# D.T2.2.5

# RETENTION CONCEPTS AND OPTIMIZATION FOR STORAGE MANAGEMENT


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# D T2.2.5 Retention concepts and optimization for storage management


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## Acknowledgements

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# Contents

## 1.1. Project context

Heavy rain events are a major environmental risk in Europe: they can hit any location with only very short warning time. Every year people die, thousands lose their homes, and environmental damages like water pollution occur. And the risks of heavy rain events are increasing all over Europe. In the project RAINMAN, partners from 6 countries have joined to develop and test innovative methods and tools for the integrated management of heavy rain risks by local, regional & national public authorities. These will be included in the RAINMAN-Toolbox, a set of five transferable tools and methods for municipalities and regional stakeholders.

In WP 2 “Risk reduction measures to reduce damages of heavy rain” the project partners jointly create RAINMAN_Tool_2 of the toolbox. The tool includes a catalogue of risk reduction measures presenting an overview over suitable heavy rain risk reduction measures. Furthermore, the tool presents guidance on five different tasks in heavy rain risk management including:

- Early warning systems for heavy rain events,
- Emergency response planning toolkit for heavy rain events,
- Heavy rain risk reduction by regional planning instruments,
- Prevention measures for urban areas and private structures,
- Retention concepts and optimization for storage management

This deliverable includes the results of T2.2.5 “Retention Concepts and Optimization for Storage Management” that is dedicated to specify the types and the possibilities of different retention forms.

Deliverable is coordinated / written by PP8 with contributions by PP9, PP7, PP3 (and PP1).

## 1.2. Goals

This document contains basic level scientific and technical background to retention related issues, gathering best practices as well. Hereby we have recommendations for property owners, municipalities and farmers for reasonable storage designing and management. These hints can be used for further municipal developments (settlement plans), or to create restrictions for risky areas.

We will gather all the existing approaches –from the participating countries- related to water retention and storage concepts.

The goal of the document is to:

- give hints to municipalities for proper storage designing and management
- show best practices from Hungary and Participating countries
- show solutions for harmonization of urban and rural retentions

This study is aiming to have common understanding and a broad view on retention measures and best practices in the participating countries. The collected best practices could be used internationally, and based on common knowledge. The gathered best practices can be transferred to the Rainman toolbox as a catalogue of specific measures.

## 1.3. Approach and structure

Central Europe is facing the effects of climate change nowadays. Every year there are severe damages related to heavy rains. In this study we would like to highlight the importance of the ability of climate change adaptation in cities and rural areas. One of the most important tool of this adaptation process and vulnerability mitigation is the retention of storm water.

The study mainly focuses on best practices in the topic of rain water retention. These examples were provided by the partner countries of the RAINMAN project. The referenced documents are available in Hungarian, Polish, Croatian, and English languages.

The content chapters of the study are organized as follows: Chapter 2. focuses on runoff regulation and influencing factors, Chapter 3. proved a technical practice guide for municipalities (storage types, designing, etc). Chapter 4. contains a number of best practices and recommendations. Chapter 5. concludes the results, in a short summary. Chapter 6. lists the references.

# 2. Runoff regulation and retention issues related to heavy rainfall

With the increment of the water-impermeable surface ratio, the evaporation is slightly reduced. So there is a significant change, a large increase of the surface runoff occurs at the expense of the infiltration. The retention of rainwater, which may result in the reduction of the surface run-off causing flooding, may be achieved by increasing the potential for infiltration or storage. However, if the precipitation intensity is greater than the infiltration it may also causes runoff on unpaved surfaces.

In the following we discuss the problems related to the runoff, the theoretical possibilities and the influencing factors of the runoff control.

## 2.1. Effects of heavy rainfall: surface water runoff & inland excess water

### 2.1.1. Problem description

The majority of the stormwater/rainwater management problems are related to inappropriate runoff regulation. Here we specify the most serious troubles related to urban rainwater management:

- The development of settlements does not take too much care of the consequences in the changes of the drainage conditions of the urban catchments
- With the increasing frequency of extreme precipitation, the drainage safety of systems has become unknown, the validity of designing storms can be questioned. It would be a serious legal problem to prove that a given rainfall exceeded the intensity of a design rainfall if the injured parties sued the owner and the operating municipality.
- The amount of damage caused by overloads and spills is also increasing from event to event, since higher values are stored in vulnerable spaces (eg boilers, cars, etc.)
- Low awareness of the problems caused by heavy rains increase the propensity of the population to discharge rainwater from the property into the sewerage network, causing significant additional costs for the operator (pumping, sewage treatment plant) and at the same time periodically reducing the efficiency of wastewater treatment.

### 2.1.2. Influencing factors

Modern urban rainwater drainage systems are capable of adapting to climate change must be self-regulating and capable of accepting increasingly extreme precipitation. Larger settlements already have, GIS databases and advanced simulation software made it possible to calculate the temporal

and spatial processes of storm water runoff in the catchments and sewerage systems, including the effects of various hydraulic features incorporated into the drainage system too.
As a basis for investments, the behaviour and operation of the entire system can be modelled, including the catchment and the grid, and even the receiving watercourse, in various rainfall cases. It is also possible to include the flooding areas of the urban surface in the modelling, which can detect areas underwater due to extreme rainfall events. In this way, investments based on detailed hydrological and hydraulic calculations can be realized.
Even more powerful is that without the simulation method, efficient, cost-effective storage, infiltration and purification systems cannot be designed.

The simulation allows the investing municipality and the contracted design engineer to choose the best option by asking "what if" type questions, comparing the impact, utility and cost of each technical intervention.
Adaptive rainfall drainage strategies should also include creating opportunities for reasonable urban water management. The figure below summarizes the basic parameters of an expedient strategy.

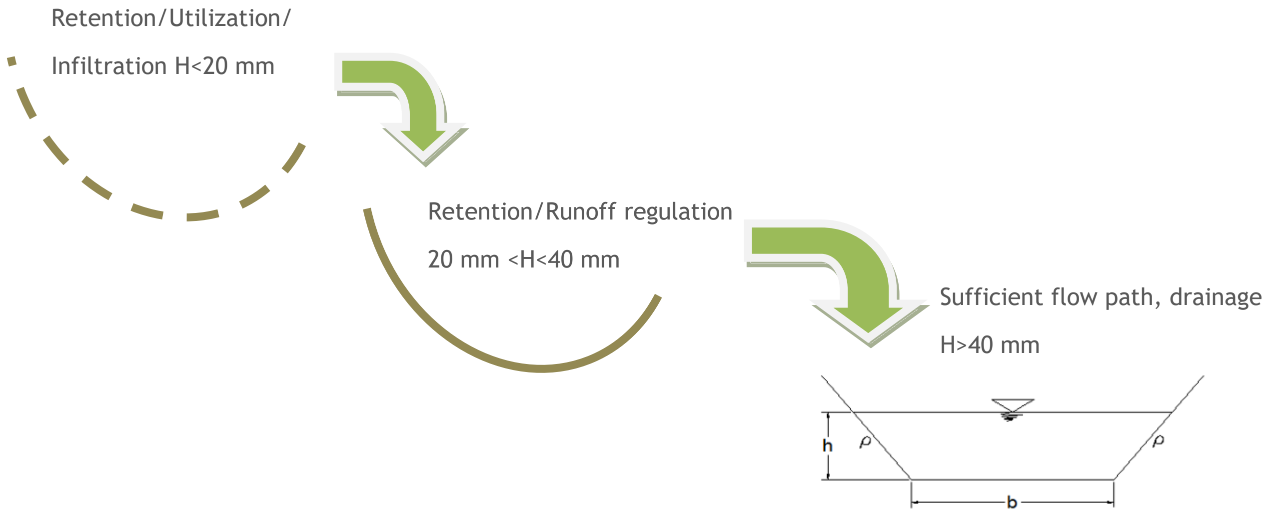



*Figure 1. Municipal rainwater management strategy (source: RBMP, Urban rainwater management guide, 2015)*

Figure 1. shows the occurrence of precipitation in mm/h broken down into three groups. Group 1. consists of minor rainfall, the water of which is kept within the municipality, for example to replenish groundwater or soil moisture. This is the so-called green infrastructure In this example, the upper limit of the group is the precipitation of 20 mm/h.

Group 2 includes precipitation whose discharge is controlled by the control elements formed on the catchment area, preferably surface water with permanent cover or temporary flooding, in some cases in the sewerage network, below the surface.

Finally, Group 3 is the extreme rainfall event where floods have occurred in the past. Changes applied systematically and correctly to the first two groups can significantly reduce the frequency of spills. In addition, with the transformation of the surface these solutions can be used in situations when events in the network that are significantly larger than the designing storm, thus causing controlled spills.

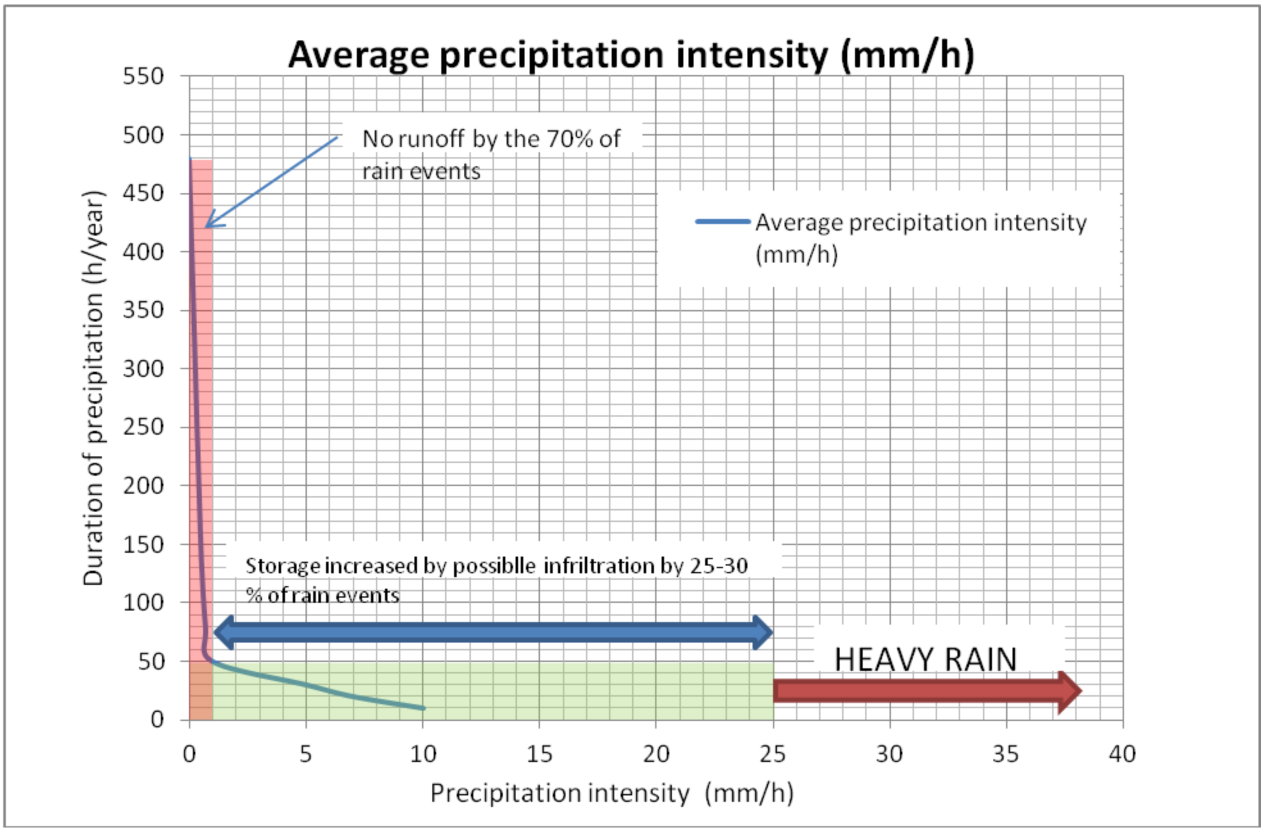
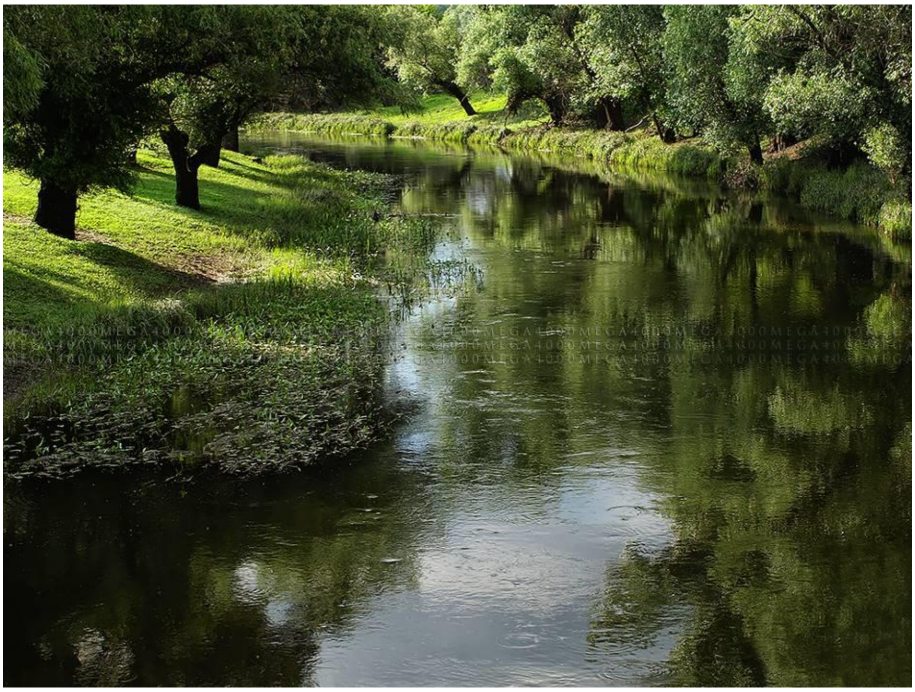



*Figure 2. The average annual precipitation intensity distribution (source: RBMP, Urban rainwater management guide, 2015)*

The figure above explains, that at almost 70% of the rain events, there is no or not accountable runoff from the surface. At 25-30% of the cases the local storage can be increased by extension of the infiltration capacity of the surface. And the rest part is heavy rain from 25 mm/h intensity, that needs drainage/storage.

In the followings we give description and details to the main influencing factors related to heavy rain events

- Precipitation: According to the latest researches, the annual precipitation does not change, but there is a significant change in the distribution of the precipitation. The frequency of heavy rains are increasing. This, together with the effects of urbanization, significantly increases the surface runoff value.
- degree of sealing/land use/levels of urbanisation: Increased production entails intensive farming. The former buffer zones, woody strips, riparian buffer zones have been eliminated, which means a significant increase in runoff, and erosion processes have also intensified. And as the urbanization progressed, the proportion of impermeable surfaces increased significantly. The growth of these surfaces types results in larger and faster run-off that cannot be adapted, sewer networks built 30-50 years ago. Particularly in the case of unified systems where a flood could pose a public health risk.



*Picture 1. Riparian zones in watersheds,*

*(source:* Zagyva river, Middle Tisza)

Fig. no. 3. illustrates the linear linkage between waterproofing surfaces and the runoff ratio.

