Version 3.0

Livable ’scapes

- a handbook of Bluegreengrey systems

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Preface

The natural water cycle has been disturbed within the modern urban environment, where there is heavy competition for a relatively small amount of space. Previously, tree roots had space to extend into the ground allowing rainwater to seep into the rootzone, but decades of urban construction have created dense superstructures above impermeable surfaces. This kind of environment lacks both adequate space for planting as well as natural water management.

Disregarding circumstances which are crucial for vegetation and stormwater management during city planning causes a number of costly problems. High water flows and floods alternate with damage from drought. Roots destroy construction as they seek better growing conditions. Continued expansion and densification of cities causes an increase of stormwater and the need to replace existing pipes. Climate change and increased demand for both water purification , and better overflow management are also consequences of increased density.

In order to address the complexities of cities both today and tomorrow, urban environments require smart infrastructure that can address multiple issues at the same time. Building separate solutions for each function becomes costly and space consuming. Instead, stormwater management and planting beds can coexist with hard surfaces and their intrinsic requirements for traffic loads and a safe environment. In this way a greener, more attractive urban environment is created which lowers the risk of flooding and damage from drought. This is a vital step towards more sustainable cities which are better prepared for future challenges.

“We cannot solve our problems with the same thinking we used to create them.”
- Albert Einstein

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Kent Fridell

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Introduction

Bluegreengrey (BGG) is a concept that aims to integrate functions encompassing stormwater management (the blue), vegetation (the green), and hard surfaces (the grey). This handbook was developed to illustrate systems for urban environments where blue, green, and grey functions work together in the same place and space. Systems like these manage traffic loads, stormwater flows, pollution, are resilient against climate change and at the same time provide vegetation with generous amounts of underground space. With this method, a small surface area can provide multiple improvements at a lower cost than if the same functions are addressed separately.

The prerequisites for designing and constructing BGG systems are different depending on what type of urban environment is being planned. For example, suburban areas have different requirements for stormwater management, traffic, and greenery than inner cities, but more often than not, the inner city has the greatest need for multifunctional infrastructure.

In the built environment, BGG systems are designed taking into account functional requirements, street width, traffic volume, pipes and more in order to find space for open subbase layers and the constructions that are part of the system. Accordingly, it is often the available space, rather than the actual need for water retention, that determines the extent of stormwater that can be retained.

The most opportune time to integrate BGG systems is during the planning stage for new developments, as this

Bioretention area which is aesthetically pleasing and at the same time filters and retains stormwater on Strandbogatan, Uppsala.
Photo: Rasmus Elleby

provides the greatest amount of flexibility in terms of design. This handbook is aimed at those who plan, build, and manage streetscapes, especially project managers and planning managers. The in-depth explanations and concrete approaches provided here can be used over the course of an entire BGG project. Emphasis is placed on planning, dimensioning, choosing appropriate solutions, and the project planning. Supplementary appendices with practical applications of construction, operation and maintenance as well as excavating for BGG systems are also part of the handbook. Standard detail drawings of the system and its design are available upon request, thus giving the reader the required knowledge for designing and maintaining systems for different purposes and areas within the city.

The BGG systems that are described in this manual are suitable for streetscapes with traffic loads up to Load Category 2. In this kind of environment, stormwater management is primarily focused on retention and purification. However, the complete treatment train for stormwater contains additional steps, including both preventative measures for built-up areas and large-scale collective water retention, which happens before being discharged to the recipient.

At the time of writing, this field of expertise is evolving rapidly which will effect the way that BGG systems are planned and implemented in the future. The handbook will be updated as knowledge and legal frameworks change. Visit our page at www.bluegreengrey.se for the latest information.

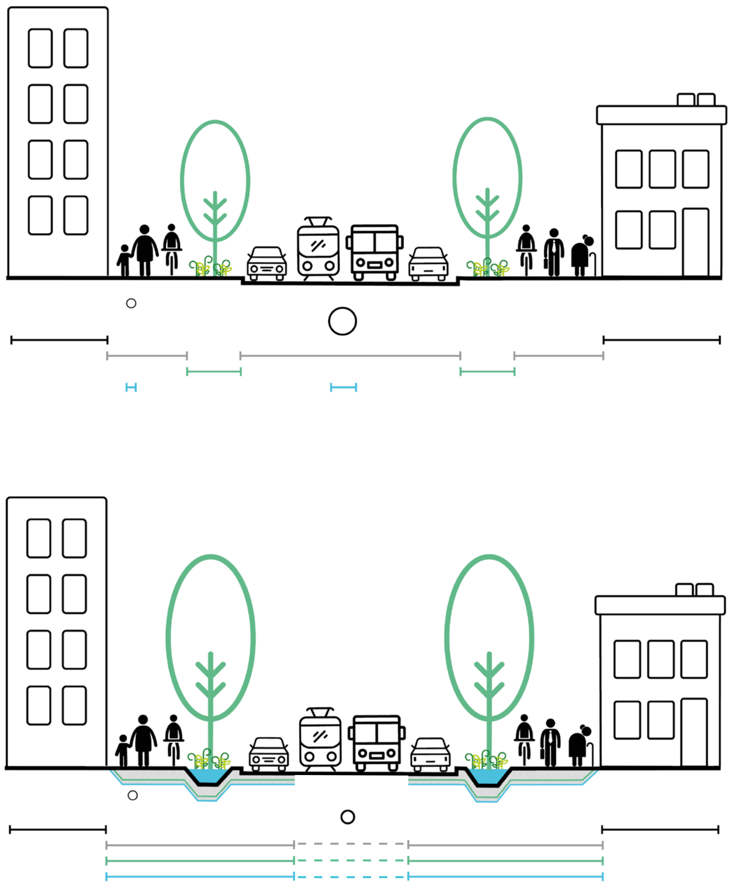


Figure 1. Top: a street where blue, green, and grey functions are implemented separately. Bottom: the same street after implementation of a BGG system which integrates stormwater management, vegetation and hard surfaces.

2 Glossary of Terms

Adsorption occurs when a substance in solution adheres to or exists in an enriched form on the surface of a material.

Crushed stone or crushed rock is commonly used during construction works.

Base layer or **load-bearing layer** - the layer of superstructure which sits between the subbase layer and surface course (pavement).

Bicycle street – a dedicated street where cyclists and motorized vehicles share the same space on cyclists' terms.

Biochar is a porous, charcoal-based material that is blended into substrate in order to improve characteristics such as filtration and storage of water and nutrients. Biochar can be nutritionally enriched so that it serves as nutrient storage in planting substrates for both plants and soil life.

Bioretention area – a sunken area of vegetation with a water retention zone for stormwater management. Also called rain garden. Read more on this in section 6.3.4.

BGG system or the Blue Green Grey system is an umbrella term for the various types of construction that utilize the same spaces for stormwater management, planting beds, and hard surfaces. Uses open subbase material.

Break refers here to a detached substructure or subsoil that divides strips of open subbase layer into smaller units. A break can be designed as a wall or a mound of earthen barrier.

Category 2 traffic loads are based on the Equivalent Standard Axel Load (ESAL) of 100 kN.

City water is an umbrella term for water that is generated in a city and can be used or reused, for example drainage, runoff from gutters or roofs, stormwater, as well as some types of grey water.

Component – elements or constituents which are part of constructions such as pits, geotextiles and inlets.

Crushed stone – particles in fractions from 0 to 200 mm.

Dimensioned rainfall refers to rainfall amounts and is used to design structures according to flow, purification and retention volume according to Swedish Water & Wastewater Association publication P110.

Extreme rain refers to rainfall which is greater than dimensioned rainfall or greater than the sewage systems can handle.

Fine particles are particles with a fraction smaller than 2 mm.

Flex zone – the area of streetscape used alternately for parking spaces and planting areas, often situated between driving lanes and combined pedestrian areas and cycling lanes.

Formation level– the level at the lower surface of the substructure or subsoil on which the superstructure is built, in other words where excavation ceases and construction begins.

Fractions are described in this handbook without specifying a unit measurement and are described by a size range in millimeters (mm).

Geomembrane – a liner or barrier that prohibits water from migrating in or out of a construction. It can be made of various materials such as rubber or bentonite clay.

Geotextile – a permeable fabric which separates material and prohibits the migration of small particles.

Grain size distribution is the percentage distribution of the size of mineral particulates within soil or aggregate. Often presented in a table or grain distribution curve, otherwise known as a sieve curve.

Hydraulic conductivity is a measure of the permeability of a substrate.

Infiltration is the movement of water into a substrate.

Inlet refers here to any component which directs water into a bioretention area.

Levelling layer is a layer of finely crushed stone packed into open subbase layers to create a level surface. Example: 8-11 mm diameter macadam.

Lesser rain refers to 1- to 2-year rains and is often used to dimension water treatment solutions.

Macadam in this context is crushed stone or gravel in fraction sizes between 2 and 90 mm. Occurs in differing fraction ranges, for example 2–4, 8–16, 16–32, 16-90 and 32-90.

Open subbase layer is a subbase layer made of macadam. Also called airy or permeable subbase layer.

Overflow happens when stormwater overflows an already filled structure to a well or pipe.

Percolation describes the movement of water within a substrate.

Permeable superstructure – a superstructure with high infiltration and percolation capacity. Read more about this in section 6.3.2.

Pits- in this handbook several types of pits or wells are described, namely:

- Control pit – the component which controls and regulates stormwater flows within the BGG system. It functions as an overflow well and assists with gas exchange.

- Gas exchange pit – the component which assists with gas exchange between planting beds under hard surfaces and the atmosphere. A gas exchange pit is usually about 1 m deep and is directly connected to the open subbase layer.

- Gas exchange stormwater pit (GES) – a form of gas exchange pit to which stormwater is directed. This pit can be connected, for example, to a distribution pipe or a stormwater chamber.

- Stormwater pit- the component intended to collect stormwater from hard surfaces.

Planting bed – the volume of area where roots are expected to grow. See also root zone.

Plant soil – defined as preexisting soil or A and B type soil according to AMA 20, the Swedish building standard reference guide.

Planting substrates - aggregate or sand-based substrates prepared for the purpose of meeting specific physical requirements e.g. permeability. To improve the conditions for the vegetation, substrate improvning materials (sim) can be added, for example biochar, compost or pumice.

Protection layer refers to a surface layer of macadam which reduces evaporation, erosion and the spreading of weeds.

Root zone refers to the area where roots are expected to grow.

Stone meal is crushed stone in fractions of 0-8 mm.

Stormwater is water that originates from precipitation including snow and ice melt.

Strip refers here to long continuous portions of open subbase layer.

Substructure – the part of a ground installation that sits between the subsoil/subgrade and the formation level.

Superstructure – the part of a ground installation that is built above the formation level. Pertains to the entire construction of a hard surface or planting bed.

Subsoil/subgrade is the untouched layer of soil underneath the formation level and subgrade.

Tree trench refers to a construction for planting trees where hard surfaces are required over planting beds. Read more in section 6.3.3.

Unit – refers to strips of open subbase layer between two disruptions.

Vegetation area refers to a plant bed above open subbase layer where running water is not led to the surface as it is in a bioretention area. Instead, stormwater is led from a pit in the open subbase layer where vegetation can absorb the water as needed. Read more in section 6.3.6.

Water retention zone – a small water reservoir situated above the surface of a bioretention area.

Wearing course – the uppermost layer in a superstructure designated for traffic. The bedding layer is often included when referring to the term wearing course.

2.1 How to Use This Handbook

For a thorough treatment of Bluegreengrey systems, reading all chapters is recommended.

For those who are familiar with the system and will be working in the planning/program phase of projects, start with chapter 5.

For those who are familiar with the system and will start planning/program after stormwater analysis and planning phases have been completed, start with chapter 6.

We refer to various publications in this handbook and assume that this information does not need to be repeated here. For further reading see the reference list below.

Bioretention area separating roadway and bicycle path with sidewalk. Norrevångsgatan, Vellinge.

3 Background

3.1 BGG System

Our urban streetscapes have developed over a long period of time. Since the introduction of the automobile into our cities, the need for streets and parking spaces has increased dramatically. Space is also required for the more sustainable modes of transportation which utilize sidewalks and bicycle paths. This leads to an above-ground struggle in the same areas that need to provide traffic safety and adequate load-bearing qualities while staying low maintenance. Even under the surface, space is scarce where everything from water and sewage pipes to electric lines and fiber optic cables need to coexist. Under these conditions, it is easy to see that space is lacking for vegetation and the natural treatment of precipitation.

Current climate trends are causing longer dry periods, higher temperatures and heavier rains, which means that cities have to be able to handle an increase in water flows. Rain causes high stormwater flows which our conventional sewage systems cannot always cope with, and the risk for flooding and inadequate water treatment has increased. The consequences of this will be severe and costly for both society and the individual.

The large variation in water supply makes life difficult for a vegetation. If powerful water flows occur after periods of water shortage, stormwater will enter the sewer system before plants have the opportunity to get the required amounts of water. Additionally, there can be issues with gas exchange in compacted planting beds and under dense superstructures. Instead of forming a deep and fine root system, trees form larger superficial roots that grow into areas with better access to oxygen, moisture and nutrients. This causes roots to damage paved surfaces and obstruct up sewer, stormwater and drainage pipes.

Flooding of hard surfaces with conventional construction and stormwater management. Folkets park, Malmö.

Damage to pavement caused by roots due to inadequate volume of planting bed.

A tree exposed to drought stress. Brno, Czech Republic.

In the last decade there has been increasing use of planting bed media formulated using aggregates with a low amount of fine materials and mixed with biochar and compost. Behind this development are studies of tree roots that have flourished in crushed rock without fine material in trenches and embankments as well as studies on extremely fertile soil in the Amazon which contains a high amount of charcoal. Crushed stone with a low amount of fine material has characteristically shown that it is well suited for this use as it creates both favorable conditions for gas exchange and high permeability for water, without risking oversaturation. Additionally, it maintains its open structure despite rough handling during modern construction processes. Under these circumstances plants develop a healthy, finely branched root system which lays the base for both beautiful and resistant vegetation and better water purification. The porosity of the material is maintained even after packing, making it possible to meet requirements for the support of traffic loads. By utilizing planting beds with crushed stone and stormwater reservoirs, BGG systems are able to make optimal use of the urban streetscape.

The key to building a BGG system is to create a subbase layer with a high amount of porosity and good load-bearing qualities and integrate it with a new stormwater control system.

The open subbase layer is connected to additional constructions at ground level that can satisfy urban

BGG systems contribute to better stormwater management by:

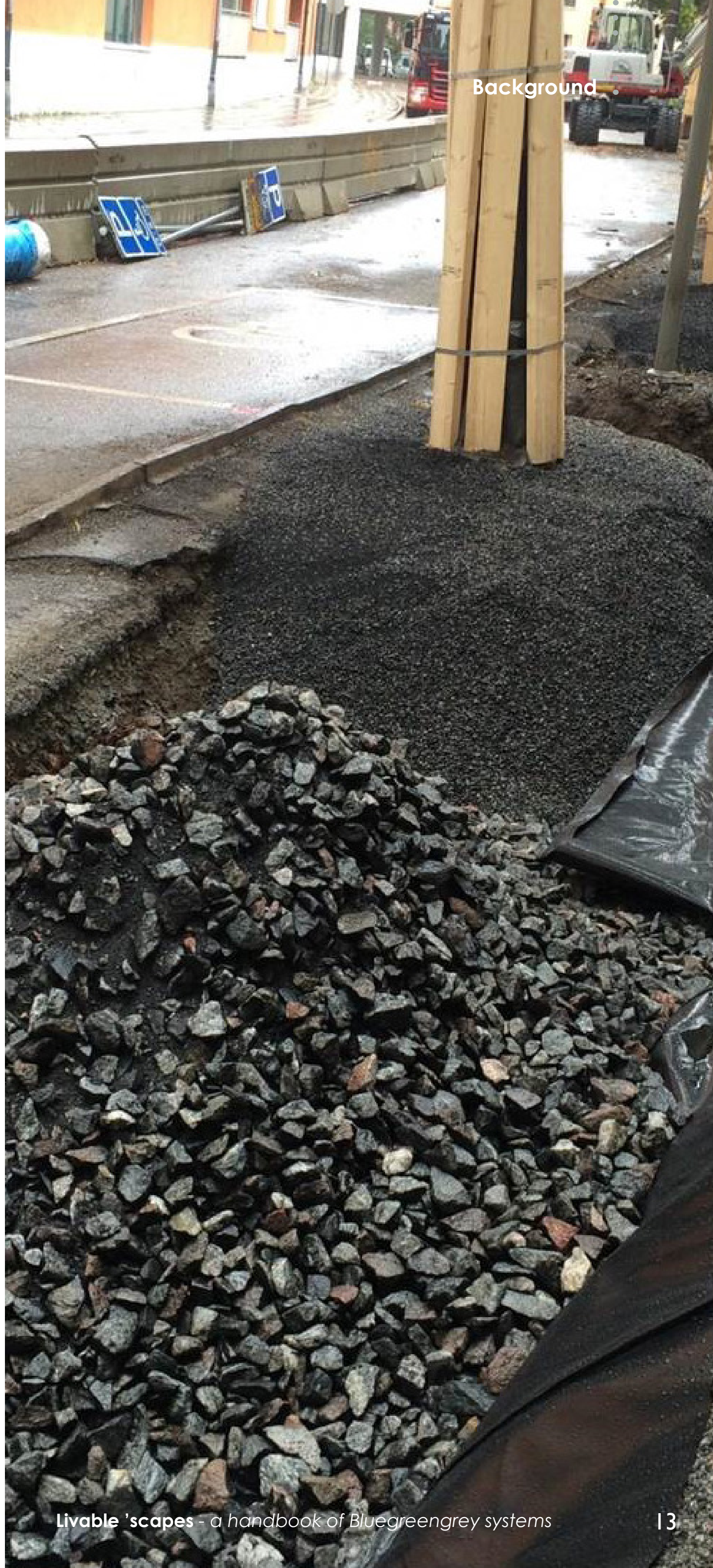
- Regulating stormwater flows
- Reducing flood risk
- Reducing pressure on sewer systems
- Purifying stormwater

BGG systems improve conditions for vegetation by:

- Creating large volumes for planting beds
- Enabling gas exchange in planting beds
- Increasing water access
- Creating a healthy environment with high biological activity and symbiosis

BGG systems additionally:

- Create aesthetically pleasing and appealing streetscapes
- Lower temperatures of urban streets and therefore minimize energy consumption caused by air conditioning
- Use rainwater runoff and grey water for watering plants
- Can replenish ground water
- Function as a carbon sink



Open subbase layer construction with biochar, which functions as a planting bed and stormwater reservoir. Stockholm requirements such as greenery, purification or parking spaces. The result is a system which cleans and retains stormwater, supports vegetation and simultaneously allows for traffic loads and flexible design. BGG systems change the image of stormwater from an issue to a resource, which makes the city more aesthetically pleasing and raises its ecological value.

BGG systems can be designed in many different ways. In the examples seen in the following images, all structures have been built on the open subbase layer, which acts as both a stormwater reservoir and a planting bed while also supporting the required traffic loads. The designs have been based on the specific requirements and functionality of each space as well as the need for purification and retention of stormwater.

Behind this handbook lies years of research and field testing in the areas of wastewater management and vegetation, the primary aim being to create more sustainable stormwater management in a predominantly urban setting. The first integration of stormwater and green space was initiated by Peter Stahre during the 1990’s in Sweden. Around this time, the Swedish Water Association started to fund basic research and research projects, for example the research into tree roots and sewer lines. The City of Stockholm published the first version of its “Handbook for Planting Beds” in 2009. Their handbook, together with two research studies (2015 and 2017) from the Vinnova project ***Climate resilient urban system solutions*** included tests of open subbase layers and led to BGG systems catching on in Sweden. The handbook you are reading is the latest product of the development and body of knowledge in this subject area.

Permeable pavement and vegetation area installed on open subbase layer. Campus area, Vellinge.

Vegetation areas over a strip of open subbase layer. Eksätravägen, Stockholm.

Narrow and shallow bioretention areas as well as bicycle lane and pedestrian walkway on open subbase layer. Perstorpsgatan, Vellinge.

Parking spaces and bioretention area on a strip of open subbase layer. Ängelholmsgatan, Malmö.

Vegetation area on open subbase layer, Växjö.

Bioretention area and hard surfaces on a strip of open subbase layer. Campus area, Vellinge.

Separate bioretention area on open subbase layer. Rundelsgatan, Vellinge.

Bicycle parking with permeable pavements on open subbase layer which acts as a water reservoir for stormwater and green space. Södervärn, Malmö.

Tree trench on a strip of open subbase layer. Liedbergsgatan, Växjö.

3.2 Climate change

The world is facing major challenges because of climate change. The temperature is expected to rise, which in turn affects urban heat islands and the resulting impact on local climate. Urban heat islands are a consequence of the way our cities are built and lead to the temperature being generally higher in cities and towns than in the surrounding landscape. Higher temperatures lead, among other things, to higher energy demands for cooling, greater health risks for the population and deteriorating conditions for urban vegetation. High temperatures have a negative effect on human health, especially children and older adults who are most vulnerable. Between 2004 and 2018, 10,527 deaths were reported in the United States where high temperatures were either an underlying or contributing factor (US EPA). Fortunately, urban trees can effectively help to counteract the urban heat island effect and lower temperatures in the city.

The cooling effect from the trees depends largely on the size of the trees and the density of the vegetation. As much as 80% of the cooling effect comes from the shade provided by the trees. Temperature differences of 1-8°C are not uncommon between areas with and without planted trees (Killicoat et al. 2002), but in exceptional cases temperature differences of up to 20°C have been observed in California, USA (Myrup 4 et al. 1993).

Lack of water and gas exchange are the biggest reasons why trees in urban areas fail and rarely reach full capacity, which leads to a lack of ecosystem services. Tables 1 and 2 depict which climate changes may occur for two different scenarios of RCP (radiation balance) compared to the meterological the reference period 1961–1990

	1961-1990	RCP 4,5 (2100)	RCP 8,5 (2100)
Annual avarage temperature		+3°C	+5°C
Duration of vegetation period approx. [days]	201	+ 60	+ < 100
Duration of heatwaves [days] daily mean temp. above 20 °C	3	10	25
Low soil moisture [days]	15	30-35	45-50
Avarage annual rainfall [mm]	609	20%	30%
Increase during winter	-	-	+6°C
Amount of days < 10 mm rain	13	+5	+8

Table 1. Compilation of changes in meteorological data for Region Stockholm. SMHI.

	1961-1990	RCP 4,5 (2100)	RCP 8,5 (2100)
Annual avarage temperature		+3°C	+5°C
Duration of vegetation period approx. [days]	210	+40	+90
Duration of heatwaves [days] daily mean temp. above 20 °C	2	-	18
Low soil moisture [days]	5-15	20	50
Average annual rainfall [mm]	800	10%	25%
Increase during winter	-	-	+5°C
Amout of days < 10 mm rain	-	-	-

Table 2. Compilation of changes in meteorological data for Region Västra Götaland. SMHI.

RCP4.5	RCP8.5
• Emissions of carbon dioxide increase slightly and peak around the year 2040 • Population is slightly below 9 billion at the end of the century • Low land requirement for agricultural production, among other things as a result of larger harvests and changed consumption patterns • Extensive reforestation program • Low energy intensity • Powerful climate policy	• Carbon dioxide emissions are three times as today by 2100 and methane emissions are increasing sharply • The world's population increases to 12 billion, which leads to increased demands on grazing and cultivation land for agricultural production • Technology development towards increased energy efficiency continues, but slowly • Heavy dependence on fossil fuels • High energy intensity • No additional climate policy

Table 3. Assumptions underlying the RCP4.5 and RCP8.5 scenarios. SMHI.

according to SMHI. Table 3 shows that for RCP4.5 society succeeds in greatly reducing carbon dioxide emissions, while in RCP8.5 emissions will increase compared to today's situation. From tables 1 and 2, it can be deduced that periods of low soil moisture will increase, for Stockholm from about 15 days/year to between 30-50. At the same time as the availability of water will decrease, the average temperature will increase and the length of periods with daily average temperatures above 20 degrees will for Stockholm increase from 3 to 10-25 depending on the scenario.

In Malmö, recent summers have been poor in rainfall and drier than normal. Above all, 2018 was extremely dry and hot, but 2020 and 2021 have also been dry. This causes great stress on the vegetation. Figure 2 shows how evaporation, precipitation and temperature change during a normal year and how it looked during the summer of 2018, Figure 3. In general, we have a large precipitation surplus during late autumn and winter, which should cover the deficit that occurs during late spring and summer due to evaporation.

Normally, the water-holding capacity of the plant bed together with the groundwater buffers against the changing availability of water during the year. Creating plant beds capable of buffering the large volumes required to meet the large deficit generated in 2018 will be a challenge. In order to secure the water supply, it is important that the vegetation systems are dimensioned against this, and here it may also be relevant to supply with City water to meet the need. Read more about drought in section 6.8 and about City water in sections 3.3 and 8.1.

Today, stormwater systems are dimensioned so that they are able to handle the runoff generated from a rainfall event with a given return period, for example a 20-year rain or a 30-year rain. It would have been interesting to investigate whether it is possible to apply the same approach to drought in urban planning. That is, to dimension the vegetation systems according to socio-economically viable return times in dry periods, e.g. 30 – 50 year drought event. With such reasoning, one also needs to take into account the risk of damage to the ecosystem services that the vegetation generates and can take a long time to recover.

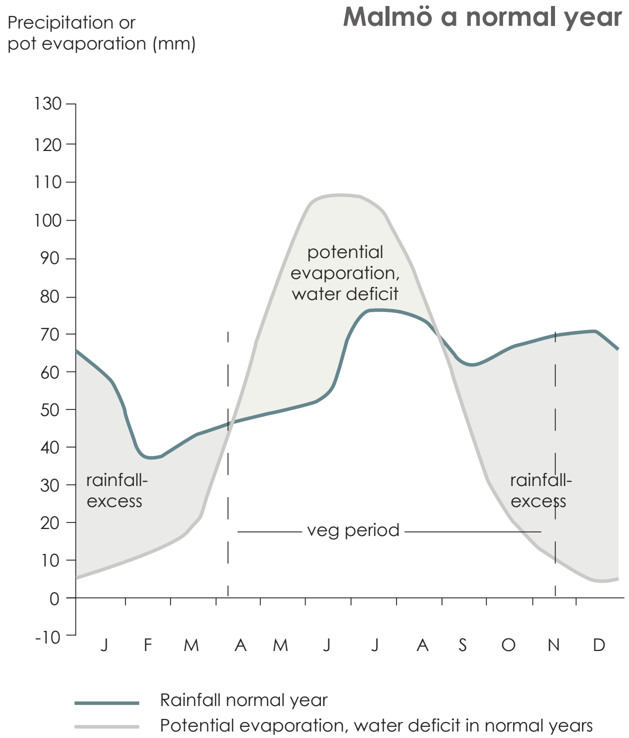


Figure 2. Shows how precipitation and evaporation change during a normal year for Malmö.

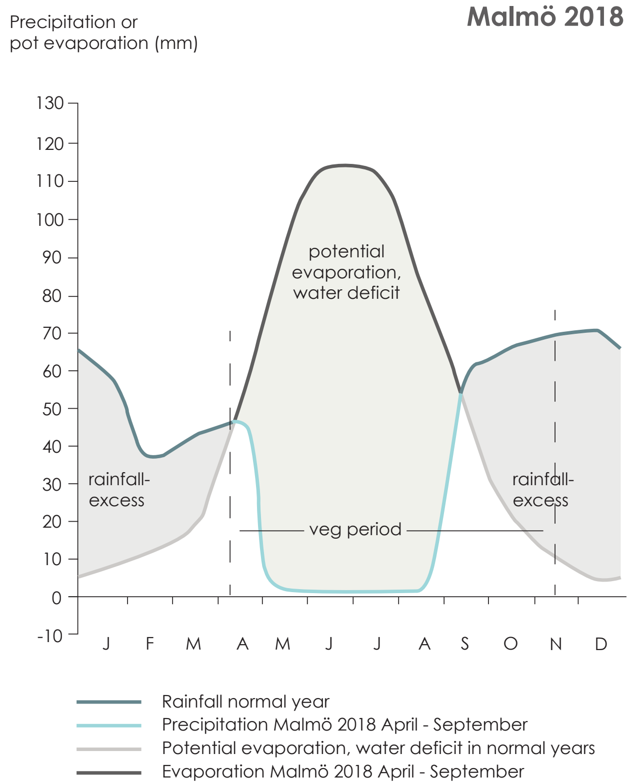


Figure 3. Shows how precipitation and evaporation looked in 2018 for Malmö.

A tree in a city exposed to drought stress in Prague.

3.3 City Water

Population growth and urbanization lead to increased number of hard surfaces, stormwater volumes, drinking water consumption, wastewater production and reduced groundwater recharge. The consequence is a great need for investments to increase the capacity of municipal pipelines, drinking water plants and sewage treatment plants. On a strategic level, there are goals to steer towards a circular water use to reduce the above negative consequences, and we are increasingly questioning usage of drinking water for things like irrigation and for washing parking decks.

The conditions created by a warmer climate, lack of water and lack of space in urban spaces can make it problematic to provide the city with large enough plant beds to support large trees and substantial ecosystem services. During the summer drought, the city's vegetation suffers, and this will become much more noticeable in the future as the climate changes. If we look at cities in southern Europe whose climate we will get in Sweden, it is a big and growing question. Trees and other vegetation in cities play a very important role in balancing climate change and making the microclimate healthier for humans. If the trees die during a dry summer, it will take decades before new trees can have the same effect on the microclimate and provide us with equivalent ecosystem services.

The stormwater systems are currently dimensioned for a certain level of safety. We will need to apply the same thinking to the availability of water for vegetation to withstand longer and more intense dry spells. In order to secure the water supply so that the vegetation will have the opportunity to survive long periods of drought, the use of new water resources is required.

In order to reduce water use and reuse water several times, on both an individual and community level, both technical measures and attempts at behavioural changes are implemented today. For example, measures against losses in pipeline networks, irrigation bans, installation of sparingly flushing fixtures as well as increased use of Blue-Green-Gray systems such as plant beds for stormwater. There is also reason to use other water sources in the city than drinking water. Continuous flows of unused water resources in the form of, among other things, storm water, drain water and gray water can be used locally via BGG systems. Here we refer to these resources as City water. Another common name for City water is technical water.

Trees and grass area on residential land under severe drought stress, Malmö.

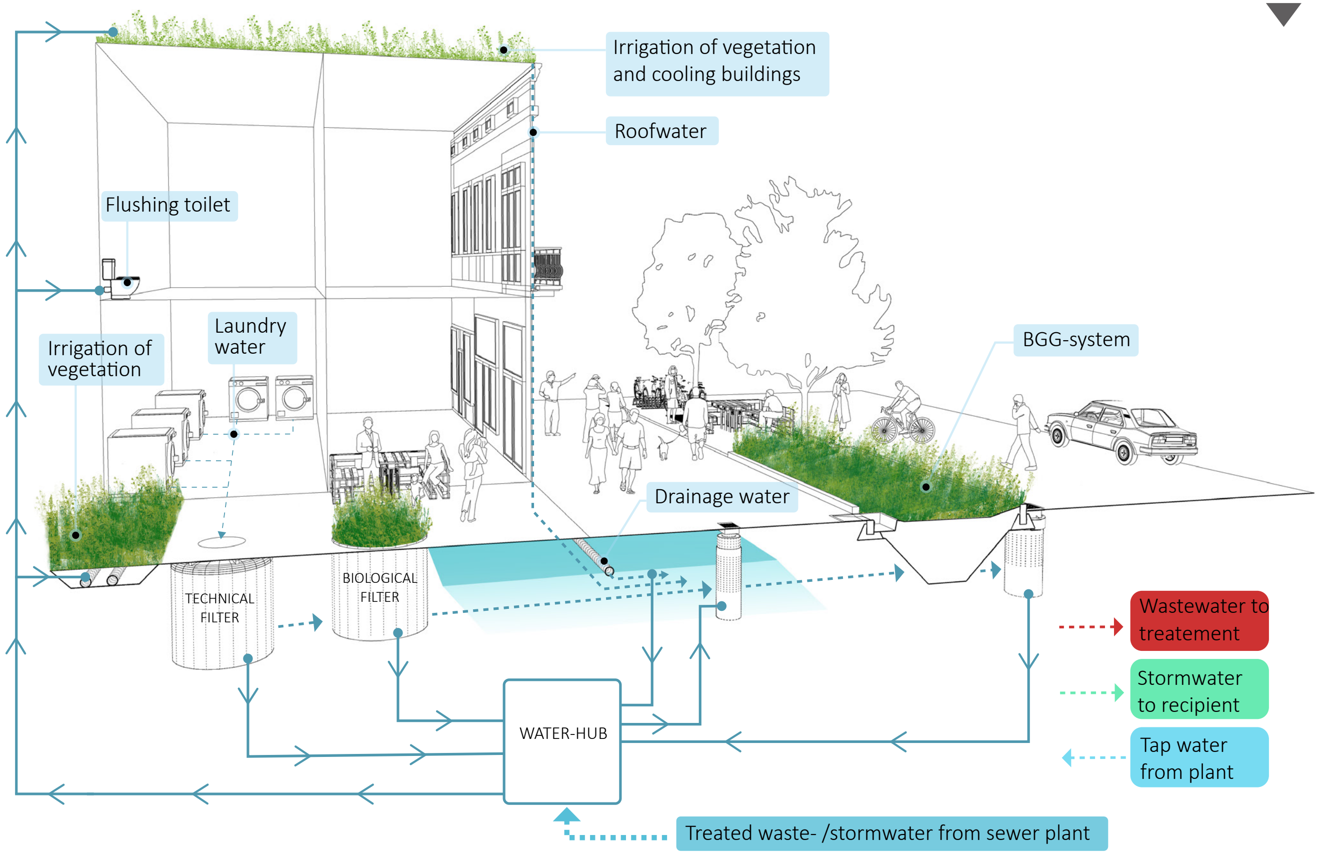
At the time of writing, research and trials are underway to use City water. The goal is to contribute to prosperous and vital urban vegetation that can withstand major climate changes and continue to deliver necessary ecosystem services to the city and society. A relatively uncomplicated way to start using City water is to lead stormwater and drain water to a nearby BGG system. Such a solution ensures a more even supply of water for the BGG system's vegetation. The more continuous flow can irrigate urban vegetation even when rainwater is not available. At the same time, the sewer network, recipient, and water treatment plant are relieved. The principle for such use of city water is presented in Figure 4.

Utilization of City Water could lead to improved water resource use in the urban environment, reduce the need for water treatment and the load on sewer networks, create benefits for property managers and companies and contribute to the goals of sustainable water supply and urban development according to Agenda 2030 and provide the city with ecosystem services.

By integrating water management on neighbourhood land and public land, there are great opportunities for improved water management. This can lead to lower costs and efficiency for property owners, developers and companies.

More information and examples of small full-scale and developed systems with City Water can be found in chapter 8.1.

Figure 4. Use of storm and drain water for irrigation and nutrient supply to BGG systems.



4 BGG System Functions

This chapter provides an overview of BGG functions. Since the system can be designed and dimensioned in a flexible way, it can be adapted to the degree of functionality required at any specific place.

4.1 Traffic Loads

BGG systems can both retain and clean stormwater and at the same time function as a planting bed. What makes the system especially adaptable is that it can achieve positive impact while meeting requirements for load bearing and traffic intensity. This makes it possible to implement the system where pedestrians, cyclists, and motor vehicles share space.

This handbook describes constructions that are tested up to Load Category 2. Load studies with and without water in the superstructure have been made and evaluated in the Vinnova project Climate resilient urban system solutions. If a crane or a crane transport truck is to be assembled on a superstructure with open subbase layer, a flatter angle of friction should be used when calculating load bearing.

For an explanation of Figure 5, see also section 6.2 pp 38-40.

Figure 5. Example of an urban street with BGG located in the flex zone. The blue area symbolizes an open subbase layer which lies alongside the entire street. Hard surfaces with bioretention areas, green space and trees are alternated at will. Stormwater can be handled in a variety of ways while at the same time allowing flexibility in the design of street.

4.2 Stormwater Retention

The open subbase layer in a BGG system is comprised of aggregate which has had the smaller fractions sieved away, thereby creating voids that water and air can permeate through. These voids give the material a porosity of 30-40%, allowing storage of up to 400 liters of water per cubic meter of open subbase layer. Since the pores are larger than with conventional fill materials, BGG systems have high hydraulic conductivity for water and gas exchange. This creates the possibility of controlling water flow within the system and discharging it to the conventional sewer system in a controlled manner. Apart from retaining water in the open subbase layer, the system can be designed with bioretention areas where stormwater can be retained in retaining zones.

BGG systems are designed and dimensioned differently depending on the volume of stormwater expected to be handled, but the principle of open subbase layers is based on the traditional water reservoir. The control of the system is flexible: one can decide that it should be be designed to cope with a lesser rainfall event (1 to 2 year rainfall), dimensioned rainfall (10 to 30-year rainfall) or extreme rain. The system can even be adjusted for intermediate amounts of rainfall. Stormwater is directed to the open subbase layer by drainage pits, permeable pavement, or bioretention areas. Moderate levels of stormwater allow for purification in conjunction with retention.

