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WATER RETENTION IN URBAN AREAS IN THE DANUBE REGION: STUDY ON FACTS, ACTIVITIES, MEASURES AND THEIR FINANCIAL ASSESSMENT

JOZEFÍNA POKRÝVKOVÁ
ĽUBOŠ JURÍK
RICHARD HANZLÍK

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Authors: Ing. Jozefína Pokrývková, PhD. (3,30 AQ)Q
prof. Ing. Ľuboš Jurík, PhD. (1,65 AQ)
Ing. Richard Hanzlík (0,55 AQ)Q

Reviewers: Dr.h.c. prof. Ing. Dušan Húska, PhD.
prof. Ing. Viliam Macura, PhD.
prof. Ing. Milan Čistý, PhD.

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Content

Introduction

In the period from 2021 to 2050, the average annual temperature is expected to increase from 0.5 ° C in the upper parts of the Danube International River Basin to 4 ° C in the lower parts of the river basin. Long-term forecasts of models on the development of temperatures from 2071 to 2100 indicate an increase in temperatures from 1 ° C in the upper parts of the International Danube River Basin, to 5 ° C in the middle and lower parts of the river basin. Studies using the latest high-resolution regional climate models show that even in countries belonging to the Danube region, large differences are reflected for different landscape units (1). Especially for countries with high mountains such as Austria, Croatia or Romania. Relatively small changes in average annual precipitation are expected and are likely to remain constant in the Danube region. Several models show a change in the amount of seasonal precipitation, when there will be more days with torrential rains. The unavoidable facts are the conditions that occur as a future increase in temperature as well as a strong seasonality of precipitation with a significant decrease in summer. The increase in extreme climate events, the effects on agriculture and the ecosystem can be considered very certain while the other effects are quite uncertain. Strong effects of climate change call for the adaptation measures development. The impacts of climate change will pose an increasing threat if the reduction in greenhouse gas emissions is not accompanied by adaptation measures to climate change.

The Danube region covers an area of 801,463 km^2, includes parts of 14 countries, several important mountain areas such as the Alps, the Carpathians and the Dinaric Alps. The main river is the Danube river with a length of 2 857 km, which is one of the main transport routes with a connection to the Rhine. The river delta is an important habitat for wildlife and fishing and has been designated for location of Ramsar Wetlands and UNESCO World Heritage Site.

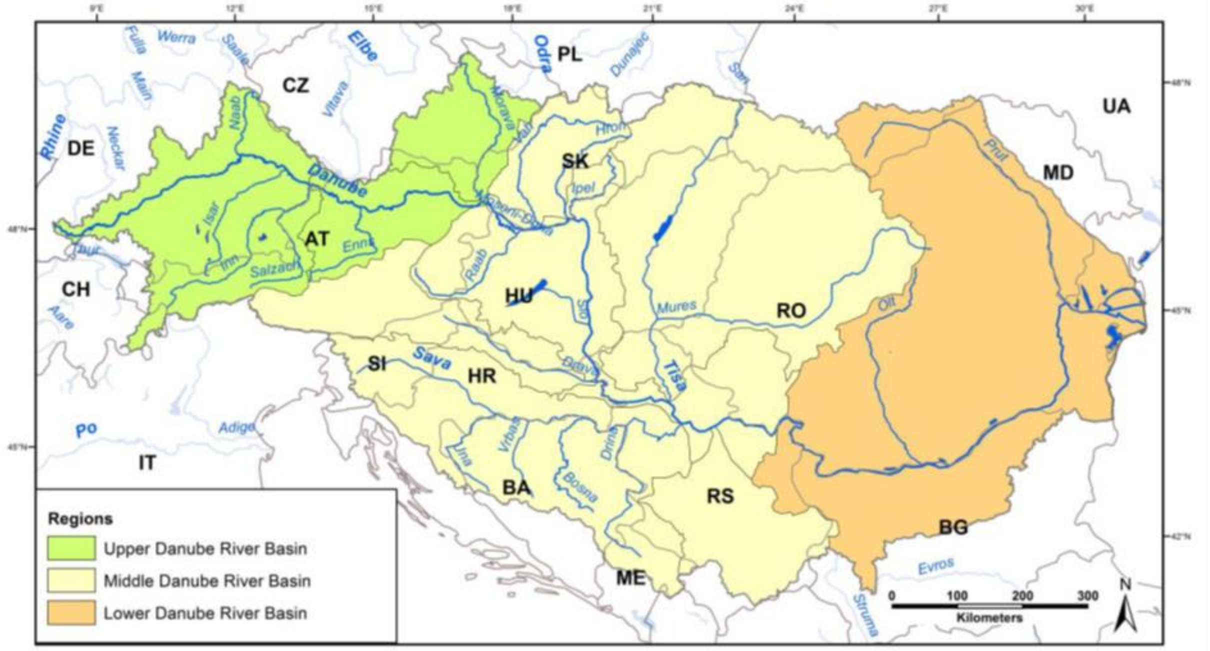


Figure 1: Main regions of the Danube River Basin (2)

The study on adaptation to climate change in the Danube region (2) shows the division into three basic parts of the region (Figure 1). The division consists of the Upper Danube River Basin District (UDRB), the Middle Danube River Basin District (MDRB) and the Lower Danube

River Basin District (LDRB). The average discharges in transitional parts of the river basin reach approximately 2 000 $m^3.s^{-1}$ at the Bratislava gauge, approximately 5 500 $m^3.s^{-1}$ at the Železná brána gauge and approximately 6 500 $m^3.s^{-1}$ in the Danube delta by the Black Sea.

Integrated Drought Management Programme in CEE and the objectives of the EU Strategy for the Danube Region Priority Area 5 (environmental risks) are emphasizing on the improvement of drought risk preparedness, proactive management and enhanced cooperation of key national and regional level actors. All to ensure the application of drought management in an integrated way. With this revision, there is a hope to spark multi-party conversation among public and private hydrological and climate change experts, water managers, those responsible for agricultural policy and major water users such as farmers and urban water suppliers.

Rainwater management (RWM) has become a global trend in the water management of cities and municipalities. The rate of urbanization first revealed the imperfections of the conventional drainage system in economically developed countries. Therefore the last twenty years have sought procedures and rules to introduce a new relationship to rainwater into the lives of these societies. Although these are cultural societies, the implementation of measures leading to RWM is lengthy and not always straightforward. There are basically two reasons why the principles of RWM cannot be applied more effectively to the rules of these societies. Firstly, it is difficult to change the way of thinking because the transition to RWM systems may not benefit the people of the cities and towns concerned immediately or in their lifetime at all. The conventional method of drainage still represents for many, albeit primarily and selfishly, a higher comfort of a tried and tested life, in which they do not have to deal with rainwater (3). The qualitative shift in the transition to RWM is perceived more by residents with a higher social feeling and a full-fledged intellectual background. The second reason is that the changes that need to be implemented are so far-reaching and fundamental that it is difficult enough to implement them into society's rules (in a democratic way) that they are mutually coordinated in the various fields of activity and therefore effective. From abroad, there is a wealth of information and experience with the complexity of the RWM implementation process. The knowledge and experience from these countries already help us to understand what awaits us to a large extent.

The presented results are based exclusively on the analysed studies, projects and adaptation activities of individual states of the Danube region.

1 Current state of knowledge on water capture and management of captured water in urbanized areas of the Danube region in the conditions of ongoing climate change

The urban environment, flood protection and maintaining the cleanliness of water bodies should be new aspects in urban and drainage planning. The development of water-sensitive cities takes into account the city's principle of sponges and uses methods that open up decentralized rainwater management, greening cities. In principle, this should reduce the runoff of rainwater from the sewer, increase its length of stay in urban areas and increase the possibilities for evaporation. The aim of these measures should be keep material and groundwater pollution to a minimum.

Water management of towns and villages faces many challenges. Aging infrastructure systems with a growing need for renewal, with the potential effects of climate change, challenges due to demographic change or growing concerns about exposure to (micro) pollutants are facing with increase of societal contradictions. If an urbanized area faces such challenges, it also offers the opportunity to adapt the drainage concept to a sustainable, flexible aspect and to propose it according to the currently available technologies and environmental requirements.

Since its inception in the 19th century, modern urban sewerage has focused on the rapid and direct drainage of wastewater and rainwater through central drainage systems, which ultimately guarantee a high standard of safety and comfort in disposal for their relatives (4). Main strategy was to drain rainwater quickly and completely, however with water management disadvantages.

According to the current climatic situation, we should be more inclined to increase the infiltration of rainwater and apply new knowledge, technologies to the construction and renewal of sewerage networks. Support the creation of groundwater resources and evaporation with effects on the urban microclimate.

Urbanization significantly changes the natural water cycle, both in terms of its quantity and quality. There is mainly a change in the quantity of surface runoff (Figure 2).

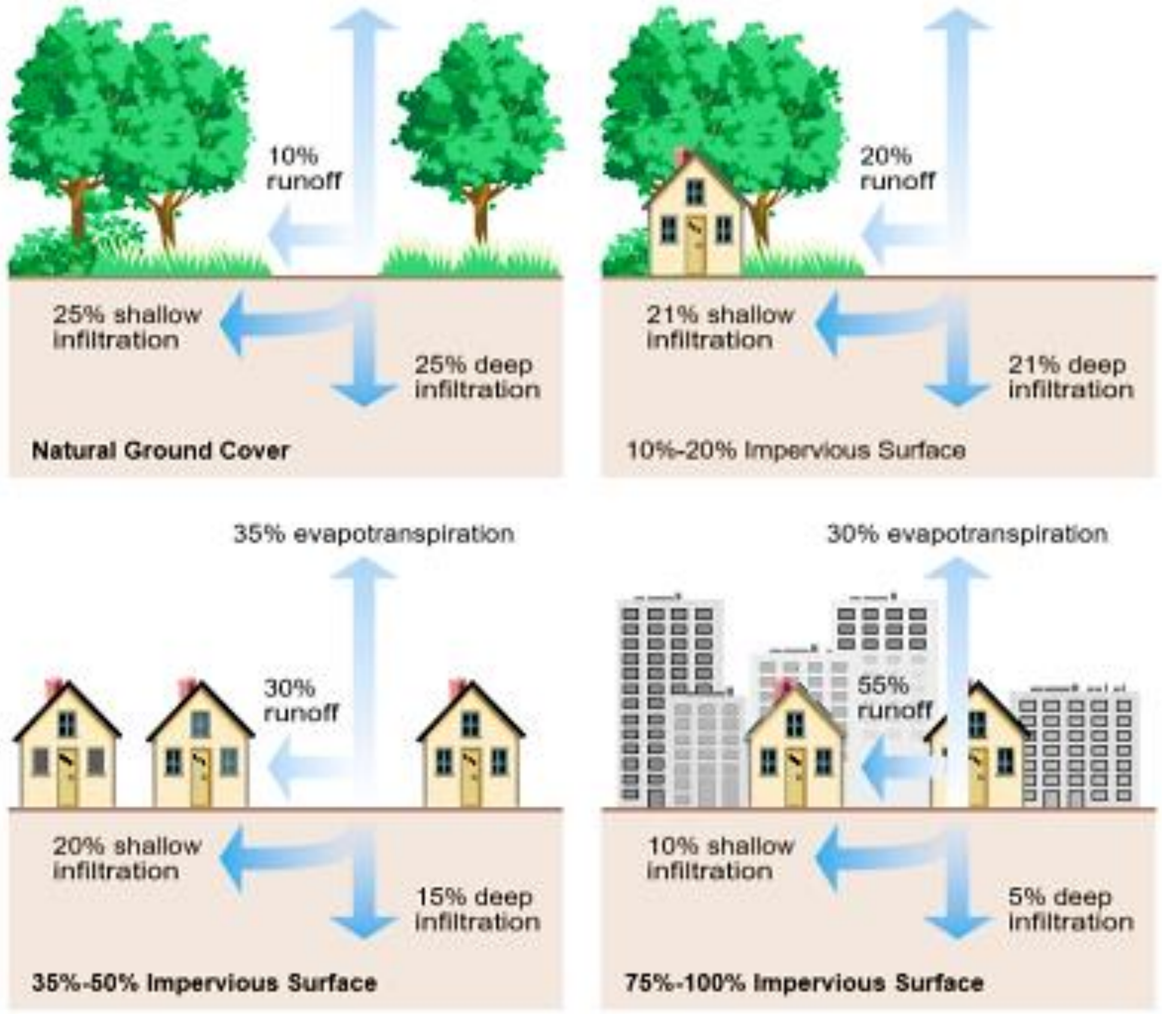


Figure 2. Changes in hydrological conditions with increasing impermeable surface (5)

Urban areas are characterized by a high proportion of impermeable areas (e.g. roads, roofs of buildings) which in the centre of urban agglomerations reaches 70 percent or more. Water falling on the surface of a river basin in a rainy weather cannot naturally infiltrate into the groundwater collector. Also the level of evapotranspiration (evaporation) is reduced compared to natural conditions (6). Most of the rainwater volume flows down the paved surface of the river basin into the rain gutters and is drained from the urbanized river basins through the sewer network. In addition to the volume the surface runoff rate is also essential which is reflected in the reduced ability to transform the peak flow.

The consequence of the increased volume of surface runoff and its velocity is a change in the hydrological regime of the watercourse (7) which is manifested by a more frequent occurrence of local floods. This is especially important in situations where a greater degree of urbanization as a unit lies in a small watercourse. A sudden increase in flow can cause damage to tangible property around the watercourse or even on health in similar to a conventional flood. Morphological changes of the flow (straightening, strengthening of the riverbed) which reduce the ability of the flow to transform the flood wave, have also a negative effect here. However, due to the higher frequency of local floods in addition to urbanization, the impacts on the watercourse are also significant. These are mainly hydraulic stress and bringing in more pollutants. Both phenomena subsequently affect aquatic fauna and flora (8). Hydraulic stress causes significant erosion of the ground and bank of the watercourse and washes away organisms living in the aquatic environment (9). The flow loses its aesthetic and ecological function.

Long-term studies, measurements and models predicting climate change for Europe (10), (11), (12) and the US (US Global Change Research Program) confirm the trend of changing the intensity and periodicity of torrential rains with short duration which are crucial to system proposal for rainwater drainage in urban areas. Increasing values of the intensity and periodicity of rainfall lead to a higher susceptibility of drainage systems to their failure (overload). In practice, this means that the hydraulic reliability of existing or currently proposed drainage systems will decrease over time (i.e. more frequent occurrences of pressure flow and runoff of wastewater to the river basin) which is an essential fact in planning drainage systems whose life is in the tens of years (13).

One of the main tasks of the city's water management infrastructure is safe drainage and eventual rainwater treatment. Various methods are available. They have begun adaptation to this trend of applying available technologies which improves the environment and reuse rainwater in many countries. Therefore, in a period of uncertain future development, decentralized solutions are increasingly being proposed as sustainable processes for the future. The basic idea is to give up costly infrastructure investment projects and to respond more flexibly to different future conditions. Another advantage is that decentralized processes, such as on-site infiltration, shift the urban water cycle towards a natural water balance and these processes also have environmental benefits such as increasing groundwater recharge, improving the microclimate or reducing rapid surface runoff.

1.1 Use of rainwater in cities

Use of rainwater is one of the oldest ways of managing water resources in the country. The use of rainwater in households or buildings for flushing toilets, washing cars or floors and last but not least, washing ourselves is often listed as examples (14). With this system, the rainwater is again converted into wastewater and needs sewage systems to drain into the wastewater treatment plant. In many buildings, rinsing or watering green with retained water has prevailed. However, its use is precisely affected by its quality, water from rain or snow belongs to special types of wastewater. Its pollution is either organic or inorganic. Depending on the origin, its quantity or pollution is also governed. Water is most often polluted mechanically by impurities on solid surfaces but also chemically by emissions from the air (so-called acid rain). Its runoff follows immediately after its occurrence. It is possible to consider their appropriate use only after the exact determination of the quality of rainwater (Table 1). Another term is natural water retention measures (NWRM). This concept is more related to measures that are being addressed in the country or to integrated water management in cities. „Natural water retention measures are multifunctional devices that aim to protect and manage water resources using natural means or processes. Their importance is especially in the country and in large open areas. Space is a basic limiting condition in cities. Retention nature-friendly measures for natural water or natural water retention measures have the primary function of increasing and / or restoring the retention capacity of the aquifer, soil and aquatic ecosystems. These enhanced features enable the delivery of more services and benefits to society while contributing to the objectives of environmental strategies and policies“ (15).

