MAURICE

Deliverable D.3.4.2

Handbook for increasing the benefits of rainwater management

Version 2

03 2026

Activities from the Application form:

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

Activity 3.4 Joint solutions for urban storm and rain water management with regard to climate change
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 organized 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.

Deliverable description: The results and solutions received in WP3 and verified in pilot actions will be developed by PL and CZ partners into draft methodological guidelines for public administration and designers. Drafts will be submitted for discussion and improvement to partners and associated partners at the workshop. Based on the discussion and evaluation of comments on the drafts, the final versions of methodological guidelines for public administration and designers will be prepared to support the introduction of beneficial rainwater management in cities (link to O3.3, O3.4 & O3.5).

Delivery period: Period 6, 31 - 36

Author: Petr Kohout [1)]

Contributions: Grzegorz Gzyl [2)], Beata Kończak [2)], Marta Wiesner-Sękala [2)], Anna Skalny [2)] Agnieszka Chećko [3)], Dominika Makowska [3)], Tomáš Lederer [4)]

[1)] City of Novy Bydzov, Novy Bydzov, Czech Republic

[2)] Central Mining Institute, Katowice, Poland

[3)] City of Jaworzno, Jaworzno, Poland

[4)] Technical University of Liberec, Liberec, Czech Republic

Table of contents:

1. Introduction

Rainwater is a natural and irreplaceable part of the water cycle. In modern urban conditions, rainwater is often perceived as a problem – which is why many cities still have a general desire to quickly drain rainwater into the sewer system. However, this puts a strain on wastewater treatment plants and causes local flooding during periods of intense rainfall, not to mention damaging the quality of surface water flows with contaminated water from relief sewers during increased rainfall totals. This traditional approach to rainwater management, where rainwater was understood only as waste, is proving to be unsustainable.

According to the European Environment Agency (EEA, 2023), extreme precipitation events in Europe have become approximately **30% more frequent over the past 40 years** , causing damage estimated at more than **€5 billion per year**. At the same time, more than **60% of European cities report water shortages** during the summer months. Studies by the European Commission (2019) show that investments in rainwater management measures can yield **returns in the form of damage reduction, energy savings and quality of life improvements** that are several times the original cost.

Modern European cities are increasingly moving towards a new concept: **rainwater harvesting (RWH)**. This approach sees rainwater as a local resource and a tool for increasing a city's resilience to climate change and its impacts.

The issue of water resource management in cities in connection with climate change is addressed by the MAURICE project (MAnagement of Urban water Resources In Central Europe facing climate change, CE0100184) implemented within the Central Europe - INTERREG program.

The MAURICE project aims to help urban public administrations achieve functional and sustainable water management that is resilient to the impacts of climate change. During its work, partners from 11 Central European countries focused on:

- the possibility of using irrigation systems (irrigation canals) to replenish groundwater reserves in the source area of the water source and improve its quality (Lombardy Pilot Action),
- evaluation of the impacts of falling water levels on the geotechnical stability of urban development and proposals for the maximum abstraction amount for the use of groundwater at the Stuttgart - Feuerbach pilot site,
- how to ensure good quality of groundwater resources threatened by reduced infiltration due to changes in weather patterns and development and deterioration of natural attenuation conditions in the rock environment due to rising temperatures (pilot site Ljubljana),
- possibilities for improving groundwater quality when replenishing collectors by infiltration of surface water from water reservoirs (pilot site Varaždin),
- how to make it easier for public administration to conceptually introduce rainwater management in the city and offer it methodological procedures and technologies for capturing, storing and treating rainwater for a wide range of uses for the city's needs, including infiltration of excess water to replenish groundwater supplies (pilot locations Novy Bydzov and Jaworzno).

This document was created as part of the output of the work package WP3 (Resilience to urban drought and urban floods in the face of climate change) Handbook for increasing the benefits of rainwater management (D.3.4.2).

The first draft of the document was prepared in September 2025 and was presented to the other partners of the MAURICE project at the partnership meeting in Ljubljana in October 2025. After mutual discussion and further numerous discussions, especially between the partners of WP3 – Central Mining Institute, City of Jaworzno, City of Novy Bydzov, Technical University of Liberec and partners of WP4 - Geological survey of Slovenia and Ljubljana Waterworks and Sewerage, this final document was prepared.

The document consists of 3 methodological guidelines, covering the main areas of activities related to the implementation of sustainable rainwater management in cities:

- Guideline for public administration to implement beneficial rainwater management,
- Guideline for the selection of rainwater treatment technologies for further use,
- Guidelines for design Blue-green Infrastructure.

Its aim is to assist cities and municipalities in implementing sustainable rainwater management and to support the resilience of urban water management to the negative impacts of climate change.

In the following chapters, the individual guidelines are briefly introduced to familiarize the reader with the topics they cover and what they can find in the individual guidelines. For a detailed study of specific parts, the reader can then use the complete version of the guidelines, which is provided in the appendix.

2. Brief description of guidelines for implementing beneficial rainwater management

2.1. Guideline for public administration to implement beneficial rainwater management

2.1.1. Introductory summary of the document

The document is intended primarily for public administration, cities, municipalities, designers and administrators of technical infrastructure. It focuses on the issue of rainwater management in cities in connection with climate change, the increasing number of torrential rainfall, urban overheating and drought. The document presents a modern approach to managing rainwater, which can no longer be understood only as a problem and quickly disposed of as waste through the sewer, but as a challenge for addressing the impact of climate change and a valuable local water source.

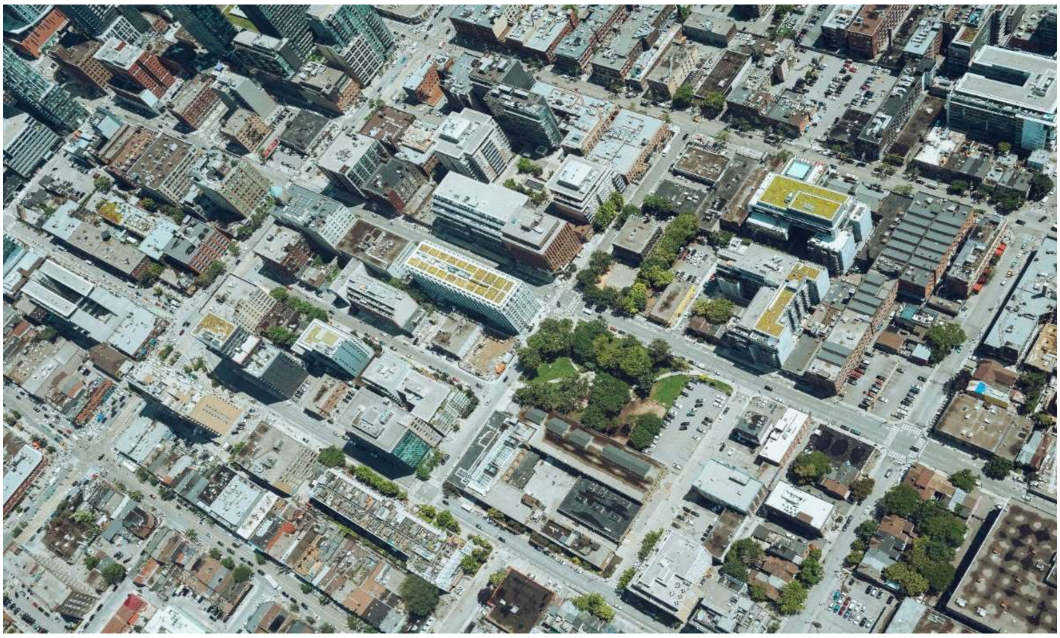


Figure 1: Urbanized areas are characterized by a high proportion of impervious surfaces

The document provides cities and public administration with methodological guidance on how to systematically implement the principles of sustainable rainwater management (RWM). The document explains the reasons why it is necessary to change the traditional way of urban drainage, describes the benefits of blue-green infrastructure and presents specific procedures for planning, implementing and financing measures. The reader will find not only strategic and legislative contexts, but also practical instructions for preparing urban concepts, implementing measures in built-up and unbuilt areas and recommendations for individual construction projects.

The document emphasizes that modern rainwater management contributes to reducing the risk of local floods, improving the microclimate of cities, protecting groundwater, limiting the overloading of sewage systems and improving the quality of life of residents. At the same time, it draws attention to the economic, technical, legislative and social barriers that complicate the implementation of these measures and suggests ways to overcome them. The document also includes examples of technical measures, recommendations for project financing and an overview of European and national subsidy programs.

Figure 2: Overloaded sewer system during heavy rains (Kluck et al, 2005)

In the following chapters, the individual guidelines are briefly introduced to familiarize the reader with the topics they cover and what they can find in the individual guidelines. For a detailed study of specific parts, the reader can then use the complete version of the guidelines, which is provided in the appendix.

2.1.2. What can be found in the individual chapters of the guideline

1. Introduction

The introduction explains the importance of rainwater in the urban environment and the impacts of climate change on European cities. The document presents the MAURICE project and its objectives. An important part is the justification for the need to change the traditional approach to rainwater drainage.

2. Rainwater Management (RWM)

The chapter describes the principles of modern rainwater management. It explains the negative impacts of impermeable surfaces and sewer overloading. The key part of the chapter summarizes the main principles of RWM:

- water retention at the point of impact,
- use of rainwater,
- support for absorption,
- separation of rainwater and sewage,
- restriction of drainage into the sewer.

The section devoted to the benefits of RWM is also important – reducing flood risks, saving drinking water, cooling cities and promoting biodiversity.

3. Obstacles to RWM implementation and their solutions

The chapter identifies the main barriers to implementing RWM:

- legislative and strategic barriers,
- economic and financial problems,
- organizational shortcomings,
- low public awareness,
- technical complications.

The section with proposed solutions, such as the introduction of uniform rules, financial incentives, training of officials or pilot projects, is very important. The chapter is significant for public administration when setting urban strategies.

4. Misconceptions often associated with RWM

The chapter refutes the most common misconceptions associated with rainwater management. It emphasizes, for example, that RWM does not mean only infiltration and that no measure is maintenance-free. An important part is the explanation that retention measures without infiltration are also important.

5. Procedure for implementing rainwater management in cities

One of the most important chapters of the document. It describes the methodological procedure for implementing RWM at the city level.

Key parts:

- evaluation of runoff conditions,
- hydrological and hydraulic analyses,
- assessment of infiltration possibilities,
- climate risk assessment,
- setting outflow limits,
- introduction of standards for new buildings.

The chapter further distinguishes procedures for:

- undeveloped areas,
- built-up areas,
- specific construction projects.

The section on investor obligations and requirements for project documentation is very important.

6. Technical measures and equipment in rainwater management

The chapter contains an overview of technical measures for blue-green infrastructure.

Important parts:

- permeable surfaces,
- green roofs,
- retention tanks,
- infiltration device,
- retention parks and wetlands,
- rainwater harvesting systems.

The chapter explains the principle of operation of individual measures and their appropriate use. **A more detailed elaboration for the application of blue-green infrastructure (BGI) is contained in Annex 3.**

7. Identifying financing for rainwater management

The chapter focuses on financing options for RWM projects. It includes an overview of:

- European funds,
- LIFE programme,
- Interreg ,
- national subsidy programs of individual states.

Recommendations for cities on how to prepare projects, combine financial resources and plan investments are important.

8. References

The final chapter contains expert sources, methodologies, technical standards and European documents used in the development of the guideline .

The document represents a comprehensive methodological material for public administration, which connects strategic planning, legislation, technical solutions and financing of rainwater management measures. Its main contribution is a practical guide on how to systematically increase the resilience of cities to climate change while effectively using rainwater as a valuable natural resource.

More detailed information is described in Annex 1.

2.2. Guideline for the selection of rainwater treatment technologies for further use

2.2.1. Introductory summary of the document

The main objective of the document is to show that rainwater can be an important alternative source of water for non-potable and some potable purposes, if it is properly harvested, treated and stored. The document explains the issues of rainwater quality, describes the main sources of pollution and presents various water treatment technologies depending on its intended use. At the same time, it emphasizes that modern rainwater management systems contribute to reducing drinking water consumption, limiting the load on sewage systems, reducing the risk of local floods and improving the sustainability and well-being of the urban environment.

The document provides an overview of technologies from simple retention systems to advanced filtration and disinfection technologies, including UV disinfection, ozonation, membrane systems or biological filters. An important part is also economic analyses and case studies from Europe and North America, which show practical experience with the operation of systems and their financial requirements. The reader will find recommendations for the design of systems, their operation, maintenance and the possibilities of using rainwater in buildings, urban infrastructure or industry.

2.2.2. What can be found in the individual chapters of the guideline

1. Introduction

The introduction presents the importance of rainwater harvesting in the context of climate change, decreasing capacity of water sources and the need to reduce the burden on sewage systems. The document draws attention to the main problem – water contamination after impact on roofs and paved areas. It also highlights the economic aspects of the systems and the dependence of the return on investment on subsidy programs and public support.

1.1 Rainwater quality

The chapter describes the quality of rainwater and the main sources of its pollution. It explains the difference between relatively clean and soft atmospheric water and water contaminated after contact with surfaces. An important part is the description of health risks and microbiological pollution caused mainly by bird droppings, organic residues or traffic. The document includes figures summarizing inorganic, organic, and microbial pollution from roof runoff in different countries.

Important parts:

- microbiological contamination,
- influence of roof material,
- heavy metal contamination,
- pollution from roads and parking lots,
- the importance of the " first flush" effect (the most polluted water at the beginning of the rain).

1.2 Harvesting of rainwater

One of the key chapters of the document. It describes the design of rainwater harvesting systems and the recommended technical solution.

Important parts:

- separation of waters according to their use,
- water pretreatment,
- first flush diverter,
- retention tanks with insect protection,
- infiltration and seepage,
- recommended accumulation volumes,
- using rainwater for flushing, irrigation or washing.

The chapter emphasizes the importance of proper system design for both water quality and economic efficiency.

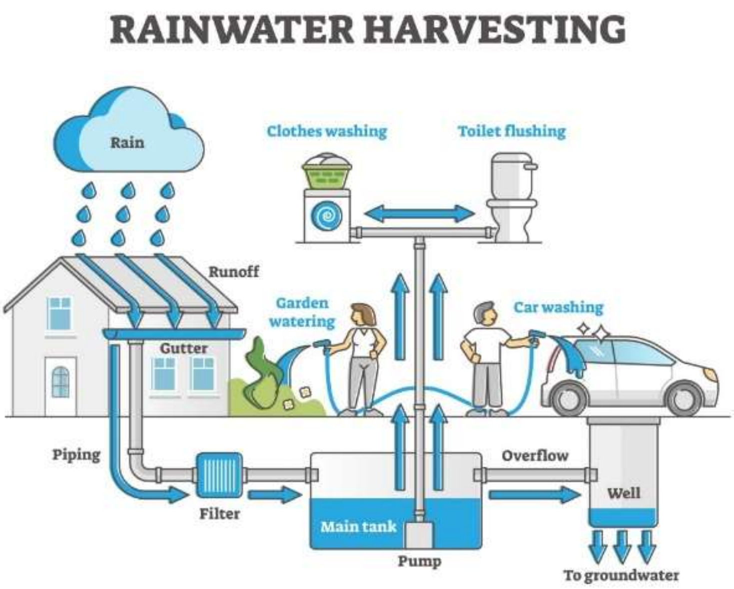


Figure 3: Rainwater harvesting diagram – conventional ([allamericangutterprotection.]())

1.3 Treatment of rainwater

The chapter focuses on rainwater treatment technologies and divides them by type of source - water from roofs and water from roads or parking lots.

Important technologies:

- various types of filtration or infiltration systems (mechanical, sand, natural ion-selective materials, activated carbon)
- biological filters,
- green roofs,
- membrane technologies,
- various types of disinfection (chlorination, UV, ozonization, solar)

The section comparing the advantages, disadvantages and cost-effectiveness of individual technologies is very important. The document also points out that most systems in Europe use simpler technologies for non-potable water use.

List of technologies and their uses

This section summarizes the types of systems according to their complexity and use.

Types of systems:

1. Basic systems – simple retention tanks without treatment (only for irrigation).
2. Intermediate systems – partial connection to buildings (toilet flushing, washing).
3. High-tech systems – advanced filtration (membranes, carbon), monitoring and use for drinking purposes.

The chapter is important for deciding on a suitable solution according to the user's needs and the project budget.

Final sanitation and cost

The chapter focuses on final treatment step - water disinfection and the operating costs of individual methods.

Important parts:

- chlorination,
- UV disinfection,
- ozonization,
- ultrafiltration,
- peroxo acids,
- plasma technology.

The document describes in detail:

- the effectiveness of individual methods,
- operating costs,
- energy intensity,
- maintenance requirements,
- suitability for different types of projects.

2. Economic perspective and performance, case studies

A very practical chapter containing case studies from the Czech Republic, Germany, the USA and Canada.

Important parts:

- economic costs of systems,
- return on investment,
- operational experience,
- specific technical solutions,
- water use in buildings and urban facilities.

The examples show the differences between simple and advanced systems and the importance of subsidy support.

3. Conclusion

The conclusion summarizes that rainwater harvesting represents a promising and sustainable part of water management. The document emphasizes the need for a comprehensive approach including proper system design, selection of appropriate technology, economic assessment and regular maintenance. At the same time, it points out that legislative support and financial incentives are important for the wider development of these systems.

4. Resources

The final chapter lists the literature and online sources used in the guideline. These include scientific papers on rooftop rainwater quality, microbial quality of rainwater supplies, car park runoff pollution, green roofs, snow as an indicator of urban pollution, and several online sources describing rainwater harvesting systems and case studies.

More detailed information is described in Annex 2.

2.3. Guidelines for design Blue-green Infrastructure

2.3.1. Introductory summary of the document

The objective of the guideline is to support cities, public administrations, planners and investors in the early-stage planning and implementation of Blue-Green Infrastructure (BGI) under urban conditions affected by climate change, increasing run-off extremes and groundwater stress.

The guideline combines a structured BGI Catalogue with the digital BGI Tool developed within the MAURICE project. Together, these components create a practical decision-support framework enabling the first assessment of suitable rainwater management measures for specific local conditions.

It presents BGI as a functional layer of urban infrastructure, not as an additional decorative element. The guideline explains how BGI measures can support local retention, infiltration, reuse, evaporation, urban cooling, biodiversity and safer management of run-off peaks, provided that they are adapted to local soil, groundwater, geological and geotechnical conditions.

A key value of the guideline is its practical, decision-oriented structure. It links sponge-city principles, risk screening, rainfall models, the BGI Catalogue and the BGI Tool into one coherent pre-design workflow. This makes it possible to identify which BGI technologies are potentially suitable for a plot, which requires additional verification and which should be excluded due to local constraints.

The guideline is particularly useful in complex urban areas, including post-industrial and post-mining sites, where infiltration-based solutions may interact with shallow groundwater, underground voids, unstable ground, contamination or other geohazards. It therefore promotes BGI implementation while maintaining safety, durability and compliance with detailed engineering verification.

2.3.2. What can be found in the individual chapters of the guideline

1. Introduction

The introduction explains why blue-green infrastructure should be treated as an integral part of climate-resilient urban development. It presents BGI as infrastructure supporting retention, groundwater recharge, local cooling, biodiversity and reduction of runoff peaks. It also defines the purpose of the guideline as a pre-design and decision-support document for investors, designers, local authorities, permitting bodies, water utilities, residents and experts.

2. Sponge-city principles for BGI planning

The chapter describes the sponge-city approach, in which rainwater is retained, stored, infiltrated, evaporated, treated or reused as close as possible to the place where it falls. Important parts:

- retention or reuse of rainwater close to the source,
- separation of rainwater from wastewater where possible,
- preference for multifunctional solutions,
- adaptation of BGI to ground and groundwater conditions,
- safe overflow planning for events above design capacity,
- maintenance planning from the beginning of the investment process.

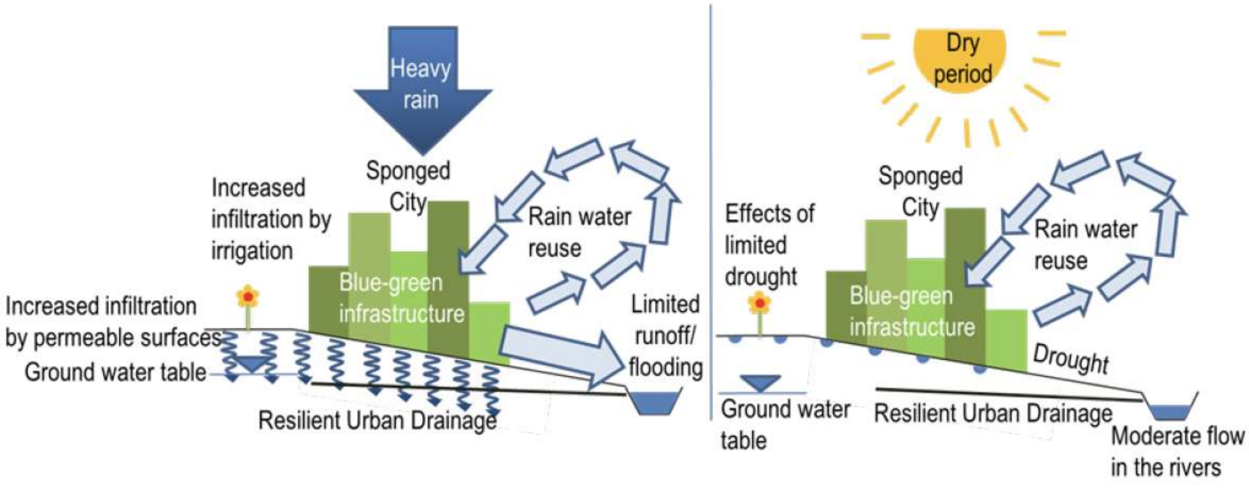


Figure 4: Sponge City approach

2.1. Design principles

This subchapter gives a concise framework for choosing BGI solutions that are technically feasible, site-responsive and effective over time. It stresses that BGI planning should begin before the plot concept is fixed, because early screening prevents the selection of attractive but technically unsuitable solutions and avoids leaving too little space for rainwater management.

2.2. Minimum input data for early screening

The subchapter defines the minimum information needed before detailed design starts. The required data include plot and land-use information, runoff sources, soil and infiltration data, groundwater conditions, safety constraints and the rainfall objective. This allows unsuitable technologies to be excluded early and supports a more realistic concept design.

3. Risks and specific considerations in the implementation of BGI

This chapter explains that BGI technologies based on infiltration, soil-water interaction and underground storage must be planned with particular care. The purpose of risk screening is not to limit the use of BGI, but to ensure that the selected measure is safe, durable and appropriate for the plot.

Important risks:

- suffusion and formation of subsurface voids,
- landslides and unstable slopes,
- heterogeneous subsidence and post-mining deformation,
- shallow groundwater and changes in groundwater regime.

Figure 5: Examples of land subsidence problem in Jaworzno, Poland

3.1. Geotechnical hazards in blue-green infrastructure planning

The subchapter describes geotechnical hazards that may affect BGI performance and safety. It explains that intensive infiltration can increase the risk of ground deformation, sinkholes or damage to buildings and networks in susceptible areas. Therefore, infiltration-dominant solutions should be preceded by appropriate geotechnical verification.

3.2. Hydrogeological risks relevant to BGI

This subchapter focuses on groundwater-related limitations. It draws attention to shallow groundwater, seasonal variability, hydraulic interaction with existing infrastructure, contamination risk and the need to decide when retention, reuse or controlled discharge should be preferred over infiltration.