If purifying stormwater isn't a determining factor, stormwater from lesser rainfall can be directed directly to sewer pipes. This allows the BGG reservoir to accommodate excess rainfall that conventional sewers lack the capacity to handle so that flooding can be avoided. Systems adapted for larger amounts of rainfall have a greater focus on water retention.

If the open subbase layer is connected with the layers above it, the construction will be able to handle both purification of lesser rainfall and the retention of greater rainfall depending on how its flood control is designed.

If a BGG system is installed with vegetation, then city water (grey water, roof runoff and drainage from nearby buildings) can be used for watering. This creates better conditions for vegetation and microscopic life while reducing load on sewers. Grey water, or water from household showers and laundry, can be used for watering if it has undergone appropriate pretreatment. This allows vegetation ample access to water, even in periods with little or no precipitation. Pressure is reduced on sewer systems and there is no need to use drinking water for watering. For more information on the design of BGG systems, see chapter 6.

If roof runoff, drainage water and grey water are directed to BGG systems, liability should be taken into account. Diverting grey water usually requires a permit from local authorities who enforce applicable environmental regulations.

Bioretention area which is retaining and purifying stormwater during a rain shower. Monbijougatan, Malmö. Photo: Rasmus Elleby

Bioretention area on the street Strandbogatan, Uppsala. Photo: Rasmus Elleby.

4.3 Planting Beds

The green parts of a plant use carbon dioxide and water for photosynthesis which produces glucose and oxygen. Under the ground, respiration - a process which is almost the inverse of photosynthesis - takes place. Roots consume oxygen and glucose and produce carbon dioxide. When carbon dioxide levels are too high, roots function less effectively, and growth slows. Carbon dioxide is poisonous to roots and causes damage to the plant much more quickly than drought. For this reason, it is extremely important that gas exchange functions well in soil. Traditional urban planting beds, however, can often be densely planted and therefore have low levels of gas exchange and water infiltration.

Treating plant roots well creates conditions for healthy, thriving plants and supports rich microscopic life in our city streets.

Larger soil volumes in planting beds results in increased tree growth in urban streets. This has a larger impact on the microclimate where large, dense tree crowns contribute to the perception of a more comfortable climate. Rain that falls on tree leaves first coats them in water, and a large proportion of this water evaporates without ever reaching the ground. Over time, the amount of water captured by tree crowns becomes an additional method of retaining stormwater. This process is called interception and has been experienced by anyone who has ever taken cover from rain under a large tree. Thriving greenery gives further advantages to people and the climate: a higher proportion of vegetation in the city leads to reduced wind intensity, lower temperatures and a richer variety of animal life, not to mention more enjoyable streets.

4.4 Stormwater Purification

Stormwater is purified in several ways within the BGG system. Particles carried away by water are collected in sand traps, stormwater tunnels and the open subbase layer. As the flow rate of water decreases, particles sink to the bottom in a process called sedimentation. Smaller particles are captured as water is filtered through the substrate in bioretention areas and the open subbase layer.

In order to improve the open subbase layer and the bioretention area's function as a purification facility, biochar, pumice and compost are sometimes added to the mix. These materials' porous structure, large surface area and chemical properties are advantageous to both vegetation and microorganisms because they are able to retain both water and nutrients. Nutrients and pollution in stormwater can bond to biochar to a certain degree instead of being drained away. When conditions are improved, symbiosis becomes more efficient: plants supply microorganisms with glucose, and in return get help absorbing nutrients and water. The microorganisms can even break down some of the pollution and contribute to water purification. This way of treating water mimics the kind of purification that occurs naturally in the ground and waterways and results in the better wellbeing of vegetation.

In order to purify water from complex organic pollutants, a zone can be laid in the bottom of BGG systems whereby water stays still for a longer period of time. The anaerobic conditions that result from this favor the growth of bacteria that have the capacity to break down pollutants to simpler, less damaging substances. Anaerobic conditions can even support bacteria that convert nitrogen compounds to nitrogen gas. This process is called denitrification, which reduces the amount of nutrients in stormwater and in turn reduces overfertilization (eutrophication).

Rundelsgatan in Vellinge before the installation of a BGG system.

Rundelsgatan in Vellinge after the installation of a BGG system with bioretention areas.

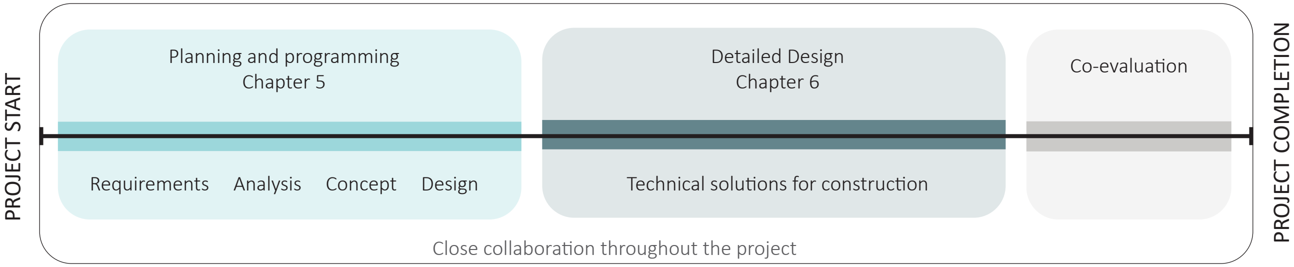
5 Project Planning and Programming

This chapter describes the preliminary work and analysis needed to lay the groundwork for BGG systems. These steps are necessary in order to be able to design and install an efficient system and a beautiful streetscape. Even if you are starting work after this stage is completed, it can still be good to review this chapter and make sure that all the steps have been completed to the desired level.

5.1 Requirements and Goals

The requirements of both the physical space and the project are critical for the design of the system. Depending on whether the system is built in the inner city or the suburbs will affect the necessary conditions for the system and the available space. Whether the system is built in areas undergoing development or in existing urban areas impacts project requirements as well.

Figure 6. Schematic timeline of a city planning project with accompanying handbook chapters



BGG systems can be designed in a variety of ways depending on the objectives of the installation. Systems that are adapted to create efficient stormwater management for greater amounts of rainfall are dimensioned differently than systems that focus on healthy vegetation and the purification of lesser amounts of rainfall.

The way in which the street will be used is important for the design of the BGG system. Pedestrian walkways, bicycle lanes, residential streets, collector roads or arterials bring with them varying traffic loads and street design. The size of drainage areas determines which system needs to be installed. Space for planting beds, cable zones, parking spots, lamp posts and more must be taken into account as well.

BGG systems are powered by gravitation and therefore need to work in conjunction with the grade of the formation level and catchment area. Slopes that are too steep limit implementation because they create faster water flows that can be difficult to control and accommodate. Steep slopes mean reduced water retention capacity for stormwater reservoirs. Since the water level stays horizontal and cannot slope along with the reservoir, only the lowest part can fill up with water, thereby greatly reducing water reservoir volumes. Gradients greater than ca. 5% require special solutions that fall outside of the framework for this handbook. Alternatively, standalone elements can be constructed for these situations.

The system described in this handbook should not be subjected to traffic loads greater than Load Category 2. For roads that require heavier loads, it is often possible to install the system under flex zones, planting areas or pedestrian and bicycle paths.

5.1.1 Quick Analysis

Before project planning and programming take place, a quick analysis should be done to be sure that the prerequisites are met for the BGG system. In the early stages of a project it may not be possible to determine all necessary requirements and desired features of the project, but the quick analysis can assist in making reasonable assumptions to determine the feasibility of a BGG system. If some prerequisite data are missing in this stage, it's a good idea to start with them in the next phase of the project.

It is problematic to present just one approach to performing a quick analysis, as this needs to account for variables such as the project's framework, individual experience, and the available information for the location and the specific project. Therefore, we present two ways to approach the quick analysis. One way is to use the ***"Quick Reference Guide"*** which is found in chapter 5.4, page 28 in this handbook. The other way is described on page 25.

5.1.2 Example of a Quick Analysis

Grade:

Question: Is the grade ca. >5% or <5%?

Answer: about >5%, The open subbase layer requires a specialized construction, alternatively standalone solutions can be constructed.
Answer: about <5%, A continuous strip of open subbase layer can be laid.

Available space:

Question: Is there a minimum width of available space to install an open subbase layer and planting beds, respectively >2 m for low-level demand and >2,5 m for high-level demand?

Answer: If the minimums stated above are not available, the requirements needed to build a BGG system are not met.

Low lines and low points:

Question: Are there already low lines and a low point adjacent to the planned area of open subbase layer?

Answer: If there aren't low lines and a low point in the immediate area it is generally not possible to install a BGG system.

Level of demand:

Question: What overall level of demand exists for aspects such as water retention, purification, load bearing, aesthetics and planting beds? Is the level of demand generally higher or lower?

Answer: Follow the corresponding demand level when examining the space.

Area cross section:

Question: Is there a minimum available depth for laying open subbase layer corresponding to >1,2 m for higher-level demand and >0,8 m for lower-level demand?

Answer: If the above depth requirements are not met, a BGG system cannot be installed.

Existing trees:

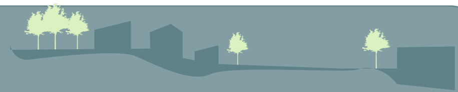
Question: Are there trees already in the area planned for the BGG system that will be preserved?

Answer: For trees that will be preserved, is there an option to lay the new area/direct water flow around them?

Generally higher demand

Retention: Ability to handle dimensioned rain at the very least. Retention amounts meet standards in the Swedish Water & Wastewater Association publication P110. 10- to 30-year rains.
Purification: General purification levels of 70-80%.
Load bearing: At least Load Class 2 or 100 kN
Planting bed attributes: Greater ability to retain water and nutrients. Larger soil volumes. Greater demands for plant vitality.
Aesthetics: Granite curbstones, shrubs and perennials as undergrowth as an example.
Operation and Maintenance: Greater assurance against operational disturbances as well as increased requirements for components in drainage pits and inlets. A protection layer can be used on all planting areas.

Generally lower demand



Retention: Ability to handle the minimum dimensioned rainfall for purification. 1- to 2-year rains.
Purification: General purification levels of 40-50%.
Load bearing: Up to Load Class 2 or 100 kN.
Planting bed attributes: Reduced ability to hold water and nutrients. Smaller soil volumes. Less demand for plant vitality.
Aesthetics: Concrete curbstones, grass undergrowth with occasional shrubs as an example.
Operation and Maintenance: Normal assurance against operational disturbances and average requirements for components in drainage pits and inlets.

Example of open storm water solution with bioretention area in a street with more than 5% grade.
Oslo, Norway.

5.2 Plan and Program Documentation

The need for a BGG system and its requirements should be studied even during the project planning phase. In this way the system requirements will be identified in an early phase allowing various technical fields to cooperate on its construction. After a quick analysis has been completed, additional information needs to be collected in order to produce a plan or program. A number of studies need to be completed in order to confirm that the location meets the requirements of a BGG system. Most important to be checked are the available space in the street, its grade, and any requirements for retention and purification. Thereafter follows a comprehensive design and rough dimensioning of the system, both above and below ground, which is entered into a design program or its equivalent.

It is also important to consider aspects of the working environment. BGG systems are often placed in urban environments, which means that personnel will be working in urban environments. When work and maintenance are to be carried out, street closures or the use of a Truck Mounted Attenuator (TMA) may be required depending on traffic volume and speed limits.

The following information should be included in the plan:

- The type of street that will be designed.
- The overall design of the streetscape i.e. flex zone.
- Traffic types (cars, bicycles, pedestrians, etc.)
- Traffic loads to be accommodated above open subbase layers.
- Longitudinal slope and low points in the street.
- The desired amount vegetation areas.
- Existing basements in nearby buildings.
- Need for lamp posts and other fixed objects.

5.3 Project Guidance

The approach used for planning a BGG system does not differ from the approach used for conventional systems. Just as conventional projects contain an early planning phase, the BGG system touches on the same points during the planning phase but with a higher level of detail.

Below is a bullet point list that can be used during project planning. The list refers to various chapters within the handbook for further reading.

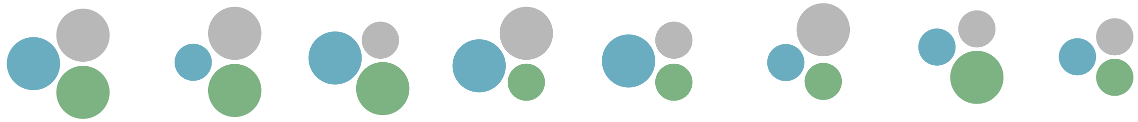
- Is there a concept design available with elevations?
  Do there need to be preconditions so that one can be done? Read more on streetscape requirements on page 24.
- Has there been a stormwater study?
  Read more on requirements for purification and retention on page 30, chapter 5.5. Check for compliance with for example EU water directives and local, federal and municipal water policies.
- Has there been a geotechnical survey?
  Read more on geotechnics on page 31, chapter 5.6.
- Choose a BGG system
  Read more in the Quick Reference Guide on page 28, chapter 5.4.

- Where are cables laid or where will they go?
  If possible, try to establish protected areas for BGG systems. Read more on cabling on page 32, chapter 5.7.
- Traffic classes
  This handbook outlines constructions that are tested up to traffic class 2 or 100 kN. Read more on traffic classes on page 20 chapter 4.1.
- Working environment
  When working with or maintaining BGG systems in the urban areas, measures may need to be taken for the safety of the personnel. Read more on the working environment on page 26, chapter 5.2.
- Dimensioning the water reservoir
  Dimensioning the water reservoir or the open subbase layer and retention zone in a bioretention area can be done using conventional methods, for example the rain-envelope method. Read more about reservoirs and retention volumes on page 91, chapter 7.3.

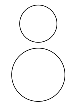
  Also be sure that there is adequate soil volume; read more on page 92, chapter 7.4.

- Dimensioning and designing flow rates of components
  All components and materials that impact flow rates in the system need to be examined for flow intensity and invert (lowest) levels. Aside from determining flow volume in pipes, one also needs to ascertain if the desired flow levels in the open subbase layer are being achieved. Read more on open subbase layers on pages 38 and 64, chapters 6.2 and 6.4.

  Dimensioning flows can be done using conventional methods, for example the rational method. Read more on the rational method on page 90, chapter 7.1.
- Purification requirements
  If water purification is required, a water purification simulation should be done. Read more on purification levels on page 92, chapter 7.5.
- Project planning prerequisites?
  Should the project be implemented in one or two stages? For recommendations on approaches to take see chapter 6.



The diagram above can be a help for the project group to discuss what applies to the specific project regarding the level of requirements and ambition. What is important for the specific project? It may be that the requirements for stormwater management are greater than the requirements for the green area. Depending on the project, the scenarios according to the above models look different. A higher requirement for stormwater management can, for example, correspond to dimensioning for a 30-year rainfall and a lower requirement corresponds to a 1-year rainfall. Regarding the grey, a lower requirement could be a pedestrian area and a higher traffic class 2. For the green, for example, a lower requirement could be a meadow area and a higher area for large trees (>15m).



5.4 Quick reference guide

The purpose of this quick reference guide is to assist in the design of the system based on the existing situation and goals for the area. The guide will help determine if the system should be large, small or separate, and which elements should be used at ground level. It will also make it easier to find the correct standard detail drawings and construction documents needed.

The quick reference guide produces a result in the form of a number and letter combination. The number indicates if a continuous strip of open subbase layer can be used (2) or not (1). A continuous strip enables greater stormwater retention capacity but requires more space. One alternative is to install open subbase layer only under separate ground level constructions. Letters indicate appropriate constructions as recommended by the guide.

This guide can be thought of as an aid in choosing a BGG system. It is important to consider the big picture when choosing a system; the values given are meant to be seen as guidelines. Covered bioretention areas, as mentioned in section 6.3.5, are not included in the guide but can bee seen as a combination of the bioretention area and tree trench elements.

For definitions of high- and low-level demands see “Quick Analysis” in section 5.1.2.

Simply put, high-level demands can be seen as solutions for inner city areas, and low-level demand solutions work for suburban areas.

The location that open subbase layer is installed in the street, as well as its width and depth, is chosen most often depending on what type of street in question (Figure 7). For a main street (arterial) and the collector streets, the main strip is often laid in a flex zone and under pedestrian and bicycle paths. For a local street (shared space), pedestrian areas and bicycle lanes, the entire breadth of the street can be replaced by open subbase layer. One could also choose one half or the other of the street or the middle of the street for the open subbase layer. The wider the area of coverage, the shallower the layer will be.

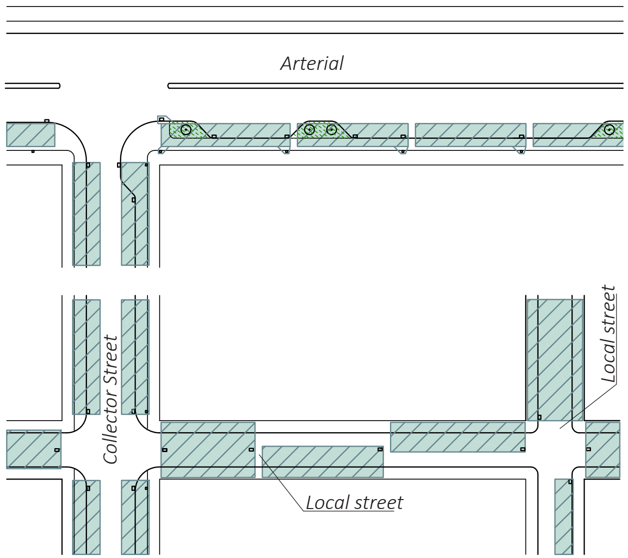


Figure 7.
Example of open subbase layer development for different types of streets.

Open Subbase Layer implementation:

1. Individual constructions with open subbase layer
2. Continuous strip of open subbase layer

Elements described in this handbook:

A. Impermeable hard surface
B. Permeable hard surface
C. Tree trench
D. Bioretention area
E. Vegetation area
F. Swale
G. Extensive permeable hard surface

Higher- or lower-level of demand:

H. Generally higher level
L. Generally lower level.

Quick Reference Guide for BGG System Design

Key:
A = Impermeable hard surface
B = Permeable hard surface
C = Tree trench
D = Bioretention area
E = Vegetation area
1 = Standalone elements
2 = Constructions on continuous strips of open subbase layer
H = Generally higher demand
L = Generally lower demand

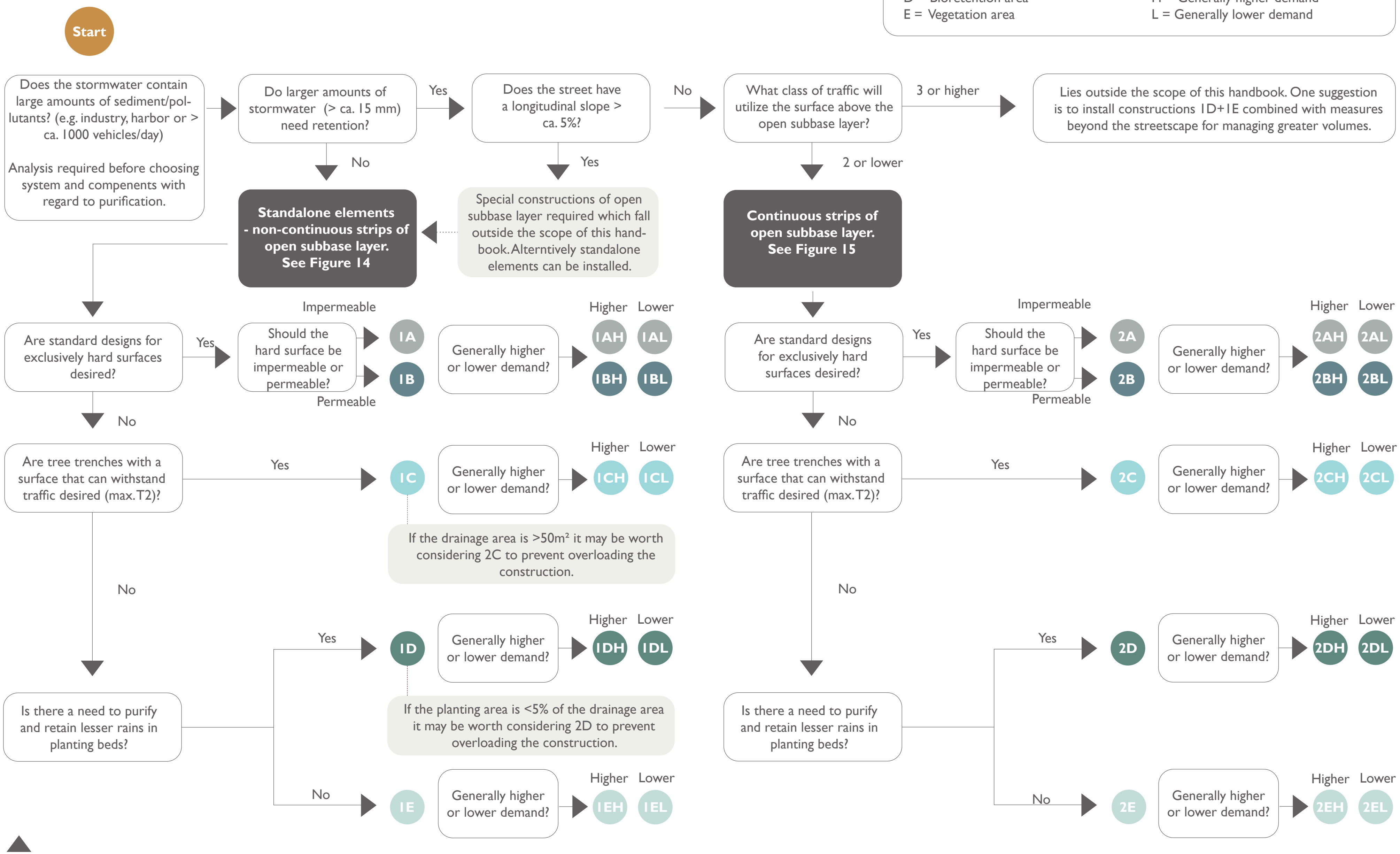


Figure 8. Quick Reference Guide for BGG system design

5.5 Stormwater Analysis

It's important to look at the big picture when planning the stormwater treatment train for stormwater in a city. We suggest following the policies laid out in the International Water Association publication ***Principles for Water-Wise Cities.***

A stormwater analysis needs to be done to see how the system in question relates to nearby systems. A well-functioning treatment train delivers a smaller and cleaner portion of stormwater to the recipient. Among other things, the water will be filtered, infiltrated into the soil, and absorbed by vegetation.

Early in the process, it needs to be clear what type of sewer system exists in the area. For example, if it is duplicate or combined. This can affect how the system is designed in terms of the type of rain that is handled.

Stormwater purification should be done as early as possible in the treatment train. In later steps, water masses will be combined from various sources and clean water mixed with dirty. This means that greater amounts of water must be treated to collect the same amount of pollutants. By treating and retaining water early on, contamination gets taken care of at the source where it is more concentrated. This allows the treatment train to focus more on retention in the later stages.

The first step is to work with preventative measures such as green roofs and infiltrated surfaces and vegetation areas to handle precipitation. In order to reduce the amount of pollutants in stormwater, it is important to work with environmentally friendly building materials and surface finishes as well as to continuously clean the outdoor environment.

Highest up in the stormwater treatment train should be measures for retaining water locally, for example in courtyards, industrial areas, and parking lots. When stormwater reaches public right-of-way, such as streets and small parks, the focus should be on both purification and retention, but also transportation in order to minimize flood risk. Lower in the treatment train are larger public parks and green spaces where there is space to create ponds and wetlands for collective retention and purification.

Early in the process, it needs to be clear which type of stormwater system exists in the area. For example if it is separated or combined system. This can affect how the system is designed regarding type of rain that the system is dimensioned for.

Having a clear picture of the BGG system's position in the stormwater treatment train will allow for its optimal design.

Despite the fact that private space constitutes 70% of all land in our cities today, no requirements can be applied on stormwater management for these areas. However, there are more and more municipalities which sets up recommendations on stormwater management for major retrofits and new constructions. There are good examples on projects where the BGG system forms a large part of stormwater management on residential land. Read more about BGG system on residential land in section 6.10.

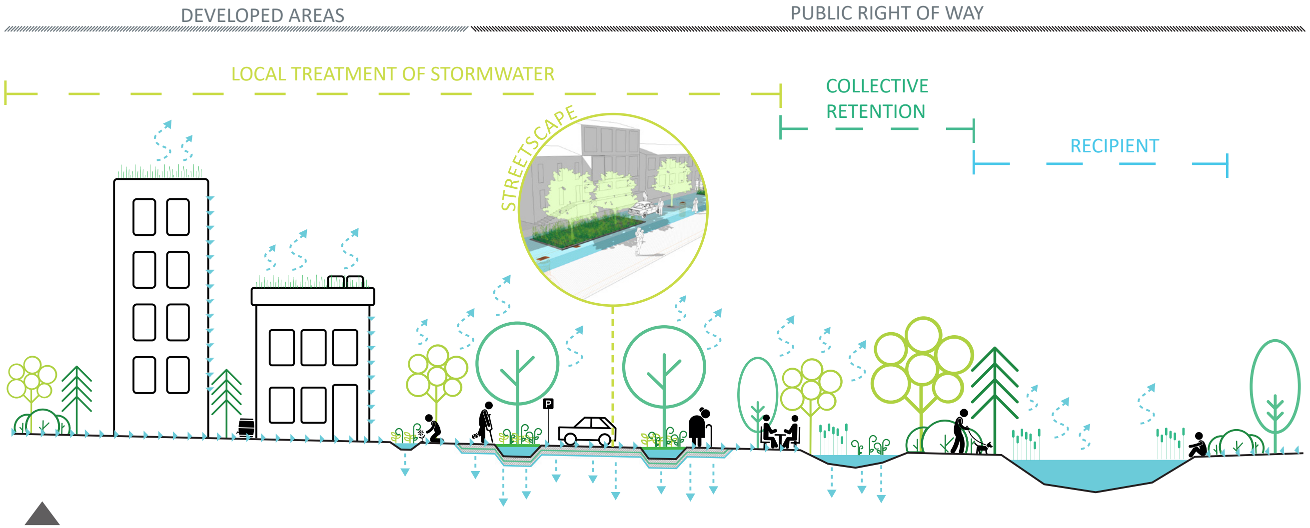


Figure 9. The entire stormwater treatment train. BGG systems contribute with purification and retention near the source.

5.5.1 Requirements for Stormwater Purification and Retention

The municipality, the county administrative board or the local water treatment authority often sets requirements for purification and retention. When designing a system, dimensioned rainfall amounts and whether city water needs to be managed should be ascertained early on. The recipients' status should be checked and additional stormwater treatment facilities up- and downstream should be mapped to get a complete picture of the local stormwater situation.

In terms of purification, it is both the recipient's status and the contaminant levels of inbound stormwater which set the requirements for the system. High traffic volumes or industrial or harbor activity often produce a large amount of pollution and sediment in stormwater. Mapping the watershed before project planning has begun provides the necessary information.

Obtain the following information in an early stage:

- Purification and retention requirements
- Additional stormwater treatment facilities up- and downstream
- The BGG system's position within the stormwater treatment train
- Status of the recipient
- Traffic intensity within the watershed
- Activities within the watershed
- Treatment of and responsibility for roof runoff

5.6 Geotechnical Surveys

A geotechnical survey includes information on the constitution of the subgrade, subsoil and surrounding area and if there are rocks which need blasting in order to create space for the BGG system. The survey also shows if it is possible for stormwater to percolate down to the ground water. In order to install a BGG system, the material in the subsoil should meet requirements for the formation level according what is normally required for superstructures for roads in a city. If the subsoil is contaminated the system should be sealed so that percolating stormwater does not draw pollutants into the ground water or potential drinking water sources.

There should also be an investigation into where ground water levels normally lie and how they change throughout the year. When the diversion of storm water is too efficient it can cause ground water levels to fall, which in turn can cause cracking and settling in buildings built on clay subgrades. A BGG-system can counteract this.

Obtain the following information in an early stage:

- Material in the subgrade, subsoil and surrounding areas
- Infiltration and percolation capacity
- Ground water level
- Existing contamination
- Need for water protection (if there is a drinking water source nearby)
- Need to infiltrate stormwater in order to minimize risk for settling in case of drought
- Incidence of rock

5.7 Utility Line Management

In situations where BGG systems will be laid near various types of buried infrastructure, it will be necessary to obtain information from and coordinate with utility owners to find the most suitable arrangement. Raising the issue of cables that are laid under and in open subbase layer should take place early on so that all parties are aware of potential risks and inconveniences.

Cables can be laid under or in BGG systems. Compared with conventional superstructures the BGG system consists of multiple layers of various materials. This can lead to additional work for future excavations and increased risk for damaging or reducing the functionality of the system. It is more advantageous to lay cables above the open subbase layer.

Circumventing cabling issues is easier in new developments where cable laying and connection points can be planned within breaks between strips of open subbase layer. See Figure 10 for suggested breaks within a BGG system. Existing areas require thorough examination in order to find the optimal combination of system design and potential cable relocation.

For more on utility lines see section 6.1.4.

Obtain the following information in an early stage:

- Placement of existing cables
- Placement of new cables
- Policies regarding the relationship between BGG systems, cabling zones and cable types.

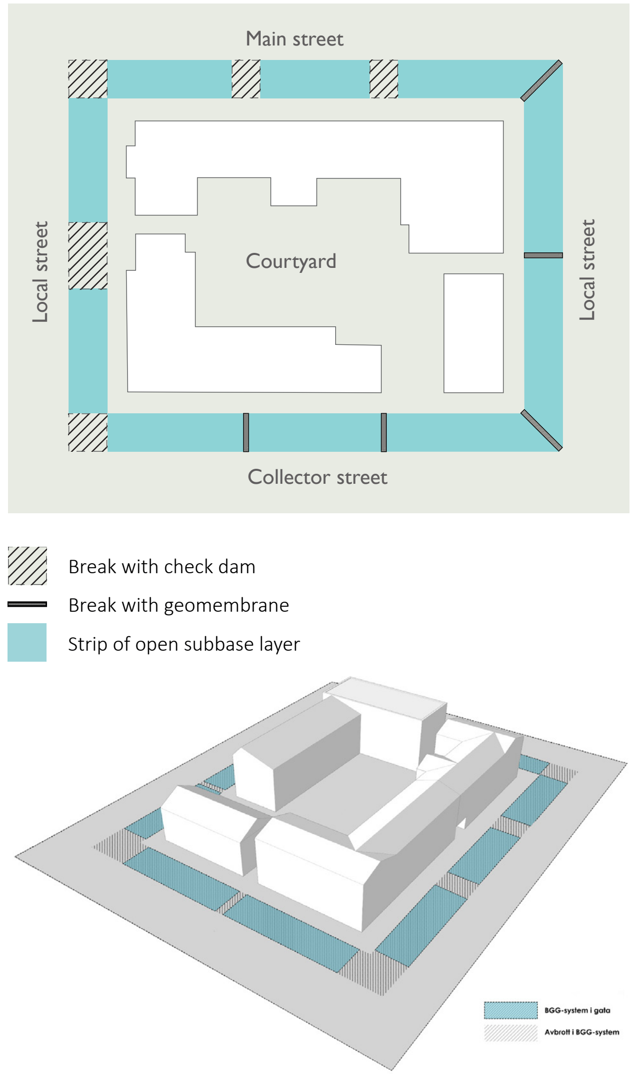


Figure 10. Suggestion for the placement of stripes with open subbase layers and breaks. In the breaks, connection/branch lines can be laid in to housing block from main lines.

5.8 Project Coordination and Finance

BGG systems touch upon many technical areas within the built environment. Street and water engineers, geotechnical engineers, city planners and others working in landscape, real estate and the environment are all involved. It can be a challenge to get everyone to work together for the same goals, however multidisciplinary thinking is important in all phases, from budget and project planning to installation and maintenance. Important information can even fall through the cracks because of unclear areas of responsibility.

Early on in the project, decisions need to be made on how costs and responsibility will be divided within project planning and installation as well as operation and maintenance. Allocating and documenting responsibilities clearly and making a single person project leader for the BGG system is an advantage for all parties and prevents details from falling through the cracks.

In order to provide everyone in the project a common foundation and knowledge of BGG systems, an informational session or training should be held. This handbook is an excellent tool which can give all involved parties understanding of the project and a common terminology. Even installers and inspectors should attend the training and be given information on common pitfalls and installation techniques which differ from traditional methods. Small mistakes in the installation process can cause the system not to function as expected.

When working with BGG systems, the traditional silo mentality with its separated working and technical areas must be transformed to create incentive and collaborative working environments.

Figure 11. BGG systems touch upon many different technical areas and administrative departments, requiring good coordination and collaboration.

Vegetation growing in open subbase layer. In this strip, a research installation, there are bioretention areas with and without vegetation. Eksätravägen, Stockholm.

6 Design Development

There is a great deal of flexibility in BGG system design which allows it to be adapted to local conditions. The system is made up of both ground level construction and the open subbase layer. This chapter describes different examples of design and construction as well as their materials.

6.1 Before Design Development Begins

Construction at ground level can provide space for landscape or hard surfaces but can also help with the drainage and purification of stormwater (see section 6.3). Systems can be interconnected or installed individually depending on requirements and desired results. Below ground, layers are constructed over an open stone subbase so that they retain and purify stormwater as well as providing a large volume for plant roots. The larger the volume of open subbase layer, the better the BGG system can fulfill its function.

6.1.1 Standard Detail Drawings

A number of standard detail drawings are included in this handbook which will assist in design development. By using the quick reference guide (section 5.4, p. 28), a number and letter combination will be produced which indicates what type of system and which ground level constructions are appropriate for an individual location. This information can be used to request the correct detail drawing on which specific designs can be based.

Standard detail drawings may not be referenced to or used in tender documents or the like. BGG systems must always be adapted to the specific features and conditions that exist within a project. Not taking this into account introduces the risk that the system will not have the desired effect, which in turn can cause considerable and costly damage.

1. Conventional superstructure
2. Substrate
3. Coconut mat with separation layer alt. mineral wool
4. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
5. Open subbase layer, if properties for plant growth are desired to be enhanced pumice can be added

Figure 12. Example of a cross section showing distribution of BGG system layers

6.1.2 Drawings and Documents

The BGG system designer drafts components that may be referred to in drawings other than their own. Control pits, stormwater tunnels, sealed and draining pipes are examples of objects that the BGG designer puts in their drawing files when the system is designed and dimensioned, but will eventually appear in water and sewer plans. Ground elevations and curb heights should be verified with the street planner as these elements are crucial for BGG system functionality. Additionally, before plants are selected one needs to have system conditions clearly formulated (see section 5.1). It is important to determine early on who will draw what and where it will be recorded, as well as regularly coordinating planning in order to prevent misunderstandings.

If possible, we recommend that both the BGG designer and other designers use 3D drawing programs. This makes it easier to see possible interference between cables and the open subbase layer, for example. If it is not possible to draw in 3D, 2D may be used, but it requires more rigorous supervision to avoid mistakes.

It is also important to have clear boundaries regarding the bill of quantities. By dividing up codes that include more than one technical area in multiple rows so that each designer only needs to quantify what they have drawn, mistakes can be avoided in later revisions. Make sure to be accurate with the nomenclature for different types of vegetation areas, for example bioretention areas, BGG system vegetation and "regular" planting.

6.1.3 Levelling

Low lines and low point drains determine the size of the drainage area and where pits and bioretention areas will be placed. Even the course in which water flows should be accounted for in order to avoid inconveniences. If the ground slopes more than 5% it will be difficult to create an efficient BGG system using the model described in this handbook. Instead, specialized solutions will be needed to capture quickly flowing water and create an effective reservoir for retention.

Since contamination levels differ between roadways and pedestrian and bicycle paths, it can be advantageous to direct water from those respective surfaces to different parts of the system. Rainbeds can be used for the more polluted water from roads, and drainage from pedestrian and bicycle paths can be routed directly to the open subbase layer, for example. This means that there will likely need to be two low lines for each half of the street. The street should therefore be divided into multiple small drainage areas where the volume and flow rate are calculated for each area.

Pine trees in structural soil with a hard surface on the uppermost layer. Flat and asphalted surfaces are built with open subbase layer. Stormwater is collected by so-called gas exchange stormwater pits. Photo: Örjan Stål

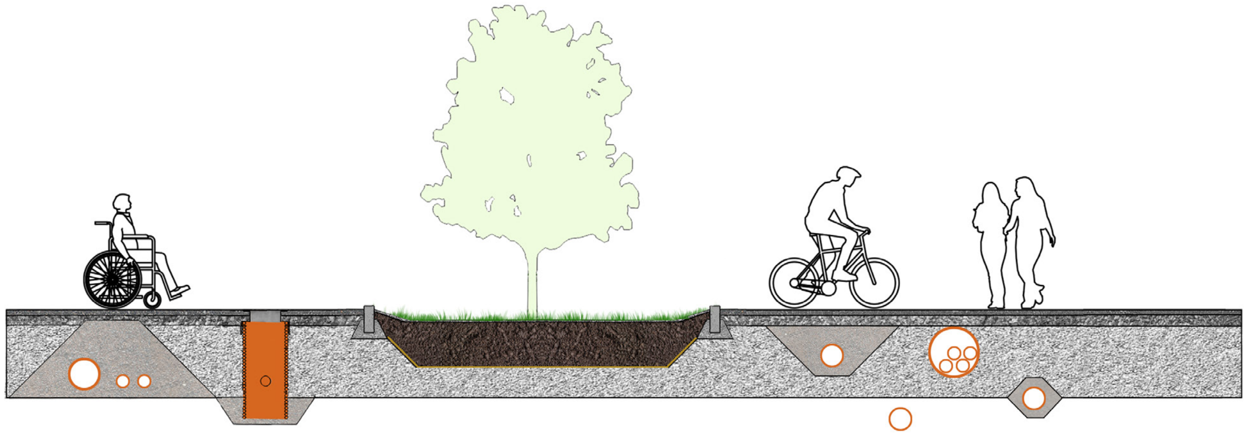


Figure 13. Example of longitudinal section where cables and pipes leads across the BGG system. The above drawing is an illustration of a possible situation and does not describe a technical solution.