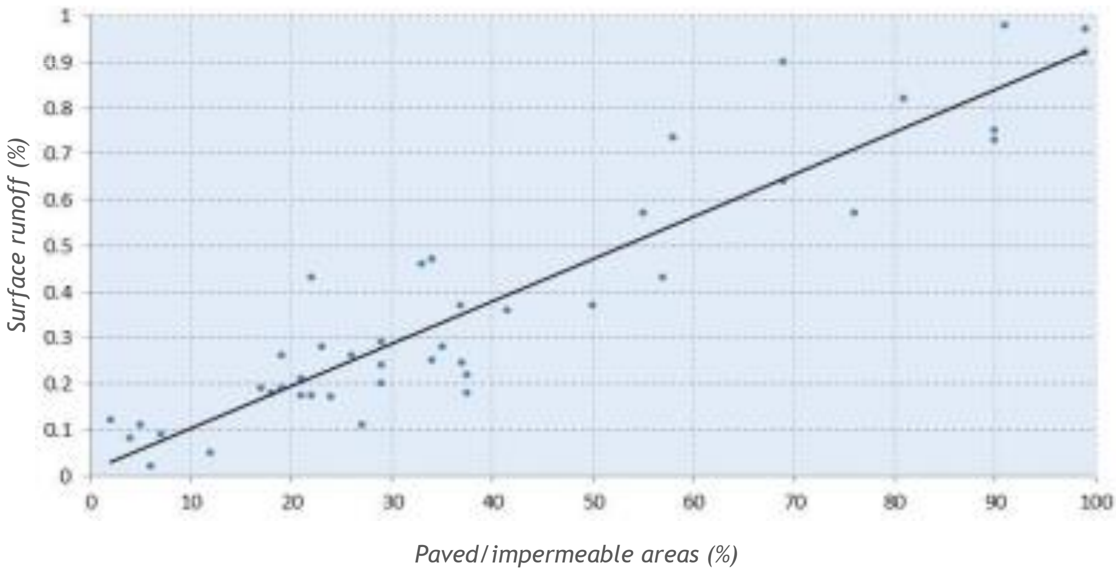



*Figure 3. (source: RBMP, Urban rainwater management guide, 2015)*

## Levels of urbanization

In this followings we will describe the levels of urbanisation from the aspects of rainwater management and retention. In terms of characteristics there are four levels of urbanization from rural to urban:

**Rural:**

In general, a rural area or countryside is a geographic area that is located outside towns and cities. Typical rural areas have a low population density and small settlements. The ratio of impermeable surfaces is low, the surface runoff rate is low (20-30%) Large storage areas can be created.

*Picture 2. Rural landscape (source:* http://www.magyartelepulesek.hu/nagyszekeres/gazdasag.html*)*

**Semi-rural:**

The semi-rural category identifies areas of the County that are appropriate for lower-density residential neighbourhoods, agricultural operations, and related commercial uses that support rural communities. Semi-Rural areas often function as a transition between the Village and Rural Lands categories, providing opportunities for development. The ratio of impermeable surfaces is low; the surface runoff rate is low (30-40%) Large storage areas can be created.

*Picture 3. Semi-Rural landscape (source:* https://hu.wikipedia.org/wiki/Alatty%C3%A1n#/media/F%C3%A1jl:Alatty%C3%A1n_l%C3%A9gi_fot%C3%B3.jpg*)*

**Semi-urban (suburban):**

Partly urban. It is a mixture of single family houses, asphalt and greenery on the fringe of the city. These areas forms and functions as suburb ring around the city core with mixed-density of landscape and houses, usually located along the major transport paths, railways, and highways. Commercial and industrial structures in these semi-urban areas are usually multi-story, but not high-rise. Two levels malls and shopping plazas are common. The ratio of impermeable surfaces, and the surface runoff ratio (40-50%) is medium, there is limited space for storages or the underground reservoirs can be created.

*Picture 4. Semi-Rural landscape (source:* https://www.civertan.hu/legifoto/galery_image.php?id=7850*)*

**Urban:**

Different countries use different measures to indicate the urban areas (population, density of inhabitants). The urban areas have large density of buildings and population, with large percentage of roads and pavements, very little greeneries (parks, playgrounds). Usually with high buildings. A classical city centre, in means of economy, education, health care, etc. High proportion of impermeable surfaces, high runoff ratio (70-90%) Reservoirs, can only be created in small green areas or under the ground.

*Picture 5. Urban landscape* ( sourcehttps://www.imperial.ac.uk/news/184656/global-project-reduce-health-inequalities-cities/)

This kind of characterisation is crucial, to assign rainwater management issues, and retention types to different kinds of area types.

- Soil type: The type of soil basically determines the rate of runoff and infiltration. (the more granular the higher the infiltration rate). However, in the case of clay soils, significant runoff occurs. Figure 4. details, the runoff coefficients depending on slope and soil type.

7. táblázat

| A vízgyűjtő terület talaja | Sokévi átlagos talajvízmélység a terep alatt (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | > 3.0 | | | 2.0—3.0 | | | 1.0—2.0 | | | < 1.0 | | |
| | lefolyási tényező (α) | | | | | | | | | | | |
| | téli-tavaszi | nyári | őszi | téli-tavaszi | nyári | őszi | téli-tavaszi | nyári | őszi | téli-tavaszi | nyári | őszi |
| homok | 0.07 | 0.01 | 0.01 | 0.10 | 0.02 | 0.02 | 0.14 | 0.05 | 0.03 | 0.18 | 0.10 | 0.07 |
| homokos vályog | 0.12 | 0.02 | 0.02 | 0.15 | 0.04 | 0.03 | 0.18 | 0.08 | 0.06 | 0.21 | 0.12 | 0.08 |
| vályog | 0.18 | 0.04 | 0.03 | 0.20 | 0.07 | 0.05 | 0.22 | 0.11 | 0.07 | 0.26 | 0.15 | 0.11 |
| agyagos vályog | 0.25 | 0.10 | 0.07 | 0.27 | 0.12 | 0.08 | 0.30 | 0.15 | 0.11 | 0.32 | 0.18 | 0.12 |
| agyag | 0.35 | 0.15 | 0.11 | 0.36 | 0.17 | 0.12 | 0.37 | 0.18 | 0.13 | 0.40 | 0.20 | 0.14 |
| szikes | 0.40 | 0.18 | 0.12 | 0.41 | 0.20 | 0.14 | 0.42 | 0.22 | 0.15 | 0.45 | 0.23 | 0.17 |
| terméketlen szikes | 0.46 | 0.25 | 0.17 | 0.47 | 0.27 | 0.18 | 0.48 | 0.28 | 0.20 | 0.51 | 0.30 | 0.21 |

Figure 4. Potential runoff coefficient for different soil types (source: Determining design inland excess water discharge on lowland catchments, MI-10-451-1988, Hungarian Standard)

- Moisture: For dry soils, the intensity of infiltration varies over time. The porous and dry soil is filled with two-phase air spaces between the soil particles. This air will be displaced by the infiltrating water. When this exchange is also biphasic, we are talking about soil and water space. Dry soil does not infiltrate, but rather absorbs water, which is of greater intensity, usually much greater than the capacity of the water-saturated soil.

- Topography: The increase of the runoff coefficient is also a result of high rainfall intensity, the high surface drop and bare vegetation. Topography basically determines the possibilities and methods of stormwater drainage, as well as the circumstances of reservoirs creating.

### 2.1.3. Interdependencies and effects

In this sub-chapter we specify the climatic, hydrological interdependencies and effects of urbanization related to stormwater drainage and runoff.

Figure 5. shows the changes in the annual water management characteristics of an area at different levels of urbanization. Urbanization is a multi-dimensional and complex process, of which in our case only the well-known feature, is the increase in the impermeable surface ratio. This has a decisive influence on the precipitation (P) that falls on to the territory of a settlement, and determines the route and the rate of the runoff. These possible routes are evaporation (E), infiltration into soil (I) (part of it reaches and refills the groundwater), and surface runoff (R). So the simple balance equation is:

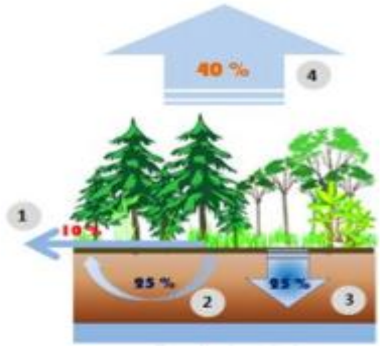
$$P = E + I + R$$

R member is also known as ΔS: change in the storage (soil, bedrock, groundwater)

In Figure 5., we can observe (in average case) how each member of the equation changes with the increment of urbanization (paved surface ratio). The average indicator here is primarily related to soil and groundwater. For example, if the groundwater is deep, and the topsoil is thin (e.g. silt) or it has high infiltration factor (eg. sandy), these proportions can change. This points that rainwater-related processes are highly depending local circumstances.

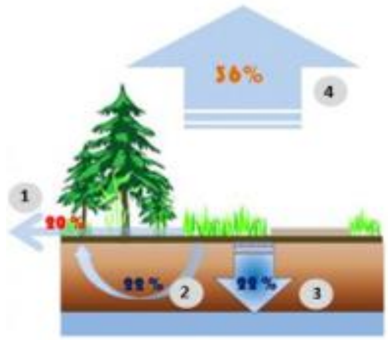
With the increase of the water-impermeable surface ratio, evaporation is slightly reduced, so the significant rearrangement and the large increase of the surface runoff (more than 5 times in this example) occur at the expense of the infiltration. The retention of rainwater, which may result in a reduction of the surface run-off causing flooding, may be achieved by increasing the potential for infiltration and / or storage. The infiltration increases with the proportion of uncoated surfaces. Reducing the proportion of waterproofing surfaces is limited but not impossible.

With the increment of the water-impermeable surface ratio, the evaporation is slightly reduced. So there is a significant change, a large increase of the surface runoff occurs at the expense of the infiltration. The retention of rainwater, which may result in the reduction of the surface run-off causing flooding, may be achieved by increasing the potential for infiltration or storage.



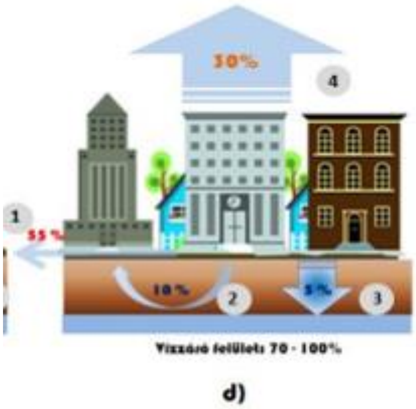

Natural surface

Paved, covered area: 0%




Paved, covered area: 10-20%


Paved, covered area: 35-50%




Paved, covered area: 70-100%

1 - Surface runoff, 2 - Shallow infiltration, 3 - Storage in groundwater, 4 - Evapo-transpiration

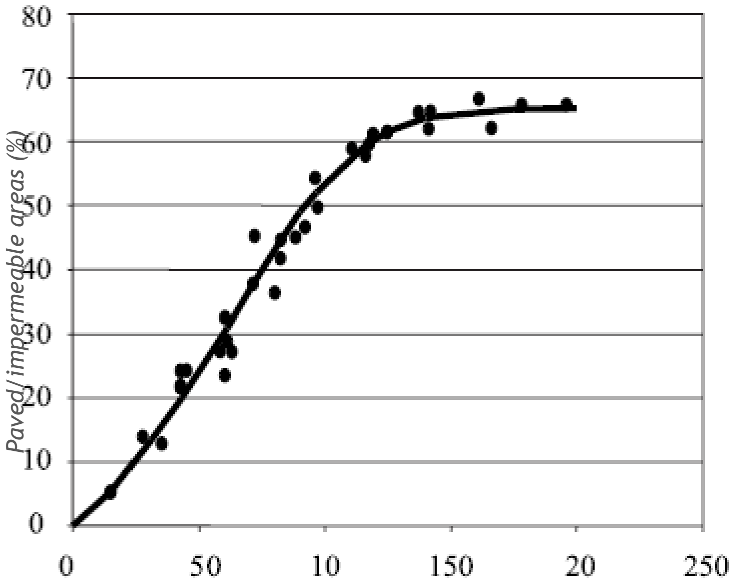
Figure 5. Water management characteristics according to the level of urbanization (source: *RBMP, Urban rainwater management guide, 2015)*

**Climatic effects**

Large cities and towns have effect on local climate. This linkage has been recognized so far. The modified microclimate depends on many factors. These factors affect the amount of precipitation and evaporation and thus the hydrological cycle. As a result of their combined effect, the annual precipitation in large cities can be 5 to 10 percent higher than in surrounding areas, and the difference in individual rain events can be as high as 30% (Geiger et al. 1987).

**Runoff influencing effects**

The most significant change is due to the increase of the paved, impermeable surfaces and the decrease of the surface storage and surface roughness. As a result of urbanization, increasing population density and the development of traffic, on the development areas asphalted or concrete roads, sidewalks and buildings appear, which creates an impermeable surface. Agricultural production and the processing of products, even in rural areas, have resulted the creation of more and more paved areas near settlements as well.




*Population density (person/hectare)*

*Figure 6. Effect of the population density on impermeable surface area (source: Campana and Tucci, 2001)*

The ratio of the impermeable surface to the total water catchment area is a very important parameter in urban hydrological processes. In residential areas there is a good correlation between the population density and the impermeable area ratio as shown above.
As a result of this, the flow and flood peaks increase meanwhile the gathering time and the peak time decrease (Figure 7.). Depending on the local conditions, the value of the flood peaks may rise by several times. The same can be observed with the amount of runoff.

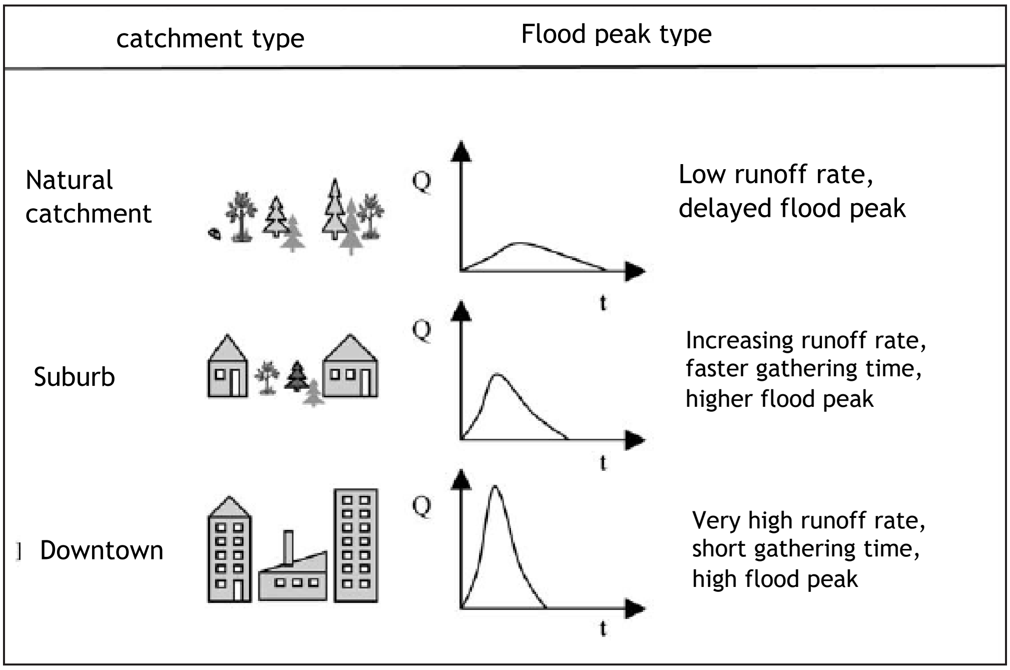



*Figure 7. Effect of the urbanization on surface runoff (source: Urban rainwater management guide, 2007)*

## 2.2 Existing concepts / solutions for water retention

The basic purpose of conventional rainwater drainage, is besides avoiding and minimizing damage, with designing, constructions and operating systems is allowing rainfall utilization.
Past rainwater sewerage planning practices have been based on determining the size of a sewer system' part that is capable of draining the runoff from an urban catchment for the predefined designing storm.
In the process of rainwater management planning, it is important to plan a reasonable alteration of in the catchment. Alteration of an urban catchment involves planning local interventions allowed by local circumstances.
Depending on the design and size, water and pollutant emissions can also be attributed to these processes. The first corresponds to the surface runoff, which also causes the transport of the second one. If we do not collect rainwater from larger areas with the pollutants contained therein, but instead intervene at the source, we can achieve significantly more cost-effective conditions, energy saving while, reducing the carbon footprint.
As a result of these interventions, less total water runoff and smaller flood peaks will occur, thus reducing the required sewer part sizes (pipes, sluices, pump stations, etc). Finally, going through the process detailed above, instead of the traditional approach of concentrating on conventional drainage, we are implementing decentralized municipal rainwater management.
It is extremely important to indicate the need for a well-thought-out scheme before proceeding with a specific form of retention concepts. It the following chapters (Chapter 3., 4) We will reveal concepts and criteria for the selection of solutions for retention of rain water.
This subchapter provides a comprehensive overview of storage options and principles.

