water

MDPI

Article

Hydrological Behaviour of Extensive Green Roofs with Native Plants in the Humid Subtropical Climate Context

Lucia Bortolini [1,*], Francesco Bettella [1] and Giampaolo Zanin [2]

[1] Department of Land, Environment, Agriculture and Forestry, University of Padova, Agripolis, Viale dell'Università 16, 35020 Legnaro, Italy; francesco.bettella@unipd.it
[2] Department of Agronomy, Food, Natural Resources, Animals and Environment (DAFNAE), University of Padova, Viale dell'Università, 16, 35020 Legnaro, Italy; paolo.zanin@unipd.it
* Correspondence: lucia.bortolini@unipd.it; Tel.: +39-049-827-2735

Abstract: Different mitigation measures with vegetation have been proposed to sustainably manage rainwater, among which green roofs have demonstrated to be a valid solution in urbanized areas. Green roofs have gained interest also in Italy, but their spreading is generally based on application of ready-to-use packages, poorly tested in the specific climate conditions. A study was carried out to evaluate the green roof solution most suitable in the humid, subtropical climate context of Veneto Plain (north-eastern Italy) to reduce outflow volumes from building roofs into the urban drainage systems. Twelve different microcosm combinations of extensive green roof (three plant mixtures × two substrates × two storage/drainage layers) were tested and compared with gravel (considered as a conventional flat roof with gravel ballast). The tested drainage/storage layers were a preformed layer in recycled HDPE (PL) and an expanded perlite mineral layer (ML), and the growth medium layers were recycled brick substrate (RS) and volcanic substrate (VS). Three different mixtures of native plant species were transplanted: *Sedum* (SE), herbaceous perennial (HE), and suffruticose (SF). Results showed that all the green roof systems have a good ability to manage rainwater, with a retention ranging on average from 46.2% (SE-RS-PL microcosms) to 62.9% (SF-RS-ML microcosms) of the precipitation in the two-year period (September 2014–August 2016), against 15.4%, retained by gravel. Over the two-year period, the retained rainfall volumes were about 100% for all the light rainy events (<10 mm) and varied within a range of 48–95% for medium rainy events (≥10 and <25 mm) and 20–88% for heavy rainy events (≥25 mm), depending on rainfall depth and the antecedent weather period. The layer that gave the highest relative contribution to the stormwater retention was the vegetation layer, followed by the drainage/storage layers and then the substrate layer. In particular, SF plants decreased the outflows by 15.2% on average compared to SE, and ML layer retained more than 10% of precipitation compared to PL layer. At last, the analysis of variance showed that, within each layer, the more effective in water retention, able to generate less outflow volumes, was similarly suffruticose and herbaceous mixtures, the crushed bricks substrate, and the mineral drainage/storage layer.

Keywords: rainwater; natural water retention measures; flooding; green infrastructure

Citation: Bortolini, L.; Bettella, F.; Zanin, G. Hydrological Behaviour of Extensive Green Roofs with Native Plants in the Humid Subtropical Climate Context. *Water* **2021**, *13*, 44. https://doi.org/10.3390/w13010044

Received: 14 November 2020
Accepted: 25 December 2020
Published: 28 December 2020

1. Introduction

Green roofs are water retention measures to effectively counter the effects of the intense urbanization of the last decades that is causing many problems, such as the increase in air and surface temperatures, with the consequent urban heat island (UHI) effect, the intensification of the flooding phenomena, the accumulation of pollutants in the air and in the ground, and a reduction of the ornamental and landscape aspects inside and outside the urban areas [1,2].

The modified urban microclimate creates problems for the health and well-being of the population, which is more severe in densely urbanized areas [3–5]. Increasing the presence of plants through green roofs can mitigate the UHI effects thanks to evapotranspiration phenomena [6–10]. Furthermore, despite the fact that vegetation suffers from pollution, at the same time it is the main means through which pollutants can be reinserted into natural environments, thanks to interception and biological re-elaboration [11], also in the green roof context [12,13]. Green roofs also improve the thermodynamic efficiency of the buildings in which they are installed [14–19], are effective in reducing the atmospheric CO_2 [20], and contribute to the increase in the ornamental and landscape value both inside and outside urban areas [21,22].

It is known globally that the progressive soil sealing increases runoff due to surface imperviousness [23] and leads the traditional drainage systems of urbanized areas to a critical level [24]. In Veneto region (north-eastern Italy), urbanisation and industrial expansion are common trends [25,26], and the increasing flood occurrence in this region is partly attributed to these land transformation processes [27], with a decrease in the drainage density of agricultural fields, water storage capacity, and peak flow buffering [28,29].

In urban environments, different mitigation measures with vegetation have been proposed to sustainably manage rainwater [30–35], and the European Commission's blueprint to safeguard Europe's waters endorses the use of natural water retention measures (NWRMs) [36], among which green roofs are the first on this list. Many researchers have shown that green roofs can be a valid solution in the mitigation of problems related to the management of rainwater runoff in urbanized areas [37–46]. In fact, covering part of the vast roof surfaces of urbanized areas with green roof systems, including craft and industrial areas, could increase their water storage capacity [47–49]. Additionally, several studies have presented socio-economic assessments of the adoption of NWRMs on direct and indirect benefits derived from flood damage reduction, as well as on other co-benefits, that is, air quality improvement, energy savings, and so forth [50–52].

The choice of the right plant species for the green roofs plays an important role because vegetation can affect the amount of water runoff depending on each plant's capacity for water interception, water retention, and transpiration [53–56].

Green roofs have gained interest also in Italy, but their spreading is generally based on application of ready-to-use packages, which are poorly tested in specific environmental conditions. The aim of this study was to evaluate the green roof solution most suitable in the humid, subtropical climate context of Veneto Plain (Italy) and able to better manage rainfall water in order to reduce outflow volumes from building roofs into the urban drainage systems.

Specifically, the main goal concerned the analysis of the hydrological behaviour of twelve green roof microcosms by comparing two different drainage/storage layers, two different cultivation substrates, and three different mixtures of native plants, as well as the growth of the vegetation over time. In this paper, only the results related to the hydrological performance are reported.

2. Materials and Methods

A two-year study was carried out from summer 2014 to summer 2016 in the Agripolis Campus of the University of Padova, located in Legnaro (45°20′26″ N; 11°58′0″ E) in the plain of Veneto region (north-eastern Italy). This area is characterized by a humid, subtropical climate [57], with quite frequent high-intensity events, often critical for the urban drainage systems. During the test, weather data (precipitation, temperature, and air humidity) were recorded by the weather station located in the Campus.

From spring 2014, 36 green roof microcosms were installed on a tubular steel structure raised about 1 m from the paved surface. Each microcosm consisted of a combination of different drainage/storage layers, substrates, and mixtures of plants placed into plastic boxes in polypropylene with a surface area of about 0.44 m^2 [58]. A drain hole in the centre of the box bottom was created to convey more precisely the percolation water (outflow) through a Y-shaped pipe in two tanks (20 L of capacity each), placed below each individual box of green roof microcosm (Figure 1).

Figure 1. Two photos of the experimental site at the Agripolis Campus: at the beginning in May 2014 (**left**) and at the end in September 2016 (**right**) of the two-year experimental period.

The drainage/storage layers were about 5 cm high and constituted of a preformed layer (PL) in recycled HDPE (Bauder DSE 40, Bauder GmbH, Germany) or a mineral layer (ML) composed of expanded perlite (Igroperlite Type 3, Perlite Italiana S.r.l., Italy) inside a fabric bag.

