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Output 3.5

Guidelines for design blue-green infrastructure for rainwater retention and groundwater recharge

Version 2

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Activities from the Application form:

WP 3 Resilience to urban drought and urban floods in the face of climate change

Activity 3.4 Partners LP1, PP2, PP4, PP5, PP8 and PP9 will jointly prepare draft of solutions (D 3.4.1) for municipalities for planning and implementing rainwater management to mitigate the effects of torrential rain (1st solution for run-off water retention and increased groundwater recharge under controlled conditions, avoiding sudden increases in underground flow) and to reduce the impact of drought (2nd solution for comprehensive use of rainwater as an alternative source of water for municipal purposes). Responsibility for preparation of the 1st solution is on LP1 and PP2, responsibility for preparation of the 2nd solution is on PP4 and PP5. The drafts will be tailored on common workshops organised on personnel or on-line basis. The draft will be posted for a feedback of partners representing public administration (PP3) and associated partners A01 and A04. LP1, PP2, PP4, PP5 based on feedback will prepare the final version (D 3.4.2).

Deliverable 3.4.2 Handbook for increasing the benefits of rainwater management - final version

O3.5 - Guideline for designing blue-green infrastructure for rainwater retention and groundwater recharge

Output description: Guidelines for designing the residential areas and urban space taking into account the needs of local water retention, decreasing run-off and increasing infiltration components of rainfall over various land coverage types, buffering the excessive run-off water and its use for watering the green area in the drought periods and groundwater recharge (link to D.3.4.2).

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1. Introduction

The transformation of municipalities and cities towards climate resilience requires the effective integration of blue-green infrastructure (BGI) with spatial planning, investment preparation and public administration procedures. BGI should not be treated as an additional decorative element. It is a functional layer of urban infrastructure that supports rainwater retention, groundwater recharge, local cooling, biodiversity and the reduction of runoff peaks. As emphasized by Kabisch et al. (2017), blue-green solutions simultaneously ensure an improvement in the quality of the microclimate, increased rainwater retention and significant support for adaptation processes to the risk of floods, extreme weather phenomena or pressure resulting from climate change.

Contemporary urban planning indicates the need to treat biologically active areas, ecological corridors and various types of retention as infrastructure with an equal status to technical and communication infrastructure (Wilker et al., 2016). This means, e.g., incorporating natural forms of retention into rainwater collection and drainage systems, implementing greenery in urban space, as well as using natural solutions to reduce the effect of urban heat islands.

The need for widespread implementation of BGI is determined by both changing European regulations and increasing investment pressure leading to the fragmentation and disappearance of biologically active spaces (European Environment Agency, 2021). Among the areas requiring special attention are post-industrial areas, including post-mining areas, characterized by a high degree of ecological degradation and limited geotechnical stability. As the literature indicates, such locations, although difficult to develop, also create great potential for the implementation of innovative natural solutions that can simultaneously perform ecological, hydrological and social functions (Kabisch et al., 2016).

Due to the growing risk of adverse phenomena, it is necessary to implement systematic, interdisciplinary spatial planning models that consider BGI as a key component of space to ensure a high quality of life for residents. As noted by Frantzeskaki et al. (2019), the development of blue-green infrastructure should not be understood as an additional element of planning, but as an integral part of the sustainable urban development strategy.

The MAURICE approach presented in this guideline is practical and decision oriented. It supports the first stage of investment planning, when the investor, designer and public administration need to understand which BGI technologies are potentially suitable for a plot, which solutions require additional verification, and which should be excluded because of local constraints.

Purpose of the guideline

This guideline supports the safe and effective selection of BGI measures before detailed design. It links local rainfall data, soil and groundwater conditions, geohazard screening, the BGI Tool and the BGI Catalogue into one coherent pre-design workflow.

The document is intended for investors, designers, local authorities, permitting bodies, water utilities, residents and experts. It is written as a pre-design and decision-support guideline: it helps define what can be considered, what should be excluded, and what requires detailed engineering verification before implementation.

Table 1-1. Target groups.

Target group	How the guideline supports decisions
Investors and property owners	Help identify feasible BGI options, understand limitations, prepare realistic assumptions for concept design and avoid unsuitable solutions at an early stage.
Designers and consultants	Provides a structured pathway for collecting site data, selecting rainfall scenarios, pre-screening technologies and preparing inputs for detailed engineering design.
Municipal officers and permitting authorities	Creates a common basis for dialogue with investors and designers and supports consistent review of BGI proposals.
Urban planners	Connects BGI measures with spatial planning, runoff control, climate adaptation and groundwater recharge objectives.
Residents and local stakeholders	Explains why BGI solutions are introduced, what benefits they provide and why some technologies cannot be applied everywhere.

2. Sponge-city principles for BGI planning

A sponge city is an urban model in which rainwater is not treated as waste to be removed as quickly as possible. Instead, precipitation is retained, stored, infiltrated, evaporated, treated or reused as close as possible to the place where it falls. In technical terms, the objective is to restore selected elements of the natural urban water balance under built-up conditions.

The implementation of blue-green infrastructure in practice still faces significant barriers. Investors, early concept designers, property owners and administration representatives often do not have sufficient technical knowledge to assess for themselves which BGI solutions can be used in each location. The problem is not only the choice of technology, but also the awareness of limitations: some solutions should not be used when groundwater levels are high, with low soil permeability, unfavorable topography, or geohazards.

To address these barriers, the MAURICE project developed two complementary outputs designed to support the preliminary selection and assessment of blue-green infrastructure solutions. The first is the BGI Catalogue, which contains information about available technologies with a description of functions, design parameters, design requirements, limitations of use, resistance to geohazards, retention capacity and groundwater recharge potential. The second component is the BGI Tool, which is a digital tool for the first selection of BGI technology. The tool indicates which solutions are applicable under given site conditions, which require caution or additional analysis, and which should be excluded. In addition, it calculates the volume of precipitation to be managed, estimates the required area for the installation and assesses the potential of groundwater recharge.

The BGI Tool has been developed as a practical tool to support the early stage of investment planning. BGI Tool supports the preparation of the investment concept, the dialogue between the investor, the designer and the public administration. However, it does not replace a detailed engineering design, formal and legal procedures or specialist geotechnical and hydrogeological verification. Such analyses remain necessary at the implementation stage, especially in areas with shallow groundwater levels, historical mining activities, landslide risk, unfavorable infiltration conditions or the possibility of underground voids.

Sponge city is a model of urban space management in which rainwater is harvested, infiltrated, or reused as close as possible to the precipitation site.

The implementation of such an approach requires linking planning decisions with the technical assessment of the plot. The following factors are of key importance: soil permeability, groundwater table level, available area for installation, as well as geotechnical and hydrogeological risks. Special caution is required in post-industrial and post-mining areas, where the ground conditions can be strongly transformed and heterogeneous. In such areas, intensive infiltration may increase the risk of suffusion, subsidence, activation of underground voids, changes in the groundwater regime or secondary activation of pollutants. Therefore, the MAURICE approach treats BGI as a technical and natural solution: it prefers local water retention and support for groundwater recharge, but only where the groundwater conditions and the assessment of site safety allow.

2.1. Design principles

The following principles provide a concise framework for selecting and designing BGI in a way that is technically feasible, site-responsive and effective over time.

Table 2.1-1. Design principle.

Design principle	Practical implication
Keep water local	Retain or reuse water close to the source.
Separate rainwater from wastewater	Avoid unnecessary mixing with sanitary wastewater where separate management is possible.
Prefer multifunctional solutions	Select technologies that combine hydrological, ecological, cooling and social functions.
Respect ground and groundwater conditions	Do not force infiltration where groundwater, geology or geohazards create unacceptable risk.
Plan overflow safely	Every BGI system must have a safe exceedance pathway for rainfall above design capacity.
Design for maintenance	Access, inspection and maintenance management must be planned.

BGI planning should start before the plot concept is fixed. Early screening prevents two common problems: selecting an attractive but technically unsuitable solution or leaving too little space for rainwater management after the building, roads and parking areas have already been located.

Recommended use in investment and municipal workflows

Figure 2.1 -1. Recommended early-stage workflow for using this guideline and the BGI Tool.

2.2. Minimum input data for early screening

Early screening should be based on a small but reliable set of input data that allows unsuitable BGI options to be excluded before detailed design begins.

Table 2.2-1. Input data for early screening.

Input category	Data needed
Plot and land-use data	plot area, building footprint, paved surfaces, biologically active area, and planned functions
Run-off source	roof water, pedestrian areas, roads, parking lots, industrial surfaces, mixed catchments
Soil and infiltration data	soil type, permeability class or infiltration test result, presence of artificial fill or compacted layers
Groundwater data	groundwater table depth, seasonal variability, risk of buoyancy or hydraulic interaction
Safety constraints	geohazards, historical mining activity, underground voids, landslide zones, contamination risk
Rainfall objective	reuse during dry periods, retention of design rainfall, reduction of peak discharge, or support for groundwater recharge

3. Risks and specific considerations in the implementation of BGI

BGI are highly effective when they are correctly matched to local conditions. However, technologies based on infiltration, soil-water interaction and underground storage must be planned with particular care. The main objective of risk screening is not to limit the use of BGI, but to ensure that the selected technology is safe, durable and appropriate for the plot.

Risk assessment should start already at the concept stage. At this point the investor should not yet be required to prepare a full technical design but should be able to identify whether the plot is suitable for infiltration-dominant measures or whether retention, treatment, reuse and controlled discharge should be preferred.

The implementation of BGI on an urban and peri-urban scale is a challenge, especially in European cities, which, due to their long history of urbanization and geological and hydrogeological diversity, are often located in areas with complex land characteristics. The most important threats include suffusion, the formation of subsurface voids, landslides, unstable steep slopes, rock outcrops, as well as heterogeneous subsidence.

These risks should be considered by BGI designers, as technologies such as absorption wells or heavy infiltration tanks may not be compatible with areas prone to subsidence or sinkholes.

What is more, changes in the water regime, resulting from both natural processes (e.g. rising groundwater levels after the decommissioning of excavations) and anthropogenic activities (infiltrations into the ground from sewage systems, intensive infiltration of rainwater), can significantly increase the risk of suffusion voids, landslides or local soil deformations. Such threats are not limited to post-mining or post-industrial areas – they can also occur in karst, sandy, clayey or rocky areas, where natural soil instability is a high-risk factor.

From a BGI design perspective, omitting these geotechnical conditions can lead to serious consequences, including: cracks in buildings and pavements, failures of technical networks, local sinkholes, and even construction disasters.

For this reason, it is extremely important to consider geotechnical and hydrological aspects for the investment area at the design stage of the BGI, to ensure the safety, functionality and durability of the infrastructure.

This guide reviews the main geotechnical and hydrogeological risks associated with the implementation of BGI in Europe, with a particular focus on a variety of terrain types, from post-mining areas to steep slopes to areas prone to suffusion and subsurface voids.

Areas with specific geological conditions, such as suffusion, heterogeneous subsidence, shallow groundwater or rock outcrops (e.g. Triassic), are one of the major challenges for effective and safe blue-green infrastructure (BGI) planning. The aim of the guide is to provide comprehensive knowledge that will allow planners, engineers and decision-makers to make informed design decisions when implementing blue-green infrastructure. The use of BGI solutions requires taking these conditions into account to optimize retention and ecological functions, while maintaining the stability and safety of buildings and protecting the health of residents.

3.1. Geotechnical hazards in blue-green infrastructure planning

The most common geotechnical hazards in Europe include: suffusion, landslides, subsurface voids, heterogeneous subsidence and changes in the water regime. Each of these phenomena can lead to serious consequences for urban infrastructure, including damage to buildings, failures of technical networks or local sinkholes.

Suffusion

Suffusion is the process of washing out fine particles of soil through an underground flow of water, which results in voids and suffusion funnels. This process can lead to:

- sudden subsidence of the land surface,
- formation of sinkholes,
- damage to buildings, road and network infrastructure,
- increase in the risk of construction disasters.

As Wiłun (2010) emphasizes, suffusion is one of the most difficult geotechnical phenomena to predict, due to the hidden nature of the processes. The consequences include, e.g.:

- sudden subsidence of the surface,
- damage to buildings, road and network infrastructure,
- increase in the risk of construction disasters.

In the context of BGI, this means the need for detailed hydrogeological studies and the use of solutions to limit water infiltration in areas prone to suffusion (Filipowicz & Florkiewicz, 2011; Liang et al. 2024).

Heterogeneous subsidence

In post-mining areas, as well as in areas of raw material exploitation, heterogeneous subsidence is a typical problem, leading to local surface deformations.

This process causes cracks in buildings, failures of linear installations, and even secondary landslides (Leśniak & Porzycka, 2007). The introduction of BGI in such locations requires combining engineering methods (ground reinforcement, deformation control) with ecological solutions, such as flexible retention systems or slope stabilization plantings.

Triassic outcrops and steep slopes

Areas with rock outcrops (e.g. Triassic) and steep slopes are characterized by instability and complexity of the terrain shape, and thus the risk of landslides, especially in the situation of changes in water conditions (Rączkowski, 2007). Landslides also occur in mountainous and foothill areas, such as the Alps, the Carpathians or the Pyrenees. They are the result of slope instability, often exacerbated by excessive rainwater infiltration. In the context of BGI, it is necessary to avoid the location of retention elements on slopes with a low safety factor.

The implementation of BGI in such areas requires:

- specialist geotechnical surveys,
- monitoring the stability of slopes,

- integration of natural solutions (stabilizing vegetation, green belts) with engineering landslide protection (Januchta-Szostak, 2020).

Subsurface voids

A particular problem in the planning of blue-green infrastructure is invisible subsurface voids, formed because of karst processes, mining exploitation, as well as in areas prone to suffusion.

Subsurface voids are typical for karst areas (e.g. Slovenia, Croatia) and can lead to sudden sinkholes.

Brinkmann & Parise (2012) note the presence of voids is often difficult to detect in standard geotechnical surveys, and their development tends to be long-term and latent. Only the inflow of rainwater or a change in water conditions can cause a rapid collapse of the void ceiling and the formation of a sinkhole.

In urban conditions, this means that intensive infiltration of rainwater from BGI systems (e.g. absorption wells) in areas at risk of voids can lead to undesirable effects such as sudden subsidence, damage to foundations and technical networks, increased risk of construction disasters and loss of site function.

Parise and Gunn (2007) emphasize that in the case of potentially karst areas or with a history of mining activity, it is necessary to combine natural systems with engineering solutions that limit infiltration and the use of geotechnical and geophysical monitoring.

Table 3.1-1. Geotechnical hazards in blue-green infrastructure planning.

Hazard	Why it matters for BGI	Recommended pre-design response
Suffusion / internal erosion	Fast or concentrated infiltration may wash out fine soil particles, causing loss of bearing capacity and sinkholes.	Avoid infiltration-only concepts until soil conditions are checked. Prefer distributed, shallow or controlled systems.
Subsurface voids	Karst cavities, old mine workings or voids in made ground may collapse after water regime changes.	Check geological records and, where needed, use geophysical survey before locating infiltration wells or deep soakaways.
Heterogeneous subsidence	Post-mining or filled areas may settle unevenly, damaging pavements, tanks and pipework.	Prefer flexible layouts, accessible systems and monitoring. Avoid heavy underground systems without foundation assessment.
Landslides and steep slopes	Additional water may reduce slope stability and increase landslide probability.	Avoid concentration of runoff on slopes. Use vegetation, surface retention and controlled drainage.

Hazard	Why it matters for BGI	Recommended pre-design response
Rock outcrops and shallow soil	Limited storage and infiltration depth may reduce BGI performance and increase uncontrolled flow.	Use shallow storage, above-ground retention or hybrid systems adapted to local geology.

3.2. Hydrogeological risks relevant to BGI

CHANGES TO THE WATER REGIME

Changes in the post-exploitation water regime are among the most important factors conducive to the creation of new zones endangered by suffusion processes. As Popiołek (2009) points out, the decommissioning of excavations and mine drainage leads to disturbances in the hydrogeological balance, including the interruption of natural flows in aquifers. Such changes may cause the concentration of underground streams and the formation of local hydraulic anomalies, which initiate the process of leaching of fine soil particles and the development of suffusion voids (Wiłun, 2010).

