Szent István University

# DEVELOPMENT OF SUSTAINABLE RAINWATER MANAGEMENT IN BUDAPEST

Dóra Csizmadia

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The candidate fulfilled all the conditions prescribed in the Doctoral Regulations of Szent István University, the remarks and suggestions made in the preliminary disputation were taken into account during the revision of the dissertation, therefore the dissertation can be submitted for defense.

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Approval of the School Leader

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| Approval of the supervisor | Approval of the supervisor |

In the decision of the Doctoral and Habilitation Council of Szent István University from the 6th of December 2019, the following Evaluation Committee was appointed to conduct the public defense:

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# List of abbreviations

BGI: Blue-green infrastructure

BMP: Best Management Practice

CAP: Climate Adaptation Plan

CMP: Cloudburst Management Plan (related to Copenhagen)

CSO: Combined sewage overflow

DEP: New York City Department of Environmental Protection

DRWM: Decentralised urban rainwater management

DWM: Directory for Water management

FCSM: Sewage Works of Budapest (Fővárosi Csatornázási Művek)

GI: Green infrastructure

GIP: Green Infrastructure Plan (related to New York)

GIS: Geographic Information System

KURAS: Konzepte für urbane Regenwasserbewirtschaftung und Abwassersysteme. (Concepts for Urban Rainwater Management and Wastewater Systems) German Research Project.

LID: Low impact development

PET: Potential evapotranspiration

RISA: Rainwater Infrastructure Adaptation Plan of Hamburg. (Regenwasserinfrastruktursanplassungplan Hamburg)

RWM: Rainwater management

SSP: Sustainable Stormwater Plan (related to New York)

SURM: Sustainable urban rainwater management

SUSM: Sustainable urban stormwater management

# 1 Introduction

## 1.1 Importance of the research topic and purpose of the thesis

The discipline of urban development concerns decade-long processes. Time to time, this slow organic process gears up by population growth, destruction due war or natural forces, or eventually the appearance of a new technology (e.g. motorization). Climate change and global environmental degradation are our current urban development catalysts compelling us to urgently and radically rethink our urban design approach.

The mitigation of environmental impacts in cities poses perhaps the most complex challenge in the history of urban development. The UN’s recent study on climate change stated, that a carbon-neutral economy must be reached until 2050 to limit global warming by 1,5 °C and prevent the most devastating environmental consequences. Synergies of climate change and environmental degradation speed up the rapid global decline of biodiversity.

As serious impacts of climate change have been gaining broad publicity in the recent years, the collective pursuit to obtain sustainable solutions has had increased political and financial support. Cities whose infrastructure can adapt faster and more flexibly to the new challenges will be more prosperous in the future – and for cities which postpone the adaptation, non-action results in increasing costs each year.

*How can we improve our cities' climate resilience and provide/improve the livability of the urban environment?*

Numerous urban designers draw up this question to themselves and start to rediscover traditional, low-tech building practises and combine them with intersectoral, high-tech solutions to protect communities and reduce their global impact. When I decided to participate in the doctoral program, I wanted to engage in a research topic which has both actuality in sustainable urban design and a relevance for my living environment. I noticed that water management lies in the focus of most climate-change related challenges. Communities are seriously impacted by its shortage, surplus, and quality problems. Therefore, the implementation of a more sustainable, integrated approach for water management by minimizing mankind’s harmful impacts and maximising the usage efficiency will be one of the most important challenges in the coming decades. This finding led me to the first research question of my thesis:

*How can landscape architecture mitigate the urban impact on the natural water cycle and improve our cities' climate resilience and livability?*

Sustainable urban rainwater management is the field that can provide answers to this question. Being a landscape architect, my attention turned to rainwater management tools, which are established by the fusion of the blue and green infrastructure and imitate natural retention and cleansing processes. For an in depth understanding of my research area, several research and best practise projects from various world regions were investigated. I realised, that while the application of blue-green infrastructure tools in new housing projects has already been well established in some countries, the integration into an existent urban structure is a much less investigated and rather challenging task. As a decade-long resident of Budapest, my choice for a study area and thus the second research question were self-evident:

*How can the principles and measures of sustainable rainwater management be implemented in Budapest?*

Budapest, the capital city of Hungary, was chosen as a study area to demonstrate the challenges and benefits of the sustainable rainwater management in the European urban context. The diverse urban structure and natural environment threatened by both droughts and extreme rainfalls make Budapest a representative example for several historical European cities.

Based on the aforementioned questions, the main goals of the research are the following:

- review the theory, principles and tools for strategic planning of sustainable urban rainwater management based on the international literature and case studies
- evaluate the applicability of the methods and design tools of sustainable rainwater management in Budapest
- establish a research base for blue-green infrastructure development in Budapest by proposing research methods and suggest recommendations for their implementation.

## 1.2 Thesis structure

The research is structured into six chapters. The structure of the dissertation is illustrated by Figure 1. Chapter 1 introduces the topic and describes the research methodology. In Chapters 2 and 3, the results of the international literature review are discussed. Chapter 2 (*Theory and design of sustainable urban rainwater management)* describes the main drivers, definitions, and benefits of sustainable urban rainwater management (SURM), followed by the introduction of the required planning data set and the element types of blue-green infrastructure. Chapter 3 *(Strategic SURM planning – international case studies)* focuses on the stakeholders, methods and implementation of the city-scale SURM strategies, analysing the case studies of New York, Copenhagen and Singapore.

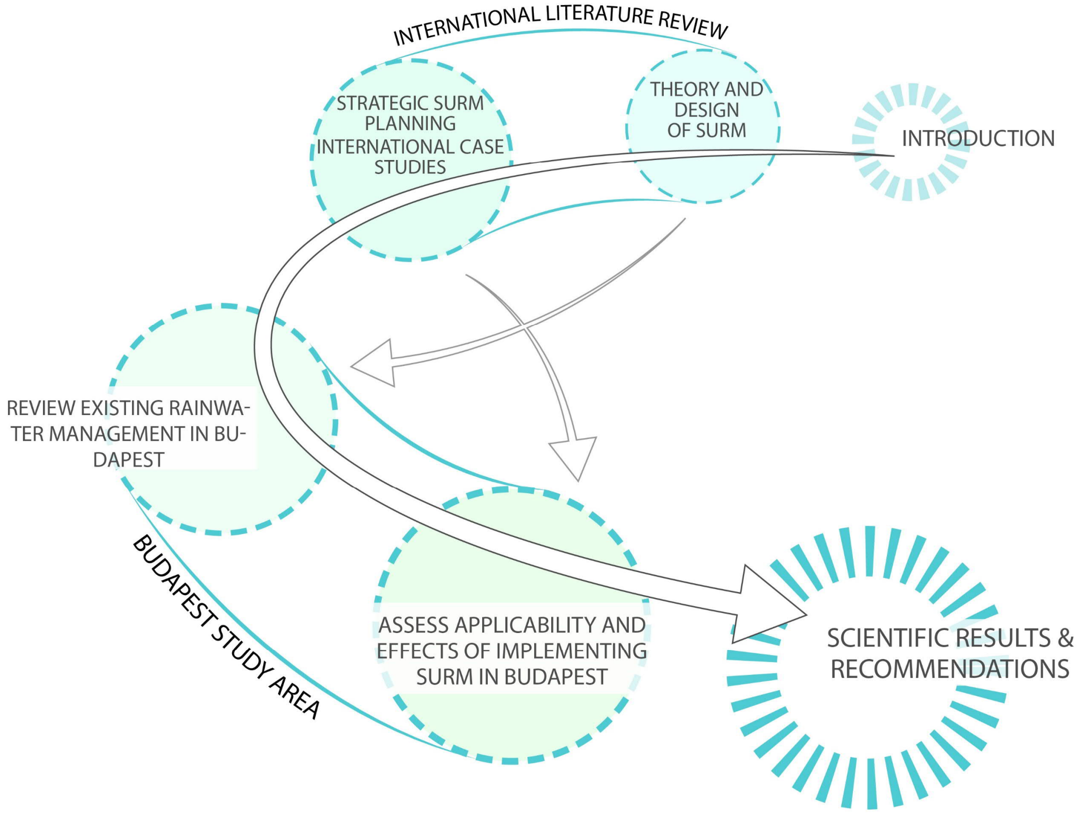


Figure 1: Structure of the dissertation

Chapter 4 and 5 focuses on Budapest. Chapter 4 investigates the urban structure of the city based on the accumulated planning data set of Chapter 2. Chapter 5 firstly reveals the applicability of SURM methods in a large-scale spatial assessment, including an estimatation of the applicability for infiltration, retention and evaporation in the city structure. Secondly, the effects of blue-green infrastructure ßwere investigated in a small-scale assessment. Chapter 6 summarises the scientific results of the thesis and highlights practical recommendations for the SURM implementation in Budapest.

## 1.3 Dissertation methodology

This chapter intoduces the research methodologies and major scientific sources in the four main pillars of the thesis: international literature review; review of Budapest’s properties; large-scale assessment of SURM; and the small-scale assessment of blue-green infrastructure (BGI) effects.

### International literature review

The collection and organization of sources were processed with the Zotero reference management software. During the research, approximately 780 sources were compiled, from which 300 journal articles, 130 webpages, 77 books and other digital publications and nearly 80 research and project reports and strategies. The languages of the used sources are mainly English and German. The data collection was also extended by personal experiences through involvement in the research scholarship program of the Deutsche Bundesstiftung Umwelt (DBU). The one-year long participation in the German research project KURAS (*Konzepte für urbane Regenwasserbewirtschaftung und Abwassersysteme* – Concepts for urban rainwater management and wastewater systems) helped to understand the broader context of the research field. This theoretical base was extended by practical experiences during a second scholarship, and later professional employment in the landscape architecture office *Ramboll Studio Dreiseitl*, which expertises in rainwater management related open space development. Due to these experiences, the German standards and planning practises have an important role in the thesis. Nevertheless, Germany is also objectively the best example for Hungary due to its developed rainwater management principles, relatively similar climate conditions, and similar regulatory and technical background. The investigation of BGI tool properties is based mostly on the German KURAS research project and the rainwater management plan of Hamburg (RISA)).

Strategic planning of SURM was the emphasis of this research. Due to the recent implementation of the first rainwater management strategies, the scientific literature surrounding this topic is still under-developed. Therefore, the strategies, their annual reports and connecting publications were used as a basis for the review.

### Methodology of Budapest´s rainwater management review

The main sources in the review of Budapest’s existing rainwater management were: the Long-term Development Plan (Budapest 2030); the Green Infrastructure Development Plan (Zöld Budapest); the Land Use Plan (Budapest Föváros Településszerkezeti Terve); and the extensive analytical studies of these plans. The applicability of the sustainable urban rainwater management methods in the different land use categories was investigated based on the information gathered in the international literature review. The main stakeholders of the municipial water management (Budapest Waterworks, Budapest Sewage Works and the District Construction Department and the Centre of Budapest Transport) supplied valuable data for the research. The meteorologic and hydrologic data originates from publications of the Hungarian Weather Service. Preparation of the Water Sensitive Design Guideline of Budapest brought me into consultation with further stakeholders from the municipality and the water infrastructure maintainance, and the attained knowledge was applied into the research. The data regarding the properties of the Budapest's existing drainage system was collected by consulting with several experts from Budapest Sewage Works. The Water Works of Budapest supported the research by providing the soil map of Budapest. The green intensity map was provided by the Municipial Department of Urban Development.

## Methodology of the large-scale applicability assessment

Analysis of the city-scale applicability of infiltration, retention and evaporation was commenced by summarizing the data sources collected in the previous chapter. The applied data and their properties are summarized in Table 1.

TABLE 1: DATA SOURCES OF THE CITY-SCALE POTENTIAL ASSESSMENT

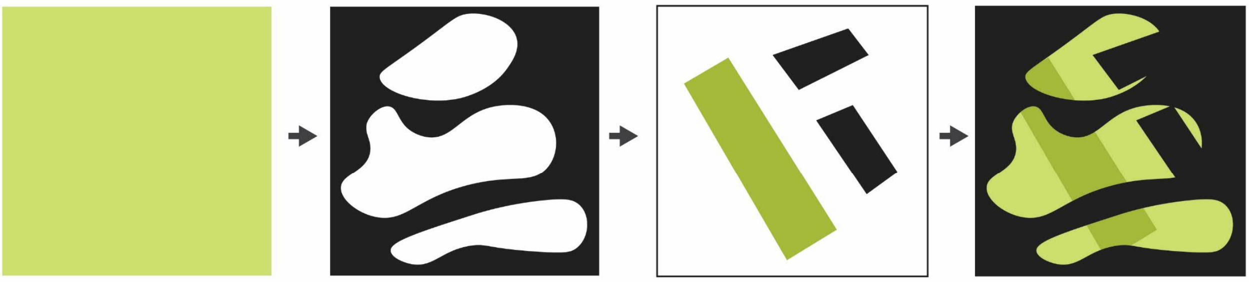
| Data name | Data type | Quality | Age | Source |
|---|---|---|---|---|
| Geophysical factors | | | | |
| Terrain | GIS database | Poor | ! | Budapest Főváros Városépítési Tervező Kft. |
| Soil type | Dgn | Good | ! | Budapest Waterworks |
| Groundwater level | Jpeg (scanned map) | Poor | !! | Map of the Uppermost Phreatic Aquifer of the Budapest Area |
| Green intensity map | Read only GIS database | Poor | ✔ | Budapest Főváros Városépítési Tervező Kft. |
| Heat map | geotiff | Poor | ✔ | Budapest Főváros Városépítési Tervező Kft. |
| Urban environmental factors | | | | |
| Area of the combined and separated wastewater and drainage systems | Pdf | Poor | ✔ | Budapest Sewage Works |
| Land use categories | Read only GIS database | Poor | ✔ | Budapest Főváros Városépítési Tervező Kft. |
| Brownfield areas | Dwg | Very Good | ✔ | Budapest Főváros Városépítési Tervező Kft. |

Data age: ✔ : 5 years or less !: 5-10 years !!: more than 10 years

The quality of the data sources was varied; while vector based data sources had a good level of detail (e.g. the map of the drainage system or brownfield areas), raster based maps were generally poor. Some data sources that were provided for the research had a deficient quality due to the age or limited accessibility. Due to diverse formats and quality, all collected data sources were transformed to raster-based format using AutoCAD, QGIS and Adobe Illustrator and were edited in Adobe Photoshop.

In the first step of the assessment, **geophysical factors** (climate, soil types, terrain, groundwater level) and **urban factors** (drainage system and the land use), were evaluated for the applicability of the three main rainwater management methods (infiltration, retention, detention). The applicability was assigned a value for each spatial category: **no** (the SURM method can not be used in a certain spatial category); or **insisted** (the SURM method would have a high positive impact, or the category is specifically suitable its implementation). In categories where neither of these two values were marked, a general applicability of the method was suggested. Nine **drivers** were defined as reasons of judgement, which are shown in the assessment table by different symbols in Annex 10.4. In some categories, the value is extended by a specific criterion, for example water permeability of the soil: the use of infiltration tools is not sufficient and therefore the value is **no if** the permeability factor $k_f < 10^{-6}$ m/s.

In the second step, this information was layered and filtered in Adobe Photoshop. Figure 2 shows the process of establishing the final applicability map.



1. Full area
Overall applicability suggested

2. Geophysical factors
Extraction of the areas, where the method is not applicable

3. Urban factors
Extraction or priorisation

4. Method applicability map
Overlaying the geophysical and urban factors

■ Not applicable (value=no) 🟩 Applicable 🟩 Insisted (value=insisted)

FIGURE 2: GENERATION PROCESS OF THE METHOD APPLICABILITY MAPS

Geophysical factors were firstly analysed to identify the naturally suitable intervention area of the method. This base map was combined with the prohibiting or prioritising values of the urban environment. The result of the process is shown on the **method applicability maps** in Annex 10.5.

## Methodology of the small-scale BGI assessment

The goals of the small-scale assessment were the appraisal of the possible runoff reduction and the estimation of the effects on the annual water balance in a specific study area. The assessment consists of:

1. Definition and collection of the required data set
2. Selection of the applicable BGI tools
3. Calculation of the required storage volume
4. Scematic design of the blue-green infrastructure and calculation of the runoff reduction
5. Modelling the effects on the annual water balance

The process is explained in Figure 3. The details of these five steps will be discussed henceforth.

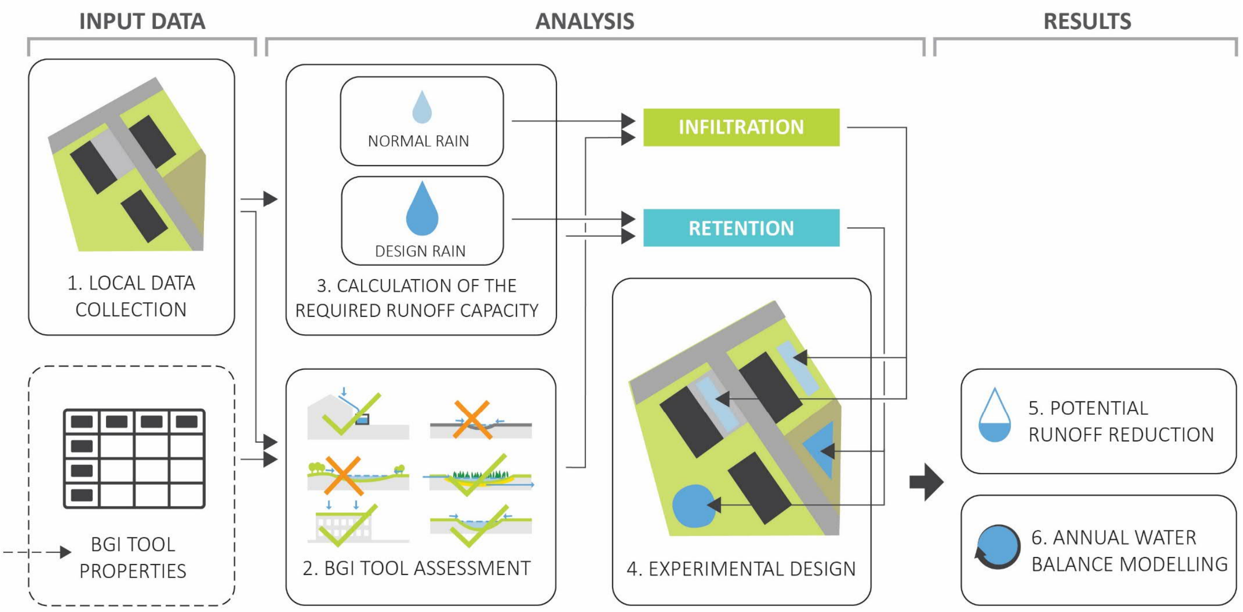


FIGURE 3: METHODOLOGY OF THE RUNOFF REDUCTION ESTIMATION

1. **Data collection:** a complex open space analysis was performed to collect the necessary ground data for the calculation and decision making, consisting of the five following steps:
   a. **Soil and terrain analysis:** The soil type and the groundwater level were defined using Busapest´s soil and groundwater map. A terrain map was generated from the elevation data of Google Maps[1].(Daft Logic 2020)
   b. **Surface coverage analysis**: Surfaces were digitalised with AutoCAD based on satellite fotos, the geoinformatical system of district XI (Újbuda Önkormányzata 2019) and Google Street View. Nine different surface types were defined: green area, asphalt or

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[1] As the area does not have large elevation differences and the runoff simulation does not use digital surface modelling, the precision of the ground data is satisfactory for the research.

concrete, grass paver, paving elements, EPDM surface, gravel, green roof, pitched roof, flat roof. Large surface green areas (more than 400m$^2$ continuous area) were also investigated as a special criterion for large surface elements.

   c. **Open space use:** the use intensity and maintenance intensity were analysed. As a former resident of the estate and participant in the design of the district's green area development plan, I could employ my personal and professional experiences in order to make a judgement on the open space use.
   d. **Building analysis:** building height and roof gradient were investigated in order to estimate the applicability of green roofs.[2] Buildings that were constructed before the beginning of the 20th century are sensitive for changes in the ground water level, therefore the estimated age of buildings was queried.[3]
   e. **Inherited method applicability values:** The relating values of infiltration, retention and evaporation were adopted from the city-level assessment for the SURM applicability.

   All data collection categories are described in text, collected in a summary table and visualised on maps in Annex 10.6. The table provides the base for the BGI tool assessment.

2. **BGI tool assessment:** the methodology combines the defined properties, impacts and implementation criteria of the BGI tools from Chapter 2.4 together with the collected local properties. The listed local properties were connected to the BGI tool properties by defining restrictive or prioritising conditions (similarly to the large-scale assessment) shown in Table 2. The tool that is assigned a "**no**" value is considered not applicable, even if all other properties would permit the implementation to be feasible. For the example of a retention pond: even if the rainwater retention and the aesthetic value is appreciated but the space demand of the tool is too high, then this single parameter makes it impossible to implement. The BGI assessment method was verified on several residential housing types and the outcome was an appropiate tool selection in each situation.
3. **Calculation of the required storage volume**: The housing estate was divided into sub-catchment areas, based on the slope conditions of the park and road profiles. The runoff calculation was processed separately in each of these areas. Considering the size of the

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[2] While steepness is an evident factor, the impacts of green roofs on high buildings are less known. Green roofs are not advisable on roofs greater than 5 storeys due to significantly higher maintenance costs, the potential damage caused by higher windspeed and minor impact on the urban climate.(Szabó 2009)

[3] In this study area, this aspect has no relevance, but because the tool assessment method was designed for a general implementation, properties of further housing types were also considered.

catchment areas, calculations were achieved by the “rational method”. Surface runoff coefficients were implemented from the German standard DIN 1986-100.[4] (DWA 2019) The calculation process is detailed in Chapter 5.2.3.

Two scenarios were calculated for the rain events with 4-year and 33-year return period.

The aim was to retain the runoff from the 4-year rain event in the catchment areas by infiltration tools. The German **standard DWA A-138** was used to dimension the surface area of the required infiltration zones. According to the calculation method of the standard, different storm periods in the range from 5 to 1440 minutes were investigated to define the maximum required storage volume, thereby also taking the infiltration loss into account.

TABLE 2: DATA SET OF THE PLOT ANALYSIS AND DEFINED CRITERIAS OF THE BGI TOOL SELECTION

| | Parameter | Variables | Impacts on the BGI tool properties |
|---|---|---|---|
| Surface analysis | Real GAR/min GAR[1] | <1 | Prioritised UNSEALING |
| | | >1 | - |
| | Continouous green area | small (<400$m^2$) | No ● space demand |
| | | large (>400$m^2$) | - |
| | Traffic & parking on the plot | yes | Prioritised ○● cleansing |
| | | no | |
| Open space use | Use intensity | low | No ● maintenance costs |
| | | high | Prioritised ○● recreational value<br>Prioritised ○● aesthetic value |
| | Maintenance intensity | low | No ● building costs<br>No ● maintenance costs |
| | | high | - |
| Building analysis | Storeys | > 5 storeys | No FLAT ROOF |
| | | < 5 storeys | - |
| | Roof type | pitched | No flat roof steepness |
| | | flat | Prioritised flat roof steepness |
| | Facade type | simple (Si) | Prioritised S facade type |
| | | segmented (Se) | No S facade type |
| | Time of building | before 1920<br>after 1920 | No ● Infiltration<br>- |
| Inherited method values | Infiltration | possible | - |
| | | not possible | No ● Infiltration |
| | Retention | possible | - |
| | | not possible | No ● Retention |
| | Evaporation | possible | - |
| | | not possible | No ● Evaporation |

[1]: minimum green area ratio (regulated by the land use plan)

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[4] Drainage systems on private ground – Part 100: Specifications in relation to DIN EN 752 and DIN EN 12056

The 33-year event is intended to be retained by utilising retention and detention tools in order to decrease and slow down runoff. The required storage volume was calculated and then reduced by the stored runoff volume for the 4-year rain event.

4. **Scematic design:** The possible locations for infiltration and retention tools were identified on the study area map in AutoCAD. Slope directions, existing open space structure and use were considered during the tool placement shown in Annex 10.7. The implemented tools were chosen from the results of the BGI tool assessment.
5. **Potential runoff and annual water balance calculation:** The actual total storage volume for the 4-year runoff was calculated by combining the volumes of all infiltration tools. The actual total storage volume for the 33-year rain was calculated by the summing the infiltration and retention tool capacities. Based on this, the reduced runoff by using BGI tools was calculated and compared to the existing stage.

   The impact on the annual water balance was estimated using the **Simplified Rainwater Balance Model "WABILA"**. This tool was developed by the German research project SAMUWA and promoted by the DWA as a supplement of the **standard draft DWA-A 102.**[5] (DWA 2016) A detailed description of the program can be seen in Annex 10.9. **Three scenarios were modelled** in the program: the original undeveloped stage (meadow); the current stage; the planned stage with the implementated BGI tools. The results were compared on graphs in Chapter 5.2.6.

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[5] DWA-A 102: Principles of the management and treatment of rainwater runoff

# 2 Theory and design of the sustainable urban rainwater management

Several research projects emerged in the past decades to establish a new theoritical base for rainwater management. The thesis firstly introduces the problems and challenges of our existing urban rainwater management practice. Thereafter, this chapter collects the main goals, principles, important definitions and benefits of a new approach to rainwater management. In this section, the main technical terms will be defined which will be recalled throughout the thesis. Finally, the required dataset for SURM planning and the elements of the blue-green infrastructure will be introduced.

## 2.1 Time to act – growing concerns and challenges in urban water management

The circulation and purification of water are self-supporting processes by the presence of natural terrain and vegetation conditions. The natural water cycle consists of **precipitation, infiltration, runoff, and evaporation**. The quantity and proportion of water transported in each of these phases are local characteristics of an area, determined by the climate zone and terrain. In vegetated natural areas, 50% of the rainwater infiltrates the soil and runoff does not exceed 10%. The soil and the microorganisms around the root system of plants filter the slowly moving water, which can take up to a week to reach the groundwater or watercourses. The combination of natural soil and dense vegetation has an immense water storage capacity. This water returns to the air by the **evapotranspiration**. It consists of **evaporation** from the soil and from the surface of the plants[6], and **transpiration** by the vegetation's metabolic functions. This process can transform up to 40% of the rainwater into water vapour and effectively cools the local environment.(Dreiseitl, Geiger 2009 p. 24)

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[6] The rougher the surface (and therefore greater the surface area) is, the more water can be stored on it. Therefore, a dense, layered vegetation can achieve the highest evapotranspiration rate. Wet rainforests are a good example for the importance of surface roughness. Due to the extreme humidity, surface water flow draws potentially 40% more water from vapor condensation on the leaf surfaces than from the rain.(Department of Environment and Forests 2019)

This natural water cycle has been disrupted by human settlements with high sealed surface coverage, inappropriate resource use and pollutants from urban land use. The major goal of current rainwater management is the fast removal and rapid transportation of rainwater into watercourses using surface sealing and urban drainage systems, which have a significant impact on the water balance (see Figure 4).

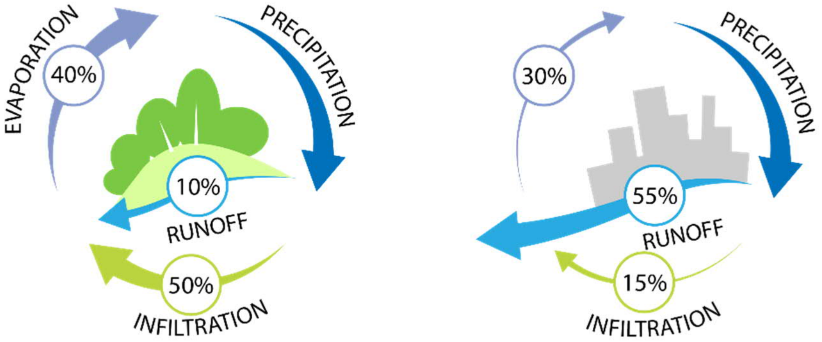

FIGURE 4: RUNOFF, INFILTRATION AND EVAPORATION RATIO OF THE NATURAL AND URBAN AREAS
(Source: own work, based on (Dreiseitl, Geiger 2009)

**High impervious ratio** is the most influential aspect for rainwater management. (Brabec et al. 2002 p. 499) Due to the exponential increase of urban traffic since the 1970's, numerous cities were designed or reconstructed to serve the needs of motorized vehicles and a large percentage of urban spaces were converted into parking lots. Paved areas have a low surface roughness that allows water to flow much faster. In Budapest, traditional basalt cobblestone and suburban gravel roads were covered by asphalt which increased the quantity and speed of urban runoff. Roads often act as dikes alongside rivers and sever the connection with the natural flood plains as well as prevent pedestrian access to the waterside.

FIGURE 5 AND FIGURE 6: USE OF THE DANUBE WHARF IN BUDAPEST IN 1916 AND 2015
(Source: (Magyar Kereskedelmi és Vendéglátóipari Múzeum), (mammaróza 2014))

Two main types of **urban drainage systems** were developed in the past three centuries. Older cities were established with a **combined sewage system**, where wastewater and rainwater are mixed and transported in one pipe system to the recipient or cleansing plant. When the conveyed flow exceeds the capacity of the pipe system or the treatment plant (typically during a heavy rain), surplus wastewater is conveyed by the **combined sewer overflows (CSO)** directly into the watercourses (see Figure 7). The **separated sewage system** uses a separated parallel pipe system for wastewater and rainwater drainage. This system conveys only the wastewater into the cleansing plant and releases stormwater directly into the watercourses. The historic development of urban water management is summarised in Annex 10.1.

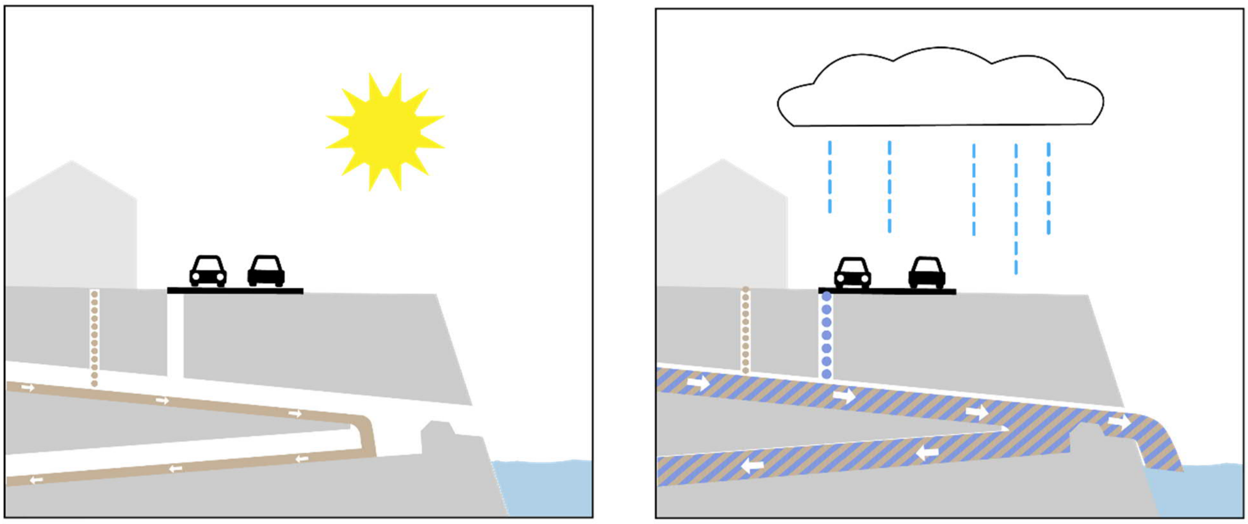

FIGURE 7: SCHEME OF THE COMBINED SEWER OVERFLOW

Consequences of these technics occur on local and global levels. On a local level, fast discharge increases the peak flow (the maximum runoff volume during the rain event) and the probability of **flash floods**. Increased runoff can overload the conveyance capacity of the sewage system and threaten low-lying areas by the spillage of mixed septic water. Thousands of cubic meters of rainwater are drained from roofs and pedestrian areas into the sewage system, while urban green areas have a lack of water and need for irrigation, even during periods while natural vegetation in unsealed areas is still flourishing. Where irrigation is not feasible, plants grow much slower, become weak and less resistant against diseases.(Mullaney et al. 2015)

Fast water removal stops groundwater recharge and exacerbates the water scarcity during dry periods. Impervious areas do not have water storage capacity, thus evaporation stops after the wet surface has dried up, radically limiting the heat extraction effect of evapotranspiration.(Susca et al. 2011) This phenomenon causes the **urban heat island effect**. The impact can be amplified by dark materials with a low albedo: the darker the surface is, the more solar radiation will be absorbed and emitted as heat.(Santamouris 2013) Gábor and Jombach’s satellite analysis showed 17.5°C temperature difference between a densely built urban area (predominantly paved by dark asphalt) and a city park of Budapest on a hot summer day.(Gábor, Jombach 2008 p. 32)

Although sewage systems have a fundamental importance in urban sanitation, they are also considered as **point source pollutions**.[7] With the further growth of cities, the danger of overloading combined sewage systems is constantly increasing. The runoff from densely populated areas may contain a significant level of pollution(Lee, Bang 2000), therefore several countries are tending to change this routine and considering to insert water cleansing solutions also at the outlet of the rainwater drainages.

TABLE 3: POLLUTION SOURCES AND TYPES OF THE URBAN RAINWATER RUNOFF
(Source: (Csizmadia 2018 p. 10) and (Budai 2011))

| Pollution source | Direct source | Chemicals |
|---|---|---|
| Roads and traffic | tyre abrasion | rubber, soot, heavy metal oxides with Zn, Pb, Cr, Cu and Ni |
| | brake pad abrasion | Ni, Cr, Cu and Pb, Fe |
| | engine combustion | Gases and aerosols, soot |
| | de-icing | $CaCl_2$, $CaSO_4$, $MgCl_2$, $MgSO_4$ |
| Heating | Combustion of gas, coal or wood | PAH, soot |
| Roofs | Oxidation of metal surfaces | Zn, Cu, Al, Pb oxids |
| Urban nature | Greenery, faeces, fertilizers, pesticides | N, P, further organic substances |
| Human activity | rubbish | Diverse materials |
| | Greenhouse gases | $CO_2$, $CH_4$ |

Urban surfaces are considered as **non-point pollution sources**[8]**,** in which urban traffic is the most significant source (see Table 3).[9] Discharged chemicals are mainly heavy metals, e.g. lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd), polycyclic aromatic hydrocarbons (PAH), mineral oil hydrocarbons (MOH) and readily soluble salts.(Pitt et al. 1994) Roofs and drain pipes made of copper, zink, aluminum, lead and other metals also should be considered as non-point pollution sources releasing heavy metals as corrosion products. (Göbel et al. 2007 p. 27) Urban nature "discharges" annually a high amount of organic materials with a peak in the autumn season. Further human activities such as littering also contributes a constant load of organic materials and various toxins.

Figure 8 shows the transportation path of urban pollutants in the urban water environment. Pollutants can enter the water cycle by subsiding on the ground and plant surfaces and wash away with the surface runoff (dry atmospheric deposition); or due to rain, snow, fog, dew and frost, which contain substances leached out of the atmosphere (wet athmospheric deposition). Pollution can also accumulate in the groundwater and surface water through discharge and infiltration. In surface water, direct contact with air and sunlight helps to oxidise and break down several pollutant

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[7] A point source pollution is a single, identifiable source of pollution, such as a pipe or a drain.

[8] See more about pollution sources in Chapter 2.2.2.

[9] Typical traffic pollution sources are road surface abrasion, tyre abrasion, brake pad abrasion, drip loss (fuel, gear oil, grease, brake fluid, antifreeze, etc.) and corrosive products.(Klein et al. 1982)[9]

types within days or weeks. Chemical processes are much slower underground and groundwater contamination can damage water resources for decades or centuries.

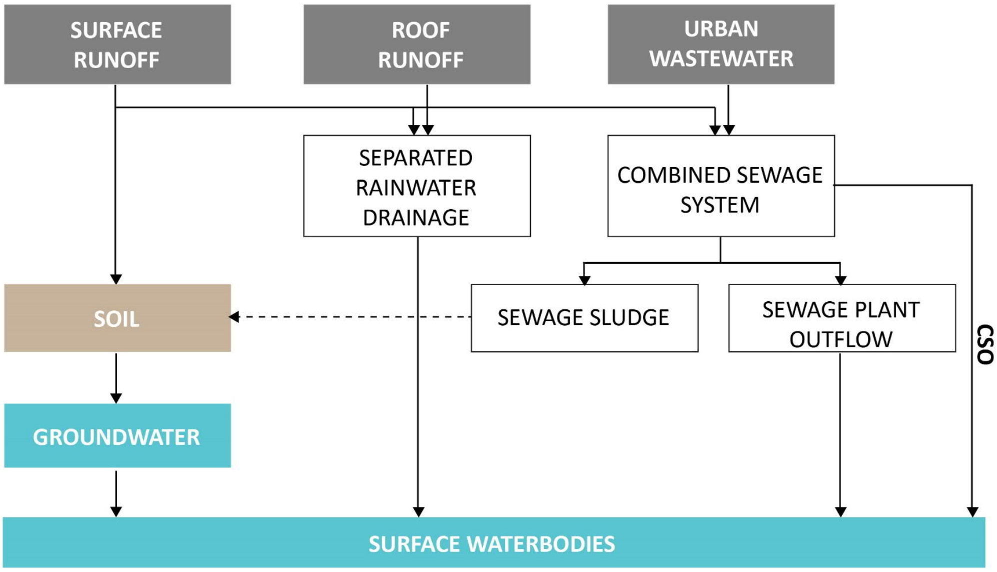

FIGURE 8: TRANSPORTATION PATH OF URBAN POLLUTANTS
(Source: based on (Gantner 2003 p. 91))

Investigating the impacts on a global level, cities have a high impact on the hydrologic balance of the planet. By producing more than 70% of the world’s carbon-dioxide emissions, this has been attributed to increasing global temperatures and thus altering the quantity and distribution of precipitation. The increasingly imbalanced distribution of rainwater further raises the probability of pluvial and fluvial flooding. In Europe, droughts will be longer and more regular in the future, and the added urban heat island effect will have a profound impact on the health and lifestyle of inhabitants. Hungarian researches showed an increased mortality rate by 15-20% during heat waves.[10] The prognosed 100-180% growth of heat wave days until 2050 would result in a 2.6-fold increase of excess mortality.(Bihari et al. 2015 p. 13) Rising temperature and water shortage accelerate the weakening and decay of urban vegetation, which will further reduce the natural cooling capactity. This process has an amplifying negative feedback on the urban climate. Cities will face with indirect, but significant economical losses, such as reduced profit due to shrinking tourism.

International and national alliances and policies were formed to understand above-mentioned concerns and solve water related issues. The Dublin Statement in 1992, established the concept for an **integrated management of water resources** and underpinned the complex and network-based characteristics of water systems.(Rolston et al. 2014 p. 1)

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[10] Between 2004-2015 (Bihari et al. 2015 p. 13)

In the last decade, the concept of sustainability became the leading keyword in urban planning. In 2015 the United Nations released the **2030 Agenda for Sustainable Development**, which defined 17 sustainable development goals (divided further into 167 targets) and are broadly accepted and quoted in urban planning. (United Nations 2017) Two of the goals are directly related to water management and clearly describe the main challenges ahead for Europe. Goal 6 is to *"ensure access to water and sanitation for all: improve water quality by reducing pollution, implement integrated water resources management at all levels, protect and restore water-related ecosystems"*. A lacking water supply and sanitation seldomly menace Europe (currently). Nevertheless, the quality of water bodies and dramatic decline in the water habitats are real concerns and make the continent more vulnerable to climate change. Goal 11 "*Sustainable cities and communities: mitigation and adaptation to climate change*" describes the second main challenge for Europe.