4. Use of rainfall models in urban stormwater management

The chapter presents the role of rainfall models in defining design rainfall objectives for BGI planning. It shows why local rainfall data and short-duration rainfall events are important for urban runoff peaks and explains how rainfall assumptions should be used consistently in planning requirements, BGI Tool inputs and project documentation.

Important parts:

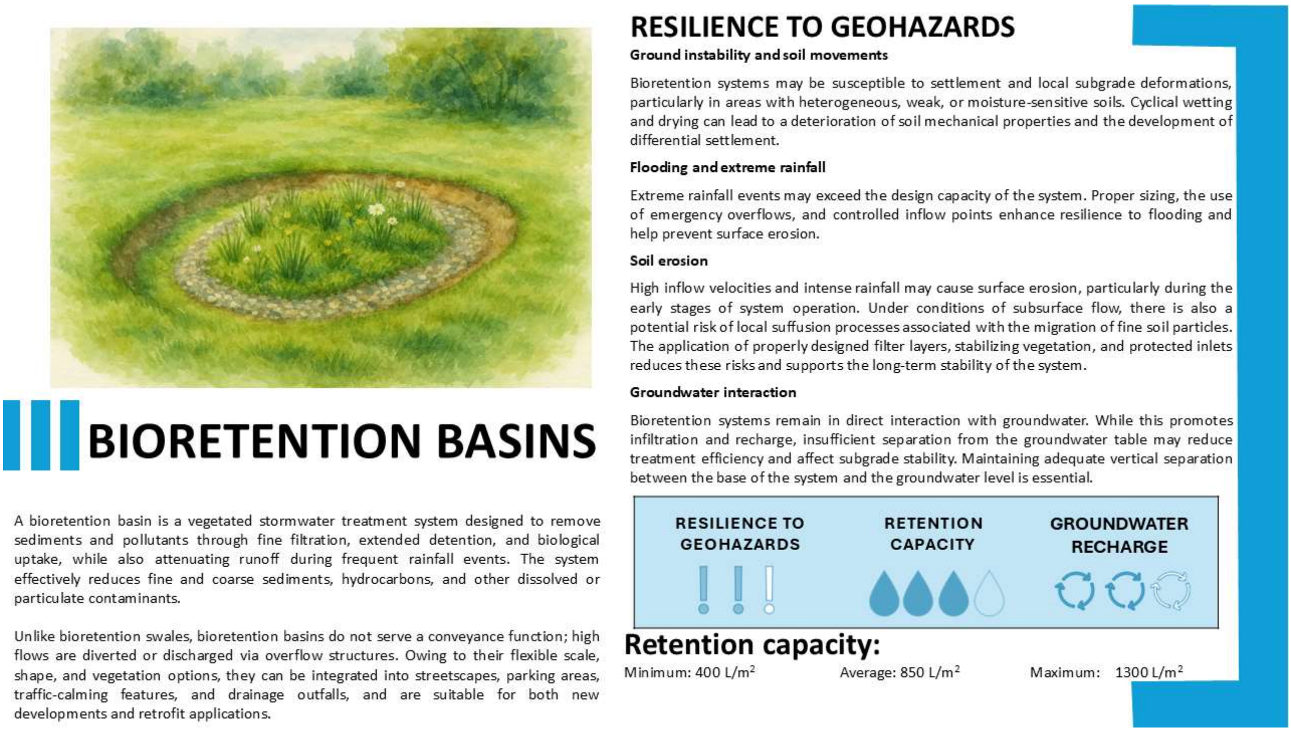
- development of the Local Rainfall Model for Jaworzno,
- transferability of the approach to other European countries,
- design value of local rainfall models,
- recommended procedure for municipalities using national rainfall atlases, meteorological datasets or locally calibrated data.

5. The BGI Catalogue: a structured knowledge base

The BGI Catalogue is presented as a standardized knowledge base for comparing available BGI technologies. Each card follows the same structure and includes a functional description, retention capacity, potential for groundwater recharge, sensitivity to groundwater and soil conditions, resilience to geohazards, construction parameters, minimum distances and maintenance requirements.

The catalogue helps users understand not only what can be built, but also under which conditions a solution is appropriate, conditional or unsuitable.

More detailed information is described in Annex 1 to the document “Guideline for design blue-green infrastructure”.



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.

RESILIENCE TO GEOHAZARDS | RETENTION CAPACITY | GROUNDWATER RECHARGE

Retention capacity:

Minimum: 400 L/m² | Average: 850 L/m² | Maximum: 1300 L/m²

Figure 6: Example of blue-green infrastructure from The BGI catalogue

6. BGI Tool

The BGI Tool is a digital pre-design instrument supporting the first selection of BGI technologies. It is intended for the early stage of investment planning and helps users compare possible technologies for a specific plot before detailed engineering design begins.

Important parts:

- Input Box for entering local plot and environmental data,
- Technology Selection for identifying feasible, conditional or excluded BGI options,
- Rainfall to Catch for estimating the volume of precipitation to be managed,
- Area Required and Groundwater Recharge Potential for estimating space needs and recharge contribution.

The tool supports dialogue between investors, designers and public administration, but it does not replace detailed design, permitting procedures or specialist geotechnical and hydrogeological verification.

More detailed information is described in Annex 2 to the document “Guideline for design blue-green infrastructure”.

6.1-6.3. Operational modules, workflow and link with the catalogue

These subchapters explain how the tool should be used in municipal and investment workflows. The catalogue explains the technologies, their functions and limitations, while the BGI Tool applies this knowledge to a specific plot. Together they reduce the gap between general climate-adaptation objectives and practical investment decisions.

7. Jaworzno pilot testing - Practical lessons for implementation

The final chapter presents lessons from the MAURICE pilot testing in Jaworzno. The pilot evaluated permeable surfaces and confirmed that, where local conditions are appropriate and the substructure is correctly designed, permeable pavements can strongly reduce surface runoff and support infiltration.

Important conclusions:

- 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 are useful as local evidence for municipal standards, investor guidance and stakeholder communication,
- monitoring results should be used to improve BGI Tool and catalogue assumptions.

The document represents a practical methodological guideline that connects planning, risk screening, rainfall analysis, technology selection and pilot evidence. Its main contribution is a safe and structured approach to the preliminary selection of blue-green infrastructure measures for urban rainwater retention and groundwater recharge.

More detailed information is described in Annex 3.

3. Conclusion

European cities are facing serious impacts of climate change, including more frequent and intense torrential rainfall (which overloads sewage systems and causes local flooding) and longer periods of drought and heat (which worsen the availability of drinking water, reduce the quality of life of residents and lead to overheating of cities).

Sustainable management of rainwater in cities is an important tool for strengthening the resilience of cities to the impacts of climate change as it is one of the few measures that can address both problems simultaneously.

The Handbook for increasing the benefits of rainwater management was created in the frame of the project MAURICE (CE0100184 implemented within the Central Europe - INTERREG program) as part of the output of the work package WP3 (Resilience to urban drought and urban floods in the face of climate change).

The aim of this document is to assist cities and municipalities in implementing sustainable rainwater management and to support the resilience of urban water management to the negative impacts of climate change.

Annexes

- Annex No. 1: Guideline for public administration to implement beneficial rainwater management
- Annex No.2: Guideline for the selection of rainwater treatment technologies for further use
- Annex No.3: Guidelines for design blue-green infrastructure for rainwater retention and groundwater recharge

ANNEX No. 1

Interreg CENTRAL EUROPE
Co-funded by the European Union

MAURICE

Output 3.3

Guideline for public administration to implement beneficial rainwater management

Version 4
03 2026

Activities from the Application form:

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

Activity 3.4 Joint solutions for urban storm and rain water management with regard to climate change 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 organized on personnel or on-line basis.

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

O3.3 - Guideline for public administration to implement beneficial rainwater management

Deliverable description: The results and solutions received in WP3 and verified in pilot actions will be developed by PL and CZ partners into draft methodological guidelines for public administration and designers. Drafts will be submitted for discussion and improvement to partners and associated partners at the workshop. Results of A.3.1 will be used by A.3.2 and A.3.3.

Delivery period: Period 5, 31 - 36

Author: Petr Kohout [1)]

Contributions: Grzegorz Gzyl [2)] , Beata Kończak [2)] , Marta Wiesner-Sękala [2)] , Anna Skalny [2)] Agnieszka Chećko [3)] , Dominika Makowska [3)] , Tomáš Lederer [4)]

[1)] City of Novy Bydzov, Novy Bydzov, Czech Republic

[2)] Central Mining Institute, Katowice, Poland

[3)] City of Jaworzno, Jaworzno, Poland

[4)] Technical University of Liberec, Liberec, Czech Republic

Table of contents

1. Introduction

In the past, most European cities were built on the principle **of draining rainwater** from urban areas as quickly as possible. Rainwater was perceived as waste that had to be safely removed outside the built-up area. This was also reflected in the technical infrastructure – extensive sewage networks, in many cases single sewers where rainwater mixed with wastewater. This approach had serious reasons at the time: protection against floods, hygienic requirements for the health safety of surface water as a source of drinking water, and the technical simplicity of the solution.

However, due to increasing urbanization, the expansion of impervious surfaces, especially in cities, and climate change, this model is showing fundamental limitations. Sewerage systems are increasingly overloaded by torrential rainfall, and cities are losing a valuable water resource that could be used locally.

Table with rainwater balance in the territory of Novy Bydzov

item	m^3/year	%
annual drainage from the roofs of building	248 183	100
annual drainage from the roads and parking lots	142 632	
annual amount of rainwater flowing through relief channels (outside the wastewater treatment plant)	58 046	15

In recent decades, traditional drainage methods (sewage and rainwater drainage, or separate sewer systems) have proven to be unsustainable in the long term. The unsustainability of the current drainage method has two main reasons:

- the increase in paved areas exacerbated by rapid urbanization,
- changing climate.

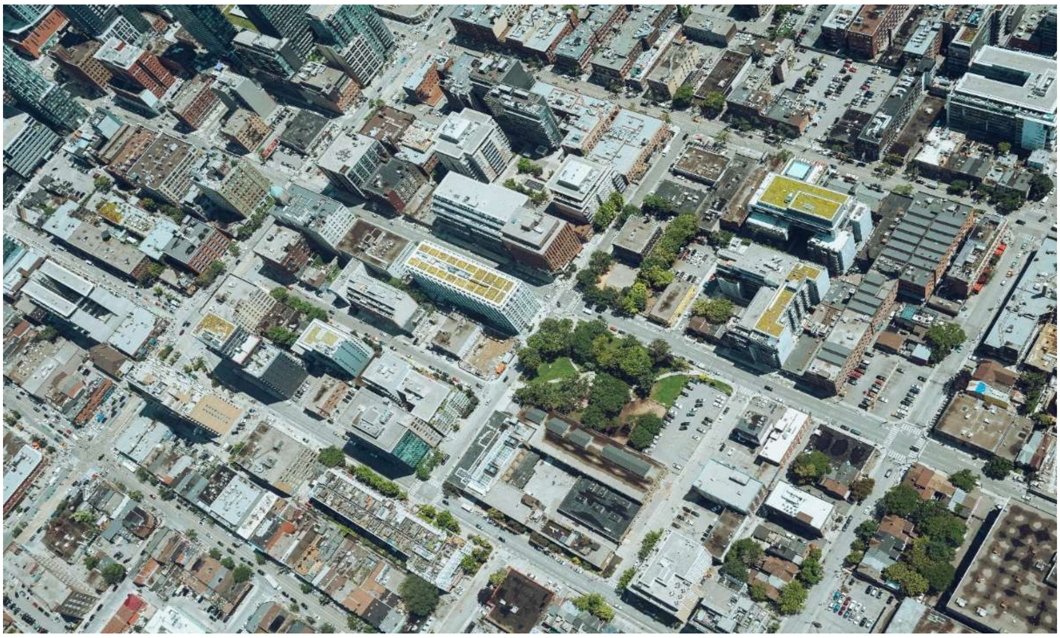


Figure 1: Urbanized areas are characterized by a high proportion of impervious surfaces

Urbanized areas – cities and towns are characterized by a high proportion of impervious surfaces (e.g. roads, sidewalks, parking lots, building roofs) in the total area of the catchment area. In the centers of urban agglomerations, this reaches 70 percent or more. Water falling on the surface of such catchments during rain cannot naturally infiltrate (seep) into the subsoil. The level of total evaporation is also reduced compared to natural conditions [Vítek et al., 2015]. In contrast, in catchments with natural vegetation cover, up to 50% of the volume of rainwater falling on the surface of the area infiltrates (approximately half of which supplies groundwater) and only 10% represents surface runoff (Figure 2).

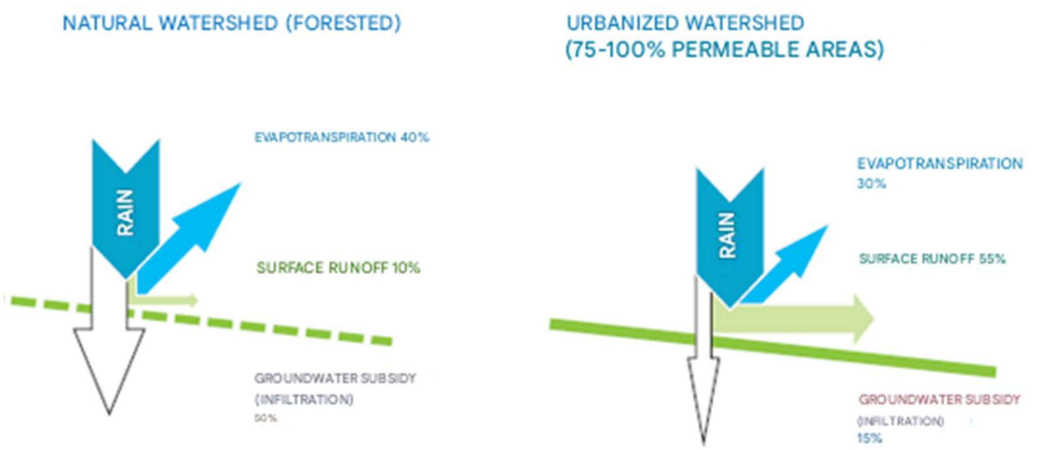


Figure 2: Comparison of rainwater runoff in a natural and urbanized catchment

In the central parts of urban agglomerations, surface runoff accounts for up to 55% of the rainfall volume. The greater part of the rainwater volume flows along the paved surface of the catchment into storm drains and is drained away from the urbanised catchments by the sewer network. In addition to the increase in volume, there is also a significant acceleration of surface runoff and suppression of the ability to transform (reduce) peak flows.

The consequence of the increased volume of surface runoff and its velocity is **a change in the hydrological regime** [Vítek et al., 2015], which is manifested by more frequent occurrence of local floods.

The impacts on the watercourse through overflows from **rainwater separators (relief sewer system)** of the combined sewer system and rainwater drainage are also significant. These include **hydraulic stress** and **the introduction of pollutants**. Both phenomena affect aquatic fauna and flora [Vítek et al., 2015]. The stream thus loses its aesthetic and ecological function.

The increased volume of surface runoff causes the capacity of the sewer system to be exceeded, transitioning to a pressure flow regime with water rising to the level of basements or directly flowing onto the terrain through inspection shafts or street drains and spilling into the surrounding area.

Figure 3: Overloaded sewer system during heavy rains (Kluck et al, 2005)

We cannot also forget the **negative impact of** increased surface runoff **on limiting groundwater recharge and replenishing its reserves.**

The change in the natural hydrological regime also threatens the environment **by disrupting the energy regime in large cities**. If solar energy falls on vegetation with insufficient water supply, the largest share of this energy cannot be consumed for water release by the plant (transpiration) as in vegetation with a good water supply (approx. 3-4 lm^{-2} per day). Urban greenery cannot therefore fulfill the role of the cheapest and most progressive climate device with an overall positive impact on the quality of life in an urban area [Vítek et al., 2015].

The ever-increasing sealing of urban surfaces, together with the pressure resulting from the impacts of climate change, is forcing public administrations in cities and municipalities to change their approach to rainwater management.

This part: GUIDELINE FOR PUBLIC ADMINISTRATION TO IMPLEMENT THE BENEFICIAL RAINWATER MANAGEMENT (RM) is intended for urban public administrations and aims to assist in the implementation of rainwater management and ensure sustainable urban water management that is resilient to the impacts of climate change.

2. Rainwater Management (RWM)

The development of rainwater management in European cities (in the last 3 centuries) can be summarized in three stages:

1. **Drain and drainage (19th-20th centuries):** The priority was to ensure hygiene and safety, so water was quickly drained away from the city.
2. **Control and regulation (second half of the 20th century):** The construction of retention tanks and separate sewers was intended to reduce the load on treatment plants and limit flood risks.
3. **Integrated management (21st century):** Rainwater is understood as part of the city's green infrastructure. The goal is to preserve or mimic the original hydrology and ecology of the area.

Modern Rainwater management (RWM) is a method of drainage of urban areas that mimics the natural hydrological regime of a river basin, mainly through decentralized facilities that aim **to retain, utilize, absorb and slow down the runoff of rainwater as much as possible directly at the point of impact**.

RWM is based on the principle: *"Water should stay as close as possible to where it falls."* This principle respects the original hydrology and ecology of urban areas before they were built up and contributes to the restoration of the natural water cycle.

The basic rules of rainwater management are...

1. REDUCTION AND TRANSFORMATION OF RAINWATER RUNOFF TAKES PLACE ON THE LAND, I.E. AT THE PLACE OF DEDUCTIONS AND AT THE EXPENSE OF THE OWNER OF THE PROPERTY FROM WHICH IT IS TO BE DEDUCTED (THE DEVICE THAT REDUCES RUNOFF IS AN INTEGRAL PART OF THE STRUCTURE BEING DRAINED);
2. RAINWATER IS NOT MIXED WITH WASTEWATER – THIS IS THE ONLY WAY IT CAN BE EFFECTIVELY EVAPORATED, INSECTED OR USED FOR HOME OPERATION;
3. THE AMOUNT OF RAINWATER RUNOFF FROM A BUILT-UP PLOT IS THE SAME AS THE AMOUNT THAT WOULD RUN OFF FROM THE NATURAL LAND SURFACE.

European cities are facing serious impacts of climate change, including:

1. **More frequent and intense torrential rainfall**, which overloads sewage systems and causes local flooding.
2. **Longer periods of drought and heat**, which worsen the availability of drinking water, reduce the quality of life of residents and lead to overheating of cities.

Rainwater management is one of the few measures that can **address both problems simultaneously**.

RWM can bring the following specific benefits in particular:

- **Reducing the risk of flooding and inundation:** Measures that retain or absorb rainwater, relieve the burden on sewer networks and reduce immediate runoff. In Germany (city of Hamburg), the introduction of a system of retention tanks and green roofs has reduced the number of local floods in densely built-up parts of the city by more than 40%.
- **Improving the availability of water resources:** Using rainwater for watering parks, cleaning roads, or flushing toilets can reduce drinking water consumption by up to 30%. Prague, for example, estimates that widespread use of rainwater could save up to 10 million m³ of drinking water annually.
- **Improving environmental quality:** Rainwater management and use contributes to groundwater recharge, promotes urban green spaces and increases biodiversity. In addition, constructed wetlands naturally purify water and improve the quality of surface streams.

- **Reducing the urban heat island effect:** Vegetated roofs and permeable surfaces retain water, which gradually evaporates and cools the surroundings. For example, a study from Copenhagen showed that the introduction of green infrastructure can reduce the temperature in the city by up to 2 °C during hot days.
- **Economic benefits:** The implementation of RWM measures creates jobs (design, construction, maintenance), reduces infrastructure renewal costs and brings long-term savings for municipalities and households. The European Commission (2020) states that the average economic benefit of investments in green infrastructure exceeds the costs by more than twice.
- **Social and health benefits:** More greenery and water in cities supports quality of life, improves microclimate, reduces dust and noise. WHO studies show that residents of cities with a higher proportion of green infrastructure suffer from lower levels of stress and respiratory diseases.

Modern rainwater management is based on several interconnected goals:

a) Water retention at the point of precipitation

The idea is to limit immediate runoff to the sewer and encourage infiltration or reuse of water. This reduces the risk of flooding and at the same time recharges groundwater.

b) Use of rainwater as a resource (rainwater harvesting)

Rainwater can be used for irrigation, flushing, road cleaning and technical use in industry. It is a cost-effective alternative to drinking water, which is irreplaceable and expensive to produce.

c) Improving the quality of the environment

Greenery and water features in urban areas contribute to reducing temperatures, improving air quality, increasing biodiversity and the attractiveness of public spaces. Also, limiting the flow of rainwater together with wastewater through relief channels directly into surface streams will reduce their contamination load and increase the quality of surface waters and life in them.

d) Relief of existing infrastructure

Every liter of rainwater that does not flow into the sewer system means less strain on the sewer network and treatment plants. This reduces operating costs and extends the life of the infrastructure.

It was found that after the application of RWM measures, 15 to 20 times less water flows away compared to conventional drainage of the design rainfall. RWM facilities and equipment thus contribute to reducing peak flows in the sewer network and, in the case of a unified sewerage system, also have a significant impact on reducing the total number of overflows from storm water separators into watercourses, which reduces their hydraulic and material load.

e) Strengthening the resilience of cities to climate change

RWM increases the city's ability to respond to extremes - on the one hand, it mitigates flood risks, and on the other hand, it ensures better water availability during dry periods.

RWM objects can very often be combined with lower or higher vegetation (green infrastructure). The connection of water management purposes with greenery has a synergistic effect and indirectly brings a number of positive effects, especially in the area of increased living comfort.

f) Citizen engagement and awareness raising

Rainwater management is not only the task of local governments, but also of citizens. When people use rainwater on their land, they contribute to the overall sustainability of the city. At the same time, their awareness of the value of water and the importance of climate adaptation is growing. Therefore, in many European countries, RWM measures are supported by subsidy titles - for example, for the installation of catchment facilities for collecting, accumulating and using rainwater (see Chapter 7).

It is crucial for city governments and state administrations to understand RWM as an investment in the future resilience of cities - similar to the case of transport or energy infrastructure.

3. Obstacles to RWM implementation and their solutions

Experience from European cities shows that rainwater management is not just a technical problem. The main obstacles often lie in the areas of legislation, finance, city administration, but also in public awareness. Identifying these barriers and proposing ways to overcome them is an essential part of every city's strategy.

Below are the main categories of barriers, with an outline of recommended solutions.

3.1. Political and strategic barriers

Obstacles

- **Outdated legislation:** Many building codes are still based on the principle of "rapid drainage" of rainwater into a unified sewer system.
- **Unclear ownership and operational relationships:** Who is responsible for public measures – blue-green infrastructure BGI (city, infrastructure manager, private investor)?
- **Lack of uniform technical standards:** It is not clearly defined how measures (BGI) should be designed and operated.

It cannot be argued that existing European Union directives or national legislative regulations generally do not support a water management policy that respects the principles of sustainable development.

Directive 2000/60/EC of 23 October 2000 on water states in paragraph 11: "*Environmental policy shall contribute to promoting the objectives of preserving, protecting and improving the quality of the environment, while making prudent and rational use of natural resources, and shall be based on the precautionary principle, on the principles of taking preventive measures, on the rectification of environmental damage at source and on the polluter-pays principle*." This definition makes it clear that the implementation of the framework directive does not mean the mere application of new technical standards, but requires a fundamental change in the approach to the management of water and water resources.