Another source of risk is uncontrolled drainage of rainwater or its infiltration without engineering protection. Research by Cao et al. (2021) indicates that in the absence of adequate filtration and flow dispersion systems, infiltrating water can reach locally high hydraulic pressure values. This leads to the initiation of internal erosion and the formation of suffusion funnels, and consequently to a rapid loss of bearing capacity of the soil. Numerous cases of technical infrastructure failures resulting from the concentration of water flows in sandy and dusty soils have been described in the literature (Parise & Gunn, 2007).

Hydrogeological screening should determine whether infiltration can be used safely. Shallow groundwater, low permeability, contaminated ground, post-exploitation water regime changes or existing drainage disturbances may significantly change the expected performance of BGI installations.

Table 3.2-1. Hydrogeological risks relevant to BGI.

Condition	Implication for technology selection	Practical decision
High groundwater table	The unsaturated zone may be too thin for safe infiltration and treatment. Buoyancy may affect underground tanks.	Prefer shallow retention, above-ground storage, sealed systems or controlled discharge.
Low soil permeability	Water may remain in the system too long, causing overflow, mosquito nuisance or failure of vegetation.	Use retention, reuse or regulated outflow; infiltration should be limited or supported by underdrainage.
Contaminated ground	Infiltration can mobilise pollutants and affect groundwater quality.	Avoid direct infiltration without environmental assessment and treatment barriers.

Condition	Implication for technology selection	Practical decision
Changed water regime	Former mining drainage or groundwater rebound may create unstable hydraulic conditions.	Use groundwater monitoring data and avoid technologies that strongly modify underground flow.
Preferential flow paths	Water may bypass treatment layers and concentrate in weak zones.	Disperse inflow, use filtration layers and avoid point infiltration in sensitive areas.

Minimum information before choosing a BGI technology
At early stage, collect: plot location, catchment area, impervious surfaces, approximate soil permeability, groundwater table depth, geohazard information, available area, planned function of the installation and the rainfall objective to be managed.

Despite the growing awareness of geotechnical and hydrogeological hazards, in planning practice, BGI is still designed without due consideration of these conditions. This results in serious consequences such as sinkholes, landslides or deformations of the surface – often observed in parking lots, public squares or road infrastructure, for example. Implementation case analyses and literature research indicate several systemic barriers that hinder the effective integration of geotechnical knowledge with spatial planning. The most frequently mentioned include:

- rigidity of local legal regulations and lack of connection between planning documents and geotechnical analyses,
- dispersion of responsibilities between different administrative units and investors,
- insufficient interdisciplinary cooperation between planners, engineers, geotechnicians and environmental specialists,
- lack of systematic education and training for project staff on terrain hazards and their impact on the sustainability of BGI.

As a result, many BGI projects are implemented in a suboptimal manner, which not only reduces their retention and ecological efficiency, but also generates technical and financial risk. It is therefore necessary to implement an integrated approach that combines spatial planning with the analysis of soil and water conditions already at the design concept stage.

4. Use of rainfall models in urban stormwater management

Accurate estimation of rainfall intensity is a fundamental prerequisite for the proper design of stormwater management systems and Blue-Green Infrastructure (BGI). Traditional approaches based on simplified empirical formulas are increasingly insufficient in the context of climate change and urbanization.

Modern practice requires the use of locally calibrated rainfall models, which reflect spatial variability, probability of occurrence, and temporal distribution of precipitation events.

4.1. Development of the Local Rainfall Model – Jaworzno

The city of Jaworzno (Poland) represents an advanced example of such an approach, where a local rainfall model based on the PANDa (Polish Atlas of Rainfall Intensities) has been developed and implemented as part of a comprehensive stormwater management strategy.

The PANDa system provides:

- high-resolution rainfall data (1-minute time series),
- intensity–duration–frequency (IDF/DDF) relationships,
- probabilistic rainfall models compliant with EN 752 standards,
- data based on long-term observations (1986–2015) from over 100 meteorological stations.

This data set forms the basis for both current rainfall modelling and design rainfall estimation. To ensure long-term reliability of infrastructure, rainfall models in Jaworzno were extended using:

- IPCC climate scenarios (RCP 4.5),
- regional climate modelling (CMIP5, CORDEX),
- scaling of daily rainfall to sub-daily intensities.

The model enables estimation of rainfall intensities for:

- durations from 5 minutes to 4320 minutes,
- probabilities from 1% to 100% (return periods from 100 years to 1 year).

This allows direct application in urban hydrology and drainage system design.

Jaworzno is an example of a city where rainfall data were translated into a practical model for stormwater and BGI planning. The model uses the Polish Atlas of Rainfall Intensities (PANDa), local spatial interpolation and climate-oriented assumptions to provide design rainfall values for different parts of the city.

A key feature of the Jaworzno model is the introduction of a spatial interpolation grid (5km × 5km cells), covering the entire city.

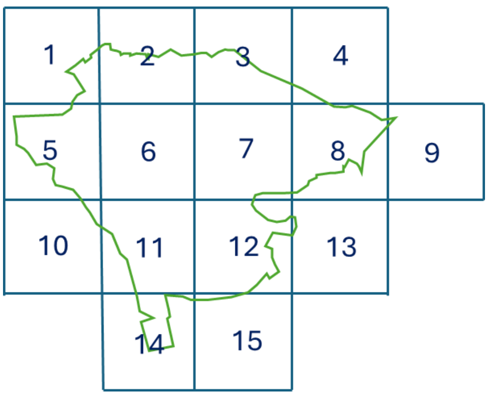

Figure 4.1 -1. Spatial interpolation grid of Jaworzno

Each cell-specific model was derived from spatial interpolation of maximum rainfall data, using not only the nearest rain gauge (Katowice), but also incorporates data from multiple surrounding meteorological stations within a radius of up to 100 km, ensuring:

- spatial representativeness,
- robustness of statistical analysis,
- reduced uncertainty of local estimates.

Based on these models, rainfall depths and corresponding intensities can be calculated for:

- probabilities ranging from 1% to 100% (return periods from 100 to 1 year),
- rainfall durations from 5 to 4320 minutes.

Importantly, the values derived from the current model particularly for short durations (5–120 minutes) are significantly higher than those obtained using the traditional Błaszczyk formula. This indicates that previously applied design values were underestimated.

As a result, stormwater drainage and retention systems designed using the updated local rainfall model are better adapted to current conditions and future challenges, including climate change.

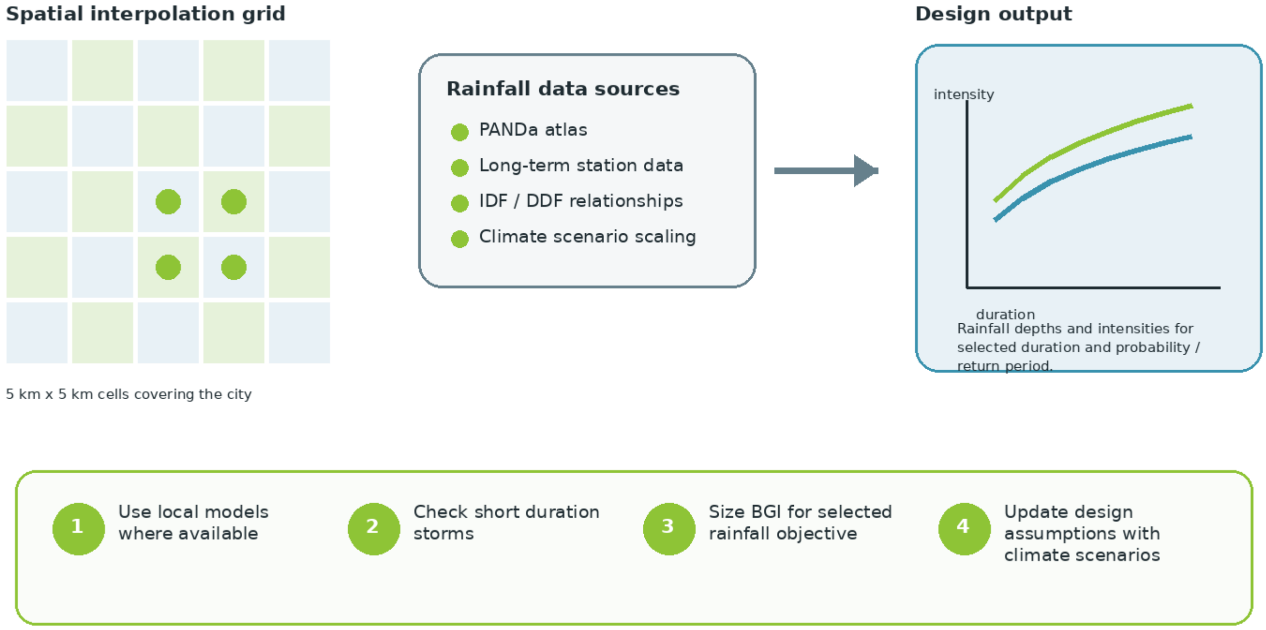

Figure 4.1-2. Jaworzno rainfall model: from rainfall data to design values for stormwater and BGI planning.

4.2. Transferability to Other European Countries

Although the Jaworzno model is based on Polish data (PANDa), the methodology is fully transferable to other European contexts.

Table 4.2-1. Methodology to estimate the rainfall intensity in European countries.

Country	Methodology to estimate the rainfall intensity
Czech Republic	• Use national datasets from the Czech Hydrometeorological Institute (CHMÚ). • Apply IDF curves and rainfall tables available at national level. • Where possible, develop local interpolation models for cities (similar to Jaworzno).
Germany	• Use KOSTRA-DWD rainfall datasets (German Weather Service). • High-resolution IDF data are widely available and should be applied as a standard. • Advanced practice includes integration with urban hydrodynamic models.
Slovenia	• Use rainfall data from the Slovenian Environment Agency (ARSO). • Apply regional rainfall statistics and IDF curves. • In karst or geologically sensitive areas, combine rainfall modelling with infiltration risk assessment.
Italy	• Use data from Regional Environmental Protection Agencies (ARPA) or ISPRA. • Apply IDF curves at regional level (often highly differentiated due to topography). • In Mediterranean climates, special attention should be given to short-duration extreme events.
Croatia	• Use rainfall intensity-duration-frequency (IDF) data from the Croatian Meteorological and Hydrological Service (DHMZ). • Where data resolution is limited, apply regional models and consider local calibration. • Importance should be given to karst conditions and rapid runoff response.

4.3. Design value of local rainfall models

The Jaworzno model supports the selection of design rainfall for different objectives: daily water retention, standard urban drainage performance and resilience to heavy or extreme rainfall. This distinction is important because not every BGI should be sized for the same event. A rain garden designed for frequent rainfall serves a different function than an emergency storage system designed to reduce flash-flood risk.

Table 4.3-1. Rainfall objectives and their planning implications.

Rainfall objective	Typical purpose	Planning implication
Light / frequent rainfall	Soil moisture, vegetation support, everyday retention and local reuse.	Suitable for small-scale systems such as rain gardens, planters and local storage.

Rainfall objective	Typical purpose	Planning implication
Moderate design rainfall	Standard stormwater management for urban plots and public spaces.	Used for comparing BGI options and defining required storage or infiltration area.
Heavy / extreme rainfall	Flood-risk reduction and emergency overflow management.	Requires safe overflow routes, controlled discharge and integration with drainage infrastructure.

4.4. Recommended procedure for municipalities

- Use national rainfall atlases or meteorological datasets as the basis for designing rainfall.
- Where possible, develop local rainfall models that reflect spatial variability within the city.
- Check short-duration rainfall events, as they often control urban runoff peaks.
- Integrate climate-change scenarios where long-term infrastructure performance is required.
- Use rainfall objectives consistently in planning requirements, BGI Tool inputs and project documentation.
- For cities without a local model, the BGI Tool can still be used in expert mode, if rainfall intensity values are supplied from national or regional hydrological datasets. The long-term objective should be to move from generic formulas to locally calibrated data that better reflect real stormwater risk.

5. The BGI Catalogue: a structured knowledge base

The BGI Catalogue is designed for planners, designers, municipal officers and investors. Each technology is presented using the same logic: description of the installation, resilience to geohazards, retention capacity, potential for groundwater recharge, construction parameters, design requirements, minimum distances from sensitive objects and examples of good practice. This standardized structure makes different solutions comparable and helps users understand not only what can be built, but under what conditions it should be built.

Figure 5-1. Example catalogue card: rain garden in the ground with retention and groundwater-recharge indicators.

5.1. Structure of a technology card

Each catalogue card follows the same logic. This is important because it allows users to compare technologies without searching through different types of descriptions or interpreting inconsistent terminology.

- functional description of the technology and typical applications,
- retention capacity and role in runoff reduction,
- potential contribution to groundwater recharge,
- sensitivity to groundwater level and soil permeability,
- resilience to geohazards and limitations in difficult ground conditions,
- construction parameters, typical layers and overflow arrangements,
- minimum distances from buildings, property boundaries, utilities and sensitive water bodies,
- maintenance requirements and examples of good practice.

5.2. Technologies covered by the catalogue

The catalogue covers the main BGI technologies commonly used for urban rainwater management, highlighting their primary functions, suitable applications and key design cautions.

Table 5.2-1. BGI technologies covered by the catalogue.

Technology	Main function	Best suited for	Main caution
Rain gardens and bioretention	Retention, treatment, evapotranspiration, partial infiltration	roofs, squares, streetscapes, public facilities	needs vegetation care and sediment control

Technology	Main function	Best suited for	Main caution
Permeable pavements	Runoff reduction, temporary storage and infiltration	parking areas, pedestrian routes, low-traffic surfaces	requires correct substructure and clogging prevention
Retention and detention basins	Peak-flow reduction and storage	larger plots, parks, public areas, housing estates	needs safe overflow and child-safety consideration
Underground tanks and chambers	Storage, reuse or controlled release	dense urban areas with limited surface space	requires access, structural design and groundwater check
Green roofs and walls	Retention, cooling, biodiversity and building performance	new and retrofitted buildings	requires structural load and maintenance assessment
Infiltration trenches / wells	Groundwater recharge and runoff reduction	suitable permeable soils with safe groundwater clearance	not suitable where geohazards or contamination risks are high

6. BGI Tool

The BGI Tool is a digital pre-design instrument supporting the first selection of blue-green infrastructure technologies. It is intended for the early stage of investment planning, when the main question is not yet how to prepare detailed construction drawings, but which type of solution is technically reasonable for the plot and what parameters should be checked before design continues.

The tool is designed for use by investors, municipal officers, planners, architects, engineers and property owners. It creates a transparent bridge between general BGI knowledge and site-specific decision-making. It does not replace detailed engineering design, permitting procedures or specialist geotechnical and hydrogeological verification.

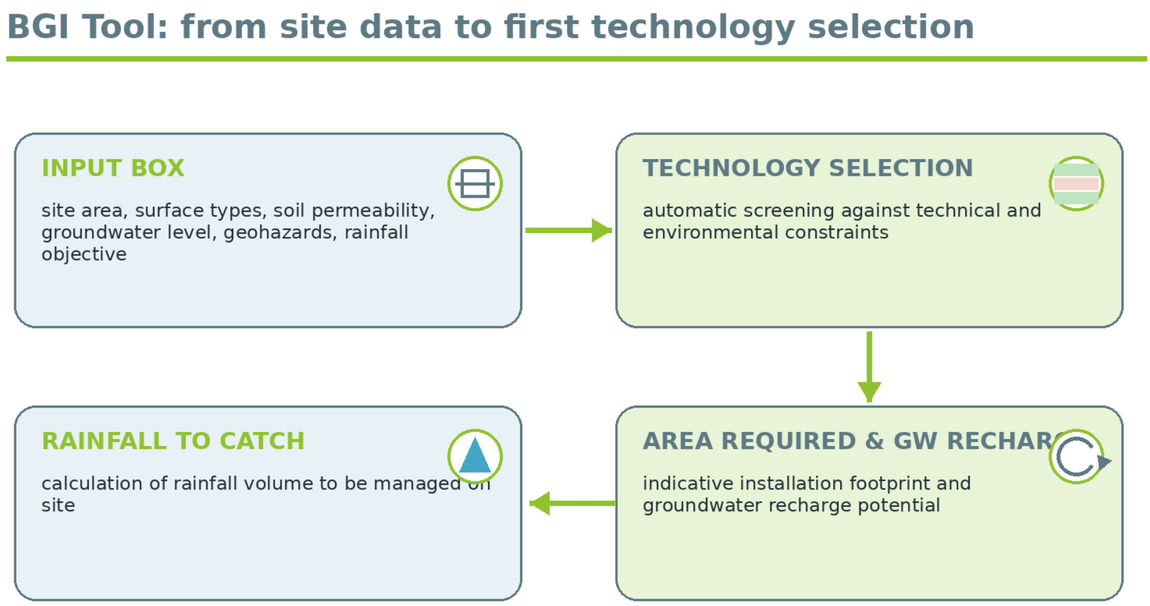

Figure 6-1. The complete BGI Tool consists of four operational modules: Input Box, Technology Selection, Rainfall to Catch, and Area Required & Groundwater Recharge Potential.