6.1.4 Utility Lines and Construction

Generally speaking, BGG systems are not unique when it comes to integrating utility lines. However, in order to prevent damage to the BGG system and the need for more complicated excavation or repairs, it is best to minimize the incidence of other types of cables or pipelines within and under the system. Try to lay line passageways in the breaks between strips of open subbase layer, see Figure 10, p. 32. The best place for utility lines such electrical and telecom to be laid is above the open subbase layer, as they are usually found around 40-60 cm deep. When lines need to cross through the system, pathways can be created using crushed stone. Empty conduit runs can be laid where desired for drawing cables through in the future; see Figure 13 for an illustration of one possible scenario.

For other solid constructions, such as various kinds of foundations, it is most often backfilling or cast concrete which can cause problems for a BGG system. Backfilling takes up large volumes which are valuable in terms of storage and flow. To get around this problem, crushed rock without fine fractions is sometimes used because it does not impede water flow. It is however important to open up a dialogue with a contractor to ensure foundation stability. For example, the foot of the foundation may need to be modified if the backfill does not contain fine particles (see photo next page).

It is particularly beneficial to work with backfill that does not contain fine particles in the lowest 50 cm of the system, as it is there that the largest volume of water will flow.

Example of foundation in BGG system

When concrete is used for embedding curbs, a small amount will run into the open subbase layer before the material has hardened. In order to prevent that volume from being taken away from the system and to minimize material costs, a slow-flowing concrete should be used. Geotextile or another fabric should not be used in this case.

If utility lines cannot be eliminated from the BGG system, the design should be modified such that water within the system always has the ability to flow unhindered to the bottom. The lowest half meter of the open subbase layer should remain free from obstacles but above this elevation it is possible to run utility line conduits.

Root intrusion into pipes can be avoided primarily by creating good conditions for trees and other plants in designated areas of planting beds. Mixing in biochar and providing proper ventilation are important details that will benefit vegetation. To further protect utility lines, they should be encapsulated in crushed rock that contains fine particles. In that case, backfill needs to be enclosed with geotextiles so that fine particles stay in their place and do not settle.

6.1.5 Installation Process

If BGG systems are being laid in new developments, the process is best done in two stages. After building what will later become underground structures, the system is covered in load-bearing layers and waste gravel. Pits are sealed tightly with covers. The construction road is now complete, and the property is ready to be built upon. This allows other activities, such as building construction, to take place without damaging the system. If components aren't sticking out of the ground, they can't be driven over and damaged. Likewise, the entire street can be used as a construction road without risk for settling or other damage. In the last phase of construction, trenches are dug for tree trenches, bioretention areas and vegetation areas. The project can be finished with planting, setting drainage pits at their final elevation and installing drain hole covers. When BGG systems are laid in an existing area there is no need to interrupt the process, since the installation can be completed in a single stage. Most of the steps are identical to the two-step installation process.

Installation of a BGG system.
Laying of open subbase layer with biochar.

6.2 Open Subbase Layer

If the street has a high longitudinal slope, high traffic loads or the unfavorable placement of existing infrastructure, it can be difficult to lay continuous strips of open subbase layer. In these situations, the BGG system is designed with distinct elements such as bioretention areas, vegetation areas, tree trenches, and permeable pavements on individual sections of open subbase layer. The capacity to handle and retain stormwater is, however, limited by the capacity of each individual section, as well as the contingency of optimal placement in the street.

It is also necessary to find out if nearby buildings have or will have a basement level, as there a risk that stormwater can reach building foundation drains via the BGG system. One should also be aware of the future need for steel sheet piling in basements and how this will affect the placement of the BGG system.

By building the BGG system with one continuous strip of open subbase layer, water retention capacity and planting bed functionality within the system is maximized. The strip can be divided into sections so that stormwater can fill the largest volume possible, and not only at the lowest end. Control pits can regulate the flow between sections and conventional sewer pipes, as well as allowing overflow if the BGG system is full. Stormwater enters the system via pits or by infiltrating structures at ground level.

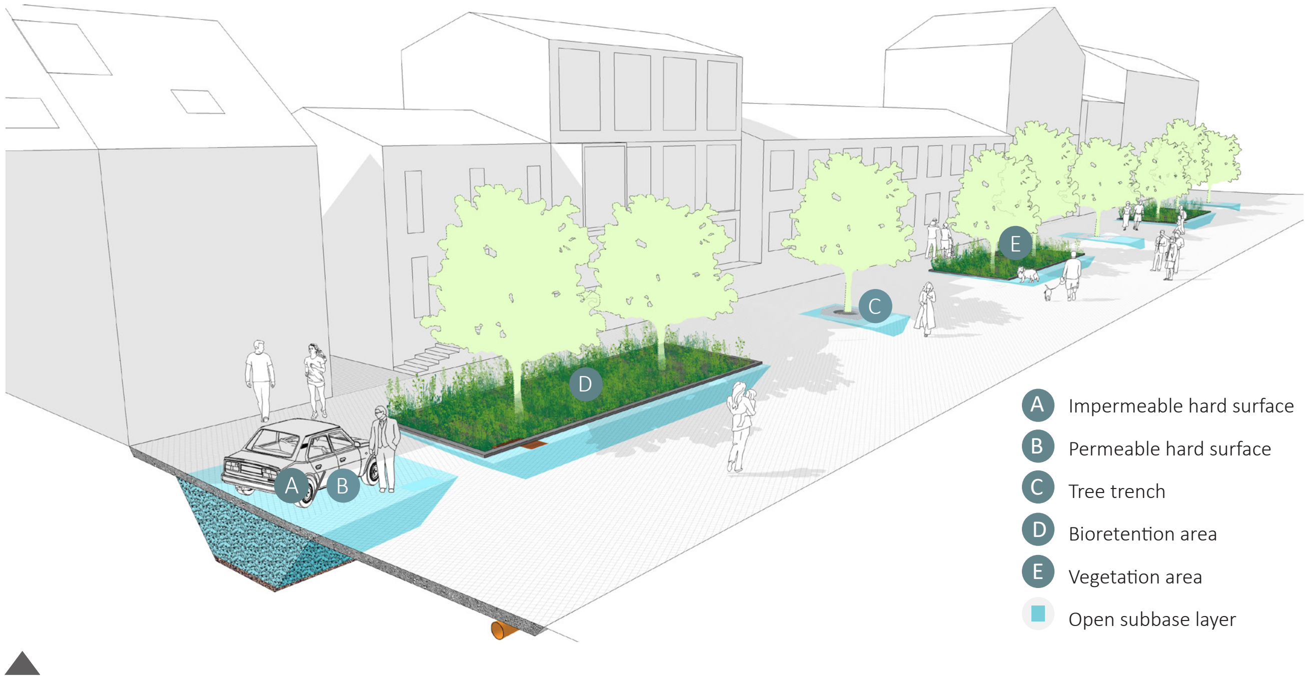


Figure 14. Example of a street with a BGG system made up of separate structures. Areas marked blue are individual sections of open subbase layer. These are laid separately under ground level structures such as bioretention areas, vegetation areas and tree trenches. The choice of structure installed is up to the designer which gives the BGG system flexibility. The open subbase layer contributes with gas exchange and water treatment or storage to a limited extent.

Site improvement around existing trees using open subbase layer with biochar, Stockholm. Photo: Björn Embrém

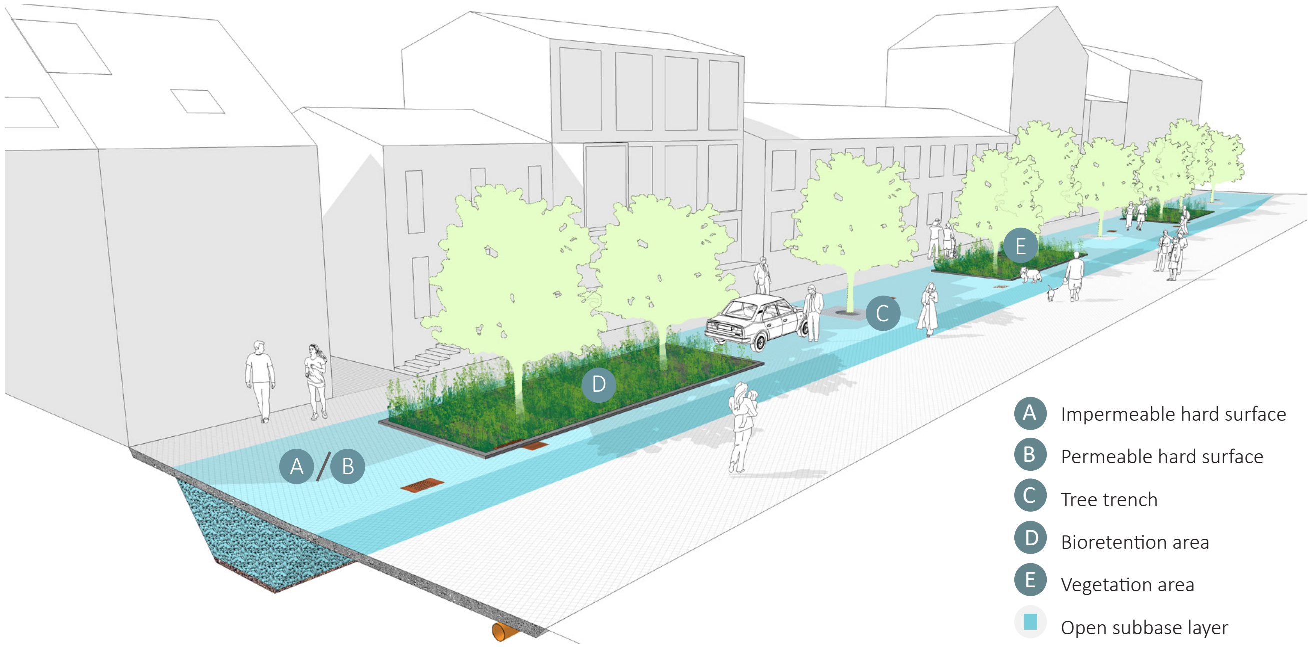


Figure 15. Example of a BGG system built in a flex zone. The blue area symbolizes a strip of open subbase layer that stretches along the entire street. Above this, hard surfaces alternate freely with bioretention area, vegetation areas and trees. This configuration creates great possibilities both for managing stormwater and allowing for flexible street design.

Higher level of demand

1. Impermeable or permeable load bearing and wearing courses
2. Open subbase layer
3. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
4. Control pit
5. Break

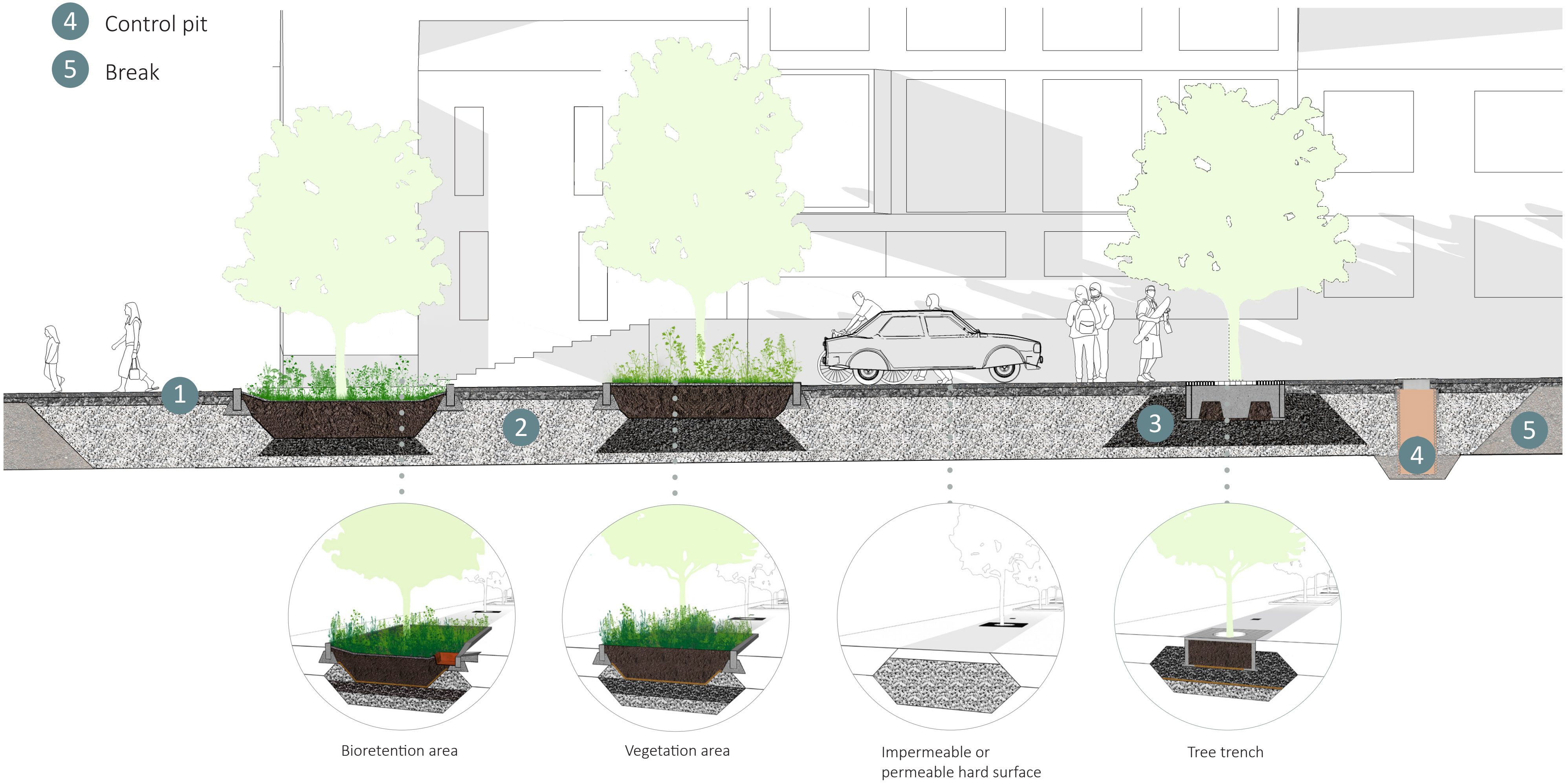


Figure 16. Longitudinal section of a system with open subbase layer and higher demand level. The breaks which border the section are placed to the left and right in the figure. Under the bioretention area, vegetation area and tree trench lies open subbase layer with biochar and optionally compost or pumice. The illustration shows the possibility of building a connected bioretention and planting area, but they can just as well be built as separate constructions.

Lower level of demand

1. Impermeable or permeable load bearing and wearing courses
2. Open subbase layer
3. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
4. Control pit
5. Break

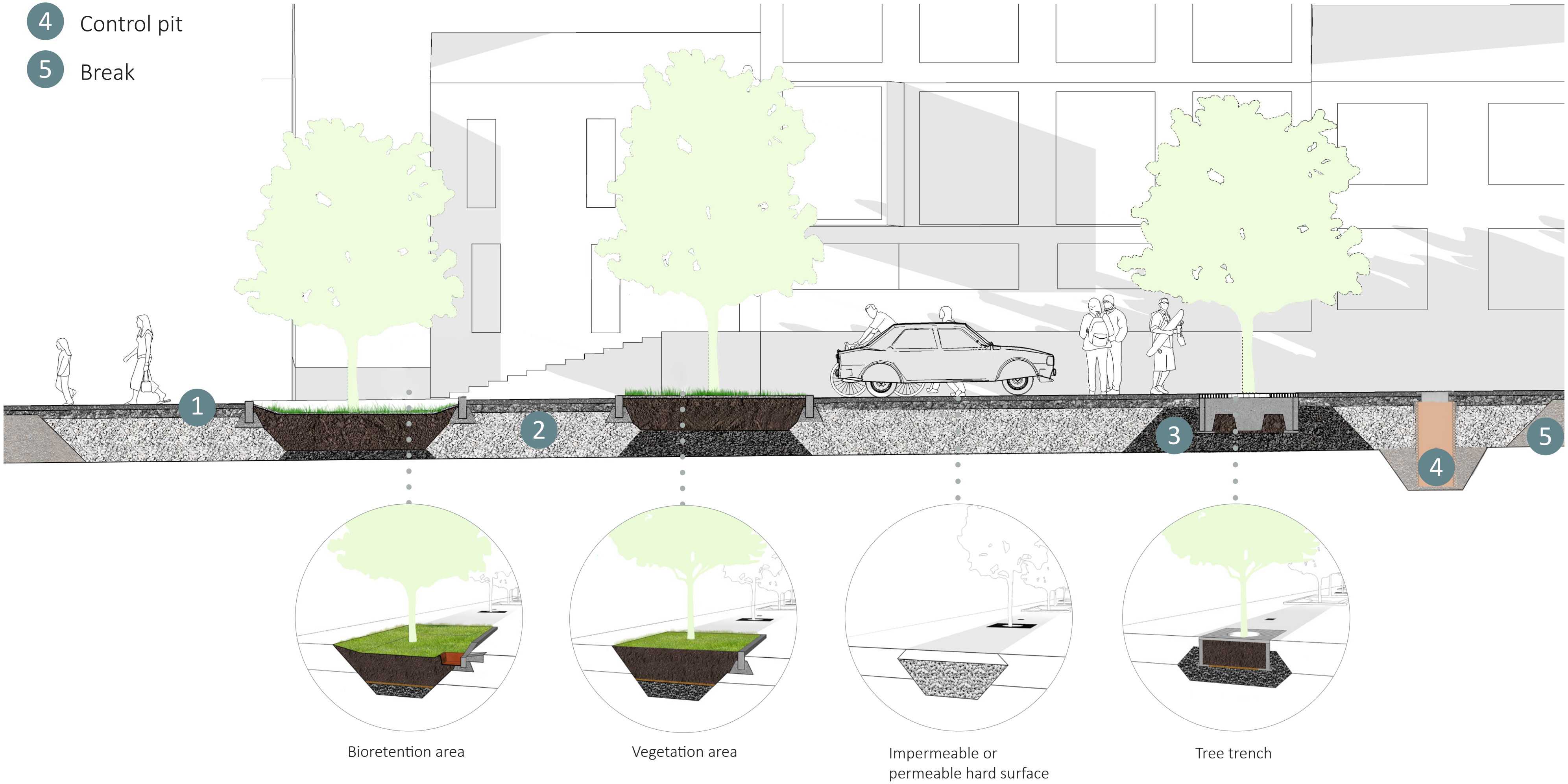


Figure 17. Longitudinal section of a system with open subbase layer and lower demand level. The breaks which border the section are placed to the left and right in the figure. Under the bioretention area, vegetation area and tree trench lies open subbase layer with biochar and optionally compost or pumice. The illustration shows the possibility of building a connected bioretention and planting area, but they can just as well be built as separate constructions.

6.2.1 Opportunities for Expansion

It is preferable to lay strips of open subbase layer under a flex zone (see Figure 15) or pedestrian and bicycle paths, ideally following the street lengthwise in order to cross utility lines as little as possible. Building under the flex zone creates freedom in placing different types of structures at ground level depending on what is most appropriate. For example, parking places along the sidewalk can be alternated with tree trenches or bioretention areas.

The width of the open subbase layer is modified according to site requirements and available space. In order to create larger volumes for stormwater management and planting beds, open subbase layer can be laid under the full or partial width of pedestrian and bicycle paths or traffic lanes; see Figure 18 for alternatives. Accordingly, this allows the system to be modified flexibly for different street layouts. For example, one could create shared space with a mosaic-like layout, streetscapes where bicycles and public transportation are given precedence, or leave options open for future designs that differ from current trends.

Open subbase layer should always be laid under planting beds so that it can improve growing conditions and function as a retention reservoir. Strips of open subbase layer can also stretch out underneath open areas, such as pubic squares or larger parking areas. In the handbook is called this type of design for construction G, extensive permeable hard surface, illustration as per figure 19. BGG systems can also be built on residential land, for design and distribution see section 6.10.

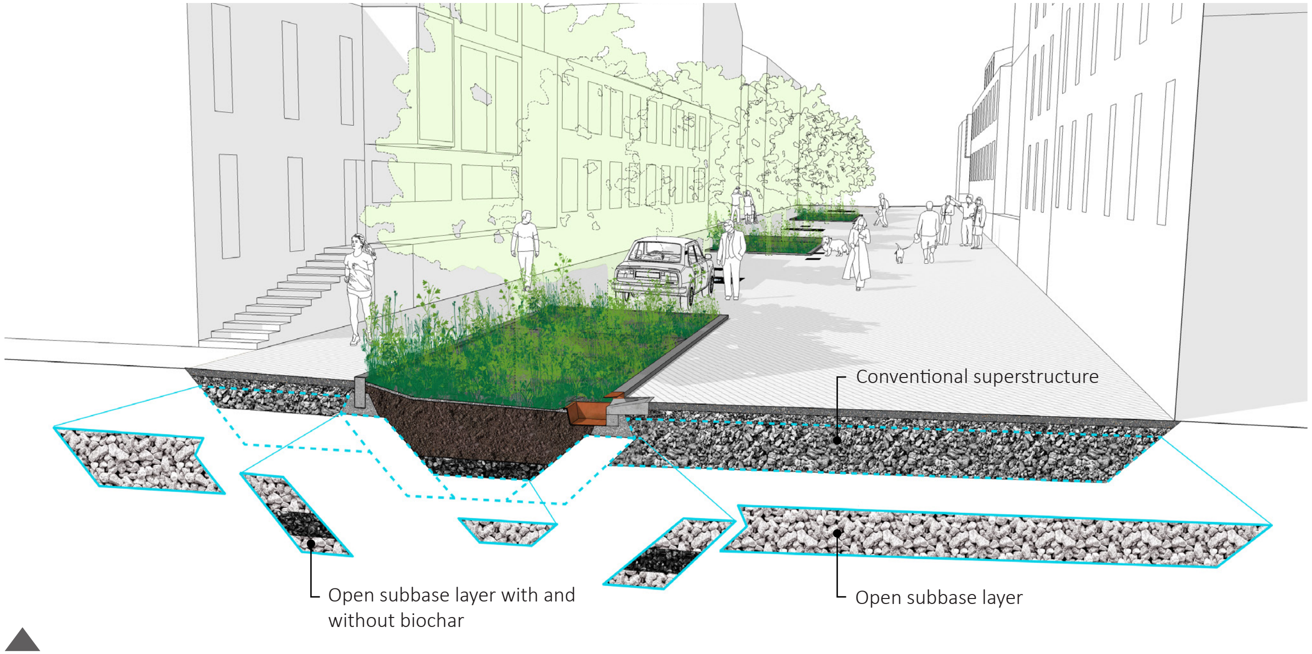


Figure 18. Open subbase layer can be expanded under pedestrian and bicycle paths and traffic lanes to increase the amount stormwater handled and the size of planting beds. Being able to determine the size and placement of open subbase layer makes it easier to combine the BGG system with other types of ground construction as well as meet future design needs and wants.

The width and depth of the open subbase layer is modified according site requirements and available space.

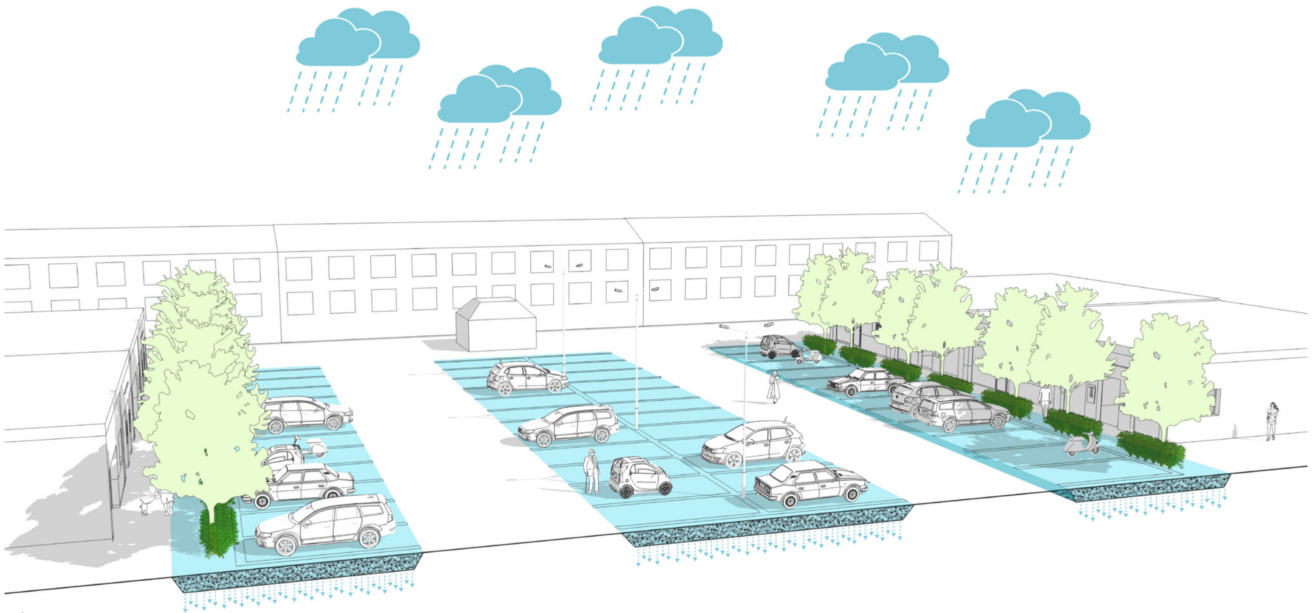


Figure 19. Open subbase layer can be extended underneath public squares and parking areas to increase the volume of stormwater that can be handled and planting bed areas. Being able to determine the size and placement of open subbase layer makes it easier to combine the BGG system with other types of ground construction as well as meet future design needs and wants.

6.2.2 Compacting Open Subbase Layer

The degree of compaction is a prerequisite for the system in order to handle future traffic load and load capacity. Studies have shown that one does not always achieve sufficient degree of compaction and bearing capacity for category B surfaces with recommended crossings according to AMA which applies for both conventional subbase layer and open subbase layer. The moisture in the material during packing and the shape of the grains may contribute to need to do more crossings than those of the AMA prescribed. Hence, it is recommended to carry out tests with static plate load or equivalent as desired degree of compaction is achieved. Open subbase layer is normally laid in layers of a maximum of 250 mm to achieve desired degree of packing. Each layer is packed carefully before the next layer is laid out. We recommend that you preferably perform static plate load test or equivalent to ensure that the desired load capacity level is achieved, see table 6 and photo p. 66. This result requirement is preferable to only the indication of a frequency, thus a performance requirement. In case of execution requirements, packing should be carried out through at least 8 crossings with vibro plate over 400 kg.

For additional information on packing of open subbase layer look to publication Svensk Markbetong-Fördröjning av dagvatten med dränerande markstensbeläggning.

6.2.3 Breaks

In order to keep stormwater from running through underground strips of open subbase layer too quickly and instead store it underground, strips are divided into smaller areas by structures with fractions with particle size 0 or similar which prevent horizontal flow. If these areas need to be connected serially, control pits can be used. Pipes connecting control pits allow water to pass through breaks in a controlled manner. This increases retention volume and utilizes stormwater more effectively. The distance placed between breaks in a strip of open subbase layer depends on the slope of the street and other local conditions but is usually between 20-30 m. As breaks are built out of conventional materials and packing methods or subsoil, they are excellent places for water and sewer lines to cross the BGG system. To read more on utility line placement, see section 6.1.4, p. 36.

Low embankments can be used between the larger ones to create a zone at the bottom of the open subbase layer where water cannot drain away, a so-called artificial groundwater zone. The embankments help spread out the water over a larger bottom surface. Read more in section 6.5.3, p. 70.

6.2.4 Controlling Water Flow

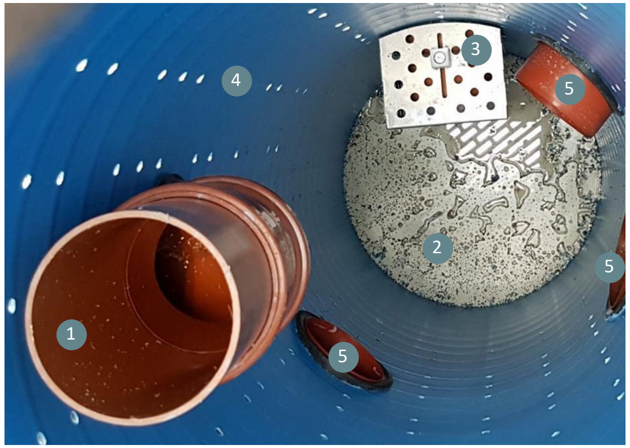
Stormwater runs to low points and along low lines and is led from there down to the strip of open subbase layer via bioretention areas, permeable surfaces or pits. Control pits are most often placed in the lowest lying area of each break unit in order to direct the water to the closest unit or conventional sewer (see Figures 20-23). Where water is directed depends on the setting of the flow regulator on the outbound connection. Water is led to the open subbase layer by perforations in the side of the pit, by a stormwater chamber or perforated pipe.

The outflow is adjusted according to the intended function of the system. If the BGG system's primary purpose is to handle water during extreme rain, water is first directed to the sewers and only led to the open subbase layer during flooding. If the system is there to manage water from dimensioned rain, water is first led to the open subbase layer and only a small amount flows into the sewer system. Every pit has overflow protection and is connected to the conventional sewer which prevents flooding when the BGG system reaches maximum capacity.

Units can be connected serially but how this is done is out of the scope of this handbook. By connecting several units, stormwater can be transported a longer distance within open subbase layer before it is released into the sewer system. This means the water is held in the system a longer time, attaining a higher degree of purification and increasing its availability to vegetation. The system is flexible as retention time can be adjusted in each individual unit. The adjustment is done with a flow regulator in each pit. The setting can be changed at any time which makes excavation or maintenance of the BGG system easier. In this case, the flow regulator is taken away and stormwater is directed to the sewer instead of the open subbase layer.

Simple stormwater and gas exchange pits can be used to manage water from pedestrian and bicycle paths. These are integrated into the system by connecting them to control pits, perforated pipes or stormwater chambers. Read more on pits and other components that are used in the BGG system in section 6.6, p. 70.

To see animation of stormwater control in BGG system visit: https://bluegreengrey.edges.se



Control pit from above.

1. *Overflow pipe*
2. Sandtrap
3. Flow regulator with protective cage
4. Perforation for percolation and discharge
5. Pipes for dispersion, discharge and roof runoff

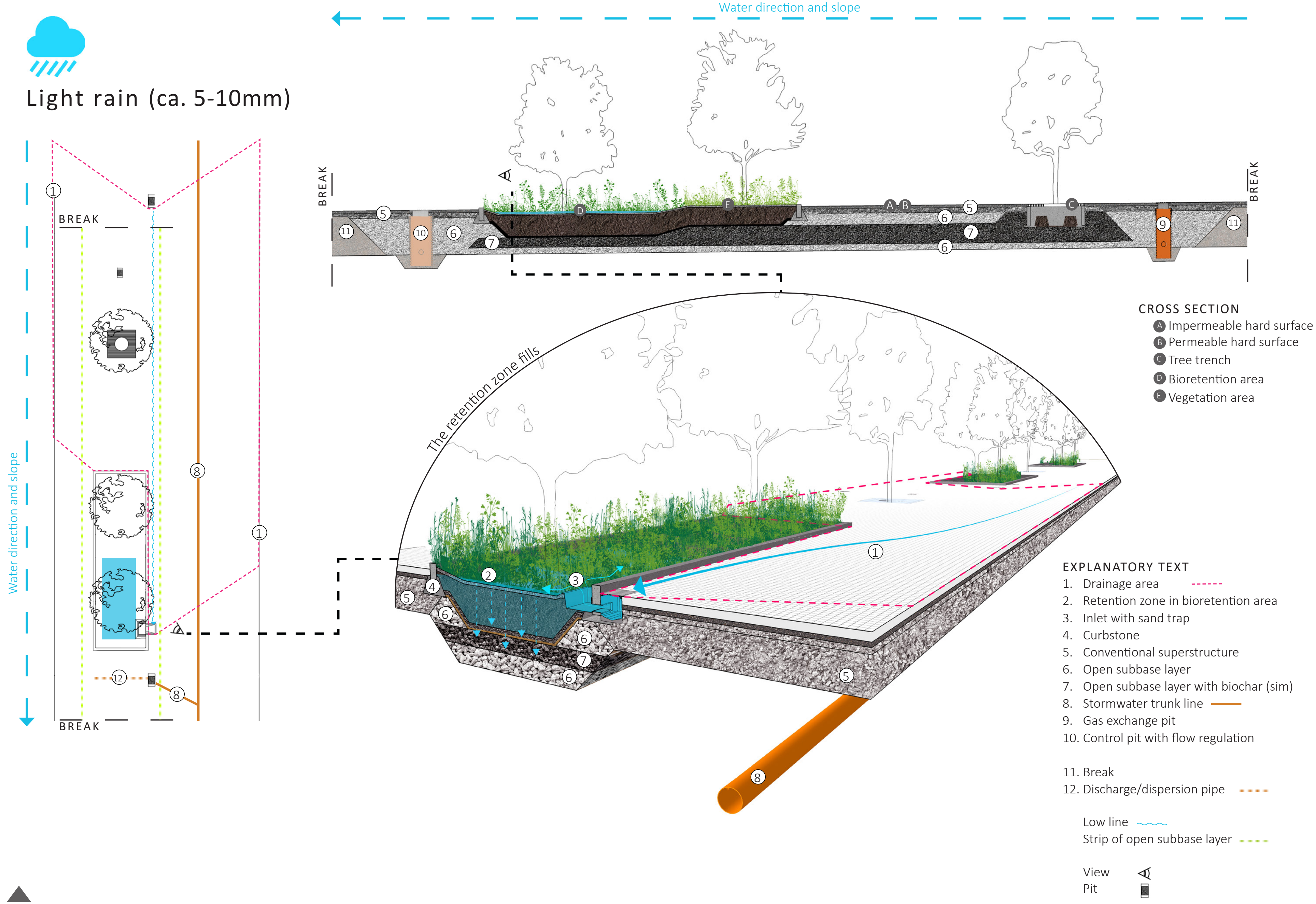


Figure 20. Illustration of water flow during light rain in a BGG system with bioretention construction. In case of lesser rain, stormwater runs to the bioretention area and infiltrates the open subbase layer. Plan view (left), longitudinal cross section (above), three-dimensional view (below).

