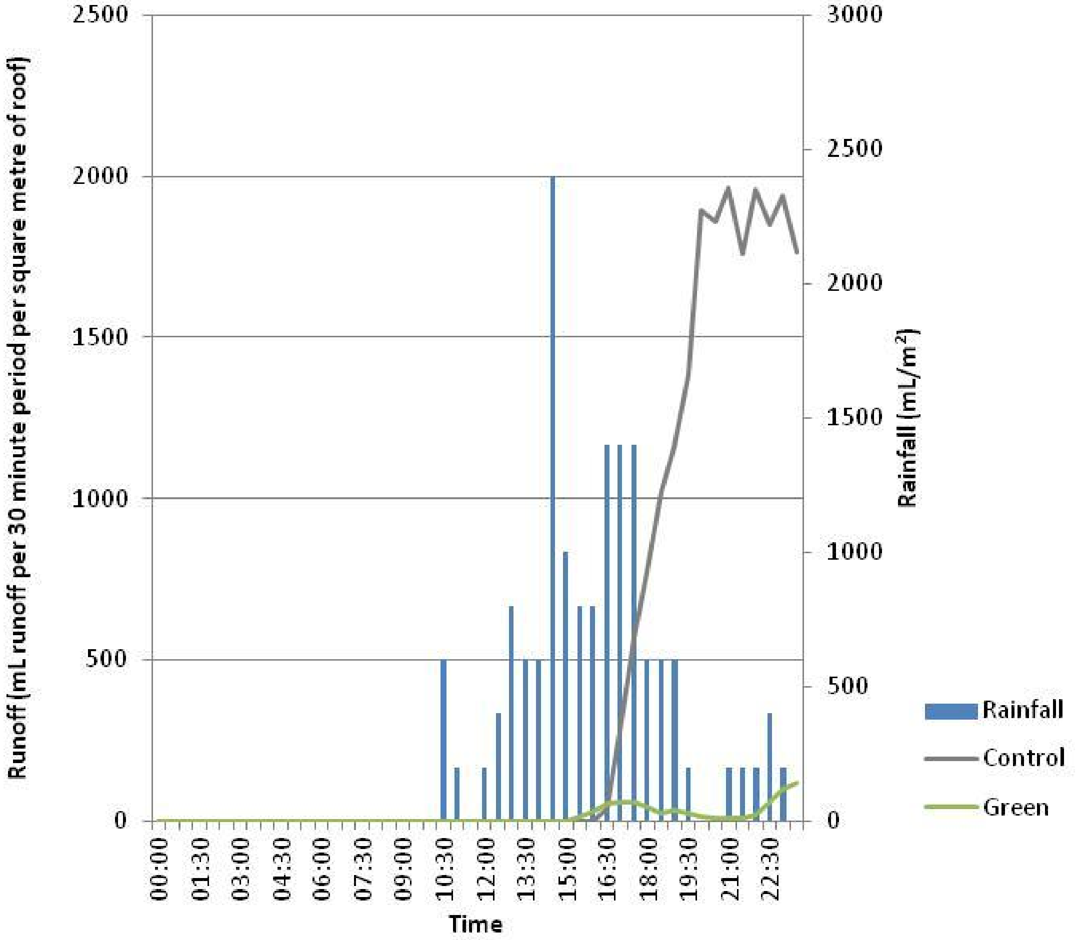


Figure 14. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 14th May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control roof appears to have temporary blockage towards end of monitoring period.

Table 1, below, represents a summary of all of the substantial summer rain events (>2 mm/day) recorded during the monitoring period. Graphs of the top five largest events can be found in the preceding section. All other summer rain event graphs are presented in Appendix 1.

Table 1. Summary of summer rain events recorded on the Museum of London green and control roofs. Table presents the performance of the green roof in terms of: Total volume of rain held by the green roof compared to the rain event size (mm). *Relative peak flow reduction (%)* - reduction in flow rate at the time of the peak flow from the control roof; *Absolute peak flow reduction (%)* - comparative reduction in peak flow between the peak flow recorded from control roof and peak flow recorded from the green roof; *Delay in peak flow (hrs)* - delay between the time peak flow was recorded from the control roof and from the green roof. Peaks are separated into the first peak following a substantial rain event then subsequent peaks following soon after the first peak over the course of a 24 hour period. Summer rain events are defined as those recorded from mid-spring to mid-autumn (April - September). *N/A represents events where no flow was recorded for at least one of the roofs*. **represents events where control roof data was missing due to power supply issues or blockage.*

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
24/05/2014	7	6.2	88.57	4.8	17.6	45	32	-1	100	100	N/A
26/05/2014	9.2	8	86.96	7.4	15.6	29	29	0	100	81	2
27/05/2014	15	12.6	84.00	19.2	13.7	66	66	0	72	68	0.5
28/05/2014	4.2	2.8	66.67	2	15.4	89	86	2	85	78	1.5
03/06/2014	2.2	2.2	100.00	12.4	20.1	N/A	N/A	N/A			
04/06/2014	3	3	100.00	4.6	15.4	100	100	N/A			
07/06/2014	2.6	2.6	100.00	17.2	23	100	100	N/A			
09/06/2014	2.8	2.8	100.00	22.2	26.1	100	100	N/A	100	100	N/A
26/06/2014	2	2	100.00	4	20.8	N/A	N/A	N/A			

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
28/06/2014	4	4	100.00	69	18.9	N/A	N/A	N/A			
30/06/2014	5.8	5	86.21	89.4	20.6	75	56	0.5			
05/07/2014	2.6	2.6	100.00	3.8	21.8	N/A	N/A	N/A			
11/07/2014	3.2	3.2	100.00	5	20.3	N/A	N/A	N/A			
13/07/2014	4	3.8	95.00	47.2	25.5	N/A	N/A	N/A			
18/07/2014	4	4	100.00	72.4	31.6	100	100	N/A			
19/07/2014	5.2	5.2	100.00	48	28.5	100	100	N/A	100	100	N/A
25/07/2014	13.6	13.5	99.26	360	26.2	100	100	N/A	100	96	-0.5
06/08/2014	8.6	8.6	100.00	24.8	26.1	100	100	N/A			
08_09/08/2015	9.4	9.4	100.00	7	24.7	100	100	N/A			
10/08/2014	19	15.6	82.11	81.2	22.4	67	67	0	100	100	N/A
11/08/2014	3	3	100.00	39.4	21.3	N/A	N/A	N/A			
14/08/2014	11.8	11.6	98.31	77.8	21.9	100	100	N/A	92	92	0
18/08/2014	4	4	100.00	11.8	20.6	100	100	N/A	100	100	N/A
25/08/2014	38.5	16.3	42.34	36	16.8	100	100	N/A	60 -3	55 -7	-0.5 0.5
26/08/2014	12.5	8.5	68.00	24	16.2	95	38	1	36	36	0
01/09/2014	4.4	4.4	100.00	30	18.8	100	71	-0.5			
19/09/2014	5.4	5.2	96.30	66	22.6	100	51	-0.5			
20/09/2014	6.8	6.5	95.59	88	19.3	66	66	0			
24/09/2014	2	2	100.00	1	19	100	100	N/A			
02/04/2015	2.8	2.3	82.14	21.2	12.2	86	55	4			

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
03/04/2015	4.8	4.4	91.67	2.4	12.9	100	100	N/A	100	-18	5
25/04/2015	2.6	2.1	80.77	3.8	18.2	100	100	N/A			
26/04/2015	5.4	4.3	79.63	14.2	12.9	87	37	-0.5			
29/04/2015	3.8	3.8	100.00	7.8	13.5	100	100	N/A			
03/05/2015	2.4	3.8	100.00	2.4	19.6	100	100	N/A			
04/05/2015	4.8	4.8	100.00	5.2	18.4	99	99	0			
05/05/2015	2.6	2.4	92.31	5.2	16.5	96	88	-0.5			
06/05/2015	7.2	5.4	75.00	198.6	14.7	*N/A	*N/A	*N/A			
14/05/2015	15.8	15.3	96.84	14.4	11.7	78	78	0	93	93	0
23/05/2015	3	3	100.00	48.8	18.3	*100	*100	*N/A			
29/05/2015	2.2	2.2	100.00	8	15.3	100	100	N/A			
31/05/2015	4.2	4.2	100.00	26.4	16.3	100	100	N/A			
Average			**92.56**								

4.3 Winter rain events

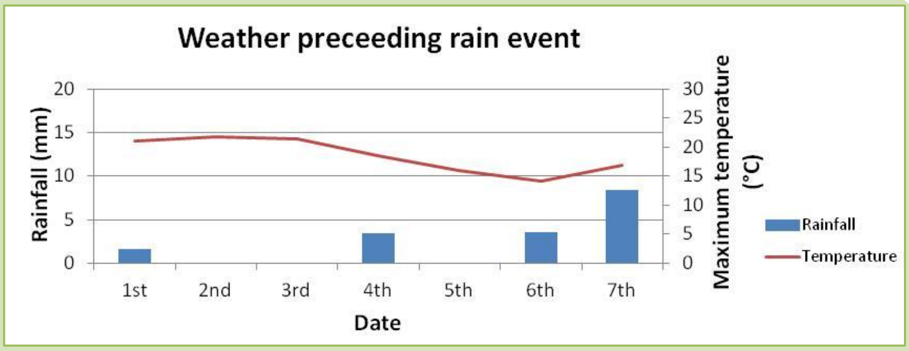
In addition to the performance of green roofs under summer weather conditions it was also important to assess their performance under winter conditions when prolonged cool wet weather is more typical. Unlike more engineered SuDs components, such as geo-cellular modules with throttle release valves, the performance of green infrastructure SuDs components can change significantly seasonally as attenuation is directly related to water storage recharge which is controlled by rates of evapotranspiration. In winter evapotranspiration rates are expected to be lower so that recharge volumes between rain events would be expected to be smaller. The five largest rain events during the winter survey periods are presented in the below Figures (Figures 15 to 19). Winter events are defined as those occurring between October and March.

Rain event: 7th October 2014

Rain volume: 8.4 mm

Rain intensity: 70.6 mm/hr

Max temp: 16.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 60%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 49%

Delay in peak flow (hrs):

Peak 1

Green roof: -0.5

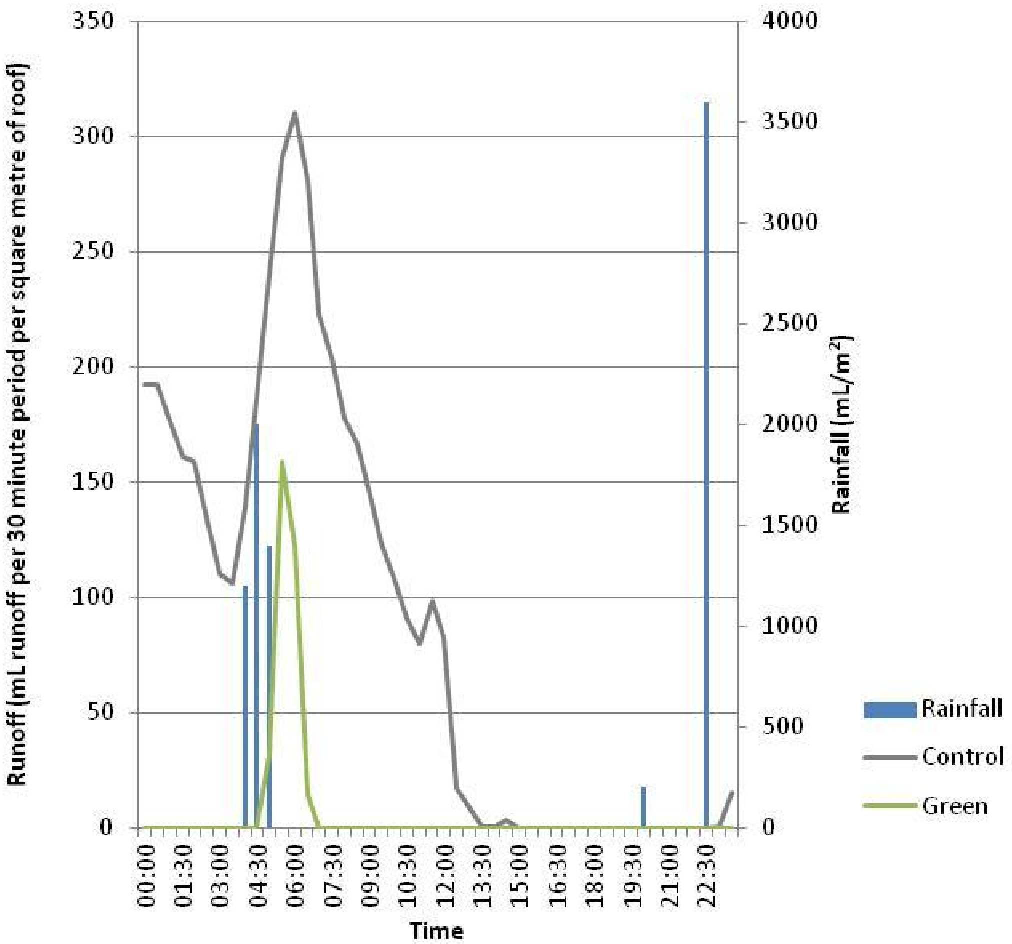


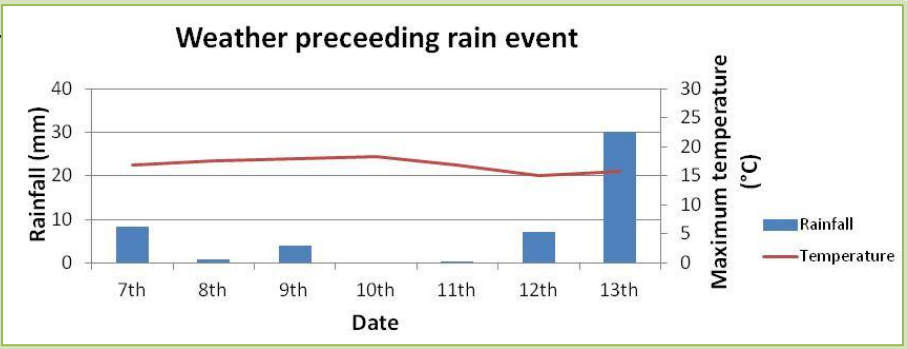
Figure 15. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 9th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 13th October 2014

Rain volume: 30.2 mm

Rain intensity: 21.4 mm/hr

Max temp: 15.7 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	96 %	-20%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	96 %	-19 %

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	0	-0.5

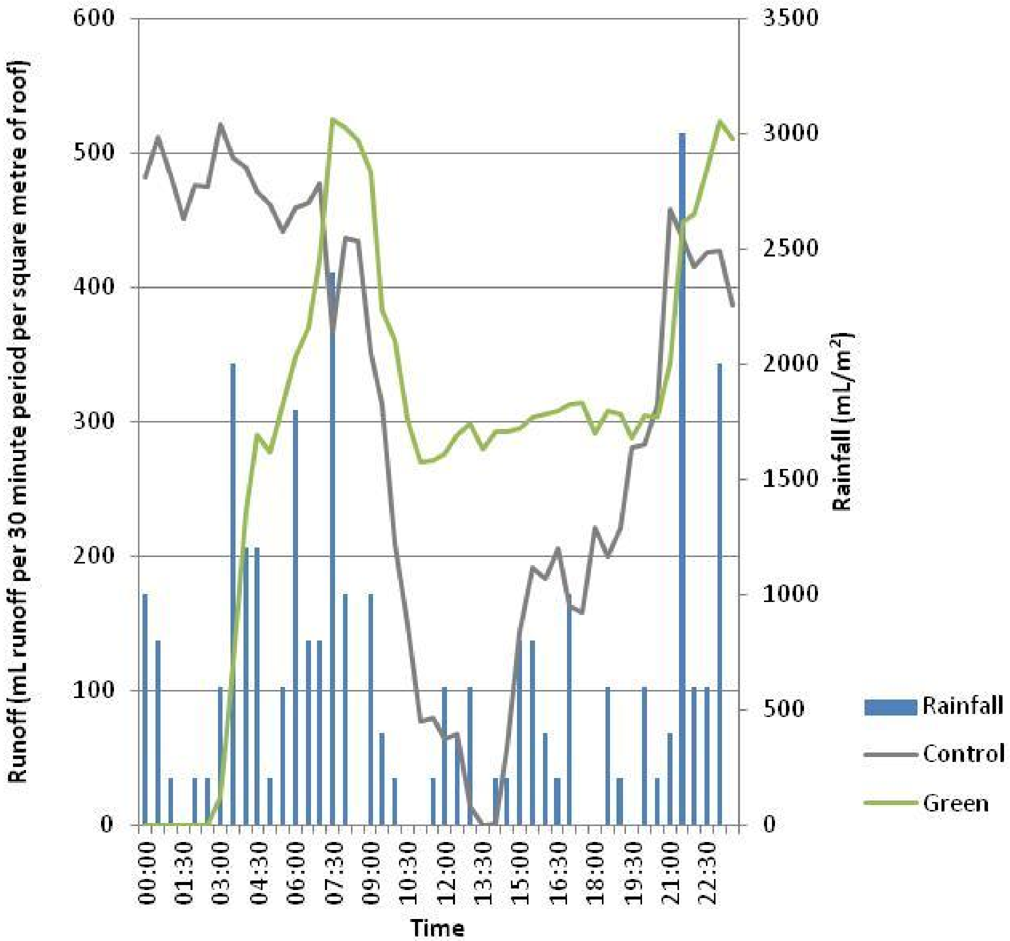


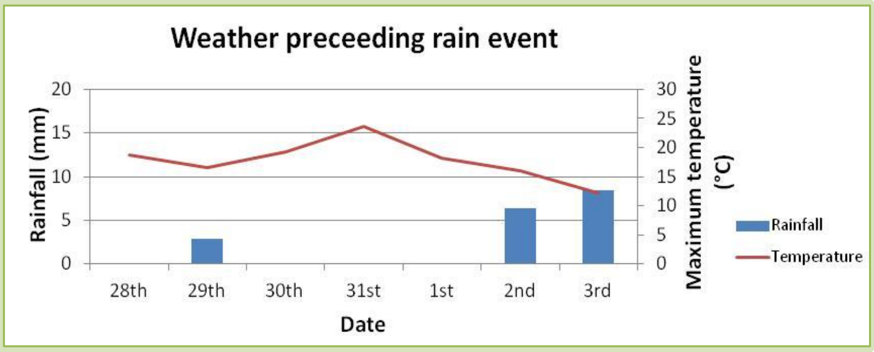
Figure 16. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 13th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were oper**ating.**

Rain event: 3rd November 2014

Rain volume: 8.4 mm

Rain intensity: 11.4 mm/hr

Max temp: 12.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 58%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% 52%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: 0 0.5

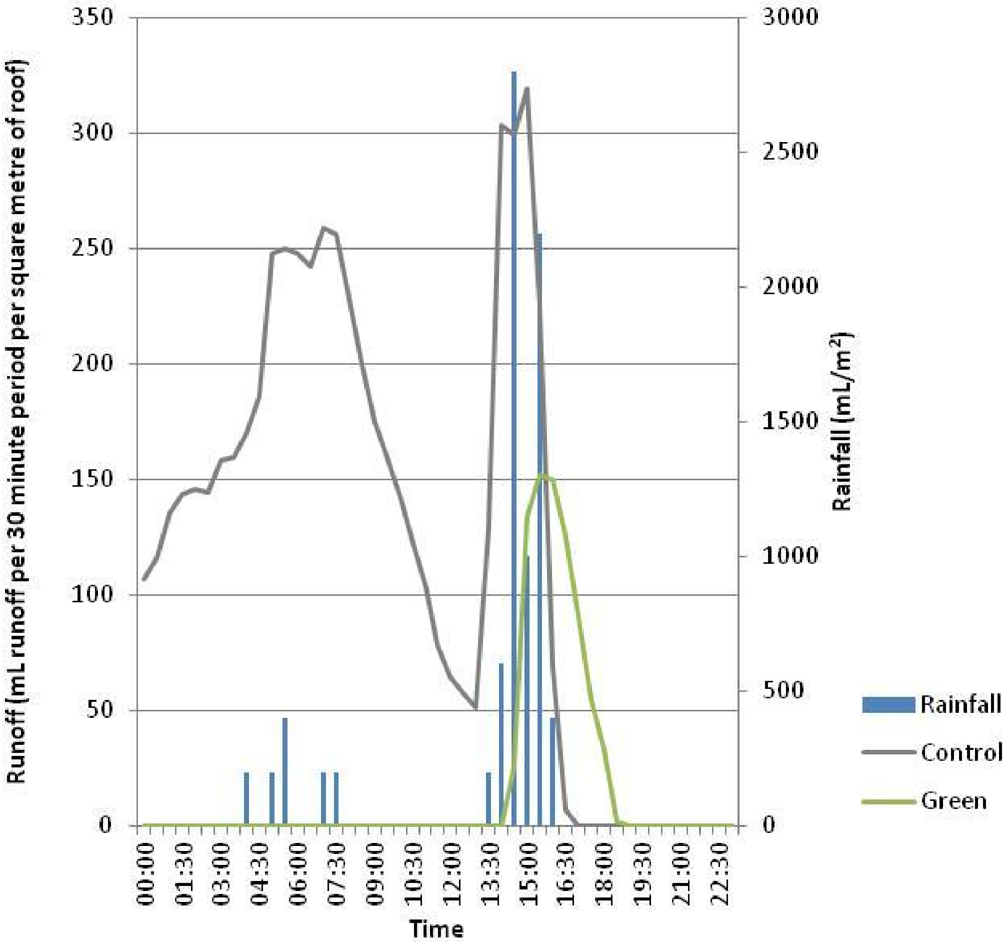


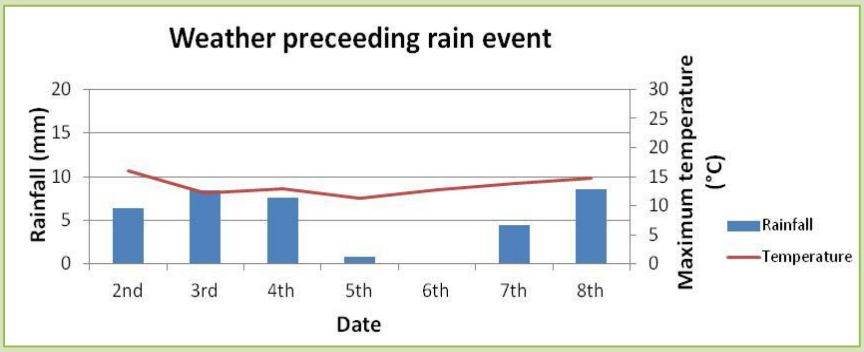
Figure 17. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 3rd November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 8th November 2014

Rain volume: 8.6 mm

Rain intensity: 25.5 mm/hr

Max temp: 14.7 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 97%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 66%

Delay in peak flow (hrs):

Peak 1

Green roof: 1

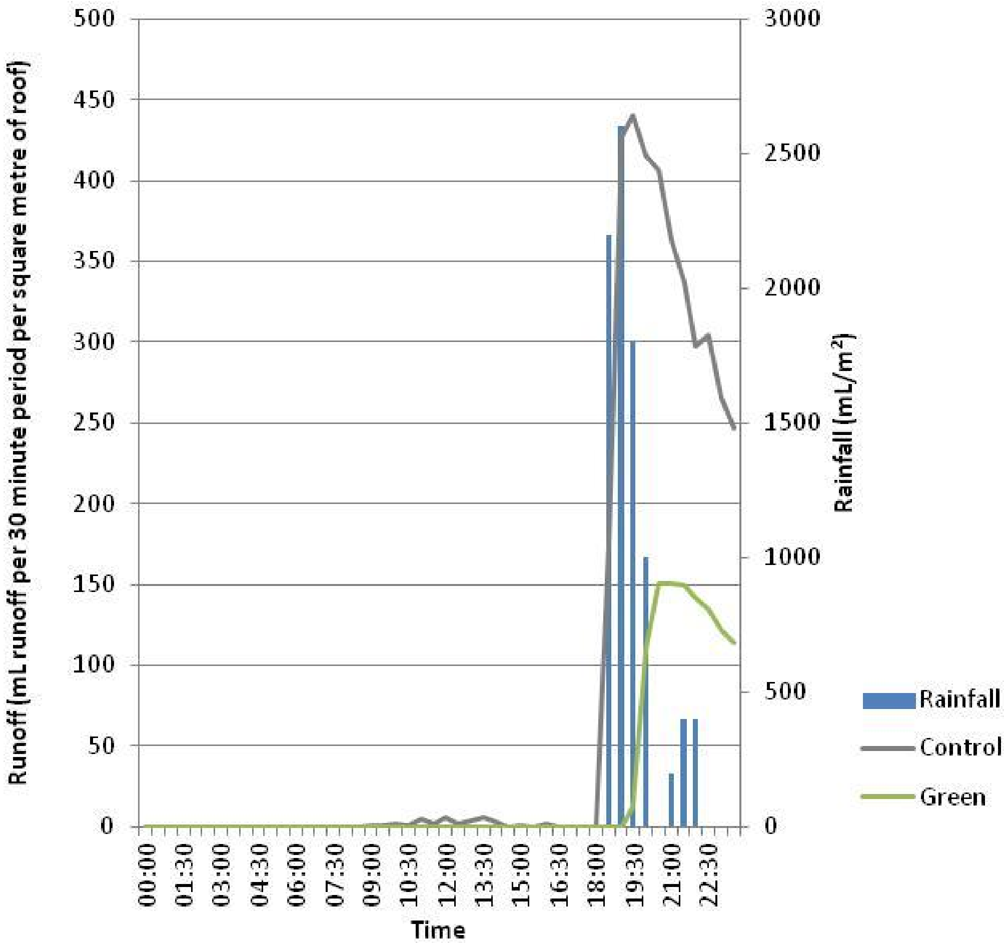


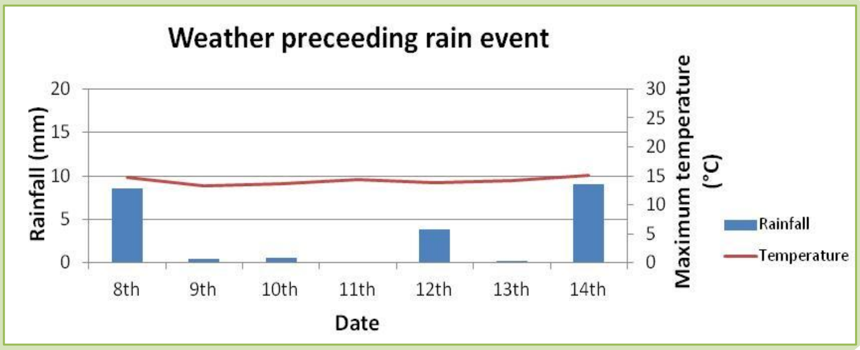
Figure 18. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 8th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 14th November 2014

Rain volume: 9 mm

Rain intensity: 16.6 mm/hr

Max temp: 15.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 73%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 57%

Delay in peak flow (hrs):

Peak 1

Green roof: 1.5

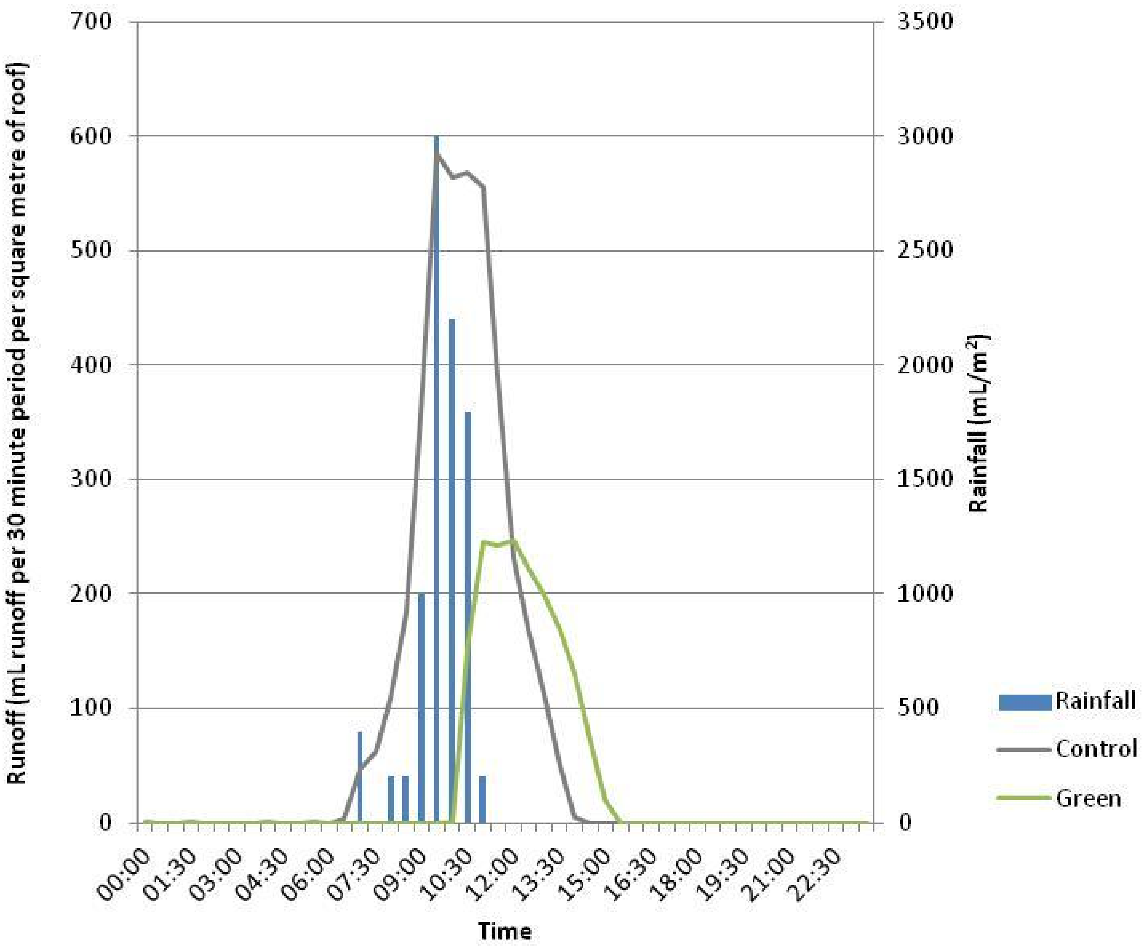


Figure 19. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 14th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Table 2, below, represents a summary of all of the substantial winter rain events (>2 mm/day) recorded during the monitoring period. Graphs of the top five largest events can be found in the preceding section. All other winter rain event graphs are presented in Appendix 2.

Table 2. Summary of winter rain events recorded on the Museum of London green and control roofs. Table presents the performance of the green roof in terms of: Total volume of rain held by the green roof compared to the rain event size (mm). *Relative peak flow reduction (%)* - reduction in flow rate at the time of the peak flow from the control roof; *Absolute peak flow reduction (%)* - comparative reduction in peak flow between the peak flow recorded from control roof and peak flow recorded from the green roof; *Delay in peak flow (hrs)* - delay between the time peak flow was recorded from the control roof and from the green roof. Peaks are separated into the first peak following a substantial rain event then subsequent peaks following soon after the first peak over the course of a 24 hour period. Winter rain events are defined as those recorded from mid-autumn to mid-spring (October - April). *N/A represents events where no flow was recorded from at least one of the roofs. *N/A represents events where control roof data was missing due to power supply issues or blockage.*

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
04/10/2014	3.4	3.4	100.00	4	18.5	N/A	N/A	N/A			
06/10/2014	3.6	3.6	100.00	4.2	14.1	100	100	N/A	100	100	N/A
07/10/2014	8.4	8.1	96.43	70.6	16.8	60	49	-0.5			
09/10/2014	4	4	100.00	76.8	18	100	100	N/A			
12/10/2014	7.2	7	97.22	42	18	86	83	1			
13/10/2014	30.2	16.6	54.97	21.4	15.7	96	96	0	-20, 75	-19, -14	-0.5, 2
15/10/2014	4.6	2.5	54.35	8.6	16.1	49	21	4			
16/10/2014	3.6	2	55.56	14.4	18.3	75	64	1.5	57	57	0
19/10/2014	4.4	3.3	75.00	12.4	20.1	75	75	0			
21/10/2014	5.6	5.6	100.00	25.4	15.2	100	97	-1			

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
29/10/2014	2.8	2.8	100.00	4.4	16.6	100	100	N/A			
02/11/2014	6.4	6	93.75	12	16	76	76	0			
03/11/2014	8.4	7.6	90.48	11.4	12.2	100	100	0	58	52	0.5
04/11/2014	7.6	5.9	77.63	4.8	13	100	100	0	7	7	0
07/11/2014	4.4	3.8	86.36	7.8	13.8	100	100	N/A	99	73	1
08/11/2014	8.6	7.5	87.21	25.5	14.7	97	66	1			
12/11/2014	3.8	3.8	100.00	11.4	13.8	100	100	N/A	97	88	0.5
14/11/2014	9	7.3	81.11	16.6	15.1	73	57	1.5			
17/11/2014	6.4	6.3	98.44	1.2	11	100	100	N/A	95	91	2
18/11/2014	2.2	2.1	95.45	12.2	12.9	84	84	0.5			
17/12/2014	7.8	7.1	91.03	3.2	14.1	100	100	N/A	*N/A	*N/A	*N/A
15/01/2015	5.8	5.1	87.93	24.8	11.7	100	100	N/A	*N/A	*N/A	*N/A
24/01/2015	2.4	2.4	100.00	6.2	9	*N/A	*N/A	*N/A			
28/01/2015	2	2	100.00	8.2	11.1	100	100	N/A			
31/01/2015	2.8	2.6	92.86	1.6	5.5	21	21	0			
13/02/2015	5.6	5.6	100.00	24.2	9.7	100	100	N/A			
14/02/2015	3.8	3.8	100.00	4.6	9	100	100	N/A			
16/02/2015	6.6	6.3	95.45	7.4	9.3	97	92	1			
19/02/2015	6	6	100.00	1.6	9.4	100	100	N/A			
20/02/2015	2.2	2.1	95.45	3	8.1	99	95	0.5			
22/02/2015	6.4	4	62.50	3	10.3	48	48	0			
25/02/2015	2.2	2.1	95.45	3.4	12.1	*N/A	*N/A	*N/A			

Date	Rain (mm)	Rain retention by green roof (mm)	Proportion of rainfall retained (%)	Rain intensity (mm/hr)	Temperature (°C)	1st peak flow from rain event			Subsequent peak flows from rain event		
						Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)	Relative peak flow (% reduction)	Absolute peak flow (% reduction)	Delay in peak (hrs)
26/02/2015	6	4.4	73.33	7.2	12.2	85	74	1			
28/02/2015	3	2.8	93.33	3.4	11	94	94	0			
01/03/2015	2.8	2.2	78.57	32.4	11.9	100	100	0			
16/03/2015	5	4.2	84.00	14.4	9.4	*N/A	*N/A	*N/A			
26/03/2015	6.2	5	80.65	2.6	12.6	*N/A	*N/A	*N/A			
29/03/2015	7	7	100.00	35.4	14.4	100	100	0			
Average			88.80								

5. Discussion

Data from the gauges demonstrated that the green roof consistently outperformed the control grey roof in terms of rainfall retention. This occurred both during summer monitoring, when the roofs would be expected to be performing optimally, and during winter, when the roofs would be expected to be more saturated for greater proportions of time. Rainfall retention comprised a reduction in the peak flow from the roofs during heavy rain events and a reduction in the total rain leaving the roof during the entire attenuation period during and following the rain event.

In general, the peak flow from the green roof was delayed compared to the control roof. However, this difference was not as clear as has been recorded in a previous Drain London green roof study (Connop *et al*. 2015). During some rain events, peak flow occurred during the same 30 minute monitoring period, and for other events the opposite was recorded. The most logical explanation for this pattern was that runoff from the control roof did not immediately occur after the start of a rain event, as would be expected on a free draining roof system. Instead, due to the uneven nature of the flat roof, the control roof had significant pooling before any runoff reached the monitored outlet and was released from the roof (Figure 3). In contrast, the exposed area around the green roof outlet did not have similar pooling. Thus, during periods of very heavy rainfall, some runoff would be recorded from the green roof, whereas equivalent runoff from the control roof would be delayed until the capacity of the control roof pooling had been reached. The repeated rain event analyses indicated that the volume of the pooling area on the control roof corresponded with an approximately 4 mm rain event when completely dry at the start of the rain event. The result of this was that, for many of the smaller rain events (events greater than 2 mm but smaller than 4 mm), no runoff was recorded from the green roof or the control roof and for larger rain events runoff from the control roof was delayed until after this storage capacity was exceeded.

For a more detailed breakdown of the green roof results, the following summary of the results is divided into summer first peak and subsequent peaks, and winter first peak and subsequent peaks:

5.1 Summer

For summer rain events, the green roof reduced the amount of runoff compared to the total rainfall by an average of 93%. During this period maximum retention was recorded as 100% and minimum retention for a single rain event was 42% (during a 38.5 mm rain event). Average attenuation for the top 5 largest summer rain events was 81%.

5.1.1. Summer first peak flows

For summer rain events, the green roof reduced the majority of the peak flow for the first peak of all rain events. Overall patterns from the data comprised:

Relative percentage reduction in peak flow

- The first relative peak flow reduction range of the green roof for summer events was 29 to 100% reduction, this included the five largest storm events;
- First relative peak flow reduction for the green roof for the five largest storm events was 66 to 100%;

Absolute percentage reduction in peak flow

- The first absolute peak flow reduction range of the green roof for summer events was 29 to 100% reduction, this included the five largest storm events;
- First relative peak flow reduction for the green roof for the five largest storm events was 66 to 100%;

Delay between peak flows

- Delay between peak flow of the control roof and peak flow coming from the green roof ranged from -1 to 4 hours after the control roof peak flow.

5.1.2. Summer subsequent peak flows

Analysis was also carried out on subsequent rain peaks for summer rain events (following the first large runoff peak) for the green roof to assess performance of the green roof during multiple rain events that occurred very close to together. Again the green roof reduced the majority of the peak flow for subsequent peaks after the initial rain peak, although generally the green roofs were not as effective at this as during the first rain peak. Overall patterns from the data comprised:

Relative percentage reduction in peak flow

- The subsequent relative peak flow reduction range of the green roof for summer events was -3 to 100% reduction (-3 corresponding to an event where the green roof appeared to become oversaturated and a slightly higher rate was recorded from this roof than the control roof), this included the five largest storm events;
- Subsequent relative peak flow reduction was recorded for all five of the largest storm events, flow reduction for these was recorded from 60 to 100%;

Absolute percentage reduction in peak flow

- The subsequent absolute peak flow reduction range of the green roof for summer events was -7 to 100% reduction (-7 corresponding to an event where the green roof appeared to become oversaturated and a slightly higher rate was recorded from this roof than the control roof), this included the five largest storm events;

- Subsequent absolute peak flow reduction was recorded for all five of the largest storm events, flow reduction for these was recorded from 55 to 100%;

Delay between peak flows

- Delay between peak flow of the control roof and peak flow coming from the green roof for subsequent peaks ranged from -0.5 to 0.5 hours after the control roof peak flow.

5.2 Winter

For winter rain events, the green roof reduced the amount of runoff compared to the total rainfall by an average of 89%. This was lower than for the summer events but still relatively high compared to other winter performance studies (Connop *et al*., 2013; 2015). During this period maximum retention was recorded as 100% and minimum retention for a single rain event was 54% (during a 4.6 mm rain event). Average attenuation for the top 5 largest summer rain events was 82%.

5.2.1. Winter first peak flows

Relative percentage reduction in peak flow

- The first relative peak flow reduction range of the green roof for winter events was 21 to 100% reduction, this included the five largest storm events;
- First peak reduction for the green roof for the five largest storm events in winter was 60 to 100%;

Absolute percentage reduction in peak flow

- The first absolute peak flow reduction range of the green roof for winter events was 21 to 100% reduction, this included the five largest storm events;
- First absolute peak flow reduction for the green roof for the five largest winter storm events was 49 to 100%;

Delay between peak flows

- Delay between peak flow of the control roof and peak flow coming from the green roof ranged from -0.5 to 4 hours after the control roof peak flow.

5.2.2. Winter subsequent peak flows

Analysis was also carried out on subsequent winter rain events (following the first large runoff peak) for the green roof to assess performance of the green roof during multiple rain events that occurred very close to together. Subsequent peak attenuation performance was also worse in the winter months than in the summer months as expected. Nevertheless, for the majority of rain events, including most of the largest, substantial reductions in peak flow were recorded. Overall patterns from the data included:

Relative percentage reduction in peak flow

- The subsequent relative peak flow reduction range of the green roof for winter events was -20 to 95% reduction, this included the five largest storm events;
- Subsequent relative peak flow reduction for the green roof was recorded for two of the five largest storm events, flow reduction for these were -20% and 58%;

Absolute percentage reduction in peak flow

- The subsequent absolute peak flow reduction range of the green roof for winter events was -19 to 100% reduction, this included the five largest storm events;
- Subsequent absolute peak flow reduction for the green roof was recorded for two of the five largest storm events, flow reduction for these was recorded -19 and 54% [-19% presumably represented an occasion when a small flow came from the control roof during a second rain peak but green roof 1 produced a larger runoff as delayed runoff was still leaving the roof following the previous peak when the second peak occurred].

Delay between peak flows

- Delay between peak flow of the control roof and peak flow coming from the green roof for subsequent rain peaks when runoff was recorded ranged from -0.5 to 2 hours after the control roof subsequent peak flow;

6. Summary

Performance of the gauges

Whilst there are still some performance issues with the prototype gauges, many of the reliability issues that impacted the Drain London Ruislip depot monitoring appear to have been improved. As such, with the exception of some blockages by debris, almost continuous monitoring was achieved throughout the monitoring period. Data generated by the gauges was comprehensive and the gauges appear to be very reactive to runoff patterns.

Nevertheless, there are still some issues that would need to be addressed, through more laboratory testing and development, before the gauges could be considered commercially viable. Primarily this relates to issues associated with very low flow rates and the problems of the gauges sitting in pooling for prolonged periods of time:

i) *Low flow rates* :- v-notch systems perform optimally at higher flow rates. At very low flow rates, drag created by the bottom of the v-notch means that measurements cannot be as precise. The design of the capacitance sensor associated with the v-notch is such that it is extremely sensitive to slight fluctuations in water level. Unless there is a slightly lowered area in which the v-notch can sit (e.g. a sloping gulley), the v-notch can sit in pooled water at the height of the v-notch for prolonged periods, particularly in winter when evapotranspiration would be expected to be low. This is exacerbated on flat roofs (and particularly on the Museum of London control roof) where pooling can occur across large areas of the roof before reaching a height to flow down the v-notch. Any debris collecting in the bottom of the v-notch creating a temporary dam can enhance this problem. All of this means that low flow rates can be recorded by the v-notch over prolonged periods which do not actually correspond to flow leaving the roof, but rather to pooled water sitting around the v-notch. This means that precise measurements of total volumes over prolonged periods cannot be performed with great accuracy. However, this was always going to be a problem with this type of rain gauge design compared to the alternative design explored in partnership with Thames Water Ltd. This rain gauge design does, however, perform much better at higher flow rates (those of most interest for in-situ green roof monitoring) and can be used in situations such as the Museum of London and Ruislip, where no access to the downpipes from the roofs is possible.

ii) *Prolonged pooling*: - a secondary problem identified during this project and the Ruislip project was that, following prolonged periods of pooling, the baseline value for raw pulse width (i.e. the zero flow rate) shifted over time. One possible reason for this identified within the Ruislip study was considered to be the gauge stilling tube dropping over time. To remove this possibility, the tube design was changed for the Museum of London gauges. Power supply reliability was considered to be another potential cause so improvements were made to the solar power source, battery pack, the Arduino circuit board, and the datalogging frequency to reduce any risk of such a problem. Another theory for why this was occurring was related to prolonged pooling causing sedimentation build up around the stilling tube which could cause changes in capacitance readings over time. Unfortunately, as it was not possible to get the prototype gauges used at the Ruislip experiment back to the lab for testing, it was not possible to test any gauges that had been in the field for a prolonged period of time to verify this.