Two different substrate layers of 12 cm height were tested: a volcanic substrate (VS) (Vulcaflor Extensive, Europomice S.r.l., Italy) and a recycled crushed bricks substrate (RS) ("Rockery Type Plants", Zinco GmbH, Germany). A geotextile fabric (polypropylene textile, thickness of 1 mm) was used to separate the substrate from the drainage/storage layer to prevent medium fines from washing into the drainage layer.

Laboratory tests were carried out to measure hydrological characteristics of the different layers and evaluate their hydrological behaviour singularly and combined. The two types of each layer (drainage/storage and substrate) and their respective combinations were analysed by means of selected rainfall simulations [59]. The main characteristics of the used materials are reported in Table 1.

Table 1. Main characteristics of the tested materials used to assemble the green-roof microcosms.

Green-Roof Layer	Layer Type	Composition	Thickness (cm)	Permeability (mm/min) *	Water Retention Capacity (mm)
Substrates	Volcanic substrate (VS)	Pumice-stones, volcanic lapillus, and blonde peat	12.0	0.6–6.0 [b]	36 [a]
	Recycled substrate (RS)	Recycled crushed bricks plus compost and fibrous matter	12.0	0.6–70 [b]	48 ± 12 [a]
Drainage/storage layers	Preformed HDPE layer (PL)	Recycled high-density polyethylene	4.4 (4.0 + 0.4)	-	16.5 (13.5 + 3)
	Mineral layer (ML)	Expanded perlite bags of calendered geotextile	5.4 (5.0 + 0.4)	400	18.0

* The PL permeability is not provided because, unlike the ML, it is not a substrate; [a] values of water retention capacity calculated as the product of water weight at maximum water capacity in kg/m^3 (obtained by subtracting the dry weight from the substrate weight at the maximum water capacity) and substrate thickness; [b] the minimum value corresponds to a compressed condition of the substrate.

Plants were collected in areas close to the experimental site (mainly arid meadows), and three different mixtures of native species were transplanted: *Sedum* (SE) (*Sedum album* L., *S. acre* L., *S. reflexum* L., and *S. sexangulare* L.), herbaceous perennial (HE) (*Melica ciliata* L., *Artemisia alba* Turra, *Bromus erectus* Huds, and *Dianthus carthusianorum* L.), suffruticose (SF) (*Potentilla pusilla* Host, *Clinopodium nepeta* L., *Thymus serpillum* L., *Euphorbia cyparissas* L., *Anthemis tinctoria* L., *Campanula spicata* L., and *Dianthus hyssopifolius* L.).

All the twelve combinations (3 plant mixtures × 2 substrates × 2 drainage/storage layers) were replicated three times, for a total of 36 microcosms. Three boxes were filled with a 5 cm layer of washed gravel on a geotextile fabric and used as control (conventional flat roof with gravel ballast). The experimental design was a randomized complete block (Figure 1).

During the initial phase, daily irrigations of 5 L (about 11 mm) were given to each microcosm to ensure the normal plant growth. From June 2014 to May 2016, 12 supplemental irrigations of about 11 mm were performed when strong symptoms of wilting occurred; during the last summer (June–August 2016) no supplemental watering was given.

Starting from June 2014, a photographic survey of each microcosm was carried out each month to evaluate the trend of the vegetation canopy cover. Monthly actual evapotranspiration and crop coefficient (Kc act) were calculated according to [60,61]. These results and their discussion are reported in [62].

Data collection began after plants were well established. The outflow volumes from each box (green roof microcosm) were recorded after each rainfall event from September 2014 until August 2016 by weighing the two tanks placed under each microcosm using an electronic scale. The collected data were converted in millimetres by considering the area of each box (0.44 m^2). Rainfall data were recorded by the weather station located in the Agripolis Campus.

The study was arranged as a 3 × 2 × 2 factorial experiment (3 plant mix × 2 substrates × 2 drainage/storage) in a completely randomized block design with three replications. Data were analysed using a three-way analysis of variance (ANOVA), and when the ANOVA was significant ($p < 0.05$), means were differentiated by Tukey's HSD test.

3. Results

3.1. Precipitation and Temperature

The meteorological data recorded during the experiment period are reported in Figure 2. From 1 September 2014 to 31 August 2016, 1695.1 mm of precipitation fell at the study site. The return period of the daily rainfall was determined based on the parameters of the Gumbel distribution provided by the Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV). These parameters refer to the time series 1991–2019 of extreme annual values of precipitation recorded by the ARPAV meteorological station located 0.5 km from the test site. The results of the frequency analysis suggest that no exceptional rainfall events occurred at the study site during the considered timespan. The highest monthly total of 191.8 mm was recorded in May 2016 (a very wet month, unusual for this climate context), while the wettest day was registered on 19 May 2016, with a total rainfall of 61.8 mm, corresponding to a return period of 2.3 years.

During the experiment, precipitation (≥0.2 mm) was observed on 228 days. For a more detailed analysis of the hydrological behaviour of the different green roof systems, according to [63], rainfall events were subdivided into light (<10 mm), medium (≥10 and <25 mm), and heavy (≥25 mm). Over the research period, 173 light rain events (<10 mm), 44 medium rain events (≥10 and <25 mm), and 11 heavy rain events (≥25 mm) occurred.

Autumn 2014 was characterized by temperatures well above the average, especially in October–November. Spring 2015 was mild overall, with above-average temperature values, following an even milder winter, and with generally below-average rainfall. Summer 2015 was overall hot, at times even very hot, especially in July, with prolonged periods of good weather and temperatures significantly above average, while rainfall was generally below average. Temperatures in autumn 2015 were close to average and in winter 2015/16 higher than normal, while precipitation was below average with total absence of rainfall during the entire month of December. Spring and summer 2016 did not present large deviations from the climatological averages, even if it rained a lot in May and June, with an anomalous frequency of intense thunderstorms with abundant rains.

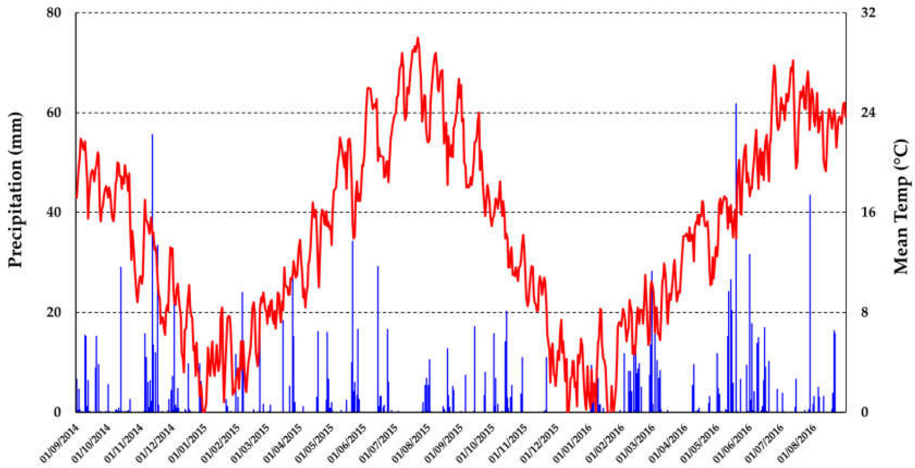

Figure 2. Meteorological data recorded during the two years of tests: daily precipitation recorded at the test site (rain gauge with tipping bucket, area 200 cm^2) and mean daily temperature recorded at the meteorological station of the Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV), located 0.5 km from the test site.