Table 1 Average values of the content of substances in precipitation in Slovakia

Indicator	Unit of measure	Range of measured values in Slovakia	Range of measured values
pH	-	4,3 až 5,8	
Electrical conductivity	$uS.cm^{-1}$	40 až 75	
Na^+	$mg.l^{-1}$	0,2 až 1,6	0,25
K^+	$mg.l^{-1}$	0,03 až 0,4	0,19
NH_4^+	$mg.l^{-1}$	0,5 až 3,4	0,9
Ca_2^+	$mg.l^{-1}$	1,9 až 5,5	0,37
Mg_2^+	$mg.l^{-1}$	0,1 až 0,5	0,06
Fe_3^+	$mg.l^{-1}$	0,02 až 0,4	0,17
Al_3^+	$mg.l^{-1}$	0,05 až 0,8	
Cl^-	$mg.l^{-1}$	0,4 až 3,7	0,31
NO_3^-	$mg.l^{-1}$	2,8 až 10	2,4
F^-	$mg.l^{-1}$	0,1 až 0,8	0,012
SO_4^{2-}	$mg.l^{-1}$	8,3 až 15,8	1,7
Zn^+	$mg.l^{-1}$		0,007

Water retention in cities

Water retention in cities and towns must be subordinated to fact what will happen to the water. There are several possibilities that are used today:

- short retention of water in underground or surface reservoirs and subsequent discharge into the sewer network at a selected distance after the end of the rain;
- longer water retention in surface or underground spaces and consequent slower consumption, e.g. for flushing, etc.;
- longer water retention in surface or underground areas and consequent slower infiltration into the soil environment;
- longer retention of water in surface or underground areas and subsequent slower infiltration into the overgrown roots environment of trees or other vegetation and subsequent evapotranspiration with an effect on the temperature and humidity of the environment;
- longer retention of water in surface or underground areas and consequent slower consumption for the needs of vegetation by means of irrigation or technical supply to plants, which are e.g. in green roofs or walls;
- longer retention of water in the soil environment and subsequent use for artificial wetland habitats;
- longer water retention in surface tanks creating evaporation and humidification of the surrounding environment;
- other options and combinations for delay (16).

The second question is where the water can be retained so that it can be used effectively. In principle, as close as possible to the place of its origin, i.e. water from roofs on roofs and water from ground level on the ground or as close as possible to the surface. Otherwise, additional energy is subsequently consumed for its use, e.g. for pumping. The method of water retention itself must be linked to its use. The retained water with an open surface is subsequently affected by sunlight, which leads to its warming and especially to the growth of algae or funnels and other organisms, which deteriorates the quality of water. Water must be treated at least by filtration or other more energy-intensive methods before use. Retaining water in enclosed spaces below the surface of the terrain is primarily more expensive but with a more stable temperature and often without access to sunlight, which removes its revitalization of algae and other organisms, and so its properties are good for further use (17) (18). It is necessary to know the occurrence of precipitation in the addressed locality to determine the amount of water to be retained and for how long. Thorough examination of the data available mainly from measurements but also from other available sources, usually informing about the development of the weather, must be performed here. They also provide longer series of quality data for some measurement locations. The assessment of the site is based on the deepest possible knowledge of the conditions in the area related to precipitation - quantity and their quality, temperature and other climatic conditions (humidity, wind, radiation and clouds, etc.), land area (land ownership and land use plan , land that can be use for infiltration and conditions for the use of retained water). Additional data, such as data on protected areas, protection zone requirements or data on possible contamination of structures or the soil environment in the past during land use, can protect us from problematic design. This is important e.g. in the revitalization of former plant premises, car parks, landfills or railway stations, sidings, etc. We could endanger surface or groundwater or the health of humans and other organisms by infiltrating the increased amount of water.

1.2 An essential element of water stability in the Danube region

Water reservoirs in the Danube region are the basic element of water stability in the country just like in the whole world. Overview of the most important water reservoirs in the Danube region (Figure 3).

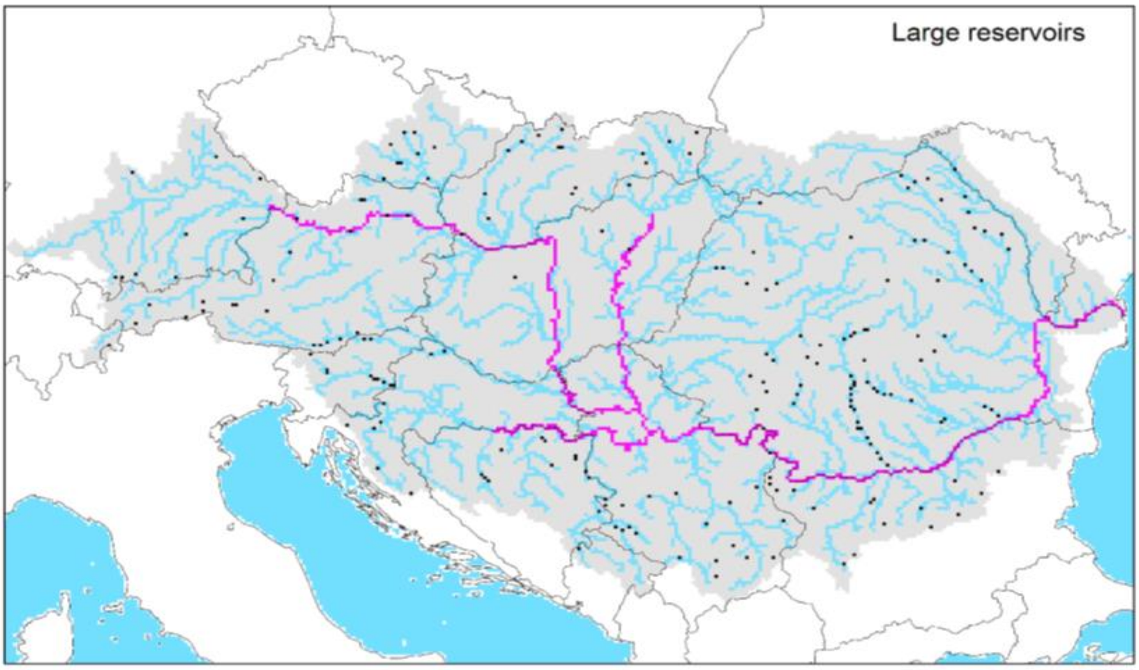


Figure 3 Water reservoirs of the Danube region as a basis for the sustainability of water resources in the country (19)

There is a predominance of developing countries which currently and according to prospective studies in the future, the movement of inhabitants from rural areas to cities and thus the growth of built-up urban areas due to the growth of residential areas but also shopping and industrial parks in the Danube region.

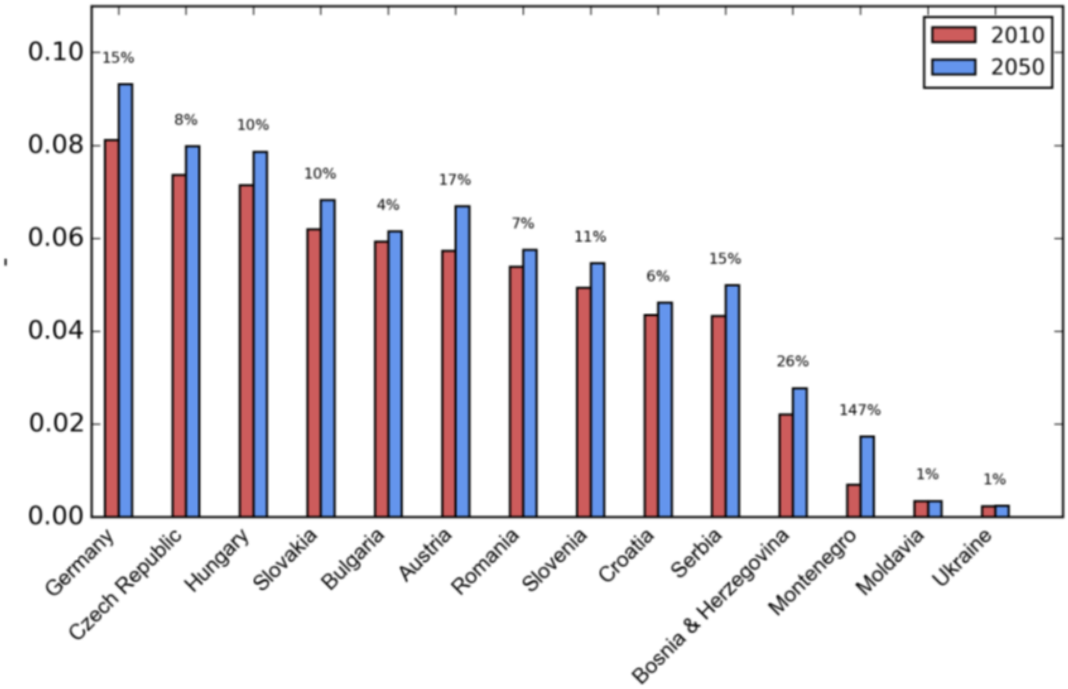


Figure 4 Barplot of fraction urban area for 2010 (red) and 2050 (blue) as simulated with the LUISA model (only pixels within Danube (2)

The increase in urban areas and, of course, the number of people in these (figure 4) areas brings many changes not only to the surrounding environment - the removal of raw materials and the need for food, the need for places for recreation but also for the urban areas themselves.

The reason is the old historical centres with old water supply systems or sewer networks. Newly built parts of cities form the packaging layers of old centres are usually connected to these networks, proposed for a small part of today's population.

Water pipes are less endangered because very high water consumption was once assumed and today the reality is often only about 30-50% of the original consumption.

An excellent example is the city of Vienna, which had a population of about 2,5 million around 1900 and now os only 1,9 million after more than 100 years. This city is almost a complete exception. Other cities have a completely opposite development. E.g. Budapest had about 300 thousand inhabitants in 1870, then more than 800 thousand in 1900 and today more than 2,5 million inhabitants. In proportion to the number of inhabitants, the built-up area and demands on the water supplied by water mains also grew which was subsequently converted into waste water. An even more significant change in population is for the city of Sofia. In 1990, the city had about 68 thousand inhabitants. Today, Sofia has a population of about 1,25 million.

The old central sewer networks became overloaded and in addition to wastewater more and more surface runoff (rainwater) entered them. The result was the construction of objects called a relief chamber (Combined sewer overflows - CSOs - Fig. 5). They are designed to reliably distribute the flow of wastewater and rainwater in the sewer network in the ratio assumed in the calculation. After intensive precipitation, a part of the storm water, after mixing with the sewage water, is led directly to the recipient through a relief drain starting in the relief chamber. This makes it possible to reduce the diameter of the pipe leading further to the wastewater treatment plant. The rainwater is thus fed into a sewage pipe and then, when it is no longer possible to carry this volume through large pipe diameters, part of the mixed water is discharged directly into the river during the rain and this process is repeated several times depending on the area (20).

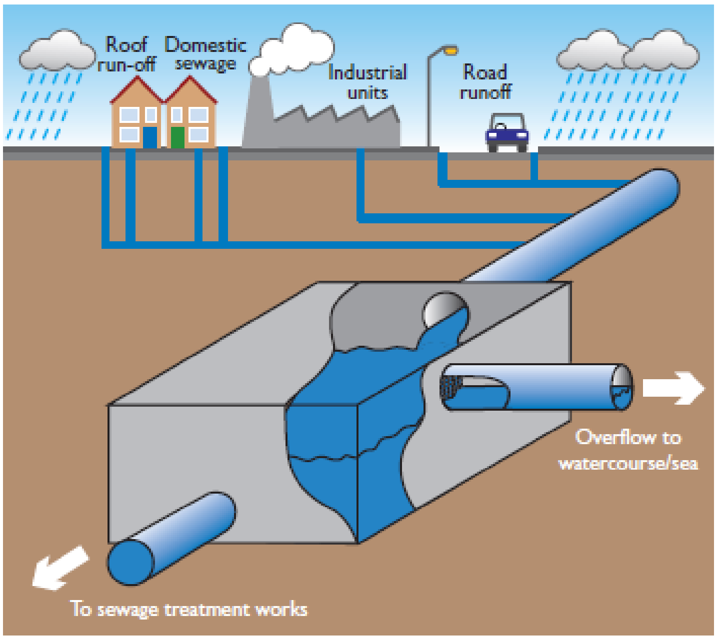


Figure 5 Combined sewer overflows - CSOs (20)

The relief chamber (Figure 5) is an economical solution for cheapening the sewer network by reducing the cost of the main sewer pipe, but from an ecological point of view it should always be discussed with the river administrator and hygienic-epidemiological authorities (21).

The system of combined relief chambers (Combined sewer overflows) is economically and ecologically very demanding. The sewer network manager pays high fees to the watercourse manager for the water thus drained. And the water introduced threatens the water quality and the environment of the organisms in the watercourse which is a source of criticism from environmentalists. Therefore, both parties are trying to remove such objects.

There are two solutions:

- Reconstruction of the sewer network and construction of large pipelines.
- Restriction resp. reduction of water flow in the sewer network.

Reconstruction of sewer networks is financially, organizationally and spatially demanding and often impossible due to the existence and intersection of other engineering networks (22).

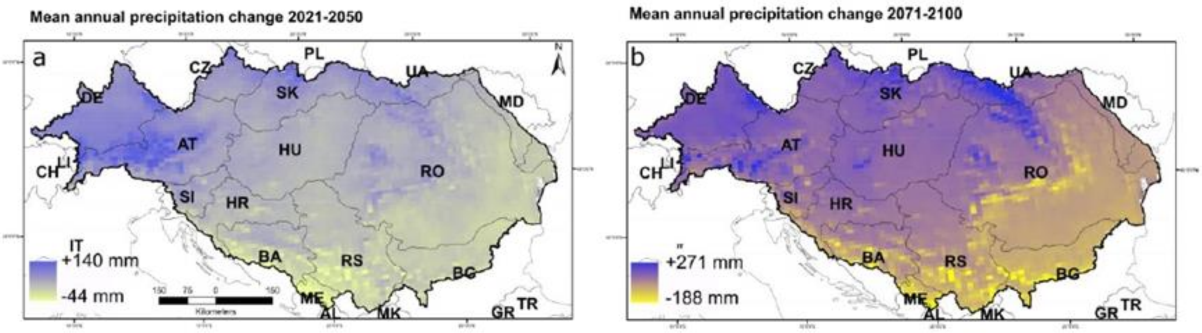
The reduction of the flow can be solved either by changing the water consumption and the production of wastewater, which took a relatively long time, e.g. by changing equipment in households - taps or toilet solutions, etc. these changes affect runoff during the rainy season. But the bad situation is after a torrential rain - a storm.

The cities have set about building huge underground tanks, where the water stays during the rain and then drains in a controlled amount after. It is a very financially and technically demanding solution. Such a solution is often used by so-called Megacities where there is no other option. Tokyo, Singapore, etc. are currently operating on this system.

The problem of all cities is climate change. Measures that have been built and oversized in recent decades are confronted with a change in the intensity of precipitation. The annual total precipitation in the Danube river basin has not changed over the last 10 years. In some areas it has even increased slightly. However, torrential rains cause an increased runoff from paved areas and an increased load on the built sewerage networks as well as flooding of urban infrastructure.

Therefore, the solution for the future is only a change of approach, namely not to drain rainwater and bring the functionality of urban areas closer to the original infiltration of water into the soil or its retention in various depressions, hollows or increasing retention in the soil. Over time, this system was given the designation rain water harvesting, rain water retention or today finally Green measures. Probably the most appropriate name is Green infrastructure because it is the forming facility for the proper functioning of the area similar to the transport infrastructure (23).

On the Upper Danube, precipitation ranges between 2 000 mm in the higher Alps and 500 - 700 mm in medium altitudes. However, actual numbers may differ significantly from long-term averages. There were already rainfall amounts on the upper Danube around 260 mm of daily increment.


Mean annual precipitation change 2021-2050

Mean annual precipitation change 2071-2100

Figure 6 Change of mean annual precipitation in the Danube River Basin for the periods 2021-2050 (a) and 2071-2100 (b) according to the EURO-CORDEX ensemble runs under RCP8.5 (24)

Figure 6 shows an overview of the expected change in precipitation for the Danube river basin. The annual total precipitation is likely to increase in the vast majority of river basins, in mountainous areas even more than 100 mm. The changes are different during the individual parts of the year and there are significant changes, especially in the summer (Figure 7). Large differences are expected in individual regions, where there will be a relatively large increase and decrease in precipitation.

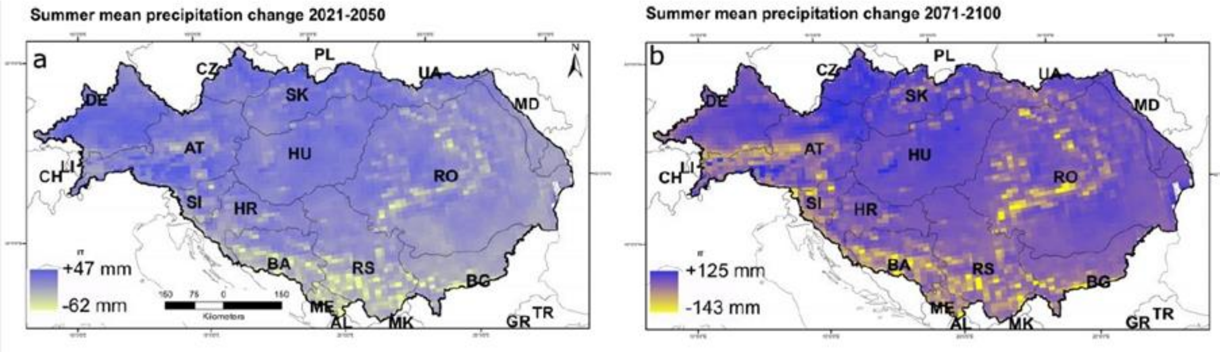


Figure 7 Change of mean summer (JJA) precipitation in the Danube River Basin for the periods 2021-2050 (a) and 2071-2100 (b) according to EURO-CORDEX ensemble runs under RCP8.5 (24)

Germany faces environmental policy challenges of increasing urbanization in agglomerations, including the associated positive or negative environmental impacts. Urban space has paramount importance not only because of its population density and the necessary effects on environmental regulation but also as a real laboratory for sustainable living.