The European Union established the **European Water Framework Directive** in 2000 in order to protect the ecological condition of water resources and provide a good water quality. While the target of the Water Directive (provide a 'good status' for all water bodies) was compulsory for all EU Member States, the exact target values could be defined and implemented in the national systems locally. Though the Water Directive could not reach it's goal until 2015, it established a European monitoring and communication system which could demonstrate significant successes and provide a large amount of data and a deeper understanding of the complex water systems.(European Parliament 2000) The **Floods Directive (2007/60/EC)** established in 2007 (European Parliament 2007), complements the Water Directive to limit the increasingly devastating consequences of European flood events. It requires the members to map flood risks and take adequate and coordinated measures to reduce it. The Floods Directive recommends the use of sustainable flood protection methods, such as restoring the natural meanders and floodplains of rivers, upland forests and wetlands. The **Groundwater Directive (2006/118/EC)** complements the WFD with more detailed monitoring and quality criteria. The **Environmental Quality Standards Directive (EQSD)** extends the requirements of the WFD by setting limit values for pollutants classified as "priority substances" that pose a significant risk to the aquatic environment. The EU nevertheless has not layed out policies or principles regarding urban rainwater management. Although sevral projects and alliances started to form in Europe to share knowledge about new technologies, there is still a long way ahead for the system-wide application of a more sustainable practice of urban rainwater management.

## 2.2 Approaches, definitions and principles of sustainable urban rainwater management

The search for a sustainable rainwater management approach started in the 1970ies. Since then, various researches were conducted to define goals, principles and methods of this new approach. Henceforward, the most important concepts for sustainable rainwater management, their used definitions, and the set of technical terms used in this thesis will be reviewed. Finally, the main goals, planning principles and methods will be summarised based on the investigated concepts.

### Approaches and definitions of sustainable urban rainwater management

Due to different drivers and local conditions in different countries, the rainwater management approaches and terms vary slightly. The following investigation introduces the most significant concepts used per country.

**Green infrastructure planning – blue in the green (USA and Canada)**

**Green infrastructure (GI)**[11] planning has historically been a highly developed discipline in North America, which enjoys a large-scale planning process. Green infrastructure includes the management of rainwater and surface water, and the network-based approach supports the management of water systems whose elements are typically connected. The EPA's (United States Environmental Protection Agency) definition underlines this by a water management focused GI definition: *"Green infrastructure is a cost-effective, resilient approach to manage wet weather impacts that provides many community benefits"*.(US EPA 2015). Nevertheless, GI has numerous further functions and advantages, therefore the term itself does not reflect the sustainable rainwater management approach. As water management gained a higher importance in the urban planning, the term **blue-green infrastructure (BGI)** was emerged to highlight the impact on water management. The term is not confined to North America but originates from green infrastructure. Alike GI, BGI can also be applied on various geographic levels and underpins a necessity of network-based thinking in rainwater management. BGI serves several interrelated purposes, such

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[11] *"Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (and water bodies if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings."*(Liquete et al. 2015 p. 269)

as water storage, flood prevention through water level regulation, nature conservation, water cleansing, production areas of wetland crops, and providing recreational activities.(Benedict 2006)

While GI and BGI are applied both on a small and regional scale, the term **Low Impact Development (LID)** is mostly used for urban green infrastructure planning. *LID is a management approach and set of practices that can reduce runoff and pollutant loadings by managing runoff as close to its source(s) as possible.* (United States Environmental Protection Agency 2012 p. 1) LID is a manner of land development that seeks to mimic predevelopment hydrology to protect waterways, habitat, baseflow, and groundwater recharge (DeLaria 2008 p. 5). The concept has a technical approach and focuses on the use of BGI tools and includes engagement of the residents regarding conservation of water resources. Due to urban pollutants, this approach also emphasizes the water cleansing function. Despite the broad scope of the term LID, rainwater management in the US is usually not a tightly integrated part of the urban development process, and its goals rarely overrule the interests of private developers. The term LID is widely used in the USA and Canada, but less known in the other parts of the world, perhaps due to its less self-expressive phrasing, which doesn’t contain a direct reference to rainwater management.

#### Sustainable Drainage Systems – sustainability and flood protection (Great-Britain)

In Great-Britain, urban rainwater management systems are called urban drainage; and measures for sustainable stormwater management are described by the term **Sustainable Drainage Systems (SuDS)**. The term is not restricted to urban areas. Four pillars of the design approach are water quality, flood protection, biodiversity and amenity. Among these, flood protection is a stressed aim.(Glen 2014) SuDS, similarly to LID, focuses mainly on the technical side of rainwater management but does not have a long term, overall vision of social transformation. The Chinese **Sponge Cities** concept also uses the main principles of SuDS, focusing on water retention in order to minimise flood events.(Li et al. 2017)

#### Decentralised rainwater management (Germany)

The German **Decentralised Rainwater Management (DRWM)** approach *aims to replicate natural systems by using cost-effective solutions with low environmental impact in order to manage polluted surface water run-off by on-site collection, storage, and cleansing before slow release into the environment.* (Sieker 2018) The German approach focuses on improving water quality, on-site treatment and reducing flood risk, controlled by detailed regulations. Rainwater management is often integrated into new and redevelopment projects at the start of the planning process. Restoration of the natural water balance has recently become the main target, which draws attention to the development of evaporation tools. “Decentralised” and “sustainable” rainwater management are not synonym terms, because centralised systems can be sustainable too (Geyler et al. 2013 p. 4); DRWM can therefore be defined as a special field of sustainable urban rainwater management. The term **Sustainable Urban Stormwater Management (SUSM)** is not only used in Germany, but also in worldwide researches which include the decentralised, as well as centralised elements.

### Water sensitive cities - a complex vision for the future (Australia)

The most complex and integrated approach for the transition to an integrated urban water management no doubtedly evolved in Australia. The **Water Sensitive Cities** concept divides city development into six phases with relation to water, namely ‘Water Supply City’, ‘Sewered City’, ‘Drained City’, ‘Waterways City’, ‘Water Cycle City’, and ‘Water Sensitive City’ illustrated on Figure 9. (Wong, Brown 2009)

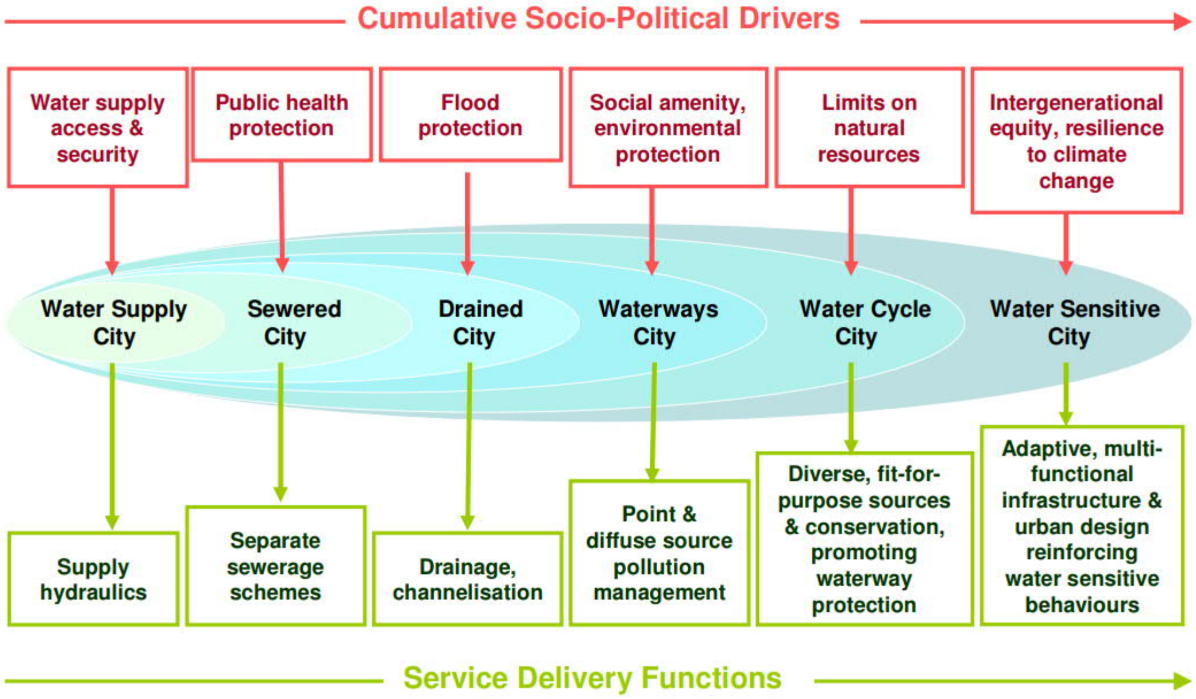

FIGURE 9: URBAN WATER MANAGEMENT TRANSITIONS NETWORK
(SOURCE: BROWN 2008, 5)

Most currently developed cities can be attributed to the ‘Waterways City’ phase. At this phase, natural values and surface water quality have already achieved social awareness, and the impacts of point and non-point pollution are measured and managed. The theory suggests two further steps: ‘Water Cycle Cities’ can successfully adopt the integrated water management approach to achieve an efficient use of resources and protect waterways. In the last step, ‘Water Sensitive Cities’ achieve a multifunctional infrastructure with the adaptation of **Water Sensitive Urban Design**

**(WSUD),** which is defined as the combination of 'Integrated Urban Water Cycle Planning and Management' and 'urban design'. The last phase underpins that a full transition can be reached just by changing the residents' perception of resource conservation in order to achieve a water-conscious behaviour. The concept sets goals for the transition and defines benchmarks through the development of an integrated framework.

There is not a single water sensitive city in the world yet, but the project accomplished remarkable changes to the implemenation of integrated water management in Australia. It was successfully implemented in Melbourne and Sydney by the cooperation of the private and public sectors. The methodology has also been applied also in other cities such as Singapore.

### Technical vocabulary of the thesis

During the analysis of parallel definitions, terms needed to be chosen that expressively and precisely describe the aim of sustainable management of urban rainwater. The suitable term must fulfill three criteria: 1) it should be clear-cut and expressive; 2) it should contain the urban context; 3) it should refer to a complex, contemporary approach, which includes not just a technical, but also a complex social and institutional transition as well.

Therefore, **"Sustainable Urban Stormwater Management" (SUSM)** was chosen as the phrase, which fulfills most of these criteria. The term 'stormwater' puts emphasis on flood protection, nevertheless every amount of rainfall should be considered as an opportunity for the mitigation of growing water shortages. To gain a broader definition, the term will be modified to 'rainwater' and will be referred to in this document as **'Sustainable Urban Rainwater Management' (SURM)**. **"Blue-Green Infrastructure" (BGI)** will be used to emphasise the importance of connectivity and network-based planning.

## Goals, principles and benefits of SURM

By synthesising several recognised strategies and research programs[12], the following main goals were identified for SURM in Europe:

- **Flood protection**: reducing flood risk caused by high seawater, groundwater, rivers or inland water body level.
- **Urban climate regulation**: decreasing the heat island effect and impacts of droughts.

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[12] Summarised from the Water Plan of Rotterdam, RISA Hamburg, Cloudburst Plan of Copenhagen, and from the Rlue-Green Cities, SWITCH, KURAS, SAMUWA research projects.

- **Climate resilience**: building a more flexible water infrastructure designed for future climate conditions that can provide a safe and livable urban environment.
- **Cost efficiency**: relieving the overloaded sewage system by reducing rainwater runoff. Decreasing development costs by creating low-maintance decentralised elements. Reduction of flood protection and renovation costs.
- **Clean water**: decreasing the pollutant load of urban water runoff and watercourses.
- **Amenity**: establishing new recreational areas.

Several researches and projects have gathered the main principles of the **water sensitive urban design approach** (United States Environmental Protection Agency 2012) (Chou 1998) (Ferguson et al. 2013) and these are summarised in the following 7 main points:

- **Restoring the natural water cycle:** Restoring the natural balance of evaporation, runoff and groundwater recharge is becoming a general design approach of SURM, to maintain a livable and sustainable urban climate.
- **On-site management:** Rainwater must be treated as close to the source as possible. On-site infiltration or retention prevents the overload of the combined sewage system or the stormwater drainage and helps to recharge the groundwater.
- **Clean water:** Urban runoff has a significal pollutant load, therefore rainwater must be cleaned before it reaches the watercourses or the groundwater.
- **Connectivity:** BGI is a network-based system. Heavy rainfalls are often concentrated on small areas - connected elements help to balance different loads and extend capacity.(Sposito, Faggian 2013)
- **Multifunctionality:** The combination of BGI tools with recreational, food production and ecological functions magnifies their benefits for the community and nature.
- **Integrated approach:** SURM should be designed together with the wastewater management and water supply system to create an urban water cycle. An integrated approach also includes social integration: active communication and cooperation between the different stakeholders and the residents.
- **Aesthetic shaping:** Well designed BGI tools must be shaped to fit into the urban context and provide an aesthetic value for residents.
- **Biodiversity:** BGI provides new habitats and green corridors for plant and animal species

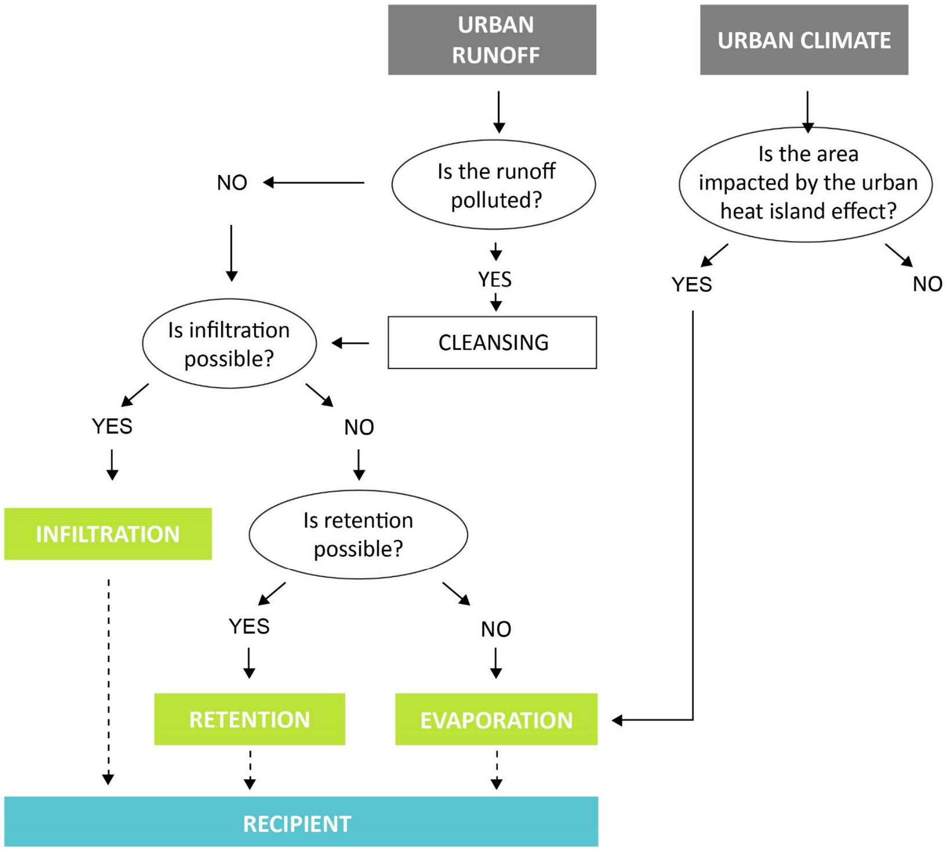

FIGURE 10: DECISION TREE SHOWING THE PRIORITISATION AMONG SURM METHODS IN THE GERMAN PRACTISE (Source: own work, based on (Dreiseitl, Geiger 2009 p. 31)

Three main, nature-based methods are used to achieve the above-mentioned principles: **infiltration, retention and evaporation**. If urban runoff is clean (e.g. the runoff from roofs or green areas), it can be directly infiltrated into the soil. If the area of available permeable surface is not great enough or infiltration is not possible, water can be permanently or temporarily retained. While the first two tools are used to decrease the runoff volume from a rain event, evaporation has a significant effect but just over a longer timespan. Nevertheless, its use is gaining mounting interest due to its effectiveness in urban climate regulation.

This grouping is sometimes extended by four further categories:

- **Detention:** Some methodologies use the term retention for long-term water storage and detention for short-term storage. Detention tools store do water temporarily to reduce the peak flow by decreasing the runoff speed. Retention tools will be discussed in this thesis to include detention.
- **Cleansing:** Specific design elements can serve the natural cleansing of the urban runoff; this property will be considered in this research not as a separate method but as a tool property.
- **Water reuse:** the aim is to reduce water consumption by storing and using rainwater for non-potable purposes e.g. toilet flushing or irrigation. This technical solution is partly integrated

into a building structure however, as this research investigates the development possibilities of open spaces, only outdoor retention solutions will be introduced in the framework of this thesis.

- **Conveyance:** the passage of rainwater to a remote place is sometimes unavoidable but can be achieved in a more sustainable way. This category will be discussed as part of the evaporation methods.

The use and prioritisation of the methods depends on local climate conditions. In Germany, infiltration is the prioritised technology (Figure 10), while retention is preferred in Denmark and The Netherlands due to the high groundwater level. In dry climates such as Australia, retention of rainwater has a high importance to allow for further consumption. In parts of Asia, cleansing tools occasionally have a high importance as an extension of the deficient wastewater treatment system.

### Benefits of SURM

While traditional water infrastructure is monofunctional, blue-green infrastruture can provide multiple ecological, social and economic benefits for the community and nature. **Ecological benefits** comprise of water bodies and wet landscapes, providing attractive habitats for numeruous plant and animal species. Connected green areas support the migration between colonies, which is a criterion for maintaining genetical diversity. But green areas improve the livability for inhabitants as well: the vegetation purifies water, reduces urban heat island effect by the evapotranspiration (Norton et al. 2015), and the foliage filters out air pollutants.(Nowak et al. 2006) Numerous researches have proven the positive **social benefits** of green areas through improved physical health and mental well-being. Green environments can increase life-expectancy as they provide sport and recreational areas. (Mitchell, Popham 2008) (Kondo et al. 2015) (Millenium Ecosystem Assessment 2005) Moreover, water features are often a highlight of open spaces and have immemorially caught human interest as they draw high aesthetical value and efficiently relieve stress.(White et al. 2010) Whilst single SURM elements cannot compete with the cost efficiency of a centralised system, an extended network of blue-green tools can provide **economic benefits** compared to grey infrastructure. The traditional water infrastructure performs best after its construction and constantly loses its value over time due to degradation. Blue-green infrastructure also needs maintenance, but the efficiency (and value) increases by the growth of plants. In the long term, maintenance costs of green infrastructure elements can be lower, than the grey infrastructure.(New York DEP 2010 p. 9) Research of the TEEB (The Economics of Ecosystems and Biodiversity) shows that BGI benefits outweigh costs by a factor of 2 to 10.(Max Berkelmans et al. 2019) Rainwater harvesting can also reduce water potable water consumption and in turn be used for example garden irrigation, washing machines and showering in private households; the cost effiency of water reuse depends on the local conditions.(Dixon et al. 1999) BGI tools reduce the probability of sewage overload, flood and drought damages, as well as the cost of flood prevention. A fundamental advantage of the system is such that due to its decentralised approach, expansion cannot overload the existing system. Indirect benefits of the blue-green infrastructure are climate regulation, reduced healthcare costs through recreational use, and increase of property prices around green areas. Some cities such as Singapore have been utilising BGI developments intentionally as a tool for transforming the city into a popular tourist destination and a preferred place for real state investments.(Lim, Lu 2016)

## 2.3 The required dataset for SURM planning

Success of the planning process is largely dependent on the accessibility and quality of base information. This chapter collects and introduces the basic raw data set of strategic SURM planning based on (Barbosa et al. 2012), (Heiko Sieker 1999), the KURAS research project, and the Rainwater Adaptation Plan of Hamburg (Axel Waldhoff et al. 2015). Barbosa defines the required information in three groups:

- geophysical factors: climate, hydrology, land, soil and topography are the main infuences of water flow. “Land” includes land use, the drainage area and the space available for the implementation of stormwater solutions.
- technical and economic factors: the structure of the drainage system, water quality and quantity and financial resources
- law and social factors: the existing legislative framework and stakeholders’ demands.

The further sources also underlined the same data set, organised into slightly different structures. I decided to disconnect land use from the natural factors and discuss it together with the technical factors because both are related to urban planning. Economic factors will be discussed together with social factors because of their close relation in project organization. Finally, law will be mentioned as an individual category due bto its importance on the overall decision-making process. On this basis, the chapter will be structured as following**Error! Reference source not found.**:

- Geophysical factors: climate, hydrology, soil and topography

- Urban environmental factors: land use, rainwater infrastructure
- Socio-economic aspects
- Legislative framework

The chapter includes the explanation of several terms, which will be used by the analysis and assessment of Budapest.

## Geophysical factors

**Climate** is a complex concept, which considers the typical averages of precipitation, temperature, humidity, sunshine, wind velocity and other factors of the weather that occur over a long period in a particular place.(NASA 2017) Urban settlements are also significant climate modifiers, therefore a city's special climate conditions are described as '**urban climate**'.

The **quantity of rainwater** is usually described by daily, monthly and annual average rainfall. **Rainfall variability** is a specific parameter of a certain climate zone: while some areas, such as monsoon climate show a huge fluctuation throughout the year, European climates have a more balanced distribution. Variability is defined not just for longer time periods but also within a single rain event. **Rainfall intensity** is an index showing the ratio of the total amount of rain falling during a given period (rainfall depth) to the duration of the period.(Jarraud, Bokova 2012 p. 258) **Precipitation frequency**[13] or **return period**[14] shows the probability of the different rain events.

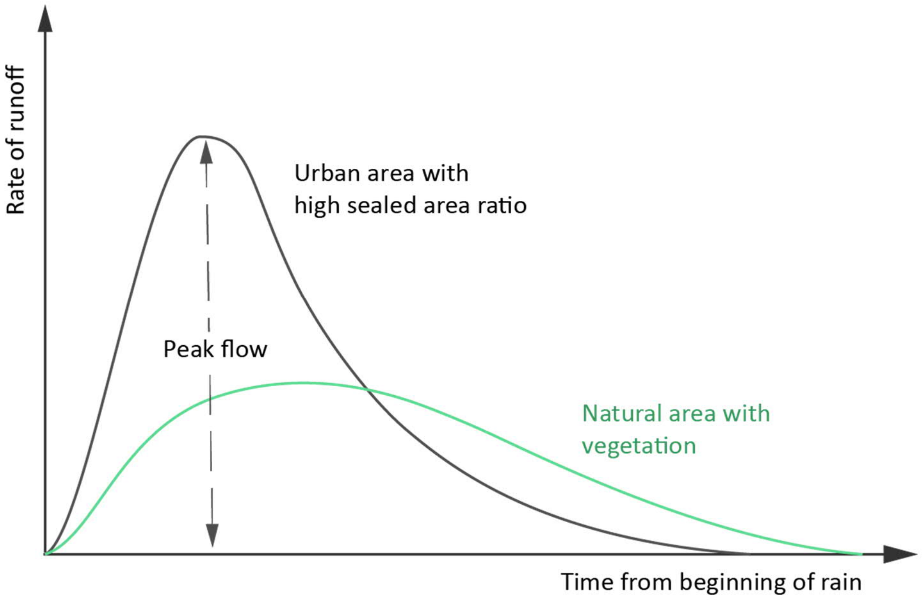

FIGURE 11: SCEMATIC HYDROGRAPH OF AN URBAN AND RURAL RUNOFF

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[13] The number of times during a specified period of years that precipitation of a certain magnitude or greater occurs or will occur in an area.(Haghighatafshar, la Cour Jansen, et al. 2014 p. 161)

[14] Return time is an average time or an estimated average time between rain events. E.g. a 10-year rain event has 0.1 precipitation frequency.

(Source: D. Csizmadia, based on (J Coombes, Roso 2019)

**Rain duration** is an essential component for dimensioning of drainage infrastructure and its importance is even more significant in on-site rainwater management. Rain intensity is usually highest in the first 10-15 minutes of a rain event. However, the presence of a large catchment area, the **peak flow** may occur several hours after the most intense rain phase due to the large water storage capacity of the soil and the vegetation surface. (Figure 11). In case of large catchment areas, runoff simulation must be employed for accurate calculations.

Rainwater management often considers three different rain intensities for calculations (Figure 12)(Haghighatafshar, Jansen, et al. 2014 p. 161):

1. **Normal rain**: a rainfall with a 1-2-year or maximum 5 year return period, which typically does not overstrain the drainage infrastructure. BGI tools can **fully infiltrate and retain** runoff.
2. **Design rain**: a cloudburst that occurs once every 10-30 years. The grey infrastructure capacity is not capable of handling the entire runoff flowrate; uncleaned water is discharged into the rivers through the CSOs. BGI tools help to **decrease peak flow using retention and detention.**
3. **Extreme rain**: rare event that usually occurs once every 100 years and causes unavoidable damage. Integrated urban planning and water management can **develop safe flow paths** to safeguard lifes, buildings and sensitive infrastructure.

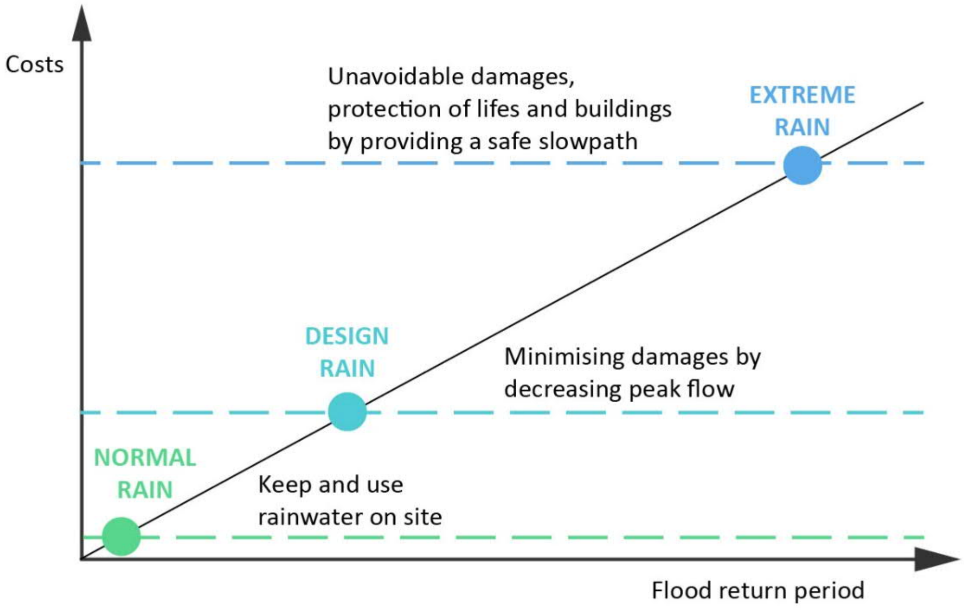

FIGURE 12: TYPICAL RAIN INTENSITIES USED FOR RAINWATER MANAGEMENT DIMENSIONING
(Source: D. Csizmadia, based on (Haghighatafshar, Jansen, et al. 2014 p. 161)

Traditional drainage system projects are typically dimensioned for recieving 2, 5 or maximum 10-year return period rain events (with a duration of 10-15 minutes) – but expectations can highly differ depending on the land use and further local conditions.

The ratio of evaporation is also a charasteristic parameter of a certain climate. **Potential evapotranspiration (PET)** shows the evaporation of an extended, vegetated surface, which is always well supplied with water. **Actual evapotranspiration** is always smaller, or at most equal to the PET, because the rainfall can be smaller than the amount of potential evaporation. (Aminzadeh, Or 2017 p. 581) Evaporation is negligible during cold months in Europe, but evaporation water loss in the summer can reach 100 mm/month and have a significant impact on the water surface level.[15]

The planning unit for large-scale blue-green projects is the **catchment area**, which is defined by the natural **terrain**. While wastewater infrastructure favours sloped terrain, sustainable rainwater management requires a preferably flat area: the smaller the gradient, the more water can be retained and infiltrated.(Heiko Sieker 1999 p. 212) Guidelines recommend to locate design features in areas with slopes of 1-4% for maximum effectiveness.(Lim, Lu 2016 p. 846)

Water flows not just on the surface of the watershed but fills the gaps of the soil and moves in a complex way, influenced by numerous effects. The most significant factor in consideration of infiltration is the **water permeability** of the soil, defined primarily by the size and distribution of soil particles. (Table 4) Coarser soil particles can store more water, but water permeability that’s too high can lower the natural purification process.

TABLE 4: INFILTRATION CAPACITY CURVES OF DIFFERENT SOIL TYPES
(Source: DWA-A 138)

| Soil type | Water permeability $k_f$ (m/s) |
|---|---|
| Coarse gravelly soil | $10^{0}$-$10^{-1}$ |
| Fine gravelly soil | $10^{-1}$-$10^{-2}$ |
| River sand | $10^{-2}$-$10^{-3}$ |
| Duna-sand | $10^{-3}$-$10^{-4}$ |
| Loamy sand | $10^{-4}$-$10^{-5}$ |
| Sandy loam | $10^{-5}$-$10^{-6}$ |
| Silt | $10^{-6}$-$10^{-8}$ |
| Loam | $10^{-8}$-$10^{-10}$ |

**Groundwater level** is also an essential factor for SURM planning. If groundwater level is close to the surface, infiltration tools cannot be applied.

## Urban environmental factors

In existing housing areas, the exclusive use of BGI is usually not possible due to lack of required surface, so the combination of a centralized and decentralized drainage system is the most efficient rainwater management solution. Therefore, the layout and properties of the **existing sewage system** (e.g. capacity, inlet points, overloaded

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[15] In a hot and dry summer month, a lake’s water level can decrease by 200 mm, which endangers the water ecosystem and enforces expensive water recharge.(Heiko Sieker 1999 p. 211)

sections, congestion points) must be known for the design of BGI. Current technology enables the complete digitalisation of the sewage system, which provides big data for the precise validation of runoff simulation models. The **road system** influences the permeability and the rainwater runoff quality. The pollutant load has a strong correlation to the traffic load(Budai 2011), therefore urban traffic models can provide important information for water management.

**Land use zoning** is commonly carried out based on usage and density categories with specific indicators e.g. allowable lot coverage, building height, road standards and parking lot requirements. Each land use type can have a different impact on rainwater management: for example, industrial and traffic uses indicate a higher presence of water pollutants; the allowed lot coverage impacts the selection of BGI tools. (Brabec et al. 2002 p. 500). On the other hand, some BGI tools can have a higher benefit in specific land use categories, for example tools with high recreational value in residential areas.

Runoff simulations and rainwater fee calculation need detailed data regarding land coverage: the exact location and **footprint of buildings, sealed and permeable surfaces**.(Heiko Sieker 1999 p. 218)

### Socio-economic aspects

Several studies pointed out that an open space project has lower maintenance costs and has a longer lifespan if the residents are involved in the planning. Thus, the analysis of the social environment (e.g. how residents **use open spaces**, their **demands**) and public partcipation in the planning process ensure a higher success and a precisely targeted development. Social aspects cannot be generalised but – similarly to green area development projects – must be synthetised with the involvement of sociologists and social workers for the areas concerned.

The inquiry of **existing financial sources** such as current maintenance costs of the water infrastructure, municipal funding and rainwater fee, and mapping **possible new sources** (tenders, Public-Private Partnership cooperations) form a fundamental base for an accurate project planning. Apart from project funding, calculable, **permanent financial sources** should be secured for the long-term maintenance of BGI tools.

### Legislative framework

Although it sounds trivial, the definitions of rainwater and urban rainwater management are not clarified in the legislation of all countries. An incomplete legislative framework can cause unclarified **responsibilities** in the topics of ownership, development, finance, maintenance and cooperation.(R. R. Brown, Farrelly 2009 p. 839) BGI planning needs the cooperation of different disciplines (urban planning, water infrastructure and green infrastructure planning); therefore, the legal **harmonisation** of these fields is an important criterion of successful BGI implementation.(Barbosa et al. 2012 p. 6792)

TABLE 5: RUNOFF QUALITY EVALUATION SYSTEM OF THE GERMAN INFILTRATION STANDARD DWA A-138
(Source: (DWA 2005 p. 14))

| Surface type | Qualitative evaluation of the runoff |
|---|---|
| Green roofs, meadows, cultivated landscape | Harmless |
| Non-metal roof surfaces, terraces in residential areas | |
| Roofs with metal components (copper, zinc, lead) | Tolerable |
| Pedestrian and bike paths in residential areas and pedestrian zones | |
| Courtyard surfaces in residential and commercial areas with occasional parking / | |
| Roads with less than 300 cars/day | |
| Roads with 300-5000 cars/day | |
| Airport runways and taxiways | |
| Roof surfaces in industrial areas with significant air pollution | |
| Roads with 5000-15000 cars/day, main roads | |
| Frequented parking lots e.g. supermarkets | |
| Roof surfaces with metal coverings (copper, zinc, lead) | |
| Roads and squares with heavy pollution (e.g. transportation, agriculture, markets) | |
| Roads with more than 15000 cars/day, motorways and highways | |
| Courtyards and roads in industrial areas with significant air pollution | Untolerable |
| Special areas e.g. truck parking lots, aircraft tarmac | |

Rainwater infrastructure must fulfill various **quality and quantity** criteria to prevent water pollution and flood damages. Urban runoff is regarded officially as sewage water in numerous countries (e.g. Germany and Hungary(Heiko Sieker 1999 p. 19)), thus the **output water quality** must correspond to the principles and emission limits of the European Union's Urban Waste Water Directive: "*no adverse effect on the environment (including receiving waters) shall occur*". Considering the Water Framework Directive, not only preservation should be achieved, but also improvement of current water quality to a 'good condition'. Further pollutant limit values are defined on state level. Due to the finite cleansing capacity of BGI tools, their **inlet water quality** must be defined in order to avoid the contamination of groundwater or water bodies. Surface typologies – based on the use and typical traffic load – are often used to consider the probable quality of the surface runoff. The German standard "*DWA A-138 for Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water*" divides urban surfaces into safe, tolerable (cleansing needed), and intolerable categories depending on their typical traffic and pollution load. (Table 5**Error! Reference source not found.**).(DWA 2005 p. 14) The runoff from green areas and non-metal roofs is usually considered to be safe for the environment and can be infiltrated without pre-cleansing. In contrast, BGI tools are not recommended for main roads and truck parking areas due to their high pollution level.

Geophysical, urban environmental, socio-economic and legal factors were collected and summarized in Table 6. The table also lists the typical sources for the raw data types needed for SURM planning.

TABLE 6: GROUND DATA SET OF THE STRATEGIC SURM PLANNING

| | Raw data | Data source |
|---|---|---|
| Geophysical factors | Terrain | Digital terrain model |
| | Soil type | Soil maps, results of borings |
| | Temperature data | Temperature time series of the weather measuring stations. Future temperature data: climate models |
| | Groundwater level and quality | Groundwater level map created from groundwater level measuring |
| | Rainfall characteristics | Rainfall model with local calibration. Future precipitation estimation from climate models |
| | Surface water quality and quantity | Regular water quality sampling and water level measuring |
| Urban environmental factors | Sewage system | Digital model of the sewage system |
| | Transportation system | Digital road model and traffic count data |
| | Land use categories | Land use plan |
| | Urban heat island effect | Satellite pictures |
| | Biodiversity | Data collection by personal inspection |
| | Runoff water quality | Water quality sampling |
| | Surface coverage | Satellite pictures and land registry |
| Socio-economic factors | Financial framework | Municipal budget of RWM, fees, taxes, tenders |
| | Open space use | Personal inspection |
| | Open space quality | Personal inspection |
| | Further social aspects | Involvement of social experts, surveys |
| Legislative framework | Lagal definition of RWM | State laws |
| | Responsibilities in RWM | State and local regulations |
| | Performance criteria | Laws and standards |

## 2.4 Introduction of the blue-green infrastructure elements

An extensive investigation of the BGI tools were presented in the “*Water sensitive design guideline of Budapest*” (“*Vízérzékeny tervezés a városi szabadtereken*”).(Csizmadia 2018) Henceforth, these tools are introduced only with a short description, complemented by pictures in Annex 10.2, and a summary table about their methods, impacts and implementation criteria (Table 7). The evaluation is based on German sources because Germany – amongst all European countries – possesses the most detailed research data regarding the properties of BGI tools. The results of the KURAS research project (A. Matzinger et al. 2017) established the base for the tool assessment, which was extended by results of the Rainwater Infrastucture Adaption Plan (RISA) of Hamburg (Axel Waldhoff et al. 2015), the Decentralised Drainage Guideline of Berlin (Heiko Sieker 2018)(Jens Novak et al. 2018) and (Dreiseitl, Geiger 2009).

The table divides the tool properties into three categories. In the first category, the three main **SURM methods** (infiltration, retention, evaporation) are listed. Most tools are multifunctional and can fulfill the function of two or all the abovementioned methods. The second category of the table demonstrates the **environmental impacts** of the tools. The tool specification charts of the KURAS research project were used for the assessment of recreational, aesthetic and ecological values. Peak runoff reduction values were determined using the KURAS charts, supplemented by the RISA. Safety concerns (e.g. deep water or height difference, hygienical concerns) were judged by personal planning experiences. The third category of **implementation criteria** shows the factors that influence the applicability of each tool. Some properties such as soil permeability, roof steepness and facade type have a relevance just by certain tools e.g. green roof. Building and maintenance costs were estimated using the KURAS databank and based on personal interviews with specialists from Ramboll Studio Dreiseitl. Appraisals were defined on 3 levels (no impact/low impact/high impact).

### Infiltration

Infiltration through the active soil layer is the best applicable on-site rainwater management method for the Central European climate. Surface infiltration can be facilitated by **green areas** or **permeable pavings** (e.g. porous permeable pavement, permeable concrete, asphalt EPDM paving, or concrete paving stones with big gaps or geocell filled by gravel).(Dreiseitl, Geiger 2009 p. 60) If the surface size or permeability is not sufficient, infiltration time can be extended by the temporary retention of water: **swales and rain gardens** are vegetated surface deflations that collect and slowy infiltrate rainwater, and the root zone cleanses polluted runoff. In case of sealed surfaces or poor permeability, **underground infiltration** (supplied by gravel filling, drainage blocks or drainage pipes) can be applied for additional capacity.

