GREEN INFRASTRUCTURE ALLIANCE

RAINWATER MANAGEMENT THROUGH URBAN GREEN INFRASTRUCTURES

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Rainwater is a resource to use, and should be managed where it falls.

Why not detain the storm on the roof? Traditional buildings treat rainwater as a waste product to shed off our roofs as quickly as possible only to channel it to a faraway place out of sight. This synchronized outflow often overwhelms the sewer system and causes subsequent flooding. Globally, cities are experiencing more frequent and much more intense rainstorms, and the practice of rapidly funneling rain out of the city all at once needs a thorough review.

Removing rainwater from the city interrupts the natural water cycle and leads to a severe disturbance of the urban climate. The predominance of sealed surfaces reduces the evapotranspiration and inhibits the natural cooling effect, creating an "Urban Heat Island". Consequently, city centers are up to 3°C hotter compared the surrounding area in summer (*Zhou et al., 2013*). These extreme temperatures not only increase extreme weather events like storms and floods *(Liu & Niyogi, 2019)*, but cause many premature deaths among older people from heat stress *(Umweltbundesamt, 2018)*. Therefore, it makes little sense to consider rainwater a waste product and send it away from the city to be cleansed. Recreating the natural water cycle in cities is a principal tool for reducing heat stress, mitigating damage from floods, increasing the life quality in cities and most important saving lives.

Green infrastructure systems like green roofs significantly grew in popularity worldwide. They have proven themselves as valuable stormwater volume reduction tools. Standard extensive green roofs reduce the stormwater volume on average by 58 %, intensive green roofs even by 79 % compared to unvegetated roofs *(Manso et al., 2021)*. Also, the peak flow is lowered by 71 % on extensive green roofs *(Manso et al., 2021)*. Thus, green roofs are able to lower the burden on the sewage system and reduce flooding, pollution and property damage.

However, the increasing intensity and occurrence of extreme rain events like cloudbursts require advanced solutions that are robust and resilient to a changing climate. In this contest green roofs provide the civil engineer with a tool that combines stormwater volume and peak flow reduction, the developer with additional space and potential cost savings, the city with a sustainable stormwater volume reduction strategy, and building occupiers with access to green spaces and a broad range of environmental benefits.

What is a blue-green roof and how does it work?

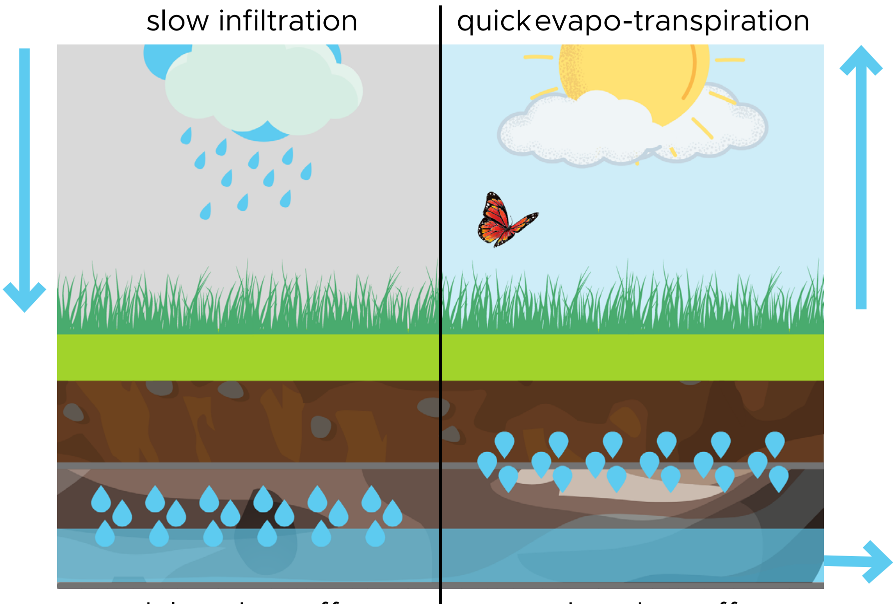
Blue-green roofs combine and maximize stormwater volume and peak flow reduction and are specifically designed to provide additional retention and detention capacity. Both components - blue and green - play a crucial role in the regeneration of the natural water cycle.