### 2.2.1 Retention concepts in conventional engineering

In this subchapter we will charaterise the different types of retentions used in conventional engineering. Storage areas can be divided to five groups by their utilization.

Surface storage
Intermittent surface storage is created to delay the runoff. This storage area can be a natural or artificial greenery area, or pit that endures short time inundation.
These assigned areas' inundations cannot obstruct their normal use for long time, and with damage. Three hours of inundation is permitted within cities.

Cross-flow storage
A cross-flow storage should be created where it is needed by hydraulic disencumbering or by alluvium elutriation causes. The rainwater flows through it, and the storage capacity is used to reduce the flood peaks, and the amount of discharge. The storage should be created considering rainwater utilize possibilities. The bottom and the bed should be built to be maintained easily, with a low-water bed within the storage. It should be easily accessed with maintaining machines.

Overflowed storage
The overflowed storage is a cross-flow storage with overflowing possibility. It is built with a spillover and should be capable to transmit the whole flood volume.

Elutriating storage
An elutriating storage could be built upon water quality causes, on the upper sections of the rainwater drainage system, where a large amount of alluvium is expected. Because of the upper section location large volume of flood storage cannot be calculated, it is for water quality reasons and to protect the lower section of the rainwater system. After a rain event, the storage should be drained, and the sludge should be excavated.

Leaking storage
The use of a leaking storage is rainwater retention for ground infiltration. It should be sized for the duration of the infiltration for the whole rainwater volume. It is used where there is no rainwater receiver river or channel. It should be built with gravel bottom reduce the obstruction of the soil. The bottom should be 0,5-1,0 m higher than the highest groundwater level.

### 2.2.2 Retention concepts in ecological engineering – “grey” and “green” solutions

Several concepts exist for runoff regulation and retention.

EU’s Natural Water Retention Measures project (2013-14) - explored a number of possibilities for rainwater storage. These solutions were based primarily on green and nature-friendly approaches, but the measure listed there are well consistent with the good practices outlined in this documentation.

NWRM: The EU Directorate General Environment promotes the use of nature-based green infrastructure solutions and Natural Water Retention Measures (NWRM). Within the EU-framework of NWRM, urban planning refers to the application of the "Grey to Green" principle within cities. A sustainable water management should be achieved by mimicking natural functions and processes especially in the urban environment (source: http://nwrm.eu/concept/3902).

According to this approach, retention systems generally can be classified into:

- Grey systems: engineering structural measures, regulation and facilities connected to it.
- Green systems: local, within-site solutions for runoff regulation and retention
- Hybrid systems

The figure below (Figure 8) shows the basic principles related to the systems mentioned above.

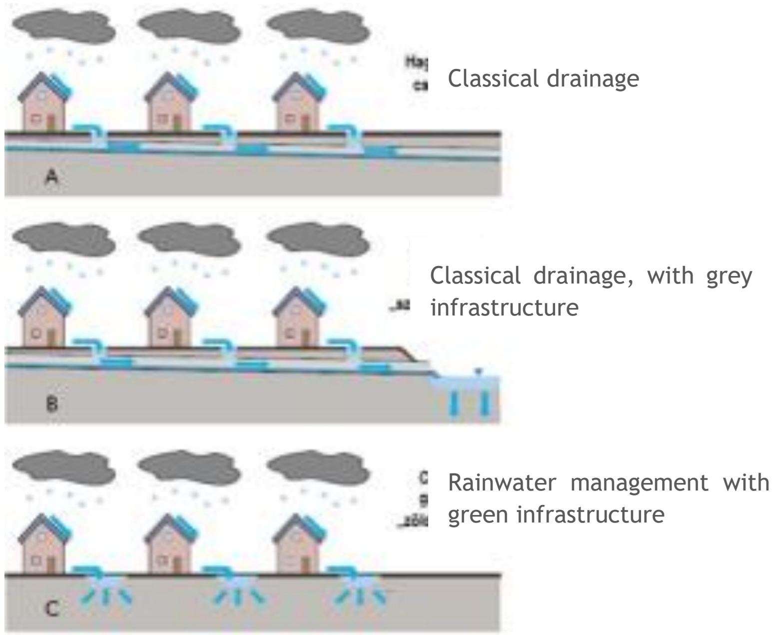



Figure 8. *Grey and green infrastructural solutions* (source: *RBMP, Urban rainwater management guide, 2015)*

With grey infrastructure we build facilities into rainwater drainage systems, that are capable to modify flood peaks, (eg. reasonable surface or underground storage areas, which not permanently inundated). The main aim in the design process is not the mainly the retention of the whole rainwater volume. These facilities can help in the purification of rainwater such as wetlands, but meanwhile these items have large catchments, (in case of main canals) so they need large space, and volume. In urbanized areas it usually needs large investment cost, especially if facilities could be placed only underground.

If we compare grey infrastructure with green infrastructure, the benefits can be easily seen. The green system can be built with small construction cost and flexible timing. The possible benefits are greater than grey systems.

This is a crucial fact with regard to climate change, as it’s circumstances and limits are not precisely defined according to present knowledge on the topic. Therefore, the more flexible and adaptable a system is, the more resistible against heavy loads, and the more the damage and the frequency of inundations can be reduced. However, a grey or green solution is cheaper than a conventional engineering facility (drainage systems, pumping stations, sluices, etc.). Thus, knowledge of these solutions from the municipal side is essential in order to establish appropriate local building regulations.

Figure 9. represents the achievable benefits in a certain timeframe between grey and green infrastructure.

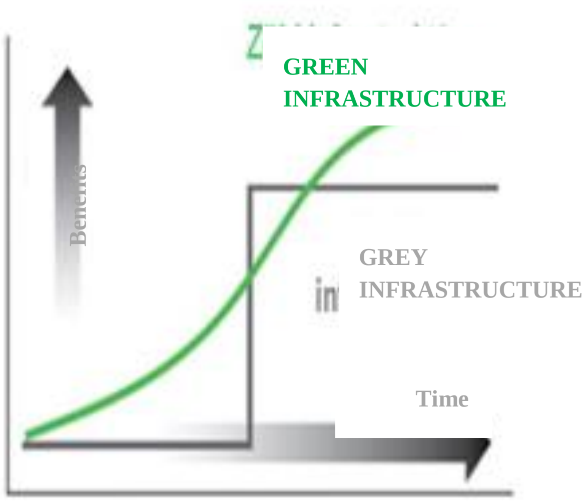



Figure 9. Advantages of green infrastructure (source: *RBMP, Urban rainwater management guide, 2015)*

The green rainwater management, has large literature in the United Kingdom, and describes the following groups of solutions:

- **R**ainwater **H**arvesting, **RH** (domestic retentions, water tanks)
- **G**reen **W**ater **I**nfrastructure, **GWI**
- **L**ow **I**mpact **D**evelopment, **LID**

The topic and the aim of Rainwater Harvesting is to retain the rainwater from roofs, gardens, other paved areas within properties.

Green Water Infrastructure is a method taking cityscape designing and water management issues into account.

The LID (Low Impact Development) is a kind of the sustainable urban rainwater management system. It is usual, that the designing process considers pollutant transport retention besides classical hydrological, and hydraulic aspects. These aspects are useful also for the cityscape and microclimate.

**The LID runoff regulation types are the followings:**

**- Change of the runoff/flowing paths:** Draining waters from paved to unpaved areas. This usually need a land use regulation in the catchment, eg: infiltrating pavements. Almost 70% -of yearly precipitation can be retained depending soil and groundwater.

- **Building infiltrating facilities:** These facilities are capable to reduce flood peaks.
- **Building storage areas:** Reducing flood peaks, with permanent or non-permanent inundation.
- **LID landscape, cityscape planning:** planting drought capable plants, trees, creating grass flow paths. These solutions reduce runoff and improves the aesthetics of urban environment, with long lifetime and small maintenance costs.

**And the combination of these system result sustainable urban rainwater management.**

### 2.2.3 Conclusions

Storage is a key element in the management and risk mitigation of heavy rains. In this chapter, we generally reviewed the principles of storm water storage options. The first problem with storm water storage is the precipitation itself. In the recent years, last decade, a trend can be observed. The annual precipitation amount does not change, only its distribution within the year has become more unequal, thunderstorms heavy rains become more frequent. Although the effects and extents of global climate change are not yet known, an even worse scenario is possible, than it is now. Fortunately, however, we need to focus on 25-30% of the rainfall events, when significant amounts of runoff occur.

Perhaps the most important parameter among the influencing factors is the runoff coefficient. As the level of urbanization rises, this value increases dramatically, creating a situation of danger for a number of reasons. On one hand, the proportion of runoff rises significantly, generating higher flood peaks, and flash floods, and on the other hand, stormwater contains pollutants (dust, heavy metals, oil, etc.), and the transport of these pollutants has great effects on water quality and biodiversity. Both situations has to be avoided according to the Water Framework Directive, therefore storage facilities (buffer zones) in drainage systems (urban and rural) are recommended to be established.

Rainwater storage facilities have long term literature in conventional engineering. (valley dams, reservoirs, spillways, etc.). These facilities are built as a result of a large investment, with a certain level of safety (10, 50, 100 years). They are typically robust, inflexible facilities, difficult to fit into the cityscapes, and their adaptability to the changing climate is questionable.

In contrast, grey and green solutions are cheaper, more adaptive to climate change, better suited to an urban environment, and their long-term benefits are indisputable.

A wide range of knowledge on stormwater storage options is essential for municipalities, decision-makers, stakeholders and practitioners. It is the responsibility of the leaders of a community to manage (not necessarily drain) rainwater problems (urban and rural as well), to determine the right way of development, to insert the selected facility into the cityscape, besides choosing the right level of safety and risk. Only this can be the basis for a well-considered local building regulation plan.

# 3. Technical practice guide

In the previous chapters, the theoretical background of stormwater storages and their advantages over conventional engineering facilities have been detailed. At the local level, the municipalities have the responsibility to create the Pluvial Flood Management Plan, according to Hungarian legislation. It is the task of the municipal decision-makers to prepare plans for stormwater management, and to construct the facilities. The basis of a municipal rainwater management plan is the definition of the designing rainfall itself, and to understand the content behind it. When designing a rainwater management system, one need to know its limitations, its capacities, and the answers to a “what if” scenario. In this chapter, we intend to provide a simplified planning guide (supported by an example) for stakeholders on stormwater storage, as well as we introduce the Polish approach.

## 3.1. Framing conditions / What needs to be considered

In the followings we describe the construction, location and designing of storage facilities according to the Hungarian standards. This method is primarily created for urban river catchments, in the classic sense of stormwater storage. It can also be used for smaller rural catchments as well. The different types of storages according to the standard are described in chapter 2.2.1.

When establishing a storage area, the following criteria should be taken into account:

- The type of stormwater retention area should be chosen so that it fits in with the municipal stormwater drainage system, the cityscape, and the principles of environmental protection and preservation of the built environment should be taken into account as well.
- The requirements for mechanized maintenance must also be taken into account when determining the size of the storage.
- The location of the storage should be designated in terms of economy and aims to be achieved.
- When several possible locations can be designated (in addition to the economic and water management aspects), preference should be given to where:
    - the storage of rainwater allows multipurpose utilization
    - it enables the construction of an aesthetic cityscape
    - in case of a malfunction event, there is the lowest risk of public health hazard and inundation
    - the lowest operating and maintenance costs
- It is an advantage to have it constructed in a site where inland excess water threat occurs, or it is defined in the settlement plan.

## 3.2 What can be done by municpalities / how to plan & realise retention measures

Since the municipalities are responsible for the designing and construction of rainwater management facilities, it is also a municipal task to preliminary assess possibilities for storage and to designate possible storage sites. Municipalities within the preliminary designation process, should consider the framing conditions mentioned above, besides, the building restrictions in the local building regulations. At the same time, aesthetic considerations must be taken into account, and storage options must be chosen so that they fit into the cityscape.

## 3.2.1 Simple palnning guide

### 3.2.1.1 Hungarian approach

In the following, the designing according to the Hungarian standard will be detailed.

#### Hydrological design

The usual designing method is if, the drainage system is designed for 2 years return time (50 percent probability), the storage volume should be planned for minimum 4 years return time precipitation according to national standards.

#### Hydraulical design

The Hungarian standard regulates, that the retained excess water should be drained, leaded to the receiver water body within 3 hours. Because of this the water regulator facilities (culverts, sluices, etc) have to be sized for these charge, flow.

**Volume of the storage area (surface storage)**

Intermittent surface storage is created to delay the runoff. This storage area can be a natural or artificial greenery area, or pit that endures short time inundation.

These assigned areas' inundations cannot obstruct their normal use for long time, and with damage.

**Volume of the storage area (cross flow storage)**

The Hungarian Standard regulates how to design the volume of storage area. The first step is to define hydrological scale. The equation below represent this method.

$$c = \frac{q_p}{Q_{1,p}}$$

where:

c – mitigation parameter, reduce the intensity of precipitation

$q_p$ - the greatest outflow through the sluice

$Q_{1,p}$ – rational method for define the standard precipitation

After this point, the standard ha instructions for the specification of the parameter of volume. This parameter depend on the mitigation parameter (c) and the runoff time. If we know those values, we can define the volume parameter from the figures. These figures are shown below.

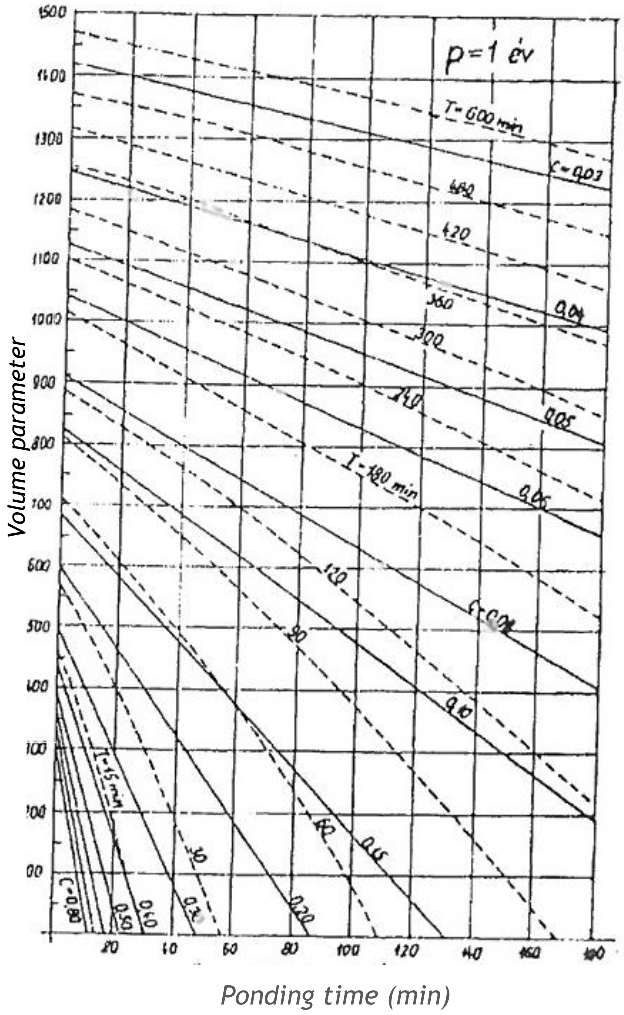



Figure 10. *figure of 1 year return time rainfall* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