Extensive use of decentralized rainwater management or integrated approaches has not been introduced in Austria yet due to the existing gas pipeline infrastructure, which has grown over the decades. Use is limited to individual measures and locally limited projects nowadays. However, in new buildings and renovations or renovations of sewerage systems, the goal is increasingly being pursued, rainwater that is not or only slightly polluted, e.g. natural drainage from roof surfaces and direct seepage. On the other hand, the street runoff usually flows to the sewage system and fed to a waste water treatment plant, as there are reservations about decentralized solutions due to pollution caused by pollutants in winter with road salt.

1.3 Basic parameters for proper rainwater retention in various ways

In order to classify these issues, it has to be seen that over the last decade, rainwater management has been reviewed as „decentralized almost natural rainwater management“ and the exclusive and systematic rapid runoff of rainwater through the sewer system has been questioned, especially in urban areas. „Decentralized management of near-natural rainwater means that precipitation is in principle recorded where it occurs and where is possible, it fed back into the natural water cycle on site by appropriate systems (25).“ It is possible to be achieved by storage, evaporation, drainage and infiltration, creation of seepage lanes, creation of rain gardens, application of green roofs or water-permeable areas (26), (27), (28). The building blocks of decentralized rainwater management are evaporation, infiltration, retention, drainage, storage, use, drainage retardation, cleaning and maintenance (28). The range of decentralised rainwater management techniques developed also offers the possibility to regulate the amount of water collected or to improve the quality of the water by filters, so there an improved and controlled supply can take place.

The planning of a multi-purpose infrastructure for rainwater using a three-point approach was presented by prof. Peter Steen Mikkelsen from Denmark at the meeting „Rainwater Management - Findings from Real Projects in the Czech Republic, Germany and Denmark“. Where he points out that the consequence of changes in the traditional way of thinking and new challenges in urban drainage associated with climate change, system maintenance and new types of water pollution (micropollutants) is a multi-purpose infrastructure. The trigger for these changes in thinking has been several large torrential rains in recent years in Copenhagen, when the worst of them (150 mm in 2 h) in 2011 caused $ 1 billion in damage.

Measures related to the management of rainwater in cities should be increasingly supported by multiple functions so as to increase the attractiveness of the city for life in addition to the classic drainage function. The so-called three-point approach describes the three levels at which rainwater management is decided and that needs to be taken into account when looking for sustainable solutions.

Domain A deals with daily rain (80% of total precipitation) and is aimed at improving the annual water balance (retention, evaporation) and using rainwater as a source to increase the sustainability or attractiveness of cities.

Domain B deals with the proposed rain (with a repetition period of 10 years) (19% of total precipitation) and the reduction of sewer network overload and flooding of the terrain using traditional technical solutions.

Domain C is the domain of extreme torrential rains (with a repetition period of about 100 years) (1% of total precipitation), when traditional sewer networks fail and it is necessary to propose measures to reduce the impact of floods in cooperation with urban planners (safe drainage of water from the city using selected streets or tunnels).

The solutions must work for all three areas. This approach also makes it possible to respond to climate change and is a good basis for communication with various stakeholders, including non-experts.

According to standard from Czech republic, ČSN 75 9010, surface runoff waters are divided into two categories with regard to infiltration:

- rainwater permissible - can be infiltrated through an unsaturated area without pre-treatment;
- Conditionally permissible rainwater - it is necessary to apply a suitable method of physical pre-treatment - depending on the type of pollution and the type of infiltration equipment.

Rainwater is permissible - does not pose a risk in terms of soil pollution and endangering the quality of groundwater. These are waters from grassy areas, roads for pedestrians and cyclists, entrances to individual garages and entrances to family houses.

Rainwater is conditionally permissible - rainwater, the quality of which may be impaired by the content of specific pollution. This is a surface runoff from roads for motor vehicles, car parks for motor vehicles up to 3.5 t and buses, roads of industrial and agricultural areas.

Basic points for the application of water retention measures:

- climatic and meteorological environmental conditions,
- hydrogeological environmental conditions,
- soil permeability - has a significant influence on the choice of drainage method, as it mainly affects the applicability of infiltration measures,
- subsoil - in addition to the seepage capacity of the soil, there are other subsoil properties that need to be taken into account, especially in the case of seepage measures.

Distribution of facilities and objects according to their function of rainwater management:

1. Measures to improve the microclimate or to prevent precipitation:
    - lawns,
    - trees,
    - semi-permeable surfaces,
    - vegetation roofs,
    - vegetation facades,
    - shallow infiltration inserts and its variants.
2. Infiltration equipment without regulated drain:
    - surface infiltration (without retention),
    - inserts and its variants (fitted inserts, etc.),
    - infiltration retention tank,
    - infiltration retention groove and its various forms,
    - infiltration pads with retention groove and its variants,
    - infiltration shaft.
3. Infiltration devices with regulated runoff:
    - infiltration pads with retention groove and regulated drain (and its variants),
    - infiltration retention tank with regulated drain,
    - infiltration retention groove with regulated runoff.
4. Retention objects with regulated runoff:
    - dry retention rain tank and its variants (e.g. water square, water playground, park),
    - retention rain tank with storage space,
    - underground retention rainwater tank,
    - artificial wetland,
5. Accumulation and use of rainwater.

1.4 Impacts of extreme events on drinking water supply

The idea of "water-sensitive urban design" (WSUD) originated in Australia and is often used in connection with "water-sensitive cities", with WSUD describing the process and "water-sensitive city" describing the objective. This is a broader approach in the field of spatial planning, where rainwater management is only part of it. The main objectives are to regulate the urban water balance, protect or improve the quality of the receiving water, support the reduction of water consumption by capturing rainwater or recycling less polluted wastewater and maintain or improve the recreational and protective function of water to maintain the water quality. The WSUD covers all aspects of the city's water balance and therefore focuses on a holistic approach. For rainwater management, as a sub-discipline of WSUD, this means mainly reducing floods, controlling and regulating flows, improving water quality and replacing drinking water with rainwater for use in areas that do not necessarily require drinking water quality (29).

1.5 Assessment of rainwater management measures to approximate the natural water balance

As already mentioned, urbanization leads to increase sealing of previously natural surfaces. This has a significant effect on the water balance, as described above (Figure 2). Runoff increases while evapotranspiration and groundwater accumulation decrease. This leads to various negative effects, such as high volumes of discharges into the recipient, increased risk of floods, city "heat islands", etc.

Rainwater management measures can mitigate the negative effects of urbanization. The aim is to restore the natural hydrological regime as much as possible or at least to approach it (natural target state). Rainwater management measures, such as green roofs, infiltration troughs or ditches, use hydrological functions along natural river basin lines, such as infiltration, evapotranspiration and (temporary) storage.

Hydrological simulations are an appropriate means of evaluating the performance of rainwater management measures with respect to water balance. In order to evaluate the required approximation of the natural water balance, the hydrological conditions in the natural and stopped state must be analysed (30). Usually, only the runoff component of the water balance is taken into account. Evapotranspiration and groundwater enrichment (or change of reserves) is often neglected, although it plays an important role, for example with regard to the effect of water balance and groundwater level (31) (32).

A holistic approach (33) that takes into account all components of the water balance should be adopted in order to assess the performance of rainwater management measures. In addition, simulations with measured continuous precipitation are used instead of average annual rainfall or artificial model rain. In particular, the hydrological conditions at the beginning of the rain event are taken into account.

Water balance in natural and urban areas

Natural catchment areas usually have a very low proportion of runoff (surface runoff). Large amounts of water can evaporate due to soil and vegetation. The proportions of evapotranspiration, infiltration and changes in deposition vary depending on vegetation, topography, subsoil and climatic conditions. In comparison, the share of runoff increases significantly in urban areas with several impermeable areas. Evapotranspiration and groundwater recharge rates are reduced or completely limited.

The basic formula for calculating the hydrological balance expresses the difference of water inputs and outputs in the area and the resulting value is the amount of water reserves, for example in mm for a certain period that remains in the area.

$$\Delta S = P - (E+T) - Q$$

Where:

ΔS - changes in water reserves in the area (hydrological balance),

P – precipitation,

ET - evaporation and transpiration (also called evapotranspiration),

Q - total runoff.

The total runoff is further divided into the following three categories:

Q_p - surface runoff,

Q_h - subsurface (hypodermic) runoff,

Q_b - basal runoff.

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1.6 Agriculture with regard to water quality in urban areas

Agriculture is one of the most significant surface sources of pollution. This involves the supply of nutrients and plant protection products to the aquatic environment, both by surface washing and then by gradual and constant washing of substances through the soil profile through shallow groundwater, sometimes intensified by surface drainage. Possible direct discharges from agricultural holdings are addressed as a point source of pollution from industry.

Pouring floods into open areas, revitalization, dams, dry reservoirs and others. This is not enough. We have to treat the water where it rains, that is. On agricultural and forest land, which make up the majority of the Danube region. Measures need to be applied that contribute to better retention of precipitation, slow down runoff and prevent erosion. Reducing erosion and better infiltration of precipitation are inseparable. Water that soaks in a field, meadow or forest, retains in a shade or dam, does not flow quickly down into a valley and does not form a flood. We can then use it in times of drought (34)(figure 8).

On a global scale, up to 80% of municipal wastewater is discharged directly into watercourses without any treatment. The industry is responsible for disposing of millions of tons of heavy metals, solvents, toxic sludge and other wastes in watercourses every year. Agriculture accounts for 70% of water consumption worldwide and plays a significant role in water pollution. Farms discharge large amounts of agrochemicals, organic matter, drug residues, sediments and drainage into water bodies.

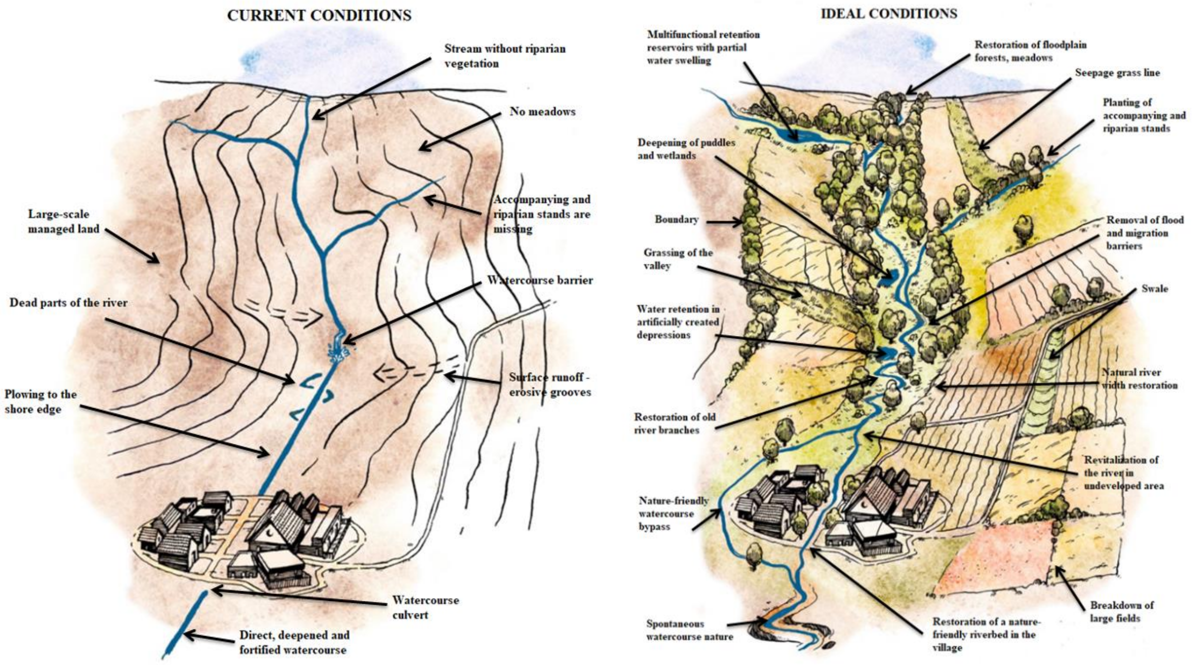

Figure 8 Current and ideal conditions of the country's layout (34)

1.7 Ecosystems with regard to water quality in urban areas

Hydromorphological measures, such as fish pipelines or the reconnection of wetlands and floodplains to the main watercourse, increase the resilience of ecosystems and their services. In view of these multiple benefits, including increased water retention capacity in the country, they contribute to flood mitigation which can lead to mutually beneficial solutions in the implementation of the WFD and the „win-win“ directive.

Green or green - blue infrastructure is the widest approach to rainwater management. It includes interconnected clusters of multifunctional, mostly green areas, that support and enable ecological and social interaction and activity (35). The basic approach of a quality urbanized landscape should be properly developed spatial plans which should also include green - blue infrastructure taking into account the increase of areas for the use or retention of rainwater. The aim is to maximize ecological green spaces in urban planning in order to achieve maximum environmental and sustainability benefits for the quality of life in urban areas (36). The approach focuses mainly on the use of green rainwater systems (e.g. green roofs, green walls, rain gardens, etc.) in the context of urban water management problems for surface water treatment which can also fulfill other ecological functions, such as improving air quality, biodiversity, quality of life and so on. Use of ponds or habitats can also be implemented with the extension as Green - Blue infrastructure. The designation "green" or "green-blue" should be seen as a contrast to the so-called "gray infrastructure" consisting of pipelines and structures (Figure 9).

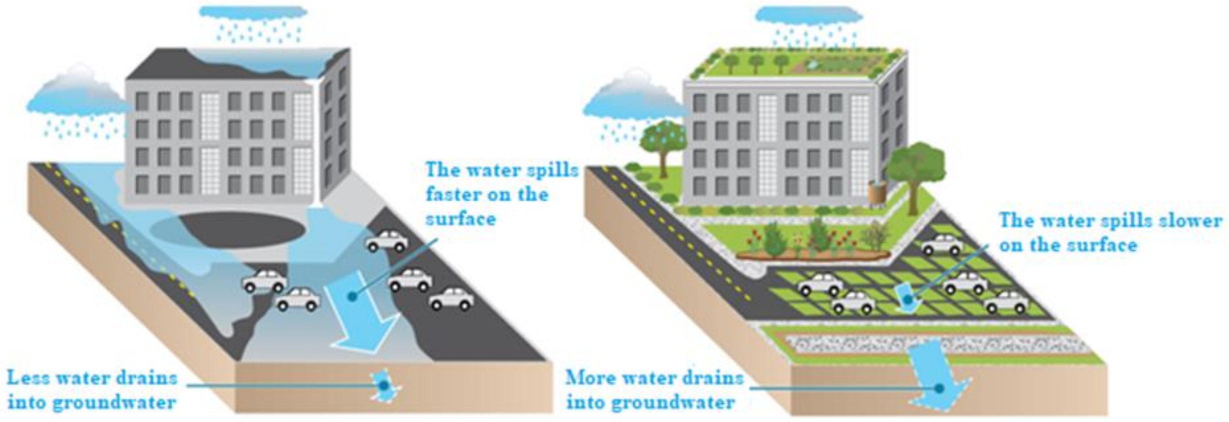

Figure 9 Blue-green infrastructure saves the country and a budget (37)

Examples of adaptation measures in the field of water management (Table 2).

Table 2 Examples of adaptation measures in the field of water management (38)

Expressions of climate changes	Consequences of climate changes	Suggested adaptive measures	Adaptation measures characteristics	Connections and synergy with water economy
Changes in total precipitation	Floods	Slowing down the runoff from the basin	Support for natural water retention measures during periods of heavy or excessive precipitation for periods of scarcity.	Provision of ecosystem services in line with the EU Biodiversity Strategy.
			Maintain and restore wetlands and meandering streams, create conditions to ensure the continuity of watercourses, maintain or remove riparian vegetation in watercourses and coastal lands so that they do not become an obstacle to flood runoff and preserve natural conditions , remove barriers in watercourses, support the revitalization of ecosystems where it is possible.	
			Ensure suitable ways of land use where is an increased risk of erosion and floods, apply good agricultural practices - tillage, sowing procedures, ensure permanent vegetation cover on exposed sites, construction of infiltration forest lanes and other elements of green infrastructure.	Agriculture, forestry, spatial planning.
			Limit the creation of impermeable zones in urban areas, move away from the drainage of rainwater from buildings, support the capture and infiltration of rainwater into the subsoil using elements of green infrastructure (e.g. vegetation paving, planting vegetation, vegetation roofs and walls, rain gardens) and technical elements, resp. their use for utility purposes (e.g. by building rainwater traps with the possibility of use for drought irrigation or utility water in buildings).	Spatial planning, building law.
		Reduction of the maximum flood discharge	Construction, maintenance, repair and reconstruction of water structures and polders, determination of the area with retention potential for the needs of flood wave flattening, assessment of the possibility of applying nature-friendly measures in the country.	Spatial planning.
		Risk assessment	Update of flood emergency maps, flood risk maps and flood risk management plans.	-
			Creating conditions for the elimination of flood risk in relation to the threat in critical infrastructure through technical measures.	Emergencies and protection of the population and environment.