When it starts to rain, the blue-green roof must prevent rainwater from flowing straight into the sewer system. The vegetation acts as an interception layer and hold back some rainwater on the leaves. With continuing rain, it starts dropping down and slowly infiltrates into the substrate. Depending on the type and thickness of the substrate, the water holding capacity is between 30-45% of the substrate volume, meaning a layer of 10 cm would hold already up to 45 l/m^2. Once the substrate saturates with water, the blue component steps in. Various engineering options prevent the water from flowing off the roof, for example by increasing the pathway length and therefore the time the water needs to reach the outflow of the roof. Other systems provide extra storage instead of a longer pathway and thereby control the amount of water that flows off the roof. The blue component is the central part of a safe and efficient stormwater management.

Once the rain stops and the sun comes out again, the vegetated side of the roof becomes the key driver of the natural water cycle. The water that infiltrated into the substrate layer evaporates directly or is taken up by plants, which transpire it and thus return it to the atmosphere. The evapotranspiration rate can reach over 4 liters per m^2/day (Cirkel et al., 2018).

Blue-green roofs thus **reduce the total runoff** and with that, the amount of water discarded into the sewer system; **delay the peak runoff**, which prevents flooding, and return the water to the atmosphere; **maintain the local water cycle and help to mitigate extreme air temperatures with the natural cooling effect** just like in nature and green areas. The more water can be retained on the roof and returned to the atmosphere, the better the flood mitigation and the better the ambient climate.

Maintenance of the Natural and Local Water Cycle



Peak runoff delay up to 90 % compared to a non-vegetated roof *(Manso et al., 2021)*

Runoff reduction up to 50 % in summer compared to conventional green roofs *(Cirkel et al., 2018)*

- Enhanced evapotranspiration with **4 L/m²/day** for green roofs with retention layer *(Cirkel et al., 2018)*

- Better cooling due to **100 L/m² higher evapotranspiration** yearly compared to conventional green roofs *(Cirkel et al., 2018)*

- **Improvement of plant survival in drought periods** *(Savi et al., 2013)* and **higher biodiversity**

Engineered blue layer of the green roof, delays and reduces runoff

Retaining the water on the roof is an essential aspect of stormwater management. But "**the blue" makes "the green" also more effective**. Having more water available on the roof brings further advantages for the environment. Climate change causes more frequent and longer drought periods *(Chiang et al., 2021)* and storing rainwater on the roofs helps the vegetation to survive (*Savi et al., 2013)* and therefore to maintain a high level of biodiversity including plant and animal species. Rainwater from the retention layer can migrate back into the substrate through capillary forces and acts as a sustainable, passive irrigation system. The stable soil moisture level ensures a healthy and vital vegetation layer, which is needed for animals in search of habitat or forage and further for the natural cooling effect and thus for the improvement of life quality in cities.

Thanks to existing technologies and the continuous expansion of professional knowledge, it is possible to build zero-runoff city quarters. The figure below shows a property of 18350 m² that has been built with the goal to produce no rainwater discharge into the sewer system by maximizing the infiltration as well as the evaporation. Blue-green infrastructure was the key to the realization of this showcase project, and results show the success in a natural water balance.

Water balance	mm/a	
Precipitation	649	100%
Sewer system inflow	0	0%
Infiltration	144	22%
Evaporation	505	78%

What is the difference between stormwater volume reduction (retention) and stormwater peak-flow reduction (detention)?