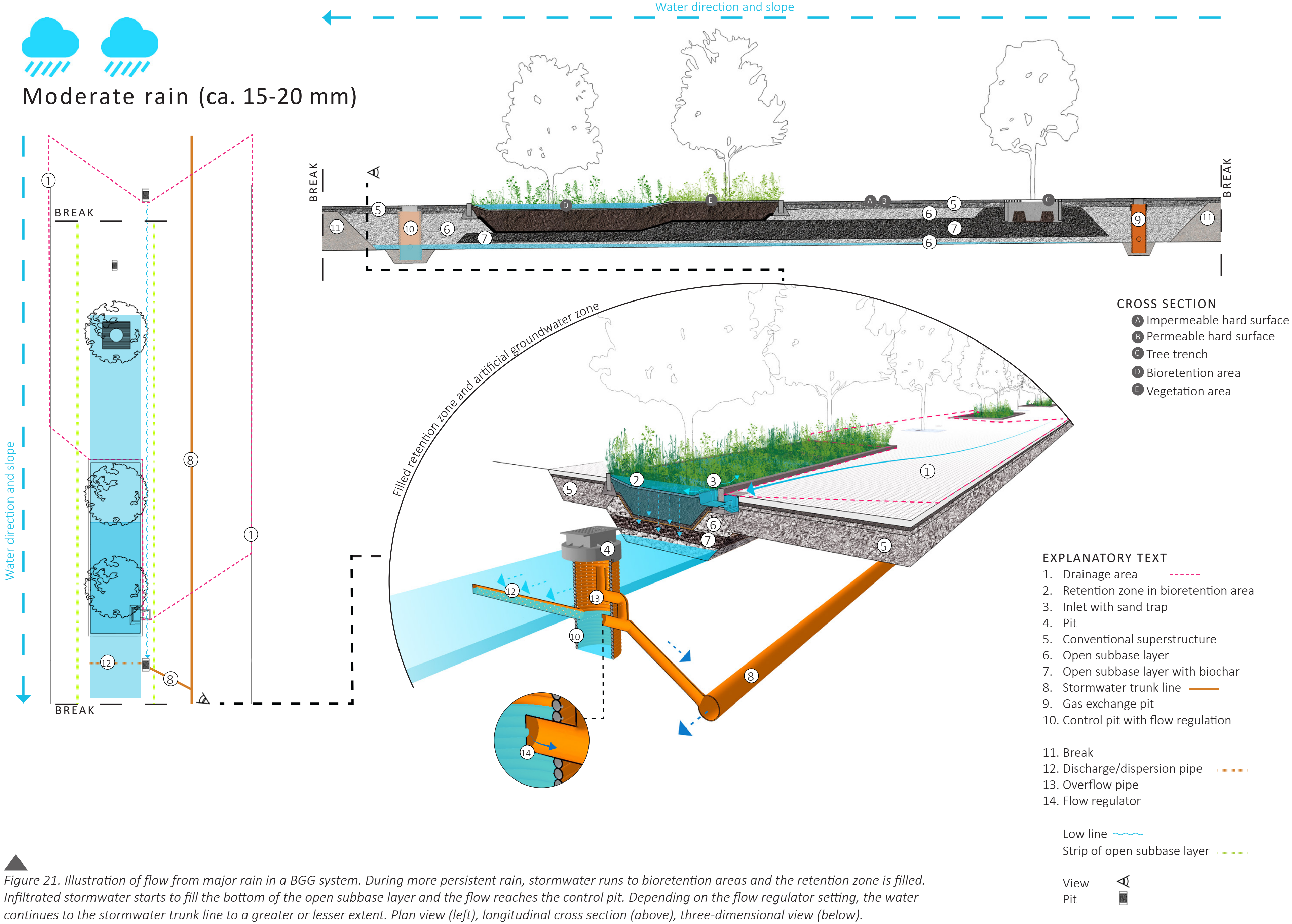


Figure 21. Illustration of flow from major rain in a BGG system. During more persistent rain, stormwater runs to bioretention areas and the retention zone is filled. Infiltrated stormwater starts to fill the bottom of the open subbase layer and the flow reaches the control pit. Depending on the flow regulator setting, the water continues to the stormwater trunk line to a greater or lesser extent. Plan view (left), longitudinal cross section (above), three-dimensional view (below).

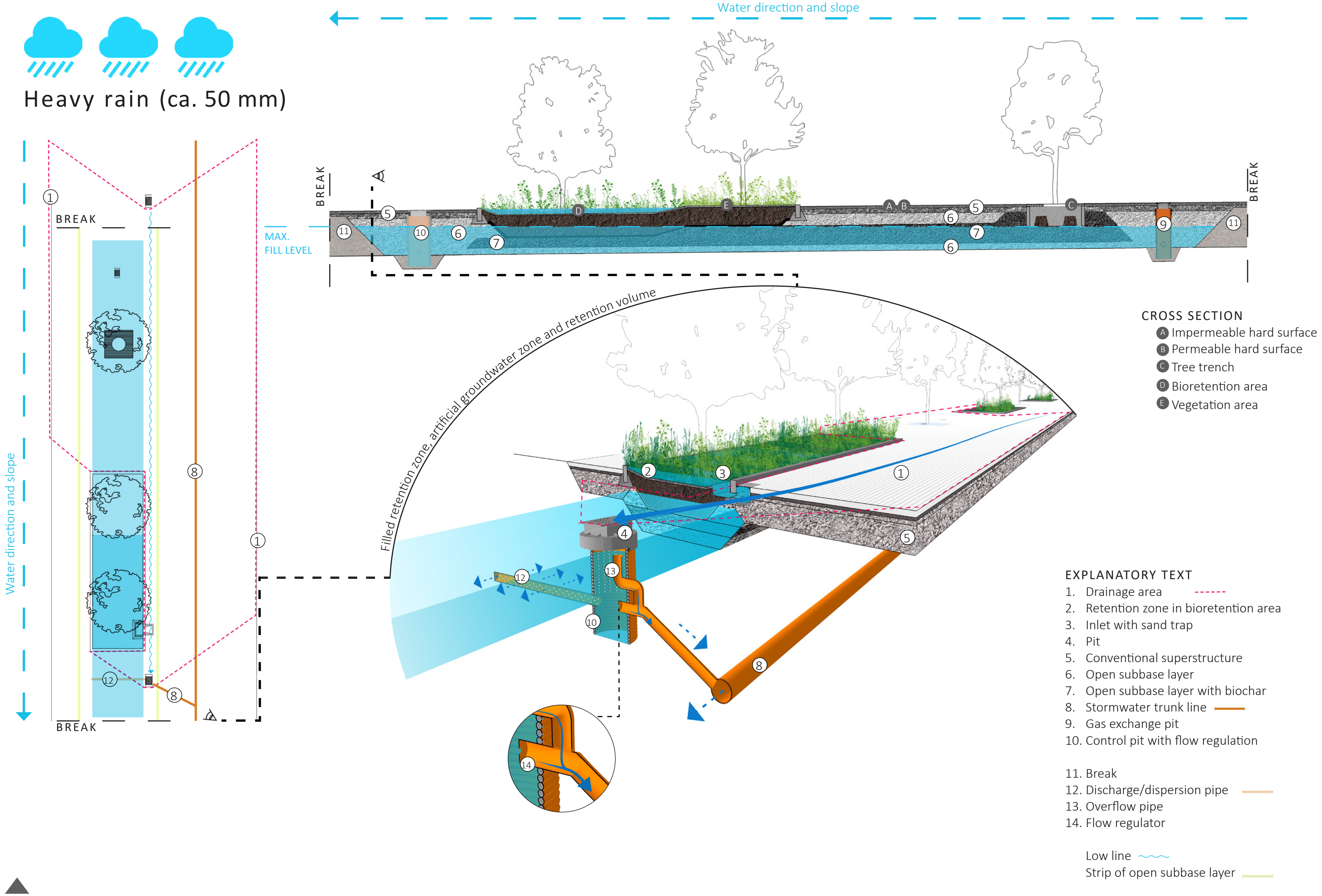


Figure 22. Illustration of flow during heavy rain in a BGG system with bioretention area. When heavy rain produces large volumes of stormwater, the retention zone is filled quickly. When it is full, stormwater runs on to the control pit which leads it down to the open subbase layer or directly to the stormwater trunk line to a greater or lesser extent. Plan view (left), longitudinal cross section (above), three-dimensional view (below).

Situation after 24 h

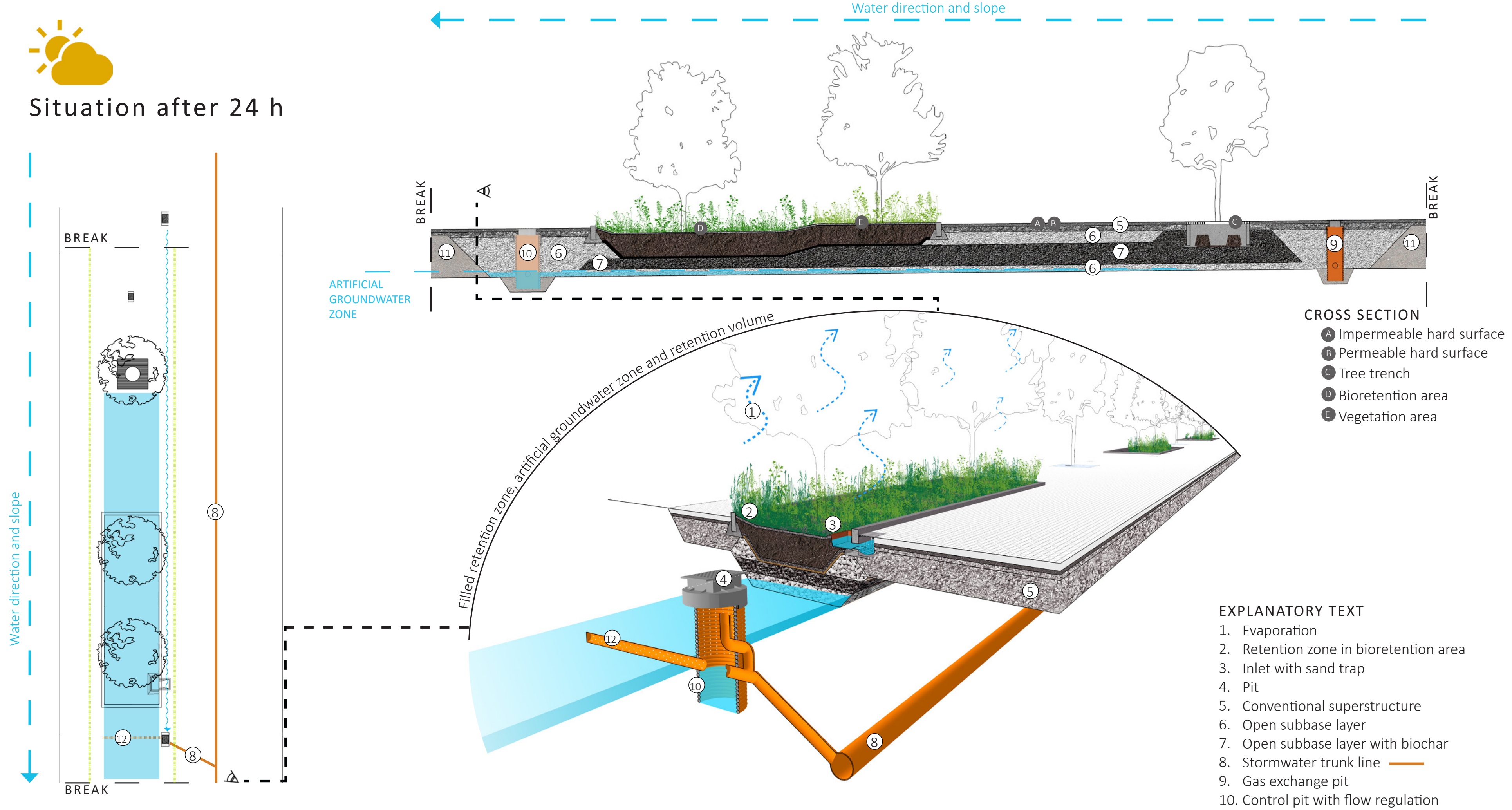


Figure 23. Illustration of the situation 24 hours after a BGG system has been filled to max. levels. After the system has been filled to overflowing it should take no more than 24 hours to empty itself of excess water. The placement of invert (lowest) levels determines how much water can be held in the bottom of the system. This water can act as an artificial groundwater zone where vegetation can access water. Plan view (left), longitudinal cross section (above), three-dimensional view (below).

Falsterbovägen, Höllviken.

6.3 Ground Level Constructions

This handbook describes five constructions that are recommended for building on open subbase layer.
Using the quick reference guide (p. 28) will give you an indication of what constructions are appropriate for a particular place. Constructions are labeled A-E in both the quick reference guide and in the text below.

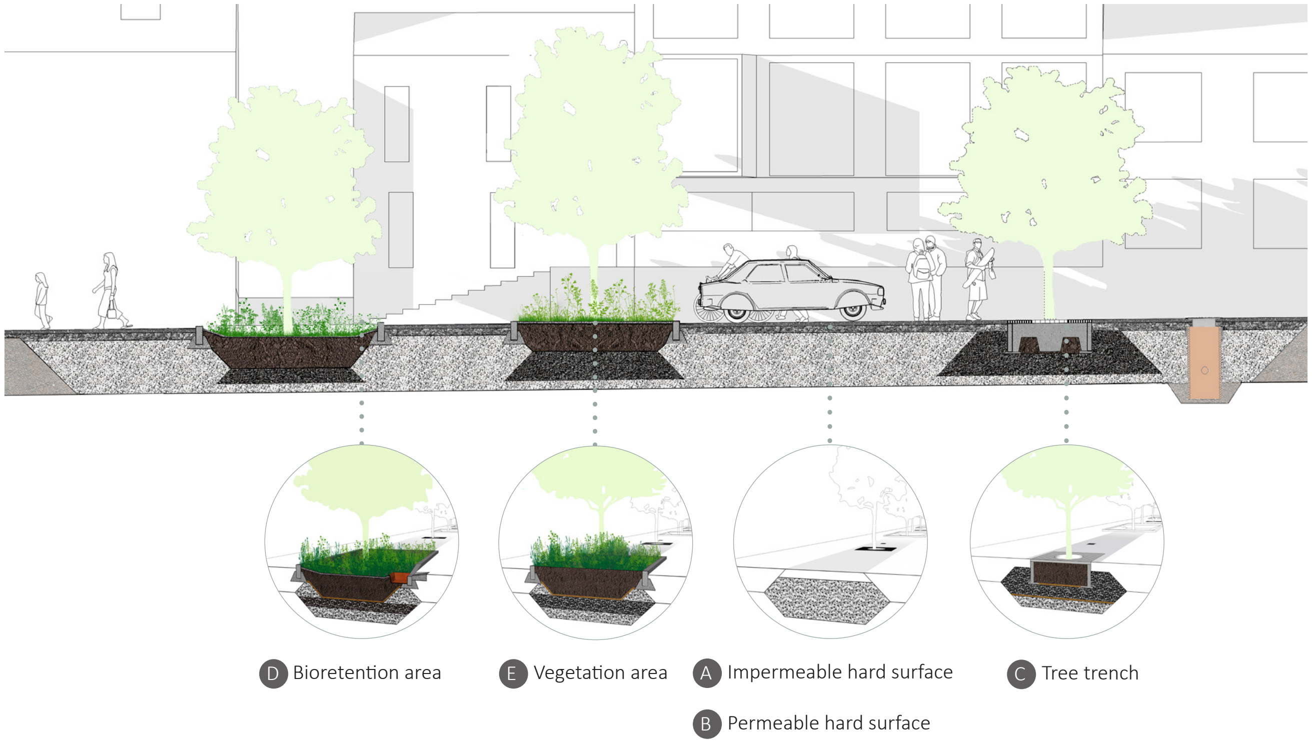
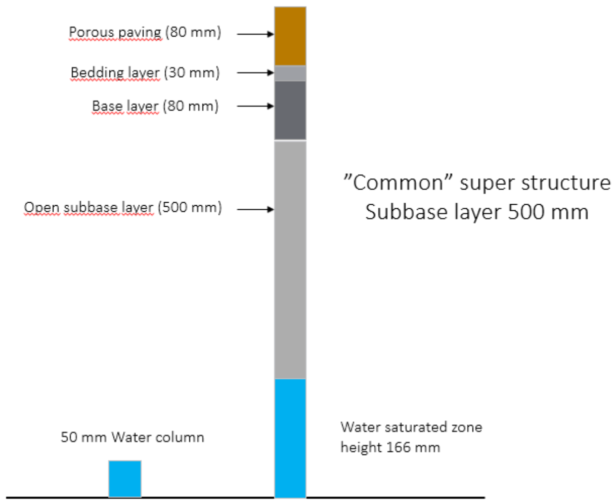


Figure 24. Longitudinal cross section of a system with open subbase layer and various constructions at ground level.

6.3.1 Impermeable Hard Surfaces (A)

Impermeable hard surfaces can be laid over open subbase layer to create roads, parking areas, and pedestrian and bicycle paths, for example. Stormwater runs off the surfaces to low lines and low points where it is then led via pits or bioretention areas to the open subbase layer. Designing and dimensioning of the wearing and load-bearing courses is done using conventional methods and is out of the scope of this handbook.
If heavy traffic will drive on the impermeable hard surfaces, it is recommended to supplement the open superstructure with a bound base layer.



Bicycle parking with open subbase layer. The entire superstructure under this area serves as a planting bed and stormwater reservoir. Södervärn, Malmö.

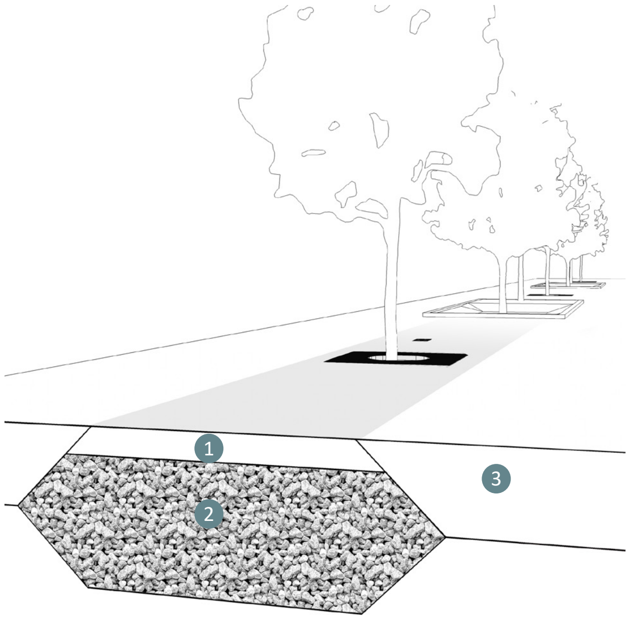
6.3.2 Permeable Hard Surfaces (B)

Permeable coverage on an open superstructure retains and purifies stormwater as soon as it touches the ground. It can be made of porous asphalt, pavers, natural stone or gravel. Depending on the type of permeable layer chosen there are a number of natural processes used for purification: filtration, adsorption, and biodegradation. Applying permeable surfaces over the entire superstructure allows stormwater to infiltrate down to the open subbase layer for additional retention and purification.

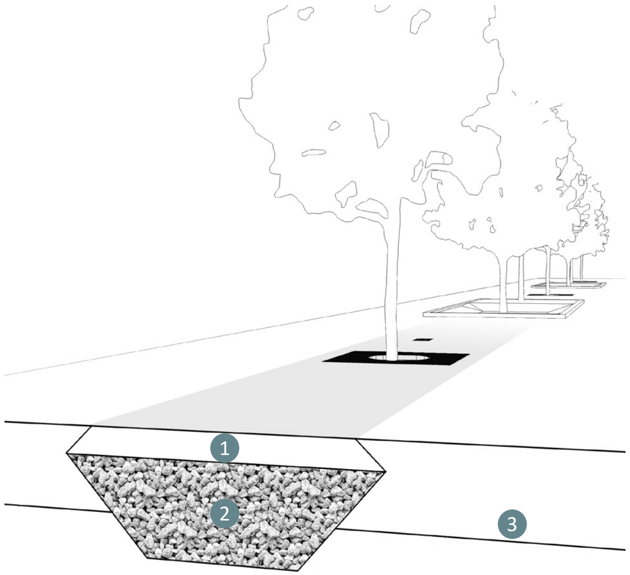
Permeable surfaces allow stormwater to drain over a large area, meaning no single area of open subbase layer is overly burdened. This means that flow rates in the subbase layer do not need to be very high and as such a material with smaller grain size can be used, i.e. 2/90. Accordingly, it is possible to lay a surface which can handle higher traffic loads than class 2. More on traffic loads can be found in the Swedish reference guide ***Fördröjning av dagvatten med dränerande markstensbeläggning*** from Svensk Markbetong or other international handbooks. There you can also find information on the design and dimensioning of the permeable wearing course and base layer, a subject that is out of the scope of this handbook.

Figure 25. A heavy rain that generates 50 mm of rainfall (left blue bar) will result in a rise of 166 mm in the open subbase layer (right bar).

Higher demand



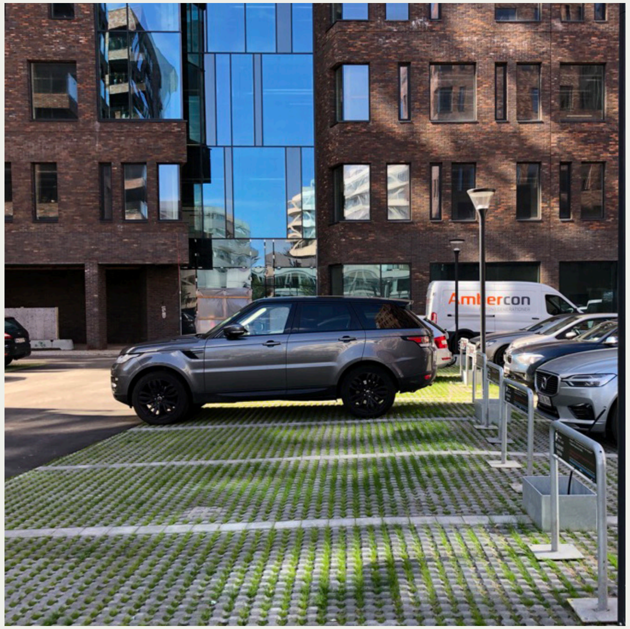
Lower demand



1. Permeable or impermeable load bearing and wearing courses
2. Open subbase layer
3. Conventional superstructure

Figure 26. Hard surface on top of open subbase layer under generally higher-demand conditions. The wearing course can be either permeable or impermeable.

Figure 27. Hard surface on top of open subbase layer under generally lower-demand conditions. The wearing course can be either permeable or impermeable.



Permeable paving with grass. Århus, Denmark.

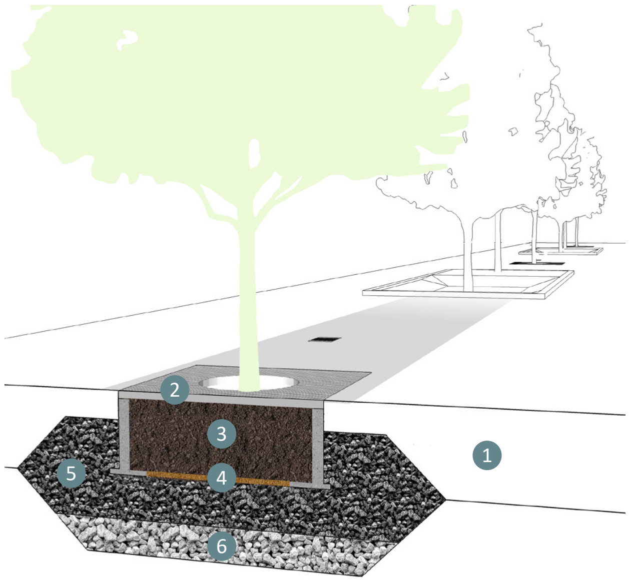
Impermeable and permeable hard surface made of asphalt.

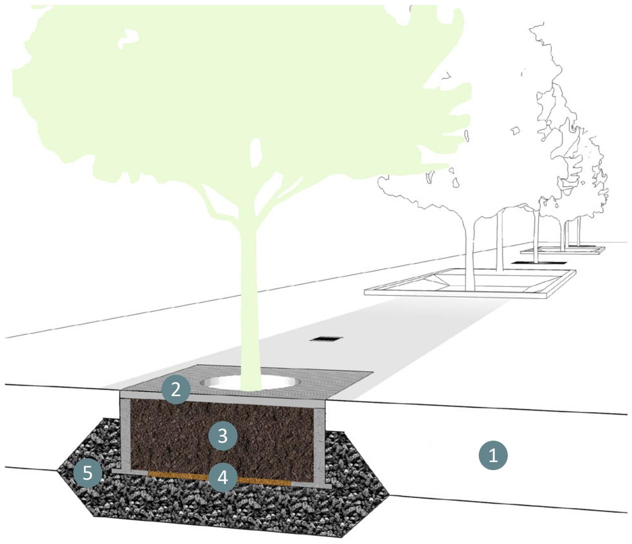
6.3.3 Tree Trenches (C)

This type of construction is suitable when one wants to plant trees, but either there is not enough space or soil sealing is required in that area. A tree is planted in a foundation which is placed in open subbase layer. Openings in the side of the foundation allow tree roots to grow out of it and make use of the large volume of the planting bed which provides good gas exchange potential and water access. This helps the tree develop a finely branched root system which grows deep into the system and lays the foundation for resistant vegetation, increased water purification and microorganisms. The design of the construction ensures that the root system does not creep under the surface and crack it open.

Within the foundation, the tree is surrounded by a growing medium which has high permeability and sufficient nutritional content. Below this, open subbase layer is mixed with biochar and compost. The open subbase mix can be beneficially spread out around the tree in order to create a larger soil volume with favorable growing conditions. The foundation can be topped with a tree grate; alternatively, plants can be planted in growing medium, depending on the need for sealing. The surface of the growing medium can be protected against drying out with a protective layer of macadam which is filled up to the grate or spread out among the plants.

In order to secure adequate gas exchange underground, a pit with the ability to aerate should be installed. Every strip should contain two pits for gas exchange, which creates a ventilation flow. For this, gas exchange pits, gas exchange stormwater pits, and control pits can be used.





1. Conventional superstructure
2. Tree grate with concrete bunker
3. Substrate
4. Coconut mat with separation layer alt. mineral wool
5. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
6. Open subbase layer, if properties for plant growth are desired to be enhanced pumice can be added

Figure 28. Tree trench on open subbase layer in generally higher-demand conditions.

Figure 29. Tree trench on open subbase layer in generally lower-demand conditions.

The foundation can be prefabricated or built with the help of granite curbstones or concrete elements which form a frame around the tree root ball. Special constructions in which multiple sections are joined together are required in order to achieve load bearing of 20 kN/m² if vehicles will be present.

Tree trenches. Below the concrete plates in the row of trees lies open subbase layer with biochar and compost. Under the bicycle lane and sidewalk is open subbase layer. Stormwater is led via channels to gas exchange pits which direct the water to the open subbase layer. Södra järnvägsgatan, Växjö. Photo: Örjan Stål

6.3.4 Bioretention Areas (D)

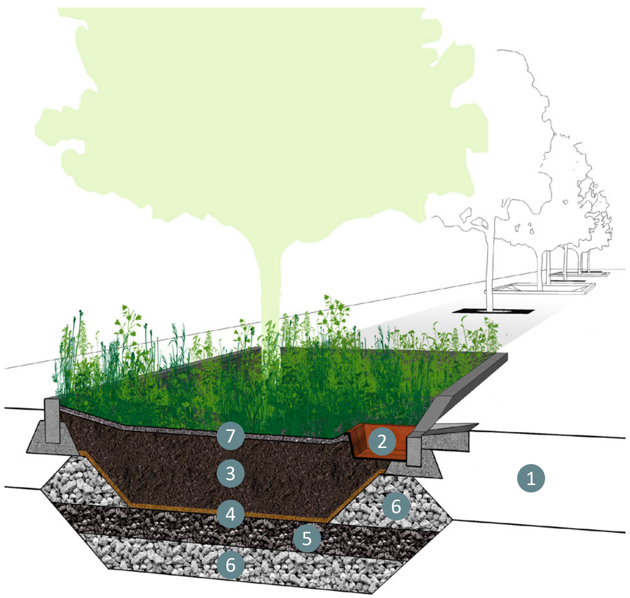
Biorientation areas are the cornerstone of the BGG system as they both retain and purify stormwater while introducing green elements into the streetscape. Bioretention areas are unique in that their surfaces are slightly concave. This creates a shape that allows water to stand on the surface before it infiltrates the ground through the planting area. This area is called the retention zone and is usually around 10-20 cm deep. If the retention zone fills up, stormwater can flow into the open subbase layer via a control pit, preventing flooding into the street.

Water purification in bioretention areas is achieved by filtration, biodegradation and absorption into plants and by particulates. Heavy metals are often bonded to particulates and are therefore already filtered out in the uppermost layer. Nutrients and organic pollutants are adsorbed by biochar and are broken down by microorganisms and plants.

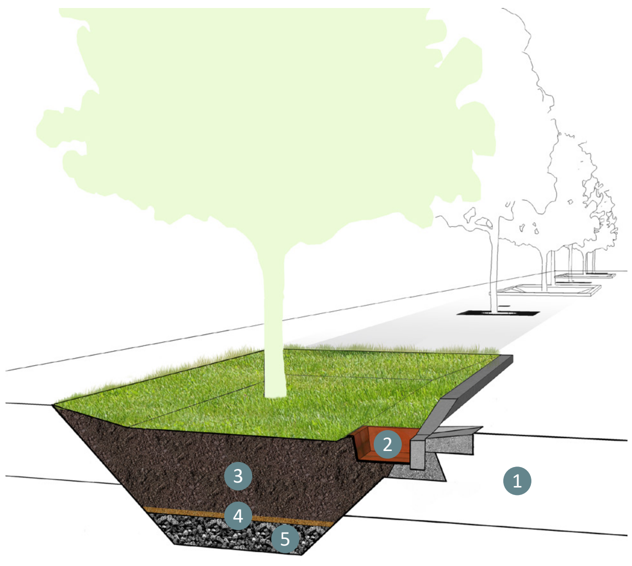
Special growing medium is used in bioretention areas to ensure permeability and low nutrient content. When water infiltrates to the open subbase layer there is a risk that fine particles from the growing medium will be drawn along with it and clog the system. This can be avoided by using materials with particles that lock to each other. The growing medium can also be separated from the open subbase layer by using coconut fiber mats.

The surface of the bioretention area should be protected with a layer of macadam 8-11 at least 50 mm thick to prevent erosion. This will also prevent evaporation and give plants added protection against weeds. If the

Higher demand



Lower demand



1. Convenctional superstructure
2. Inlet with sandtrap
3. Substrate
4. Coconut mat with separation layer alt. mineral wool
5. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
6. Open subbase layer, if properties for plant growth are desired to be enhanced pumice can be added
7. Cover layer

Figure 30. Bioretention area on open subbase layer in generally higher-demand conditions. Can also be planted as grass area.

Figure 31. Bioretention planter on open subbase layer in generally lower-demand conditions. Can also be planted with perennials and shrubs.

bioretention area will be planted with grass, a protection layer is not needed.

The bioretention area can also be covered with solid or perforated plates, creating a covered bioretention area, see section 6.3.5. This means that the bioretention area contributes to retention and filtration but does not contribute to as much to urban greenery.

The design of the inlet is a determining factor in the success of a bioretention area and therefore overall street function. A well-thought-out inlet can prevent multiple issues in the future, for example erosion damage or damage to snowplowing equipment as it goes by. Most important is that water enters the bioretention area.

6.3.4.1 Inlets

There are two general design principles for bioretention area inlets: wide or focused inlets. Letting in stormwater over a wide area is done by placing the long side of the bioretention area at the same level as a low line so that water flows freely into the planter. A focused inlet consists of a conduit or opening in a raised curb that lets water from the street flow into the bioretention area at a certain point. Both solutions have pros and cons that are presented in greater detail below.

Wide inlets ensure that stormwater is distributed equally over the bioretention area. This in turn minimizes the risk for erosion damage and the settling of material that can obstruct inflow. The disadvantage of this method is that large amounts of sediment and deicing materials can be introduced into the area requiring manual maintenance for removal. Reducing the height of the curbstone also increases the risk that vehicles can drive into the bioretention area and damage it as a result.

When employing focused inlets, it is important to take the stormwater current into account as it can result in erosion damage to the bioretention area. It is not uncommon for flow at the inlet to reach the intensity of 10-20 l/s during heavy rain. Laying coarse macadam near the inlet or slowing the water in a sand trap reduces current. Sand and sediment will also be caught in a sand trap meaning that water that enters the bioretention area will be cleaner. This lenghtens the time between necessary maintenance.

If flow rate on the street is high, there is a risk that a great deal of water will flow right by the inlet. For this reason, the inlet should be at least 50 cm wide. If this is not possible, a steep slope or a pit can be used to change the flow of water. However, inlets which are narrower present the risk of being obstructed by leaves or trash, for example. The inlet should not be designed with sharp edges as these can present a hazard for snow removal. Below are three examples of suitably designed focused inlets.

Inlet with lowered curb edge. Strandbogatan, Uppsala.
Foto: Rasmus Elleby

Inlet. Amanuensgatan Rosendal, Uppsala.

6.3.5 Covered Bioretention Areas

If retention and purification are needed above and in a bioretention area but undergrowth is inappropriate for the situation, i.e. the surface needs to accommodate pedestrians or lighter vehicles, covered bioretention areas can be used as an alternative. Covered bioretention areas combine components (grates, solid or perforated plates and tree root foundations) from tree trenches with a retention zone from bioretention areas. Using a concrete foundation is an effective way to separate materials and increase the load-bearing qualities of the surrounding hard surfaces. Keep in mind that this also generates additional costs for both construction and eventual excavation or modification of the structure.

One advantage of this element is that different functions can be placed over the bioretention area, for example bicycle parking, trash cans, furniture and more. The surface can also be used for storage during snow clearing.

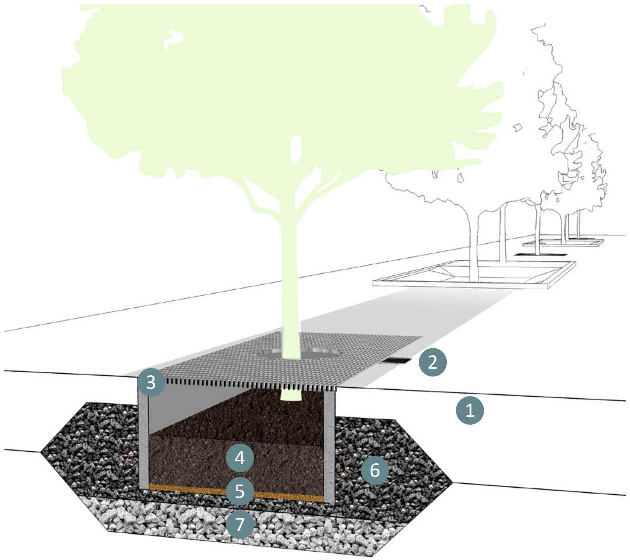
When undergrowth is taken away from a bioretention area, the growth rate and the introduction of organic material are limited and therefore also the production of biopores which are important for infiltration capacity. Exactly how infiltration capacity is affected by this is still unclear and needs to be researched.

Covered bioretention area on open subbase layer.
Nacka.
Foto:Agata Wehlin.

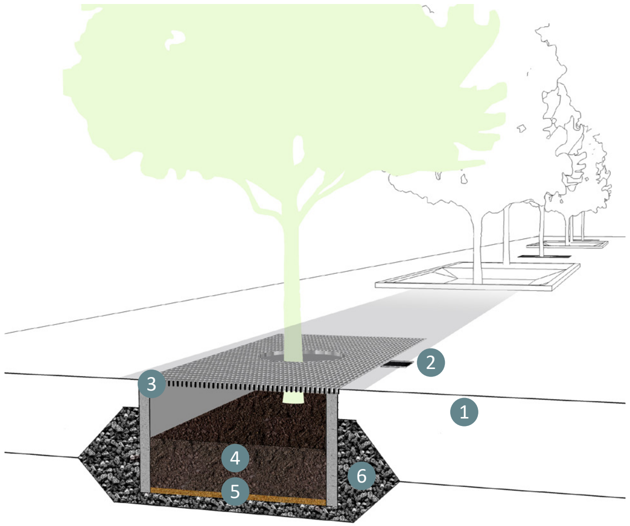
Concrete frame for covered bioretention area.
Foto: Agata Wehlin

Covered bioretention area under construction, Nacka.
Foto: Agata Wehlin.

Higher demand



Lower demand



1. Convenctional superstructure
2. Gas exchange pit
3. Concrete bunker
4. Substrate
5. Coconut mat with separation layer alt. mineral wool
6. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
7. Open subbase layer, if properties for plant growth are desired to be enhanced pumice can be added

Figure 32. Covered bioretention area on open subbase layer in generally higher-demand conditions.

Figure 33. Covered bioretention area on open subbase layer in generally lower-demand conditions.

Example of how a covered bioretention area can look at street grade. This construction does not contain a retention zone. Norra Djurgårdsstaden, Stockholm

6.3.6 Vegetation Areas (E)

One green alternative for areas that do not require as much stormwater purification is to place vegetation areas on top of open subbase layer. Water is handled by being sent directly to the open subbase layer via pits. Vegetation areas within the BGG system have plant substrate lying directly above the open subbase layer. This gives roots a good opportunity to grow into the large volume of macadam and biochar within the subbase layer.

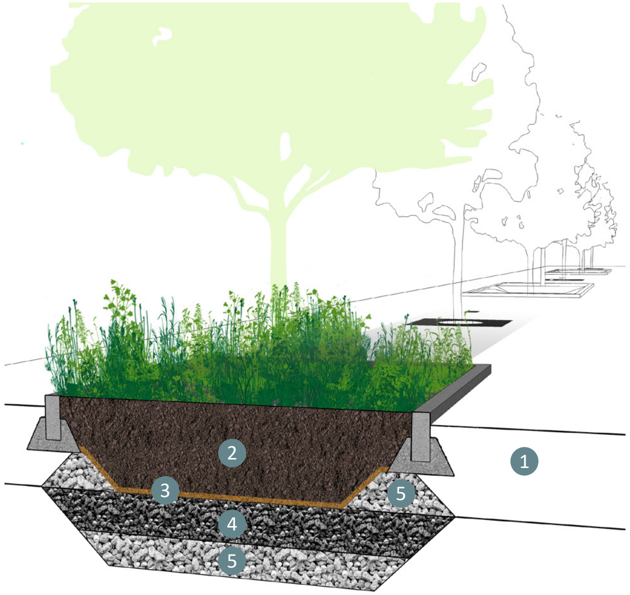
Water reaches the vegetation from below via the open subbase layer. In a bioretention area, growing medium is separated from the open subbase layer by a coconut fiber mat. In a vegetation area, however, only a small amount of water seeps down into the subbase layer from the planting surface meaning that a coconut fiber mat is not needed as long as there isn't a large change in particle size.

Aside from the type of growing medium, a vegetation area is not much different in a BGG system than in its conventional counterpart.