### Retention

Rainwater retention involves short- or long-term collection of rainwater in an overground or underground storage space. The usability and effectiveness of this method depends on the local landscape features.(Coombes, Barry 2008 p. 1008) In Northern Europe, **retention basins** are often prioritised tools due to the high precipitation and groundwater level and low evaporation. Retention areas can be integrated into the urban landscape as picturesque vegetated lakes or basins and provide a high recreational and aesthetic value. In the dry Southern European climate, permanent open surfaces cannot be maintained without water supply due to high evaporation losses, but **underground retention** or closed **water harvesting tanks** can successfully mitigate water scarcity. (Santos, de Farias 2017 p. 1008) **Constructed wetlands** are large-surface water cleansing biotopes that are periodically or permanently shallowly flooded. These retention elements are more space demanding but have a high water cleansing performance.(Haberl et al. 1995 p. 306)

Short-term retention of water aims to slow down runoff and decrease peek runoff. **Dry detention basins** are technically similar to an infiltration swale but have a larger capacity and an overflow to the recipient. Their main function is peak flow reduction. **Wet detention ponds** consist of a deep zone with a constant water level and a dry zone which can be temporarly flooded. **Floodable open spaces** have been gaining an increasing popularity in dense urban areas due to their multifunctional use (floodable sport courts, squares or park surfaces). Also, flat roofs can be used for temporary retention: **blue roofs** can store a shallow layer of water on the roof surface, which help to decrease runoff peak, but also provide additional evaporation surfaces in a dense city centre. Converting flat roofs into **green roofs** can possess – besides retention – certain water cleansing abilities and a high ecological value.[16] Remarkably though, while extensive roofs can be almost self-sustainable, intensive roofs need irrigation and more maintenance, which questions their sustainability in dryer climates. Semi-intensive roofs or natural roofs offer a good compromise because they just need irrigation during extremely dry periods and can host a high biodiversity. **Bioretention swales** have a special fine-grained soil layer that filters out solid particles and the vegetation absorbs nitrates and phosphates. Cleansed water can be infiltrated or conveyed into another retention tool or a recipient.

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[16] A classical extensive green roof with a 5 cm thick growing medium can retain 18 l/m$^2$ rainwater. On an intensive green roof, storage capacity can reach 110-160 l/m$^2$. The special retention roof systems can reach even a retention capacity of 230 l/m$^2$. (Optigrün, 2018)

### Evaporation

The experimentation and implementation of evaporation tools has been gaining a higher importance in several metropoles due to increasing heat waves. **Trees** are the most cost-efficient evaporation tool. During a rain event, a single mature tree canopy is able to store and later evaporate 500 litres of rainwater.(Berland et al. 2017 p. 170) The integration of vertical building surfaces into the water cycle can be achieved by two main methods: on **green facades**, plants root in the ground, water can be soaked up from the natural soil and are not frost sensitive. **Living walls** consist of plants, whose root system is fixed in a hydroponic or modular soil system to the wall and need a complex irrigation system and are sensitive for cold temperatures. Living walls are not sustainable for dry or cold climates due to their high water demand and frost sensitivity.

**Water features** such as misting systems, fountains and reflecting basins efficiently cool down their immediate environment and create popular community places.(Direction des Espaces Verts Agence d'Écologie Urbaine 2015 p. 37) Using **open drains**, water flow can be integrated into the cityscape and the conveyance system can contribute to evaporation.

TABLE 7: ASSESSMENT OF THE BLUE-GREEN INFRASTRUCTURE TOOL PROPERTIES

| | SURM METHOD | | | ENVIRONMENTAL IMPACTS | | | | | | IMPLEMENTATION CRITERIA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TOOLS | Infiltration | Retention | Evaporation | Water cleansing | Reduction of peak runoff (detention) | Recreational value | Aesthetic value | Ecological value | Safety concerns | Space demand | Roof steepness | Façade type | Building costs | Maintenance costs |
| Permeable paving | ● | - | ○ | - | ○ | ○● | ○ | - | | ○● | - | - | ○ | ○ |
| Desealing hard surface | ● | - | ● | ○ | ● | ○ | ○ | ● | | - | - | - | ○● | ○ |
| Swale and rain garden | ● | ● | ● | ○ | ● | ○ | ○● | ● | | ○ | - | - | ○ | ○ |
| Underground infiltration | ● | ● | - | - | ○ | - | - | - | | - | - | - | ● | ○ |
| Dry detention basin | - | ● | ○ | - | ● | - | ○ | - | ! | ● | - | - | ○● | ○ |
| Retention pond/basin | - | ● | ● | ○ | ● | ● | ● | ● | ! | ● | - | - | ● | ● |
| Underground retention | - | ● | - | - | ● | - | - | - | | - | - | - | ● | ○ |
| Harvesting tank | - | ● | - | - | ● | - | - | - | | ○ | - | - | ○ | ○ |
| Floodable open space | - | ● | ● | - | ● | ● | ● | - | ! | - | - | - | ○● | ○ |
| Green roof | - | ● | - | ○ | ● | ○● | ● | ● | | - | F | - | ○● | ○● |
| Blue roof | - | ● | ● | - | ● | - | - | - | | - | F | - | ● | ○ |
| Green wall | - | - | ● | - | - | - | ● | ○● | | - | - | S | ○● | ○● |
| Tree planting | ● | - | ● | ○ | - | ● | ● | ● | | ○ | - | - | ○ | ○ |
| Water feature | - | - | ● | - | - | ● | ● | - | | ○ | - | - | ● | ● |
| Open drain | - | - | ● | - | - | ○● | ● | - | | - | - | - | ○ | ○ |
| Bioretention swale | - | ● | ● | ● | ○ | - | ● | ● | | ○ | - | - | ○● | ○ |
| Cleansing wetland | - | ○ | ● | ● | ○ | ● | ● | ● | ! | ● | - | - | ● | ○● |

-: no effect or the property is not relevant; ○: low effect; ●: high effect; F: flat; S: simple

A higher performance can be reached by the combination of the abovementioned elements.[17] Linking tools with the same function can balance local deficiencies and provide a higher system safety because of the combined capacity. Linking tools with different functions can create a full water treatment chain: for example, roof runoff can be collected and cleaned in a bioretention swale and clean water can be transported into an underground infiltration tool.

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[17] In Germany, several tool combinations are in use: e.g. a combination of underground infiltration with tree planting ("Baumrigole"); underground infiltration with surface infiltration (Rigolenmulde); and the combination of water evaporation surfaces and infiltration swales (Verdunstungsmulde). The KURAS research project analysed the effect and proved the efficiency of different tool combinations in a case study area of Berlin.(A. Matzinger et al. 2017)

# 3 Strategic SURM planning – international case study analysis

Recently, climate change adaptation has become the main driver for urban planning. The first complex, long-term urban water management strategies were established in cities that are seriously threatened by flooding. Three metropols' SURM strategies were investigated to attain a deeper understanding of the planning processes and implemented solutions. New York, Copenhagen, and Singapore are all highly acclaimed and serve as models for other cities. Table 8 introduces general information of the three analysed metropols. The cities' different cultural, climatic and institutional characteristics enable the reader to study a wide range of approaches and measures and to identify elements that have universal expediency.

TABLE 8: GENERAL INFORMATION OF THE ANALYSED CITIES
(Based on (Lim, Lu 2016), (Liu, Jensen 2017a), (de Blasio, Sapienza 2019), (McLaughlin et al. 2014), (United Nations 2020))

| | New York | Copenhagen | Singapore |
|---|---|---|---|
| Area (km²) | 1213 | 86.4 | 725.1 |
| Population (thousand) | 8175 | 633 | 5639 |
| Climate | humid subtropical climate | marine west coast climate | tropical rainforest climate |
| Annual rainfall (mm) | 1.270 | 646 | 2339 |
| PET (mm) | 650 | Approx. 600 | Approx. 1800 |
| Sewage system | 60% combined<br>40% separated | Mostly combined, designed for 10-year event | Separated |
| Main driver | Water pollution and sewage system overload | Flood risk | Freshwater scarcity and water pollution |
| Project coordinator | NYC DEP¹ | The city of Copenhagen | PUB² |

¹: New York City Department for Environmental Protection ²: Public Utilities Board

The following topics were investigated in the case studies:

- Background and drivers: existing situation and main drivers facilitating the planning process.
- Stakeholders: actors and coordinators of SURM planning.
- Analysis methods: methods used to identify risks and opportunities.
- Decision-making: strategic goals and their validation.
- Implementation: measures taken to implement projects.

Finally, the main principles of SURM planning that were introduced in Chapter 2.2 will be evaluated for all three case studies.

## 3.1 New York City – blue-green infrastructure in a dense city

New York City (NYC), like other U.S. municipalities, is mandated by the federal Clean Water Act[18] to reduce contamination in waterways. Several water bodies around NYC did not fulfill the required quality criteria even after upgrades to sewerage pipes and wastewater treatment plants, mainly due to the CSO discharge of its expansive combined sewage system. The establishment of a rainwater management strategy served two goals: to seek cost-efficient solutions for CSO pollution decrease and to enhance sustainability and urban liveability.

NYC established bluebelts, greenstreets and green roofs since 2007, but the **Sustainable Stormwater Plan (SSP)** from 2008 was the first document that tried to estimate the opportunities and performance of the city-wide SURM development. The document reviewed the city's properties, such as water quality (especially around CSOs), groundwater level, and land use, to estimate the applicability and costs of blue-green solutions. The plan stated that CSO discharge from low-intensity rain events have a higher pollution load than high-intensity events, thus the reduction of CSO from normal rain events using BGI tools can have a significant impact on the water quality. A **land use analysis** identified that streets and rooftops are the most important runoff sources, while open spaces are possible receptors of these areas. A combination of overall building regulations (for new developments and renovations) and focused action projects (in existing housing areas) were identified as the most effective measures for BGI development. BGI tools were introduced and their implementation and maintenance costs were estimated through the **review of numerous case studies** (mostly from other states). The goals of the plan were to establish an overall framework and collect further data, such as: enacting policies that allow and faciliate the use of BGI tools and establish new design guidelines; continuing construction of planned BGI projects and initiating new ones in ongoing green initiatives; and forming a maintenance program for BGI tools.(de Blasio, Sapienza 2019 p. 61)

New York's **Green Infrastructure Plan (GIP)** was released in 2010. The planning process and implementation is coordinated by the Mayor's Office and New York City Department of Environmental Protection (DEP) and includes a multitude of other city departments.[19] Despite its

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[18] The Clean Water Act lays out an overall framework for water management in the USA, similar to the Water Framework Directive in the European Union.(Robin 2018)

[19] Department of Transportation (DOT), Department of Parks and Recreation (DPR), Department of Design and Construction (DDC), Department of City Planning (DCP), Department of Education (DOE), Department of Sanitation (DSNY), Department of Citywide Administrative Services (DCAS), Department of Housing and Preservation and Development (HPD), New York City Economic Development Corporation (EDC), and New York City Housing Authority (NYCHA).

name, the plan is a complex rainwater management strategy, considering the development of both green and grey infrastructure.[20] The GIP was built upon the CCP and extended it with a project budget and milestones for the following 20 years.

The strategy lays out a very detailed calculation to estimate the costs of reducing CSO discharge by two scenarios (Figure 13): “Grey Strategy” (purely grey infrastructure development), and “Green Strategy” (BGI development with optimasitation of the existing grey infrastructure). The overall costs were estimated from the cost calculations of each catchment area and CSO. It was stated that the Green Strategy has lower costs over a 20-year time period. The costs of the Green Strategy can be significantly reduced by implementing on-site water management standards, which forces a large portion of the GI development costs to be taken over by public and private construction or renovation projects.

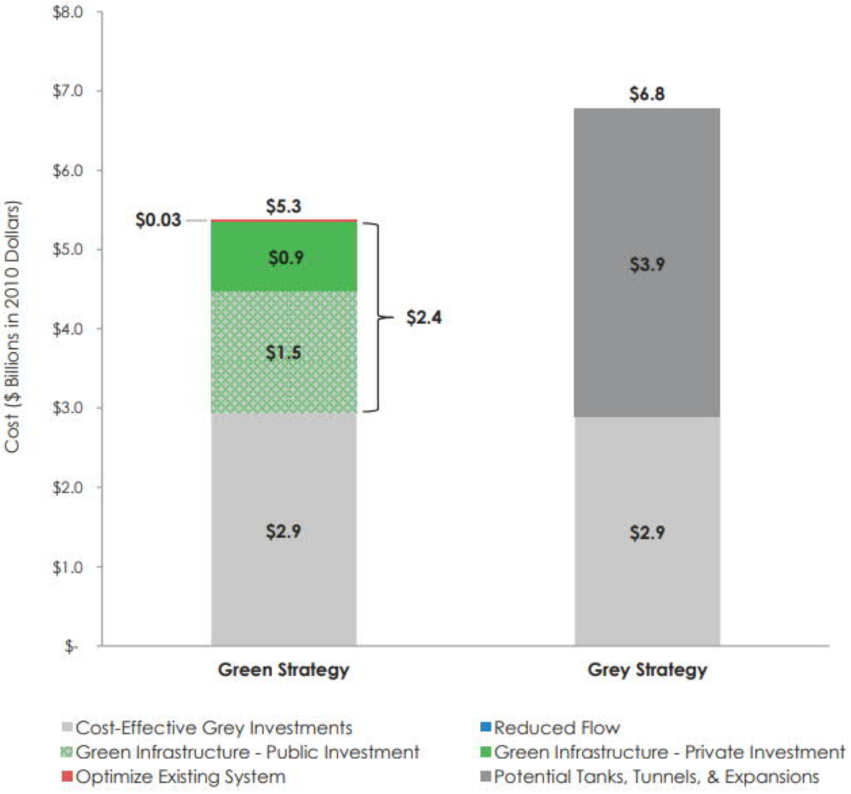

FIGURE 13: CITYWIDE COSTS OF CSO CONTROL SCENARIOS (IN 20 YEARS)
(Source: (New York DEP 2010 p. 30)

The Green Strategy was selected for implementation and **five main goals** were defined (Carter H. Strickland 2012):

1. Build cost-effective grey infrastructure
2. Optimize the existing wastewater system
3. Control runoff from 10% of impervious surfaces through green infrastructure
4. Institutionalize adaptive management and monitoring
5. Engage and enlist stakeholders

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[20] As mentioned in Chapter 2.2, “green infrastructure” also means “blue-green infrastructure” in Northern-American practice.

Thus, the Green Strategy is a combination of grey and green infrastructure, but grey investments focus only on optimising the existing system and on areas where green infrastructure cannot be sufficiently implemented.

The runoff control in green areas must be accomplished by: 1. roadside green infrastructure (street trees, swales, and sidewalks); 2. new and expanded developments including bioinfiltration, blue and green roofs, subsurface detention/infiltration, or other tools; 3. existing developed areas, such as schools and residential areas; and 4. additional vegetated surfaces in open spaces and waterfront areas.(New York DEP 2010 p. 5)

A comprehensive program was launched to optimize 138 miles of existing sewers, including drainage plans and hydraulic studies. Adaptive management and monitoring were achieved by establishing a high number of water monitoring points. The monitoring results and better impervious data were applied to recalibrate the sewer system model and to update wastewater flow projections. The model was upgraded in order to estimate the impacts of detention and infiltration on water quality.

DEP initiated several meetings with environmental groups, city agencies and other associates, and held public meetings to explain the vision of the GIP. The cooperation continued during the project design and supported communities that wished to propose, build, and maintain green infrastructure projects. An intense **information campaign** was initiated to inform communities about new GI projects. 25,000 postcards were posted to inform residents in the surrounding neighbourhoods about the upcoming bioswale and greenstreet projects. DEP also gave presentations upon request to officials, community boards, schools and universities.

The project implementation is evaluated in annual reports, which allows us to study its progress since conception nine years ago. In the first two years, numerous tasks were accomplished to implement large-scale BGI projects. A Green Infrastructure Fund was set up to cover the costs. A **Green Infrastructure Task Force** was established to manage the green infrastructure development, which "*includes various agencies with experience in planning, designing, and building cutting-edge stormwater management techniques with the goal to manage runoff from 10% of the impervious surfaces in 13 combined sewer watersheds, supported by a dedicated DEP staff of engineers, landscape architects, and planners with experience in the design and construction of green infrastructure.*"(New York DEP 2010 p. 49) The DEP initiated the construction of more than 30 **pilot projects** in 2010 at public-owned sites, including public housing, roads, parks and parking lots. Tools were divided into two groups: "rights-of-way" (solutions for linear streetscapes), and “on-site” (solutions for parks or squares). The implemented tools were: tree pits, street-side infiltration swales, bioretention areas in parks and parking lots, subsurface storages, blue roofs, porous pavements, wet meadows, and green roofs. The results from monitoring[21] during 2011-2012 have demonstrated that all pilot projects provide effective stormwater management, particularly for low-intensity rain events (with depths of one-inch or less). (Bloomberg 2012 p. 3) Based on the experiences, a **Stormwater Management Standard** and **Guidelines for the Design and Construction of Stormwater Management Systems** were published for the new construction and reconstuction areas.

The city introduced the **Green Infrastructure Grant Program** to support local organisations and private property owners to build GI projects on private land and public walkways. Simultaneously, a trial **sewer charge** was implemented for stand-alone parking lots. The third financial tool facilitates the establishment of green roofs in New York: **Green Roof Property Tax Abatement** aims to partially offset the construction costs.

As the number of projects increased, the city decided to develop a Geographic Information System (GIS)-based **tracking and asset management program** in 2013 *“to track and report on the program’s progress toward its goals, as well as to manage and monitor the operation and maintenance of its assets citywide”*. Furthermore, a **database** called “GreenHUB” was established to collect all **possible BGI locations**. This database helps to quickly identify new BGI development areas and store the sites, which were proven to be unfeasible to implement due to the abundance of mature trees, underground utilities, high bedrock or any other reasons.(New York DEP 2019 p. 7) As new BGI projects were implemented, the number of maintenance employees grew in the **Green Infrastructure Maintenance Program**.

5 years after initiation of the Green Infrastructure Plan, it became important to easily compare the performance of the BGI projects and validate their runoff reduction. Thus, a new term “**green acre**” was devised, which means an impervious area that can retain 1 inch of runoff.(New York DEP 2018 p. 12) A green acre covered by a rain garden can fulfill this criterion with a much smaller surface area than for example, a permeable pavement. As the capacity of different BGI

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[21] The monitoring used soil infiltration tests, water quality, and soil quality sampling, reducing the volume and/or rate of stormwater runoff, as well as qualitative issues such as maintenance requirements, appearance, and community perception, vegetation surveys.

tools is already known by monitoring, the project's overall retention capacity can be calculated from the tools' surface area.[22]

The city's stormwater management is also discussed in other plans. New York's **Stormwater Management Plan** was released in 2018 in order to fulfill the discharged water quality criteria of the Clean Water Act for separate storm sewer systems in municipal ownership. The plan coordinates the work done by several agencies to monitor water quality and tackle the pollution sources of pathogens, floatables and nutrients. Individual **action plans** were established for some high priority areas such as the Jamaica Bay Watershed Protection Plan or focusing on specific topics like the Bluebelt Initiatives.

Although the DEP stated that the milestone targets for 2020 were too ambitious, the Green Infrastructure Plan of New York continues to be a clear success story, which serves as an important example for BGI development in dense cities.

## 3.2 Copenhagen – managing cloudburst events

Following the Copenhagen Climate Change Conference, Copenhagen released its **Climate Adaptation Plan (CAP)** in 2011 with the aim to be carbon neutral by 2025. The plan also considered the adaptation of the drainage system with the following goals (Liu, Jensen 2017a p. 11): 1. grey infrastructure must be extended city-wide to cope with the capacity of a 10-year rain event; 2. disconnect 30% of the sealed surfaces that are currently allowing discharge into the combined sewers to correspond with the future 30% increased intensity of 10-year rain events (projected to occur by 2100).

Months after the release of the CAP, a 1000-year rain event hit the city causing US$1 billion damage. Considering this and the further 100-year rain events that occurred in 2010 and 2014, it was proven that dimensioning for 10-year events is insufficient and recent extreme events can no longer be managed by conventional pipe systems.(Ramboll and Ramboll Studio Dreiseitl 2016) The mayor immediately decided to extend the Climate Adaptation Plan with a **Cloudburst**

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[22] The German practice uses a similar approach to compare runoff volumes from different surface types but using the opposite logic. It defines the "absolute impervious area" as the surface size that would release the same amount of runoff if it was completely impervious with 100% runoff.

**Management Plan (CMP)** that was first released in 2012 and completed in 2015. The plan focuses on the city’s core zone called Frederiksberg, which is the most vulnerable in flood events.

The CMP was developed by the City of Copenhagen in cooperation with Køben-havns Energi (Copenhagen Energy), the City of Frederiksberg, Frederiksberg Forsyning (Frederiksberg utility company) and the utility company of greater Copenhagen (HOFOR). Furthermore, collaboration was initiated with the local authorities of neighbouring areas that lead surface water and wastewater through the city to the common sewage treatment plants or to common water courses and lakes. The complex urban environment necessitated a truly collaborative effort to be established between planners, engineers, economists, residents, utility providers, politicians, and investors to integrate climate adaptation within regulatory planning.(Ramboll and Ramboll Studio Dreiseitl 2016)

Data regarding the city’s hydrology, land use, society and infrastructure was collected and analysed in three steps. **Flood modelling** based on a mathematical runoff model was used to analyse existing conditions and project the impact of climate change. Floods for the years 2010 (as the baseline), 2060 and 2110, and the frequency of 10, 20, and 100-year flood events were investigated. Results of the calculations were presented on maps showing the variation in water depth for the flooded areas. (Jan Rasmussen 2016) Runoff simulations were combined with the land use by **risk mapping** to estimate the the probability and costs of flooding. Risk values were visualised on risk maps by combining costs and probability factors as shown on Figure 14.

| COST<br>PROBABILITY | Low | Medium | High |
|---|---|---|---|
| Likely | Risk can be tolerated | Risk can be tolerated | Moderate risk |
| Likely | Risk can be tolerated | Moderate risk | Risk cannot be tolerated |
| Very likely | Moderate risk | Risk cannot be tolerated | Risk cannot be tolerated |

FIGURE 14: RISK ASSESSMENT CHART FOR THE CLIMATE ADAPTATION PLAN OF COPENHAGEN (Source: (COWI et al. 2011 p. 10))

The **“Costs of doing nothing”** were calculated considering the effect of climate change. This cost would amount to approximately US$60-90 million a year up to 2110.(Ramboll and Ramboll Studio Dreiseitl 2016)

The Cloudburst Plan focuses on safety in extreme events and extends the goals of the CAP by (Liu, Jensen 2017b p. 11):

- preventing flood depths which exceed 10cm on urban surfaces, occuring less than once every 100 years (except areas designated for flood control)
- detaining and discharging floodwaters that exceed the 10-year volume.

Two masterplan options (a purely green infrastructure development, and a combined grey and blue-green solution) were tested on a 10km$^2$ catchment by a detailed socio-economic **cost-benefit analysis**. Three aspects were analysed:

- **Cost analysis:** cost of the establishment
- **Cost-benefit analysis:** relation of the establishment cost to the benefits gained by reducing future damage
- **Cost-effectiveness analysis:** a comparison for the most advantageous solution that meets the municipality’s service objectives.

The assessment found that both scenarios reach the municipality’s planning goals, and the **blue-green solution results in higher net benefits**, creating potential savings of 50% (U$200 million) more than conventional solutions alone. Additional qualitative social benefits such as health improvement, and the quality improvement of the urban environment would push this amount even higher.(Ramboll and Ramboll Studio Dreiseitl 2016)

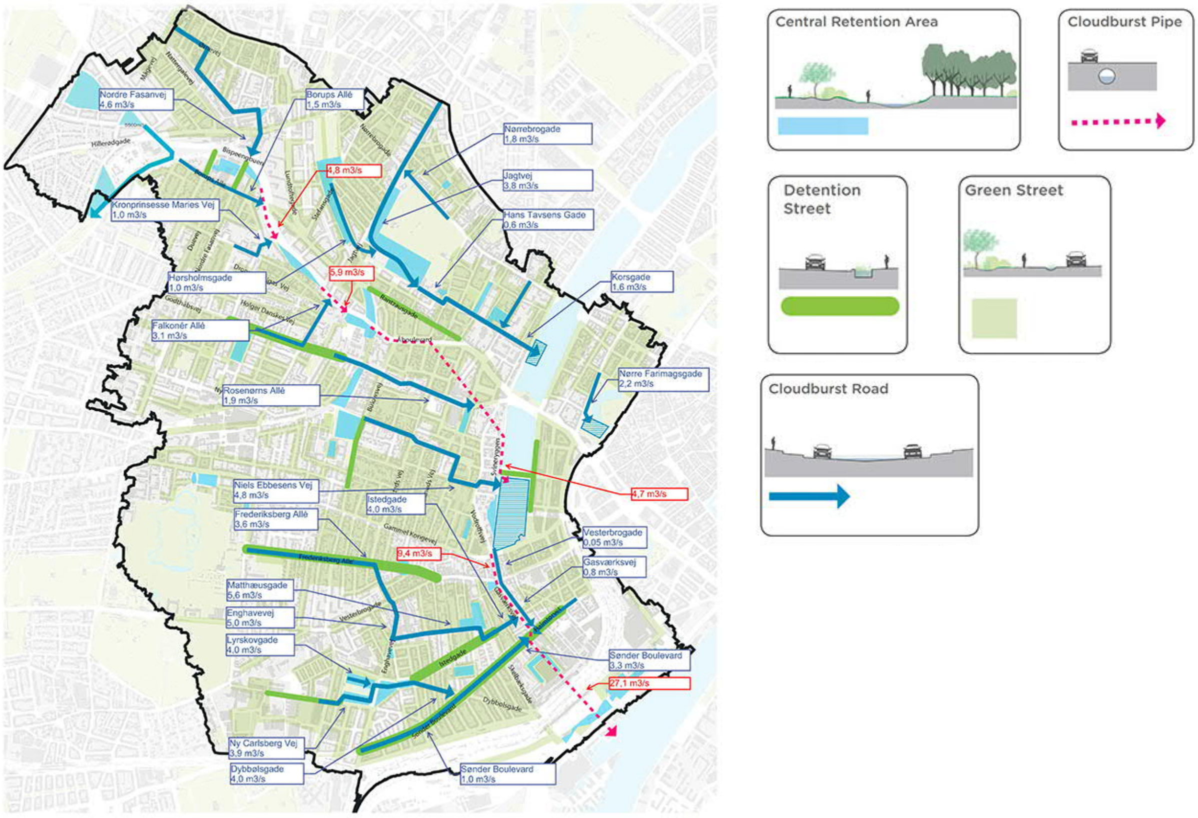

FIGURE 15: SURFACE AND PIPE-BASED SOLUTIONS OF CLOUDBURST BRANCHES IN THE 10 KM$^2$ PLANNING AREA (Source: (Ramboll and Ramboll Studio Dreiseitl 2016))

The CMP identified 60 cloudburst branches and 4 new cloudburst tunnels for detention (normal rain) and discharge (extreme event) of runoff, grouped into the typology shown in Figure 15.

Approximately 350 projects have been identified to re-profile roads and squares and to create new underground construction projects. Due to high costs of the overall investment, project priority was assessed to define the order of implementation. The decision was based on four aspects (Jan Rasmussen 2016):

- **High risk:** based on the risk analysis, city areas with the highest risk of flooding, where adaptive measures would have the highest effect
- **Easy implementation**: areas where pluvial flood water can be drained by relatively simple measures, for example areas close to the harbour by creating outlets in the quay
- **Ongoing urban development projects**: the costs of pluvial flood projects can often be considerably reduced if they are implemented in ongoing urban projects (e.g. new development projects or road renovation)
- **Areas with synergistic effects**: combining flood risk initiatives with other urban schemes.

The plan identified that legislative changes are required. Current regulations do not allow cross-financing between sectors, for example utility companies are only permitted to finance projects related directly to wastewater management and cannot fund detention and discharge tools on road surfaces because roads are legislatively not elements of the drainage system.

Between 2012 and 2033, around 15 projects would be carried out annually. Of the approximately 350 proposed projects, the conventional engineering projects will be completely funded by water-fees collected by HOFOR. About 290 projects in urban areas are municipal tax-funded projects, co-funded by HOFOR. Private owners and communities are also encouraged to establish BGI tools on their roofs and courtyards and to disconnect stormwater from the sewer system. These activities are however not covered by the CMP budget.(Liu, Jensen 2017a p. 11)

The city facilitates the private sector and local communities in various ways to join the initiative – the Sankt Kjelds Quarter, Copenhagen's first "climate-resilient neighbourhood", is a good example of this. A local centre for climate and neighbourhood regeneration was founded to share expertise, innovative knowledge and technical knowhow, and facilitate local collaborations between residents, NGOs, and small businesses to develop local solutions, especially for rainwater retention., The Technical and Environmental Administration also offers assistance for local initiatives, for example at environmental offices located in local communities of the city.

Furthermore, most of the relevant free information is available on the city's homepage.(Andreas Hastrup Clemmensen et al. 2015)

## 3.3 Singapore – active, beautiful, clean waters

After the independence of Singapore in 1963, the rapidly developing country had to deal with high water pollution, floodings caused by intense monsoon rains, and a dependence on imported drinking water. Lee Kuan Yew, the country's first prime minister assigned water management as the Singapore`s top development priority and created an ambitious plan to solve the supply and pollution issues. The Public Utilities Board (PUB) coordinates all water related investments since nationalisation. In the first ten years, polluting riverside land use was terminated or relocated and the sewage system was intensely developed along the two main rivers of Singapore. As a result of these strict measures, water quality increased immensely, aquatic life returned to Singapore's rivers and the separated sewage system significantly decreased the risk of flooding.

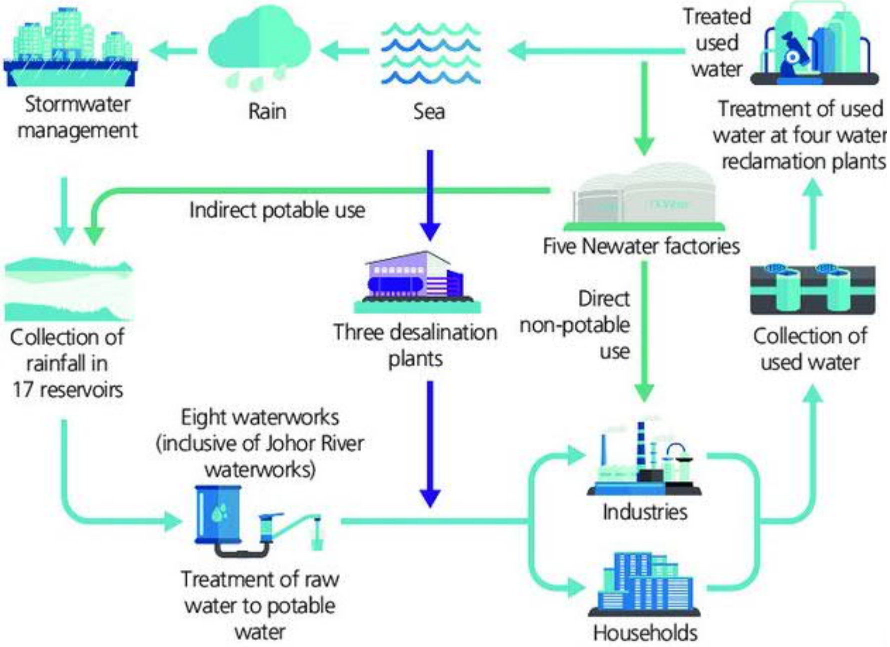

FIGURE 16: INTEGRATED WATER MANAGEMENT IN SINGAPORE: CLOSING THE WATER LOOP
(Source: (Dolman, Ogunyoye 2018 p. 26)

During this procedure, a complex, **integrated water management approach** evolved through the cooperation of different governmental departments and research institutes. Figure 16 shows the urban water cycle's elements and their interconnections. Drainage development struggled to keep up with the rapid urbanisation. New reservoirs were established, and creeks were often converted into concrete channels to mitigate increasing flood danger. The four pillars of the city's current water supply are: 1. Water from local catchments; 2. Imported water; 3. NEWater (ultra-clean, high-grade reclaimed water); 4. Desalinated water. By the late 1980s, these developments provided a suitable level of flood control and freshwater storage, and the city broadened its development approach. Authorities started a collaboration with the PUB to create new opportunities for the recreational use of waterways and reservoirs. Motivated by the success of the initial projects, the PUB continued to look for further projects options for blue-green development and established Singapore's water management strategy, the "Active, Beautiful, Clean" (ABC) Waters Programme.(Khoo et al. 2017 p. 3)

The **ABC Waters Programme**, launched in 2006, strives to transform waterways and waterbodies into beautiful urban assets, integrating the drainage infrastructure with the urban environment while bringing people closer to water, and transforming Singapore into the "*City of gardens and water*".(Lim, Lu 2016 p. 844) The programme was coordinated by the PUB, which recognised the crucial importance of winning political support and public acceptance for the programme. The PUB set up an inter-agency working committee and held monthly meetings with various stakeholders to resolve the early scepticism. The director of the Catchment and Waterways Department within the PUB recalled speaking to MPs over lunch during parliamentary sessions to explain the ABC Waters Programme to them. A **3P-Network** (People, Private, Public) was created, which formed the backbone of the project in the later implementation phases.(Khoo et al. 2017 p. 44) The PUB also realised the high importance of landscape architectural expertise in the planning process. The first demonstration projects were widely communicated to the public and gained popularity amongst the residents. In addition, the ABC Waters Exhibition was launched in 2007 to invite the public to learn more about the programme and unveil the ABC Waters Master Plan. The six-day exhibition was a success as residents were generally excited about the forthcoming projects near their estates. The early set-up of a communication strategy and continuous close engagement with the residents was a key element for the programme's success and long-term sustainability.

The **ABC Waters Master Plan** divided the city's area into three catchment areas (Western, Central, Eastern) and each was investigated by a water management expert team. Almost 100 sites were identified by the initial master plan, with development spanning 20 to 30 years – this formed the programme's institutional basis in the following years.(Khoo et al. 2017 p. 48) Among these sites, several large **flagship projects** were implemented first to increase public and political acceptance, such as the Bishan-Ang Mo Kio Park.(Figure 17) These projects also hosted **experiments** with numerous materials, plant species, natural retention and cleansing systems, and bioengineering solutions, closely monitored by research projects. The later projects focused on enhancing livability in residential areas. Since 2017, 36 ABC Waters projects were implemented.

FIGURE 17: BISHAN-ANG MO KIO PARK BEFORE (2008) AND AFTER (2011) THE REVITALISATION
(Source: (Pagodashophouse 2011))

The appropriate BGI implementation is supported by the **"ABC Waters Design Guideline"**.(Public Utilities Board, Singapore 2018) The document introduces the approach and design tools of SURM and introduces numeruous BMPs. Two **design standards** are included in the document for designers and investors: 1. *Planning, design and performance of ABC Waters Design Features*; and 2. *Construction and maintenance of ABC Waters Design Features*. These standards provide exact data for dimensioning and construction. Mosquito control is an important aspect of maintenance to prevent malaria, which must ensure that water surfaces permanently flow.

In the later phases, further tools were introduced to facilitate knowledge sharing and establish partnership with the private sector. The **ABC Waters Certification system**, launched in 2010, "*provides recognition to public agencies and private developers who have embraced and incorporated the ABC Waters concepts and features in their developments*".(Public Utilities Board, Singapore 2018 p. 65) Nominated projects receive points in four categories (active, beautiful, clean, innovation) and can be qualified as "ABC Waters Certified" or "ABC Waters Certified (Gold)", if related standards are fulfilled. Another certification system was concurrently established to train **ABC Waters Professionals**, who receive a qualification in the design of ABC Waters features and are permitted to conduct the compulsory annual inspection of the tools.(Public Utilities Board, Singapore 2018 p. 71)

The growing number of implemented projects revealed that although construction costs of renaturised waterways are higher than the traditional water infrastructure, maintenance costs of natural systems can be significantly lower. Due to the complexity of these projects, maintenance responsibilities must be clarified at an early stage to avoid conflicts and quality problems.

Since the ABC Waters Programme was started in 2006, planning and design parameters have been updated based on collected experiences. Since January 2014, developers and owners of all industrial, commercial, institutional and residential developments greater or equal to 0.2 hectare are required to manage their peak runoff by implementing on-site detention measures (e.g. detention tanks and/or ABC Waters design features) to hold back or slow down runoff before discharging it to the public drainage system. These on-site detention measures will provide a higher level of protection against flood risks in the catchments, and support PUB`s long-term goal to transform Singapore’s entire surface into a water catchment area and ultimately the *City of Gardens and Water*. (Public Utilities Board, Singapore 2018 p. 16)

## 3.4 Summary of the international case studies

The three studied cities had different drivers for establishing their water strategies. While New York strived to improve the water quality of its rivers and beaches, Copenhagen aimed to protect inhabitants and businesses from flooding. Singapore has been developing its water management practice over several decades and its recent strategy continues this work by focusing on greening and humanising the urban environment. Key measures of the strategies were identified and grouped into four main phases of the strategic planning shown in Table 9: framework establishment, analysis, decision-making, implementation. While these phases are usually chronological, iterations after implementation are performed to refine methods and targets.

New York demonstrated the best example for creating a framework consequently, fast and efficiently. The city identified and implemented actions within the first two years, which were needed for an extensive BGI implementation: establishing a legal framework; raising an interagency expert group; laying out project funds; collecting and sharing technical knowledge. Singapore needed more time to establish a steady institutional framework, nevertheless the city commenced work earlier and there were no existing examples which could be adopted. The political system of Singapore provided profound opportunities for implementing large drainage developments and radical land use changes at the early development phase. In all three cities the initiation and coordination are provided by a state or municipal organization. The case studies showed that the presence of committed leaders who follow and coordinate the strategy over a long term is an essential element for success. The work of municipal participants is supported by private expert groups. The founding of expert teams was common in establishing a common understanding amongst different municipal departments.

TABLE 9: PLANNING PHASES AND IMPLEMENTATION TOOLS OF THE CASE STUDIES

| Framework → | Analysis → | Decision-making → | Implementation |
|---|---|---|---|
| Legal framework | Digital sewage modell and runoff simulation | Scenario establishment | Education |
| Working group and stakeholder involvement | Surface coverage map | Cost-benefit analysis | Community involvement |
| Funding | Pilot projects | Planning targets | 3P projects |
| Technical framework | Climate simulation | Project prioritisation | Maintenance program |
| Communication framework | Risk analysis | Milestones | Expert program |
|  | Case study analysis |  | Standards |
|  | Potential analysis |  | Taxes, fees and incentives |
|  |  |  | Monitoring and revision |

Iteration

The funding of BGI tools is usually shared between private and public stakeholders. The required budget for public projects is covered by various sources: state funding (e.g. funding for environmental protection projects); rainwater management fees; the budget for open space or water infrastructure development. All cities are looking for synergies with ongoing or planned development projects, which can significantly reduce the implementation costs. In Singapore, close cooperation with private stakeholders started as the strategy was conceptualised.

The analysis methods are best documented in the cases of New York and Copenhagen. All cities used pilot projects to gain knowledge about the performance and applicability of BGI tools. Further data was processed by analysing case studies. It was extended by complex water management calculations and simulations. Data sources and calculation methods were continously improved because of the deficiencies revealed through the planning and implementation. While Copenhagen's strategy is built upon an extensive risk assessment, New York's and Singapore's plans concentrated more on the identification of possible BGI implementation areas. Copenhagen's concept also included the aspects of climate adaptation in the planning, most significantly by preparing for the simulated future effects of climate change.

The different drivers of the three cities resulted in various approaches in the decision-making process, which can be tackled in the planning hierarchy. Copenhagen's water concept originates from the Climate Strategy and aims to fulfill its strategic goals. New York`s strategy melded into the green infrastructure planning and uses the available open spaces for SURM. The blue-green city is the leading vision of Singapore's urban planning, thus BGI development and its space demand are considered in the early phase of city development.

The three cities used different approaches to define goals. Both New York and Copenhagen specified a ratio of the city's area, from which runoff should be controlled by BGI tools. In addition, Copenhagen defined an exact maximum flood height and outlined its plans to reach this target. Singapore has not set exact targets but facilitates an overall paradigm shift in the planning practice of water management and requires the use of detention and retention tools for all new development projects larger than 0.2ha. Different scenarios were established in New York and Copenhagen to narrow down the vast possible combinations of BGI development. These scenarios were used to estimate the costs of implementing and maintaining BGI, and assess the benefits. The cost estimation required the calculation of a baseline scenario, in which BGI scenarios could be compared. Milestones were defined to fragment the development process towards the final long-term goal and continously assess its progression. Due to budget limitations, various measures were used to prioritise the planned interventions. BGI projects were insisted that: 1. can be integrated into ongoing development projects; 2. have a high cost-benefit ratio; 3. provide good publicity and acceptance for the strategy (e.g. flagship projects of the ABC Waters Programme).