With the European Union directive on waste water management Urban Wastewater Treatment Directive (UWWTD) - **Directive (EU) 2024/3019** now includes the area **of rainwater management** within the broader urban wastewater management. It introduces key principles for rainwater management:

- Large cities are **required** to develop **integrated** rainwater management plans to reduce the risk of **urban flooding** and **water pollution** during heavy rainfall events. Smaller settlements must prepare such plans if there are such risks due to rainwater runoff. Environment .

- Plans must **prioritize nature-based measures,** such as green infrastructure (such as infiltration areas, green roofs, retention belts, etc.) that help to naturally retain, drain, or potentially use rainwater Environment .
- The directive **supports rainwater retention and reuse** as part of broader measures towards **circularity.** This means: collection, treatment and subsequent use of rainwater (e.g. for technical purposes, irrigation or other local needs) PreventionWeb .

In the legislation of national states, measures for nature-friendly rainwater management are generally enshrined in a number of regulations (Water Act, Building Act), however, legal regulations defining the rules for a new method of drainage are included in the laws and their implementing decrees in **an unsystematic and uncoordinated manner.** The current legislation requires the application of RWM principles only **in a restrictive form** and **does not motivate** owners of drained buildings with financial efficiency.

The individual **regulations are chaotic** as a result and **do not provide** the state administration with **clear and unambiguous rules** that would ensure their equal enforcement throughout the entire territory of the state. Since the state has in this regard fallen out of the role of organizer of its own water management policy, it leaves the public administration to solve the problem responsibly, incompetent and unprepared.

One of the obstacles is the lack of clarity regarding ownership and operational relations to the infrastructure forming the framework of the RWM. For example, who is responsible for blue-green infrastructure (city, infrastructure manager, private investor)?

Another problem is that rainwater management is not unified in the field of European and national technical standards. There is currently no single EN standard specifically for rainwater management, so a combination of different European standards must be used. The scope and level of national technical standards for RWM are different and some partner countries do not have technical standards for RWM and are adapting European standards. This issue has been developing particularly in the last 10 years. The largest base of technical standards and procedures for RWM in the partner countries can be found in the Czech Republic and Germany.

Possible solutions

- HARMONIZATION OF THE APPROACH TO LEGISLATION – unification of the approach of regional and local state administration;
- COORDINATION OF RWM PRINCIPLES – embedding a priority approach to RWM needs in city rules (standards) for the creation of land and transport structures;
- ENFORCEMENT OF RWM RULES – approval of uniform rules for rainwater drainage valid throughout the city;
- ACTIVE APPROACH TO PROMOTING THE WATER MANAGEMENT CONCEPT.

3.2. Economic and financial barriers

Obstacles

- **Higher initial investment costs** compared to classic sewage.
- **Limited budgets of cities and municipalities.**
- **Lack of economic motivation for citizens and developers.**

Support for decentralized approaches to rainwater management in cities is neglected, even though from the city's perspective they can bring a number of other positives in addition to flood protection (Chapter 2). Moreover, the vast majority of decentralized rainwater management measures are financed by private investors and can thus bring significant financial savings to public budgets.

A serious shortcoming in the possibilities of financing RWM is **the existence of a number of exceptions to the payment of fees for the drainage of rainwater from buildings and construction areas into the sewerage system** (e.g. in the Czech Republic, these fees do not apply to areas of motorways, roads, local roads and purpose-built publicly accessible roads, to areas of national and regional railways, including facilities necessary for the smooth and safe operation of rail transport, to zoos, hospitals and real estate intended for permanent housing and households). This neglects the principle of the Water Framework Directive, i.e. that the "polluter pays" and as a result, there is a lack of funds for the implementation of appropriate RWM measures. These measures are then perceived as unnecessarily expensive compared to the common practice of draining rainwater into the sewerage system.

Table with annual rainwater drained free of charge in sewer network in Novy Bydzov.

item	m^3/year	%
annual drainage in city area	390 816	100
annual amount of rainwater free of charge (excluded from law)	227 822	58

Possible solutions

- **Financial incentives and subsidy programs:** support for rainwater tanks in households, benefits for developers who apply RWM.
- **Introduction of the "you pay for the drain" principle:** the amount of the drain fee depends on the size of the impervious areas.
- **Economic arguments for politicians:** present savings associated with lower sewage load, improved microclimate and reduced flood damage.

3.3. Institutional and organizational barriers

Obstacles

- **Fragmentation of responsibilities:** RWM falls between multiple organizations (sewer system owner or sewer system administrator, technical services, investment department).
- **Lack of professional capacity in the authorities:** officials are not trained to assess RWM.
- **Lack of practical examples:** municipalities lack inspiration and hesitate to implement.

Ensuring the right procedures and decisions for drainage with the new RWM principles is such a complex process that individual officials who comment on the documentation are usually unable to handle it. In the case of larger territorial units and cities with a more complex organizational structure, it is therefore **necessary to introduce systematic measures to solve the problem by appointing a specific specialist or department, acting as the administrator of the city's water management concept,** who will be responsible for adhering to the new approach to rainwater and will actively promote it.

The administrator should communicate and cooperate with the relevant authorities and organizations in approving documentation and permitting construction. Based on the activities that appear in the builders' plans, the administrator should initiate necessary measures, the implementation of which will make it possible to comply with the principles of the city's drainage concept (e.g., area drainage studies or mathematical model calculations).

The administrator should cover the entire issue of water management in the city and be responsible for it.

Possible solutions

- **Establishment of interdepartmental working groups** for project coordination.
- **Training and education of officials and politicians** in the field of RWM.
- **Pilot projects and demonstration facilities** that will demonstrate feasibility and benefits.

3.4. Social and cultural barriers

Obstacles

- **Low citizen awareness:** Rainwater is often seen as a problem, not a resource.
- **Concerns about hygiene risks:** fear of mosquitoes, odors or contamination.
- **Limited willingness to change behavior:** People are used to drinking water "for everything."

For decades, rainwater has been perceived as a safety risk, bringing flooding and inundation. Therefore, citizens (also in connection with epidemics caused by insufficient wastewater infrastructure) see the classic solution of rapid rainwater drainage (using sewers) as the optimal measure to solve these problems. However, climate change and a high level of built-up areas require this familiar way of thinking to change and perceive rainwater as a valuable water source and look for ways to save drinking water sources for purposes where rainwater can be used as technological water (irrigation, toilet flushing, industrial use, etc.).

Possible solutions

- **Awareness campaigns and education:** clearly explain the benefits of rainwater management.
- **Citizen involvement in projects:** community gardens, participatory budgets.
- **Sample implementations in public buildings:** schools, kindergartens, offices as examples of good practice.

3.5. Technical and operational barriers

Obstacles

- **Geological and hydrogeological conditions:** unsuitable subsoil, high groundwater level.
- **Maintenance of measures:** concern about difficulty and cost.
- **Lack of data for dimensioning measures:** local monitoring of precipitation and runoff is missing.

In many cities, there may not be suitable geological and hydrogeological conditions for rainwater infiltration. However, as shown by expert studies and in many European cities, **unsuitable geological conditions for infiltration must not lead to the abandonment of the application of natural rainwater**

management. A detailed geological survey is necessary for each construction project **and based on it, identify the optimal solution** to reduce rainwater runoff at the point of origin.

When implementing blue-green infrastructure, designers often encounter concerns from owners about the future maintenance of these facilities and their economic demands. However, this area has also seen tremendous progress in recent years, and there are standard solutions that require only simple maintenance.

The fundamental problem **in dimensioning** blue-green infrastructure must be **sufficient and reliable data,** which should be based on high-quality local monitoring of precipitation, climate observations, knowledge of hydrogeological conditions, so that the implemented measures work. Cities should help builders and investors in implementing RWM by operating such monitoring and providing this data for building design.

Possible solutions

- **Detailed analysis of the site before implementation** (geology, hydrology).
- **Easy maintenance and clearly defined procedures:** administrator manuals.
- **Building databases and maps of RWM measures** at the city level.

3.6. Summary - recommendations for removing barriers to RWM implementation

The obstacles to the implementation of rainwater management need to be addressed at all levels - with the support of the European Union and its institutions, at the level of national parliaments and governments, at the regional and local levels. The following table summarizes the recommendations for each level.

Level		
European/national	**regional**	**local**
political and strategic areas		
creation of understandable and unambiguous rules of legislative rules	unification of the regional administration's approach to the interpretation of existing legislative regulations	unification of local government's approach to the interpretation of existing legislative regulations
development of European and national standards for RWM		active approach to promoting the water management concept
		enforcement of RWM rules during construction and renovations
economic and financial areas		
financial incentives and subsidy programs	financial incentives and subsidy programs	financial incentives
cancellation of exemptions for payment for discharging rainwater into the sewer system		
institutional and organizational area		
training and education of officials and politicians	training and education of officials and politicians	training and education of officials and politicians
		establishment of interdepartmental working groups for the coordination of RWM projects
		establishment of the position of administrator of the city's water management concept
social and cultural area		
awareness campaigns and education	awareness campaigns and education	awareness campaigns and education
		citizen involvement in RWM projects
examples of good practice	examples of good practice	examples of good practice - exemplary implementations of RWM in public buildings
technical and operational area		
support local and regional authorities by providing sufficient and reliable data (free of charge data from government institutions)	support local authorities by providing sufficient and reliable data (free of charge data from regional institutions)	sufficient and reliable data for dimensioning RWM measures (analysis of climatic conditions and their variability)
		Incorporating RWM principles into spatial planning, development documents and decision-making processes of urban administration
		processing of analyses of rainwater runoff in individual parts of the city (hydrological analysis, hydraulic capacity of the sewerage system, analysis of the infiltration potential of the area, analysis of the possibilities of using rainwater in the city)
		assessment of risks associated with managing rainfall in the city
		setting general drainage limits
		introduction of standards for the application of RWM for new and renovated buildings
		consistent control and enforcement of RWM by public administration

4. Misconceptions often associated with RWM

When perceiving the concept of rainwater management, we often encounter misconceptions that are often associated with RWM. These include the following examples:

1. **RWM is not just the infiltration of rainwater into the subsoil.** The sentence: "There is nothing you can do about it, there is no infiltration there", is completely absurd from the point of view of RWM. Even though the possibility of infiltration is the first thing that must be checked when designing the drainage of a building, it is far from the only solution. **When rainwater cannot be safely infiltrated, its outflow from the building can almost always be delayed in the object,** which fulfills the purpose of sustainable development, just as when it is possible to infiltrate the water.

   Combination of retention and infiltration devices, or purely retention devices

2. **RWM does not represent a 100% protection of urban areas from flooding.** Just as street sewers are dimensioned for a certain design rainfall, so is the case with RWM facilities. When the design capacity is exceeded, they become overloaded. This is mainly due to the fact that from an economic point of view it is simply not possible to design such measures that have absolute reliability. For this reason, it is **necessary to pay maximum attention to the outlet of overflows from individual facilities, which should safely drain excess rainfall into the recipient.**
3. **RWM facilities,** like other water management facilities, are not **"maintenance-free".** Concerns that RWM facilities may become inoperable in the long term without proper maintenance are justified, but they are completely irrelevant as an argument excluding the introduction of RWM. This is because **when designing any technical work, it is necessary to consider a certain procedure for its maintenance and operation.** If it were assumed that the work would not be maintained after its completion, only structures that do not require any operational measures could be permitted.

5. Procedure for implementing rainwater management in cities

5.1. Concept for implementing rainwater management for the city as a whole

Rainwater management (RWM) cannot be seen as a set of individual technical measures, but as a long-term strategy for the entire city. Success is conditional on a conceptual approach – i.e. **the integration of RWM principles into spatial planning, development documents and decision-making processes of the city administration.** A strategic approach to rainwater management (RWM) at the city level requires that individual steps be interconnected, systematically managed and supported by current knowledge from hydrology, urban planning and landscape engineering. Professional literature clearly points out that **random and isolated measures** often **do not fulfill their purpose** and can lead to inefficient use of investments.

The steps below represent a methodological framework for developing a RWM concept in an urban environment.

5.1.1. Assessment of rainwater runoff in individual parts of the city

The assessment of rainwater runoff is a crucial step in planning rainwater management (RWM) measures in a city. Its aim is to comprehensively assess how rainwater behaves in individual parts of the city, what are the runoff volumes generated during design precipitation, what is the capacity of the existing sewerage infrastructure and what are the local conditions for infiltration or use of rainwater. The results of the assessment serve as a basis for the design of the most suitable RWM measures that respect the conditions and constraints of individual urban locations and support the principle of using rainwater at the point of impact.

The rainwater runoff assessment includes a detailed assessment of individual parts of the city in the following areas:

- ***Hydrological analysis***

Hydrological analysis is aimed at determining the amount of rainwater that flows from the assessed areas during defined rainfall episodes. The starting point of this assessment is the determination of the character of individual surfaces and their runoff coefficients. For each location, built-up, paved and permeable areas are identified, from which the overall ability of the area to absorb or retain rainwater is determined. Runoff coefficients are subsequently applied in the calculations of runoff quantities for design rainfall specified in technical standards.

For the needs of the conceptual document, short-term, intense rainfall is evaluated in particular, which is a critical factor for the load on the sewage system. At the same time, longer-term rainfall totals are also assessed, which can be decisive for the effectiveness of retention and infiltration measures. The result of the hydrological analysis is the quantification of runoff for individual parts of the city, their comparison with the capacity of the existing infrastructure and the identification of locations where the sewage network is or may be overloaded.

Hydrological analysis is usually carried out by specialized experts: Hydrologists, water management engineers, urban and spatial planning experts, environmental engineers, blue-green infrastructure specialists.

- ***Hydraulic capacity of the sewer system***

Hydraulic assessment of the sewerage system evaluates the ability of the existing infrastructure to discharge the runoff volume generated during design rainfall. The analysis collects available data on the dimensions and technical condition of the sewers, the shape and profile of the pipes, the capacity ratios of individual sections and their connections to recipients or wastewater treatment plants. Special attention is paid to parts of the city with a unified sewerage system, which experience significant overflow during rainfall.

Based on these data, a hydraulic model is developed that simulates the behavior of the system under various precipitation scenarios. The model allows identifying critical points in the sewer network, such as sections with insufficient profile, backflow points, point elements exposed to overflow or sections where the unified sewer system is relieved into recipients. This diagnosis creates a basis for decisions on places where it is appropriate to implement RWM measures in order to limit or slow down the runoff and reduce the load on the sewer infrastructure.

To solve the hydraulic assessment, it is advisable to cooperate with hydraulic engineers, sewerage designers, water management infrastructure operators, water management engineers, experts in modeling drainage systems, etc.

Figure 4: Historic sewer in Prague

❖ ***Infiltration potential of the territory***

Assessment of the infiltration potential of an area is crucial for deciding whether it is possible to effectively use infiltration as the basic method of rainwater management in individual locations of the city. The assessment is based on geological and hydrogeological information, which includes the grain size composition of soils, their permeability, the composition of the rock environment and available data on the groundwater level. In areas with sandy or gravelly soils, infiltration is usually well feasible, while areas with clayey or impermeable sediments have very limited potential.

It is necessary to identify zones with high, medium and low potential for infiltration within the city.

Within the framework **of spatial planning, these zones** need to be clearly defined and **the principles of rainwater management** defined and **their criteria established.**

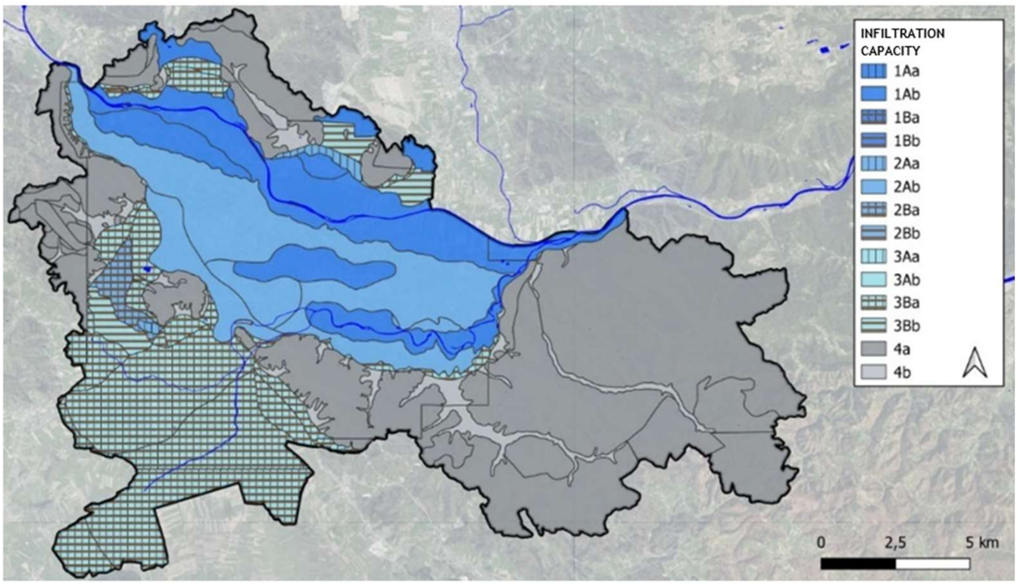


Figure 5: Graphic representation of the Infiltration Capacity Map for the Ljubljana example

The assessment also includes the identification of risks associated with possible groundwater contamination, especially in industrial zones or areas with historical burdens. If the groundwater level is located at a shallow depth below the terrain, it is necessary to consider measures to prevent its undesirable influence. The output of the infiltration assessment is the categorization of the area in terms of suitability for infiltration facilities, which becomes one of the basic inputs for the design of specific RWM measures.

Specialists dealing with this issue are geotechnicians, hydrogeologists, water management engineers, pedologists, and experts in ecology and groundwater protection.

- ***Rainwater use options***

The assessment of runoff also includes an evaluation of the possibilities for active use of rainwater (rainwater harvesting). The aim of this analysis is to determine in which locations it is appropriate to accumulate rainwater and subsequently use it, either for small-scale user purposes or on a larger scale. The evaluation is based on the nature of the development, its functional use and the technical capabilities of the buildings.

In residential areas with single-family homes, the use of rainwater is usually very promising, especially for garden irrigation, replenishment of retention elements around houses or as a source of domestic water. In commercial and industrial areas, rainwater can be used for technological purposes, cleaning paved areas, cooling or refilling fire tanks. In public areas, rainwater can be used for irrigation of urban greenery or refilling water features.

This type of assessment makes it possible to determine in which parts of the city the accumulation and use of rainwater is an appropriate part of RWM measures, and where, on the contrary, the main emphasis will be placed on retention, runoff slowdown or infiltration.

The hierarchy for choosing a drainage method must always be followed:

- **rainwater infiltration** should always be preferred,
- if it is not technically possible, **retention with regulated drainage follows**, or **the possibility of further use of rainwater**,
- **discharging it into the sewer should be a last resort.**

This hierarchical principle proves to be key and it is essential to reflect it in urban concepts.

Individual parts of the city can differ significantly in their hydrological behavior. The different character of the districts (historical center, housing estates, industrial zones, new residential complexes) requires a separate approach.

5.1.2. Assessment of climatic conditions and their variability

The basis of the conceptual preparation is the evaluation of the precipitation and temperature conditions of the given location and their changes over time. The concept should therefore be based not only on historical data, but also on predictions of future climate changes – for example, the expected increase in the frequency of torrential rains and dry periods. This information must form the basic framework for the dimensioning and selection of measures. An example of the evaluation of climatic conditions and their variability can be the water management study supporting the implementation of rainwater management prepared for the city of Novy Bydzov within the framework of the MAURICE project.

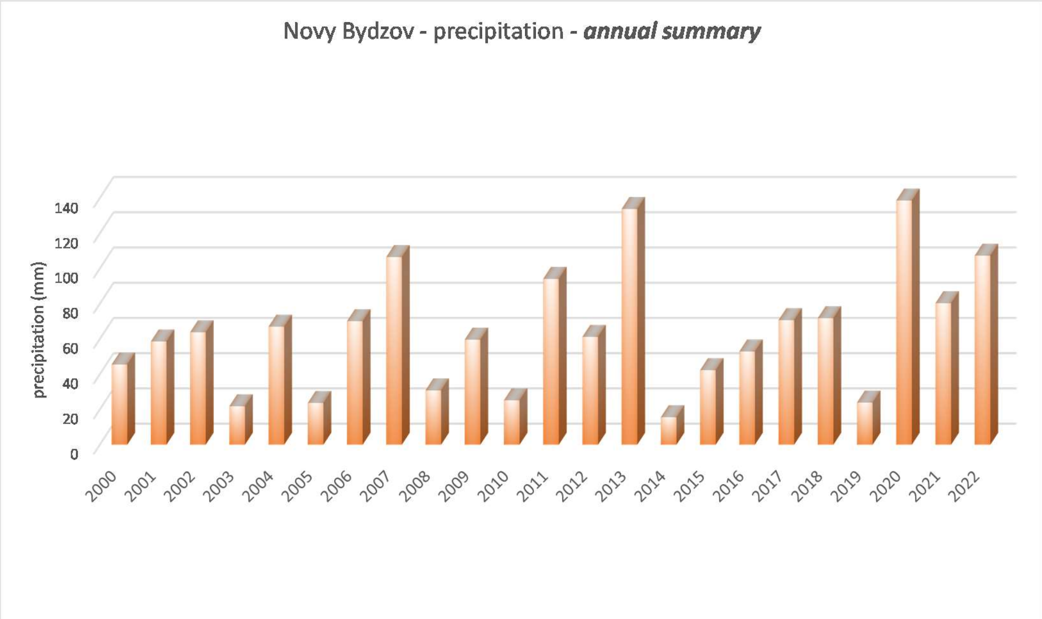


Figure 5: Annual precipitation summaries in Novy Bydzov (2000 - 2022)

5.1.3. Risk assessment associated with rainwater management in the city

City management must have a comprehensive assessment of the risks associated with rainwater management in the city.

These risks include primarily:
- overloading of the unified sewage network,
- local flooding and erosion phenomena,
- damage to surface flows due to pollution from relief channels,
- lack of water in the soil environment and a decrease in groundwater levels.

It is necessary to evaluate all risks in terms of their economic impacts, environmental impacts and quality of life in cities and **to set priorities and a concept for their solution**.

Risk assessment must therefore be part of every decision-making process and serves to determine priorities - whether to prefer measures to retain water, to absorb it, or to use it.

5.1.4. Setting general drainage limits

General drainage limits are one of the most important drainage parameters from the point of view of the application of RWM in existing and prospective urban development. These limits should be universally valid for any construction throughout the entire territory of the city or municipality - i.e. both for new construction and for reconstructions and reconstructions.

General drainage limits can be divided into two groups:

a. Key indicators that are essential for determining the maximum allowable runoff from the territory and for determining the dimensions (capacity) of RWM facilities and objects;
b. Mandatory requirements for technical solutions that will ensure appropriate operational reliability and economic independence for future property owners.

Drainage limits should be discussed and agreed upon by the relevant water management organizations (e.g. river basin manager, sewer network owner and operator, water authority, etc.) to create a unified approach to RWM that will be jointly promoted by all stakeholders.

- For each location, set runoff limits (l/s/ha) according to infiltration possibilities.
- These limits must be binding for new construction projects and renovations.
- The aim is to gradually reduce the load on the sewage network and wastewater treatment plant.