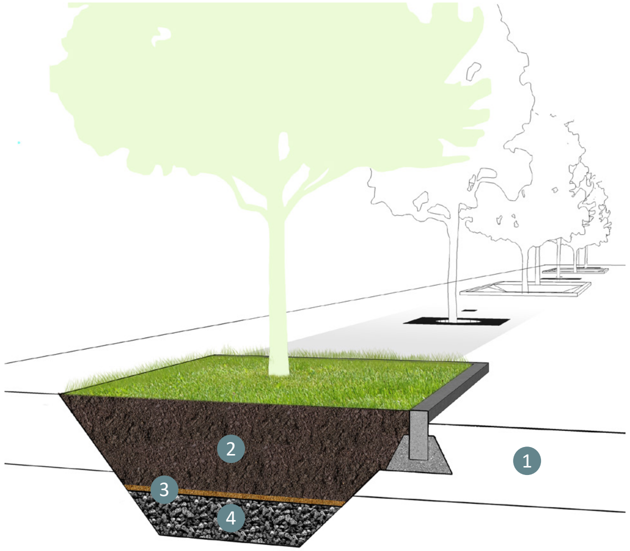
A vegetation area can be protected for example by a layer of macadam 8-11 around 50 mm deep. This prevents evaporation and gives plants an edge over weeds. If grass will be planted, there is no need for a protection layer.

Vegetation area on open subbase layer. Graz, Austria.

Higher demand



Lower demand



1. Conventional superstructure
2. Substrate
3. Coconut mat with separation layer alt. mineral wool
4. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added
5. Open subbase layer, if properties for plant growth are desired to be enhanced pumice can be added

Figure 34. Vegetation area on open subbase layer in generally higher-demand conditions. Can also be planted with grass.

Figure 35. Vegetation area on open subbase layer in generally lower-demand conditions. Can also be planted with perennials and shrubs.

Vegetation area on open subbase layer. Stormwater enters the open subbase layer via a pit. Rosendal, Uppsala.

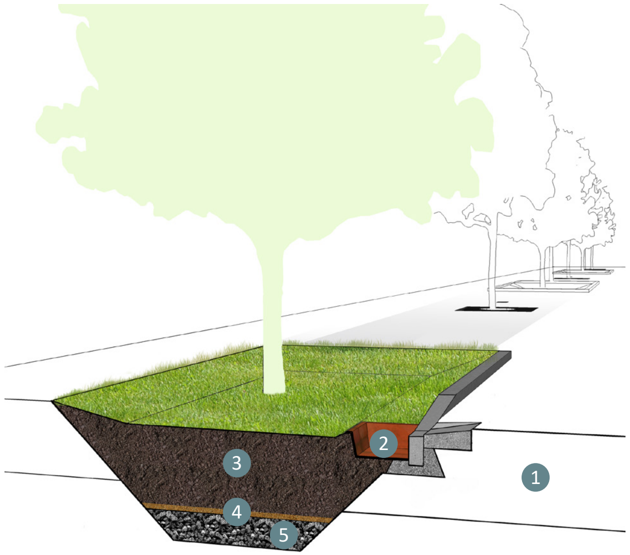
Figure 36. Illustration of a swale with meadow. Baravägen, Lund

6.3.7 Swale (F)

Swale is a construction at ground level that is very similar to the bioretention area in its design and construction. The main difference between the two constructions is how the storm water on the ground surface is drained. The goal of a swale is usually to collect and divert the storm water on the ground surface to a well. The emptying of the swale then takes place mainly from the ground surface and into the well, which leads it down to the open subbase layer. The rainwater well then has no display but is at ground level. For a bioretention area, the main discharge is through plant substrate down to the open subbase layer. The top of the overflow well for the bioretention area is thus at the top of the surface magazine, usually approx. 50 – 200mm above the surface of the planting – that is the difference between a swale and a bioretention area in its purest form. Several different versions are available where it is emptied through regulation pit and through the plant substrate. In the same way, a strip of vegetation can first be a swale that diverts stormwater and at the end it turns into a bioretention area.

Compared to a bioretention area, the goal of the swale is to divert larger flows on the ground surface and greater focus should therefore be placed on erosion protection. Creating mowed grass areas or meadows is advantageous over shrub and perennial plantings in order to reduce the risk of erosion damage in the swales. Incidentally, bioretention areas and swales are similarly structured in a BGG system, so recommendations that apply to bioretention areas also apply to swales.

Inlet from pedestrian/bicycle lane to swale. Baravägen, Lund



1. Convenctional superstructure
2. Inlet with sandtrap
3. Substrate
4. Coconut mat with separation layer alt. mineral wool
5. Open subbase layer, if properties for plant growth are desired to be enhanced biochar or pumice can be added

Figure 37. Swale with open subbase layer.

Extensive permeable hard surfaces without curb support and stormwater wells in a residential area, Netherlands.

6.3.8 Extensive permeable hard surfaces (G)

This type of construction is suitable for squares and parking areas where desire is to design large hard surfaces. The conventional subbase layer is here replaced by an open subbase layer. The open subbase layer is made 20% deeper than the conventional superstructure's thickness. Permeable coating on open superstructure delays and cleans the stormwater as soon as it infiltrates into the superstructure. It can consist of permeable asphalt, ground stone, natural stone, gravel and more. Depending on the type of draining pavement, there are a number of natural processes for water purification; filtration, adsorption and biodegradation. By having permeable materials throughout the superstructure, conditions are created for stormwater to infiltrate down to the open subbase layer for further delay and purification.
Since the storm water is infiltrated over a large surface and fills the open subbase layer via a vertical flow (horizontal flow otherwise), a crushed stone with a lower fraction of downwards limit can be used. For example macadam 4/90. This gives the opportunity to create a surface that can withstand a higher traffic load than traffic class 2. Read more about traffic load, dimensioning and superstructure in Svensk Markbetong's handbook *Fördröjning av dagvatten med dränerande markstensbeläggning*, 2019.

If a draining coating is installed, elevation of the project is facilitated as the surface can be completely flat and there is no need for surface drainage. This reduces the need to design curbs and stormwater pits.

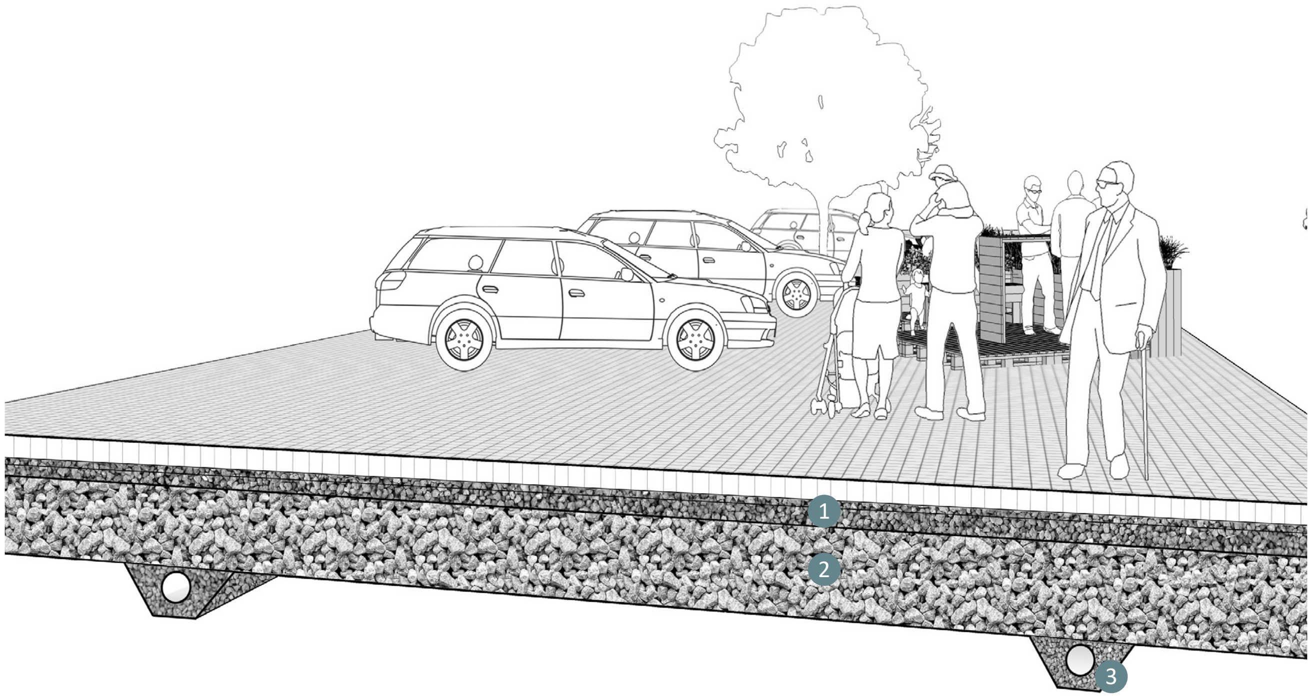
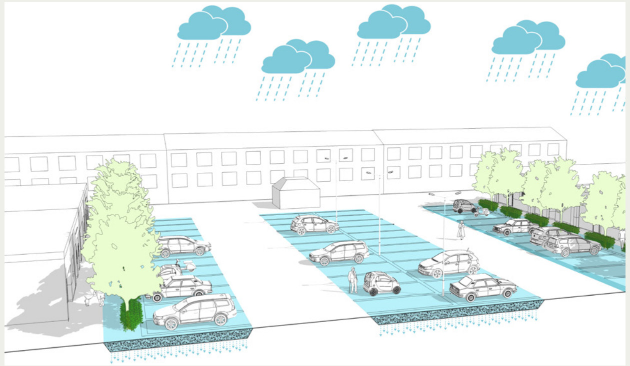


Figure 38. Extensive permeable hardsurface. The open subbase layer has different depths depending on the traffic class the surface is designed for. The choice of macadam fraction for the open subbase layer has greater importance when the higher traffic class is chosen.

1. Wearing, binder and base course layers
2. Open subbase layer
3. Drainage

Extensive permeable hardsurface, construction G. The surface is completely flat with neither slopes or pits, which are not needed on this construction. In this way, bearing course can be placed completely freely over the entire surface. Jem & fix, Vara. Photo: Oscar Svensson.



Open subbase layer can be extended under squares and parking areas to create larger rootzone and retention volume for stormwater. By being able to choose the extent and location of the subbase layer, it becomes easier to combine the BGG system with other constructions in the ground.

Vegetation areas can be built along the hard surface. The plants can then use the open subbsase layer as part of their plant bed.

6.4 Material

In this chapter, the various materials used in BGG systems are touched upon.

6.4.1 Macadam in open subbase layer

In order for the subbase layer to become open and thus accessible to storm water and plant roots, it is built up with crushed rock where the smaller fractions have been screened away, so the result is so-called macadam. A subbase layer consisting of macadam is referred to in these contexts as an open subbase layer. Examples of suitable fraction spans are 4/90, 22/90, 32/63 or 32/90. As open subbase material, the material 16/90 has previously been specified, which has now been changed to 22/90. It's still the same material being referred to, it's just two different ways of specifying a material. What separates them both is where the limit is for how much sub-grain may be present in the material. In the research project, the limit of 10% was used for the maximum amount of subgrains, and then the material was named 16/90. In the swedish construction sector is used standard SS-EN 13242 that specifies the limit where there may be a maximum of 20% subgrain and thus the value is moved from 16 to 22. Crushed wood chips 90/150 can also be used, which is outside the scope of this handbook and we refer to Stockholm's tree handbook for further reading.

The smaller fractions in crushed stone mean that it has very small pores. The size of these small pores/cavities means that the flow rate and gas exchange of the storm water will be so very low that it can be negligible. If the flow rate is too low, the material cannot be used for retention because the water cannot penetrate it quickly

> ***As open subbase material, the material 16/90 has previously been specified, which has now been changed to 22/90. It's the same material that we reffer to, it's just two different ways of specifying a material.***

enough. By using macadam as the base material in the open subbase layer can be created a construction that has large pores, high flow rate of water and gas and high bearing capacity. In the open subbase layer, water cannot be transported up via capillary forces and thus no ice lenses can form which could create frost heaving and lifting of the ground level. Likewise, all excess water must be gone within 24 hours after a rain has stopped.

Open subbase layer is laid in several layers with a maximum thickness of 250 mm. Each layer must be carefully packed before the next is laid out. Inadequate packing is a major cause of subsidence in hard surfaces. Depending on which functions (bearing capacity, plant bed and retention) are most important in the project, different fraction spans can be used. For example, if only

	Traffic class ≤ 1a (inkl. flexzone)	**Traffic class ≥ 1b**
Upper subbase layer approx.: 0-250mm	22/90, 4/90	4/90
Next subbase layer approx.: 250-500mm	22/90, 32/90, 32/63, 4/90	4/90, 22/90
Remaining subbase layer 500mm and deeper	32/63, 32/90, 22/90, 4/90	22/90, 4/90, 32/90*, 32/63*
*Under dimensioning thickness of subbase layers to achieve the traffic class		

Table 4. Proposals, in descending order, for open subbase material for different traffic classes.

Priority function with suggested fraction span (mm)			
Layer	**Retention/ load Permeable coating**	**Retention/ load plantbed, No permeable coating**	**Plantbed/ retention**
Base layer	4/32	0/32	(substrate)
Open subbase layer	4/90, 22/90	4/90, 22/90	32/63, 22/90, 32/90

Table 5. Examples of suitable fraction limits for BGG systems with different main purposes. All fraction limits are stated in mm.

the functions of load-bearing capacity and retention of stormwater entering vertically are desired, macadam 4/90 can be used. Under vegetation areas where delay and plant bed are prioritized, macadam 32/63 can be used. For surfaces where all three functions are prioritized and desired, macadam 22/90 can be used. A factor that also affects the choice of material is which fraction span the next material consists of. This is to prevent particle migration and settling. Through a gradually increasing lower fraction limit, the transition to leveling layer, lower plant substrate and open subbse layer becomes small and the smaller particles can more easily bridge to the larger pores of the coarser material. Tables 4 and 5 show examples of fraction limits that can be used in BGG systems with different main purposes.

In the open subbase layer, cleaning and plant bed improving material is sometimes added, see section 6.4.3.2. Type of material and amount is controlled by the goal of the system regarding vegetation, purification and retention. Regarding biochar and macadam's properties and function as part of a plant bed, see chapter 6.4.3.1 Plant substrate. How open subbase layer 22/90 relates to the Swedish Transport Administration's requirements for subbase layers with limit curves for material composition can be read in figure 39.

Reference values for unbound superstructure materials				
	Subbase		Base	Joits & bindermaterial
Sorting	4/90[1]	22/90	4/32[2]	2/5
Referens value for hydraulic conductivity[3]	$1{,}0\text{x}10^{-3}$ m/s		$1{,}0\text{x}10^{-2}$ m/s	$1{,}0\text{x}10^{-2}$ m/s
Available porevolume[3]	> 25%	>35%	> 25%	> 35%
Max fillercontent	3%		3%	3%
Max content < 2mm	5%		5%	10%
Min content < 4mm[9]	10%	-	10%	-
LA[4]	[7]		[7]	< 20[6]
M_{DE}[5]	[7]		[7]	< 15[6]
Bearing capacity with plate load Ev2[7], [8]	> 140 MPa			-

(1) According to SS-EN 13242 and AMA Facility 20, the grading is called 4/90 Gc 80-20.
(2) According to SS-EN 13242 and AMA Facility 20, the classification is called 4/32 Gc 80-20.
(3) Reference values mean values established in the project "Climate-proof surfaces for urban environments." These values are the basis for the dimensioning developed and should be pursued in municipal projects.
(4) Resistance to fragmentation measured with the Los Angeles method according to SS-EN 13242.
(5) Requirements for abrasion properties according to SS-EN 13242 measured with the micro-Deval method.
(6) The recommendations are an adaptation of Belgian national requirements [20], and may be waived after investigation.
(7) Values according to the Swedish Transport Administration's requirements [17], [46].
(8) Attention should be drawn to the fact that more passes than the AMA specifies are often required to ensure good compaction.
(9) Note that for load bearing reasons the amount of material between 2 and 4 mm is important. The guideline value for passing quantity at 4 mm sieve should be a minimum of 10 percent.

Table 6. Reference values for unbound superstructure materials. Svensk Markbetong.

Permitted number of axles	Traffic class	Description
0	G	Entrance hall, patio, play areas, courtyard without traffic
0	GC	Pedestrian and cycle path, occasional light vehicles, garage entrance
< 50 000	0	Low-traffic areas, such as pedestrian and cycle paths or parking lots. The surfaces can also carry traffic from lighter goods transport as well as occasional heavy vehicles.
50 000- 250 000	1a	Fire escape, square areas, pedestrian areas/streets.
250 000 - 50 000	1b	Shared Space, smaller streets with elements of heavy traffic.
50 000 - 1 000 000	2	Streets, roads.
1 000 000- 2 500 000	3	Streets, roads.
2 500 000- 5 000 000	4	Streets, roads.

Table 7. Description of traffic classes. Svensk Markbetong.

Climate zone 1-5, crushed draining material in the subbase layer										
System	Unbound construction		System I							
	Bound construction (permeable/impermeable)		System II och III							
Traffic	Permitted number of standard axles		0	0	< 50 000	50 000 - 250 000	250 000 - 500 000	500 000 - 1 000 000	1 000 000 - 2 500 000	2 500 000 - 5 000 000
	Traffic class		G	GC	0	1a	1b	2	3	4
Superstructure	Thickness (mm)									
	Pavers		50	60	80	80	80	80	80(1)	80(1)
	Binder course (2/5)		30	30	30	30	30	30	30	30
	Unbound base layer (4/32)(2)(3)		80	80	80	80	80	80	80	80
	Thickness of subbase layer (h):	1	0	0	0	88	88	125	238	313
		2	0	88	88	133	188	263	363	438
	System I, f-layer 4/90	3	20	88	88	183	300	363	438	500
	System II/III. f-layer 4/90 alt. 16/90	4	45	88	88	200	338	413	513	588
		5	95	213	213	341	500	575	725	850

(1) In special circumstances, 100 mm thickness is recommended.
(2) In System II, the unbound base layer is replaced with a draining bitumen-bound bearing layer (type ABO) and the thickness of the subbase layer (h) can then be reduced by 200 mm.
(3) In System III, the unbonded base layer is replaced with a 55 mm bonded base layer (type Ag) and the thickness of the subbase layer (h) can then be reduced by 200 mm.

Table 8. Calculation of subbase layer thickness (System I, II and III). Svensk Markbetong.

22/90 vs 0/90

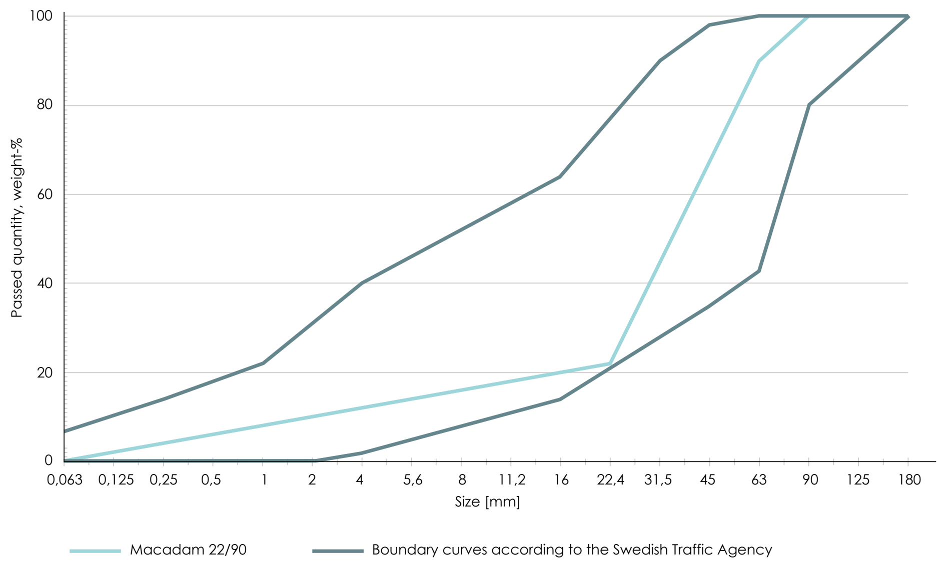


Figure 39. Shows the Swedish Transport Administration limit curves for a subbase layer 0/90 and how open subbase layer 22/90 relates to it.

Static plate load test is performed on open superstructure
Foto: Anders Friberg

6.4.2 Geotextile

Geotextile is used to keep fine materials out of BGG systems because otherwise they can cause the system to clog and function to be impaired. All parts of the system which contain fine materials, for example breaks and infilling around conventional pits, should be covered in geotextile. Depending on the constitution of the surrounding soil, the bottom and sides of the system may also need to be covered.

For areas underneath stormwater chambers (see section 6.6.6, p. 71), an especially durable woven textile should be used. This is necessary to withstand the forces generated when chambers are flushed to clean them of accumulated sediment.

6.4.3 Planting Beds

When used in planting beds, planting substrates function together with the open subbase layer, biochar, and to a certain extent the subsoil/substructure as well as the surrounding material.

6.4.3.1 Planting Substrates

Planting substrates refer to the materials used in a planting bed above the open subbase layer. Because planting beds in BGG systems are laid with permeability, the building process and purification in mind, commonly available soils will be unsuitable for use. B-soil as defined by the Swedish AMA or a soil with over 70% sand can, however, be used in planting beds that do not require a high level of infiltration.

Stormwater flows though bioretention areas through the planting substrate down to the open subbase layer. To prevent the substrate from being pulled along with the water, it should be composed of particles whose size ensure that they brace against and lock each other into place. If requirements set out in Table 9 are met in terms of the textural differences between planting substrates and the underlying materials, bridging between materials will occur.

The recommended planting substrates based on fine macadam are more tolerant of harsh treatment during the installation process. Common planting soils risk getting compacted if they are subjected to handling by construction equipment or dumped in piles that are too large unless very dry. For these reasons we recommend using planting substrates instead. A planting substrate based on fine macadam with low clay particle content and normal to low organic material content is more resistant to damage from compaction, salt or wet conditions.

In order to reduce consumption of resources and transportation, it can be desirable to reuse existing soil. In this case, it should be limited to adjoining green spaces to prevent substandard functioning or clogging of the system. It should also be separated from the open subbase layer using the bridging concept seen in Table 9. Handling and storage of the soil can also damage its structure, meaning that it often may need to be broken up and improvements added before use.

Performance Factors	Recommendation
Bridging Factor	D^{15} (underlying course material) less than or equal to 5 X D^{85} (above finer material)
Permeability Factor	D^{15} (underlying course material) greater than or equal to 5 X D^{15} (above finer material)

Table 9
Recommendations for underlying course material texture and connexion to above finer material

For more information on biochar and biochar certificates see www.biokol.org/en/ and www.european-biochar.org/en

The left hand is holding biochar which has undergone pyrolysis. In the right is the raw material, in this case pellets of surplus organic material.

6.4.3.2 Biochar and Other Substrate Improvement Materials in BGG Systems

To improve the function of the open subbase layer and planting substrate within a planting bed and purification facility, biochar, pumice and compost are mixed in where planting will be done. The ability of biochar and compost to bind nutrients is used in BGG systems to purify stormwater. The nutrient amounts carried by stormwater to planting beds ensures that constant supplementation will be provided thereby benefitting vegetation. For planting areas that aren't fed stormwater to the same degree as BGG systems, nutritional deficiencies can occur. Biochar which has been enriched with nutrients beforehand will be used in these beds.

By using a planting substrate with biochar, compost and pumice, precipitation is retained and made available to the plants. Since biochar and pumice are porous, they have a larger pore volume which can retain large amounts of water per volume while at the same time maintaining a high permeability.

Biochar is produced with organic surplus materials that undergo pyrolysis, or heating in anaerobic conditions. The process is done under high temperatures which causes all contaminants such as heavy metals and PAH[1] to be gasified. Biochar has a porous structure which gives it the ability to bind water, nutrients and pollutants thus benefitting both plants and microorganisms. It also functions as a long-term carbon sink because of its slow rate of decomposition.

The manner in which the pyrolysis process has taken place and the raw material used impacts to a large degree the characteristics of the biochar produced, i.e. its appearance, size, nutrient content, pH, structure, amount and size of pores, contaminant levels, water retention ability, and more. At the current time there is no biochar being produced which is optimized for BGG systems. The Vinnova project Rest till Bäst is currently studying ways to gain more knowledge in this area. In the meantime, it is recommended to used certified biochar in order to ensure high quality as well as ensuring that appropriate production methods and materials were used. The ***European Biochar Certificate*** (EBC) is working on a biochar certification. When choosing biochar for a project consult their website.

The ability of biochar to bind contaminants diminishes over time. However, vegetation which has benefitted from biochar contributes to increased purification. At the same time, new materials in the form of fine sediment and humus are constantly being added to the system, presenting pollutants with additional material to which they can bind. More research is needed to determine how these processes function and how fast they occur. There is a risk with new BGG systems that biochar, as well as other fine particles such as compost, pumice and more that are mixed with it, get flushed away with the stormwater and accordingly burden the recipient with nutrients. When the system has matured, that is when tree roots and microscopic life have developed, this effect diminishes. This inconvenience can be prevented by installing a filter in a well upstream from the recipient which can capture those small particles.

[1] Polycyclic aromatic hydrocarbons. Carcinogenic substances that occur during combustion.

6.5 Drainage Principles

There are two main principles for draining a BGG system: percolation through the subgrade and discharge to the stormwater pipe system. Depending on how the drainage pipe is laid, the principles can be combined. The variant chosen depends on among other things the infiltration capacity of the subgrade, water requirements of vegetation and the need to protect the subgrade and natural subgrade.

6.5.1 Percolation to Natural Subgrade

If the stormwater is relatively clean and the subgrade is unpolluted and consists of material which supports percolation, the subgrade can remain exposed under the open subbase layer. This allows stormwater to seep down and recharge ground water. The speed at which the subgrade percolates determines how quickly the open subbase layer is emptied.

Percolation that happens too fast is not recommended since it will reduce the amount of water the planting bed receives, causing it to dry out too quickly.

When calculating drainage capacity by percolation to the subgrade, be aware that the formation level can be clogged by sediment over time.

To se animation with drainage principles visist: https://bluegreengrey.edges.se

Figure 40. Excerpt from movie about drainage principles in BGG systems. BGG systems enable large amounts of stormwater to infiltrate and percolate down and replenish the groundwater.

6.5.2 Drainage/Discharge

Draining open subbase layer is done using conventional principles, e.g. via drainage pipes or stormwater chamber connected to a pit or via percolation holes in the side of a pit. A BGG system gives the opportunity to use control pits and flow regulators to adjust drainage amounts according to the goals for the system. Read more on this in section 6.2.4 Controlling water flow, p. 44, as well as Figures 20-23 p.45. If it is necessary to protect groundwater, the bottom and sides of the system can be sealed with geomembrane. In this case, water will only be discharged by pipe to the control pits.

6.5.3 Artificial Groundwater Zones

An artificial groundwater zone is created by setting the drain level in the system a few decimeters above the bottom of the subbase layer. This keeps water standing at the bottom for a longer time and provides it to the vegetation. The water in an artificial groundwater zone can also contribute to improved saturation of the entire system which also improves conditions for vegetation. This effect can be enhanced by creating small walls (dams) inside the zone. These walls prevent water from running to the low point of the system so that it covers a larger part of the bottom surface area. Walls can be built in the same way as the breaks that divide continuous strips of open subbase layer into units, but they do not have to be as high. Read more on breaks in section 6.2.4 above.

After water spends a length of time in this kind of zone, anaerobic conditions may arise. This environment is favorable to microbes that can clean stormwater by transforming complex organic pollutants to simpler, less damaging compounds.

6.6 BGG System Components

Development happens quickly in this area and we are constantly receiving feedback from operating systems and facilities while they are being built. For the latest on components, visit our homepage.

6.6.1 Control Pits

Control pits allocate water within the open subbase layer and to conventional sewers in a controlled way. Water flows in and out of the pits through covers, pipes, or perforations in the walls of the pit. Pits can also collect water from nearby roofs. Flow regulators control outflow. The amount of water let through can be adjusted at any time by swapping out the so-called regulator paddle. This makes controlling water flow simple and makes maintenance and excavation tasks easier.

In continuous strips of open subbase layer, the control well can be placed pretty much anywhere along the strips' length within a unit. If the control well is placed at the lowest part within the unit, the system is filled towards the street connection while gravity is used to empty the subbase layer. If you want to take advantage of gravity both when filling and emptying, the well is placed in the highest part of the unit. If the control well is placed in the upper part, it can be used to control the emptying of the unit that is above. In this way the magazines can be connected in series. To avoid damage and overloading of the system, there is an overhead line which directs the stormwater past the flow regulator and runs unimpeded to the stormwater network.

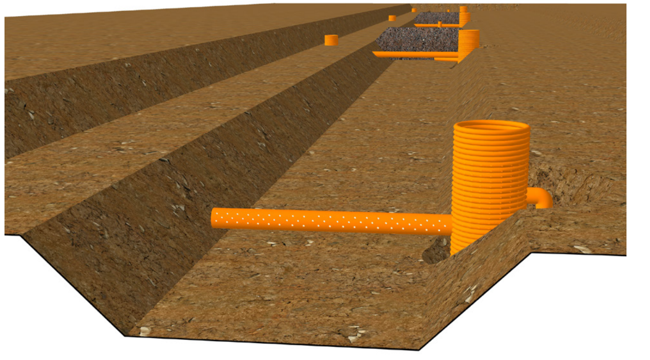
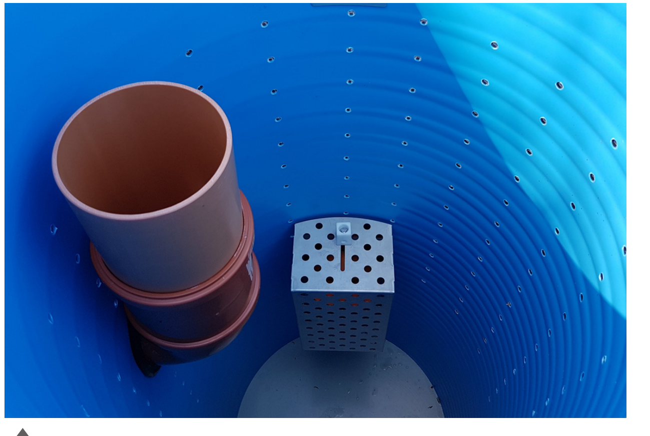


Figure 41. Illustration of control pit and discharge and dispersion pipes before open subbase layer has been filled in.



Inside of a control pit. The walls of the pit are perforated so that water and air can pass through them. In the middle of the image is the cage which protects the flow regulator. An orange overflow pipe can be seen on the left.

An example of Curb Support Anchore called Locstone.

An example of application of Locstone that holds together blocks of curbstone without usage of concrete.

A plantbed that has direct connection to curbstone after application of Locstone.

6.6.2 Gas Exchange Stormwater Pits

Gas exchange stormwater pits are placed in low lines or low points where they collect stormwater. They perform gas exchange within the system in the same way as control pits, except without the control pits' system of pipes and flow regulators. Stormwater is instead led directly to the open subbase layer through perforations in the sides of the pit, to a stormwater chamber or control pits via a closed pipe or drainage pipe. If drainage pipe is used, water will seep into the open subbase layer on its way to the control pit. Gas exchange stormwater pits have perforated sides and when they are connected to drainage pipes, air is able to flow into or out of the subbase layer.

6.6.3 Gas Exchange Pits

Ordinary gas exchange pits have perforated sides but are not connected to control pits or a stormwater pipe system. Air can enter via the cover and flow out into open subbase layer through the perforated sides.

6.6.4 Pit Placement

The need for pits to control stormwater or aeration depends on how the BGG system is designed. If the ground composition around the system is very dense, each element may need its own pits. If a system includes a continuous strip of open subbase layer, it may suffice to have pits installed as described below.

6.6.5 Curb Support Anchore

The curb support anchore is an alternativ to traditional curbstone that is layed in concrete. One example is to use a product called Locstone that replaces the need for concrete when setting curbstones. The product consits of three parts – link arm, back plate and front plate - and are put together to create a strong and durable construction that both resists collisions, promotes infiltration into rainbeds and gives posiblity to create planbad in direct connection to the curb .

6.6.6 Stormwater Chambers (additional equipment)

Stormwater chambers are primarily needed if stormwater is led directly from a surface with a lot of sediment, for example highly trafficked areas, directly into open subbase layer.

Stormwater chambers are buried half cylinders made of plastic. Water which is led into them seeps out again through perforations in the chamber walls or is filtered through geotextile. This separates sediment from stormwater and prevents it from coming into the open subbase layer. Stormwater chambers are connected to control pits and from there can be flushed clean when too much sediment has accumulated (see images on this page). An especially durable woven geotextile is laid in the bottom of the chamber that can withstand the forces generated when chambers are flushed clean.

6.6.7 Pit Filters (additional equipment)

Pit filters may be necessary if a water runoff carries a lot of sediment or specific pollutants. However pit filters are not addressed in this handbook.

6.7 Stormwater Purificiation

In order to contribute towards reaching the EU water directive's requirement that water bodies must achieve good ecological and chemical status, a great focus on optimizing the purification function in BGG systems is required.

Treatment of stormwater takes place in several ways within BGG systems. Particles entrained by the water can be collected in sand traps, vegetation, plant substrates, storm water tunnels and in the open subbase layer or it is being separated as it passes through the permeable pavement. As the water's flow rate decreases in the bioretention area and in the open subbase layer, the particles sink to the bottom- a process called sedimentation. Smaller particles can be captured as the water passes through plant substrate in bioretention areas and in the open subbase layer via mechanical filtration. Dissolved pollutants are primarily bound to particle's surfaces, but are also cleaned by the vegetation and microbiological processes. The chemical cleaning is specific for different substances, because the different substances have different charges and thus attraction to different surfaces. In general, the purification effect in absolute terms is higher in autumn and winter, and lower in spring and summer, but it varies between substances. The reason for this may be that the load on the systems is then greater.

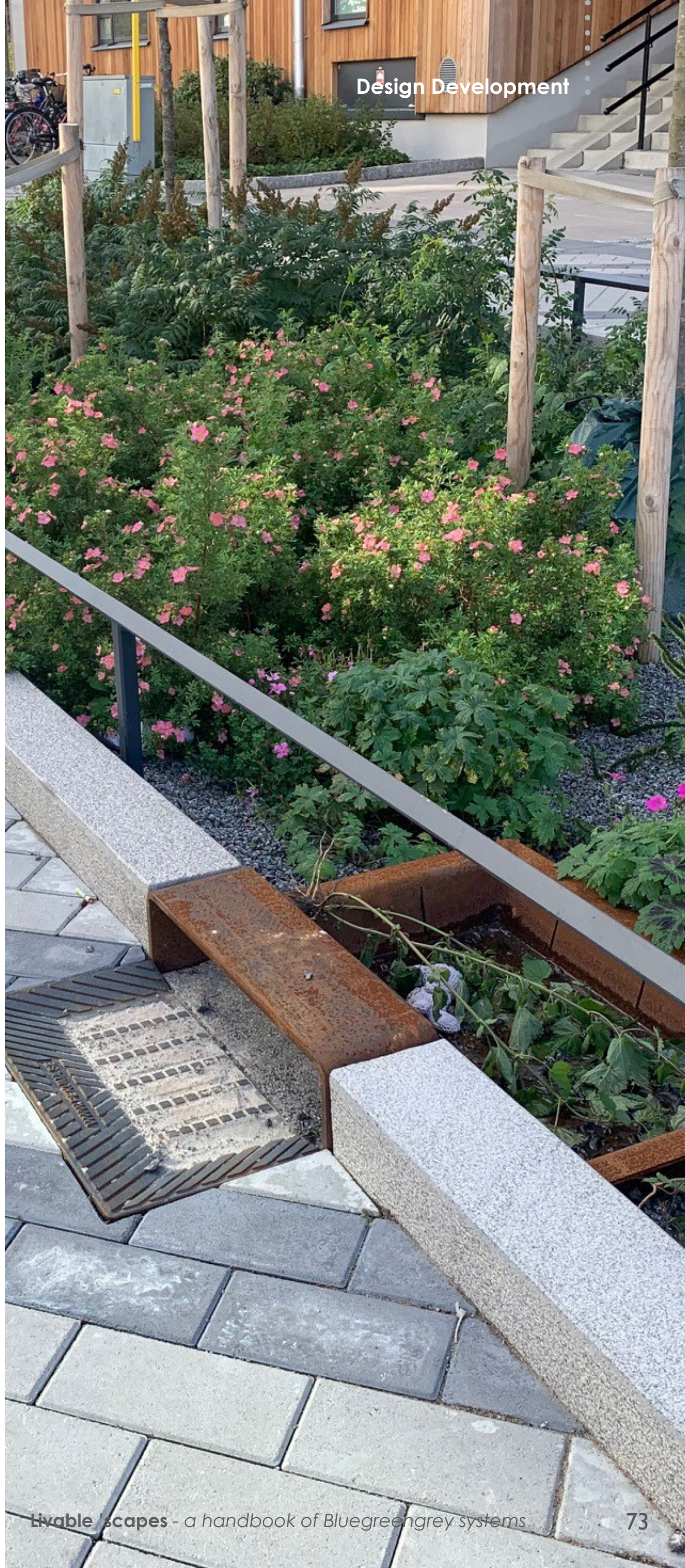
When choosing treatment functions and level, it is important to choose the right one in relation to the recipient's status and expected pollution load and their relation between dissolvable and non-dissolvable substance. The location's unique conditions and aspect of maintenance should also be taken into account.