			Regular inspection of the actuality of hydrological and meteorological data with design flood discharges and stage and summary stage reports of water structures from the performance of supervision, resp. other documents from control measurements and inspections of water structures and technical safety inspections. Based on them, re-evaluate the safety of flood protection structures and structures built directly on watercourses.	-
	Droughts	Water management	Increasing the management efficiency of existing water constructions in non-stationary conditions.	-
			Take into account the solution of non-stationary conditions for the dry season in the regular revision of the Manipulation regulations of water structures, so that also reflects the criteria for aquatic and water-related ecosystems.	-
			Ensure the management of water resources in accordance with environmental ethics based on the balance of resources and water needs, resp. water accounting in the river basin.	-
			Ensure the identification and protection of potential groundwater sources and potential surface water reservoirs and their use depending on the needs caused by climate change.	EU biodiversity strategy.
			Retain surface water by technical or nature-friendly measures for accumulation and retention.	-
			Ensure protection and restoration of wetlands.	EU biodiversity strategy.
			Optimally adjust ecological flows so the ecological status of watercourses is maintained throughout the year, taking into account the qualitative and quantitative assumptions of the water body when allocating water for different uses in order to save water through measures for more efficient water use.	-
General			Setting up monitoring of climate system elements (including hydrological and meteorological elements) to observe the effects of climate change.	-
			Continue in using the existing information systems for the purpose of water management, rebuild them and create an integrated system that will also contain information on water resp. water sources (consumption for more than 50 persons or more than 50 m^3 per day).	Informatization of state and public administration.

2 Overview of legislative regulations related to water capture and management in urban areas of the Danube region

From a legal point of view, rainwater management is a cross-cutting issue. The feasibility of rainwater management measures is affected by various laws and guidelines at the international, state and municipal levels. Only an overview of the legal situation for selected countries of the Danube region can be given here due to the large number of provisions. It is necessary to check the exact framework conditions in individual cases.

The Water Framework Directive (WFD), as a framework for achieving adaptation to the adverse effects of climate change in the field of water management, follows an approach that provides flexibility, as the program of measures of the Water Plan of Slovakia is updated in 6 annual cycles. If new knowledge on climate change and its related impacts becomes available, it will be used to increase resilience and reduce the vulnerability of river basins.

Austria (Table 3) and Germany (Table 4) together offer a detailed compilation of the legal basis for rainwater management. At the international level, the General Waste Water Emissions Regulation (AAEV) and the Water Law Act (WRG) are of particular importance. The definition of rainwater can be found in AAEV (§ 1 sec. 3 Z 3).

„Water which falls on a river basin such as rain, dew, hail, snow or the like as a result of natural or artificial hydrological processes and discharges into a body of water on the surface of the land in the river basin or is drained by technical measures."

The WRG regulates, inter alia, the requirement to permit measures that affect water quality (WRG § 32). In order to comply with quality, chemically acceptable and environmentally accessible parameters, the degree of rainater pollution plays a crucial role. The basis is the classification of area types (ÖWAV - Worksheet 45, 2014), which includes rainwater treatment. In addition, the regulation provides an overview of infiltration and discharge requirements for surface waters in each type of area.

Rainwater management is primarily covered by law through building regulations and measures to drain rainwater into the sewer. These include the Sewerage Act, the Municipal Sewerage Act, the Lower Austrian Canal Act, Upper Austria. The Waste Water Disposal Act, the Styrian Sewerage Act, the User Charges Act (Salzburg), the Tyrolean Sewerage Act, the Vorarlberg Sewerage Act and the Sewerage Charges Act (Vienna).

State laws leave municipalities a different degree of self-determination about rainwater management. While the Upper Austrian municipality has to issue its own sewerage regulations and can thus define the conditions of the discharge, the Lower Austrian municipalities can only set fees for the discharge of rainwater. Although they are also limited by regional law and /or decrees.

European regional planning laws contain various options for tackling the rainwater problem in local spatial planning tools. Consideration of the topic in the medium-term development strategies of cities and municipalities is the future and protection of the territory in the event of infiltration by atmospheric precipitation.

Table 3 Austria - Relevant regulations and standards for rainwater management

ÖWAV - Regulations	
ÖWAV – Worksheet 9	„Guidelines for the application of drainage methods“
ÖWAV – Worksheet 11	„Guidelines for calculation and dimensioning of sewage effluents“
ÖWAV – Worksheet 19	„Instructions for dimensioning mixed water discharges“
ÖWAV – Worksheet 35	„Rainwater treatment“
ÖWAV – Worksheet 45	„Surface drainage with seepage into the subsoil“
Road System Directives and Regulations (RVS)	
RVS 03.08.65	„Road drainage“
RVS 04.04.11	„Water protection on roads“
DWA - Regulations	
ATV A 105	„Selection of drainage system“
ATV A 111	„Guidelines for hydraulic sizing and performance verification of rainwater relief systems in sewers and pipelines“
ATV A 121	„Precipitation - evaluation of heavy rain according to the duration and time of return, precipitation measurements, evaluation“
ATV A 128	„Guidelines for dimensioning and proposal of rain relief in combined sewers“
ATV A 200	„Principles of wastewater disposal in rural structured areas“
ATV-DVWK-M 176	„Instructions and examples of design and equipment of buildings for central treatment and retention of rainwater“
ATV-DVWK-A 157	„Sewer structures“
ATV-DVWK-M 165	„Requirements for precipitation and runoff calculations in urban drainage“
ATV-DVWK-M 177	„Dimensioning and proposal of rain relief systems in combined sewers - explanations and examples“
ATV-M 101	„Planning of drainage systems - new construction, sanitation and renovation“
DWA A 100	„Integrated Guidelines for Urban Drainage (ISIE)“
DWA A 102	„Principles for the control and treatment of rainwater runoff for discharge into watercourses“
DWA A 110	„Hydraulic dimensioning and proof of functionality of sewers and pipes“
DWA A 112	„Hydraulic dimensioning and performance verification of special structures in sewers and drains“
DWA A 117	„Dimensioning of rain-retaining areas“
DWA A 118	„Hydraulic dimensioning and verification of drainage systems“
DWA A 133	„Valuation of wastewater systems - systematic recording, evaluation and updating“

DWA A 138	„Planning, construction and operation of rainwater infiltration systems“
DWA A 166	„Constructions for central rainwater treatment and retention, proposal and equipment“
DWA A 178	„Retention soil filtration systems“
DWA M 153	„Recommendations for rainwater management measures“
DWA M 178	„Recommendations for planning, construction and operation of soil retention filters for advanced rainwater treatment in a mixed and separate system“
Standards	
ÖNORM B 2400	„Hydrology - hydrographic expressions and symbols“
ÖNORM B 2500	„Wastewater technology - creation and disposal of wastewater - terms and their definitions, as well as symbols“
ÖNORM B 2506-1	„Rainwater infiltration systems for roof and paved drainage - applications, hydraulic sizing, construction and operation“
ÖNORM B 2506-2	„Rainwater infiltration systems for drains from roof surfaces and paved surfaces - Part 2: Qualitative requirements for rainwater seepage as well as requirements for sizing, construction and operation of cleaning systems“
ÖNORM B 2506-3	„Rainwater - Percolation systems for drains from roof surfaces and paved surfaces - Part 3: Filtration materials (requirements and test methods)“
ÖNORM B 2572	„Principles of rainwater use“
ÖNORM B 2607	„Playgrounds - planning instructions“
ÖNORM B 4422-1	„Earthworks and foundations - Examination of soil samples. Determination of water permeability - Laboratory tests“
ÖNORM B 4422-2	„Earthworks and foundations - Examination of soils. Determination of water permeability - Field methods for near-surface layers“
ÖNORM B 5101	„Separation systems for light liquids (eg oil and petrol) - Additional requirements to ÖNORMEN EN 858-1 and -2, marking of conformity with standards“
ÖNORM B 5102	„Rainwater cleaning systems from traffic and parking areas - fuse boxes“
ÖNORM EN 1433	„Drainage channels for traffic areas“
ÖNORM EN 16192	„Waste characterization - analysis of eluates“
ÖNORM EN 752	„Drainage systems outside buildings“
ÖNORM EN 858-1	„Separation systems for light liquids (eg oil and petrol), part 1: Design, functional and test principles, marking and quality control.“
ÖNORM EN 858-2	„Separation systems for light liquids (eg oil and petrol), part 2: Selection of suitable size, installation, operation and maintenance.“

ÖNORM EN ISO 22475-1	„Geotechnical investigation and research - Methods of sampling and measurement of groundwater - Part 1: Technical principles for implementation“
ÖNORM L 1050	„Soil as a plant location - concepts and research methods“
ÖNORM L 1066	„Physical tests of soil - Determination of infiltration intensity using a double ring infiltrometer (field method)“
ÖNORM L 1080	„Soil chemical tests - Determination of organic carbon by dry combustion with or without carbonates“
ÖNORM L 1081	„Soil chemical studies - Determination of organic carbon by wet oxidation“
ONR 121131	„Quality assurance on green areas. Green Roof - Instructions for planning, construction and maintenance“
Research Society for Landscape Development and Landscaping e.V. (FLL)	
	„Guidelines for the planning, implementation and maintenance of green walkways“
	„Guidelines for planning, implementation and maintenance of green roofs“
	„Recommendations for water infiltration and retention“

This results in requirements for the quality of rainwater runoff, as rainwater from streets or car parks can be heavily polluted. The DWA guideline “DWA-A 138 - Planning, construction and operation of rainwater infiltration systems” (DWA 2005) provides information on when it is necessary to clean rainwater runoff before it enters the area.

Table 4 Germany – Technical standards

Conception	
Worksheet A 100	„Guidelines for integral urban drainage“
Worksheet A 121	„Precipitation heavy rain evaluation according to return time and duration; Evaluation of precipitation measurements“
Worksheet A 200	„Principles for wastewater disposal in rural structured areas“
Worksheet A 531	„Heavy rain depending on return time and duration“
Leaflet M 153	„Recommendations for rainwater management“
Leaflet M 180	„Framework for planning the control of discharges in sewerage networks“
DWA - topics	„Department of Measures in Urban Drainage“
Evaluation and Dimensioning	
Worksheet A 110	„Hydraulic dimensioning and proof of functionality of sewers and pipes“
Worksheet A 117	„Dimensioning of rain-retaining areas“
Worksheet A 118	„Hydraulic dimensioning and verification of drainage systems“
Worksheet A 128	„Guidelines for the sizing and construction of rain relief systems in combined sewers“ in conjuction with the relevant explanations and examples in leaflet M 177

Worksheet A 138	„Planning, construction and operation of rainwater infiltration systems“
Leaflet M 165	„Requirements for precipitation and runoff calculations in urban drainage“
Leaflet M 178	„Recommendations for planning, construction and operation of retention soil filters for the coming years. Rainwater treatment in a mixed and separated system“

With the countries of the Danube region, apart from Austria and Germany, the development of legislation in the field of water retention in the Czech Republic is the most adapted (Table 5).

Table 5 Czech republic legislation

Act No. 183/2006 Coll.	On town and country planning and building code (Building Act)
Act No. 183/2006 Coll. (§ 80)	§ 80 of the Building Act requires that the Decision on the change of land use determine a new method of land use and conditions of its use, in the case of land improvements that affect the infiltration ability of water in related to or condition housing or family recreation, does not serve for storage of flammable substances or explosives, is not in conflict with land use planning documentation and the area of the part of land capable of absorbing rainwater after their implementation will be at least 50% of the total land area of family house or family recreation building
Act No. 185/2001 Coll.	On waste and amending some other acts
Act No. 254/2001 Coll.	On waters and on amendments to some acts (Water Act)
Decree No. 268/2009 Coll.	On technical requirements for buildings
Decree No. 268/2009 Coll. § 6 sec. 4	Requires that structures from which surface water runoff resulting by the impact of atmospheric precipitation (hereinafter referred to as "precipitation water") must be provided for their drainage, unless the precipitation water is retained for further use. Pollution of these waters by harmful substances or their excessive amount is soluted by appropriate technical measures. Rainwater drainage is ensured preferably by seepage. If infiltration is not possible it is discharged to surface waters; if the rainwater cannot be drained separately, it is drained through an uniform sewer.
Decree No. 501/2006 Coll.	On general land use requirements
Decree No. 501/2006 Coll. § 20	Defines the building plots of constructions for housing and for family recreation in such a way that they are solved, inter alia: • management of waste and wastewater according to special regulations of Act No. 185/2001 Coll. which arise on the land by its use or by the use of buildings located on it,

	• infiltration or drainage of rainwater from built-up areas or paved areas, unless other uses are planned; in doing so, the following must be addressed: 1. preferably their infiltration, in case of their possible mixing with harmful substances, the location of the device for their capture, if infiltration is not possible; 2. their retention and regulated drainage divided by sewers for the drainage of rainwater into surface waters, in case of their possible mixing with harmful substances the location of the equipment for their capture; 3. if separate drainage into surface waters is not possible, then their regulated discharge into a single sewer.
Decree No. 501/2006 Coll. § 22	Specifies the requirement for land of residential buildings and for family recreation so that the infiltration of rainwater on the land of residential buildings according to § 20 sec. 5 letter (c) is complied with if the ratio of the acreage of parcel part is capable of rainwater infiltration to the total acreage of the parcel in the following cases: a) detached family house and a building for family recreation of at least 0,4; b) terraced family house and apartment house 0,3.

3 Examples of best practices in water capturing and management of captured water in urbanized areas of the Danube region

In practice, we encounter rather exemplary solutions for certain forms of water retention. However, if we want to respect their role - to eliminate changes in the natural water cycle in the country, caused by the cessation or use of land - we should create a set of follow-up measures for all types of water in the city. We should also include wastewater in the current approach and try to create places to live or work where all types of water are treated together, not separately. By combining the solution of precipitation and wastewater, the sustainability of the area solution will be achieved as well as the effort for an ecological approach. An interesting example is a residential house in a model development on the outskirts of Hamburg, where a non-traditional local wastewater solution has also come into complex solution. The glass façade of the building consists of a wide double glazing into which waste water enters and colonies of special algae transform the pollution into its oily content. It can be used similarly to biodiesel for fast energy production. The surrounding area and the roof are used to collect rainwater and runoff from the area is minimized in quantity and in the production of pollution.

Most examples from practice come from Germany, Austria and the Czech Republic, which play the role of green-blue infrastructure.

Germany

The first German rain playground

The first German rain playground was opened in the Neugraben-Fischbek district of Hamburg in October 2013. The starting point for the construction was the multiple flooding of neighbouring schools. The existing rain-catchment basin was extended to the maximum possible volume as early in 2004. As floods continued to occur in the event of heavy rain and the adjacent playground was to be renovated at the same time, it was decided to redesign it for temporary rainwater storage (Figure 10). In addition to the classic playground function which offers children a place to play, it now also contributes to the drainage of the district. This is made possible by the basin and the rain tank located on the surface. When it rains heavily, the playground absorbs excess rainwater from the sewer. Immediately after filling the tank, additional rainwater is directed to the adjacent protective area of the HAMBURG WASSER well by means of a transport gutter. There, water seeps in and contributes to the formation of new groundwater. Special play equipment along the floodplain invites you to play with water and allow small and large seniors to experience the water cycle up close. In addition, the information boards clearly explain the hydrological cycle of precipitation, seepage, recharge and abstraction of groundwater. The rain playground has many positive effects. On the one hand, it supports the local water cycle in the city, on the other hand, it significantly contributes to preventive measures in the area of heavy rain in the district (39).

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Figure 10 Playground for rainwater catchment (39)

During the house construction adjacent to the park and the associated new construction of the existing car park, as well as road maintenance, there was a clear synergy in the implementation of the measure. These basically consisted of three parts: Slight adjustments to the road profile were made to increase traffic safety. Together with a new road connection to the park, which was part of the construction of a new car park, a waterway was built to transfer the leaking water to the park. In the park itself, the waterway was continued so, in the event of future torrential rain, the natural depression could be used for intermediate storage and infiltration of temporarily accumulated water (39).

