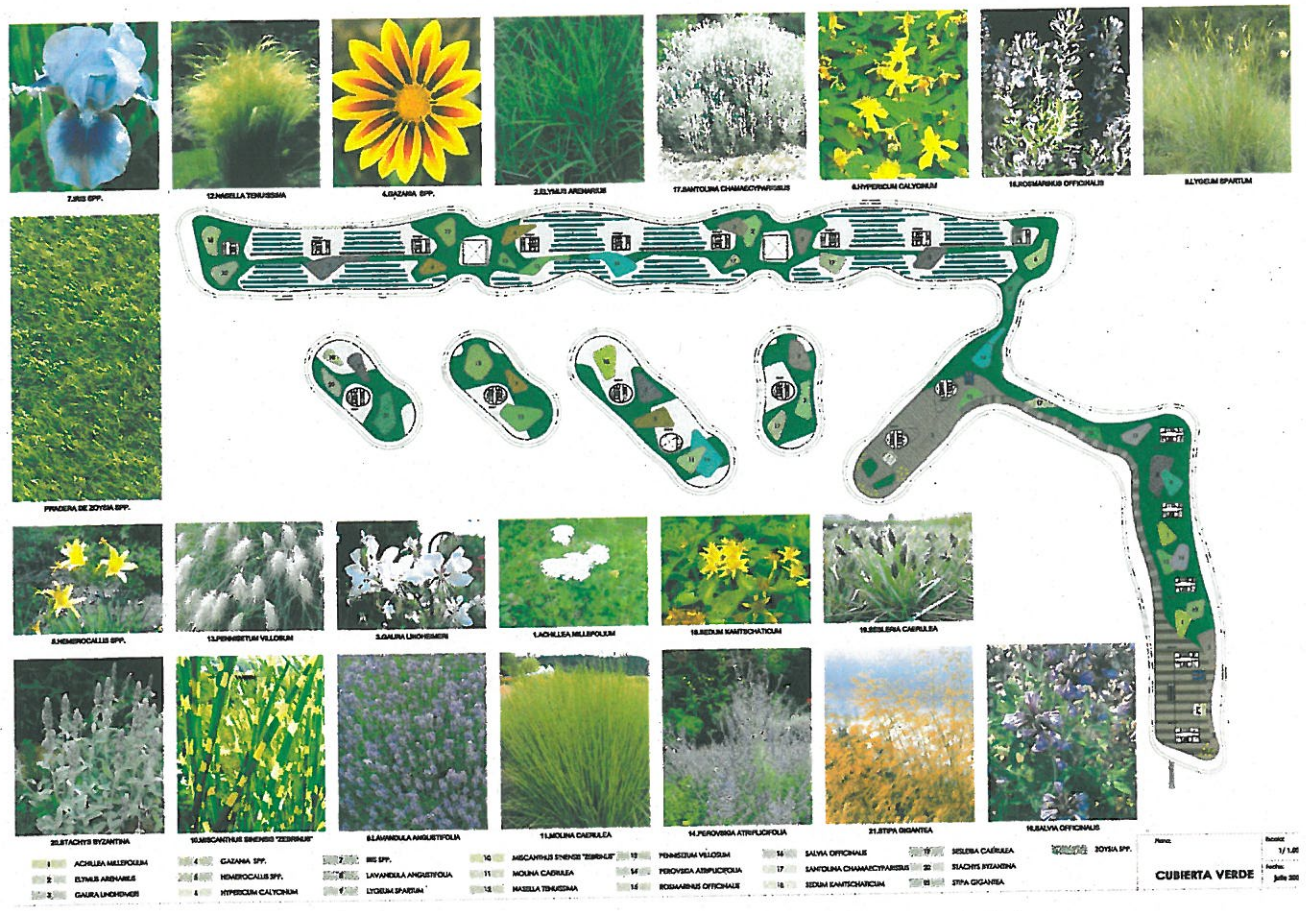

Fig 2. Final design of the green roof with photographs of the planted species.

Finally, there appeared leaks in certain areas due to works done on the roof after the insulation layer had been tested. This forced to temporarily cancel irrigation on the affected areas and, as a consequence, those plants suffered greatly since they had not had enough time to become acclimatized properly.

