Rainwater Discharge from Green Roofs

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Abstract

In the context of sustainable construction, green roofs* are considered as being a possibility for improving the water balance in urbanized areas, i.e. by reducing the amount of rainwater discharged within the sewer. However, about the in Belgium commercialised systems, little information was available on the real rainwater discharge and on the quality of this water. In order to get a better view on these issues, the Belgian Building Research Institute monitored from June 2002 till December 2003, 9 commercially available roof gardens of different composition, together with 2 traditional roofs, all having dimensions of about 7.5 m by 1 m and exposed to the outdoor climate.
The study demonstrated that green roofs reduce considerably the amount of rainwater discharged into the sewers. They also have a tempering effect on the peak flows in case of storm showers, which allows the design of drainage systems with reduced diameters. Because of the specificity of the roofs the discharge factor needed for this calculation must be measured. A method for this measurement was identified. The study also showed that the water discharged by green roofs must be considered as polluted and needs treatment before being able to be used in the building.

Keywords

Green roofs, roof gardens, rainwater discharge, sustainable construction

1 Introduction

Green roofs and roof gardens are multilayer constructions with on the top a vegetation layer. Some typical compositions are indicated in the figure 1. They incorporate intensive and extensive roofs. Intensive roofs allow creating roof gardens with even large trees, while extensive green roofs are not designed for public use. Green roof systems are not a new concept; in fact they can be traced to the hanging gardens of Babylon, one the Seven Wonders of the World. Green roof systems are actually promoted as a sustainable building technology for urbanized areas, because of the presumed advantages they provide, e.g.:

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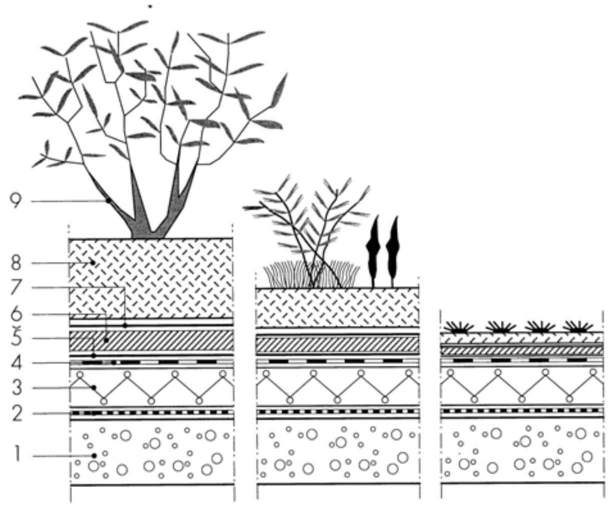
* also written as « greenroofs »

- They improve the energy efficiency of buildings by slowing building heat gain and loss.
- They optimise the indoor climate by keeping the building cool during summer and by improving the acoustical characteristics of the roof.
- They allow to improve the urban water management: by enlarging the amount of rainwater returned into the atmosphere mainly through the evapotranspiration of the plants and hereby lowering the amount of water drained rapidly away by the sewers; by reducing the frequency of combined sewage/stormwater overflow events which pollute seriously rivers and streams; by reducing the flooding frequency in some of the lower parts of the public drainage system; and by reducing the amount of contaminants brought by the rainwater into the receiving surface waters as a result of the filtering effect of the green roof layers; this filtering effect also improves the ability to use the water within the building, eg for rinsing WCs.



1:structural support
2:vapour barrier
3:thermal insulation
4:waterproofing membrane
5:root barrier
6:drainage layer
7:filter membrane
8:growing medium or substrate
9:vegetation

	intensive roofs		extensive
Depth of substrate(m)	>0.25	0.1 – 0.25	<0.1
Green load (kg/m²)	>400	100 - 400	30 - 100

Figure 1 – Green roofs: typical compositions

As these advantages were not clearly demonstrated for the typical green roofs used in Belgium, BBRI was requested to study 9 such roofs with respect to these supposed advantages.

2 The monitoring campaign

2.1 Description of the roofs

Besides the 9 commercially available green roofs, also 2 reference roofs were considered: one with a naked waterproofing membrane and one where the membrane is covered with about 50 mm of gravel with a diameter between 4 and 30 mm. These 11 roofs, with a surface of about 7.5 m² each, were located side by side on top the main office building at the BBRI test centre. Their characteristics are indicated in table 1. The structural support had a slope of 2%, causing a lengthwise drainage of the roofs. The water of each roof was evacuated by an outlet in the middle of its lowest side, connected to a closed vertical pipe DN 125 with a length of 3 m, where the volume of accumulated water is measured with a pressure gauge. Automatic discharge is provided when the water reaches its maximum level, by opening a valve.