For example, the Prague *Standards for Rainwater Management* (2021) establish as a key principle **the limitation of maximum runoff into the sewer system** in both new and reconstructed buildings. This parameter must be considered **a binding tool for spatial planning.**

Its importance lies not only in the technical protection of the sewage network, but also in supporting the investor in finding solutions on the land (retention, infiltration, utilization).

Example of specific values for general building drainage limits (Czech Republic)

binding regulation	**binding rule**		**reference to a technical or legislative regulation**
	rule description	value, execution	
key indicator	specific rainwater runoff	max. 3 $l.s^{-1}.ha^{-1}$	TNV 75 9011 rainwater management
	frequency of BGI capacity exceedance	max. once every 5 years ($p = 0{,}2\ rok^{-1}$)	
	emptying time of BGI	max. 24 h	
binding requirement for technical solutions and initial design documents	safety overflow	the building must be connected to surface water or sewage	Decree No. 146/2024 Coll. on construction requirements
	ownership principle	BGI objects must be on the construction site	
	detailed hydrogeological survey	to demonstrate the quality of the rock environment and hydrogeological conditions in a timely manner	

5.1.5. Introduction of standards for new and renovated buildings

It is very practical for the construction of new buildings and for the reconstruction of buildings in the city to introduce clear rules (standards) for rainwater management. These should contain technical manuals, binding parameters, design principles, general drainage limits, recommended types of measures, etc. **for new and reconstructed buildings,** which the builder must comply with. The standards create a uniform procedure for designers and investors and at the same time define the requirements for operation and maintenance.
Without binding standards, there is a risk of implementing measures with very different quality and the result is **unsystematic management.** The introduction of binding standards is therefore one of the key pillars of the concept. A good example can be the standards for rainwater management for the capital

of the Czech Republic, Prague
(https://iprpraha.cz/assets/files/files/bddf4f520d27099cbc0f7a3609918e90.pdf)

5.1.6. Incorporating RWM into strategic documents

The conceptual framework for rainwater management must be **firmly anchored in** the city's strategic and spatial planning documents.

The principles of RWM must be reflected in:

- Zoning plan (runoff limits, requirements for infiltration areas).
- City climate strategies.
- Climate change adaptation action plans.

Inclusion in the spatial plan, climate change adaptation action plans and investment strategies ensures that RWM measures will have long-term support and funding and that RWM will not be just an isolated project, but part of the systemic development of the city.

As part of the MAURICE project, the partner Novy Bydzov prepared a water management study for the needs of implementing the RWM. The aim of the water management study was to examine the possible impacts of climate change on the water management of the city of Novy Bydzov in terms of risks to water supply (drinking, technical, utility) and to determine the benefits of using rainwater as a substitute for drinking water in facilities owned by the city.

5.2. Implementing rainwater management in undeveloped parts of the city

Undeveloped areas represent a unique opportunity to incorporate rainwater management (RWM) principles into the urban framework before construction. It is therefore necessary to apply a systematic and integrated approach that links spatial planning, legislative framework and nature-based measures.

5.2.1. Necessary studies for the given area

The basic step is to prepare hydrological and urban studies of the given area, which will determine the level of infiltration, retention and runoff in the area (listed in Chapter 5.1). The studies should also include **maps of impervious surfaces and infiltration capacities.** However, it is necessary to realize that these documents can only serve as a rough initial orientation and certainly cannot replace the function of a detailed hydrogeological survey in their details. The specific drainage solution depends on a well-evaluated and applied hydrogeological survey.

Additional European experience recommends applying the concept of **Water-Sensitive Urban Design (WSUD),** which integrates rainwater management into green infrastructure planning. This approach is also recommended by the European Environment Agency (EEA, 2020; climate-adapt.eea.europa.eu).

5.2.2. Access to the territory as a whole

Undeveloped areas must be understood as a whole, not as a collection of isolated plots. This corresponds to the principles of **the "sponge city"** applied in Vienna, Berlin or Copenhagen (EEA, 2022; time.com).

Although future development of the area may take place individually in different time stages, it is necessary to proceed conceptually in managing rainwater throughout the area and prevent RWM in one part from limiting the functionality of RWM in another part of the area and complicating RWM in the entire area as a whole.

Based on this approach, the costs of operating the sewer network and WWTP can be reduced, the material and hydraulic load on watercourses will be reduced, watercourses will be sufficiently supplemented with groundwater during periods of drought, and not overfilled during torrential rainfall. Life in cities will thus be of better quality and safer.

5.2.3. Selection and application of measures

It is always necessary to base oneself on the valid water legislation and technical standards. It is important that cities create clearly defined rules based on them and follow them in their territory.

Urban Wastewater Treatment Directive (2024), which also focuses on rainwater and supports the implementation of **nature-based solutions** (European Commission, 2024; environment.ec.europa.eu), is essential.

The set of recommended measures is briefly presented in Chapter 6 of this guideline.

5.3. Implementing rainwater management in built-up areas of the city

The implementation of rainwater management (RWM) in built-up areas is significantly more complex than in unbuilt areas. The reasons are spatial constraints, a high proportion of impervious surfaces and a complex structure of ownership relations. Nevertheless, significant benefits for the urban environment and the quality of life of residents can be achieved by applying appropriate technical and organizational measures. A suitable means for the implementation of RWM is an analysis of the potential of existing development in terms of bringing rainfall-runoff conditions closer to natural conditions. On its basis, **it may be possible to disconnect certain parts of paved areas from the sewerage system within a defined area of existing development.**

Unfortunately, it must be stated that **until the exemptions from the obligation to pay fees for rainwater drainage (valid in many European countries) are abolished, no major changes can be expected in this area - rainwater is still largely drained in a conventional way.** However, public administration in cities should pay attention to buildings owned by the city and located on city land in existing developments. Redevelopment of drainage of city properties also has a positive effect on other property owners (examples of "good practice").

The most common barriers to implementing RWM in built-up areas include:

- **Lack of space** – densely built-up areas lack areas for retention and infiltration elements.
- **Ownership relations** – complex property rights complicate the implementation of area-wide measures.
- **Technical infrastructure** - existing sewerage networks are not designed for torrential rainfall (Vítek et al., 2015).
- **Insufficient awareness and motivation of investors** – absence of legislative incentives and pressures.

The city's first step should be **to analyze the potential of existing development** in terms of bringing rainfall and runoff conditions closer to natural conditions - a necessary part of the spatial plan, which is one of the main goals of the general drainage plan.

The methodological procedure for analyzing the potential of existing development can be divided into three parts:

1. **Categorization of existing development** – in this phase, the area of interest is divided into individual areas according to ownership relations and spatial parameters. The output of the categorization of existing development is the definition of several coherent locations in the city, for which a more detailed survey of the watershed is subsequently carried out.

2. **Terrain reconnaissance** – the aim of terrain reconnaissance is to collect additional data on the existing development in terms of its possibilities and prerequisites for the introduction of RWM. The reconnaissance is not carried out across the entire territory, but only for locations selected during the process of categorizing the existing development.

3. **Determining the potential of RWM in existing development** – the last step in analyzing the potential of existing development is to assess the impact of "disconnecting" specific impermeable paved areas from the sewer network using a mathematical model. Based on this, it is then possible to evaluate the return on the proposed measures or, alternatively, to solve problems with overloading of non-capacity sections of the sewerage system and watercourses. In the case of an intention to introduce RWM in existing development on a large scale, it is appropriate to evaluate the impact of this step on the introduction and transport of sediments (undissolved substances) in the sewer system. This applies in particular to sections where sedimentation problems already occur in the current state.

Despite the obstacles, the benefits of implementing RWM in built-up areas can be significant:

- **Reduction of flood risk** due to relief of the sewage network (Vítek et al., 2015).
- **Improving the microclimate and reducing heat islands** – e.g. using rain gardens and green roofs (Water in the City, 2018).
- **Increasing the quality of public space** – more greenery and water supports social interactions and the health of residents.
- **Economic efficiency** – EEA (2021) states that blue-green infrastructure is cheaper than sewer expansion in the medium term (eea.europa.eu).

Example: **Enghaveparken in Copenhagen** combines parkland with retention functions and can hold up to 24,000 m^3 of water during heavy rainfall.

RWM is best applied in built-up areas to the following types of structures:

- **Public buildings and spaces** – schools, offices, parks, squares (Vítek et al., 2015).
- **New housing construction and reconstruction -** where RWM can be incorporated into the project (RWM Standards Prague, 2021).
- **Industrial areas** – often have large roof areas suitable for retention tanks or water recycling.

Foreign practice shows that **the public sector** is often the pioneer in the development of RWM. **Cities should first pay attention to buildings owned by the city and located on city land in existing developments. Rebuilding the drainage of city properties also has a positive effect on other property owners (examples of "good practice").** For example, in Amsterdam, the city invested in the *RESILIO project*, where over 10,000 m^2 of blue-green roofs were built (wired.com).

The introduction of RWM in built-up areas must be consistently applied:

- **In new buildings** – integration from the beginning (e.g. obligation to design retention elements).
- **During reconstructions** - an opportunity to renew roofs, yards or parking lots (Water in the City, 2018).
- **When revitalizing public spaces** – street trees, rain gardens, infiltration strips.

The EEA (2020) recommends a strategy of **"no-regret solutions",** i.e. measures that are always beneficial – even with uncertainty in climate scenarios.

The following measures are most often applied in built-up areas:

- **Rain gardens and bioswales** – effective even in limited street space.
- **Infiltration strips and drainage ditches** – use green areas along roads.
- **Green roofs and facades** – multifunctional measures that retain water and cool the microclimate.
- **Permeable surfaces of sidewalks and parking lots** - also recommended in *the RWM Prague Standards* (2021).
- **Multifunctional retention parks** – such as Enghaveparken (Copenhagen) or Seeliger Park (Berlin).

According to the European Commission (2021), **nature-based solutions** in urban spaces are key to climate resilience (environment.ec.europa.eu).

The following figure (Fig. 6) highlights flat roofs with an area greater than 100 m^2 in the built-up area of Novy Bydzov, which would be suitable for the implementation of green roofs.

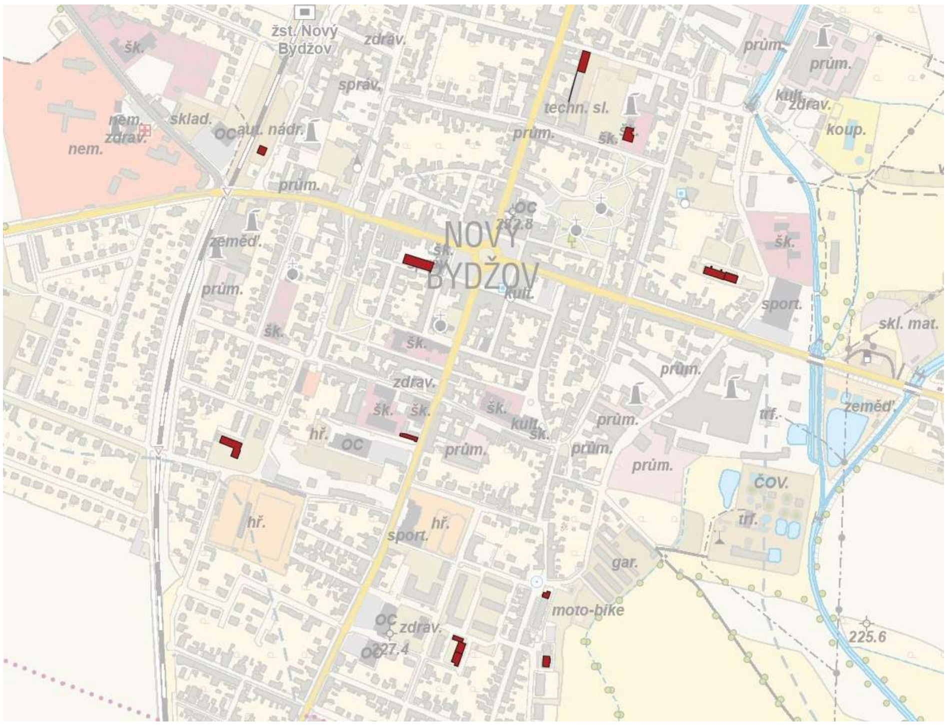


Figure 6: Flat roofs on buildings owned by the City of Novy Bydzov with floating roofs larger than 100 m^2

5.4. Implementation of rainwater management for specific buildings (projects)

The implementation of the principles of rainwater management (RWM) at the level of individual buildings is a key step towards the comprehensive implementation of the city concept. In this phase, legislation, methodological guidelines and technical standards are applied, which must be respected by the builder and consistently enforced by the public administration. In contrast to a comprehensive strategy or solutions for entire urban areas, the focus here is on individual buildings and their construction and technical conditions, ownership relationships and the construction process.

Rainwater management (RWM) at the level of individual buildings represents the most concrete level of implementation. While strategic documents and spatial planning determine the general framework, it is only at the level **of building permits and project documentation** that decisions are made as to whether and how the RWM principles will actually be implemented.

5.4.1. Legislative framework and documents at the city level

For specific projects, it is necessary to clearly require the application of relevant legislation and binding standards:

- **Water Act** – establishes the obligation to manage rainwater in such a way as to prevent its pollution and to prefer its disposal on the land.
- **The Building Act** – emphasizes the obligation to respect the principles of sustainable development of the territory and allows the inclusion of requirements for RWM directly into the spatial planning documentation.
- **Technical standards** – provide a methodology for the design and assessment of infiltration devices and retention structures.
- **Municipal standards** – an example is *the Standards for Rainwater Management in the Capital City of Prague* (ČVUT, 2021), which specify technical and procedural requirements and recommendations that can be considered a model for other cities.

To effectively enforce these requirements, it is appropriate for the city to adopt its own **methodological regulation or decree,** which sets out uniform rules for developers in advance. According to European practice (European Commission, 2021; CIRIA, 2015), it is crucial that the rules are clear, transparent and binding already at the stage of zoning and construction procedures.

According to *the RWM Prague Standards* (2021), it is necessary for cities to adopt clear methodological regulations that specify to builders:

- **requirement for infiltration or retention of rainwater on the property,**
- **limits on maximum discharge into the sewer system** (e.g. in Prague max. 2 l/s/ha for new construction),
- **obligation to assess water recycling options,** especially for larger projects.

The legislation of EU countries currently only sets out general frameworks for RWM, which is why **the role of urban standards** and **territorial regulations** is crucial.

European cities (e.g. Berlin, Hamburg) have introduced **“rainwater fees”** to incentivise developers to implement RWM. These fees can be reduced if the project includes retention tanks, green roofs or infiltration systems (EEA, 2020; climate-adapt.eea.europa.eu).

5.4.2. Control and enforcement of RWM by public administration

A control mechanism is essential for the effective implementation of RWM:

- **The building authority** requires documentation of a hydrotechnical calculation and a draft measure.
- **The Water Authority** assesses whether the solution is in accordance with the Water Act.
- **A municipal authority** (e.g. the environmental department) checks whether the measure corresponds to the city's strategy.

The role of building authorities and water authorities is crucial. The inspection focuses on:

- **completeness and quality of the submitted documentation,**
- **compliance of the design with binding regulations and standards,**
- **implementation of the construction in accordance with the project** (inspection during the final approval),
- **setting conditions for maintenance and operation of the device.**

Abroad (e.g. in Copenhagen), controls are reinforced by **monitoring the real behavior of systems,** which allows the city to monitor the effectiveness of measures even after construction is complete (EEA, 2020).

Experience shows that without consistent control, RWM principles are circumvented – e.g., a formal design of a seepage device, which is not technically feasible or remains unmaintained (CIRIA, 2015; VÍTEK et al., 2015).

5.4.3. Procedure of the investor, builder and designer

Every investor (builder) should be obliged to submit and prove the following when approving a construction project:

- Evaluation of **the possibility of infiltration and retention** on the land.
- Assessment of **rainwater use in the building** (flushing, irrigation).
- Compliance with the specified **maximum discharge into the sewer.**
- Ensuring **maintenance of the proposed measures** (e.g. regular cleaning of retention tanks).

European practice shows that in many cities (e.g. Malmö, Vienna) the investor is obliged **to submit a rainwater audit** (rainwater plan), which systematically evaluates all options for managing rainfall (EEA, 2021).

In a number of European countries (e.g. Germany, the Netherlands), such a procedure is firmly enshrined in legislation and the builder cannot obtain a building permit without documenting the measures (EEA, 2020).

5.4.4. Solving inadequate infiltration conditions

Infiltration is not always possible – e.g. due to **low soil permeability, high groundwater levels or subsoil contamination** (Vítek et al., 2015). If infiltration is completely impossible, it is necessary to demonstrate that all alternative measures have been considered and that runoff to the sewer is effectively minimized.

In such cases, it is necessary to choose alternative measures:

- **Retention tanks with regulated outflow** – water is used for irrigation or flushing.
- **Green roofs** – retain up to 50–80% of precipitation (Water in the City, 2018).
- **Permeable surfaces** – allow partial infiltration and slow down runoff.
- **Relief facilities** – multi-chamber tanks with the possibility of gradual discharge.

The European Commission (2021) highlights that **nature-based solutions** are a suitable alternative to technical measures where direct infiltration is not possible (environment.ec.europa.eu).

5.4.5. Practical examples

Procedure for the builder when applying the principles of rainwater management (RWM)

STEP 1 - Preliminary land analysis

- Assess **hydrogeological conditions** (soil infiltration capacity, groundwater level, risk of contamination)
- Evaluate **area ratios** (proportion of impervious surfaces, greenery)
- Take into account **climatic conditions and precipitation intensity** (VÍTEK et al., 2015; EEA, 2020)

STEP 2 - Drafting a water management concept

- Determine **the maximum permissible discharge into the sewer** according to city standards (e.g. Prague: 2 l/s/ha - RWM Prague Standards, 2021)
- Examine the possibilities **of using rainwater** in the building (flushing, irrigation, technical purposes)
- Design a combination **of technical and nature-based measures** (retention tanks, green roofs, permeable surfaces, ditches, rain gardens)

STEP 3 - Choosing the right solution

- **Prefer infiltration** if conditions allow
- If infiltration is not possible, choose **retention with controlled drainage** or **water recycling**
- In the case of large-scale constructions, require **a comprehensive rainwater audit** (rainwater plan - practice from Vienna, Malmö; EEA, 2021)

STEP 4 - Submission of documentation

- The project documentation must include:
  - Hydrotechnical calculation (precipitation, runoff and retention balance)
  - Proposal of measures in accordance with city standards
  - Investor's declaration on ensuring maintenance of measures

STEP 5 - Review and approval

- **The building authority** verifies the completeness of the documentation
- **The Water Authority** assesses compliance with the Water Act
- **The city's environmental department** ensures compliance with city standards and the zoning plan

STEP 6 - Implementation and acceptance

- The investor must prove that the measures were implemented according to the project
- For larger buildings, **monitoring of the system's function may be required** (practice from Copenhagen and Hamburg)

STEP 7 - Operation and maintenance

- **a regular maintenance** system (cleaning retention tanks, checking the function of infiltration facilities, caring for vegetation on green roofs)
- It is recommended to establish **a registry of measures** at city level for long-term monitoring (EEA, 2020)

6. Technical measures and equipment in rainwater management

Modern rainwater management uses a wide range of technical measures. All measures have a common goal – **to retain, slow down or use rainwater as close as possible to its point of impact,** thereby approaching natural hydrological processes.

Technical measures form the practical backbone of rainwater management. Each city can choose a combination of solutions according to its conditions and create Standards for RWM in the city area for its needs. It is important to understand that the greatest effect is achieved by a combination of multiple measures - from small individual solutions (tanks at homes) to large urban projects (retention reservoirs, wetlands).

The introduction of RWM measures is technically feasible, economically beneficial and proven by many European examples. **However, political will, clear legislation and systemic support are necessary for success.**

The main groups of blue-green infrastructure are listed below. For each group and subgroup, the principle, meaning and typical use are described. Detailed specifications and possible uses of blue-green infrastructure are elaborated in a separate guideline: **GUIDELINES FOR DESIGNING BLUE-GREEN INFRASTRUCTURE FOR RAINWATER RETENTION AND GROUNDWATER RECHARGE**, elaborated within the MAURICE project.

6.1. Reduction or prevention of precipitation runoff at the source

The purpose of these technical measures is to reduce or completely minimize the occurrence of rainwater runoff at the source. Therefore, when designing a rainwater drainage system, it is necessary **to preserve permeable unpaved surfaces as much as possible,** preferably with vegetation cover in low-lying terrain and with natural drainage. When designing drainage, it is also advisable to minimize the number of impermeable paved areas.

The technical measures to achieve this goal are described below.

6.1.1. Unpaved surfaces

- **Description:** Grasslands, parks, gardens, tree-lined avenues and other vegetation elements.
- **Meaning:** They soak up water directly on site, support groundwater recharge and improve the microclimate.
- **Example of use:** Establishing parks instead of paved parking lots, restoring front gardens of apartment buildings.

6.1.2. Permeable paved surfaces

- **Description:** Surfaces made of grass tiles, gravel or permeable paving.
- **Meaning:** They allow water to seep into areas that are functionally used (e.g. parking lots, sidewalks).
- **Example of use:** Parking for residents, pedestrian zones, cycle paths.

6.1.3. Vegetation and gravel roofs

- **Description:** Roofs that are planted with vegetation or covered with gravel.
- **Meaning:** They retain and evaporate water, reduce the load on sewers and cool buildings.
- **Example of use:** Administrative and public buildings, new apartment buildings.

6.2. Accumulation and use of rainwater

Accumulated rainwater can be used primarily as a source of water for watering city parks or green infrastructure, cooling city surfaces by sprinkling or cleaning them. In city buildings, it can also be used as a source of utility water for flushing toilets or cleaning (usually it is necessary to build a separate utility water distribution system). Rainwater can also be used for other purposes.

In Novy Bydzov, a complete technical solution was developed for the Winter Stadium location as part of the MAURICE project, which replaced drinking water for the production of ice for the ice rink with rainwater from the roof of the winter stadium.

A brief description of the accumulation and use of rainwater is given below.

- **Description:** Systems that collect rainwater in tanks and allow its further use.
- **Meaning:** It saves drinking water and ensures a supply for drier periods.
- **Example of use:** Underground or above-ground tanks near family houses, reservoirs near schools and public buildings, accumulations in industrial areas.

6.3. Infiltration device without regulated drain

These devices are generally usable for all types of common areas. Their feasibility is limited by hydrogeological conditions, i.e. the absorption capacity of the subsoil, the height of the groundwater level (maximum groundwater level at least 1 m below the foundation joint of the building/RWM facility), the slope of the terrain (if there is a risk of landslide). Feasibility must be confirmed by a detailed hydrogeological survey. Their application is unsuitable in cases where there is a risk of groundwater or soil contamination, i.e. unsuitable for areas from which highly polluted rainwater can flow (e.g. areas where hazardous substances are stored) or in cases where there is an unremediated ecological burden.

Individual examples of technical measures in this category are characterized in the following text.

6.3.1. Surface infiltration without retention - surface infiltration

- **Description:** Unpaved areas where water spills and the infiltration area is large enough.
- **Meaning:** The simplest method, suitable for smaller plots of land.

6.3.2. Surface infiltration with retention - infiltration gap

- **Description:** A depression in the terrain covered with grass or planted with vegetation.
- **Meaning:** It captures a larger amount of water, which gradually soaks in.

6.3.3. Surface infiltration with retention - infiltration tank

- **Description:** A reservoir in the field without a permanent water level.
- **Meaning:** It serves to temporarily retain water and gradually absorb it.