6.1. Operational modules of the BGI Tool

The table below presents the four operational modules of the BGI Tool, showing what information is provided or generated at each stage and how it supports preliminary decision-making.

Table 6.1-1. Operational modules of the BGI Tool.

Module	What the user enters or receives	Decision value
Input Box	Plot area, impermeable and semi-permeable surfaces, biologically active area, soil permeability, groundwater level, geohazards, location and rainfall objective.	Converts site information into a comparable screening dataset.
Technology Selection	Automatic classification of technologies based on the local constraints.	Shows feasible, conditionally feasible and non-recommended solutions.
Rainfall to Catch	Rainfall intensity or local model values for selected rainfall objective.	Calculates the rainfall volume that should be captured or managed on site.
Area Required & GW Recharge Potential	Required footprint and qualitative groundwater-recharge potential.	Help verify whether the option fits the plot and supports aquifer recharge.

6.2. Recommended use in municipal and investment workflows

The BGI Tool is most effective when it is used early. At concept stage, it can direct the user toward measures consistent with local geology, hydrology and available space. For public administration, the BGI Tool can also create a common language between planners, environmental departments, water utilities, designers and investors.

1. Define plot	2. Check local constraints	3. Select rainfall objective	4. Compare BGI options	5. Prepare project of installation

Typical use cases include:

- screening BGI options for municipal sites, schools, sports facilities, or housing estates;
- preparing requirements for local spatial plans, development conditions or design competitions;
- supporting grant applications by providing transparent, comparable assumptions;
- communicating with residents and investors using clear visual outputs rather than expert-only calculations.

How to use the tool in an investment workflow

- Start before the detailed design stage, when the location, catchment area and general investment concept are known.
- Use the tool to compare several BGI options rather than to confirm only one preferred solution.
- Treat conditionally applicable technologies as a signal for additional technical assessment, not as automatic rejection.
- Attach the tool output to concept documentation, grant applications or municipal consultations as a transparent decision basis.

Table 6.2-1. BGI Tool outputs.

Output	Meaning	Recommended next step
Recommended	Technology is consistent with the input conditions at screening level.	Proceed to concept design.
Conditional	Technology may be possible, but one or more constraints require attention.	Request expert check, adjust design or add safeguards.
Not recommended	Technology conflicts with key site constraints or safety assumptions.	Select alternative technology or redesign the rainwater management strategy.
Rainfall volume	Volume of water to be retained, reused, infiltrated or safely discharged.	Proceed to concept design.

Area required	Indicative footprint needed by the selected technology.	Check whether the selected technology fits the plot, then proceed to concept design.
GW recharge potential	Qualitative indication of contribution to aquifer recharge.	Use to compare options where recharge is a planning objective and safe.

Limit of the BGI Tool
The BGI Tool is not a substitute for detailed engineering design, building-permit procedures, water-law requirements, geotechnical documentation or hydrogeological verification. It is a pre-design screening and decision-support instrument.

6.3. How the catalogue and BGI Tool work together

The catalogue explains the technologies, their functions and limitations. The BGI Tool applies this knowledge to a specific plot. Together, they reduce the gap between general climate-adaptation objectives and practical investment decisions.

Table 6.3-1. How to use the BGI Catalogue and the BGI Tool together.

Planning question	Catalogue contribution	BGI Tool contribution
What solutions exist?	Provides technology descriptions and examples of good practice.	Filters the list of solutions relevant to the selected plot.
Can infiltration be used?	Explain groundwater, soil and geohazard limitations.	Checks input constraints and classify technologies.
How much water should be managed?	Explains technology function and capacity logic.	Calculates rainfall volume based on selected rainfall objective.
Will the solution fit the site?	Shows spatial and design requirements.	Estimates required area or installation size.
What is the benefit for groundwater?	Describes recharge potential qualitatively.	Compares the recharge potential of suitable options.

Final guidance for users
Use the BGI Catalogue to build the knowledge about the technology. Use the BGI Tool to check the plot. Use detailed design to confirm dimensions, safety and regulatory compliance.

7. Jaworzno pilot testing - Practical lessons for implementation

The MAURICE project in Jaworzno evaluated pilot plots with different permeable surfaces to verify whether they could be used in sponge cities.

The results of the pilot studies showed that when using permeable surfaces, surface runoff accounts for less than 5% of the water balance. In addition, the permeable surface reduced surface runoff by approximately 65–80% compared with the most impermeable reference surfaces. Approximately 20% of precipitation was retained and infiltrated into the ground. These results confirm that permeable pavements can be a very effective BGI solution in urban areas where local conditions are appropriate and the substructure is properly designed and maintained.

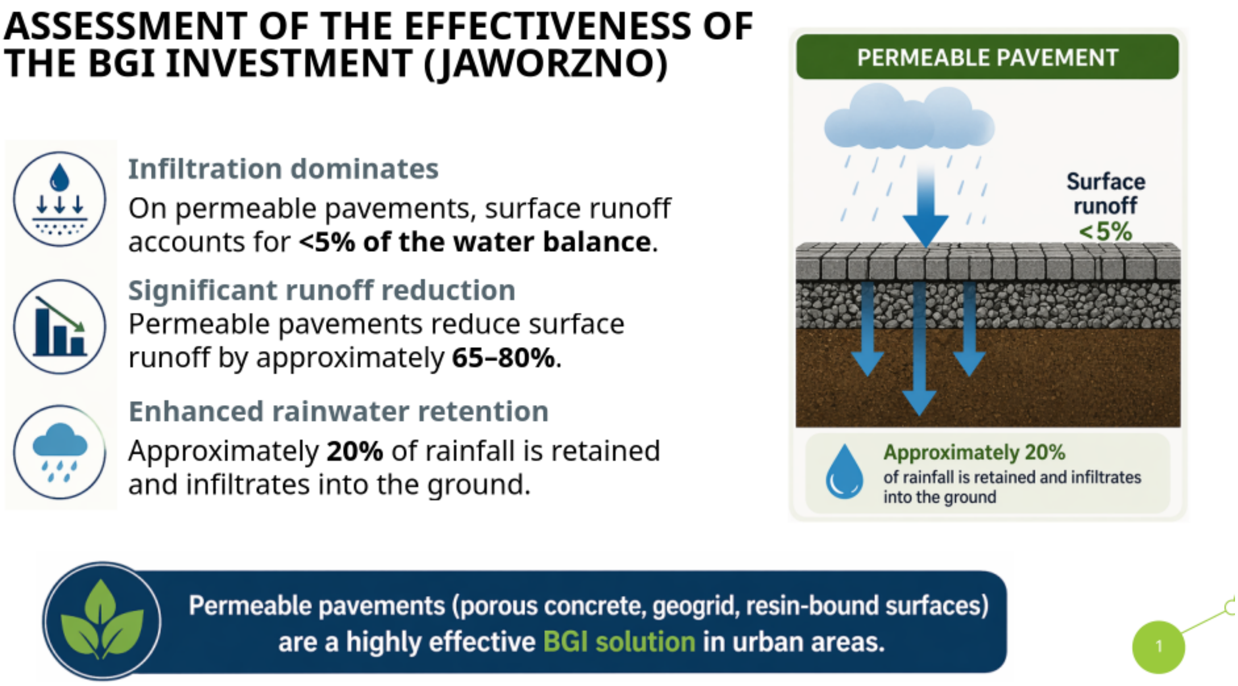

Figure 7-1. Jaworzno pilot plot results in permeable pavement BGI: infiltration-dominated performance and reduced surface runoff.

What the pilot adds to the guideline

The pilot activities showed the practical dimension of the application of BGI solutions. They are a local place for demonstrations of solutions, education and workshops.

The pilot demonstrated that practical BGI testing is valuable not only for technical verification, but also for communication with stakeholders. Pilot plots can serve as demonstration sites for investors, municipal departments, residents and designers, making the hydrological benefits of BGI visible and easier to discuss.

- permeable surfaces are effective only when the full pavement structure is designed for water storage and infiltration;
- surface runoff can be strongly reduced, but clogging prevention and maintenance must be planned from the start;
- pilot plots should be used as local evidence for municipal standards and investor guidance;

- monitoring results should feed back into the BGI Tool and catalogue assumptions.

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Annexes

- Annex A: BGI Catalogue
- Annex B: BGI TOOL

Interreg CENTRAL EUROPE

Co-funded by the European Union

MAURICE

Catalogue of Blue Green Infrastructure Technologies

IN-GROUND RAIN GARDEN

A rain garden is a nature-based solution classified as a bioretention system. It consists of retention and infiltration surfaces formed as shallow depressions in the terrain, typically incorporating subsurface drainage layers and planted with vegetation. Rain gardens can be implemented in several configurations, in-ground installations, and basin-type (depressed) forms.

For the drainage of roads, parking areas, and pedestrian or shared-use surfaces, rain gardens are most designed as in-ground depressions. The selection of a specific rain garden type depends on the size of the contributing catchment and local site conditions, such as soil and groundwater characteristics, available space, and land-use constraints.

RESILIENCE TO GEOHAZARDS

Flooding and prolonged waterlogging

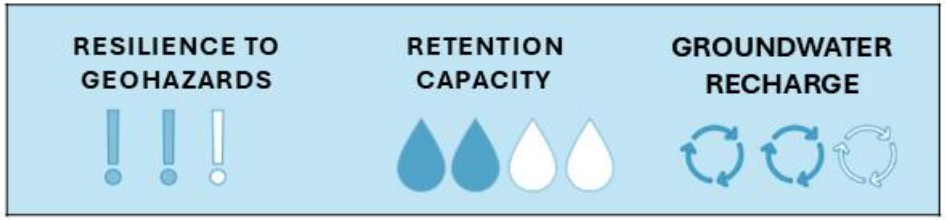
Rain gardens are installations designed for the temporary storage and infiltration of stormwater, which results in a localized increase in soil moisture. Under conditions of excessive water inflow, low soil permeability, or a high groundwater table, prolonged soil saturation may occur, promoting processes such as settlement and suffusion. These phenomena can lead to a deterioration of the soil's mechanical properties and adversely affect ground stability.

Soil erosion

Surface erosion may occur during high-intensity rainfall, especially before vegetation becomes established. The use of erosion-resistant planting schemes, mulch layers, and controlled inflow points reduces sediment transport and maintains soil structure.

Groundwater interaction

In-ground rain gardens interact directly with groundwater systems. When properly designed, they contribute to groundwater recharge; however, insufficient separation from the groundwater table may reduce treatment efficiency and pose stability risks. Maintaining adequate vertical separation is essential.



Retention capacity:

Minimum: 150 L/m^2 Average: 200 L/m^2 Maximum: 250L/m^2

Groundwater Recharge Potential

In-ground rain gardens have high potential for groundwater recharge, as they are designed to infiltrate and percolate stormwater directly into the underlying soil layers.

The effectiveness of groundwater recharge depends primarily on soil permeability, depth to the groundwater table, and hydraulic loading rates. Well-drained soils (e.g. sandy loams) and sufficient vertical separation between the garden base and the groundwater table allow for efficient infiltration while maintaining water quality protection.

By temporarily storing runoff and promoting slow percolation, in-ground rain gardens reduce surface runoff volumes and peak flows, thereby enhancing natural recharge processes and supporting local groundwater balance. Vegetation and soil media further improve recharge quality through filtration, adsorption, and biological uptake of pollutants before water reaches deeper soil horizons.

Recharge potential may be limited in areas with low-permeability soils, high groundwater tables, or contaminated subsurface conditions. In such cases, underdrains, soil amendments, or alternative stormwater management solutions may be required to ensure both hydraulic performance and environmental safety.

Construction parameters

System type: shallow vegetated bioretention basin designed for temporary storage, filtration, and infiltration of stormwater from impervious surfaces.

- Vegetation layer: diverse plant species tolerant to periodic flooding and drought, providing evapotranspiration, pollutant uptake, and surface stabilization.
- Topsoil / planting layer: engineered soil mix composed of 50–60% sand or permeable soil, 20–40% compost or peat, and 0–30% fertile topsoil, supporting plant growth and filtration.
- Filter layer (sand / permeable soil): layer of medium sand or permeable soil mixture improving infiltration and supporting the upper vegetation layer.
- Drainage layer (gravel): 0.20 – 0.25 m layer of washed gravel (grain size 8–16 mm) located at the bottom of the basin to enhance drainage and temporary water storage.
- Drainage pipe: perforated drainage pipe wrapped in geotextile placed within the gravel layer to collect excess water and convey it to the overflow system.
- Overflow pipe: overflow structure installed to safely discharge excess water when the garden reaches its storage capacity.
- Decorative surface layer: optional gravel or decorative stones (>16 mm) placed on the surface to reduce erosion and improve aesthetics.
- Ponding depth: surface depression designed to allow temporary water storage, typically 0.20 – 0.30 m below the surrounding ground level.
- Geotextile: protective layer used around drainage pipes or as a separation layer preventing migration of fine soil particles into drainage layers.
- Impermeable liner (optional): PVC liner or geomembrane used in sealed rain garden systems where infiltration into native soil is not desired.
- Infiltration function: stormwater infiltrates through soil layers into the ground or is drained through the perforated pipe system to a receiving system.
- Maintenance requirement: periodic removal of sediment, inspection of inlet and drainage pipes, and maintenance of vegetation to ensure long-term performance.

Design requirements

PLANT GROWTH CONDITIONS:

sunny and shaded areas

SOIL PERMEABILITY:

$1{\cdot}10^{-5}$ m/s ≤ k < $1{\cdot}10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:

minimum 1.0 m below the bottom of the garden (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:

2-6%

PRETREATMENT:

sediment forebay or filter strip to prevent clogging

SITE TOPOGRAPHY:

low-relief terrain

Photos: https://sztuka-krajobrazu.pl

Design requirements

Minimum distance from:

1. **buildings:** 5.0 m (infiltration rain garden); 0.5 m (lined rain garden)
2. **plot boundary:** 1.0 m
3. **underground infrastructure:** 1.5 m
4. **surface waters & drinking water wells:** 30 m
5. **septic tanks:** 30 m

Photos: https://zielonyogrodek.pl

Best practice - examples

Rain garden at the Municipal Flood Protection Storage Facility on Kaczeńce Street in Gdańsk

Rain garden on the campus of Gdańsk University of Technology

Rain gardens in Gdańsk, Poland are a pioneering example of nature-based stormwater management, making Gdańsk the first city in the country to implement in-ground rain gardens as part of its urban drainage strategy. Designed to retain excess runoff from impervious surfaces through terrain shaping and hydrophytic vegetation, these systems provide significant retention capacity.

Rain garden on the campus of Gdańsk University of Technology, Poland was implemented in 2023 as part of the international NICE project under the Horizon 2020 programme. With a surface area of 63 m^2 and a retention capacity of 12 m^3, the system combines stormwater retention with treatment processes such as energy dissipation, sedimentation, and sorption of pollutants, while supporting local biodiversity through hydrophytic vegetation.

Application

- Receivers for drainage systems for road lanes and parking lots
- Roof drainage

Features & Benefits

- Improves water quality by filtering nutrients, heavy metals, and suspended solids.
- Enhances urban biodiversity and provides microclimate regulation.
- Reduces pressure on sewer systems during heavy rainfall.

RAISED-BED RAIN GARDEN

A rain garden in a box is a nature-based solution classified as a bioretention system. Unlike in-ground rain gardens, boxed rain gardens operate independently of native soil and are suitable for locations with limited infiltration capacity, high groundwater levels, or sealed surfaces.