2.2 The monitoring campaign

The thermal behaviour of the roof complex and the rainwater discharge of each roof were monitored continuously from June 2002 till May 2003.

Table 1 – Composition of the green roofs tested at BBRI

<table>
<tr><th rowspan="2">roof n°</th><th>drainage layer:</th><th>Filter:</th><th>substrate</th><th>vegetation</th></tr>
<tr><th colspan="3">Type; thickness (bottom up)</th><th></th></tr>
<tr><td>1</td><td colspan="4">Reference roof with 50 mm gravel covering</td></tr>
<tr><td>2</td><td>Felt covered with a cup-shaped PE-sheet (with a water capacity of 3 l/m²), filled with expanded clay pellets; 30 mm</td><td>Felt; 5 mm</td><td>Peat; 40 mm</td><td rowspan="4">Extensive vegetation: mainly sedum and moss</td></tr>
<tr><td>3</td><td colspan="2">Mats of curled PE-wires covered by a felt; 20mm</td><td>Mineral pellets; 80 mm</td></tr>
<tr><td>4</td><td>Mats of foamed PUR-flakes; 30 mm</td><td>PE-felt (ie. mats of non woven PE-fibres); 5 mm</td><td>Mixture of pozzolana, peat and composted bark; 50 mm</td></tr>
<tr><td>5</td><td colspan="2">Mats of curled PE-wires, covered by a felt; 15 mm</td><td>Potting compost; 20mm</td></tr>
<tr><td>6</td><td>Agglomerated expanded PS-pellets; 65 mm</td><td>PP-felt; <1 mm</td><td>Potting compost; 140 mm</td><td>Intensive vegetation: spindle tree, broom, tormentil,…</td></tr>
<tr><td>7</td><td>Expanded clay pellets; 30 mm
Felt; 15 mm
Expanded clay pellets; 70 mm</td><td>Felt; 15 mm</td><td>Potting compost mixed with expanded clay pellets; 200 mm</td><td>Intensive vegetation: ground ivy, lavender, honeysuckle, strawflower,…</td></tr>
<tr><td>8</td><td>Cup-shaped expanded PS panels (water capacity : 13 l/m²); 54 mm</td><td>PP-felt: 2 mm</td><td>Mixture of mineral (lava pellets) and organic (potting compost, peat, …) materials; 80 mm</td><td rowspan="3">Extensive vegetation: mainly sedum and moss</td></tr>
<tr><td>9</td><td>Cup-shaped PVC sheets (water capacity : 5 l/m²); 20 mm</td><td>PP-felt; 2 mm</td><td>Mixture of mineral (lava pellets) and organic (potting compost, peat, …) materials; 40 mm</td></tr>
<tr><td>10</td><td>Extruded polystyrene panels; 80 mm</td><td>PP-felt; 15 mm</td><td>65 mm</td></tr>
<tr><td>11</td><td colspan="4">Reference roof with naked membrane.</td></tr>
</table>

Punctually, from April till December 2003, samples of the water discharged by the roofs and of the rain were analysed bio-chemically. Afterwards the roofs were also submitted to artificial showers with constant intensity, in order to evaluate their hydraulic

response. In situ, on some real roofs, the acoustical performance was measured. The research made also a comparative study of some current methodologies for evaluating the root-resistance of roofing membranes.
Only the results related to the rainwater discharge, i.e. the hydraulic behaviour and the water quality will be discussed in this paper.

3 The hydraulic performance

3.1 Long term rainwater discharge

The total volume of rainwater discharged by the different roofs, during the different seasons, is indicated in table 2 for the period from 23/06/03 till 24/05/03.