Summing up, despite the difficulties and drawbacks, we think the result is interesting as the photograph shows.

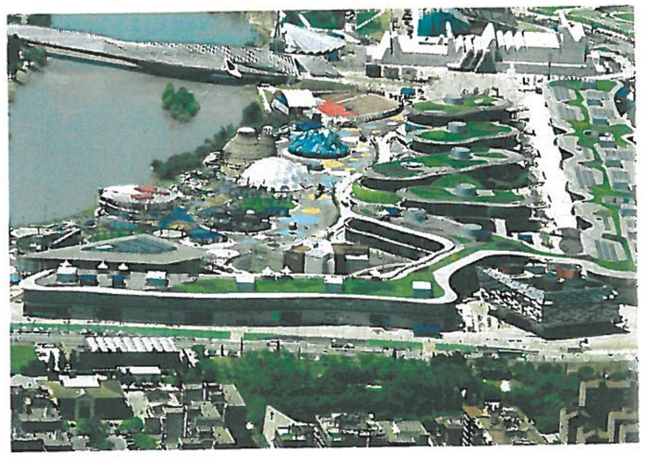

Fig 3. Aerial view of the whole green roof.

Authors

CARLOS ÁVILA CALZADA (Botanist and Landscape Architect. Head of Landscaping Expo Zaragoza 2008)

PABLO DE LA CAL (Architect Expo Zaragoza 2008)

SONIA DE LAS HERAS (Architect Expo Zaragoza 2008)

TOMÁS RODRIGO (Agricultural Engineer Expo 2008)

PROF. DR.-ING. STEPHAN ROTH-KLEYER

Landscape Designer
University of Applied Science Wiesbaden
(Germany)
www.campus-geisenheim.de

Green Roofs as a Module of Urban Water Management

Summary

The strain of new housing developments and transport routes is leading to an increase in soil sealing. Rainwater can no longer percolate naturally on the premises, leading to changes in the ground-water balance and resulting in drainage systems and purification plants being burdened with additional loads of relatively clean rainwater. Over the last few years a clear rethink has been taking place in the field of urban water management. One aim is to deal with precipitation in an economically and ecologically orientated way. The precipitation should, as far as is possible, percolate directly. Suitable containment measures for flow balancing are just some of the things being used here. These can include green roofs, which store water and release excess water gradually over time. Green roofs are just one "module" of an environmentally sound drainage system for settlements. The individual solution packages for each local and structural situation have the aim of realising optimum concepts.

General information is provided below about the possible methods of rainwater retention in green roofs – and key terms like discharge coefficient, top discharge coefficient, water retention and maximum water capacity will be defined to give a basic understanding of the subject. Discharge coefficients for green roofs are given in relation to the roof gradient and the green roof construction; water retention in terms of the annual rainfall is of particular interest here, as is the water retention during heavy periods of rainfall. Afterwards, the construction and vegetation criteria which influence the rainwater retention of green roofs will be identified. All green roofs, including thin-layer green roofs, have the following effects in the context of precipitation:

- Reduction of the water discharge from precipitation
- Delay of the discharge of water, or the proportion of excess water which surpasses the water absorption capacity of the green roof
- Retention of water available to plants
- The water is transpired by the plants and evaporated by the system substrate (evapo-transpiration)

Water retention measures offered by green roofs do not require any additional space and thus no extra land investments are necessary. Furthermore, green roofs count as compensatory and replacement measures within the framework of the Federal Nature Conservation Act.