Rain gardens in boxes are used for the drainage of roofs, paved courtyards, and other urban spaces with limited area. In such cases, they take the form of elevated bioretention units. The selection of this solution depends on the size of the contributing catchment and local conditions, including soil permeability, groundwater levels, structural load-bearing capacity, available space, and constraints related to land use.

RESILIENCE TO GEOHAZARDS

Landslides and mass ground movements

Rain gardens in boxes, as structures placed on the ground surface, are not directly connected to the native soil and therefore are not subject to landslides or soil creep. Their stability depends primarily on the bearing capacity and uniformity of the supporting surface. Insufficient bearing capacity or differential settlement may lead to tilting or deformation

Flooding and temporary waterlogging

The elevated position of rain gardens in boxes reduces the risk of direct impact from flooding and temporary inundation. Excess water is discharged through drainage layers and overflow outlets, allowing controlled outflow and reducing the risk of excessive saturation within the system.

Soil erosion

The substrate within a rain garden in a box is confined within a closed structure, which significantly limits both water and wind erosion. The lack of direct interaction with native soil eliminates the risk of suffusion. Minor migration of fine particles may occur within the filter layers of the box; however, with proper material selection and grading, this does not compromise system stability.

RESILIENCE TO GEOHAZARDS	RETENTION CAPACITY	GROUNDWATER RECHARGE
! ! !	2 of 4 drops	1 of 3

Retention capacity:

Minimum: 200 L/m² | Average: 250 L/m² | Maximum: 450L/m²

Groundwater Recharge Potential

Raised-bed rain gardens have limited to indirect groundwater recharge potential, as they are hydraulically separated from native soil and groundwater systems.

Rainwater is temporarily retained and treated within the engineered soil media, with infiltration typically controlled through drainage layers and overflow structures.

Groundwater recharge may occur indirectly where the system is designed with a permeable base or underdrain outlet that allows treated water to infiltrate into the underlying soil at a regulated rate. This approach reduces the risk of uncontrolled seepage toward building foundations or underground infrastructure.

In locations with high groundwater tables, low-permeability soils, or contaminated subsurface conditions, raised-bed rain gardens provide effective stormwater management while minimizing direct interaction with groundwater. When fully lined and drained, their contribution to groundwater recharge is minimal, and excess water is safely conveyed to downstream drainage systems.

Construction parameters

System type: container-based bioretention system designed to collect, temporarily store, and filter stormwater from roof downpipes.

- Container structure: durable planter box made of plastic, wood, concrete, or metal capable of withstanding substrate pressure and outdoor weather conditions.
- Waterproof liner: PVC membrane or geomembrane lining the container to prevent water leakage and protect the container structure.
- Drainage layer (gravel): 0.15 – 0.25 m layer of washed gravel placed at the bottom to store excess water and improve drainage.
- Drainage pipe: perforated drainage pipe wrapped in geotextile installed within the gravel layer to collect excess water and convey it to the overflow pipe.
- Filter layer (sand): 0.10 – 0.20 m layer of medium sand improving filtration and supporting infiltration through the soil layers.
- Planting soil layer: engineered soil mix consisting of sand, compost or peat, and fertile soil providing adequate conditions for plant growth and stormwater filtration.
- Vegetation layer: plants tolerant to periodic flooding and drought, ensuring evapotranspiration and pollutant removal.
- Surface protection layer: decorative gravel, stones, or mulch protecting the soil surface and reducing erosion.
- Overflow pipe: overflow outlet connected to drainage system or discharge point to remove excess water during heavy rainfall events.
- Inlet connection: roof downpipe connected to the container system via inlet pipe directing stormwater into the garden.
- Ventilation / air gap: minimum 0.30 m distance from the building wall to allow air circulation and prevent moisture accumulation near the facade.
- Ponding depth: temporary water storage depth typically 0.10 – 0.20 m below the container edge.
- Maintenance requirement: periodic inspection of inlet and overflow pipes, removal of accumulated sediment, and regular vegetation maintenance.

Design requirements

PLANT GROWTH CONDITIONS:
sunny and shaded areas

SOIL PERMEABILITY:
not applicable

GROUNDWATER TABLE LEVEL:
not applicable

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
1-3%

PRETREATMENT:
sediment forebay or filter strip to prevent clogging

SITE TOPOGRAPHY:
not applicable

Photos: https://deszczowe-ogrody.pl/

Design requirements

Minimum distance from:

Photos: https://zielonyogrodek.pl

1	2	3	4	5
buildings: 0.3 m	**plot boundary:** not applicable	**underground infrastructure:** not applicable	**surface waters & drinking water wells:** not applicable	**septic tanks:** not applicable

Rain gardens in Bydgoszcz

Rain gardens along London Road

Best practices - example

The rain garden at the City Hall in Bydgoszcz, Poland was implemented as part of the City Water Circles (CWC) pilot project as a small-scale, easily replicable rainwater solution. Rainwater collected from the building roof is conveyed to specially designed containers planted with hydrophilic vegetation, where it is retained and treated before excess water is discharged to the sewer system. The project combines technical stormwater management with community involvement and educational functions, demonstrating the potential of container-based rain gardens in dense urban areas.

Croydon's SuDS (Sustainable Drainage Systems) rain gardens in the UK were installed along London Road in the town centre to manage surface water runoff and mitigate flooding while enhancing urban green infrastructure. The project used large raised rain garden planters with layered soil and resilient vegetation to capture rainwater from an approximate 400 m^2 catchment area, slow runoff, and integrate biodiversity and air quality improvements into the streetscape.

Application

- Receivers for drainage systems from road lanes, parking lots and impervious surfaces.
- Roof drainage.

Features & Benefits

- Filters pollutants via elevated soil layers and native plants.
- Boosts biodiversity and cools urban microclimates.
- Reduces pressure on sewer systems during heavy rainfall.

UNDERGROUND RETENTION TANK

An underground retention tank is an engineering solution used in stormwater management systems. It consists of a watertight, subsurface storage structure designed for the temporary collection of runoff from roofs and impervious surfaces. These tanks, typically made of concrete or plastics such as polyethylene, may be equipped with filtration systems, flow control devices, and emergency overflow.

An underground retention tank is used to store excess stormwater and release it in a controlled manner, reducing the risk of overloading drainage systems and local flooding. Unlike infiltration-based solutions, it does not require water to percolate into the ground and is installed below the surface, allowing the preservation of functional and biologically active land above. This solution is particularly suitable for areas with limited space, high groundwater levels, and where precise control of runoff from roofs and impervious surfaces is required.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Underground retention tanks, when properly designed and founded on adequately prepared subsoil, demonstrate high resistance to settlement and ground movements. In soils susceptible to the washout of fine particles, the risk of suffusion should be considered, and appropriate filter layers should be applied to prevent particle migration.

Flooding and surface water extremes

Tanks located below ground level are largely protected from the direct impact of surface flooding and intense rainfall. Properly designed inlet and outlet systems ensure hydraulic stability even under peak flow conditions.

Soil erosion

Placement below ground surface eliminates exposure to water and wind erosion. However, where groundwater flow or infiltrating water occurs around the structure, there is a potential risk of suffusion, particularly in non-cohesive soils. The use of properly designed filter and separation layers reduces the risk of fine particle washout and ensures long-term subsoil stability.

Groundwater interaction

The performance of underground retention tanks is closely dependent on groundwater conditions. A high groundwater table may generate uplift forces, which must be accounted for in design calculations. Appropriate measures, such as structural weighting or anchoring, are required to ensure stability.

RESILIENCE TO GEOHAZARDS	RETENTION CAPACITY	GROUNDWATER RECHARGE
! ! !		Not applicable

Retention capacity:

Minimum: 400 L/m^2 Average: 1600 L/m^2 Maximum: 2800 L/m^2

Groundwater Recharge Potential

An underground retention tank typically has low to negligible groundwater recharge potential, as it is designed primarily for sealed storage and controlled discharge rather than infiltration.

Rainwater is retained within a watertight structure and released to downstream drainage systems (e.g., sewers, receiving waters, or treatment units) at a regulated rate.

Recharge potential becomes site- and design-dependent only if the tank is configured as an infiltration/soakaway system (e.g., with a permeable base, infiltration galleries, or controlled exfiltration elements). In such cases, treated or pre-filtered water can percolate into the surrounding soil, provided that soil permeability is adequate and sufficient separation to the groundwater table is maintained.

In areas with high groundwater tables, low-permeability soils, or contaminated subsurface conditions, infiltration is often restricted for stability and water-quality reasons; therefore, fully sealed tanks remain the preferred solution and contribute minimally to groundwater recharge.

Construction parameters

- Installation type: underground, buried structure
- Construction materials: reinforced concrete, prefabricated concrete elements, or high-density polyethylene (HDPE) / polypropylene modules
- Foundation: compacted granular bedding or reinforced concrete base, depending on soil conditions and load requirements
- Depth of installation: site-specific; dependent on hydraulic design, frost depth, and groundwater level
- Soil / subgrade: stable, leveled excavation bottom free of large stones and sharp elements; suitable hydrogeological conditions required.
- Bedding / Base Layer (sand or gravel): 0.15 – 0.20 m compacted bedding layer of sand or gravel with grain size 8–16 mm.
- Backfill material: gravel backfill with grain size 8–16 mm, placed and compacted in layers of approx. 0.30 m during simultaneous tank filling.
- Filter unit: mandatory mechanical filter installed upstream of the tank to remove debris and improve stored water quality.
- Inlet pipework: roof downpipes connected to the tank through a pretreatment filter system.
- Overflow system: emergency overflow provided to discharge excess water safely to a receiving system or storm sewer when the tank is full.
- Pump system: pump installed for water abstraction and distribution for garden irrigation or domestic non-potable use.
- Access opening / inspection shaft: opening sized to allow maintenance access, pump installation, and sediment removal.
- Traffic load resistance: where installed in trafficable areas, the tank neck, cover, and top slab should be designed for the required load class.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
not applicable

GROUNDWATER TABLE LEVEL:
minimum 1.0 m
below the bottom of the installtion (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
0.05%

PRETREATMENT:
not applicable

SITE TOPOGRAPHY:
not applicable

Photos: https://titanenviro.com

Design requirements

Minimum distance from:

1. **buildings:** 3 m
2. **plot boundary:** 2 m
3. **underground infrastructure:** 1.5 m
4. **surface waters & drinking water wells:** 15 m
5. **septic tanks:** 15 m

Photo: https://summitprecastconcrete.com/

Construction of a underground retention tanks in Park Słowiański in Gorzów Wielkopolski

Installation of Atlantis Tank underground retention system for the Zaandam Distribution Centre project, Netherlands

Best practice - examples

Underground retention tanks in Park Słowiański, Gorzów Wielkopolski (Poland) represent a large-scale implementation of rainwater storage. The system comprises nine reinforced concrete tanks with a total capacity of 22,600 m^3, designed to capture runoff from surrounding streets, prevent local flooding, and support secondary uses such as irrigation and public utilities. This approach forms part of a comprehensive stormwater infrastructure upgrade, including improvements to the existing drainage network.

Stormwater storage tank at a distribution centre in Zaandam, Netherlands demonstrates the use of tank system a reinforced concrete stormwater storage solution that can be installed underground to capture and manage rainwater runoff from commercial infrastructure. The tank supports flood mitigation by retaining peak flows and can be covered by green areas or surfaces above, illustrating how underground stormwater tanks integrate with urban land use.

Application

- Stormwater retention from roads, parking lots and rooftops in dense urban areas
- Peak flow control under public spaces, lawns and heavy vehicle traffic zones
- Rainwater storage for reuse in industrial/commercial sites with high groundwater tables

Features & Benefits

- Subsurface system maximizes land use under heavy traffic areas while providing controlled stormwater storage, flood protection, and sewer relief.

ABOVEGROUND RETENTION TANK

An above-ground retention tank is a structure installed on the ground surface, used in stormwater management systems. It is designed for the temporary storage of stormwater, most commonly collected from roofs, and for its subsequent controlled use or discharge.Unlike underground systems, it remains visible and accessible above ground and is often integrated into the surrounding landscape. It may take the form of tanks or modular units equipped with overflow systems and optional filtration.
These tanks are typically made of materials such as polyethylene, steel, or concrete. They are particularly suitable in locations where excavation is limited, groundwater levels are high, or where easy monitoring and adjustment of storage capacity are required.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Aboveground retention tanks are less affected by deep ground movements but may be vulnerable to differential settlement if founded on poorly prepared subsoil. Proper foundation design and ground compaction are essential to ensure long-term stability.

Flooding and surface water extremes

As surface-based structures, aboveground tanks may be exposed to flooding during extreme rainfall events. Elevation above surrounding terrain and controlled inlet and overflow systems reduce the risk of structural damage and uncontrolled discharge.

Soil erosion

Surface runoff may cause localized erosion around the base of the tank, particularly during intense rainfall events. The use of a stable foundation layer, edge protection, and proper site drainage reduces the risk of undercutting and loss of bearing capacity.

Groundwater interaction

Direct interaction with groundwater is typically negligible due to the aboveground placement. This eliminates risks related to buoyancy and groundwater contamination.

RESILIENCE TO GEOHAZARDS	RETENTION CAPACITY	GROUNDWATER RECHARGE
! ! !	1 of 4 drops	Not applicable

Retention capacity:

Minimum: 50 L/m^2 Average: 500 L/m^2 Maximum: 1000 L/m^2

Groundwater Recharge Potential

An above-ground retention tank does not contribute to groundwater recharge, as its function is limited to the surface storage of stormwater and its controlled discharge, without involving infiltration processes.

Stormwater is collected within a watertight structure and conveyed to receiving systems such as sewer networks, drainage ditches, or surface water bodies. The lack of contact with native soil precludes any direct groundwater recharge.

The tank therefore serves solely a storage and flow-regulation function within the drainage system and does not participate in groundwater recharge processes.

Construction parameters

- Installation type: aboveground, surface-mounted structure
- Construction materials: reinforced concrete, prefabricated concrete elements, steel, or high-density polyethylene (HDPE) / polypropylene tanks
- Foundation / base layer: stable and level base made of compacted soil, paving slabs, or concrete pad to ensure structural stability and prevent tank tilting.
- Inlet connection: roof downpipe connected to the tank using a rainwater diverter or flexible hose directing runoff into the tank.
- Pretreatment filter: leaf filter or debris screen installed in the downpipe diverter to remove coarse contaminants before water enters the tank.
- Overflow outlet: overflow pipe located near the upper edge of the tank to safely discharge excess water away from the building during heavy rainfall.
- Outlet tap / valve: tap installed at the lower part of the tank to allow water withdrawal for watering cans or connection of a garden hose.
- Connection system: optional hose connections enabling linking of multiple tanks to increase total storage capacity.
- Tank cover: lid installed on the tank to prevent debris entry, reduce evaporation, and limit mosquito breeding.
- Hydraulic function: temporary storage of rainwater for non-potable uses such as irrigation, cleaning, or other domestic purposes.
- Maintenance requirement: regular cleaning of filters, gutters, and tank interior to maintain water quality and system efficiency.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
not applicable

GROUNDWATER TABLE LEVEL:
not applicable

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
0.05%

PRETREATMENT:
not applicable

SITE TOPOGRAPHY:
not applicable

Photos: https://www.muratorplus.pl/

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: not applicable	**plot boundary:** not applicable	**underground infrastructure:** not applicable	**surface waters & drinking water wells:** not applicable	**septic tanks:** not applicable

Photos: https://sztuka-krajobrazu.pl

Best practice - example

Aboveground retention tanks for residential stormwater management (Poland) are available in a wide range of capacities (e.g. from 100 L to over 20,000 L) and supported by the national "Moja Woda" programme, are used to store and reuse rainwater collected from roofs and paved surfaces. The tanks are installed on prepared ground surfaces and connected to downpipes and filtration systems, enabling efficient collection, retention, and reuse of rainwater for garden irrigation, cleaning, and other.

In the **Moreton Bay region of Queensland, Australia**, **aboveground rainwater tanks** are recognised in local building and planning regulations as acceptable stormwater harvesting solutions. Voluntary installation of rainwater storage systems is permitted under the Queensland Development Code, requiring minimum capacities of 5,000L for detached houses (50% roof catchment or 100m^2) and connection to toilets, washing machines, and outdoor taps. Tanks reduce potable water demand by capturing roof runoff for garden irrigation and non-potable household uses.