6.3.4. Underground infiltration with retention - infiltration trench

- **Description:** Underground gravel or block element.
- **Meaning:** Allows for absorption even where there is no free surface area.

6.3.5. Underground spaces filled with gravel or blocks

- **Description:** Prefabricated box or gravel bed systems.
- **Meaning:** High retention capacity, suitable for larger paved areas.

6.3.6. Infiltration shaft

- **Description:** A vertical element leading into deeper soil layers.
- **Meaning:** Usable where surface infiltration is limited.

6.4. Infiltration device with regulated drainage

These devices are generally usable for all types of common areas. In contrast to infiltration without regulated drainage, they can be used in conditions with poorer permeability of soil layers. They are also limited by the availability (distance) of the recipient (i.e. surface water or sewage system) into which the regulated drainage and water from the safety overflow will flow. The use of infiltration devices with regulated drainage is inappropriate in cases where there is a risk of groundwater or soil contamination.

Individual examples of technical measures in this category are characterized in the following text.

6.4.1. Infiltration trench with regulated drainage

- **Description:** Combination of a spillway and a controlled discharge.
- **Meaning:** Provides both infiltration and controlled discharge into the sewer.

6.4.2. Soaking tank with regulated drain

- **Description:** A tank that gradually releases water.
- **Meaning:** Reduces sewer overload during heavy rains.

6.4.3. Infiltration trench or underground spaces with regulated drainage

- **Description:** A variant of underground infiltration devices supplemented with a control element.
- **Meaning:** Allows for better runoff management during extreme rainfall events.

6.5. Retention facilities with regulated outflow

When discharging rainwater into surface waters, it is necessary to delay the outflow by means of a retention facility. Each retention facility must be equipped with an outflow regulator that regulates the outflow from the facility to a value that must be lower than the prescribed permissible outflow. Each retention facility must be equipped with a safety overflow that is hydraulically and structurally designed to safely transfer the flow caused by a rainfall higher than the design rainfall.

The feasibility of measures in this category is limited by the availability of surface water or sewage into which the regulated drain and water from the safety spillway will flow.

Individual examples of technical measures in this category are characterized in the following text.

6.5.1. Dry rainwater retention basins (polders)

- **Description:** A space that is dry most of the time and only fills up during precipitation events.
- **Meaning:** Flood protection, suitable for larger urban areas.

6.5.2. Underground rainwater retention tanks

- **Description:** Tanks located below the surface, often under parking lots or squares.
- **Meaning:** They enable efficient farming in cramped urban conditions.

6.5.3. Rainwater retention tanks with storage space

- **Description:** They combine a retention function with the possibility of accumulation for water use.
- **Meaning:** Double effect – protection against sewer overload and water supply.

6.5.4. Artificial wetlands

- **Description:** Ecological elements simulating a natural wetland.
- **Significance:** They retain and purify water, support biodiversity and recreational functions.

7. Identifying financing for rainwater management

Currently (probably due to the existence of a number of exceptions to the charging of rainwater discharge into the sewerage system and often also due to the inconsistency of administrative authorities in promoting environmentally friendly RWM) financing a new concept of rainwater management is relatively complex. The EU and a number of Member States are aware of the importance of RWM for the sustainability of water management and the quality of life in urban environments, therefore they allocate various subsidy titles for its successful implementation. The following chapters summarize some of the subsidy sources in the EU and the partner countries of the MAURICE project.

7.1. European resources

7.1.1. European Regional Development Fund (ERDF) & Cohesion Fund (CF)

- *For what*: blue-green infrastructure in cities, SUDS, flood and drought measures, modernisation of water management (mostly through national/regional operational programmes).
- *Examples of use*: streets with infiltration, retention parks, compartments/sewerages, smart rainwater management.
- *Where to watch*: national portals "EU Funds" and calls for OP Environment/OP Environment, etc. (see countries below).
- *Note*: in the period 2021-2027 often under the priorities "Climate adaptation", "Environment" or "Sustainable cities". funduszeeuropejskie.gov.pl

7.1.2. EU Mission "Climate Change Adaptation" (Horizon Europe, Mission 3)

- *For what*: pilot and demonstration projects of cities/regions for adaptation – including rainwater management, blue-green infrastructure, resilience plans.
- *Who*: municipalities, city associations, regions, research + partners.
- *Note*: emphasis on "mission cities/regions", joint learning and replication.

7.1.3. LIFE program (Environment/Climate sub-programme)

- *For what*: innovative nature-based solutions (NBS), SUDS, watercourse renaturation, urban wetlands, green roofs/walls, water quality measures.
- *Past/current projects*: a number of urban SUDS/LID applications across the EU.
- *Who*: municipalities, public enterprises, universities, NGOs.

7.1.4. Interreg (Cross-border, Transnational - e.g. Central Europe, Europe)

- *For what*: cross-border planning, pilots and exchange of know-how (storm risk mapping, SUDS catalogues, common standards).
- *Who*: cities, regions, universities, water managers.

Note: Until 2020, similar projects were typically financed from OPs 2007–2013 and 2014–2020 (ERDF/CF), LIFE and Interreg; 2021–2027 they continue, "Mission" calls have been added.

7.2. Examples of funding opportunities in the partner countries of the MAURICE project

7.2.1. Czech Republic

<u>European/national operations (ERDF/CF implementation):</u>

- **Operational Programme Environment (OPŽP) 2007-2013, 2014-2020, 2021-2027** *What for*: comprehensive adaptation measures, SUDS, retention and infiltration, separate sewerage, improvement of water quality, urban greenery with retention function. Beneficiaries: municipalities, urban companies, SVS/VK, SVJ, NGOs (according to the call).

<u>National programs (ME/SEF):</u>

- **"Rainwater" (SEF, 2017-present - waves opened several times)** *What*: retention and use of rainwater in households (retention, use in toilets/flush, grey water). Recipients: individuals - family houses.
- **New Green for Savings (NZÚ)** – selected sub-programmes support rainwater utilization systems in family homes/residential buildings (in combination with energy/savings).

<u>Regional/municipal:</u>

- **Capital City of Prague - Rainwater Management Standards** – the standard is not a grant, but is key to the eligibility of projects in urban investments and development areas (often connected to urban/OPE resources).

7.2.2. Germany

<u>Federal framework:</u>

- **"National Program for Natural Climate Protection" (Aktionsprogramm Natürlicher Klimaschutz, BMUV/ZUG)** - support for renaturation, blue-green infrastructure, natural water retention in municipalities (grants to municipalities/states/NGOs).
- **"Klimaanpassung in Kommunen" (BMUV/ZUG)** – investments and planning for climate adaptation (including rainwater, heat islands, blue-green networks).

<u>Provincial/municipal programs (examples):</u>

- **Berlin - "GründachPLUS / Regenwasseragentur"** – subsidies for green roofs, retention measures for buildings; methodological and project support for the municipality.
- **Hamburg – Support for Green Roofs and Retention Measures (BUKEA)** – long-term city grant program for "Schwammstadt" projects.
- **North Rhine-Westphalia (NRW) – "Directive on the granting of grants for climate adaptation in municipalities"** – finances concepts and investments (SUDS, retention parks, blue-green corridors).

7.2.3. Poland

<u>European/national:</u>

- **The Operational Programme Infrastructure and Environment (POIiŚ) 2014-2020 - Priority "Adaptation"** – included urban rainwater management systems (separate sewers, retention facilities, SUDS). Its successor is **FEnIKS 2021-2027** (adaptation, small retention).
- **NFOŚiGW – "Moja Woda" (2020-2024, continuously opened waves through regional WFOŚiGW)** – subsidies to households for small retention systems (tanks, infiltrations, rainwater utilization). Beneficiaries: individuals with RD.
- **NFOŚiGW - "Adaptation to climate change" programs** – support for cities (over 100 thousand inhabitants) and smaller municipalities for infrastructure and nature-friendly solutions; in the past co-financing from POIiŚ, now from FEnIKS.

7.2.4. Italy

<u>National/European – PNRR (National Recovery and Resilience Plan, NGEU):</u>

- **M2C4 – "Protection of the territory and water resources"** – investments in water infrastructure and adaptation, financed in a number of metropolitan cities by "Città Spugna" (SUDS, invarianza idraulica). Beneficiaries: cities/metropolitan areas, water ATOs, road administrations.

<u>Thematic national initiatives:</u>

- **Strategia Nazionale del Verde Urbano (MASE)** – framework for urban green infrastructures; follows up on urban/afforestation planting programmes (including metropolitan cities).

<u>Regional/municipal (examples):</u>

- **Milan – BE2 grants** (municipal energy subsidies + *tetti/pareti verdi* and depavimentazione as rain measures). Beneficiaries: private owners and SVJ; can be combined with regional FESR calls.
- **Regional Rural Development Programmes (PSR/FEADR 2021-2027)** – some regions (e.g. Emilia-Romagna) allow the use of green/retention at the urban-rural interface (through agricultural entities – e.g. agroforestry, water retaining landscape elements).

7.2.5. Slovenia

National/municipal:

- **Eko sklad - subsidies for "zbiralnik deževnice" (rainwater retention tanks for households)** – regularly opened calls; can be combined with municipal support (e.g. for reconstructions).
- **City programs (e.g. Ljubljana)** – have long-term support for green roofs and blue-green infrastructure interventions (mostly from city budgets and ERDF). (Background information, check in the city's current budget calls.)

7.2.6. Croatia

European/national:

- **Competitiveness and Cohesion Programme (ERDF/CF) 2014-2020, 2021-2027** – finances water management and adaptation projects (including drainage with rainwater retention, green infrastructure in cities). Beneficiaries: LGUs (local self-government units), municipal enterprises.
- **NPOO/PNRR Croatia** – investments in water and adaptation infrastructure, part of projects with a rainwater management component (according to calls).
- **FZOEU - Fond za zaštitu okoliši i energetsku utvoriti** – ongoing national calls for municipalities/citizens; annual allocation plan includes environment, energy and selected adaptation interventions (it is recommended to follow "eFZOEU" and annual call plan).

7.3. Recommendations for using subsidy programs

7.3.1. Practical notes on requests and resource combinations

1. **Start with a strategy and standards** - city "rain plan" and standards (Prague, Berlin...) increase the chance of funding and make it easier to assess the benefits (retention, water quality, heat islands).
2. **Connect energy, greenery and water** – combinations (e.g. Milan: energy + green roofs + depaving) are often subsidized.
3. **Community and "pilot" components** – LIFE/Interreg often require measurable pilots and sharing of results.
4. **Phase your investments** – EU funds like to see "packages": concept (runoff/infiltration studies) → fast pilots → large investments (OP / PNRR).
5. **Follow the annual plans of the funds** - some national funds issue calls cyclically (NFOŚiGW, FZOEU; for municipalities/countries in DE often spring/autumn rounds).

7.3.2. Recommended procedure for your city hall (checklist)

1. **Map "what I want to fund" vs. source** (investment × study × pilot).
2. **Verify eligibility** (type of applicant, territory, publicity, sustainability).
3. **Prepare the package** :
   - *Concept & data* (map of impervious areas, infiltration maps, runoff limits).
   - *Quick interventions* (permeable parking lot near the school, infiltration ditch near the road).
   - *Flagship project* (retention park / "mushroom district").
4. **Fill in the co-financing** (municipal budget + national fund + EU).
5. **Keep track of time** (ETŘ calls: OP/ERDF, national funds, LIFE/Interreg – various calendars).
6. **Consider a partnership project** (metropolitan areas/ATOs, water utilities, universities).
7. **Keep an eye on operating costs** (from the city/municipal corporation budget; some programs recognize 5 years of O&M as eligible to a lesser extent).

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ANNEX No. 2

Interreg CENTRAL EUROPE

Co-funded by the European Union

MAURICE

Output 3.4.

Guideline for the selection of rainwater treatment technologies for further use

Version 2

03 2026

Contents

Table of figures

1. Introduction

Rainwater treatment is a future way of sustainable use of water, which depends on factors such as the average rainfall in the region, water contamination, environment, surrounding location, air contamination, and many others. The main problem regarding rainwater is that even though the majority of the water went through evaporation to a gas state which left some of the contaminants like salts, metals, or bacteria in solid residue, there are still volatile contaminants such as NH_3 or SO_2 which can change the water pH level (acid rains) thus making the water toxic.

The biggest problem starts when the water from the rainfall falls. Water is contaminated by running over the roofs or streets by various types of contaminants such as pathogens from animal excrement, heavy elements from the materials on roofs, organic compounds from residues, and others.

This all leads to lower water quality and increased health risks for the general population as well as for it is surroundings including agriculture, rainfall treatment is an effective method how to reduce the stress on wastewater treatment facilities and save water - money, but the problem is mainly economic, it depends on several factors to choose the best cost-effective technology-based of factors such as the environment and location coupled with it's desired use. it has relatively high inputs and the return of investment depends on grants and financial support "green solution → financial aid", without financial support it wouldn´t be economically feasible on majority of the projects to even get to some return of investment, with it - it can be still as long as 15 years.

1.1. Rainwater quality

One possible source of water is rainwater. Its quality plays a key role in its usability. Generally, the rainwater is soft, slightly acidic which has advantages for some type of use. Therefore, it is necessary to characterize rainwater, identifying sources of contamination. This will make it possible to prevent contamination or to develop technology for its treatment and thus increase its usability. Another aspect is to determine the quality of rainwater due to environmental contamination. As will be shown later, rainwater is relatively clean, and the main contamination occurs when it reaches the surface. The surface itself and the location of the abstraction then play a major role in the resulting quality of the rainwater.

The tailored solutions and approach to cleaning of rainwater can be physical, chemical, or even hydrological, which all have different inputs and can clarify the water differently. Sometimes, a combination of two or more techniques gives the best cost-effective solution for the desired water quality level.

Emphasis is placed on pathogens transmitted by wild birds and rodents. The study of the Czech National Institute of Public Health highlights the lack of legislative requirements in the Czech Republic, the need for technical safeguards, and the danger of unintended cross-connections between potable and non-potable systems. The authors recommend a precautionary approach and continuous disinfection of the water.

Key findings:

- 40 rainwater samples were analysed.
- *Escherichia coli* was detected in 29% of samples (up to 980 CFU/100 ml).
- Enterococci were found in 53% of samples (tens to hundreds CFU/100 ml).
- *Clostridium perfringens* was repeatedly detected in some objects (up to dozens CFU/100 ml).
- No *Salmonella* or *Campylobacter* were detected (limited sampling).
- Atypical mycobacteria (*Mycobacterium gordonae*) were detected in one case.
- Water quality varied significantly based on roofing material, location, and maintenance.

https://hygiena.szu.cz/cz/artkey/hyg-202203-0002_zdravotni-rizika-pri-vyuziti-recyklovanych-vod-v-budovach-cast-1-8211-srazkove-vody.php

1.1.1. Rainwater contaminants

- Atmospheric contaminants
  - Oxides of sulphur (SO_2, SO_3)
  - Carbon dioxide (CO_2)
  - Dust, pollen, volatile organic contamination

- Contaminants from materials collection sites
  - Asphalt on roads ¤ Release of polyaromatic carbons
  - Iron roofs ¤ Cu, Pb, Zn, Cd
  - Green coloured roofs = roof garden ¤ can influence the colour and turbidity of the Water

- Organic compounds and other pollutants
  - Leftovers of pesticides and herbicides from atmosphere or fields
  - Oil contamination - parking lots etc.
  - Excrements of birds and mammals

  Creation of organic contamination that supports the growth of microorganisms.

  Creation of Pathogens – Diseases

1.1.1.1. Rainwater from roofs

Main contaminants

Analyses of rainwater on roofs showed many pollutants. Main pollutants being microbial contamination which is caused by bird droppings, leaves and insects. Huge influence on water contamination has roofing materials, which are often made of metals, such as zinc or copper.[1,2,]

Influence of roofing materials

Condition and type of roofing materials could play a significant role in runoff quality. Roofs made out of metal give off increased concentrations of Zn, Pb and Cu into runoff. Of course, the age of roofs is very important as well. The older the surface on roof is, the more pollutants it releases.

Sl. no.	Location/country	Samples collected from	No. of samples analysed	Heavy metals tested	Concentrations	Salient findings	Reference
1.	Tuffeon wies, Zurich	Roof catchment	14 rain events	Cu, Zn, Pb, Cd, Cr, Mn, Fe	Concentration in µg/l in the first 0.2 mm run off depth: Cr 0.6–1.7, Fe 90–415, Pb 2.7–41, Zn 9–115, Cu 18–842, Cd 0.1–0.4	Fe and Pb exceeded quality standard in drinking water. Cu, Pb, Cd in moderately reactive forms. Gravel roof retained heavy metals	Zobrist *et al.* (2000)
2.	Marais, Paris	Roof catchment	31 rain events	Cd, Cu, Pb, Zn	Median values: Pb 392 µg/l, Zn 29 998 µg/l	High Zn and Cd concentration observed for Zn roof, and Pb for slate roof	Gromaire *et al.* (2001)
3.	Auckland, Newzealand	Water faucet	125 Samples	Zn, Cu, Pb, As	Median values: Pb <0.01 mg/l Cu 0.06 mg/l Zn 0.4 mg/l As <0.005 mg/l	14.4% samples exceeded maximum acceptable values of Pb. For Cu, Zn and As 2.4%, 0.8% and 7.1% exceeded maximum acceptable limit	Simmons *et al.* (2001)
4.	Zurich Switzerland	Roof catchment	–	Cu, Zn, Cd, Pb	Average conc. from tile and polyester roofs: Pb 16 µg/l, Cd 0.17 µg/l, Cu 225 µg/l, Zn 42 µg/l	Storm water from roof accounted for 60% Cu in combined sewer	Boller (1997)
5.	Texas, USA	Roof catchment	31 storms	Cu, Mn, Pb, Zn, Mg, Al	Median values in mg/l: A1 0.169–0.224, Mg 0.292–0.646, Mn 0.01–0.022, Cu 0.018–0.22, Pb 0.025, Zn 0.859–9.717	Cu and Zn exceeded US freshwater standards. Zn increased as rainwater contacted all four types of roofs	Chang *et al.* (2004)
6.	Austin Texas, USA	Roof catchments	12	As, Cd, Cr, Cu, Hg, Ni, Pb, Zn	Metal concentration from different roofs: Metal Asphalt roof GI roof (µg/m^2) As 0.97–8.0 1.3–5.7 Cd 0.32–3.4 1.1–5.7 Cr 6.9–69.0 8.1–44 Cu 7–91 11–75 Hg 0.012–0.24 0.04–0.062 Ni 3.9–30 5.1–27 Pb 28–310 21–93 Zn 120–1,200 680–3,500	Metal roof tops were a source of particle-bound Zn, and Cd. As, Cr, and Cu found to be from atmospheric sources. Pb found high for asphalt roof	Metre & Mahler (2003)
7.	Maryland, USA	Roof catchment	38	Cu, Zn, Cd, Pb	Zinc concentration >100 µg/l in all samples. Mean Zn concentration from residential, commercial and institutional buildings 100, 1,100 and 1,100 µg/l respectively and Cu 7.5, 200 and 5,000 µg/l	Metal levels in institutional and commercial buildings were higher than that in residences	Davis *et al.* (2001)

Figure 1: Pollution of rainwater in different countries taken from rooftops (Meera 2006)

Setting	Parameter	Roof run-off (/100 ml)	Tank water (/100 ml)	Comments	Reference
EUROPE					
Denmark, urban area	*E. coli*		Prevalence 78.6% (*n* = 14) Range 4 – 990 Median 245	Samples taken from 7 rainwater harvesting systems	Albrechtsen (2002)
London, urban area	*E. coli*	Prevalence 94% (*n* = 88) Range 0 – 16 000 Median 52		Rainwater collected (prior to treatment) from the roof of the Millennium Dome	Birks *et al.* (2004); Birks (pers. com.)
	Enterococci	Prevalence 97% (*n* = 34) Range 0 – 680 Median >200			
England, semi rural	*E. coli*		Prevalence 34.6% (*n* = 26) Range 0 – 53	Samples taken from outside tap, possibility of mains water top-up	Day (2002)
	Faecal streptococci		Prevalence 57.7% (*n* = 26) Range 0 – 79		
Germany, urban	*E. coli*		*n* = 972 Median 26 Maximum >10 000	102 rainwater tanks	Holländer *et al.* (1996)
	Faecal streptococci		*n* = 969 Maximum > 10 000		
Scotland, rural area	Thermotolerant coliforms	Geometric mean range 383 – 3627 (*n* = 68)		Sampling from farm roofs (3 of the 4 farms were housing livestock at the time of sampling). The lowest counts were recorded from the farm without livestock.	Kay and Edwards (2003)
	Faecal streptococci	Geometric mean range 482 – 46580 (*n* = 68)			
AUSTRALIA					
Australia, rural towns	*E. coli*		Prevalence 25.5% (*n* = 47) Range 0 – 370 Mean 15		Bannister *et al.* (1997) cited by Sinclair *et al.*, 2005
Australia, urban area	Thermotolerant coliforms	Highest average figure (743) recorded at rain depths of 0.5 – 1 mm	*n* = 30 Maximum 800 Mean 119	Poor design and construction of gutters and tanks (including the installation of stormwater detention tanks rather than rainwater tanks) believed to contribute to poor water quality	Coombes *et al.* (2000, 2002)
Australia, rural, urban + industrial	Thermotolerant coliforms	Prevalence 100% (*n* = 24) Range 75 – 125	Mean counts <5 – 125	Data presented in graphical form	Thomas and Greene (1993)
Australia	*E. coli*		Not detected		Thurman (1995) cited by Sinclair *et al.* 2005
NEW ZEALAND					
New Zealand, rural area	*E. coli*		Prevalence 38% (*n* = 24) Range 0 – 111	MPN	Savill *et al.* (2001)
New Zealand, rural area	Thermotolerant coliforms		Prevalence 56% (systems) Range 0 – 840	125 rainwater harvesting systems examined, with sampling from the household tap	Simmons *et al.* (2001)
	Enterococci		Range 0 – 4900		
USA					
USA, rural area	Thermotolerant coliforms		Prevalence 3% (tanks) Typical values 10 – 20	30 tanks sampled	Lye (1987)

Figure 2 microbial pollution of rainwater in different countries taken from rooftops (Fewtrell 2007)

1.1.1.2. Surface and ground rainwater

Rainwater that is found in urban areas such as roads and parking lots often carry many pollutants. Main pollutants found in this water are Total suspended solids (TSS) which comes from dust, sand and road ashes. Heavy metals are also common pollutants (Zn, Cu, Pb, Cd). They come from vehicle emissions and tires. Hydrocarbons and oil residues from fuel leaks and asphalt degradation also often pollute rainwater. Another main contaminant are microplastics, tire wear particles and anti-cooling mixtures.