3.2. Analysis of the Outflows from the Microcosms of the Green Roof

In general, the data related to the rainwater drained after each rainfall event (outflow) showed that all the green roof systems were able to retain rainwater effectively, producing less outflow than the conventional roof with gravel. In fact, all of them have shown a good ability to manage the rainwater volumes, with a retention ranging from 46.2% (SE-RS-PL microcosms) to 62.9% (SF-RS-ML microcosms) of the precipitation in the two-year period, against 15.4%, retained by the control boxes filled with gravel (Figure 3 and Table 2).

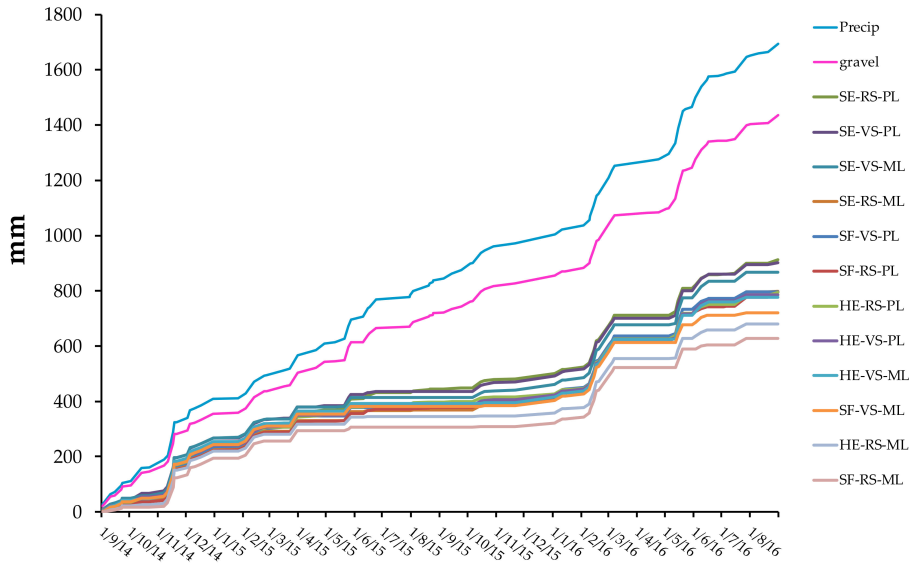

Figure 3. Cumulative outflow from each type of green roof microcosm and comparison with precipitation and gravel. SE = *Sedum* mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

Table 2. Precipitation and outflow volumes (in mm) from each microcosm type (in brackets is the percentage of precipitation).

	Fall 2014	Winter 2014–15	Spring 2015	Summer 2015	Fall 2015	Winter 2015–16	Spring 2016	Summer 2016	Total
Precipitation	326.0	169.3	200.6	143.1	133.6	177.7	316.0	228.8	1695.1
Gravel	281.5 (86.3%)	155.0 (91.6%)	176.7 (88.1%)	105.4 (73.7%)	109.2 (81.7%)	158.0 (88.9%)	259.0 (82.0%)	189.8 (83.0%)	1434.6 (84.6%)
SE-RS-PL	182.4 (56.0%)	134.1 (79.2%)	91.4 (45.6%)	35.9 (25.1%)	37.0 (27.7%)	142.2 (80.0%)	186.8 (59.1%)	102.1 (44.6%)	911.9 (53.8%)
SE-VS-PL	197.0 (60.4%)	137.9 (81.5%)	91.0 (45.4%)	11.0 (7.7%)	33.7 (25.2%)	146.5 (82.4%)	183.5 (58.1%)	101.5 (44.4%)	902.1 (53.2%)
SE-VS-ML	197.2 (60.5%)	139.0 (82.1%)	79.2 (39.5%)	0.0 (0.0%)	25.0 (18.7%)	148.3 (83.5%)	185.9 (58.8%)	92.5 (40.4%)	867.1 (51.2%)
SE-RS-ML	159.6 (49.0%)	132.9 (78.5%)	70.7 (35.2%)	5.2 (3.6%)	24.4 (18.3%)	150.0 (84.4%)	175.6 (55.6%)	80.9 (35.4%)	799.2 (47.1%)
SF-VS-PL	167.2 (51.3%)	135.8 (80.2%)	74.7 (37.2%)	4.0 (2.8%)	28.0 (15.0%)	140.7 (79.2%)	183.8 (58.2%)	62.7 (27.4%)	796.9 (47.0%)
SF-RS-PL	153.2 (47.0%)	134.0 (79.1%)	68.7 (34.2%)	21.0 (14.7%)	21.5 (16.1%)	135.7 (76.4%)	179.4 (56.6%)	81.2 (35.5%)	794.7 (46.9%)
HE-RS-PL	171.7 (52.7%)	132.2 (78.1%)	76.4 (38.1%)	16.5 (11.5%)	19.1 (14.3%)	129.0 (72.6%)	174.5 (55.2%)	74.5 (32.6%)	793.9 (46.8%)
HE-VS-PL	172.4 (52.9%)	133.6 (78.6%)	78.0 (38.9%)	2.5 (1.7%)	19.7 (14.7%)	134.8 (75.6%)	175.5 (55.5%)	68.9 (30.1%)	785.4 (46.3%)
HE-VS-ML	183.0 (56.1%)	136.9 (80.9%)	72.9 (36.3%)	0.9 (0.6%)	1.6 (1.1%)	142.2 (80.0%)	175.4 (55.5%)	63.6 (27.8%)	776.5 (45.8%)
SF-VS-ML	172.2 (52.8%)	137.9 (81.5%)	73.0 (36.4%)	0.0 (0.0%)	2.0 (1.5%)	141.1 (79.4%)	152.5 (48.3%)	43.2 (18.9%)	721.8 (42.6%)
HE-RS-ML	150.8 (46.3%)	129.6 (76.6%)	62.9 (31.4%)	1.9 (1.3%)	2.8 (2.1%)	124.3 (69.9%)	156.7 (49.6%)	51.2 (22.4%)	680.2 (40.1%)
SF-RS-ML	124.4 (38.2%)	131.8 (77.8%)	50.1 (25.0%)	0.7 (0.5%)	2.4 (1.8%)	131.5 (74.0%)	147.5 (46.7%)	40.2 (17.6%)	628.5 (37.1%)

SE = *Sedum* mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

It is interesting to note how the outflows reduction varied according to the time of the year, with the minimum values in summer and the highest volumes in winter, an effect also observed in traditional roofs with gravel. The trend of the cumulative outflows reported in Figure 3 shows the particular behaviour of the green roofs during the most intense rainy events. In fact, it can be noted the rapid rise of all the curves in correspondence with the rainy events from 5 to 18 November, 2014 (about 160 mm of precipitation) and with the rainy events from 27 February to 8 March, 2016 (about 94 mm of precipitation), with outflow values on average higher than 86% of total precipitation (97% for gravel). Much more attenuated was the response to rainfall in periods characterized by higher temperatures, including the most intense event on 19 May, 2016 with a total of 61.8 mm of rainfall. After this rainy event, fairly high outflow values were measured in all green roof microcosms, ranging from 60.5% to 72.3% of the precipitation for SF-RS-ML and SE-VS-PL microcosms, respectively, and 79.4% for gravel.

The green roof system proven to better manage rainfall was SF-RS-ML (mixture of suffruticose, recycled crushed bricks medium, and perlite mineral drainage/storage layer) in both years, but in the second year also SF-VS-ML and HE-RS-ML performed well (Figure 4).

In all the light rainy events (<10 mm), about 100% of precipitation was retained by all the green roof systems over the two-year period.