Table 2 – Volume of rainwater discharged by the different roofs (l/m²)

roof		summer	autumn	winter	spring
n°	type	(23/06/02-22/09/02)	(23/09/02-23/12/02)	(24/12/02-20/03)	(21/03/03-24/05/03)
2	Ext (40 mm)	83	152	229	29
3	Ext (80 mm)	148	170	238	40
4	Ext (50 mm)	135	176	243	39
5	Ext (20 mm)	142	180	250	51
8	Ext (80 mm)	154	181	230	48
9	Ext (40 mm)	153	181	249	51
10	Ext (65 mm)	157	169	234	43
6	Int (140 mm)	74	112	220	7
7	Int (200 mm)	87	120	220	13
1	Ref: gravel	214	200	237	83
11	Reference	226	230	256	122

More telling is to look to the long term discharge-ratio, i.e. the ratio between the volume of water discharged by a roof and the volume of water discharged by the naked reference roof n°11, expressed as a percentage: figure 2. From this figure it is clear that the retention-effect of the green roofs depends upon the season: the retention is important in spring (discharge ratio only 6-51%) and less important in winter (discharge ratio between 86 and 98%).
But also the type of roof is influencing the long term discharge of green roofs:

- In general one can say that the thicker the substrate, the lesser is the discharge ratio; this trend can be seen on figure 3. On yearly basis one can conclude that the extensive roofs retained about 30% of the total rainfall, whereas the intensive roofs (6 and 7) retained about 50%.
- But a low discharge ratio can also be realised by having an appropriate composition of the roof, as is illustrated by roof n°2 -which has a substrate of only 40 mm - where the good performance is probably linked to the combination of different layers with a water-retention ability at the level of the drainage, i.e. the cup-shaped PE sheet, its underlying felt and the pellet filling of the sheet.

It’s thus obvious that it is impossible to characterise the retention effect of green roofs by one single value usable for all types of green roofs.

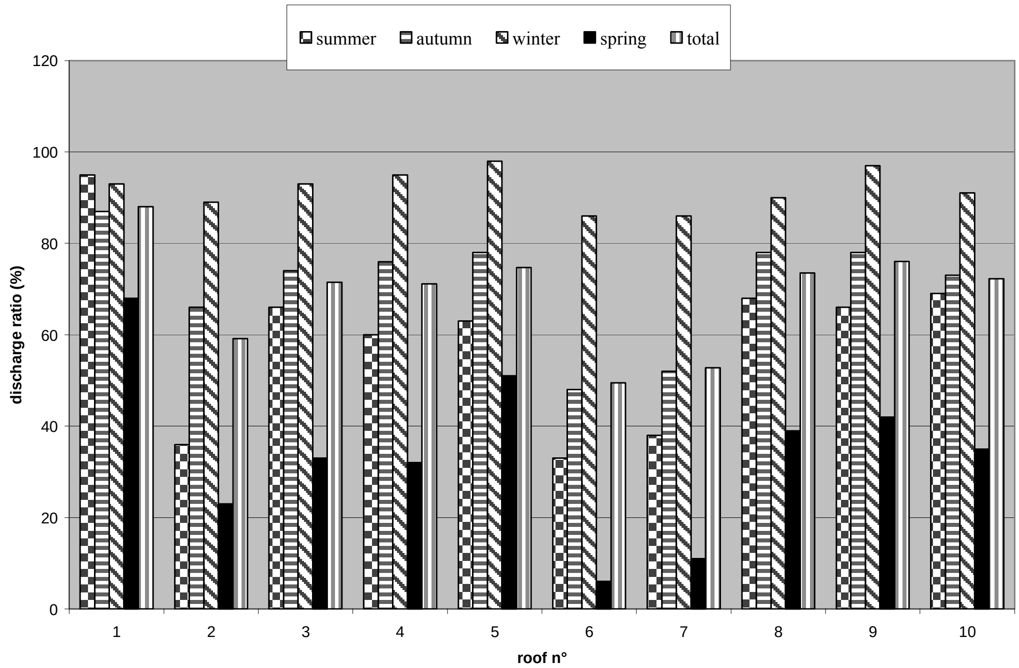


Figure 2 – Long term discharge ratio of the different roofs

3.2 Stormwater discharge

3.2.1 Discharge under a thunderstorm

During the monitoring of the roofs, some days occurred with storm showers. The discharge of the roofs during such a storm is presented in figure 4.

With respect to the naked reference roof 11 we see that the green roofs have a peak flow discharge which is later in time and less intense. This effect is clearer illustrated in the figure 5:

The naked reference roof n°11 has a peak flow rate of 0.832 l/min.m² at 14.32.

The extensive green roof n°2 has a maximum discharge of 0.433 l/min.m² at 14.40, which means a decrease to 52% of the naked roofs' flow rate and a delay of 8 minutes with respect to the time of the peak flow of roof 11.