Športové ihrisko Möllner Landstrasse

In the past, flooding on the Möllner Landstraße in Billstedt between the entrances to the "Merkenstraße" underground station occurred several times during heavy rains, as the sewers could no longer fully absorb large amounts of water. Parts of the Möllner Landstraße were then flooded and the traffic and operational safety of the underground station was endangered. The expansion of the sewerage capacity was out of the question, as it was not possible to supply more water to Schleemer Bach which was already heavily hydraulically loaded. As part of a unique project in Germany, an underground storage and infiltration system was built under the Hein-Klink stadium (Figure 11) which relieved rainwater runoff. In the event of heavy rain, excess water is now drained from the road to the sports field. Underground storage elements absorb excess water and gradually drain it into the ground. The pilot system designed by HAMBURG WASSER can hold more than 500 000 litres of water. The pilot project being implemented here is a model and is included as a concept in the Hamburg-Mitte district in the modernization program for other sports facilities (40).

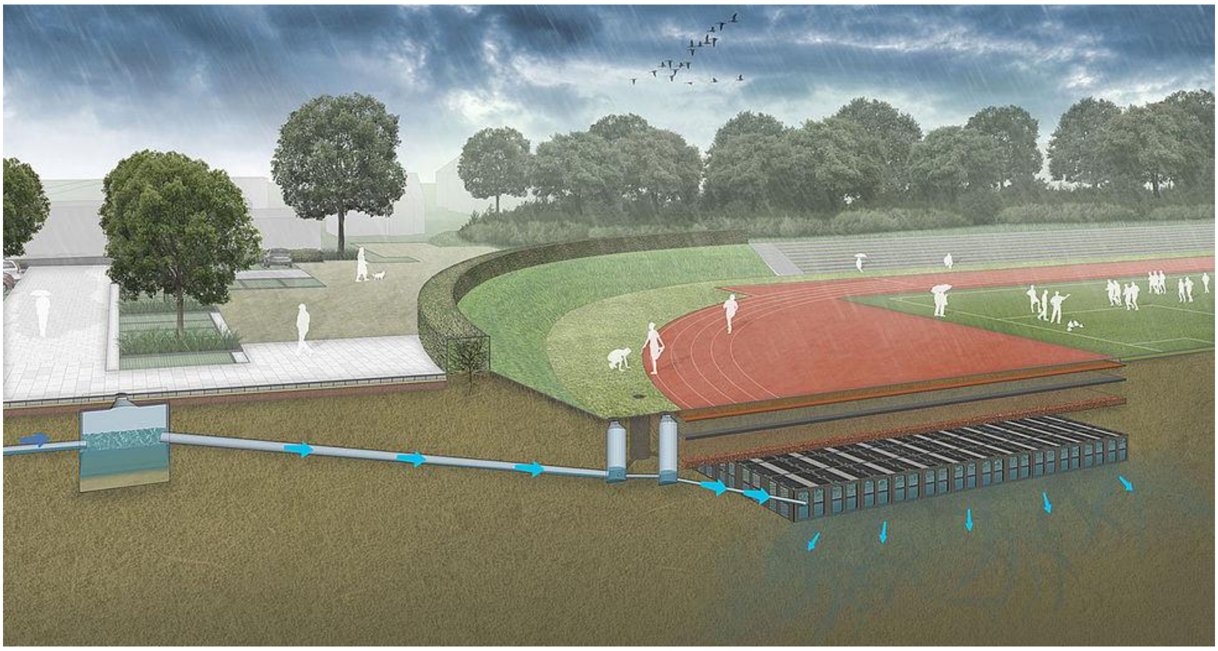

Figure 11 Möllner Landstraße pitch (40)

Rellinger Straße school

Schools have large open spaces that can potentially be used for rainwater management. By integrating rainwater management into the school environment, it is possible to experience an almost natural water cycle and the sustainable use of rainwater, while at the same time creating a contribution to a high-quality educational environment. In addition to high social benefits, decentralized management of natural rainwater also brings economic benefits.

School complexes can retain water like a sponge and reuse it with appropriately designed drainage systems (e.g. emergency waterways, drainage gutters, trenches), schoolyards can relieve drainage. Roofs are also enhanced with greenery and delays drainage from roof surfaces. Positive side effect: green roofs as well as drain and seepage tanks allow evaporation and have a refrigerant effect on the microclimate. These mostly above-ground elements also take over ecological functions and increase the quality of the stay. In cooperation with Schulbau Hamburg, Hamburg Wasser and BUKEA, schools will be rebuilt and new buildings with rainwater management will be planned in the coming years. Schools in Wegenkamp, Moorflagen, Lutterothstraße and Rellinger Straße are among the first to successfully implement natural rainwater management in Hamburg.

The "Rellinger Straße" was given a schoolyard as part of the renovation which will make a significant contribution to the prevention of heavy rains in the future. It was achieved by equipping the schoolyard with cavities and ditches (Figure 12), in which rain can naturally escape. Thanks to the gutter, which leads the rainwater from the roofs and around the school yard to the depressions and trenches, the flow of rainwater is visible and tangible for students (41).

Figure 12 Rellinger Straße school (41)

As a result, the area associated with the sewerage has been significantly reduced and relief has been achieved. Overall, the amount of water entering the sewer will be reduced by about 50 litres per second, which is a reduction of 30%. This significantly reduces the risk of local flooding due to heavy rain. In order to strengthen the sponge effect of the school complex, the roof area of the new building, which houses a cafeteria, common and all-day spaces and a sports hall, has been improved with a green roof. It also helps to mitigate runoff through its accumulation and runoff effects (41).

Retention soil filter

Retention soil filters are primarily used to purify harmful rainwater before it is discharged into water bodies. Retention soil filters (Figure 13) are sand/gravel packages with vertical flow, the surface of which is fitted with reeds and equipped with a retention space. In the filter layer, chemical-physical and biological treatment takes place mainly. Coarse and fine particles are captured and contamination is reduced by up to 95%. The purified water is collected by a drainage system and drained into surface water by a drainage structure. The soil retention filter also contributes from preventing heavy rain and relieving water and sewage due to the retention space and the delayed discharge,.

There are already several such systems in Hamburg. One example is the retention soil filter on Manshardtstrasse (42).

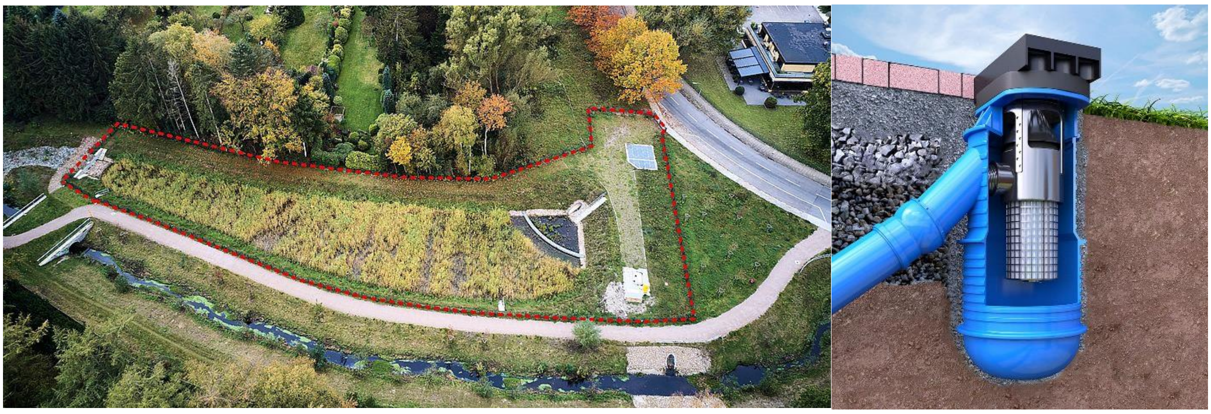

Figure 13 Retention soil filter on Manshardtstraße (42)

Source: Ľuboš Jurík (2020)

Figure 14 Stepped terraces

Ostfildern, Scharnhauser Park – Stuttgart - Rainwater retention and infiltration

Scharnhauser Park is an area of ecologically exemplary residential buildings, especially suitable for families. There is housing for 9 000 people and 2 500 jobs.

The ecological approach is also applied to drainage. Although the subsoil is not permeable throughout the area, all surface water from roads, public spaces, roofs and all other private lands does not enter the sewers, but infiltration is encouraged over an unusually large area and only the rest of the water is drained into streams. The water is drained by open ditches and grassy outcrops. In these areas, the water is retained, partially evaporated and cleaned by infiltration through the humus layer and through the gravel body which is inserted under the humus layer and whose depth reaches up to 1,5 m. These ditches and enclosures are located in the vast green areas of the city district, in Baumhain (tree grove), in the

Landschaftstreppe (so-called natural stairs) - a park area running from north to south through the city district (Figure 15) and ending in Holzwiesen Park (43).

Source: Ľuboš Jurík (2020)

Figure 15 City district Stuttgart

The attachments are always arranged in a cascade (Figure 14), i.e. there is a drop from one attachment to the next. Finally, the water is brought into a natural water recipient, i.e. into both watercourses to the west and east of the Scharnhauser Park. The basis for calculating the amount of water, which is discharged, is arable land. This means that the entire urban district does not drain more water into the water recipient than the undeveloped area of arable land due to water retention in cities. This serves to protect the water system as it prevents high flood flows and intense erosion. Sewage treatment plants are not exposed to clean rainwater. In addition, it is possible to meet and experience water in the entire city district which in turn increases the quality of housing. The approximate price of the construction was 1,5 billion Euro.

More photos from the excursion in Stuttgart and a visit to ZinCo GmbH in Annex 1.

Falling rainwater is drained underground into seepage ditches, water seeps into seepage manholes along roads. Two cane beds have been built in the area of the promenade. It means the use of rainwater is visible. Vegetation roofs have been set up on the houses. There is a large share of fertile land in the area of residential houses because only a small part of the undeveloped area is undermined by underground garages. The implementation took place in 2011.

Austria - Rainwater infiltration

Solar city Linz - ecology in the urban concept

Linz, an Austrian city located in a narrow area between the Travna and Danube rivers, needed to be expanded. However, because it is literally crowded between the two rivers, it has not been easy to find a suitable space for such an extension. Plans for construction in an agriculturally and ecologically significant floodplain (along the banks) were accompanied by great concern. As a result, it was clear from the beginning that it was necessary to implement an architecturally and ecologically high quality project. Therefore, the renowned Austrian urban planner Roland Rainer was asked to create a zoning plan. The design was inspired by green garden cities with smooth transitions between gardens, parks and the landscape (44).

The name Solar City was chosen as a symbol that clearly reflects the new expansion goals of the city. Great efforts have been made to ensure low consumption of fossil fuels. Finally, Solar City is divided into five central areas, home to 25,000 people. The first phase of the project is implemented on 32,5 hectares of building plots and will provide housing to 4 500 inhabitants together with the necessary accessories and a 20 hectare park (Figure 16).

In order not to address the concerns of nature conservationists, adjacent floodplains have been assigned the function of a protected landscape area (Natura 2000). Therefore, the mission of the landscape architect was to choose a form for residential areas that would ensure that the natural values of protected areas are not damaged by the construction project. The project includes a range of recreational features, such as a natural swimming pond, a water playground and a large amount of vegetation to keep residents close to the built-up area. As far as the water concept was concerned, this meant that the balance of groundwater had to be maintained and that the new water management system could best preserve the current situation. Rainwater from houses to forests in the floodplain is drained by a sophisticated system of small channels for rainwater drainage, biotechnical gaps, ponds and streams. Groundwater recharge permanent and temporary wetlands maximize the existing balance of the water system. Artificially created wetlands and green areas have been filled with local flora and fauna and rare species are also appearing where the built-up area is already beginning. According to surveys, the population greatly appreciates the considerable amount of vegetation and the pond with the inflowing rainwater. The dry riverbed, the Aumühle, has been restored to its original beauty. A total of 1 500 new trees were planted in the park and along the Aumühle stream, further enhancing the quality of the green area (44).

Figure 16 Ecological model settlement bordering the Traun river (45)

As part of the pilot project, a decentralized wastewater treatment system was created for 88 houses and a primary school. The system serves as a research facility for the study of various aspects of decentralized wastewater treatment and, if it is possible, contributes to the effort to change the current legislation. As in the Netherlands, in Austria all buildings in urban areas must be connected to the sewer system. Toilets that separate urine and feces have been installed. The solid is converted to compost, while the liquid waste passes through cleaning helophyte filter. Urine is collected in the basement for use as fertilizer. The helophyte filter is part of the park but for safety reasons it had to be fenced. The acceptance of the system by the population and its functioning is monitored. The system as such is not error-free and places certain demands on the user. Therefore, it is uncertain whether the system is suitable for large-scale use (45).

Innovative approaches have been implemented in many areas when planning Solar City in Linz. In addition to quality architecture and citizen-friendly infrastructure, particular importance has been attached to energy efficiency and sustainability issues. Particular attention was also paid to integrating sustainable rainwater management into the overall concept. In line with this ambitious philosophy, a so-called modified rainwater management concept has been developed for Solar City based on the following principles:

- Rainwater is handled in a predominantly surface,, decentralized system where it rains and that makes the natural rainwater cycle visible and understandable.
- Drainage, capture and disposal of rainwater is carried out primarily through troughs, retention ditches and vegetation overgrown areas.
- These elements are included in a comprehensive, interconnected system that uses the Aumühle stream in the southern part and the alluvial meadows in the northern part of the district as recipients.
- The above elements of the rainwater management system are an integral part of open space planning.

One of the concept elements is represented by retention ditches and vegetated overgrowth overhangs. These are shallow grass ditches, which are connected in the open space as harmoniously as possible and which in the event of intense rainfalls, which statistically occur every five years, retain water with a maximum depth of 30 cm. This accumulated water drains by infiltration into the vegetated surface or by a defined drainage pipe. The duration of such accumulation generally does not exceed 12-16 hours and, as already mentioned, statistically it has reached this maximum approximately every five years. The slope of the banks of these ditches and overhangs is very gradual - it is not steeper than 1:2 - and because it accumulates a maximum of 30 cm of water, they are not too deep. In addition, they are overgrown with grass and can be easily walked on, even when wet (44).

4 Conclusions and recommendations for improving the current situation

In addition to the effects of climate change, other factors, such as social, demographic and economic development, are also decisive for other adaptation strategies.

Naturally, economic considerations also play a decisive role in choosing other measures for rainwater management. Both production, operating and reinvestment costs should be taken into account here. Together with the period of one measure application.

The aim of cities must be to ensure that blue-green infrastructure becomes not only a regular part of spatial planning and spatial development, but also that it is fully integrated into the implementation of policies whose objectives can be achieved in whole or in part through natural solutions.

4.1 Effective and rational measures proposal for improving the situation as well as their financial evaluation

Set planning goals

The first step in implementing appropriate rainwater retention measures in the Danube region is to set a specific planning goal.

The reason for planning appropriate rainwater retention measures often stems from a specific cause, problem or need. This can be, for example, poor ecological status or great damage caused by floods, lack of water, the fight against climate change. If the problem is assessed as serious, planning begins and a project is defined. The project requires a clear goal such as improving the adaptability of settlements to extreme climates; biodiversity, greater resilience to climate change and other added values (e.g. more aesthetic environment); in integration with urban planning better places to live.

The formulation of specific planning goals facilitates the entire planning process. Renaturation is only effective if the causes of the problems are taken into account in the planning. In addition to local ones (e.g. transverse structures, subsoil, climatic conditions), higher-level factors are often decisive for locally changed urban areas (e.g. changed runoff regime or disturbed balance of ecological stability). Therefore, each sub-basin area should be examined separately and each site should be treated as unique.

Conceptual planning

They provide a framework for planning local projects. These concepts are often lacking for smaller areas of territory. But even there, preliminary planning makes sense. A feasibility study or concept of water development in an urbanized landscape is the first step in this regard.

Water retention financing in urban areas of the Danube region

Depending on the type of measure, implementation costs can be very high. To ensure that these measures can still be implemented, there are many funding and financing options for those responsible. These include European Union funding programs; in some countries of the Danube region, there are also types of funding as compensatory measures under the Nature Conservation Act. However, foundations and sponsors are also possible.

The key step is to identify and define the elements of the green and blue infrastructure measure that are the subject of the evaluation. It is very often necessary to take into account their synergy and link to other elements, as the interaction of different elements and measures often significantly strengthens the overall elements effect of the measure. The resulting effect of two measures is usually not just a simple sum.

Costs are all society-wide resources that need to be spent. Costs also include those related to the actual construction of green and blue infrastructure (investment costs), and consequently all costs related to maintenance (operating costs). In many cases, other possible uses of the area may be thwarted during the implementation of the element / measure. These alternative costs (occasional costs) should also be included in the evaluation, as well as other possible negative impacts of the measure (negative externalities or reduction of some ecosystem services production due to land use change). However, these costs are difficult to define in practice, as the transaction costs.

A quantitative analysis is performed for the costs and benefits defined in the previous step. This defines the scope of costs incurred (investment, regular and one-off) and provided ecosystem services and other benefits. It is usually possible to express the costs in individual steps already in this step for individual tasks connected with the construction and maintenance of the given element - measures.