Patterns recorded during the Museum of London experiment mirrored those recorded for the Ruislip study. After repeated rain events, the baseline capacitance values again shifted.

This was most pronounced for the gauge that sat in pooled water for the longest periods (the control roof gauge) and was not as pronounced for the green roof. As this occurred despite upgrades to the gauge design. It seems likely that this issue is related to one of two problems. Either there are problems with sedimentation building up around the base of the stilling tube and impacting the capacitance readings or, perhaps more likely, the issue is related to gradual degradation of the battery power supply caused by increased frequency of readings from gauges sitting in prolonged pooling. If this was the case, then changing the battery to a more substantial power supply, or replacing the battery more frequently, could be a simple resolution to this problem. To investigate this further, the gauges from the Museum of London would need to be returned to the laboratory and checked.

Despite these issues, it was possible to post-process raw data to ascertain baseline levels (zero flow rate levels) by careful analysis of the raw data recorded by each gauge to identify the baseline at the time of pooling. Whilst this added an additional level of complication, and thus error, preventing the precise measurement of overall volumes at very low flow rates, it would not be expected to substantially affect the results of the gauges during peak flow events when the gauges were operating nearer to their maxima.

Overall, therefore, the gauges still appear to be a potentially effective solution for monitoring runoff from roofs when no access to the downpipes is available, for example in retrofit opportunities in older buildings where downpipes disappear into inaccessible areas of the building's interior (as is often the case in Central London). For short terms studies, where rain events could be simulating on the roofs, the gauges would be able to be installed in their current form. For longer more prolonged studies, where pooling and long-term power supply issues would occur, it would be recommended that more development on the gauges be carried out.

Summer performance

Overall, green roof water retention and attenuation was good and, as expected, performance was better in the summer than in the winter with the green roof capturing all of the rainfall for over half of the summer rain events. This performance dropped during the top five largest summer rain events, but even during the largest of these (38.5 mm) 42% of the rain that fell on the roof was held by the green roof. This included a 100% reduction in relative peak flow compared to the control roof for the first heavy rain during this rain event and a 60% reduction in peak flow for a second runoff peak that occurred soon after the first. This represents a substantial potential contribution in terms of reducing flash flooding in urban areas.

On the whole, patterns of peak flow water attenuation were good, although comparative patterns with the control roof were somewhat complicated by the large amount of pooling associated with the control roof (equivalent to an approximately 4 mm rain event) before rain was recorded running off. Nevertheless, in general, substantial reductions in peak flows were recorded by the green roof compared to control roof. The green roof also delayed peak flow compared to the control roof, but this again appeared to be complicated by the control roof pooling and, presumably, evaporating faster than rain held in the green roof substrate and drainage layer.

Winter performance

Results from the winter analysis indicated that performance of the green roofs was reduced compared to summer performance, this was particularly so for the five largest storm events. However, winter results were very encouraging in terms of the impact that green roofs can make on peak flow storm water reduction. Winter performance from this study was comparable with that from the Drain London Ruislip study (Connop *et al.* 2015). Both of which were higher than for a previous green roof experimental trial carried out in London (Connop *et al*. 2013). It is impossible to substantiate the reasons for this without more detailed monitoring data including evapotranspiration data and soil moisture sensors. However, it is likely that this difference was related to one or more of several different factors:

- The roof at the Museum of London is situated between several tall buildings in the centre the City of London. As such, in addition to being subject to drying due to exposure to the wind, the area would also be expected to suffer from the urban heat island effect with warmer temperatures due the surrounding grey infrastructure and reflective buildings;
- The roof itself was situated over heated offices and was a relatively old building. It would thus not be expected to be well insulated during winter. Heat loss from the rooms below and surrounding offices would therefore be expected to exacerbate drying of the green roof between winter rain events;
- Winter 2014/15 was not a particularly wet winter and the majority of rain events were spaced out giving time for the green roofs to dry and thus recharge storage volume between each rain event;

Whist there was no direct evidence for these drying effects, anecdotal evidence came from the temperatures on the roof during project maintenance visits where a warm microclimate seemed to exist above the roof felt.

These potential influences on local microclimate were reflected in the green roof winter performance, with proportion of rainfall retained ranging from 54% to 100% for the five largest rain events recorded. Also in the relative peak flow reduction for first peaks with green roof performance ranging from 21% to 100% compared to control roofs. The analytical area where the effect of winter temperatures and volume recharge were most apparent were for subsequent winter peaks, with relative peak performance of -20% to 95% for all rain events and -20% and 58% for the two largest storm events which included subsequent rainfall peaks.

Conclusions

Overall, patterns of peak flow water attenuation were good with substantial reductions in the peak flows compared to total rainfall and the control roof performance even during rain events large enough to cause flood warnings across the south of the UK. This study therefore provides additional data to the emerging evidence base of the stormwater retention and attenuation potential of green roof systems in urban areas.

The evidence generated in this study indicated that green infrastructure could play a key role in terms of reducing issues related to the overflowing of storm drains and thus reducing the occurrence of flooding in high density urban areas if mechanisms for unlocking and up-scaling infrastructure retrofit can be identified.

The gauges developed in partnership with Thames Water Ltd provided a cost-effective solution to the generation of novel data on the performance of retrofit green roofs in situations where more typical monitoring equipment cannot be utilised. Overall, however, the conclusion has to be that they are not yet market-ready. There would need to be more development carried out on the gauges for them to be rolled out for more long-term monitoring applications.

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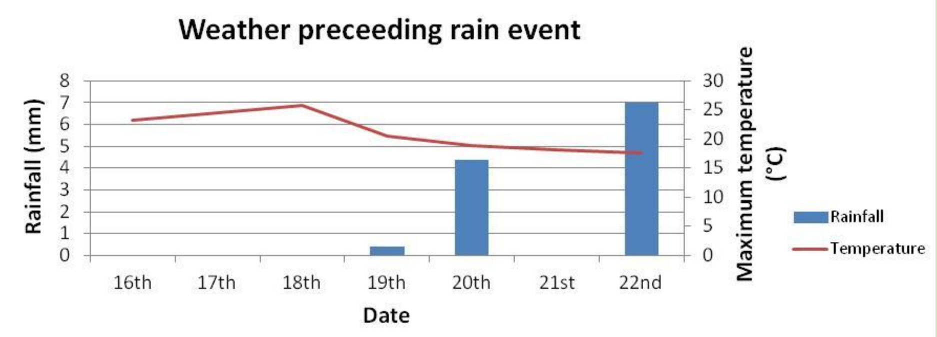
Appendix 1 - Summer rain events

Rain event: 24th May 2014

Rain volume: 7 mm

Rain intensity: 4.8 mm/hr

Max temp: 17.6 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	45%	100%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	32%	100%

Delay in peak flow (hrs):

	Peak 1	**Peak2**
Green roof:	-1	N/A

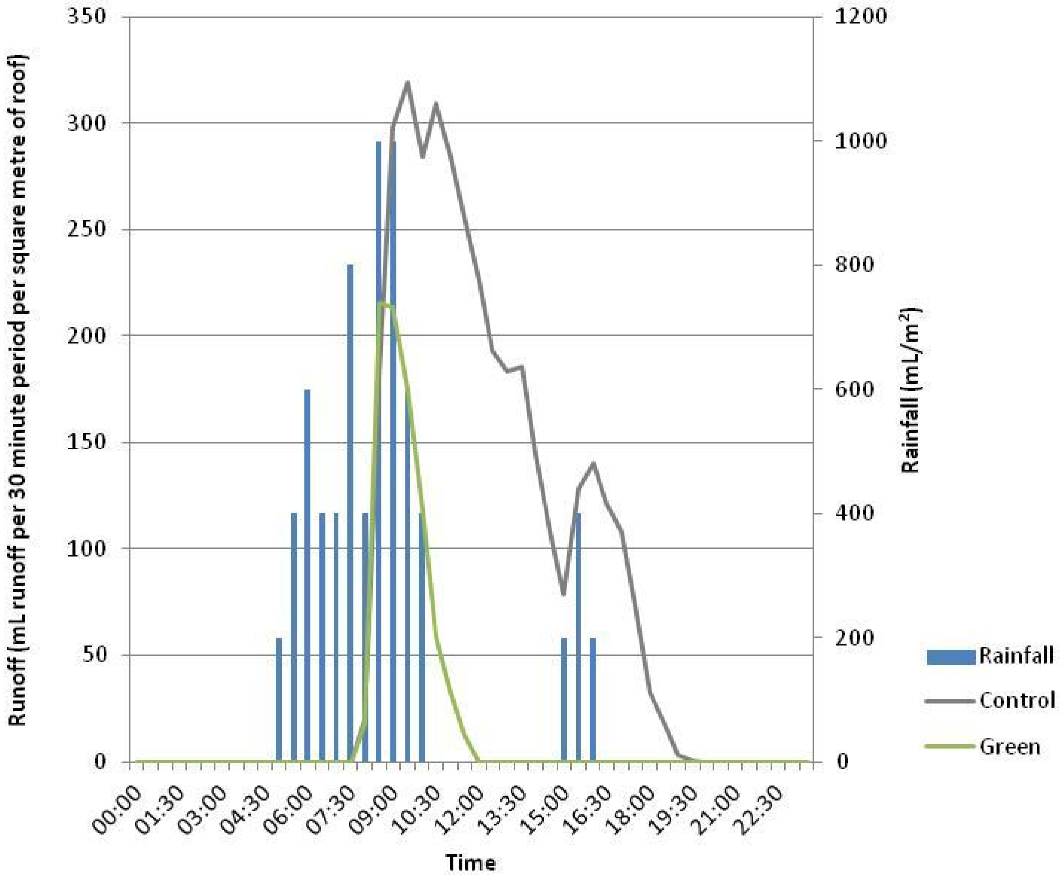


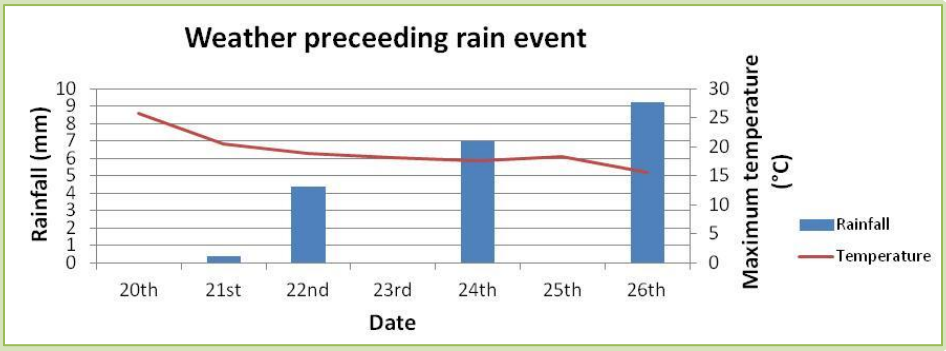
Figure 20. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 22nd May 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 26th May 2014

Rain volume: 9.2 mm

Rain intensity: 7.4 mm/hr

Max temp: 15.6 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	29%	100%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	29%	81%

Delay in peak flow (hrs):

	Peak 1	**Peak2**
Green roof:	0	2

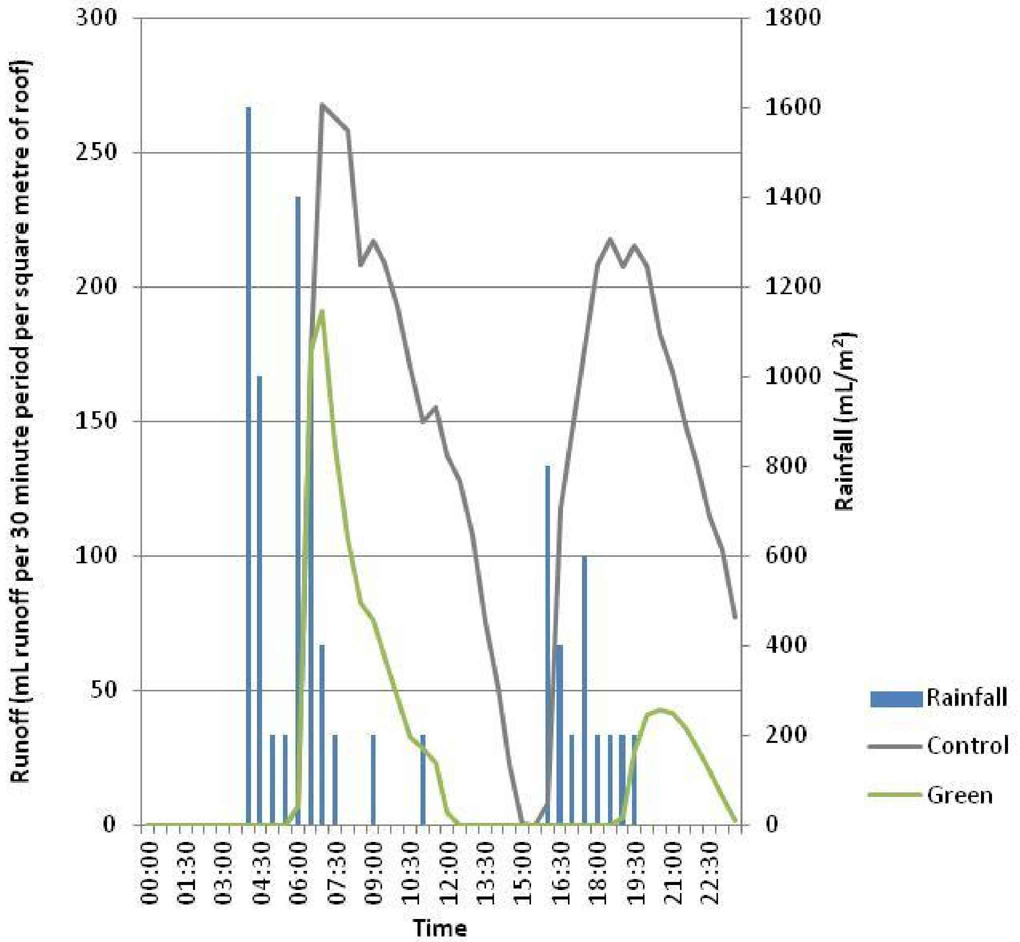


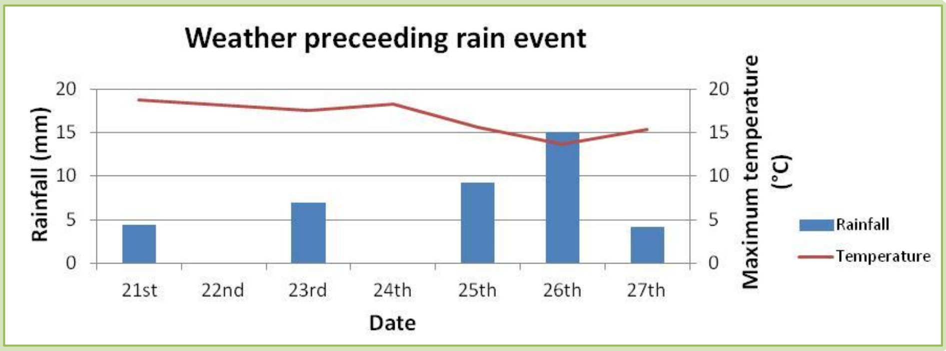
Figure 21. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th May 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 28th May 2014

Rain volume: 4.2 mm

Rain intensity: 2 mm/hr

Max temp: 15.4 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	89%	85%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	86%	78%

Delay in peak flow (hrs):

	Peak 1	**Peak2**
Green roof:	2	1.5

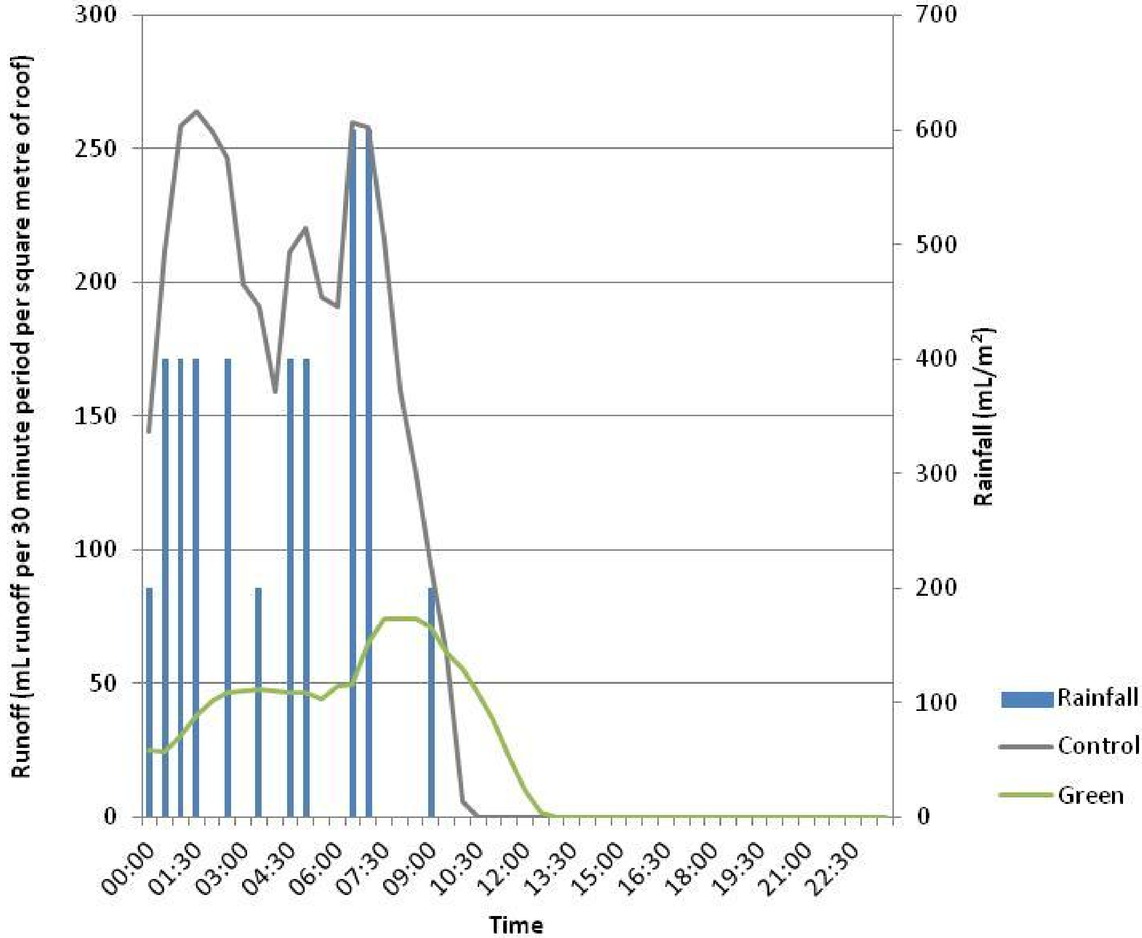


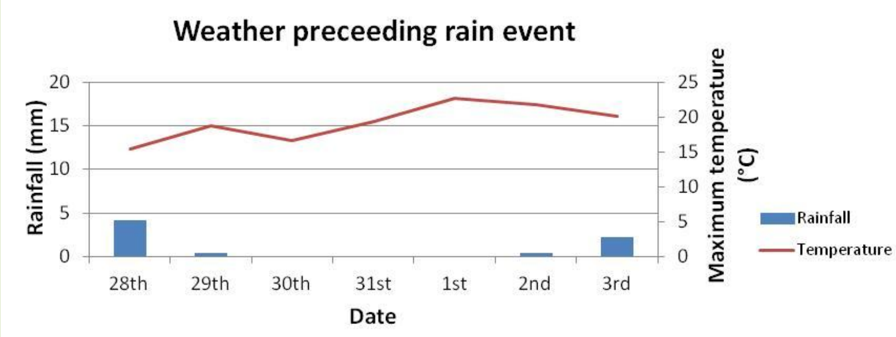
Figure 22. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 28th May 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 3rd June 2014

Rain volume: 2.2 mm

Rain intensity: 12.4 mm/hr

Max temp: 20.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

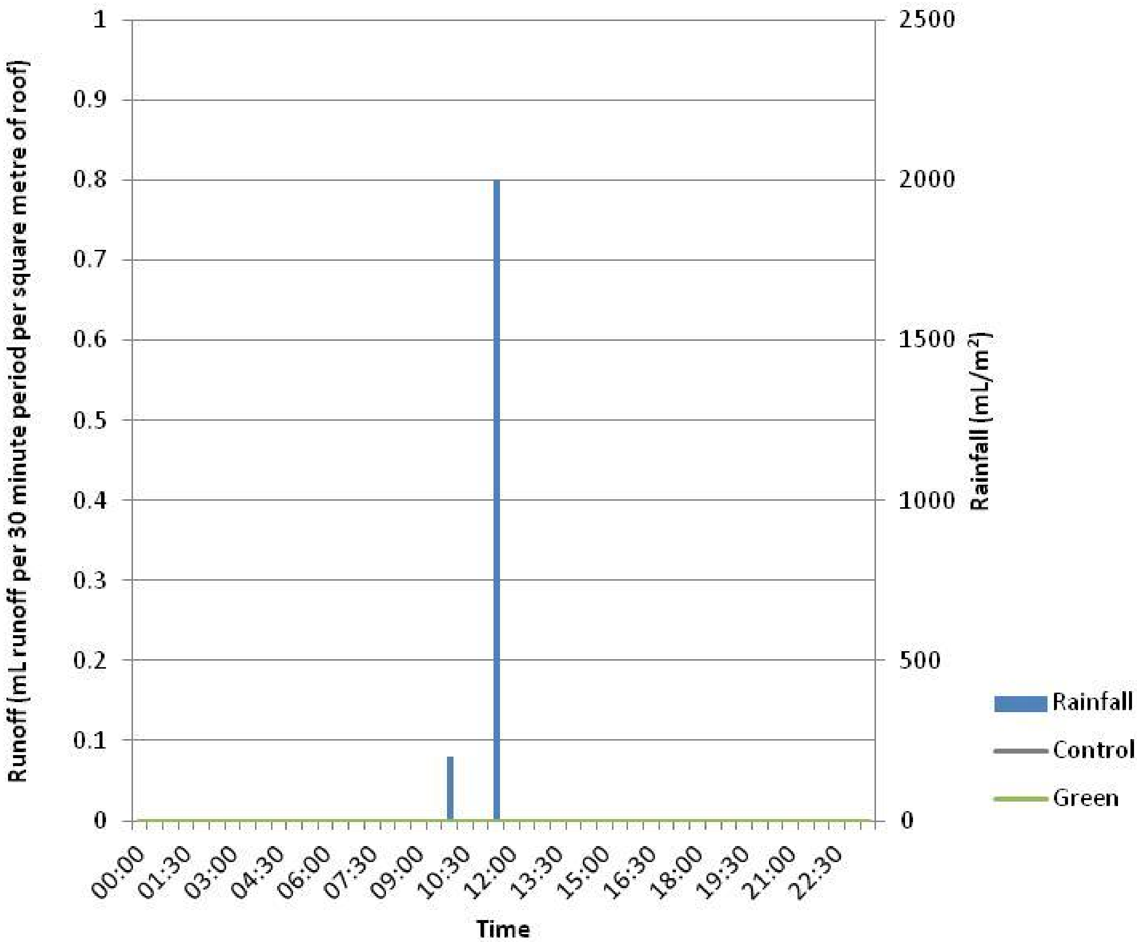


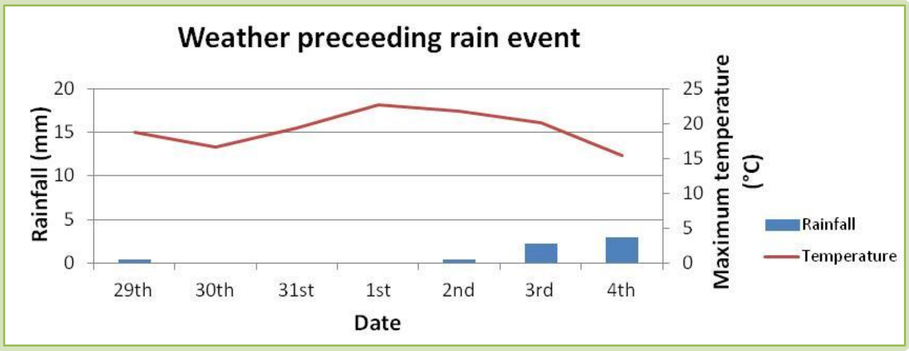
Figure 23. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 3rd June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 4th June 2014

Rain volume: 3 mm

Rain intensity: 4.6 mm/hr

Max temp: 15.4 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	

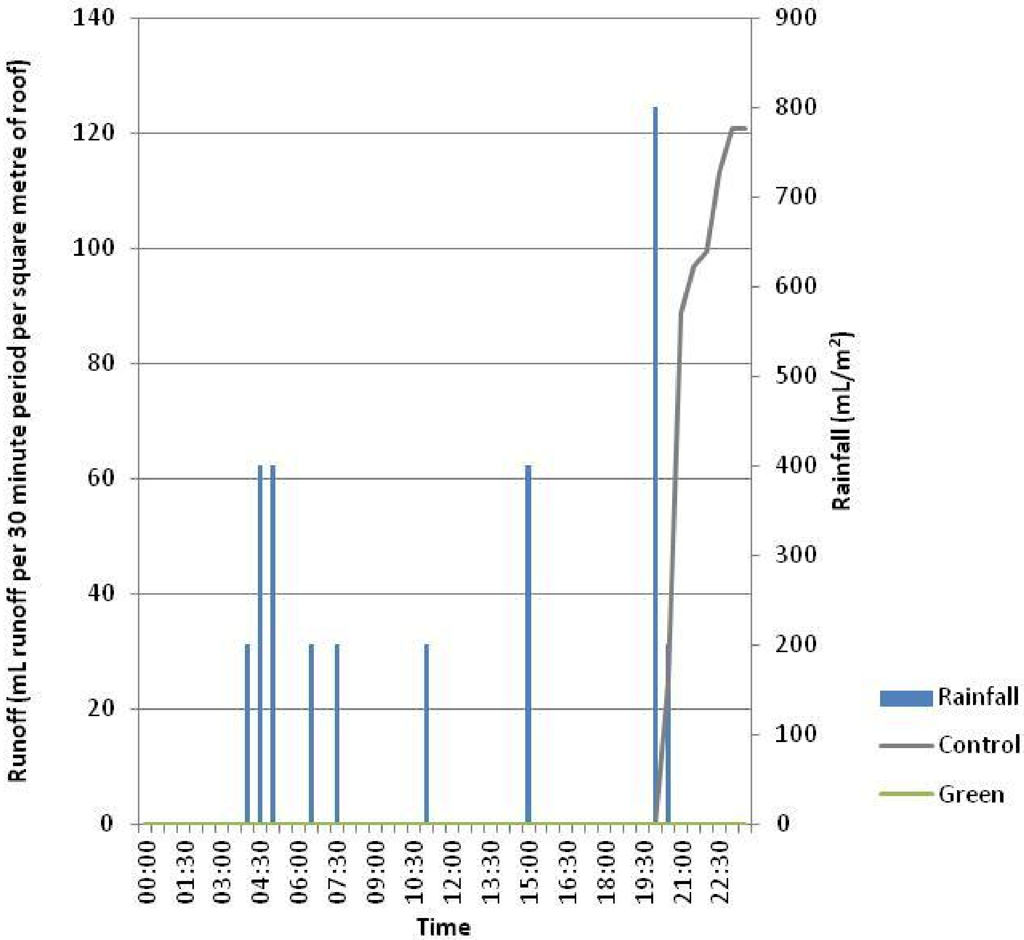


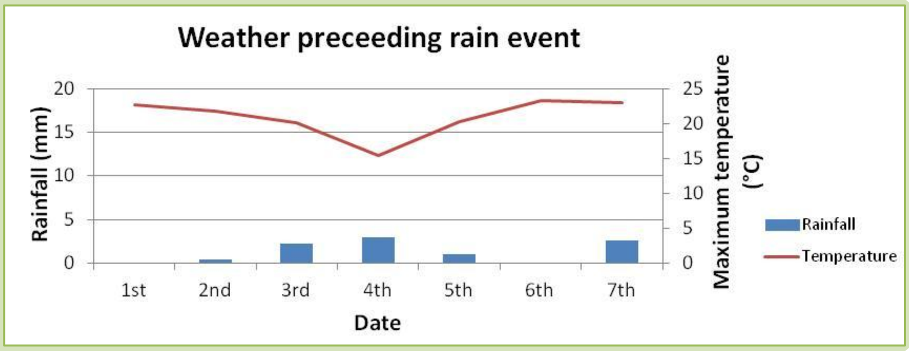
Figure 24. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 4th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 7th June 2014

Rain volume: 2.6 mm

Rain intensity: 17.2 mm/hr

Max temp: 23 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	

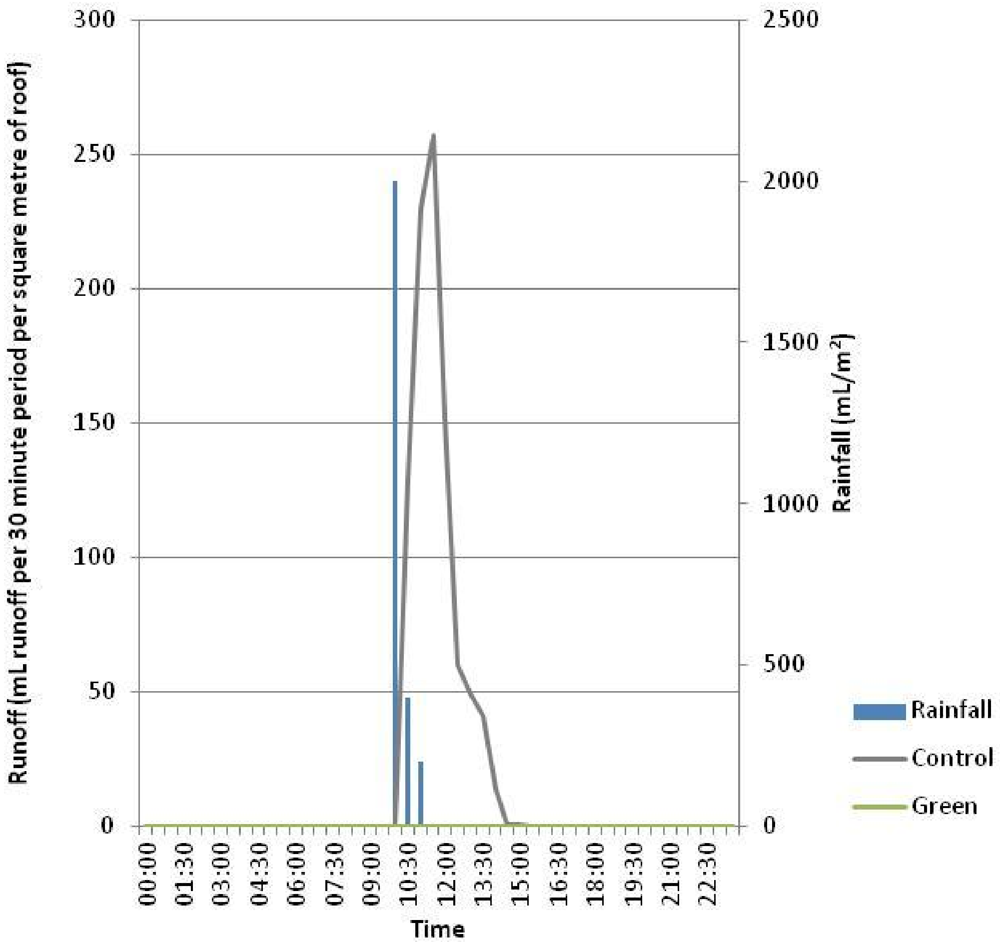


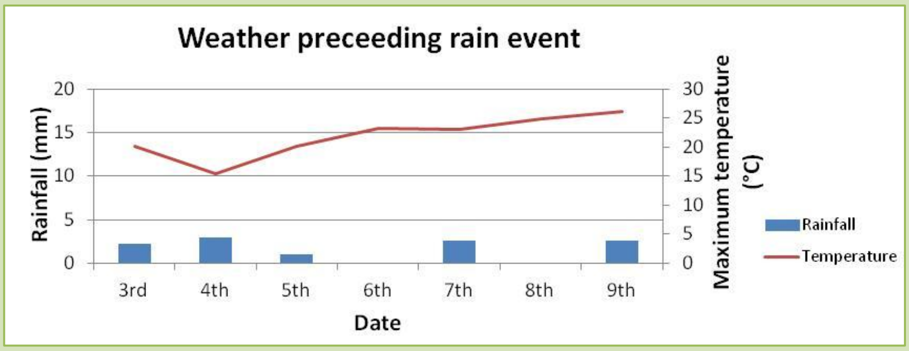
Figure 25. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 7th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 9th June 2014

Rain volume: 2.8 mm

Rain intensity: 22.2 mm/hr

Max temp: 26.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 100%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100 % 100%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: N/A N/A

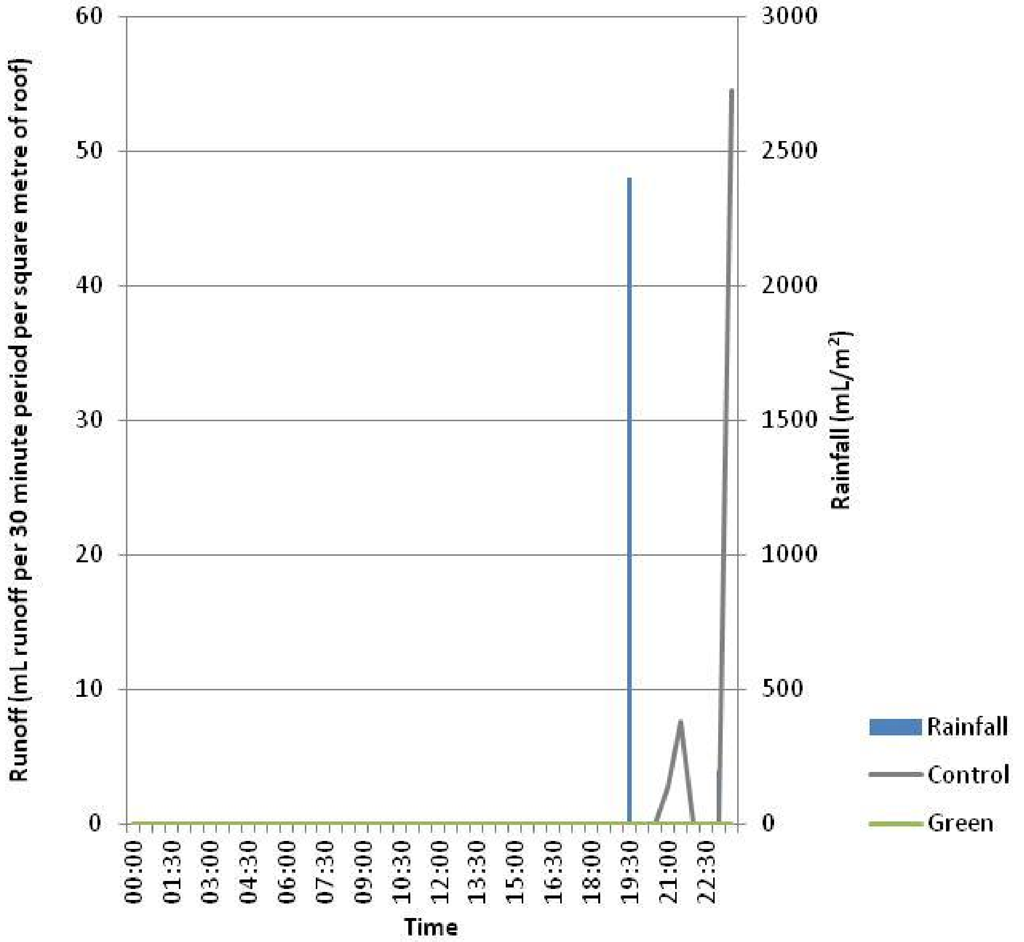


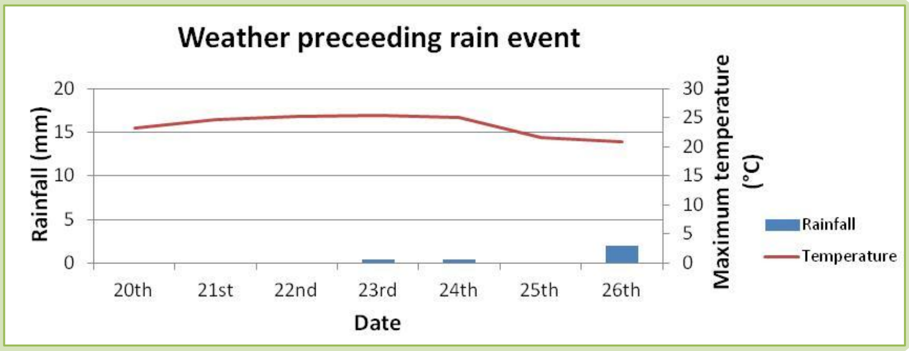
Figure 26. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 9th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 26th June 2014

Rain volume: 2 mm

Rain intensity: 4 mm/hr

Max temp: 20.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

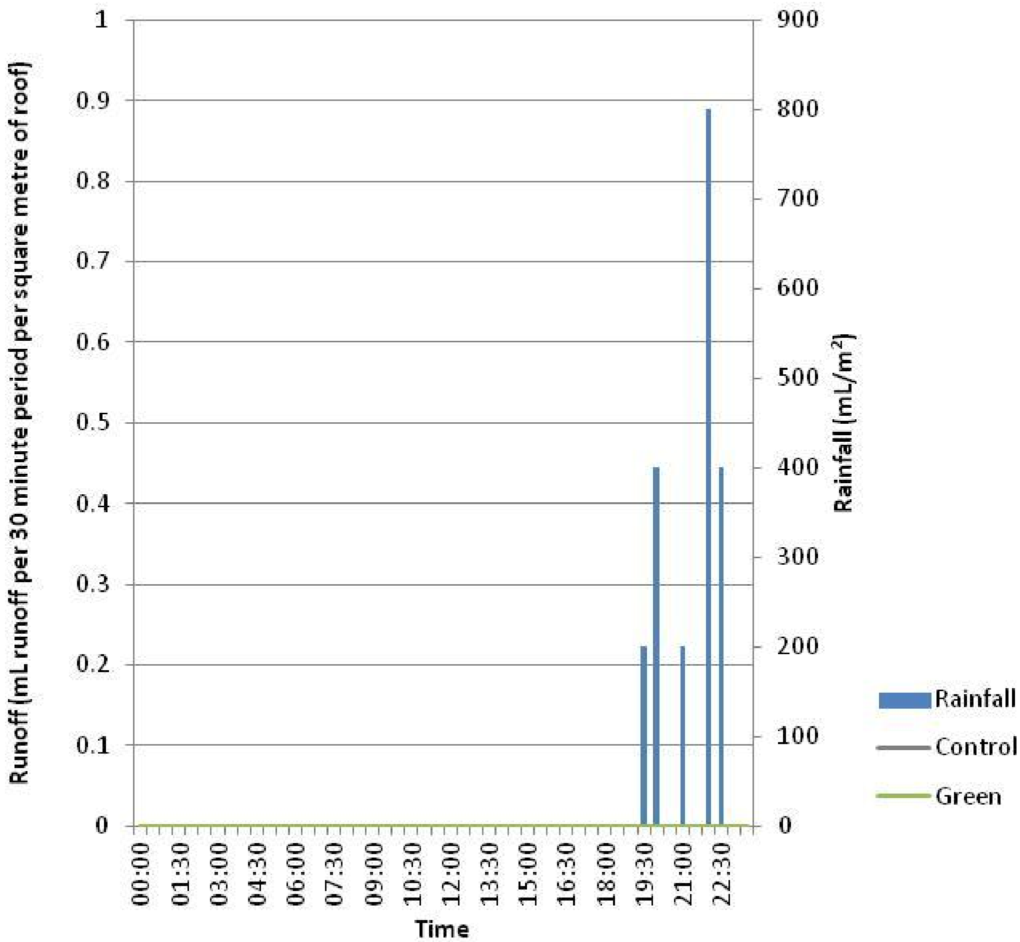


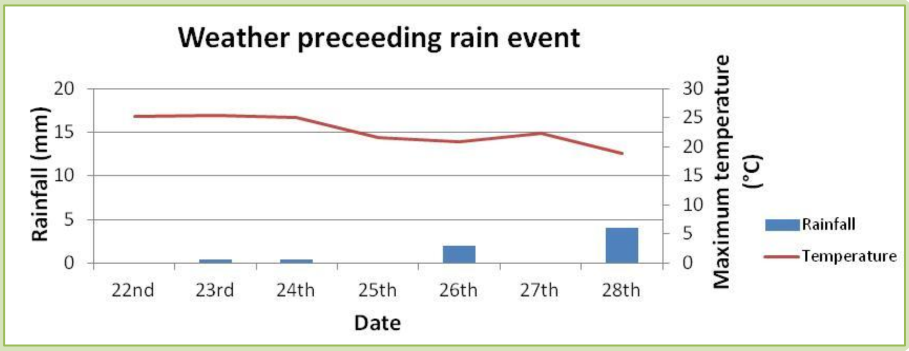
Figure 27. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 28th June 2014

Rain volume: 4 mm

Rain intensity: 69 mm/hr

Max temp: 18.9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

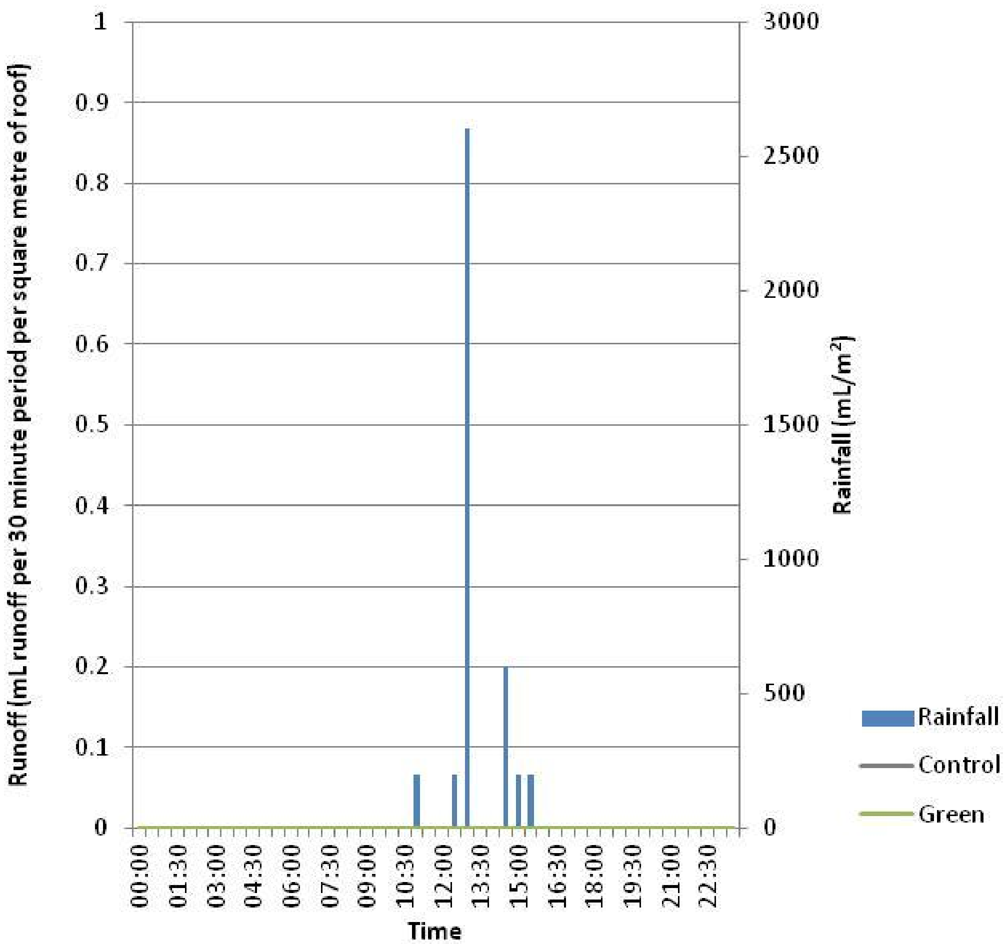


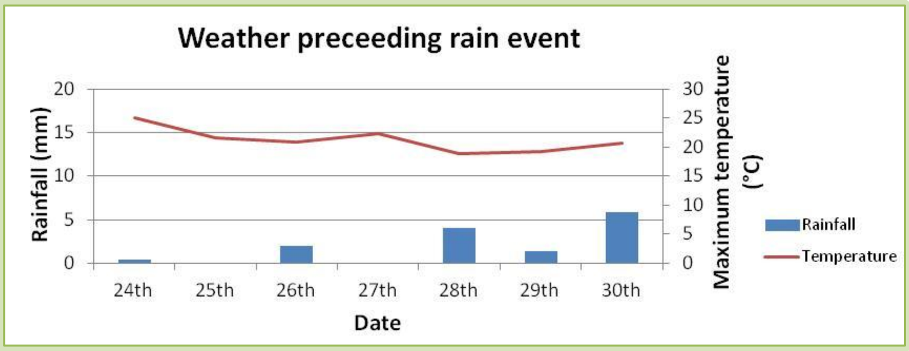
Figure 28. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 28th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 30th June 2014