1 | The Necessity of an Ecologically Orientated Urban Water Management System

In the future rainwater management will become an increasingly central topic in urban water management, for a range of different reasons. The much-discussed problem of climate change necessitates a change in guidelines for the measurement of drainage systems. An increasing environmental awareness, combined with cost pressures, is accelerating a movement from previous approaches – which involved diverting the water away as quickly as possible – to an ecologically orientated rainwater management in settlement areas. For years the land consumption or, rather, the land usage, has been unabatedly high in the Federal Republic of Germany. Based on figures for the whole of Germany, the amount of land used for housing and transportation increased by 2,111 km² between 2002 and 2006, or an average of 116 ha/day. The demand for new housing and transport routes has led to an increase in soil sealing. Rainwater can no longer seep into the ground on the premises, leading to changes in the ground-water balance and resulting in drainage systems and purification plants being burdened with additional loads of relatively clean rainwater. The prevailing large-scale incidence of soil sealing and the complete diversion of rainwater has meant that, at times, the drainage systems are completely overloaded. The low rates of percolation means that the ground-water table is sinking, flooding is increasing and the microclimate is being negatively influenced. The high costs of constructing and maintaining the rainwater drainage systems have led to the introduction of soil sealing fees.

The local retention and percolation of precipitation is increasingly being prioritised, whether for the purposes of naturally replenishing the ground-water, reducing the total discharge and peak flows and providing relief to the drainage network. The savings in building costs and adjoining property costs for sewer construction and its maintenance and usage costs (wastewater taxes) also speak in favour of local water retention and the percolation of rainwater and surface water.

Rainwater should be directed back into the groundwater as close as possible to the place where it fell, in order to save unnecessary costs. Many state water laws, local drainage ordinances and technical directives already have this aim. As an aside it should be noted that the planning and realisation of the various options regarding water retention and percolation comprise a key field in today's "green industry". For the developers of gardens, landscapes and sports fields – who are themselves representatives of "green industry" with a focus on design, construction and ecology – the various options for water retention and percolation provide important fields of activity.

2 | Local Possibilities for Water Retention and Percolation

The local percolation of non-harmful, un-treated rainwater is a generally recognised option that is used for both economic reasons (relieving the strain on the sewage system) and ecological reasons (natural ground-water replacement in particular). The following installations for local percolation and water retention are differentiated between [1, 2 et al.].

2.1 | Ground Percolation

Percolation occurs in several stages in adjoining surfaces (mostly areas of vegetation), where a sufficient area of these is available, but also through areas that have a permeable surface themselves: paving with broad grooves that are either filled with stone chippings or with grass; paving stones made from single-sized concrete; grass pavers; gravel, stone chipping and gravel surfaces and crushed aggregate surfaces.

2.2 Trough Percolation

If there is not enough space for ground percolation, green troughs, with depths of between 20 and 30 cm, can be built. These can often be easily integrated into green areas between buildings and paved areas. They can be landscaped with either grass or shrubs and bushes.

2.3 | Reservoir Percolation/Retention Soil Filter

When dealing with larger water heights and longer water spreading times the term is "reservoir percolation". These reservoirs simultaneously act as rainwater retention troughs. They are built as technical constructions with more or less equal, relatively steep banks, for example in motorway construction.

2.4 | Infiltration Ditch Percolation

The infiltration ditch is an underground, level reservoir, which is filled with coarse gravel, and which serves the purpose of gradually allowing the water to percolate into the ground below. It can be filled evenly across its entire length from above, or through selected points [3].

2.5 | Pipe Percolation

Percolation takes place through large drainage pipes with a diameter of at least 300 cm, which are laid more than 80 cm underground. Generally the pipes are surrounded by gravel, as with the ditches described above, and they can also be covered with a filter sheet to prevent contamination with small pieces of grit and soil. The ground-water level should be at least 1 m below the bottom of the ditch.

2.6 | Canal Percolation

Percolation canals are especially suited to inner city areas with a dearth of space but with good to moderately good permeable soil. They are also used in cases where non-permeable layers lie close to the surface and thus prevent other methods of percolation.

2.7 | Green Roofs

The reduction of water discharge from precipitation, the retention of rainwater for the use of plants and the delay in the discharge of excess water are all key effects of green roofs. They are significant from ecological and economical viewpoints, as well as from a technical perspective with regard to drainage systems.

In order to identify these effects, the following parameters are used [1]:

- Maximum water capacity;
- Water permeability;
- Discharge coefficient;
- Delay of water discharge;
- Annual discharge coefficient.