TABLE 10: EVALUATION OF THE BGI DEVELOPMENT PRINCIPLES IN THE THREE ANALYSED CASE STUDIES

| | New York | Copenhagen | Singapore |
|---|---|---|---|
| Restoring the water-cycle | ○ | - | ○ |
| Integrated approach | ○ | ○ | ● |
| On-site management | ● | ○ | ● |
| Clean water | ● | ○ | ● |
| Connectivity | ○ | ● | ○ |
| Multifunctionality | ● | ● | ● |
| Aesthetic shaping | ● | ● | ● |
| Biodiversity | ○ | - | ○ |

●: high significance ○: low significance -: no significance

Different implementation measures were defined for the development of public and private areas. Public BGI developments were financed by compulsory taxes, fees, funds and combined with broad public involvement. 3P projects are a combination of private and public investments. The close cooperation between municipal and private stakeholders needs a flexible approach and individual solutions from the municipality and can result in benefiting synergies. Cities offer guidelines and trainings for experts and residents and facilitate private BGI developments by tax abatements. In Singapore, the planning of the ABC Waters tools can only be performed by experts who accomplished the ABC Waters Professionals program, which ensures a standardised planning quality.

The BGI planning principles introduced in Chapter 2.2 were evaluated for the case studies. All three cities use an integrated water management approach that considers rainwater and wastewater infrastructure and the management of natural water bodies as one system. Singapore shows the most complex approach by including the water supply into the urban water cycle. Restoring the original water balance was not a specific aim in New York and Singapore due to the cities’ density, however the implemented on-site tools increase the ratio of infiltration and evaporation. In contrast, Copenhagen’s plan primarily applies a fast discharge on sealed road surfaces, which does not support the natural water cycle. The connectivity of BGI was mostly employed in Copenhagen, where the tools of the catchment areas were calculated and designed as one coherent system. The project selection in New York and Singapore was based on a catchment analysis, but the projects along the flow path have less influence on each other. Improving water quality served as an important planning condition in the mentioned two cities. In Copenhagen, this topic acquires a lower importance. Increasing amenity by esthetical shaping was a common goal of all cities. Enhancement of biodiversity was not emphasized in any of the strategies but was observed in Singapore and New York as a “positive side-effect” of BGI development. Nevertheless, this topic has gained an increased awereness in recent years and a more intentional use of local plant species will be expected in future planning.

Despite the different climatic and cultural environment, the three cities’ actions showed numerous similarities. The strength of New York’s and Singapore’s strategy is their complex approach and the intensive public and private involvement, while Copenhagen’s strategy is focused on flood events and creates a strong connectivity between the BGI tools. Among the three analysed cities, Singapore’s water management approach includes the most SURM principles in its strategy and promotes blue-green infrastructure as the most characteristic element in its urban planning vision.

# 4 Review of the existing rainwater management in Budapest

The Hungarian capital city is situated in Central Europe’s Carpathian Basin on the floodplain of the Danube. This diverse metropolis – shaped by the Danube and formed by numerous iconic phases of European urban development – exhibits similarities to numerous historic cities of Europe. The city’s features were investigated based on the required dataset which was defined in Chapter 2.3. The city’s geophysical and urban environmental factors were investigated to ascertain the availability and data quality of the required ground information and to collect the base dataset for the further potential analyses. Finally, the current institutional and legislative framework will be introduced. Due to restricted time, resources and available information, economic and social aspects were not investigated in this research. The sources referenced in this chapter were introduced in Chapter 1.3.

## 4.1 Geophysical factors

### 4.1.1 Climate

In the Köppen-Geiger climate classification system, Hungary falls into the Dfb (warm-summer humid continental) climate zone, which is characterised by cold winters, hot summers and a relatively balanced annual precipitation pattern. Frost occurs regurarly in the winter months, while heat waves in the summer months can often reach 40 degrees.(Table 11) The high number of windless days (Tatai et al. 2018 p. 26) restrains the motion of cool air, which, combined with high sealed surface ratio, results in the **urban heat island effect**. On a hot summers day, the surface temperatures of the Városliget city park and the densest urban area of the city measured a difference of 15°C.(Tatai Zsombor et al. 2017 p. 39) The heat map of Budapest on Map 1, Annex 10.3 shows that the effect is the most severe in the large industrial zones and Pest side of the city centre. Forests on Buda hill, larger city parks and the Danube characterise the coolest zones of the metropolis and have an important cooling effect on their surrounding environment. Table 11 shows that evaporation exceeds the amount of precipitation in the seven warm months and overall annualy, which means a **negative water balance**. Therefore, rainwater should be often supplemented by irrigation to maintain the urban vegetation in a good condition.

TABLE 11: AVERAGE MONTHLY TEMPERATURE, PRECIPITATION AND EVAPORATION IN BUDAPEST
(Source: (Dániel Vincze 2016)

| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Okt | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | | | | | | | | | | | | | |
| Maximum | 6.2 | 7.1 | 10.8 | 16.6 | 20.3 | 23.8 | 25.1 | 26.7 | 20.4 | 14.9 | 9.4 | 4.6 | |
| Average | 0.6 | 2.3 | 7.1 | 12.6 | 17.4 | 20.2 | 22.6 | 22.0 | 17.2 | 12.0 | 6.1 | 1.5 | |
| Minimum | -4.0 | -3.1 | 2.1 | 9.0 | 13.6 | 17.0 | 19.8 | 19.1 | 13.5 | 9.3 | 1.4 | -2.8 | |
| Water balance | | | | | | | | | | | | | |
| Precipitation | 34 | 28 | 31 | 38 | 59 | 64 | 45 | 52 | 41 | 35 | 49 | 40 | 516 |
| Evaporation | 0 | 2 | 22 | 52 | 97 | 114 | 107 | 89 | 59 | 43 | 14 | 2 | 601 |
| P surplus | 34 | 26 | 9 | -14 | -38 | -50 | -62 | -37 | -18 | -8 | 35 | 38 | -85 |

The ALADIN-Climate and REMO climate models are used to simulate the impacts of climate change in Hungary. Based on their results, the country's climate is estimated to shift to the hot-summer humid (Dfa) climate zone by the end of the century.(Rubel, Kottek 2010) As a consequence of global warming, Budapest's annual midrange temperature has already risen 1°C in the past century and the number of sunshine hours are continuously increasing.(Tatai et al. 2018 pp. 25–26)

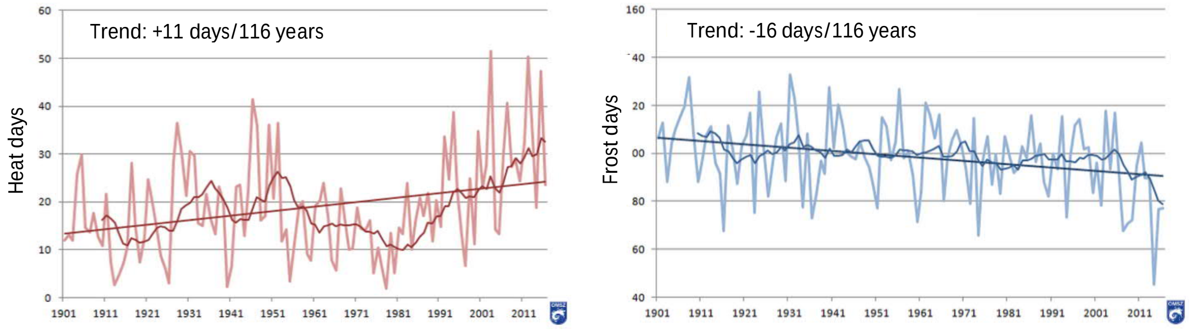

FIGURE 18: THE NUMBER OF HOT AND FROSTY DAYS IN THE LAST CENTURY
(Source: (Magyar Meteorológiai Szolgálat 2018))

The Hungarian Meteorological Service predicts a 3,5°C increase in the average annual temperature between 2021-2050 and a maximum increase of 6°C by 2100.(Csima et al. 2010 pp. 3–4) Higher temperatures will induce more heat days and greater evaporation losses in the warm months, therefore urban vegetation will suffer more from water shortages during hot periods.(Tatai et al. 2018 p. 26)(Figure 18) There are high uncertainities regarding the change of long-term precipitation in climate prognoses. Nevertheless, it can be shown that a higher proportion of the annual precipitation will be provided by intense rainfalls and due to this the number of the dry days will rise. While water engineers in Hungary typically consider a rain event with 100 l/s/ha intensity as an extreme event, the intensity of several events in the last decade exceeded 300 l/s/ha.(Oszoly 2015)

### 4.1.2 Topography and soil

The city is divided by the line of the Danube into two different geographical zones. The western side (Buda) is dominated by the diverse terrain of the Buda Hills, which consists of limestone and dolomite (Map 2. Annex 10.3). The cracks and cavernous rock layers lead the rainwater directly into the groundwater, they are therefore sensitive to water pollution. The eastern side is a flat floodplain built up by the alluvium of the Danube. These gravel, sand and loess layers have a good permeability and filtering ability and play an important role in the city's drinking water supply. (Dövényi 2010) The abovementioned soil types are rarely found in the top layer of the historical city centre due to intense urban construction and organised landfilling to elevate the city after the Big Icy Flood in 1838. The existing urban soil has been mixed with several imported soil types and building debris, which has degraded the water balance. (Tatai et al. 2018 p. 25)

### 4.1.3 Groundwater

Budapest is rich in underground water sources. The metropole's drinking water is filtered and supplied by the thick gravel layer of the Danube banks. The groundwater level shows a high variability, a higher level is typical along watercourses and low-lying areas. (Map 3 Annex 10.3) The latter is seasonally influenced by groundwater flooding. Monitoring of 417 groundwater wells was provided by the FŐMTERV until 2007. Since then, the city has not had a unified groundwater monitoring system and the current groundwater level values are unknown.(Andó, Tolmács 2015 p. 12)

## 4.2 Urban environmental factors

### 4.2.1 Rainwater drainage infrastructure

Rainwater collection and conveyance is provisioned by a combined sewage system in the city centre and by a separated rainwater drainage system and open ditches on the outskirts, as shown in Figure 19. (Map 4, Annex 10.3) The combined system was mostly built between the second half of the 19th century and middle of the 20th century, but some extensions were constructed in the second half of the 20th century. (Gerőfi-Gerhardt 2017) To maximise the catchment area, sewage pipes were designed with a shallow gradient, thus sedimentation and odours can occur during long summer droughts when there is not enough rainwater for regular flushing.(Preisich 2004) Most of the combined sewage system is dimensioned for a 2-year rain event, with 10 minutes rain duration on hillsides or 15 minutes duration on flat areas.(Tatai et al. 2018 p. 30) The pipes transport the wastewater to the water cleansing plants of Budapest. If pipe load increases five times more than the average wastewater volume due to a rain event, the excess flow passes through the CSOs directly into the Danube. If the fluvial flood level exceeds the height of the CSO outlets, the outlets are closed to prevent backflow and the wastewater must be transported over the flood protection line by pumping stations. Due to the limited pumping capacity, a simultaneous presence of high flood and an extreme rain event would threaten the city center with a backflow of mixed septic water.(Oszoly 2015) The backwater of the combined system  Enlargement of the city centre’s pipe system would be not just expensive but physically impossible in most areas: the subway tunnels, pipes and cable systems for various utilities occupy almost all underground space.(Geröfi-Gerhardt 2017)

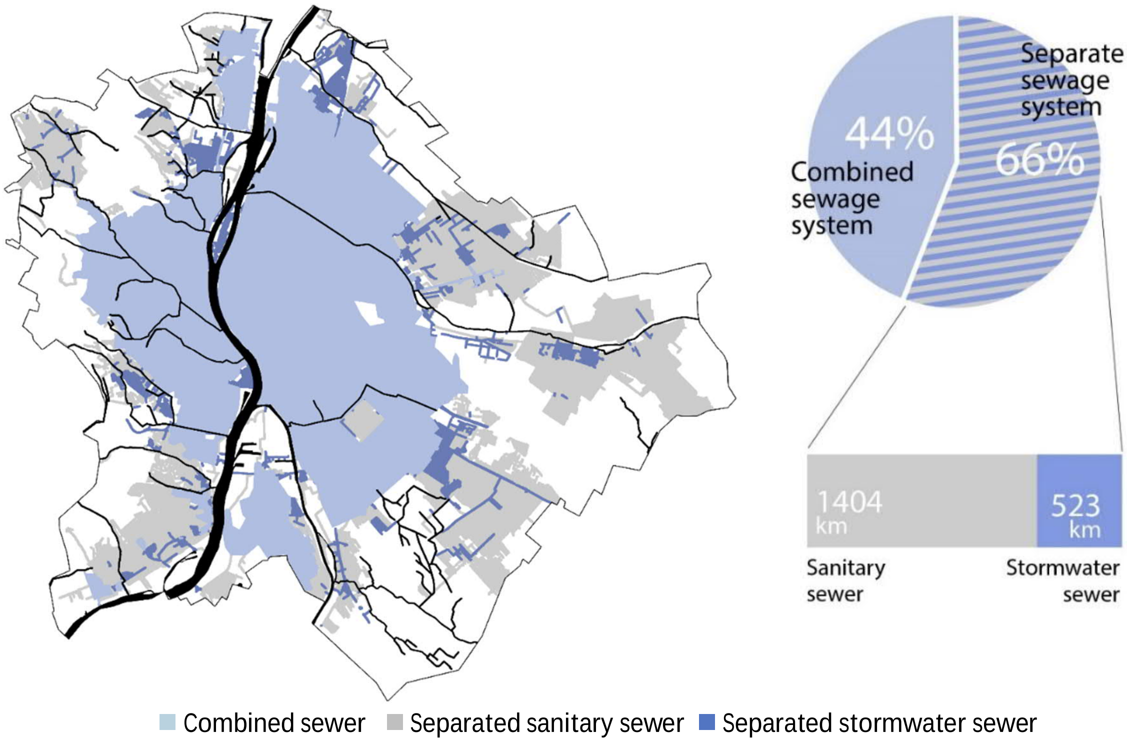

FIGURE 19: THE SEWAGE SYSTEM TYPES OF BUDAPEST
(Raw data from (Csizmadia 2018) and (Oszoly 2015), recompiled and edited by D. Csizmadia)

Since 1960’s, the implementation of a separated sewage system became the new standard. The system is designed for 2- or 4-year rain events and transports the runoff directly into the watercourses (without cleansing). This water load significantly contributes to the flash flooding of smaller creeks in Budapest. While use of the separated drainage system was common in socialist prefabricated housing estates, other housing areas usually lack this cost-intensive infrastructure. In 2000’s, the European Union provided funds for the establishment of wastewater systems in order to improve the water quality of natural water bodies, but funding did not target the construction of rainwater drainage. As a result, the separated wastewater system was extended without a rainwater drainage. Furthermore, numerous gravel roads were concurrently sealed by asphalt, which radically increased the sealed surface ratio in public areas.(Preisich Gábor 2004) In areas without a sewage system, many residents illegally directed the runoff from roofs into the sewage system or to the street. This immense quantity of unexpected water and decreased infiltration occasionally cause unsafe backflow from the sewage system, which floods buildings and open spaces with septic water and creates a risk of infectious diseases. The few constructed drainage pipes provide drainage for streets and public spaces but not for private grounds. Grass ditches – the traditional drainage elements of suburban areas – have often been discontinued by residents to make way for parking space in front of their properties.(Oszoly 2015) As a consequence of these factors, 20% of Budapest's housing areas are endangered by flash floods and pluvial flooding.(Tatai et al. 2018 p. 70)

### 4.2.2 Land use

The city's land use categories were analysed by the investigation of the Land Use Plan of Budapest and its analysis studies.(Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály 2017b) (Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály 2017a) The city is spread over a land area of approximately 525km$^2$ that consists of 52% built-up areas and 48% non-built-up areas. Development and land use plans divide the city historically into five uban zones based on their individual characteristics, shown in Figure 20.

**Built-up areas** are composed by housing areas (L),[23] mixed areas (Vt), commercial areas (Gksz), holiday areas (Ü) and special built-up areas (Kb). **Non-built-up** areas are divided into traffic areas (Kö), water management areas (V), parks (Z), forests (E), agricultural areas (Mg), nature areas (Te) and special areas (K), and the sub-categories of these units. Brownfields have an immense size and high importance in urban development of Budapest. They are dispersed among several land use categories, but

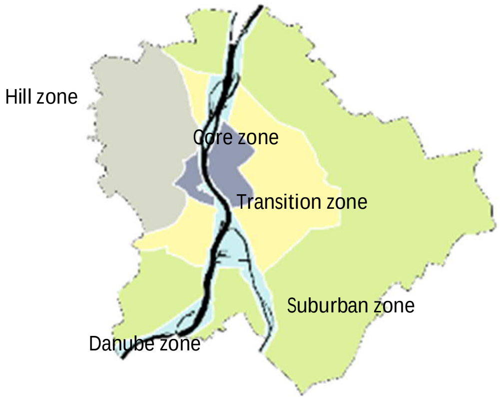

FIGURE 20: THE TRADIIONAL LAND USE ZONES OF BUDAPEST
(Source: Land Use Plan of Budapest)

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[23] This research uses the traditional abbreviations of the Land Use Plan for easy identification.

historically regarded as an individual category in urban planning. Therefore, this area type will be analysed as a separate land use category.

The Land Use Plan "*aims to define the same land use category for those areas of the city, which are located in different parts, but possess identical or very similar properties*".(Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály 2017a p. 30) The most important properties that are considered and regulated by the Land Use Plan are: type of use; role in the city structure; building character; building height; floor area ratio; and minimal green area ratio.

During the investigation of the sub-categories, it was stated that some of the categories define areas with very heterogenous urban planning parameters. For example, educational or healthcare centres – depending on their location and historical development – have a large diversity of architectural styles and permeable surface ratio.[24] Therefore the land use categories of "Built-up special areas" were omitted from the investigation.

The investigated land use categories were devided into six large groups for the analysis: Non-built-up areas in the groups: "water management areas", "green areas" and "transportation areas". Built-up categories were divided into the groups "residential areas" and "commercial areas" and "brownflieds" and are shown in Figure 22. In addition, the ratio and distribution of the six groups are noted below the map.

**Green areas** (agricultural areas, forests, semi-natural areas and parks) cover 29% of the city's area (green areas in other land use categories, such as private gardens are not included here). The second most spacious land use category is **residential areas**, which occupy 28% of the city area and 62% of the built-up areas. In third place, **traffic areas** cover 18% of the city surface. Since the regime change in 1989, **industrial areas** have significantly contracted in Budapest, amounting to merely 6% of the city. **Bownfields** (and further disused areas) take up 4%. 3% of Budapest's area is **water surface**. The remaining land use categories that were not analysed occupy solely 13% of the city's area.

Henceforth the relation of land use categories to rainwater management will be **analysed** using these **six main groups**. The description of each group is complemented by a list of the relevant landuse categories. Complementing maps that show their locations in the city's urban fabric are referenced in Maps 6-11 in Annex 10.3.

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[24] As also shown in the international case studies, these governmental institutes are sometimes managed by individual development programs.

Water management areas

| | |
|---|---|
| Vf | Riverbeds and riverbanks |
| Vá | Lakebeds and lakeside areas |

Related maps:
Annex 10.3 Map 6: Budapest‘s watercourses and water supply zones

Budapest’s water surfaces largely consist of watercourses. The proportion of lake surfaces is not significant in the city structure. The Danube, seven main creeks and further artificial channels serve as recipients of the city’s rainwater runoff. The Danube’s water quality and quantity depends largely on weather conditions and upstream land use, which is monitored and coordinated by international strategies and cooperation programs.

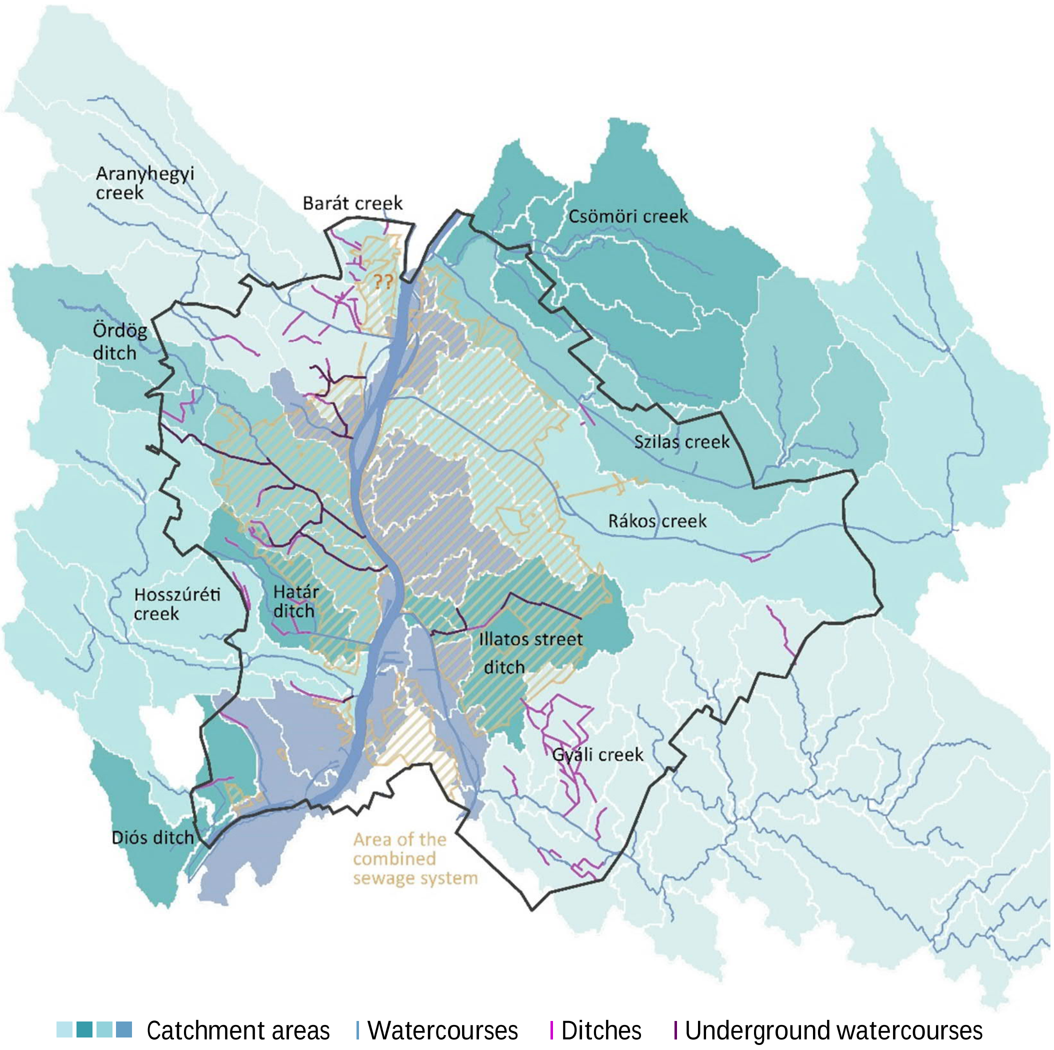

Figure 21: Water catchment areas of Budapest
(Raw data from (Rácz 2016) and (Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály 2011 p. 224), recompiled and edited by D. Csizmadia)

**NON-BUILT-UP AREAS**

### Water management areas

| | |
|---|---|
| Vf | Riverbeds and river banks |
| Vá | Lakebeds and lakeside areas |
| Vb | Water supply areas |

**Water management areas**

### Parks

| | |
|---|---|
| Zkp | Public gardens, parks |
| Zvp | City park |

### Forests

| | |
|---|---|
| Ev | Protectional forests |
| Ek | Recreational forests |
| Eg | Economy forests |

### Nature areas

| | |
|---|---|
| Tk | Semi-natural areas |

### Agricultural areas

| | |
|---|---|
| Má | General agricultural areas |
| Mk | Horticultural areas |

### Special areas

| | |
|---|---|
| Kb-Rek | Recreational areas with high green area ratio |
| Kb-Ez | Conditioning areas with high green area ratio |
| Kb-T | Graveyard |
| Kb-Rég | Archeologic area |
| Kb-En | Renewable energy producing |
| Kb-Hv | Military area |

**Green areas**

### Transportation system

| | |
|---|---|
| KÖu | Road transport areas |
| Kök | Rail and other track-based modes |
| KÖv | Waterborne transport area |
| KÖl | Air transport area |

**Transportation areas**

**BUILT-UP AREAS**

### Residential areas

| | |
|---|---|
| Ln-1 | Metropolitan, high-intensity development typically in unbroken row |
| Ln-2 | Metropolitan development typically in unbroken row and framing structure |
| Ln-3 | Metropolitan, high intensity development typically free-standing buildings |
| Ln-T | High housing estates |
| Lk-1 | Small-townish development, typically in unbroken row |
| Lk-2 | Small-townish development, typically free-standing buildings |
| Lk-T | Low housing estates |
| Lke-1 | Intensive low-intensity suburb |
| Lke-2 | Loose low-intensity suburb |
| Lke-3 | Hillside low-intensity suburb |

### Mixed areas

| | |
|---|---|
| Vt-V | City centre |
| Vt-M | City subcentre |
| Vt-H | Local centre with high priority |
| Vi-1 | Institutional area typically in unbroken rows |
| Vi-2 | Institutional area, free standing buildings |
| Vi-3 | Institutional area, local public service |

**Residential areas**

### Commercial areas

| | |
|---|---|
| Gksz-1 | Typically trading and service area |
| Gksz-2 | Typically storage and manufacture area |
| Gip-E | Energy producing area |

### Holiday areas

| | |
|---|---|
| Üh | Weekenend house area |

### Special areas

| | |
|---|---|
| K-Ker | Shopping mall |
| K-Log | Large surface transportation, storage and logistic area |
| K-Vás | Market, exhibition and congress area |
| K-Okt | Educational center |
| K-Eü | Medical area (hospital, sanatorium) |
| K-Sp | Large surface sport area |
| K-Rek | Large surface recreational area |
| K-Kv | Complex riverside area |
| K-ÁN | Zoo and botanical garden |
| K-Hon | Military area |
| K-Hull | Landfill area |
| K-Sz | Wastewater treatment area |
| K-Közl | Traffic system related building area |
| K-Klk | Harbour |
| K-Rept | Airport |
| K-T | Graveyard |
| K-Mü | Agricultural maintenance area |
| K-Tp | Tematical institutional park |
| K-Vke | Water management area |

**Commercial areas**

**Brownfields**

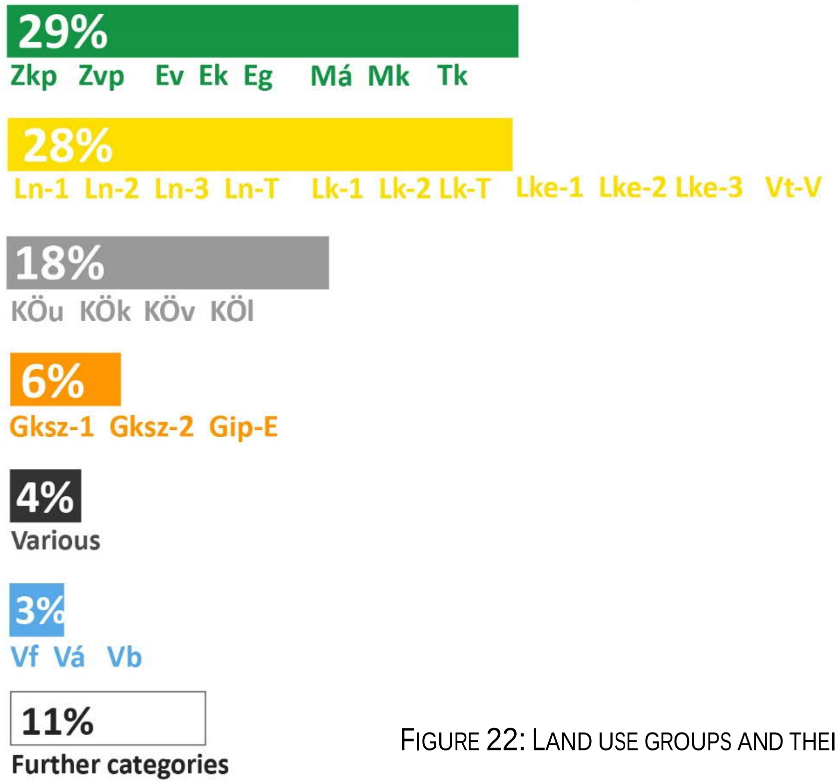

FIGURE 22: LAND USE GROUPS AND THEIR SURFACE RATIO IN THE CITY

All seven small watercourses in Budapest (Aranyhegyi-creek, Ördög-creek, Hosszúréti-creek, Csömöri-creek, Szilas-creek, Rákos-creek, Keserű-creek,) spring outside of the city, but as shown in Figure 21, they are also appreciably impacted by the city's runoff. Most of the creeks have been significantly modified. Apart from the artificial concrete riverbed, creeks scarcely have space to overflow due to housing areas that are built on the floodplain. Thus, flash floods caused by heavy rains can cause extensive damage to the housing areas in many sections along the watercourses, especially along the Hosszúréti, Rákos and Gyáli creek. (Tatai et al. 2018 p. 25) The integrated ecological condition of the creeks is classified as weak or poor, which do not fulfill the targets of the Water Framework Directive.(BM OVF Területfejlesztési Tervezési Főosztály 2016) The system of watercourses is extended by artificial drainage channels to drain areas with high groundwater level. Map 6 of Annex 10.3 shows Budapest's natural and artificial water bodies and their connection to the drainage system.

Green areas

| | |
|---|---|
| Parks | |
| Zkp | Public gardens, parks |
| Zvp | City park |
| Forests | |
| Ev | Protectional forest |
| Ek | Recreational forest |
| Eg | Economical forest |
| Semi-natural areas | |
| Tk | Semi-natural area |
| Special areas | |
| Kb-Rek | Recreational area with high green area ratio |
| Kb-Ez | Conditioning area with high green area ratio |
| Kb-T | Graveyard |
| Related maps | |
| Annex 10.3 Map 7: Green areas of Budapest | |

While the proportion of green areas (28%) is significant, Map 7 in Annex 10.3 shows that this consists mostly of **forests, agricultural** and **horticultural areas** around the edge of the city, which barely influence the runoff ratio of the urbanised areas. In the built-up areas (shown by black hatch on the map), there are "islands" of green areas consisting of **public parks**, **public gardens** and **special areas** such as cemeteries.[25] The green infrastructure of Budapest lacks robust linear elements. Green corridors along watercourses are highly fragmented due to the intense

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[25] Elements of the green infrastructure in other land use categories (e.g. private gardens) will be discussed later.

development in the flood zones over the last decades. Green areas are presently not designed to play a role in the retention or infiltration of the runoff from surrounding built-up areas. Often paved park surfaces are drained into the drainage system instead of infiltrating it.

### Traffic areas

| | |
|---|---|
| KÖu | Car traffic area |
| KÖk | Railway traffic |
| KÖv | Water transportation area |
| KÖl | Air transportation area |
| Related maps | |
| Annex 10.3 Map 8: Transportation system of Budapest | |

Traffic areas are dominated by non-water permeable asphalt roads and parking lots. Streets and parking surfaces are mostly drained into the combined sewage system or the separated rainwater drainage system. Runoff pollution varies depending on the traffic load. No mapping has been produced for the pollution discharge of the road system, therefore traffic load can be used to estimate the runoff pollution level. Roads with smaller traffic load (typically in family house areas) or in unbuilt areas are partially drained into sealed or grassed trenches. Another significant pollutant is sodium-chloride, which is still used for winter deicing and this impairs urban vegetation.(Magyar Közút Nonprofit Zrt. 2020)

### Residential areas

| | |
|---|---|
| Mixed areas | |
| Vt-V | City centre |
| Metropolitan housing | |
| Ln-1 | Metropolitan, high intensity development typically in unbroken row |
| Ln-2 | Metropolitan development typically in unbroken row and framing structure |
| Ln-3 | Metropolitan, high intensity development typically free-standing buildings |
| Ln-T | Metropolitan housing estates |
| Small-townish housing | |
| Lk-1 | Small-townish development typically in unbroken row |
| Lk-2 | Small-townish development with typically free-standing buildings |
| Lk-T | Small-townish housing estates |
| Low-density suburbs | |
| Lke-1 | Intensive low-density suburb |
| Lke-2 | Loose low-density suburb |
| Lke-3 | Silhouette sensitive, hillside low-density suburb |
| Related maps | |
| Annex 10.3 Map 9: Residential areas of Budapest | |

Residential zones have a high variability of permeability, plot size and building styles, which influences the choice of usable BGI tools. Residential categories are introduced in the order of increasing green area ratio as follows.

Historical buildings of the city core built between 1880-1920 compose 10% of the residential areas and are represented by the **Ln-1** and **Vt-V** categories[26]. They have the lowest green area ratio (0-10 %) and a relatively small average plot size (under 2000m$^2$). (Tatai et al. 2018 p. 27) This combination results in small yards, which are often completely sealed by impervious surfaces and runoff is collected by the combined sewage system. Old buildings typically have gable roofs and five storeys, younger infill housing sometimes have flat roofs. Due to the old materials and foundation construction, the structural integrity of these buildings is sentitive to changes in groundwater levels.

The **Lk-1** category has a similar historical character as an unbroken row of buildings, but the building height and floor area ratio is significantly lower. The 3-4 storey buildings were often located in the city centres of smaller towns that later fused into Budapest. These buildings generally have green courtyards and street trees. In category **Lk-2**, buildings stand alone on a plot, or several free-standing buildings share one (like the 3-5 storey housing estates built since 2000).(Kanczlerné Veréb Mária 2012 p. 75)

Many housing estates were established in Budapest since World War II[27] to resolve the housing shortage. Buildings with a frame layout (**Ln-2**) are typically contained within the socialist-realist housing estates built between 1950-55. The open space system is generous: street trees and occasionally front gardens are provided on the street side and large gardens inside the frames. The most widespread type are the socialist prefabricated housing estates, built between 1960-1990 to satisfy another urgent housing shortage due to a rapid forced industrialisation. These estates are home to 34% of the citizens. While buildings of the early and late period of socialist housing construction were established with at most 4-storeys and flat-roof (category **Lk-T)**, the most intense building period of the 1970's consisted mainly of 7-10 storey blocks (category **Ln-T**). The green area ratio is minimum 35%. Buildings are embedded into a large public park surface that

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[26] Although the subcategory Vt-V belongs to the mixed land use category, the buildings are identical to the Ln-1 and the partially different functions do not influence the rainwater management properties

[27] The few housing estates built before World War II had a smaller, garden-city scale architecture and belong to other land use categories (such as the Wekerle estate)(Körner 2004 p. 63). They are therefore not mentioned here.

can allow use of diverse rainwater management tools. Nevertheless, runoff from the parking lots and roofs is conveyed into the separated drainage system.

The newest type of housing estates appeared in the 1990's and became the most frequent residential housing type of the last two decades. These estates with a high density, building height of 7-10 storeys, and good transportation connections are typical of the category **Ln-3**. Lower 3-5 storey buildings are more typical in the suburban zones. Estate gardens are not accessible to the public but just to local residents. Gardens are often configured as roof gardens because of large underground garages and have a relatively shallow soil layer, which inhibits the use of infiltration tools or tools requiring a large depth.

Low-density suburbs (**Lke**) take up the largest area: 63% of all residential areas. Plot sizes are usually lower than 1000m$^2$ and the average green area ratio can be as much as 50%. Roof runoff is occasionally collected for garden irrigation. The green area ratio of indivual plots is highly variable depending on the private owners' developments. The largest proportion of this category consists of **Lke-1**: intense low-density suburb subcategory. **Lke-2** is typical form in Buda as a transition between Lke-1 and Lke-3. Hillside low-density suburbs (**Lke-3**) mostly evolved from holiday houses at the beginning of the 20th century. Plots with steep terrain are often terraced, which help to slow down the runoff. The green area ratio is very high (over 50%) with old, valuable vegetation.

### Commercial areas

| | |
|---|---|
| Gksz-1 | Typically trading and service area |
| Gksz-2 | Typically storage and manufacturing area |
| Gip-E | Energy producing area |
| Related maps | |
| Annex 13.3 Map 10: Commercial areas | |

Commercial areas are categorised by the Land Use Plan primarily according to their environmental impacts. The **Gksz-1** category collects trading and service areas, which provide direct services to residents such as supermarkets and have a low environmental impact. They have a very high impervious surface ratio, consisting of large roof and parking surfaces. The category **Gksz-2** comprises the areas of logistics, electric and gas stations, and dumps. **Gip-E** includes the areas used for energy production. These latter two categories are considered as sources of significant runoff pollution.

### Brownfields

| |
|---|
| Various categories, areas taken from the Brownfield Cadastre of Budapest |
| Related maps |
| Annex 10.3 Map 11: Brownfields |

Most of the disused areas are **brownfields** that originate from former industrial and railway use. Due to spontaneous vegetation, several abandoned plots have a high and constantly increasing green area ratio. Some areas have contaminated soil and buried unexploded bombs from World War II. These difficulties have hampered revitalisation, and instead green areas were sacrificed for the extension of built-up areas during the last three decades.(Budapest Főváros Önkormányzata 2014 p. 29) As Map 11 shows, a large part of the brownfields are located on watersides (mostly along the Danube) or are embedded into the dense urban tissue. Thus, their location makes them very suitable for rainwater management. The large continuous areas of the former railway areas possess a high potential for large-scale BGI development.

## 4.3 Current legislative framework of rainwater management

Present regulatory framework and current strategies of rainwater management have been investigated in order to understand motivations, conflicts and institutional deficiencies. To gain a deeper view into these topics, personal interviews were carried out with experts of Budapest Sewage Works, the Budapest Főváros Városépítési Tervező Kft. (Municipal Office for Urban Planning), and the Law Department of the General Directorate of Water Management. After the introduction of the main stakeholders, the current legal framework of rainwater management will be analysed. Finally, the role of rainwater management in the existing urban planning documents will be reviewed.

### 4.3.1 Stakeholders of urban rainwater management in Budapest

The introduction of stakeholders, their rights and responsibilities, are divided into the topics: ownership; and development & maintenance; which are summarized in Table 12.