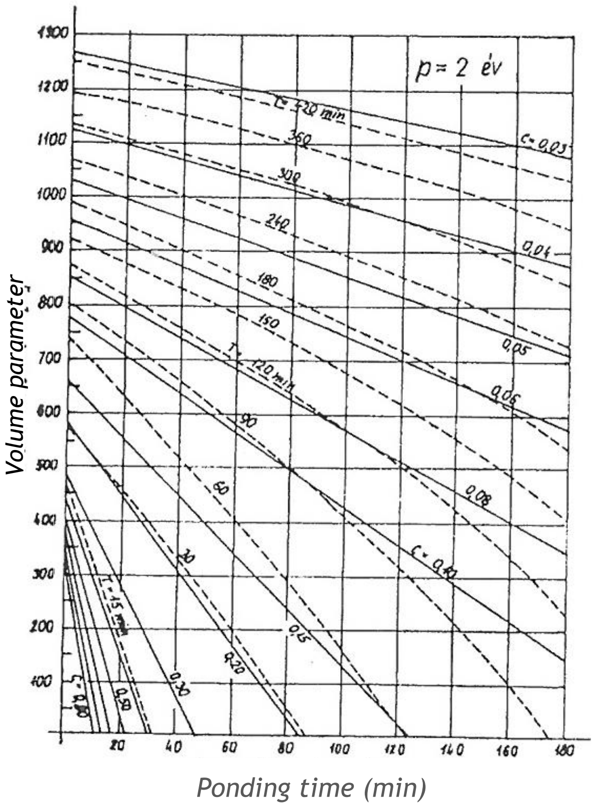



Figure 11. *figure of 2 year return time rainfall* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

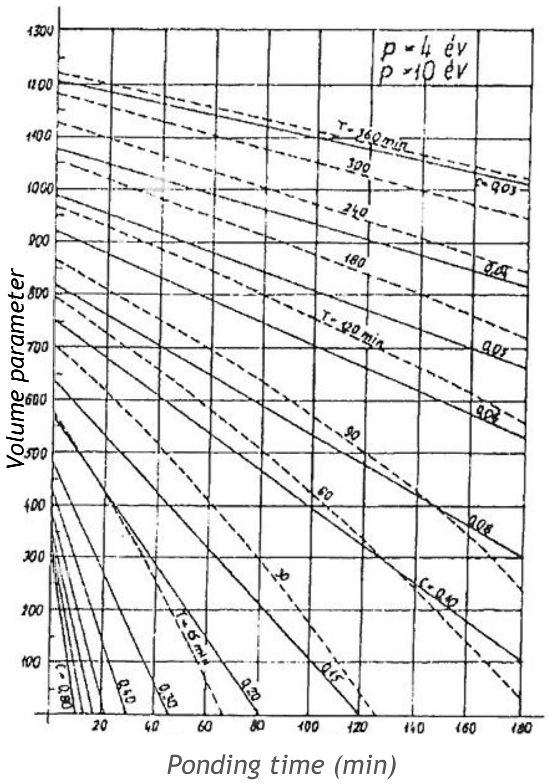



Figure 12. *figure of 4 year return time rainfall* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

where:

c – mitigation parameter

M – volume parameter

$t_c$ - gathering time/runoff time

T – duration of standard precipitation

It known, the equation formula is:

$$V = \frac{M * Q_{1,p}}{1000}$$

**Volume of the storage area (overflow storage)**

Within this type of storage area, the primary point of view is that the volume have to be greater than the dissolved amount of rainwater (at the beginning of the duration of precipitation the rainwater contains pollutant).

After this, the method of design is the same than the previous one (the figures also).

**Volume of the storage area (leaking storage)**

The method of design is the same than the cross flow storage.

**Sample calculation:**

Hereby we present the Hungarian calculation method through a sample calculation:

First of all, there are some parameters that have to be defined:

n=0.5 % roughness factor of the ground (-)

| Ground type | Roughness factor (n) |
|---|---|
| Arable land | 0,4 - 0,5 |
| Forest, meadow, pasture | 0,3 - 0,4 |
| Grassy park | 0,2 - 0,3 |
| Rocky pavement | 0,15 - 0,25 |
| Concrete, asphalt pavement | 0,1 - 0,15 |

Figure 13. *roughness factor of different ground types* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

L1=100 standard lenght of the catchment (m)
I=0.01 slope of the catchment (m/m)
L2=500 length of the channel (m)
v1=1 allowed velocity in the channel (m/s)

ta=10 standard duration time of the precipitation

α=0.3 runoff ratio (-)

| Ground type | Runoff ratio (α) |
|---|---|
| Roofs | 0,8 - 0,95 |
| Paved roads | 0,8 - 0,95 |
| Unpaved roads | 0,2 – 0,4 |
| Parks, gardens, cemeteries | 0,1 – 0,15 |
| Sport facilities | 0,1 – 0,2 |
| Business areas | 0,7 – 0,95 |
| Family house territories | 0,3 – 0,5 |
| Industrial areas | 0,7 – 0,95 |

Figure 14. *runoff ratios of different ground types* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

m=0.72 standard value of the index (-)

ap=270 standard precipitation value for 4 years return period (l/s*ha)

| Return period (year) | ap<br>standard precipitation value for 4 years return period (l/s*ha) | m<br>standard value of the index (-) |
|---|---|---|
| 1 | 133 | 0,69 |
| 2 | 203 | 0,71 |
| 4 | 270 | 0,72 |
| 10 | 364 | 0,72 |
| 20 | 439 | 0,73 |
| 33 | 500 | 0,74 |
| 50 | 562 | 0,74 |
| 100 | 662 | 0,75 |

Figure 15. *values of the standard precipitation* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

A=100 area of the catchment (ha)
d=0.5 diameter of the pipe from the reservoir (m)
c=0.6 coefficient, standard value
g=9.81 gravity
h=0.05 standard afflux (m)

**The calculation as follows:**

Outflow of the pipe of the reservoir (m3/s):

$$q_1 = \frac{d^2 * \pi}{4} * c * \sqrt{2 * g * h} = 0{,}1167 (m^3 / s)$$

Gathering time (min):

$$t_1 = 1{,}2 * \sqrt{\frac{n * L1}{\sqrt{I}}} = 26{,}83 (\min)$$

Runoff time in channel (min):

$$t_2 = \frac{1}{60} * \frac{L2}{v1} = 8{,}33 (\min)$$

standard runoff time (min):

$$t_c = t_1 + t_2 = 35{,}16 (\min)$$

Standard intensity of the precipitation (l/s*ha):

$$i_p = a_p * \left( \frac{t_c}{t_a} \right)^{-m} = 109{,}18 (l / s * ha)$$

Design flow (m3/s):

$$Q = \frac{\alpha * i_p * A}{1000} = 3{,}275 (m^3 / s)$$

Mitigation parameter (-):

$$c = \frac{q1}{Q} = 0{,}0356 (-)$$

Required volume of the reservoir ($m^3$)

$$V = M * Q = 3356 (m^3)$$

Remark: M value is selected from the figure below

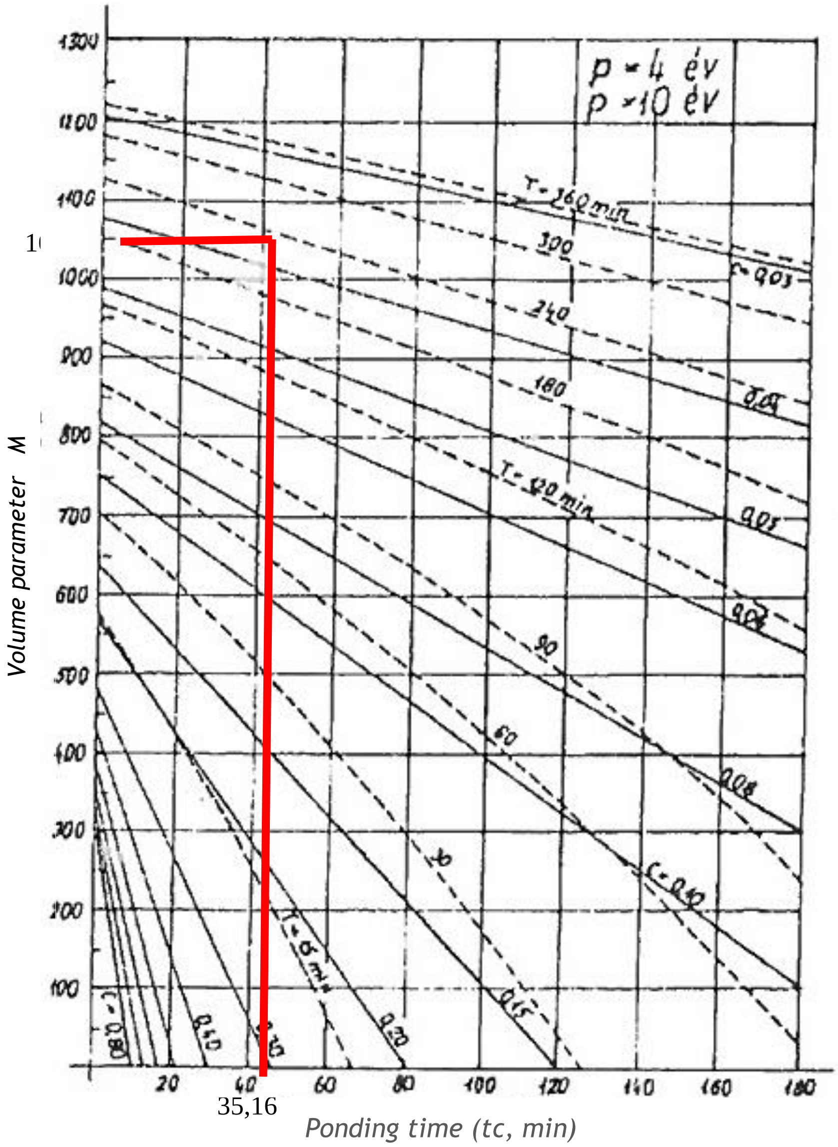



Figure 16. *figure of 4 year return time rainfall* (source: Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard*)*

3.2.1.2 Polish approach

Protection against the impacts of heavy rain requires taking action in areas that are not directly exposed to fluvial risk (river floods), but whose development has a significant impact on the flow dynamics. The striving to reduce surface runoff plays a key role in flood prevention, especially in urban and sub-urban areas. Heavy rainfall is often of an intensity that exceeds the capacity of municipal sewage systems. Hence, rainwater management systems that mimic the processes occurring in the natural environment, i.e. retention, infiltration, purification and evapotranspiration, are of particular importance in reducing the volume of surface runoff in urbanized areas [Januchta-Szostak 2012]. Our good practise (see chapter 4) are kind of Low Impact Development solutions. The possibility of applying a specific solution depends on several conditions. This fact requires a few steps before any investment. It means the need of determination of some criteria or indicators, for example:

- ✓ area availability (depending on type of area: rural, sub-rural, sub-urban, urban),
- ✓ soil type,
- ✓ retention value [litre/m$^2$] and assumption of the additional function (infiltration, purification and evapotranspiration),
- ✓ low / high need of pre-treat rainwater (surface runoff),
- ✓ durability of the solution,
- ✓ maintenance aspects
- ✓ costs

The most important indicator shows a wide range of potential retention value. The retention value ranges for the solutions listed in the Good Practice Catalogue are presented below [Lejcuś et al 2017].

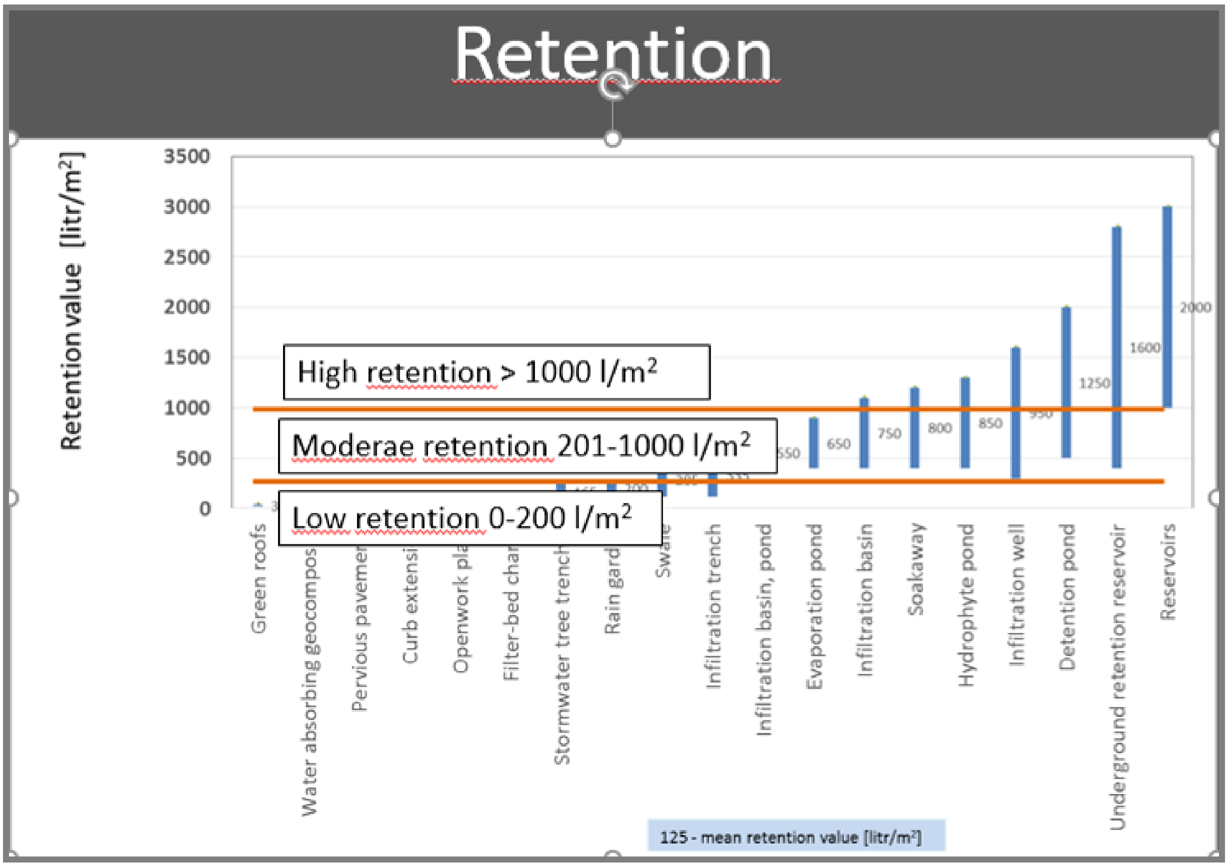



Figure 17. *retention values and solutions* (source: presentation "Good Practice Catalogue – the Rules for Sustainable Mangement of Stormwater from Road Surface" K. Lejcuś. Wrocław 04.06.2019*)*

The figure above shows that reservoirs, underground retention reservoir, detention pond, infiltration well or hydrophyte pond have the highest retention. But other solutions may be sufficient to provide protection against heavy rain and additionally could have additional roles. For example rain water can accumulate appear as excess water (mean retention value 200 litre/m$^2$) but also infiltration, purification of water and it is landscaped good.

Furthermore in the Best Practice Examples chapter specific solutions are detailed. This is important because these solutions are a kind of hybrid system or green systems. That solutions are visually acceptable also. In this document the approximated plant species are good for three zones (deep, median and riparian). In the first one the species are resistant against floods (water level > 0.2 m) and water infiltrates within 24-48 hours. In the median zone – inundations occur for shorter time than in deep zone and water level is <0,2 m. In riparian zone the widest range of plant species are possible.

In the Best Practice Examples, the choice of the solutions is based on the consideration of the mentioned influencing factors (**assessment by means of a matrix of solutions utility, matrix of additional indicators**). In the next steps should specify:

- ✓ area availability (type of development: rural, sub-rural, sub-urban, urban; the need for a surface (linear or area) or underground solution)
- ✓ soil type (cohesive, non-cohesive; filtration coefficient)
- ✓ retention value [litre/m$^2$] and assumption of the additional function (infiltration, purification and evapotranspiration)
- ✓ low / high need to pre-treat rainwater (surface runoff)
- ✓ durability of the solution
- ✓ maintenance aspects
- ✓ costs

Solutions of retention concepts (e.g. Low Impact Development) have advantages like rainwater goes to under the surface instead of the sewage system and rainwater can be used by vegetation, are pre-treated and improve the microclimate. They also require certain rules - the use of permeable soils, checking inheritance or need to use of appropriate plants. These solutions mean protection against excess rainwater of heavy rain and **help change people's attitude that rainfall is a natural resource, not just a threat**.