Application

- Rainwater collection and storage from residential roofs for garden irrigation
- Temporary retention of stormwater and meltwater in small-scale urban environments

Features & Benefits

- Allows simple installation and maintenance.
- Provides flexible and scalable storage capacity.
- Supports rainwater reuse and water conservation.

BIORETENTION BASINS

A bioretention basin is a vegetated stormwater treatment system designed to remove sediments and pollutants through fine filtration, extended detention, and biological uptake, while also attenuating runoff during frequent rainfall events. The system effectively reduces fine and coarse sediments, hydrocarbons, and other dissolved or particulate contaminants.

Unlike bioretention swales, bioretention basins do not serve a conveyance function; high flows are diverted or discharged via overflow structures. Owing to their flexible scale, shape, and vegetation options, they can be integrated into streetscapes, parking areas, traffic-calming features, and drainage outfalls, and are suitable for both new developments and retrofit applications.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Bioretention systems may be susceptible to settlement and local subgrade deformations, particularly in areas with heterogeneous, weak, or moisture-sensitive soils. Cyclical wetting and drying can lead to a deterioration of soil mechanical properties and the development of differential settlement.

Flooding and extreme rainfall

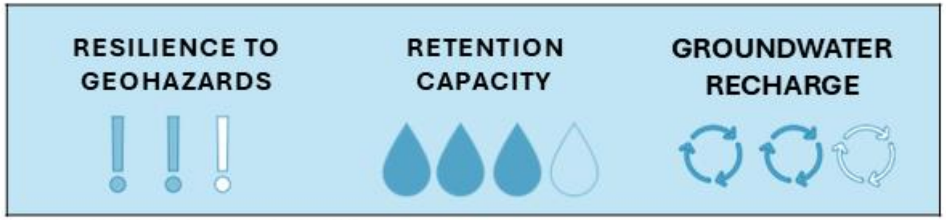
Extreme rainfall events may exceed the design capacity of the system. Proper sizing, the use of emergency overflows, and controlled inflow points enhance resilience to flooding and help prevent surface erosion.

Soil erosion

High inflow velocities and intense rainfall may cause surface erosion, particularly during the early stages of system operation. Under conditions of subsurface flow, there is also a potential risk of local suffusion processes associated with the migration of fine soil particles. The application of properly designed filter layers, stabilizing vegetation, and protected inlets reduces these risks and supports the long-term stability of the system.

Groundwater interaction

Bioretention systems remain in direct interaction with groundwater. While this promotes infiltration and recharge, insufficient separation from the groundwater table may reduce treatment efficiency and affect subgrade stability. Maintaining adequate vertical separation between the base of the system and the groundwater level is essential.



Retention capacity:

Minimum: 400 L/m^2 Average: 850 L/m^2 Maximum: 1300 L/m^2

Groundwater Recharge Potential

Bioretention systems exhibit a moderate to high potential for groundwater recharge, as they are designed to retain, treat, and infiltrate stormwater directly into the ground. The effectiveness of this process depends primarily on soil permeability, system depth, and adequate vertical separation from the groundwater table. In permeable soils with a sufficiently thick unsaturated zone, bioretention systems promote gradual infiltration, supporting natural recharge processes while maintaining water quality.

Filter media and vegetation improve the quality of infiltrating water through filtration, adsorption, and biological uptake of pollutants before the water reaches deeper soil layers. Controlled infiltration also reduces surface runoff volumes and peak flows, contributing to the improvement of the local water balance.

The recharge potential may be limited in areas with low-permeability soils, high groundwater levels, or contaminated subsurface conditions. In such cases, measures such as underdrains or impermeable liners are applied to restrict infiltration, shifting the system's function toward retention and treatment rather than recharge.

Construction parameters

- Soil: well-draining substrate with organic matter to support vegetation (engineered soil mix composed of 20–30% humus, peat or compost, 50–60% non-cohesive permeable soil, and 20–30% fertile topsoil, thoroughly mixed to support infiltration and plant growth).
    - Filter soil: 0.3 – 0.6 m
    - Drainage layer (gravel, aggregate): 0.2 – 0.3 m
    - Surface layer: approx. 0.05 m mulch, crushed stone or pebbles, or alternatively a grassed surface planted with a suitable seed mix.
- Longitudinal slope: mild slope enabling slow conveyance and temporary ponding of stormwater without erosion.
- Water depth at maximum flooding: 15 - 30 cm
- Maximum ponding time: temporary water stagnation up to 48 hours is acceptable.
- Emergency overflow: upon filling of the basin
- Side slope ratio: gently sloped for stability, maintenance access, and integration with the surrounding terrain
- The infiltration rate of rainwater into the soil shall not be lower than 1.25 cm/h
- Vegetation cover: grass or zone-based planting to slow runoff, enhance pollutant removal, and improve landscape integration.

Design requirements

PLANT GROWTH CONDITIONS:
sunny and shaded areas

SOIL PERMEABILITY:
$1{\cdot}10^{-4}$ m/s ≤ k < $1{\cdot}10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m below the bottom of the installtion (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
3-8%

PRETREATMENT:
sedimentation forebay, grit chamber, oil–grit separator

SITE TOPOGRAPHY:
flat to gently sloping terrain

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: 5 m	**plot boundary:** 1.5 m	**underground infrastructure:** 1.5 m	**surface waters & drinking water wells:** 30 m	**septic tanks:** 30 m

Photos: https://www.northstarenv.com/case-studies/bio-retention-system/

Bioretention area inTemple Farm, Chelmsford (UK)

This bioretention area is located in the Stormwater Demonstration Site in Anne McCrary Park located on Randall Parkway (USA)

Best practice - examples

Bioretention basin at Temple Farm, Chelmsford (UK) is a shallow landscaped system using engineered soil and vegetation to treat stormwater runoff and reduce peak flows. The basin is designed with groundwater separation, overflow facilities for extreme events, and a controlled contributing catchment area of up to 0.8 ha.

Bioretention area in the Stormwater Demonstration Site at Anne McCrary Park, Wilmington (USA) showcases practical urban stormwater treatment. The shallow vegetated basin captures polluted runoff from surrounding impervious surfaces, filtering sediments, nutrients, heavy metals, and bacteria through engineered soil and wetland plants while providing flood storage and groundwater recharge.

Application

- Urban parks and recreational areas
- Residential neighborhoods and subdivisions
- Commercial parking lots and medians

Features & Benefits

- Pollutant Removal: filters sediments, nutrients, metals, and bacteria through multilayer filtration with plants.
- Flood Control: reduces peak flows, stores water, and recharges groundwater.
- Landscape Integration: enhances park aesthetics, boosts biodiversity, and educates the community.

INFILTRATION TRENCH

Infiltration trenches are shallow excavations filled with gravel, crushed stone, or similar permeable materials, designed for the temporary storage and infiltration of stormwater into the ground. Their primary function is to enhance the natural infiltration capacity of soils and reduce surface runoff from impervious areas.

Stormwater treatment within infiltration trenches occurs through physical filtration, adsorption onto the aggregate material, and biological processes in the surrounding soil.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Infiltration trenches may be susceptible to settlement and local deformations of the side slopes and trench bottom, particularly in weak or heterogeneous soils. Prolonged exposure to water and fluctuating moisture conditions can lead to a reduction in soil strength and the development of differential movements.

Flooding and extreme rainfall

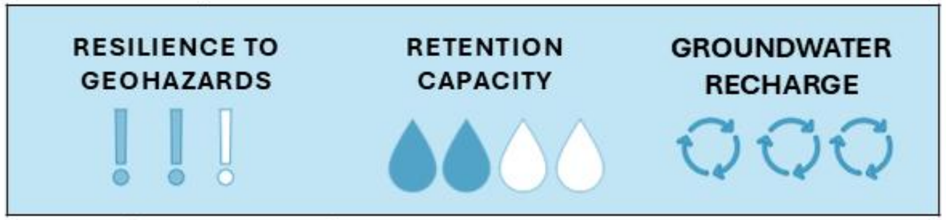
Infiltration trenches are designed to store and infiltrate stormwater; however, extreme rainfall events may exceed their infiltration capacity, leading to surface surcharge or bypass flow.

Soil erosion and clogging

High inflow velocities and the presence of suspended solids may cause surface erosion and displacement of filter media. Under seepage conditions, there is also a risk of suffusion, particularly in non-cohesive soils, involving the washout of fine particles and gradual degradation of the soil structure.

Interaction with groundwater

Infiltration trenches directly interact with groundwater systems. A high groundwater table may reduce infiltration efficiency and increase the risk of prolonged saturation, uplift effects, or contaminant transport. Maintaining sufficient vertical separation between the trench base and the groundwater table is essential for both hydraulic performance and geotechnical stability.



Retention capacity:

Minimum: 120 L/m^2 Average: 285 L/m^2 Maximum: 450 L/m^2

Groundwater Recharge Potential

Infiltration trenches provide a high potential for groundwater recharge by promoting direct percolation of stormwater into the underlying soil profile. By temporarily storing runoff within a porous aggregate matrix, these systems facilitate gradual infiltration, reducing surface runoff volumes and supporting local aquifer replenishment.

Recharge effectiveness is strongly dependent on subsoil permeability and stratigraphy. Trenches constructed in well-draining soils (e.g. sands or sandy loams) allow efficient vertical infiltration, whereas low-permeability layers (e.g. clays or silts) may limit recharge and lead to prolonged water retention within the system.

The depth of the trench and its proximity to the groundwater table influence recharge dynamics. Adequate vertical separation between the trench base and the seasonal high groundwater level is required to maintain unsaturated flow conditions, enhance pollutant attenuation, and prevent direct short-circuiting to the aquifer.

Pretreatment of inflowing runoff is essential to sustain long-term recharge performance. Sediment and pollutant accumulation can clog pore spaces, significantly reducing infiltration rates. The inclusion of upstream sediment controls and filter layers supports hydraulic conductivity and protects groundwater quality.

When properly sited and designed, infiltration trenches contribute to sustainable groundwater recharge, enhance baseflow in receiving water bodies, and support local water balance without imposing significant risks to subsurface stability or water quality.

Construction parameters

- Soil: permeable native soil with high infiltration capacity allowing effective percolation of stormwater.
- Filter soil / vegetation layer: approx. 0.20 m humus layer on side slopes to support vegetation and protect against erosion.
- Aggregate infiltration layer (gravel / crushed stone): 0.30 – 0.50 m layer of coarse aggregate (grain size ≥ 31.5 mm) providing temporary storage and facilitating infiltration.
- Bedding / Base Layer (Sand): 0.20 m medium or coarse sand layer ensuring uniform distribution of infiltrating water.
- Geotextile: non-woven geotextile (minimum 200 g/m^2) separating soil from the aggregate layer and preventing clogging of the infiltration medium.
- Minimum trench width: ≥ 0.40 m.
- Maximum trench depth: 0.60 m (open infiltration trench).
- Side slope ratio (open trench): ≤ 1:3 to ensure stability and safe maintenance.
- Stone protection at inlet: riprap layer placed on geotextile at concentrated inflow points to prevent erosion of slopes and trench bottom.
- Optional drainage pipe: perforated drainage pipe installed within the aggregate layer to distribute inflow and improve hydraulic performance.
- Emergency overflow: overflow structure (typically a vertical manhole) provided to discharge excess stormwater when the trench storage capacity is exceeded.
- Maximum drainage time: stored stormwater should infiltrate into the soil within 48 hours after the rainfall event.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
$1 \cdot 10^{-5}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m below the bottom of the installation (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
2-5%

PRETREATMENT:
rarely applied; limited to basic sediment control where necessary.

SITE TOPOGRAPHY:
flat or gently sloping terrain


Photos: https://awwatersheds.org/infiltration-trench-do-it-yourself-conservation-practices/

Design requirements

Minimum distance from:

1. **buildings:** 5 m
2. **plot boundary:** 1.5 m
3. **underground infrastructure:** 1.5 m
4. **surface waters & drinking water wells:** 30 m
5. **septic tanks:** 30 m

Photos: https://uslugiekosystemow.pl/system-zagospodarowywania-wody-opadowej-podkowa-lesna/

Infiltration trench in Gdańsk

Infiltration trench in Lino Lakes (US)

Best practice - examples

Infiltration trench in Gdańsk, Poland is applied as a local stormwater management solution to reduce surface runoff from impervious areas and promote infiltration into the ground. The trench temporarily stores stormwater within a gravel-filled structure, where pollutants are reduced through filtration and adsorption processes before infiltration. This solution supports groundwater recharge and helps mitigate local flooding while being easily integrated into existing urban infrastructure.

Infiltration trench in Lino Lakes (USA) is used as a stormwater management practice to capture and temporarily store runoff before allowing it to infiltrate into underlying permeable soils. Pollutant removal occurs through physical, chemical, and biological processes during infiltration, while peak stormwater flows are delayed.

Application

- Near sports fields, recreational areas, or open public spaces

Features & Benefits

- Runoff reduction and infiltration through temporary storage in permeable trench structures.
- Improved water quality via filtration and biological treatment processes.
- Groundwater recharge and flood mitigation in areas with suitable soil and groundwater conditions.

DRAINAGE CHAMBER

A drainage chamber is a subsurface rainwater management solution designed to temporarily store and gradually infiltrate stormwater into the surrounding soil. The system typically consists of modular infiltration tunnels or chambers installed below ground level, providing structural void space for water retention and controlled percolation.

Rainwater entering the system is released into the soil through the base and sidewalls, where natural filtration, adsorption, and biological processes contribute to water quality improvement. Drainage chamber require permeable soils and sufficient vertical separation from the groundwater table to ensure safe and effective infiltration.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Drainage chamber rely on subsurface infiltration and may be affected by settlement, differential compaction, or soil displacement, particularly in poorly consolidated or heterogeneous soils.

Flooding and extreme rainfall

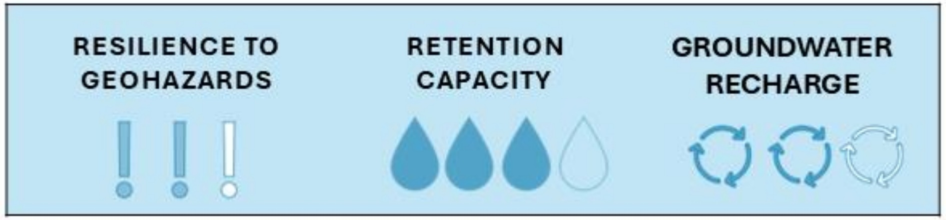
These systems are designed to infiltrate rainwater into the surrounding soil; however, extreme rainfall events may exceed infiltration capacity, resulting in surcharge or reduced drainage efficiency. Adequate storage volume, emergency overflow connections, and staged discharge pathways enhance resilience during high-intensity events.

Soil erosion and clogging

The transport of fine particles with runoff may result in their migration into the filter zone and gradual clogging of pore spaces, reducing the system's infiltration capacity. Under seepage conditions, there is also a risk of suffusion, involving the washout of fine particles from the native soil, particularly in non-cohesive soils. These processes may lead to local loosening of the subsoil structure and secondary settlement.

Groundwater interaction

Drainage chambers remain in direct interaction with groundwater. A high groundwater table may reduce infiltration efficiency and lead to prolonged soil saturation, affecting subgrade stability and increasing the risk of deformation. Maintaining adequate vertical separation between the system and the groundwater table is essential for both hydraulic performance and geotechnical safety.



Retention capacity:

Minimum: 400 L/m^2 Average: 750 L/m^2 Maximum: 1100 L/m^2

Groundwater Recharge Potential

Drainage chamber provide a moderate to high groundwater recharge potential by distributing stormwater into the surrounding soil through perforated drainage elements. This promotes diffuse infiltration and supports local aquifer replenishment while reducing direct surface runoff.

Recharge efficiency depends primarily on soil permeability and subsurface stratigraphy. Systems installed in permeable soils such as sands or gravels allow effective infiltration, whereas fine-grained or layered soils may restrict drainage and reduce recharge rates.
The depth of installation and separation from the groundwater table are critical factors. Adequate vertical clearance from the seasonal high groundwater level is required to maintain unsaturated flow conditions, ensure pollutant attenuation, and prevent direct short-circuiting to the aquifer.

Long-term recharge performance may decline due to clogging of drainage perforations or surrounding filter media. Proper material selection, filter layers, and periodic inspection help sustain infiltration capacity and protect groundwater quality.

When appropriately designed and sited, drainage chamber contribute positively to groundwater recharge and local water balance, with relatively low surface impact.