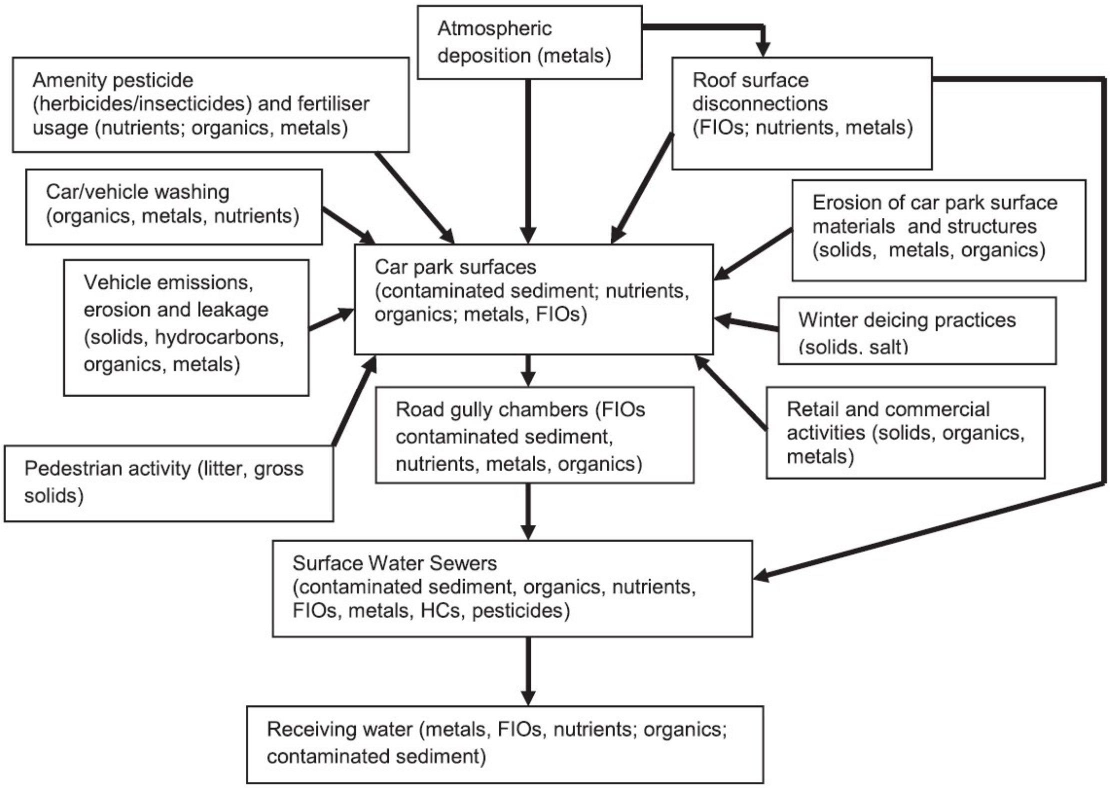


Figure 3 Principal sources and pathways of pollutants contributing to car park runoff (Lundy 2014)

The purity of rainwater is relatively high, but contamination occurs when it interacts with the surface. Water collected from roofs is mainly burdened by microbial contamination caused by organic fallout on roofs. The quality of water collected in other urban areas (roads, car parks, parks, etc.) is much lower. The main sources of contamination are traffic and human activity. It is therefore necessary to address this quality and ensure that such contaminated water does not enter the environment. In all cases, the first flush effect has a great influence on the quality. The water quality in the first minutes of rain is much lower than the water quality later.

1.1.1.3. Snow as an indicator of urban pollution

Seasonal snow covers can serve as an effective indicator of urban environmental pollution, especially in regions with cold climates. Snowflakes efficiently capture airborne particles and dissolved pollutants during precipitation, allowing the snowpack to accumulate contaminants over the winter period. Because snow samples are relatively easy to collect and represent deposition over a defined time period, they provide a useful medium for studying the spatial distribution of pollutants in urban environments (Kuoppamäki et al., 2014).

Traffic has been identified as one of the major sources of pollutants in cities, including heavy metals, nutrients and polycyclic aromatic hydrocarbons (PAHs). Studies have shown that concentrations of these contaminants in snow are significantly higher near roads and decrease rapidly with increasing distance from the roadway. The highest concentrations are typically observed within the first meters from the road, reflecting the direct influence of traffic emissions (Pilecka et al., 2019).

Pollutant accumulation in roadside snow is particularly important because during spring snowmelt these contaminants can be washed into stormwater systems and subsequently transported to surface waters. Monitoring the chemical composition of urban snow therefore provides valuable information about the intensity and spatial distribution of traffic-related pollution and helps to assess potential environmental risks associated with snowmelt runoff (Kuoppamäki et al., 2014).

1.2. Harvesting of rainwater

Designing an efficient rainwater harvesting (RWH) system starts with separating water streams based on their intended use, followed by smart pretreatment like screens and first flush diverters. To ensure water safety and usability, systems often include sedimentation units and underground storage tanks made of durable materials. For added sustainability, combining storage with infiltration supports groundwater recharge. Real-time monitoring and modelling help fine-tune the system, especially in regions like Czechia, where storage for at least 21 days is advised based on local rainfall data.

Domestic RWH is locally feasible, widespread implementation in urban areas can contribute to multiple water management objectives which have **important direct benefits**:

1. Provides non-potable water source.
2. Reduces demand from distribution system.
3. Mitigates urban floods.
4. Reduces water pollution by reducing the combination of combined sewer overflows (New Directive to urban wastewater management)
5. Preserves high-quality water sources.
6. Could supply about 50% of the domestic water demand.

Non direct benefits

- Reduction in the need to upgrade water infrastructure (tap water from distribution system and sewer system)
- Energy saving and emission reduction due to reduce water abstraction, transport and treatment.

Possible use of rainwater:

1. Toilet flushing (60%)
2. Irrigation (15-20%)
3. Washing machines 20%
4. Surface washing
5. Boilers

RWH systems composition:

1. Roof, gutter protection screening, gutter, rain head, first flush diverter, tank screen, tank, insect proof flap valve, auto-fill system, pump system, irrigation filter, water level sensor (indicator)
2. Roof painting without heavy metals
3. First flush diverter for the first 3-5 mm of rainfall
4. Storage tank is operated by gravity or pump (outside or underground)
5. Storage tank should contain at least 40% of runoff volume – in Czechia average storage volume should cover 21 days of consumption.

The use as Drinking water is disregarded in developer countries.

In Australia they successfully developed a good step system to build effective rainwater harvesting systems.

- Understand your rainwater needs (measurable goals: Quality and Quantity)
- Store your rainwater (underground/surface, material of vessel)
- Assess your rainwater collection area (roof, gutters, surrounding environment)
- Clean your rainwater (filter leaves and debris)
- Clean your rainwater: Divert the First Flush of rainwater.
- Secure your rainwater system (securing entry and exit points of the system)
- Decide on a pump or gravity fed system.
- Manage standing water.
- Final stage rainwater filtration / advanced treatment (reduce sediment, colour, odour before use)
- Optimise your overflow (could remove sediment from collection tank, optimum infiltration)
- Monitor your rainwater level.
- Care for your system.

https://rainharvesting.com.au

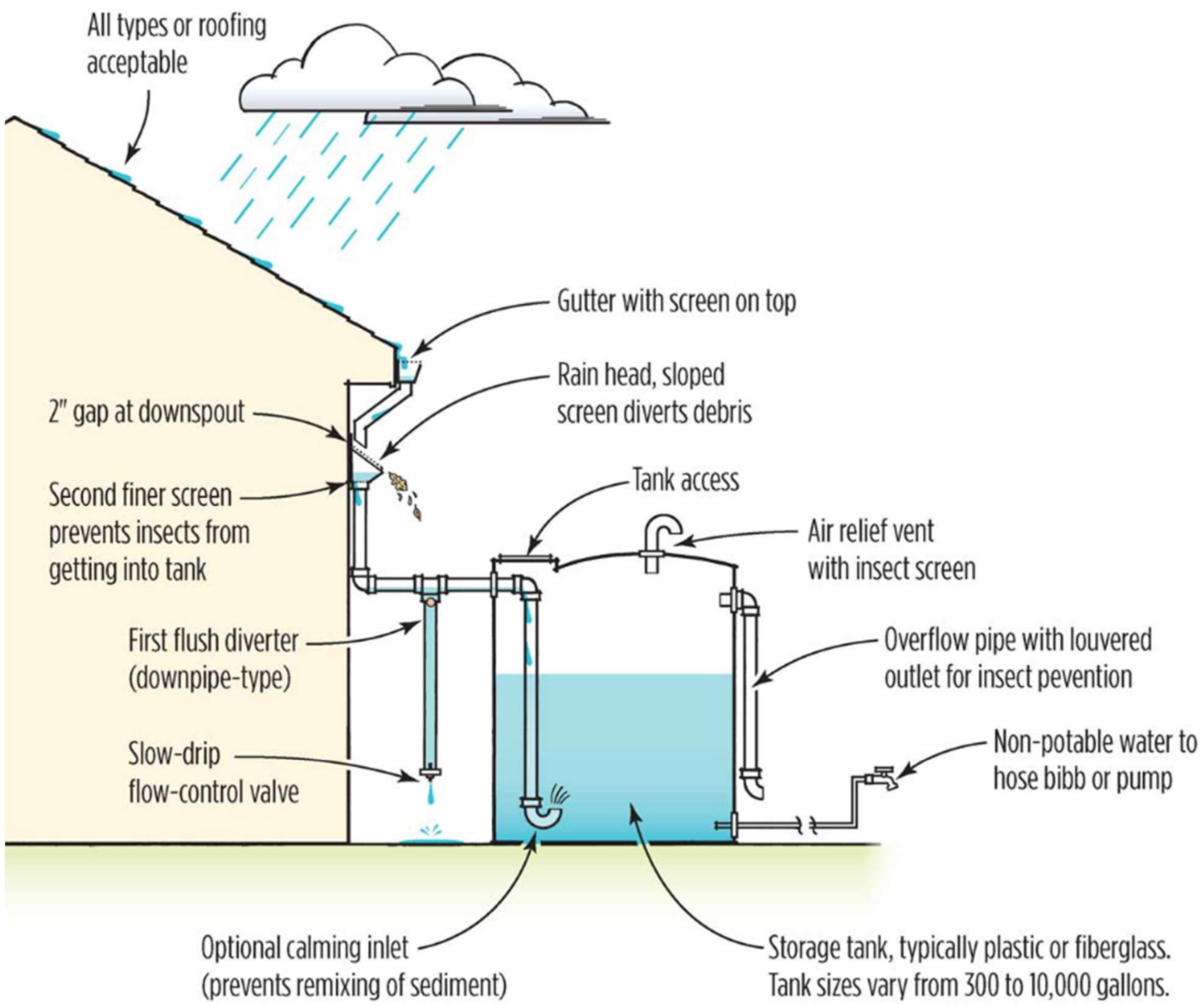


Figure 4 Rainwater harvesting diagram (energy.gov)

1.3. Treatment of rainwater

We must distinguish among the sources of rainwater, the most important are two types – those are rainwaters from roofs, and the other category is rainwater from roads, parking lots and in general from surface. The catchment system is crucial because it determines the quantity and quality of collected rainwater. A well-designed catchment (e.g. roof, ground surface) ensures efficient collection, minimizes contamination, and protects downstream treatment components. Its material, slope, and cleanliness directly affect system performance and water safety.

1.3.1. Treatment of rainwater from ground surfaces

Treatment of rainwater from ground surfaces often relies on infiltration systems, which allow water to percolate through soil layers, naturally filtering out sediments, nutrients, and pollutants. Common systems include infiltration trenches, swales, and permeable pavements.

Surfaces of transport infrastructure

- Light liquid separators - equipment designed to separate oils and other light substances from water, which is crucial when collecting water from car parks and roads.

List of technologies

- Infiltration Trenches – Low cost, prone to clogging.
- Sand Filters – Moderate cost, good for urban use, needs maintenance.
- Coagulation & Flocculation – High efficiency, chemical/sludge handling required.
- Bioretention Systems – Natural look, space-demanding.
- UV Disinfection – Chemical-free, energy-dependent.
- Activated Carbon – Broad removal, costly replacement.
- Zeolite Filters – Reusable, ion-selective.
- Granulated Ferric/Aluminum Oxides – Effective for nutrients, pH-sensitive.
- Chlorination – Cheap and effective, risk of by-products.
- Ozonation – Very effective, expensive to operate.

1.3.2. Treatment of rainwater from roofs

The following technological steps are applied in the frame of rainwater treatment.

- 1. Mechanical Treatment (Filtration Systems):
  - Gutters and Downspouts: (First flush diverters) Installing and regularly cleaning gutters and downspouts help capture and direct rainwater while preventing debris from entering the storage system.
  - Inlet Filters: Screen filters placed at the entry point of the storage system catch large debris, ensuring cleaner water collection.
- 2. Disinfection:
  - UV Sterilizers: Ultraviolet light systems can be used to inactivate microorganisms.
  - Chemical Disinfection: chlorine or ozone can eliminate pathogenic organisms.
- 3. Stabilization:
  - Biological Treatment: specific bacteria into the storage tank can aid in breaking down organic matter, reducing odors, and improving water quality.
- 4. Photocatalytic Coatings:
  - Titanium Dioxide (TiO_2) Coatings: Applying these coatings to roofing materials can facilitate the breakdown of organic pollutants on the roof surface when exposed to sunlight, thereby reducing contaminants in the collected rainwater.
- 5. Green roofs - vegetation can naturally filter rainwater, reduce runoff, and improve the quality of water collected.
  - Extensive x Intensive
    - Extensive – max depth of substrate = 0.2m
      - The weight of the vegetation layer is between 80 and 300 kg/m² in the water-saturated state.
    - Intensive - max depth of substrate = 0.2 to 1.5m or more
      - The weight of a green roof can range from 300 to 2,000 kg/m².

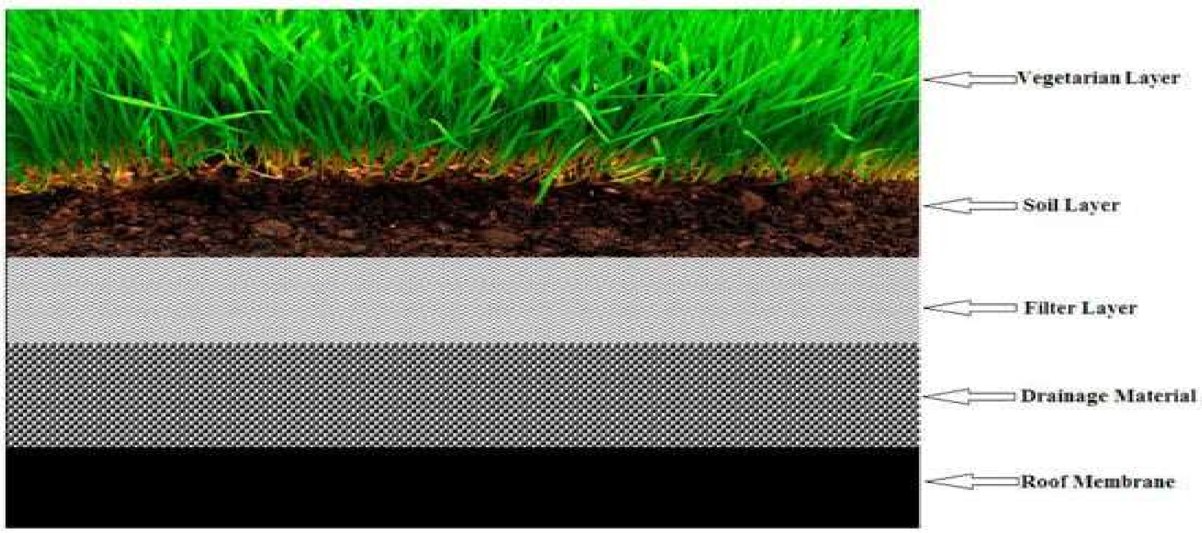


Figure 5 Green roofs – layers (Kohler 2008)

1.3.3. List of technologies and methods

Category	Technology	Sustainability	Costs	Category	Technology	Sustainability	Costs	Category	Technology	Sustainability	Costs
Passive Treatment	Slow Sand Filters (SSF)	Highly sustainable, low maintenance	Low setup, minimal maintenance	**Conventional Technologies**	Rapid Sand Filters	Moderate sustainability, requires energy	Medium setup, periodic maintenance	**High-Tech Technologies**	Ultrafiltration (UF)	Energy-intensive, effective for multiple contaminants	High cost, membrane replacement needed
Passive Treatment	Constructed Wetlands (Vertical Flow)	Highly sustainable, natural-based	Medium setup, low maintenance	**Conventional Technologies**	Coagulation-Flocculation	Chemical use, generates sludge	Medium setup, recurring chemical costs	**High-Tech Technologies**	Advanced Oxidation Processes (AOP)	Highly effective, but energy-intensive	Very high cost, operationally intensive
Passive Treatment	Solar Water Disinfection (SODIS)	Eco-friendly, solar-powered	Very low cost, minimal maintenance	**Conventional Technologies**	Ozonation	Energy-intensive, produces no residuals	High cost, requires energy input	**High-Tech Technologies**	Granulated Activated Carbon (GAC)	Sustainable, but needs periodic replacement	Medium cost, requires periodic media replacement
Passive Treatment	Permeable Pavements	Sustainable, supports groundwater recharge	Moderate setup, long lifespan	**Conventional Technologies**	Chlorination	Chemical use, produces by-products	Low cost, but requires chemical supply	**High-Tech Technologies**	Nanoparticle-Based Disinfection	Advanced, requires specialized materials	Expensive, but very effective
Passive Treatment	Biofiltration Systems	Natural filtration, low energy	Low-cost, dependent on natural processes	**Conventional Technologies**	Engineered Wetlands	Moderate sustainability, requires land	Medium cost, requires land use	**High-Tech Technologies**	Reverse Osmosis (RO)	Highly effective, but high energy and brine waste	Very high cost, operationally expensive

Figure 6 List of technologies for treatment of rainwater (ChatGPT 4o)

In EU only 1% of all systems for rainwater harvesting and treatment are using nano-membranes and advanced technologies since it is used mainly for hospitals and other place where the treatment requirement is high. The rest is mainly used for flushing toilets and for storing the rainwater into storage tanks that can be used for agriculture, garden-management, and flushing toilets, depending on the quality of the filtered and cured water it can be also used for showering.

The general water consumption is as follows:

- Potable (Drinkable) Water Need (kitchens and bathrooms): ~30–40% of total use
- Grey/Reused Water (Toilet, garden, laundry): ~60–70%

This clearly shows that even if the harvested water is not treated enough to be potable – drinkable, it can still be used for the majority of total use of water. Advanced treatment methods are typically used in facilities that produce wastewater that could pose a problem for conventional water treatment technologies or bypass them, such as antibiotics from hospitals or heavy metals from factories.

1.3.4. List of technologies and their uses

1. Conventional Systems

Description: Basic rooftop collection → gutter → storage tank (e.g. barrel or underground cistern), often without filtration.

Typical Use: Rural areas, gardens, off-grid cabins.

Uses:
- Irrigation
- Toilet flushing (manually transferred)
- Car washing

Advantages:
- Very low cost and easy to install.
- No energy needed
- DIY-friendly

Disadvantages:
- No treatment = non-potable
- Risk of contamination (debris, animals, algae)
- Limited seasonal use

Cost-Effective When: Budget is tight, and water is needed for non-potable use only.

Purpose: Simple reuse for outdoor or low-risk purposes.

2. Semi-Centralized / Intermediate Systems

Description: Rooftop collection → first-flush diverter→ sediment filter → storage tank (with pump). Partial integration into home water system.

Typical Use: Eco-homes, suburban homes with water-saving focus.

Uses:
- Toilet flushing
- Laundry
- Garden irrigation

Advantages:
- Safer and cleaner than basic systems
- Reduces mains water use by up to 40%.
- Can be automated.

Disadvantages:
- Moderate cost and some maintenance
- May require plumbing modifications.

Cost-Effective When: Municipal water is expensive, or local policies encourage reuse.

Purpose: Reliable source of greywater for household use.

3. High-Tech Systems

Description: Smart collection + real-time monitoring + multi-stage filtration (UV, carbon, membranes) → integration with household supply.

Typical Use: Smart buildings, green-certified projects, areas with water scarcity.

Uses:

- Drinking and cooking (where regulations allow)
- Full indoor and outdoor use

Advantages:

- High purity, self-regulating
- Enables near-complete water independence.
- Data logging and remote management

Disdvantages:

- High upfront and maintenance cost
- Complex installation and system management

Cost-Effective When:

- Long-term savings and water security are valued.
- In drought-prone or isolated regions

Purpose: Full-scale integration of rainwater into the home's water system.

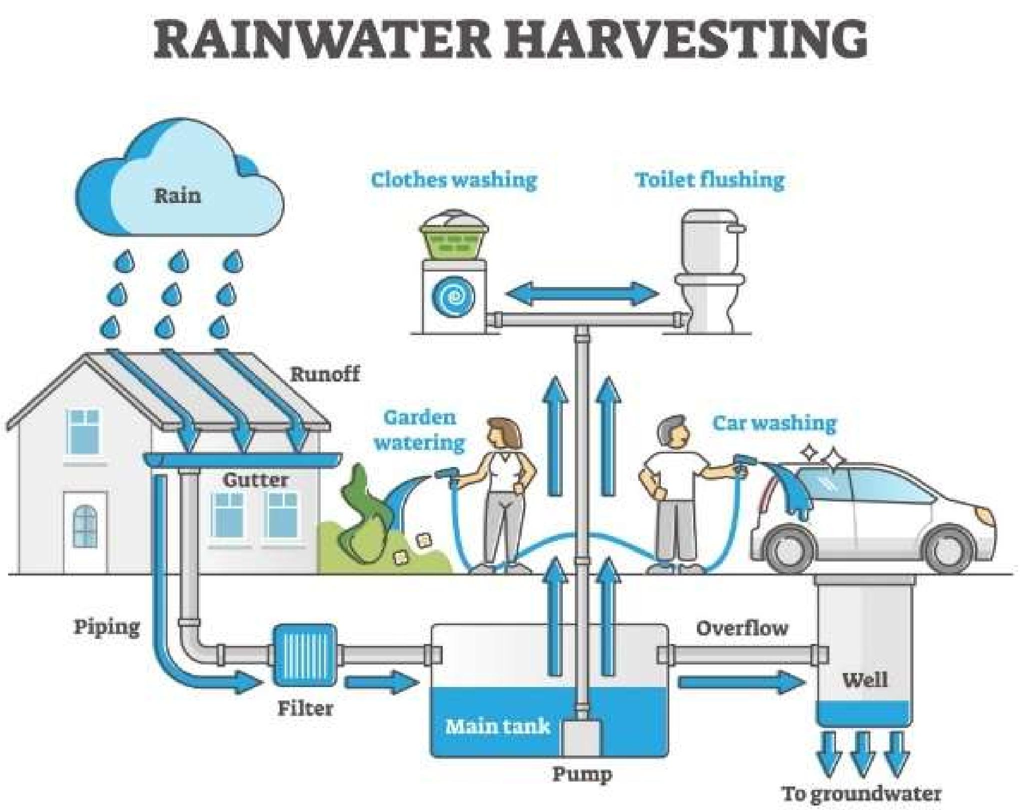


Figure 7 Rainwater harvesting diagram – conventional (allamericangutterprotection.)

1.3.5. Final sanitation and cost

Chlorination

Used primarily for stabilization and disinfection of stored or reused rainwater — especially for toilet flushing, irrigation, or street cleaning. It provides a residual effect that prevents microbial regrowth during storage and distribution.

- Hypochlorite, gaseous chlorine (water treatment, hospitals and many others)
- Chloramines (pools, agriculture)
- Chlorine dioxide (treatment of hot water distribution networks) does not form chlorinated by-products.

✔ **Advantages:** Cost-effective, simple operation, strong residual protection

✕ **Disadvantages:** Formation of disinfection by-products (trihalomethanes, trichloroacetic acid)

Figure 8 Simple operation of the chlorine dosing system for rainwater disinfection.