In turn in document - Guidelines for the implementation of small retention facilities in Forest Districts [Wytyczne et al 2008] are advices on verification of environmental conditions and design of small retention facilities with more emphasis on the indication of important environmental information (because this document is dedicated to rural areas). Where the suggestions are:

- Quantitative and qualitative identification of the problem of water deficiency in the forest ecosystem (verification of wetland habitats, geomorphology, hydrological system, soils, groundwater level, state of fauna and flora, presence of species and protected habitats),
- Determination of the main factor affecting the occurrence of water scarcity in the forest ecosystem,
- Analysis of possible actions and selection of the optimal solution.

This analysis aims to determine what type of activity will be needed, where and to what extent:

- pile construction (type, quantity, technical parameters),
- construction and renovation of artificial surface reservoirs (type, quantity, technical parameters),
- meandering of watercourses, restoring oxbow lakes, enabling natural floods, removal of unnecessary tree stands from peatland areas (increase in natural retention of peat lands).

The last step defines the effect and profitability of the investment based on the index of the amount of water retained (in m$^3$ - in the reservoir and in the soil) and the retention cost factor of 1 m$^3$ of water [Wytyczne et al 2008].

## 3.3 Monitoring, evaluation and maintenance issues

In this sub-chapter we detail the maintenance and inspection requirements in Hungary.

During the preparation period, the rainwater management facilities should be provided with a yearly, regular maintenance to ensure the drainage capacity without inundations. Vegetation (trees, shrubs, bushes, aquatic vegetation), sediment and waste must be removed from the channel, reservoir beds. This includes the following maintenance work:

| **Type of work** | **Intended frequency** |
|---|---|
| Regular maintenance of the channel beds, reservoirs, ensuring water drainage, primarily between the main collectors and the recipient | between May and October each year |
| Check capacity of the main collecting channels | monthly |
| Regular maintenance of culverts | between May and October each year |
| A removing sewer sediment from channel beds, reservoirs | 2 – 4 years |
| A removing waste from channel beds, reservoirs | occasionally |
| A removing vegetation from channel beds, reservoirs | at least twice a year |
| Removing waste from underground tanks | occasionally |
| A removing sewer sediment from underground reservoirs | 1 – 3 years |

Figure 18. Maintenance related issues (Gábor Harsányi MTDWD, 2019)

The detailed instructions for the works above are included in the operating regulations and maintenance instructions of the rainwater drainage system in every city.

The condition of the municipal rainwater facilities, the equipment needed in emergency cases must be checked at least once a year, – usually in autumn - and the identified deficiencies must be eliminated.

During the inspection it is advisable to monitor the changes occurring in the peripheral areas (change of land uses, deforestation, etc.), and to reveal the changes in the groundwater level of lower areas if there are any buildings. A representative of the competent Water Directorate and other stakeholders are invited to the inspection event.

A review and update of the Pluvial Flood Risk and Action Plan should be carried out during the pre-emergency preparation period in order to ensure the smooth execution of the defence tasks.

# 4. Best practice examples, alternative measures & recommendations

Within this chapter, we present a wide range of storage options through concrete examples of good practice. For each type, a factsheet was prepared summarizing the main parameters of the storage types.

## 4.1. Best practice examples

**In this sub-chapter we would like to introduce the Hungarian approach through the case study of the Pilot Investment**

**Introduction**

The operational territory of the Karcag Branch Office consists of 3 main catchments The largest of these is the Kakat catchment which is just above 400 km$^2$. The Kakat-channel is the main recipient of the drainage systems of Kunhegyes, Kenderes and Kisújszállás towns. The main aim of the Rainman project is to mitigate the negative effects of the heavy rain events. Regarding to this goal the Branch Office of Karcag designed a reservoir – namely Kakat-reservoir – next to Kunhegyes town to increase the flexibility against of the pluvial floods in rural and urban areas as well.

**Designing basis - modeling**

The pluvial floods in this area is an existing problem due to the hydro meteorological effects that causes inundation on lowlands. To observe and evaluate the different situations in this area the 1D model of the Kakat-channel was developed with HEC-RAS. It is a calibrated and validated model.

In this situation the upper boundary condition was defined as flow hydrograph taking into consideration of the additional flows from the drainage system of Kunhegyes. To ensure the free outflow from the drainage system of Kunhegyes water level should be guaranteed on the Kakat-channel under: 83,60 m B.f. The reservoir supports this aim.

The main outcomes of the model is shown below:

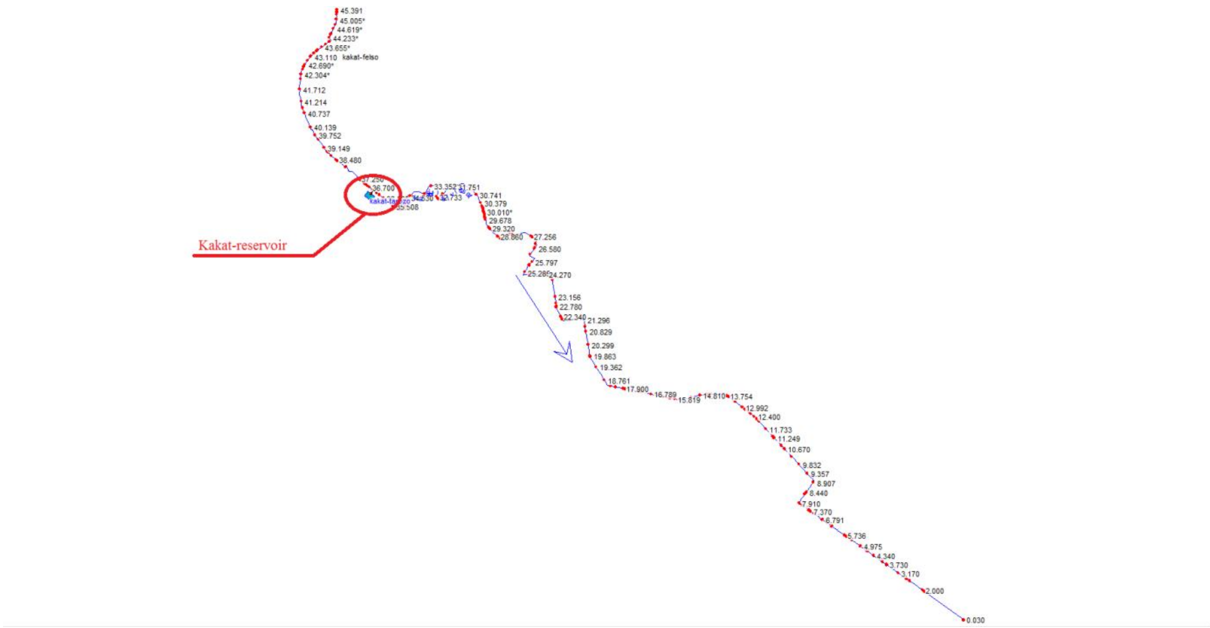



Figure 19. Geometry of the Kakat-channel (Runoff model analysis of the Kakat catchment, 2019)

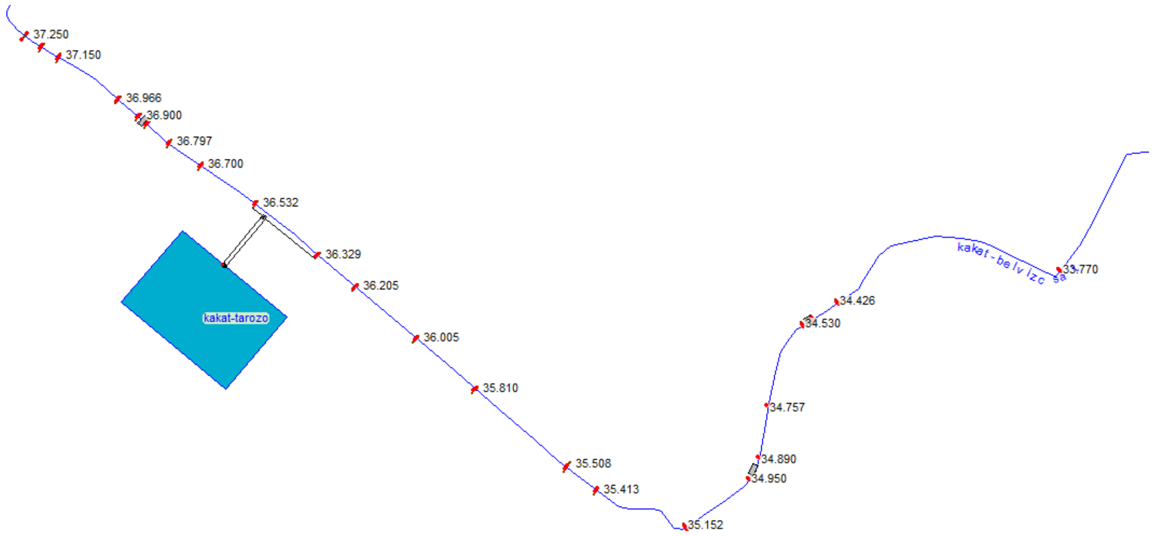



Figure 20. Geometry of the Kakat-channel (Runoff model analysis of the Kakat catchment, 2019)

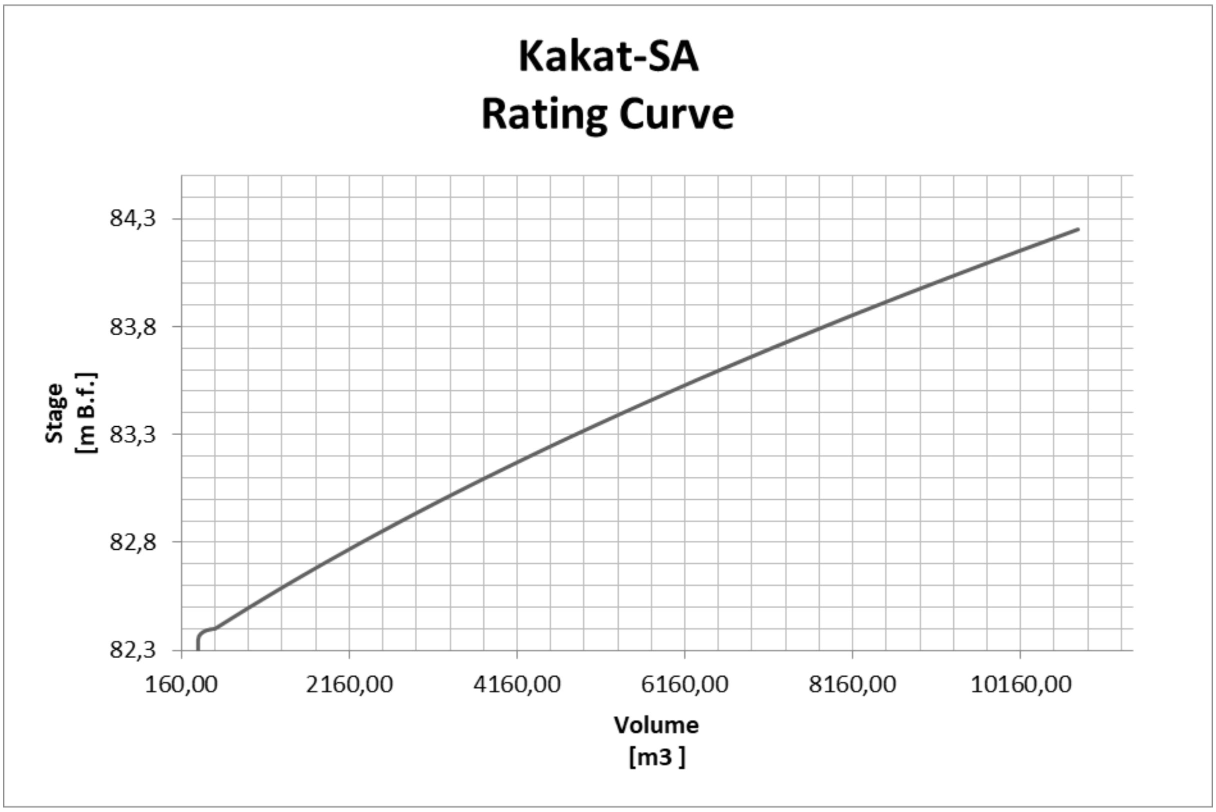



Figure 21. Rating cure of Kakat-reservoir (Runoff model analysis of the Kakat catchment, 2019)

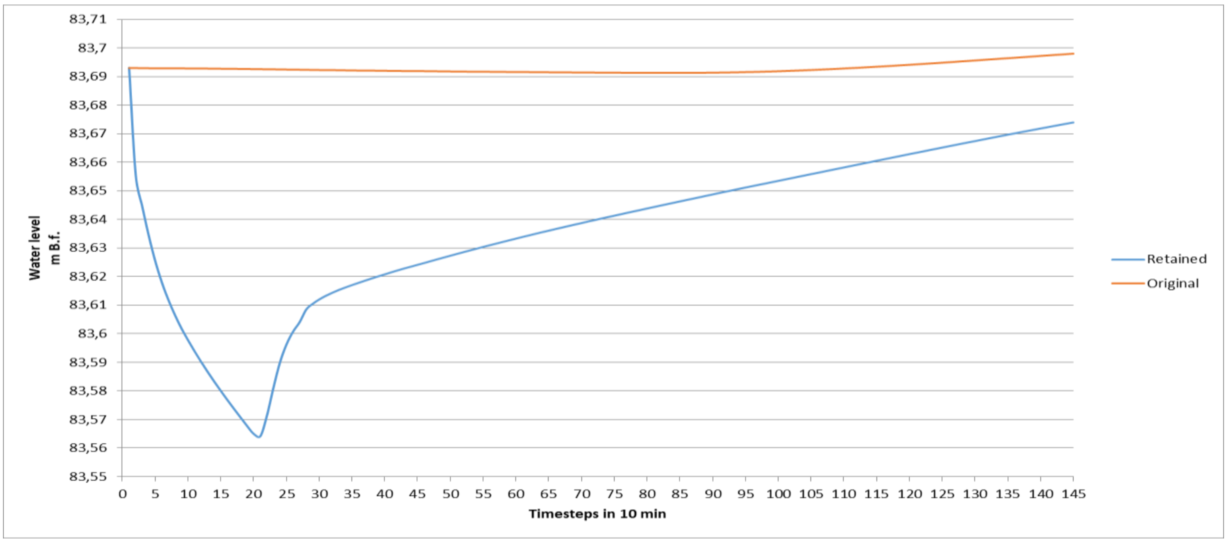



Figure 22. Decreased water level in Kakat-channel (Runoff model analysis of the Kakat catchment, 2019)

The previous figure shows how the Kakat-reservoir can decrease the water level of the main channel in pluvial flood situation (blue line). With a right operation the reservoir can decrease the water level by 15 cm so that means that the right water level (83,60 m B.f.) is guaranteed.

The expected impact and benefits of the investment are:

- to mitigate the peak of floods,
- to gather the excess water faster from the catchment without inundations,
- to decrease the operation at pumping stations
- to mitigate the effects of heavy rains in the urban areas (inundations)

This reservoir decreases the peak of flood, gather the excess water faster from the catchment without inundations This was made to prevent the territory of Kunhegyes. This retention basin can store more than 10000 $m^3$ water above the standard volume from the sub-catchment. This amount of excess water can be retained after rainy periods, to mitigate the effects of drought, and to refill ground water sources. Thus, the investment could also reduce other negative effects of climate change.