For medium rainy events (≥10 and <25 mm), the ability of green roofs to retain water was high. In general, the retention capacity varied within a range of 85–95%. Unlike the rule, in the event of 3 February 2016 (11.8 mm of precipitation preceded by 31 mm fairly distributed over the previous days), the average retained rainfall volume was 48%.

As for heavy rainy events (≥25 mm), the range of the retained rainfall volume varied from 20% to almost 88%, depending on rainfall depth and the antecedent weather period, which influenced moisture conditions of the green roof systems. In particular, the lowest value was observed on 17 November 2014, during which 33.4 mm was registered after a two-week rainy period with 124 mm of precipitation. A similar behaviour was observed during the event of 19 May 2016. A precipitation of 61.8 mm occurred after a very rainy period, and the retention capacity was only 33% on average. On the contrary, the maximum rainwater retention was observed on 14 June 2015 after a dry period (Table 3).

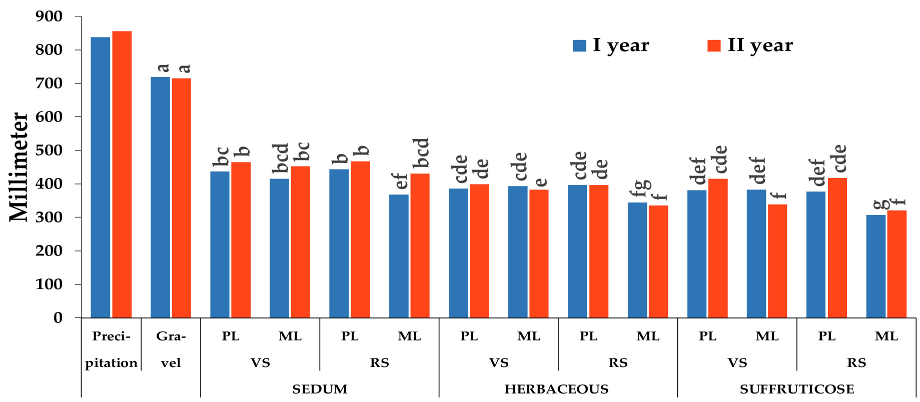

Figure 4. Rainfall outflows from the green roof microcosms in the two-year study in comparison with precipitation and the control (gravel). Histogram values with different letters indicate significant differences according to Tukey's HSD test ($p < 0.05$). SE = *Sedum* mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

Table 3. Average percentages of rainwater retained from each green roof microcosm type for the three heavy rainfall events with significant interaction.

Event	13 October 2014	14 June 2015	28 July 2016
Precipitation	31.2	29.2	44.0
SE-VS-PL	52.0 e	83.0 de	31.0 de
SE-VS-ML	66.5 cd	99.8 a	37.6 d
SE-RS-PL	62.5 de	55.8 g	25.7 e
SE-RS-ML	84.7 b	87.8 cd	41.3 d
HE-VS-PL	62.9 d	94.8 bc	59.8 bc
HE-VS-ML	74.6 c	100 a	68.2 b
HE-RS-PL	66.5 cd	73.6 ef	35.9 d
HE-RS-ML	87.4 b	94.2 bc	59.2 bc
SF-VS-PL	69.1 cd	97.1 ab	53.3 c
SF-VS-ML	73.7 c	100 a	82.9 a
SF-RS-PL	75.6 c	65.6 fg	36.4 d
SF-RS-ML	98.6 a	99.5 a	54.7 c
Significance			
Plant mix (P)	***	***	***
Substrate (S)	***	***	***
Drain/storage layer (D)	***	***	***
P × S	*	n.s.	***
P × D	n.s.	*	***
S × D	***	***	n.s.
P × S × D	*	***	***

Values with different letters indicate significant differences according to Tukey's HSD test ($p < 0.05$). ***, **, and * = significant at $p \leq 0.001$, 0.01, and 0.05, respectively. n.s. = not significant difference according to ANOVA. SE = sedum mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

ANOVA statistical analysis showed a significant second-order interaction for the 11 heavy events. In particular, in Table 3, three interesting events are shown. On 13 October 2014, 31.2 mm of precipitation fell after a fairly rainy period (42.0 mm in the previous 24 days). SF plant mix, RS substrate, and ML drainage/storage layer gave the greatest water retention (on average, 79.3%, 79.2%, and 80.9%, respectively), while the green roof systems with PL layer registered the lowest retention value (on average, 64.8%). The SF-RS-ML green roof system outperformed with 98.6% of rainwater retained.

The other two events with a significant second-order interaction both occurred in summer. These performances were also affected by the rainfall amount and the antecedent weather conditions. In fact, on 14 June 2015, the precipitation was 29.2 mm with no rain in the previous 17 days. The average rainwater retention was 87.6%, and the green roof systems with ML drainage/storage layer retained on average 96.9% of the precipitation. On 28 July, 2016, precipitation of 44.0 mm fell after a three-month period characterized by very frequent rainfall events, and only 48.8% of rainwater was retained on average by the green roof microcosms (only 33.9% on average by the systems with *Sedum*). However, in both the events, the retention capacity was higher for SF and HE plant mixes, vs. substrate and ML drainage layer, and the SF-VS-ML treatment combination had the highest rainwater retention (Table 3). At last, in one out of the 11 heavy events, no statistical difference was found among treatments. It was the event of 19 May 2016 with 61.8 mm of precipitation.

ANOVA statistical analysis showed that all the layer elements under study (plant mix, substrate, and drainage/storage layer) had an effect on the amount of outflow (Table 4). In particular, on average, in both years during winter season, the highest outflow volumes (almost 80% of precipitation) were observed, whereas the lower outflow volumes were observed in summer and in fall 2015 (5.8% and 13.5%, respectively).

As for plant mix effect, suffruticose plants were the most effective during the first year, whereas performances were similar to those of herbaceous perennials in the second year (Table 4). For instance, the yearly rainwater outflow was reduced by 50.6% in the first year and by 47.3% in the second with the *Sedum* mixture and by 56.8% in the first year and by 56.6% in the second with the suffruticose mix. In other terms, suffruticose plants decreased the water runoff by 12.6% and 17.8% compared to the *Sedum* mix.

The type of substrate also significantly affects the outflow volumes (Table 4). In three out of the four seasons in the first year and in two in the second year, the recycled brick substrate was the more effective and, on average, decreased runoff by 6.4% and 3.4% in the two years compared to the volcanic substrates.

Regarding the effect of the drainage/storage layer, in the three warmer seasons of both years, with the only exception of fall of the first year, the mineral layer (i.e., perlite) significantly further decreased outflow volumes by 8.4% and 11.8%, on average, in the first and second year, respectively, compared to the plastic preformed layer (Table 4).

Table 4 also highlights that, in different occasions, main factors interacted on affecting rainwater outflow. In Figure 5, the significant interaction on yearly values is reported. In both years (Figure 5A,B), in green roof with volcanic substrates, the outflow was higher and not affected by drainage/storage layer, whereas in recycled substrate when the mineral layer was used, the outflow decreased. In the second year, plant mix × drainage/storage layer was also significant: in all plant mixes, the mineral layer reduced drainage, but with suffruticose species the decrease was much higher, in particular with the *Sedum* mix (20.7% vs. 5.4%; Figure 5C).

Table 4. Main effects of plant mix, substrate, and drainage/storage layer on the rainwater outflow (mm) from the green roof microcosms in the two-year study in comparison with precipitation and the control (gravel).