Rain volume: 5.8 mm

Rain intensity: 89.4 mm/hr

Max temp: 20.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 75 %

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 56 %

Delay in peak flow (hrs):

Peak 1

Green roof: 0.5

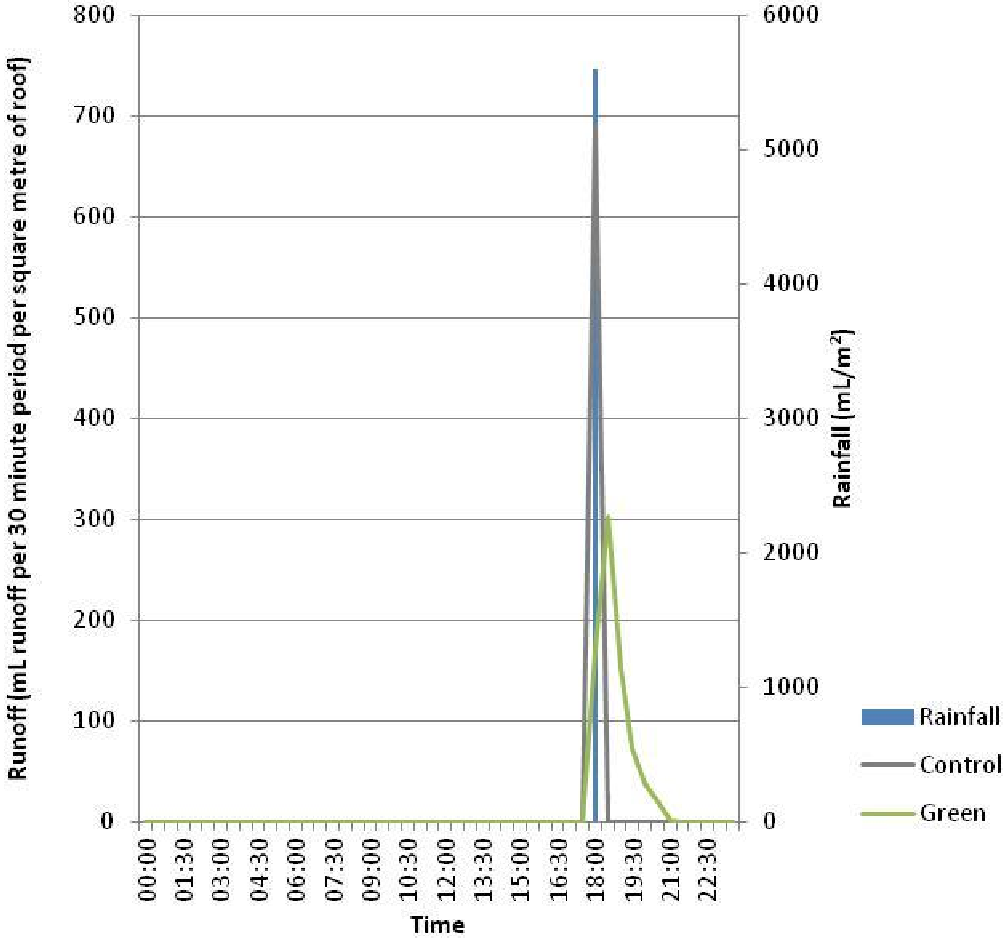


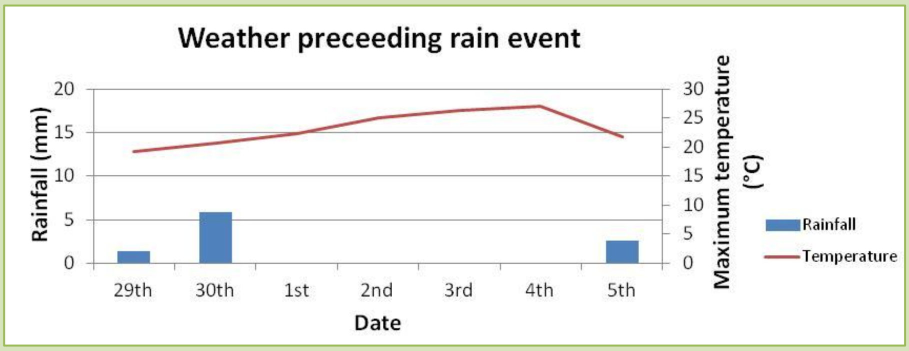
Figure 29. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 30th June 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 5th July 2014

Rain volume: 2.6 mm

Rain intensity: 3.8 mm/hr

Max temp: 21.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof : N/A

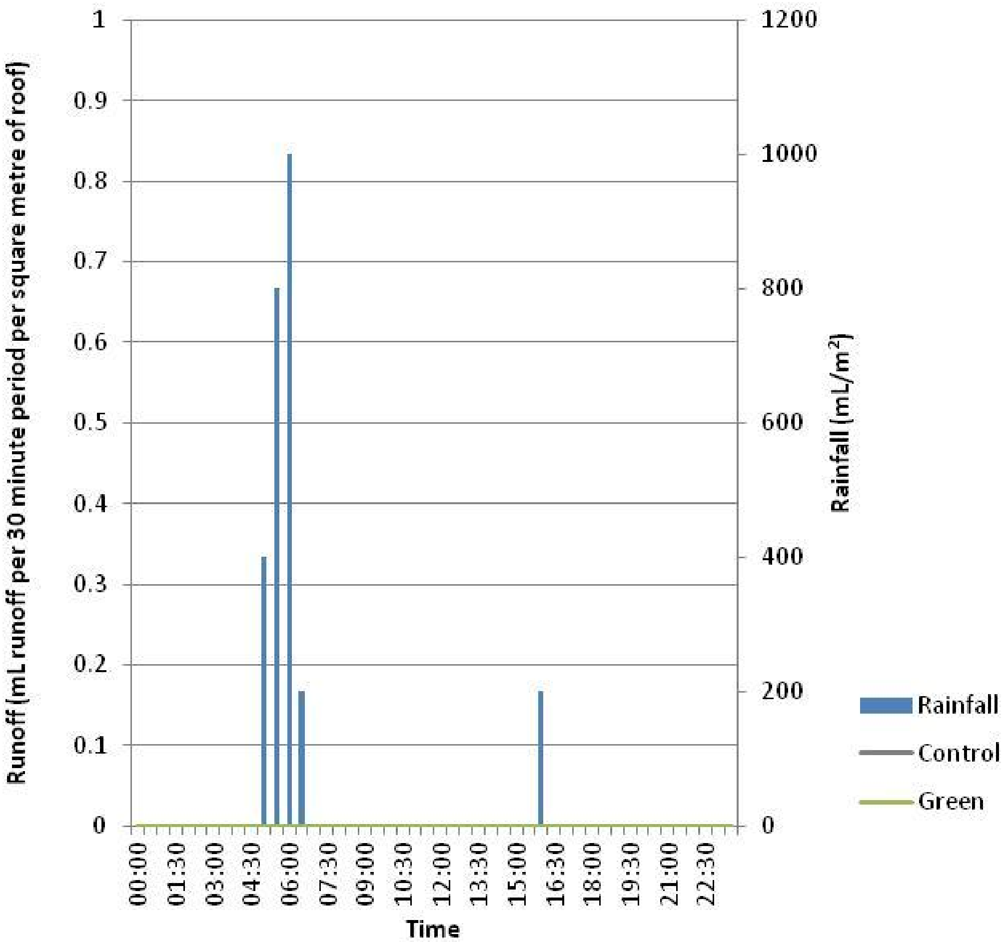


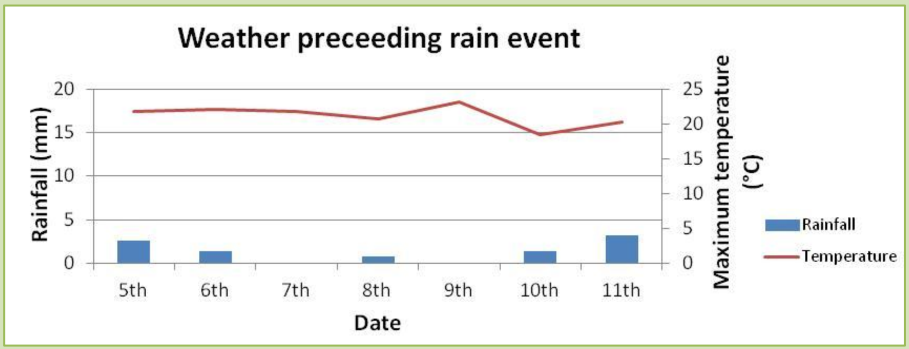
Figure 30. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 5th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 11th July 2014

Rain volume: 3.2 mm

Rain intensity: 5 mm/hr

Max temp: 20.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof : N/A

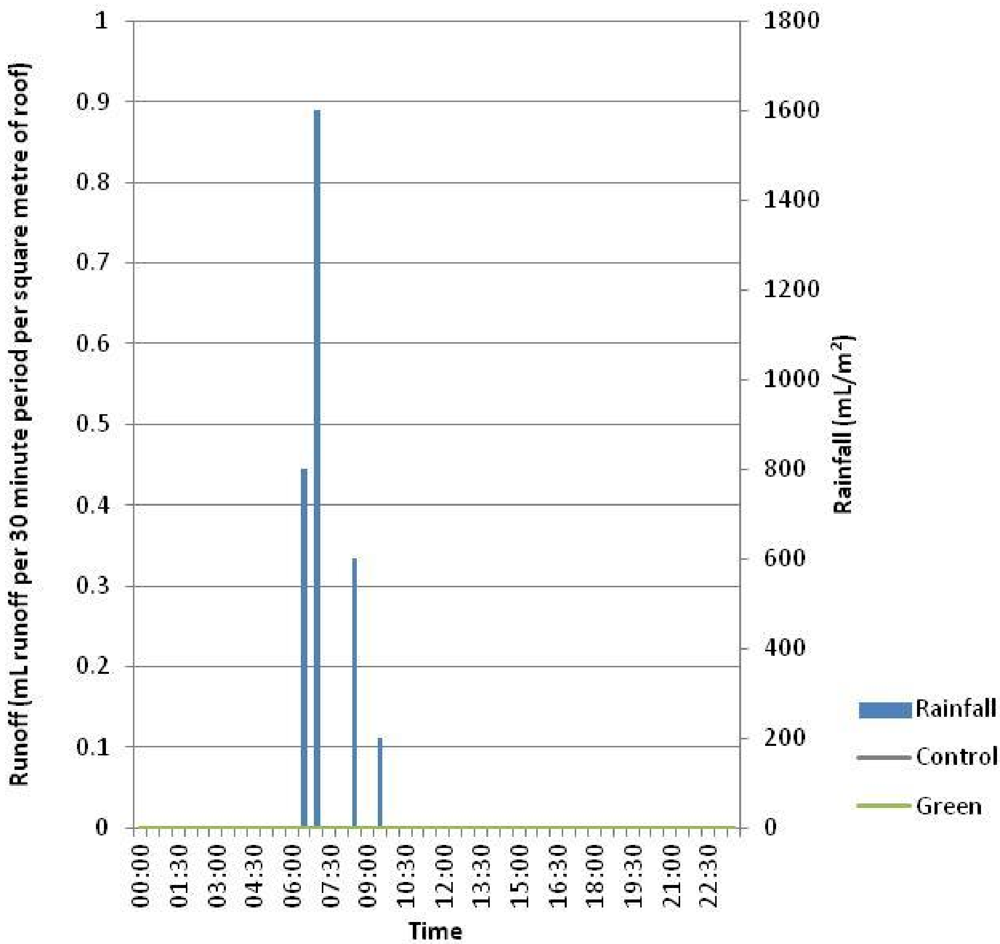


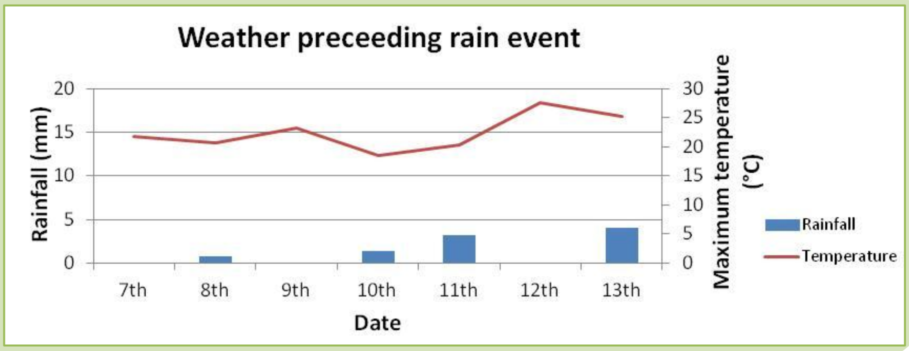
Figure 31. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 11th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 13th July 2014

Rain volume: 4 mm

Rain intensity: 47.2 mm/hr

Max temp: 25.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: -100 %

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: -100 %

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

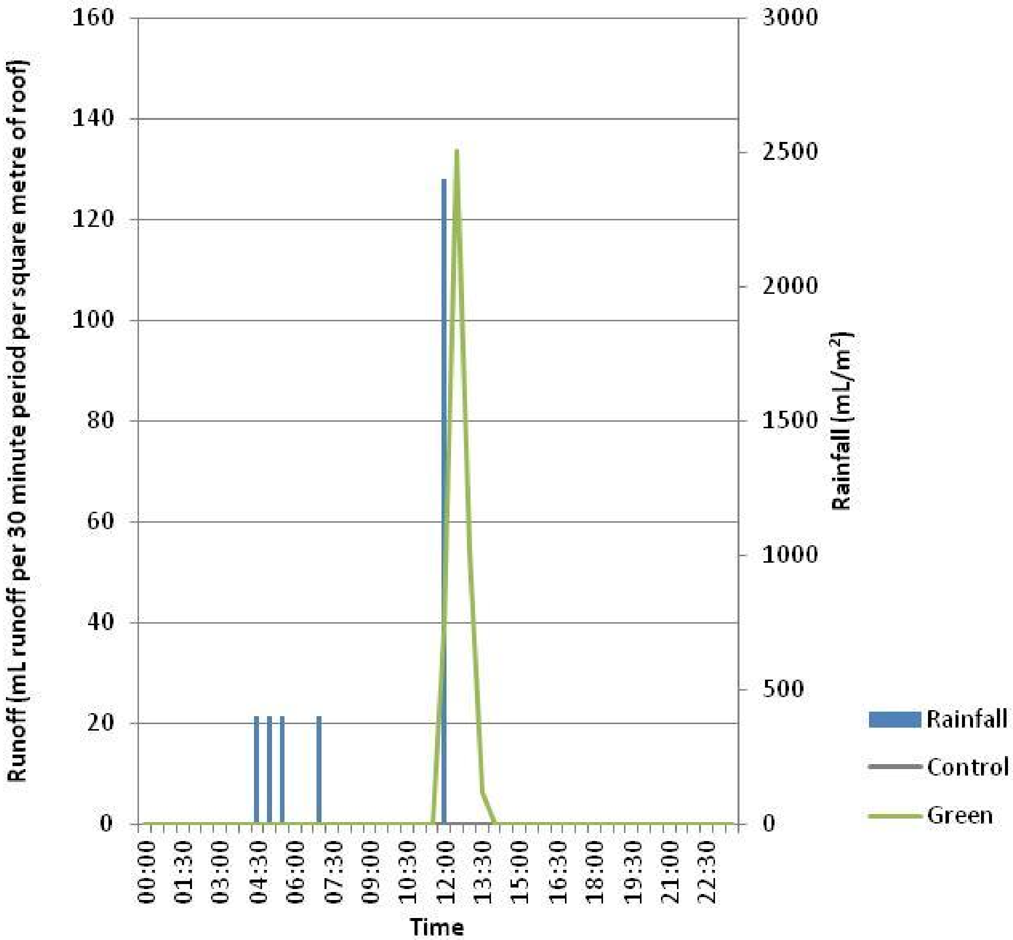


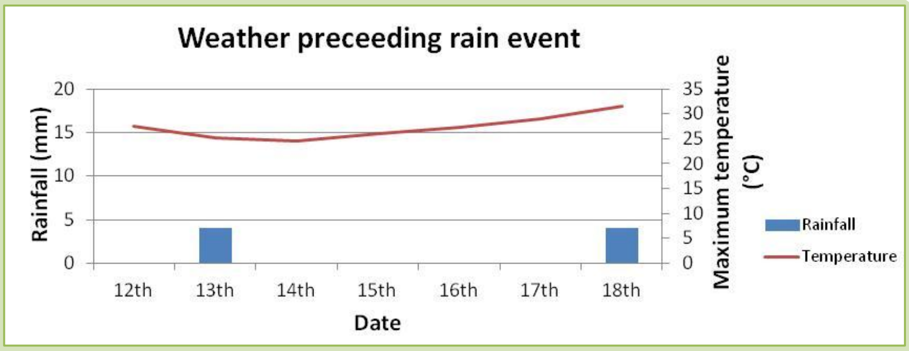
Figure 32. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 13th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 18th July 2014

Rain volume: 4 mm

Rain intensity: 72.4 mm/hr

Max temp: 31.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 0%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

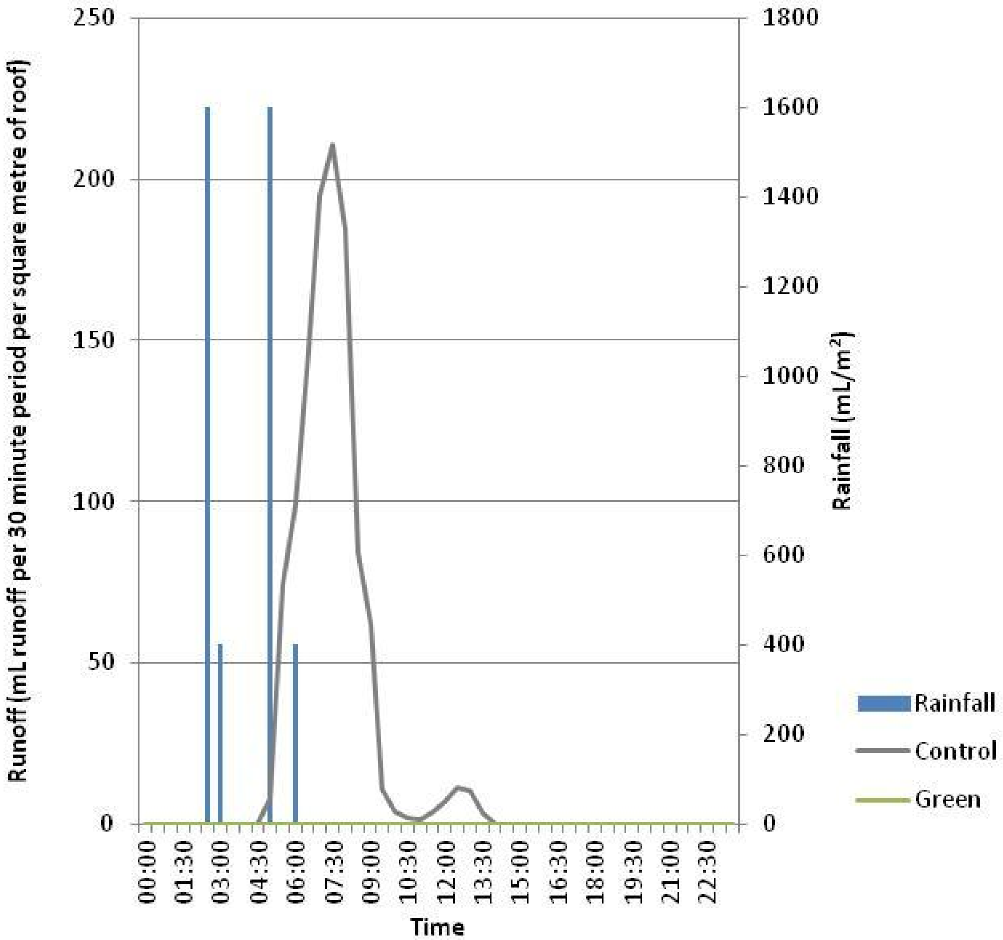


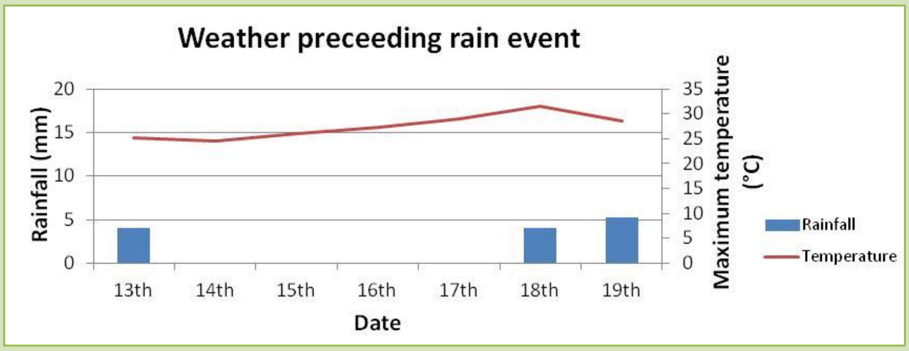
Figure 33. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 18th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 19th July 2014

Rain volume: 5.2 mm

Rain intensity: 48 mm/hr

Max temp: 28.5 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 100%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% 100%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: N/A N/A

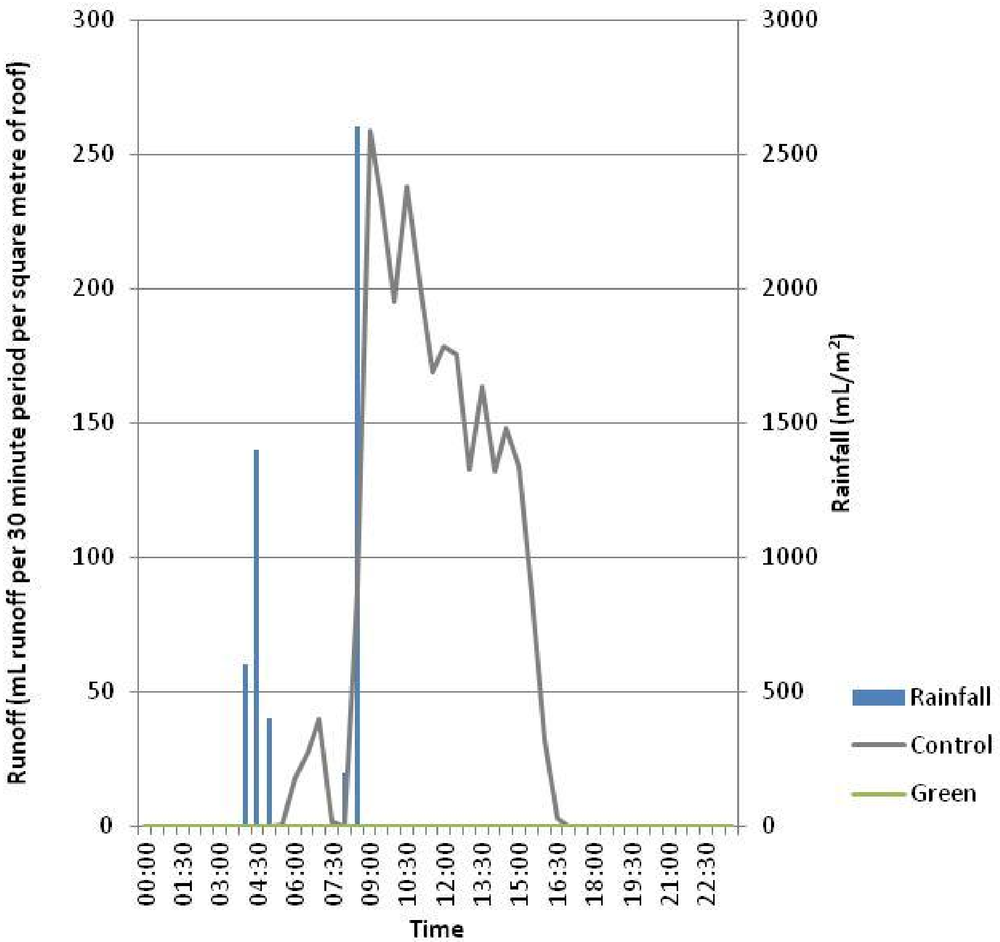


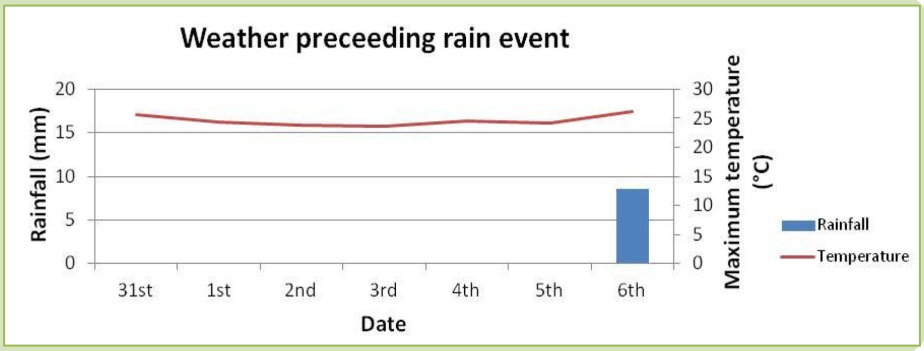
Figure 34. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 19th July 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 6th August 2014

Rain volume: 8.6 mm

Rain intensity: 24.8 mm/hr

Max temp: 26.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

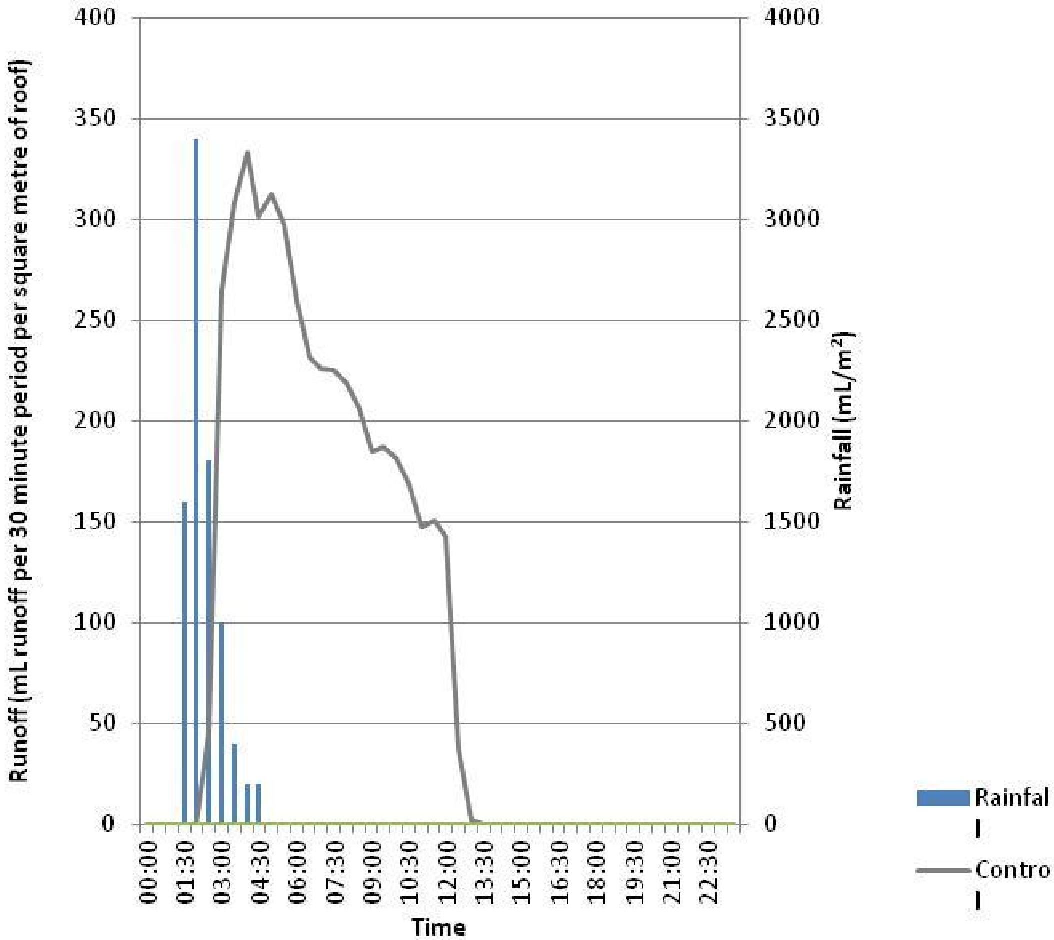


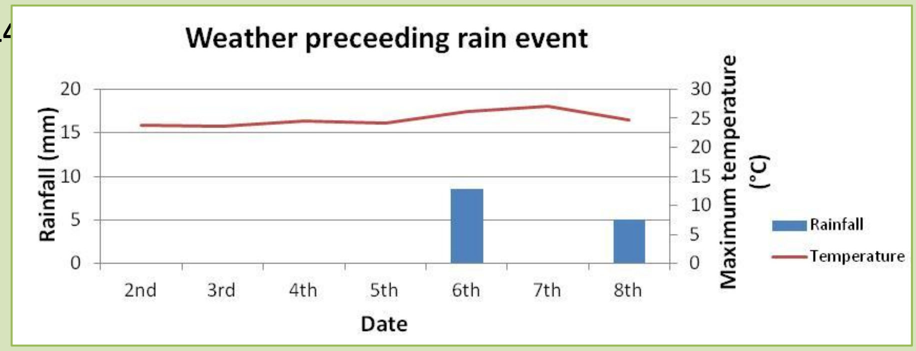
Figure 35. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 6th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 8/9th August 2014

Rain volume: 9.4 mm

Rain intensity: 7 mm/hr

Max temp: 24.7 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

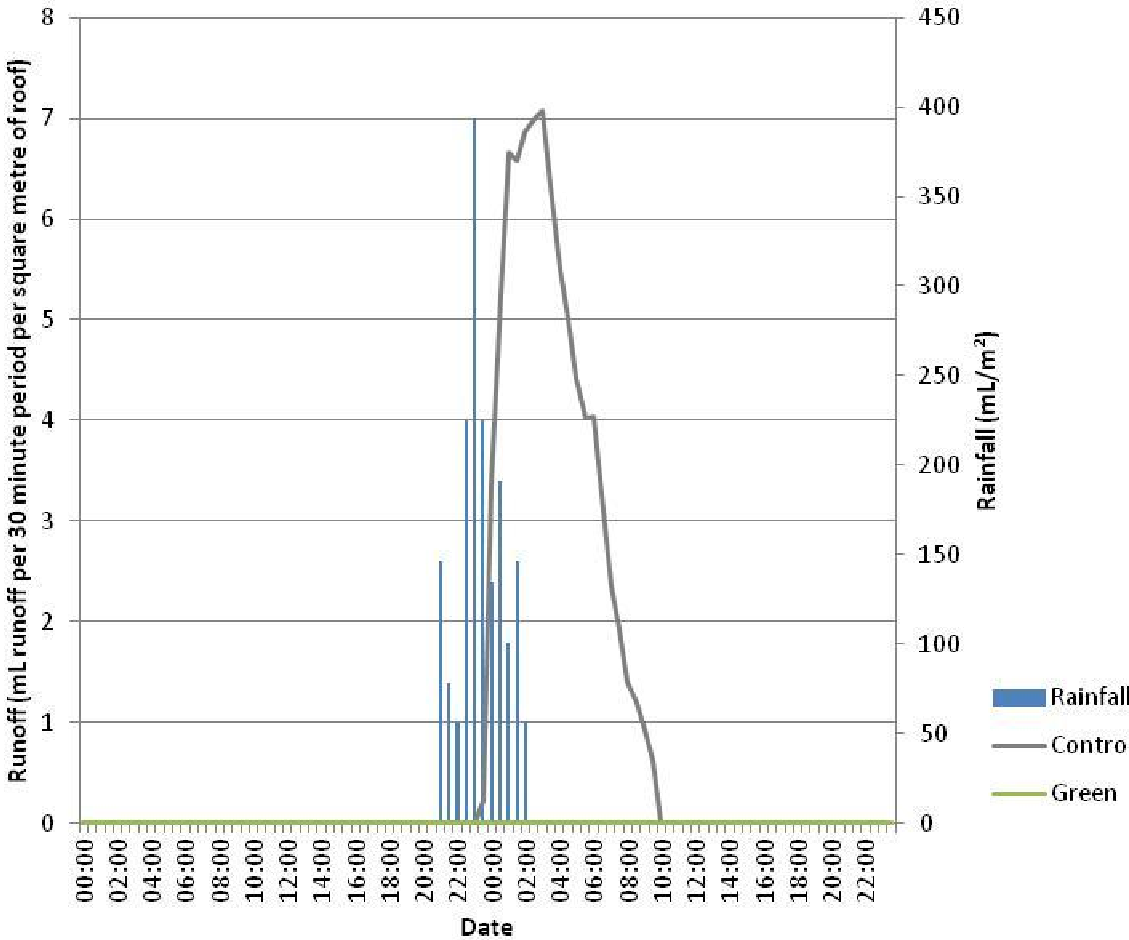


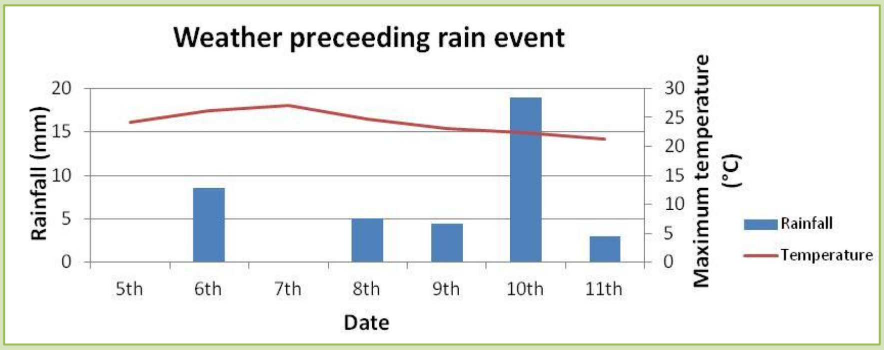
Figure 36. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 8th and 9th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 11th August 2014

Rain volume: 3 mm

Rain intensity: 39.4 mm/hr

Max temp: 21.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

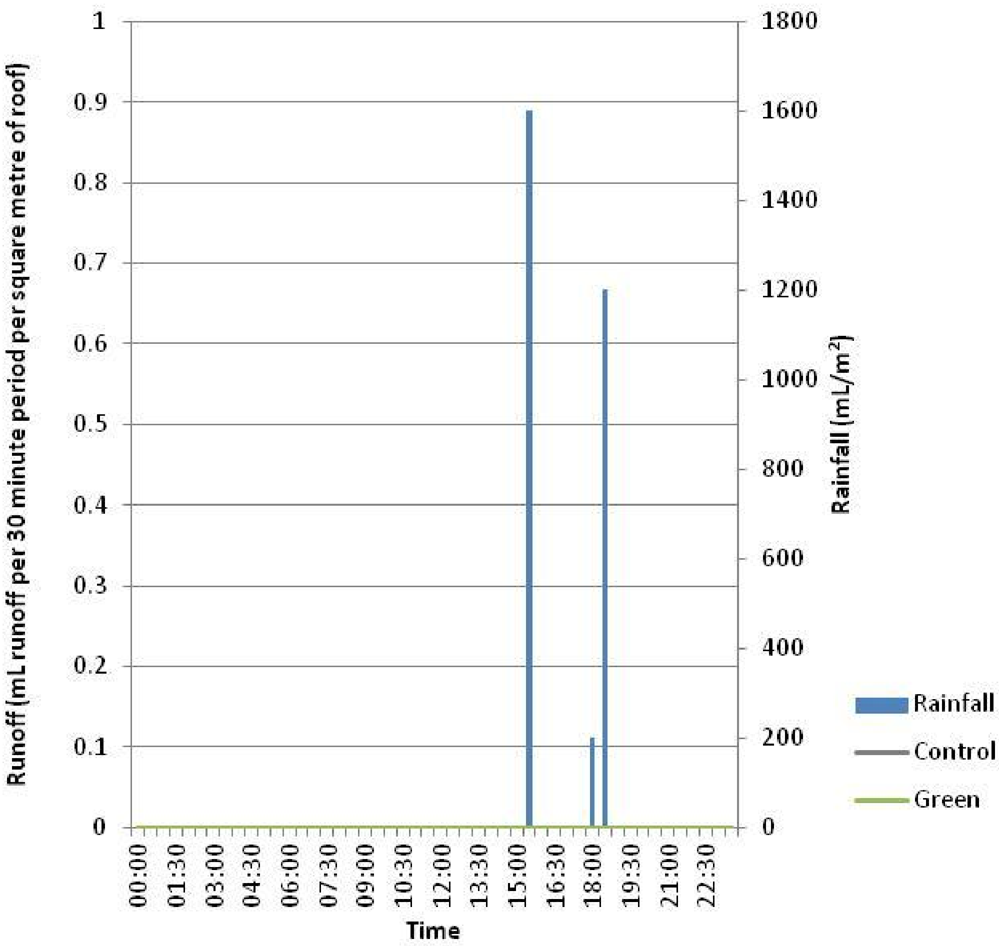


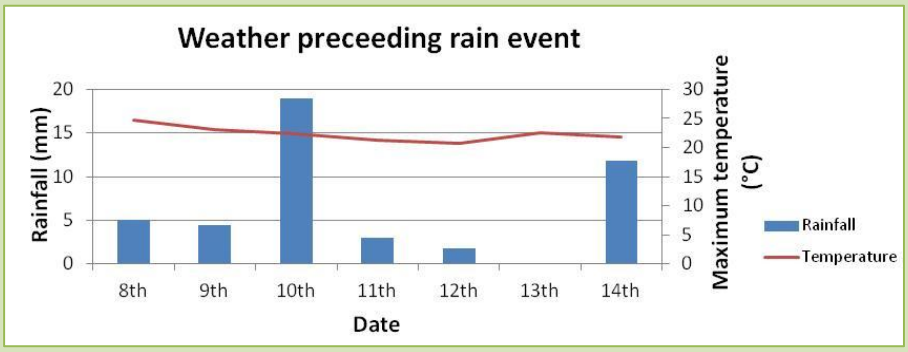
Figure 37. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 11th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 14th August 2014

Rain volume: 11.8 mm

Rain intensity: 77.8 mm/hr

Max temp: 21.9 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	92%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	92%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	0

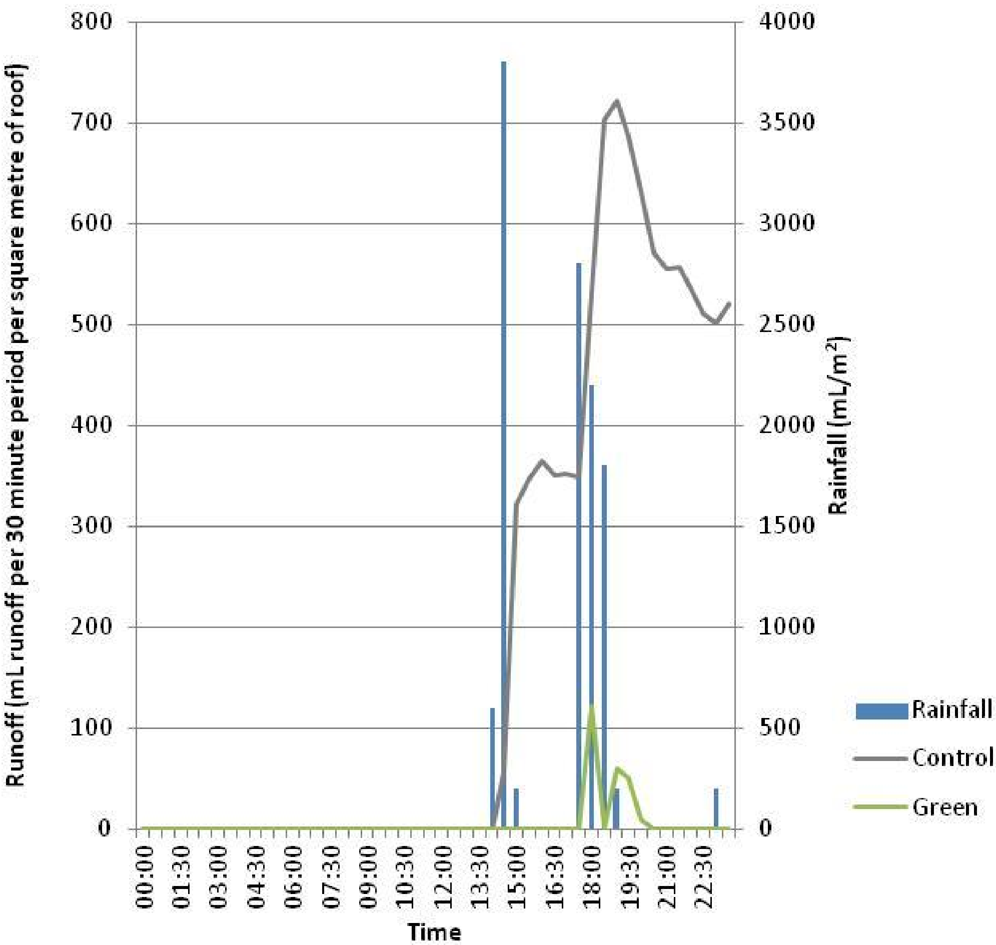


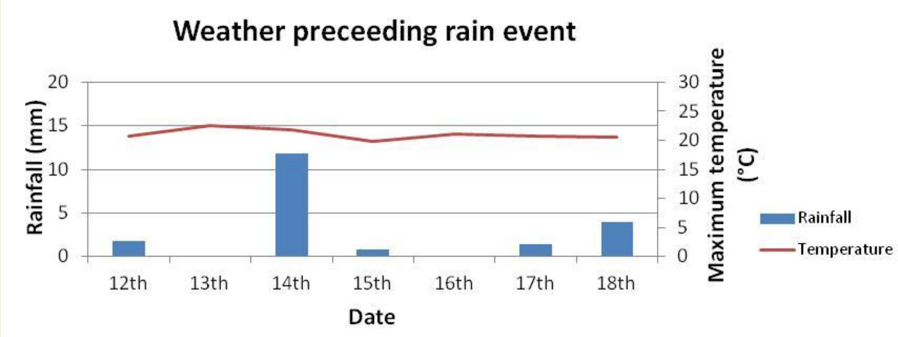
Figure 38. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 14th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 18th August 2014