Inlet to bioretention area with sandtrap. Strandbogatan, Uppsala. Foto: Rasmus Elleby.

To improve the open subbase layer and the function of the bioretention ares as a stormwater filter, biochar is sometimes used. The porous structure, large surface area and chemical properties of this material can promote the intake of pollutants and nutrients. Nutrients and pollutants in the stormwater can to some extent be bound to the biochar instead of being carried away. Biochar also supports development of microorganisms and vegetation which can contribute to higher purification. The microorganisms can break down some pollutants and thus contribute to water purification.

In order to purify the water from complex, organic pollution, a water accumulation zone can be created at the bottom of the BGG system where water is left standing for a longer time. The oxygen-poor conditions that can then arise favour bacteria with the ability to break down the pollution into simpler, less harmful substances. In low-oxygen conditions, bacteria that convert nitrogen compounds into nitrogen gas can also occur. The process is called denitrification and leads to less nutrients in the stormwater, which in turn can lead to reduced eutrophication.

In recent years, cities have started to use plant substrates with very high permeability (>1000 mm/h). The main reason why a substrate with high permeability has been chosen is that the gas exchange for the vegetation and



Inlet to bioretention area with sandtrap. Amanuensgatan, Uppsala.

microorganisms will be high and in some cases it fulfils also need to empty retention zone in time. In recent years, however, bioretention areas have started to be dimensioned for rain with a shorter return period, usually one to two year rains, because it has been noticed that they do not clean as effectively when the substrates are very permeable.

A plant substrate with high permeability usually has a lower moisture and nutrient retention capacity and may therefore require extra fertilization and watering during establishment. The substrate is often fertilized a little extra at the beginning to get vegetation to quickly establish itself and get a developed root system. In case of saturated flow through the plant substrate, the plant bed under these circumstances unfortunately leaks nutrients. Mainly the dissolved pollutants previously adsorbed by organic material, fine mineral particles and colloids are at risk of leaking out. The risk of erosion of material from the plant bed is also higher with greater permeability capacity.

To minimize nutrient leakage from the plant bed, a substrate with more fine material and thus lower permeability can be used to favor purification. So that the emptying time of the delay zone does not become too long and disadvantage the vegetation and microorganisms, the depth of this should be reduced. The overflow should therefore be placed at a lower height (approx; 50–100 mm) above the plant substrate and thus only the first part of the rain that runs off is allowed to infiltrate down through the plant substrate. The remaining part of the rain then overflows directly into the open subbase layer. This places lower demands on the drainage capacity of the plant substrate than the bioretention area with a deep retardation zone and thus an AMA B soil can possibly work in this type of bioretention area.
Several investigations have shown that the largest part of the purification takes place in the top 200 mm of the substrate in bioretention area, with which 200 mm of plant substrate/soil should be fully sufficient regarding the purification function. An AMA B soil or sandy soil type golf greens substrate with a lower infiltration rate (<150mm/h) than the substrates usually used in bioretention areas, can thus generate a higher purification. This is because a soil with a lower infiltration rate has a greater opportunity to increase the fixation of fine sediments and adsorb dissolved pollutants. Traditional plant bed materials that have been fertilized should not be used in the construction of bioretention areas. To a large extent, the nutrition needed for the establishment must be provided through the supply of nutrition in irrigation bags and for the undergrowth via long-acting fertilization that is applied in small doses to the surface on several occasions. To the above reasoning must be added that this can deteriorate the environment for the desired vegetation and microorganisms.

In general, when it comes to fertilizing bioretention areas in ongoing operation, this should only be done if there is a clear need in advance. Regarding nitrogen and phosphorus, there will probably be no need to add these nutrients. As an example, if we dispose of the runoff from a streetscape in a bioretention area, it receives a fertilization amount corresponding to 200kg N & 10kg P/ha bioretention area and year. In the example, we assume that a streetscape emits approx. 10kg N & 0.5kg P/ha (approx. 1000 vehicles/day) and that the rain bed is about 5% (1/20 part) of a streetscape. Choosing

Construction of BGG-system
Norra infarten, Vellinge

plant bed substrate for BGG systems and specifically for bioretention areas can be a tough task as the functions of cleaning and plant bed properties collide with each other. If both are of extra high priority, it takes a lot of focus on this throughout the process to get it right. For more info see the chapter on plant bed substrate 6.4.3.1.

In BGG systems, a secondary retention volume is created under the bioretention areas, which means that the plant substrate only needs to receive the first part of the rain (first flush). It is usually above all the first flush that brings with it the highest levels of pollution. However, the degree of pollution also depends on how much time has passed since the last rain fall. In order to increase the cleaning in a rain bed, it is therefore suitable to let it receive only the first flush.

An advantage of allowing the substrate to receive only the most polluted stormwater is that it reduces the risk of contamination leaking from the substrate. If the topsoil has 5–10 percent pore volume to receive the initial flow pulse, then large parts of a rain shower can be absorbed into the plant substrate without generating draining water that leaks nutrients. In addition, the soil can gain a higher moisture-holding capacity and thus a greater water supply for the vegetation. It is also important to know that delaying a larger volume of precipitation in the surface reservoir would only result in an insignificantly greater separation of pollutants each year.

According to SMHI, a moderate rain shower lasts 10–20 minutes, with a flow of 10–30 l/s ha. This can be compared to a year's rain which gives 75–100 l/s ha in 10–20 minutes and where the latter part of the year's rain probably already has a greatly reduced level of pollution. In the case of other longer-lasting rains, it is mainly the delay that is relevant.

A soil with a lower infiltration rate has a greater opportunity to increase fixation of fine sediments and adsorb dissolved pollutants

	Rainfall			
Intensity	Light	Moderate	Heavy	Extreme (cloudburst)
mm/10 min	< 0,4	0,4-2	2-8	≥ 8*
l/(s•ha) during 10 min	< 6,7	6,7- 33,3	33,3-133,3	≥133,3

Table 10. Indicative classification of rain falls based on intensity. Source: L.Ek, T. Grönvall, LTH (2018).

Construction of BGG-system
Norra infarten, Vellinge

6.7.1 Retention Zone under Plan Bed

A bioretention area with a retention zone under the plant substrate with a safety outlet for overflow and a throttled outlet for emptying, usually has a greater delay capacity compared to a traditional bioretention area without a lower retention zone. The bioretention area receives water run-off in the surface retention zone and only forwards additional volumes of rain, which are not as polluted, to delay in the lower reservoir (open subbase layer).

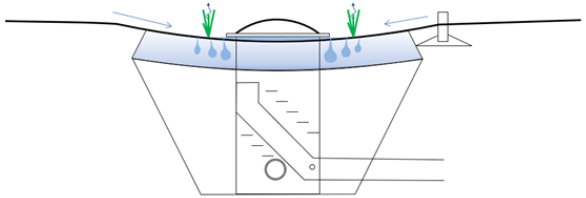


Illustration: Bert Sandell

Figure 42. If there would have been a week without rain and then light rain would arrive, all the run-off water from the rainfall will infiltrate into the topsoil and no part of the run-off will be diverted to the open subbase layer. Purification takes place mainly through filtration and adsorption in the plant soil.

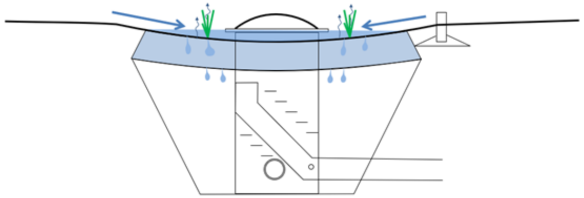


Illustration: Bert Sandell

Figure 43. A moderate flush will in most cases only replenish water in the topsoil and not be diverted to the lower retention zone (the open subbase layer). Purification is done by adsorption in plant soil and sedimentation in erosion protection and in case of overflow.

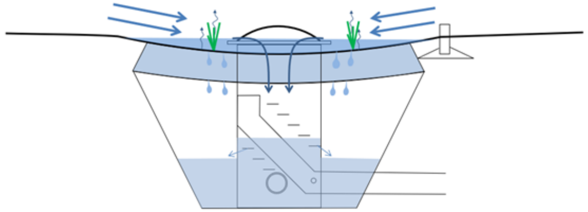


Illustration: Bert Sandell

Figure 44. A larger rainfall causes the topsoil to become saturated and surface water begins to be channelled down into the lower retention zone. Some sedimentation happens in the upper retention zone, but mainly purification by filtration and sedimentation in sand trap and open subbase layer happens.

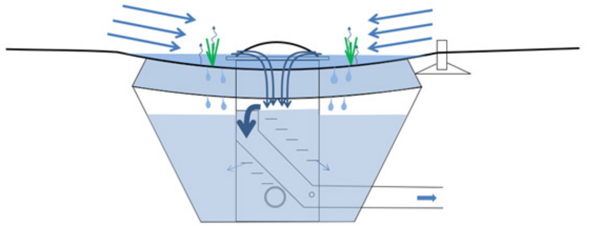


Illustration: Bert Sandell

Figure 45. The construction usually withstands the dimensioned rain thanks to the two retention zones.

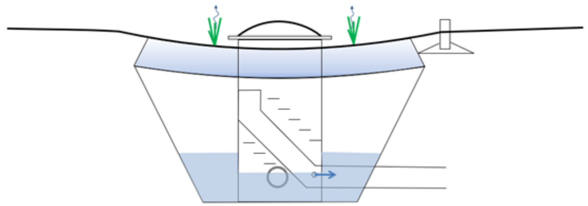


Illustration: Bert Sandell

Figure 46. An alternative could be to divert rain greater than a 2-year rain directly to the storm water network or widen to another recipient if that is desired.

A tree exposed to drought stress.
Brno, Czech republic.
Foto: NEXT INSTITUTE

6.8 Design and Dimensioning against Drought and Heat Waves

The text in this section is based on the master's thesis Modeling of drought stress on vegetation in BGG systems in the modeling tool MIKE SHE (2022) by Arvid Backlund in the MSc program Environment and Water Technology, which was written with the supervision of Edge & DHI within SLU and Uppsala University.

In the future, Sweden's climate is expected to change with increasing temperature, a longer vegetation period and increased evapotranspiration. This increases the risk of more dry periods, which in turn are harmful to the urban vegetation. To compensate for dry periods, smarter stormwater management is needed, such as BGG systems, which can contribute to positive effects for the city's vegetation, climate and reduction of urban heat islands.

Despite all the ecosystem services that urban trees contribute with, the urban environment is a place where they are rarely given the opportunity to reach their full potential. Even under the best conditions, urban trees are exposed to a number of different stress factors. These stressors can be divided into biotic and abiotic stresses. Biotic stresses include attacks by diseases and pests. While abiotic stresses are closely related to the tree's growth environment and include factors such as insufficient sunlight, air pollution, lack of oxygen, soil compaction, extreme temperatures, water scarcity, salt supply and tree pruning. In general, however, it is the lack of water and gas exchange that is the biggest contributing factor to the stunted growth of the trees. One reason for the problem is that the soil volume in which the trees are planted is often too small to hold an adequate amount of water. The lack of water is often due to the fact that the volume of land in which the trees are planted is far too small and that the ground is too tightly compacted, which is a consequence of the trees competing with a number of other social functions in urban spaces. The lack of water has a number of negative effects on the trees, causing them to experience conditions that often stress the tree's health and growth. This means that trees in the urban space can exhibit a size corresponding to a tree 40 years younger that grew in more natural environments and that they rarely reach their full potential. The hard surfaces in the city store and radiate a lot of heat, which on hot days leads to a microclimate that is not optimal for the trees. However, how the urban vegetation copes with longer periods of drought and higher temperatures is an area that needs to be taken into account in the future and more research is needed.

A tree in the urban space can exhibit a size equivalent to a tree 40 years younger that grew in more natural environments and rarely reaches its full potential.

According to SMHI, a dry period is defined as one or more consecutive days without measurable precipitation. In order for the trees in the urban spaces to cope with periods without precipitation, it is required that the systems in which they are planted are well designed for both today's and future conditions. With the BGG system, the vegetation is given a greater space for root development compared to conventional vegetation

A tree exposed to drought stress.
Brno, Czech republic.
Foto: NEXT INSTITUTE

surfaces, as roots can develop down into the open subbase layer and out into the superstructure for hard surfaces and adjacent terrace. But space is still limited and many of the ecosystem services that vegetation contributes to risk becoming low and ineffective when exposed to longer periods of water deficit.

Today, stormwater systems are dimensioned so that they are able to handle runoff generated from a rainfall event with a given return period, for example a 20-year rain or a 30-year rain. It would have been interesting to investigate whether it is possible to apply the same approach to drought when planning and dimensioning plant beds and the trees that are planted there. Simply dimensioning the vegetation systems according to socio-economically justifiable return times in dry periods, e.g. 30 – 50 year drought. With such reasoning, one also needs to take into account the risk of damage to the ecosystem services that the vegetation generates and can take a long time to recover.

Trees use water for a number of vital functions such as nutrient uptake, photosynthesis, mineral and sugar

We should dimension plant beds according to socio-economically justifiable dry return periods, e.g. 30 – 50 year drought.

transport, and to provide structure to cells. However, only 1-2% of the water is used to meet these needs, the rest is released via transpiration from the leaves and needles of the trees. In studies, it has been shown that the actual evaporation (transpiration) from four different tree species related to the evaporation from an open water surface. The result showed small differences in transpiration between the different tree species and that for all tree species, under optimal conditions, it corresponds to approximately 30% of the evaporation from an open water surface. Thus, the main contributing factor to the trees' water consumption is the size of the tree crown rather than the tree species, when optimal growth is desired.

The water consumption for a selection of trees with varying crown sizes is reported in table 11. These calculations are estimated at the theoretical maximum size of the trees, a size which urban trees rarely reach. Trees planted in urban vegetation areas rarely reach a size above 75–80% of their theoretical maximum size, which is often due to the limited space of the plant bed. However, this does not mean that the limited growth automatically stresses the trees to a shorter lifespan. There are no straight answers to how long a given tree can cope with a lack of water.

Vegetation in BGG-system. Rundelsgatan, Vellinge.

6.8.1 Trees and Drought Resilience

Trees have a number of different defense strategies available when exposed to water shortages. The extent to which this occurs depends on whether the trees are anisohydric or isohydric. Anisohydric species tend to continue to transpire to a greater extent even when the amount of water decreases, while isohydric plants close their stomata already at early stages of water shortage. Anisohydric species thereby have a more risk-taking strategy where the production of biomass is maintained longer during dry periods.

What happens when a tree is exposed to a lack of water is that the roots sense this and start producing the hormone abscisic acid, which is sent on to the leaves. The hormone causes the leaves to close or completely close their slits in order to reduce the tree's water consumption. The

Species	Crown radius [m]	Water consumption [l/day]
Whitebeam	3	107
Birch	3,5	146
Wild cherry	4	198
Maple	6	428
Linden	7,5	669
Horse chestnut	10	1189
Oak	12,5	1857

Table 11. Water consumption for different tree species. The calculations performed by Ericsson (2009).

A tree exposed to drought stress.
Brno, Czech republic.
Foto: NEXT INSTITUTE

hormone also inhibits growth above ground, causing new leaves to become smaller and the distance between the new leaves to decrease, while more resources are allocated to forming new roots. If the water shortage continues to worsen further, the tree will be forced to reduce its leaf area to further reduce water consumption. They do this by sacrificing the oldest leaves, which is done by the leaves either falling off immediately or first turning yellow before they fall off.

The water-saving responses have a further effect on the tree's photosynthesis. During shorter periods of drought, photosynthesis is first inhibited as the leaves find it more difficult to absorb carbon dioxide when the stomata close before it stops completely if the water shortage continues. Photosynthesis recovers slowly but often returns to normal function when water again becomes available to the tree's roots, but in some cases the tree can be permanently damaged by prolonged drought. Through photosynthesis, glucose is formed which the tree then consumes during cellular respiration (respiration). When photosynthesis is inhibited during dry periods and cellular respiration continues unaffected, the tree will run out of its glucose reserves. The long recovery time of photosynthesis after drought will thereby affect the tree's glucose reserves for longer than the drought lasts. This can lead to a lack of glucose to support other vital functions, such as defence mechanisms, reducing the tree's vitality. This in turn leads to the trees suffering an increased risk of suffering from diseases and attacks from pests.

Tree species are differently sensitive to drought and dry periods, often depending on where they originally come from. Tree species found in arid regions have developed several strategies to better cope with the lack of availability of water. Examples of strategies are deep fine root systems, deep taproots with the ability to store water and leaves adapted to warm and sunny climates. These leaves often have a high proportion of biomass per area

Dry period distribution over the vegetation period - Uppsala

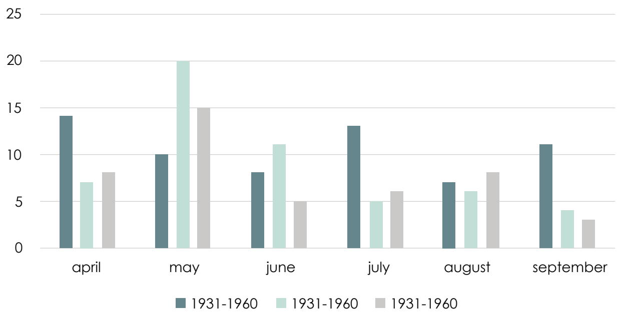


Figure 47. Monthly distribution for dry periods over 10 days during the vegetation period. Compilation of data taken from measuring stations in Uppsala (SMHI).

Dry period frequency - Uppsala

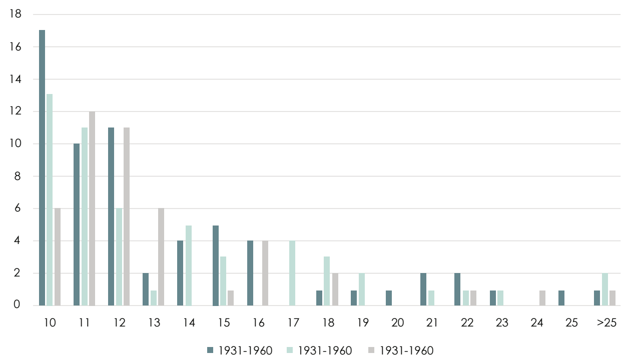


Figure 48. Number of occasions when dry periods of more than 10 days have occurred during the period April-September. Compilation of data taken from measuring stations in Uppsala (SMHI).

and thick cell walls, which means that they can handle higher negative water pressure (turgor pressure) in the leaf before they wither and suffer damage. Choosing trees that will cope with the cities' dry microclimate is difficult as certain strategies, such as deep root systems, are difficult to utilize in an urban environment with heavily compacted soils and terraces. Common to many trees is that they tend to redistribute their resources when the water supply decreases. Instead of growing above ground, growth is focused to the roots to increase the ability to absorb water from a larger volume of soil.

Trees that are considered drought tolerant have a particularly large amount of roots and then often focus on producing a lot of fine roots. This means that they reach out into a larger volume of soil per produced root mass. How much root growth increases varies greatly and although root growth tends to increase, studies have shown that root biomass does not change as much. This seems to be due to some of the roots (often fine roots) dying by themselves in favour of new growth of roots, which have a better opportunity to absorb water. Root mortality can create long-term problems and make the tree more susceptible to drought in subsequent years. Tree root systems are complex and root growth only occurs where external factors are favourable. The vast majority of root biomass is found in the top 0.6 m of the soil, where the soil is least compact and the water, oxygen and nutrient supply is most available.

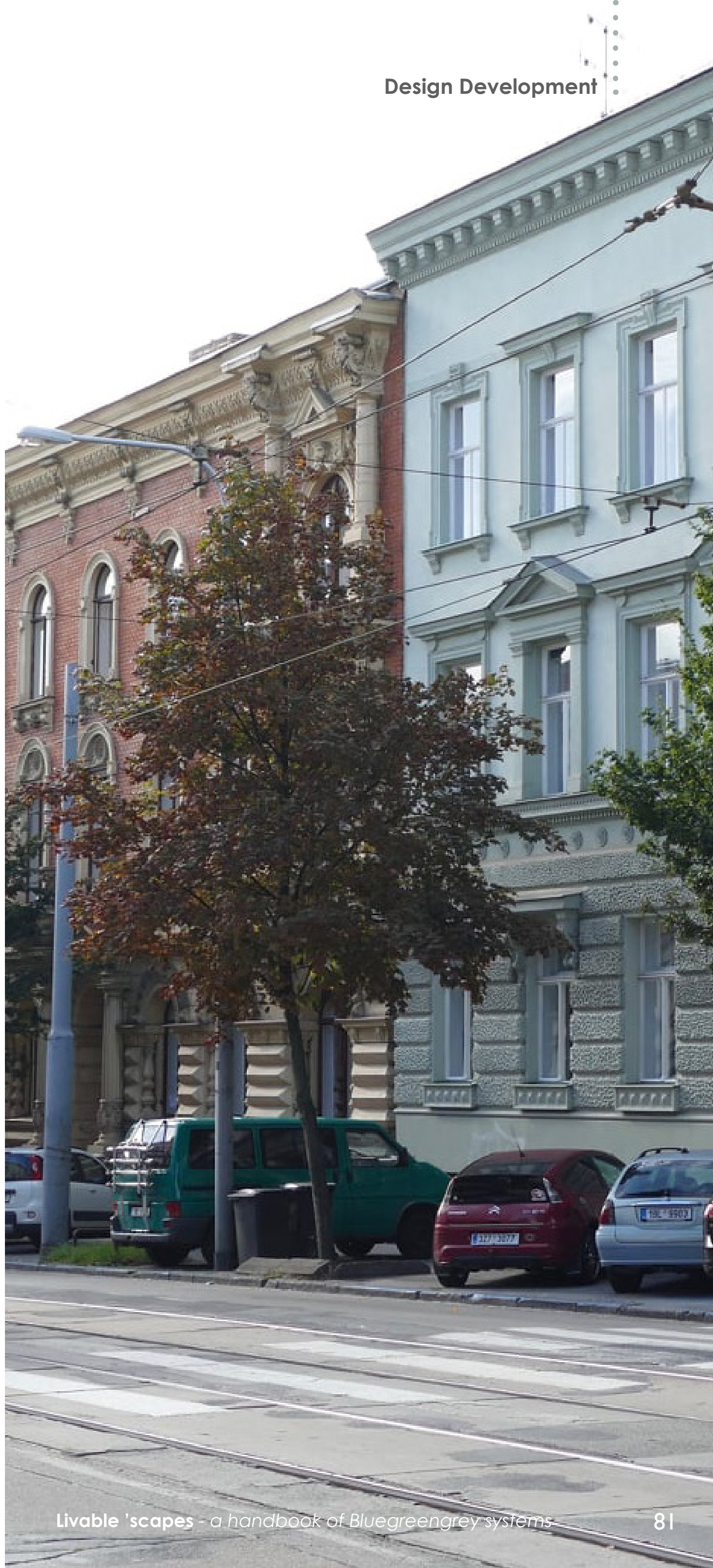
A tree exposed to drought stress.
Brno, Czech republic.
Foto: NEXT INSTITUTE

6.8.2 Plant Beds and Drought Resilience

The structure of the soil or plant bed is crucial to the vitality of the tree. The soil's pores are the system that provides the tree's roots with space for growth, water and gas exchange. Pores can be divided into three classes. The pores larger than 0.03 mm are called macropores, between 0.03–0.0002 mm are called mesopores and micropores are the pores smaller than 0.0002 mm. When all pores in the soil are filled with water, the soil has reached its maximum water capacity. After a while, the water in macropores will be drained away by gravity as the pores are too large to be able to retain the water, the soil will then have reached its drainage equilibrium (field capacity). When the soil reaches field capacity, approximately 60-80% of the pore system is filled with water, while 20-40% is air-filled. However, the entire amount of water is not available to the vegetation.

The plant-available water is given as the difference between the drainage equilibrium and the permanent wilting limit varies between different plant substrates and soils. The permanent wilting limit (theoretical limit) occurs when the plant's roots can no longer absorb the water from the soil's pores. In this case water is found only in micropores. How much plant-available water can be stored depends on the composition and structure of the plant substrate. A sandy soil can hold relatively little water, but almost all of it is available to the plant. While a stiff clay soil can hold very large amounts of water, close to 50% of that water may be too tightly bound to be available to the plant. There is also biochar and volcanic products such as pumice that have very high porosity and can contain very large amounts of plant-available water. In a plant bed, it is thus an advantage to have a soil that has a large proportion of mesopores that can hold a lot of plant-available water.

A tree exposed to drought stress.
Brno, Czech republic.
Foto: NEXT INSTITUTE



6.8.3 Methods for Estimation of Plant Bed Volume

How big a plant bed a tree needs varies with the type of tree and the size of the tree, but in general, as large a volume as possible is always the best option, as the tree's roots occupy a much larger area than the tree crown if the space is given. A widespread plant bed may be needed to give the tree strength to withstand wind loads. In an urban environment with limited space, it is not always possible to create plant beds that large. Lindsey & Bassuk have compiled a number of studies that have come up with suggestions for what are considered adequate plant bed volumes for an individual tree, see figure 49. The suggestions have been developed using different methods and are based on different factors that are relevant to the vitality of the trees, while some suggestions can almost be seen as rules of thumb to adhere to. The results show that there is a large variation between what is considered a suitable plant bed volume. Also, it depends which plant factor is being studied, there will be great variation in the results. It is also clear that many of the suggestions become unrealistically large and thus unrealistic to implement in an urban area where the plant bed will compete with other socially important functions. In several urban situations, it may be relevant to add city water or technical water to compensate for reduced plant bed volume.

Recommended sizes of plantbeds

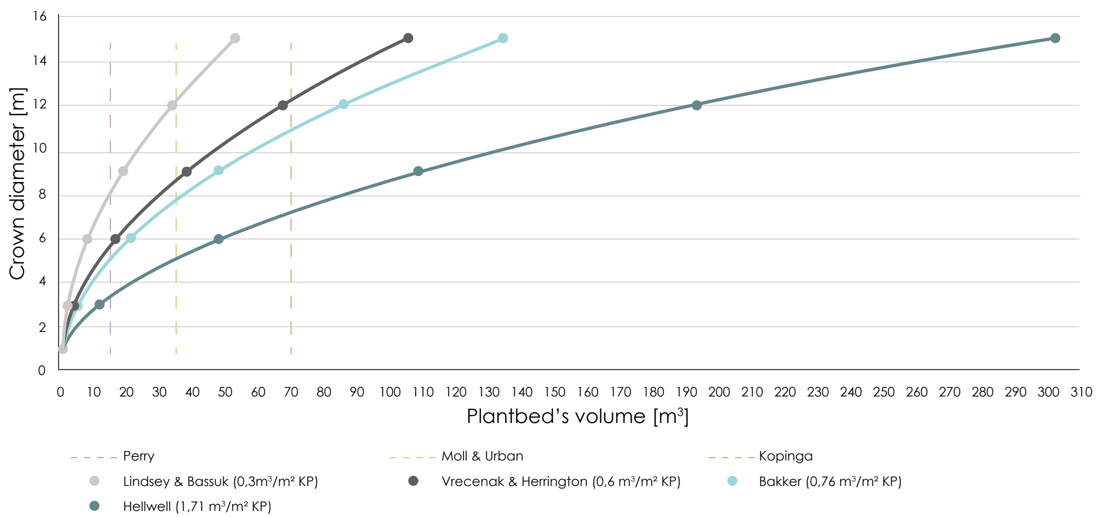


Figure 49. A number of recommended plant bed sizes. Dashed lines indicate minimum size for fully grown trees. Solid lines are estimates based on expected crown size. Results taken from Lindsey and Bassuk.

6.9 Choosing Vegetation for the BGG System

In order to ensure the long-term viability of sustainable vegetation in our streetscapes, it is important to choose plants adapted to the location. Requirements for plants in a BGG system do not differ much from conventional planting in the public right of way. Plants should be adapted to many kinds of environmental pressure. For a BGG system, this means that plants need to be able to withstand longer dry periods, short periods of standing water and low nutrient levels. One shouldn't be deceived by the term "rain garden" by thinking it implies an overly damp growing area. On the other hand, bioretention areas can fill quickly – even with lesser rains – since they are so much smaller than the total drainage area. As an example, if 5 mm precipitation falls and the bioretention area is 5% of the drainage area, it will receive a water volume of 100 mm per square meter. Plants which naturally grow in areas with fluctuating groundwater levels or can withstand various environmental pressures are usually well suited for the moisture levels present in BGG systems.

Standing water is problematic for many plants because it causes the soil to become oxygen deficient. Both the lack of oxygen and the surplus of gas created by anerobic decomposition and carbon dioxide are harmful to roots. This damage leads to reduced water and nutrient uptake, which is expressed as drought damage and inferior rooting. Most plants can however manage well with shorter periods of standing water, especially if this occurs during winter when they are dormant and not affected as much by their surroundings. A bioretention area which receives a lot of water from snowmelt can for that reason support healthy plants as long as the water has sunk through before the temperature rises and root activity begins in the spring.

It is advantageous to choose vegetation that retains appealing foliage during winter. This helps penetrate ice if it forms, allowing gas exchange function and stormwater infiltration to continue, creating both aesthetic and biological value. In general, BGG systems have a structure that creates a high gas exchange rate and allows microscopic life to thrive. An effective symbiosis between plants and microscopic life contributes to a greater uptake of nutrients and water, which in turn supports woody plant material.

When choosing plants for a bioretention area, remember that they will be in a sunken area compared to the ground levels around them. This means it will be advantageous to choose taller varieties so that passers-by can see them. Plants that are a little taller and have rigid stalks are a good choice for bioretention areas. Taller plants are also better at dealing with standing water as parts of the plant will always be above the water level. Additionally, rigid stalks are better at withstanding water currents.

The next page contains a list of suitable plant material for BGG systems containing macadam-based substrates and superstructures.

In a BGG system, plants should be able to tolerate longer dry periods, short periods of standing water and low levels of nutrients.

6.9.1 Plant Establishment

Growing media for BGG systems can have lower water content at the time of delivery than regular soil, so if there isn't much rain, the growing medium will need to be watered in order for plants to establish themselves. When planting woody plant material during winter, it is important to water early in the spring. This ensures high moisture content in the planting bed a few weeks before expected leafing. Watering should be deep enough and frequent enough that the substrate around root balls never risks drying out during the establishment phase.

Our experience of plants in BGG systems shows that trees planted in these types of growing media should have a well-developed root system and be cultivated in so-called root control bags. Planting in late fall should be avoided in areas that have a risk for cold winters.

Pits supply bioretention areas with oxygen and vent harmful gases while at the same time leading water directly to plant roots. Combining this with a good choice of plants creates excellent conditions for healthy and beautiful plantings. No plants, however, will be able to realize their natural potential if they are not well established at the growing site. In the period following planting, the plants will need maintenance, mostly in the form of water, which they cannot yet provide themselves.

When plants are well-established, they tend to thrive in BGG systems which results in strong growth. When their root system is healthy, trees and shrubs especially can grow very large; this needs to be kept in mind when choosing plants to mitigate issues with maintenance, namely the need for pruning. In other words, be sure not to choose varieties which grow very large.

On the next page are suggestions for suitable plant material for BGG systems which contain macadam-based growing media and superstructures.

Growing media for BGG systems can have lower water content at the time of delivery than regular soil, so if there isn't much rain, the growing medium will need to be watered in order for plants to establish themselves.

Suggestions for how an application of the vegetation concept presented in the master's degree project "Three-dimensional climbing plants" could look like. Here from a pedestrian street in Malmö.

Green inspiration! To read further visit: https://stud.epsilon.slu.se/18058/3/brattstrom-m-20220704.pdf

6.9.2 Three-Dimensional Climbing Plants

The text in this section is based on the master's thesis Three-dimensional climbing plants - the potential of using free-standing climbing plants as an alternative to conventional urban trees to create urban ecosystem services (2022) by Martin Brattström in the Landscape Architecture Program at Alnarp SLU.

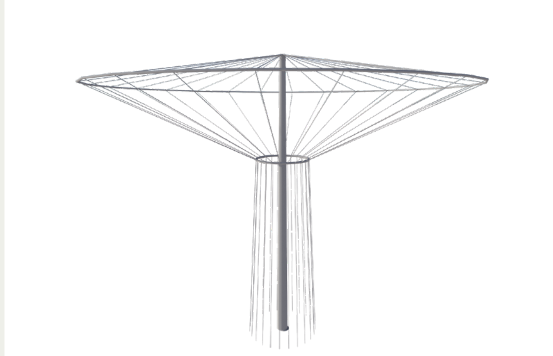
An interesting urban vegetation building concept that is on the rise is the so-called three-dimensional greenery, where climbing plants are used to create green volumes. By integrating three-dimensional greenery into BGG systems, it is possible to bring in volume-forming greenery even in places where the space for trees is limited. Above ground, the tree crowns compete for space with facades, lampposts and clearances, and below ground the tree's roots are crowded with wires and pipes. That results in risks where volume-forming trees have stunted growth or in the worst case are selected out. This also eliminates the important ecosystem services that the trees could otherwise have provided. The street does not get the much-needed shade during the hot summer day, cannot absorb the air pollution from the traffic, or regulate the wind when it blows.

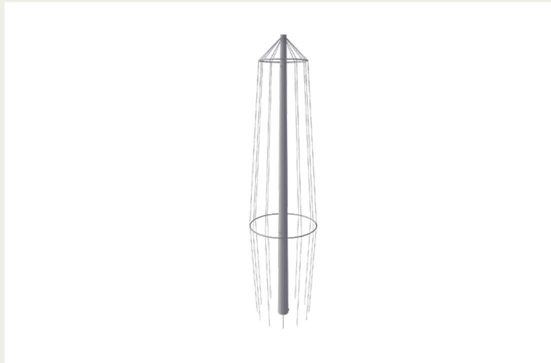
By offering climbing plants an independent climbing support designed for the purpose, it is possible to create volume-forming vegetation that can be tailored to the spatial conditions of the street space. The support gives the user the opportunity to adapt the climbing support according to the size of the street, the characteristics and requirements of the chosen climbing plant, and in some cases also which ecosystem service is to be benefited. This is done through a system where metal rings are suspended from wires anchored in a central post. By changing the number, size and order of the rings it is possible to control the shape of the support, and by adjusting the height of the center post and the distance between the wires it is possible to satisfy the wishes of the selected climbing plant.

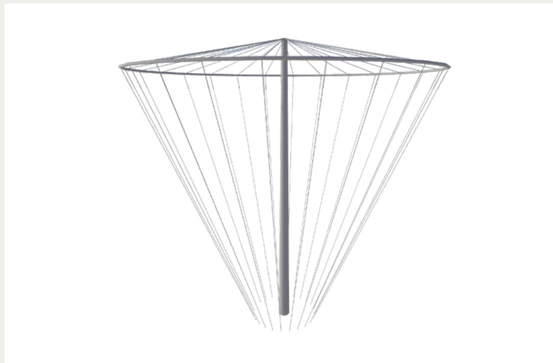
In addition to the above-ground advantages, a vegetation solution like this also has advantages to draw underground. Comparative studies on the distribution of biomass in climbing plants and trees show that with an equivalent leaf mass, climbing plants only have a root system half as large as the tree. This smaller root system favors the use of climbing plants in places where underground space is limited. The relatively smaller root system is made possible, among other things, by the fact that the roots of climbing plants do not need to have any anchoring properties, which trees need, because climbing plants instead rely on external support to be able to grow upright. For the same reason, climbing plants do not need to invest energy in extensive wood formation, but the plant group is instead characterized by the characteristically narrow and climbing trunks. This means that climbing plants can instead, as a rule, invest more energy in leaf and height growth. Consequently, a rapid greening can be expected, which can be relevant in places where the green transformation needs to happen immediately. Other advantages that a vegetation construction method like this can have is the possibility of working with a composition of climbing plants on one and the same climbing support. It not only provides an opportunity to create visual qualities but can also be a way to extend the flowering period for pollinating insects.

Knowledge of the ecosystem services that such a vegetation method with climbing plants would generate is today somewhat hampered by the sometimes deficient state of knowledge when it comes to climbing plants. The studies that have been made regarding the ability of climbing plants to generate ecosystem services in the street space show, however, that climbing plants can be successfully used to create shade, clean the air of pollution and locally lower the temperature through evapotranspiration. Regarding its ability to regulate stormwater, trials with species of climbing plants have been shown to have a good purifying effect on polluted stormwater with the help of its root system and plant bed.

A challenge when climbing plants are to be used in the city is that they usually have their natural origins in forest systems with a good supply of soil moisture. Climbing plants are therefore generally poorly equipped for the dry conditions that can occur in a city where there is a water imbalance. Using three-dimensional climbing plants in combination with a plant bed that utilizes the BGG system’s ability to take advantage of daytime and city water and make it available to plants can therefore increase the growing conditions of the climbing plants considerably. However, studies on the ability of climbing plants to stand for longer periods in the wet conditions that can periodically affect a stormwater bed are lacking today, and improving the general state of knowledge regarding climbing plants would also have been to encourage an evidence-based and target-focused plant use of the plant group.