#### Ownership

The ownership of Budapest’s open spaces is divided between the city, districts and private owners. The city owns properties and infrastructure elements with high importance: water infrastructure is therefore mostly in municipal ownership, along with the most important streets and green areas (e.g. parks, old tree rows and the green areas of the large socialist housing estates.(Bíró 2019) The ownership of Budapest's watercourses is complex and fragmented: for example, the sections of Hosszúréti creek are divided between the state, district municipalities, private owners and the Budapest Transport Corporation (BKV).(VTK Innosystem Kft. 2018 p. 45) Opened ditches officially belong to streets, therefore some are also in municipality ownership. The city established non-profit companies for the development and maintenance of some special infrastructure elements. The 75% city owned Budapest Sewage Works Pte Ltd. (Fővárosi Csatornázási Művek, FCSM) is not only the developer and maintainer of the sewage and drainage system, but also the owner of their infrastructure elements.(Fővárosi Csatornázási Művek ZRt. 2020) A small part of the drainage system belongs to the districts and private investors.[28] The remaining green areas, sealed open spaces, and the roads and ditches along them, belong to the district municipalities. The lack of a central register of green and blue infrastructure elements often hampers the clarification of tasks and responsibilities.(Oszoly 2015)

In built-up areas, residential buildings and their gardens or courtyards are predominantly owned and used by a community of landlords. Commercial areas are owned by private companies, while brownfields have various owners. The proportion of former railway areas owned by the national railway company (MÁV) is significant amongst the brownfields.(Hutter 2015 p. 146)

### Development & maintenance

The responsibilities related to rainwater infrastructure development projects are often unclarified. The long-term development of water bodies should be decided and financed by the city, but due to general under-funding the city municipality prefers to delegate development to the districts.(Somlyódy László 2011 p. 264) Some districts with flood problems and a strong financial balance take infrastructure development into their own hands and decide on investments – but these projects are mostly initiated due to a flood event and which aims are fast runoff discharge.(Rácz 2015) Flood problems often originate from the runoff of other districts, therefore local solutions can only rectify the symptoms but not solve the root cause. This reveals the lack of a common platform where goals and experiences can be harmonised and shared. FCSM is generally responsible just for the maintenance of watercourses, channels, the sewage system, and sampling the water quality of the CSOs. Quality monitoring of water bodies is conducted by the local Directorate of Water Management with an unsatisfactory regularity and sampling density.

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[28] Recently, private companies of big development projects have on occasion adopted the costs for construction and maintenance of the stormwater drainage system. Therefore these projects are like small subsystems and do not appear in the registry of the FCSM.(Oszoly 2015)

Maintainance of ditches along streets is the responsibility of the street maintainer: the Budapest Public Road Nonprofit Ltd. (Budapest Közút Zrt., (BK)) or the district municipalities.

The lack of financial resources is also a common hurdle for the development of green areas. Due to the high dependency on currently available EU funds, long-term planning and self-funded projects have decayed for public green areas and open space development. While the city-owned company for green area maintenance, Főkert Zrt. can still finance some development and research projects alongside general maintenance tasks, the districts' maintenance companies can barely accomplish the most essential works. Low budget for maintenance often leads to rapid degradation of the green infrastucture. Nevertheless, there are some good counter examples. District XIII considers green area development as the most important element of its image. Its green strategy has been founded and upheld since 2012. District XVI – due to its earlier severe flooding problems – is the only district with a rainwater management strategy. (Csizmadia 2018)

TABLE 12: STAKEHOLDERS OF THE ANALYSED LAND USE TYPES OF BUDAPEST

| | | Owner | Developer | Maintainer |
|---|---|---|---|---|
| Blue infrastructure | Combined sewage system | FCSM[1] | FCSM | FCSM |
| | Separated rainwater drainage | FCSM | FCSM | FCSM |
| | | City | | |
| | | District municipalities | District municipalities | District municipalities |
| | Opened ditches | City | BK[2] | BK |
| | | District municipalities | District municipalities | Contracted private company<br>Municipality owned company<br>Private house owners |
| | Recipients (rivers) | City municipality | City municipality<br>District municipalities | FCSM<br>DWM[3] (quality monitoring) |
| | | Districts | Municipality department<br>Municipality owned company | Municipality department<br>Municipality owned company<br>Contracted private company |
| Green areas & open space | Parks and squares | City | Főkert Zrt.[3] | Főkert Zrt. |
| | | Districts | Municipality department<br>Municipality owned company | Municipality department<br>Municipality owned company<br>Contracted private company |
| | Private gardens | Private house owners | Private house owners | Private house owners |
| | Roads and parking lots | City | BK | FKF[4] |
| | | Districts | Private building companies | FKF |
| | | Private companies (e.g. supermarkets) | Private companies | Private companies |
| Housing areas | Residential areas | Private owners (renting or own use) | City or district municipality (housing estates) | City or district municipality (telepszerű housing) |
| | | | Investor companies | Private owners |
| | | | Private owners | Private owners |
| | | City or district municipality | City or district municipality | Municipality and renters |
| | Commercial areas | Investor companies (renting) | Investor companies | Investor companies |
| | Brownfields | Private companies (own use) | Private companies | Private companies |

| | | | | |
|---|---|---|---|---|
| | | State (e.g. MÁV)[5] | State (e.g. MÁV) | State (e.g. MÁV) |

[1] Budapest Sewage Works Pte Ltd. (Fővárosi Csatornázási Művek)
[2] Hungarian Public Road Nonprofit Ltd. (Budapesti Közút ZRt.)
[3] Főkert Zrt. City owned green area maintenance and development company
[4] Budapest Open Space Maintenance Works (Fővárosi Közterület Fenntartó)
[5] Hungarian Railway Company (MÁV Magyar Államvasutak Zrt.)

The increased demand for residental buildings within the last decade was fulfilled by the development of dense housing estates. Because builders are investor companies and not the subsequent owners of the flats, they are primarily interested in maximising profit and less concerned about sustainability and livability of the urban environment. This fact and the weak governmental control have already been revealed by missed opportunities for green area development.(Kanczlerné Veréb Mária 2012 p. 31)

### 4.3.2 Present regulatory framework

The regulatory framework will be reviewed based on the related laws and standards and interviews with the Law Department of the General Directorate of Water Management. Four different viewpoints will be summarized: responsibilities; groundwater protection; water cleansing and building law; and existing standards of the rainwater management.

Responsibilities are mentioned in two important national laws. Exlusion to private plots, municipalities are responsible for the management of urban rainwater. **Act LVII of 1995 on Water Management** defines the public duties for local governments. *Rainwater management, local water management, flood prevention and inland water drainage* are defined as municipal public duty, but not mandatory public duty (Országgyűlés 1995 p. 4§(1)), therefore deficient service does not implicate penalties. Minimal service requirements are also not clarified by the regulations. **Act CLXXXIX of 2011 on Hungary's local governments** also mentions *water management and flood prevention* as duties and powers of local governments without further detailing or consequences. (13 § (11)) Rainwater drainage is also not considered officially as public works, which means that it does not have a dedicated budget. Despite the European Water Framework discipline, Hungarians pay less for water infrastructure as its real costs(Belényesi 2018 p. 165) and there is no separate rainwater management fee. The wastewater and rainwater management sectors are underfinanced and can focus just on the short-time prevention of the most threathening floodings.

**Government decree of 219/2004 (VII 21) on the protection of groundwater** directs an approval process for all new facilities that may cause pollutants to enter the groundwater. All activities that endanger the groundwater by any quantity of contaminants are basically prohibited. An exception can be "*surface water for mitigating the effects of floods, inland waterways and droughts, and for management of water and waterways"*(§10 (2 d.)), if the water authority assures the existence of an effective groundwater quality monitoring.(§10 (5)) Nevertheless, constant monitoring of groundwater quality for all BGI tools would not be possible, therefore the existing regulation is not suitable for large-scale implementation of BGI tools.

From the viewpoint of the water treatment, urban rainwater in Hungary is categorised as wastewater (similarly to Germany) and rainwater management elements are considered as water facilities that require approval. The quality limit values are defined by **KvVM decree of 28/2004 (XII 25.) on the limit values for emissions of water pollutants and certain rules for their application**.[29] In practise, infiltration surfaces and swales that collect water from roofs and green areas can be built without permission – however this distinction is not clarified in the regulations. The authorisation procedure is accomplished by the responsible local Directorate in Water Management.[30] If the area is particulary sensitive for groundwater pollution (e.g. karst area, drinking water base, nature reserve, or close to a natural water body), a professional commitment from the Directorate in Water Management or from the maintainer of the water resource is required.[31]

**Government decree of 253/1997 (XII 20) on the National Settlement Planning and Construction Requirements (OTÉK)** states that a building can only be positioned on a plot or construction site where the connection to the wastewater and rainwater system is provided or the on-site water management can be ensured without harm to the natural surroundings. (§33 (1 c.)). Only if the centralised sewage system or rainwater drainage is not accessible, rainwater should be kept inside the plot. Therefore, the rainwater drainage system is preferred compared to on-site infiltration. As the law defines, rainwater can be infiltrated within the plot, if the neighbouring plot is not endangered, and the buildings' stability and use is not impaired. (§47 (9)) In the expired **decree of 47/1998 (X 15.) on City-planning and Building Framework of Budapest (BVKSZ)** customised and detailed the regulations of the OTÉK to the urban environment of Budapest. The decree was overruled in 2015 and since then it has had no operative version. The last valid version didn't contain aspects or special regulations about rainwater management.

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[29] The process is called "conceptual water licensing procedure" (***elvi vízjogi engedélyezési eljárás***)

[30] The process is described in 41/2017 (XII 29) BM

[31] Types of sensitive and particularly sensitive areas are listed in 219/2004 (VII 21) Government Decree.

The establishment of standards for water management in Hungary lags significantly compared to Western Europe. The last published Hungarian standards concerning urban rainwater were the **MI 10-455-1:1988 (Urban water regulation: general criteria)**, the **MI 10-455-2:1988 (Urban water regulation: water drainage system)** and **MSZ-04-134-1991** that defined surface runoff coefficients and rainfall intensities based on older rainfall data sets, which do not consider the effects of climate change. (VM Környezetügyekért Felelős Államtitkárságának Vízügyért Felelős Helyettes Államtitkársága 2013 p. 30)). All of them were annulled in former decades. The European **MSZ EN 12056-3:2001** and **MSZ EN 752** for dimensioning roof drainage and urban drainage systems have not been implemented in Hungary yet.

As the dimensioning and performance criteria of blue-green infrastructure elements are not defined in standards yet, their approval is accomplished on an individual basis, which is carried out by the FCSM and the Directorate for Water Management. The FCSM is responsible for the inspection of discharge into the sewage system (including the maximum discharge rate) while the DWM audits the impact on the recipient's water quality.("Interview with the Law Department of the General Directorate of Water Management" 2017)

### 4.3.3 Rainwater management in the urban planning

The approach for a more sustainable rainwater management appears in several important urban planning documents. Figure 23 shows the environmental and urban planning hierarchy related to RWM on state, city and district levels. **The National Water Strategy** underpins that water management should be based on catchment areas. Water reuse, infiltration, retention and detention should be the preferred approaches in the future. Private and public water retention investments must be supported by subvention programs. To reach these goals, related laws and standards should be revised.(Országos Vízügyi Felügyelőség 2017)

There is no specific plan for water management in Budapest, however the topic is mentioned in parts of the urban planning documents. **The Budapest 2030 Long-Term Urban Development Concept** adopts the approach of the National Water Strategy and extends it with two further goals: 1. the introduction of the rainwater management fee with discounts for the application of water retention systems; and 2. public information about a conscious water management approach.(Budapest Municipality Mayor's Office Urban Construction Department 2030 p. 118) On behalf of preventing flash floods, intermediate reservoirs and lakes are proposed for retaining precipitation. Mitigation measures against urban heat island effect contain several blue-green tools, which are specifically: increasing the proportion of green areas, green roofs and green facades; the application of water surfaces in public areas; implementing permeable pavers; and prevention of further building development in green areas.(Budapest Municipality Mayor’s Office Urban Construction Department 2030 p. 124)

Thematic development programs were created for further detailing of some important topics, two of them are water management related. The **Harmonised Development Concept of the Danube-side Areas** was established to harmonise the European Union funded development projects on the

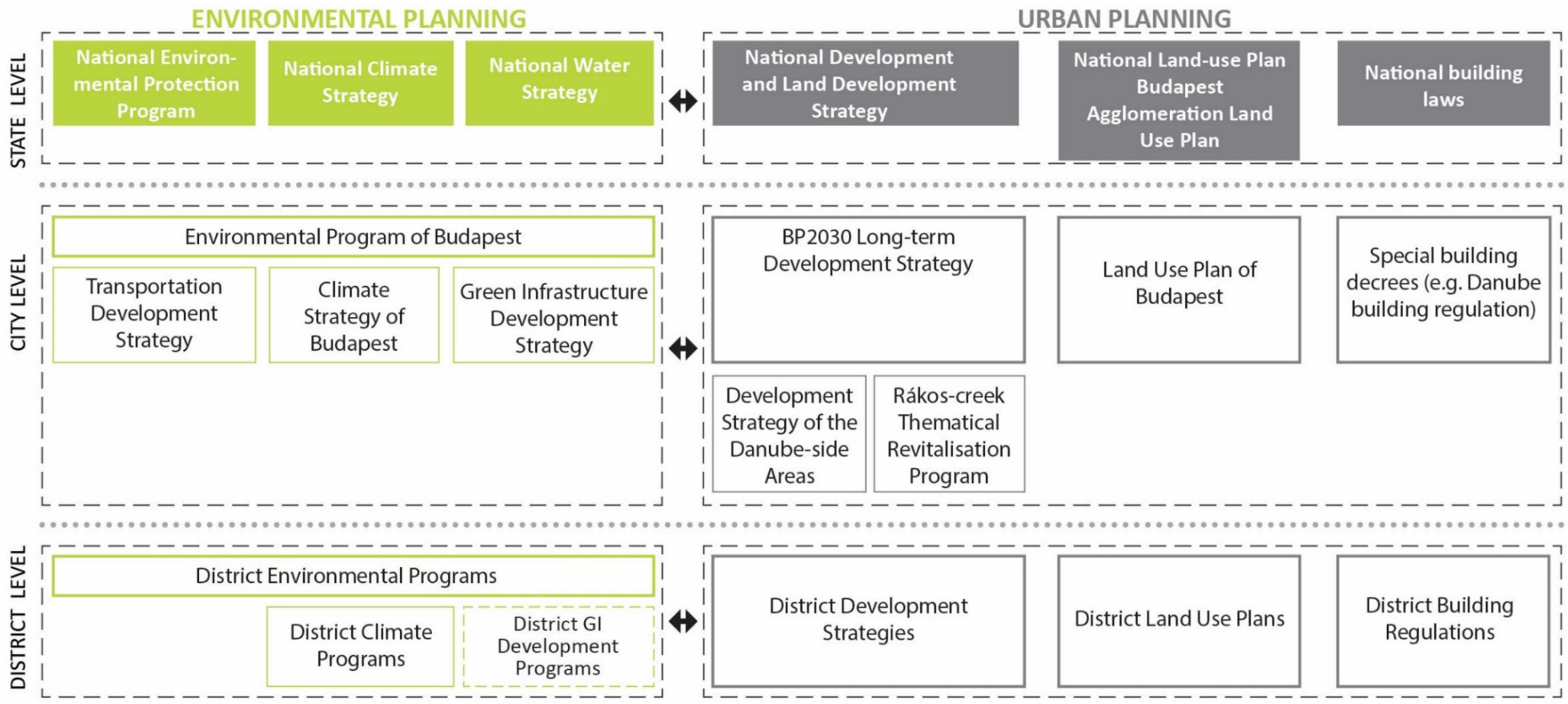

FIGURE 23: PLANNING HIERARCHY OF THE URBAN AND ENVIRONMENTAL PLANNING
(Source: Own work, based on (Tatai et al., 2018, p. 11)

Danube riverside. Therefore, the analysis and concept focus mainly on recreational and touristic potential of the riverside development areas and establishment of the required institutional system. The **Rákos-creek Thematical Revitalisation Program** has more specified water-management related actions. The program analyses the creek's properties and environment and presents an advanced recommendation for its revitalisation. The extension of the flood zone and different bioengineering solutions are advised for the creek sections depending on their character. It also suggests the establishment of retention lakes – unfortunately the biological cleansing of the combined sewage and rainwater drainage outlets – are not integrated into the concept.

**The Environmental Program of Budapest** is an umbrella program for all environment related topics, such as greeen infrastructure development, nature and soil protection, noise pollution, waste management, water management, and climate change adaptation and mitigation. The program discusses water supply, wastewater and stormwater management, and flood protection are treated separately from one another. The program requests the creation of strategic documents for detailed and coordinated actions in particular topics, such as a Climate Adaptation Strategy and a Sustainable Energy Strategy. For water management, the creation of a "rolling development plan" is suggested, which would help to track and synchronise the planning, development and maintenance for the water infrastructure. This plan would nevertheless only serve the existing system and would not enhance a sustainable and integrated water management approach.(Tatai et al. 2017)

The mentioned **Climate Adaptation Strategy of Budapest** defines flood protection and heat mitigation as strategic goals. The need for a new rainwater management approach is mentioned, but there is no specific action and budget which target the development of on-site rainwater management.

**Budapest's Regional Development Concept** assigns the spatial demand to achieve the goals of the development concept. This plan hardly mentions the development of blue-green infrastructure. The establishment of four new city parks is advised, primarly for recreational needs. The space demand for water management is not discussed in the document.

This overall urban concept is executed by the **Land Use Plan of Budapest**, which sets the main characterictics of open spaces and housing areas such as building height, density, functions and restictions. The plan specifies several creek and rainwater ditch sections for renovation, but the suggested methods barely contain the principles of SURM. The land use categories related to water management (introduced in Chapter 4.2.2) are restricted to water bodies and their direct surrounding and orders firm limitations on their use.(Ute, András 2017 pp. 60–61) Thus, existing land use categories do not facilitate the integration of rainwater management with other land use types, e.g. water retention zones in residential areas.

Due to the two-level regulatory system, district municipalities also create their own, more detailed **District Development Strategies** and **District Land Use Plans**, which are harmonised with the city and state level policies. The required bi-directional, vertical communication (top down and bottom up governance) between the city and district municipalities, and horizontal connections among the districts are often missing. These problems also appear in water management. Neither Budapest, nor the districts (except for District XVI) have specialists with the required knowledge to work on rainwater management concepts.

## 4.4 Summary of the rainwater management review of Budapest

Budapest is endangered by pluvial, fluvial floods and heat waves, and must confront the worsening of these phenomena due to climate change. The city has very diverse geophysical features and urban texture. A large part of the city was built on sand and gravel soils, but high groundwater level and clay soils can occasionally limit the use of infiltration. The wastewater system struggles from overloading during heavy rains due to the high sealed area ratio, and illegal rainwater connections in the suburban zone. Thus, **the use of sustainable rainwater management has a relevance in the city**. The analysis also showed hurdles in access to planning data: numerous required **data sources are outdated, have a low quality, are not publicly accessible or do not exist yet**, which limit the possibilities of creating a rainwater management strategy.

The analysis of the city's **land use** showed that the examined **categories** describe such homogenous urban areas, which are **suitable for the investigation of rainwater management**. The analysis of non-built-up land use categories underpinned that the high average green area ratio is associated with an uneven distribution; green areas are missing especially in the city core and along watercourses. In the built-up land use categories, some residential areas possess a high green area ratio, which can support simple BGI tool implementation. Brownfields have potential for establishing new green areas with large retention capacity.

Summarizing the present institutional and regulational system, we can state that **Budapest does not have a coherent, long-term rainwater management vision**. The stakeholder analysis showed that: **missing knowledge and interest** in long-term visions**; lack of communication;**

**complicated ownership rights; unclarified responsibilities;** and **under-financing of the blue and green infrastructure development and maintenance;** are common deficiencies of Budapest's current institutional system. The investigation of the regulatory system revealed that the financial problems and unclarified responsibilities are anchored already in the national regulations – or rather the lack of regulation. **Outdated and missing standards** of rainwater management encumber the large-scale implementation of BGI tools.

Rainwater management plays a marginal role in the development and land use plans of the city, and SURM is confined merely on the review of the basic principles. These principles **do not reach the planning and implementation** level due to the lack of comprehensive analyses such as flood simulation or groundwater level mapping of the city.

# 5 Investigation of the applicability and effects of sustainable rainwater management in Budapest

The review of the current rainwater management in Budapest proved that there is a definite potential and need for a new RWM approach, but no research has been undertaken yet to lay out the basis for a city-scale strategy. For this reason, this chapter introduces an assessment of SURM applicability and implementation effects based on an own methodology, which analyses the city on two different scales of intervention. The first part focuses on the overall urban texture and examines the applicability of the three main BGI methods (infiltration, retention and evaporation). The second part of the analysis appraises the performance of the BGI tools in a specific study area.

## 5.1 Large-scale spatial assessment for the applicability of the SURM methods

Applicability of the three BGI methods (**infiltration, retention** and **evaporation**) was investigated in relation to the geophysical and urban environmental factors. The research methodology was introduced in Chapter 1.3 and summarised in Figure 24. A prioritisation of the method application was used in areas, where local conditions require the use of the method (e.g. flood danger facilitates the development of retention) or the category has favourable properties for BGI development.

The SURM methods will be introduced in the following order: 1. Infiltration; 2. Retention; 3. Evaporation. Properties of the urban environment will be investigated in the same order as they were introduced in Chapter 4. The assessment table for the applicability of the methods can be found in Annex 10.4. The **restrictive and prioritising value** is shown in the table by colors. The **drivers of the decisions** for the method prohibition and priorisation are explained by four restriction and six prioritistion drivers, shown with different symbols. Conclusions will be analysed at the end of Chapter 5.1, extended by a review of the limitations of this study and recommendations for further research.

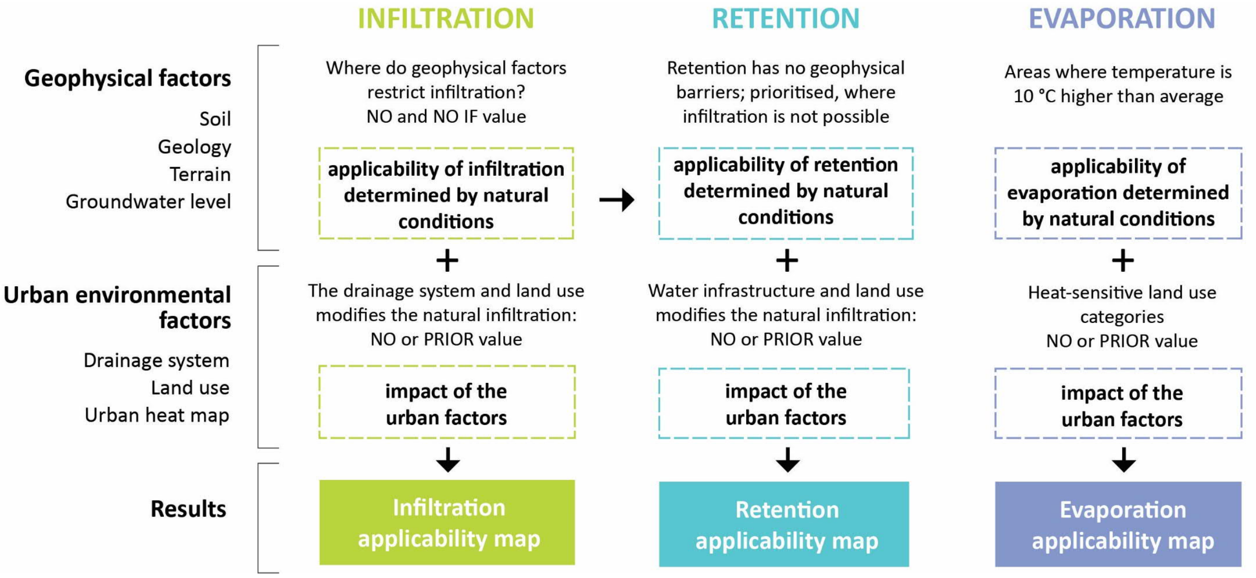

FIGURE 24: ESTABLISHMENT OF THE SPATIAL ANALYSIS METHOD

## 5.1.1 Assessment on the applicability of infiltration

As stated in Chapter 2.2, infiltration is the prioritised SURM method in Hungary's climate zone. The applicability of this method is influenced by geophysical features such as soil type, groundwater level and gradient. These define the **natural infiltration applicability** in the city area (Map 1, Annex 10.5). The impacts of urban environmental factors (rainwater infrastructure, land use and the urban heat map) are summarised in Map 2, Annex 10.5. Overlaying these maps produces the infiltration applicability map (Map 3, Annex 10.5), which shows the areas, where the use of infiltration tools either could be applied, or are insisted.

### 5.1.1.1 Evaluation of the applicability and prioritisation in the spatial categories

#### Applicability of infiltration based on natural conditions

Sufficient soil permeability and groundwater quality protection are the two key criteria to determine infiltration. Based on the German DWA A-138 standard, soils with **permeability $k_f<1\times10^{-6}$m/s** were not advised for the use of infiltration tools.(DWA 2005 p. 15)[32] Infiltration is not advised in areas with rocks that convey rainwater directly into the groundwater layer, such as **karst and limestone**.

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[32] Soils with more than $1\times10^{-3}$ m/s permeability value are also not ideal for infiltration due to the inadequate cleansing performance, but this deficit can be rectified with a special soil mixture in the top infiltration layer.

Based on the standard, the highest groundwater level must be at least 1m below the deepest point of the infiltration tool. Considering this and the categories of the groundwater map, areas with **groundwater level** higher than **-2.5m** were defined as not suitable for infiltration.

Gradient has a high impact on the effectivity of infiltration. As mentioned in Chapter 2.3, infiltration tools demand a flat and relatively large area for efficient performance. For this reason, infiltration was not advised for a surface **gradient greater than 15%**.

### Urban environmental factors

The urban environment was analysed and specified by prioritising or prohibition in the summary map of urban environmental modifiers Map 2, Annex 10.5. The dark green color shows the areas of insisted and white showes the prohibited method application. In the light green areas, the urban environment has no modifying effect and the value of natural infiltration applicability will be conserved.

Areas with a separate sewerage but **without rainwater drainage** are sensitive for extreme rain events, therefore rainwater infiltration should be insisted. As described in Chapter 4.2.1, existing drainwater drainage pipes only serve the drainage of street surfaces but not private plots; thus, infiltration is also a insisted method in **areas with existing separated rainwater drainage**. Since **water bodies** are already retention areas they were subtracted from the applicable areas. Considering protection of water quality, **water supplying areas** were excluded from the selection. Several **green areas** already have a satisfactory infiltration performance (forests, natural areas) or their infiltration capacity cannot be further improved due to conflicts of usage (agricultural areas and special green areas such as cemeteries). In these areas, additional infiltration tools are not advised. Parks and other recreational areas present a high potential for infiltration and were defined as insisted infiltration zones. Due to the lack of precise traffic load data, road pollution was estimated from the land use category. **Motorways** and most **primary roads** have a constant volume of high traffic, therefore direct infiltration is not advised.

As mentioned earlier, **historic buildings** are sensitive to fluctuating groundwater levels, thus infiltration is not advised in the land use categories Vt-V and Ln-1. **Housing estates** (Ln-3, Ln-T, Lk-T) have a high green area ratio and relatively large plot sizes allowing the implementation of complex SURM concepts, therefore these categories receive prioritisation. Infiltration is not advised in **storage and energy production areas** due to the risk of groundwater pollution.

#### 5.1.1.2 Results: infiltration applicability

The infiltration applicability map is visualised in Map 3, Annex 10.5. By overlaying the maps of natural infiltration applicability and the impacts of urban environmental factors, the size of the infiltration applicability area was significantly decreased. Considering the area ratio suitable for infiltration, the transition zone of Budapest is most appropriate for the use of infiltration tools: almost all areas were suitable for infiltration except for the creekside areas and the traffic surfaces (such as the Ferencváros Switching Yard Station). This zone also includes several large green areas that can serve as a water storage buffer for their surrounding environment. Insisted infiltration areas are mainly found in the following three area types:

1. Low-density suburbs of the suburban zones without a rainwater drainage system
2. The urban tissue around the historic city core
3. Brownfield areas in the transition zone and along the Danube, mainly in South Buda and the Csepel island.

FIGURE 25: LOCATION OF THE INSISTED INFILTRATION AREAS

### 5.1.1 Assessment on the applicability of retention

The retention applicability determined by the natural factors, impacts of the urban environmental factors and the applicability map are shown in Maps 4-6, Annex 10.5.

#### 5.1.1.1 Evaluation of the applicability and prioritisation in the spatial categories

##### Natural retention applicability

Retention is not influenced by geophysical factors, water harvesting areas could be established theoretically anywhere. Additionally, areas which are **unsuitable for infiltration** due to their geophysical features were defined as insisted retention zones.

#### Urban environmental factors

**Areas with a separated wastewater system (with or without rainwater drainage)** are prioritiesd for retention in order to decrease peak flow and the likelihood of pluvial flooding and flash floods. **Water management** areas and **natural or agricultural areas** are not advised for retention tools due to their already high retention capacity or conflict of usage.

Categories with **large plot size and a high unsealed area ratio** (parks, recreational areas and housing estates) present a high potential for large surface retention, collecting rainwater from the surrounding sealed surfaces and roofs to maximise the recreational and aesthetic benefits of water. For the same reason, **brownfields** also become insisted application areas. Lastly, the **very high sealed area ratio** (greater than 80%) does not permit the efficient use of infiltration and loads the sewage system with a large and fast runoff. Therefore, retention is insisted in the categories Gksz-1 and Gksz-2 and in the historical city core, Vt-V and Ln-1. The summary map of urban environmental modifiers is shown in Map 5, Annex 10.5.

### 5.1.1.2 Results: retention applicability

As shown in the retention applicability map in Map 6, Annex 10.5, the lack of geophysical restrictions results, a much larger area is applicable for retention than for infiltration. The application of retention is insisted mainly in:

1. the hill zone of Buda due to steep slopes and sensitive soil layers
2. floodplains of the creeks
3. the historic city core
4. low-density suburbs without rainwater drainage system.

FIGURE 26: LOCATION OF THE INSISTED RETENTION AREAS

### 5.1.1 Assessment on the applicability of evaporation

Evaporation does not play a significant role in decreasing the runoff from single rain events, but its implementation is important in areas where the urban heat isand effect has a high impact on human health and wellbeing. Results of the applicability assessment for evaporation are illustrated in Maps 7-9 of Annex 10.5.

#### 5.1.1.1 Evaluation of the applicability and prioritisation in the spatial categories

##### Geophysical factors

The heat map of Budapest captured on 31st August 2016 was used to identify the areas with the need for an increase of evaporation. Areas with a ground surface temperature at least 10°C higher than current air temperature were considered as the most impacted by the urban heat island effect. The heating effect of dense urban areas (with the main poles at the centres of Óbuda, Újpest, and the historic city centre) and large industrial zones (e.g. Csepel-West or the Ferencváros train station and industrial zone) can be clearly identified. The significant heating effect of the airport on the Eastern border of the city is also remarkable.

##### Urban environmental factors

Evaporation tools have the highest benefits in areas where they can directly impact the health and wellbeing of the inhabitants. Therefore, the method will be insisted in **residential areas**. Insisted application areas of the urban environmental modifiers are summarised in Map 8, Annex 10.5.

#### 5.1.1.2 Results: evaporation applicability

Evaporation has the smallest applicatibility area of the three methods. Three main area types can be identified as target zones of evaporation tools:

**1. large industrial and transportation areas with a high sealed area ratio**: Evaporation is not insisted in these areas due to their lower sensitivity for heat waves, but their impact can remotely influence other areas, as it can be seen in point 3.

**2. the city centre inside the Nagykörút and the centre of Újpest** are dense residental areas that are most affected by the heat island effect and gained therefore an insisted method application.

**3. residential areas neighboured by large industrial areas**: Several residental areas have a sufficient green area ratio but are impacted by the warming effect of the neighbouring large sealed surfaces. Pestszenterzsébet is a good example: the low-density suburbs south of the Ferencváros industrial zone are highly affected by urban heat island effect – the thin forest buffer along the

Határ street is visibly not sufficient enough to protect the area from the heating effect of the industrial zone. While the József Attila housing estate on the Eastern side of the industrial park is more protected by the shade from its higher buildings and mature vegetation. (Figure 27)[33]

FIGURE 27: EVAPORATION APPLICABILITY MAP. EXAMPLES OF THE HEATING EFFECT IMPACT FROM INDUSTRIAL AREAS

### 5.1.2 Discussion and conclusions of the large-scale applicability assessment

The applicability maps of the three methods were overlayed in order to analyse the overall applicability of the three SURM methods, shown in Figure 28. Insisted application was also included in the areas. The applicability of the SURM methods in each urban development zones are estimated from the map and visualised in the radar charts of Figure 29. The axes symbolise the three methods (infiltration, retention, evaporation). Values of the charts represent the typical characters of the zones on a scale of 0 to 3, where: Origin = no; 1st circle = applicable; 2nd circle = mixed applicable and insisted application; 3rd circle = mainly areas with insisted application.

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[33] The height and position of prefabricated buildings may block the motion of hot air and provide a larger ratio of shaded surface.

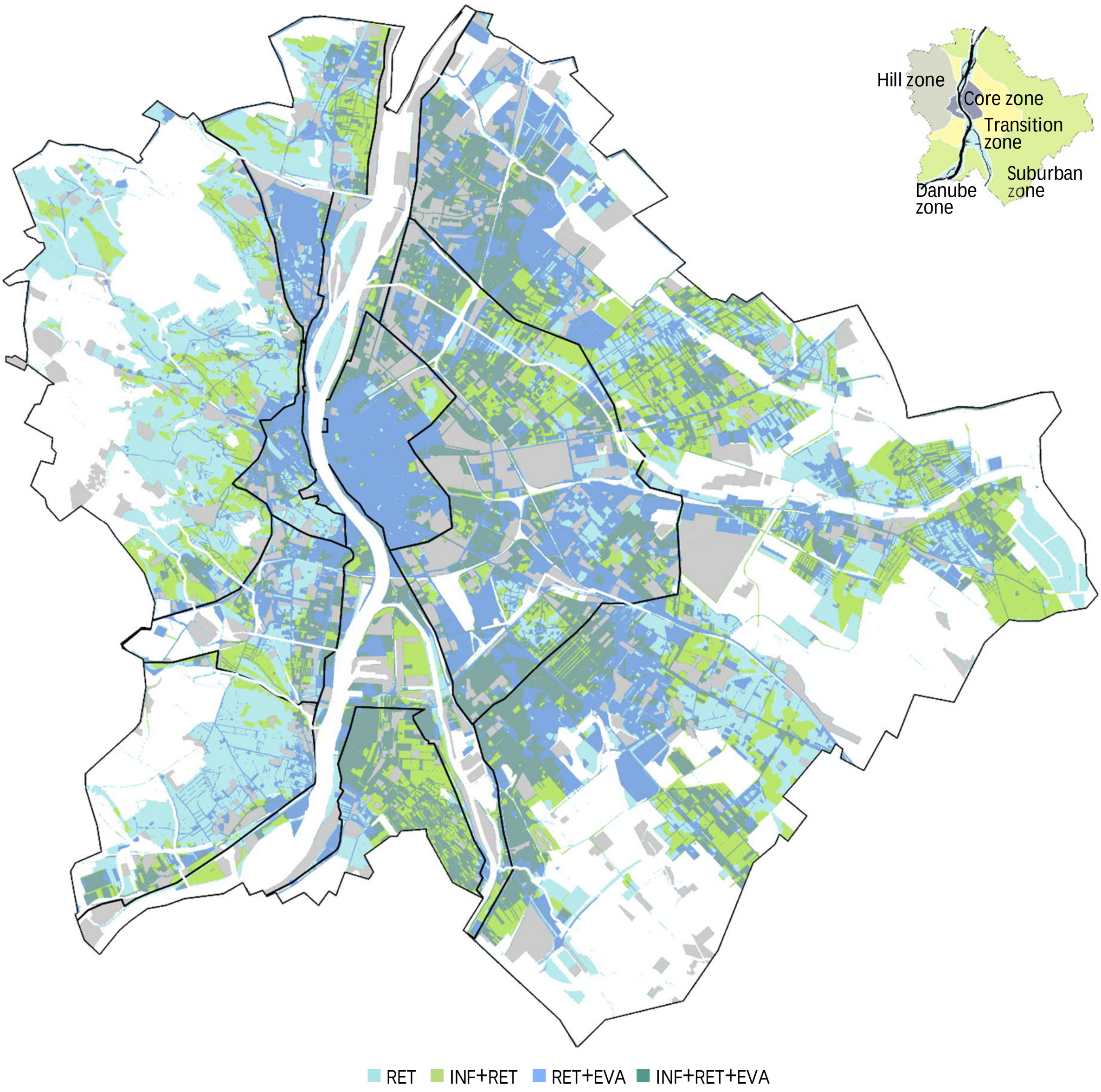
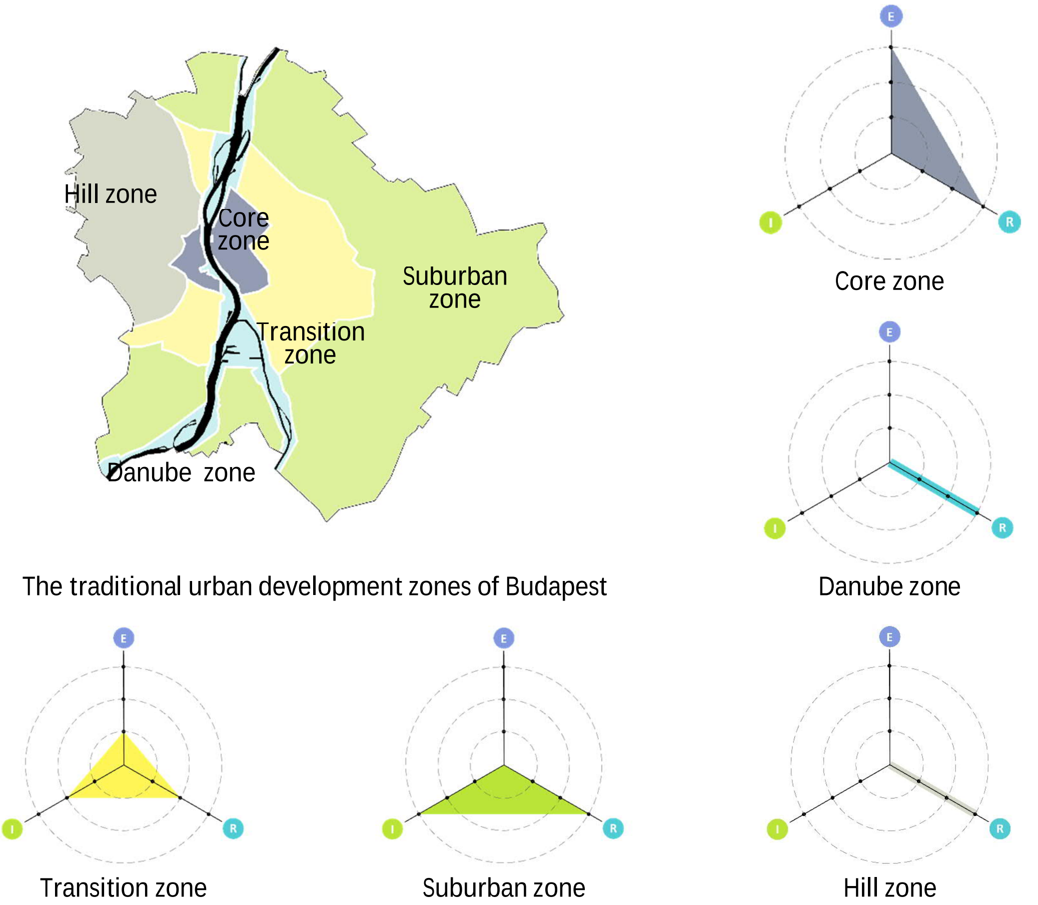


FIGURE 28: OVERLAPPING THE AREAS WHERE SURM METHODS ARE APPLICABLE

The radar charts show that **the classical urban development zones of Budapest** (core zone, Danube zone, transition zone, hill zone and suburban zone) **possess different characteristics in SURM**. The broadest range of BGI tools can be applied in the transition zone, which is suitable for all three methods. Two insisted methods are frequent in the dense core zone, (insisted retention and evaporation) and in the suburban zone (insisted infiltration and retention). The Danube and the hill zone are mostly suitable for using retention tools. In these two zones infiltration is often not applicable, and the existing evaporation rate is satisfactory.