Rain volume: 4 mm

Rain intensity: 11.8 mm/hr

Max temp: 20.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 100%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% 100%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	N/A

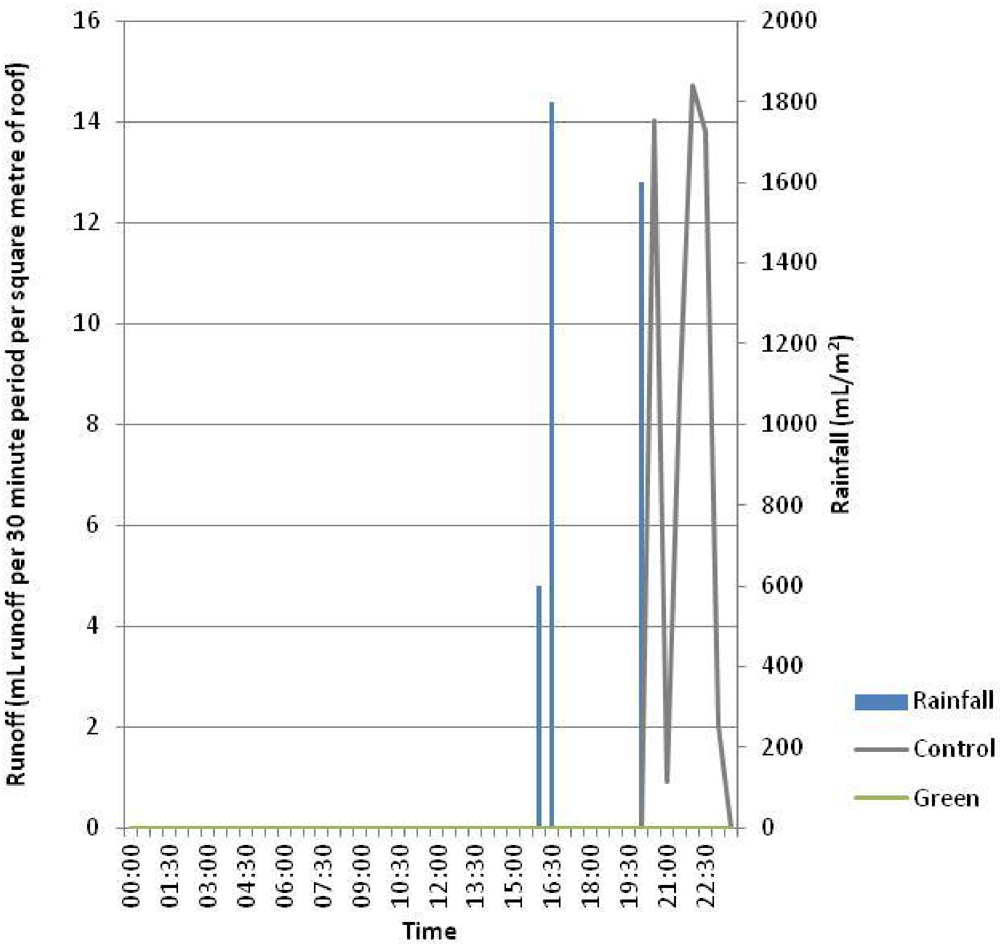


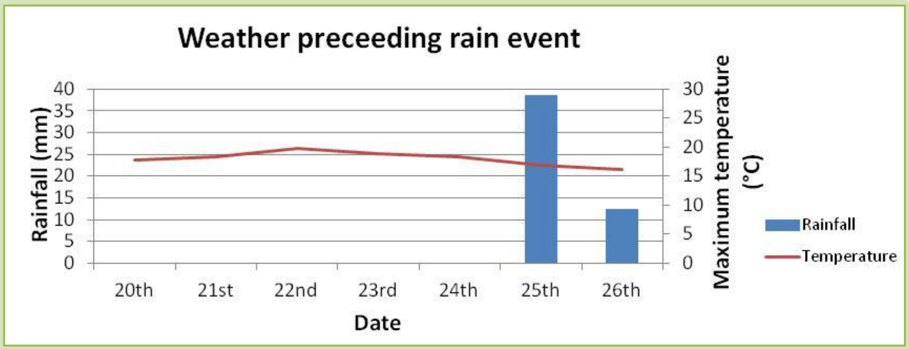
Figure 39. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 18th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 26th August 2014

Rain volume: 12.5 mm

Rain intensity: 24 mm/hr

Max temp: 16.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 95% 36%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 38% 36%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: 1 0

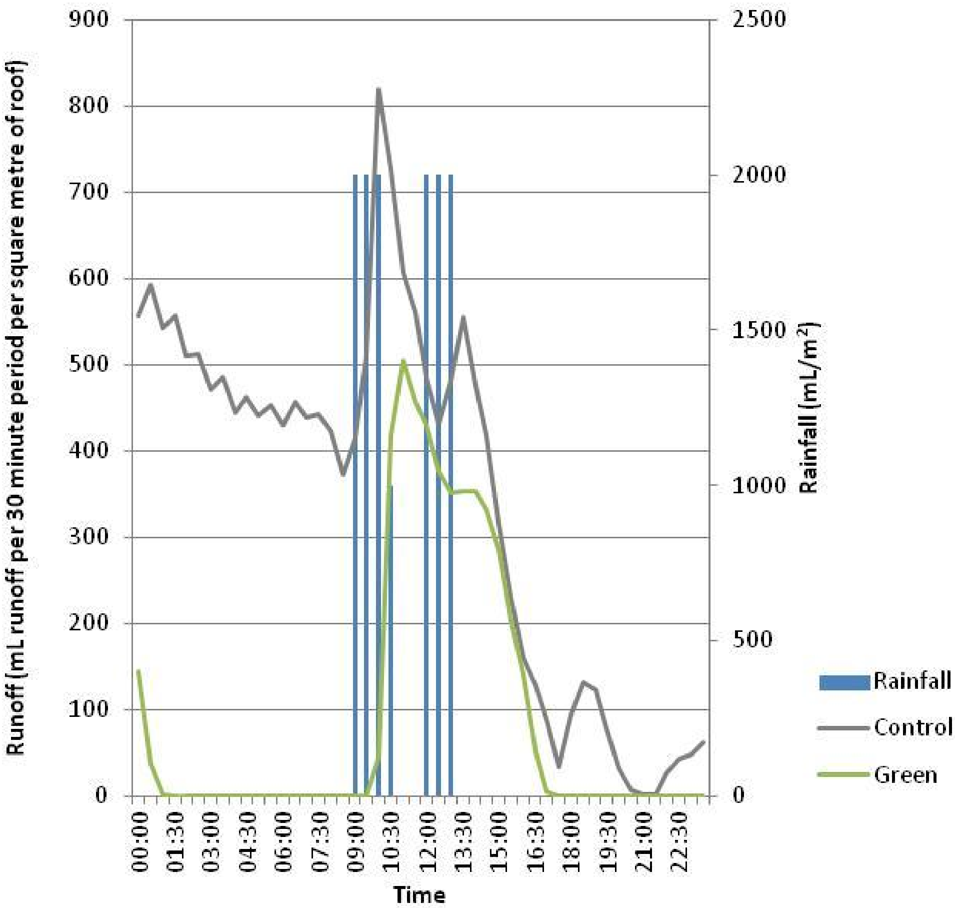


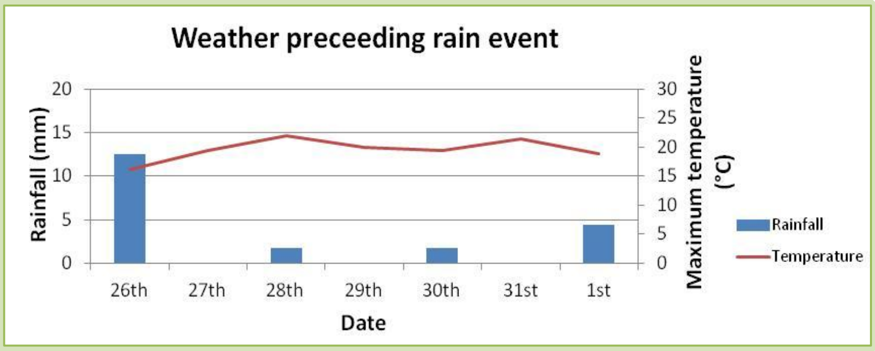
Figure 40. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th August 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. *N.B. weather data based on Hampstead weather station, approx 4.5 miles from Museum of London due to weather station datalogger malfunction.*

Rain event: 1st September 2014

Rain volume: 4.4 mm

Rain intensity: 30 mm/hr

Max temp: 18.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 71%

Delay in peak flow (hrs):

Peak 1

Green roof: -0.5

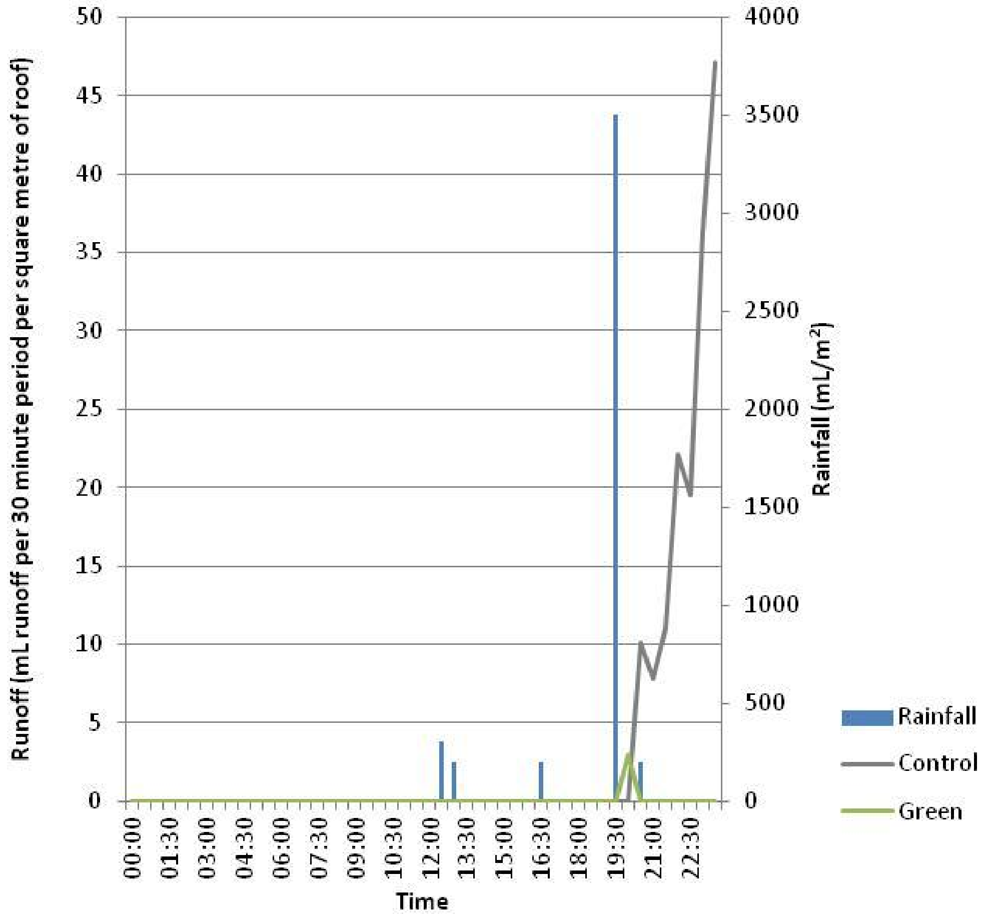


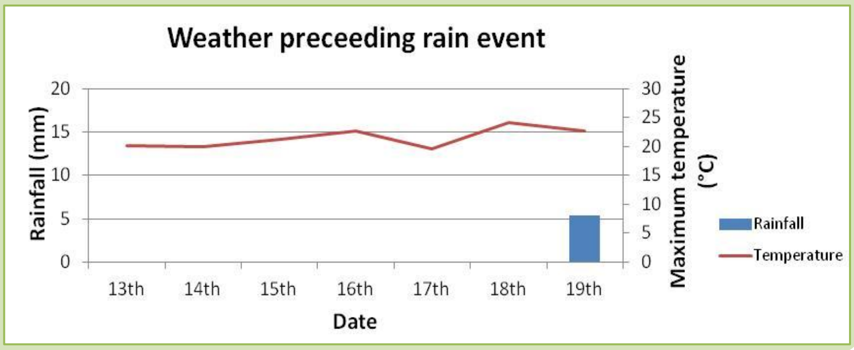
Figure 41. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 1st September 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. *N.B. weather data based on Hampstead weather station, approx 4.5 miles from Museum of London due to weather station datalogger malfunction.*

Rain event: 19th September 2014

Rain volume: 5.4 mm

Rain intensity: 66 mm/hr

Max temp: 22.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 0 %

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 51% 0 %

Delay in peak flow (hrs):

Peak 1

Green roof: -0.5

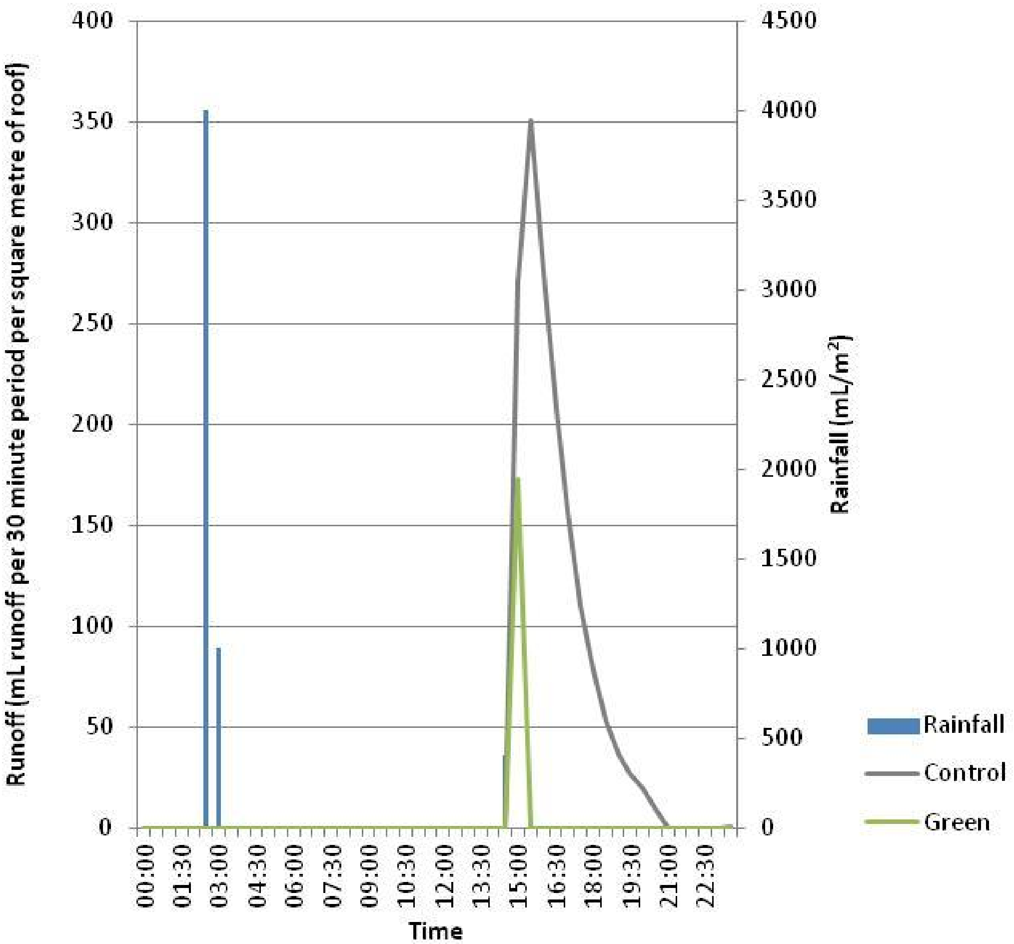


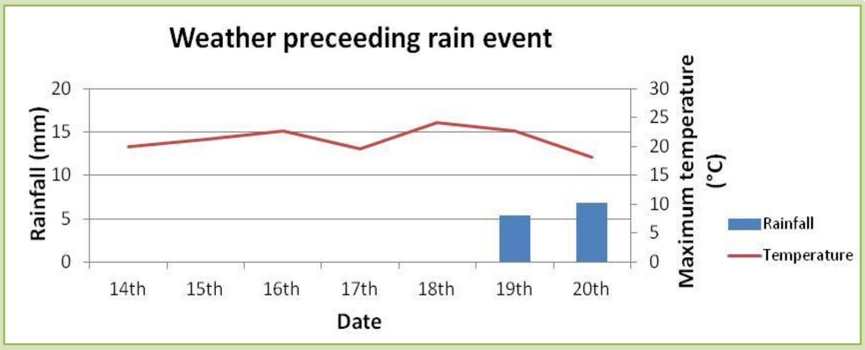
Figure 42. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 19th September 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 20th September 2014

Rain volume: 6.8 mm

Rain intensity: 88 mm/hr

Max temp: 19.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 66%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 66%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

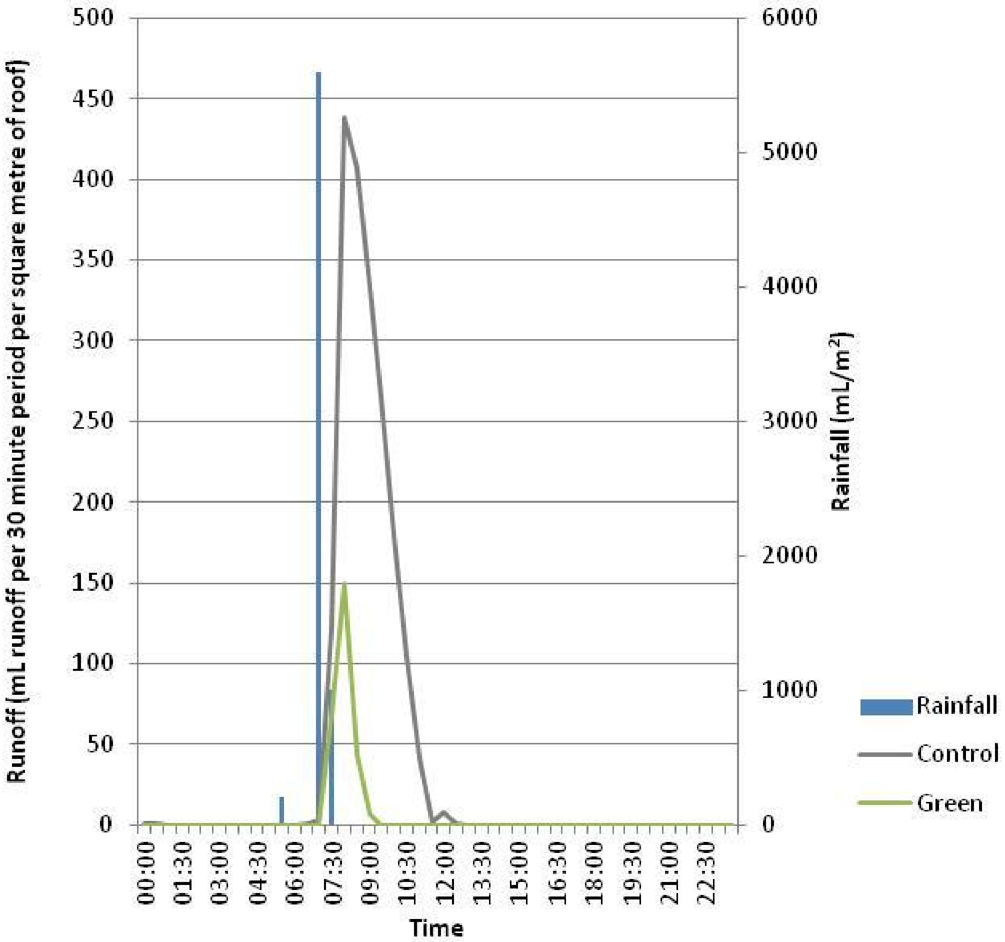


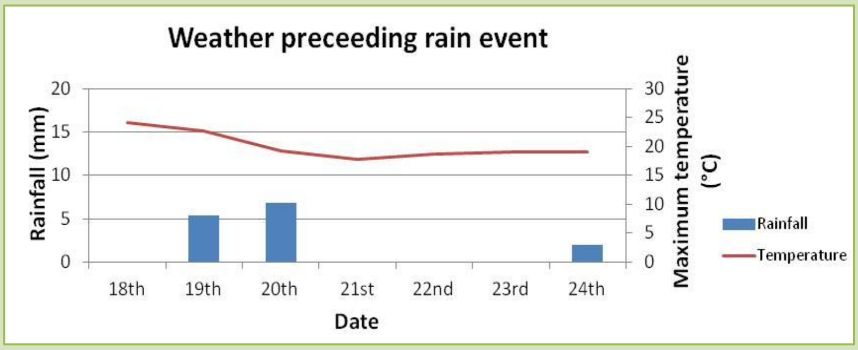
Figure 43. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 20th September 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 24th September 2014

Rain volume: 2 mm

Rain intensity: 1 mm/hr

Max temp: 19 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

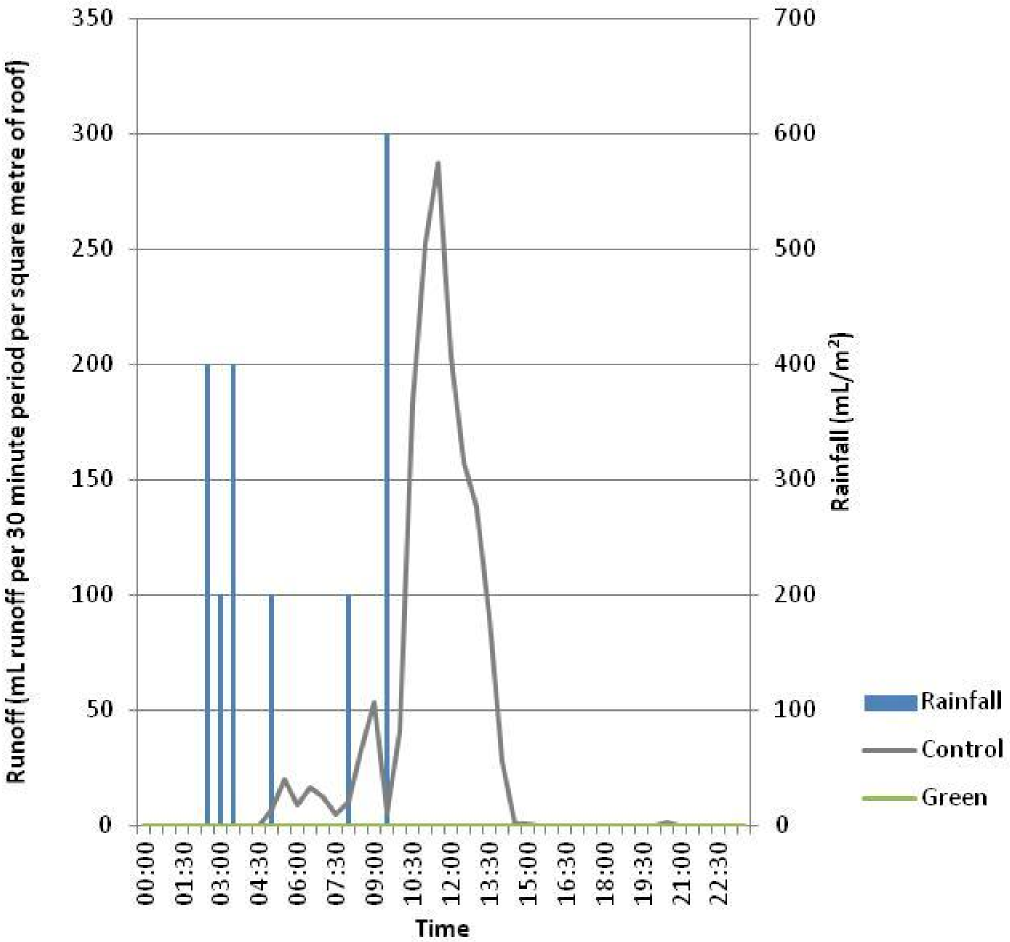


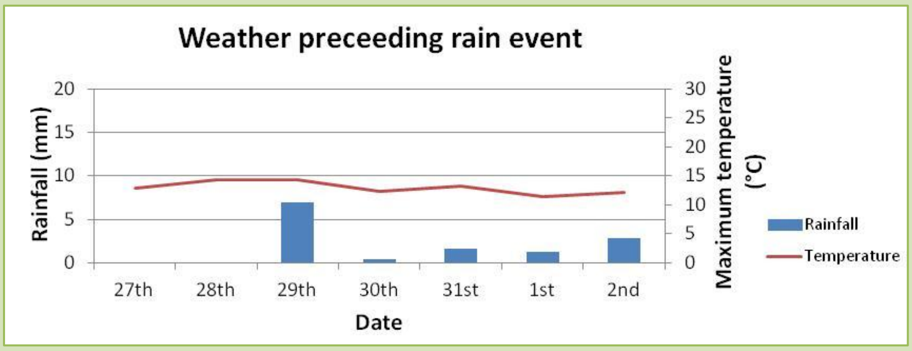
Figure 44. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 24th September 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 2nd April 2015

Rain volume: 2.8 mm

Rain intensity: 21.2 mm/hr

Max temp: 12.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 86%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 55%

Delay in peak flow (hrs):

Peak 1

Green roof: 4

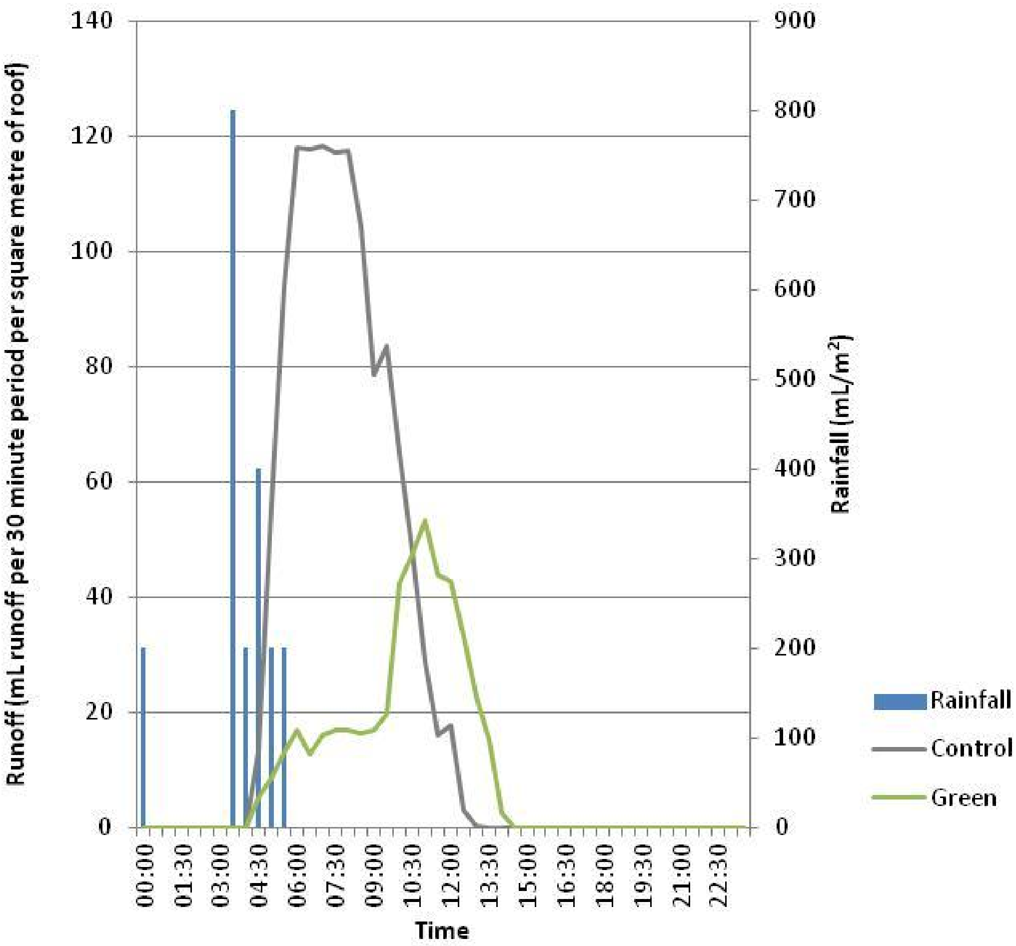


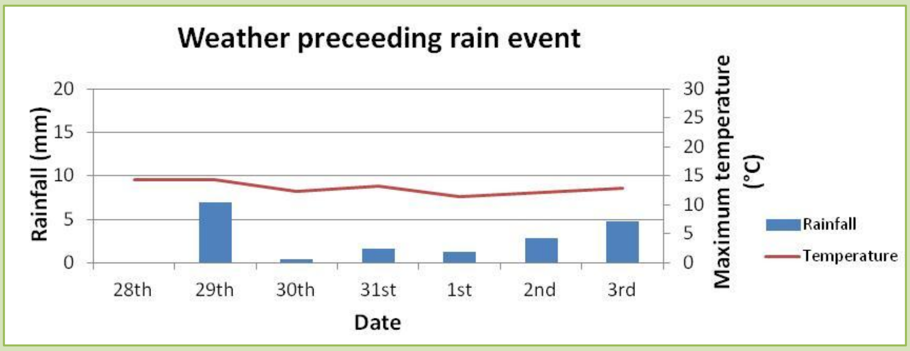
Figure 45. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 2nd April 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 3rd April 2015

Rain volume: 4.8 mm

Rain intensity: 2.4 mm/hr

Max temp: 12.9 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 100%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% -18%

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: N/A 5

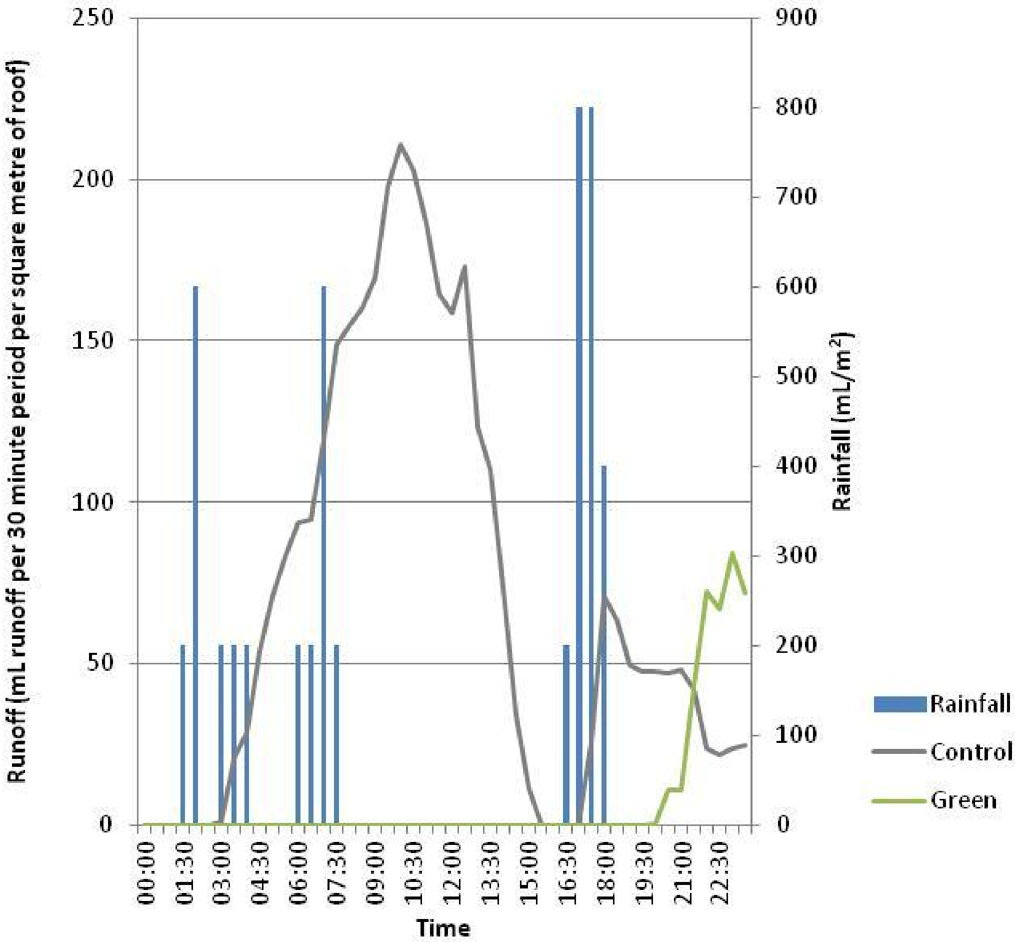


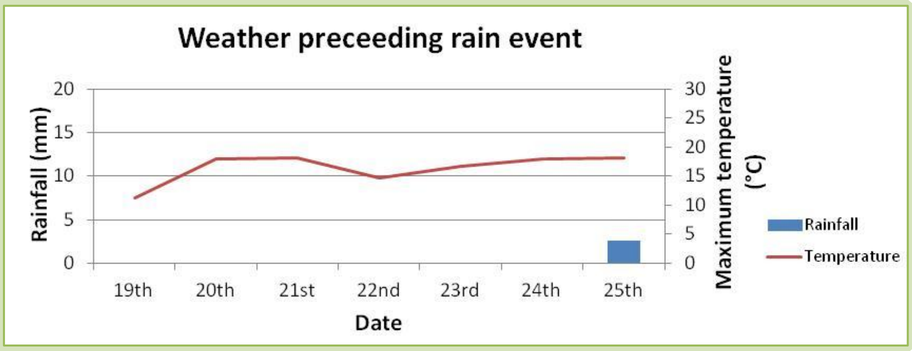
Figure 46. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 3rd April 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 25th April 2015

Rain volume: 2.6 mm

Rain intensity: 3.8 mm/hr

Max temp: 18.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

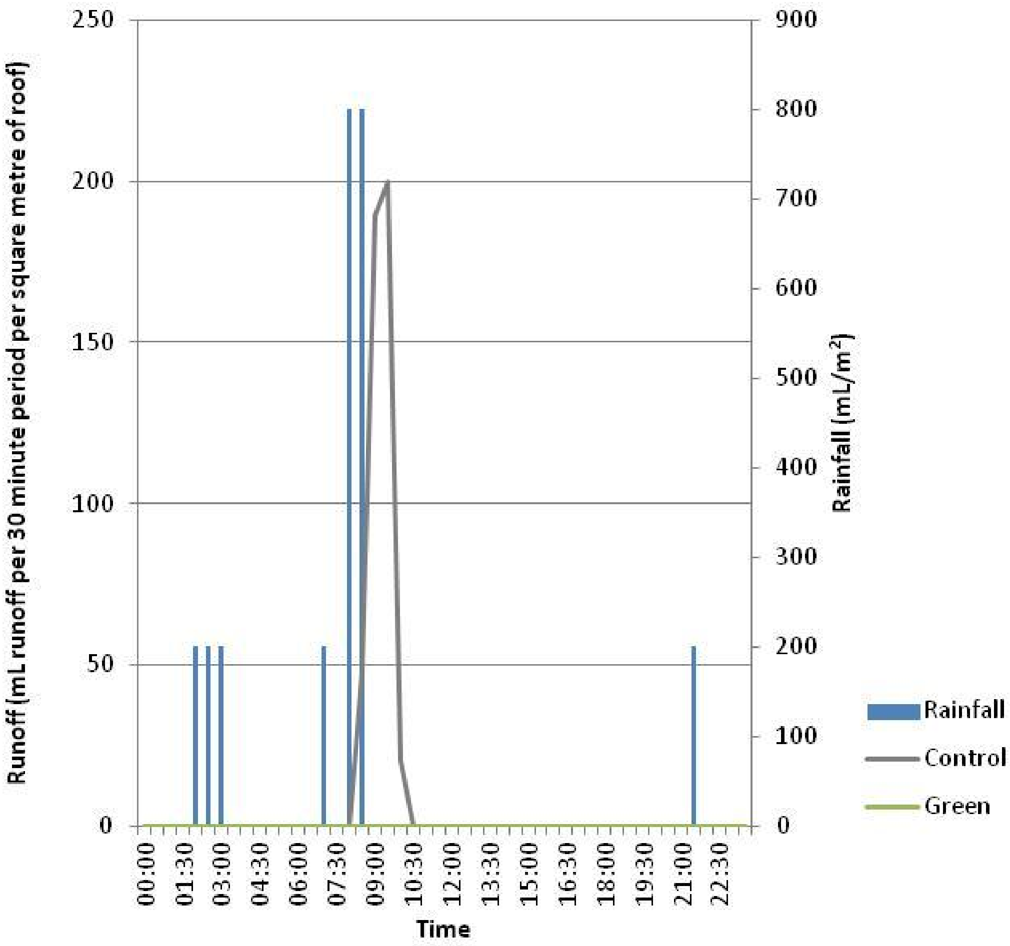


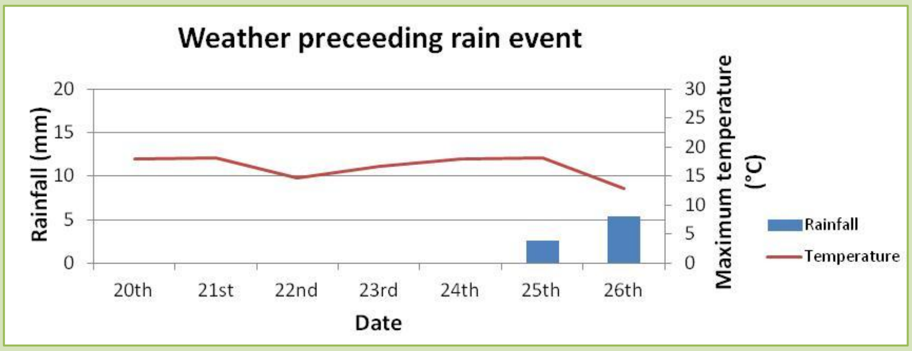
Figure 47. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 25th April 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 26th April 2015

Rain volume: 5.4 mm

Rain intensity: 14.2 mm/hr

Max temp: 12.9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 87%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 37%

Delay in peak flow (hrs):

Peak 1

Green roof: -0.5

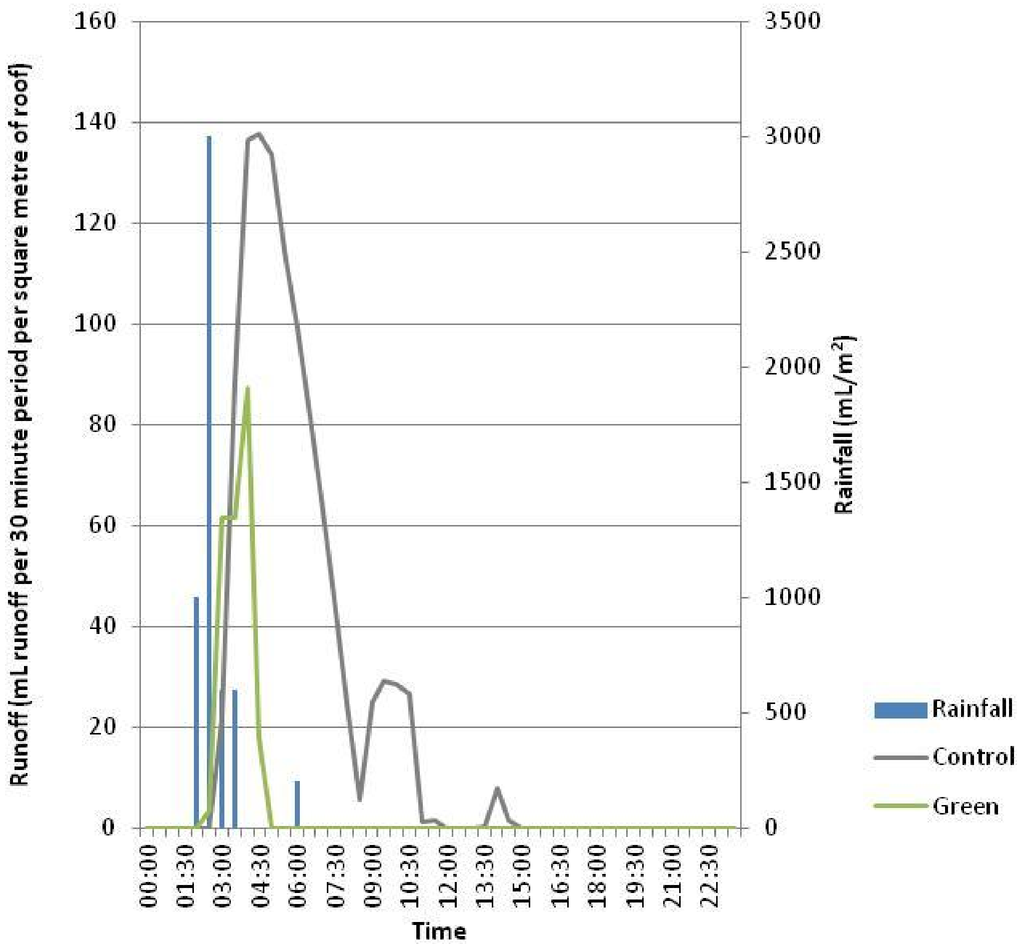


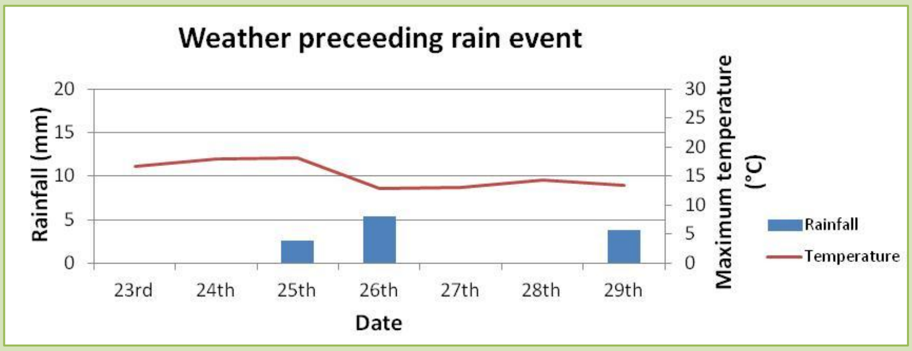
Figure 48. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th April 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 29th April 2015