Sketches of the climbing support developed in the degree project ”Three-dimensional climbing plants”. Through its design, the climbing support can be adapted to the conditions of the site and the wishes of the climbing plants.

Rain beds on residential land along the house facade for management of stormwater from the roof. Hagsätra, Stockholm.

6.10 BGG system on Residential Land

In our cities, there are often several functions that must be combined in a limited space. This lack of space shows up both on public land and on residential land where, for example, entrances, plant beds, bicycle parking, environmental houses and patios compete for space. Even on residential land, BGG systems can contribute to greater surface efficiency, flexibility and multi-functionality. Design of BGG systems on residential land may need to be adapted to a more mosaic-like surface design compared to a conventional street space where the design often results in straight BGG lines, which can be divided into rectangular surfaces with similar constructions. Along a house facade, the BGG system should therefore be adapted to the different measurements, depths and changing shapes that often occur on residential land. Calculations on a BGG system along the facade have shown that it can supply vegetation with water despite the absence of precipitation for at least two months. In addition to this, the system is able to handle the runoff from a rain of 20 mm from the roof. The possibility of supplementing BGG systems on residential land with alternative blue-green constructions is often very good. By connecting green roofs, swales, rainbeds and infiltration lines with an open subbase layer, new values can be created through sustainable stormwater management and irrigation of vegetation.

In general, stormwater from the residential land has a lower degree of pollution compared to stormwater from streetscape, as it often flows from the roofs of the properties or arises in the yard. However, there may be a need for cleaning even on residential land, for example from a street, parking area or similar.

By creating irrigation zones for stormwater, it is possible to minimize drinking water consumption for irrigation and instead use stormwater that is stored.

In connection with these surfaces, rain beds can be built. Around the courtyard there is a risk of traffic and compaction of the plant bed, which means that infiltration can decrease, and that the system can be blocked. Therefore, the location of rain beds should be chosen with care. If there are also large differences in height and a need for frames or L-supports to get to the surface magazine, there will also be a cost issue to consider. Where the need for cleaning is not as great, for example inside the courtyard, the vegetation surface construction can be used instead of a rain bed. The construction can be made shallower in a way that no surface reservoir is created, and the stormwater can be led directly down to the open subbase layer. In general, there is also a greater need for irrigation zones on residential land than in a street environment because the plant beds are usually forced to be made shallower and to be built on construction that doesn't have connection to subgrade. Distribution of stormwater can then be achieved by interconnecting the system below the ground surface. By creating irrigation zones for stormwater, it is possible to minimize drinking water consumption for irrigation and instead use the stored stormwater.

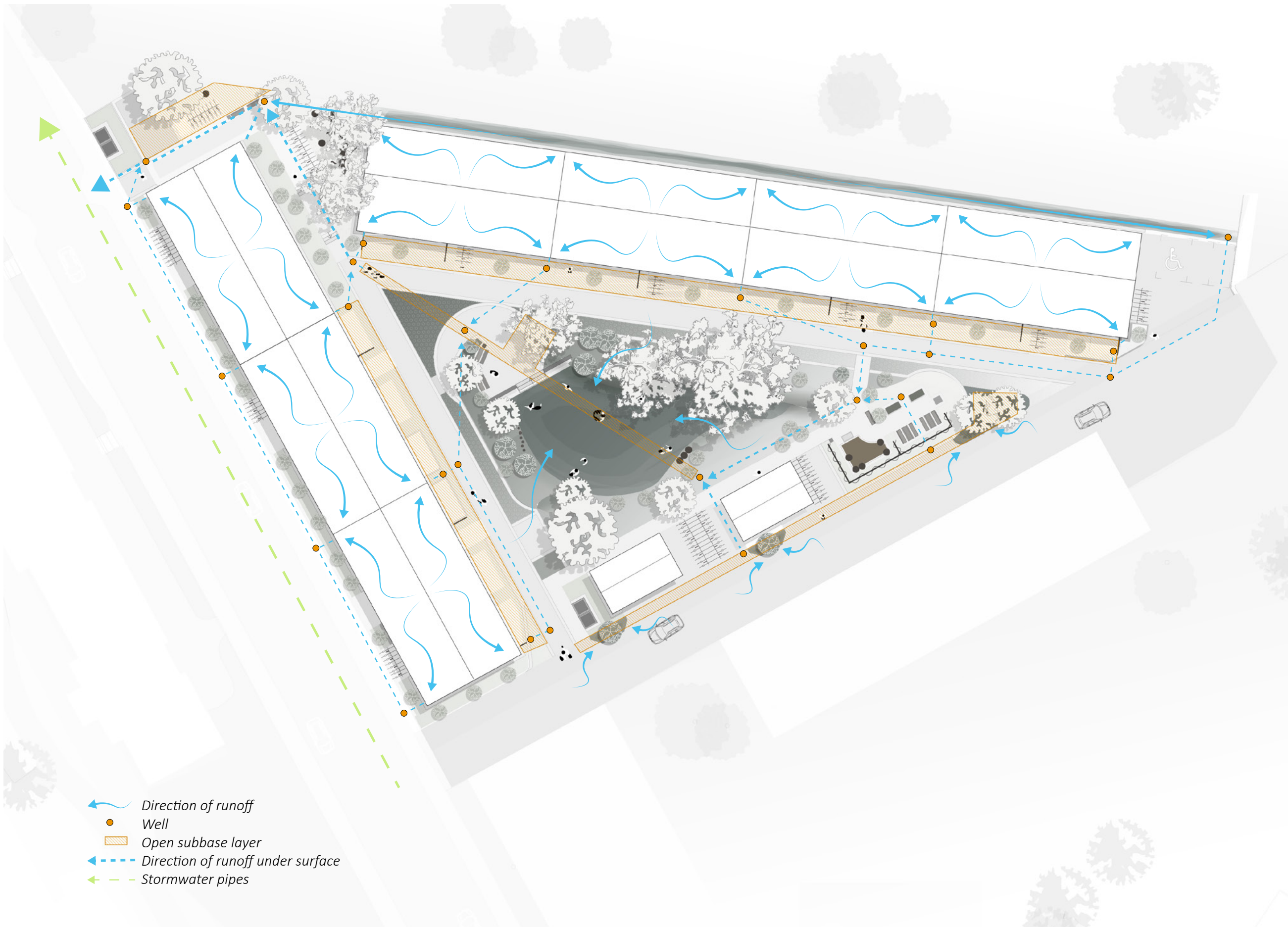


Figure 50. Illustration of housing estate with BGG system on residential land Bjurbäcken, Stockholm

Within residential land, catchment area identification can be difficult as house facades can form a large contributing surface. A reworked area calculation may therefore be required to obtain a more manageable surface, so that the dimensioned flow better matches reality. It should also be considered that water falling from a high ceiling height can cause erosion damage in the plant bed. It is not certain that a plant bed can be placed exactly where the downpipe is. The water can then be transported via a gutter, well or open subbase layer to reach the plant bed.

Parking lots with a permeable hard surface can be constructed as an extensive BGG construction under a larger continuous surface. If the location allows, it will work also to build BGG systems in the form of strips along the extensive permeable pavement.

Inside block land where there is generally a low traffic class, it is possible to use only macadam in all superstructures for hard surfaces. When using the same material in superstructures for the hard surfaces such as the open subbase layer, the number of fractions can be lowered. By using fewer materials and fewer fractions, installation errors and misunderstandings can be lowered. It can also contribute to keeping costs down, while at the same time the area for storage of materials during the construction process can be reduced.

When constructing a BGG system on residential land, it should be considered that the stormwater that is present during construction should not be led into the open subbase layers if it has not been cleaned of sediment first. In general, water from construction site can contain very large amounts of sediment that can clog the system when it arrives in these quantities in a short time. One recommendation is to install temporary pipes during construction, for temporary stormwater management during the construction period. Building courtyards on construction, for example above a parking garage, is relatively common today. Load and depth for BGG systems placed on a construction is limited and is governed by what load is allowed. This at the same time as the vegetation makes demands on plant substrate and access to water. When designing, knowledge of the location's conditions, construction and plant selection is required. To avoid risks such as leakage of water in the building structure, the system should be built with root protection and the right drainage for the specific location. If stormwater is to be delayed, it is possible to replace the macadam in the BGG system with pumice or hasopor to increase porosity and reduce weight. This allows the

Figure 51. Illustration of a continuous stripe with an open subbase layer along the house facade and courtyard street.

dimensioning depth to be reduced. If there is a greater need for stormwater storage, stormwater cassettes can be used instead of pumice to further increase capacity per surface unit. By using a rainwater cassette, the porosity increases to 95–98%.

Rain bed on neighborhood land that takes care of stormwater from surrounding asphalt surfaces and roofs. Södertälje. Photo: Fredrik Ohls.

Figure 52. Illustration of individual constructions with an open subbase layer along the house facade and courtyard street.

Permeable hard surface on open subbase layer with joints of grass on residential land. Rosendal, Uppsala.

7 Dimensioning

Dimensioning a BGG system is done based on the requirements for the system and local site conditions. Systems which are adapted for maximal stormwater retention are dimensioned differently than systems adapted for maximal purification. The design and choice of ground level components have an impact as well. The most commonly calculated attributes are retention volume, flow rates, available planting area volume and the degree of purification.

7.1 Dimensioned Flow

The dimensioned flow is the amount of water per unit of time which comes into the system during a dimensioned rain. It is affected by both precipitation intensity and shape of the drainage area. To calculate dimensioned flow, one also needs to know the return period and duration of the dimensioned rain. The municipality and water utility company can suggest benchmark values, otherwise guidance can be found in Swedish Water publication 110.

Dimensioned flow is used to determine the construction of components such as inlets, the choice of pit and erosion protection as well as the size of pits and pipes that will be needed. The flow is calculated with the formula below, called the rational method.

Intensity-duration-frequency (IDF) curves have been created based on statistics for various return periods. These show the greatest precipitation intensity per unit of time that is expected within a certain return period, as a function of duration. Depending on the return period of the dimensioned rain and duration, one can thus read from the curve how much rain intensity can be expected. Swedish Water publication 110 contains a number of curves one can view.

The size of the catchment area and its degree of soil sealing influences the amount of water that will reach the BGG system. For this reason, the formula below makes use of a runoff coefficient which is a measure of how much a surface within the catchment area contributes to surface drainage. The size of the coefficient varies between zero and one, where a higher number represents a higher proportion of runoff. One can find a table which contains values of runoff coefficients for various surfaces in Swedish Water Publication 110.

Since rain statistics are built upon historical data, a climate factor is used to allow for expected increases in precipitation amounts due to climate change. SMHI, the Swedish Meteorological and Hydrological Institute, often has guidelines for the value that should be used for dimensioning stormwater facilities.

A calculation should also be done regarding transport flow within the open subbase layer. To calculate transport flow, see ***Fördröjning av dagvatten med dränerande markstensbeläggning*** from Svensk Markbetong (Swedish Concrete).

Rational method

Dimensioned flow [l/s] = rain intensity [l/s ha] • drainage area [ha] • drainage coefficient [-] • climate factor [-]

7.2 Discharge Rate

BGG systems are developed to ensure that water is retained for short periods in the superstructure without taking damage under traffic loads. This is achieved party by designing the system so that is emptied within 24 hours after a dimensioned rain, excepting a potential artificial groundwater zone. Discharge flow is determined by the relation between the desired discharge time and the retention volume as well as potential requirements for limited release to sewer lines.

7.3 Retention Volume

Open subbase layer and retention zones in bioretention areas are examples of reservoirs that can retain stormwater. The required retention volume in a BGG system can be comprehensively calculated with the rain-envelope method. This method produces the required retention volume by calculating the maximum variance between water flowing into and out of the system. The volume is adjusted to allow for both porosity of the open subbase layer and the slope of the subgrade.

Below is an example of how retention volumes in a BGG system can be calculated, both in a reservoir with open subbase layer and in a bioretention area's retention zone. Additional information can be found in Swedish Water publications P104 and P110 as well as the publication The Rain-Envelope Method (Sjöberg 1982).

7.3.1 Example Calculation: Reservoir with Open Subbase Layer

A unit of open subbase layer is 25 m long. The street it is laid in has a slope which is repeated in the subgrade. When the unit is filled up with stormwater, the end lying lowest will fill up with more water than the end lying highest. At the lowest end, the volume of water has a cross-sectional area of 3,7 m². At the highest end the respective cross-sectional area is 2,3 m². Since the street slopes evenly, a mean value for area can be used in the following calculations. The mean cross-sectional area is multiplied with the length of the unit to determine its volume. The open subbase layer is filled with coarse macadam, for example 32/63, that has 40% porosity. Only this part of the total volume is therefore available for water retention.

$$\text{length} \cdot \frac{\text{higher cross-sectional area} + \text{lower cross-sectional area}}{2} \cdot \text{porosity} = \textbf{retention volume}$$

▼

$$25\ \text{m} \cdot \frac{3{,}7\ \text{m}^2 + 2{,}3\ \text{m}^2}{2} \cdot 0{,}4 = \mathbf{30\ m^2}$$

▼

The **Retention volume** in this unit with open subbase layer is thus **30 m³**.

7.3.2 Example Calculation: Retention Volume of a Bioretention Area

A bioretention area is 6 m long. Its growing area is slightly concave with a horizontal bottom. The retention zone has an average cross-sectional area of 0,45 m2. To calculate the retention volume, the length is multiplied with the average cross-sectional area.

length · cross-sectional area = **retention volume**

▼

6 m · 0,45 m² = **2,7 m³**

▼

The **retention volume** in the bioretention area's retention zone is thus **2,7 m³**.

A volume for factors of safety as well as volumes of sedimentation and roots should be subtracted from this volume.

7.4 Planting Area Volumes

Planting areas with large trees and shrubs usually lack sufficient volume in urban environments. A tree needs approximately 10-30 m³ available for its roots depending on size. Without this, the conditions needed to grow normally and develop into a healthy, beautiful tree with high resiliency are not met. Insufficient planting area volumes force the tree to search for water and nutrients outside of the planting area or stay underdeveloped and a potential risk for its surroundings.

7.4.1 Example Calculation: Planting Area Volume

Three trees are growing in a planting area in open subbase layer. The planting area lies above a strip of open subbase layer 25 m long. The trees' roots are able to grow through the entire strip. The total area available to roots is made up of both growing medium and open subbase layer. The mean cross-sectional area for these layers is 3,6 m². The trees therefore have access to a total volume of:

length · cross-sectional area = **planting area volume**

▼

25 m · 3,6 m² = **90 m³**

▼

This constitutes a **planting area volume** of **30 m²** per tree within the BGG system, volume which is well-aerated and has access to water.

7.5 Degree of Purification

The most efficient stormwater purification is achieved in bioretention areas. Water there is treated with filtration, adsorption, and taken up by plants and microorganisms. Bioretention areas should have a surface area corresponding to 2-10% of the total drainage area in order to have sufficient capacity and be economically tenable. If they are connected to a continuous strip of open subbase layer, 2-5% of the drainage area will suffice. Additional purification will be done in the open subbase layer (see section 6.3.3).

The degree of purification attained depends to a large extent on which pollutants are present, how the street is designed and how much pressure is put upon it. Complete dimensioning with respect to purification falls outside the scope of this handbook. It is, however, recommended to use simulation programs which have information on typical pollutant levels and purification capabilities. Alternatively see the Swedish Water report *Kunskapssammanställning dagvattenrening.*

7.6 Tree's water demand

Lindsey & Bassuk have developed a formula that is often used to calculate a tree's water consumption. By calculating the relationship between the tree's crown projection (CP) and leaf area index (LAI) and with information on the potential evaporation, the tree's daily water consumption (DWC) can be estimated. The crown projection refers to the area below the tree's drip line and is usually calculated as the area of a circle. LAI is a description of how large the total leaf area of a specific tree is in relation to the area of the tree crown.

For example, an LAI of 3 says that for every square meter of crown area there are 3 square meters of leaf area. The index varies between 1 and 12, but a value of 4 can be seen as a relevant maximum, as values above this increase the internal air humidity of the tree crown, which in turn counteracts a further increase in evaporation. For columnar trees, however, an increase to 5–6 is relevant due to the design of the tree crown. If the vegetation area is created with undergrowth in the form of ground cover and lower bushes, the LAI should be compensated for this and adjusted up to 5.

The evaporation factor, k, considers the actual evaporation in relation to the potential evaporation from a water surface. Under optimal transpiration conditions this factor is 0.3.

Equation for a tree's daily water consumption DWC = CP · LAI · PE · k

At the same time, they point out that the real evaporation decreases with increased size of the tree crown and already for tree crowns > 1.2 m2 the evaporation factor is down to 20% of the real evaporation. It is estimated to be able to decrease further for even larger trees as the internal leaf shading increases.

Lindsey & Bassuk have also developed a way to calculate an adequate plant bed volume by focusing on the trees' water needs. The trees' daily water consumption is calculated according to the previous equation.

At least approx. 2.5 mm of precipitation is required before the interception layer is full and that the plant bed should be able to begin to absorb the precipitation and refill the soil's pores with water. The calculation method requires knowledge of the amount of plant-available water (PAW) that the substrate can hold, the rainfall frequency (RF), i.e. that interval between a given amount of rainfall, as well as the daily water consumption (DVC).

The method is well-proven and can be adapted to the climate that prevails where the plant bed is planned. Some weaknesses in the calculation are the assumption that the plant bed will be completely replenished by precipitation alone at a given interval, which is not always the case, as well as the use of an average value for evapotranspiration.

Equation for a tree's plant bed volume based on water demand Plant bed volume = DVC · RF / PAW

DeGaetano has developed a method to calculate how much plant bed volume a tree needs in order not to be exposed to water shortages during a given return period. He developed Lindsey & Bassuk's calculation and carried out in his study simulations with climate data to see how often trees are exposed to water shortages during a certain period. In the new model, they have considered that the trees' daily water consumption decreases with reduced soil moisture and therefore added an adjustment factor to the equation for a tree's plant bed volume based on water demand.

The adjustment factor depends on the plant-available water found in the soil, every single day. In the method, 10% of the plant-available water is used as the limit for when the soil is considered so dried out that it damages the tree. However, the trees can be damaged before this limit. A plant bed that survives 12 days without water addition dries out five times over a 10-year period, which then corresponds to a return period of 2 years. The study also examined what volume the plant bed needs to have for it to dry out only once during a given period. The result can be seen in table 12 on the next page.

The results come from simulations made with meteorological data from Boston, Massachusetts, USA. The simulations are based on the fact that only one tree is found in the plant bed and possible surface runoff that is led to the plant bed has also not been taken into account. The plant bed is supplied with water solely through precipitation. In the simulations, the amount of plant-available water has been assumed to correspond to 15% of the volume of the plant bed.

The results show that a ratio between the volume of the plant bed and the tree's crown projection of approximately 0.2 m3/m2 results in the plant bed drying out on average every two years. But just by increasing this ratio to approximately 0.33m3/m2, the return period is increased to 50 years.

The trees in BGG systems may have a better opportunity to recover during shorter showers and less rain as the runoff is actively directed to the system making them less sensitive to longer periods of drought. How often drought of a certain length recur has received little attention in society. From an international perspective Sweden has been relatively spared from severe drought.

For Uppsala the average dry period during the vegetation period for the period 1931-2020 has been on average about 15 days long. The length of the dry periods varies relatively strongly between years. However, the longest dry period has been close to or over 30 days long for each of the three normal periods, see figure 53.

However, it may be more relevant to study how frequently a certain length of drought has occurred historically, see figure 53. For the normal period 1931–60, dry spells lasting at least 10 days occurred on 45 occasions, for 1961-90 and 1991-2020 the number was occasions 53 and 63 respectively. Which could indicate a trend where longer dry periods have become more frequent. However the long dry spells lasting 15 days or longer are rare and for the most recent normal period they accounted for only about 5% of the occasions, which is slightly more than for the previous periods.

Canopydiameter [m]	Volume for given return period [m³]				
	2 years	5 years	10 years	25 years	50 years
2	0,5	0,6	0,6	0,8	0,8
4	2,5	3,1	3,6	3,9	4,2
6	5,4	7,1	8,1	8,8	9,3
8	9,6	12,5	14,1	15,6	16,5

Table 12. Plant bed volumes in m3 for different sized trees for a given return period when the plant bed dries out without irrigation. The reported values in the table are results taken from DeGaetano (2000)

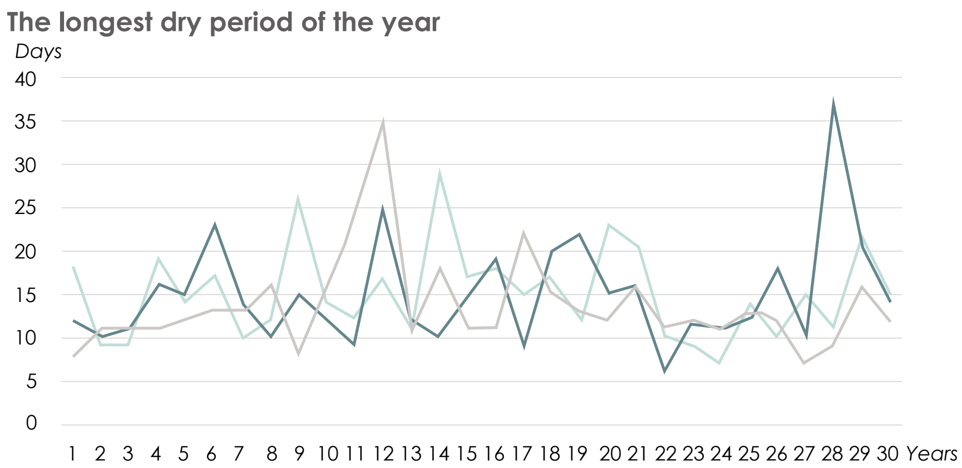


Figure 53: Number of days for the longest continuous dry period for the period April-September. Compilation of data retrieved for measuring station Uppsala Aut (SMHI u.å.[c]).

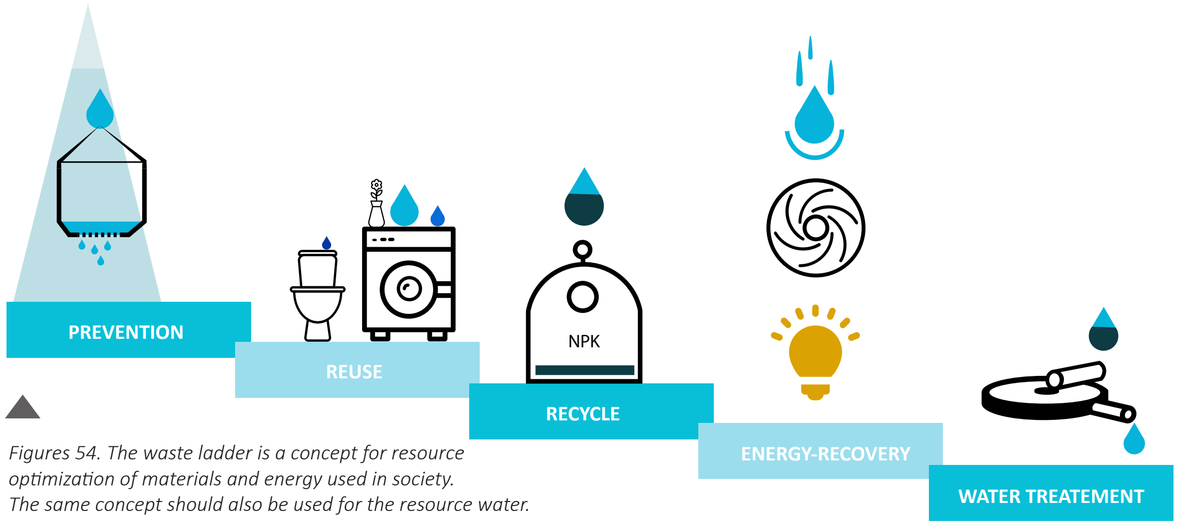
8 Extras

In this chapter, we will go into depth and broadening of various aspects of BGG system. It will relate to both the planning process and detailed planning of BGG systems1

8.1 City Water – extra

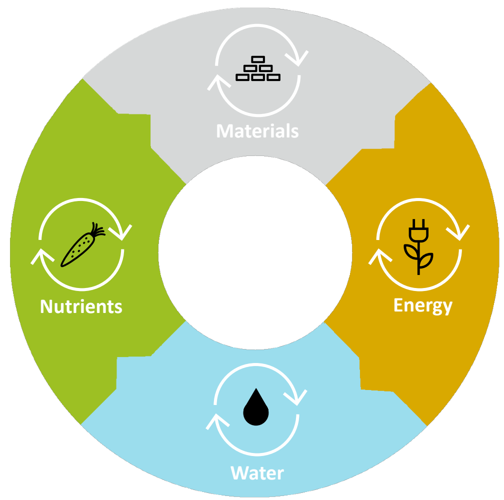
Today most resources such as materials and energy are consumed in a linear flow. Natural resources are extracted, produced, consumed and disposed of. However, there are examples of circular material flows. For most people in Sweden it has been taken for granted to sort and recycle their waste, which is based on a concept called the waste ladder (resource optimization ladder). The waste ladder is a principle with the goal of creating a circular flow of resources by working in several steps with preventive measures, reuse and recycling of materials such as plastic, glass and metals, etc.

Human use of water is almost always linear. In contrast the water cycle, the hydrological cycle, is naturally circular. Today's conventional water systems send water from wells to water treatment plants and then to buildings. The water is then used by many different actors for a variety of purposes. After use, it is flushed down drains or wells, or infiltrated into the ground. The water that is categorized as wastewater, i.e. most waste water from buildings, is directed directly to the regional treatment plant for treatment. The waste water is purified and directed directly into the recipient. Stormwater is also diverted away, either to a treatment and delay facility or straight to the recipient without any use whatsoever. In order to optimize the potential of water in society and reduce its negative impact as a result of the linear water system, such as floods, water shortages and high costs for infrastructure, the principle and mindset of the waste ladder can also be applied to the resource water for a circular water use.



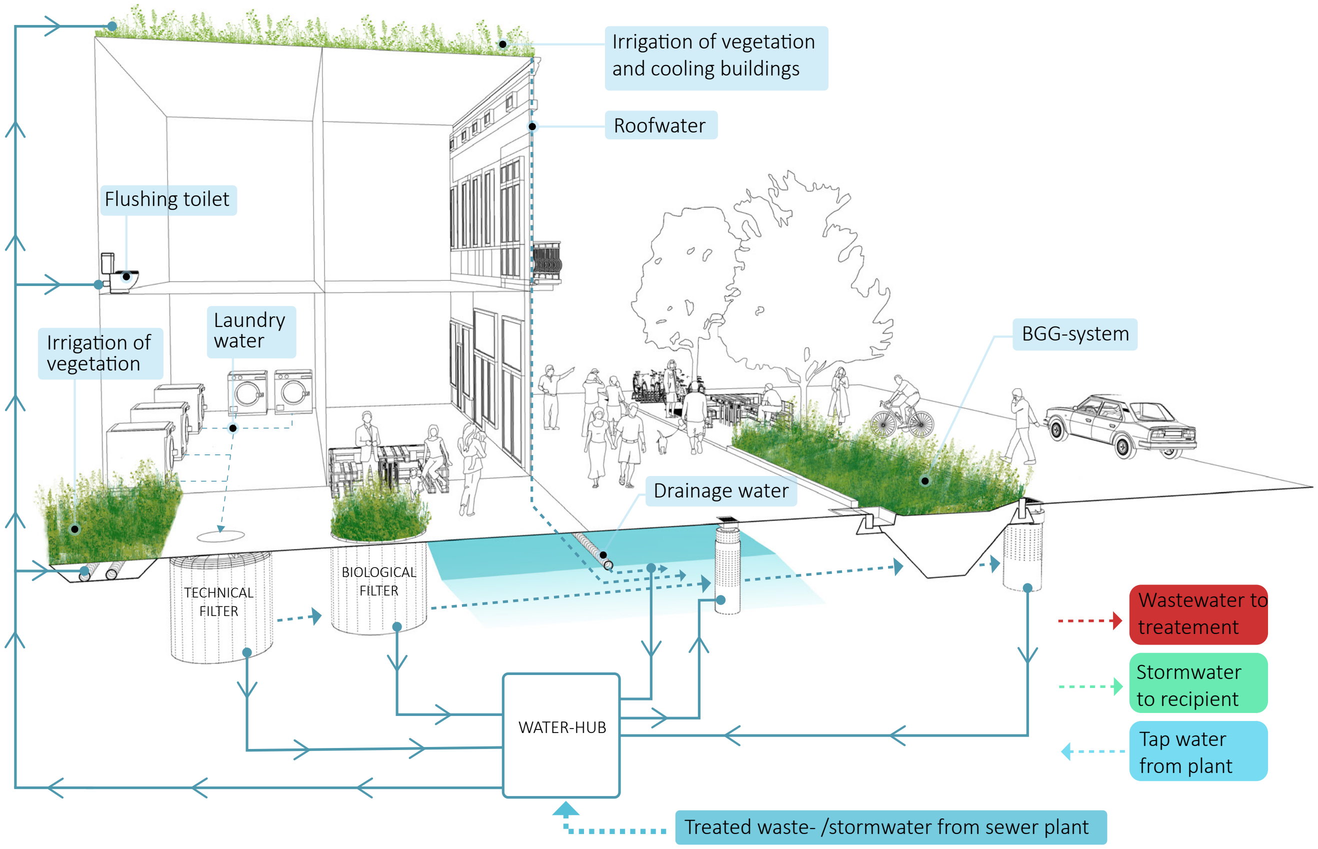
Figures 54. The waste ladder is a concept for resource optimization of materials and energy used in society. The same concept should also be used for the resource water.

Illustrates the principle of a society based on circular materials and energy flows where water will become an important resource to circulate.



Prevention - Resource optimization of water according to the waste ladder requires preventive work. In this case, preventive work would mean minimizing the consumption of drinking water and the generation of waste and storm water and then also pollution in them. This can be done through the exclusion of water in processes, sparingly flushing fittings and nozzles, irrigation bans and behavioral changes linked to water use. Through nature-based solutions such as green roofs, vegetation surfaces and draining covering, the occurrence of stormwater can be reduced.

Figure 55. Use of drainage water for local irrigation and use where drinking water quality is not required.



The volume of drainage water from a residential plot where the groundwater level is lowered by one meter can be between 0.4–60 m³ per day.

Reuse - The drinking water from the treatment plant is not used at all largely for actual drinking. Is there then a need for all water to still achieve drinking water quality? Different types of water can be produced and used for different purposes. Instead of continuing to expand freshwater withdrawals, especially in places where there is a great shortage, water treatment and use could match the needs of users in order to ensure society's water resources. All water should be seen as a resource and must be reused as many times as possible before discharge to the recipient- with as short distances as possible.

One flow that today is diverted away is drainage water from buildings. It resembles groundwater in terms of quality, it has a continuous flow and can be relatively easily collected for reuse in connection with re-digging or new construction. The volume of drainage water that is currently led to the VA network can be very large and can exceed both waste and stormwater volumes on an annual basis. The volume of drainage water from a residential plot where the groundwater level is lowered by one meter can be between 0.4–60 m3 per day. By connecting the drain water to the BGG system instead of the traditional VA network, it would leave room in the network, not be mixed with pollutants from other fractions, but used locally in its existing, often good water quality. For example see figure 55.

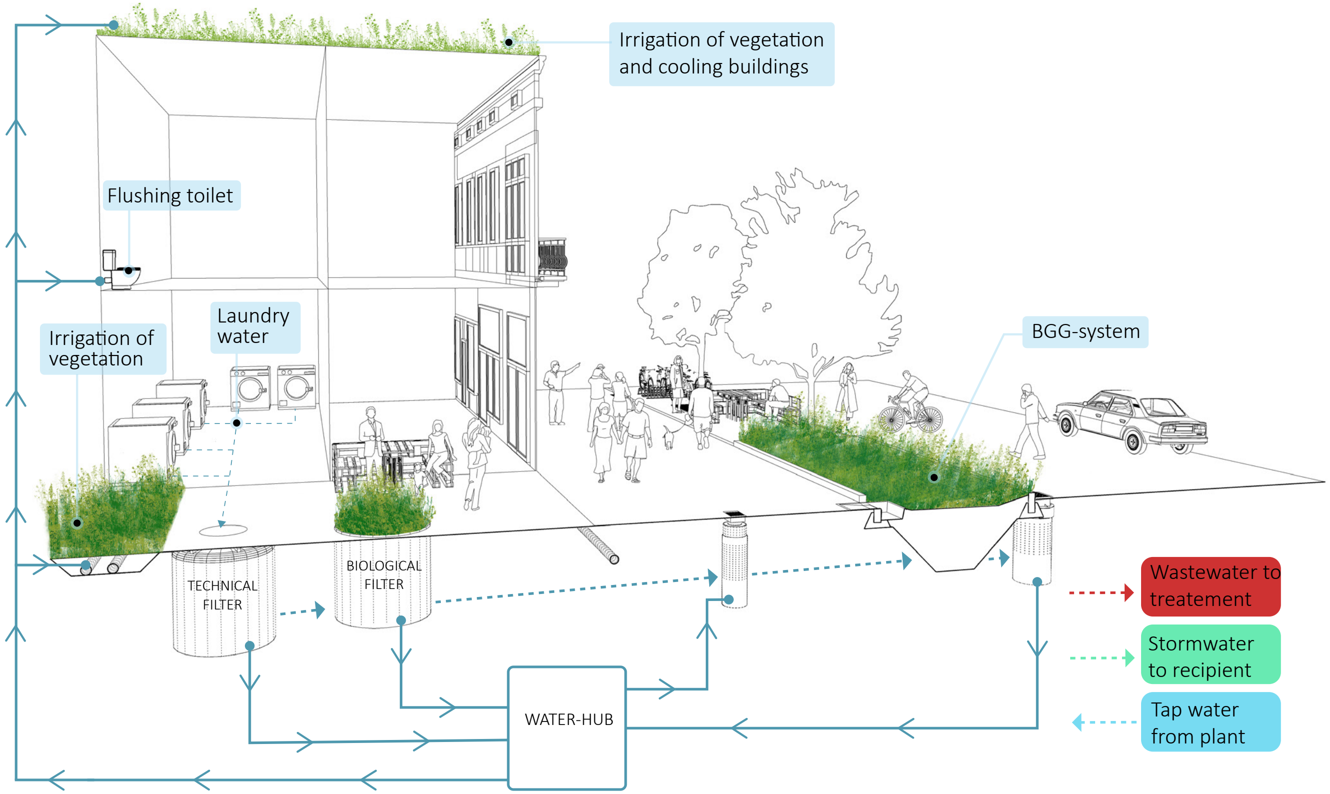
Gray water reuse is another interesting and growing idea but it faces practical problems as it is difficult to distinguish it from toilet water in existing properties and it is also quite polluted. However, there is a fraction of gray water that can be diverted relatively easily to another use, namely laundry water.

Laundry water can correspond to 10% of drinking water consumption. From a stairwell in an apartment building, the amount of water can be 1 m3 per day. Storage of, for example, drainage and purified storm water and washing water in so-called water hubs are an example of a system to achieve a more even supply of water for irrigation, cooling, flushing toilets and other needs that do not require water of drinking water quality, for example see figure 56. Even shower water could be separated from the wastewater and led to BGG- system after purification.

Material recycling - Stormwater can contain significant amounts of organic matter and nutrients that could be recycled and made available to vegetation through irrigation. For example see figure 57.

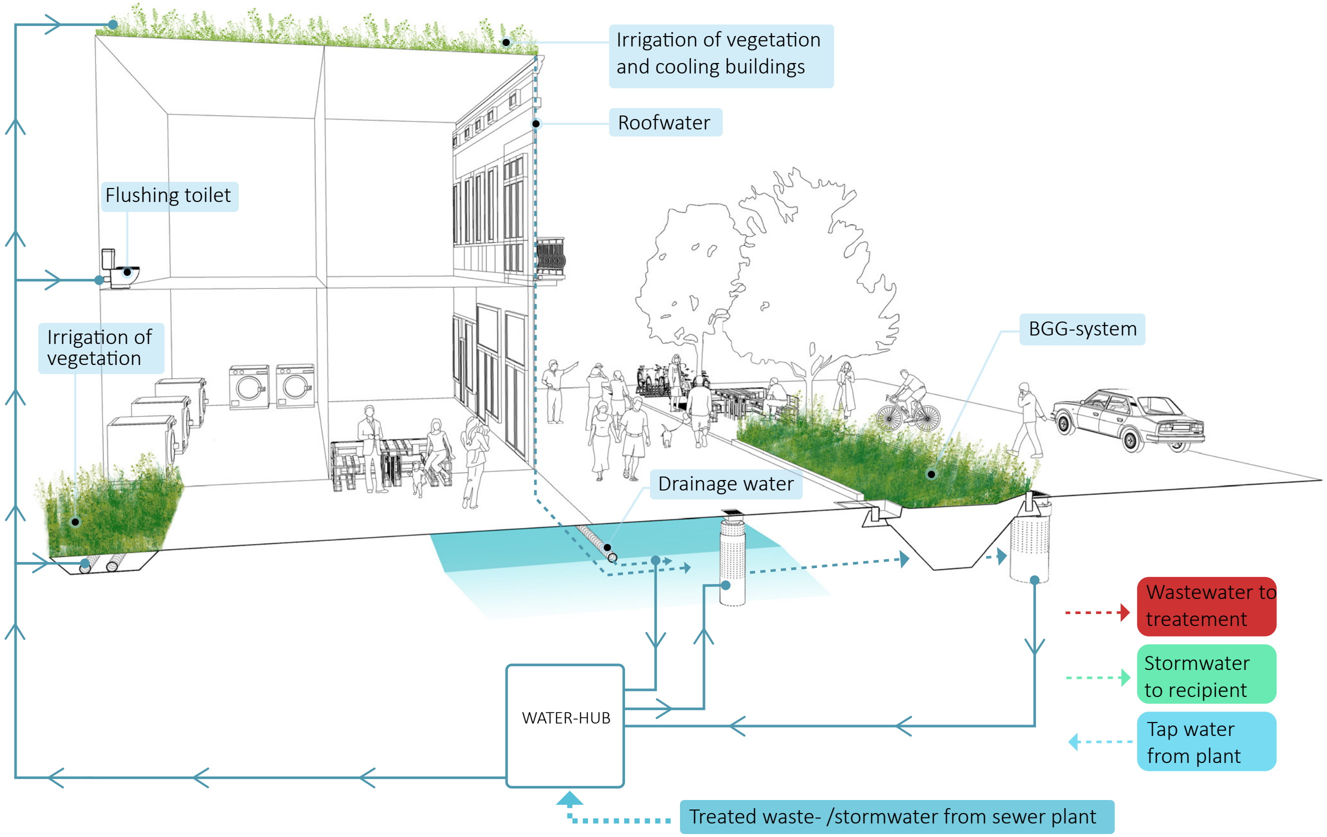
Energy recovery - Waste water leaving our properties can contain a lot of heat energy. Instead of letting it go with the waste water from the property, the energy could be recycled within the property.