	First Year					**Second Year**				
	Fall 2014	**Winter 2014–15**	**Spring 2015**	**Summer 2015**	**Year**	**Fall 2015**	**Winter 2015–16**	**Spring 2016**	**Summer 2016**	**Year**
Precipitation	326	169.3	200.6	143.1	**839**	133.6	177.7	316	228.8	**856.1**
Gravel	281.5	155	176.7	105.4	**718.6**	109.2	158	259	189.8	**716**
Tr. Average°	169.3	134.6	74.1	8.3	**386.3**	18.1	138.8	173.1	71.9	**401.9**
Plant mix (P)										
SE	184.0 ^{a}	136.0 ^{a}	83.1 ^{a}	13.0 ^{a}	**416.1 ^{a}**	30.0 ^{a}	146.7 ^{a}	182.9 ^{a}	94.2 ^{a}	**453.9 ^{a}**
HP	169.5 ^{b}	133.1 ^{b}	72.6 ^{b}	5.4 ^{b}	**380.6 ^{b}**	10.8 ^{b}	132.6 ^{c}	170.5 ^{b}	64.6 ^{b}	**378.4 ^{b}**
SF	154.3 ^{c}	134.9 ^{a,b}	66.6 ^{c}	6.4 ^{b}	**362.2 ^{c}**	13.4 ^{b}	137.2 ^{b}	165.8 ^{b}	56.8 ^{c}	**373.3 ^{b}**
Substrate (S)										
VS	181.5 ^{a}	136.8 ^{a}	78.1 ^{a}	3.1 ^{b}	**399.5 ^{a}**	18.3	142.3 ^{a}	176.1 ^{a}	72.1	**408.7 ^{a}**
RS	157.0 ^{b}	132.4 ^{b}	70.0 ^{b}	13.5 ^{a}	**373.0 ^{b}**	17.9	135.4 ^{b}	170.1 ^{b}	71.7	**395.0 ^{b}**
Drainage/storage layer (D)										
PL	174	134.6	80.1 ^{a}	15.2 ^{a}	**403.8 ^{a}**	26.5 ^{a}	138.1	180.6 ^{a}	81.8 ^{a}	**427.0 ^{a}**
ML	164.5	134.7	68.1 ^{b}	1.5 ^{b}	**368.8 ^{b}**	9.7 ^{b}	139.1	165.6 ^{b}	61.9 ^{b}	**376.8 ^{b}**
Significance										
P	***	*	***	***	***	***	***	***	***	***
S	***	***	***	***	***	n.s.	***	*	n.s.	**
D	n.s.	n.s.	***	***	***	***	n.s.	***	***	***
P × S	n.s.	n.s.	**	**	**n.s.**	n.s.	**	n.s.	n.s.	**n.s.**
P × D	n.s.	n.s.	n.s.	***	**n.s.**	**	*	***	*	**
S × D	**	*	***	***	***	n.s.	n.s.	n.s.	**	*
P × S × D	n.s.	n.s.	n.s.	n.s.	**n.s.**	n.s.	*	n.s.	n.s.	**n.s.**

° Average of all the treatments. Values with different letters indicate significant differences according to Tukey's HSD test ($p < 0.05$). ***, **, and * = significant at $p \leq 0.001$, 0.01, and 0.05, respectively. n.s. = not significant difference according to ANOVA. SE = *Sedum* mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

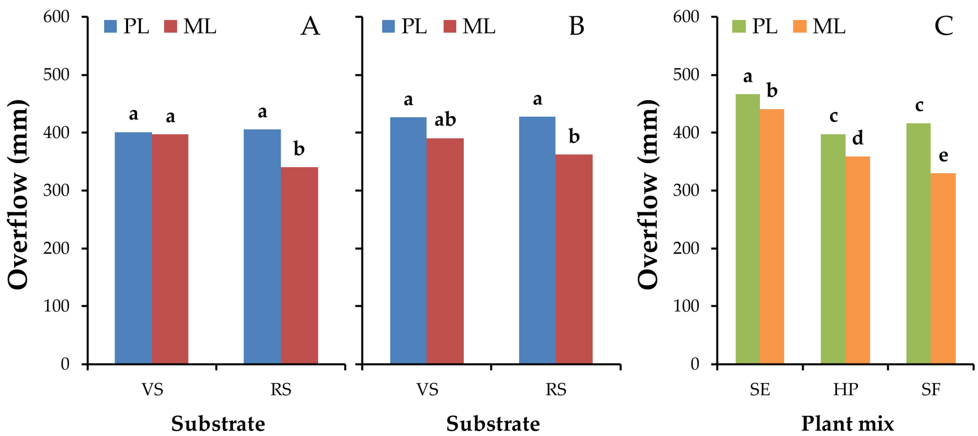

Figure 5. Interaction effect of substrate × drainage/storage layer in the first evaluated year (**A**), and substrate × drainage/storage layer (**B**) and plant mix × drainage/storage layer (**C**) in the second evaluated year on the yearly runoff volumes. Histogram values with different letters indicate significant differences according to Tukey's HSD test ($p \leq 0.05$). SE = *Sedum* mix, HP = herbaceous perennial plants, SF = suffruticose, VS = volcanic substrate, RS = recycled crushed bricks substrate, PL = preformed plastic drainage/storage layer, and ML = mineral drainage/storage layer.

4. Discussion

The capability of the green roof microcosms to reduce rainwater runoff was remarkable. In both years, the rainwater drained from the microcosms was less than the 50% of precipitation as annual average. This means that more than 50% was stored and evapotranspired by the system, reducing the peak flow rates in the urban drainage system during rainy periods. The higher performances were observed in summer and in fall 2015 (94.2% and 86.5%) when temperature and coverage were higher, and thus the evapotranspiration increased, and lower in winter (about 20%) when the evapotranspiration reduced. Summer 2016 had poorer performances than summer 2015, likely due to greater quantity and frequency of precipitation, with an average retention capacity of 68.6%. The influence of seasonal and weather conditions is known; for instance, Schroll et al. [64] reported a study in which the retention was on average about 27% in wet season (November–April) and about 65% in dry season (June–October). Mentens et al. [65] observed a runoff significantly higher during winter (80% winter runoff versus 52% summer runoff).

Palla et al. [66] reported that the annual outflow reduction of a green roof ranges from 40% to 80%. Mentens et al. [65] extended this range to 27–81% for extensive green roofs. In an experiment on different extensive green roofs in a subtropical climate, Simmons et al. [67] found that the maximum rainwater retention could vary in a large range depending on the size of the rain event and green roof components and design. However, our results are in accordance with two studies carried out with extensive green roofs in Northern Italy [66,68], which obtained an average runoff reduction of 48% and 51.9%.

According to [67,69], the tested green roof systems were able to retain all rainwater during light rainy events (<10 mm). As for events greater than 10 mm, our results confirmed what was demonstrated in other studies, namely, the important role of rainfall depth and the antecedent weather period. In particular, the antecedent dry days strongly influence the water content of green roof systems, resulting therefore crucial in determining the performance of green roofs, in terms of retention and detention capacity, especially under extreme rainfall conditions [70–72].

Evaluating the retention performances of the 12 green roofs microcosms, the relative differences in outflow reduction between the best (SF-RS-ML) and the worst (SE-RS-PL) configurations were similar (25.7% and 27.4% in the first and second year) to that of Stovin et al. [41] (27%), who adopted 80 mm substrate depth and considered nine green roof configurations differing in substrate and plant species, and also considered a non-vegetated green roof.