Rain volume: 3.8 mm

Rain intensity: 7.8 mm/hr

Max temp: 13.5 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

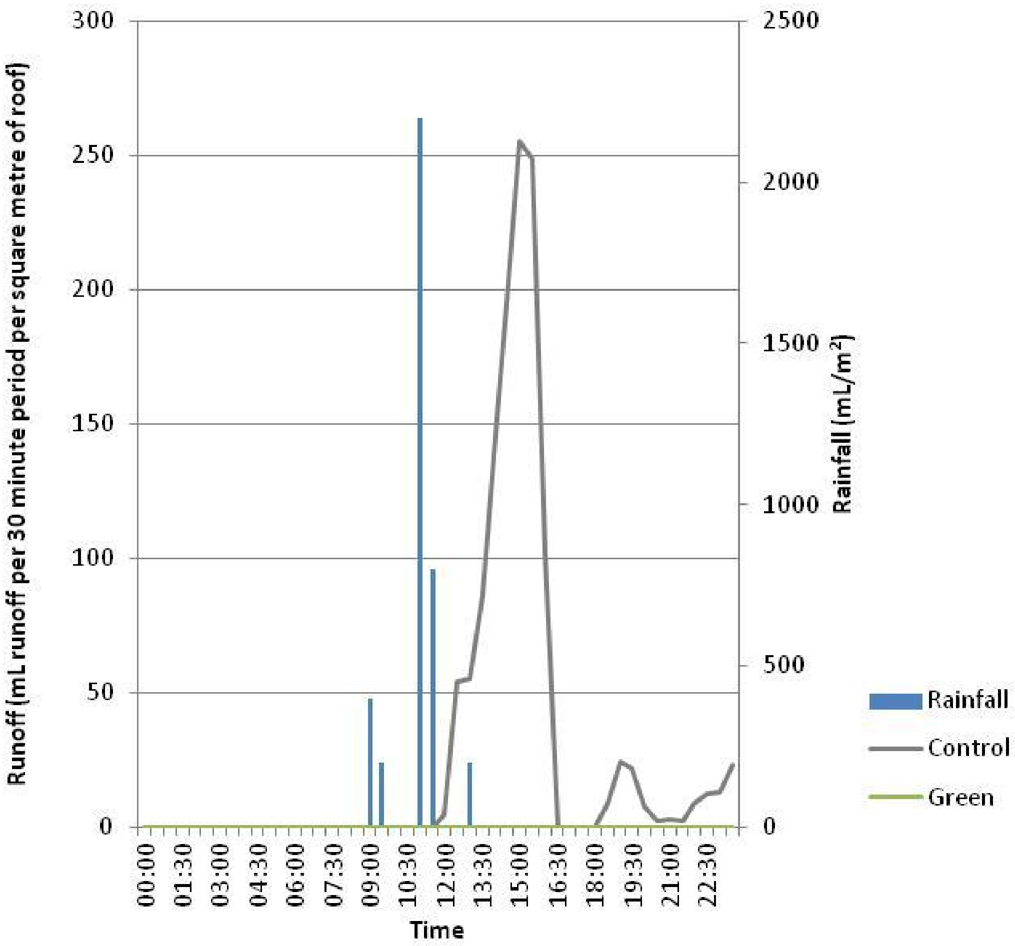


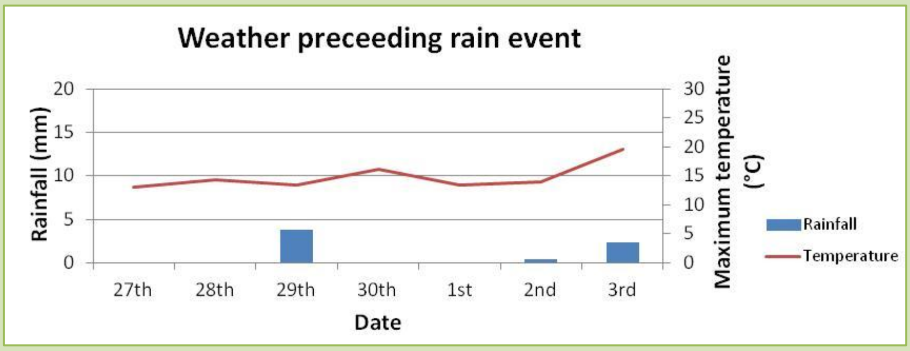
Figure 49. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 29th April 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 3rd May 2015

Rain volume: 2.4 mm

Rain intensity: 3 mm/hr

Max temp: 19.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

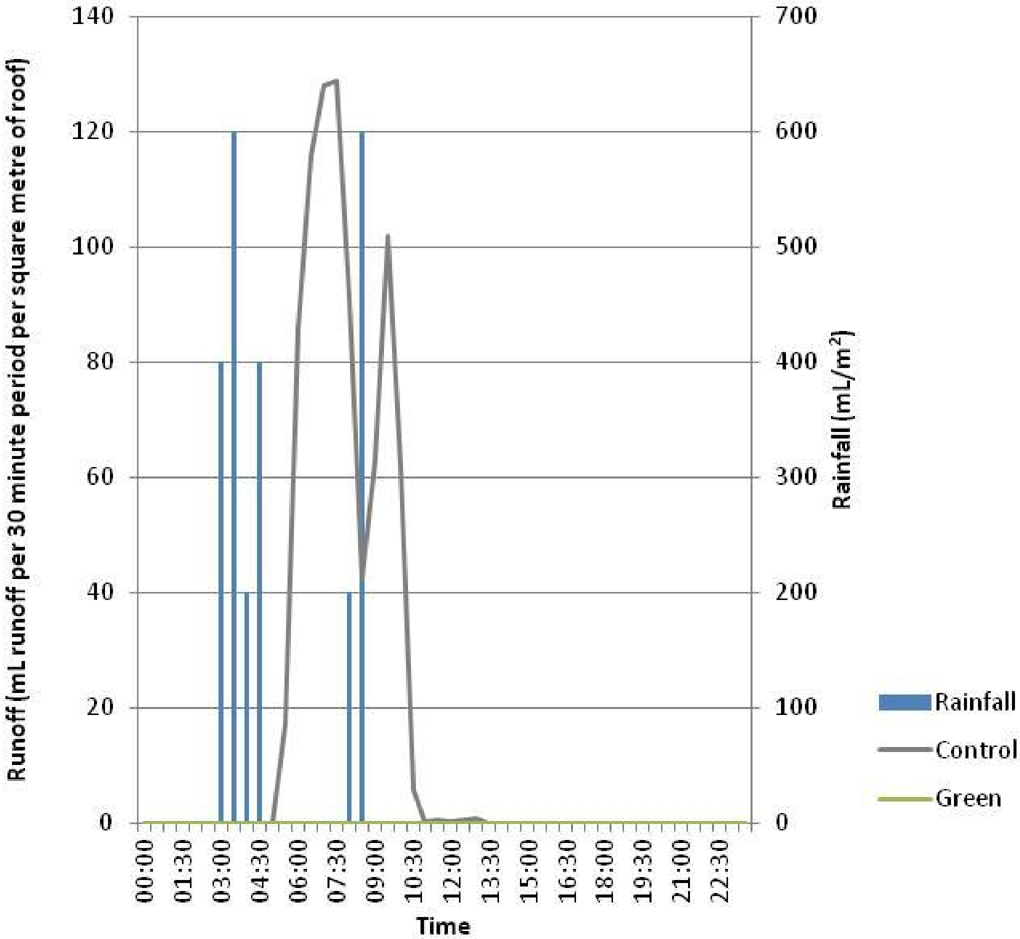


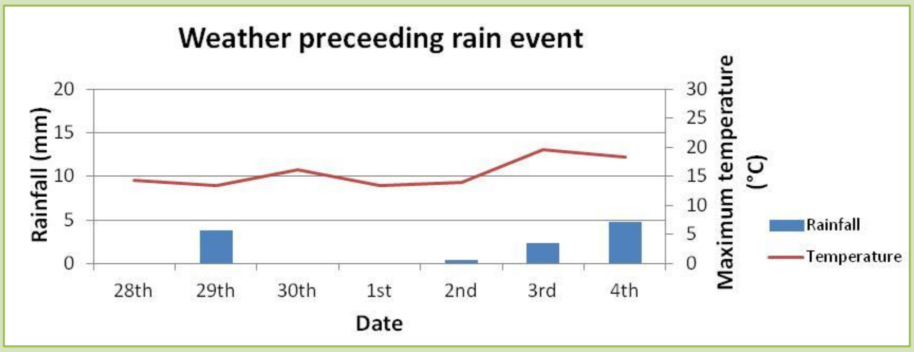
Figure 50. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 3rd May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 4th May 2015

Rain volume: 4.8 mm

Rain intensity: 5.2 mm/hr

Max temp: 18.4 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 99%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 99%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

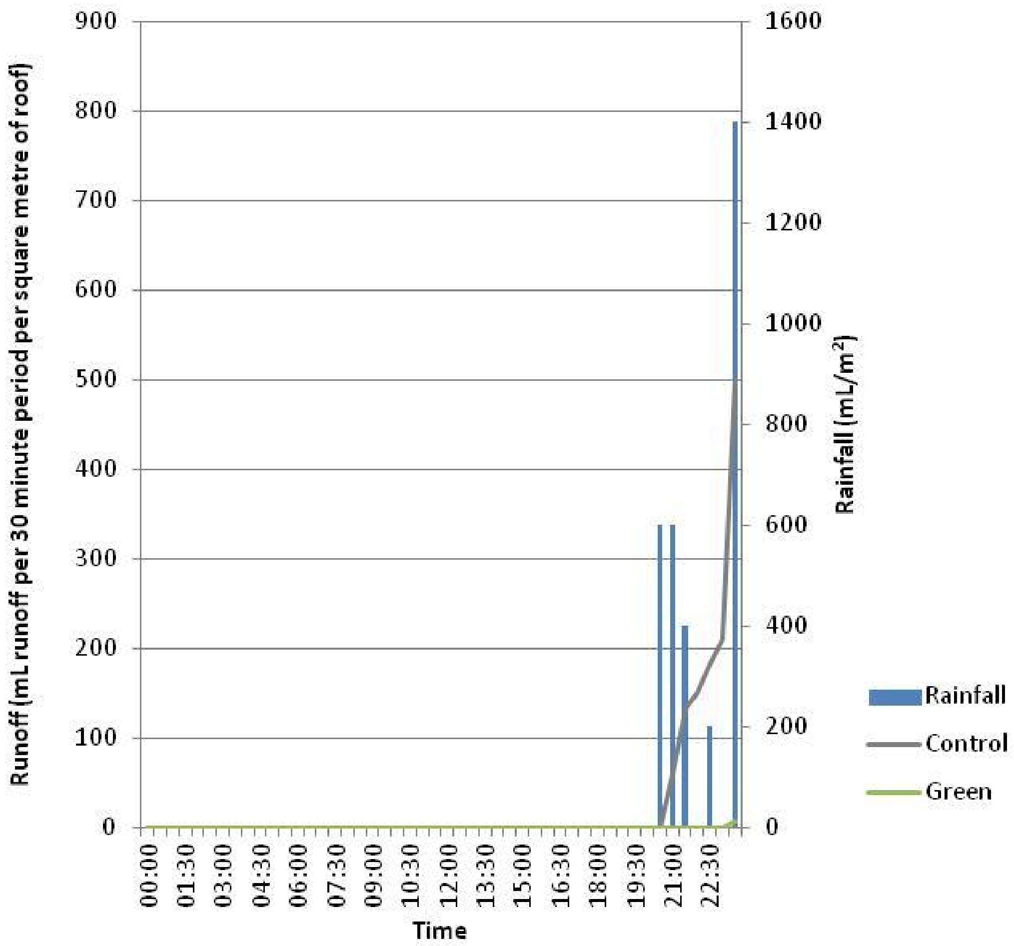


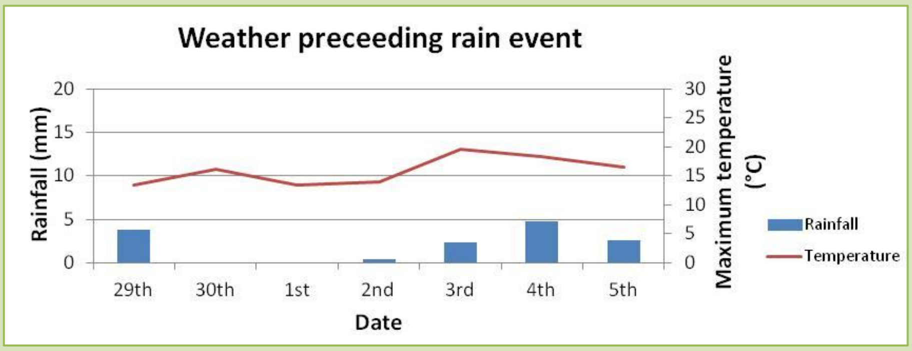
Figure 51. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 4th May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 5th May 2015

Rain volume: 2.6 mm

Rain intensity: 5.2 mm/hr

Max temp: 16.5 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 96%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 88%

Delay in peak flow (hrs):

Peak 1

Green roof: -0.5

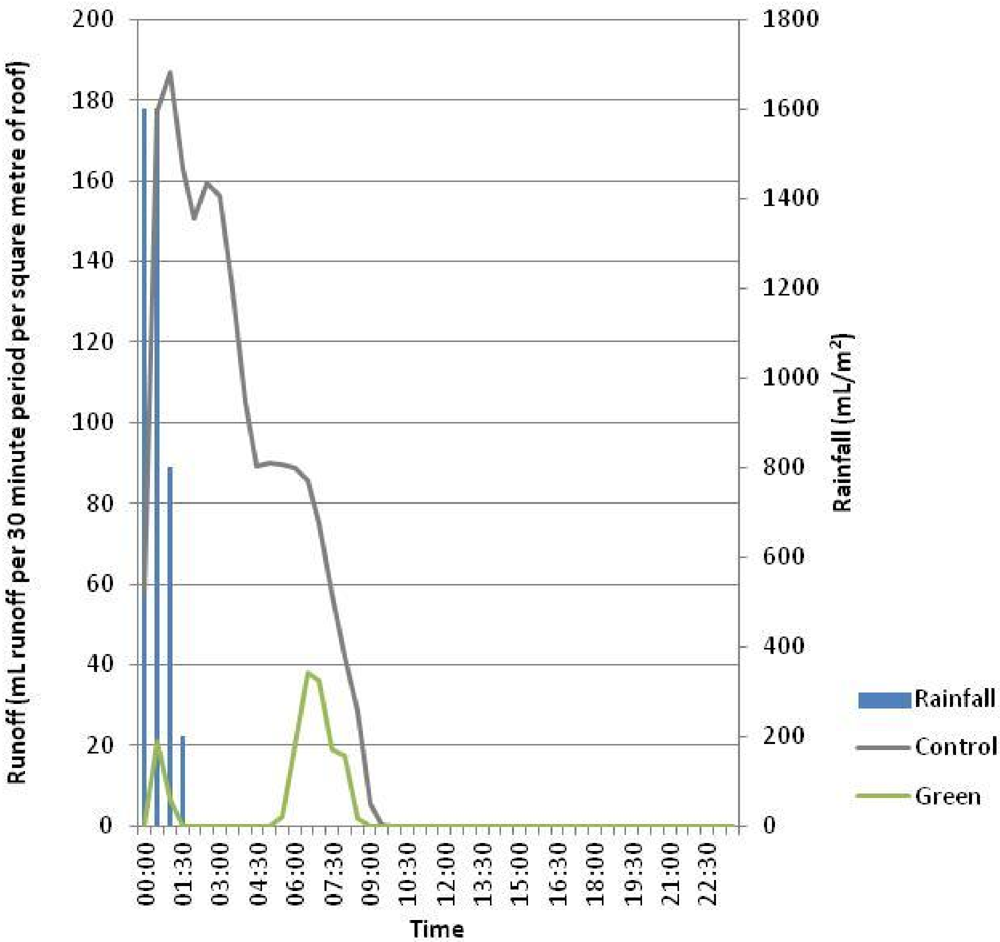


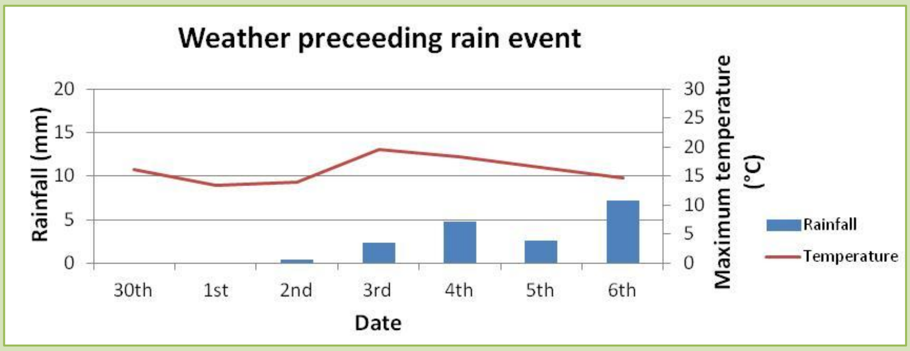
Figure 52. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 5th May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Green roof appears to have temporary blockage later in morning.

Rain event: 6th May 2015

Rain volume: 7.2 mm

Rain intensity: 198.6 mm/hr

Max temp: 14.7 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	

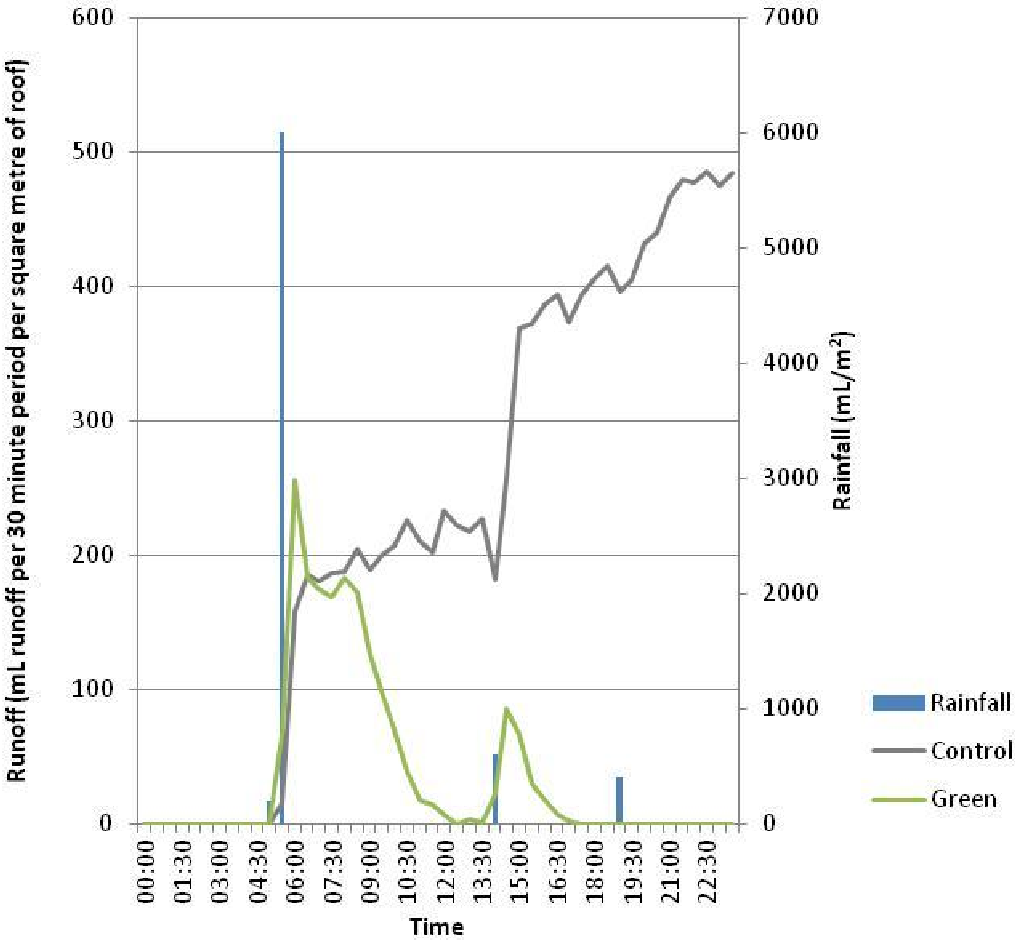


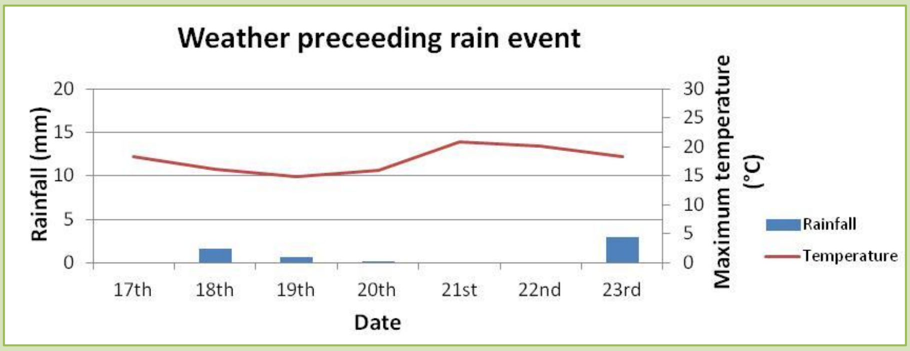
Figure 53. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 6th May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control roof appeared to have blockage.

Rain event: 23rd May 2015

Rain volume: 3 mm

Rain intensity: 48.8 mm/hr

Max temp: 18.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

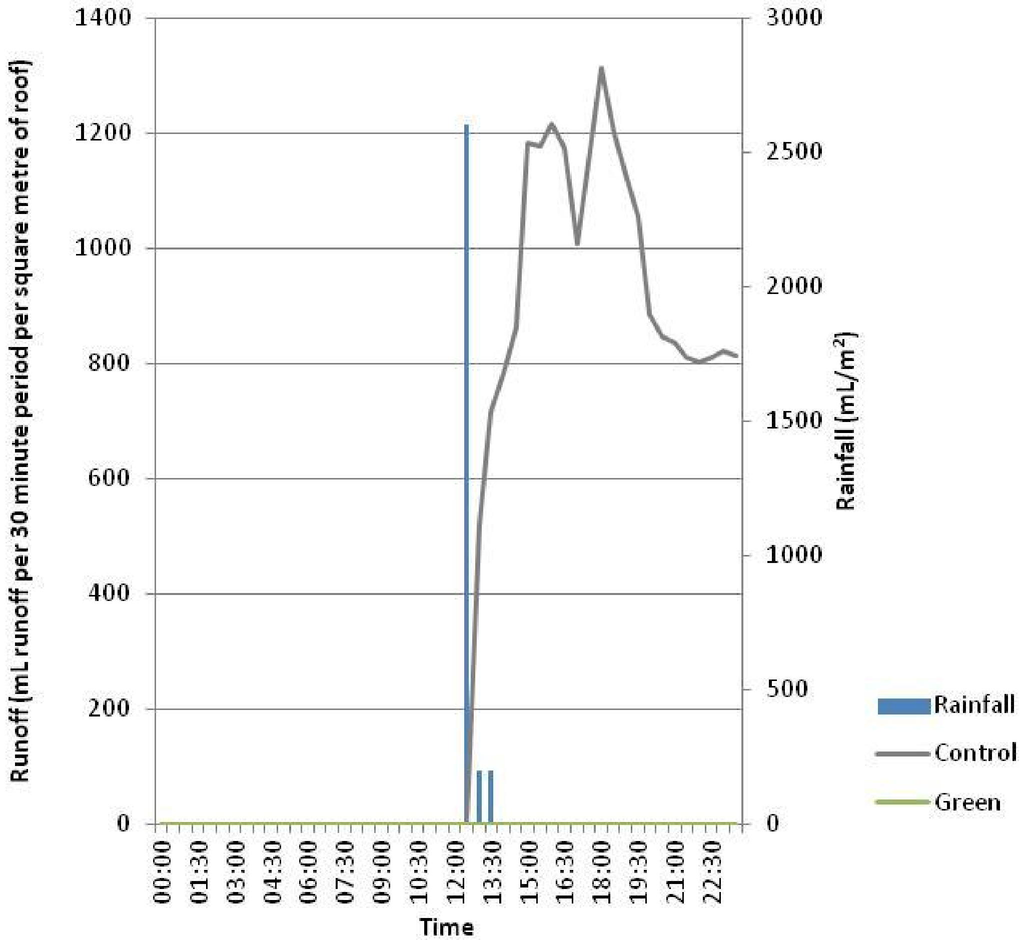


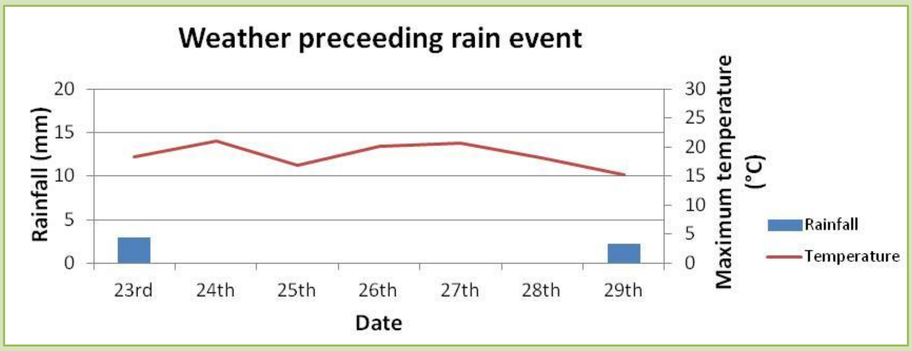
Figure 54. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 23rd May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control roof appeared to have blockage at around 14:30.

Rain event: 29th May 2015

Rain volume: 2.2 mm

Rain intensity: 8 mm/hr

Max temp: 15.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof : 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

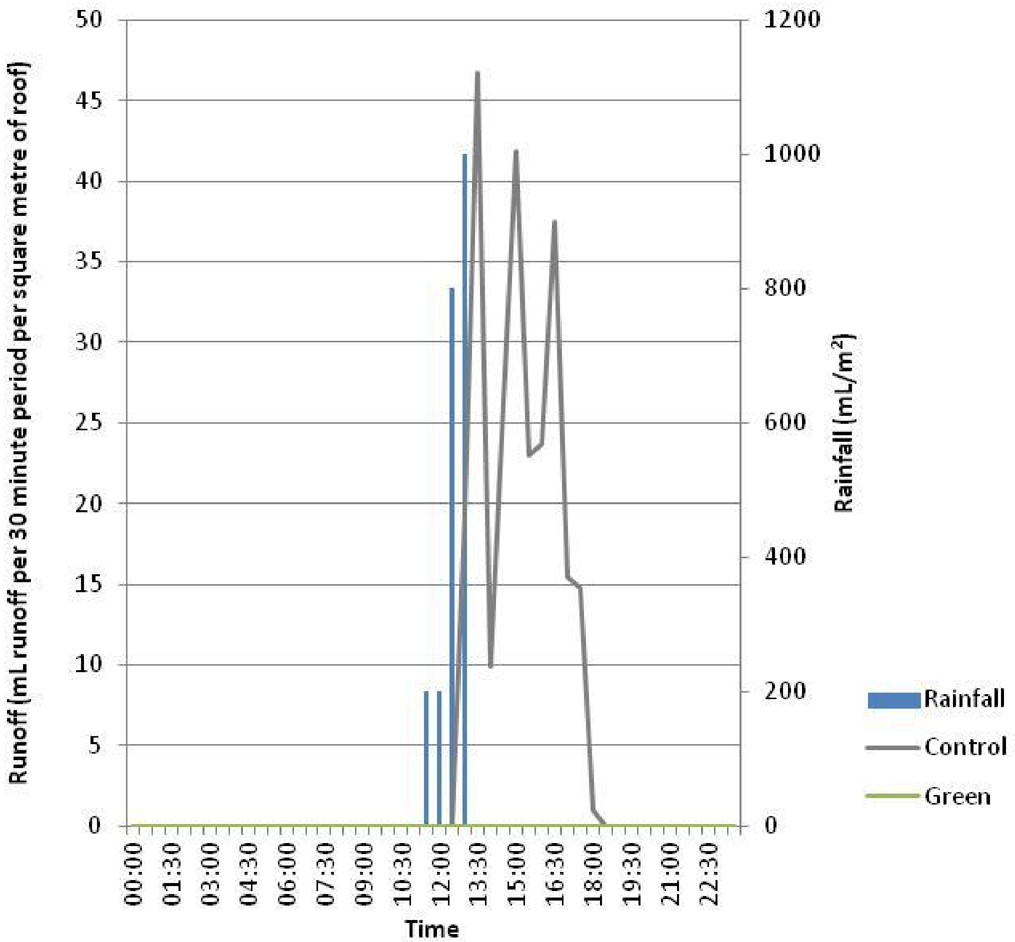


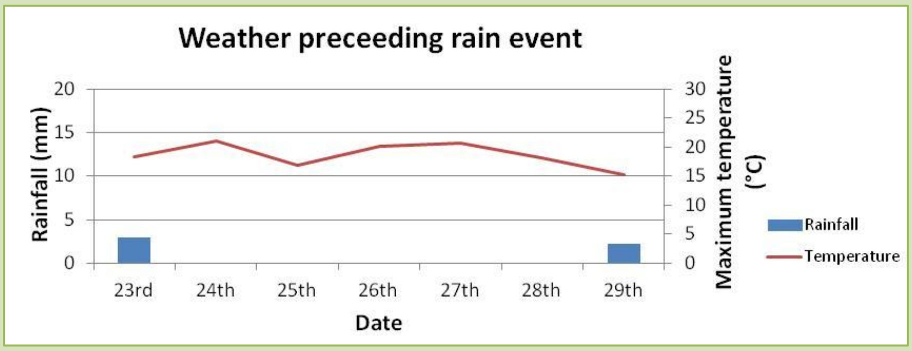
Figure 55. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 29th May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 31st May 2015

Rain volume: 4.2 mm

Rain intensity: 26.4 mm/hr

Max temp: 16.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

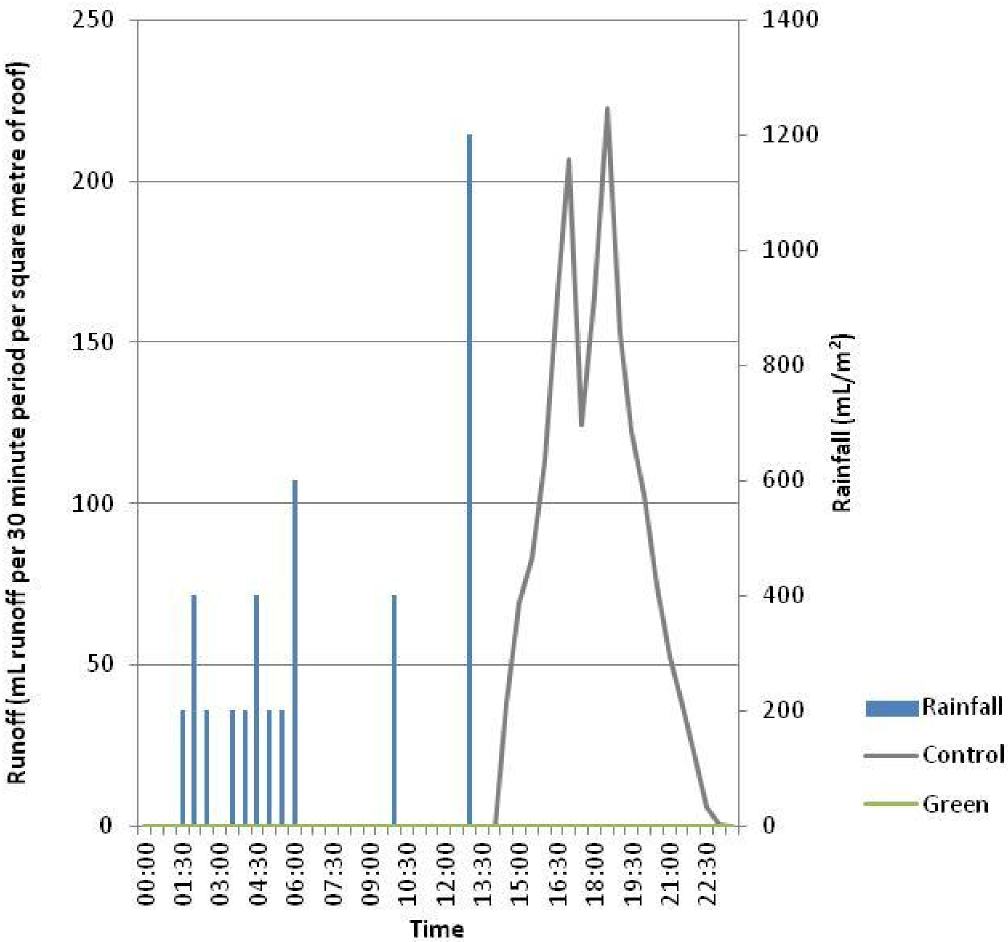


Figure 56. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 31st May 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

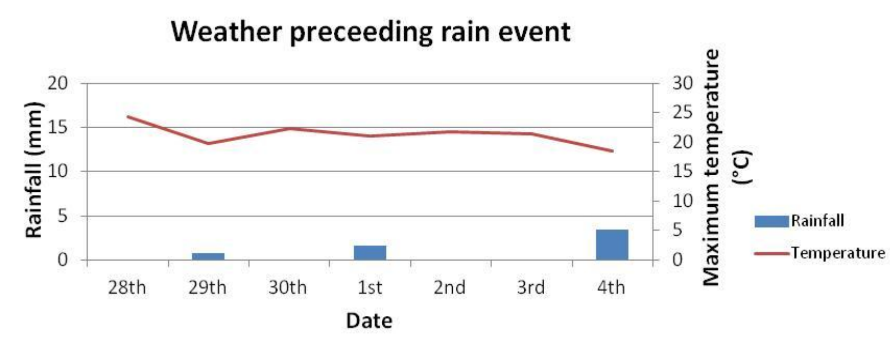
Appendix 2 - Winter rain events

Rain event: 4th October 2014

Rain volume: 3.4 mm

Rain intensity: 4 mm/hr

Max temp: 18.5 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

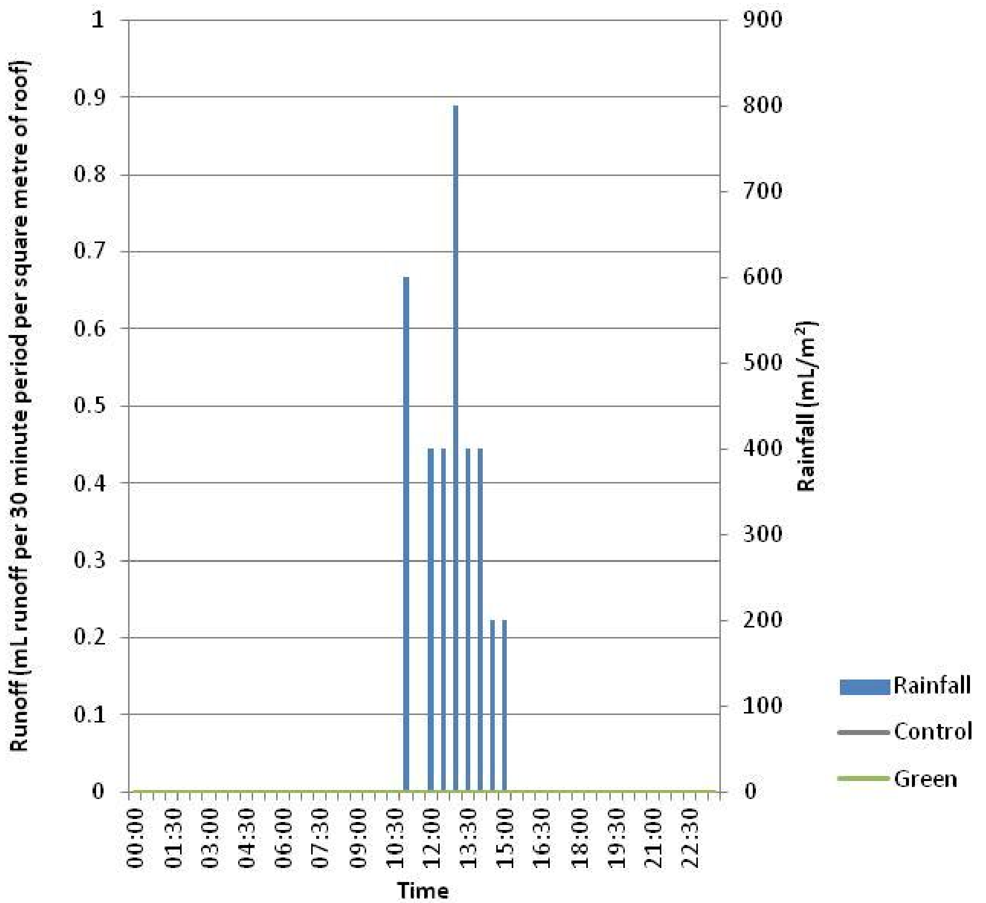


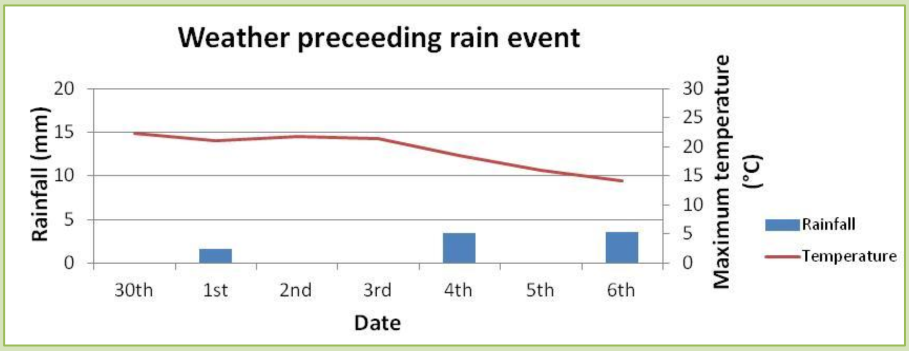
Figure 57. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 4th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 6th October 2014

Rain volume: 3.6 mm

Rain intensity: 4.2 mm/hr

Max temp: 14.1 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	100%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	100%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	N/A

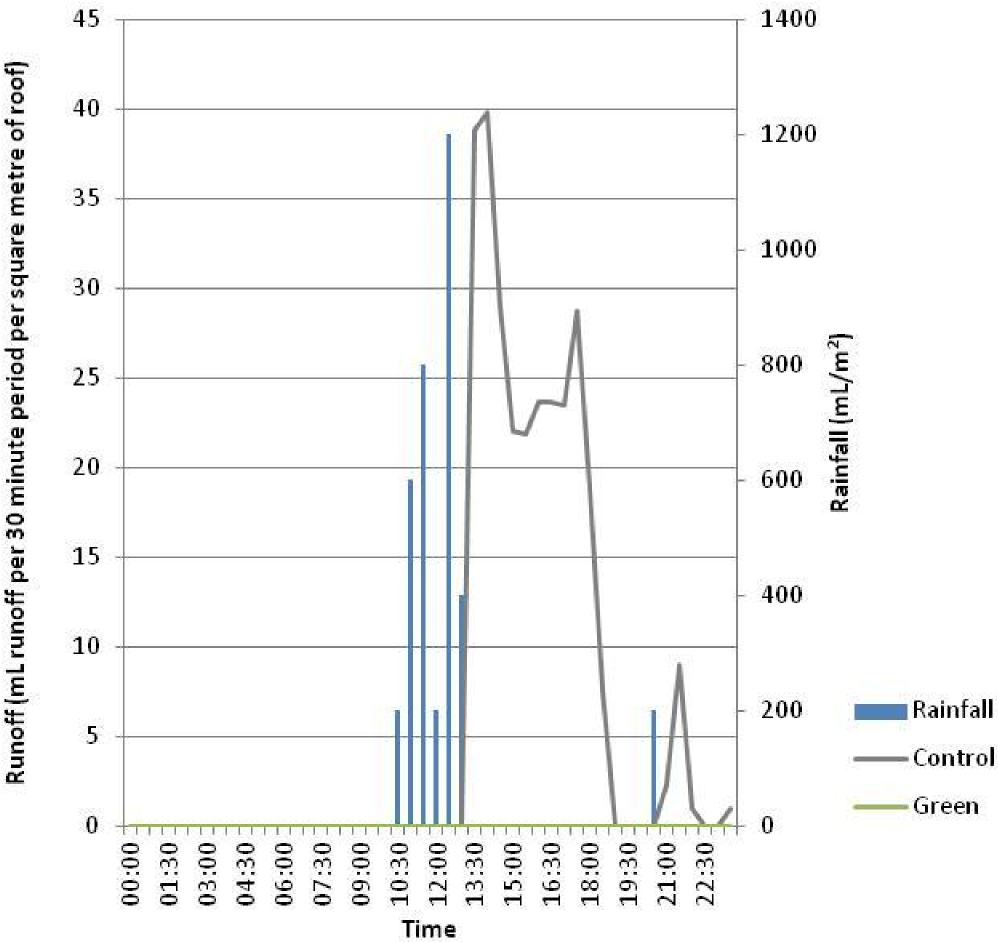


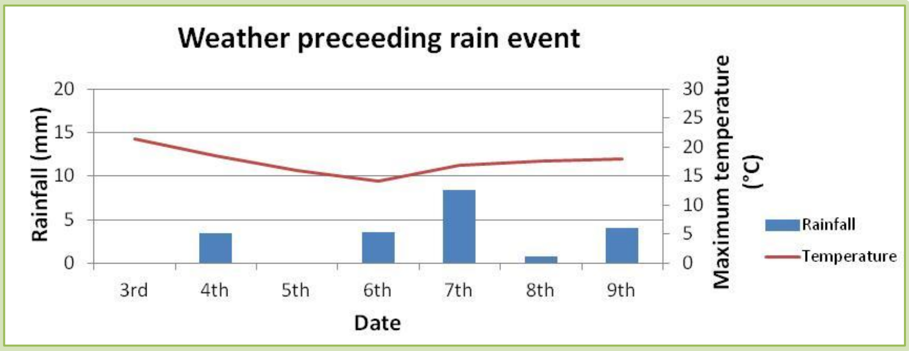
Figure 58. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 6th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 9th October 2014

Rain volume: 4 mm

Rain intensity: 76.8 mm/hr

Max temp: 18 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof : 100%

Delay in peak flow (hrs):

Peak 1

Green roof : N/A

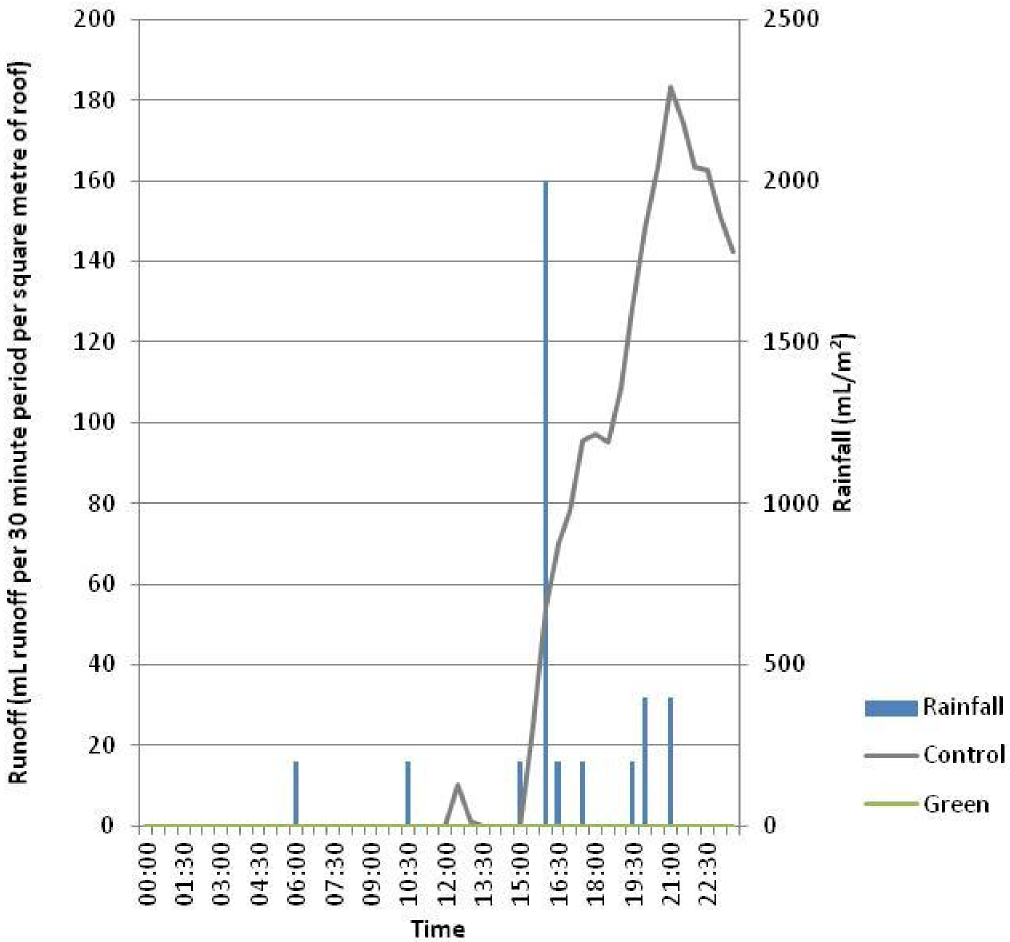


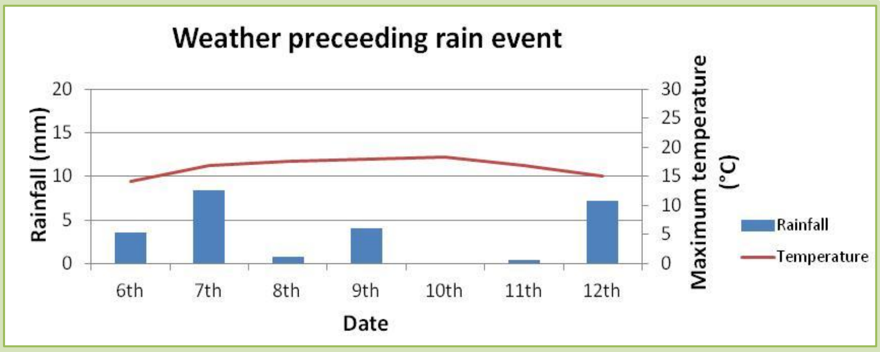
Figure 59. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 9th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 12th October 2014