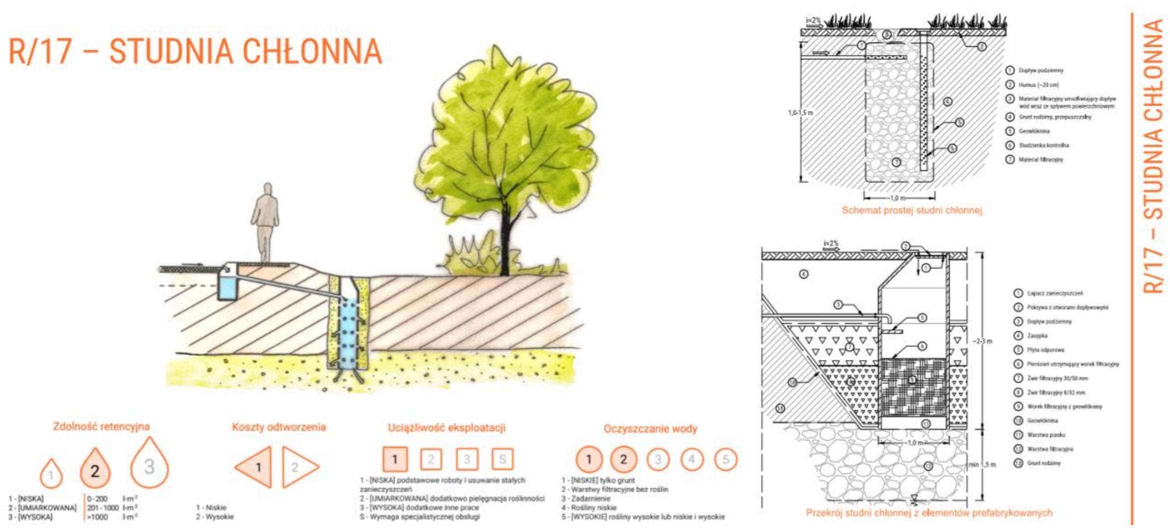
## 4.2. Alternative measures (factsheets)

### 4.2.1 Infiltrating cells:

| Retention type: **Infiltrating cells** | | | |
|---|---|---|---|
|   Figure 23.Infiltrating cells *(source: RBMP, Urban rainwater management guide, 2015)* | | | |
| Land use | **Urban** | | |
| Catchment area | 0-0,1 $km^2$ | | |
| Dimensions | Along pavements maximum 0,5 m deep | | |
| Location | Anywhere at urban catchments | | |
| Target group | Municipalities | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | LOW/ MEDIUM | Filtering soil, with plants planted on gravel zone. These cells modify the runoff by infiltration and storage in the gravel zone |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | MEDIUM | |
| | Increase soil water retention | LOW | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | LOW | |
| | Achieve Good | NO | |

| | | | |
|---|---|---|---|
| | Surface Water Status | | |
| Maintenance requirements | Gravel zones can gather sediment which should be moved every 3 years. Cutting trees and bushes planted in the areas. | | |

### 4.2.2 Infiltrating wells:

| Retention type: **Infiltrating wells** | | | |
|---|---|---|---|
|   Figure: 24. Infiltrating wells (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017”) | | | |
| Land use | **Urban** | | |
| Catchment area | 0-0,1 $km^2$ | | |
| Dimensions | Along pavements maximum 1,0 – 1,5 m deep | | |
| Location | Anywhere at urban catchments, where the soil is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | LOW/MEDIUM | Filtering soil, with plants planted on gravel zone. These cells modify the runoff by infiltration and storage in the gravel zone |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | LOW | |
| | Increase soil water retention | LOW | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | It is advisable to remove impurities from the water tank at the level of the pavement (1-2 per year) | | |

**4.2.3 Rain Gardens:**

Retention type: **Rain gardens**

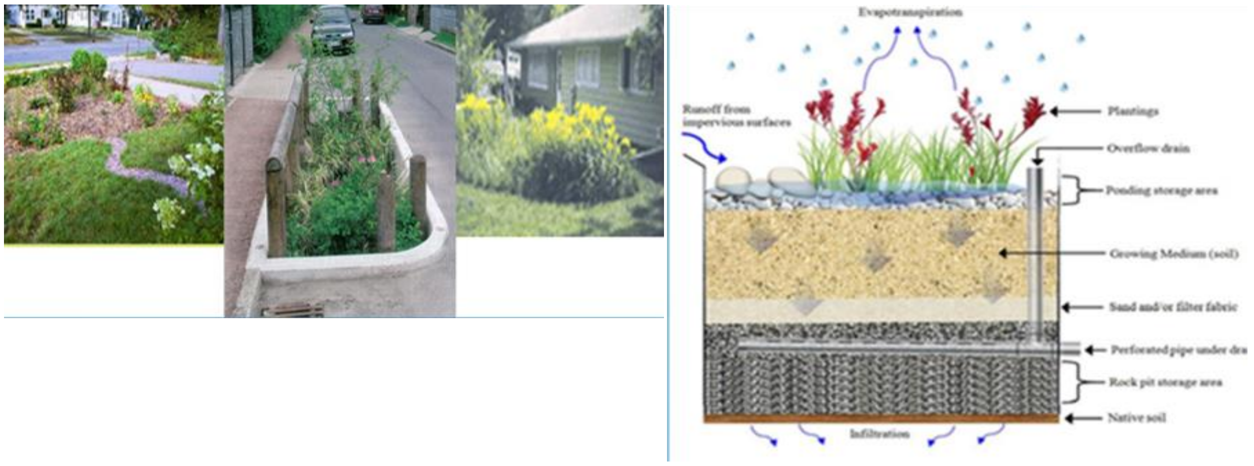



Figure 25. Rain gardens *(source: RBMP, Urban rainwater management guide, 2015)*

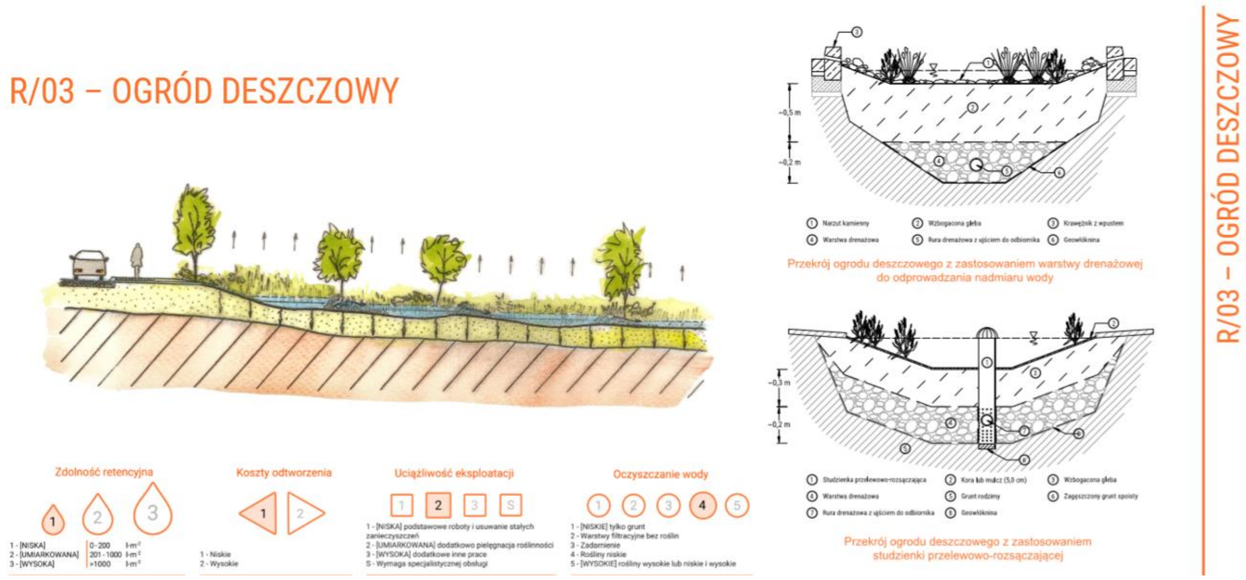



Figure: 26. Rain gardens (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban** | | |
| Catchment area | 0-0,1 km$^2$ | | |
| Dimensions | On top of buildings, along pavements maximum 0,5 m deep | | |
| Location | Anywhere at urban/rural catchments, where the terrain/building is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | LOW/MEDIUM | Artificially created pit areas planted with plants, mitigates runoff |

| | | | |
|---|---|---|---|
| | Increase Evapotranspiration | LOW | Facilitates evapotranspiration. |
| | Increase Infiltration | LOW | Facilitates infiltration. |
| | Increase soil water retention | LOW | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Cutting trees and bushes planted in the areas. | | |

4.2.4 Infiltrating trenches:

Retention type: **Infiltrating trenches**

Figure 27. Infiltrating trenches *(source: RBMP, Urban rainwater management guide, 2015)*

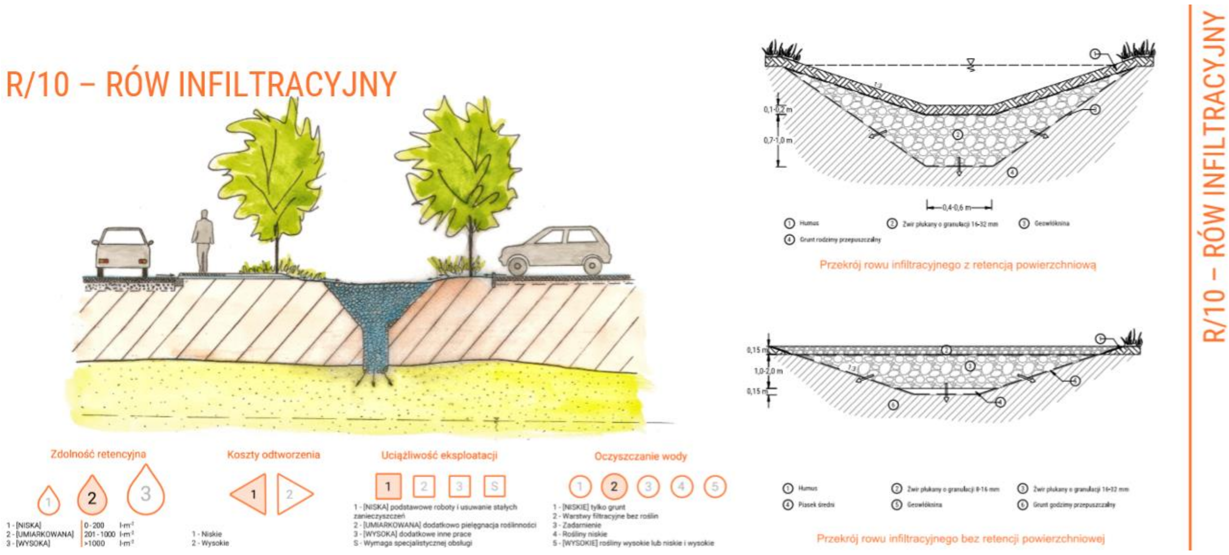



Figure: 28. Infiltrating trenches (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 km$^2$ | | |
| Dimensions | Along paved areas, or in green areas | | |
| Location | Anywhere at urban/rural catchments, where the terrain is suitable | | |
| Target group | Municipalities, Private property owners, Farmers | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | It is created for areas without runoff, retaining rainwater |
| | Increase Evapotranspiration | NO | |

| | | | |
|---|---|---|---|
| | Increase Infiltration | MEDIUM | Facilitates infiltration. |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Cutting the grass next to the designing area. | | |

### 4.2.5 Grassy ditches and swales:

Retention type: **Grassy ditches and swales**

Figure 29. Grassy ditches and swales *(source: RBMP, Urban rainwater management guide, 2015)*

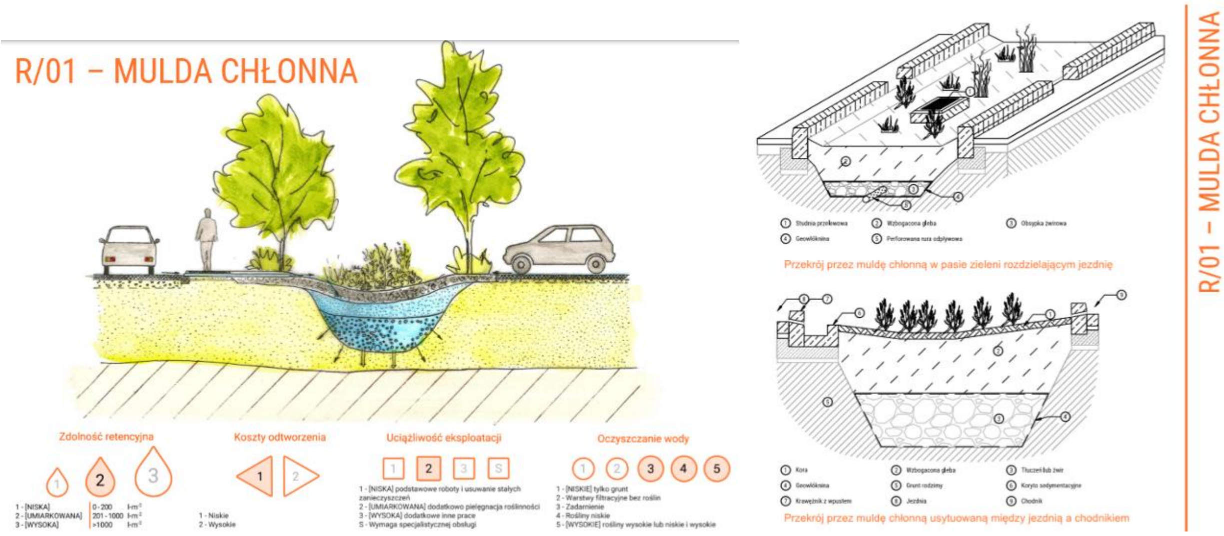



Figure: 30. Grassy ditches and swales (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-1,0 $km^2$ | | |
| Dimensions | Along paved areas, or in green areas | | |
| Location | Anywhere at urban/rural catchments, where the terrain is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store | MEDIUM | Grassy diches slows the runoff, |

| | | | |
|---|---|---|---|
| | runoff | | and stores rainwater. |
| | Increase Evapotranspiration | LOW/ MEDIUM | |
| | Increase Infiltration | LOW | Facilitates infiltration. |
| | Increase soil water retention | LOW / MEDIUM | |
| | Reduce pollutant sources | MEDIUM | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Cutting the grass in the designing area. | | |

### 4.2.6 Temporary inundated areas:

<table>
<tr><td colspan="4">Retention type: Temporary inundated areas</td></tr>
<tr><td colspan="4"><br>Figure 31. Temporary inundated football field (source: Gábor Harsányi, Kisújszállás, 2005.)</td></tr>
<tr><td>Land use</td><td colspan="3">Urban/Semi urban/Semi-rural</td></tr>
<tr><td>Catchment area</td><td colspan="3">0-1,0 $km^2$</td></tr>
<tr><td>Dimensions</td><td colspan="3">Maximum size of a tennis court or a football field</td></tr>
<tr><td>Location</td><td colspan="3">Anywhere at urban/rural catchments, where the terrain and land use is suitable</td></tr>
<tr><td>Target group</td><td colspan="3">Municipalities, Farmers</td></tr>
<tr><td rowspan="3">Effects of measure</td><td></td><td>Size of effect</td><td>Description</td></tr>
<tr><td>Slow/Store runoff</td><td>HIGH</td><td>Temporary inundated areas can be assigned to reduce the flood peaks, and to increase infiltration. There are extreme examples for these kind of reduction solution eg. football fields, tennis courts, which are usually not used while rain events. The normal draining times for these facilities is 2-3 hours.</td></tr>
<tr><td>Increase</td><td>LOW</td><td></td></tr>
</table>

| | | | |
|---|---|---|---|
| | Evapotranspiration | | |
| | Increase Infiltration | MEDIUM | Facilitates infiltration. |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant sources | MEDIUM | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Cutting the grass and ensure the volume in the designing area. | | |

### 4.2.7 Infiltration basin:

Retention type: **Infiltration basin**


Figure: 32. Infiltration basin (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural/Rural** | | |
| Catchment area | 0-1,0 $km^2$ | | |
| Dimensions | Should be designed for 50-100 years flood | | |
| Location | Anywhere at urban/rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities, Farmers | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | HIGH | The properly designed infiltration basin is capable to receive the volume of 50-100 year flood totally. |
| | Increase Evapotranspiration | LOW | |
| | Increase Infiltration | HIGH | Facilitates infiltration. |
| | Increase soil water retention | HIGH | |
| | Reduce pollutant sources | MEDIUM | |

| | | | |
|---|---|---|---|
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Cutting the grass and ensure the volume in the designing area. | | |