2.8 | Cisterns

Cisterns are used to capture and retain rainwater. Nowadays cisterns storing water for general usage are much more common than drinking water cisterns. They can be favourably combined with green roofs. Even in central Europe, which has a relatively high availability of water, cisterns are used by private households to store water for washing machines, toilets and gardening. This is because the water does not need to be treated for these purposes and the cistern water is therefore of a sufficient quality.

2.9 | Combining Installations with Green Roofs

Combining some of the systems described above with green roofs often works well, particularly in the case of cisterns, trough-ditch systems and pipe-ditch systems, as well as the consecutive use of the same type of systems.

3 | Related Measurable Benefits of Green Roofs

All green roofs, including thin-layer green roofs, have the following effects in the context of precipitation:

- Reduction of the water discharge resulting from precipitation
- Delay of the discharge of water, or the proportion of excess water, which surpasses the water absorption capacity of the green roof
- Retention of water available to plants
- The water is transpired by the plants and evaporated by the system substrate (evapo-transpiration)

Thus green roofs have beneficial ecological, economical and microclimatic effects, which are already known and which can, in part, already be quantified. The water retention ability of green roofs has been under scientific investigation in Germany for several years now [4]. At the end of 2001 a binding regulation for the measurement of the discharge coefficient/the discharge parameter was developed. After revision due to new findings, it was included in the FLL guidelines "Planning, Execution and Upkeep of Green-Roof Sites" ("Planung, Ausführung und Pflege von Dachbegrünungen") [1], which was republished and revised in early 2008.

3.1 | Terminology

Below, key parameters used to identify the retention ability of green roofs will be addressed and defined to provide a greater understanding for the reader. The definitions have been taken from the FLL guidelines "Planning, Execution and Upkeep of Green-Roof Sites", 2008 edition [1].

The water retention ability/maximum water capacity defines the materials used stratum composition of the layers in the green roof. The water retention ability of the materials used in the build-up of layers is reflected in the maximum water capacity. The maximum water capacity identifies the water content of a material or system substrate in % of volume after the material has been prepared by being saturated by water in a compressed condition and then being allowed to drain off for two hours. It is used, among other things, to describe the technical characteristics of system substrates and filter layer materials. Converting the value into litres/square metre gives the maximum water capacity that the material can retain.

The water permeability (mod. K_f) denotes the vertical water through-flow in millimetres per minute after the material has been saturated by water in a compressed condition and then been allowed to drain off for two hours.

The rainwater drainage from the landscaping construction is reflected by the discharge coefficient Ψ, which corresponds to the discharge index C. The discharge coefficient/discharge index C, as described in DIN EN 12056-3 and DIN 1986-100 (previously identified as discharge coefficient Ψ in DIN 1986-2), is integrated as a non-dimensional value in the calculation of the rainwater drainage (l/s). For their practical application concerning areas of varying gradients and surface structures, discharge coefficients Ψ/discharge indexes C are defined in the norms to represent the correlation between the drainage of inflowing rainwater and the total amount of rainwater. This discharge coefficient/discharge index thus represents the amount of water that must be absorbed by the drainage system on a piece of land during a period of rainfall. Areas that are permeable to water, which may or may not have an insignificant water outflow pipe, e. g. parks and areas of vegetation, or garden paths with water-bound surfaces, have a discharge coefficient/ discharge index C (Ψ) = 0; areas that are non-permeable to water, for example concrete areas, paving with grouting or bituminous pavement have a discharge coefficient/ discharge index C (Ψ) = 1.

The peak discharge coefficient Ψ_s is a non-dimensional parameter that represents the correlation between the discharge rate and the rain yield factor of a defined period of rainfall in the form of a block of rainfall (a model amount of rainfall with a defined intensity over a defined duration of time).

The annual water retention by green roofs is represented by the percentage of annual water retention or by the annual discharge coefficient Ψ_a. The water retention percentage is calculated from the difference between the amount of annual rainfall and the amount of water which drains off the green roof, in relation to the annual rainfall. This results in the non-dimensional annual discharge coefficient Ψ_a as the correlation between the total annual rainwater run-off and the annual volume of rainfall.