Construction parameters

- Chamber type: modular plastic infiltration chambers with open bottom and side slots enabling water infiltration into the surrounding soil.
- System configuration: chambers arranged in one or multiple parallel rows at the same elevation, forming modular underground storage and infiltration structures.
- Bedding / Base Layer (aggregate): minimum 0.15 m layer of washed crushed stone with grain size 31–63 mm placed under the chambers to ensure drainage and load distribution.
- Surrounding aggregate layer: washed crushed stone 31–63 mm surrounding the chambers to provide additional storage volume and infiltration surface.
- Geotextile: non-woven geotextile wrapping the aggregate layer to prevent migration of fine soil particles and system clogging.
- Chamber spacing / arrangement: chambers installed in overlapping modular rows without additional connectors, allowing flexible system length and layout.
- Pretreatment system: sediment trap, grit chamber, or oil separator installed upstream to remove sediments and pollutants before water enters the chamber system.
- Inlet distribution pipe: perforated or distribution pipe delivering stormwater evenly along the chamber row.
- End plates: closing plates installed at the beginning and end of each chamber row to prevent aggregate intrusion into the chamber interior.
- Backfill material: structural fill or native soil placed above the aggregate layer according to design requirements and expected surface loads.
- Traffic load capacity: chambers may be designed for pedestrian areas or vehicular loads depending on cover depth and structural specifications.
- Minimum cover above chambers: determined by manufacturer specifications and expected load conditions.
- Inspection and maintenance access: inspection pipes or access shafts enabling periodic inspection and cleaning of the system.
- Hydraulic function: temporary storage of stormwater followed by gradual infiltration into the soil or controlled discharge to a receiving system.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
$1 \cdot 10^{-4}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m below the bottom of the installation (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
1-3%

PRETREATMENT:
basic sediment pretreatment (e.g. catch basin or silt trap)

SITE TOPOGRAPHY:
flat to gently sloping sites

Photos: https://cultec.com/Asset/CULG010-residential-drainage-imperial-english.pdf

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: 5.0 m	**plot boundary:** 2.0 m	**underground infrastructure:** 1.5 m	**surface waters & drinking water wells:** 30 m	**septic tanks:** 30 m

Photo:
https://navotech.com.pl/oferta/komory-drenazowe

Best practice - examples

House in Gdańsk(PL)

Housing estate in the Morena district, Gdańsk (PL)

A good practice example of the application of drainage chambers in Poland and across Europe can be found in modern stormwater management systems implemented in urban areas such as parking lots, commercial zones, and residential developments. These systems are often installed beneath parking areas or green spaces, allowing efficient stormwater retention and infiltration without occupying valuable surface space.
In many municipalities, drainage chamber systems are used as an alternative to traditional stormwater pipes or underground concrete tanks. The chambers are typically installed in rows within an excavation lined with geotextile and filled with washed aggregate. Stormwater collected from roofs, roads, or parking areas is first directed through a pretreatment system such as a sedimentation chamber or oil separator to remove suspended solids and pollutants. The treated water then flows into the chamber system, where it is temporarily stored and gradually infiltrates into the surrounding soil.

Application

- Stormwater drainage from road lanes, parking areas, and paved surfaces
- Roof runoff storage and infiltration systems
- Decentralized stormwater retention and infiltration installations
- Roof runoff management

Features & Benefits

- Provides underground stormwater storage and controlled infiltration into the soil.
- Reduces peak runoff and hydraulic load on stormwater sewer systems.
- Enables efficient use of space by installing the system beneath parking areas or green spaces.
- Modular structure allows flexible system sizing and easy expansion.
- High storage capacity due to large internal void space.

Plastic stormwater chamber system installed beneath a bicycle path along Boulevard Hymus in Pointe-Claire (Canada) for underground stormwater detention.

Plastic stormwater chamber system installed at the Prinsburg yard expansion in Minnesota (USA) for underground stormwater detention and controlled infiltration.

Best practice - examples

A stormwater detention system using plastic stormwater chambers was installed along **Boulevard Hymus in Pointe-Claire (Canada)** to reduce flooding risk and relieve pressure on the local drainage network. The system consists of modular thermoplastic chambers surrounded by crushed stone that temporarily store stormwater and release it gradually into the drainage system. Two underground detention structures with capacities of approximately 1 400 m^3 and 1 550 m^3 were constructed beneath a bicycle path between the roadway and nearby residential areas.

A stormwater detention system using plastic stormwater chambers was installed during the expansion of the **Prinsco yard in Prinsburg, Minnesota (USA)**. The HydroStor® chamber system provides underground storage for stormwater runoff, with a capacity of approximately 5,991 cubic feet within a footprint of about 1,800 square feet. The system collects rainwater and runoff, allowing controlled release to drainage ditches while enabling infiltration into the surrounding soil.

Application

- Stormwater management from roads, parking areas, and paved surfaces
- Roof runoff storage and infiltration systems
- Decentralized stormwater retention and infiltration installations

Features & Benefits

- Provides underground stormwater storage and controlled infiltration into the soil.
- Reduces peak runoff and hydraulic load on stormwater sewer systems.
- Enables efficient use of space by installing the system beneath parking areas or green spaces.
- Modular structure allows flexible system sizing and easy expansion.
- High storage capacity due to large internal void space.

SOAKAWAY SYSTEM

A soakaway system is a solution that enables the capture of surface runoff from roofs, roads, and other impermeable surfaces, temporary storage of water, and its gradual infiltration into the ground. This helps reduce the risk of flooding, relieves stormwater drainage systems, and supports the natural water cycle. The system may take the form of pits or trenches filled with permeable materials such as gravel or crushed stone, or it may consist of modular soakaway crates made of plastic. The porous structure of these systems creates void spaces where water can be retained before it infiltrates into the soil.

Soakaway systems are widely used in residential construction as well as in commercial and infrastructure projects, where they serve as key elements of stormwater management systems. They contribute to improved water balance, reduced erosion, and enhanced local water retention.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Soakaway systems are exposed to settlement, local collapse, and subgrade deformation, particularly in loose, heterogeneous, or poorly compacted soils. These conditions can lead to uneven settlement, reduced structural integrity, and decreased system performance.

Flooding and extreme rainfall

During heavy rainfall or storm events, the inflow volume may exceed the system's storage and infiltration capacity. In extreme cases, this can result in system overloading, structural damage, or uplift of elements due to buoyancy forces, especially where groundwater levels are high.

Soil erosion and clogging

Fine particles transported with stormwater can cause clogging (colmation) of the system, significantly reducing infiltration efficiency. Without adequate filtration, this process can progressively degrade hydraulic performance over time.

Groundwater interaction

Soakaway systems interact directly with groundwater. High or fluctuating groundwater levels can significantly affect the performance of retention–infiltration systems. They reduce infiltration capacity, lead to prolonged soil saturation, and may generate uplift forces acting on the structure. Additionally, they increase the risk of soil softening and secondary settlement. Maintaining adequate vertical separation from the groundwater table and accounting for seasonal fluctuations are essential design considerations.

Retention capacity:

Minimum: 400 L/m² Average: 800 L/m² Maximum: 1200 L/m²

Groundwater Recharge Potential

Soakaway systems provide a high groundwater recharge potential by allowing concentrated stormwater infiltration into the surrounding soil. Stored runoff is gradually released through the soakaway base and sidewalls, promoting vertical and lateral percolation into the subsurface.

Recharge efficiency depends primarily on local soil permeability and geological conditions. Soakaways installed in permeable soils such as sands and gravels achieve effective recharge, while clay-rich or layered soils significantly limit infiltration and may lead to prolonged water retention.

The depth of the soakaway and separation from the groundwater table are critical to recharge performance and water quality protection. Adequate vertical clearance above the seasonal high groundwater level ensures unsaturated flow conditions and allows natural attenuation of pollutants before reaching the aquifer.

Long-term recharge capacity may be reduced by sediment clogging of surrounding soils or structural voids. Pretreatment of inflow and appropriate filter layers are essential to preserve infiltration performance and protect groundwater quality.

When properly designed and sited, soakaway systems contribute positively to local groundwater recharge and water balance, with minimal surface impact.

Construction parameters

- Crate type: modular plastic stormwater crates with openwork walls designed for underground retention and infiltration of stormwater.
- System configuration: crates connected modularly in horizontal and vertical arrangements, forming single-layer or multi-layer storage structures depending on required volume.
- Storage efficiency: approx. 90–95% void ratio, providing high storage capacity within a compact footprint.
- Bedding / Base Layer (gravel or sand): 0.10 – 0.15 m layer of gravel (grain size 8–16 mm or 16–32 mm) or coarse sand ensuring stable support and drainage.
- Surrounding aggregate layer: gravel envelope around the crate system with thickness 0.15 – 0.30 m to improve infiltration and protect the structure.
- Geotextile: non-woven geotextile wrapping the crate system (in infiltration configuration) to prevent soil particles from entering the void space and clogging the system.
- Impermeable liner (retention variant): PVC or PE membrane used instead of geotextile when the system is designed for stormwater storage without infiltration.
- Inlet pipework: stormwater conveyed by solid-wall drainage pipes connected to pretreatment devices before entering the crate system.
- Pretreatment system: sedimentation chamber, grit trap, or oil separator installed upstream to prevent clogging and maintain hydraulic efficiency.
- Ventilation pipe: air vent pipe installed in the crate module and extended approx. 0.5 m above ground level to ensure proper system ventilation.
- Inspection and maintenance access: inspection chambers or access points enabling monitoring and periodic cleaning of the system.
- Backfill material: gravel envelope followed by compacted soil or structural layers depending on surface load conditions.
- Load capacity: system may be installed under landscaped areas, pedestrian zones, or trafficable surfaces depending on structural design and cover depth.
- Hydraulic function: temporary storage of stormwater with subsequent infiltration into surrounding soil or controlled discharge to a receiving system.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
$1 \cdot 10^{-4}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m
below the bottom of the installation (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
1-3%

PRETREATMENT:
basic sediment pretreatment (e.g. catch basin or silt trap)

SITE TOPOGRAPHY:
flat to gently sloping sites

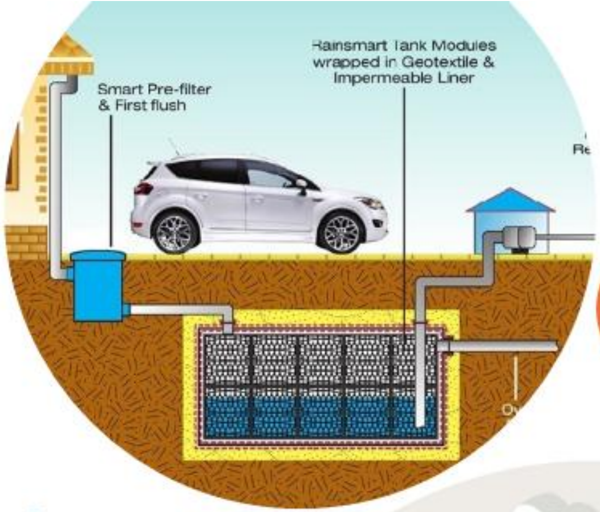
Photo: https://budujemydom.pl/irbj/porady/95652-drenaz-i-wody-deszczowe

Photo: https://www.candi24hrdrainage.co.uk/wp-content/uploads/2023/07/Soakaway-systems-drainage-crates.webp

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: 5.0 m	plot boundary: 2.0 m	underground infrastructure: 1.5 m	surface waters & drinking water wells: 30 m	septic tanks: 30 m



Photos: https://www.drainagesuperstore.co.uk/help-and-advice/project-guides/surface-water-drainage/tips-and-advice-on-using-a-soakaway/

Best practice - examples

Large Soakaway System for Sustainable Stormwater Management at Griffeen Community College (Ireland).

Geocellular soakaway crate system at Residential development in Killarney (Ireland)

At Griffeen Community College in Ireland, a large underground soakaway system was installed to manage stormwater runoff from roofs and paved surfaces within the school campus. The system provides temporary storage of rainwater and enables its gradual infiltration into the soil, reducing pressure on the drainage network. The project was implemented under the Department of Education's Public–Private Partnership programme as part of a sustainable stormwater management strategy.

Residential development in Killarney (Ireland) implemented a geocellular soakaway crate system to manage stormwater runoff from housing units and a large parking area. The installation included an underground storage structure with a capacity of approximately 120 m^3, designed to temporarily retain rainwater and gradually release it into the ground or drainage network. The system helps ensure effective stormwater management while meeting local planning and drainage requirements.

Application

- Receivers for drainage systems from road lanes and parking areas
- Roof drainage from buildings and other structures
- Stormwater management from impermeable surfaces
- Local infiltration systems in residential and commercial developments
- Supplementary elements of Sustainable Drainage Systems (SuDS)

Features & Benefits

- Reduces surface runoff by temporarily storing stormwater and allowing gradual infiltration into the soil.
- Supports groundwater recharge and restores natural water cycle processes.
- Reduces pressure on sewer and drainage systems during heavy rainfall.

WATER RETENTION PONDS

Retention ponds are engineered basins designed for the storage and treatment of stormwater runoff. They function as permanent water bodies, typically supported by emergent and aquatic vegetation that enhances natural treatment processes. These systems are characterized by high storage capacity, allowing them to retain excess stormwater and release it in a controlled, gradual manner to receiving waters or drainage systems. The retention process promotes natural treatment mechanisms such as sedimentation, biodegradation, and sorption of pollutants, improving overall water quality.

In addition, retention ponds provide significant ecological and landscape benefits. They enhance urban biodiversity, create habitats for flora and fauna, and increase the aesthetic and environmental value of green spaces.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Water retention ponds may be affected by settlement, slope instability, or embankment failure, particularly in areas with weak or heterogeneous soils. Proper geotechnical investigation, embankment design, controlled compaction, and slope stabilization measures are essential to ensure structural integrity.

Flooding and extreme rainfall

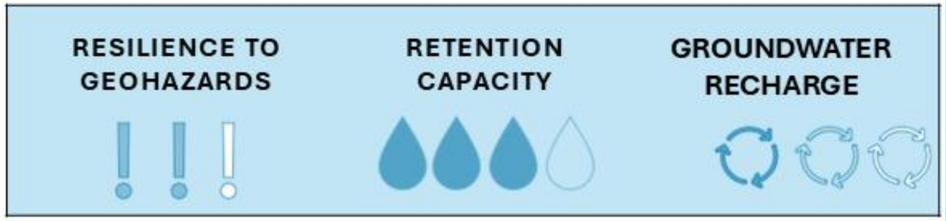
Retention ponds are designed to capture and temporarily store stormwater during rainfall events; however, high-intensity or prolonged precipitation may exceed their design capacity. This can result in overtopping, overloading of hydraulic structures, and increased hydraulic stress on pond slopes and the basin bottom. Adequate storage allowances, overflow structures, and safe discharge pathways are required to ensure system resilience

Soil erosion

High inflow velocities, water level fluctuations, and wave action can cause erosion of pond banks and bottoms. To mitigate these risks, erosion control measures such as riprap, geosynthetics, erosion control mats, stabilizing vegetation, and properly designed gentle slopes are applied.

Groundwater interaction

Retention ponds may directly interact with groundwater, depending on the presence and type of bottom lining.



Retention capacity:

Minimum: 400 L/m^2 Average: 650 L/m^2 Maximum: 900 L/m^2

Groundwater Recharge Potential

Water retention ponds generally provide a low to moderate groundwater recharge potential, depending on their lining and subsoil conditions. Unlined ponds may allow limited infiltration through the pond bottom and side slopes, contributing to local groundwater recharge. Recharge efficiency is primarily controlled by soil permeability and geological stratification beneath the pond. Permeable soils such as sands and gravels facilitate infiltration, while clay-rich or compacted soils significantly restrict percolation and limit recharge.

In many designs, retention ponds are partially or fully lined to control seepage, protect embankment stability, or prevent groundwater contamination. In such cases, groundwater recharge is minimal or intentionally restricted.

The interaction with groundwater levels is a critical consideration. High groundwater tables may reduce effective storage volume and increase seepage forces, potentially affecting slope stability. Adequate separation or hydraulic control measures are therefore required.

Overall, water retention ponds primarily function as surface water storage and flow attenuation systems, with groundwater recharge being a secondary or site-dependent benefit rather than a primary design objective.