UV (Ultraviolet) Disinfection

Widely used for point-of-use or small-scale rainwater systems, where water is reused for toilet flushing, cleaning, or garden irrigation. It inactivates microorganisms using high-energy UV-C light, without adding chemicals.

- Short retention time: typically, 20–30 seconds.
- Easy installation and compact design.
- Operational cost: ~0.5-1 €/m³.
- Can be combined with H_2O_2 (AOP process) to enhance removal of organic micropollutants.

✔ **Advantages:** Chemical-free process, no harmful residues, relatively easy operation, small footprint, short contact time

✕ **Disadvantages:** No residual protection after treatment, reduced efficiency in turbid water, electricity consumption (1–2 kWh/m³)

MAURICE experience from Nový Bydžov pilot: UV disinfection was applied for the sanitation of harvested rainwater from three different buildings. Samples were stored at 12-13°C to simulate underground tanks. After 1 month, sanitation tests were carried out, and subsequent storage of sanitized rainwater (2 weeks).

Sampling	E. Coli	Coliform bacteria	Enterococci	total 22°C	total 36°C	Clostridium Perfigens
	CFU/100ml	CFU/100ml	CFU/100ml	CFU/ml	CFU/ml	CFU/100ml
3rd week of stortage						
Aquapark	0	>2000	0	>5000	>5000	0
Minkovice	0	0	0	>5000	>5000	0
Winter stadium	0	52	0	>5000	4590	0
4th week of stortage						
Aquapark	0	>5000	0	>5000	>5000	0
Minkovice	0	4	0	>5000	1850	2
Winter stadium	0	420	0	>5000	2440	2
after UV						
Aquapark	0	0	0	108	2	0
Minkovice	0	0	0	9	2	0
Winter stadium	0	0	0	820	720	0
2nd week after UV						
Aquapark	0	0	0	>5000	>5000	0
Minkovice	0	0	0	2160	1790	0
Winter stadium	0	0	0	>5000	>5000	0

Figure 9 Sanitation of stored rainwater after one month using UV irradiation followed by storage under controlled conditions.

blue-drinking water quality green - unlimited use for irrigation orange – limited irrigation (without aerosol) red – limit for any irrigation.

In-line Coagulation + Sand Filtration + Ultrafiltration

A multi-barrier process combining particle coagulation, filtration, and membrane separation. Ideal for decentralized rainwater reuse where high-quality water is required (e.g., irrigation, washing, or animal enclosures).

- Ultrafiltration with pore size < 20 nm.
- Operational cost: ~1-2 €/m³.

✔ **Advantages:** Reduces turbidity and organic matter, removes up to 99.9% of bacteria and viruses

✕ **Disadvantages:** High energy demand (especially for RO systems), membrane fouling requiring maintenance, and retentate production that must be properly treated or disposed of

TUL experience – Life4zoo project: Applied for the sanitation of a pool for tapirs in Liberec Zoo, by ultrafiltration or combined microfiltration with UV disinfection, achieving excellent microbial and physical water quality.

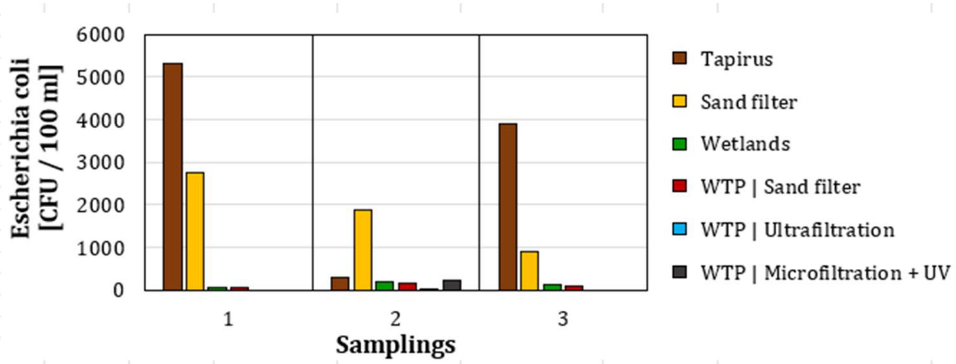


Figure 10 Results of Escherichia coli *analysis showing effective bacterial reduction after disinfection treatment.*

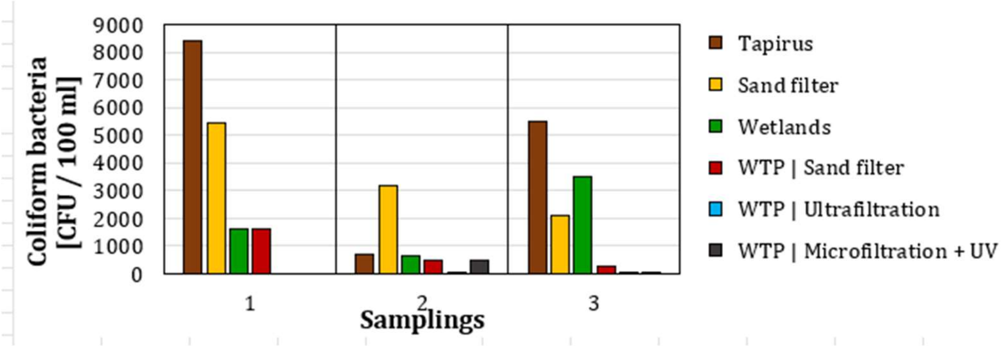


Figure 11 Results of coliform bacteria analysis showing effective bacterial reduction after disinfection treatment.

Ozonation

An advanced oxidation process suitable for centralized or large-scale rainwater reuse, where high aesthetic and hygienic quality is required (e.g., irrigation, cooling systems, or industrial reuse).

- Mechanism: O_3 acts as a strong oxidant, decomposing to reactive oxygen species (•OH) that destroy pathogens and degrade organic micropollutants
- Suitable for systems where residual disinfection is not required.

✔ **Advantages:** Effective disinfection and micropollutant oxidation; improves color, taste, and odor

✕ **Disadvantages:** High capital and operational costs (~0.3 kWh/m³), requires durable materials and monitoring, may form harmful bromates in bromide-rich water

<u>TUL experience:</u> Used at the Liberec WWTP (quaternary treatment stage) primarily for micropollutant removal, but also provides effective sanitation of treated wastewater, significantly reducing bacterial counts.

Figure 12 Ozonation process applied to treated effluent from a wastewater treatment plant (WWTP Liberec, Czechia).

Sample	Concentration /contact time	E. Coli	Enterococci	total 22°C
		CFU/100ml		
13.9.				
Pilot WWTP Liberec		8 800	7 600	5 960
Ozone	0,5 mg/l	2	0	127
22.9.				
Pilot WWTP Liberec		15 600	6 200	28 800
Ozone	0,5 mg/l	2	1	12
UV irradiation + peroxide (25 mg/l)	3 seconds	22	32	16
	6 seconds	14	6	2

Figure 13 Reduction of bacterial counts achieved by ozonation at WWTP pilot unit and UV irradiation at laboratory scale.

Peroxo acids

Strong oxidants suitable for decentralized or emergency rainwater disinfection. Performic acid decomposes into formic acid, oxygen, and water, leaving no harmful residues.

✔ **Advantages:** Fast-acting, low CAPEX, minimal space requirements, environmentally friendly by-products

✕ **Disadvantages:** Higher OPEX, short shelf life, and chemical transport requirements

Plasma treatment (Caviplasma)

An emerging technology combining plasma discharge and hydrodynamic cavitation to generate reactive radicals (•OH, O_3, H_2O_2) that destroy pollutants and microorganisms.

✔ **Advantages:** No chemicals required, generates strong oxidants in situ, high efficiency in microbial inactivation, long-lasting residual effect by formation of hydrogen peroxide

✕ **Disadvantages:** High energy demand and currently limited large-scale applications.

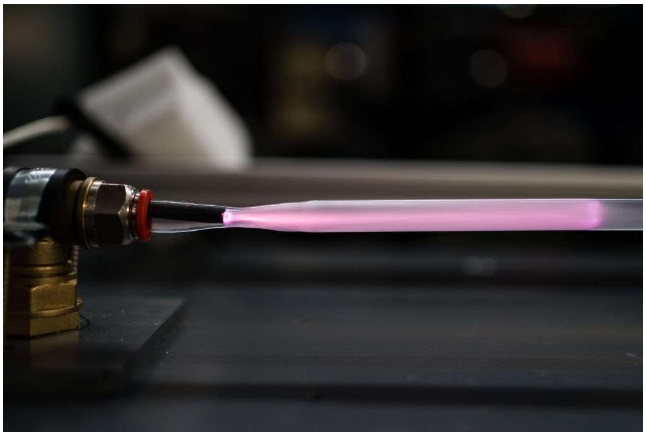


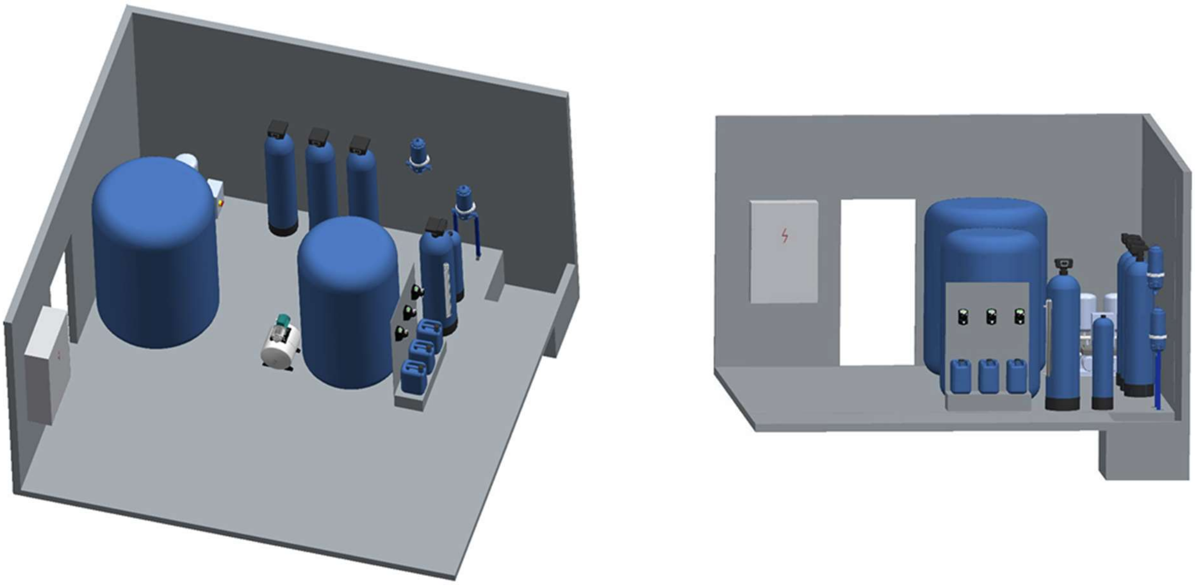
Figure 14 Plasma discharge generated by the CaviPlasma system, producing reactive species for water sanitation and micropollutant degradation.

2. Economic perspective and performance, case studies

This chapter presents well-documented case studies as inspiring examples of rainwater harvesting and treatment. The first example is a design proposal developed as part of the MAURICE project for the city of Nový Bydžov. Subsequent chapters then present well-documented case studies from abroad (primarily the United States), whose significance lies primarily in the quantification of costs.

2.1. MAURICE pilot - Winter Stadium in Nový Bydžov (Czech Republic)

The utilization of rainwater at the Winter Stadium in Nový Bydžov is part of the MAURICE project. Rainwater is collected from a metal roof covering approximately 3,850 m². This system effectively minimizes potable water consumption from the public supply, thereby reducing overall operational costs. By storing rainwater in tanks and using treated groundwater from an on-site well, the facility establishes an eco-friendly, cost-effective model for maintaining the ice surface.



3D model of the pilot unit at the Winter Stadium

- **Area:** ~3850 m^2
- **System Type**: Rainwater harvesting for non-potable use.
- **Storage**: 2 steel tanks (200 m^3)
- **Treatment:**
    - Disc filter
    - Activated carbon filter.
    - UV sterilizer
    - Dosing of perchlorate bleach
    - Mixing with groundwater (Fe removal, softening)
    - Capacity 1,2 m3/h

- **Cost**: Total ~6 404 000 CZK (253 615 €) – storage tanks 122 670€, pumping pit 59 130€, Mechanical & technological part 34 550€, Mechanical electrical installation and I&C 18 450€, Additional budgetary costs 18 810€
- **Usage**: The collected and pumped water is used for filling the skating rink, preparing the ice surface, and irrigating municipal greenery.

2.2. United States and Canada

The United States has extensive experience in utilizing rainwater for various applications, and its case studies also include economic factors (both investment and operating costs). These case studies are highly inspiring, whereas there are not as many documented installations in Europe.

1. Tyson Living Learning Center (Missouri, USA)

An educational and administrative building for the Tyson Research Center (Washington University)—a 2,000-acre environmental field station dedicated to ecological research. Completed in 2009, it was one of the first buildings in the world to achieve full Living Building Challenge certification. Built on a reclaimed parking lot, the facility features net-zero energy and water systems, utilizing native landscaping (rain gardens) to manage stormwater and reduce runoff.

https://tyson.wustl.edu/living-learning-center

- **Area:** ~280 m^2
- **System Type**: Potable rainwater system with full treatment
- **Storage**: 11,360 liters underground fiberglass cistern
- **Treatment:**
  - Two sediment filters
  - Activated carbon
  - UV disinfection
  - Point-of-use bacterial filters (filters at taps)
- **Cost**: $75,000 (potable system: $60,000; non-potable system: $15,000)
- **Annual Operations & Maintenance**: ~$665

- **Usage**: All interior uses (drinking, flushing, sinks)
- **Notes**: Monthly water testing sent to the state department; cistern is chlorinated (shocked) once a year
- **Link**: https://tyson.wustl.edu/living-learning-center

2. Eco-Sense Home (British Columbia, Canada)

A multi-family "cob" residence (earthen construction) for six people, designed and built by owners Ann and Gord Baird. The home features living roofs, rainwater harvesting, composting toilets, and solar systems. It was the first internationally Petal Certified project under the Living Building Challenge. The seismically engineered load-bearing cob structure is designed to function as part of the ecosystem, emphasizing food independence and multi-generational living.

https://www.robaid.com/tech/green-architecture-eco-sense-house.htm

- **Area:** ~200 m^2
- **System Type**: Rainwater harvesting for potable and non-potable use.
- **Storage**: 37,850 liters in cisterns
- **Treatment:**
  - Green roof pre-filtration (from 185 m^2 catchment area)
  - Sequential filters: 50µm, 10µm, 1µm carbon, 0.5µm ceramic
- **Installation Costs (Hard Costs):**
  - **Potable system:** $16,000 (cistern + filtration)
  - **Non-potable system:** $16,200 (Tanks $6,700, Pumps $2,100, Filtration $2,900, Piping $2,000, Electrical $2,000, Aerator $500)
- **Annual Operations & Maintenance:** Filters $200 | Water testing $150
- **Maintenance Summary:**
  - Monthly: Clean pre-filter and flush 50-micron filter
  - Annually: Water testing, carbon media replacement, ceramic filter sterilization
- **Usage:** Potable water for all indoor household needs (drinking, cooking, bathing); non-potable water for exterior irrigation.

- **Link:** https://www.robaid.com/tech/green-architecture-eco-sense-house.htm

3. Desert Rain (Oregon, USA)

A residential compound of five structures designed for net-zero water and energy, located in Bend's high desert climate. It is the world's first Living Building Challenge certified single-family residence. The project includes a main residence, guest house, and office, all constructed with non-toxic materials and designed to mimic natural water cycles in an arid environment (receiving only ~12 inches of rain annually). It was the first permitted potable rainwater system in Oregon.

https://living-future.org/case-studies/desert-rain/

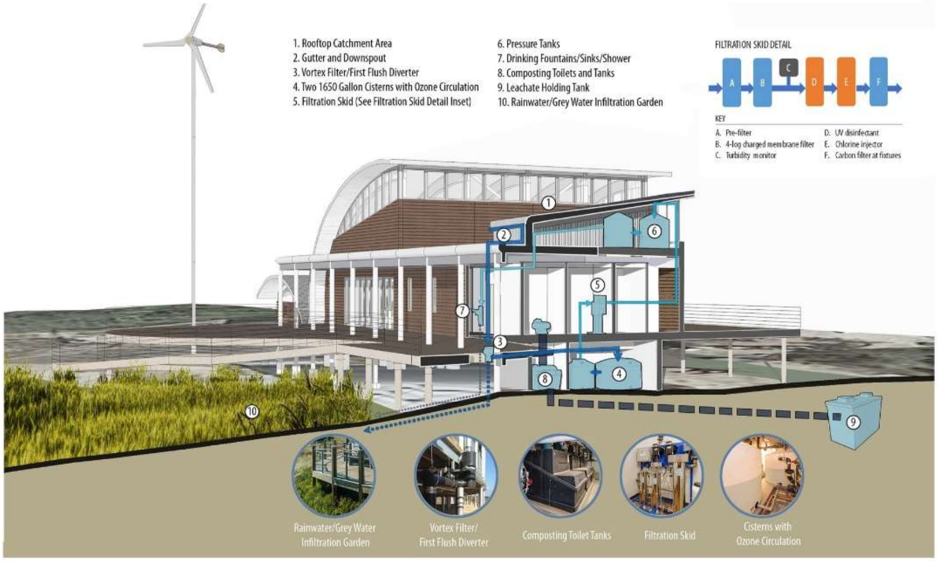
- **Area:** ~450 m^2
- **System Type**: Rainwater harvesting for full household supply (Potable)
- **Storage**: 132,500 liters from 650 m^2 roof
- **Treatment:**
    - Stainless steel gutter screen
    - Gravel filter
    - 20-micron filter (pre-cistern)
    - Two 20-micron filters (post-cistern)
    - UV disinfection
- **Cost**: $35,539 (hard costs) + $105,948 (soft costs)
- **Annual Operations & Maintenance**: ~$370 ($100 for new filters three times per year, $70 UV lamp)
- **Usage**: Full household potable supply
- **Link:** https://living-future.org/case-studies/desert-rain/

4. Brock Environmental Center (Virginia, USA)

Headquarters for the Chesapeake Bay Foundation, located at Pleasure House Point in Virginia Beach. It serves as an education, advocacy, and restoration hub and it is the first commercial building in the continental U.S. permitted to treat rainwater for potable uses. Designed for resilience, the building is raised above sea level to anticipate climate change and utilizes wind turbines and geothermal wells to achieve net-zero energy.

https://www.cbf.org/facilities/brock-environmental-center/

- **Area:** ~980 m^2
- **System Type**: Rainwater covers entire water supply (potable and non-potable)
- **Storage**: Cistern with ozone injection and attic-level pressure tank
- **Treatment**: Filtration and Disinfection
    - Multi-stage filtration (sediment, cartridge, and point-of-use filters)
    - Ozone injection
    - UV disinfection
    - Minimal chlorination (for compliance and residual safety)
    - pH adjustment via limestone contactor
- **Hard Costs**: $81,000 – total for filtration ($48,000) and tanks ($33,000)
- **Annual Operation & Maintenance**: $11,000 (includes professional waterworks operator and daily monitoring by center manager)
- **Usage**: Entire water supply needs (both potable and non-potable) of the facility
- **Link**: https://www.cbf.org/facilities/brock-environmental-center/



https://www.archdaily.com/869556/aia-selects-top-10-most-sustainable-projects-of-2017

5. Battery Park City (New York, USA)

A large urban district in Lower Manhattan serves as a model for district-scale water conservation in high-density settings. The district integrates rainwater harvesting into several buildings and public spaces as part of New York City's green infrastructure program. The district's comprehensive water reuse systems reduce wastewater discharge by over 60% compared to typical NYC buildings.

- **System Type**: Rainwater for non-potable use
- **Storage**: 30-38,000 litres
- **Treatment**: Various filtration and disinfection methods (sand, carbon, UV – depending on site)
- **Annual Operation & Maintenance**: Exact costs vary per building; systems are maintained by the Battery Park City Authority
- **Usage**: Rainwater is reused for landscape irrigation, toilet flushing, and street cleaning, reducing potable water demand in the densely populated district

6. Arch Nexus SAC (California, USA)

An adaptive reuse project in Sacramento that transformed a 1950s warehouse into a certified Living Building. This regenerative retrofit serves as a public demonstration site ("learning lab") to advocate for sustainable policy changes in California. It is designed to be net-positive for both water and energy, meeting all on-site water needs despite the region's history of drought.

https://living-future.org/case-studies/arch-nexus-sac/

- **Area:** ~770 m^2
- **System Type**: Rainwater harvesting (planned for potable and non-potable use)
- **Storage**: Two underground cisterns collecting all roof runoff
- **Treatment:**
    - Microbial filter
    - Sand filter
    - UV disinfection
- **Hard Costs**: $110,000 ($60,000 RW cisterns, $50,000 potable water treatment and storage)
- **Annual Operation & Maintenance**: Negligible, performed by in-house maintenance staff.
- **Usage**: Currently irrigation (at time of study publication). Once permitted by the State of California, it will supply sinks, showers, and dishwashers.
- **Link**: https://living-future.org/case-studies/arch-nexus-sac/

2.3. Germany

In this project, located in Berlin, rainwater infiltration was excluded from the beginning due to unfavorable soil permeability and the intensive use of limited open spaces. Instead, a rainwater collection and treatment system were implemented to supply non-potable water for residential use.