The intensive roof n°7 has a peak flow of only 0.221 l/min.m² at 14.48, ie a decrease to 26% and a delay of 16 minutes.

It is obvious from these measurements, that the reduction in peak flow rate, as well as the time delay, depend upon the type of green roof and we see that in some cases they can be considerable.

3.2.2 Establishing discharge factors for green roofs

A reduction of the rate of flow to be drained away from a roof means a drainage system with reduced diameters.

The European standard EN 12056-3 [1] for roof drainage proposes to calculate the flow rate (Q) discharged by a roof, with the formula:

$$Q = r*A*C \quad - (l/s)$$

Where r is the rainfall intensity (to be chosen by each country), in (l/s.m²); A is the effective roof area (m²) and C is the discharge factor, to be chosen by each country, (-). It is thus through the discharge factor C that the attenuating effect of green roofs on the peak flow can be introduced in the calculations. However, the European standard does not give any value for this C-factor. In Germany some values where proposed in their draft standard DIN 1986-2 of 2001 (table 3).

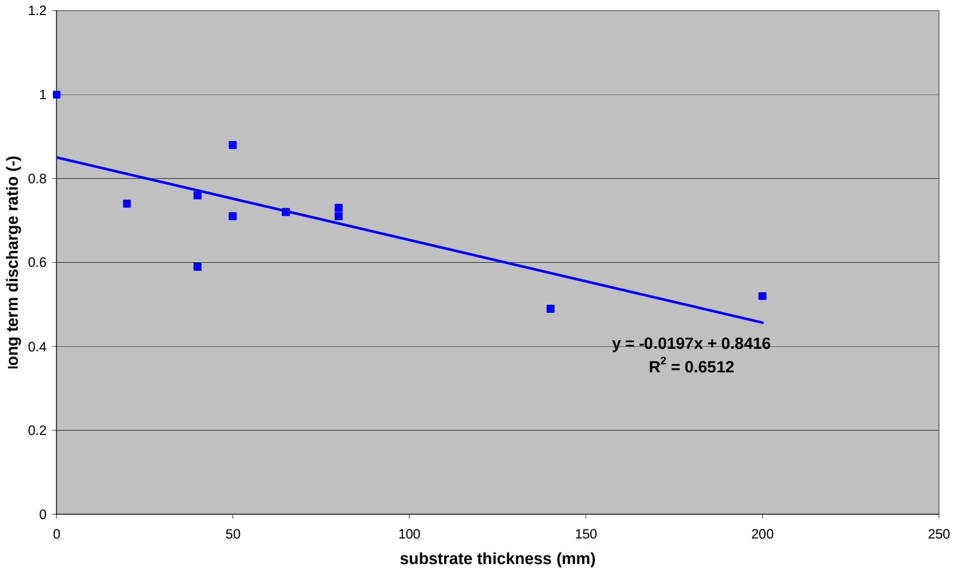


Figure 3 – Relation between the long term discharge ratio and the thickness of the substrate