Rain volume: 7.2 mm

Rain intensity: 42 mm/hr

Max temp: 18 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 86%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 83%

Delay in peak flow (hrs):

Peak 1

Green roof: 1

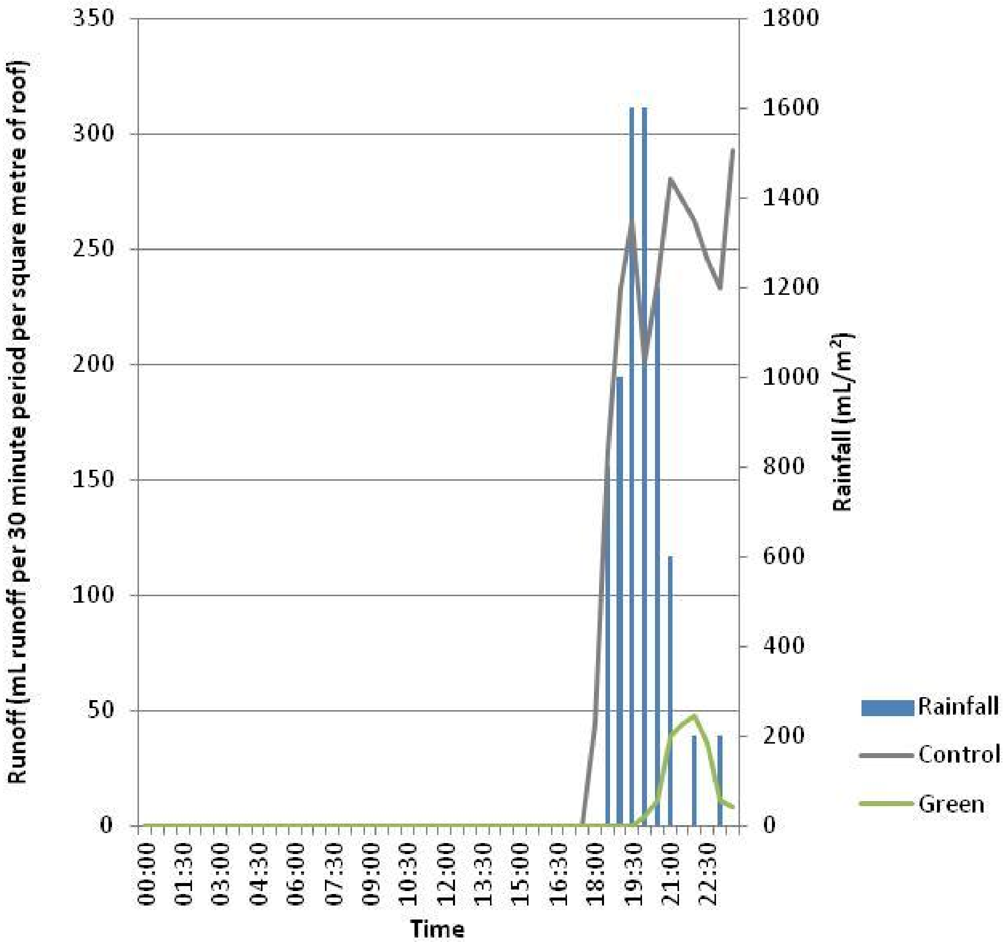


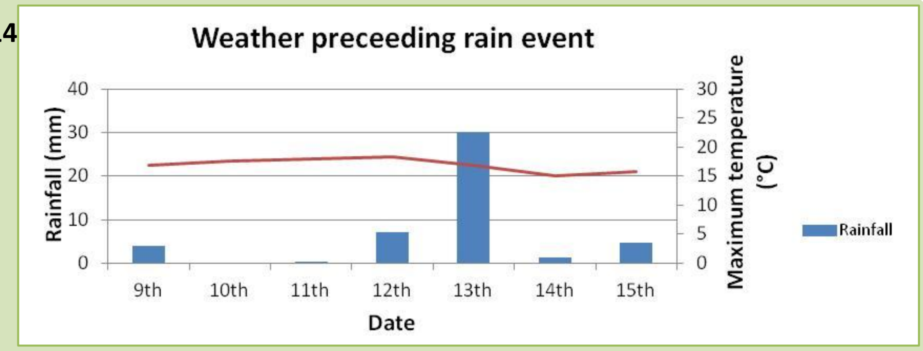
Figure 60. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 12th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 15th October 2014

Rain volume: 4.6 mm

Rain intensity: 8.6 mm/hr

Max temp: 16.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 49%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 21%

Delay in peak flow (hrs):

Peak 1

Green roof: 4

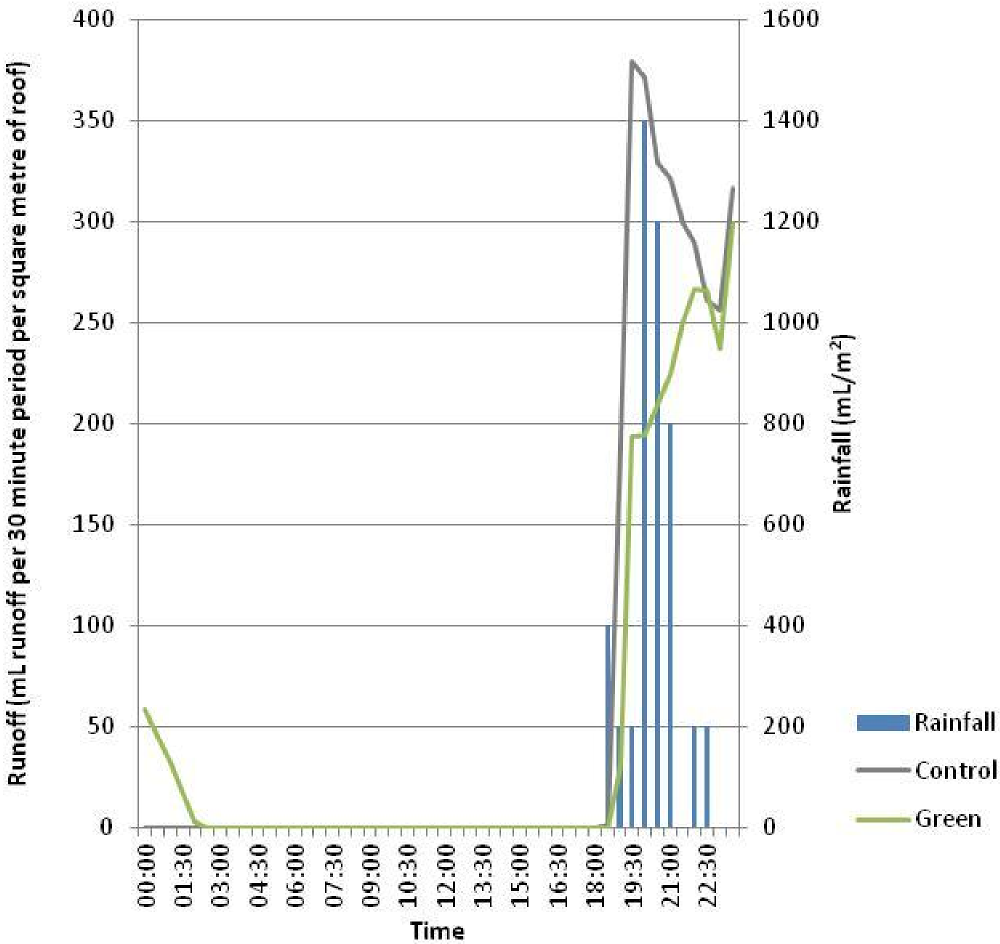


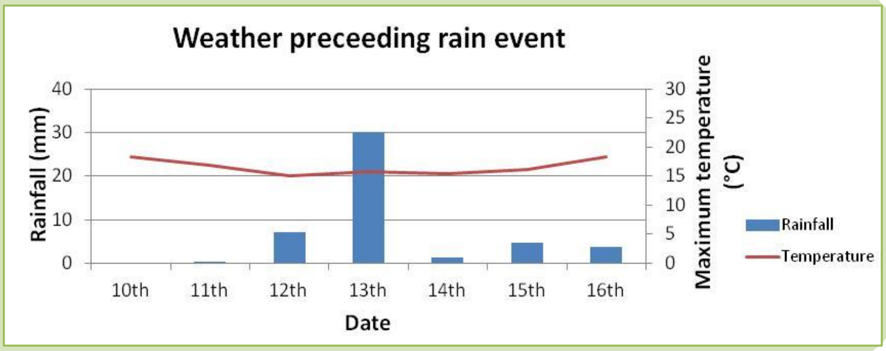
Figure 61. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 15th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 16th October 2014

Rain volume: 3.6 mm

Rain intensity: 14.4 mm/hr

Max temp: 18.3 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	75%	57%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	64%	57%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	1.5	0

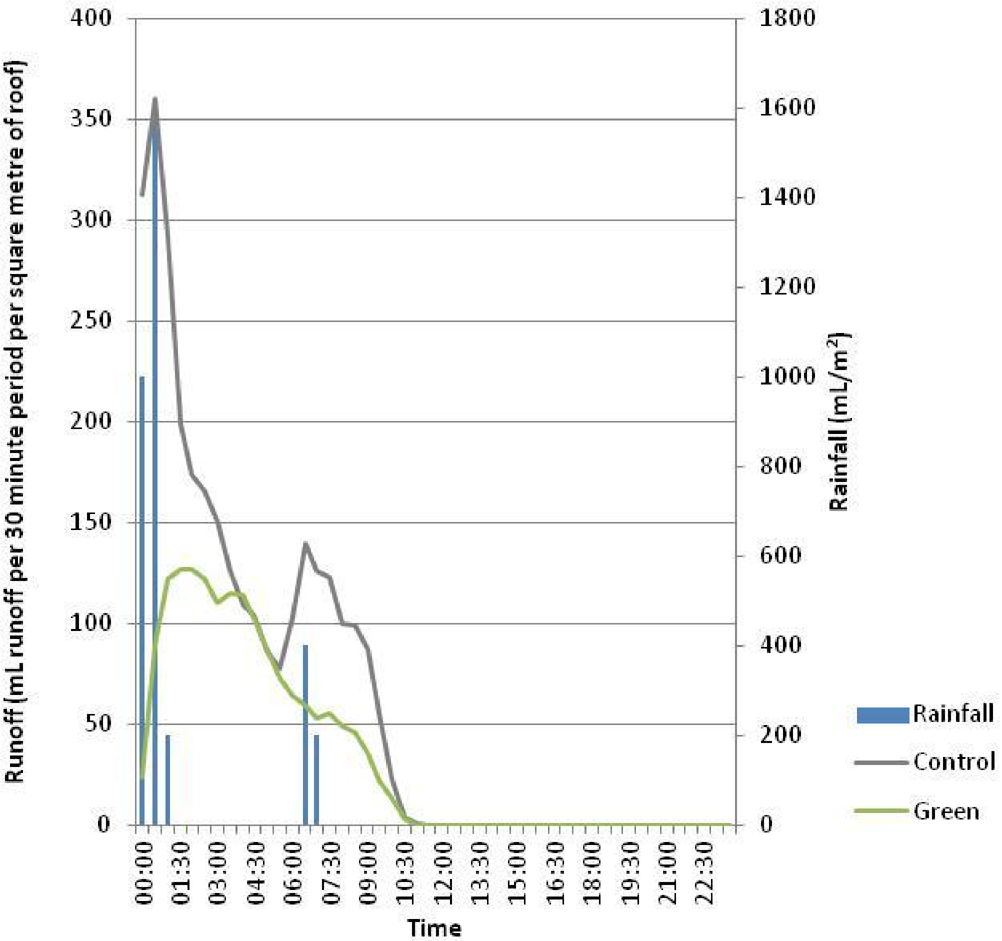


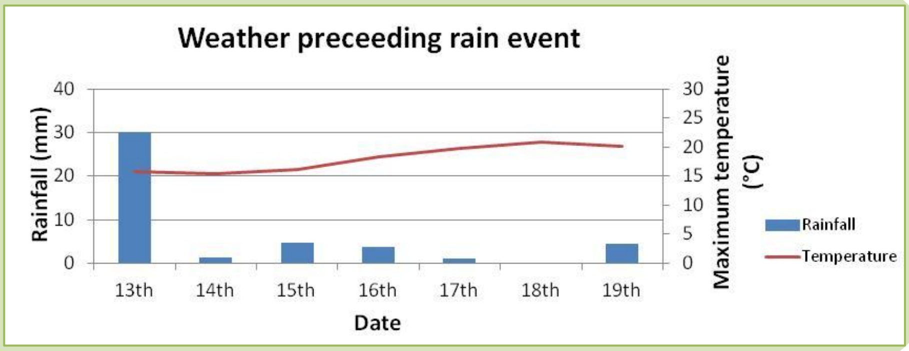
Figure 62. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 16th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 19th October 2014

Rain volume: 4.4 mm

Rain intensity: 12.4 mm/hr

Max temp: 20.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 75%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 75%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

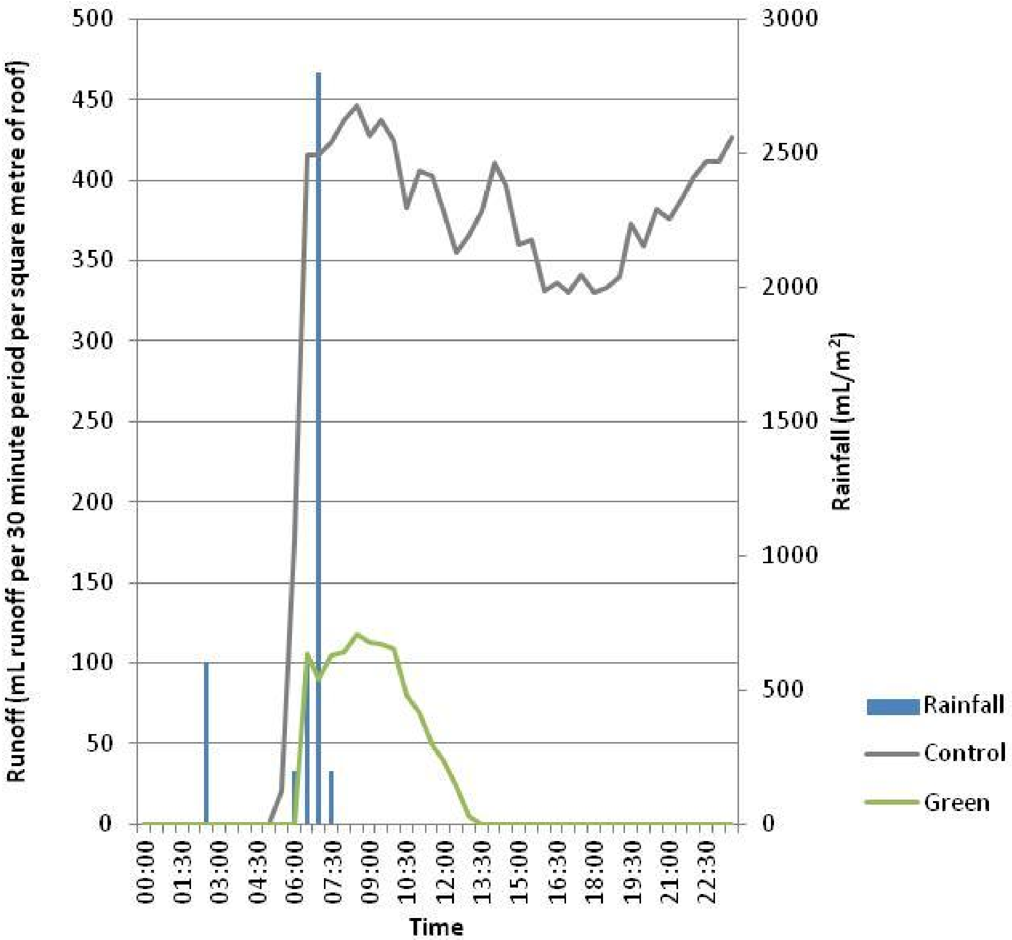


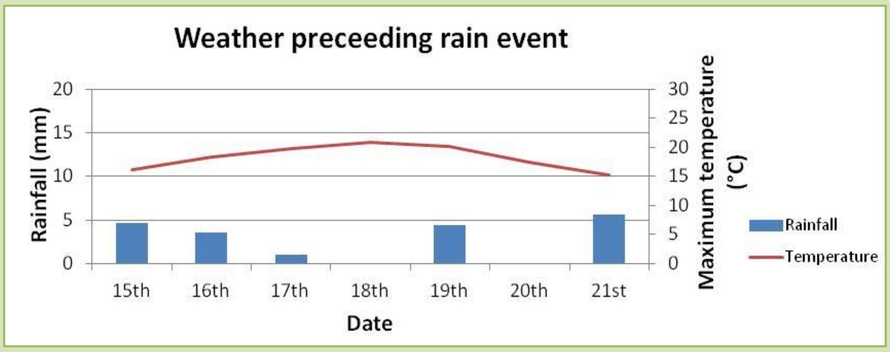
Figure 63. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 19th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control gauge appeared to have a blockage after rain event.

Rain event: 21st October 2014

Rain volume: 5.6 mm

Rain intensity: 25.4 mm/hr

Max temp: 15.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 97%

Delay in peak flow (hrs):

Peak 1

Green roof: -1

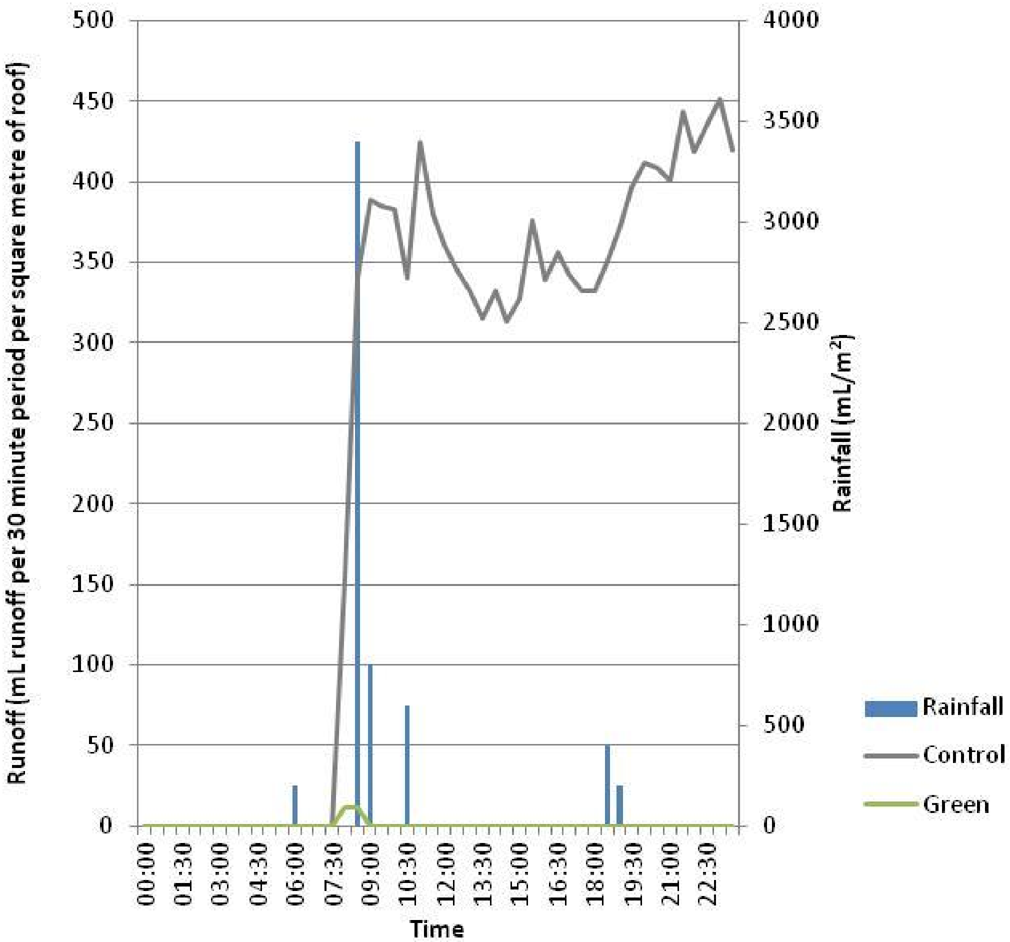


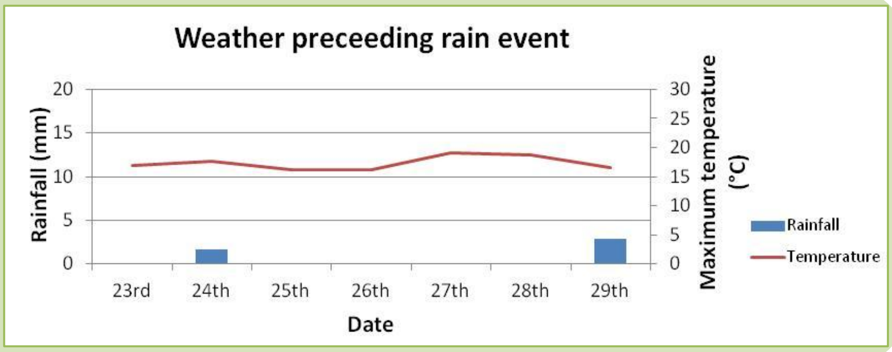
Figure 64. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 21st October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control gauge appeared to have a blockage after rain event.

Rain event: 29th October 2014

Rain volume: 2.8 mm

Rain intensity: 4.4 mm/hr

Max temp: 16.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

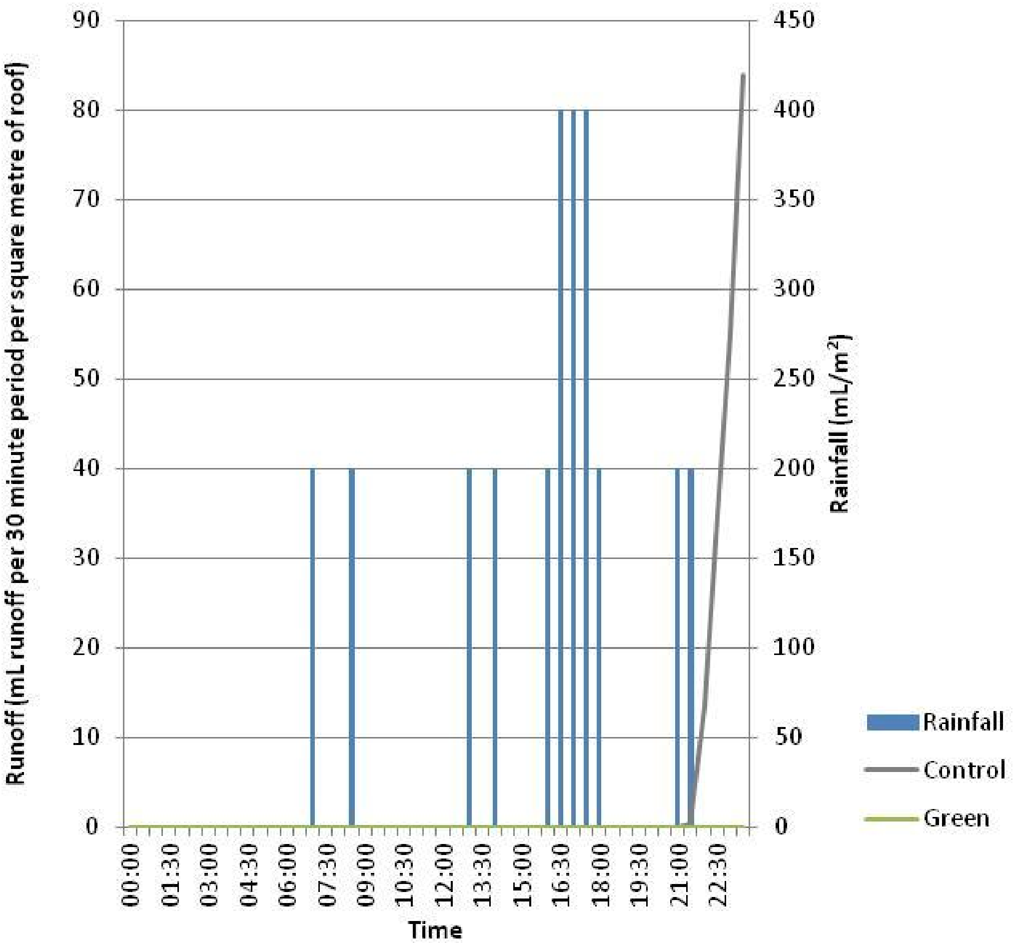


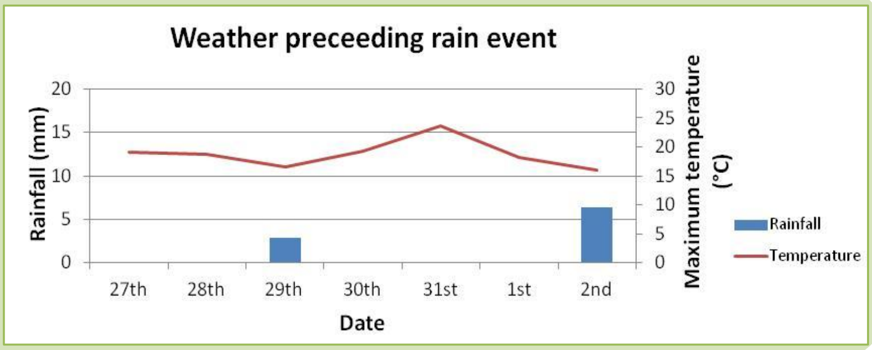
Figure 65. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 29th October 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 2nd November 2014

Rain volume: 6.4 mm

Rain intensity: 12 mm/hr

Max temp: 16.0 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 76%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof : 76%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

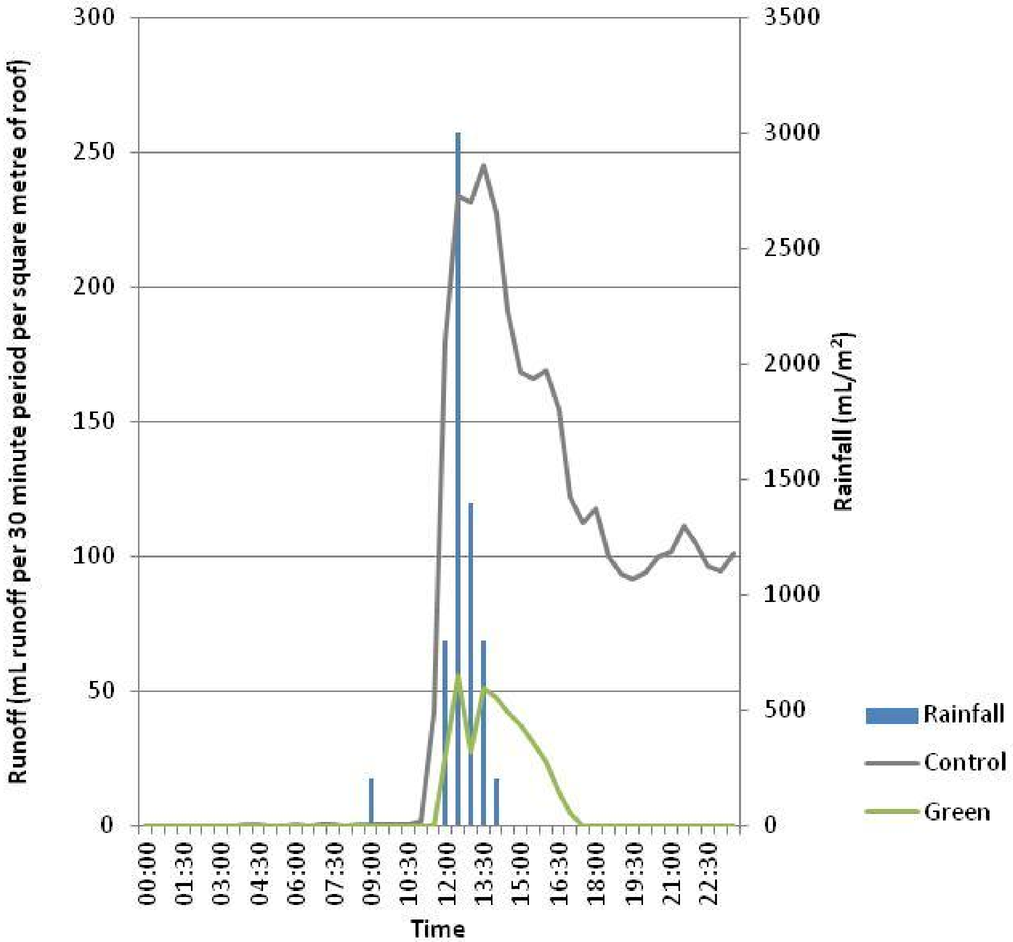


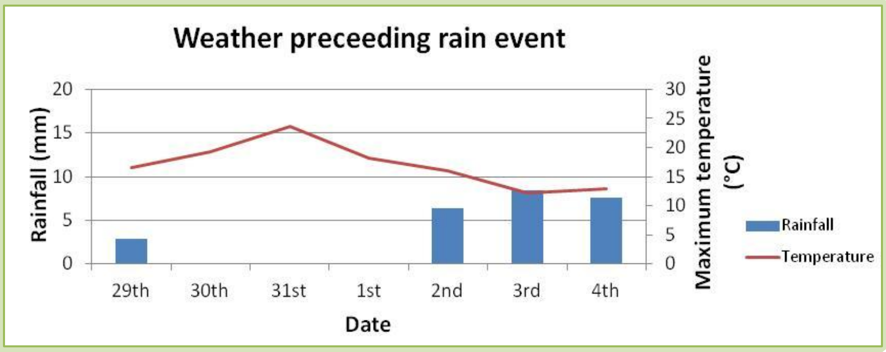
Figure 66. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 2nd November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control gauge appeared to have a blockage after rain event.

Rain event: 4th November 2014

Rain volume: 7.6 mm

Rain intensity: 4.8 mm/hr

Max temp: 13 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	7%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	7%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	0	0

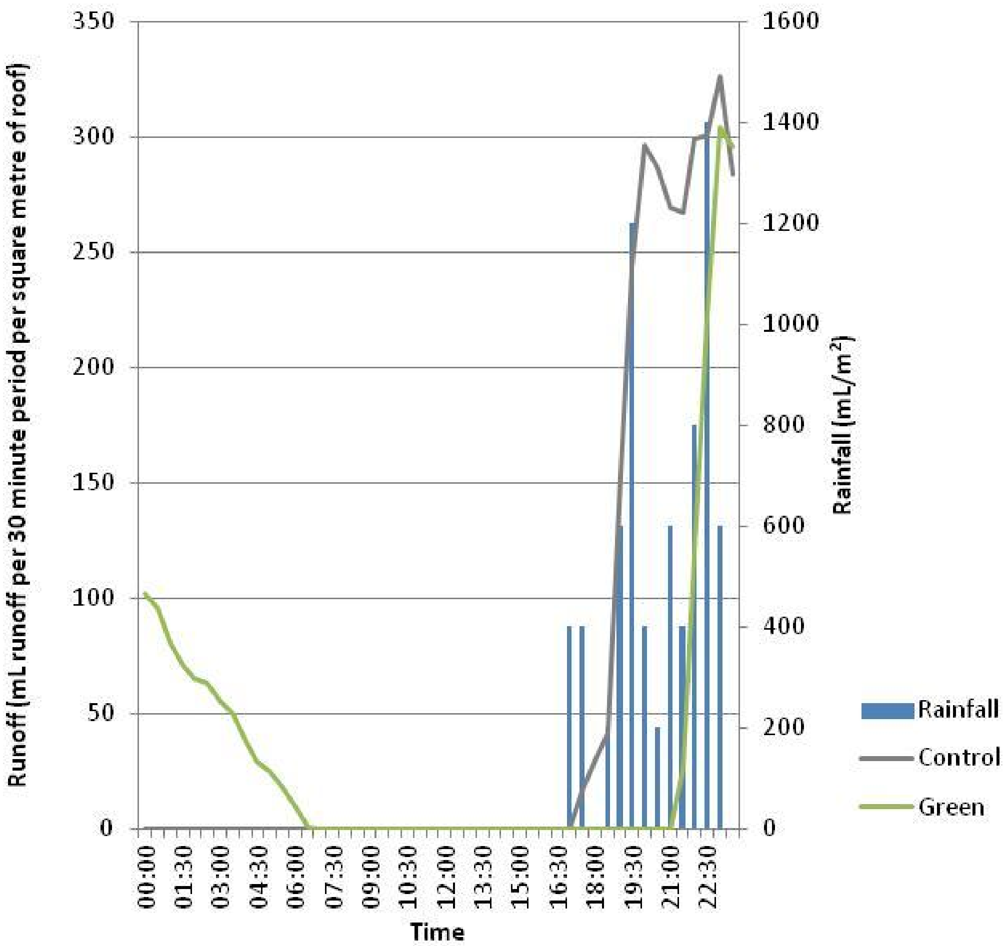


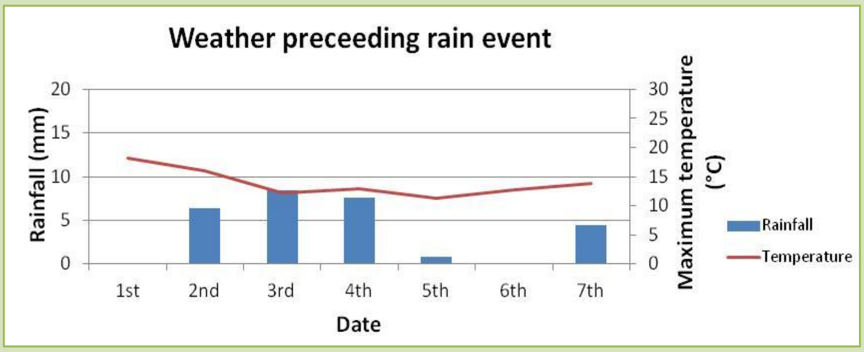
Figure 67. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 4th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 7th November 2014

Rain volume: 4.4 mm

Rain intensity: 7.8 mm/hr

Max temp: 13.8 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	99%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	73%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	1

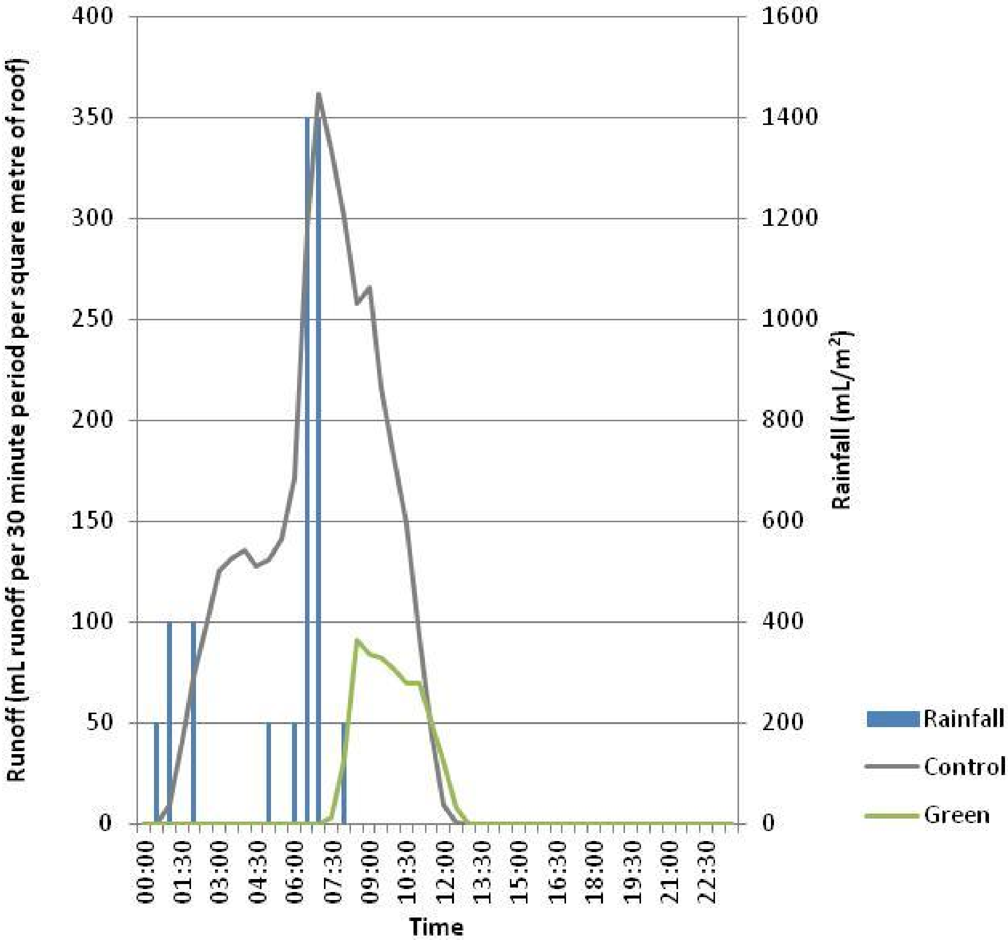


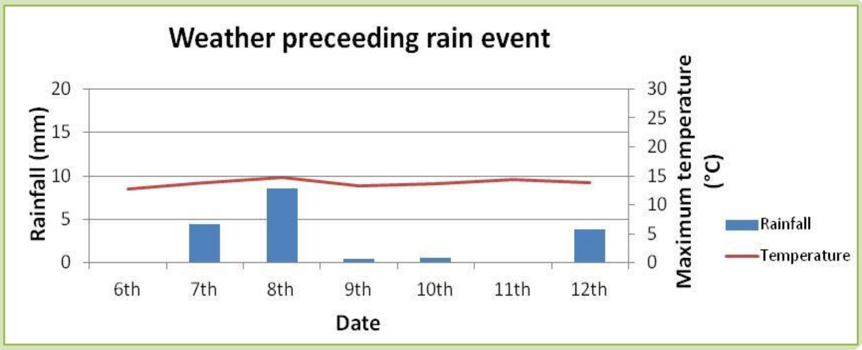
Figure 68. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 7th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 12th November 2014

Rain volume: 3.8 mm

Rain intensity: 11.4 mm/hr

Max temp: 13.8 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% 97%

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% 88%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	0.5

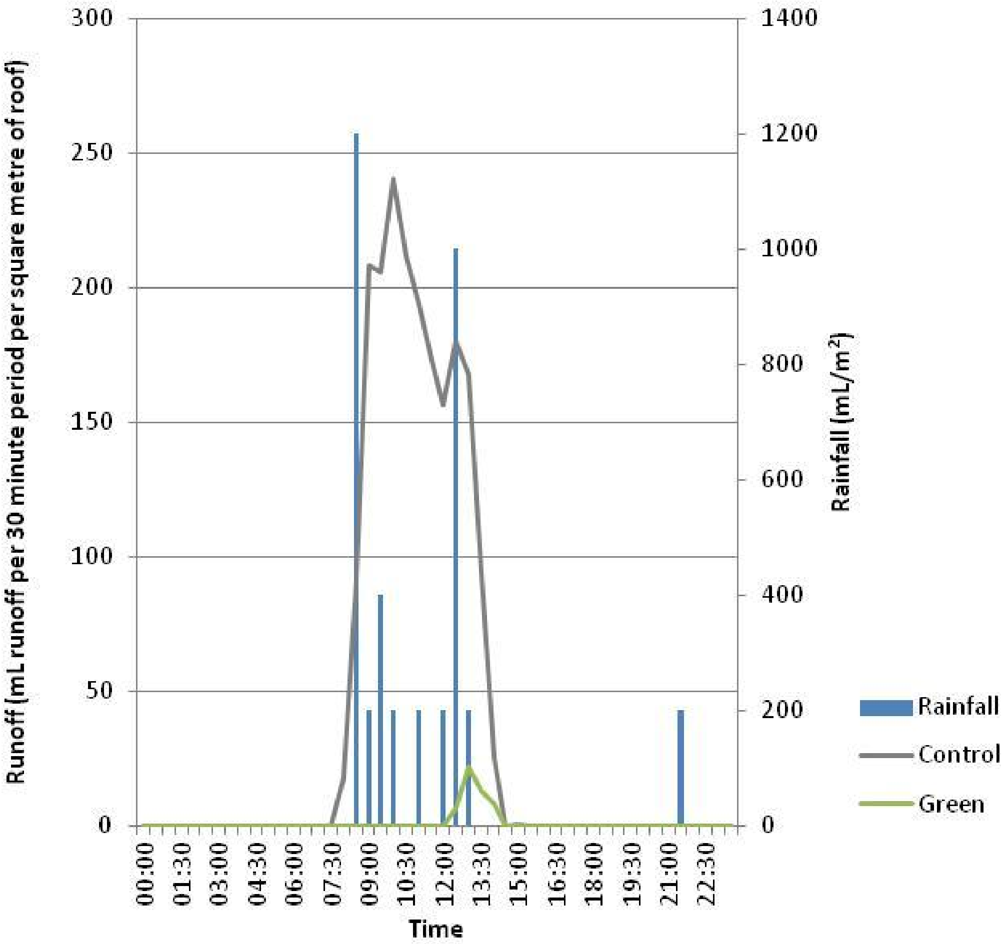


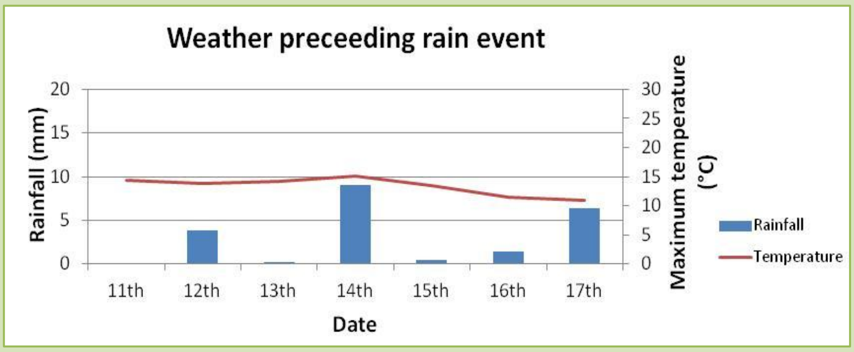
Figure 69. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 12th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 17th November 2014