The delay in the water discharge during a period of rainfall is determined by the period of time during and after the end of the rainfall and by the landscaping construction. The parameters of maximum water capacity and water permeability, as well as the pre-saturation of the landscaping construction with water, are of particular significance here. In the case of short periods of rainfall, the delay in the water discharge can lead to cases where there is either no water run-off at all or where the water run-off is delayed considerably. This delay to the water run-off is also labelled "priming time".

3.2 Measurable Benefits of Green Roofs

The orientation values cited in Table 1 can be applied to green roofs as discharge coefficients C, depending on the thickness of the ballast-filled drainage layer and depending on the incline of the roof. The use of drainage layers with high drainage capabilities can lead to deviations in the actual discharge coefficient and generally lie far higher.

Tests can be used to ascertain specific values for the location and/or product. Depending on the local rain yield factors, the discharge coefficients can be higher or lower. The discharge coefficients, calculated in accordance with the procedure described in the FLL guidelines [1] are researched in non-landscaped constructions and are valid for the stratum composition during a 15-minute period of rainfall of r(15) = 300 l/(s x ha) after pre-saturation with water and a 24-hour drainage period. The vegetation and root penetration have a delaying effect on the drainage: 0.05 units can be calculated for this and subtracted from the final results. In the case of constructions that can only be landscaped in advance, e. g. vegetation matting, the additional calculation does not apply. An alternative to the procedure described above is calculating location or product-specific values using simulation procedures common in urban water management. The values created by the simulation procedures also enable calculations to be made of pipeline networks in the area concerned as part of urban water management.

The annual water retention, i. e. the actual retention, is calculated as the difference between the amount of fallen rainfall and the amount of water run-off as a yearly average [1]. According to DIN 4045, the reverse of this results in the annual discharge coefficient Ψ_a as the correlation between the annual total of rainwater run-off and the annual amount of rainfall. In the case of drainage statutes with split fees, this is also used as a sealing factor.

The annual water retention is dependent on both the type of construction and the thickness of the construction. Both the substance-specific water retention ability on the one hand and the water permeability on the other hand are to be taken into account. Differences between the thickness of constructions have a greater significance during summer weather conditions; they are increasingly equal in the case of cooler weather conditions and are almost identical in wintry weather conditions. Although a higher proportion of annual rainfall falls during the summer months, the water retention is significantly higher here. Winter weather conditions, on the other hand, mean lower rainfall but also lower evaporation levels from the stratum composition and the lowest plant transpiration, so that the water drain-off is at its highest. Table 3 compiles the reference values for the percentage of annual water retention. In order to take account of drainage statutes with split fees, the annual discharge coefficient/evaporation factors are displayed simultaneously.

Table 1: Discharge coefficients for green roofs depending on the depth of the course and the roof gradient [1]

	Roof gradient up to 5°	Roof gradient larger 5°
at > 50 cm course depth	C = 0,1	-
at > 25-50 cm course depth	C = 0,2	-
at > 15-25 cm course depth	C = 0,3	-
at > 10-15 cm course depth	C = 0,4	C = 0,5
at > 6-10 cm course depth	C = 0,5	C = 0,6
at > 4-6 cm course depth	C = 0,6	C = 0,7
at > 2-4 cm course depth	C = 0,7	C = 0,8

Table 2: Reference values for the percentage of annual water retention and the annual discharge coefficient for green roofs depending on the course depth and the amount of ballast 1) [1]

Type of greening	Course depth in cm	Water retention Annual average in %	Annual discharge coefficient Ψ_a sealing coefficient
Extensive greening	2-4	40	0,60
	> 4-6	45	0,55
	> 6-10	50	0,50
	> 10-15	55	0,45
	> 15-20	60	0,40
Intensive greening	15-20	60	0,40
	> 25-50	70	0,30
	> 50	≥ 90	≤ 0,10

1) The values relate to locations with 650-800 mm of annual rainfall and with several years of investigation. The water retention is higher in areas with lower annual rainfalls and is lower in regions with higher annual rainfalls.