Total catchment area: 11,770 m² (63% originates from roofs, 35% from courtyards and sidewalks, and 2% from traffic surfaces)

Reservoir volume: 190 m³ (main) + 6 m³ (treated water tank)

Average treated volume: 10 m³/day

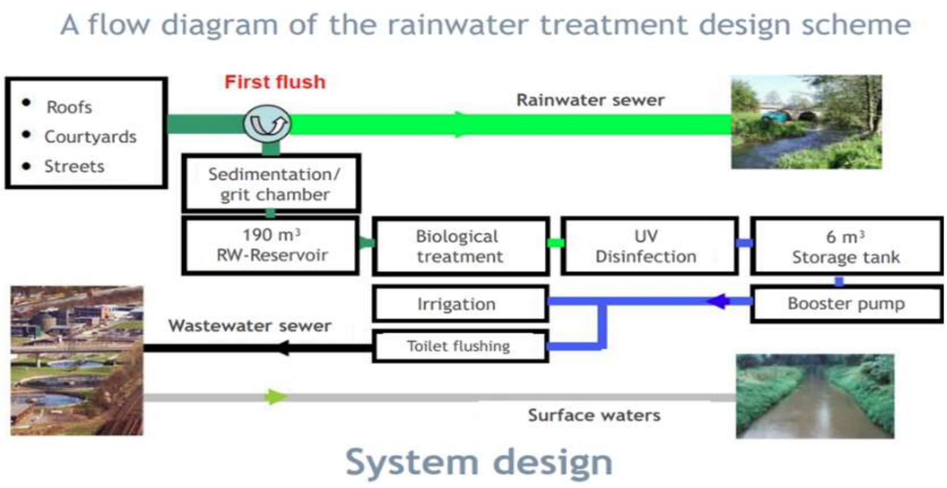
Treatment process: biological planted filter – the **upper layer** is made of expanded clay particles (8–16 mm), while the **lower layer** contains gravel (4–8 mm), separated by a 1-meter gap to ensure uniform percolation and aeration, followed by **UV disinfection** (28 W),

Supplies: 80 apartments + 6 small businesses (~200 people)

Use: toilet flushing, garden irrigation

Operation started: in 2000

Performance: stable, no clogging, consistent water quality



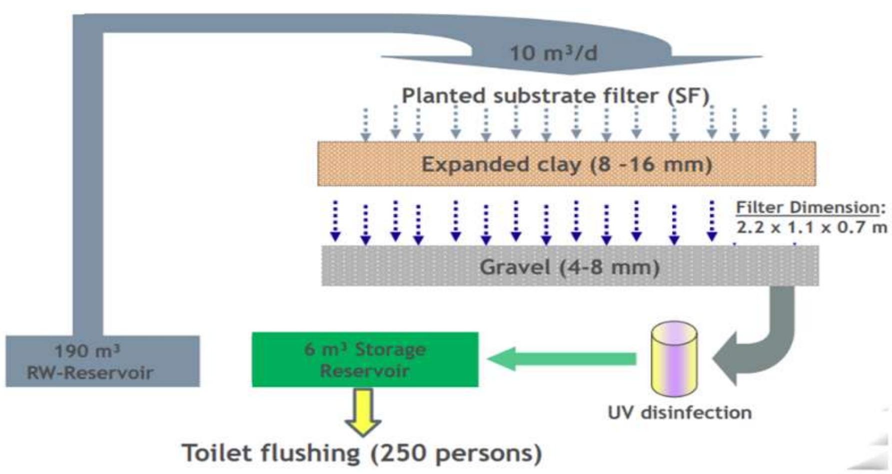


Figure 15: Rainwater treatment system in Berlin

2.4. Czech Republic

Pavilion of Tropical AgriSciences (Prague, Czechia)

The Pavilion of Tropical Agriculture is part of the Faculty of Tropical AgriSciences at the Czech University of Life Sciences in Prague. The facility serves as a research and educational centre focused on tropical and subtropical crops, integrating sustainable design principles such as green roofs and rainwater reuse. Opened in September 2020, the building replaced an older facility to improve energy efficiency and meet faculty needs. The rainwater harvesting system reduces potable water consumption and supports vegetation management around the building.

https://www.adapterraawards.cz/en/databaze/2021/pavilon-tropickeho-zemedelstvi

System Overview:

- **Catchment surfaces:**
    - **Green roof area:** ~590 m², maintained by university botanists.
    - **Surrounding landscaped areas:** Runoff is collected from the land and roof through an infiltration system.
    - **Green facades:** A metal structure on the south side supports creepers intended to shade and cool the facade.
- **Storage capacity:** 60 m³ underground tanks
- **Overflow management:** Soak-away system using four gravel-filled boreholes, enabling infiltration of excess water into the ground.
- **Water treatment:** Rainwater is filtered and mixed with tap water before distribution to ensure appropriate quality standards.

Usage: Toilet flushing, irrigation of the green roof, and climbing vegetation on facades and exterior spaces

Costs & Performance:

- **Investment cost:** 374,000,000 CZK (for the whole building)
- **Estimated ROI:** ~25 years
- **System longevity:** 25-50 years

Link: https://www.adapterraawards.cz/cs/pavilon-tropickeho-zemedelstvi

3. Conclusion

Rainwater harvesting represents a viable and sustainable alternative for water supply, especially in the context of increasing water scarcity and the need to relieve pressure on central infrastructure. This document has demonstrated that although rainwater is relatively clean in its atmospheric form, significant contamination occurs upon contact with surfaces such as roofs and urban ground areas. Therefore, the quality of collected rainwater is highly dependent on catchment material, environmental conditions, and maintenance practices.

The treatment of rainwater must be tailored to its intended use—non-potable uses like toilet flushing, irrigation, and washing require less intensive treatment, while potable uses demand multi-stage, often high-tech solutions. Technological approaches range from conventional systems (basic tanks and screens) through semi-centralized setups (with filtration and pumps) to advanced systems with membranes, UV, and real-time monitoring. Notably, green roofs and pre-filtration techniques like first-flush diverters play a key role in improving initial water quality before treatment even begins.

The economic analysis shows that systems vary widely in cost and return on investment. Simple systems are affordable but limited in application, while complex systems, though effective and sustainable—often rely on public subsidies or long-term environmental policy goals to become viable. In the EU, less than 1% of systems use nano-membranes or advanced purification, underscoring a strong focus on cost-effective, non-potable reuse. Real-life examples from the U.S., Canada, and Czech Republic illustrate how system design, investment, and functionality vary based on local conditions, regulation, and ambition.

Rainwater systems not only reduce freshwater consumption but also offer co-benefits such as flood mitigation, improved urban microclimates, and energy savings. However, to fully leverage these advantages, a holistic approach is needed—considering catchment design, storage, appropriate treatment technology, economic feasibility, and maintenance. Where legislation lags behind, precautionary design and consistent disinfection are recommended.

4. Resources

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ANNEX No.3

Interreg CENTRAL EUROPE

Co-funded by the European Union

MAURICE

Output 3.5

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

Version 2

03 2026

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).

Delivery period: Period 6, 31 - 36

Author: Grzegorz Gzyl [1), Beata Kończak [1), Marta Wiesner-Sękala [1), Anna Skalny [1)

Contributions: Petr Kohout [2), Agnieszka Chećko [3), Dominika Makowska [3), Tomáš Lederer [4)

[1) Central Mining Institute, Katowice, Poland

[2) City of Novy Bydzov, Novy Bydzov, Czech Republic

[3) City of Jaworzno, Jaworzno, Poland

[4) Technical University of Liberec, Liberec, Czech Republic

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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.

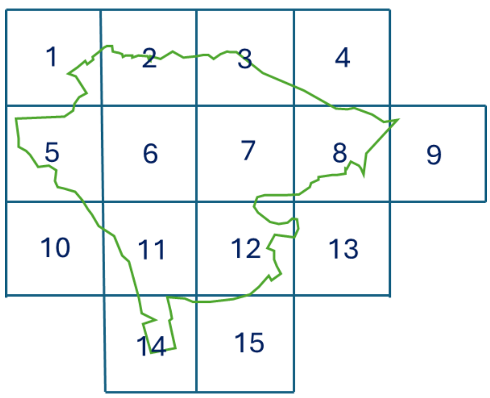

Figure 4.1 -1. Spatial interpolation grid of Jaworzno

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.

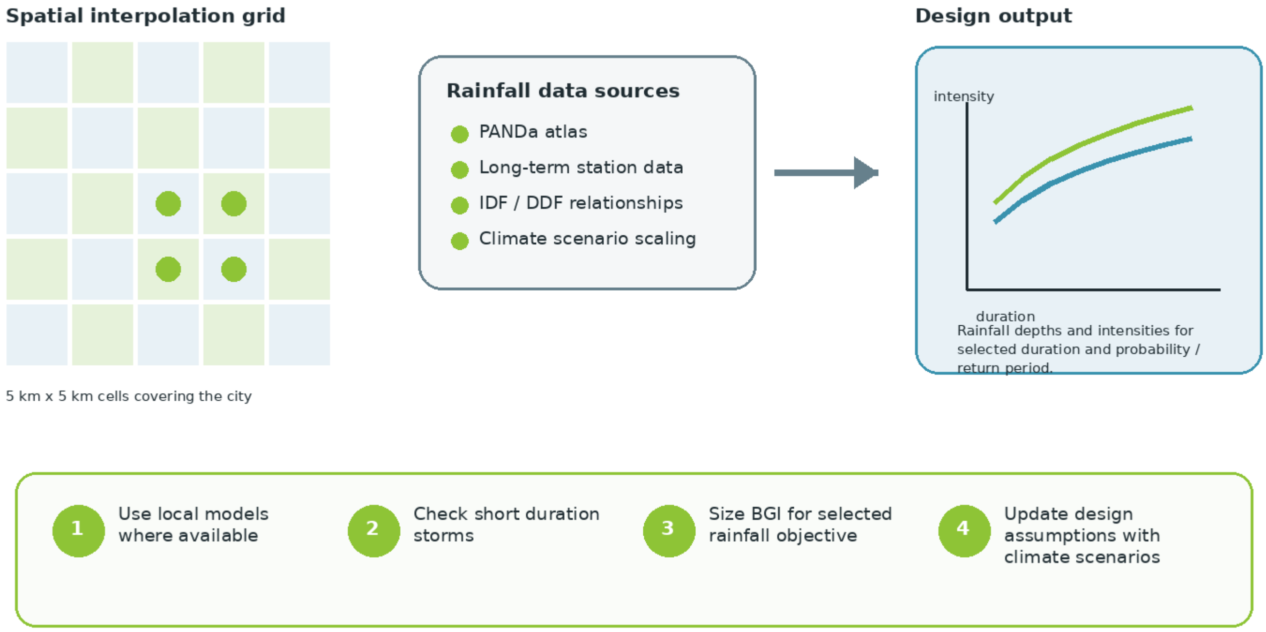

Figure 4.1-2. Jaworzno rainfall model: from rainfall data to design values for stormwater and BGI planning.

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.

BGI Tool: from site data to first technology selection

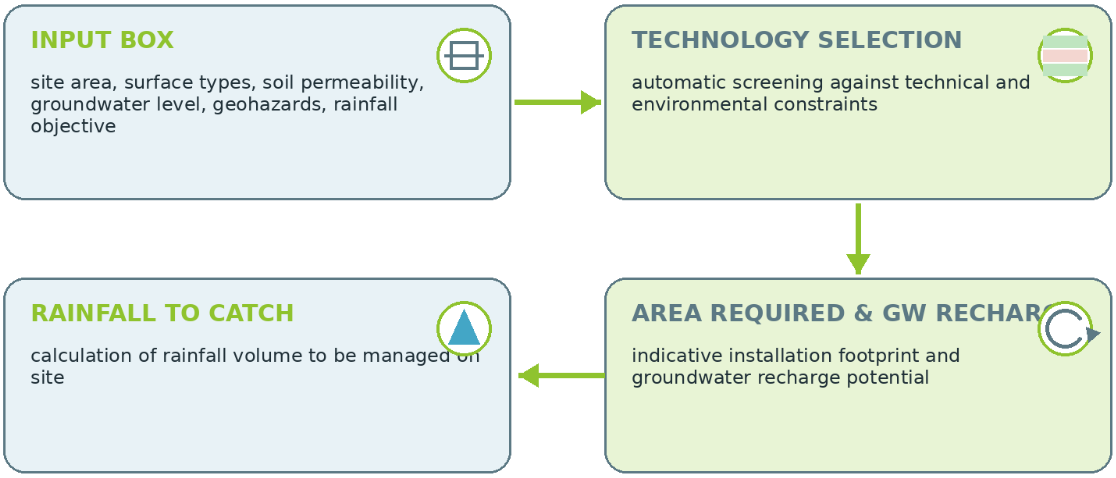

Figure 6-1. The complete BGI Tool consists of four operational modules: Input Box, Technology Selection, Rainfall to Catch, and Area Required & Groundwater Recharge Potential.

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.

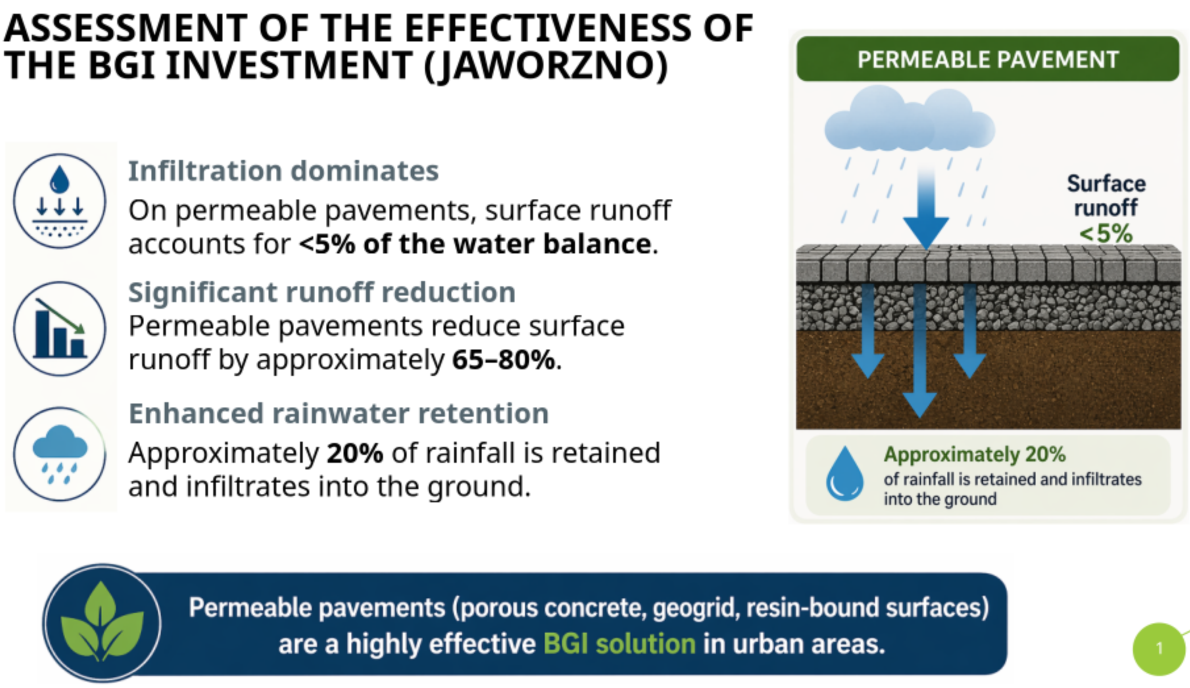

Figure 7-1. Jaworzno pilot plot results in permeable pavement BGI: infiltration-dominated performance and reduced surface runoff.

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.

RESILIENCE TO GEOHAZARDS	RETENTION CAPACITY	GROUNDWATER RECHARGE

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 requirments

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

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

Rain garden on the campus of Gdańsk University of Technology

Best practice - examples

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

Retention capacity:

Minimum: 200 L/m^2 Average: 250 L/m^2 Maximum: 450L/m^2

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 requirments

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 requirments

Minimum distance from:

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

Photos: https://zielonyogrodek.pl

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 requirments

Minimum distance from:

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

Photo: https://summitprecastconcrete.com/

Best practice - examples

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

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
		Not applicable

Retention capacity:

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

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 requirments

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 requirments

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

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

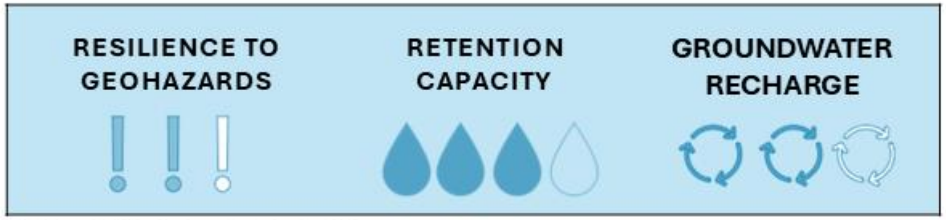
Extreme rainfall events may exceed the design capacity of the system. Proper sizing, the use of emergency overflows, and controlled inflow points enhance resilience to flooding and help prevent surface erosion.

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 requirments

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

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.

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

Retention capacity:

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

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/m²) 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 requirments

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 requirments

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

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

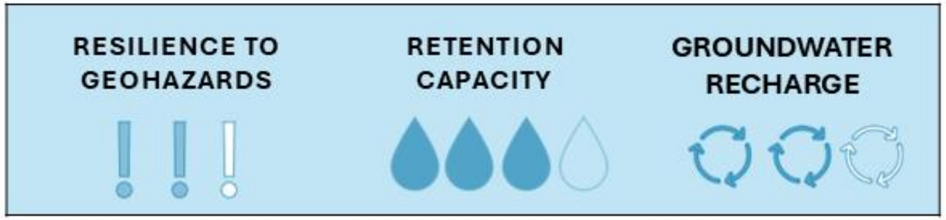
These systems are designed to infiltrate rainwater into the surrounding soil; however, extreme rainfall events may exceed infiltration capacity, resulting in surcharge or reduced drainage efficiency. Adequate storage volume, emergency overflow connections, and staged discharge pathways enhance resilience 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/m² Average: 750 L/m² Maximum: 1100 L/m²

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 requirments

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

House in Gdańsk(PL)

Housing estate in the Morena district, Gdańsk (PL)

Best practice - examples

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.

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 requirments

PLANT GROWTH CONDITIONS:
not applicable

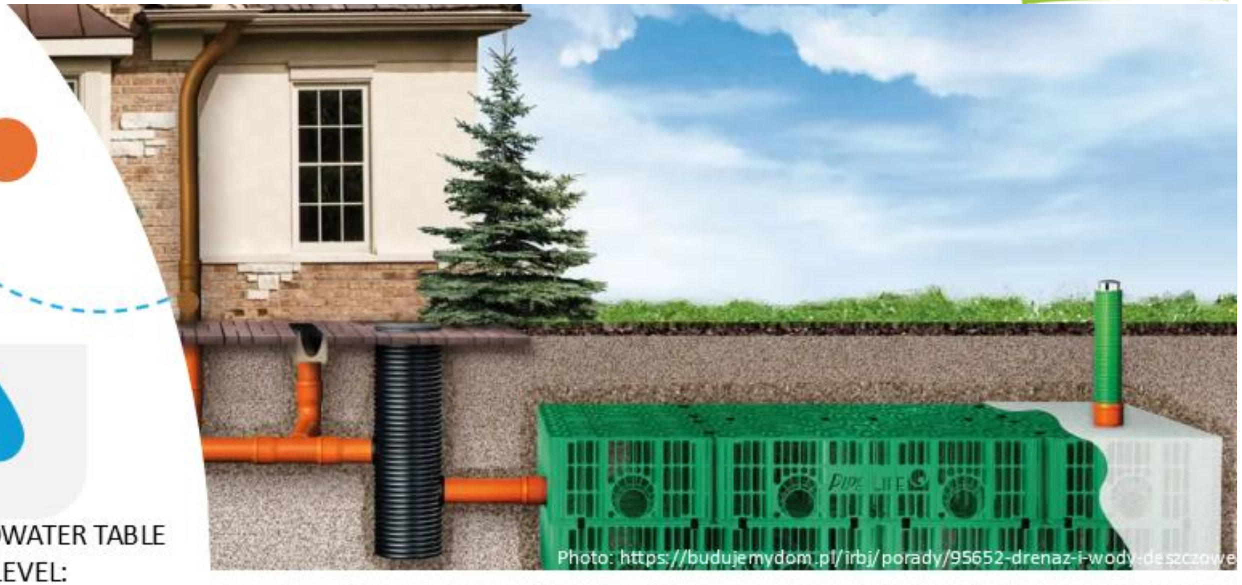
SOIL PERMEABILITY:
$1 \cdot 10^{-4}$ m/s ≤ k < $1 \cdot 10^{-7}$ m/s

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



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

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

Best practice - examples

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.

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

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.

Design requirments

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 requirments

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.

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.

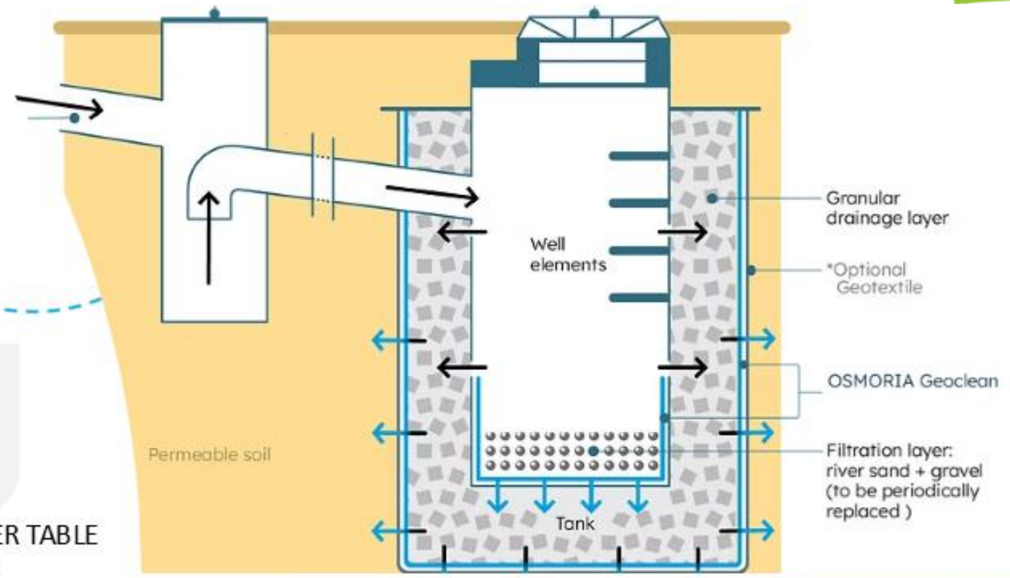
Long-term recharge capacity may decline due to clogging of well screens or filter media. Regular inspection, maintenance access, and sediment control measures are required to sustain infiltration efficiency.

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 requirments



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%

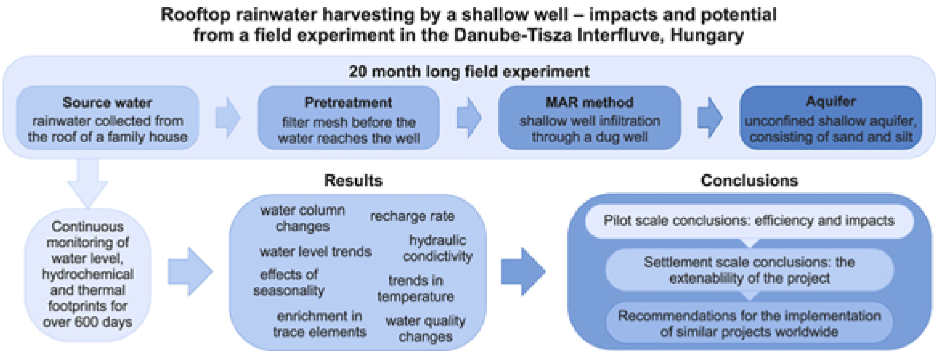
PRETREATMENT:
not applicable

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

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

Best practice - examples

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.

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.

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.

Design requirments

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 requirments

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/

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.

Best practice - examples

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.

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 requirments

PLANT GROWTH CONDITIONS:
not applicable

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 applicable

SITE TOPOGRAPHY:
surfaces with gentle slopes

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

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

MAURICE

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

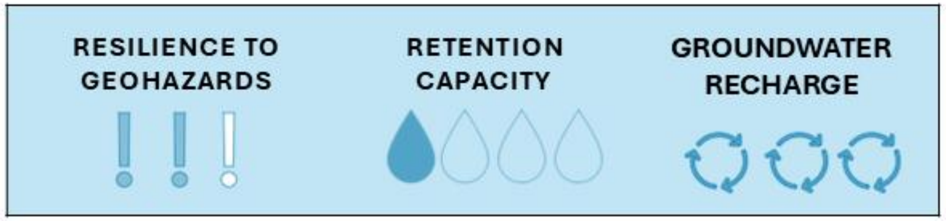
These types of pavements allow for infiltration and temporary storage of stormwater within the base layer. However, during intense rainfall events, the infiltration capacity may be exceeded, resulting in temporary surface ponding.

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.

Design requirments

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=AfmBOopZW7E4LoCbFjUQ8ZYgnsT0JCIW3MrqobxYny5AmKsXLfuBxGH2

Design requirments

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=AfmBOopZW7E4LoCbFjUQ8ZYgnsTOJCIW3MrqobxYny5AmKsXLfuBxGH2

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.