Construction parameters

- Soil: well-draining native soil with sufficient permeability to allow infiltration of stormwater.
- Filter soil (topsoil / humus): 0.20 – 0.30 m layer supporting vegetation and providing preliminary filtration.
- Drainage layer (sand): 0.10 – 0.20 m compacted sand layer improving water distribution and infiltration into the native soil.
- Geotextile: non-woven geotextile (min. 200 g/m^2) separating soil layers and preventing clogging of the drainage layer.
- Stone protection at inlet: 0.20 – 0.30 m riprap layer placed on geotextile to prevent erosion at concentrated inflow points.
- Longitudinal slope: 0.0 % at the basin bottom; surrounding terrain graded toward the basin.
- Water depth at maximum flooding: ≤ 0.6 m.
- Side slope ratio: ≤ 1:3 to ensure slope stability and safe access.
- Emergency overflow: provided to discharge excess water when the basin reaches full capacity.
- Maximum drainage time: stored stormwater should infiltrate within 48 hours after the rainfall event.
- Minimum infiltration rate of native soil: ≥ 1.25 cm/h.

Design requirements

PLANT GROWTH CONDITIONS:
open basin surface allowing natural evaporation and supporting vegetation growth

SOIL PERMEABILITY:
$1 \cdot 10^{-4}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
1.5 m above the groundwater table to ensure infiltration and to prevent contamination of groundwater

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
8.5%

PRETREATMENT:
basic sediment pretreatment (e.g. catch basin or silt trap)

SITE TOPOGRAPHY:
in a natural depression or a locally lowered area


Photo: https://aqualisco.com/the-importance-of-retention-pond-


Photo: https://www.landshapes.net/landscape-design/run-off-water-retention-ponds/

Design requirements

Minimum distance from:

1. **buildings:** 4.0 m
2. **plot boundary:** 2.0 m
3. **underground infrastructure:** 1.5 m
4. **surface waters & drinking water wells:** 15 m
5. **septic tanks:** 15 m

Photos: https://zaprojektujiwybuduj.pl/2022/05/27/budowa-i-realizacja-stawow-retencyjnych/
https://westernliner.com/blog/stormwater-retention-ponds/

Niedźwiednik retention pond in Gdańsk (Poland)

A new retention pond in residential area in Kiekrz district of Poznań (Poland)

Best practice - examples

The **Niedźwiednik retention pond in Gdańsk (Poland)** was restored to improve local stormwater management and increase water retention in the district. The project included supplying the pond with stormwater from the existing drainage network through a new pipeline, as well as removing accumulated sediments and reinforcing the pond banks. The revitalized pond helps maintain a stable water level, enhances local biodiversity, and supports the city's blue-green infrastructure strategy.

A new **retention pond** was constructed in the **Kiekrz district of Poznań** to store rainwater and snowmelt from the surrounding catchment. The reservoir has a storage capacity of approximately 3,000 m^3 and helps reduce the risk of flooding of nearby streets and buildings during heavy rainfall. The project also included the modernization of stormwater infrastructure and installation of devices capturing solid pollutants before water enters the reservoir.

Application

- Stormwater management in urban and suburban areas
- Runoff control from roads, parking lots, and other impermeable surfaces
- Drainage support for residential, commercial, and industrial developments
- Flood mitigation and temporary storage of excess rainwater during heavy rainfall

Features & Benefits

- Stores excess stormwater and reduces the risk of flooding during heavy rainfall.
- Improves water quality through sedimentation and natural filtration by aquatic vegetation.
- Supports urban biodiversity and enhances the ecological and landscape value of urban green spaces.

INFILTRATION WELL

An infiltration well is an underground engineering structure designed to disperse stormwater into the ground. Rainwater is conveyed through a system of pipes and then distributed and partially treated within a filter medium (e.g., gravel or aggregate), after which it gradually infiltrates into the surrounding soil layers.

This solution enhances the local infiltration capacity of the subsoil, reduces surface runoff, and supports the natural water cycle. Infiltration wells are commonly used to improve site drainage, reduce stormwater ponding, and limit erosion processes.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Infiltration wells discharge stormwater into deeper soil layers, which may lead to local changes in seepage conditions and subsoil behavior. In weak, loose, or heterogeneous soils, there is a risk of settlement and, in extreme cases, the formation of local subsidence or sinkholes. These processes may be associated with the washout of fine soil particles and the loosening of the soil structure within the zone affected by infiltration.

Flooding and extreme rainfall

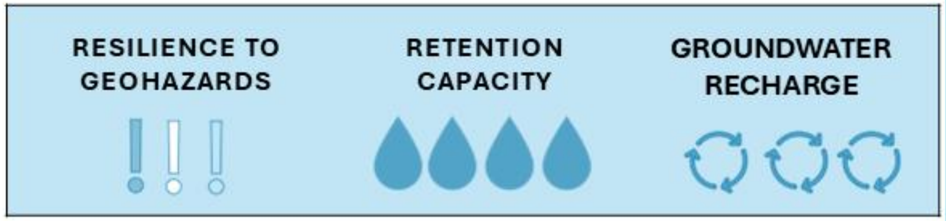
During high-intensity rainfall events, the infiltration capacity of the system may be exceeded, resulting in hydraulic overload or backflow.

Soil erosion and clogging

Fine mineral particles and organic matter may gradually clog filter components, reducing the permeability of the system. Under conditions of intensive seepage, suffusion may also occur, involving the washout of fine particles from the native soil. This process can lead to loosening of the subsoil structure and secondary settlement.

Interaction with groundwater

Infiltration wells interact directly with groundwater systems and may increase the risk of contaminant transport into groundwater.



Retention capacity:

Minimum: 300 L/m^2 Average: 950 L/m^2 Maximum: 1600 L/m^2

Groundwater Recharge Potential

Infiltration wells provide a high groundwater recharge potential by conveying stormwater directly into deeper permeable soil or aquifer layers. Unlike surface-based infiltration systems, recharge occurs at depth, allowing efficient replenishment of groundwater resources.

Recharge effectiveness depends on the hydraulic conductivity of the receiving strata and the design of the well screen and filter pack. Wells installed in highly permeable formations such as sands, gravels, or fractured rock achieve high recharge rates, while low-permeability layers limit performance.

Because infiltration wells may bypass upper soil horizons, the risk of direct contaminant transfer to groundwater is higher than in shallow infiltration systems. Adequate pretreatment, filtration, and sufficient unsaturated zones are therefore essential to protect groundwater quality.

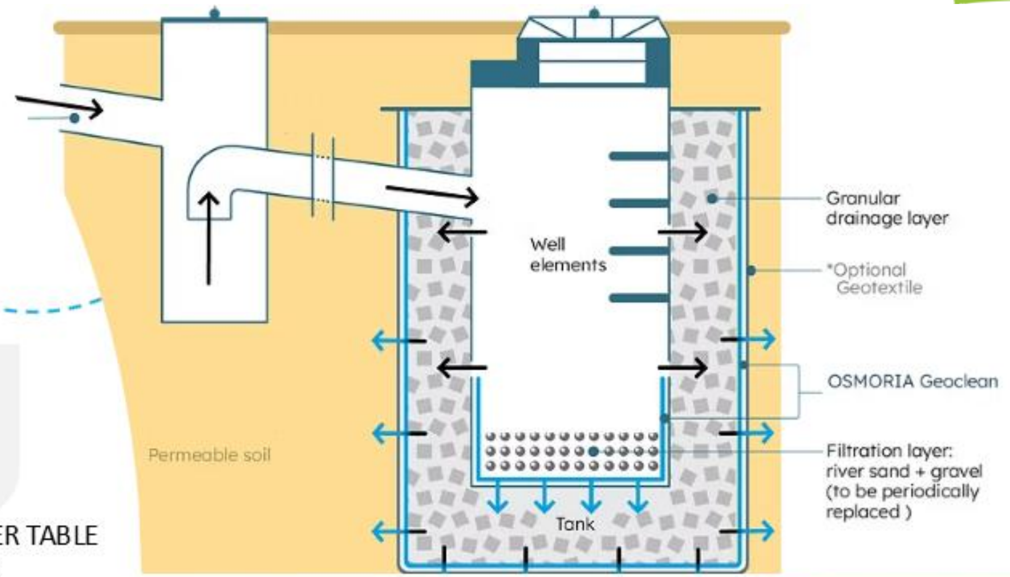
Long-term recharge capacity may decline due to clogging of well screens or filter media. Regular inspection, maintenance access, and sediment control measures are required to sustain infiltration efficiency.

When properly designed, sited, and maintained, infiltration wells can play a significant role in groundwater recharge and local water balance, particularly in space-constrained urban environments.

Construction parameters

- Well type: vertical infiltration well constructed from concrete rings or prefabricated plastic units with perforated walls and an open bottom.
- Well diameter: typically 0.8 – 2.5 m, depending on required infiltration capacity and site conditions.
- Well depth: usually 2 – 3 m, determined by local hydrogeological conditions and soil permeability.
- Filter layer (gravel): 0.15 – 0.20 m layer of washed gravel (grain size 8–32 mm) placed at the bottom to ensure filtration and infiltration.
- Additional filtration layer: gravel backfill around the well extending up to approx. 0.20 m below the inlet pipe level.
- Geotextile: protective geotextile layer separating soil from the gravel filter to prevent clogging by fine particles.
- Inlet pipe: stormwater conveyed via PVC pipe entering the well approx. 0.20 m above the filter layer.
- Perforated wall openings: infiltration openings with diameters approx. 2–4 cm located at the level of the filter layer to allow lateral infiltration into surrounding soil.
- Backfill material: gravel or cleaned native soil compacted in layers of approx. 0.20 m around the well structure.
- Hydraulic function: point infiltration of stormwater into deeper permeable soil layers.
- Maximum drainage time: stored stormwater should infiltrate into the soil within 48 hours after the rainfall event.

Design requirements



PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
$1 \cdot 10^{-5}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

GROUNDWATER TABLE LEVEL:
the bottom of the well must be located at least 1.5 m above the highest seasonal groundwater table)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
3%

PRETREATMENT:
not applicable

SITE TOPOGRAPHY:
should be located in the lowest part of the drainage area

Photos: https://www.aquatextilesosmoria.com/infiltration-wells

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: 5.0 m	**plot boundary:** 2.0 m	**underground infrastructure:** 1.5 m	**surface waters & drinking water wells:** 30 m	**septic tanks:** 30 m

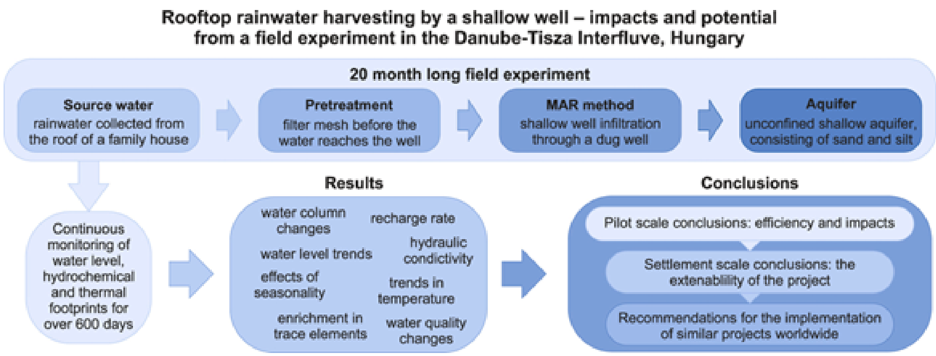
Photos:
https://ctstormwatermanual.nemo.uconn.edu/chapter-13-structural-stormwater-bmp-design-guidance/dry-well-infiltrating-catch-basin/
https://prolandscapesmd.com/dry-wells-vs-infiltration-trenches-key-differences/

Best practice - examples

Infiltration wells were implemented along Leśna Street in **Hornówek, Izabelin Municipality (Poland)** as part of a subsurface road drainage system. The solution supports local stormwater management by reducing surface runoff and promoting infiltration into deeper soil layers.

An experimental rainwater harvesting system using shallow well infiltration was implemented in the **Duna–Tisza Interfluve region of Hungary** to address declining groundwater levels. Rainwater collected from a residential rooftop was directed into a dug infiltration well, while nearby monitoring wells recorded changes in groundwater level and water quality. The results show that rooftop rainwater infiltration can support groundwater recharge and contribute to climate-adaptation strategies in water-scarce regions.

ul. Leśna w Hornówku, gm. Izabelin



Conceptual scheme of rooftop rainwater harvesting using shallow well infiltration and groundwater recharge (Duna–Tisza Interfluve, Hungary).

Source: Szabó, Z., Pedretti, D., Masetti, M., Ridavits, T., Csiszár, E., Falus, G., ... & Mádl-Szőnyi, J. (2023). Rooftop rainwater harvesting by a shallow well–Impacts and potential from a field experiment in the Danube-Tisza Interfluve, Hungary. Groundwater for Sustainable Development, 20, 100884.

Application

- Stormwater infiltration from roofs, roads, and paved surfaces
- Local drainage systems in residential, commercial, and urban areas
- Groundwater recharge and decentralized stormwater management

Features & Benefits

- Reduces surface runoff by directing stormwater into permeable soil layers.
- Supports groundwater recharge and helps restore the natural water cycle.
- Requires relatively small surface area and can be installed in space-limited urban environments.

Green facades and walls

Green facades and walls are vertical systems partially or fully covered with vegetation growing directly on building surfaces or in specially designed containers and support structures. They help mitigate the impacts of climate change in urban areas by regulating building temperatures, reducing heating and cooling demand, and contributing to the mitigation of the urban heat island effect through shading and evapotranspiration.

In addition, green walls improve air quality by capturing pollutants, provide acoustic insulation, and protect building façades from temperature fluctuations and UV radiation. As vertical greenery systems, they allow the introduction of vegetation in densely built environments without occupying ground space and can support urban biodiversity by providing habitats for birds and insects.

RESILIENCE TO GEOHAZARDS

Ground instability and structural movements

Green facades and walls are attached to building façades or freestanding support structures and may be affected by structural movements, differential settlement, or vibration of the supporting elements.

Flooding and extreme rainfall

While green facades and walls are not designed for rainwater storage, extreme rainfall can overload irrigation and drainage systems, leading to uncontrolled runoff or water accumulation at the base.

Groundwater interaction

Green facades and walls generally have minimal direct interaction with groundwater, as they are vertically oriented and isolated from subsurface conditions. However, poor drainage at the base may cause localized saturation, affecting adjacent soils or foundations. Proper base drainage and waterproofing are therefore required.

Retention capacity:

Minimum: 20 L/m^2 Average: 30 L/m^2 Maximum: 40 L/m^2

Groundwater Recharge Potential

Green facades and living walls are characterized by a negligible or very low potential for groundwater recharge, as they are not infiltration-based systems. Rainwater and irrigation water are largely retained within the growing medium, taken up by vegetation, or lost through evapotranspiration.

Excess water is typically collected by integrated drainage systems and discharged into stormwater networks or reused for irrigation. As a result, green façades and living walls do not play a significant role in groundwater recharge.

However, they may indirectly contribute to reducing surface runoff volumes and delaying runoff, which can positively influence the local water balance.

Green facades and living walls should therefore be considered as non-infiltrating green infrastructure elements that primarily provide ecosystem and microclimatic benefits, rather than directly supporting groundwater recharge processes.

Construction parameters

- System type: vertical greening system installed on building facades, consisting of climbing plants (green facade) or modular vegetated panels (living wall system).
- Supporting structure: steel, aluminum, or polymer support frame fixed to the building wall, providing structural stability and spacing for plant growth.
- Distance from wall: 0.10 – 0.30 m ventilation gap between vegetation layer and facade to allow air circulation and prevent moisture accumulation.
- Vegetation layer: climbing plants, shrubs, or herbaceous species adapted to vertical growth and local climate conditions.
- Growing medium / substrate: 0.08 – 0.20 m layer of lightweight substrate (soil, mineral wool, coconut fiber, or engineered planting media) supporting plant growth and water retention.
- Drainage layer: 0.02 – 0.05 m drainage layer preventing water stagnation and ensuring proper excess water removal.
- Waterproof membrane: protective waterproof layer installed on the facade surface to protect the building envelope from moisture.
- Irrigation system: drip irrigation system providing controlled water supply and maintaining adequate moisture in the substrate.
- Nutrient supply: fertilization system integrated with irrigation or periodic manual fertilization to maintain plant health.
- Structural load capacity: facade and supporting system designed to withstand additional loads from vegetation, substrate, water, and wind.
- Maintenance access: provision of access for pruning, inspection of irrigation systems, and replacement of vegetation modules.
- System depth: typically 0.15 – 0.40 m depending on the type of vertical greening system.