Based on the application of valuation methods, the cost and benefit are expressed in monetary units. This information must be expressed then for a predetermined time horizon (or more time horizons). Recommendations of several economists say it is advisable to use at least two time horizons. Due to their previous experience (46) they recommend working with a horizon of 25 and 50 years, or if is possible to choose your own time horizon. It should always be realistically chosen with regard to the lifetime of the measure. If the chosen length of the period exceeds the useful life, it is necessary to include the estimated expenses in the costs for the gradual renewal of the element. To deal with the time mismatch of costs and benefits, either the expression of costs and benefits by analysis e.g. (47), (48), or the present value method (46), (49). It is recommended to use the present value method in the assessment of green and blue infrastructure. This method is based on converting future costs and benefits into their accumulated value expressed in the present value of money. The calculation of the present value is captured in Equation 1. By comparing costs and benefits, we obtain the so-called net present value (Equation 2).

Equation 1:

Formula for calculating the present value

$$PV = \sum_{t=1}^{T} \frac{V_t}{(1+r)^t}$$

Where:

PV - present value,

Vt - value (of utility cost) at time t,

r -discount rate (according to the EC recommendation, it is appropriate to use a discount rate of 4%, i.e. 0.04), T - time horizon for evaluation,

t - year (in the range of 1-horizon$T$).

Equation 2:

Formula for calculating the net present value

$$NPV = PVb\text{-}PVc$$

Where:

NPV - net present value,

PVb - total present value of the benefits,

PVc - total present value of costs.

In the case of the analysis, we try to convert the known value of current costs and benefits into a future flow of the same values based on annual costs that, when cumulated, correspond to the known value at present (50). The formula for calculating the analysis of the investment value and operating costs is contained in Equation 3 and Equation 4. The calculation of the total analysed costs is in Equation 5. The calculation of the analysed benefits can be performed in a similar way as the calculation of costs. The last step is to calculate the net analysed benefit, where the analysed costs are deducted from the analysed benefits.

Equation 3: Analysis of investment costs

$$ACi = \sum_{l=1}^{L} ACi_l = \sum_{l=1}^{L} \left(PVi_l \times \frac{r \times (1+r)^l}{(1+r)^l - 1} \right)$$

Where:

ACi - total annual investment costs in annualised form,

ACi_l - investment costs with a lifetime of a positive measure,

PVi_l -present value of investment costs associated with a certain life,

r - discount rate (according to the EC recommendation it is possible to use a discount rate of 4%, i.e. 0.04),

L - the maximum life expectancy of the measure,

l - service life of the measure part.

Equation 4: Analysis of operating costs

$$ACm = \sum_{y=1}^{Y} ACm_y$$

Where:

ACm - total value of operating costs,

$ACmy$ - annual operating costs in year y,

Y - time horizon for evaluation.

Equation 5: Calculation of the total analysed costs

$$Ctot = ACi + ACm + ACo$$

Where

$ACtot$ - total cost analysed,

ACi - investment costs in the form analysed,

ACm - operating costs in the form analysed,

ACo - other costs 4 in the form analysed.

The result of this step is the overall net benefit of the measures from the company's point of view. At the same time, it is possible to express the return on the measure element on the basis of the present costs value and the present value of benefits. From the perspective of society. It is the determination of the time (year) when the cumulative value of the valued benefits exceeds the cumulative value of the costs. An alternative indicator can then be the so-called benefit-cost ratio, which expresses how many times the monetary benefits provided exceed the costs incurred in a given time horizon. The formula for calculating this ratio is captured in Equation 6.

Equation 6: Benefit-cost ratio

$$B/C = \frac{B}{C}$$

Where:

B/C -benefit-cost ratio,

B - total benefits (at present value, or at analysed value),

C - total costs (at present value, or at analysed value).

Water restoration costs money but there are many financial instruments and grants that can be combined. In addition, compensatory measures and overlapping interests with other actors (e.g. flood protection, nature protection and others) can be used.

4.2 Effective and rational measures proposal for improving the situation - technical solution

The main technical criteria for choosing the method of infiltration include:

- geological and hydrogeological conditions (suitability for infiltration),
- the amount of rainwater that needs to be absorbed (depending on the size and nature of the drained area and hydrological conditions),
- the quality of the water to be infiltrated,
- local conditions and spatial arrangement of the construction site and the wider surroundings of the building,
- architectural integration into the urbanized area,
- requirements for future operation and maintenance, long-term sustainability of measures;
- economic demands for the implementation of the measure.

Hydrogeological survey

In areas of landscaping, landslides and erosion, in mined areas and with a possible leaching effect, the impact of infiltration on geological stability needs to be investigated. It is necessary to pay close attention to the possible case of soils in certain localities which become unstable after soaking in water.

Permeability of infiltration space

An essential condition for infiltration of precipitation runoff is sufficient permeability of soil and underground rock layers. The permeability of soils depends mainly on the grain size, the curve of their grain size and ease, in soils the soil structure and water temperature are equally decisive. It is expressed by the permeability coefficient k_f (Table 6)

Table 6 Rock permeability classification according to ATV-DVWK A 138

Permeability class	Rocks according to degree of permeability	Filtration coefficient k_f [$m.s^{-1}$]
I	Very strongly permeable	
II	Strongly permeable	1.10^{-2}
III	Quite strongly permeable	1.10^{-3}
IV	Slightly permeable	1.10^{-4}
V	Quite poorly permeable	1.10^{-5}
VI	Poorly permeable	1.10^{-6}
VII	Very poorly permeable	1.10^{-7}
VIII	Subtly permeable	1.10^{-8}

In the case of incoherent rocks, the value of the coefficient is generally between 1.10^{-2} and 1.10^{-10} $m.s^{-1}$. K_f values lower than 1.10^{-6} can only be used for infiltration with accumulation (controlled retention), so it is necessary to complete the design by draining the runoff. With a permeability coefficient greater than 1.10^{-3} $m.s^{-1}$, in small thicknesses of the overburden, rainwater seeps so fast up to the groundwater level that it is not possible to achieve a residence time for sufficient purification by chemical and biological processes.

Surface types

The type (Table 7, 8) or use of the drained area is also part of the urban development framework (ÖWAV,2008). Depending on the nature of the surface, different guidelines can be expected for the treatment of rainwater with heavy discharges of organic and inorganic substances (CVC a Toronto and Region Conservation Authority2010,). In ÖWAV Worksheets (ÖWAV45, 2015a,b) a classification of low-level runoff pollution depending on the area of the runoff origin can be found. If effluent is used for irrigation, the presence of biocide-contaminated areas with drainage effect must also be checked (51).

Table 7 Classification of rainfall runoff by area of origin (ÖWAV, 45, 2015a)

Surface mark	Surface type
F1	• Roof surfaces (glass, green, gravel and clay roofs, roofs connected with cement and plastic), slightly polluted. • All other roofing materials and terraces (slightly polluted) with a total area not exceeding the projected area of 200 m. • Bike paths and sidewalks. • Non-used front yard and driveways for emergency vehicles.
F2	• Roof areas and terraces, slightly polluted, which could not be assigned to an F1 type area. • Parking areas for cars no larger than 20 parking spaces or 400 m^2 (including parking areas access). • Parking spaces for cars larger than 20 parking spaces and not larger than 75 parking spaces or 2 000 m^2 (including parking spaces driveway) with rare vehicle changes (residential buildings, company parking spaces. Park-and-Ride systems and parking places with frequent vehicle changes). • Driving areas with JDTV up to 500 vehicles in 24 hours or track systems up to 5 000 Bto with the exception of the free route.
F3	• Parking spaces for cars larger than 20 parking spaces and not larger than 75 parking spaces or 2 000 m^2 (including parking spaces access) with frequent vehicle changes (e.g. parking spaces for customers of retail companies such as supermarkets). • Parking areas for cars larger than 75 parking spaces and not larger than 1 000 parking spaces. • Tracks with JD from 500 to 15 000 vehicles in 24 hours or track systems larger than 5 000 Bto with the exception of the free route. • Parking lots and parking spaces for trucks, provided the significant pollution of rainwater by vehicle emissions (e.g. loss of pollutants and lubricants, antifreeze, brake or air conditioning fluids, etc.) can be ruled out with a high probability. • Storage and handling areas, as well as transhipments (terminals), provided the significant contamination of rainwater with cargo waste or handling (activities in these areas) can be ruled out with a high probability.

F4	• Parking areas for cars with more than 1 000 parking spaces (e.g. shopping centres). • Operating areas with JDTV over 15 000 vehicles in 24 hours (roads with usually more than two lanes). • Corporate management areas. Places and areas with heavy pollution e.g. through agriculture, freight companies and markets.
F5	• Parking and storage areas. If significant pollution of rainwater by vehicle emissions can not be ruled out with high probability. • Storage and handling areas, as well as transhipments (terminals), provided the significant rainwater pollution by loss of cargo or handling (activity in these areas) is unlikely to be ruled out. • Roof surfaces, heavily polluted (e.g. in industrial areas with high emissions). • Other surfaces. very polluted (dirty).

Table 8 Areas of origin and associated drainage systems (ÖWAV, 45, 2015a)

	Mineral filter systems		**Lawn systems**			**Soil filter systems**		**Systems with technical filter**		
	Drainage shaft	Underground infiltration tank	Flat grassy area	Grassy area in the shape of trough	Grassy area in the shape of basin	Soil filter in the form of a gutter / drain	Soil filter in the form of a basin	Drainage shaft with technical filter	Technical filter in the form of a gutter	Technical filter in the form of a basin
F1	M	M	x	x	x	x	x	x	x	x
F2	-	-	x	x	x	x	x	M	x	x
F3	-	-	M	-	-	x	x	i. B.	M	M
F4	-	-	-	-	-	x	x	i. B.	M	M
F5	-	-	-	-	-	i. B.	i. B.	i. B.	i. B.	i. B.

Recommended (x): The application of these drainage systems should be focused on the relevant type of area in terms of groundwater protection.

Allowed (M):	These drainage systems represent a minimum requirement in terms of groundwater protection and can be used for the relevant type of area.
Allowed by individual assessment (i. B.):	These drainage systems can be used only for the relevant surface type if there is separate evidence of the required cleaning act.
Not allowed(-)	These drainage systems must not be used for the type of surface concerned.

4.3 Methods of terrain rainwater management including examples, cuts and construction solutions

When designing and implementing infiltration devices and rainwater retention devices, it is necessary to follow the principles for the selection of filter materials to ensure the required hydraulic characteristics. Also, the design of the vegetation stand should be aligned with the possibilities of supporting the infiltration capacity of the facility, the expected pollution, operational needs, plant life in connection with changes in the degree of the filtration environment saturation and their suitability for relevant geomorphological and climatic characteristics.

We design surface infiltration devices so they are easy to maintain and must allow animals to escape. Surface infiltration devices are divided into several types:

- surface infiltration objects,
- infiltration wells,
- rain gardens,
- rainwater tanks,
- artificial wetlands.

Surface infiltration objects

This type of infiltration can be used in large areas where short-term retention of rainwater is not expected. Area infiltration objects (Fig. 17) are designed as areas with a grassy area or in car parks with vegetation blocks.

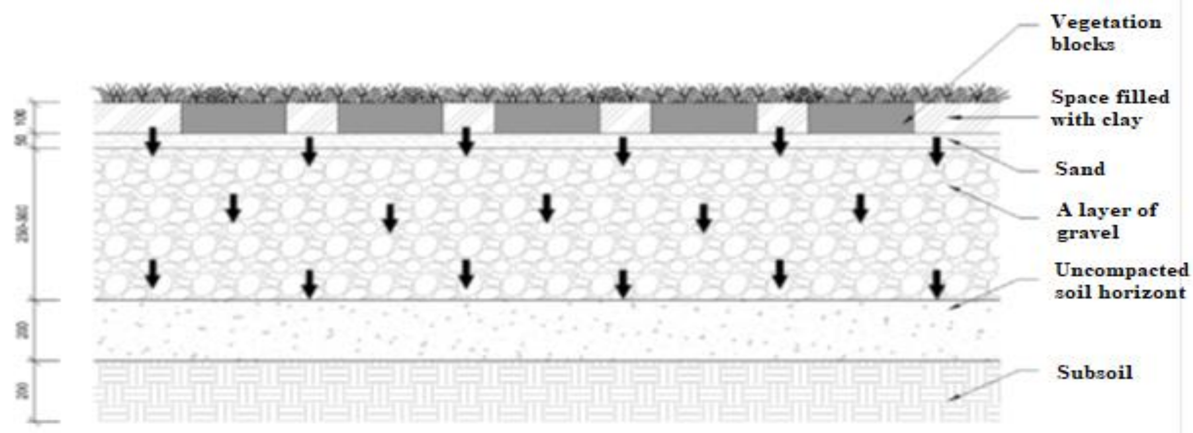

Figure 17 Example of a surface infiltration object solution.

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Infiltration wells

Infiltration wells are artificially created shallow depressions in the terrain with grassing the surface, intended for infiltration with short-term retention of rainwater (Fig. 18). These objects are proposed for space constraints where are not large enough areas on the plot for surface infiltration.

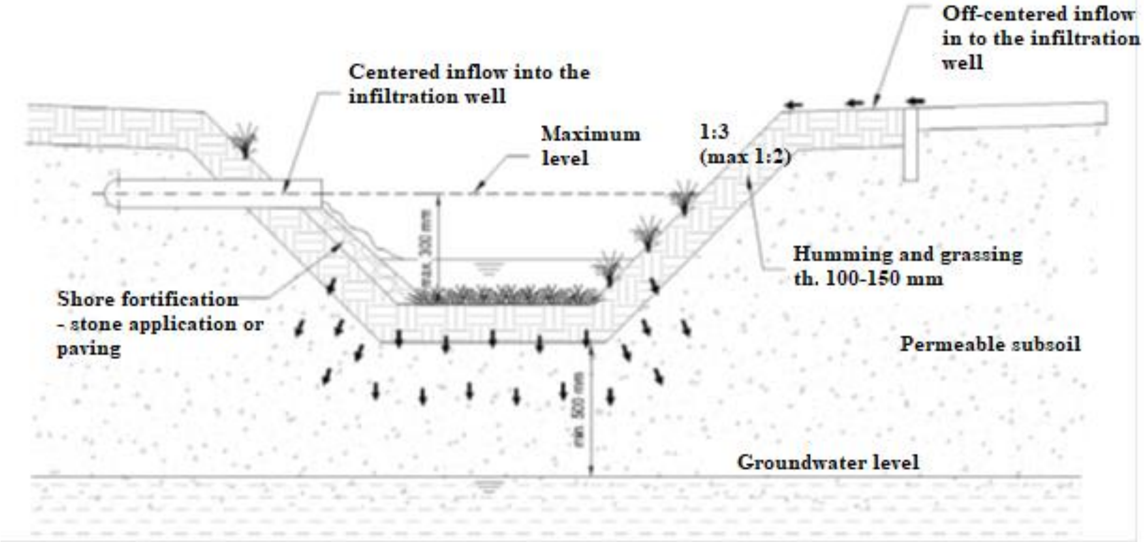

Figure 18 Example of an infiltration well solution

Rain gardens

There are several ways to collect rainwater from the roof and paved areas into the rain garden. You can simply disconnect the rain gutters from the rain sewer and redirect the water to the rain garden (Fig. 19, 20) through a surface-sloping ditch. Alternatively, you can install an underground PVC pipe under the surface with rainwater from the roof to the rain garden. To protect against strong water jets and erosion from the pipeline to the rain garden, it is advisable to install the pipeline outlet with geotextiles and stones. The rain garden can be combined before by installing a barrel into which rainwater flows from the roof.

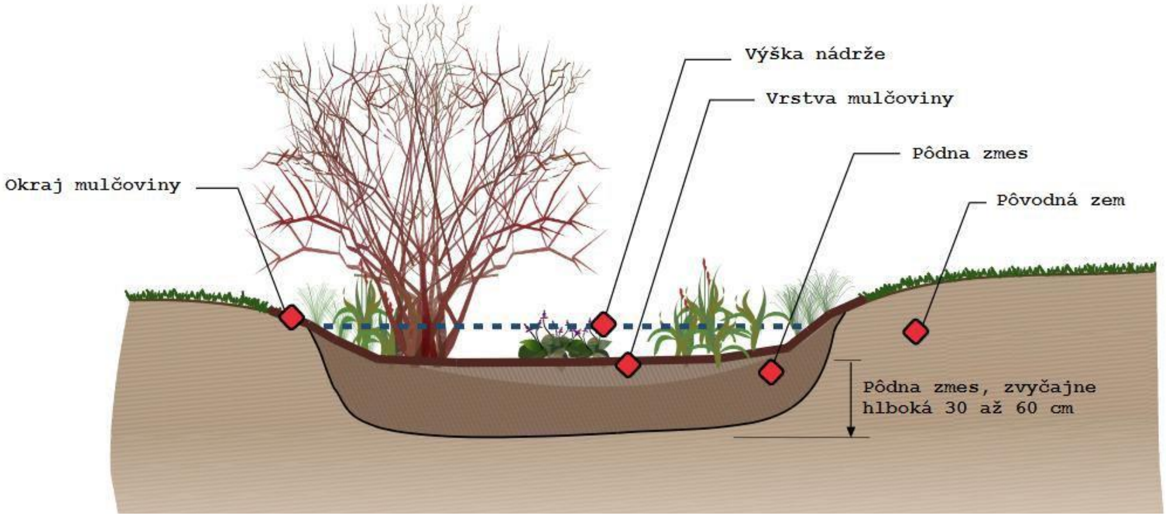

Figure 19 Example of a rain garden solution

Figure 20 Examples of the rain garden (52)

Underground infiltration equipment is divided into:

- infiltration lines,
- infiltration ditches,
- infiltration shafts,
- pipe infiltration,
- rainwater harvesting facilities.