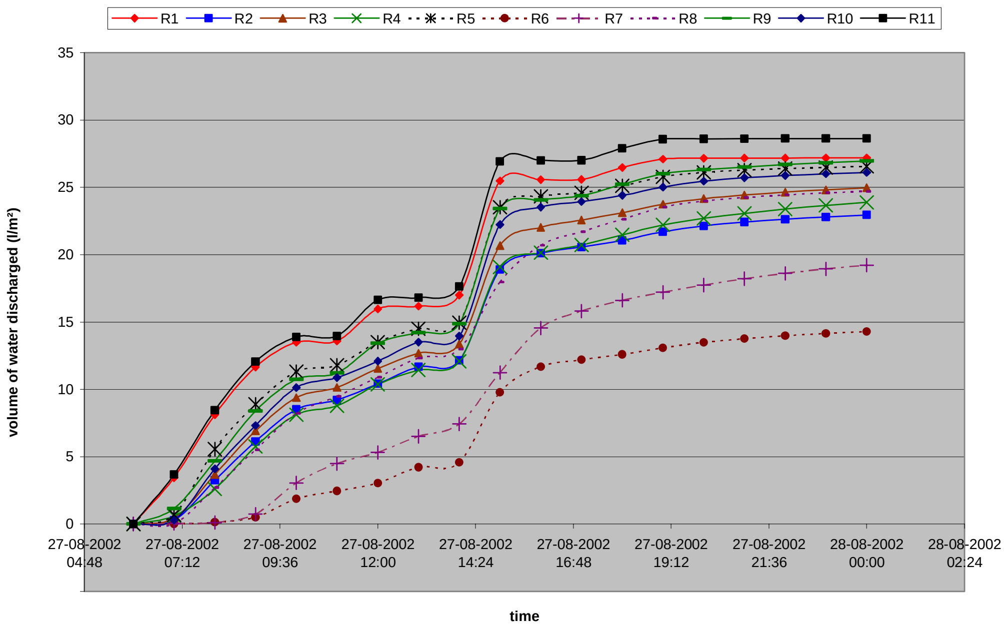


Figure 4 – discharge during storm (storm shower at 14.32)

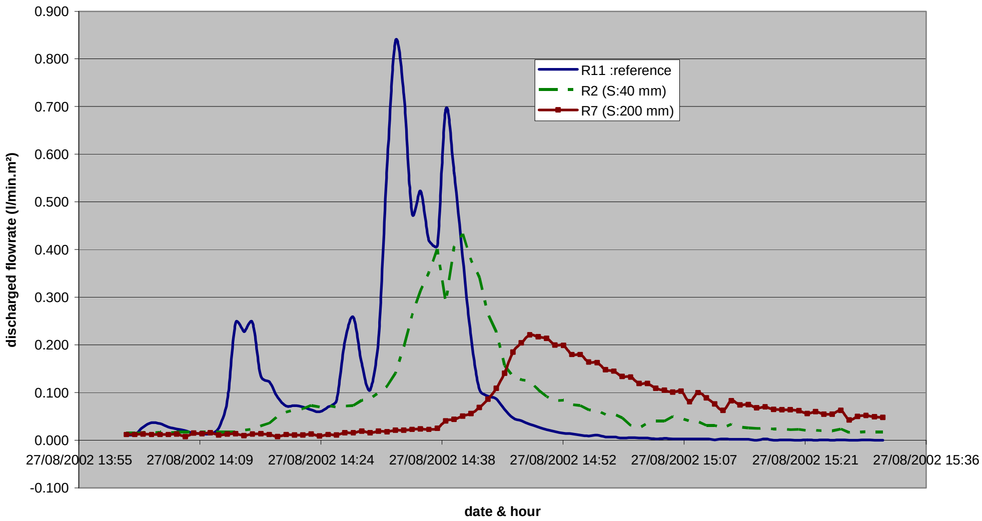


Figure 5 – Discharge flow rate of roofs 2,7 and 11 during a storm shower

They also propose a methodology for measuring these factors [3]. Hereto they measure the volume of water discharged over a period of 30 minutes, by models of green roofs with a width of 1.25 m, a length of 10 m and a slope of 2%, while submitting them at the beginning to a 15 minutes shower with a constant intensity of 0.03 l/s.m² (sprinkling). The discharge factor is then calculated as the ratio between the maximum measured discharge flow rate and the sprinkled flow rate. Before doing the test, the roof is saturated by sprinkling at 0.03 l/s.m² until there is for 10 minutes a constant discharge flow. This approach implies that the Germans consider a shower of 0.03 l/s.m², with 15 minutes duration, as being their design shower. In Belgium such a shower happens once every 250 years.

Table 3 – German proposal for discharge factors for green roofs [2]

Substrate thickness (mm)	**Reduction factor(*)**
20-40	0.7
60-100	0.6
100-150	0.4
150-250	0.3
250-500	0.2
>500	0.1
(*)for slopes up to 5%	

At BBRI, a first attempt was made to evaluate the discharge factors for the studied green roofs. We adopted hereto a slightly different method (table 4), using a sprinkling installation as shown in figure 6. The reason for this different way of working was

- that we wanted to be nearer to a worst case scenario, ie. simulating a situation where the roof is already discharging water when a storm shower occurs (cfr. fig.5);

- that we actually have a discussing in the country, about the rainfall intensity to adopt for the above calculation according to EN 12056-3: 0.0167, 0.025 or 0.033 l/s.m².