The traditional urban development zones of Budapest

Core zone

Danube zone

Transition zone

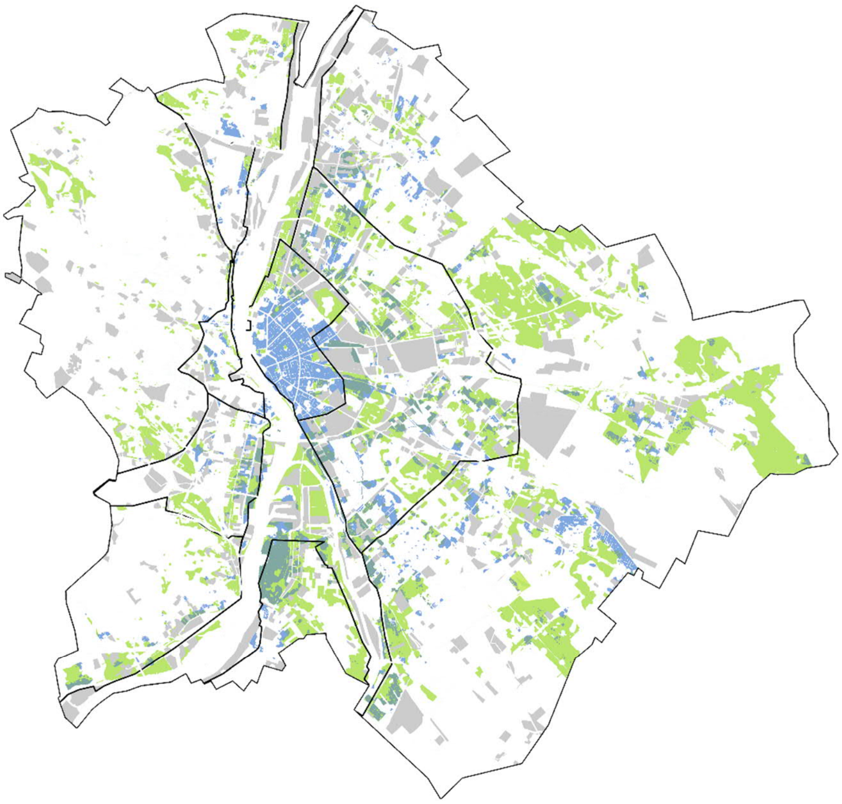
Suburban zone

Hill zone

FIGURE 29: APPLICABILITY OF THE METHODS IN THE FIVE URBAN DEVELOPMENT ZONES OF BUDAPEST (based on the urban planning zoning of (Budapest Municipality Mayor's Office Urban Construction Department 2030))

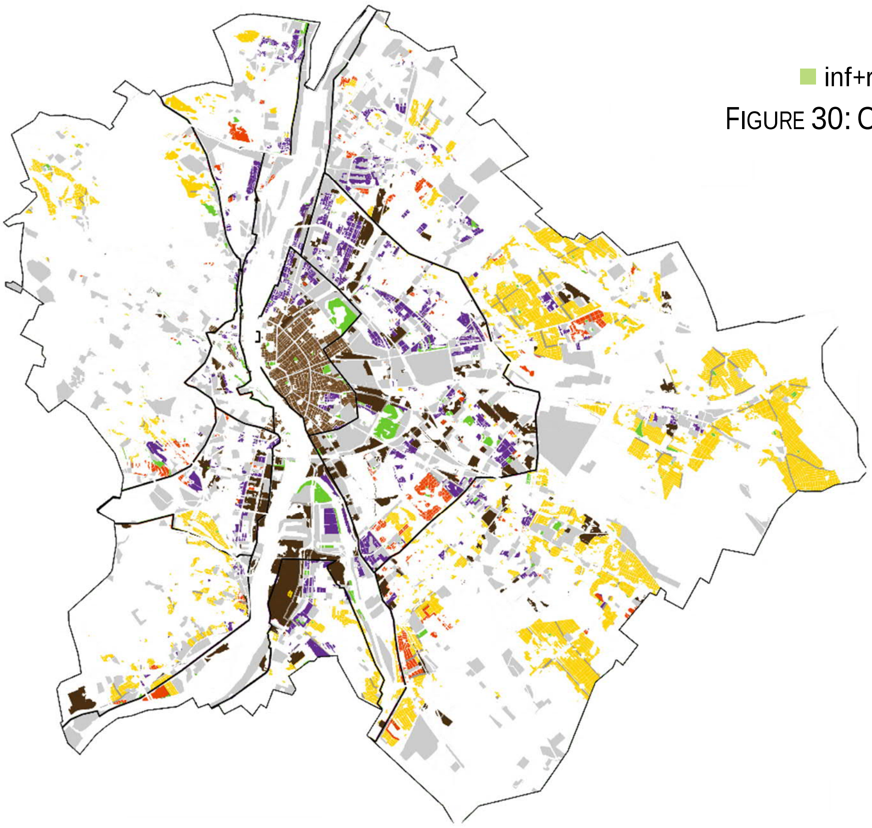
As introduced in Chapter 2.4, a combination of methods can increase the effectivity of BGI projects. The insisted application areas of infiltration, retention and evaporation were overlayed to identify areas with facilitated BGI development and a possibility to establish synergies between several methods. Figure 30 shows the areas with at least two overlapping insisted methods and Figure 31 reveals their land use. The following area types were found to characterise the overlapping insisted areas:

a. **Low-density suburbs in the suburban zone**, characterised by insisted retention and infiltration
b. **Brownfields and housing estates** of the transition zone with insisted infiltration and retention.
c. **Dense historic development of the core** zone with insisted retention and evaporation.



🟩 inf+ret 🟦 ret+eva ■ inf+ret+eva

FIGURE 30: OVERLAPPING PRIORITY AREAS OF AT LEAST TWO METHODS



🟩 parks ■ brownfields 🟫 dense historic housing 🟪 housing estates with framed or free-standing structure 🟧 small-townish housing 🟨 Low-density suburbs

FIGURE 31: LAND USE CATEGORIES OF THE OVERLAPPING INSISTED METHOD AREAS

Table 13 shows the drivers for the method prioritisation in the abovementioned four land use categories, which were defined in Chapter 4.2.2. Some drivers for insisted application are determined from existing deficiencies (e.g. drainage system overload), while others from an advantageuos property for BGI implementation (e.g. large green area ratio). Based on this, drivers were distinguished in the table as **"compulsion" (C)**, or "**incentive" (I)**.

TABLE 13: PROPERTIES OF THE FILTERED LAND USE CATEGORIES

| | Insisted methods | Drivers | Potential developer |
|---|---|---|---|
| Low-density suburbs | Infiltration + Retention | drainage system overload (C)<br>high green area ratio (I) | Private owners |
| Brownfields | Infiltration + Retention | large (potential) green areas (I)<br>high (potential) green area ratio (I) | Various public and private owners, (future) real estate investors |
| Housing estates | Infiltration + Retention | large green areas (I)<br>high green area ratio (I)<br>municipal ownership (I) | Mostly municipal ownership |
| Historic housing | Evaporation + Retention | high sealed area ratio (C)<br>Urban heat island effect (C) | Municipality (open spaces) and private owners (courtyards) |

The use of SURM in the historic housing areas is advised due to deficiencies, and there are no incentives to facilitate its implementation, which may therefore be challenging. In contrast, housing estates and brownfields in the transition zone only feature incentives for SURM. Due to this and the layout of the centralised sewage system, **the transition zone can play an important role in the peak flow reduction of the core zone**. The last coloumn of the table presents the possible BGI developers for the four categories based on Chapter 4.3.1. Considering these, **1. the preventional land use regulation of the brownfields; 2. the BGI integration into public large-scale open space development projects;** and **3. the involvement and encouragement of private owners (detached house owners and housing communities of the historic housing); are the most effective measures for SURM implementation.**

The methodology of this research is based on the existence of a clearly categorised and well-maintained land use regulation. Nevertheless, a few inconsequences were identified, which occasionally limited the opportunities of the analysis. For example, contemporary housing estates are often built in land use categories that were designated for other uses, such as institutional areas. Therefore, this category could not be deeply investigated in this research despite its high importance in rainwater management. Further researches are needed to renew, refine and extend the outdated and imperfect data sources, which could result in a more precise outcome and possible further findings. Research and digitalisation are needed to establish a unified database for green areas, digital maps of the sewage system and street network, updating the rainfall datasets and integration of climate simulations. The collection and linkage of these data sources in a GIS database could provide many opportunities for further research.

The methodology in Chapter 5.1 is applicable for the analysis of the “status quo”, but it is not suitable for the suggestion of land use changes. The combination with other research fields could resolve this limitation. Runoff simulations and flood risk analyses can be used to localise the important intervention areas, as was shown in the Copenhagen case study. The determination of flow paths is particularly important in Buda, where the terrain is very diverse, and the high runoff speed creates an increased risk of erosion and damage. A combined risk analysis with the geophysical features and land use analysis could provide a solid research base for a future urban rainwater concept.

## 5.2 Small-scale assessment of the BGI effects on the urban runoff and water balance

The second part of the assessment appraises the effects of BGI implementation in an exact study area. The large-scale investigation in Chapter 5.1 proved that housing estates and brownfields are a prominently valuable for rainwater management. Considering this, a socialist housing estate was chosen for the assessment due to the following reasons: 1. large green areas of socialist housing estates in municipal ownership allow an easy and cost-efficient implementation; 2. due to the high population of the estates, green area development provides large social benefits; 3. universal design principles of the estates enable an easy reuse of the gained experiences in other similar areas; and 4. housing estates were typically constructed with a separated drainage system that collects the roof and street runoff, therefore the decrease of drainage runoff can significantly reduce fash flooding on smaller creeks.

The goal of the small-scale potential assessment is to appraise the effects of BGI implementation on the runoff quantity and local climate. The methodology is detailed in Chapter 1.3 and summarised on the Figure 32.

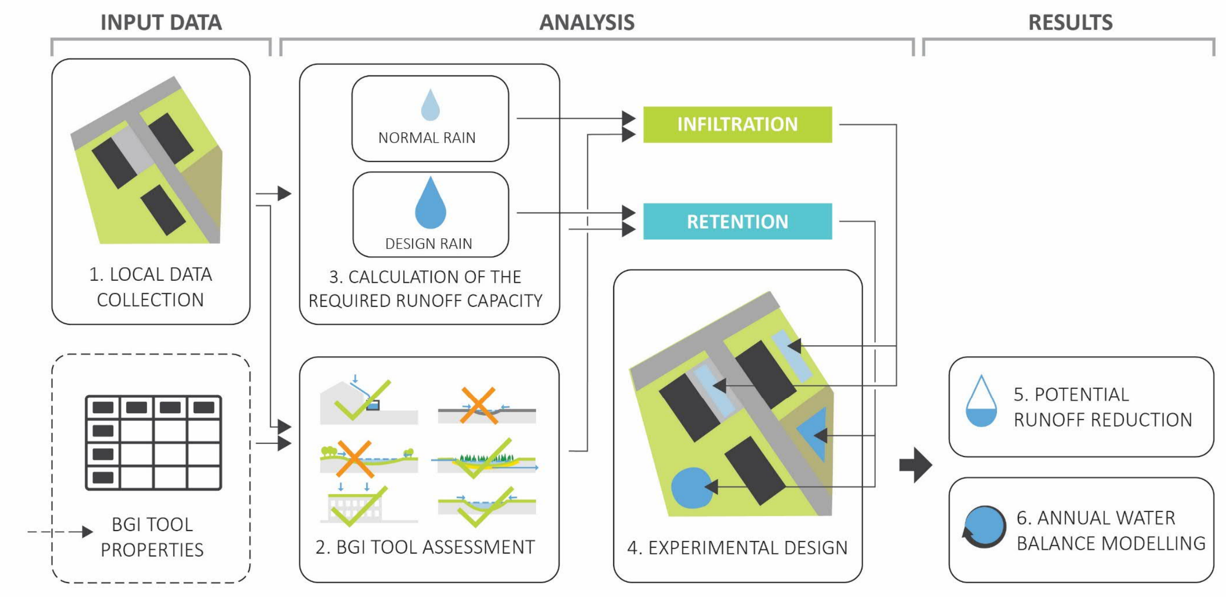


FIGURE 32: METHODOLOGY OF THE RUNOFF REDUCTION ESTIMATION

Őrmező socialist housing estate was chosen for the study, which is a classical example for large housing estates mostly built 1970-1990.(M. Nagy, Zsuzsa 2006 p. 454). Őrmező (Figure 33) was constructed between 1977 and 1983 and located in district XI. Residential buildings, green areas and road infrastructure were designed together with essential social/welfare infrastructure (post, police station, shops, health centre, schools and kindergarden). As schools and kindergardens have a very specific open space use and are usually managed by individual development programs, their plots were omitted from the analysis. The estate was constructed with a separated drainage system, which collects the roof and street runoff into the Sasadi ditch.

FIGURE 33: LOCATION AND SATELLITE PICTURE OF THE ŐRMEZŐ HOUSING ESTATE
(Source: Own work, based on Google Earth)

### 5.2.1 Data collection

Relevant properties for the BGI design will be introduced in five groups of analysis: **soil & terrain**, **surface coverage**, **open space use**, **building**, and the **inherited properties of the BGI methods** from the large-scale analysis. Each topic is presented with a description and summary table (Table 14), and illustrated by analysis maps in Annex 10.6.

#### 5.2.1.1 Soil and terrain

Map 1 of Annex 10.6 shows the terrain and soil types of the housing estate. Based on the soil map of the Budapest Water Works, three different soil types occur in the area:

1. The largest part has “clay, sandy or clay aleurit clay, sand or marl” soil, with an average water permeability $k_f = 1*10^{-6}$ m/s. This permeability is not ideal for infiltration but is still in the acceptable range.
2. A small part of the western side has “sandy loam, loamy sand, sandy gravel” soil, with a permeability factor in the range $10^{-1} > k_f > 10^{-4}$ m/s that allows very fast infiltration.
3. “Mixed urban soil” can be found on the eastern side next to the train station, which usually also enables a fast permeability.

Due to the lack of exact soil information, **$1 \cdot 10^{-6}$ m/s permeability coefficient** as a “worst case scenario” will be assumed for the whole area in the runoff calculation.

The groundwater level is **deeper than 2.5 meters** which makes the area suitable for infiltration. Örmezö has a relatively **flat area** – the average slope is 2% and the surface gradient does not exceed 5% at any point. The slope direction of paved road and parking surfaces follows 3 main scenarios shown in Figure 34. Runoff is led into drainage holes of the drainage system located at the deepest points. Common to all scenarios are the use of high curbs and complete drainage of rainwater so that the runoff cannot reach the neighbouring green areas.

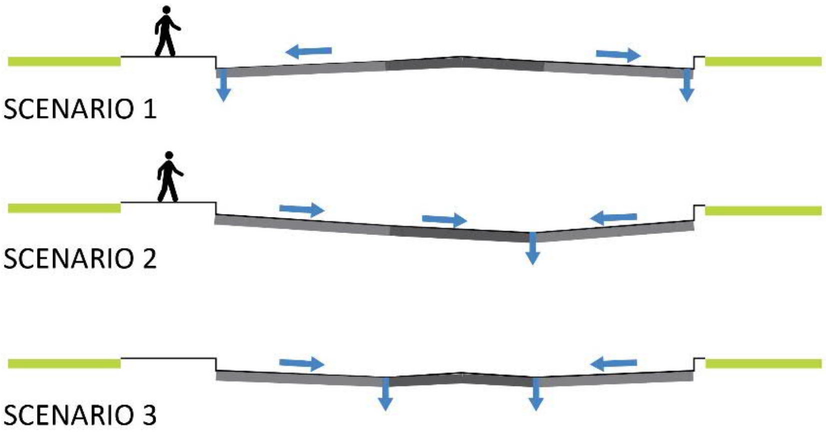


FIGURE 34: TYPICAL ROAD CROSS-SECTIONS

Due to the low gradient, the area is assumed to be flat in the runoff calculation, but slope directions will be considered for the placement of tools in the experimental design.

#### 5.2.1.2 Surface Coverage

The results of the surface analysis are summarized in Table 14 and on Map 2 of Annex 10.6. Seven existing surface types were identified in the area (green area, asphalt or concrete, paving elements, EPDM surface, gravel, pitched roof and flat roof). Breakdown of the subcatchment surface types can be found in Annex 10.8.

TABLE 14: SURFACE COVERAGE ANALYSIS OF THE ÖRMEZÖ HOUSING ESTATE

| Surface type | Area ($m^2$) | Surface ratio (%) |
|---|---|---|
| Green area | 97360 | 45.7 |
| Asphalt or concrete | 77396 | 36.3 |
| Paving elements | 4615 | 2.2 |
| EPDM surface | 2834 | 1.3 |
| Gravel | 1949 | 0.9 |
| Pitched roof | 1455 | 0.7 |
| Flat roof | 27501 | 12.9 |
| Total surface: | 213110$m^2$ | |

The estate has a high (45.7%) green area ratio with valuable trees and several large continuous green areas. This ratio corresponds to the minimum green area ratio criterion of the land use plan for the Ln-T category (35% green area ratio). The most typical sealing material is asphalt, which covers more than a third of the estate, of which 5.5 ha is occupied by asphalt roads and parking lots. The roof area (consisting predominantly of flat roofs) is also significant and covers 13.6% of the total area. The proportion of permeable pavers (gravel and concrete paving elements) is less than 3%.

#### 5.2.1.3 Open Space Use

All open spaces of the estate are public spaces and used as recreational areas for the local residents. As shown on Map 3 of Annex 10.6, the central park surfaces have high intensity usage, the smaller and peripheral green areas have a low intensity usage. Maintenance is more intensive in the central areas (central square, playgrounds), while less frequented areas without specific recreational functions receive minimal maintenance. Overall, the estate gives an impression of a diverse but developing area, therefore both simple tools with low maintenance costs and more expensive ones with a high aesthetic value can be placed in the open space.

### 5.2.1.4 Building Analysis

While residential buildings have 4 or 10 storeys, service buildings are maximum 2 storeys in height (see Map 4, Annex 10.6). All buildings were originally constructed with flat roofs, but three of them were later extended with pitched roofs. All flat roofs except for the 10 storey buildings[34] are suitable for implementation of extensive green roofs. Most of the building facades are segmented by windows and balconies; the short sides of the 4-storey buildings are the most suitable for establishment of green facade due to the large surfaces without windows and balconies.

### 5.2.1.5 Inherited method applicability values

The applicability of infiltration, retention and evaporation was inherited from the large-scale assessment. Infiltration and retention are insisted in the area, while an increase of evaporation was not required.

TABLE 15: SUMMARY OF OPEN SPACE PROPERTIES RELEVANT FOR THE BGI TOOL ASSESSMENT

| | Properties | Values |
|---|---|---|
| Soil and terrain | Permeabilty coefficient | 10-6 |
| | Gradient | Flat (<3 %) |
| | Groundwater level | -2,5 m |
| Surface coverage | Real GAR/min GAR | >1 |
| | Large coninuous GA | yes |
| | Traffic & parking on the plot | yes |
| Open space use | Use intensity | low / high |
| | Maintenance intensity | low / high |
| Building analysis | Storeys | 1, 4, 10 storeys |
| | Roof type | pitched, flat |
| | Facade type | Simple / segmented |
| | Construction year | After 1920 |
| Inherited properties | Infiltration | insisted |
| | Retention | insisted |

The outcomes of the five thematical analyses are summarised in Table 15.

## 5.2.2 BGI tool selection

Results of the local analysis summarised in Table 15 were used to select the applicable BGI tools based on the key chart in Table 2 and the methodology introduced in Chapter 1.3. The cells in the BGI tool assessment in Table 7 were coloured green for a priority value and orange to indicate a restrictive value. The BGI tool assessment **confirmed the** finding of the large-scale assessment

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[34] As mentioned in Chapter 2.4, the implementation of green roofs is not advised on buildings higher than 5 storeys due to their high maintenance and construction costs and low impact on the urban climate.

regarding the **high potential of this housing category**, since none of the properties had a restrictive value. Thus, all BGI tools can be used in the study area.

TABLE 16: CROSS-REFERENCE TABLE OF THE BGI TOOL ASSESSMENT

🟩 Priority value
🟧 Restriction value

| | WATER MANAGEMENT FUNCTIONS | | | ENVIRONMENTAL IMPACTS | | | | | | IMPLEMENTATION CRITERIA | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Infiltration | Retention | Evaporation | Water cleansing | Peak flow reduction | Recreational value | Aesthetic value | Ecological value | Safety concerns | Space demand | Roof steepness | Facade type | Building costs | Maintenance costs |
| Permeable paving | 🟩 ● | - | ○ | - | 🟩 ○ | 🟩 ○● | ○ | - | | ○● | - | - | ○ | ○ |
| Unsealing | 🟩 ● | - | ● | 🟩 ○ | 🟩 ● | ○ | ○ | 🟩 ● | | - | - | - | ○● | ○ |
| Swale and rain garden | 🟩 ● | 🟩 ● | ● | 🟩 ○ | 🟩 ● | ○ | 🟩 ○● | 🟩 ● | | ○ | - | - | ○ | ○ |
| Underground infiltration | 🟩 ● | 🟩 ● | - | - | 🟩 ○ | - | - | - | | - | - | - | ● | ○ |
| Dry detention basin | - | 🟩 ● | ○ | - | 🟩 ● | - | ○ | - | ! | ● | - | - | ○● | ○ |
| Retention ponds/basin | - | 🟩 ● | ● | 🟩 ○ | 🟩 ● | 🟩 ● | 🟩 ● | 🟩 ● | ! | ● | - | - | ● | ● |
| Underground retention | - | 🟩 ● | - | - | 🟩 ● | - | - | - | | - | - | - | ● | ○ |
| Harvesting tanks | - | 🟩 ● | - | - | 🟩 ● | - | - | - | | ○ | - | - | ○ | ○ |
| Floodable open spaces | - | 🟩 ● | ● | - | 🟩 ● | 🟩 ● | 🟩 ● | - | ! | - | - | - | ○● | ○ |
| Green roof | - | 🟩 ● | - | 🟩 ○ | 🟩 ● | 🟩 ○● | 🟩 ● | 🟩 ● | | - | 🟩 F | - | ○● | ○● |
| Blue roof | - | 🟩 ● | ● | - | 🟩 ● | - | - | - | | - | 🟩 F | - | ● | ○ |
| Green wall | - | - | ● | - | - | - | 🟩 ● | 🟩 ○<br>● | | - | - | 🟩 Si | ○● | ○● |
| Tree planting | 🟩 ● | - | ● | 🟩 ○ | - | 🟩 ● | 🟩 ● | 🟩 ● | | ○ | - | - | ○ | ○ |
| Water feature | - | - | ● | - | - | 🟩 ● | 🟩 ● | - | | ○ | - | - | ● | ● |
| Open drain | - | - | ● | - | - | 🟩 ○● | 🟩 ● | - | | - | - | - | ○ | ○ |
| Bioretention swale | - | ● | ● | 🟩 ● | 🟩 ○ | - | 🟩 ● | 🟩 ● | | ○ | - | - | ○● | ○ |
| Cleansing wetland | - | ○ | ● | 🟩 ● | 🟩 ○ | 🟩 ● | 🟩 ● | 🟩 ● | ! | ● | - | - | ● | ○● |

-: no effect or the property is not relevant; o: low effect; •: high effect; F: flat; Si: simple

The tools “swale and rain garden”, “retention pond/basin”, “green roof” and “tree planting” have the highest amount of prioritised properties (at least five), and therefore they are the most suitable for implementation. Nevertheless, the BGI assessment provides just a general overview about the possibile implementation in a certain area – in the design process, specific local conditions can refine or occasionally override these results.

### 5.2.3 Calculation of the required storage capacity

Two different rain intensity scenarios: a small, normal rain event and a large, design rain event were considered for the calculations in the study area. The design aimed to hold the runoff from the **normal rain event** onsite by implementing **infiltration tools**. The required infiltration area was calculated using the German standard *DWA A-138 (Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water*)(DWA 2005). The runoff from the **design rain event** is kept onsite by implementing **retention tools**. The required storage capacity was calculated using the standard *DWA A-117 (Dimensioning of Retention Areas).*(DWA 2013) German calculations typically use the 5-year and 30-year return periods for normal and design rain events, respectively. The Hungarian practice uses different values for the return periods. The 4-year and the 33-year return periods were chosen for the study, since they are the closest used values to the German practice. The study area was divided into 27 catchment areas based on the gradient and open space structure. The runoff calculation was performed independently for each catchment area. The calculation will be introduced in the following steps: 1. Input data collection; 2. Calculation of the required infiltration surface; 3. Calculation of the required retention volume.

#### 5.2.3.1 Input data collection

The following input data is required for the runoff calculation:

a) The absolute impermeable area ($A_i$, [$m^2$]) of each catchment area, calculated from the area (A, [$m^2$]) and the runoff coefficient (C, -) of the different surface types
b) Permeability coefficient of the soil ($k_f$, [m/s])
c) Value of the throttled outflow ($Q_{th}$, [l/(s·ha)])
d) Rainfall duration (D, [min]) and Rainfall intensity ($i_{D(a)}$, [l/(s·ha)])

Henceforth, the determination of the above input variables will be described:

a) **Absolute impermeable area:** The absolute impermeable area ($A_i$) is a theoretical value that is used to quantify the portion of a catchment area, from which the remaining precipitation (after deduction of all water losses) leaves the area as surface runoff.(DWA 2005 p. 10) $A_i$ was calculated for each catchment area by multiplying the measured surface size ($A_n$) with the runoff coefficients for both the 4-year ($C_4$), and for the 33-year rain ($C_{33}$) events, based on the standard DIN 1986-100, shown in Table 17.[35]

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[35] These runoff coefficients are defined by the standard for the 5-year and 30-year return period rains, but due to the small difference from the analysed return periods, the values were considered to be adoptable for the calculations of the 4-year and 33-year rain events.

$$\mathbf{A_1 \cdot C_1 = A_{i1}}$$

$$\mathbf{A_2 \cdot C_2 = A_{i2}}$$

$$\mathbf{\ldots .}$$

$$\mathbf{A_{i1} + A_{i2} \ldots + A_{in} = A_i}$$

**$A_1$, $A_2$,…**: areas of the different surface types ($m^2$)

**$C_1$, $C_2$,…**: runoff coefficients of the surface types, based on DIN 1986-100

**$A_i$**: absolute impermeable area ($m^2$)

The surface types of the 27 catchment areas and the calculated absolute impermeable areas are provided in Annex 10.8.

TABLE 17: RUNOFF COEFFICIENTS OF THE DIFFERENT SURFACE TYPES AND RAIN INTENSITIES
(based on DIN 1986-100)

| Surface type | $C_4$ 4 year | $C_{33}$ 33 year |
|---|---|---|
| Green area | 0.1 | 0.2 |
| Asphalt or concrete | 0.9 | 1 |
| Grass paver | 0.2 | 0.4 |
| Paving elements | 0.7 | 0.9 |
| EPDM surface | 0.5 | 0.6 |
| Gravel | 0.7 | 0.9 |
| Pitched roof | 1 | 1 |
| Green roof | 0.4 | 0.7 |
| Flat roof | 0.9 | 1 |

BGI tools that modify the surface coverage to reduce the runoff coefficient must be considered before starting the calculation of the impermeable area. Two BGI tools were implemented for this goal.

80% of the asphalt and concrete surfaces consist of roads and parking surfaces, from which runoff is completely discharged into the drainage system. Different strategies are suggested in Figure 35 for the implementation of **green paver** for the three different street cross-sections as introduced in Chapter 5.2.1:

- Scenario 1: if the slope leads the runoff in the direction of the curb, simple channels or gaps in the curb can help to guide rainwater to the green area. This solution is very cost-effective because it does not require the road surface to be reconstructed. If parking surfaces slope in the direction of the street, this method cannot be implemented. Thus, a reversion of slope direction is advised by reconstructing the parking surface with grass paver.
- Scenario 2: smaller streets with drainage inlets on one side, implementation on a single side can achieve the goals of on-site water management.
- Scenario 3: in the case of large streets with drainage inlets on both sides, implementing grass paver is advised on both sides.

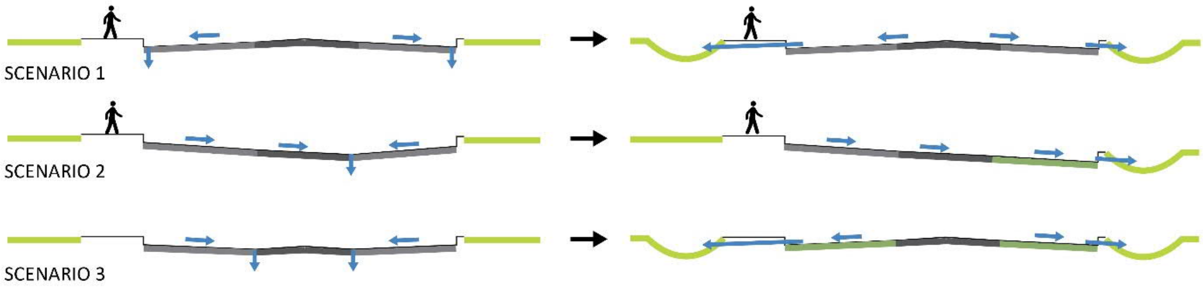

FIGURE 35: SCEMATIC CROSS-SECTIONS OF THE TRANSFORMATION OF PARKING SURFACES

Considering the poor condition of numerous parking surfaces, these interventions could be feasible a part of a future long-term open space revitalisation program.

**Extensive green roof** is the second BGI tool that was considered to reduce the runoff coefficient. The tool was suggested for every flat roof that is not higher than 5 storeys.

b) **Permeability coefficient:** As defined in Chapter 5.2.1, the permeability coefficient $\mathbf{k_f=1 \cdot 10^{-6}}$ **m/s** will be used for the calculations in every catchment area.

c) **Throttled outflow:** BGI tools can be designed for complete water retention or with a constant outflow. This study adapts the approach, which is gaining an increasing acceptance amongst practitioners. The runoff allowed through the throttled outflow aims to be equivalent to the natural runoff from the undeveloped area. The runoff simulation software SWWM was used to model the natural runoff using the rainfall time series of five years (2000-2004). Based on the results, **4 l/(s · ha)** was found to be the average runoff for the 4-year rain event with a rain duration of one hour. This value was used for the discharge rate of the throttled outflow. In the case of the design rain, the goal is to decrease the peak runoff. Therefore, the calculation for the 33-year rain event does not use a throttled outflow.

d) **Rainfall duration and rainfall intensity:** German runoff calculations are based on the ready-to-use raster values of the heavy precipitation statistics and analyses from the KOSTRA-DWD storm rainfall event catalogue.[36] (Deutsche Wetterdienst 2020). The Hungarian practice uses the IDF (intensity-duration-frequency) curve parameters for calculations.(Table 18) (Gayer 2004 p. 55) Rain intensity was calculated using these parameters for the 4-year and 33-year return

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[36] The dataset's grid is available for 18 duration thresholds (5 min to 72 h) and for nine return periods (1 year to 100 years), referring to the time span 1951-2010.(OASIS HUB 2018)

periods and for various rain durations (5, 10, 15, 20, 30, 45, 60, 90, 120, 180, 240, 360, 540, 720, 1080, and 1440 minutes[37]) using the following formula:

$$\mathbf{i_{D(a)} = (i_a \cdot D^{-m}) \cdot 2.778}$$

($\mathbf{i_{D(a)}}$: rainfall intensity of **D** duration and **a** return period [l/(s·ha)]; $\mathbf{i_a}$: rain intensity of the rainfall with **a** return period with 10 minute of rain duration [mm/h]; **m**: probability factor; **D**: duration in 10 minute segment; **2.778**: conversion from mm/h to l/(s·ha))

TABLE 18: PARAMETERS OF THE HUNGARIAN INTENSITY-DURATION-FREQUENCY (IDF) CURVE (Source: (Gayer 2004 p. 55))

| a | $i_a$ | m |
|---|---|---|
| 1 | 47,8 | 0,69 |
| 2 | 73,0 | 0,71 |
| 4 | 97,0 | 0,72 |
| 10 | 131,0 | 0,72 |
| 20 | 158,0 | 0,73 |
| 33 | 180,0 | 0,74 |

a: return period [year]; $i_a$: rain intensity of the corresponding return period rainfall [mm/h]; m: probability factor [-]

TABLE 19: RAIN INTENSITIES OF DIFFERENT RAIN DURATIONS FOR 4-YEAR AND 33-YEAR RAIN EVENT

| D [min] | 4-year event $i_{D;4}$ [l/(s·ha)] | 33-year event $i_{D;33}$ [l/(s·ha] |
|---|---|---|
| 5 | 443.86 | 835.09 |
| 10 | 269.47 | 500.00 |
| 15 | 201.24 | 370.39 |
| 20 | 163.59 | 299.37 |
| 30 | 122.17 | 221.77 |
| 45 | 91.24 | 164.28 |
| 60 | 74.17 | 132.78 |
| 90 | 55.39 | 98.36 |
| 120 | 45.03 | 79.50 |
| 180 | 33.63 | 58.89 |
| 240 | 27.34 | 47.60 |
| 360 | 20.42 | 35.26 |
| 540 | 15.25 | 26.12 |
| 720 | 12.39 | 21.11 |
| 1080 | 9.26 | 15.64 |
| 1440 | 7.52 | 12.64 |

#### 5.2.3.2 Calculation of the required infiltration surface

The required swale volume was calculated with the Excel-based calculation guideline of the DWA A-138. The calculation is based on the following formula:

$$V_{\mathrm{inf}} = \left(\left(A_{i(4)} + A_{inf}\right) \cdot 10^{-7} \cdot i_{D(n)} - A_{inf} \cdot \frac{k_f}{2} - \left(Q_{th} \cdot A_{i(4)}\right)\right) \cdot 60 \cdot D \cdot fz$$

$V_{\mathrm{inf}}$: Swale volume [m$^3$]; $A_{i(4)}$: absolute impervious area of the 4-year runoff [m$^2$]; $A_{\mathrm{inf}}$: surface of the infiltration area [m$^2$]; $i_{D(4)}$: rainfall intensity of the 4-year return period [l/(s·ha]; $k_f$: water permeability factor [m/s]; $Q_{th}$: throttled outflow [l/s·ha]; D: duration of rainfall [min]; fz: safety factor [-]

The required infiltration swale volume (**$V_{in}$**) was calculated from the runoff volume of the absolute impermeable area and the area of the swale, decreased by the infiltration loss through the soil and the runoff of the throttled outflow. The **fz** safety factor (with the value of 1.1 based on DWA-A

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[37] These rain durations are used in the standard (DWA A-138)

117) oversizes the volume to compensate the calculation inaccuracy of the rational method compared to a runoff simulation.

Based on the standard's advise and normal planning practice, the water depth of the infiltration areas will be a constant value of 30 cm.[38] At the intense start phase of the rain, the infiltration process is not fast enough to absorb the whole downpour and the water collects in the swale. The stored amount increases until a point in time when the infiltration counterbalances the calming rainfall. From this point onwards, the amount of stored water decreases slowly as it perculates through the soil.

Figure 36 shows the required retention volume of the infiltration swales calculated for the 4-year rain event versus the rainfall duration in Catchment Area 1. The highest volume demand occurs 540 minutes after the start. Due to the same permeability ratio in all catchment areas, the same retention volume is expected. Thus, **540 minutes rain duration** was used for the calculation of the required infiltration swale volumes in all catchments.

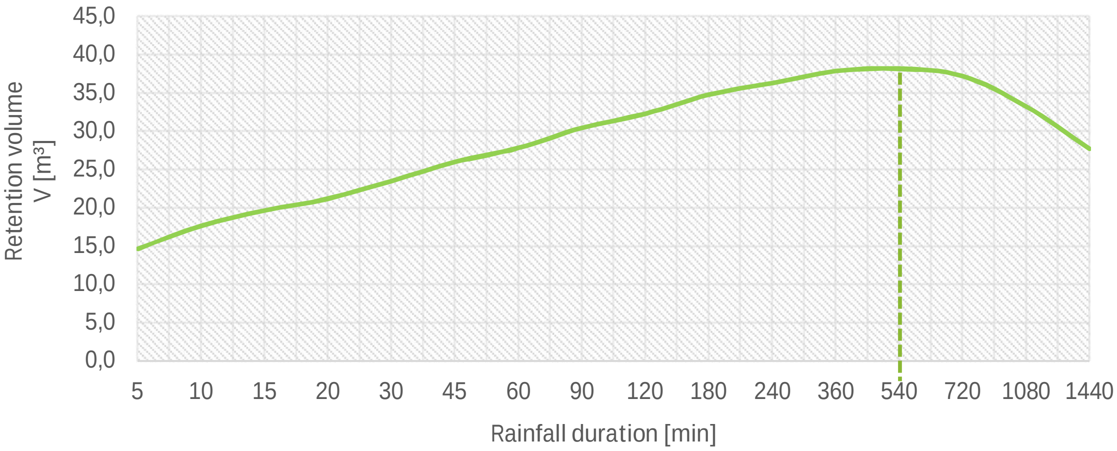

FIGURE 36: REQUIRED INFILTRATION SWALE VOLUME OF CATCHMENT AREA 1

THE CURRENT 4-YEAR RUNOFF OF THE ENTIRE ESTATE AREA CAN BE SEEN IN

Table 20. The calculation reveals, that the asphalt surfaces comprise 37% of the estate's area but are the source for 66% of the 4-year runoff. Flat roofs are the second most significant runoff sources, releasing around one sixth of the total runoff.

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[38] According to the standard, the maximum 30 cm water coverage insures a maximum 24 hour-long emptying time and avoids herewith the rotting of the vegetation.

TABLE 20: CURRENT RUNOFF OF ÖRMEZÖ HOUSING ESTATE FOR 4-YEAR RAIN EVENTS

| | | | 4-year rain event | |
|---|---|---|---|---|
| | A (ha) | % | Runoff ($m^3$) | % |
| Green area | 9,733 | 45 | 479 | 9 |
| Asphalt or concrete (road and parking) | 5,5 | 26 | 2445 | 46 |
| Asphalt or concrete (pedestrian) | 2,344 | 11 | 1042 | 20 |
| Paving elements | 0,461 | 2 | 158 | 3 |
| EPDM surface | 0,279 | 1 | 69 | 1 |
| Gravel | 0,195 | 1 | 69 | 1 |
| Pitched roof | 0,914 | 4 | 182 | 3 |
| Flat roof | 1,982 | 9 | 879 | 17 |
| Σ | 21,46 | | 5123 | |

After the calculation of the required swale volume, the swale surfaces were determined by "trial and error" to find the surface size that results in a swale depth of 30cm. The required infiltration surface areas of all the 27 catchment areas are listed in Table 21.

TABLE 21: REQUIRED INFILTRATION SURFACES OF THE CATCHMENT AREAS

| Catchment area | $A_{inf}$ ($m^2$) | Catchment area | $A_{inf}$ ($m^2$) | Catchment area | $A_{inf}$ ($m^2$) |
|---|---|---|---|---|---|
| 1 | 129 | 11 | 650 | 21 | 320 |
| 2 | 155 | 12 | 280 | 22 | 360 |
| 3 | 160 | 13 | 500 | 23 | 143 |
| 4 | 1050 | 14 | 1200 | 24 | 350 |
| 5 | 640 | 15 | 380 | 25 | 78 |
| 6 | 380 | 16 | 350 | 26 | 560 |
| 7 | 1100 | 17 | 950 | 27 | 320 |
| 8 | 180 | 18 | 185 | | |
| 9 | 955 | 19 | 400 | | |
| 10 | 560 | 20 | 570 | | |

### 5.2.3.3 Calculation of the required retention volume

The 33-year runoff was managed using retention tools. Without infiltration, the captured volume of the retention tools constantly increases. Thus, the complete retention of a very large rain event is usually not achievable. A rain duration of 15 minutes was chosen for the calculation of the retention volume, as this duration is most frequently used in practice.