**4.2.8 Wetlands:**

Retention type: **Wetlands**

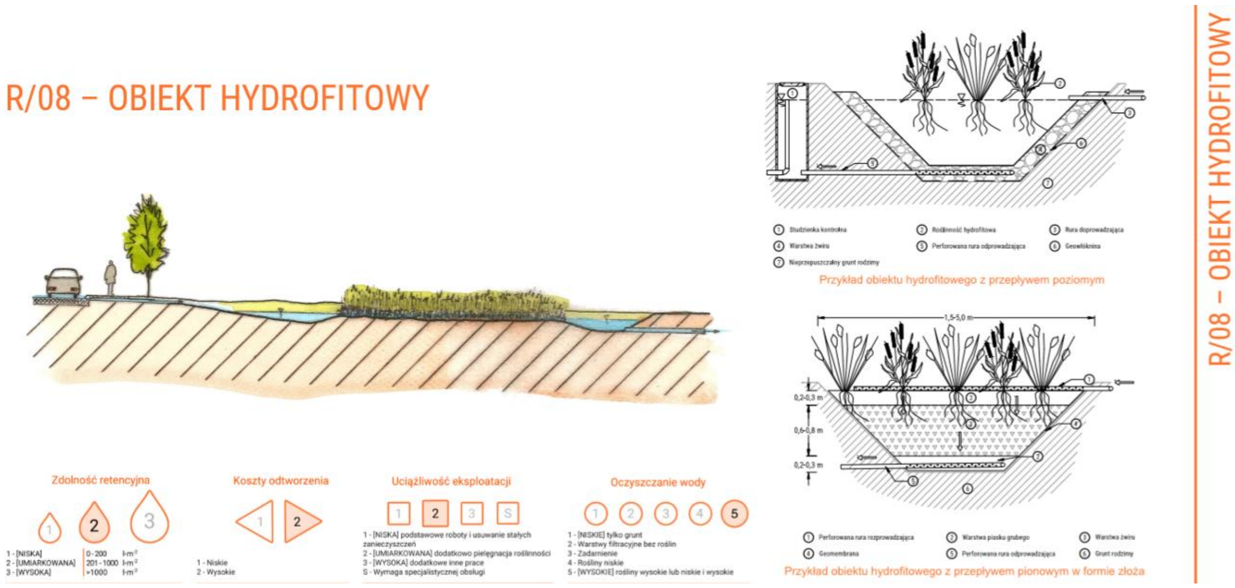



Figure: 33. Wetlands (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

Figure 34. Wetlands. (source:

https://architektura.um.warszawa.pl/sites/default/files/files/04%202017%2001%2019%20Ma%C5%82a%20Retencja%20w%20LP. pdf)

| | |
|---|---|
| Land use | **Urban/Semi urban/Semi-rural/Rural** |
| Catchment area | 0-1,0 $km^2$ |
| Dimensions | Should be designed for 50-100 years flood |
| Location | Anywhere at urban/rural catchments, where the terrain and land use is suitable |
| Target group | Municipalities, Farmers |

| Effects of measure | | Size of effect | Description |
|---|---|---|---|
| | Slow/Store runoff | HIGH | Wetlands are artificial ponds or swamps. They are facilities that regulates runoff and besides they can form cityscape and can be utilized for recreation. |
| | Increase Evapotranspiration | MEDIUM | |
| | Increase Infiltration | HIGH | Facilitates infiltration. |
| | Increase soil water retention | HIGH | |
| | Reduce pollutant sources | MEDIUM | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Cutting the grass and ensure the volume in the designing area. | | |

#### 4.2.9 Pervious pavements

Retention type: **Pervious pavements**

Figure 35. Grassy ditches and swales *(source: RBMP, Urban rainwater management guide, 2015)*

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 $km^2$ | | |
| Dimensions | Designed for open street parking places | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | Traffic areas upon gravel zones. The upper layer can be porous concrete, a mixture of asphalt or plastic grid. |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | MEDIUM | Facilitates infiltration. |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Ensuring infiltration capacity. | | |

### 4.2.10 Openwork Plate

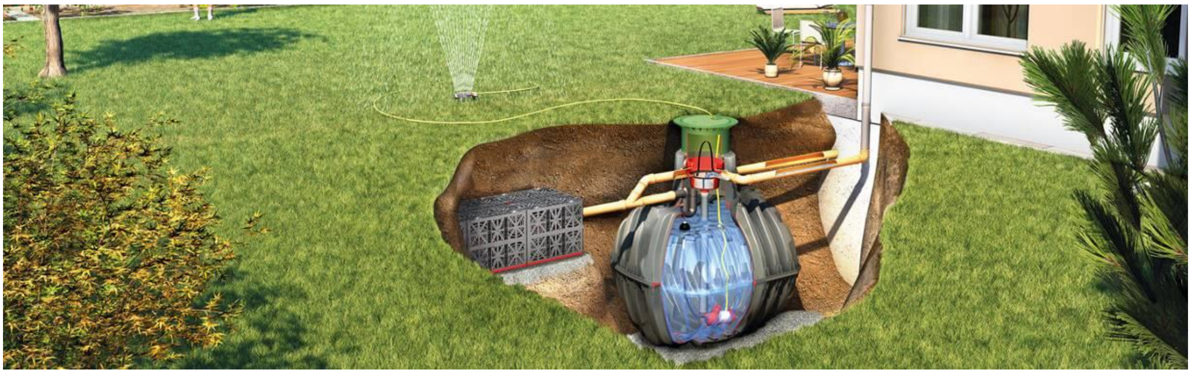
Retention type: **Openwork plate**

Figure 36. Openwork plate *(source: https://betongyepracs.hu/beton-gyepracs_ar.php)*

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 $km^2$ | | |
| Dimensions | Designed for open street parking places | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | Traffic areas upon gravel zones. The upper layer is openwork plate. The lower layers are pervious gravel, or soil. |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | MEDIUM | Facilitates infiltration. |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant | LOW | |

| | | | |
|---|---|---|---|
| | sources | | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Ensuring infiltration capacity. | | |

#### 4.2.11 Underground tanks for rainwater retention

| Retention type: **Underground tanks for rainwater retention** | | | |
|---|---|---|---|
| <br>Figure 37. Underground tanks for rainwater retention *(source: RBMP, Urban rainwater management guide, 2015)* | | | |
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 $km^2$ | | |
| Dimensions | Designed paved places where there is no possibility for surface storage | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | These tanks retain rainwater coming from roofs or surface runoff. The rainwater can be utilized for e.g. irrigation. Upon these tanks parking zones can be built. This solution is expensive, complicated but don't requiring a suitable surface. |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | NO | |
| | Increase soil water retention | NO | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |

| | | | |
|---|---|---|---|
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Ensuring storage capacity. | | |

### 4.2.12 Soakaway

Retention type: **Soakaway**

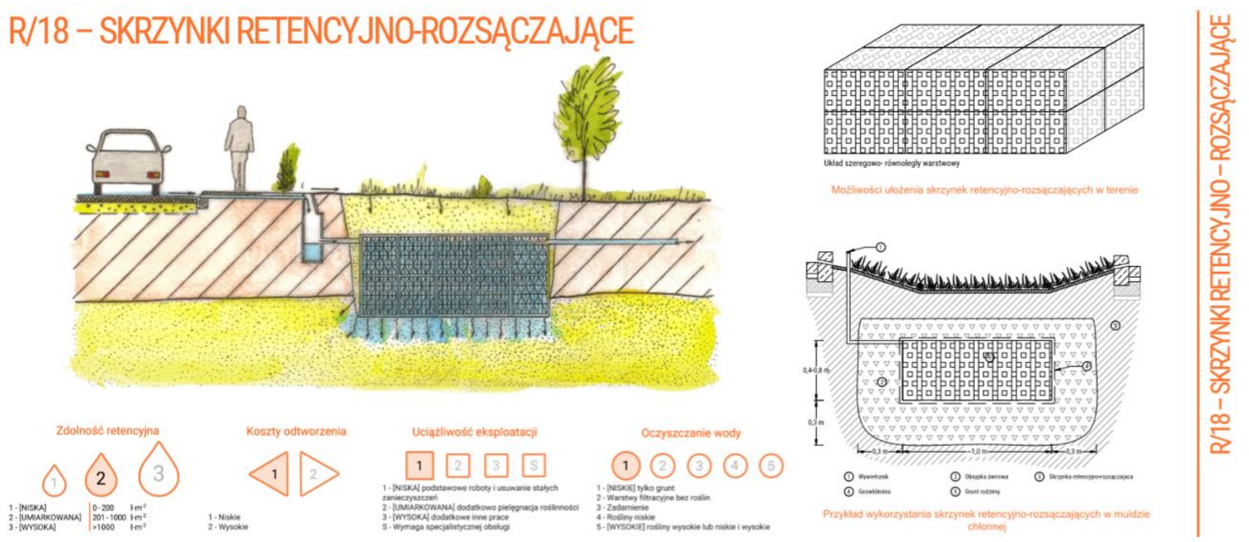
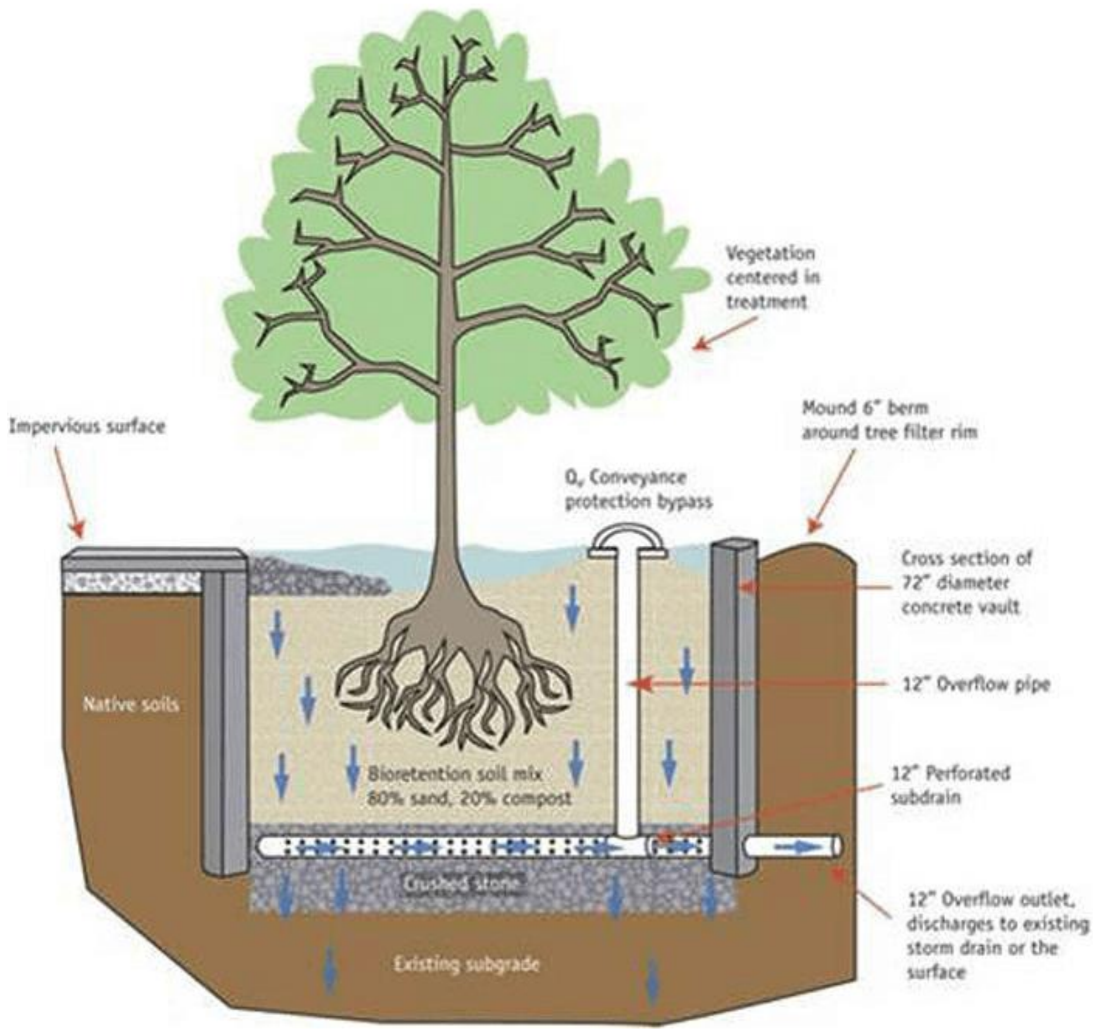



Figure: 38. Soakaway (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 km$^2$ | | |
| Dimensions | Designed paved/unpaved places where there is no possibility for surface storage | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities, Private property owners | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | These soakaway facilities retain rainwater coming from roofs or surface runoff, increasing infiltration. Upon these tanks parking zones can be built. This solution is expensive, complicated but don't requiring a suitable surface. |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | MEDIUM | |
| | Increase soil water retention | MEDIUM | |

| | | | |
|---|---|---|---|
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Ensuring storage capacity. | | |

### 4.2.13 Stormwater tree trenches

| Retention type: **Stormwater tree trenches** | | | |
|---|---|---|---|
| <br><br>Figure: 39. Stormwater tree trench *(https://mediaborough.blog/2018/05/17/stormwater-projects-in-the-borough/#jp-carousel-108*) | | | |
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 km$^2$ | | |
| Dimensions | Designed paved/unpaved places where there is no possibility for surface storage | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | These trenches retain rainwater coming from |

| | | | |
|---|---|---|---|
| | | | infiltration. Near these tree trenches pavements can be built, or places of recreation and sport activities. |
| | Increase Evapotranspiration | NO | |
| | Increase Infiltration | MEDIUM | |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | In addition to plant care (tree), specialist service (underground system) may occasionally be required. | | |

4.2.14 Detention pond

| Retention type: **Detention pond** | | | |
|---|---|---|---|
| <br>Figure: 40. Detention pond (source: *https://pl.wikipedia.org/wiki/Zbiornik_retencyjny#/media/File:2016_Zapora_zbiornika_retencyjnego_w_Stroniu_%C5%9Al%C4%85skim_1.jpg)* | | | |
| Land use | **Semi-rural/Rural** | | |
| Catchment area | 0-1,0 $km^2$ | | |
| Dimensions | The maximum size of the pond should be based on the catchment area, which is 1,0 $km^2$ | | |
| Location | Anywhere at semi-rural/rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities, Farmers | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | HIGH | These ponds retain rainwater coming from surface runoff. Usually it is dry, hence it can be used as a recreation area. It is filled only periodically in the period after rainstorms. It should be capable to receive 100 year flood. |
| | Increase Evapotranspiration | LOW | |
| | Increase Infiltration | HIGH | |
| | Increase soil water retention | MEDIUM | |

| | | | |
|---|---|---|---|
| | Reduce pollutant sources | MEDIUM | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Ensuring storage capacity. Remove of the sediment, and debris occasionally after floods. Cutting the grass, and shrubs every year. | | |

**4.2.15 Reservoirs**

<table>
<tr><td colspan="2">Retention type: Reservoirs</td></tr>
<tr><td colspan="2"><br>Figure 41. Reservoirs (source:<br>https://architektura.um.warszawa.pl/sites/default/files/files/04%202017%2001%2019%20Ma%C5%82a%20Retencja%20w% 20LP.pdf)<br><br>Figure 42. Reservoirs (source: Majewicz R. Wpływ działań retencyjnych w Lasach Państwowych na obszary rolnicze i zurbanizowane, dobre przykłady, Wrocław 14.12.2016)</td></tr>
<tr><td>Land use</td><td>Semi Urban/Semi-rural/Rural</td></tr>
<tr><td>Catchment area</td><td>0-10 $km^2$</td></tr>
<tr><td>Dimensions</td><td>The maximum size of the pond should be based on the catchment area, which is 10 $km^2$. It requires the 3-7% percent of the upstream catchment size.</td></tr>
<tr><td>Location</td><td>Anywhere at semi urban/semi-rural/rural catchments, where the terrain and land use is suitable. Reservoirs are typically sited at a lowest point in the catchment where it can receive drainage by</td></tr>
</table>

| | | | |
|---|---|---|---|
| | gravity | | |
| Target group | Municipalities, Farmers | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | HIGH | Reservoirs reduce runoff peak through storage. These facilities retain rainwater coming from surface runoff. They must be sized to cope with the 100 years flood volume. Usually these reservoirs have a certain amount of water permanently, but there is extra capacity in case of floodings. |
| | Increase Evapotranspiration | LOW | |
| | Increase Infiltration | HIGH | |
| | Increase soil water retention | HIGH | |
| | Reduce pollutant sources | HIGH | |
| | Reduce erosion | LOW | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Ensuring storage capacity. Remove of the sediment, and debris occasionally after floods. Cutting the grass, and shrubs every year. | | |

<u>Polish approach comments dedicated especially to rural and forest areas:</u>

In document - Good practices in the implementation of small retention facilities in the mountains [Dobre praktyki … 2010] are advices on creating reservoirs with more emphasis on the indication of important environmental information (because this document is dedicated to rural areas → forest). There are comments that small water reservoirs are characterized by the following parameters:

- water damming up to 1.5 m
- surface up to 10 ha,
- flow up to 2.0 $m^3/s$,
- for permanent retention reservoirs, the depth should exceed 1.5 m in the deepest places (conditions enabling the wintering of fish and amphibians).