Table 4 – Determination of reduction factors: sprinkling scheme adopted by BBRI

Phase		action
1	saturation	Constant sprinkling at 0.033 l/s.m²(*)
2	rest	No sprinkling (***)
3	High intensity	Constant sprinkling at 0.033 l/s.m² (**)
4	rest	No sprinkling (***)
5	Medium intensity	Constant sprinkling at 0.025 l/s.m²(**)
6	rest	No sprinkling (***)
7	Low intensity	Constant sprinkling at 0.0167 l/s.m²(**)
(*) up to when there a noticeable flow rate during 10 minutes (**) up to when there is a constant discharge flow rate during 10 minutes (***) up to when there is no noticeable discharge flow rate anymore for 10 minutes		

Measuring of the accumulated volume of water discharged and sprinkled, gives results as presented in figure 7. This allows the calculation of the discharge factor C, as defined in the German method above, i.e. the maximum flow rate, recorded 15 minutes after starting the sprinkling, divided by the sprinkled flow rate: see table 5.

Table 5 –Discharge factors measured by BBRI

Intensity	**Green roof n°**								
(l/s.m²)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.033	0.89	0.57	0.53	0.87	0.86	0.75	0.90	0.92	0.96
0.025	0.95	0.86	0.81	1	0.88	0.58	0.67	0.91	0.98
0.0167	0.99	0.96	0.50	0.93	0.94	0.29	0.81	1	0.90

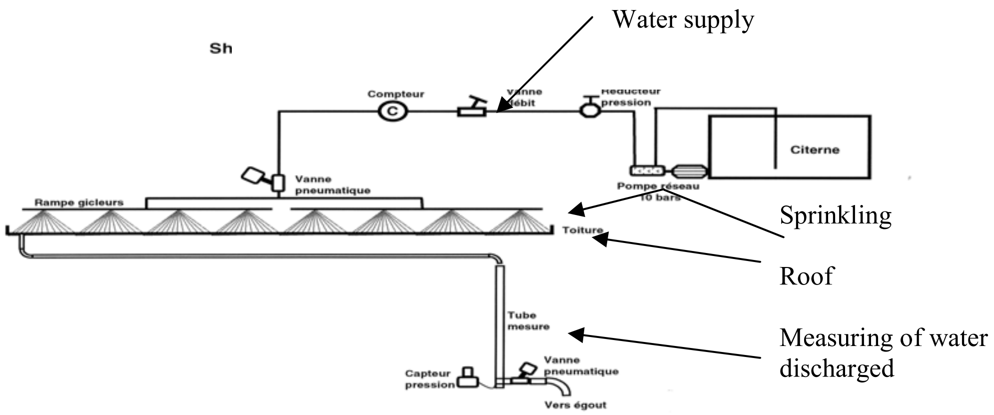


Figure 6 - Measuring discharge factors : principle scheme

In case a roof is fully saturated, the discharged flow rate equals the sprinkled flow rate and the C-factor would be equal to 1. If the C-factor is less than 1 for the high intensity sprinkling, one should then await a lower C-value for the lower sprinkling intensities. This seems not to be the case when looking to table 5: in many cases there is even an increase of the C-factor. This is probably due to the adopted way of working where the tests at the different intensities were conducted each after another starting with the highest intensity, creating full saturation after a while for certain roofs. This means concretely that only the values established for the highest sprinkling intensity might be considered for characterising the roof with respect to a shower a of 15 minutes duration. And also here caution is in order as all roofs were –for the time being- only measured once.