Hydrologically speaking, traditional green roofs retain all or a portion of a storm instead of rushing all that storm water to the sewer. This retained portion returns to the atmosphere as vapor instead, thereby reducing the annual outflow volume. A metric used for volume reduction is **retention capacity.**

Retention capacity is driven by evapotranspiration and local climatic conditions limit the maximum retention capacity a traditional green roof can offer. Project specific climatic modeling combined with better retention tools such as sponge layers can improve the retention. But retention capacity alone cannot capture 100% of the annual rainfall for 2 reasons. About 10-15 times per year the green roof releases outflow caused by a '2nd-day' (or '3rd-day' storm), as the '1st-day' storm already filled the green roof to maximum capacity. Add this outflow with 1-2 more cloudburst per year that are simply too large to be fully retained, and it caps the annual stormwater volume retention at around 50-60%.

Ironically, these few '2nd-day' and cloudburst storms cause most of the flooding, pollution and property damage. It is not the volume per se but the intensity of these storms that is the culprit and we can solve this by adding detention capacity to a green roof. Detention is in the form of stormwater peak-flow reduction levels the outflow curve of a storm's overwhelming intensity. A detention green roof can hold or detain 90-95% of the peak volume during a singular storm and release it evenly and gradually over 12-24 hours, and is able to repeat this every time it rains.

There are multiple stormwater management solutions to retain and detain the water on the roofs. Here are some examples:

Flat roof stormwater retention and detention concepts:

- A blue-green roof concept detains the excess stormwater underneath the green roof profile in an open cavity space and controls the outflow either passively with a drain restrictor or what is called a smart flow control. The latter allows you to retain the water over long periods of time and perhaps use a wicking mechanism to absorb water, minimizing the need for much irrigation. Blue/green concepts can re-use water which further promotes maximum vegetation development, widens the plant palette, and offers the most biodiversity.

Sloped or Flat roof stormwater retention and detention concepts:

- A purple-roof concept is fundamentally similar to a blue-green roof concept as it stores the water underneath the green roof but can do it on a slope as well. Water is confined laterally inside a honeycomb structure and the detention layer only allows water to escape horizontally using hydraulic friction as a tool to restrict the outflow. This is an engineered concept that can be modeled to match the project.

Grey-green tanks supplement green IF green infrastructure falls short:

Sometimes the roof space is limited. What to do then? Grey-green tanks can be a solution. Sometimes there are multiple hard to reach roof levels on a building, some roofs store heating and cooling equipment, some cannot carry the load, and some membranes are simply not suited for blue-green or purple-roof concepts; thus, at times there is a need to detain water under or next to the building (at grade).

But even tank solutions can be smart and green(er). To increase capacity yet still maintain safety, we often suggest building bio-retention cells and/or ponds with stormwater storage voids underneath them. The combination can act as a water quality cleansing, volume and peak flow reduction tool.

In some cases however, tanks are necessary complements to green roofs in the value chain of rainwater management. The choice of installing a tank has to be done on a case by case basis, depending on the storage potential of the green roof and climate conditions. In those events,if the project does rely only on a tank, it at least allows us to re-use the collected stormwater for use in the landscape and irrigate the gardens, green walls or green roofs between rain events.

List of literature and sources:

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The Green Infrastructure Alliance (GIA) was established in 2019 and brings together 6 multinational companies. Each of them has extensive knowledge and experience in designing and developing green infrastructures and notably green roofs and walls, that help cities become greener, resilient to climate change, while improving citizens' wellbeing.

Our goal is to disseminate information, knowledge and promote research for the uptake of green solutions in urban areas. Together, we share 125 years of collective knowledge and we have designed and built about 1000's hectares/acres of green roofs all over Europe, North America, and Asia.

With regard to stormwater management, we share the firm belief that water should be retained and detained where it falls...on the roof. Each GIA member offers multiple stormwater management solutions that address different niches on the rooftop, but all with the common objective to leverage the multiple positive benefits of green infrastructure in urban areas.

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