Rain volume: 6.4 mm

Rain intensity: 1.2 mm/hr

Max temp: 11 °C



Percentage peak flow rate reduction:

Relative: Peak	**1**	**2**
Green roof:	100%	95%

Percentage peak flow rate reduction:

Absolute: Peak	**1**	**2**
Green roof:	100%	91%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	2

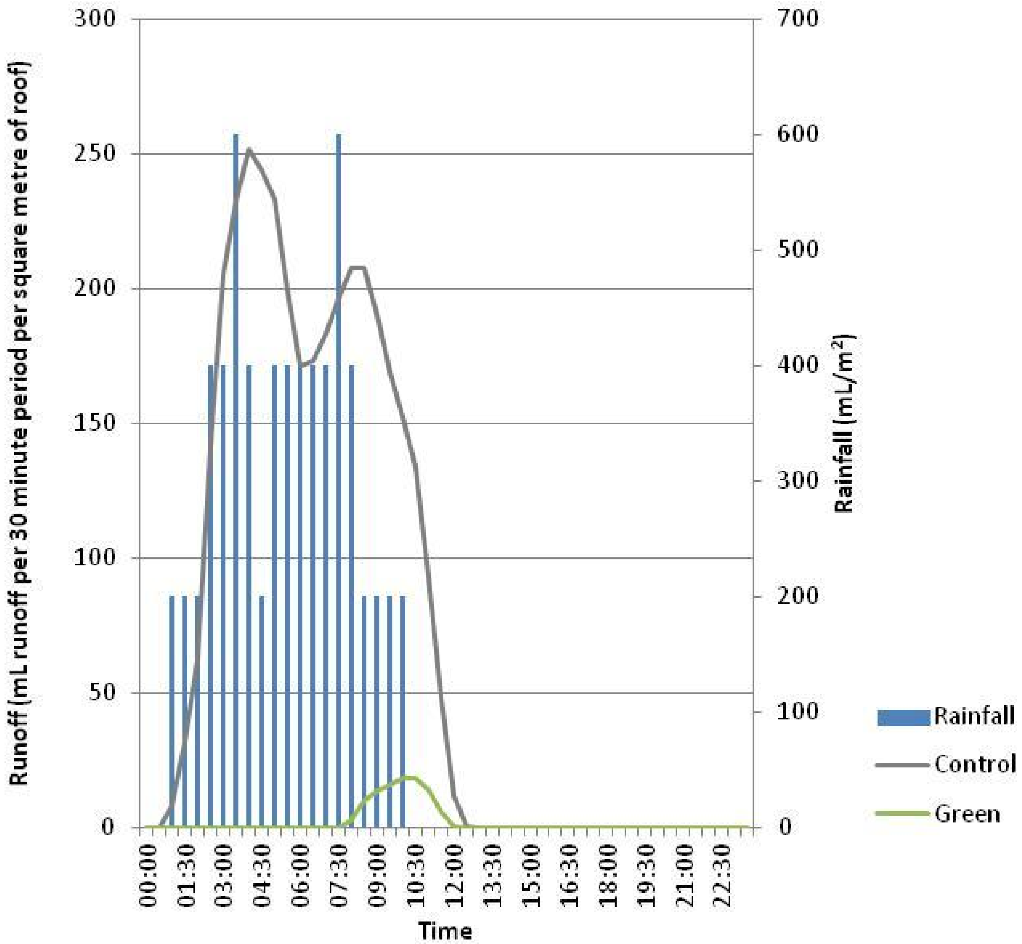


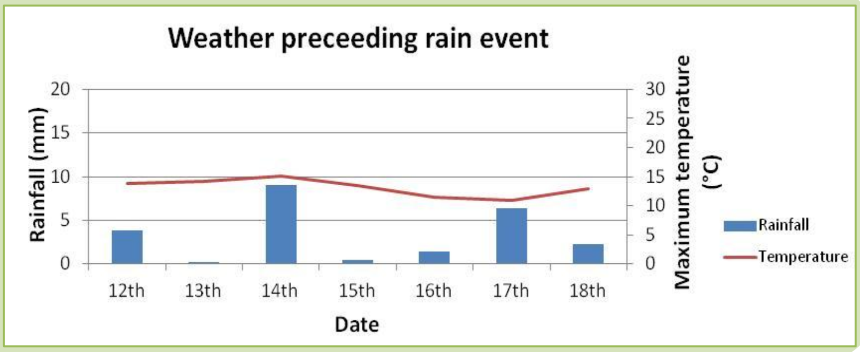
Figure 70. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 17th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 18th November 2014

Rain volume: 2.2 mm

Rain intensity: 12.2 mm/hr

Max temp: 12.9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 84%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 84 %

Delay in peak flow (hrs):

Peak 1

Green roof: 0.5

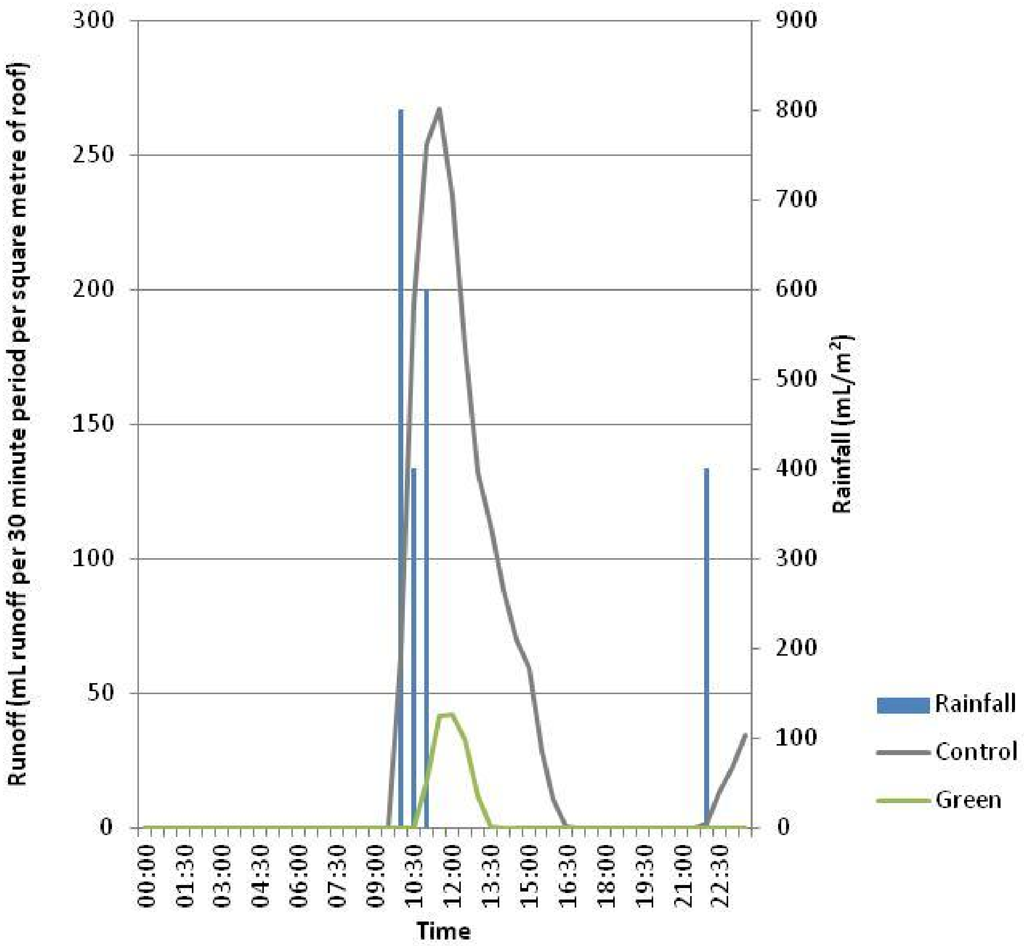


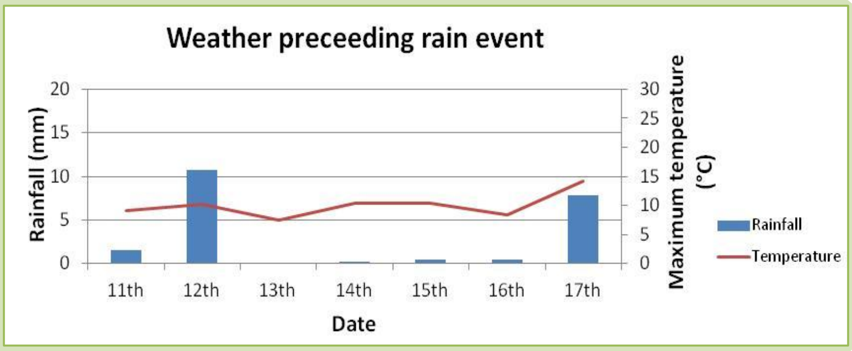
Figure 71. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 18th November 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 17th December 2014

Rain volume: 7.8 mm

Rain intensity: 3.2 mm/hr

Max temp: 14.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% N/A

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% N/A

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	N/A	N/A

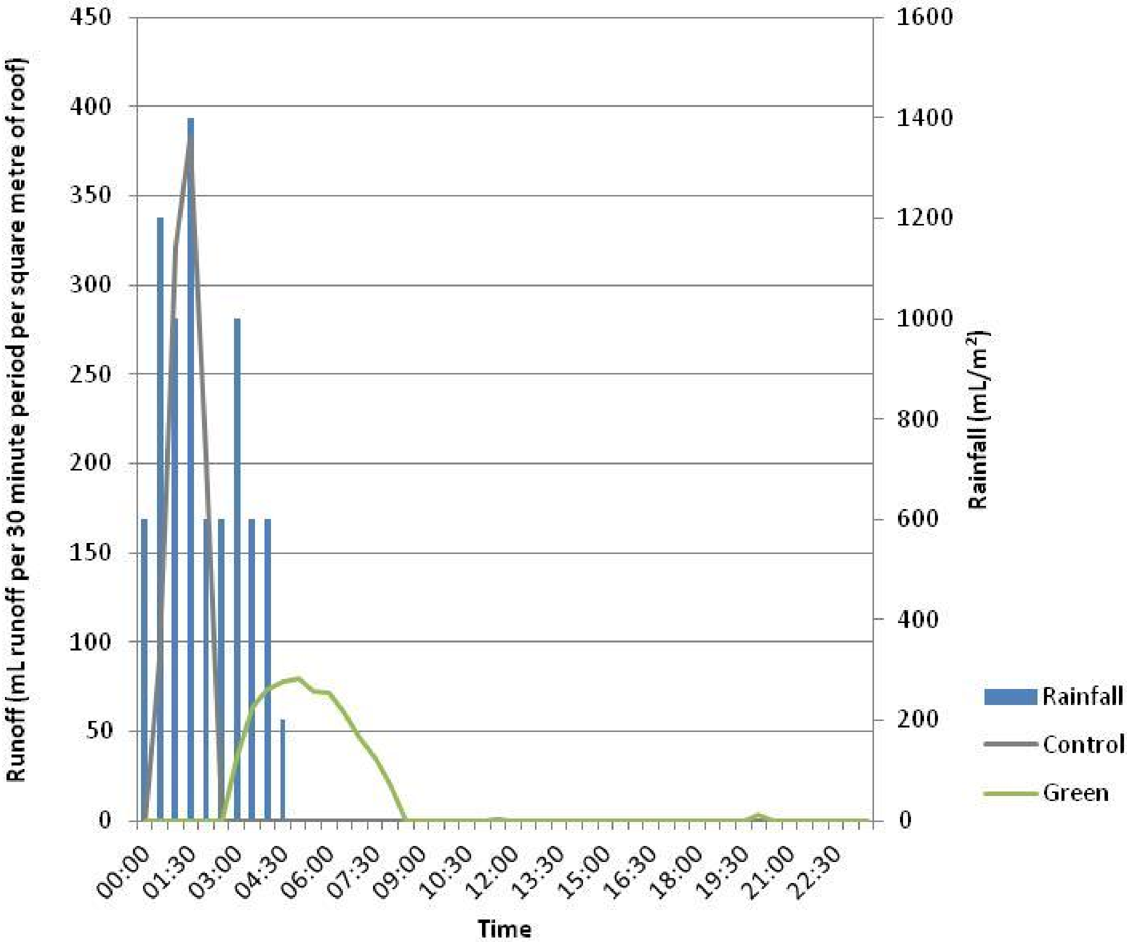


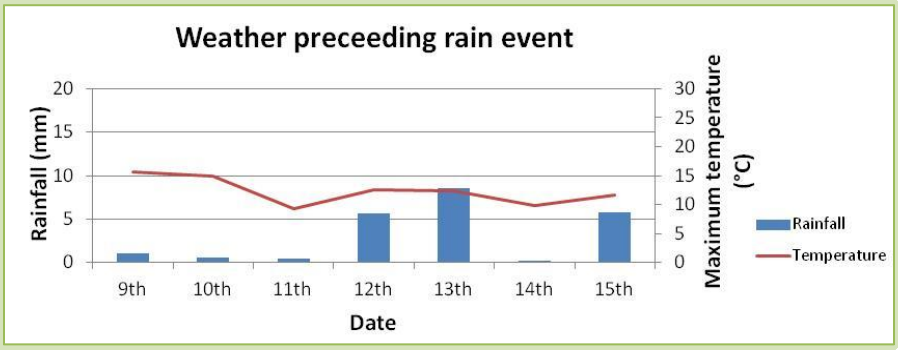
Figure 72. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 17th December 2014. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. N.B. Rain gauges suffered data loss after rain event started (Control at 2am and Green at 8am), so total run off volumes would be affected.

Rain event: 15th January 2015

Rain volume: 5.8 mm

Rain intensity: 24.8 mm/hr

Max temp: 11.7 °C



Percentage peak flow rate reduction:

Relative: Peak 1 2

Green roof: 100% N/A

Percentage peak flow rate reduction:

Absolute: Peak 1 2

Green roof: 100% N/A

Delay in peak flow (hrs):

Peak 1 Peak 2

Green roof: N/A N/A

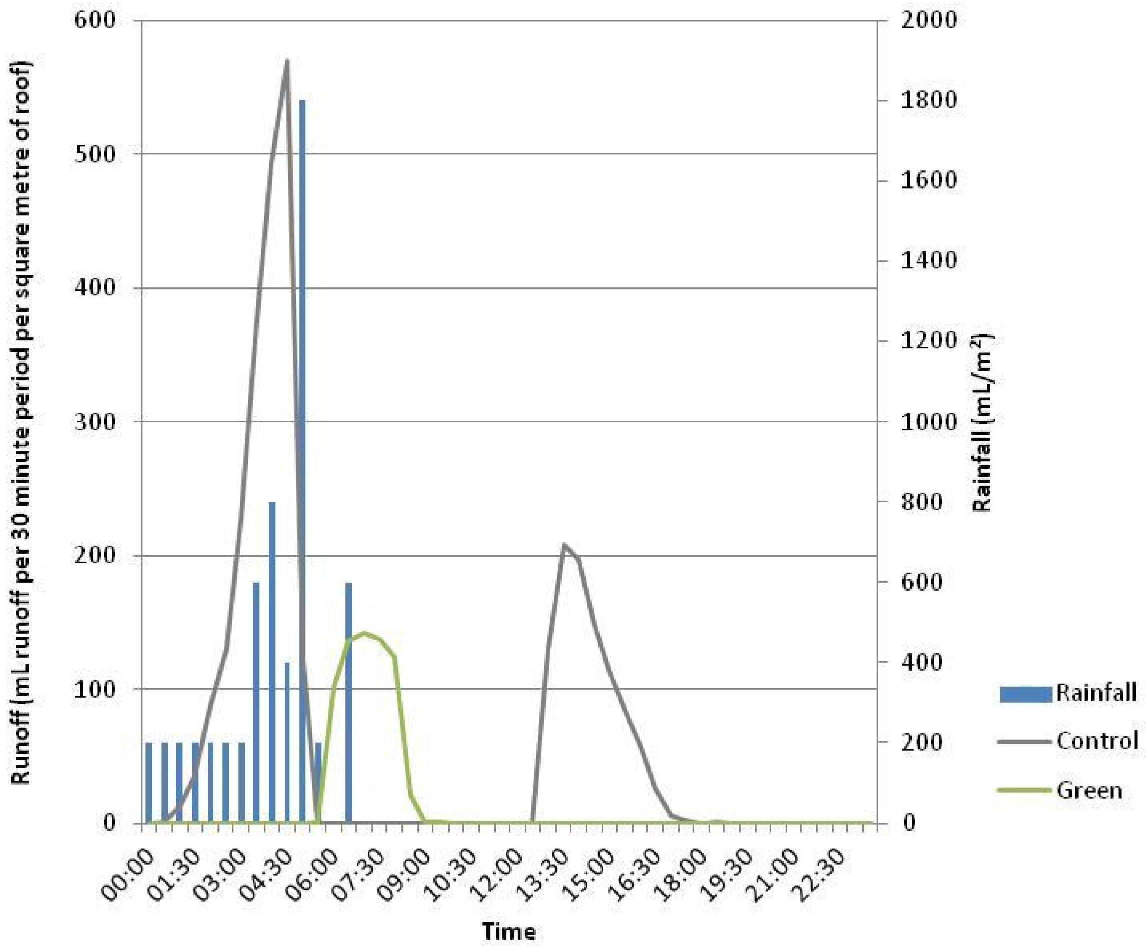


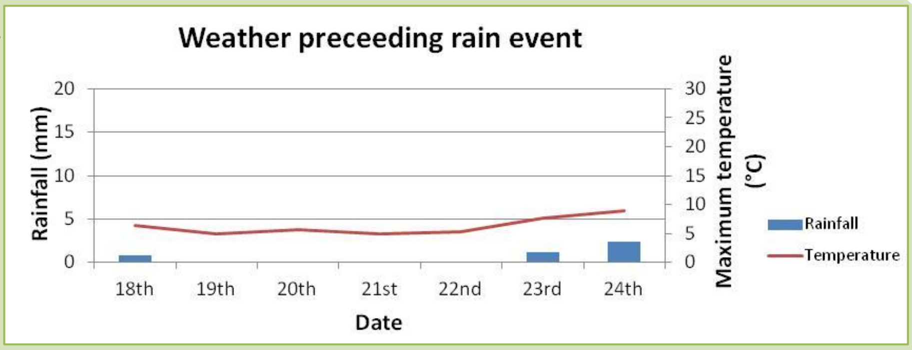
Figure 73. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 15th January 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. N.B. Control suffered data loss after rain event started (5:30am) so total run off volumes would be affected.

Rain event: 24th January 2015

Rain volume: 2.4 mm

Rain intensity: 6.2 mm/hr

Max temp: 9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

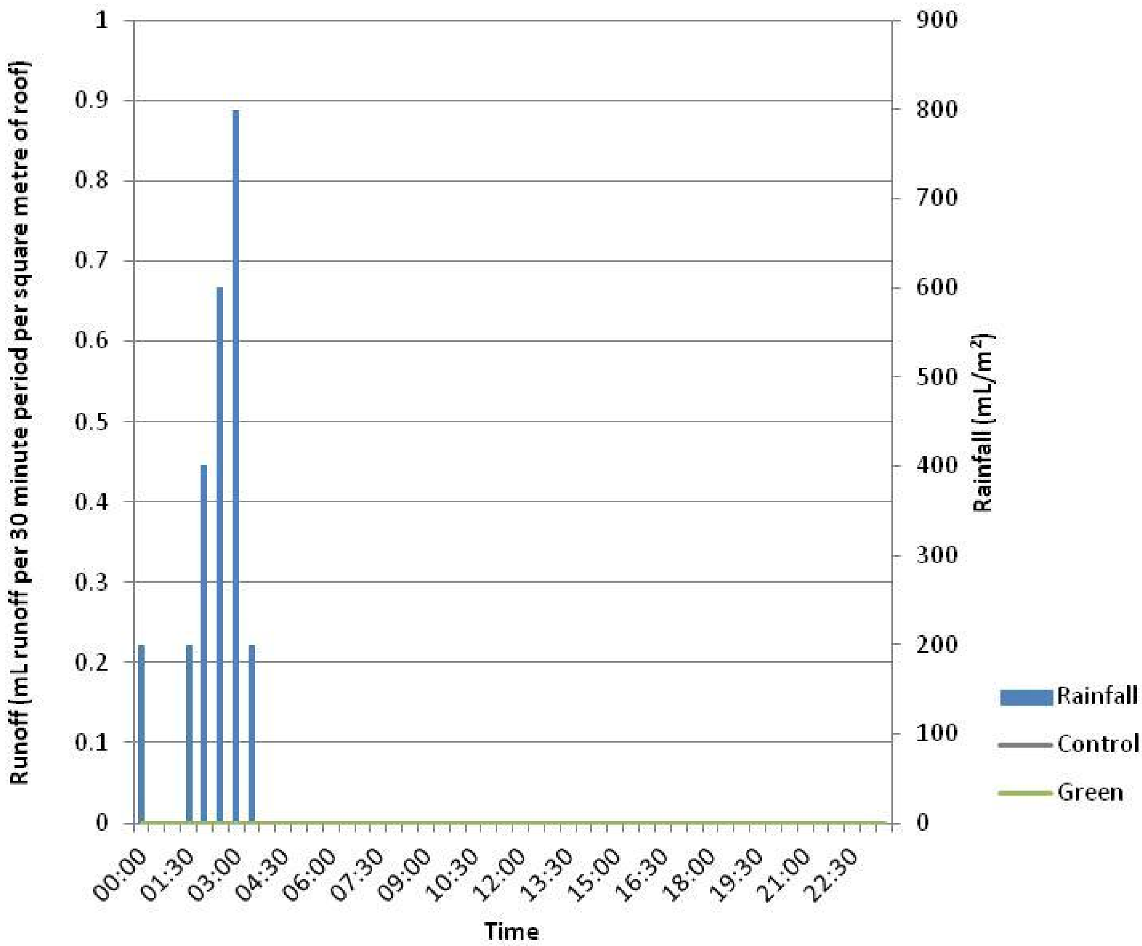


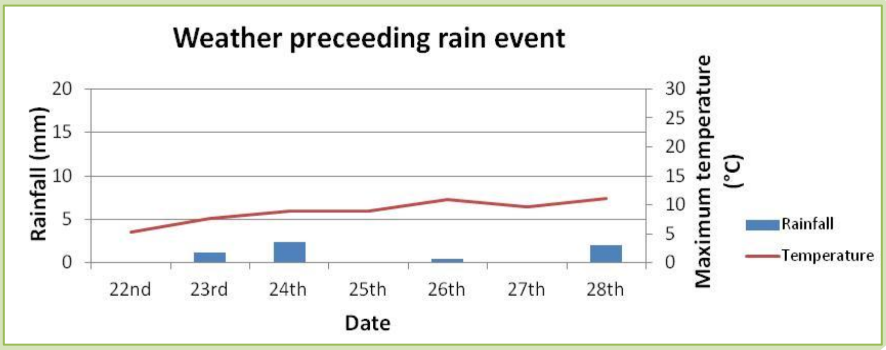
Figure 74. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 24th January 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. Control gauge data loss but green roof gauge working during rain event.

Rain event: 28th January 2015

Rain volume: 2 mm

Rain intensity: 8.2 mm/hr

Max temp: 11.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

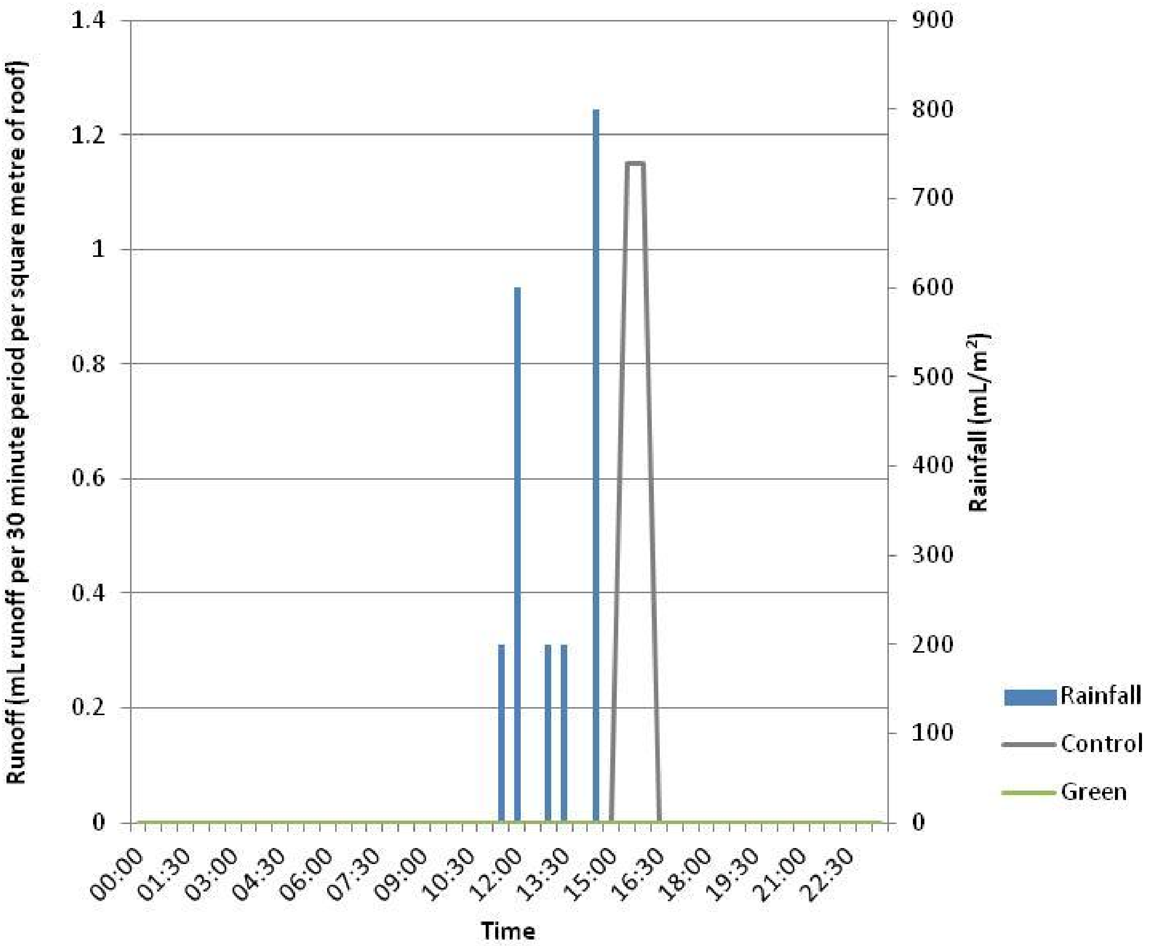


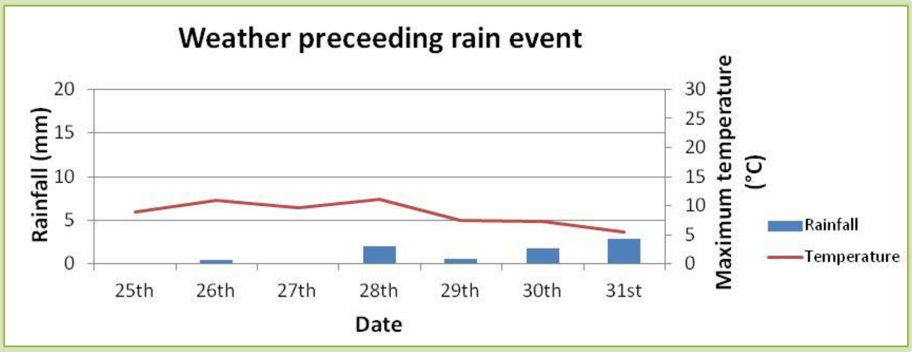
Figure 75. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 28th January 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 31st January 2015

Rain volume: 2.8 mm

Rain intensity: 1.6 mm/hr

Max temp: 5.5 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 21%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 21%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

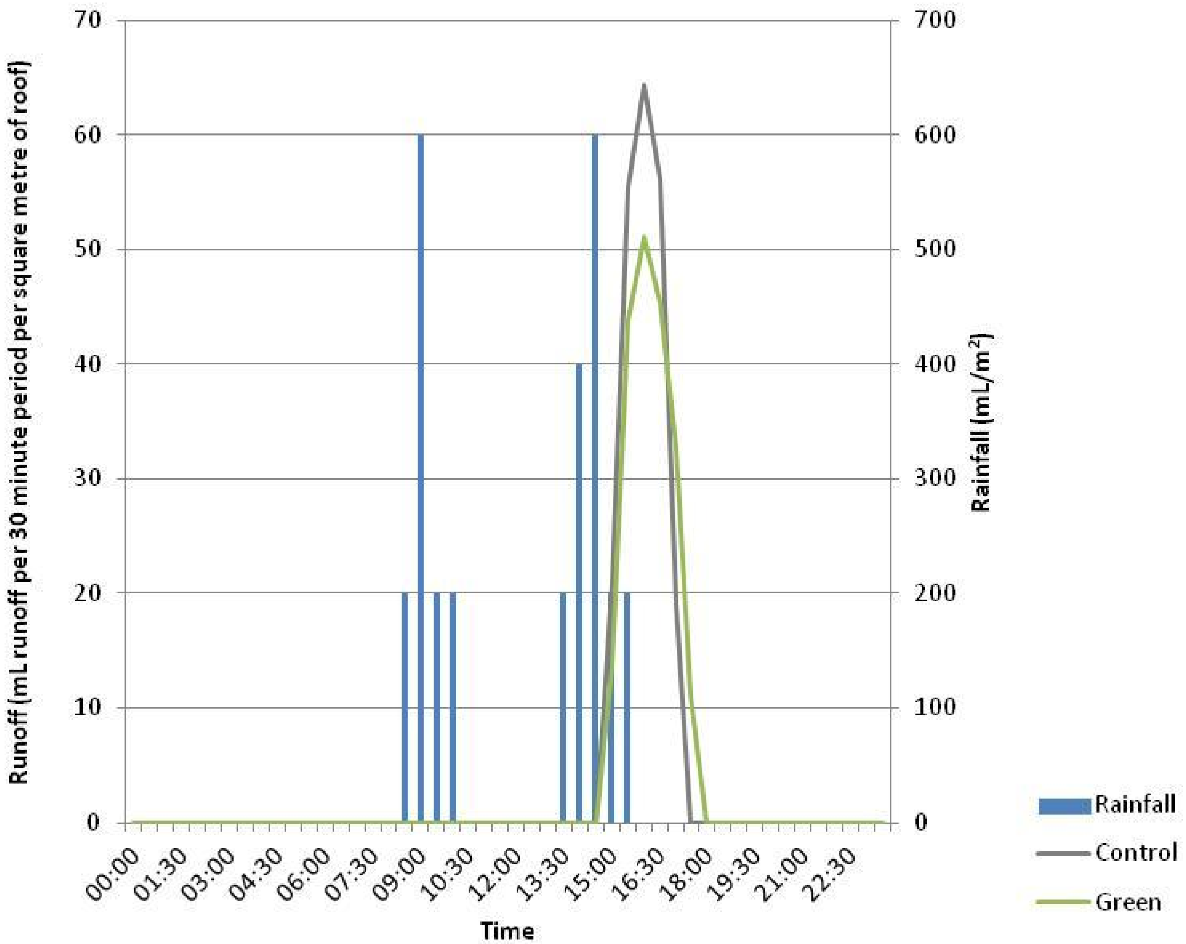


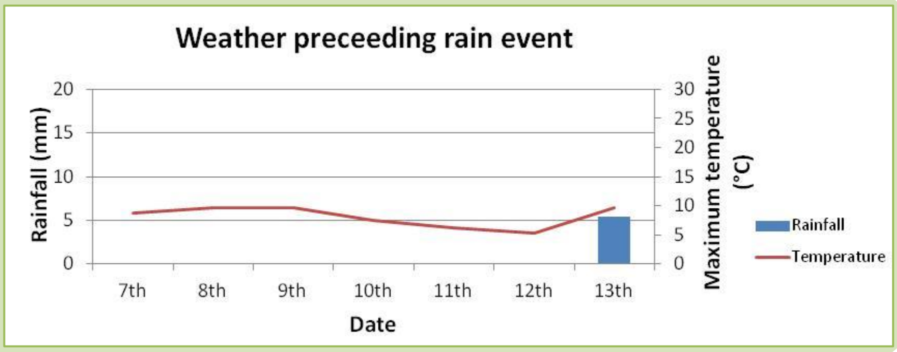
Figure 76. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 31st January 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. Control roof gauge not functioning for first rain event.

Rain event: 13th February 2015

Rain volume: 5.6 mm

Rain intensity: 24.2 mm/hr

Max temp: 9.7 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

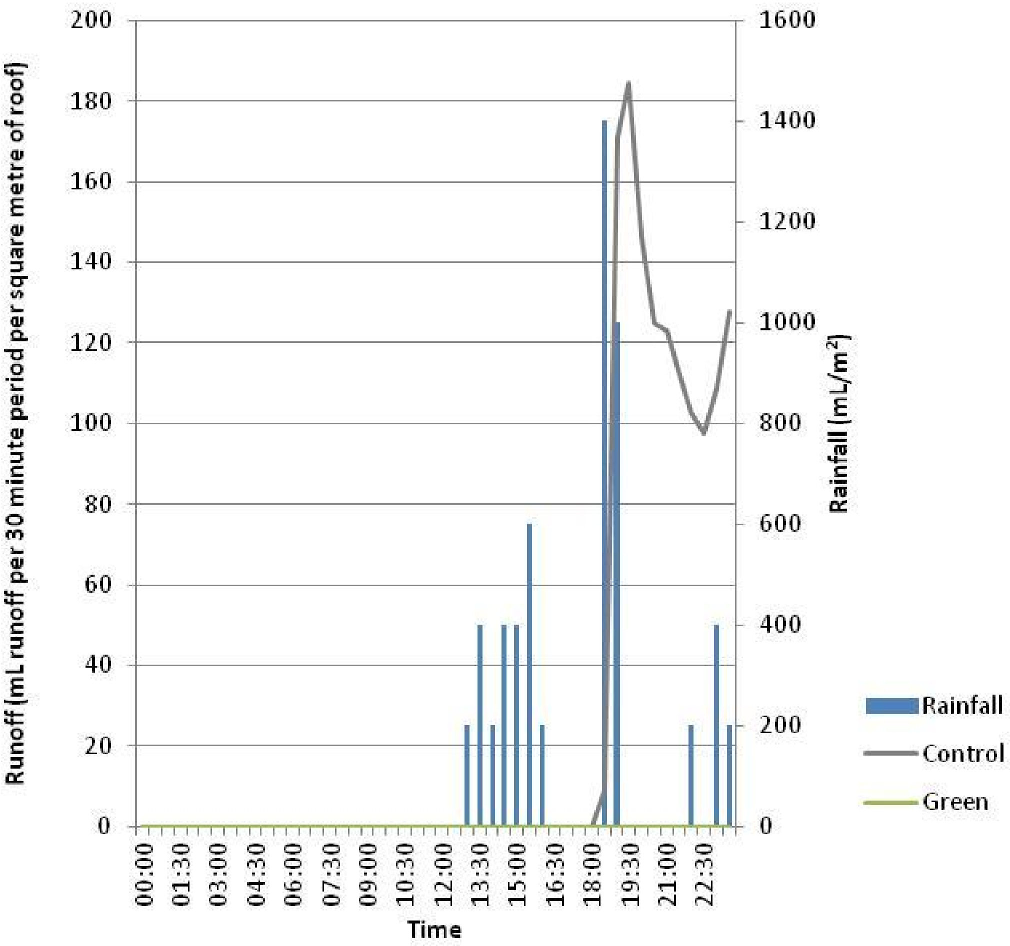


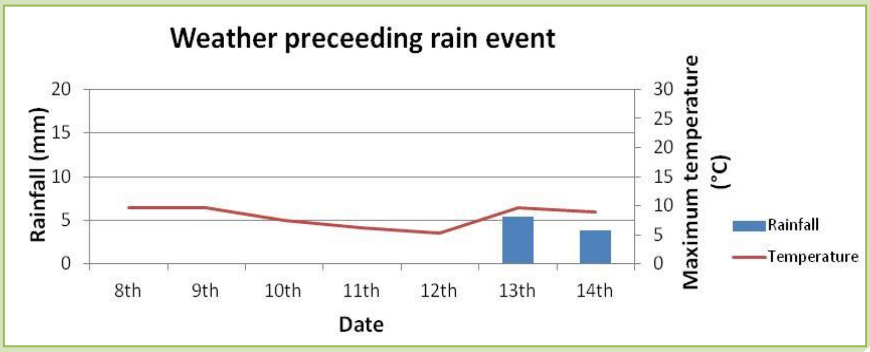
Figure 77. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 13th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 14th February 2015

Rain volume: 3.8 mm

Rain intensity: 4.6 mm/hr

Max temp: 9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

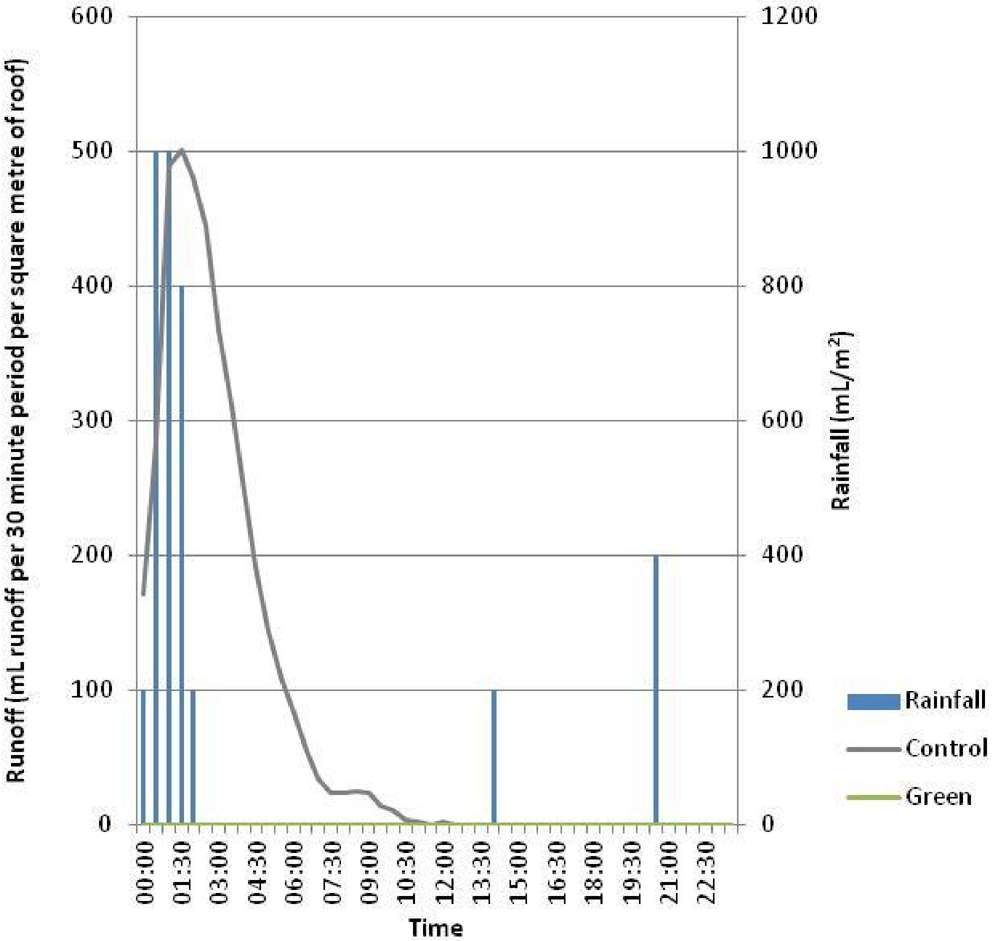


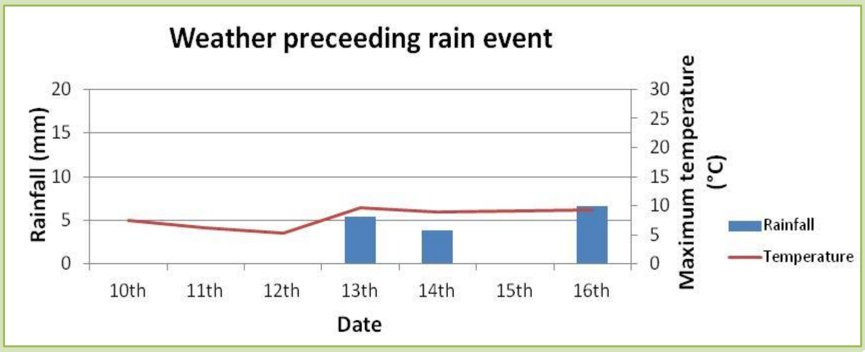
Figure 78. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 14th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 16th February 2015

Rain volume: 6.6 mm

Rain intensity: 7.4 mm/hr

Max temp: 9.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 97%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 92%

Delay in peak flow (hrs):

Peak 1

Green roof: 1

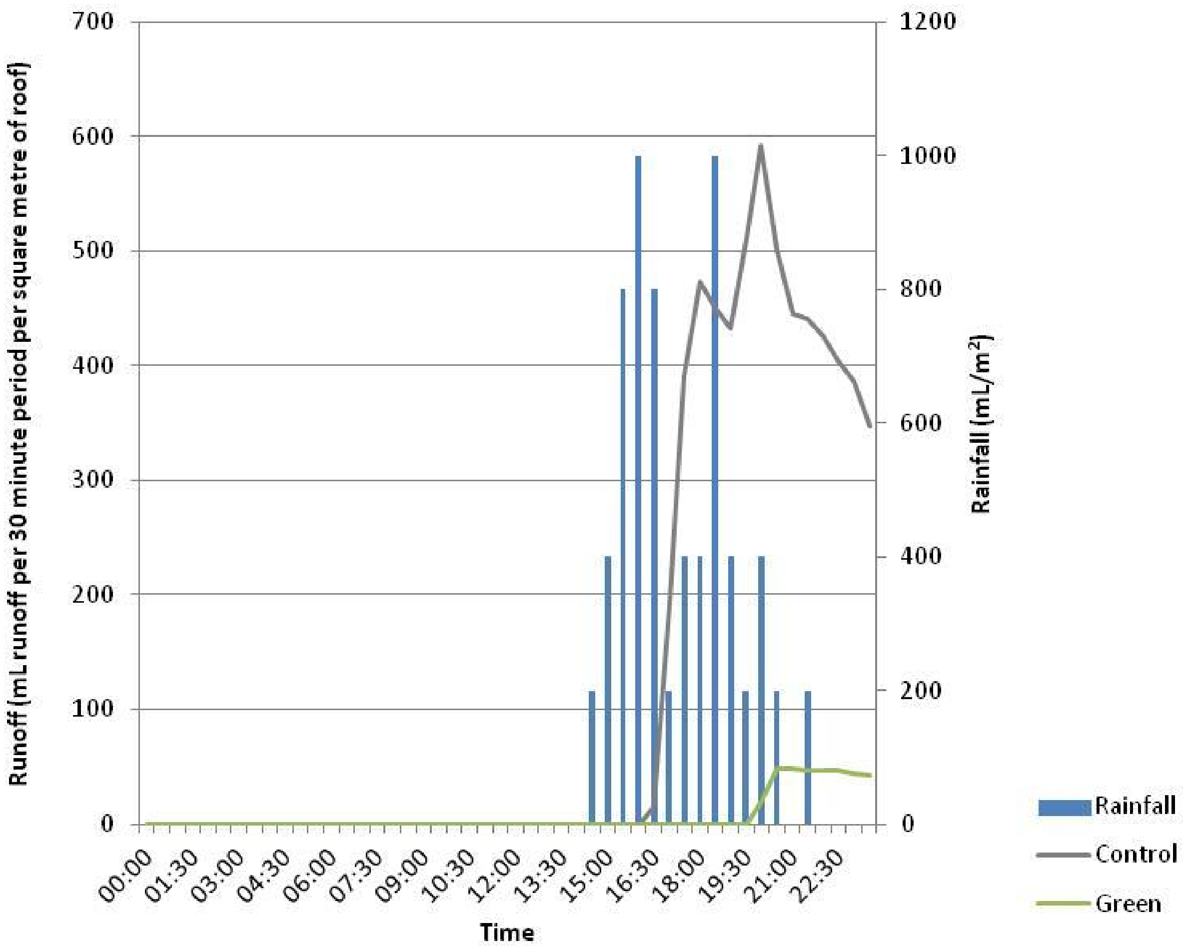


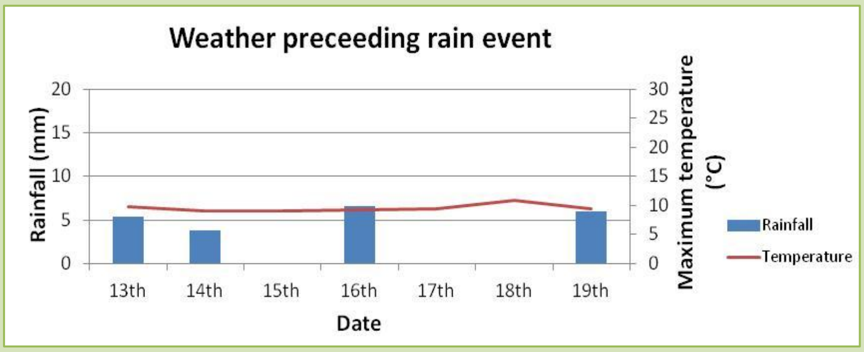
Figure 79. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 16th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 19th February 2015