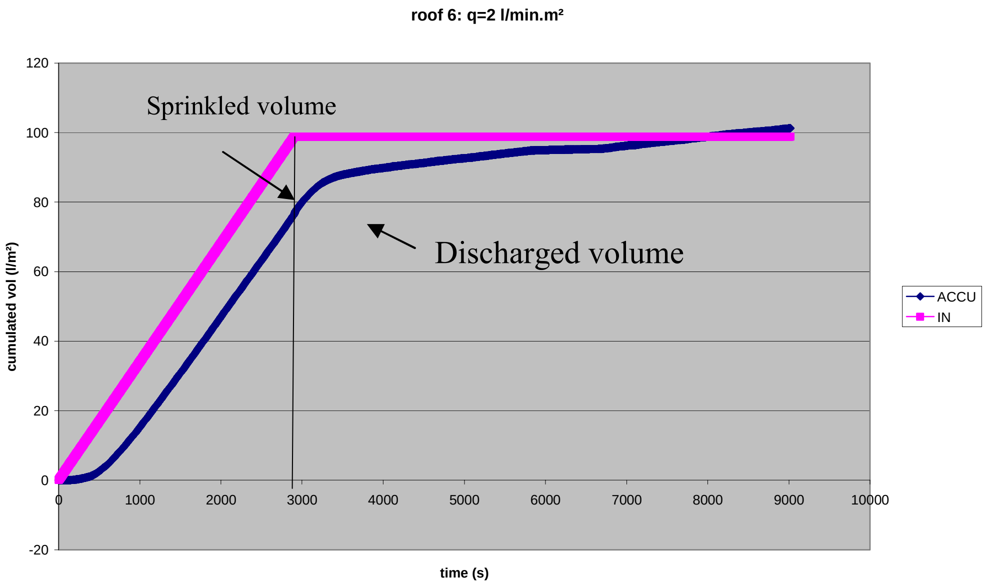


Figure 7 – Volume of water discharged in time by roof 6 (intensive with 140 mm substrate) when sprinkled at 0.033 l/s.m²

Focussing upon the C-values for the 0.033 l/s.m² sprinkling intensity, we can notice (figure 8) that the reduction tends to become more important (C decreases) when the substrate becomes thicker, which seems to be normal. For a green roof with a substrate thickness of 100 mm, the German test gave C-values of 0.83, which fits quite well into our findings. Less coherent is the relation with the German values proposed in 2001 (table 3): the proposed values seem to are a lot more optimistic than those of real roofs submitted to the German “type shower”.
On the other side we also have to notice that for some roofs (especially 3 and 4) not only the substrate thickness is influencing the reduction effect, also the other layers composing the green roof seem to be involved in a significant way, in particular the drainage layer. This means that with for the determination of reduction factors for green roofs, one can not only rely upon the substrate thickness, which implies that this characteristic can only be established with some confidence, by prototype testing. This underlines the necessity of having a reliable standardised methodology, which could be based upon the German approach.

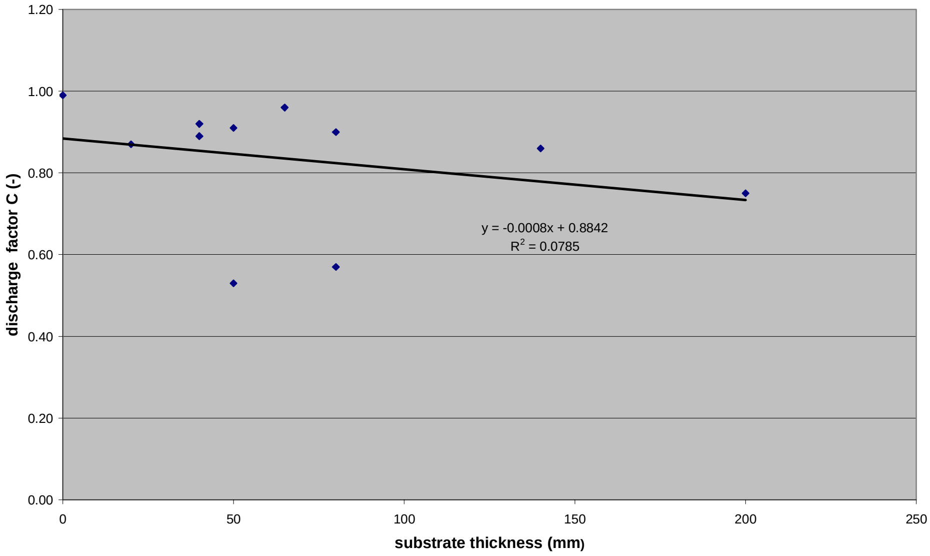


Figure 8 –Discharge factor C: substrate thickness dependency

4 The quality of the water discharged by green roofs

In the course of 2003, ie in the second year of the monitoring, water samples were regularly collected from the different roofs and analysed for different parameters. The aim was to get an idea of the quality of these waters in view of its possible reuse in or around the building. As in Belgium there are no regulations in this context, the choice of the parameters to be analyzed was made after having looked to the parameters considered in different regulations about water, e.g.: surface water for swimming, fishing waters, drinking water, waste water. The mean values for the most important parameters analysed are given in table 6. Looking to the pH, one can say that all green roofs, except n°7, do have a neutralisation effect on the initial acid character of the Belgian rain.

Important is also to underline the fact that the naked reference roof n°11 does have an acidifying effect, which is probably due to the formation of organic acids by the weathering (UV-irradiation) of the membrane material.The claim that the rainwater is "purified" by passing through a green roof is clearly not true:

All roofs do colour the water: most of them deliver a brown liqueur.