The shoreline of the reservoir should be as varied and irregular as possible with respect to nature:

- bays,
- headlands,
- varied slope of slopes (1: 1.5-1: 10).

It is also recommended to create shallows and islands (among others for amphibians, patches), as well as large areas that will be flooded or uncovered as water levels change.

### 4.2.16 Water absorbing geocomposite

Retention type: **Water absorbing geocomposite**

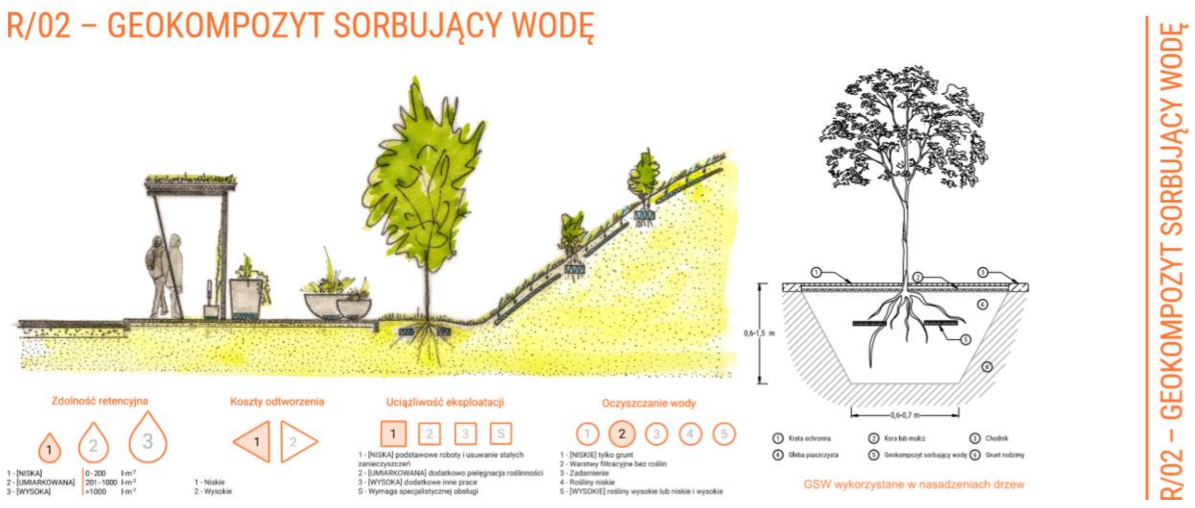



Figure: 43. Water absorbing geocomposite (source: Lejcuś K. at all "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. Wrocław 2017")

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-0,1 km$^2$ | | |
| Dimensions | Designed unpaved places where there is no possibility for surface storage | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where the terrain and land use is suitable | | |
| Target group | Municipalities | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | MEDIUM | These solutions retain rainwater coming from infiltration. Everywhere where vegetation solutions are used for supporting retention, regardless of whether they are grass, trees, shrubs, plants used to create green roofs or green walls, the development of these plants can be supported by water absorbing geocomposite (GSW). |
| | Increase Evapotranspiration | HIGH | evaporation in this activity is improved, because better conditions of existence (life) of plants are created |

| | | | |
|---|---|---|---|
| | Increase Infiltration | MEDIUM | |
| | Increase soil water retention | MEDIUM | |
| | Reduce pollutant sources | LOW | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | NO | |
| Maintenance requirements | Ensuring storage capacity. | | |

### 4.2.17 Combining *good practices*

| Retention type: **Combining *good practices*** |
|---|

Figure 44. Combining good practices, eg Coppenhagen Masterplan (source: http://landezine.com/index.php/2015/05/copenhagen-strategic-flood-masterplan-by-atelier-dreiseitl/)

| | | | |
|---|---|---|---|
| Land use | **Urban/Semi urban/Semi-rural** | | |
| Catchment area | 0-10,0 $km^2$ | | |
| Dimensions | The combined solutions reach the level of the settlement plan. These measures take a lot of influencing factors into consideration. Structure of the settlement, catchment size, available spaces, land uses, etc. | | |
| Location | Anywhere at urban/ semi urban/semi-rural catchments, where there is possibility for combined measures. | | |
| Target group | Municipalities | | |
| Effects of measure | | Size of effect | Description |
| | Slow/Store runoff | LOW÷HIGH | The combined storage measures have high importance in the mitigation of the effects of heavy rain. There is a wide range of these combinations |

| | | | |
|---|---|---|---|
| | | | eg. temporary inundated areas, detention ponds, stormwater tree trenches or underground tanks. |
| | Increase Evapotranspiration | LOW÷HIGH | |
| | Increase Infiltration | LOW÷HIGH | |
| | Increase soil water retention | LOW÷HIGH | |
| | Reduce pollutant sources | LOW÷HIGH | |
| | Reduce erosion | NO | |
| | Achieve Good Surface Water Status | YES | |
| Maintenance requirements | Each element of the system has special maintenance work, we have detailed them in the monitoring, evaluation and maintenance issues chapter. | | |

# 5. Summary and Conclusions

The objective of this study is a summary of theoretical knowledge and practical information on stormwater storage. These storage measures are key elements of urban and rural water management systems. The facilities help to mitigate the effects of climate change and heavy rainfall.

## 5.1. Discussion of approach

The theoretical background of the study was based on the results of international researches, supplemented by reservoir designing according to the Hungarian standards. As far as best practices are concerned, Hungarian and Polish solutions are presented.

From the factors influencing the runoff, through the runoff control to the conventional and green engineering solutions, we have fully described the processes influencing storage opportunities. In determining the size of the reservoir and in the technical practice guide, the Hungarian and Polish approaches were described in details.

Based on the theoretical background, stormwater storage measures are discussed in details, both in urban and rural landscapes. In this way, the user can on the one hand, get estimations for the size of a reservoir and on the other hand, get useful practical advice on the form of the retention that fits for the settlement or rural land structure or building regulations.

As mentioned, the study was mainly based on Hungarian and Polish theoretical, practical results with an international perspective.

## 5.2. Summary

Extreme rainfall is a growing problem in Central European countries every year. There are two basic solutions to deal with heavy rainfalls: Drainage and storage. The flexibility of aging drainage networks is questionable today, due to increasing volumes and the effects of climate change. Therefore, the exploitation of storage opportunities is becoming more and more valuable, especially in urban landscapes. The theoretical background of stormwater storage, the factors influencing the runoff and the possibilities of the runoff control were described in the study. Based on this, best practices on stormwater storage were presented - in 17 factsheets. Some of these best practices can be adapted to some urban and others rural areas. The study will greatly assist municipalities in their work by providing a knowledge base for selecting the appropriate storage type for their area and for simplified sizing. Besides municipalities, the study also provides useful solutions and knowledge for property owners, and farmers as well.

## 5.3. Conclusions

**Urban rainwater management is an integral part of water management and an element of urban management that affects the structure of cities, the quality of life of their inhabitants and their daily living, and is thus an important factor in urban planning.**

The impact of proper rainwater management on everyday life is to prevent flooding, and improve traffic conditions, making a vital contribution to safe and healthy living conditions. At the same time, solutions to rainwater management following the principles of sustainability can provide, recreational, cultural and other opportunities as well.

**The concept of supplies for urban water use needs to be reassessed and rainwater should be included in the recycling process.**

The decline of available water resources is a worldwide trend. The expected effects of the climate change could lead to a higher occurrence of weather extremes, which will also have a negative impact on the availability of sources. Rainwater is suitable for a variety of household and domestic water needs and, since it does not require any special training in treatment, may provide an alternative water source for the property owners. A simpler case of this is irrigation which is already being experienced, and other techniques of in-house use is under development.

**Rainwater should be given a more prominent role in shaping the urban environment and landscape, as it plays a special role in displaying aesthetic values.**

The negative effects of urban development, and the appearance of overcrowded or desolate areas, make the most people of big cities inconvenient. In addition to providing public services, the notion of a liveable city includes many elements that are physically hard to monetize, many of which are related to water. Many settlements have a waterfront location which is already determined by the water. The direct appearance of surface waters is provided by the closeness of rainwater to the formation, with aesthetically pleasing design that provides both recreational and habitat as well.

Indirect display of water is provided by city parks and groves, which are large consumers of water and whose water supply can be ensured by rainwater reservoirs. One of the great opportunities for reasonable source management is to irrigate large parks in or near the city centre with environmentally clean rainwater. The prerequisite for both solutions is the collaboration of landscape architects, urban planners and water management professionals. The result can be a harmonious relationship between the urban and the natural environment for the benefit of the city inhabitants.

# 6. References


**Figures:**

Figure 1., 2, 3, 5, 8, 9, 23, 25, 27, 29, 35, 37: Vízgyűjtő-gazdálkodási Terv – 2015 8-6 melléklet: Települési csapadékvíz- gazdálkodási útmutató, Buzás Kálmán (2015)
On line: https://www.vizugy.hu/vizstrategia/documents/10B9EE2E-D889-4C94-815D 5CB2D53C846A/8_6%20VGT2_Telepulesi_csapadekviz_gazdalkodas_utmutato.pdf (2020.02.26)

Figure 4. Potential runoff coefficient for different soil types (source: Determining design inland excess water discharge on lowland catchments, MI-10-451-1988, Hungarian Standard, 1988)

Figure 6.: Campana, N.A. and Tucci C.E.M. (2001). Predicting floods from urban development scenarios: Porto Alegre. In *"Urban drainage in the humid tropics"*. Tucci (Ed.) UNESCO International Hydrology Programme (IHP-V) Technical Documents in Hydrology, No. 40, Vol. 1, UNESCO, Paris 2001. pp. 186-194.

Figure 7. József Gayer – Ferenc Ligetvári: Urban rainwater management guide, 2007, VITUKI Nr. 80. pp. 31.

Figure 10-16. Designing Rainwater systems , MI-10-455-2-1988, Hungarian Standard, 1988*)*

Figure 17, 24, 26, 28, 30, 32, 33, 35, 38, 43: Lejcuś et al 2017, Lejcuś K. at all, "Katalog dobrych praktyk zasady zrównoważonego gospodarowania wodami opadowymi pochodzącymi z nawierzchni pasów drogowych. (Wrocław 2017)

Figure 18. Gábor Harsányi: Maintenance related issues (Middle Tisza District Water Directorate, 2019)

Figure 19-22. Imre Nagy: Runoff model analysis of the Kakat catchment (HEC-RAS 1d Model, Middle Tisza District Water Directorate, 2019)

Figure 31.: Gábor Harsányi, (Middle Tisza District Water Directorate Kisújszállás, 2005.)

Figure 34:

https://architektura.um.warszawa.pl/sites/default/files/files/04%202017%2001%2019%20Ma%C5%82a%20Retencja%20w%20LP. pdf)

Figure 36: https://betongyepracs.hu/beton-gyepracs_ar.php

Figure 39: https://mediaborough.blog/2018/05/17/stormwater-projects-in-the-borough/#jp-carousel-108

Figure: 40.:

https://pl.wikipedia.org/wiki/Zbiornik_retencyjny#/media/File:2016_Zapora_zbiornika_retencyjnego_w_Stroniu_%C5%9Al%C4%85skim_1.jpg)

Figure: 41.:

https://architektura.um.warszawa.pl/sites/default/files/files/04%202017%2001%2019%20Ma%C5%82a%20Retencja%20w% 20LP.pdf)

Figure 42.: Reservoirs (source: Majewicz R. Wpływ działań retencyjnych w Lasach Państwowych na obszary rolnicze i zurbanizowane, dobre przykłady, Wrocław 14.12.2016)

Figure 44. Combining good practices, eg. Coppenhagen Masterplan:

http://landezine.com/index.php/2015/05/copenhagen-strategic-flood-masterplan-by-atelier-dreiseitl/)

**Pictures:**
Picture 1.: Hely: Szolnok Zagyva folyó, https://www.flickr.com/photos/mega4000/9440370411 (2020.02.26)

Picture 2. :http://www.magyartelepulesek.hu/nagyszekeres/gazdasag.html)

*Picture 3.:* https://hu.wikipedia.org/wiki/Alatty%C3%A1n#/media/F%C3%A1jl:Alatty%C3%A1n_l%C3%A9gi_fot%C3%B3.jpg*), (2020.02.26) Készítette: CivertanS - A feltöltő saját munkája, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=44530275*

*Picture 4:* https://www.civertan.hu/legifoto/galery_image.php?id=7850*) (2020.02.26)*

*Picture 5.* https://www.imperial.ac.uk/news/184656/global-project-reduce-health-inequalities-cities/ (2020.02.26)

Dobre praktyki w realizacji obiektów małej retencji w górach. Przeciwdziałanie skutkom odpływu wód opadowych na terenach górskich. Zwiększanie retencji i utrzymanie potoków oraz związanej z nimi infrastruktury w dobrym stanie. Centrum Koordynacji Projektów Środowiskowych, Lasy Państwowe, Warszawa 2010

http://www.ckps.lasy.gov.pl

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Januchta-Szostak A., 2012: Usługi ekosystemów wodnych w miastach. Zrównoważony Rozwój – Zastosowania nr 3. Politechnika Poznańska

Lejcuś K., Burszta-Adamiak E., Dąbrowska J., Wróblewska K., Orzeszyna H., Śpitalniak M., Misiewicz J. Katalog Dobrych Praktyk Zasady Zrównoważonego Gospodarowania Wodami Opadowymi pochodzącymi z nawierzchni pasów drogowych Wrocław 2017 (on-line version is available here: https://www.wroclaw.pl/srodowisko/files/dokumenty/8811/Katalog%20Dobrych%20Praktyk%20-%20drogi.pdf)

Majewicz R. Impact of retention actions in State Forests on agricultural and urban areas, good examples.pdf

Wytyczne do realizacji obiektów małej retencji w Nadleśnictwach. Część techniczna Zwiększanie możliwości retencyjnych oraz przeciwdziałanie powodzi i suszy w ekosystemach leśnych na terenach nizinnych. Centrum Koordynacji Projektów Środowiskowych, Lasy Państwowe, Warszawa, 2008

## RAINMAN Key Facts

| | |
|---|---|
| Project duration: | 07.2017 – 06.2020 |
| Project budget: | 3,045,287 € |
| ERDF funding: | 2,488,510 € |
| **RAINMAN website & newsletter registration:** | **www.interreg-central.eu/rainman** |

Interreg CENTRAL EUROPE RAINMAN
European Union European Regional Development Fund

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## Project Partner

Saxon State Ministry of the Interior — STAATSMINISTERIUM DES INNERN | Freistaat SACHSEN

Environment Agency Austria — umweltbundesamt

Office of the Styrian Government — Das Land Steiermark → Wasserwirtschaft

T. G. Masaryk Water Research Institute, p.r.i — VÚV TGM

Region of South Bohemia — The Region of South Bohemia

Croatian Waters — HRVATSKE VODE

Middle Tisza District Water Directorate

Institute of Meteorology and Water Management National Research Institute — IMGW

Leibniz Institute of Ecological Urban and Regional Development — Leibniz Institute of Ecological Urban and Regional Development

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