Rainwater tanks

It is a device in which the collected water is concentrated and its size depends on the need of rainwater for the normal building operation. Therefore, when determining the size of the tank, it is necessary to determine what we want to use water for. The tank is equipped with an opening for water inflow and an opening for drainage - safety runoff. Due to the location of the reservoir, we divide them into underground and aboveground. When deciding where the tank will be located, it is necessary to take into account the size of the tank itself, the size of the plot or the layout of the lowest floor of the building in the case of placing the tank inside the building. Today, tanks are most often manufactured in plastic or concrete. Each material has its advantages and disadvantages.

Concrete tank

They can be either monolithic or prefabricated. In the case of prefabricated parts which are not formed in one piece, the tightness at the joints deteriorates over time. Concrete tanks are resistant to high pressures, so in cases where it is necessary to place them, for example, under a road, it is possible to use a concrete tank. They are produced in larger volumes than plastic ones.

Plastic tanks

They are made of polyethylene. They have a low weight, which allows easy installation in the trench without the use of lifting mechanisms. The tanks have all the necessary openings ready at the factory. It is possible to make mobile tanks to order - tanks resistant to higher pressures. In the case of large volumes, it is possible to supply several tanks to each other.

The tanks can be seamless or welded, cylindrical or rectangular, self-supporting, or intended for concreting. They are mounted on a compacted gravel bed or on a concrete slab.

Depending on the location, the tanks are underground, above ground or possibly located inside the building.

Underground reservoir

Placing the tank outside the building below ground level is the most advantageous solution. Thus, the water is not heated by sunlight, which has resulted in a deterioration of water quality. Water stored underground maintains a constant temperature and good quality for a long time.

The big advantage is that there are no space requirements for the size of the object. It is only necessary to provide the necessary land area for the location of the tank.

Above ground reservoir

It is located in close proximity to the building in which the water will be used. The advantage of this type of tank is its easy operation, availability, monitoring and maintenance. The disadvantages are the space requirements given mainly by the required size, resp. tank volume.

A tank located inside the building

With such a tank, the demands on the premises of the building increase. The location and maintenance of the tank itself is much easier than with an underground storage tank due to the easy access, but with such a location there is a risk of flooding the building, which is necessary to think about when designing a security against flooding. The size of the tank is therefore limited by space. The water in the tank is not heated by sunlight.

Technology ensuring the operation of a rainwater using system

Pumps

They are an essential part of the whole system, which ensures the flow of water with sufficient pressure throughout the building. The most commonly used rainwater pumps are centrifugal pumps controlled by a pressure unit that starts the pump during water withdrawal and compensates for pressure fluctuations. The pump types used, depending on the location, are self-priming or submersible pumps.

Self-priming pumps - located independently of the tank. The distance is limited by the pump's ability to draw water. A non-return valve and a suction line with a suction basket is connected to the pump, on which a ball float is placed, ensuring that clean water without sediment particles at the bottom of the tank or dirt floating on the surface will be taken.

During the implementation it is necessary to ensure:

- the pump will be protected from the cold,
- dry-running protection,
- noise reduction by means of a flexible hose connection between the pump and the piping,
- the rise of the suction line from the tank to the pump,
- the end of the suction pipe is permanently below the water surface.

Submersible pumps - are located directly in the storage tank, suspended approximately 15 cm above the bottom of the tank to prevent the suction of contaminated water. If the pump is equipped with a suction line with a ball float, it is possible to place the pump on the bottom of the tank. A switch must be placed in the tank which shuts off the pump in case of lack of water.

The advantages of the submersible pump are:

- there is no need to consider the location,
- pumps noise reduction pump with water in the tank.

Benefits of using collection tanks:

- reduced water consumption from public water mains, protection of scarce water resources in the country,
- rainwater is soft, so it is more suitable for washing and more gentle on domestic plumbing and equipment,
- in terms of its chemical composition, rainwater is more suitable for watering plants,
- water retention in the environment promotes a small water cycle and cools the environment,
- savings on payments for water, sewage and rainwater fees in tens of euros per year,
- in precise processing, it can be used even as drinking water, which would, however, require orders of magnitude higher expenses.

Combined infiltration devices - these devices can be a combination of said infiltration devices. An example is a combination of an infiltration well and an infiltration groove, or rain tanks with a combined retention and detention function can be used.

Aspects influencing the technical solution of infiltration are:

- spatial possibilities that are decisive for the size of the soaking area and the retention volume of the soaking device,
- the ratio of the connected reduced drainage area to the infiltration area of the A_{red} / A_{vsak} infiltration device, which is decisive for the hydraulic load of the infiltration device and its cleaning effect; the lower the hydraulic load of the device, the higher its cleaning effect,
- spatial possibilities that affect whether it is possible to implement a surface infiltration device or whether it is necessary to use an underground infiltration device,
- terrain slope, when in sloping terrain (more than 5%) surface infiltration (especially flat) is often inappropriate or impossible.

Permissibility of discharged rainwater

Depending on the type of surface, precipitation water is classified in terms of pollution in STN 75 9010 as precipitation surface water for infiltration, permissible, conditionally permissible and water from potentially more heavily polluted areas, i.e. rainwater potentially highly polluted.

Infiltration equipment may be used for water-permissible surface and underground.

Conditionally permissible water may be infiltrated superficially through the grassed humus layer or in underground infiltration facilities after pre-treatment.

The infiltration of potentially highly polluted waters poses a significant environmental risk. If these waters are to be infiltrated in exceptional cases, their entire volume must be captured, pre-treated accordingly and demonstrated to a suitable quality by sampling before being discharged into the infiltration plant. The consent of the water authority is required for their infiltration.

In the case of roofs with untreated metal parts, the surface area of untreated metal parts of 50 m^2, connected to one infiltration device, is considered to be a minor boundary of contamination for infiltration. Surface area means the area that comes into contact with rainwater.

The permissibility of infiltration of rainwater draining from the areas near warehouses, handling areas and special-purpose roads of agricultural areas must be assessed individually with regard to their pollution and the possibility of purification.

If there is a possibility of accumulation of contaminants in the soil due to seepage, the soil of seepage devices must be considered as part of the seepage device; no crops intended for human consumption may be grown on it. Infiltration in places with an old ecological burden is prohibited.

The following spatial principles must be observed in the design:

- 5 m from residential buildings that are not waterproof,
- 2 m from residential buildings, which are watertight insulated,
- 3 m from local vegetation sites (trees, shrubs, etc.),
- 2 m from the boundary of the plot, public road, etc.,
- 1.5 m from gas and water mains,
- 0.8 m from the power line,
- 0.5 m from the telecommunication line,
- 0.5 m distance from the groundwater level,
- (bottom surface = bottom of infiltration systems).

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4.4 Rainwater retention from roads, examples, construction solutions

Multi-component infiltration elements are suitable for rainwater retention. The combination of infiltration during pipe or groove infiltration is ideal for draining rainwater from roads (Fig. 21, 22).

With a low permeability of the subsoil, the low permeability cannot be compensated by a temporary accumulation of precipitation runoff, so the element must be provided with a drain. In the case of a combination of overhangs and a groove, the accumulation of the groove is emptied in part by not too intense infiltration, in part by a restricted runoff, directed either into the piping system or into the ditch. As a rule, a shaft is assigned to each infiltration line, where the throttling can be regulated. Attachment/groove systems are expensive as infiltration devices. But they still bring good results in combination with cleaning and retention.

Figure 21 Rainwater retention with roads

Figure 22 Drainage and water retention from roads

Infiltration ditches

Infiltration ditches (Figure 23) are a combination of a road ditch and an infiltration groove. They are used to drain water from the road into the infiltration and water that does not soak in on the spot is drained through the ditch using its retention space into the recipient. These devices are used for drainage of surface layers of roads, but also for drainage from structural layers of the road body.

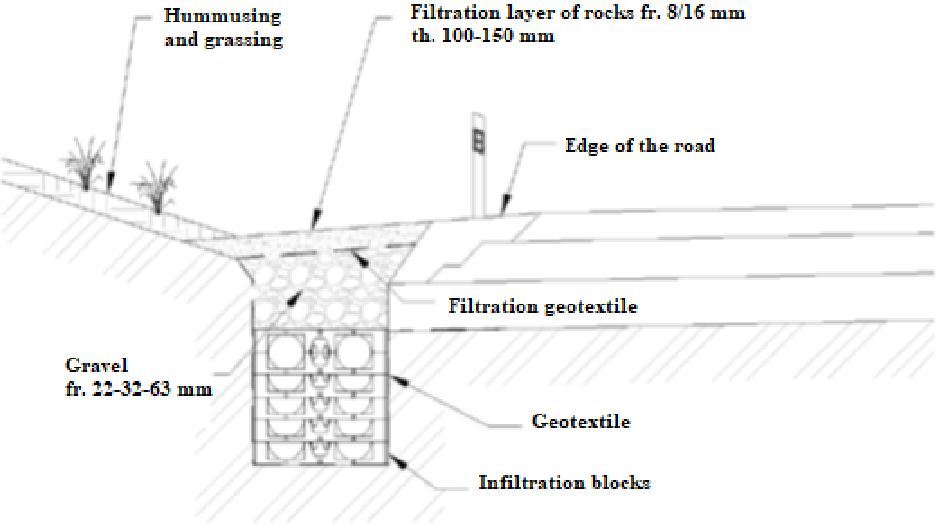

Figure 23 Example of an infiltration ditch solution using plastic blocks

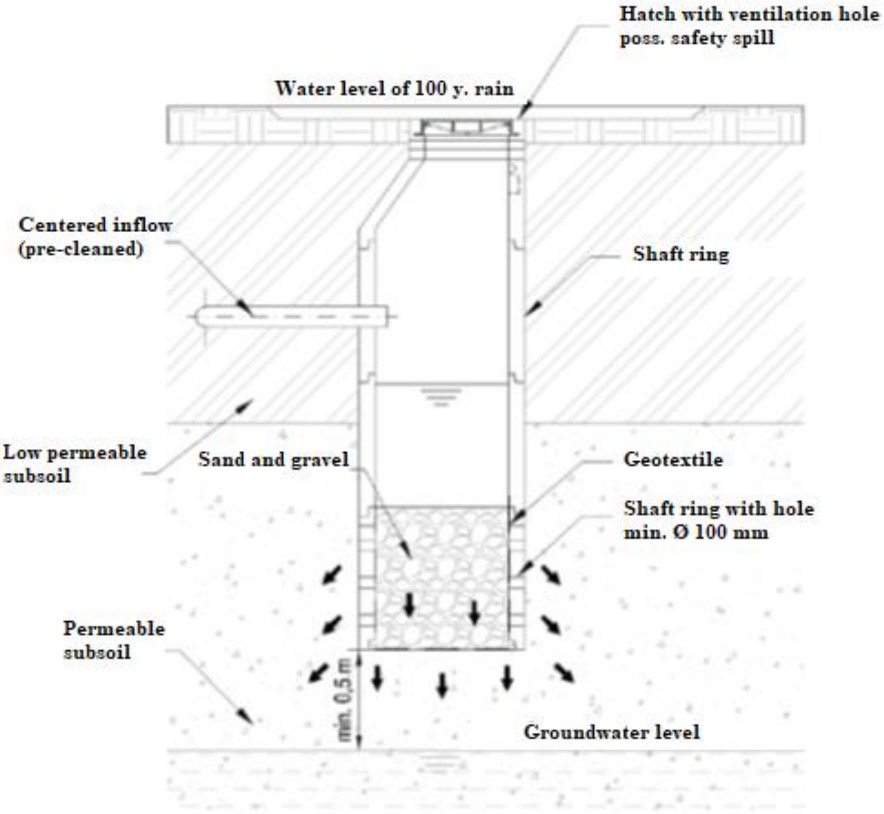

Figure 24 Example of infiltration shaft solution

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Infiltration shafts

Infiltration shafts are underground decentralized infiltration devices that are used for point infiltration and are made of rings of concrete or plastic inspection shafts (Figure 24). Before the mouth of the water it is necessary to precede the element for pre-treatment of rainwater, e.g. in the form of a sediment trap.

Rainwater retention from car parks, including examples, cuts and construction solutions

Surface infiltration

The term surface infiltration (Fig. 25) means infiltration through a permeable, reinforced or overgrown surface in which no rainwater is retained. In the case of surface infiltration, it must be ensured that the soil infiltration capacity is greater than the expected rain runoff, which leads to relatively high infiltration area requirements. Drainage of the ground plan by drainage is desirable if the ability of the soil base is not able to absorb water sufficiently. The advantage of surface infiltration is that in the cover layer overgrown with vegetation and with high humus content, the seepage rainwater is cleaned. In this layer, not only some contaminants are trapped, but also degraded.

Surface infiltration can be realized through the following surfaces:

- grassy areas,
- grassed gravel areas,
- vegetation blocks,
- permeable paving,
- permeable asphalt (porous concrete).

Figure 25 Area infiltration options: a) permeable paving, b) gravel areas, c) vegetation blocks, d) grass areas

Roads in parks, sports grounds, squares (Fig. 26), yard areas, entrance to residential houses are particularly suitable for the use of surface infiltration.

Proposal

The tributaries must be distributed as evenly as possible over the area. The decisive parameters are the degree of infiltration and the infiltration area.

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Infiltration surface with unpaved surface – A_S [m^2]:

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f}{2. i_{T_i n}} - 1}$$

Where :

A_{red} the relevant paved area

i_{Tin} the design rain intensity [$l.s^{-1}.ha^{-1}$]

k_f the saturation zone permeability coefficient [$m . s^{-1}$]

If the infiltration areas are also used as operating areas (car parks), a reduction k_f is expected on the basis of additional soil clogging. For this case, specific values of the infiltration coefficient are used.

Infiltration on partially paved surfaces – A_s [m^2]:

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f . (1 - \psi_s)}{2. i_{T_i n}} - 1}$$

Where:

ψ_s inflow coefficient of the infiltration area [-]

Example of infiltration on an unpaved surface

Given:

$A_{red} = 2000$ m^2, $k_f = 10^{-4}$ $m.s^{-1}$, $i_{15;0,2} = 159$ $l.s^{-1} . ha^{-1}$

a) The infiltration area is not used as an operating area

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f}{2. i_{T_i n}} - 1} = \frac{2000}{\frac{10^7 . 10^{-4}}{2.159} - 1} = 933 \text{ m}^2$$

b) The infiltration area is used as a parking lot, considerable clogging of the soil is expected, which brings with it a reduction of the coefficient k_f by 25 %.

$$k_f = 10^{-4} . 0{,}75 = 7{,}5 . 10^{-5} m. s^{-1}$$

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f}{2. i_{T_i n}} - 1} = \frac{2000}{\frac{10^7 . 7{,}5. 10^{-5}}{2.159} - 1}$$

Example of infiltration on a partially paved surface

The infiltration surface should be lined with concrete blocks with a 40% content of holes. The punching of these blocks is filled with gravel ($k_f = 5 . 10^{-4}$ $m.s^{-1}$).

Infiltration area A_s [m^2] at the level of the blocks:

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f}{2. i_{T_i n}} - 1} = \frac{2000}{\frac{10^7 . 5. 10^{-4} . (1 - 0{,}6)}{2.159} - 1} = 378 \, m^2$$

Infiltration area A_s [m^2] below the level of the blocks:

$$A_S = \frac{A_{red}}{\frac{10^7 . K_f}{2. i_{T_i n}} - 1} = \frac{2000}{\frac{10^7 . 10^{-4}}{2.159} - 1} = 933m^2 > 378m^2$$

The decisive infiltration plane here lies below the partially paved surface, so that an area As of size 933 m^2 is required.

Figure 26 Flat infiltration in the square

Permeable asphalt (porous concrete)

Porous concrete is made of a material that can release up to 200 litres of water per square meter per minute and at the same time offers sufficient strength for the construction of roads (Fig. 27).

Figure 27 Permeable asphalt (porous concrete)

Paved surfaces in cities are often sloped into a single sewer. During torrential rains, water can overfill the sewer and damage the surrounding buildings and infrastructure. If water does not seep through paved surfaces, the groundwater level may drop.

Last but not least, it is important to create at the state level a concept or methodology of a general scale for a given country, the procedures of which would be taken over by individual local governments and implemented in their territory. They would provide guidance on how to link nature-friendly drainage to land-use plans.