As expected, the outflow reduction was poor in the conventional roof with gravel, even if VanWoert et al. [73] observed higher values (27.2% of the precipitation) in a green roof study in Michigan with a 2 cm gravel roof and Baryła el al. [74] reported a retention capacity ranging from 8.9% to 100% of the daily precipitation. This might depend on the different depth and size of the gravel layer as well as the intensity and the frequency of the precipitation in the analysed period.

As for plant mix effect, the results show that the *Sedum* mixture was found to be significantly less effective in retaining rainwater, while the use of herbaceous perennial and suffruticose plants, instead, was an excellent solution to reduce outflows. However, it has to be stated that the latter two treatments have shown the lowest resistance to summer water stress and progressively succumbed, when in the summer of 2016 irrigation was stopped [62]. Vice versa, *Sedum* plants were minimally affected by the summer drought, showing that they are able to ensure almost complete survival after two years from planting [75].

Interestingly, among the tree factors studied, in both years the right choice of the plant mix gave the major contribution in improving hydrological performances of green roofs, followed by the drainage/storage layer and the substrate. The results of our experiment are in accordance with Talebi et at. [76], who stated that the contribution of vegetation types had a greater effect than substrate type or thickness. On the other hand, the different ability of different species to affect runoff is highlighted by several authors [53,77]. This study also highlights the influence of drainage/storage layer on overflow volumes, with higher values for preformed plastic layer (+11.4% over the two years), contrary to what was reported in other studies; for instance, in [44], no effect on retention performances was observed between a bump plastic board and a granular ceramsite drainage layer.

In our experiment, the interaction effect of the green roof components studied was observed, indicating that the effect is not simply additive. Results show that the ability to better manage rainwater volumes of the two different substrates (RS and VS) depends on their combination with the drainage/storage layer and, in general, the ML was found to be better performing than the PL layer with a high-water-retention capacity, arriving in summer periods to limit outflows by up to 75% of the total precipitation when combined with the recycled brick substrate. These results confirm the statement of Baryla et al. [78] about the importance of the combination of plant species, substrate, and drainage layer.

5. Conclusions

The study and the performed tests clearly demonstrated the positive effect of extensive green roofs with native plants, compared with a traditional roof, to reduce the outflows originating from rainfall events in a humid, subtropical climate.

Over the two-year period, the retained rainfall volumes were about 100% for all the light rainy events (<10 mm), and varied within a range of 48–95% for medium rainy events ($\geq$10 and <25 mm) and 20–88% for heavy rainy events ($\geq$25 mm), depending on rainfall depth and the antecedent weather period.

The layer that gave the highest relative contribution to rainwater retention was the vegetation layer, followed by the drainage/storage layers and then the substrate layer.

Overall, within each component of green roofs, the less effective in water retention was the mixture with *Sedum*, the volcanic substrate, and the preformed drainage/storage layer, while the more effective, able to generate less outflow volumes, was similarly suffruticose and herbaceous mixtures, the crushed bricks substrate, and the mineral (perlite) drainage/storage layer. In particular, over the experimental two-year period, suffruticose plants decreased the outflows by 15.2% compared to *Sedum*, and mineral layer was able to better retain rainwater than a preformed layer, with a difference of 10.1% on average. The outflow reduction in the green roof systems with crushed bricks substrate was 4.9% higher than in those with volcanic substrate. However, the ability to manage rainwater volumes of the two different substrates depended on their combination with the drainage/storage layer, and the water retention capacity was higher for the recycled brick substrate combined with mineral drainage/storage layer.

The results show, therefore, that the use of extensive green roofs can be an excellent solution to be adopted in humid, subtropical climate environments to obtain a good reduction in the rainwater outflow volumes into urban drainage systems. To this important advantage, other benefits should be added, including the increase in aesthetic and landscape value of buildings in the city, proving that green roofs are a key element in the sustainable land management. However, the different components have different characteristics and performances, so a targeted choice is essential in green roof design to maximize their positive impact on the environment.

Author Contributions: Conceptualization, L.B.; Data curation, L.B. and G.Z.; Investigation, L.B., F.B. and G.Z.; Methodology, L.B. and G.Z.; Validation, L.B. and G.Z.; Formal analysis, L.B., F.B. and G.Z.; Writing—original draft, L.B., F.B. and G.Z.; Writing—review and editing, L.B. and G.Z.; Supervision, L.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was financed by the Progetto di Ateneo 2012 N. CPDA122584 entitled "In situ sustainable management of stormwater runoff by mean of green roofs: evaluation of systems suitable for Venetian Plain" (University of Padova).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Busato, F.; Lazzarin, R.M.; Noro, M. Three years of study of the Urban Heat Island in Padua: Experimental results. *Sustain. Cities Soc.* **2014**, *10*, 251–258. [CrossRef]
2. Scalenghe, R.; Marsan, F.A. The anthropogenic sealing of soils in urban areas. *Landsc. Urban Plan.* **2009**, *90*, 1–10. [CrossRef]
3. Mirzaei, P.A.; Haghighat, F. Approaches to study Urban Heat Island–Abilities and limitations. *Build. Environ.* **2010**, *45*, 2192–2201. [CrossRef]
4. Salata, F.; Golasi, I.; Petitti, D.; Petitti, D.; Vollaro, E.d.L.; Coppi, M.; Vollaro, A.d.L. Relating microclimate. human thermal comfort and health during heat waves: An analysis of heat island mitigation strategies through a case study in an urban outdoor environment. *Sustain. Cities Soc.* **2017**, *30*, 79–96. [CrossRef]
5. Schinasi, L.H.; Benmarhnia, T.; De Roos, A.J. Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-Analysis. *Environ. Res.* **2018**, *161*, 168–180. [CrossRef]
6. Rosenfeld, A.H.; Akbari, H.; Romm, J.J.; Pomerantz, M. Cool communities: Strategies for heat island mitigation and smog reduction. *Energy Build.* **1998**, *28*, 51–62. [CrossRef]
7. Onmura, S.; Matsumoto, M.; Hokoi, S. Study on evaporative cooling effect of roof lawn garden. *Energy Build.* **2001**, *33*, 653–666. [CrossRef]
8. Ouldboukhitine, S.E.; Belari, R.; Jaffal, I.; Trabelsi, A. Assessment of green roof thermal behavior: A coupled heat and mass transfer model. *Build. Environ.* **2011**, *46*, 26242631. [CrossRef]
9. Qiu, G.; Li, H.; Zhang, Q.; Chen, W.; Liang, X.; Li, X. Effects of Evapotranspiration on Mitigation of Urban Temperature by Vegetation and Urban Agriculture. *J. Integr. Agr.* **2013**, *12*, 1307–1315. [CrossRef]
10. Speak, A.F.; Rothwell, J.J.; Lindley, S.J.; Smith, C.L. Reduction of the urban cooling effects of an intensive green roof due to vegetation damage. *Urban Clim.* **2013**, *3*, 40–55. [CrossRef]
11. Nowak, D.J.; Crane, D.E.; Stevens, J.C. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green.* **2006**, *4*, 115–123. [CrossRef]
12. Viecco, M.; Vera, S.; Jorquera, H.; Bustamante, W.; Gironás, J.; Dobbs, C.; Leiva, E. Potential of Particle Matter Dry Deposition on Green Roofs and Living Walls Vegetation for Mitigating Urban Atmospheric Pollution in Semiarid Climates. *Sustainability* **2018**, *10*, 2431. [CrossRef]
13. Yang, J.; Yu, Q.; Gong, P. Quantifying air pollution removal by green roofs in Chicago. *Atmos. Environ.* **2008**, *42*, 7266–7273. [CrossRef]
14. Barrio, E.P.D. Analysis of the green roofs cooling potential in buildings. *Energy Build.* **1998**, *27*, 179–193. [CrossRef]
15. Eumorfopoulou, E.; Aravantinos, D. The contribution of a planted roof to the thermal protection of buildings in Greece. *Energy Build.* **1998**, *27*, 29–36. [CrossRef]
16. Akbari, H.; Pomerantz, M.; Taha, H. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Sol. Energy* **2001**, *70*, 295–310. [CrossRef]
17. Hodo-Abalo, S.; Banna, M.; Zeghmati, B. Performance analysis of a planted roof as a passive cooling technique in hot-Humid tropics. *Renew. Energy* **2012**, *39*, 140–148. [CrossRef]
18. Coutts, A.M.; Tapper, N.J.; Beringer, J.; Loughnan, M.; Demuzere, M. Watering our cities: The capacity for Water Sensitive Urban Design to support urban cooling and improve human thermal comfort in the Australian context. *Progr. Phys. Geog.* **2013**, *37*, 2–28. [CrossRef]
19. Coma, J.; Pérez, G.; Cabeza, L.F. Green Roofs to Enhance the Thermal Performance of Buildings and Outdoor Comfort. In *Nature Based Strategies for Urban and Building*; Butterworth-Heinemann: Oxford, UK, 2018; pp. 109–117.
20. Kuronuma, T.; Watanabe, H.; Ishihara, T.; Kou, D.; Toushima, K.; Ando, M.; Shindo, S. CO_2 Payoff of Extensive Green Roofs with Different Vegetation Species. *Sustainability* **2018**, *10*, 2256. [CrossRef]
21. Brenneisen, S. Space for Urban Wildlife: Designing Green Roofs as Habitats in Switzerland. *Urban Habitats* **2006**, *4*, 1541–7115.
22. Shazmin, S.A.A.; Sipan, I.; Sapri, M.; Jalil, R.A.; Mohammad, I.S. The effect of green envelope components on green building value. *Prop. Manag.* **2017**, *35*, 181–201.
23. Cirella, G.; Iyalomhe, F. Flooding conceptual review: Sustainability-Focalized best practices in Nigeria. *Appl. Sci.* **2018**, *8*, 1558. [CrossRef]
24. Lee, E.; Lee, Y.; Joo, J.; Jung, D.; Kim, J. Flood reduction in urban drainage systems: Cooperative operation of centralized and decentralized reservoirs. *Water* **2016**, *8*, 469. [CrossRef]
25. Fabian, L. Extreme cities and isotropic territories: Scenarios and projects arising from the environmental emergency of the central Veneto città diffusa. *Int. J. Disast. Risk Sci.* **2012**, *3*, 11–22. [CrossRef]
26. Munafò, M.; Congedo, L. Soil consumption monitoring in Italy. In *Urban Expansion. Land Cover and Soil Ecosystem Services*; Gardi, C., Ed.; Routledge: London, UK, 2017; pp. 217–230.
27. Sofia, G.; Roder, G.; Dalla Fontana, G.; Tarolli, P. Flood dynamics in urbanised landscapes: 100 years of climate and humans' interaction. *Sci. Rep.* **2017**, *7*, 40527. [CrossRef]