3.3 | Factors Which Affect the Water Retention

Ability

The water retention ability of functional layers used in green roofs is dependent on the substance characteristics of the mixed components used, as well as on the thickness of the construction. Table 3 displays the average water retention of some common mineral components used in system substrates and drainage layers. Gravel, for example, has a water retention, displayed as maximum water capacity, of 5-10 % of volume; pumice has a water retention of 30-42 % of volume. Brick-based gravel that is 2/12 mm in size has a maximum water capacity of 28 % of volume, i. e. a water retention ability of 28 litres for a 10-cm-thick layer or 11 litres of water for a layer that is 4 cm thick. The decline in the maximum water capacity is pronounced when the size of the pieces of gravel changes and when the porosity – the interior grain structure of the water-absorbing material – decreases. Adding sands or other organic substances, like compost, bark humus or turf, can significantly increase the maximum water capacity. This is demonstrated in Figures 1-3.

The maximum water capacity is significant when evaluating the vegetative properties of system substrates for green roofs. The aforementioned FLL guidelines "Planning, Execution and Upkeep of Green-Roof Sites" [1] stipulates the following requirements for the maximum water capacity of vegetation system substrates:

- Intensive greening, multi-course construction: ≥ 45 Vol.-% ≤ 65 Vol.-%
- Extensive greening, multi-course construction: ≥ 35 Vol.-% ≤ 65 Vol.-%
- Extensive greening , single-course construction: ≥ 20 Vol.-% ≤ 65 Vol.-%
- Intensive greening , single-course construction: ≥ 30 Vol.-% ≤ 65 Vol.-%
- Drainage course: no requirements

Table 3: Average water-storage capacity at the maximum water-holding capacity of different substances for draining layers in relation to the layer thickness

Type of substances	Grain size in mm	Water-holding capacity in l/m² at a layer thickness of			Max. water-holding capacity (Vol.-%)
		40 mm	60 mm	80 mm	
Gravel	4/8-8/16	2-4	3-6	4-8	5-10
Lava	1/5-4/12	5-9	8-13	10-18	12-20
Pumis, washed	2/4-4/12	12-17	18-25	18-25	30-42
Broken expended clay	4/8-8/16	3-7	5-11	7-14	9-17
Unbroken expended clay	2/4-4/8	5-9	7-13	10-18	13-22
Unbroken expended shale	4/8-8/16	3-7	5-11	7-14	9-17
Broken expended shale	2/4-4/11	5-9	7-13	10-18	13-22
Bricksand	0/3	20	30	40	50
Broken clay, tiles and bricks	5/10	11	16	22	27
Broken clay, tiles and bricks	0/12	18	26	35	44
Broken clay, tiles and bricks	2/12	11	17	22	28

(source: LIESECKE, 1988, amended by ROTH-KLEYER, 1995).

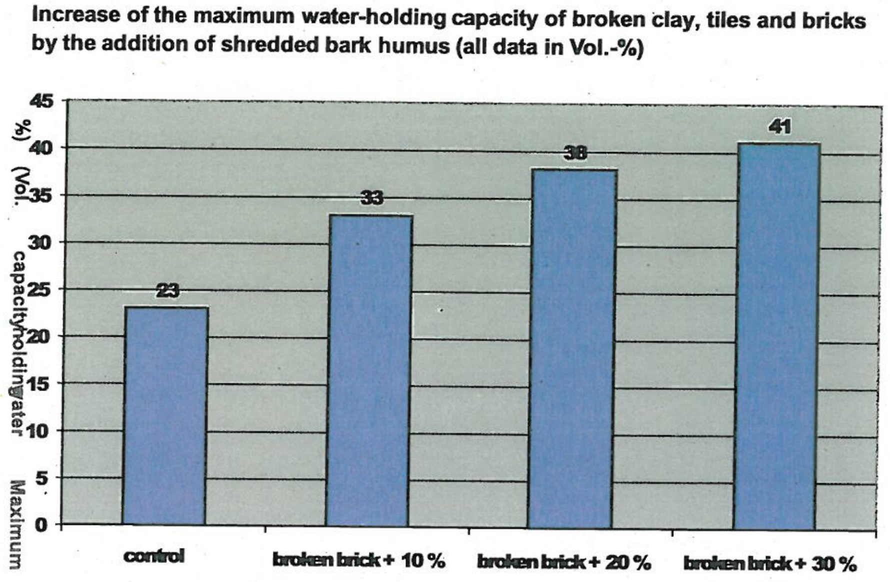
Increase of the maximum water-holding capacity of broken clay, tiles and bricks by the addition of shredded bark humus (all data in Vol.-%)