Design requirements

PLANT GROWTH CONDITIONS:
plants should be selected according sun exposure, local climate, and wind conditions

SOIL PERMEABILITY:
not applicable

GROUNDWATER TABLE LEVEL:
not applicable

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
5-10% of the building facade

PRETREATMENT:
filtration

SITE TOPOGRAPHY:
not a determining factor

Photos: https://architizer.com/blog/product-guides/product-guide/eantka-green-walls/

Design requirements

Minimum distance from:

1. **buildings:** installed directly on building facades
2. **plot boundary:** no specific minimum distance required
3. **underground infrastructure:** not applicable
4. **surface waters & drinking water wells:** not applicable
5. **septic tanks:** not applicable

Photos: https://www.archdaily.com/1031869/paul-clemence-captures-ingenhoven-architects-ko-bogen-ii-and-its-landmark-green-facade?ad_campaign=normal-tag

https://green-walls.co.uk/projects/view/sihl-city-green-wall-zurich/

Best practice - examples

Green wall at the McArthurGlen Designer Outlet Cheshire Oaks in Ellesmere Port, UK, constructed using modular GSky planter units.

Kö-Bogen II building in Düsseldorf (Germany) featuring one of the largest green facades in Europe, located at Gustaf-Gründgens-Platz along Schadowstraße.

McArthurGlen Designer Outlet Cheshire Oaks (United Kingdom)

A modular green wall with a total area of approximately 400 m² was installed in 2019 at the McArthurGlen Designer Outlet Cheshire Oaks in Ellesmere Port, UK. The living wall was constructed using GSky modular planter units arranged at a 45° angle and planted with a variety of ornamental and drought-tolerant species. The system is supported by a high-pressure irrigation installation and serves as a vegetated façade along a new parking area, enhancing the environmental and aesthetic quality of the site.

Kö-Bogen II, Düsseldorf (Germany)

The Kö-Bogen II office and retail complex in Düsseldorf features one of the largest green facades in Europe. The building facade is planted with more than 30,000 hornbeam plants, forming a six-storey vegetated wall equivalent to approximately 8 km of hedging. The green facade helps reduce building overheating, improves air quality, absorbs noise, and contributes to urban biodiversity while enhancing the environmental performance of the building.

Application

- Greening of building facades in dense urban areas with limited ground space
- Thermal regulation of residential, commercial, and public buildings
- Integration with sustainable urban drainage and rainwater harvesting systems
- Improvement of environmental quality in urban streets and public spaces

Features & Benefits

- Improves water quality by filtering nutrients, heavy metals, and suspended solids.
- Enhances urban biodiversity and provides microclimate regulation.
- Support rainwater management by intercepting rainfall and using harvested rainwater for irrigation.

PERMEABLE PAVEMENT

Permeable pavement is a surface designed to allow stormwater to infiltrate through openings or porous materials into the underlying soil. Such pavements are made from materials that create void spaces, enabling water from surface runoff to percolate into the ground. Different types of permeable pavements are used depending on their intended function, including permeable concrete blocks, porous concrete, gravel, wood chips.

RESILIENCE TO GEOHAZARDS

Ground instability and soil movements

Permeable pavements may be affected by settlement or deformation if installed over weak or poorly compacted subgrades.

Flooding and extreme rainfall

Permeable pavements are designed to infiltrate the rainwater; however, extreme rainfall events may exceed infiltration capacity.

Soil erosion and clogging

Fine sediments can clog surface pores or subbase voids, reducing permeability over time. The use of appropriate filter layers, edge restraints, and routine maintenance (e.g. vacuum sweeping) mitigates clogging and preserves infiltration capacity.

Groundwater interaction

Permeable pavements may contribute to shallow groundwater recharge, depending on local soil and groundwater conditions.

RESILIENCE TO GEOHAZARDS	RETENTION CAPACITY	GROUNDWATER RECHARGE
! ! ! (2 of 3)	1 of 4 drops	3 of 3

Retention capacity:

Minimum: 60 L/m^2 Average: 80 L/m^2 Maximum: 100 L/m^2

Groundwater Recharge Potential

Permeable pavements provide a moderate to high groundwater recharge potential by allowing stormwater to infiltrate through the pavement surface and be temporarily stored within the permeable subbase before percolating into the underlying soil.
Recharge effectiveness depends on subsoil permeability and pavement design. Systems constructed over permeable soils with an unlined subbase promote effective vertical infiltration, while installations over low-permeability soils or with lined subbases limit recharge and rely on controlled drainage.

The depth of the subbase and separation from the groundwater table are critical factors. Adequate vertical clearance is required to maintain unsaturated flow conditions, prevent prolonged saturation, and ensure effective pollutant attenuation prior to groundwater recharge.

Long-term recharge capacity may decline due to surface or subbase clogging. Proper material selection, pretreatment of inflow, and routine maintenance are essential to sustain infiltration performance.

When appropriately designed and maintained, permeable pavements contribute positively to local groundwater recharge, runoff volume reduction, and urban water balance, while also supporting traffic loads and surface functionality.

Construction parameters

- Surface type: permeable pavement made of gravel, permeable concrete, porous asphalt, grass reinforcement grids, or resin-bound aggregate allowing stormwater infiltration into the soil.
- Surface layer: permeable top layer composed of grass, decorative gravel, porous concrete, porous asphalt, or mineral–resin mixture enabling water infiltration.
- Base layer (gravel): 0.20 – 0.30 m load-bearing layer of crushed stone or gravel (grain size approx. 8–16 mm) providing structural support and temporary water storage.
- Bedding layer (sand): 0.02 – 0.03 m leveling layer of sand ensuring proper placement and stability of surface elements.
- Geotextile: separation layer preventing migration of fine particles from the subgrade into the aggregate layers and maintaining permeability.
- Subgrade soil: permeable native soil enabling infiltration of stormwater into deeper soil layers.
- Edge restraints: curbs or edge supports stabilizing the pavement structure and preventing lateral displacement of aggregate layers.
- Surface slope: gentle slope typically ≤ 2–2.5 % to allow controlled runoff while maintaining infiltration capacity.
- Infiltration function: rainfall infiltrates through the surface and aggregate layers into the underlying soil, reducing surface runoff and improving groundwater recharge.
- Load capacity: thickness of structural layers should be adjusted according to expected traffic loads (pedestrian areas, bicycle paths, parking areas, or light vehicle traffic).Maintenance requirement: periodic cleaning (sweeping or vacuuming) to prevent clogging of pores and maintain infiltration efficiency.

Design requirements

PLANT GROWTH CONDITIONS:
not applicable

SOIL PERMEABILITY:
$1\cdot10^{-2}$ m/s ≤ k < $1\cdot10^{-5}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m
below the bottom of the installation (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
It depends

PRETREATMENT:
not applicable

SITE TOPOGRAPHY:
surfaces
with gentle
slopes


Photo: https://modutile.com/interlocking-permeable-pavers/


Photo: https://digbystone.co.uk/blogs/news/permeable-paving

Design requirements

Minimum distance from:

1	2	3	4	5
buildings: ≥ 2 m to prevent infiltration near building foundations	**plot boundary:** 1.0-2.0 m	**underground infrastructure:** 1.0 m	**surface waters & drinking water wells:** 15 m	**septic tanks:** 15 m

Photos: https://korotkinassociates.com/permeable-paving/
https://www.stonesetresin.co.uk/project/resin-driveway-installation-lincoln/

Best practice - examples

Permeable pavement systems tested around urban trees in Como (Italy)

Permeable pavement installation in Barcelona (Spain)

A multi-year experiment conducted in **Como (Italy)** compared impermeable pavements with permeable paving systems around urban trees to assess their ecological and hydrological performance. The study showed that permeable pavements allow stormwater infiltration while maintaining soil moisture and enabling gas exchange between soil and atmosphere, which supports healthier root development. The results highlight the potential of permeable pavements to integrate sustainable stormwater management with improved growing conditions for urban trees.

A pilot permeable pavement system has been implemented in **Barcelona (Spain)** as part of the European MULTICLIMACT project to improve urban climate resilience. The project includes a permeable bike lane constructed with draining asphalt that allows rainwater to infiltrate into the ground instead of entering the drainage system. The pilot installation is monitored to evaluate its performance in reducing surface runoff, improving drainage capacity, and mitigating urban heat effects.

Application

- Pedestrian paths, sidewalks, playgrounds, and private gardens
- Parking areas and low-traffic roads
- Urban squares and public spaces
- Areas requiring stormwater infiltration and runoff reduction

Features & Benefits

- Reduces surface runoff and helps mitigate urban flooding.
- Supports groundwater recharge and natural water cycle processes.
- Improves water quality by filtering pollutants through pavement layers and reduces surface temperature.

GRASS GRID PERMEABLE PAVEMENT

Grass grid permeable pavement is a reinforced vegetated surface composed of modular grid systems filled with soil and grass. The grid structure stabilizes the ground while allowing vegetation to grow through the openings and supporting pedestrian or light vehicle traffic. The system allows rainwater to infiltrate through the surface into the underlying soil layers, reducing surface runoff and enhancing groundwater recharge. Grass grid pavements are commonly used in sustainable urban drainage systems as a green alternative to conventional impermeable paving.

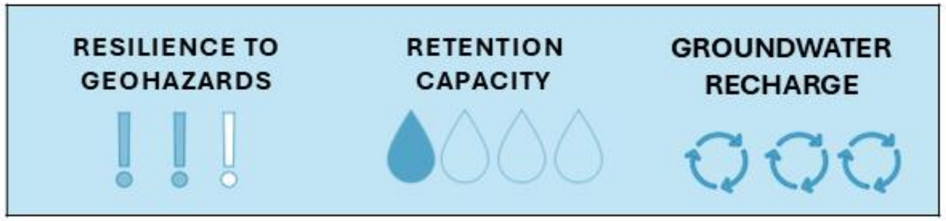
RESILIENCE TO GEOHAZARDS

Ground instability and settlement
Permeable grid pavements with vegetated infill (grass grids) may be susceptible to settlement and rutting, particularly when installed on weak or inadequately compacted subsoil.

Flooding and intense rainfall
These types of pavements allow for infiltration and temporary storage of stormwater within the base layer. However, during intense rainfall events, the infiltration capacity may be exceeded, resulting in temporary surface ponding.

Soil erosion and surface degradation
High rainfall intensity, heavy traffic loads, or insufficient vegetation establishment may lead to soil erosion, loss of infill material, and degradation of the turf layer. The use of appropriate grass mixtures, stabilized growing media, and controlled traffic loading helps reduce the risk of surface degradation.

Interaction with groundwater
Permeable grid pavements with vegetated infill may contribute to shallow groundwater recharge, depending on local soil and groundwater conditions.



Retention capacity:

Minimum: 40 L/m^2 Average: 60 L/m^2 Maximum: 80 L/m^2

Groundwater Recharge Potential

Grass grid permeable pavements show good resilience to common geo-hazards when properly designed and installed. The system distributes loads through a reinforced cellular structure, reducing the risk of localized settlement on moderately stable subgrades.
Infiltration through the surface limits surface runoff and erosion; however, extreme rainfall may temporarily exceed infiltration capacity, resulting in short-term ponding without structural failure. Proper subbase design and overflow provision improve flood resilience.

The system has limited sensitivity to groundwater conditions, provided adequate separation from the groundwater table is maintained. Risks related to soil erosion or material loss are mainly associated with poor vegetation establishment or excessive traffic loads.
Overall, grass grid pavements are well suited to flat or gently sloping sites and perform reliably under variable hydrological conditions when routine maintenance is applied.

Construction parameters

- Surface type: permeable grassed surface allowing direct infiltration of stormwater into the soil while maintaining biologically active ground cover.
- Vegetation layer: grass cover established on fertile topsoil, providing surface protection, evapotranspiration, and runoff reduction.
- Topsoil / growing medium: fertile soil layer suitable for grass growth; for reinforced grass systems, a soil–sand mixture may be used to improve drainage and root development.
- Base layer (gravel): 0.20 – 0.30 m load-bearing gravel layer (typically 8–16 mm) providing structural stability and temporary water storage.
- Bedding layer (sand): 0.025 – 0.03 m leveling layer of sand or soil–sand mixture ensuring even placement of the surface reinforcement system.
- Geotextile: separation layer placed above the gravel base to prevent migration of fine soil particles and preserve long-term permeability.
- Surface reinforcement (optional): grass reinforcement grids or cellular confinement system used to improve load resistance and protect the turf under pedestrian or light vehicular traffic.
- Subgrade soil: permeable native soil enabling infiltration of stormwater into deeper soil layers.
- Edge restraints: curbs or edge supports used where necessary to stabilize the pavement outline and prevent lateral spreading of the structure.
- Surface slope: gentle slope, typically ≤ 2–2.5 %, allowing infiltration while reducing erosion and surface runoff.
- Infiltration function: rainfall infiltrates through the grass cover and underlying layers into the soil, reducing runoff and supporting groundwater recharge.
- Load capacity: suitable mainly for pedestrian areas, green access routes, and lightly loaded parking or driveway areas when reinforced.
- Maintenance requirement: regular mowing, reseeding if needed, and periodic removal of sediment to maintain vegetation cover and infiltration efficiency.

Design requirements

PLANT GROWTH CONDITIONS:

adequate sunlight, fertile topsoil, and proper irrigation conditions

SOIL PERMEABILITY:
$1 \cdot 10^{-2}$ m/s ≤ k < $1 \cdot 10^{-5}$ m/s

GROUNDWATER TABLE LEVEL:
minimum 1.0 m below the bottom of the installation (approx. 1.5 m bgl)

NEEDED SPACE - PERCENTAGE OF CATCHMENT AREA:
It depends

PRETREATMENT:
not required

SITE TOPOGRAPHY:
flat to gently sloping sites


Photo: https://mudcontrolgrid.ca/hdgg/


Photo: https://www.truegridpaver.com/grass-parking pavers/?srsltid=AfmBOopZW7E4LoCbFjUQ8ZYgnsTOJCIW3MrqobxYny5AmKsXLfuBxGH2

Design requirements

Minimum distance from:

1. **buildings:** ≥ 2 m to prevent infiltration near building foundations
2. **plot boundary:** 1.0 – 2.0 m
3. **underground infrastructure:** 1.0 m
4. **surface waters & drinking water wells:** 15 m
5. **septic tanks:** 15 m

Photos:
https://omconcreteproducts.com/blog/reasons-to-consider-a-grass-paver-system
https://www.truegridpaver.com/grass-parking-pavers/?srsltid=AfmBOopZW7E4LoCbFiUQ8ZYgnsTOJCIW3MrqobxYny5AmKsXLfuBxGH2

Best practice - examples

Grass grid permeable pavement installed in Stainforth near Doncaster (United Kingdom) to create off-road parking while maintaining a permeable vegetated surface.

Grass grid permeable pavement installed around a groundwater abstraction facility in Golina near Jarocin (Poland).

Stainforth, Doncaster (United Kingdom)

A permeable grass reinforcement grid system was installed in Stainforth near Doncaster to create off-road parking for residential properties located behind a public green area. The cellular grid structure stabilizes the grass surface while allowing rainwater to infiltrate into the soil, preventing surface runoff and ground degradation. The project demonstrates how grass grid permeable pavement can provide functional parking areas while maintaining permeable green surfaces.

Golina (Poland)

A vegetated grass grid system was installed in Golina near Jarocin to create a functional green area used for water extraction. The solution uses geoSYSTEM GS cellular grids that stabilize the ground while allowing grass roots to develop and maintain a permeable surface. The system integrates green space with technical infrastructure while supporting natural infiltration and maintaining the aesthetic quality of the site.

Application

- Permeable parking areas and access roads supporting stormwater infiltration
- Reinforced grass surfaces for emergency and service vehicle access
- Green surfaces in parks, residential areas, and water management zones

Features & Benefits

- Reduces surface runoff and supports stormwater infiltration.
- Stabilizes the ground while maintaining a vegetated surface.
- Maintains soil permeability and enhances urban green spaces.