28. Cazorzi, F.; Dalla Fontana, G.; Luca, A.D.; Sofia, G.; Tarolli, P. Drainage network detection and assessment of network storage capacity in agrarian landscape. *Hydrol. Process.* **2013**, *27*, 541–553. [CrossRef]
29. Pijl, A.; Brauer, C.C.; Sofia, G.; Teuling, A.J.; Tarolli, P. Hydrologic impacts of changing land use and climate in the Veneto lowlands of Italy. *Anthropocene* **2018**, *22*, 20–30. [CrossRef]
30. Wong, T.H.; Brown, R.R. The water sensitive city: Principles for practice. *Water Sci. Technol.* **2009**, *60*, 673–682. [CrossRef]
31. Dietz, M.E. Low impact development practices: A review of current research and recommendations for future directions. *Water Air Soil. Poll.* **2007**, *186*, 351–363. [CrossRef]
32. Woods-Ballard, B.; Kellagher, R.; Martin, P.; Jefferies, C.; Bray, R.; Shaffer, P. *The SuDS Manual*; CIRIA C697; CIRIA: London, UK, 2007.
33. Davis, A.P.; Hunt, W.F.; Traver, R.G.; Clar, M. Bioretention technology: Overview of current practice and future needs. *J. Environ. Eng.* **2009**, *135*, 109–117. [CrossRef]
34. Zanin, G.; Bortolini, L.; Borin, M. Assessing stormwater nutrient and heavy metal plant uptake in an experimental bioretention pond. *Land* **2018**, *7*, 150. [CrossRef]
35. Bortolini, L.; Zanin, G. Hydrological behaviour of rain gardens and plant suitability: A study in the Veneto plain (north-Eastern Italy) conditions. *Urban For. Urban Green.* **2018**, *34*, 121–133. [CrossRef]
36. Burek, P.; Mubareka, S.; Rojas, R.; De Roo, A.; Bianchi, A.; Baranzelli, C.; Lavalle, C.; Vandecasteele, I. Evaluation of the Effectiveness of Natural Water Retention Measures-Support to the EU Blueprint to Safeguard Europe's Waters. *Hum. Organ.* **2012**, *259*, 7–11.
37. VanWoert, N.D.; Rowe, D.B.; Andresen, J.A.; Rugh, C.L.; Xiao, L. Watering regime and green roof substrate design affect Sedum plant growth. *HortScience* **2005**, *40*, 659–664. [CrossRef]
38. Berndtsson, C.J. Green roof performance towards management of runoff water quantity and quality: A review. *Ecol. Eng.* **2010**, *36*, 351–360. [CrossRef]
39. Berardi, U.; GhaffarianHoseini, A. State-Of-The-Art analysis of the environmental benefits of green roofs. *Appl. Energ.* **2014**, *115*, 411–428. [CrossRef]
40. Li, Y.; Babcock, R.W. Green roof hydrologic performance and modelling: A review. *Water Sci. Technol.* **2014**, *69*, 727–738. [CrossRef]
41. Stovin, V.; Poë, S.; De-Ville, S.; Berretta, C. The influence of substrate and vegetation configuration on green roof hydrological performance. *Ecol. Eng.* **2015**, *85*, 159–172. [CrossRef]
42. Soulis, K.X.; Ntoulas, N.; Nektarios, P.A.; Kargas, G. Runoff reduction from extensive green roofs having different substrate depth and plant cover. *Ecol. Eng.* **2017**, *102*, 80–89. [CrossRef]
43. Ercolani, G.; Chiaradia, E.A.; Gandolfi, C.; Castelli, F.; Masseroni, D. Evaluating performances of green roofs for stormwater runoff mitigation in a high flood risk urban catchment. *J. Hydrol.* **2018**, *566*, 830–845. [CrossRef]
44. Gong, Y.; Yin, D.; Fang, X.; Li, J. Factors affecting runoff retention performance of extensive green roofs. *Water* **2018**, *10*, 1217. [CrossRef]
45. Pęczkowski, G.; Kowalczyk, T.; Szawernoga, K.; Orzepowski, W.; Żmuda, R.; Pokładek, R. Hydrological performance and Runoff water quality of experimental green roofs. *Water* **2018**, *10*, 1185. [CrossRef]
46. Palermo, S.A.; Turco, M.; Principato, F.; Piro, P. Hydrological effectiveness of an extensive green roof in Mediterranean Climate. *Water* **2019**, *11*, 1378. [CrossRef]
47. Oberndorfer, E.; Lundholm, J.; Bass, B.; Coffman, R.R.; Doshi, H.; Dunnett, N.; Gaffin, S.; Köhler, M.; Liu, K.K.Y.; Rowe, B. Green roofs as urban ecosystems: Ecological structures, functions and services. *BioScience* **2007**, *57*, 823–833. [CrossRef]
48. Morgan, S.; Celik, S.; Retzlaff, W. Green Roof Storm-Water Runoff Quantity and Quality. *J. Environ. Eng.* **2013**, *139*, 471–478. [CrossRef]
49. Shafique, M.; Kim, R.; Kyung-Ho, K. Green roof for stormwater management in a highly urbanized area: The case of Seoul. Korea. *Sustainability* **2018**, *10*, 584. [CrossRef]
50. Locatelli, L.; Guerrero, M.; Russo, B.; Martínez-Gomariz, E.; Sunyer, D.; Martínez, M. Socio-Economic Assessment of Green Infrastructure for Climate Change Adaptation in the Context of Urban Drainage Planning. *Sustainability* **2020**, *12*, 3792. [CrossRef]
51. Zhou, Q.; Halsnæs, K.; Arnbjerg-Nielsen, K. Economic assessment of climate adaptation options for urban drainage design in Odense, Denmark. *Water Sci. Technol.* **2012**, *66*, 1812–1820. [CrossRef]
52. Alves, A.; Gersonius, B.; Kapelan, Z.; Vojinovic, Z.; Sanchez, A. Assessing the Co-Benefits of green-Blue-Grey infrastructure for sustainable urban flood risk management. *J. Environ. Manag.* **2019**, *239*, 244–254. [CrossRef]
53. Dunnett, N.; Nagase, A.; Booth, R.; Grime, P. Influence of vegetation composition on runoff in two simulated green roof experiments. *Urban Ecosyst.* **2008**, *11*, 385–398. [CrossRef]
54. Wolf, D.; Lundholm, J.T. Water uptake in green roof microcosms: Effects of plant species and water availability. *Ecol. Eng.* **2008**, *33*, 179–186. [CrossRef]
55. Szota, C.; Farrell, C.; Williams, N.S.; Arndt, S.K.; Fletcher, T.D. Drought-Avoiding plants with low water use can achieve high rainfall retention without jeopardising survival on green roofs. *Sci. Total. Environ.* **2017**, *603*, 340–351. [CrossRef] [PubMed]
56. Zhang, Z.; Szota, C.; Fletcher, T.D.; Williams, N.S.; Werdin, J.; Farrell, C. Influence of plant composition and water use strategies on green roof stormwater retention. *Sci. Total. Environ.* **2018**, *625*, 775–781. [CrossRef] [PubMed]
57. Barbi, A.; Cagnati, A.; Cola, G.; Checchetto, F.; Chiaudani, A.; Crepaz, A.; Delillo, I.; Mariani, L.; Marigo, G.; Meneghin, P.; et al. *Atlante Climatico del Veneto*; Regione del Veneto: Mestre, Italy, 2013.