The increase, with respect to rainwater, of the conductivity, suspended solids and hardness indicate that a lot of substances are extracted by the water from the green roof, ie there is enrichment, not a filtering.

Also the parameters characterising the organic load (BOD and COD) increase in all cases, indicating pollution by organic matter. One should also notice that the rainwater itself had already an organic charge. The fact that the COD/BOD ratio is quite high for some roofs indicates that, beside organic matters, also oxidizable chemicals are present in the pollution. These products are probably resulting from the fertilizers used on the roofs for the plants.

Except for roofs 2 and 4, there is a certain increase of the number of total germs. Also from the microbiological point of view one can thus not say that the green roofs do improve the rainwater quality.

From this analysis it is clear that the green roofs do influence the quality of the water discharged in such a way that one could speak of pollution. This pollution makes it impossible, in all cases, to use this water directly for flushing WC's or cloth washing. In some cases the water will even not be allowed to be discharged in the surface waters (BOD max 25 mg/l in Belgium), fishing water or swimming water.

Table 6 – Mean quality of the rainwater and of the water discharged by the roofs

parameter	unit	roof n°					
		1	2	3	4	5	6
pH		6.81	7.28	7.22	6.99	6.76	7.34
apparent color	**Pt/Co unit**	67.32	878.19	532.41	350.94	228.58	671.25
conductivity	**µS/cm**	92.9	130.41	207.98	83.82	155.16	273.31
settleable matter	**ml/l**	0.24	0.1	0	0	0.1	0.1
suspended solids	**mg/l**	20.5	9.13	15.53	8.82	9.29	12.27
hardness	**°F**	5	8.01	5.34	4.15	4.15	17.8
COD	**mgO2/l**	24.01	265.25	178.76	100.18	147.6	312.47
BOD	**mgO2/l**	4.5	19.3	29.01	46.1	14.16	46.1
COD/BOD	**(-)**	5.34	13.74	6.16	2.17	10.42	6.78
total phophorus	**mgP/l**	0.06	0.17	0.53	0.08	0.13	3.14
P205	**mgP/l**	0.14	0.21	0.61	3.61	0.21	3.61
SO4--	**mgSO4/l**	14.21	0	1.9	0.15	52.5	86.92
total germs at 22°C	**CFU/ml**	6100	5800	6400	3700	8400	11000
total germs at 37°C	**CFU/ml**	3500	2300	2300	1300	1100	4500
total Coli germs 37°C	**% of pos. samples**	25	25	29	33	33	50
parameter	**unit**	**roof n°**					**rain**
		7	**8**	**9**	**10**	**11**	
pH		5.4	6.52	6.43	6.67	4.89	**5.61**
apparent color	**Pt/Co unit**	46.78	264.9	219.04	250.17	230.55	**23.36**
conductivity	**µS/cm**	1727.8	99.07	87.22	160.93	90.35	**50.87**
settleable matter	**ml/l**	0.15	0	0.1	0.24	0.2	**0**
suspended solids	**mg/l**	37.5	8.9	6.85	12.83	13.9	**5**
hardness	**°F**	5.34	2.37	3.12	4.15	1.78	**1.78**
COD	**mgO2/l**	35.31	99.68	103.15	116.08	106.31	**16.33**
BOD	**mgO2/l**	8.26	5.16	9.15	33.39	9.3	**3.6**
COD/BOD	**(-)**	4.27	19.32	11.27	3.48	11.43	**4.54**
total phophorus	**mgP/l**	0.24	0.06	0.08	15.25	0.16	**0.15**
P205	**mgP/l**	0.35	0.19	0.12	4.46	0.15	**0.09**
SO4--	**mgSO4/l**	1397.5	18.19	11.85	20.68	2.65	**5.4**
total germs at 22°C	**CFU/ml**	12000	9900	9300	10000	13000	**5900**
total germs at 37°C	**CFU/ml**	4700	3900	3500	4100	6200	**4900**
total Coli germs 37°C	**% of pos. samples**	0	17	50	44	67	**67**

5 Conclusions

Green roofs can improve the urban water management by reducing the amount of rainwater discharged into the sewer and by tempering the peak flow. For the design of the drainage system for green roofs, discharge factors must be measured for each type of green roof, no general values can be given. Hereto a standardised method is needed, which could be based upon a German proposal. Green roofs do polluted to a certain extend the rainwater. The reuse of the water discharged by these roofs or their discharge in some environments requires appropriate treatment.

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