TABLE 22: CURRENT RUNOFF OF ÖRMEZÖ HOUSING ESTATE FOR 33-EYAR RAIN EVENTS

| | | | 33-year rain event | |
|---|---|---|---|---|
| | A (ha) | % | Runoff ($m^3$) | % |
| Green area | 9,77 | 45 | 650 | 15 |
| Asphalt or concrete (road and parking) | 5,5 | 26 | 1833 | 42 |
| Asphalt or concrete (pedestrian) | 2,36 | 11 | 781 | 18 |
| Paving elements | 0,46 | 2 | 140 | 3 |
| EPDM surface | 0,28 | 1 | 57 | 1 |
| Gravel | 0,20 | 1 | 60 | 1 |
| Pitched roof | 0,91 | 4 | 153 | 4 |
| Flat roof | 1,98 | 9 | 660 | 15 |
| Σ | 21,46 | | 4334 | |

With this duration, existing runoff was firstly calculated and summarised in Table 22. The volume of overall runoff from the 540-minute 4-year rain is 5325.73 m$^{3}$, whereas the 15-minute 33-year event results only in 4851.39 m$^{3\cdot}$ runoff. These results show that rain events with a lower intensity can also produce a significant amount of runoff. Similar to the 4-year rain, the most significant runoff source is the asphalt surface (60%). The runoff from green areas can be significant during intense rains, equally high as the flat roofs but disperses over a much larger area.

The required retention volume was calculated by multiplying the absolute impervious area with the rainfall intensity of the 33-year rain event and adjusted by deducting the amount of water already stored by the infiltration tools, using the following formula of DWA A-117:

$$V_{ret} = \mathbf{A_{i,33}} \cdot ((i_{15(33)} - Q_{th}) \cdot D \cdot f_Z \cdot 0{,}06) \mathbf{- V_{inf}}$$

$V_{ret}$: required retention volume [m$^{3}$]; $A_{i,33}$: absolute impervious area of the 33-year runoff [m$^{2}$]; $i_{D,33}$: rainfall intensity of the 33-year return period [l/(s·ha]; $Q_{th}$: throttled outflow [l/s·ha]; D: duration of rainfall [min]; fz: safety factor [-] 0,06: Conversion factor from l/s in m$^{3}$/min; $V_{inf}$: Retention volume of the infiltration tools [m$^{3}$]

Table 23 shows the required retention volume of the catchment areas.

TABLE 23: REQUIRED RETENTION AREAS OF THE 27 CATCHMENT AREAS

| Catchment area | $V_{ret}$ (m$^{3}$) | Catchment area | $V_{ret}$ (m$^{3}$) | Catchment area | $V_{ret}$ (m$^{3}$) |
|---|---|---|---|---|---|
| 1 | 14.15 | 11 | 24.01 | 21 | 15.98 |
| 2 | 11.93 | 12 | -0.41 | 22 | 12.87 |
| 3 | 9.45 | 13 | 20.01 | 23 | 9.16 |
| 4 | 56.08 | 14 | 60.69 | 24 | 21.88 |
| 5 | 38.67 | 15 | 23.75 | 25 | 7.36 |
| 6 | 16.36 | 16 | 29.16 | 26 | 20.38 |
| 7 | 79.42 | 17 | 45.66 | 27 | 22.77 |
| 8 | 12.32 | 18 | 7.52 | | |
| 9 | 41.59 | 19 | 16.29 | | |
| 10 | 34.51 | 20 | 38.54 | | |

Despite of the lower overall water amount, retention tools still need to be implemented in most of the catchment areas due to the higher runoff of the sealed surfaces.

### 5.2.4 Scematic design and estimation of the runoff reduction

After the calculation of the required infiltration area and retention volume, the possible positions of the BGI tools were investigated on the AutoCAD groundplan. The following seven tools were used during the planning process:

FIGURE 37: THE IMPLEMENTED INFILTRATION AND RETENTION TOOLS AND LEGEND FOR THE SCEMATIC DESIGN PLAN

The capacity of these tools was quantified by the water depth or by the runoff surface ratio in the case of grass pavers and green roofs. There two tools were already discussed in the runoff calculation.

Infiltration tools:

1. Grass paver ($c_4 = 0.2$; $c_{33} = 0.4$)
2. Extensive green roofs ($c_4 = 0.4$; $c_{33} = 0.7$)
3. Infiltration swale area (30 cm water depth)
4. Rain garden (30 cm water depth)

Retention tools:

5. Floodable open space (25 cm water depth):
6. Underground retention zone (60 cm water depth)
7. Retention pond with 30 cm water buffer: Retention pond

The tool placement considered the open space use, existing vegetation and slope directions, but kept planning on a scematic level. The scematic plan is shown in Map 4, Annex 10.7. The planning decisions for each catchment area were described in Annex 10.9.

Except for the infiltration areas in Catchment Area 6, the required infiltration and retention capacity could be fulfilled in every area. Figure 38 summarises the results of the runoff calculation for the existing and the developed BGI scenario.

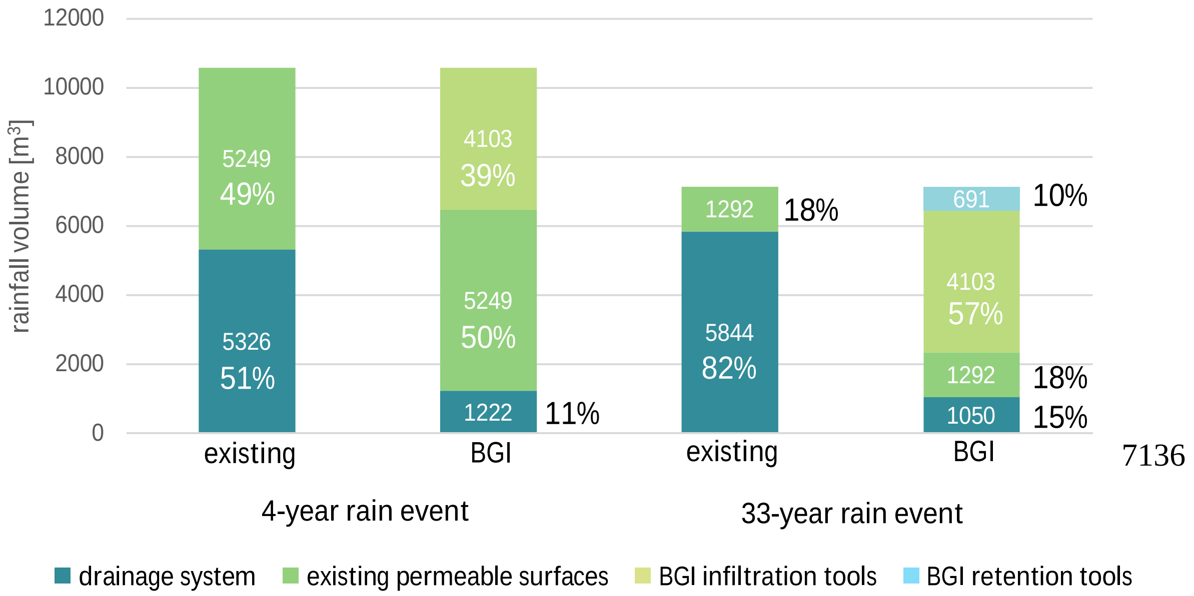
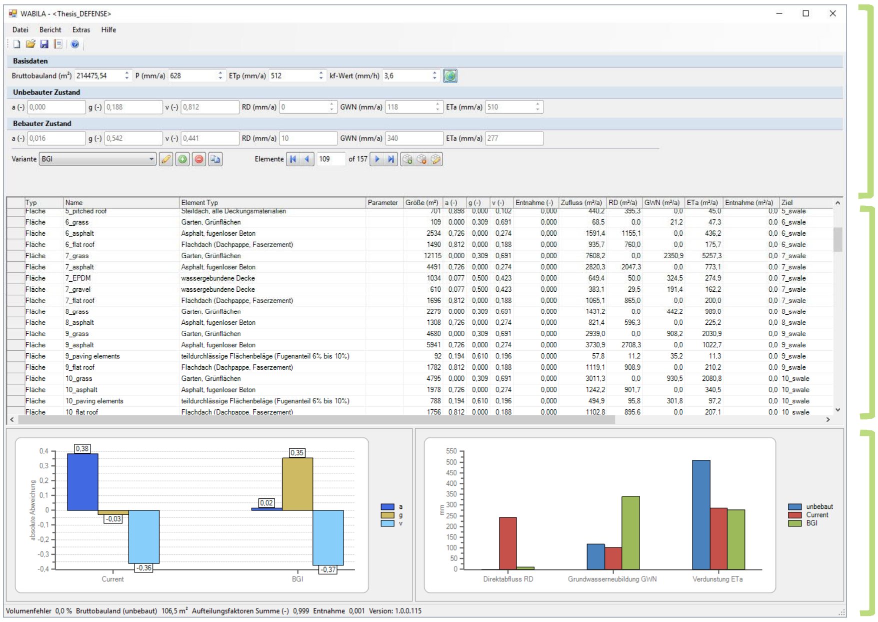


Figure 38: Managed water volume broken down by the receptors for the rainfall before and after BGI implementation, 4-year and 33-year events

Currently, as seen in the figure, almost half of the 4-year rain is kept by the existing green areas on-site and slightly more than the half of the precipitation is conveyed into the drainage system. The ratio of rainwater managed on-site could be significantly increased by implementing BGI tools. Infiltration tools could keep 4103 m$^3$ on site. Due to the large infiltration capacity, a realtively low, 691 m$^3$ retention volume was implemented a further onsite. The change in the case of the 33-year rain is even more remarkable: the ratio of discharged rainwater amount reduced from 82% to 15%. Altogether, the BGI scenario could reduce the 4-year runoff by 77% and the 33-year runoff by 78% compared to the current runoff.

### 5.2.5 Modelling the impacts on the annual water balance

The impact on the annual water balance was calculated with the WABILA software and based on the created schematic plan. Figure 39 shows the user interface of WABILA with it's three main parts.



**Basisdaten**

Bruttobauland ($m^2$) 214475,54 P (mm/a) 628 ETp (mm/a) 512 kf-Wert (mm/h) 3,6

**Unbebauter Zustand**

a (-) 0,000 g (-) 0,188 v (-) 0,812 RD (mm/a) 0 GWN (mm/a) 118 ETa (mm/a) 510

**Bebauter Zustand**

a (-) 0,016 g (-) 0,542 v (-) 0,441 RD (mm/a) 10 GWN (mm/a) 340 ETa (mm/a) 277

Variante BGI

Elemente 109 of 157

| Typ | Name | Element Typ | Parameter | Größe ($m^2$) | a (-) | g (-) | v (-) | Entnahme (-) | Zufluss ($m^3/a$) | RD ($m^3/a$) | GWN ($m^3/a$) | ETa ($m^3/a$) | Entnahme ($m^3/a$) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 5_pitched roof | Steildach, alle Deckungsmaterialien |  | 701 | 0,898 | 0,000 | 0,102 | 0,000 | 440,2 | 395,3 | 0,0 | 45,0 | 0,0 | 5_swale |
| Fläche | 6_grass | Garten, Grünflächen |  | 109 | 0,000 | 0,309 | 0,691 | 0,000 | 68,5 | 0,0 | 21,2 | 47,3 | 0,0 | 6_swale |
| Fläche | 6_asphalt | Asphalt, fugenloser Beton |  | 2534 | 0,726 | 0,000 | 0,274 | 0,000 | 1591,4 | 1155,1 | 0,0 | 436,2 | 0,0 | 6_swale |
| Fläche | 6_flat roof | Flachdach (Dachpappe, Faserzement) |  | 1490 | 0,812 | 0,000 | 0,188 | 0,000 | 935,7 | 760,0 | 0,0 | 175,7 | 0,0 | 6_swale |
| Fläche | 7_grass | Garten, Grünflächen |  | 12115 | 0,000 | 0,309 | 0,691 | 0,000 | 7608,2 | 0,0 | 2350,9 | 5257,3 | 0,0 | 7_swale |
| Fläche | 7_asphalt | Asphalt, fugenloser Beton |  | 4491 | 0,726 | 0,000 | 0,274 | 0,000 | 2820,3 | 2047,3 | 0,0 | 773,1 | 0,0 | 7_swale |
| Fläche | 7_EPDM | wassergebundene Decke |  | 1034 | 0,077 | 0,500 | 0,423 | 0,000 | 649,4 | 50,0 | 324,5 | 274,9 | 0,0 | 7_swale |
| Fläche | 7_gravel | wassergebundene Decke |  | 610 | 0,077 | 0,500 | 0,423 | 0,000 | 383,1 | 29,5 | 191,4 | 162,2 | 0,0 | 7_swale |
| Fläche | 7_flat roof | Flachdach (Dachpappe, Faserzement) |  | 1696 | 0,812 | 0,000 | 0,188 | 0,000 | 1065,1 | 865,0 | 0,0 | 200,0 | 0,0 | 7_swale |
| Fläche | 8_grass | Garten, Grünflächen |  | 2279 | 0,000 | 0,309 | 0,691 | 0,000 | 1431,2 | 0,0 | 442,2 | 989,0 | 0,0 | 8_swale |
| Fläche | 8_asphalt | Asphalt, fugenloser Beton |  | 1308 | 0,726 | 0,000 | 0,274 | 0,000 | 821,4 | 596,3 | 0,0 | 225,2 | 0,0 | 8_swale |
| Fläche | 9_grass | Garten, Grünflächen |  | 4680 | 0,000 | 0,309 | 0,691 | 0,000 | 2939,0 | 0,0 | 908,2 | 2030,9 | 0,0 | 9_swale |
| Fläche | 9_asphalt | Asphalt, fugenloser Beton |  | 5941 | 0,726 | 0,000 | 0,274 | 0,000 | 3730,9 | 2708,3 | 0,0 | 1022,7 | 0,0 | 9_swale |
| Fläche | 9_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) |  | 92 | 0,194 | 0,610 | 0,196 | 0,000 | 57,8 | 11,2 | 35,2 | 11,3 | 0,0 | 9_swale |
| Fläche | 9_flat roof | Flachdach (Dachpappe, Faserzement) |  | 1782 | 0,812 | 0,000 | 0,188 | 0,000 | 1119,1 | 908,9 | 0,0 | 210,2 | 0,0 | 9_swale |
| Fläche | 10_grass | Garten, Grünflächen |  | 4795 | 0,000 | 0,309 | 0,691 | 0,000 | 3011,3 | 0,0 | 930,5 | 2080,8 | 0,0 | 10_swale |
| Fläche | 10_asphalt | Asphalt, fugenloser Beton |  | 1978 | 0,726 | 0,000 | 0,274 | 0,000 | 1242,2 | 901,7 | 0,0 | 340,5 | 0,0 | 10_swale |
| Fläche | 10_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) |  | 788 | 0,194 | 0,610 | 0,196 | 0,000 | 494,9 | 95,8 | 301,8 | 97,2 | 0,0 | 10_swale |
| Fläche | 10 flat roof | Flachdach (Dachpappe, Faserzement) |  | 1756 | 0,812 | 0,000 | 0,188 | 0,000 | 1102,8 | 895,6 | 0,0 | 207,1 | 0,0 | 10 swale |

Volumenfehler 0,0 % Bruttobauland (unbebaut) 106,5 $m^2$ Aufteilungsfaktoren Summe (-) 0,999 Entnahme 0,001 Version: 1.0.0.115

Base data input field

Surface and BGI tool selection and configuration

Visualisation of the impact on the annual water balance

FIGURE 39: USER INTERFACE OF THE WABILA WATER BALANCE MODELLING SOFTWARE (Source: WABILA)

The required input data for the simulation and their values are shown in Table 24:

TABLE 24: REQUIRED INPUT DATA OF THE WABILA WATER BALANCE MODELLING SOFTWARE

| Data type | Value |
|---|---|
| Average annual precipitation [mm] | 628[39] |
| Actual evapotranspiration [mm] | 512 |
| Permeability coefficient [mm/h] | $10^{-6}$ |
| Soil type | Loamy sand |
| Original surface cover | Meadow |
| Height difference [$m/km^2$] | 0-20 |
| Groundwater depth [m] | -2-3 |
| Total area [$m^2$] | 214476 |

The impact of the different surface types and BGI tools on the evaporation, runoff and groundwater recharge were calculated by the software.[40] Two scenarios were established in the program: **Scenario 1. the existing development**; and **Scenario 2. the planned development with BGI tools**. The program compares these scenarios to the original, undeveloped stage with natural vegetation (meadow).

Firstly, all existing surface types and sizes of the catchment areas were entered. This information established Scenario 1, which modelled the existing situation. For Scenario 2, new green paver and green roof areas were entered, and the asphalt and flat roof surfaces were accordingly decreased. Finally, the implemented infiltration and retention surfaces were entered, and the green

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[39] The precipitation and actual evaporation values were gained from (Ács F. et al. 2007).

[40] The software's manual describes the detailed calculation methods, which due to copyright are not published in this thesis.

area was reduced by the area of these tools. The runoff of the surfaces was linked to the infiltration surface of each catchment area, and the infiltration surfaces were further linked to the retention tools. Retention tools discharge the surplus water into the sewage. Annex 10.11 lists the surfaces, tools and their properties for the Scenario 2.

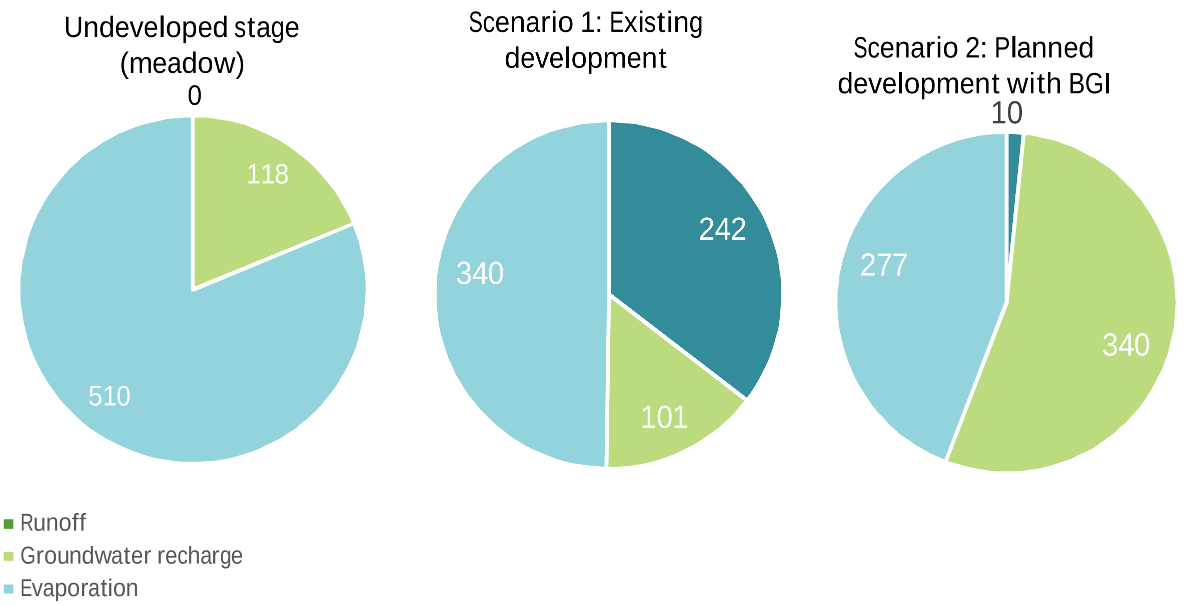

FIGURE 40: WATER BALANCE OF THE NATURAL, EXISTING AND PLANNED SCENARIO (IN MM)

Figure 40 shows the calculated water balance of the undeveloped state and the two described scenarios. The water balance of the undeveloped state with grassland coverage is comprised of 81% evaporation and a 19% groundwater recharge. The existing developement has a significantly lower evaporation rate and a slightly lower infiltration rate. Almost two third of the annual water volume departs the area as runoff.

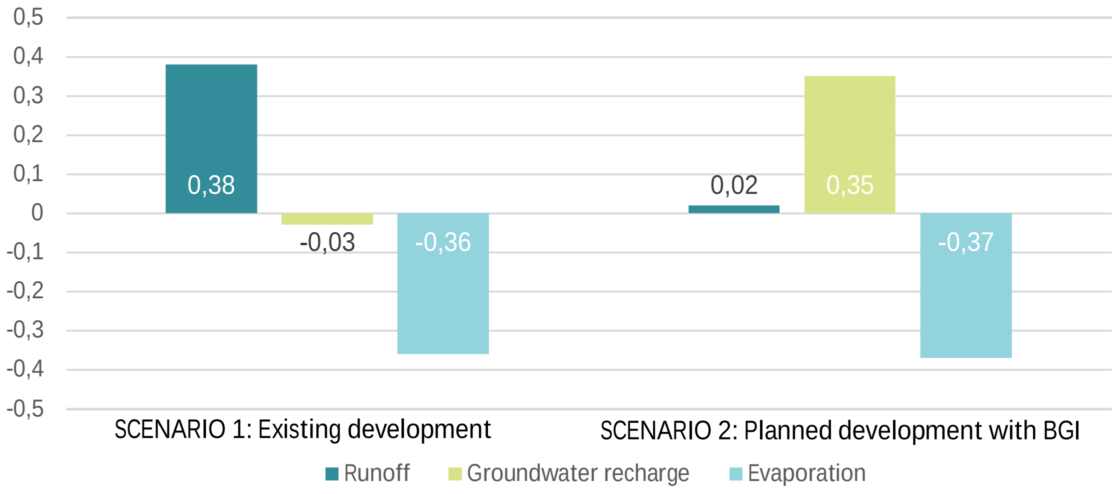

FIGURE 41: DEVIATION OF THE TWO SCENARIOS FROM THE NATURAL WATER BALANCE

Figure 41 shows the deviation of the two scenarios from the natural water balance. Scenario 2 successfully eliminated most of the runoff and converted it into groundwater recharge. The proportion of infiltration is even greater than the undeveloped stage, which causes a similarly low evaporation ratio compared to the existing development. The impact of high infiltration on evaporation is therefore similar to having high runoff: the water rapidly departs the surfaces and there is no time for evaporation which is a slow process. The short-term water coverage of the infiltration tools has a negligable impact on the annual evaporation rate. Nevertheless, the infiltrated runoff can be absorbed by the vegetation which could indirectly increase the evaporation and cool the environment.

### 5.2.6 Discussion and conclusions for the small-scale assessment of BGI effects

The runoff calculation and water balance modelling provide several important lessons for the BGI implementation. The runoff calculation proved that a low-intensity rain event can produce a higher overall runoff than a short period high-intensity event. Therefore, **short, 10-15-minute rain durations, which are widely used for dimensioning the drainage system, can not be implemented in the design of the on-site rainwater management.**

The runoff calculation showed that more than half of the runoff originated from traffic surfaces. **This fact points out the importance for integrating SURM principles into the street planning.** Reshaping and repaving road surfaces have high costs, but if the SURM principles are considered in the design, the implementation will not generate extra costs.

The appraisal also proved the **high applicability of BGI in socialist housing estates**: the BGI tool assessment allowed the use of all BGI tools and the green area ratio is sufficient for their implementation. Due to the low soil permeability, a large surface area was required for the infiltration. Nevertheless even under these circumstances, the implemented BGI tools were able to reduce the normal runoff by 77% and the peak flow of the design rain by 82%. **The calculation proved that BGI can have an important role in the runoff and peak flow decrease.**

The long-term impacts were investigated by the annual water balance modelling. The model validated that BGI tools have a high groundwater recharging effect: in this housing estate study, it is significantly larger than the natural infiltration. The increased groundwater level can improve the condition and evaporation of the vegetation and reduce the need for irrigation but could also damage the buildings' basement level. Another impact of the high infiltration is that the evaporation rate of the BGI scenario did not increase compared to the current state. BGI tools do not necessary increase evaporation and improve the urban climate. **Annual water balance modelling must be integrated into the planning of BGI in order to ensure a positive effect of on-site rainwater management on the urban climate.**

The precision of the runoff calculation was limited by several factors. In reality, the permeability of the soil is more heterogenous than it was modelled, which can influence the size of the infiltration tools. The available rainfall data is outdated and does not include the effects of climate change. The calculation could not take the underground infrastructure and buildings into account, which can limit the use of BGI tools in some areas. The runoff pollution level of the roads was not considered by the tool implementation, which could eventually influence the implementation of infiltration along the Menyecske street (main street of the housing estate).

The implemented water balance model also has some limitations. The software WABILA uses rainwater data from German weather stations. Even though the annual precipitation and evaporation data of Budapest is similar to some German areas, the rainfall dispersion and intensity can be somewhat different. Therefore, the modelling results should be performed using Hungarian rainfall time series. The program does not consider changes in the canopy cover but calculates with an average canopy cover of the green area. If a development plan causes a large modification of the canopy coverage, it could potentially influence the evaporation ratio. This deficiency is probably related to the challenging modelling of the evaporation process: trees of different sizes and species have different evaporation rates, depending on the temperature and their position. All of these factors would make the model too complicated. Green facades are also not defined in the software, although they can provide a significant impact on the urban climate in some special cases (such as dense urban areas with high impervious ratio). In the study area, neither of these two tools would have made a difference to the water balance modelling: the canopy coverage was not modified; and the wall surfaces, which are suitable for green facades, are negligible compared to the overall area.

The appraisal of BGI implementation effects opens numerous avenues for further research. Revising the rainfall data is the highest priority task for new researches. The use of predicted future time series from climate simulations could estimate the effects of climate change on the urban drainage system. The validation of the calculation with a runoff simulation would add valuable further results to future research. A simulation also provides opportunities for further detailing of the experimental design through the connection of particular BGI tools. Further researches could also investigate other study areas with different land use. Finally, the most reliable and efficient validation method is experimentation in a pilot area. The monitoring data and practical experiences could be used to refine the calculation method, which would result in a methodology for use by the practitioners.

# 6 Discussion

## 6.1 Scientific results

The results of the research are summarized in the following theses:

1. Modifications of the current legal, institutional and technical environment are necessary to allow and facilitate the use of on-site rainwater management in Budapest. The most vital areas of improvement were identified as:
    a. A legal definition and clear responsibilities encompassing rainwater management, and a legal obligation to prioritise the implementation of on-site rainwater management
    b. Clarification of ownership and developer rights for blue- and green-infrastructure elements
    c. Political commitment to provide sufficient and calculable resources
    d. Access to good quality planning data
    e. Expansion of expert knowledge

2. The land use classification system of Budapest offers a suitable framework in order to assess the applicability of sustainable rainwater management in the urban structure. Based on this, a unique methodology was established to identify the urban areas where infiltration, retention and evaporation tools either could be applied, or are insisted. The five urban development zones of Budapest have different characteristics:
    a. The transition zone can host tools from all three SURM methods.
    b. The suburban zone is typified by an insisted application of infiltration and retention tools
    c. The core zone is typified by an insisted application of retention and evaporation tools
    d. The hill zone and the Danube zone are characterised by an applicability for retention tools.

3. In areas with an overlap of at least two insisted methods, high synergic benefits can be achieved by the implementation of complex BGI projects, thus their development would be most profitable for the city. Overlapping areas of insisted methods exist typically in the low-density suburbs of the suburban zone, brownfields and housing estates of the transition zone, and dense historic development of the core zone.

4. The transition zone is the most suitable area to apply large-scale blue-green infrastructure projects due to the vast amount of large areas where sustainable rainwater management tools could be easily implemented. The establishment of a “blue-green belt” with a large retention capacity in the transition zone can assist to unload the core zone’s water infrastructure.

5. The most effective measures to facilitate the implementation of sustainable urban rainwater management in Budapest are:
    a. Preventional land use regulation of brownfield areas to secure the required space of future blue-green infrastructure
    b. Inclusion of sustainable urban rainwater management into public open space development projects
    c. Involvement of private owners (detached house owners and housing communities within the historic core) and the provision of incentives.

6. A unique methodology was established in order to select the locally applicable blue-green infrastructure tools for different urban environments. In a typical socialist housing estate, a large variety of BGI tools can be applied which can effectively reduce the urban runoff and peak flow.

7. The development of blue-green infrastructure does not necessarily increase the evaporation rate. Therefore, annual water balance modelling must be included in the design of blue-green infrastructure in order to ensure that a positive effect on the urban climate can be achieved.

## 6.2 Recommendations for the implementation of SURM in Budapest

The analysis of Budapest in Chapter 4.3 pointed out several deficiencies in the technical, institutional and legislative framework, which currently impede the implementation of SURM. In addition, the large-scale applicability assessment identified the possible measures which would create the largest benefit for SURM implementation. Henceforth, recommendations will be introduced for the extension and modification to the existing technical, institutional and legislative systems. This will enable the overall SURM implementation and facilitate the application of the three measures[41] defined in Chapter 5.1.2, based on the lessons of the international study cases.

### 6.2.1 Shaping a receptive legislative and institutional framework

The need for adjustment of the legal system was underlined both by the analysis and the applicability assessment. Initially, a clear definition of the tasks and responsibilities of the stakeholders must be accomplished. If urban RWM was **classified as a utility** and a **compulsory municipal task** by modifying Act of 2011/CLXXXIX on Hungary's local governments and Act LVII of 1995 on Water Management, an individual budget for RWM would be ensured. Furthermore, **on-site management should be specified as the preferred method** of RWM. The **rainwater fee** and a **discount system** for implementing on-site SURM may motivate developers and owners to invest in BGI implementation and establish funding for municipal BGI development projects.[42]

The general use of BGI requires the **establishment of related norms**, which detail the performance and dimensioning of the tools. The adaptation of foreign norms (especially from Germany) could serve as a basis for this work, but also **local characteristics** must be considered by establishing and monitoring pilot projects, as seen in the case study of New York. An urgent task requiring further research is the update of outdated rainfall data and calculation methods. The runoff appraisal in the Őrmező housing estate revealed that **further laws and norms** that are not directly connected to water management can influence the implementation of SURM, e.g. road

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[41] Namely: the regulation of future development for brownfields; large public open space development projects; and involvement of and support for private owners (detached house owners and communities in the historic housing areas

[42] The rainwater fee and it's possible implementation forms in Budapest have been dicussed by several experts and the concept has an general acceptance amongst professionals.(Buzás et al. 2012)

design standards. Further research is needed to identify these documents and outline recommendations for the modification or extension of their content.

After establishment of the legal and financial background, the institutional framework of SURM must be formed. All the international case studies demonstrated that rainwater management needs a city-level strategic coordination. In Budapest, this could be achieved by the coordination of the City Development Office and participation of FCSM, Budapest Water Works, the Directorate of Water Management and further stakeholders (Figure 42).

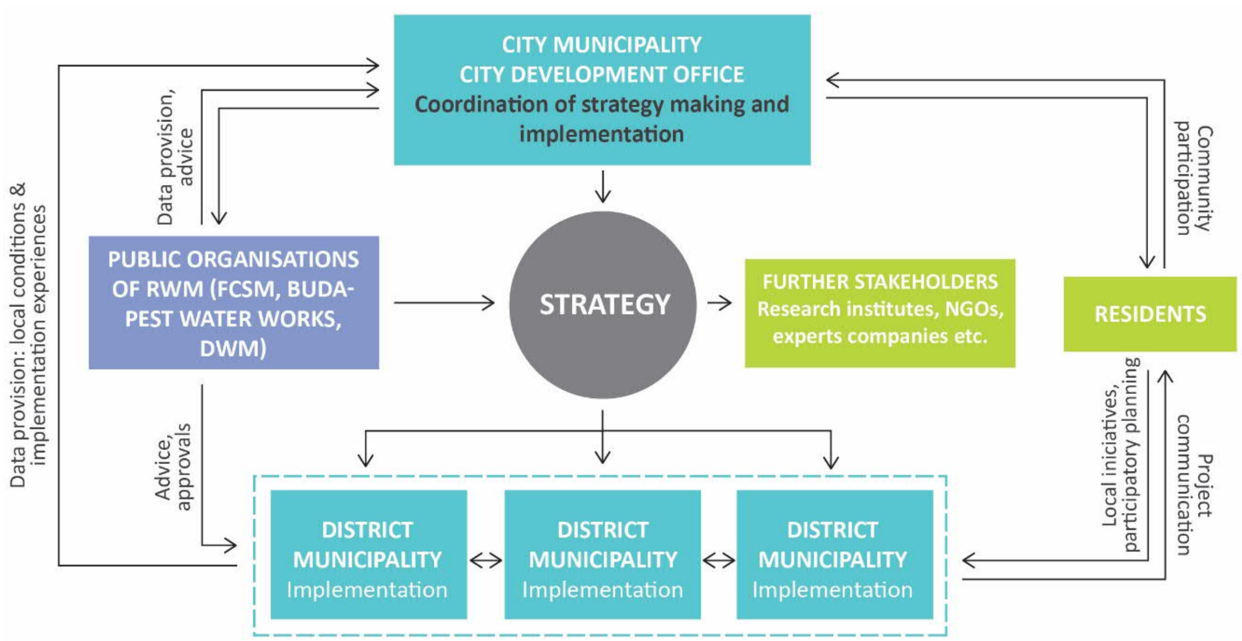

FIGURE 42: INTERACTIONS BETWEEN PUBLIC STAKEHOLDERS

Rainwater management needs **a permanent expert team within urban planning** that can organise a knowledge base, specify city-scale goals and follow up on the implementation progress. District municipalities should be responsible for coordinating the local implementation and sending feedback to the City Development Office. Horizontal and vertical communication must be established and strengthened among municipal stakeholders.

### 6.2.2 Anchoring SURM in the urban planning hierarchy

The international case studies and city-scale applicability assessment pointed out that the SURM planning should be tightly connected to both urban planning and overall urban water management. Therefore, an extension of the existing planning hierarchy is suggested.(Figure 43) Surveying and coordinating the water supply, wastewater, and rainwater infrastructures in Budapest present a complex engineering challenge, which requires a dedicated planning document. I recommend the extension of the Environmental Program of Budapest by establishing an **Integrated Water Management Strategy** to create a comprehensive analysis of the city’s water infrastructure and provide targets for the integrated development. The strategy could also include BGI as part of the water infrastructure system.

The establishment of a **Rainwater Management Program** is recommended to outline the mid-term goals (such as runoff targets) in the city's water catchment areas. This plan is similar to the existing Thematic Development Programs of Budapest. To form this plan, the active involvement of the district municipalities is required. The implementation in specific areas (e.g. large-scale green-area development in housing estates or school gardens) can be described by short-term **Rainwater Management Action Plans**.

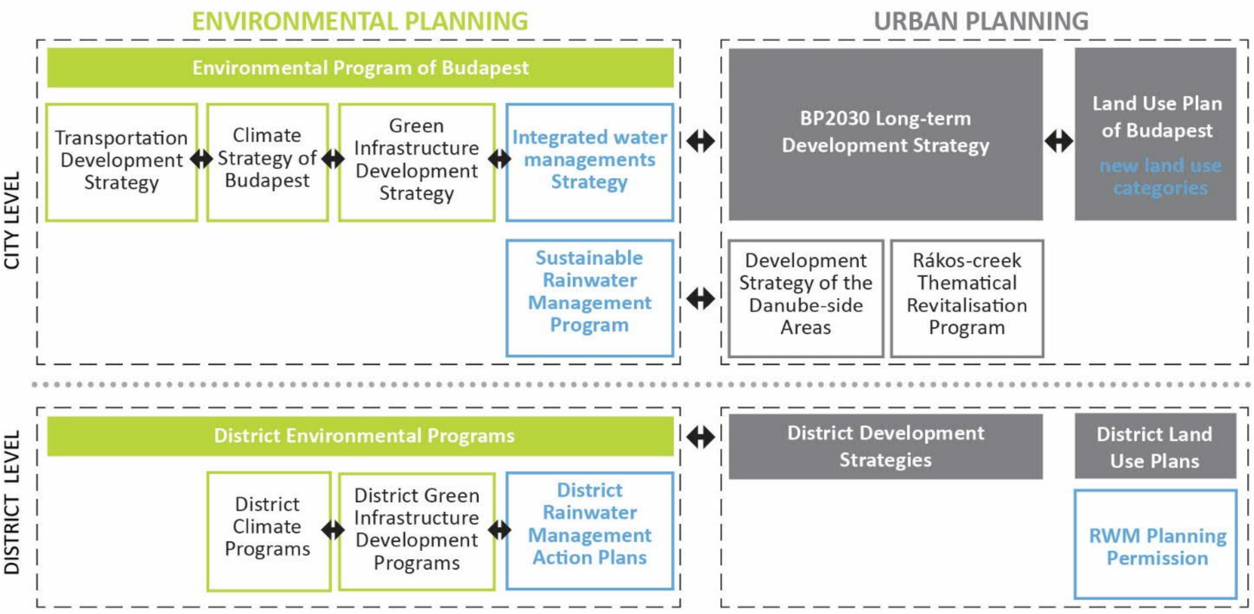

FIGURE 43: RECOMMENDATION FOR EXTENSION OF BUDAPEST'S PLANNING HIERARCHY

The SURM goals must also be considered during the land use planning process. **The goals and space demand of long-term SURM planning must be included in the Urban Development Strategy of Budapest**. The analysis of the city's land use categories showed that each category has unique characteristics for rainwater management. Based on this, the thesis suggests three methods to regulate SURM through land use planning:

1. **Revision of the minimum green area ratio**: this criterion is already defined in several categories. The revision of existing values is advised by considering the space demand of on-site RWM tools.
2. **Definition of a "maximum runoff ratio" value:** this new value can provide an easy-to-understand criterion for designers, which defines the maximum allowed runoff departing from a plot. The local runoff targets of the Rainwater Management Program could be customized for each urban block, under the same principle that building height is regulated.

3. **Establishment of a “water management buffer zone” category:** the previous two recommendations help to decrease plot runoff but cannot enforce the establishment of areas with a large storage capacity. Such areas could collect and retain runoff from the neighbouring areas or provide a water buffer against flash floods. The existing land use categories for water management do not allow the combination of water retention tools with other uses e.g. the integration of a retention lake into a housing estate. Therefore, the establishment of a new category is advised, which could overlap other categories and specify required retention targets. This solution would oblige developers of brownfields to include SURM from the start of the planning process.

To police the implementation in development projects, a new authorization plan type – the **Rainwater Management Authorisation Plan** – is recommended. This plan would inspect whether the required maximum runoff ratio is fulfilled by the design.

As mentioned in Chapter 2.3, several developed countries have evolved the approach to define the accepted retention goal using the natural runoff. This sensitive approach takes the local geophysical features (such as steepness or soil type) into account but demands a large base dataset and customized calculations. Based on this approach, the loss of water storage capacity caused by a new housing project can be rather accurately calculated and the **developer could be obliged to compensate** this loss by funding BGI development in another area of the city.[43] This method could ensure that the city’s water storage capacity does not further decrease by new developments and could provide important financial backing for municipal investments.