58. Zanin, G.; Bettella, F.; Bortolini, L. Hydrological and plant performance of green roofs in the climate context of the Veneto Plain (north-Eastern Italy): Preliminary results. *Acta Hortic.* **2018**, *1215*, 95–100. [CrossRef]
59. Bettella, F.; D'Agostino, V.; Bortolini, L. Drainage flux simulation of green roofs under wet conditions. *J. Agric. Eng.* **2018**, *49*, 242–252. [CrossRef]
60. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and Drainage Paper 56*; FAO: Rome, Italy, 1998.
61. Berti, A.; Tardivo, G.; Chiaudani, A.; Rech, F.; Borin, M. Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy. *Agric. Water Man.* **2014**, *140*, 20–25. [CrossRef]
62. Zanin, G.; Bortolini, L. Performance of three different native plant mixtures for extensive green roofs in the humid subtropical climate context. *Water* **2020**, *12*, 3484. [CrossRef]
63. Sherrard Jr, J.A.; Jacobs, J.M. Vegetated roof water-balance model: Experimental and model results. *J. Hydrol. Eng.* **2012**, *17*, 858–868. [CrossRef]
64. Schroll, E.; Lambrinos, J.; Righetti, T.; Sandrock, D. The role of vegetation in regulating stormwater runoff from green roofs in a winter rainfall climate. *Ecol. Eng.* **2011**, *37*, 595–600. [CrossRef]
65. Mentens, J.; Raes, D.; Hermy, M. Green roofs as a tool for solving the rainwater runoff problem in the urbanised 21st century. *Landsc. Urban Plan.* **2006**, *77*, 217–226. [CrossRef]
66. Palla, A.; Gnecco, I.; Lanza, L.G. Hydrologic restoration in the urban environment using green roofs. *Water* **2010**, *2*, 140–154. [CrossRef]
67. Simmons, M.T.; Gardiner, B.; Windhager, S.; Tinsley, J. Green roofs are not created equal: The hydrologic and thermal performance of six different extensive green roofs and reflective and non-Reflective roofs in a sub-Tropical climate. *Urban Ecosyst.* **2008**, *11*, 339–348. [CrossRef]
68. Cipolla, S.S.; Maglionico, M.; Stojkov, I. A long-Term hydrological modelling of an extensive green roof by means of SWMM. *Ecol. Eng.* **2016**, *95*, 876–887. [CrossRef]
69. Villarreal, E.L.; Bengtsson, L. Response of a Sedum green-Roof to individual rain events. *Ecol. Eng.* **2005**, *25*, 1–7. [CrossRef]
70. Stovin, V. The potential of green roofs to manage urban stormwater. *Water Environ. J.* **2010**, *24*, 192–199. [CrossRef]
71. Stovin, V.; Vesuviano, G.; Kasmin, H. The hydrological performance of a green roof test bed under UK climatic conditions. *J. Hydrol.* **2012**, *414*, 148–161. [CrossRef]
72. Viola, F.; Hellies, M.; Deidda, R. Retention performance of green roofs in representative climates worldwide. *J. Hydrol.* **2017**, *553*, 763–772. [CrossRef]
73. VanWoert, N.D.; Rowe, D.B.; Andresen, J.A.; Rugh, C.L.; Fernandez, R.T.; Xiao, L. Green roof stormwater retention: Effects of roof surface, slope, and media depth. *J. Environ. Qual.* **2005**, *34*, 1036–1044. [CrossRef]
74. Baryła, A.; Karczmarczyk, A.; Brandyk, A.; Bus, A. The influence of a green roof drainage layer on retention capacity and leakage quality. *Water Sci.Technol.* **2018**, *77*, 2886–2895. [CrossRef]
75. Getter, K.L.; Rowe, D.B. The role of extensive green roofs in sustainable development. *HortScience* **2006**, *4*, 1276–1285. [CrossRef]
76. Talebi, A.; Bagg, S.; Sleep, B.E.; O'Carroll, D.M. Water retention performance of green roof technology: A comparison of Canadian climates. *Ecol. Eng.* **2019**, *126*, 1–15. [CrossRef]
77. Nagase, A.; Dunnett, N. Amount of water runoff from different vegetation types on extensive green roofs: Effects of plant species, diversity and plant structure. *Landsc. Urban Plan.* **2012**, *104*, 356–363. [CrossRef]
78. Baryła, A.; Karczmarczyk, A.; Bus, A. Role of substrates used for green roofs in limiting rainwater runoff. *J. Ecol. Eng.* **2018**, *19*, 86–92. [CrossRef]