Figure 1

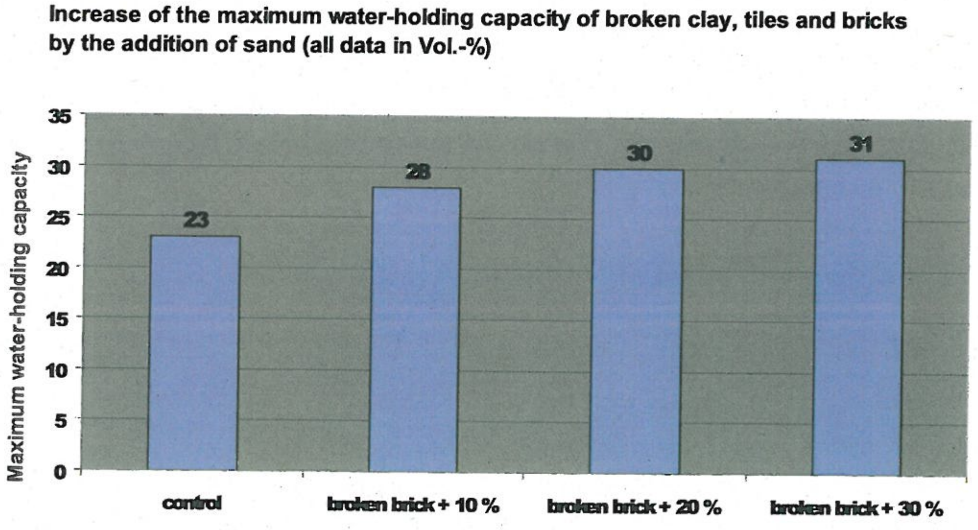
Increase of the maximum water-holding capacity of broken clay, tiles and bricks by the addition of sand (all data in Vol.-%)

Figure 2

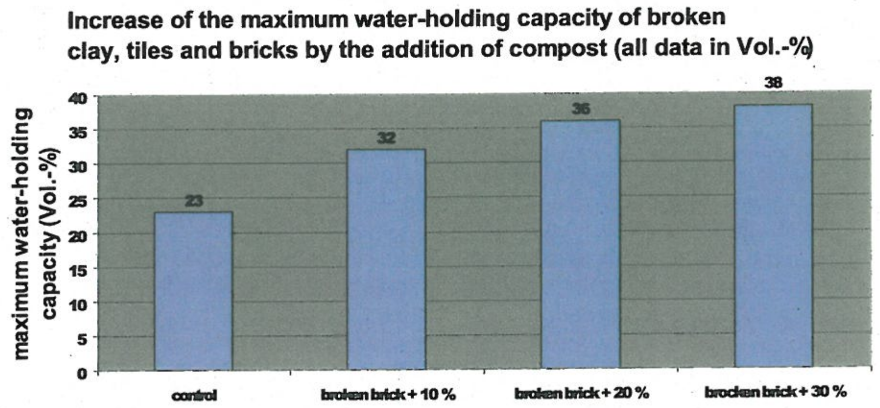
Increase of the maximum water-holding capacity of broken clay, tiles and bricks by the addition of compost (all data in Vol.-%)

Figure 3

Figure 4 displays the chronological sequence of the drainage retention and the delay in run-off in relation to time and the depth of the system substrate. A drainage index of C = 0.27 is achieved for a 10-cm system substrate combined with a drainage plate. Experience suggests that the drainage index would have been much lower for a single-layered green roof construction.