Rain volume: 6 mm

Rain intensity: 1.6 mm/hr

Max temp: 9.4 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

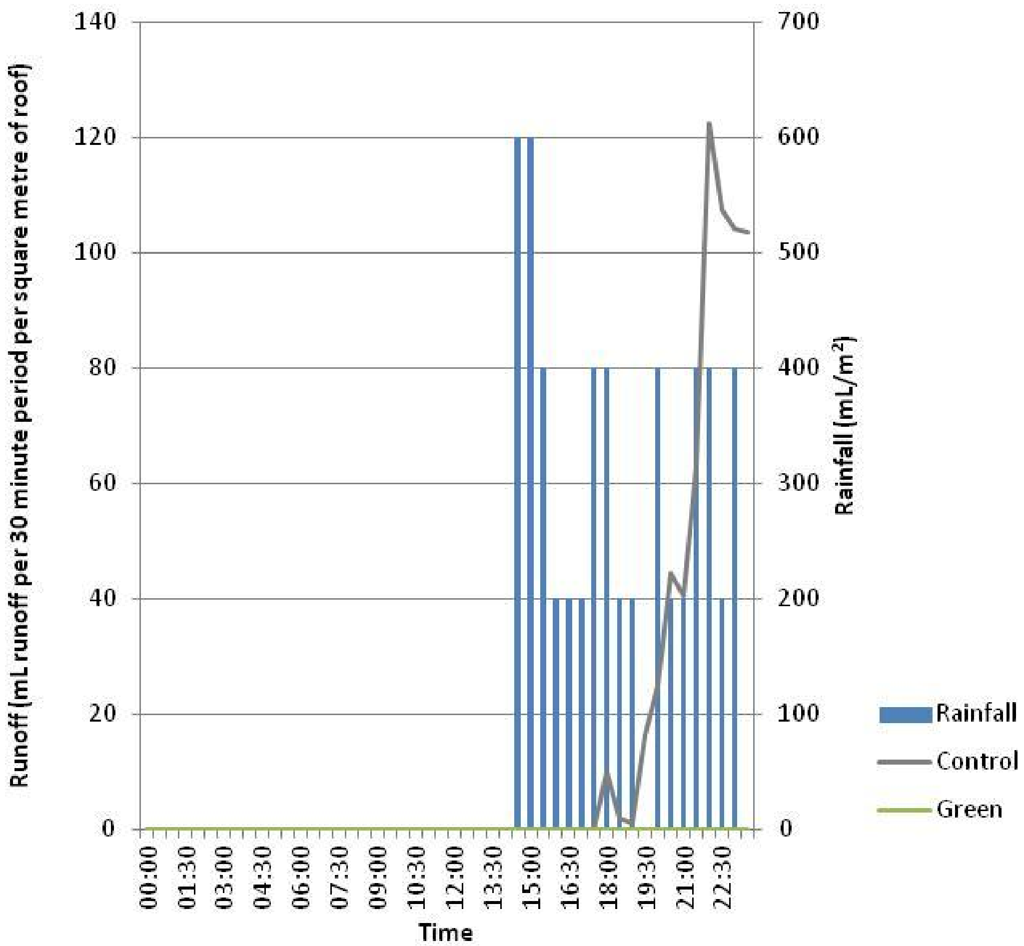


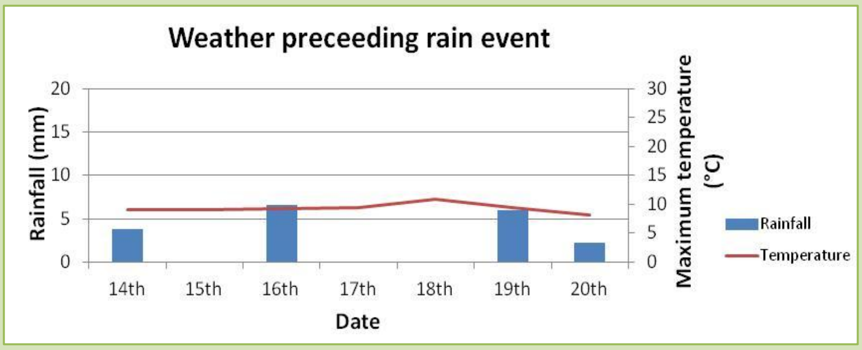
Figure 80. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 19th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 20th February 2015

Rain volume: 2.2 mm

Rain intensity: 3 mm/hr

Max temp: 8.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 99%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 95%

Delay in peak flow (hrs):

Peak 1

Green roof: 0.5

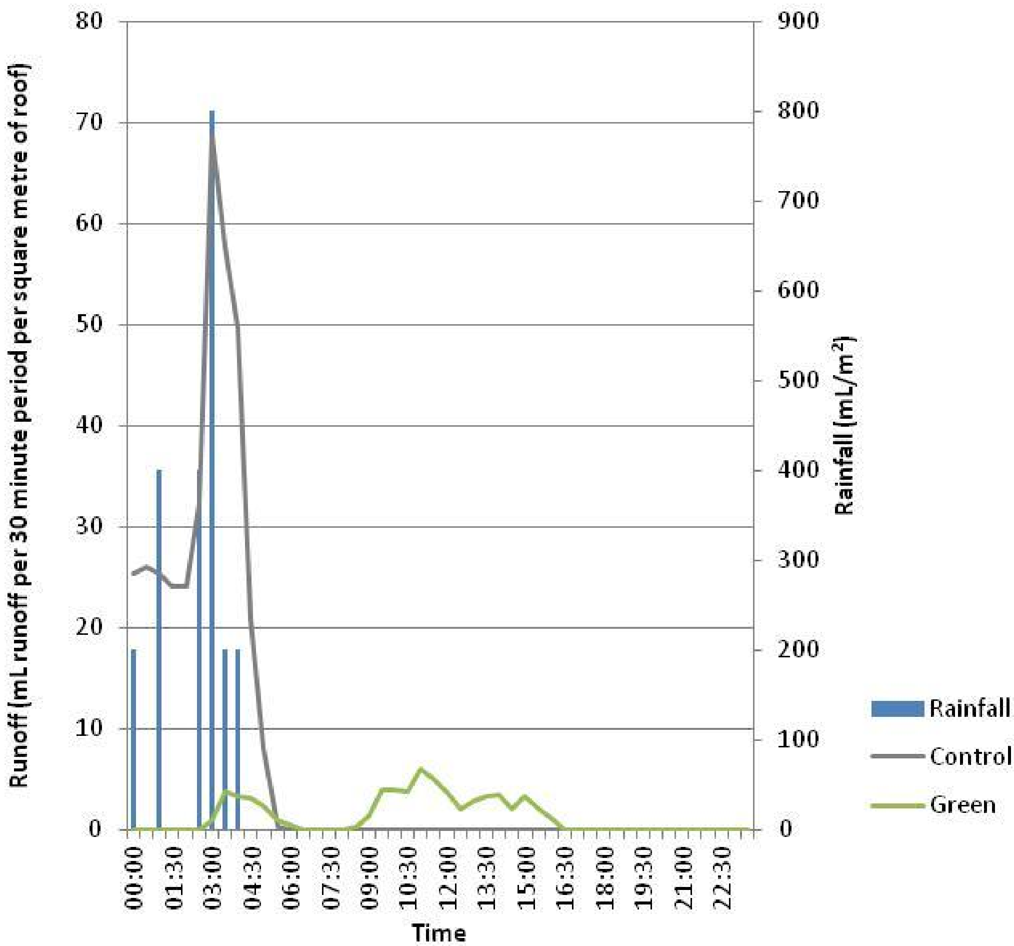


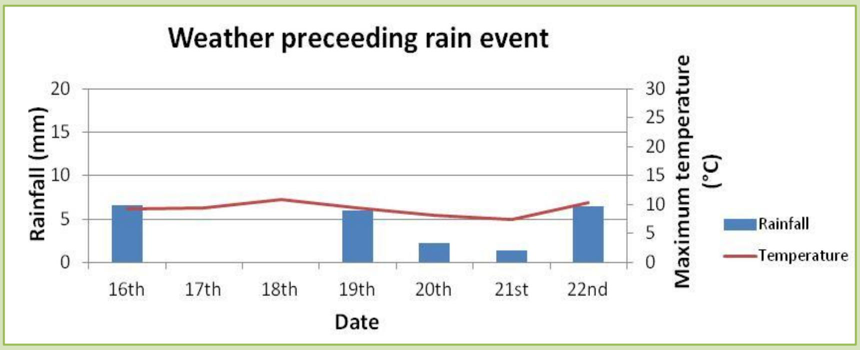
Figure 81. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 20th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 22nd February 2015

Rain volume: 6.4 mm

Rain intensity: 3 mm/hr

Max temp: 10.3 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 48%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 48%

Delay in peak flow (hrs):

	Peak 1	**Peak 2**
Green roof:	0	

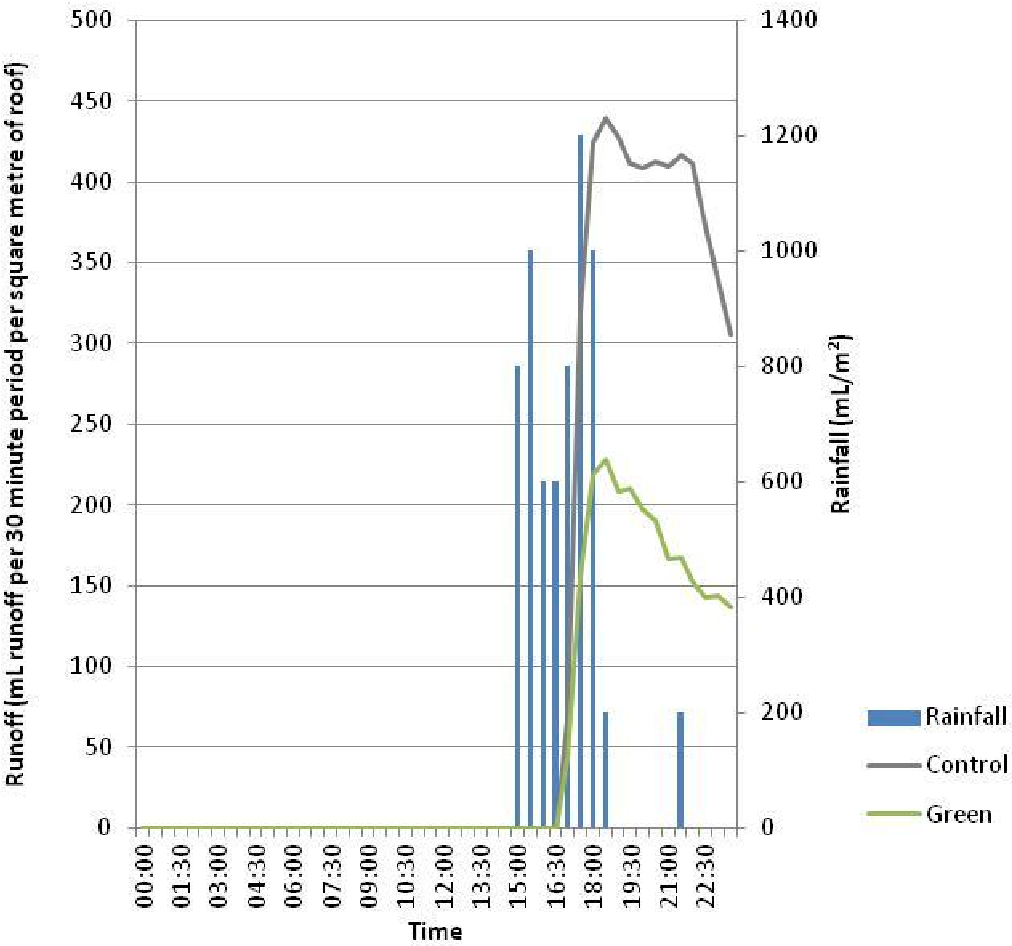


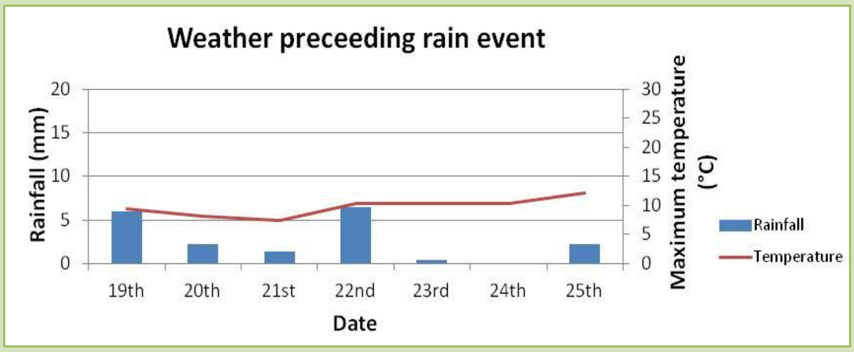
Figure 82. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 22nd February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 25th February 2015

Rain volume: 2.2 mm

Rain intensity: 3.4 mm/hr

Max temp: 12.1 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof : N/A

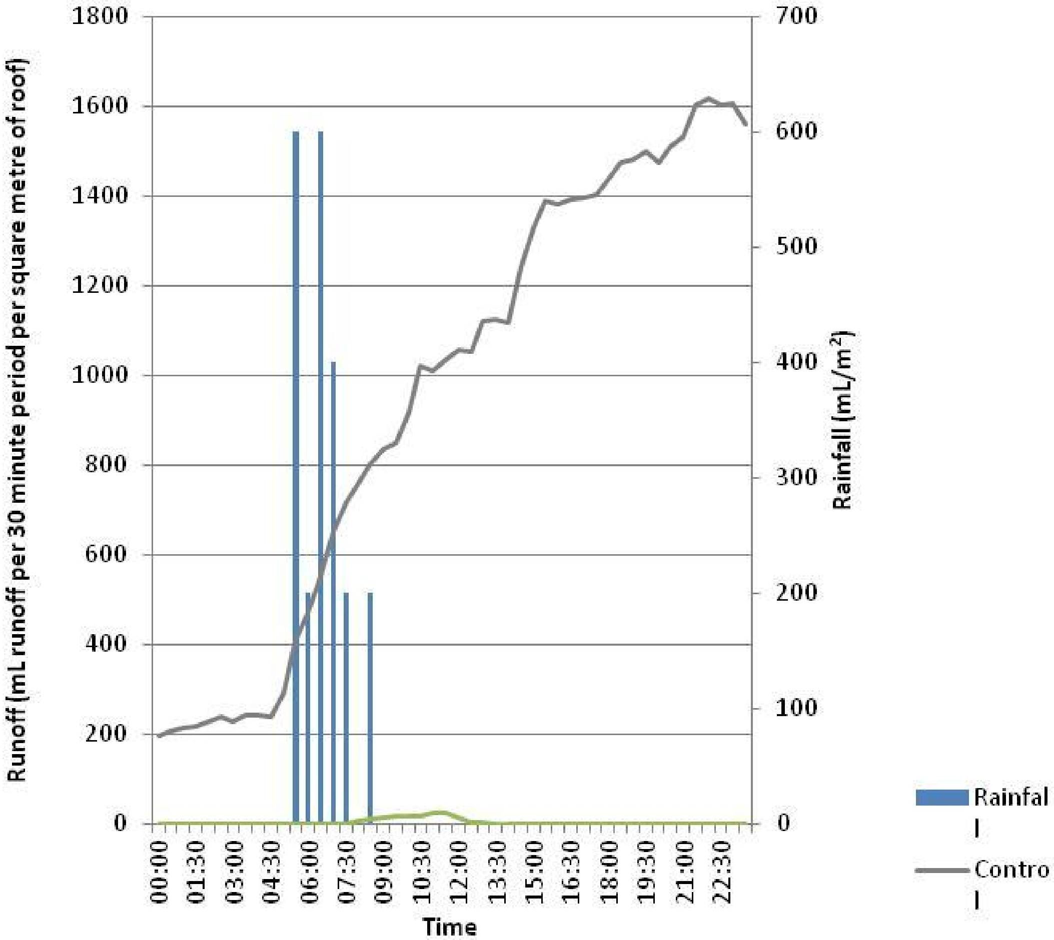


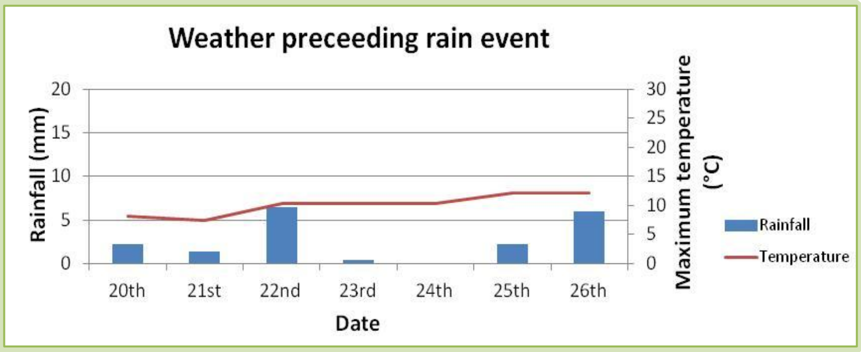
Figure 83. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 25th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating. Control appears to be blocked.

Rain event: 26th February 2015

Rain volume: 6 mm

Rain intensity: 7.2 mm/hr

Max temp: 12.2 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 85%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 74%

Delay in peak flow (hrs):

Peak 1

Green roof: 1

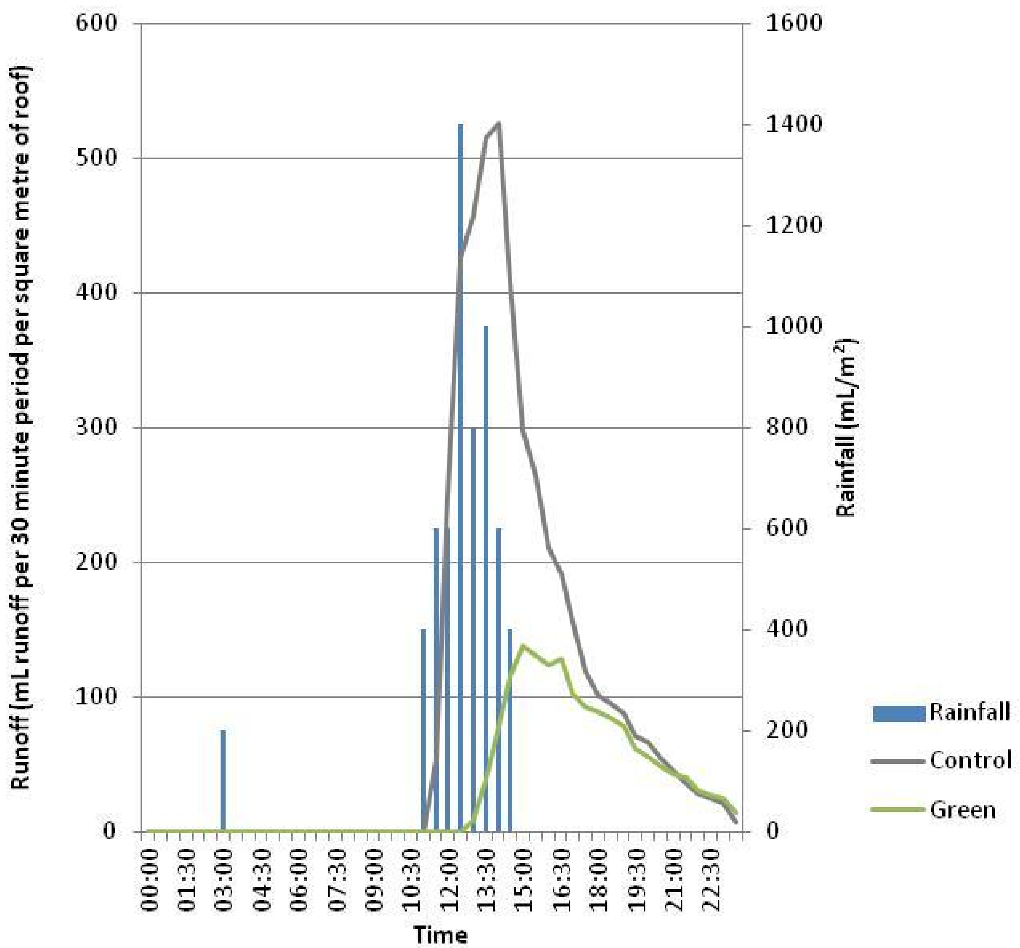


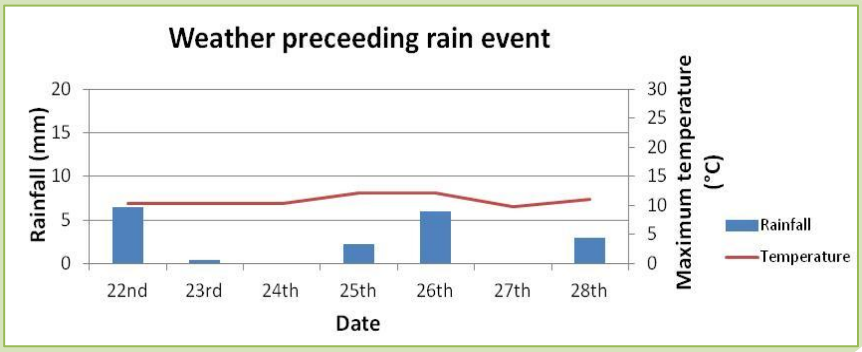
Figure 84. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 28th February 2015

Rain volume: 3 mm

Rain intensity: 3.4 mm/hr

Max temp: 11 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 94%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 94%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

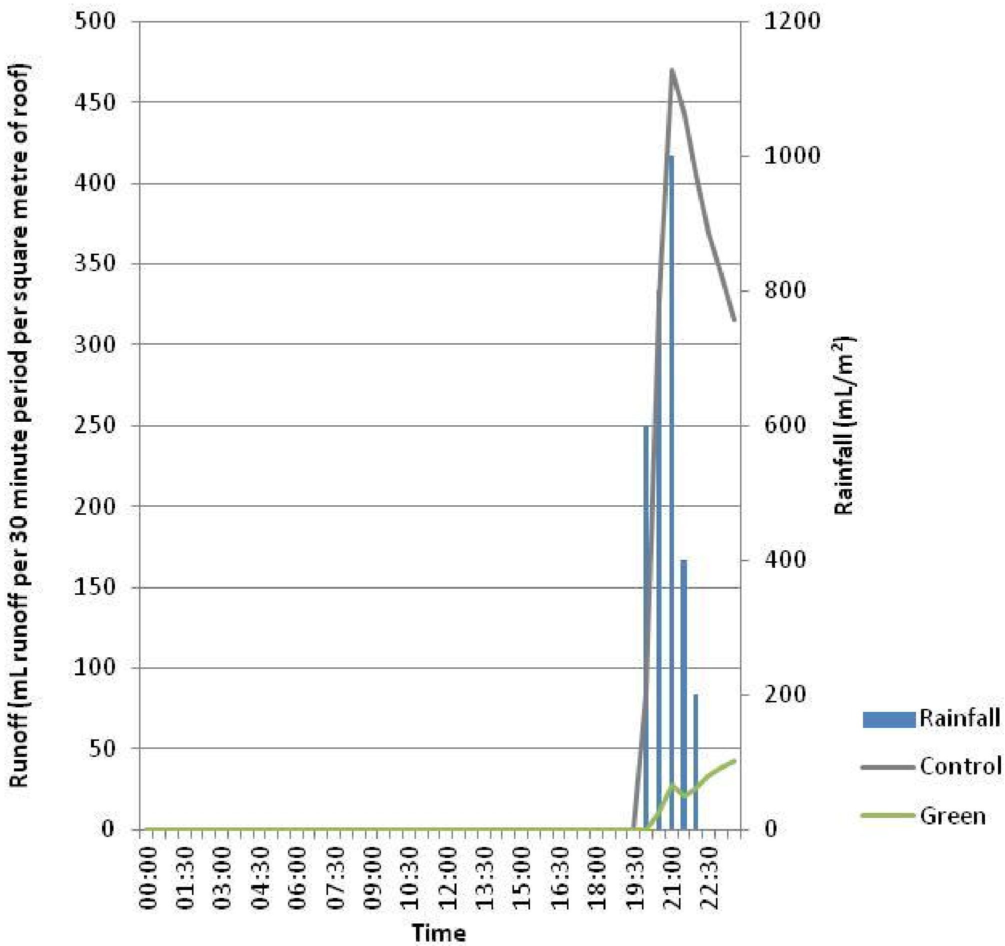


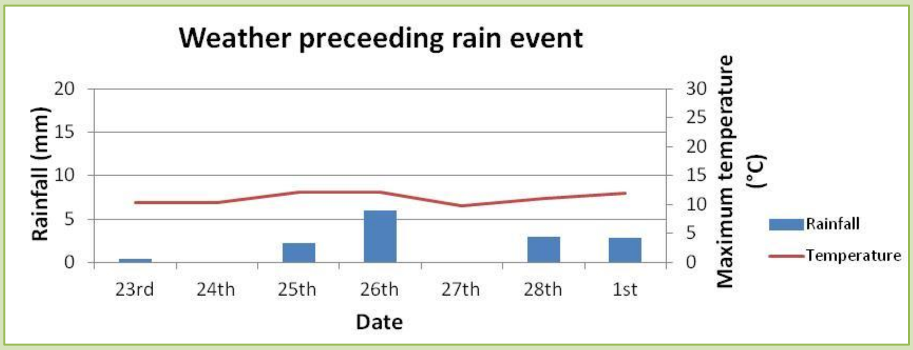
Figure 85. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 28th February 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m^2) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 1st March 2015

Rain volume: 2.8 mm

Rain intensity: 32.4 mm/hr

Max temp: 11.9 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: 0

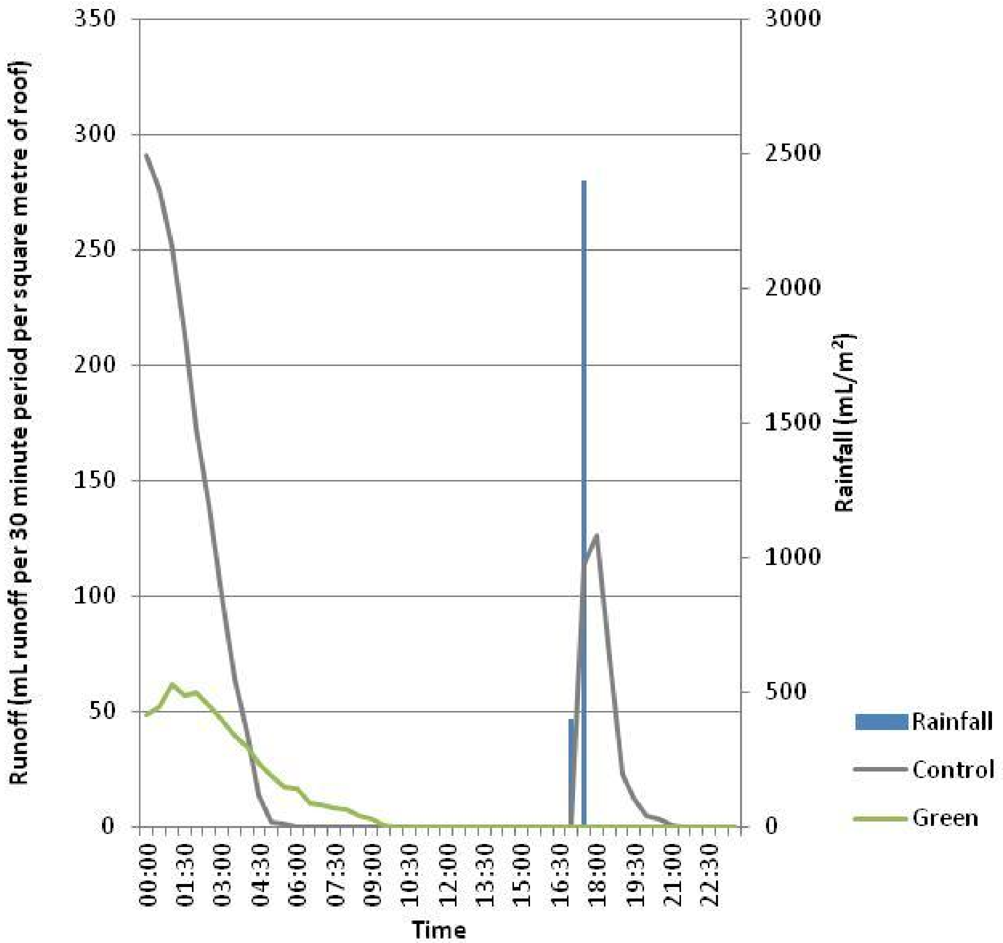


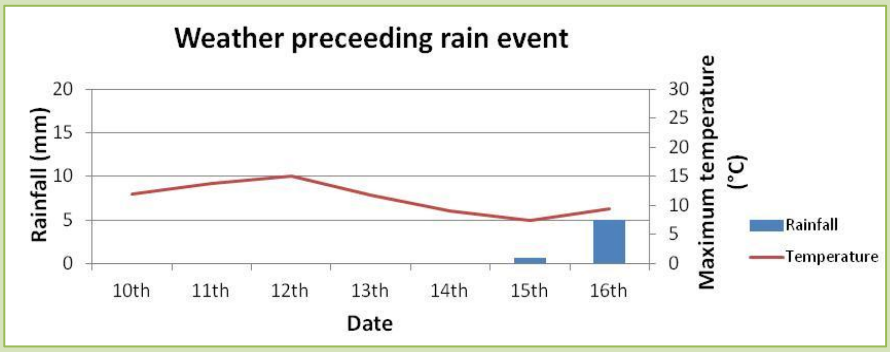
Figure 86. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 1st March 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.

Rain event: 16th March 2015

Rain volume: 5 mm

Rain intensity: 14.4 mm/hr

Max temp: 9.4 °C



Percentage peak flow rate reduction:

Relative: Peak   1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak   1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

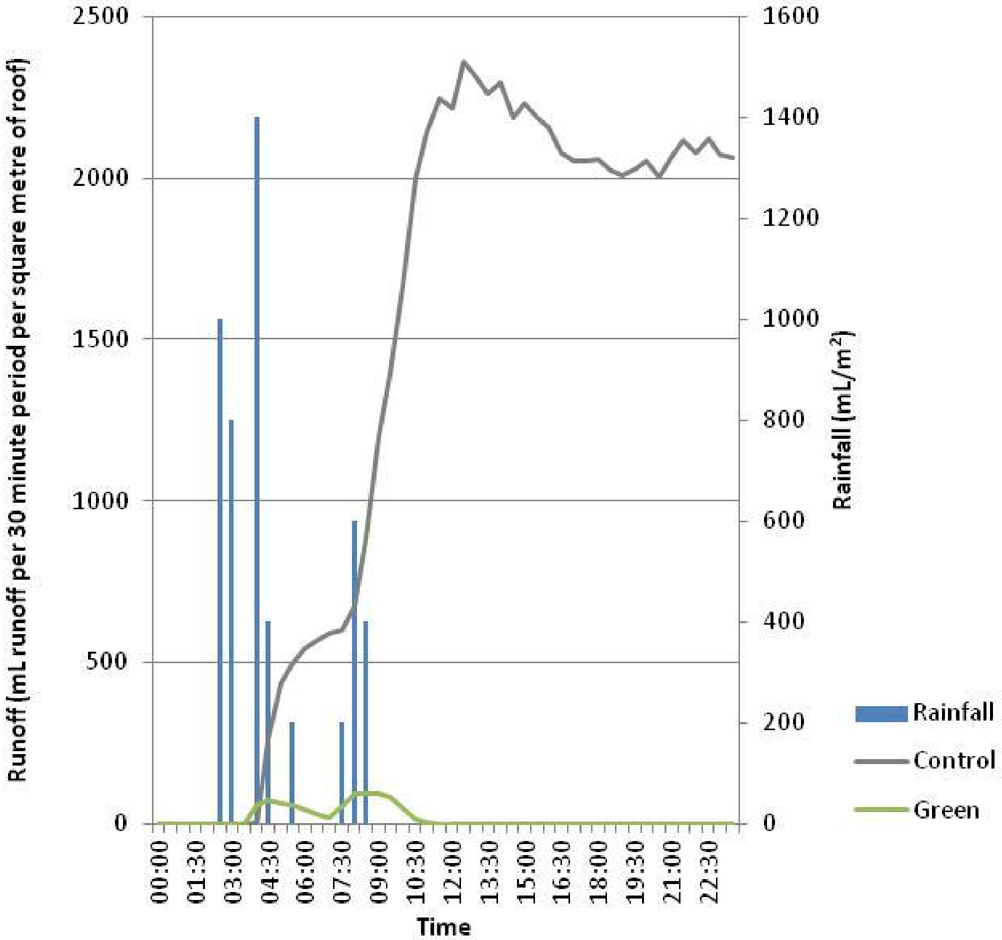


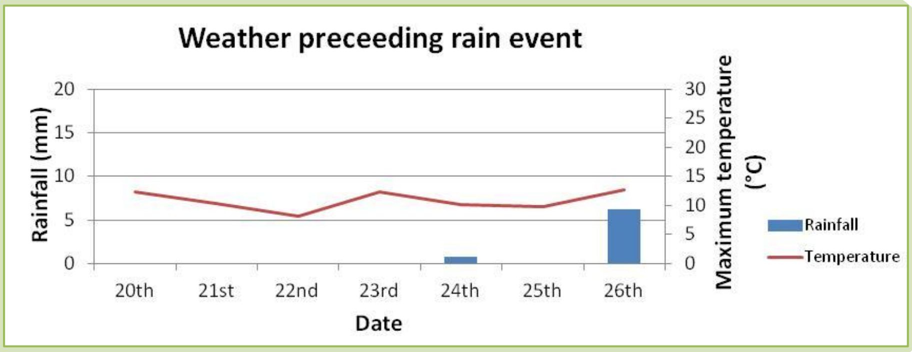
Figure 87. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 16th March 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating, control gauge blocked.

Rain event: 26th March 2015

Rain volume: 6.2 mm

Rain intensity: 2.6 mm/hr

Max temp: 12.6 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: N/A

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: N/A

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

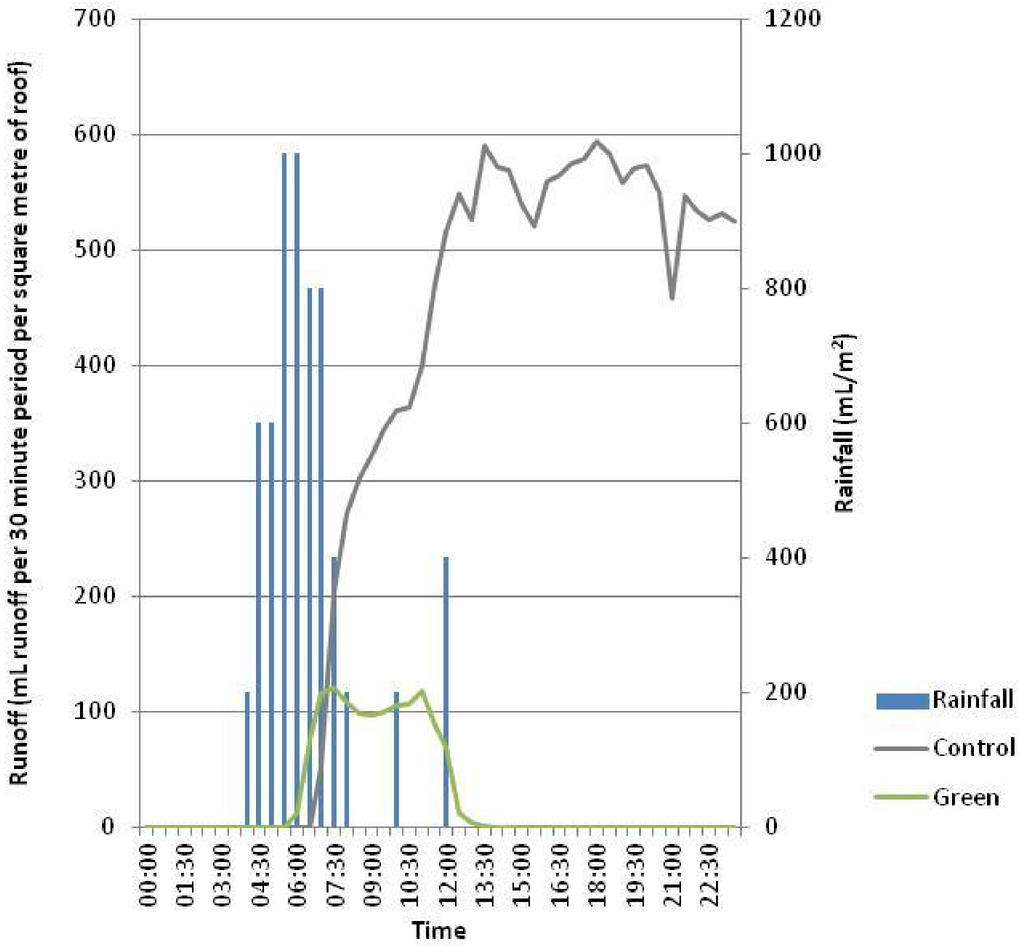


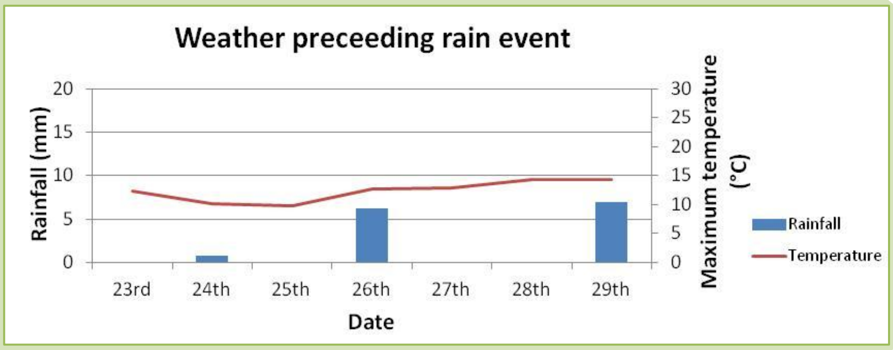
Figure 88. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 26th March 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating, control gauge blocked.

Rain event: 29th March 2015

Rain volume: 7 mm

Rain intensity: 35.4 mm/hr

Max temp: 14.4 °C



Percentage peak flow rate reduction:

Relative: Peak 1

Green roof: 100%

Percentage peak flow rate reduction:

Absolute: Peak 1

Green roof: 100%

Delay in peak flow (hrs):

Peak 1

Green roof: N/A

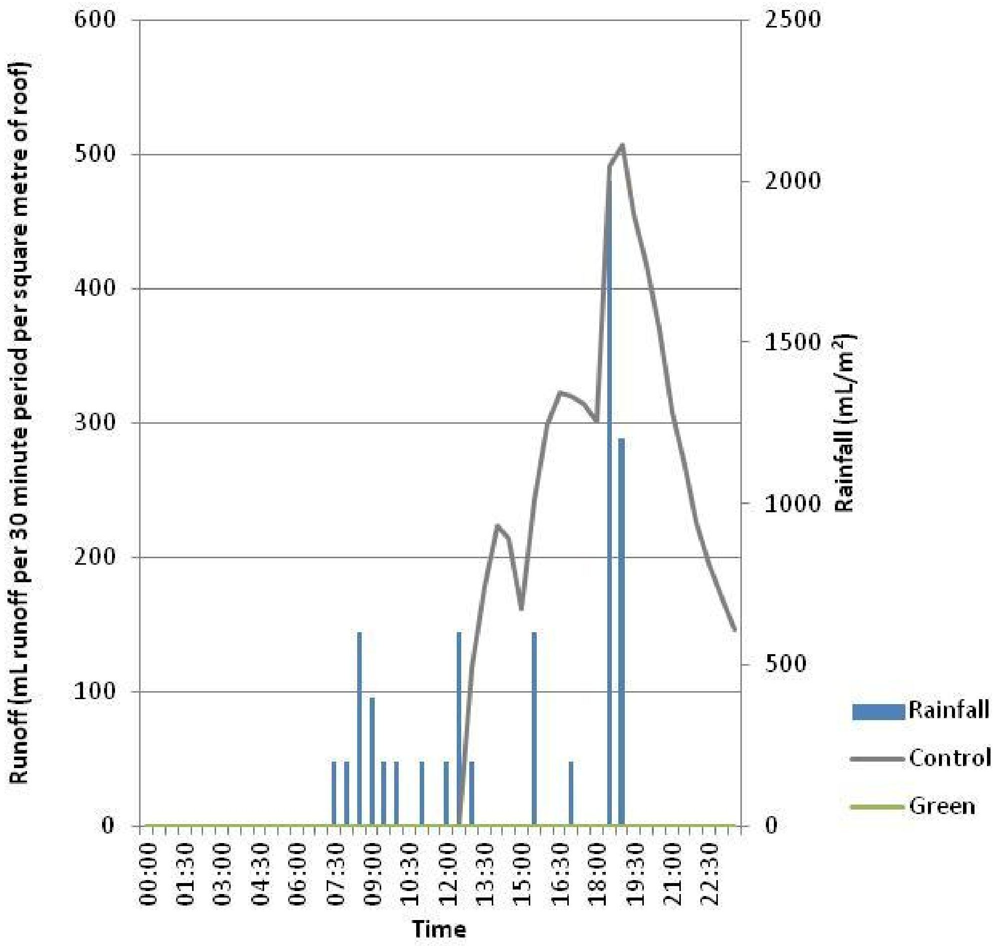


Figure 89. Rainfall and rainfall runoff patterns from green and control roofs at the Museum of London, 29th March 2015. The first axis represents the runoff from the control and green roof areas in terms of mL of rainfall per square metre of roof area summed for every 30 minute period (this includes the gravel margin around the green roof). The second axis represents the size of the rain event recorded by the weather station (in mL/m²) summed for every 30 minute period. The two axis have been normalized for purpose of display. Where data is listed as N/A this means that gauge was not working or there was a 100% reduction in flow rate so no delay could be calculated. All gauges were operating.