Rainwater, it is necessary to take into account surface drainage not only in the construction process, but already in the context of local spatial planning.

4.5 Recommendations on what aspects to focus project on the capture and utilization of water in urban areas, which would be financed within the available EU financial mechanism

Cost estimates for the application of water retention measures can vary significantly depending on the country or even the region and the current market situation. Therefore, it is difficult to achieve general approaches. The costs for the application of measures must be prepared for the direct location according to the current situation and the needs of the urbanized country.

The authors of the Czech Republic which participated in the creation of water retention methodology in the urbanized country are also inclined to develop a project for a specific city which would deal with the concept of the city and rainwater management. The given concept would include all branches of spatial planning necessary for a specific city.

The main objectives of the concept for rainwater management or the implementation of green-blue infrastructure would be defined as follows:

- establishing a long-term concept of city drainage according to the principles of sustainable development,
- identification of risk areas needed as a priority solution,
- creation of a territorial analytical basis for the creation of a new spatial plan and investment policy of the city,
- definition of principles and criteria for systemic management of rainwater in the city,
- ensuring the protection of surface and groundwater in accordance with applicable state and European legislation.

The goals could also be adjusted for the needs of the territory and also for the needs of the population.

An important step in such a concept or manual would be to take a few steps:

- Monitoring and survey of the territory - which would consist of:
    - monitoring of precipitation, levels and discharges on watercourses,
    - physical-chemical monitoring of small watercourses
    - monitoring the ecological status of small watercourses,
    - exploring the potential of rainwater management,
    - addition of information for small watercourses and gutters.
- Models of sewer network, gutters and watercourses:
    - the sewer model,
    - model of small watercourses.
- Evaluation of the current state of runoff conditions:
    - evaluation of capacity possibilities of the drainage system,
    - the impact assessment of relief chambers on the watercourse.
- Other preparatory work:
    - Call in the regional press "Citizens' comments on the function of the drainage system."

The output of such a concept should be:

- basic criteria for drainage, which must be taken into account in the construction and planning of further development in the city;
- definition of principles for spatial planning documentation, especially for the elaboration of a new spatial plan of the city;
- categorization of the area in terms of rainwater management options;
- drainage concept proposal of development sites;
- rules and procedures for the preparation, approval, permitting and operation of works.

Thus, the city should have a tool for simple procurement and they would know what they want from the projector and what are the specific approval processes that are needed to finance the measures through the available EU financial mechanism.

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5 Terms and definitions

Construction - all construction works that arise from construction or assembly technologies, regardless of their construction, technical design and used construction products, materials and structures, for the purpose of use and duration.

Temporary construction - is a construction for which the building authority limits the duration in advance. A product fulfilling the function of a building is also considered to be a construction.

Rainwater - water from atmospheric precipitation which is drained from the surface of the terrain or structure, do not lose its character, flows through temporarily covered sections, natural cavities below the earth's surface or in overhead lines.

Rainfall surface water permissible - rainwater, the quality of which does not pose a risk in terms of soil pollution and endangering the quality of groundwater.

Rainwater surface conditionally permissible - rainwater, the quality of which may be degraded by the content of specific pollution but the risk of groundwater or surface water pollution can be reduced or eliminated by appropriate measures, e.g. pre-treatment of rainwater drained from the surface or buildings.

Infiltration device - a device designed for infiltration of precipitation surface waters into the rock environment.

Underground infiltration device - an infiltration device located below ground level which is intended for infiltration of precipitation surface waters into the rock environment.

Surface infiltration device - an infiltration device located on the surface and is intended for infiltration of precipitation surface waters into the rock environment by the terrain.

Retention volume of the infiltration device - the size of the space in the infiltration device, intended to retain the precipitation surface water before its infiltration.

Annexes - a shallow-shaped depression in the terrain (surface infiltration device) intended for infiltration of precipitation with short-term surface retention.

Safety overflow - a part of the infiltration device or retention object which enables the safe water transfer in the case of a larger than proposed collision or due to failure of the infiltration object.

Central method of drainage - a method of drainage which deals with the treatment of rainwater together for several buildings.

Decentralized method of drainage - a method of drainage that deals with the treatment of rainwater at the place of origin (i.e. usually directly on the site of the building from which rainwater is drained or in close proximity to the road from which rainwater is drained) and returns rainwater into the natural water cycle. In the narrowest sense, these are measures, devices and objects that support evaporation, infiltration and slow runoff into the local water cycle.

Rainwater drainage - underground pipelines used to drain rainwater to the appropriate water recipient.

Rainwater management (RM) - a method of rainwater management (mostly rainwater) which emphasizes the preservation of the natural water balance in the area after its urbanization; the basic approach of RM is a decentralized method of drainage.

Rainwater pre-treatment - measures to protect the facility and / or recipient of rainwater with emphasis on retention of coarse impurities and insoluble substances, reduction of heavy metals, retention of petroleum substances, decomposition of oxygen-consuming organic substances, reduction of nutrient concentration and reduction of pathogenic organisms ; it can take place in nature-friendly or technical facilities.

Grassed humus layer - soil environment with increased humus content, with maintained grass cover and with specific properties.

A_{red} - connected reduced drainage area.

Coefficient of inflow K_v - characterizes the rate of rainwater infiltration into the rock environment by the infiltration device at atmospheric pressure at a hydraulic slope I = 1.

A_{vsak} - the infiltration area of the infiltration device.

Gaps – are determined as the volume ratio of gaps in the aggregate mixture to the unit volume of the mixture. For infiltration purposes, the bulk density of compacted aggregate is used. It is expressed in [%].

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7 Annex

Annex 1. City of Stuttgart. Personal visit to the city and consultation with members of ZinCo GmbH (Source: Ľuboš Jurík, 2020)

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Annex 2. Examples of practical calculations (53)

1. Pond in the park

Pond in Under Sail park

Location: Brno – Nový Lískovec
Designers: Ing. Petr Förchtgott, Ing. arch. Jan Zezůlka, Ing. Vojtěch Joura
Green wall implementer: Cooptel, stavební a.s.

Source: Petr Förchtgott (2015)

Description of the measures

Pond in Under Sail park was created as part of the cultivation of a public area between panel buildings on a housing estate in the town district of Nový Lískovec in Brno and also became a pilot project exploring the possibilities of using rainwater. The retention pond is situated in the centre of the park and is fed by rainwater drained from the roofs of three panel buildings in the vicinity, which have an area of approximately 1 600 m^2. Originally, water was to be drained from four roofs. The volume of water in the pond at the operating level, which is a maximum of 1,2 m, is 630 m^3. The maximum volume of the tank is then 890 m^3, which means that the retention capacity of the pond is 260 m^3. In addition to its retention capacity, the lake has a positive effect on the local microclimate and, thanks to the introduction and breeding of fish and various species of animals, it functions as a natural habitat and has an educational function.

Costs

Investment costs: According to the documents of the Municipal Office Brno - Nový Lískovec, the total direct investment costs of the project for the construction of the park amounted to 10 274 915 CZK including the 21% VAT. The cost of building the lake itself, together with the drainage of water from the surrounding roofs, amounted to 6,1 million CZK. The remaining part was the cost of the park.

Operating costs for the maintenance of the park, according to the records of the Brno - Nový

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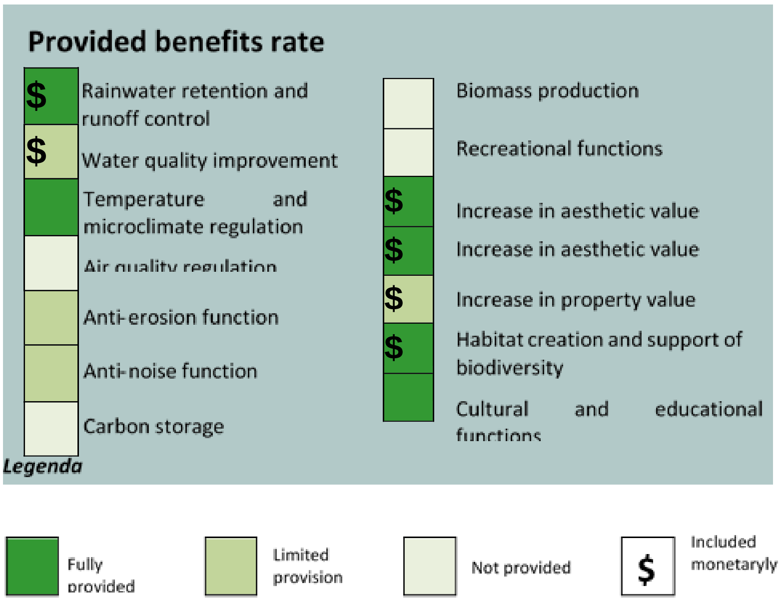
Lískovec district office, are approximately 10 CZK/m^2/year. In case of the pond, it is necessary to take into account the costs of regular maintenance of the pond and elements related to it, such as a footbridge, as well as less regular costs of mud removal from the pond (approx. 300 CZK/m^3), channel maintenance and restoration of the footbridge with railings.

The subject of the economic evaluation in this case is the lake itself, including the channels supplying water from the three roofs of panel buildings. In this case, the adjacent park greenery is excluded from the evaluation, so no costs or benefits associated with it are included in the evaluation.



Provided benefits rate

🟩 $	Rainwater retention and runoff control	⬜	Biomass production
▨ $	Water quality improvement	⬜	Recreational functions
🟩	Temperature and microclimate regulation	🟩 $	Increase in aesthetic value
⬜	Air quality regulation	🟩 $	Increase in aesthetic value
▨	Anti-erosion function	▨ $	Increase in property value
▨	Anti-noise function	🟩 $	Habitat creation and support of biodiversity
⬜	Carbon storage	🟩	Cultural and educational functions

Legenda

🟩 Fully provided ▨ Limited provision ⬜ Not provided $ Included monetaryly

Cost-benefit analysis (CBA) in the form of net present value for the time horizon of 25 and

25 years	Time horizon	50 years
7,968,586 CZK	Cumulative present value of COSTS	9,138,589 CZK
13,601,368 CZK	Cumulative present value of social BENEFITS	16,187,239 CZK
5,632,782 CZK	**Net present value of social benefits in the given horizon**	**7,048,651 CZK**
	Scenario	
Return of investment in years		
(discount rate)		
Optimistic (2 %)	Basic (4 %)	Pesimistic (6 %)
3 years	3 years	3 years

EFTEC, 2010. Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal Case Study 3 – Valuing Environmental Benefits of a Flood Risk Management Scheme. Report for Defra. London.

2. Water areas Lobezská louka

Location: Plzeň – Lobzy
Designers: ATELIER FONTES, s.r.o., VALBEK, s.r.o.
Green wall implementer: HABAU CZ s. r. o.

Source: Markéta Dvořáková (2015)

The lakes together with the adjacent greenery provide a wide range of ecosystem services. As part of the economic evaluation, attention was focused on the benefits arising from the very existence of the lakes, as well as the benefits associated with the adjacent greenery. These are mainly regulatory services (regulation of rainwater, retention capacity, microclimate, air quality, carbon storage) production benefits associated with biomass and crops, recreational and aesthetic function and support of biodiversity. The development of social relations between the population and educational functions is also important.

Provided benefits rate

🟩 $	Rainwater retention and runoff control	🟩 $	Biomass production
▨ $	Water quality improvement	▨ $	Crop production
▨	Temeprature and microclimate regulation	🟩 $	Recreational function
▨ $	Air quality regulation	🟩 $	Increase in aesthetic value
▨	Anti-erosion function	▨	Increase in property value
▨	Anti-noise function	🟩 $	Habitat creation and support of biodiversity
🟩 $	Carbon storage	🟩	Positive effect on health

Legenda

🟩	Fully provided	▨	Limited provision	☐	Not provided	$	Included monetaryly

Cost-benefit analysis (CBA) in the form of net present value for the time horizon of 25 and

25 years	**Time horizon**	**50 years**
24,294,589 CZK	Cumulative present value of COSTS	29,663,820 CZK
261,486,763 CZK	Cumulative present value of social BENEFITS	359,574,842 CZK
237,192,174 CZK	**Net present value of social benefits in the given horizon**	**329,911,022 CZK**

Scenario

Return on investment in years - the perspective of society

(discount rate)

Optimistic (2 %)	Basic (4 %)	Pesimistic (6 %)
1 rok	1 rok	1 rok

EFTEC, 2010. Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal Case Study 3 – Valuing Environmental Benefits of a Flood Risk Management Scheme. Report for Defra. London.

3. Permeable surface - Car parking Štruncovy sady

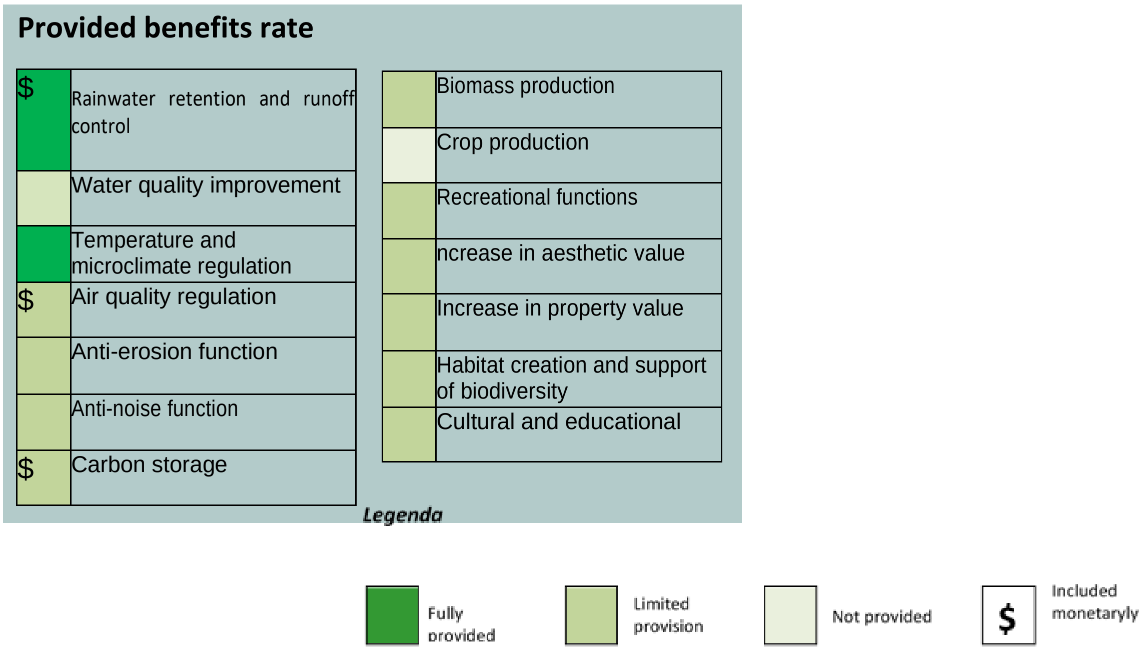
Location: Plzeň – Štruncovy sady
Desginer: VALBEK, s.r.o.
Green wall implementer: Sdružení RC Štruncovy sady

Source: Eva Velebná-Brejchová

Investment costs - 927 500 CZK including VAT. The evaluation of this measure is based on a comparison of the costs and benefits associated with the construction of a permeable surface beyond the costs and benefits of a conventional asphalt surface. After deducting the costs that would have to be incurred in the case of a common asphalt surface, the costs incurred additional amount of 609 000 CZK including VAT.

Operating costs - estimated at 9 000 CZK per year.

The benefits have the nature of cost savings to ensure the drainage of water into the sewer (sewer construction) and its treatment, as well as to a limited extent the reduction of pollutants in the air and the storage of carbon (mainly through trees). There are also savings on construction of the asphalt surface itself. A significant part of the benefits in the case of a car parking is associated with cost savings for the construction of rainwater drainage, which would otherwise have to be built. In the case of the implementation of a car park with an asphalt surface, it would be necessary to complete the connection to the sewer.



Provided benefits rate

🟩 $	Rainwater retention and runoff control
□	Water quality improvement
🟩	Temperature and microclimate regulation
▨ $	Air quality regulation
▨	Anti-erosion function
▨	Anti-noise function
▨ $	Carbon storage

▨	Biomass production
□	Crop production
▨	Recreational functions
▨	ncrease in aesthetic value
▨	Increase in property value
▨	Habitat creation and support of biodiversity
▨	Cultural and educational

Legenda

🟩 Fully provided

▨ Limited provision

□ Not provided

$ Included monetaryly

Cost-benefit analysis (CBA) in the form of net present value for the time horizon of 25 and

25 years	Time horizon	50 years
726,216 CZK	Cumulative present value of COSTS	778,957 CZK
892,841 CZK	Cumulative present value of social BENEFITS	982,140 CZK
166,625 CZK	**Net present value of social benefits in the given horizon**	**203,183 CZK**

Return on investment in years - the perspective of society

Scenario (discount rate)

Optimistic (2 %)	Basic (4 %)	Pesimistic (6 %)
1 year	1 year	1 year

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Water retention in urban areas in the Danube Region: Study on facts, activities, measures and their financial assessment

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