The runoff performance of a roof substrate is dependent on the thickness of the substrate and the time

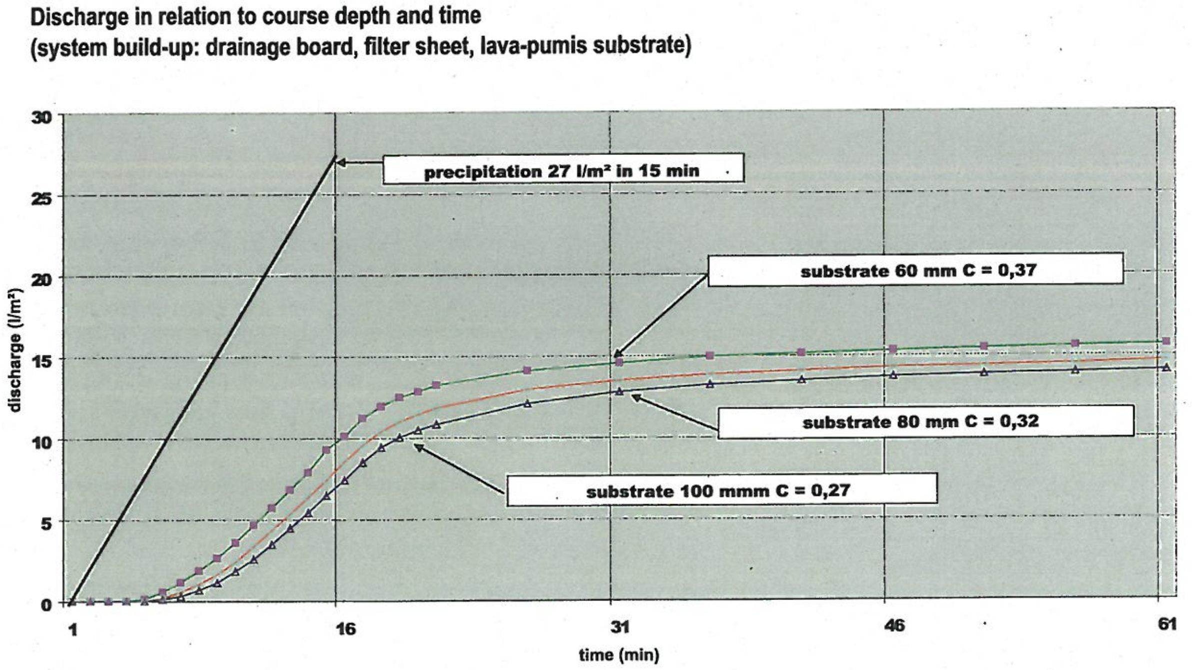
Discharge in relation to course depth and time
(system build-up: drainage board, filter sheet, lava-pumis substrate)

Figure 4: Retention and delay of a period of rainfall by a green roof

4| Conclusion

The prevailing use of the construction methods in civil and structural engineering have led to the surfaces of plots of land becoming sealed by the buildings themselves. When it rains, the precipitation that falls on the built-up areas is directed into the drainage system and then discharged via purification plants or drainage channels. This reduces the natural replenishment of the local ground-water whilst the drainage system itself cannot be reduced; in fact the opposite is the case. Green roofs can be used in urban areas with soil sealing factors of 60-80% to significantly reduce extreme surface run-offs, which can in turn help to reduce the amount of sewers and drainage channels and purification plants required. Unfortunately the surplus water from green roofs is not yet considered a worthy resource. Instead it is often diverted as "wastewater" into the wastewater treatment plants or drainage channels, which are usually already overburdened, particularly during periods of heavy rainfall. Landscaping roofs can demonstrably reduce the peak run-off after periods of rainfall. As Figure 4 shows, a green roof with a vegetation support course of 6 cm can reduce the peak run-off after a block of rainfall of r15 of 300l/ha x s by a factor of 2.7.

Besides delaying the rate of discharge, green roofs also help to retain precipitation. Table 2 shows how an extensive green roof with a depth of 6 to 10 cm can offer an average annual water retention level of around 50 %; intensive landscaping offers an even better retention level (cf. table 2). A technically proficient combination of different water retention and percolation methods (cf. section 2), e. g. combining a green roof with cisterns and percolation close to the plot of land, can mean that, in suitable hydro-geological conditions, diverting rainwater from the piece of land into the sewage channels can be largely avoided.

Figure 5: Equipment for the determination of the discharge coefficient

5. Literature:

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