Treatment plant/recipient - Through small changes, we can greatly reduce the amount of water that needs to be piped in and out of an area and ultimately reaches the recipient or treatment plant, and thus also the need for infrastructure. Through an integrated reuse of City Water, waterworks, treatment plants and pipeline networks can be relieved.



Washroom water can correspond to 10% of the drinking water consumption. From a stairwell in an apartment building, the amount of water can be 1 m³ per day.

Figure 56. Use of laundry water for local irrigation and use where drinking water quality is not required.



The City Water concept is based on the following principles:

- All water should be seen as a resource and should be reused as many times as possible before release to recipient – with short distance as possible.
- Minimize inflow and outflow to the property self-sufficiency of water consumption should be in primary focus.
- Start with the least contaminated water.
- Purify the water to the level required for selected use – no more and no less – and use robust blue-green-grey technology.
- Continuous flows have the best potential lasting benefits.
- Identify synergies and multi-functional installations on residential and public land.

Figure 57. High level example of the City Water concept incorporated with BGG system.

8.2 Challenges

Below we compare BGG systems to the traditional way of building streetscapes, i.e. streets where blue, green and grey infrastructure do not work together but instead stormwater is directed directly to the recipient by way of pits and sewers.

PROJECT PLANNING

BGG systems require more of the planner because of the knowledge required of their own area as well as other technical fields. Cooperation is also necessary with additional technical areas in order to make sure that volume (of reservoir capacity and bioretention area capacity) is not occupied by other technical areas. This could be an issue with backfilling around foundations for light posts and road signs or intersecting utility lines, for example.

Utility lines that cross into and introduce breaks into the open subbase layer can introduce serious complications into the system, so it is of great importance to coordinate utility infrastructure. The same is true for backfilling foundations if the section allocated to BGG systems is too narrow.

BGG system design should be done in 3D in order to prevent issues, however few contracting authorities are ready to pay the additional costs for this. Existing programs are designed for traditional construction which makes 3D design of BGG systems more difficult. For this reason, not many designs are done in 3D.

MAINTENANCE

Knowledge of how to operate and maintain BGG systems has been accumulating for several years. The individual elements, however, are much more common and have been implemented in the past 5-30 years. Conditions for vegetation in BGG systems are better than in traditional vegetation areas in public squares, parking areas and street environments, which leads to increased plant growth. Maintaining vegetation in BGG systems is similar to that of conventional vegetation areas.

In some municipalities, maintenance workers take short education courses before they start taking care of BGG systems. This increases their confidence and ensures proper system function. Since there are more components than in a traditional system, maintenance of water and sewer components (pits, pipes and stormwater chambers) is expected to increase somewhat. This is offset by a much greater retention and purification effect than in a traditional system with just pits and sewer lines.

TIME

Compared to traditional streets and stormwater management systems, these systems take a longer time to both design and construct. The process can be more complicated in existing built-up areas than in new developments because there are more parameters to oversee.

PURIFICATION

Due to the lack of research regarding purification levels of this type of serially connected elements, it is difficult to know exactly how clean the water will get. There is a risk that phosphor will leak from the biochar and compost into the stormwater pipe system during the establishment period before microscopic life and vegetation have developed, but in the long term the system will serve as a phosphor trap. To counteract this drawback, it is possible to install a special phosphor trap into the system or downstream before stormwater reaches the recipient.

FUTURE EXCAVATION

The system can cause a higher workload when excavation or restoration is required in the future. This is especially the case if the system has been sealed with textile to prevent percolation into groundwater. To ensure proper system function after reconstruction, the requirements set out in the excavation manual should be met. Photographic documentation should also be done to prove that critical steps have been performed correctly.

VEGETATION

The current state of knowledge regarding which plant varieties should be used in BGG systems is lacking and needs to be researched further. When choosing plant varieties, it must be taken into account that vegetation will have the opportunity to develop into full-sized individuals, i.e. trees can grow up to 20 meters high and wide. Choosing trees that can grow large can generate a great deal of pruning work, particularly near building facades. Generally speaking, the system and its vegetation can handle stormwater containing road salt, but if the system is loaded with high amounts of salt, salt tolerant plants should be chosen for the area.

Another challenge is that the protective distance between water and sewer components and trees is reduced in BGG systems. Control pits must often be placed near trees because the distance between trees can be limited. Additionally, dispersion pipes (drainage pipes/stormwater chambers) need to be placed more or less under trees due to a lack of space. There have not been any reports of tree roots growing into gas exchange pits but there is a risk that this can happen.

MATERIALS AND COMPONENTS

At the present time, the availability of material suppliers and components is more limited than for conventional systems. Because of this, it can be difficult to ensure that all components are classified according to the project's current certification. Once the system becomes more commonly implemented, there is an increased likelihood that the available supply will increase along with it.

COOPERATION

BGG systems require both healthy cooperation and collaboration in order to achieve a good result. This applies to the entire duration of the project and includes everything from utility management to the consultants doing the planning. Contracts should be drawn up between administrations, utility management and construction companies depending on how responsibility will be divided. BGG systems are cross-boundary projects that encompass several technical areas. Consultants should make clear lists where boundaries will be drawn so that is straightforward which technical area is responsible for each aspect of the project.

CURRENT KNOWLEDGE

There can be gaps of knowledge between consultants and the contracting authority because the way of working with BGG systems differs from conventional construction. There may be a need to train all people working on the project before, during, and after the project is finished.

Another challenge is that there isn't always a perfect answer for all questions and issues. One risk factor we have noticed is the clogging of open subbase layer and regulator components if the system design has not taken sedimentation into account.

DESIGNS GET "LOCKED IN"

BGG systems can be built in several stages, for instance when built in new developments. Open subbase layer and pits are installed early in the process and are then covered with base layer (bound or unbound) while construction takes place at the building site. It is difficult to move the system once it has been laid, but it is possible to lay a new system which can be connected to the existing one. One can avoid reworking the system by more or less "locking in" the design and being sure that all investigations have been completed (e.g. traffic analysis relating to the turning radii of dimensioned vehicles, ensuring an adequate amount of HKP, and more) by the time BGG system construction begins. It is possible, however, to shift the position of different components at ground level up until they are constructed.

AMA

Today the Swedish AMA building standard reference guide (and perhaps others internationally) is not adapted for BGG systems, which require multiple infrastructures to cooperate with each other around the same area and volume. Since many components, materials, and practical tasks do not have standard codes in the AMA for construction, planners need to create a number of new codes. When more people start working with BGG systems, there is an increased possibility that these new codes will be brought into the official AMA.

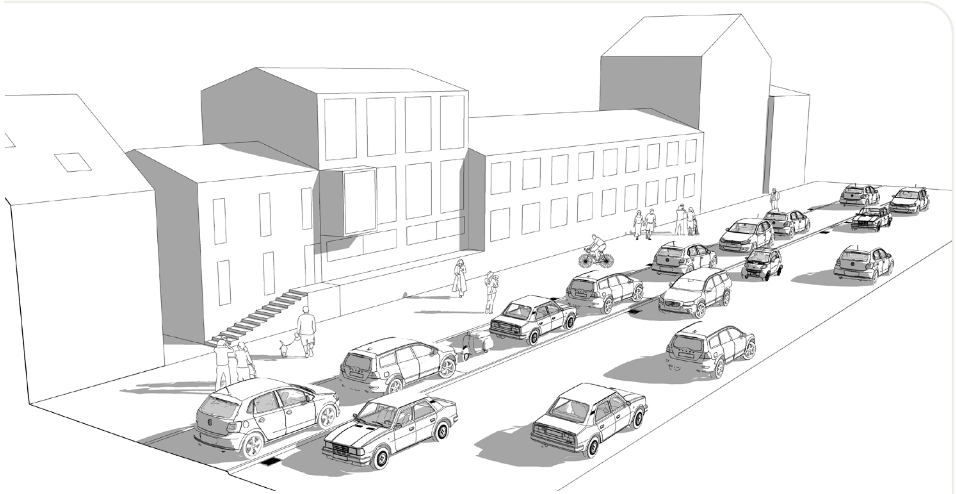
8.3 Impacts

In this chapter all the examples are based on a continous BGG system with higher demands.

STREETSCAPE WITH BGG SYSTEM

A streetscape focused on human beings and where vegetation is allowed to thrive; this creates attractive and resilient streets with a comfortable microclimate. Drainage is handled by the BGG system, which can be implemented even if 95% of the street is covered in hard surfaces. The street can be dimensioned for traffic class 2.

STREETSCAPE WITH CONVENTIONAL STORMWATER MANAGEMENT

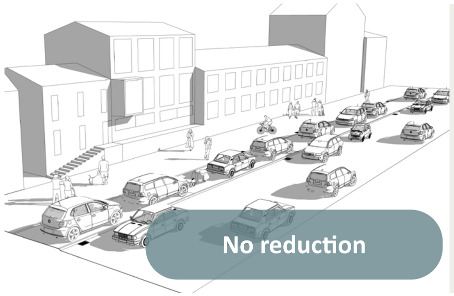


A streetscape focused on cars, with no notable vegetation. Blue, green and grey infrastructure do not cooperate. Stormwater management is done using traditional methods whereby it is directed to pits and through sewer lines to the recipient. The street can be dimensioned for traffic class 2.

IMPACT ON CARBON DIOXIDE REDUCTION WITH BIOCHAR

In a BGG System carbon dioxide can be stored as biochar at a possible amount of 135-300 ton CO_2e/ha.

Read more at:
https://bluegreengrey.edges.se/article/urban-space-as-carbon-sink/



No biochar- no effect on carbon dioxide reduction.

STREETSCAPE WITH BGG SYSTEM

STREETSCAPE WITH CONVENTIONAL STORMWATER MANAGEMENT

IMPACT ON WATER FLOW

Stormwater flow is slowed by areas of vegetation but is also safeguarded by flow regulators in control pits. This results in a stormwater outflow of 5-30 l/s/ha including climate factor 1.25.

Water flow is not slowed down. Stormwater flow generated by the street itself is also directed to stormwater pipes. A 10-year rainfall (with a duration of 10 minutes) can produce a flow of around 250 l/s/ha.

IMPACT ON RETENTION

The system is dimensioned for at least a 30-year rainfall including climate factor 1.25. The system can retain 40-100 mm of precipitation from the street including front yards and 50% of roof runoff from nearby properties.

The sewer system is traditionally dimensioned for a 2- to 10-year rainfall and lacks the ability to retain water onsite.

IMPACT ON POLLUTION LOAD

Bioretention areas have shown to produce an impact on purification. Studies are currently underway to measure purification levels in BGG systems. Keeping in mind that BGG systems purify water with the help of biochar, plant roots, microbiotic life, filtration and sedimentation, they are expected to make a purification level of 70-80%

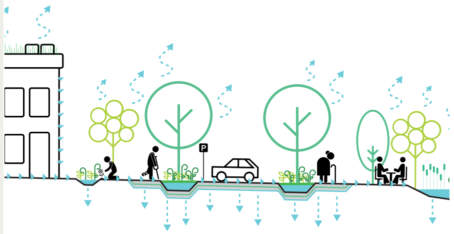
No purification. Stormwater is led out of the area unpurified.

STREETSCAPE WITH BGG SYSTEM

STREETSCAPE WITH CONVENTIONAL STORMWATER MANAGEMENT

IMPACT ON GROUNDWATER LEVELS

Stormwater infiltration in BGG systems results in increased groundwater recharge. In addition to increasing water availability to vegetation, it also lowers the risk for settling due to lowered groundwater levels, which otherwise can result in cracking in both building facades and constructions.



Little or no inflow of precipitation to groundwater causing lowering of groundwater levels which can cause expensive damage to buildings.

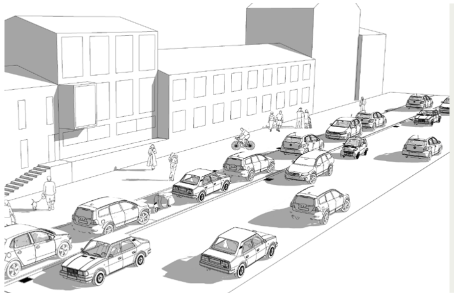
IMPACT ON PLANTING AREA VOLUME AND WATER ACCESS

Planting areas in BGG systems are at least 15 m³ per tree, and usually much larger. Roof runoff can be directed to planting areas which improves access to water even during drier periods. The system is adapted to be able to collect city water (drainage and grey water) in the future.

It is not unusual to see traditional planting beds with planting volumes of 1-2 m³. Additionally, drainage that could go to planting areas is not made use of for watering.

IMPACT ON BIODIVERSITY

Integrating more vegetation and plant varieties in our urban environments improves the opportunities for microorganisms, plants, and animals to survive and flourish. Green corridors between green areas further improve circumstances.



Little or no effect on biodiversity.

STREETSCAPE WITH BGG SYSTEM

STREETSCAPE WITH CONVENTIONAL STORMWATER MANAGEMENT

IMPACT ON PLANTING AREAS

Systems contain a macadam-based growing medium which has a simple grain structure that neither falls apart under loads during construction nor in contact with road salt. This creates improved growing conditions with good infiltration and gas exchange qualities.


Photo: Björn Embrém


Photo: Björn Embrém

Traditional planting areas usually contain soil with a high clay content (>5%). As a result, it is difficult for this soil to withstand the construction process. Furthermore, the influx of road salt causes the soil structure to collapse. This results in poorer growing conditions and inadequate gas exchange and water infiltration.

IMPACT ON HEAT AND ENERGY

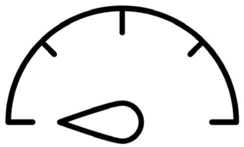
Vegetation which creates a tree canopy over urban streets helps to keep temperatures from rarely exceeding 25°C by casting shadows and the evaporation effect. Both reduced outdoor temperatures and the shading of facades reduces the need for interior air conditioning, thereby reducing energy consumption.

Streets without vegetation can reach temperatures closer to 50°C in European conditions.

IMPACT ON ECOSYSTEM SERVICES

Ecosystem services are the functions of ecosystems that maintain or improve human well-being and living conditions. They are divided into cultural, regulatory, support and supply services. BGG systems can have positive effects on approx. 14 out of 22. Read more at: www.boverket.se


Illustration: The New Division/Boverket



No positive effect on ecosystem services.

8.4 Cost per delayed m³

One way to compare different systems and designs is to add up all the costs of materials and components needed and then divide by the delay volume that is generated. In this way, the cost per delayed m3 for a system is achieved. For a BGG system, the cost per delayed m3 is different depending on where it is created and which materials are included in the system. In figure 57, it can be read that the cost varies from about SEK 1,000/m3 to about SEK 6,000/m3.

The cost can then be used to compare with an alternative design or system. As a comparison, e.g. a cassette magazine can cost approx. 6,000-8,000 SEK/m3. Costs are based on the price situation that was in 2021. The above method of calculation can be a bit misleading as costs are only calculated on one function- in this case delay. A broader reasoning about which other functions are generated also needs to be carried out.

Figure 58. Cost per delayed m3 of stormwater in different designs of BGG systems. Constitutes from cost situation in 2021.

9 Livable 'scapes

For outdoor environments to be long lasting and function well, their design should be led by site-specific requirements and circumstances. Our vision at Edge is to design urban spaces that are intrinsically safe, welcoming for pedestrians and cyclists of all ages, and support inclusive human-focused mobility. Integrating ecosystem services such as the Blue-green-grey system can help make the design more resilient to extreme weather and contribute to better stormwater management. In this chapter we present several subjects which should be considered when designing urban spaces into #liveablescapes.

We have compiled our thoughts on Liveable 'scapes into five categories: Appeal, Versatility, Safe and Secure, Sustainable Mobility, and Climate Smart.

9.1 Appeal

The appeal of a place shows its ability to attract people and activities as well as support biodiversity. In order to create an attractive and robust environment, it is important to consider the context of the particular space and to identify its soul and inherent potential. When urban spaces and streetscapes are designed, the conditions that support (street) life in that space will also be affected. In other words, the design sets the framework for the activities and events that can take place there, and for whom, as well as the behaviors that are to be encouraged. It is therefore important to ask oneself who will be using the space, what functions ought to be created, and whose interests should be served.

The design of an urban space determines the rules of the game for life at that site

By working on a human scale with generous amounts of greenery, one can lay down positive groundwork for users' well-being. The careful design of the space can also create potential for visual contact and physical encounters, which in turn increases the sense of trust and security. The appeal of an urban space is largely determined by the conditions made available to pedestrians. This is due to the fact that most of the movement through the area begins and ends on foot. Creating an intuitive and efficient environment for pedestrians will lay the groundwork for attractive and healthy spaces – shaped by our most fundamental way of moving.

Environments that are designed according to various functions and interests often signal that the site is meant for certain types of behavior or modes of transport. This impacts the behavioral patterns of people that use or move through the space, which is often linked directly to whether the space is perceived as being attractive. For example, bicycle parking can be placed near building entrances while car parking is located farther away. This would have a large impact on the perception of the preferred method of transportation for the site. Staking out generous areas for people to use the space alongside pedestrian and bicycle paths is another example of how physical design can be used to create positive living conditions and at the same time support people in making more sustainable choices in daily life.

Plaza designed as a shared space, the same paving can be seen both in surfaces for pedestrians and for cars. Bokdalsplatsen, Höllviken

9.2 Versatility

Multifunctional spaces accommodate several functions and requirements at the same time. In public environments within an urban context, there is often a significant demand for user-friendliness. At the same time, there may be technical issues that need to be solved. This could include anything from various modes of transport and stormwater management to encounters between people and access to services and business. With careful design, flexible spaces can be created that contain several functionalities with positive synergistic effects. This encourages collaboration between various actors and users. Having the space for multiple functions at the same time can also contribute to the location being used optimally, meaning the return on investment for the design will improve.

Versatile spaces accommodate multiple functions and requirements at the same time.

Increasing population density in urban areas generates higher demand for essential public functions per unit of area. Conflicts often erupt between the different demands when multiple functions need to coexist within a limited space. In order to create vital and robust environments, versatility needs to be sought after by taking into account both current and future needs and uses, then examining and coordinating them in relation to each other. Achieving lasting and dynamic solutions will require actors representing various interests to be allowed to contribute to this process.
Versatility can be achieved by using both technical systems and solutions which integrate soft values. For example, several socially important functions can be combined to produce a positive synergistic effect in a relatively small area using Blue-green-grey systems. With this method stormwater management, traffic resistant areas and good planting bed conditions can all be provided while sharing the same surfaces and volumes.

For more information see:

Jan Gehl –
Life Between Buildings: Using Public Space.

David Sim –
Soft City: Building Density for Everyday Life.

Wide sidewalks where shops and cafés can use the public areas. Bantorget, Lund.

9.3 Safe and Secure

When designing urban space, it is important to think about how the physical form will influence the perceived security and the actual safety of the site. Security is a subjective point of view that can be defined as an absence of fear, worry and perceived vulnerability to risks, while safety refers to the actual risk that some kind of accident can occur. Spatial conditions can influence the sense of security in several ways, for example by the effect of perceived risk of being subjected to crime or getting into an accident.

Despite the fact that a sense of security is subjective, there are physical measures that can be taken that most feel increase security. For example, it will generally increase the sense of security when one strives for good visibility and orientation and while providing good lighting and carefully planned vegetation. This type of initiative usually causes the number of people who will use the space to increase, which further raises the sense of security and level of attractiveness.

It is important that the design of physical spaces is permeated by an experience-based mindset.

Transport-related issues impact both security and safety in urban spaces to a high degree. In order to prevent traffic accidents and aim for the goal set out by Vision Zero that no one should be killed or badly injured in traffic, it is important to implement safety measures within design, operation, and maintenance of transport infrastructure. Speed reduction measures for motorized traffic are especially important as they bring with them increased security, lowered risk for accidents and a reduced degree of seriousness when accidents do occur. Reduced speeds for motor vehicles mean better possibilities for interaction between road users, increased reaction time for avoiding potential accidents and increased appeal of alternate modes of transport through a reduced travel time ratio.

Street spaces should be designed according to the needs of the weakest road users, who are often young and unprotected. In order to secure children a place in the streetscape and ensure that they can move through it independently, their perspective needs to be included in multiple stages of planning. A safe traffic system is important so that parents can, for example, let their children walk or cycle to school on their own. Safe and play-friendly streetscapes additionally create the foundation for increased physical activity and improved health for children. Research shows that people who cycled regularly as children have a higher probability of cycling after they grow up. It has also been shown that children that walk or cycle to school perform better at school on average than children who are driven by car.

Park with skate plaza.
Kanalparken, Kristianstad.

9.4 Sustainable Mobility

The design of streetscapes and individual places influences people's choice of transport and the conditions of their mobility. In order to increase sustainable modes of mobility such as walking, cycling, as well as use of public transport, there need to be favorable conditions for both people and goods to be able to move through the city using environmentally friendly transport systems. Furthermore, stimulating routes should be made available that support health for travelers of any age.

Sustainable mobility means offering environmentally friendly, accessible transport systems that promote health

The framework for sustainable mobility can be created by reprioritizing the shaping of the physical environment according to transport mode, i.e. from a traditional approach where a premium is put on cars to a more modern focus on environmentally friendly and space-efficient means of transport. The bicycle is an example of this and could play an important role within the transformation to increased use of sustainable transportation. Besides being space-efficient, the bicycle is a form of transport that neither pollutes nor makes noise while improving the mental and physical health of the rider. Travelling by bicycle can be facilitated by reallocating space within the street in order to increase accessibility for cyclists, placing convenient bicycle parking areas and prioritizing bicycle traffic in intersections managed by traffic signals.

Prioritizing sustainable types of traffic through bicycle friendly streets Århus.

When making a sustainable transport system widely available, it is important to consider road users’ preferences and abilities, which usually varies depending on their age, gender, and the purpose of their trip. Owing to the diversity of various modes of transport available, e.g. bicycles, electric bicycles and cargo bikes, consideration needs to be taken and spatial adjustments made to create an accessible transport system. It is also important to adapt mobility solutions according to site-specific requirements and circumstances. For example, it may be necessary to separate traffic clearly to achieve a good design at one place, while at another place shared areas for bicycles and cars may be preferred.

Sustainable mobility is about offering an environmentally friendly, accessible and health-promoting transport system.

In order to increase both accessibility and feasibility within a system for sustainable transportation, it is important to create so-called seamless transitions between various forms of transport. For example, access to bicycle parking near important destinations and good accessibility for pedestrians and cyclists to public transport stops can be crucial factors for competitiveness vis-a-vis car trips. Since a trip is never more attractive than its least attractive segment, public transport can be rejected due to a missing link between home and a transport stop, or between the stop and the destination. This can occur, for example, when accessibility for pedestrian or bicycle traffic is poor.

Example of a streetscape where pedestrians and public transportations are prioritized, with specially separated bus files. Some plantation areas are made as bioretention areas that delay stormwater.
Neptunigatan, Malmö

For more information see:

Alexander Ståhle –
***Closer Together: This Is the Future of Cities*.**

Mikael Colville-Andersen –
***Copenhagenize: The Definitive Guide to Global Bicycle Urbanism*.**

Mikael Colville-Andersen –
Bicycle Culture by Design TEDxZurich
(https://www.youtube.com/watch?v=pX8zZdLw7cs).

9.5 Climate Smart

A great deal of greenhouse gas emissions come from our cities, which are a driving force behind continuing climate change. At the same time, cities and their inhabitants are deemed vulnerable for the consequences of future climate change. In order to alleviate cities' impact on climate and strengthen their resilience to climate change, there needs to be an accordingly climate smart approach to the design and planning of urban spaces.

Global warming is expected cause a number of significant impacts within urban areas, such as rising sea levels and more intense and frequent extreme weather events in the form of rainfall, heat waves, and droughts. The physical environment within cities will thus need to adapt in order to cope with these kinds of future conditions. Examples of climate change adaption measures include creating resilience to flooding by renovating systems to be able to handle intense precipitation, as well as to ensure good thermal conditions by making use of the temperature regulating qualities inherent in vegetation. Even working with the design of urban spaces which support climate smart transportation choices such as walking or cycling as well as public transport can help reduce the use of finite resources in cities.

Kanalparken, Kristianstad.

10 References

Literature

Avledning av dag-, drän- och spillvatten. Funktionskrav, hydraulisk dimensionering och utformning av allmänna avloppssystem. Svenskt Vatten AB. Publikation P110. ISSN 1651-4947, 2016

Blue-Green Fingerprints In the City of Malmö, Sweden, Peter Stahre. VA SYD, 2008

Fördröjning av dagvatten med dränerande markstensbeläggning, Erik Simonsen, Svensk Markbetong, 2020

Förebyggande av rotinträngningar i VA-ledningar- utveckling av beslutsstöd. Svenskt Vatten Utveckling . Rapport 2010-04, 2010

Kunskapssammanställning dagvattenrening, Svenskt Vatten Utveckling. Rapport 2016-05, 2016

Nederbördsdata vid dimensionering och analys av avloppssystem, Svenskt Vatten AB. Publikation P104. ISSN 1651-4947, 2011

Regnenveloppmetoden, Sjöberg, A. et al. Chalmers Tekniska Högskola, Meddelande 64, ISSN 0347-8165, 1982

Trädrötter och ledningar - goda exempel på lösningar och samverkansformer, Svenskt Vatten . VA-Forskningsrapport nr 31, 2003

Electronic Sources

Cost comparison, https://bluegreengrey.edges.se/

EU Water Framework Directive, http://www.svensktvatten.se/globalassets/organisation-och-juridik/eu-information-om-vattenforvaltning.pdf

Klimatsäkrade systemlösningar för urbana ytor- Ett Vinnova-projekt, http://klimatsakradstad.se/

Kostnadsjämförelse, https://bluegreengrey.edges.se/

Nacka kommuns Tekniska handbok, https://www.nacka.se/underwebbar/teknisk-handbok/

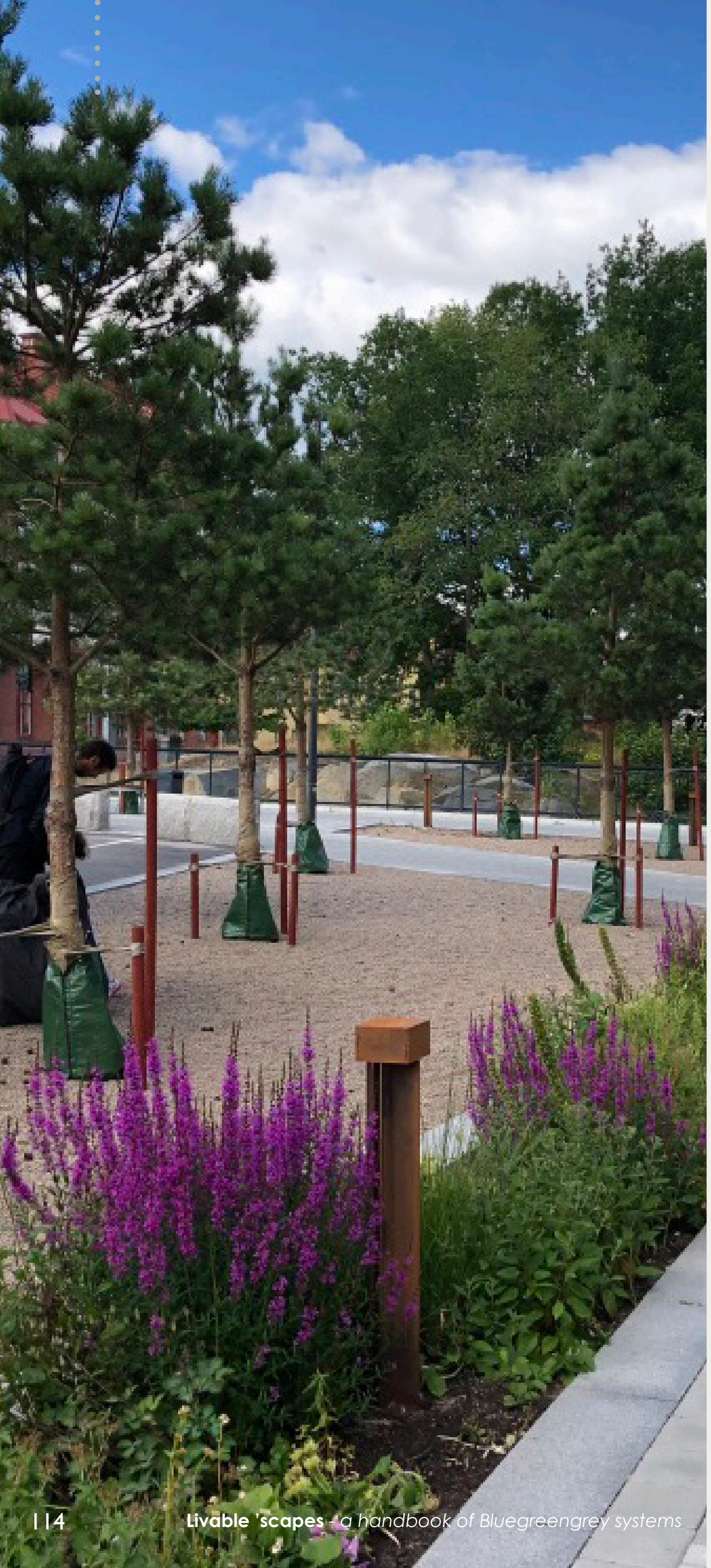
Regnbäddar, Movium Fakta 2015, http://www.movium.slu.se/system/files/news/11238/files/movium_fakta_2-2015_rangbaddarslutlig.pdf

Root zones and drainage solutions for sports lawns, Kent Fridell, https://bluegreengrey.edges.se/article/root-zones-and-drainage-solutions-for-sports-lawns/

Växtbäddar i Stockholms stad – en handbok 2017, https://leverantor.stockholm/entreprenad-i-stockholms-offentliga-rum/vaxtbaddshandboken/

Water Wise Cities, https://iwa-network.org/wp-content/uploads/2017/05/IWA_Brochure_Water_Wise_Communities_SW_screen.pdf

https://iwa-network.org/wp-content/uploads/2016/08/IWA_Brochure_Water_Wise_Cities.pdf



Tree in permeable hard surface on open subbase layer. In the foreground is a rainbed with perennials, Växjö

Plant list

TREES
Acer x freemanii 'Autumn Blaze'
Acer negundo
Acer rubrum 'Red Sunset'
Acer saccharinum
Acer tataricum
Alnus cordata
Alnus glutinosa
Alnus incana
Alnus x spaethii
Betula pendula
Betula pubescens
Catalpa bignonioides
Cedrus sp.
Celtis occidentalis
Cercidiphyllum japonicum
Elaeagnus angustifolia
Fraxinus angustifolia
Fraxinus excelsior
Fraxinus ornus
Ginkgo biloba
Koelreuteria paniculata
Liquidambar styraciflua
Metasequoia glyptostroboides
Paulownia tomentosa
Pinus heldrechii
Pinus sylvestris
Pinus nigra
Platanus x hispanica
Prunus cerasifera
Prunus padus
Prunus virginiana
Pterocarya sp.
Pyrus sp.
Salix alba var. Chermesina
Salix caprea
Sorbus aria
Sorbus frutescens FK ÅS E
Sorbus intermedia
Sorbus terminalis
Styphnolobium japonicum
Taxodium distichum
Tilia tomentosa
Zelkova serrata

SHRUBS
Aronia sp.
Amelanchier sp.*
Buddleja davidii sp.
Callicarpa bodinieri var. giraldii
Cornus sp.*
Cotinus cogyggria 'Grace'
Crataegus monogyna
Crataegus sp.
Dasiphora fruticosa
Diervilla lonicera
Frangula alnus
Hedera helix 'Arborescens'
Hippophaë rhamnoides
Hydrangea arborescens
Lonicera caerulea var.
kamtschatica ANJA E
Myrica gale
Parrotia persica
Physocarpus opulifolius
Pyracantha coccinea 'Anatolia'
Rhus glabra 'Laciniata'
Rosa glauca
Rubus odoratus
Rubus parviflorus
Salix purpurea
Salix rosmarinifolia
Salix viminalis
Spiraea sp.*
Syringa sp.*

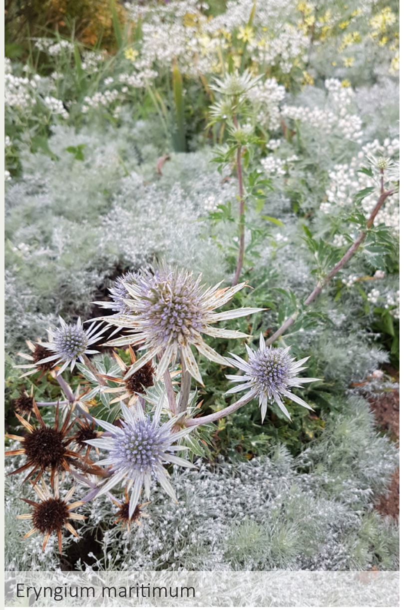
GRASS
Ammophila arenaria
Calamagrostis acutiflora 'Overdam'
Calamagrostis epigeios
Carex arenaria
Carex pilosa 'Copenhagen Select'
Imperata cylindrica
Juncus effusus
Molinia caerulea 'Edith Dudszus'
Panicum amarum
Pennisetum spp.
Phalaris arundinacea 'Picta'
Sesleria spp.
Stipa gigantea

** Within this genus there are red-listed species that have a potential negative effect on Swedish native biodiversity. Avoid these species when choosing plants.*

PERENNIALS
Achillea spp.
Agastache spp.
Anaphalis triplinervis
Anemone coronaria
Anemone sylvestris
Anemone tomentosa ’Robustis-sima’
Artemisia Schmidtiana
Aster macrophyllus ’Twilight’
Astrantia major ’Shaggy’
Bistorta amplexicaulis
Brunnera macrophylla
Calamintha nepeta
Ceratostigma plumbaginoides
Coreopsis verticillata
Crambe maritima
Dianthus carthusianorum
Echinacea spp.
Eremurus spp.
Eryngium maritimum
Euphorbia polychroma ’Bonfire’
Gaura lindheimeri
Geranium spp.*
Gypsophila paniculata
Helianthus salicifolius
Helleborus spp.*
Hemerocallis spp.
Hosta ’Purple Heart’
Hylotelephium spp.*
Iris spp.*
Knautia macedonica
Liatris pycnostachya
Lychnis flos ’Cuculi’
Lythrum salicaria
Nepeta faassenii
Oregano ’Herrenhausen’
Persicaria spp.
Persicaria Amplexicaulis
Phlox spp.
Potentilla nepalensis
Potentilla tridenta ’Nuuk’
Pulsatilla vulgaris
Salvia nemorosa ’Sensation rose’
Sanguisorba officinalis
Sanguisorba tenuifolia
Scabiosa ochroleuca
Thalictrum spp.
Tricyrtis hirta
Verbascum chaixii ’Album’
Verbena spp.
Veronica longifolia ’Blauriesin’
Veronica spicata
Veronicastrum virginicum ’Album’

BULBS
Allium carinatum ssp. pulchellum
Allium sphaerocephalon
Allium flavum
Allium ’Purple Sensation’
Anemone blanda ’White Splen-dours’
Camassia chamach
Camassia leichtlinii ’Alba’
Crocus ancyrensis
Crocus tommasinianus
Galanthus elwesii
Hyacinthoides hispanica
Hyacinthoides hispanica ’Excelsior’
Narcissus ’February Gold’
Narcissus ’Trena’
Tulipa maximowiczii

** Within this genus there are red-listed species that have a potential negative effect on Swedish native biodiversity. Avoid these species when choosing plants.*


Eryngium maritimum


Verbascum chaixii


Verbena

Allium sphaerocephalon


Sanguisorba officinalis