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[43] A similar system is used in the green area management of Munich: the reduction of green area must be compensated on the plot or immediate surrounding. If this is not possible, the developer finances a green area development project chosen by the municipality.(Hutter-von Knorrig, Blahak 2014)

# 7 Conclusion

This dissertation sought answers concerning the two research questions:

The first question involved investigation of the opportunities in landscape architecture for the improvement of our cities' climate resilience and liveability through the mitigation of urban impacts on the natural water cycle.

Initially, a comprehension of the problems and challenges in our existing urban rainwater management practice was gained, deepened by a short review of the historic development regarding the urban water infrastructure. Next, current research theories and principles of a more sustainable urban rainwater management approach were investigated. Important definitions and technical terms were compiled, which were recalled throughout the thesis. The phrase “sustainable urban rainwater management” was devised to describe the applied planning approach. Henceforth, the research introduced blue-green infrastructure tools and assessed their main properties based on the results of international research projects.

The second part of the international literature review focused on city-level SURM strategies. Three international case studies were investigated to analyse: the used approaches; measures and methods for the planning framework, analysis, decision-making, and the implementation. Finally, the three case studies were evaluated and compared based on the application of SURM planning principles.

The second research question investigated the implementation of SURM principles and measures in Budapest. The answer required an extensive analysis of the current situation regarding rainwater management and its synthesis with the findings from the international literature review.

The city’s geophysical and urban environmental factors were investigated to ascertain and compile the base dataset for the large-scale applicability assessment. In addition, the current institutional and legislative framework was introduced. The analysis indicated that Budapest’s land use categories provide a suitable framework for the investigation of SURM applicability. While the city has a definite potential and need for a more sustainable rainwater management approach, there is a lack of research in urban rainwater management to support its development. To fill this knowledge gap, a dual scale assessment of SURM applicability was developed and applied to the whole city area and in a specific study area.

In the first part of the assessment, a methodology was established for the large-scale analysis for the applicability of the SURM methods (infiltration, retention, evaporation). The assessment established applicability maps for the three SURM methods and identified development zones and land use categories with the highest benefits for BGI implementation.

The second part of the assessment evaluated the performance of BGI tools in a specific study area. Based on the results of the city-scale assessment, a socialist housing estate was chosen to assess the short-term and long-term impacts of BGI tools. The short-term assessment calculated the BGI retention capacity for both a normal (4-year) and a design (33-year) rain event. The tools were proven to be capable of reducing more than three-quarters of the study area's runoff. The long-term impact was estimated using annual water balance modelling. While the implemented BGI tools significantly increased the groundwater recharge, the evaporation did not improve compared to the current state. The assessment therefore concluded that BGI tools can effectively decrease the overall runoff and peak flow, however the high infiltration rate can reduce the positive effect on the urban climate. The BGI tool selection must be accomplished using annual water balance modelling in order to attain a certain increase of the evaporation rate.

In addition to the scientific results, the research laid out recommendations to reshape the legislative system and integrate SURM planning and control into the existing planning hierarchy. The results of this thesis will hopefully inspire further researches and contribute to the establishment of a future Sustainable Rainwater Management Plan for Budapest.

# Összefoglalás

A disszertáció két fő kutatói kérdésre keresett válaszokat. Az első kérdés a tájépítészeti tervezés azon lehetséges szerepét és eszközeit kutatta a városi vízgazdálkodáson belül, mely hozzájárulhat városaink klímaadaptációjához.

Ennek a kérdésnek a megválaszolását egy széleskörü nemzetközi irodalomkutatás és esettanulmány elemzés támasztotta alá. A problémák és kihívások megértéséhez röviden összefoglaltam a jelenlegi csapadékvíz-gazdálkodás kialakulásának történetét, valamint annak hatásait a vízháztartásra és a környezetre. Ezután ismertettem a fenntartható települési csapadékvíz-gazdálkodás (SURM) nemzetközi kutatási hátterének fontosabb elemeit és tervezési elveit. Bemutattam a témához kapcsódó definíciókat és lehatároltam a tézis által használt fogalmakat. A dolgozat több külföldi kutatás eredményeit szintetizálva összefoglalta az SURM tervezéséhez szükséges alapadatokat és ismertette a kék-zöld infrastruktúra tervezői elemeit.

Az irodalomkutatás második része három nemzetközi esettanulmány elemzésén keresztül mutatja be és a stratégiaalkotás folyamatát és annak eszközeit. A dolgozat A három város straégiaalkotási folyamatát értékeltem az SURM tervezés alapelveinek alkalmazása szempontjából.

A második kutatói kérdés a fenntartható csapadékvíz-gazdálkodás elveinek és eszközeinek Budapesti alkalmazási lehetőségeit kereste. A nemzetközi analízisben megalkotott vizsgálati módszertan alkalmazásával elemeztem a város természeti és épített adottságait, valamint a budapesti csapadékvíz-gazdálkodás jelenlegi jogi és szervezeti helyzetét. A vizsgálat megmutatta, hogy a budapesti szabályozási kategóriák megfelelö keretrendszert nyújtanak a fenntartható csapadékvíz-gazdálkodás alkalmazhatóságának elemzésére. A vonatkozó városfejlesztési tervek áttekintése feltárta, hogy bár az új tervezési szemlélet alkalmazására igény és szükség is lenne, hiányoznak a megalopozott városi szintü kutatások, amelyekre egy városi stratégiát építeni lehetne. Ennek a hiánynak a betöltésére saját módszertant alkottam a kék-zöld infrastruktúra alkalmazás kétszintű potenciálanalízisére. A Budapest adottságainak elemzése során gyűjtött adatok és a nemzetközi irodalomkutatás eredményeinek szintézise szolgáltattak alapot a vizsgálatokhoz.

A vizsgálat első részében az SURM három fő módszerének, a szikkasztásnak, a vízvisszatartásnak és a párologtatásnak az alkalmazhatóságát vizsgáltam Budapest városszövetében. A komplex térképes analízis három alkalmazhatósági térképet eredményezett a lehetséges alkalmazási területek és a kiemelkedö potenciálú területek feltüntetésével. A térképek összevetítésével kimutattam, hogy a város mely területei bírnak a legnagyobb jelentöséggel a kék-zöld infrastruktúra fejlesztés számára.

A vizsgálat második részében egy szocialista lakótelep példáján vizsgáltam a kék-zöld infrastruktúra fejlesztésének hatásait a lefolyásra és az éves vízmérlegre. A lefolyáscsökkentés számítását egy 4 és egy 33 éves gyakoriságú csapadékeseményre vonatkoztatva készítettem el. A kék-zöld infrastruktúra több mint háromnegyedével volt képes csökkenteni mindkét eset közvetlen lefolyását. Az éves vízmérlegre gyakorolt hatás számítása kimutatta, hogy míg az alkalmazott eszközök nagyban növelték a beszivárgást, a párolgás nem növekedett a jelenlegi állapothoz képest. A vizsgálat ezzel szemléltette, hogy míg a kék-zöld eszközök sikeresen csökkentik a lefolyást és a csapadékcsúcsot, a magas beszivárgás ezzel együtt csökkentheti az eszközök pozitív hatását is a környezetre. A kék-zöld infrastruktúraelemek klímaszabályozó hatásának érvényesítéséhez ezért vízmérleg modellezés alkalmazására van szükség a tervezés során.

A tudományos eredmények mellett a dolgozat gyakorlati ajánlásokat tett a fenntartható csapadékvíz-gazdálkodás budapesti alkalmazásának megvalósítására. A dolgozat eredményei újabb kutatások alapjául szolgálhatnak és remélhetően hozzájárulhatnak Budapest Csapadékgazdálkodási Tervének megszületéséhez.

# 8 References

## Books, book chapters

BARNES, D. S., BARNES, P. D. S. (2006): *The Great Stink of Paris and the Nineteenth-Century Struggle Against Filth and Germs*. JHU Press. 338 p.

BELÉNYESI P. (2018): Árazási kérdések a vízszolgáltatások piacán. In: *Verseny és szabályozás 2017*. Budapest

BENEDICT, M. A. (2006): *Green infrastructure: linking landscapes and communities*. Washington, DC: Island Press. 320 p.

BUZÁS, K., BUDAI PÉTER, CLEMENT ADRIENNE, HORVÁTH ADRIENN (2012): *Települési csapadékvíz-gazdálkodás*. Budapest: Terc Kiadó. 148 p.

CSIZMADIA, D. (2016): Die Rolle der Donau in der Entwicklung des ökologischen Netzwerks der Stadt Budapest. In: *Donau-Stadt-Landschaften*. Berlin

CSIZMADIA, D. (2018): *Vízérzékeny tervezés a városi szabadtereken*. Budapest: Budapesti Fővárosi Főpolgármesteri Hivatal. 88 p.

DÖVÉNYI, Z. (2010): *Magyarország kistájainak katasztere I-II*. Budapest: MTA FKI. 876 p.

DREISEITL, H., GEIGER, W. (2009): *Neue Wege für das Regenwasser: Handbuch zum Rückhalt und zur Versickerung von Regenwasser in Baugebieten*. München: Deutscher Industrieverlag. 266 p.

GEYLER, S., BEDTKE, N., GAWEL, E. (2013): *Nachhaltige Regenwasserbewirtschaftung - aktuelle Steuerungstendenzen im Siedlungsbestand*. 56 p.

J COOMBES, P., ROSO, S. (2019): Australian Rainfall and Runoff Book 9: Runoff in Urban Areas. In: *Australian Rainfall and Runoff*. Engineers Australia National Committee on Water Engineering. Vol. 9

JARRAUD, M., BOKOVA, I. (2012): *International Glossary of Hydrology*. Geneva: World Meteorological Organisation. 461 p.

KHOO, T. C., CHEW, V., CENTRE FOR LIVEABLE CITIES, SINGAPORE (EDS.) (2017): *The Active, Beautiful, Clean Waters Programme: water as an environmental asset*. Singapore: Centre for Liveable Cities. 93 p.

KÖRNER, Z. (2004): *A telepszerű lakásépítés története Magyarországon 1850-1945 - Urbanisztikai füzetek 3*. TERC Kft. 196 p.

NAGY, L. (1975): *Budapest története III. A török kiűzetéstől a márciusi forradalomig*. Budapest: Budapest Főváros Tanácsa. 594 p.

NAGY, M., ZSUZSA, K. (2006): *Az európai és a magyar telepszerű lakásépítés története 1945-től napjainkig*. Budapest: TERC Kft.

PITT, R., CLARK, S. E., LABORATORY (U.S.), R. R. E., PARMER, K. (1994): *Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration*. DIANE Publishing. 194 p.

PREISICH, G. (2004): *Budapest városépítésének története - Buda visszavételétől a II. világháború végéig*. Budapest: Terc Kiadó. 379 p.

PREISICH, G. (2004): *Budapest városépítésének története 1945-1990 - Tanulmányok.*

ROBINSON, Y. (2000): The European cholera epidemic, 1826-1837. In: M. Bradford & R. S. Carmichael (Eds.), *Natural disasters*. Salem Press. Vols. 1–3

## Papers

ÁCS F., BREUER H., SZÁSZ G. (2007): A tényleges párolgás és a talaj vízkészlet becslése tenyészidőszakban. In: *Agrokémia és Talajtan*, *56* (2) 217–236 pp.

AMINZADEH, M., OR, D. (2017): The complementary relationship between actual and potential evaporation for spatially heterogeneous surfaces. In: *Water Resources Research*, *53* (1) 580–601 pp.

BARBOSA, A. E., FERNANDES, J. N., DAVID, L. M. (2012): Key issues for sustainable urban stormwater management. In: *Water Research*, *46* (20) 6787–6798 pp.

BERLAND, A., SHIFLETT, S. A., SHUSTER, W. D., GARMESTANI, A. S., GODDARD, H. C., HERRMANN, D. L., HOPTON, M. E. (2017): The role of trees in urban stormwater management. In: *Landscape and Urban Planning*, *162* 167–177 pp.

BRABEC, E., SCHULTE, S., RICHARDS, P. (2002): Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. In: *Journal of Planning Literature*, *16* 499–514 pp.

BROWN, R. R., FARRELLY, M. A. (2009): Delivering sustainable urban water management: a review of the hurdles we face. In: *Water Science and Technology: A Journal of the International Association on Water Pollution Research*, *59* (5) 839–846 pp.

BROWN, R. R., KEATH, N., WONG, T. H. F. (2009): Urban water management in cities: historical, current and future regimes. In: *Water Science and Technology*, *59* (5) 847–855 pp.

BURIAN STEVEN J., EDWARDS FINDLAY G. (2012): Historical Perspectives of Urban Drainage. In: *Global Solutions for Urban Drainage*, 1–16 pp.

CHOU, L. M. (1998): The cleaning of Singapore River and the Kallang Basin: approaches, methods, investments and benefits. In: *Ocean & Coastal Management*, *38* (2) 133–145 pp.

COOMBES, P. J., BARRY, M. E. (2008): The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. In: *Australasian Journal of Water Resources*, *12* (2) 85–100 pp.

DIXON, A., BUTLER, D., FEWKES, A. (1999): Water saving potential of domestic water reuse systems using greywater and rainwater in combination. In: *Water Science and Technology*, *39* (5) 25–32 pp.

DOLMAN, N., OGUNYOYE, F. (2018): How water challenges can shape tomorrow's cities. In: *Proceedings of the Institution of Civil Engineers - Civil Engineering*, *171* (6) 22–30 pp.

FERGUSON, B. C., FRANTZESKAKI, N., BROWN, R. R. (2013): A strategic program for transitioning to a Water Sensitive City. In: *Landscape and Urban Planning*, *117* 32–45 pp.

GÁBOR, P., JOMBACH, S. (2008): A zöldfelület intenzitás és a városi hősziget jelenségeinek összefüggései Budapesten. In: *Falu város régió*, (1) 31–36 pp.

GHOFRANI, Z., SPOSITO, V., FAGGIAN, R. (2017): A Comprehensive Review of Blue-Green Infrastructure Concepts. In: *International Journal of Environment and Sustainability, 6* (1) pp.

GÖBEL, P., DIERKES, C., COLDEWEY, W. G. (2007): Storm water runoff concentration matrix for urban areas. In: *Journal of Contaminant Hydrology, 91* (1) 26–42 pp.

HABERL, R., PERFLER, R., MAYER, H. (1995): Constructed wetlands in Europe. In: *Water Science and Technology, 32* (3) 305–315 pp.

HAGHIGHATAFSHAR, S., JANSEN, J. la C., ASPEGREN, H., LIDSTRÖM, V., MATTSSON, A., JÖNSSON, K. (2014): Storm-water management in Malmö and Copenhagen with regard to climate change scenarios. In: *Vatten: Tidskrift För Vattenvård /Journal of Water Management and Research, 70* (3) 159–168 pp.

HAGHIGHATAFSHAR, S., LA COUR JANSEN, J., ASPEGREN, H., LIDSTRÖM, V., MATTSSON, A., JÖNSSON, K. (2014): Storm-water management in Malmö and Copenhagen with regard to Climate Change Scenarios. In: *VATTEN–Journal of Water Management and Research, 70* 159–168 pp.

KLEIN, H., KRAUTH, K. H. (1982): Menge und Beschaffenheit der Regenabfluesse von Autobahnen. In: *Schriftenreihe ag "Erd -und grundbau"* (363) 23–43 pp.

KONDO, M. C., LOW, S. C., HENNING, J., BRANAS, C. C. (2015): The Impact of Green Stormwater Infrastructure Installation on Surrounding Health and Safety. In: *American Journal of Public Health, 105* (3) 114–121 pp.

LEE, J. H., BANG, K. W. (2000): Characterization of urban stormwater runoff. In: *Water Research, 34* (6) 1773–1780 pp.

LI, H., DING, L., REN, M., LI, C., WANG, H. (2017): Sponge City Construction in China: A Survey of the Challenges and Opportunities. In: *Water, 9* (9) 594 pp.

LIM, H. S., LU, X. X. (2016): Sustainable urban stormwater management in the tropics: An evaluation of Singapore's ABC Waters Program. In: *Journal of Hydrology, 538* (Supplement C) 842–862 pp.

LIQUETE, C., KLEESCHULTE, S., DIGE, G., MAES, J., GRIZZETTI, B., OLAH, B., ZULIAN, G. (2015): Mapping green infrastructure based on ecosystem services and ecological networks: A Pan-European case study. In: *Environmental Science & Policy, 54* 268–280 pp.

LIU, L., JENSEN, M. B. (2017): Climate resilience strategies of Beijing and Copenhagen and their links to sustainability. In: *Water Policy, 19* (6) 997–1013 pp.

MAYS, L., ANTONIOU, G. P., ANGELAKIS, A. N. (2013): History of Water Cisterns: Legacies and Lessons. In: *Water, 5* (4) 1916–1940 pp.

MCLAUGHLIN, J., JONES, M., LEO, W., NEWMAN, T., STEIN, J. (2014): Green Infrastructure to Reduce Stormwater Runoff in New York City: Post-Construction Monitoring over Multiple Years and Lessons Learned. In: *ICSI 2014 - Creating Infrastructure for a Sustainable World. Proceedings of the 2014 International Conference on Sustainable Infrastructure,* 1001–9 pp.

MITCHELL, R., POPHAM, F. (2008): Effect of exposure to natural environment on health inequalities: an observational population study. In: *The Lancet, 372* (9650) 1655–1660 pp.

MULLANEY, J., LUCKE, T., TRUEMAN, S. J. (2015): A review of benefits and challenges in growing street trees in paved urban environments. In: *Landscape and Urban Planning, 134* 157–166 pp.

NORTON, B. A., COUTTS, A. M., LIVESLEY, S. J., HARRIS, R. J., HUNTER, A. M., WILLIAMS, N. S. G. (2015): Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. In: *Landscape and Urban Planning, 134* 127–138 pp.

NOWAK, D. J., CRANE, D. E., STEVENS, J. C. (2006): Air pollution removal by urban trees and shrubs in the United States. In: *Urban Forestry & Urban Greening, 4* (3) 115–123 pp.

RUBEL, F., KOTTEK, M. (2010): Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification. In: *Meteorologische Zeitschrift, 19* (2) 135–141 pp.

SACK, D. A., SACK, R. B., NAIR, G. B., SIDDIQUE, A. K. (2004): Cholera. In: *The Lancet, 363* (9404) 223–233 pp.

SANTAMOURIS, M. (2013): Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. In: *Renewable and Sustainable Energy Reviews, 26* 224–240 pp.

SANTOS, S. M. dos, DE FARIAS, M. M. M. W. E. C. (2017): Potential for rainwater harvesting in a dry climate: Assessments in a semiarid region in northeast Brazil. In: *Journal of Cleaner Production, 164* (Supplement C) 1007–1015 pp.

SPOSITO, V. A., FAGGIAN, R. (2013): Systemic Regional Development – A Systems Thinking Approach. In: *Informationen Zur Raumentwicklung, 1* 1–12 pp.

SUSCA, T., GAFFIN, S. R., DELL’OSSO, G. R. (2011): Positive effects of vegetation: Urban heat island and green roofs. In: *Environmental Pollution, 159* (8) 2119–2126 pp.

WHITE, M., SMITH, A., HUMPHRYES, K., PAHL, S., SNELLING, D., DEPLEDGE, M. (2010): Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. In: *Journal of Environmental Psychology, 30* (4) 482–493 pp.

WILSON, A. (2012): Water, power and culture in the Roman and Byzantine worlds: an introduction. In: *Water History, 4* (1) 1–9 pp.

WONG, T. H. F., BROWN, R. R. (2009): The water sensitive city: principles for practice. In: *Water Science and Technology, 60* (3) 673–682 pp.

## Dissertations

BUDAI, P. (2011): *A közúti közlekedés nehézfém kibocsátásának hatása a csapadékvizek szennyezettségére.* (Doctoral thesis) Budapesti Műszaki és Gazdaságtudományi Egyetem, Budapest

GANTNER, K. (2003): *Nachhaltigkeit urbaner Regenwasserbewirtschaftungsmethoden.* (Doctoral thesis) Technische Universität Berlin, Berlin

GAYER, J. (2004): *Települési csapadékvíz-elhelyezés az integrált vízgazdálkodás tükrében.* Budapesti Corvinus Egyetem, Budapest

HUTTER, D. (2015): *Budapest zöldfelületi rendszerének fejlesztése vasúti rozsdaterületek felhasználásáva*. (Doctoral thesis) Budapesti Corvinus Egyetem, Budapest

KANCZLERNÉ VERÉB MÁRIA (2012): *Budapesti lakótelepek és lakóparkok szabadtereinek elemzése a második világháborútól napjainkig*. Budapesti Műszaki és Gazdaságtudományi Egyetem, Budapest

SIEKER, Heiko (1999): *Generelle Planung der Regenwasserbewirtschaftung in Siedlungsgebieten*. (Doctoral thesis) Technische Universität Darmstadt, Berlin

SZABÓ, L. (2009): *A zöldtetőépítés hazai kilátásainak vizsgálata Budapest példáján*. (Bachelor thesis) Budapesti Corvinus Egyetem, Budapest

## Reports and strategies

BIHARI, Z., HOFFMANN, L., LAKATOS, M., MARTON, A., NÉMETH, Á., SÁBITZ, J., PÁLDY, A., BÓDI-KOÓS, N., KOVÁCS, A. (2015): *KRITéR – A klímaváltozás okozta sérülékenység vizsgálata, különös tekintettel a turizmusra és a kritikus infrastruktúrákra*. (No. EEA C12-13) Budakeszi: Országos Meteorológiai Szolgálat

BLOOMBERG, M. R. (2012): *NYC Green Infrastructure Plan: 2012 Green Infrastructure Pilot Monitoring Report*. New York, NY: New York City Department of Environmental Protection

Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály (2011): *Budapest Közmű Infrastruktúrája*. Budapest: Budapest Főváros Főpolgármesteri Hivatal

Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály (2017a): *Budapest főváros településszerkezeti terve.* Budapest: Budapest Főváros Főpolgármesteri Hivatal

Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály (2017b): *Budapest főváros településszerkezeti terve. Helyzetfeltáró, helyzetelemző és helyzetértékelő munkarész.* Budapest: Budapest Főváros Főpolgármesteri Hivatal

Budapest Főváros Önkormányzata (2014): *Barnamezős területek fejlesztése tematikus fejlesztési program*. (Development program) Budapest: Budapest Főváros Főpolgármesteri Hivatal

Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály (2012): *Budapest 2030 Long-Term Urban Development Concept*. (Long-Term Urban Development Concept) Budapest: Budapest Főváros Főpolgármesteri Hivatal

CSIMA, G., SZÉPSZÓ, G., KRÜZSELYI, I., SZABÓ, P., HORÁNYI, A., BARTHOLY JUDIT, PIECZKA ILDIKÓ, PONGRÁCZ RITA, TORMA CSABA (2010): *Összefoglaló Magyarország éghajlatának várható alakulásáról.* Budapest: Országos Meteorológiai Szolgálat

COWI, KU-LIFE, DMI, DELOITTE, RAMBOLL (2011): *Copenhagen Climate Adaptation Plan*. Copenhagen: City of Copenhagen

DE BLASIO, B., SAPIENZA, V. (2019): *NYC Stormwater Management Program*. New York, NY: New York City Department of Environmental Protection

DELARIA, M. (2008): *Low Impact Development as a Stormwater Management Technique*. Denver: The Rocky Mountain Land Use Institute

DWA (2018): *Wasserbilanz-Expert – Handbuch. Software zum Arbeitsblatt DWA-A 102.* DWA

HUTTER-VON KNORRIG, S., BLAHAK, K. (2014): *Ausgleichsflächen. Gesamtstädtisches Konzept und Umsetzung*. München: Landeshauptstadt München, Referat für Stadtplanung und Bauordnung

MATZINGER, A. RIECHEL, M. C- REMY, H. SCHWARZMÜLLER, P. ROUAULT, M. SCHMIDT, M. OFFERMANN, C. STREHL, D. NICKEL, PALLASCH, M. SIEKER, H. KÖHLER, M. KAISER, D. MÖLLER, C. (2017): *Zielorientierte Planung von Maßnahmen der Regenwasserbewirtschaftung - Ergebnisse des Projektes KURAS*. Berlin

MILLENIUM ECOSYSTEM ASSESSMENT BOARD (2005): *Ecosystems and human well-being*. (Synthesis Report) Washington, DC: Millenium Ecosystem Assesment Board

MONIGL I. (1983): *Az utolsó nagy kolerajárvány demográfiai képe Európában és az Egyesült Államokban (1872 - 1873)*. (Központi Statisztikai Hivatal Népességtudományi Kutató Intézetének Kutatási Jelentései No. 9) Budapest: Központi Statisztikai Hivatal Népességtudományi Kutató Intézet

NEW YORK DEP (2010): *New York Green Infrastructure Plan*. New York: City of New York

NEW YORK DEP (2018): *New York Green Infrastructure Plan Annual Report 2017*. New York: City of New York

NEW YORK DEP (2019): *New York Green Infrastructure Plan Annual Report 2018*. New York: City of New York

NOVAK, J. RÜHMLAND, S. RUSTIGE, H. POST, M. SOMMER, H. (2018): *Leistungsfähigkeit von Praxiserprobten Formen der dezentralen und zentralen Regenwasserbewirtschaftung im urbanen Kontext.* Berlin: Senatsverwaltung für Umwelt, Verkehr und Klimaschutz Berlin

Országos Vízügyi Felügyelőség (2017): *Nemzeti Vízstratégia*. Budapest: Országos Vízügyi Felügyelőség

PUBLIC UTILITIES BOARD, SINGAPORE (2018): *ABC Waters Design Guidelines*. Singapore: Public Utilities Board, Singapore

ROLSTON, A., ELEANOR JENNINGS, SUZANNE LINNANE (2014): *Towards Integrated Water Management (TIMe)*. (No. 2014- W- DS-20) Wexford: Environmental Protection Agency

SIEKER, H, PETERS, C., JIN, Z., ECKART, J. (2011): *Assessing future uncertainties associated with urban drainage using flexible systems – the COFAS method and tool*. (Sustainable Water Management in the City of the Future No. 018530-SWITCH) Berlin

SIEKER, H. (2018): *Planungshilfe für eine dezentrale Straßenentwässerung.* Berlin: Berlin Senatsverwaltung für Umwelt, Verkehr und Klimaschutz

SOMLYÓDY LÁSZLÓ (2011): *Magyarország vízgazdálkodása: helyzetkép és stratégiai feladatok*. (Köztestületi Stratégiai Programok) Budapest: Magyar Tudományos Akadémia

TATAI, Z., BÓDI-NAGY, A., OROSZ, I., SZŐKE, B., BEDŐCS, B. (2018): *Budapest klímastratégiája*. Budapest: Budapest Főváros Önkormányzata

TATAI Z., ZÉTÉNYI D., OROSZ I., HORVÁTH A., BECSÁK P., PÁLVÖLGYI T., SIMON A., MOLNÁR Z. (2017): *Budapest Környezeti Programja*. Budapest: Budapest Főváros Önkormányzatának Főpolgármesteri Hivatala Városigazgatóság Főosztály

TATAI, ZS. MÁRTONFFY, M. MACZÁK, J. DEÁK, K. E. HÁMORI, P. KERESZTES-SIPOS, A. RADNÓCZI, P. M. SZILÁGYI, K. (2017): *Budapest zöldfelületi* *rendszerének fejlesztési koncepciója. Helyzetelemzés és értékelés.* Budapest: Budapest Főváros Önkormányzata

United Nations (2017): *Transforming Our World: The 2030 Agenda for Sustainable Development*. (agenda No. A/RES/70/1) New York, NY: United Nations

United States Environmental Protection Agency (2012): Terminology of Low Impact Development. Distinguishing LID from other Techniques that Address Community Growth Issues. EPA, Office of Wetlands, Oceans, and Watersheds

UTE, A., ANDRÁS, I. (2017): *Budapest Főváros Településszerkezeti Terve III. kötet.* Budapest: Budapest Főváros Főpolgármesteri Hivatal Városfejlesztési Főosztály

VM Környezetügyekért Felelős Államtitkárságának Vízügyért Felelős Helyettes Államtitkársága (2013): *Nemzeti Vízstratégia a vízgazdálkodásról, öntözésről és aszálykezelésről*. Budapest: Vidékfejlesztési Minisztérium

VTK INNOSYSTEM KFT. (2018): *A Hosszúréti-patak által okozott vízkárok értékelése, valamint kockázatcsökkentési terv elkészítése*. Budapest

WALDHOFF, A. BISCHOFF, G. SCHMITT, T. G. KRIEGER, K. ZIEGLER, J. (2015): *RISA Strukturplan Regenwasser 2030. Zukunftsfähiger Umgang mit Regenwasser in Hamburg*. Hamburg: Hamburger Behörde für Umwelt und Energie

World Commission On Environment and Development (1987): *Our Common Future*. World Commission on Environment and Development

World Resources Institute (2005): *Millenium Ecosystem Assessment. Ecosystems and human well-being*. Washington DC: World Resources Institute

## Online sources

ÁCS A., KOVÁCS K., KOVÁTS N., STENGER-KOVÁCS C. (2012): Természetes vizek védelme. Digitális Tankönyvtár. In: https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2010-0012_termeszetes_vizek_vedelme/ch03.html. Accessed: 2019. 1. 20.

ANDREAS HASTRUP CLEMMENSEN, ANNE HAUGVALDSTAD, ANNE JENSEN (2015): Implementation of the Copenhagen “Cloudburst” Strategy (Copenhagen, Denmark). In: https://base-adaptation.eu/implementation-copenhagen-cloudburst-strategy-copenhagen-denmark. Accessed: 2020. 2. 16.

BERKELMANS, M. VAN HERK, S. SHAFFER, P. GERSONIUS, B (2019): Valuation tools for strong narratives around Blue Green Infrastructure: a possible solution for bridging the finance gap in climate adaptation? In: https://www.ecca2019.eu/valuation-tools-for-strong-narratives-around-blue-green-infrastructure-a-possible-solution-for-bridging-the-finance-gap-in-climate-adaptation/ Accessed: 2019. 1. 22.

BM OVF Területfejlesztési Tervezési Főosztály (2016): Felszíni víztestek (folyó- és állóvizek) integrált ökológiai minősítése a VGT2 alapján, 2015. Map. In: http://www.terport.hu/tematikus-terkepek/felszini-viztestek-folyo-es-allovizek-integralt-okologiai-minositese-a-vgt2-alapj. Accessed: 2020. 01. 04. BM OVF

DAFT LOGIC (2020): Google Maps Find Altitude. In: https://www.daftlogic.com/sandbox-google-maps-find-altitude.htm. Accessed: 2020. 3. 17.

Deutsche Wetterdienst (2020): Deutscher Wetterdienst - KOSTRA-DWD. In: https://www.dwd.de/DE/leistungen/kostra_dwd_rasterwerte/kostra_dwd_rasterwerte.html. Accessed: 2020. 2. 13.

Direction des Espaces Verts Agence d'Écologie Urbaine Mairie de Paris (2015): Paris Climate & Energy Action Plan. Paris: Mairie de Paris

Fővárosi CSatornázási Művek Zrt. (2020): Fővárosi Csatornázási Művek Zrt. - Tulajdonosok. In: http://www.fcsm.hu/ceginformacio/tulajdonosok/. Accessed: 2020. 2. 29.

GLEN, J. (2014): An introduction to Sustainable Urban Drainage Systems. In: https://www.thenbs.com/knowledge/an-introduction-to-sustainable-urban-drainage-systems. Accessed: 2018. 10. 22.

Magyar Közút Nonprofit Zrt. (2020): Téli üzemeltetéssel kapcsolatos információk. In: https://internet.kozut.hu/teli-uzemeltetessel-kapcsolatos-informaciok/. Accessed: 2020. 2. 28.

Magyar Meteorológiai Szolgálat (2018): A fagyos és a hőség napok éves számának idősora (Homogenizált, interpolált országos átlagok alapján) a tízéves mozgó átlaggal és a becsült lineáris trenddel 1901–2016 között. Diagram. In: https://www.met.hu/eghajlat/eghajlatvaltozas/megfigyelt_valtozasok/Magyarorszag/ Accessed: 2018. 10. 22.

MAMMARÓZA (2014): *Budai rakpart kékóra*. Photo. In: http://indafoto.hu/mammaroza/image/20641665-9c87e648

NASA (2017): What's the Difference Between Weather and Climate? In: http://www.nasa.gov/mission_pages/noaa-n/climate/climate_weather.html. Accessed: 2019. 1. 22.

OASIS HUB (2018): Germany - Heavy precipitation return periods (KOSTRA) - DWD. In: https://oasishub.co/dataset/germany-heavy-precipitation-return-periods-dwd. Accessed: 2020. 2. 13.

PAGODASHOPHOUSE (2011): Before and After Aerial View of Kallang River. In: https://commons.wikimedia.org/wiki/File:Before_and_After_Aerial_View_of_Kallang_River.jpg. Accessed: 2020. 2. 28.

RAMBOLL AND RAMBOLL STUDIO DREISEITL (2016): The Copenhagen Cloudburst Formula: A Strategic Process for Planning and Designing Blue-Green Interventions. 2016 ASLA Professional Awards. In: https://www.asla.org/2016awards/171784.html. Accessed: 2020. 2. 15.

RASMUSSEN, J (2016): The economics of managing heavy rains and stormwater in Copenhagen – The Cloudburst Management Plan. In: https://climate-adapt.eea.europa.eu/metadata/case-studies/the-economics-of-managing-heavy-rains-and-stormwater-in-copenhagen-2013-the-cloudburst-management-plan. Accessed: 2020. 2. 16.

ROBIN, K. C. (2018): Water Quality Law in the US and EU: A Comparison of the Clean Water Act and Water Framework Directive. In: https://www.europenowjournal.org/2018/12/10/water-quality-law-in-the-us-and-eu-a-comparison-of-the-clean-water-act-and-water-framework-directive/. Accessed: 2020. 2. 27.

SIEKER (2018): Concept of decentralized stormwater management. In: https://www.sieker.de/en/fachinformationen/dealing-with-rainwater/article/konzept-der-dezentralen-regenwasser-bewirtschaftung-76.html. Accessed: 2018. 8. 17.

STRICKLAND, C. H. (2012): Case study - The NYC Green Infrastructure Plan. In: https://www.c40.org/case_studies/the-nyc-green-infrastructure-plan. Accessed: 2020. 2. 17.

Újbuda Önkormányzata (2019): Budapest XI. kerület, Újbuda Önkormányzata térinformatikai rendszer. In: https://terinfo.ujbuda.hu/. Accessed: 2020. 2. 9.

US EPA (2015, September 30): What is Green Infrastructure? In: https://www.epa.gov/green-infrastructure/what-green-infrastructure. Accessed: 2018. 10. 22.

VINCZE, D. (2016): Az éghajlati elemek időbeli és térbeli változásai magyarországon párolgás, légnedvesség, köd, felhőzet. In: https://docplayer.hu/14047641-Az-eghajlati-elemek-idibeli-es-terbeli-valtozasai-magyarorszagon-parolgas-legnedvesseg-kod-felhizet.html. Accessed: 2020. 3. 1.

## Conference presentations

ABELLÁN, J. (2017): Water supply and sanitation services in modern Europe: developments in 19th-20th centuries. Presented at the XII International Congress of the Spanish Association of Economic History. Salamanca

ANDÓ, A., TOLMÁCS, D. (2015): Városi környezeti állapot „monitoringja” és problémái a budapesti településgeológiai kutatások keretében. Presented at the Magyar Hidrológiai Társaság XXXIII. Országos Vándorgyűlés. Szombathely

BABÁK. K. (2002): A hullámterek jelentősége Magyarországon. In: Presented at the Földrajzos Doktoranduszok VII. Országos Konferenciája. Budapest

BÍRÓ, B. (2019): A főváros zöldfelület-gazdálkodási rendszere. Presented at the Green City Conference. Budapest

BROWN, Rebekah R., NINA, K., TONY WONG (2008): Transitioning to Water Sensitive Cities: Historical, Current and Future Transition States. Presented at the 11th International Conference on Urban Drainage

## Laws and standards

1995/LVII: 1995 Törvény a vízgazdálkodásról. Országgyűlés

2000/60/EC: 23 October 2000 Directive of the European Parliament and of the Council of establishing a framework for Community action in the field of water policy. Pub. L. No. 32000L0060, 327 (2000) European Parliament

2007/60/EC: 23 October 2007 Directive of the European Parliament and of the Council of on the assessment and management of flood risks. Pub. L. No. 32007L0060, 2007/60/EC (2007) European Parliament

DWA-A 138 2005: Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser. DWA.

DWA-A117: 2013 Bemessung von Regenrückhalteräumen. DWA

DWA-A 102: 2016 *Grundsätze zur Bewirtschaftung und Behandlung von Regenwetterabflüssen zur Einleitung in Oberflächengewässer - Entwurf*. DWA

DIN 1986-100: 2016 Entwässerungsanlagen für Gebäude und Grundstücke – Teil 100: Bestimmungen in Verbindung mit DIN EN 752 und DIN EN 12056. Beuth

## Further sources

Department of Environment and Forests: Information plate, Mossman Gorge, Daintree National Park. In: Mossman, Australia. (2019)

GERÖFI-GERHARDT, A. (2017, October 17): Interview with András Geröfi-Gerhardt department leader, Department of Operations, Budapest Sewage Works Pte Ltd. In: [Telephone interview]

Interview with the Law Department of the General Directorate of Water Management. (2017, September 10): [Telephone interview]

Magyar Kereskedelmi és Vendéglátóipari Múzeum: Dunapartie piac. Dinnyevásár. Postcard. (1916) Budapest

OSZOLY, T. (2015, October 17): Interview with Tamás Oszoly, Technical Deputy Manager of the Budapest Sewage Works Pte Ltd. In: [Personal interview]

RÁCZ, T. (2015, October 17): Interview with Tibor Rácz, Director of the Flood Protection Department, Budapest Sewage Works Pte Ltd. In: [Personal interview]

RÁCZ, T. (2016): Budapest és környezetének vízrajzi térképe. In: Budapest: Fővárosi Csatornázási Művek

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# 10 Annexes

## 10.1 Historical overview and urban impacts on the rainwater management

The challenge of controlling urban water flow originates from the time when first human settlements were established – the early phase of water management from ancient times to the industrialization is summarized in Annex 1. This short review focuses on the intense technical development phase of European water management from the 19th century until today and provides some further details specifically to the development of Budapest. From the second half of the 20th century, environmental consciousness gained constantly greater importance and determined the approaches of contemporary water management. Therefore, the introduction of this ecological learning process is also a subject of the historical review. The fields of urban water management (water supply, wastewater management and rainwater management) are closely connected, therefore – with an emphasis on rainwater aspects – all three disciplines are reviewed.

### The early phase of urban water management

Advanced urban water management and efficient resource management were already employed in ancient civilizations. The advancement of stormwater management depended on the local climate and terrain. Stormwater drainage was essential in steep or rainy areas, while developed water harvesting had a higher importance in areas with water shortages. The two types of urban drainage, the ***combined*** and ***separate sewage system***[44] were invented in the ancient periods. The introduction of separate stormwater drainages was usually found in areas with dry climates, where water collection had a higher importance. Some civilisations, such as cities in the Indus River Valley even relied on biological water cleansing systems. Wastewater flowing out from buildings was connected first by terracotta pipes to a sump where solid particles settled and subsequently a cleaner fluid reached the public channel. (Burian Steven J., Edwards Findlay G. 2012 pp. 2–3)

In Europe, advanced ancient Mediterranean cultures developed the first complex urban water management systems. Due to local climate, drinking water collection and distribution were the

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[44] Combined sewaege system: a single pipe system, where stormwater and wastewater flows mixed in the channel. Separate sewage system: A double pipe system, where stormwater wastewater is separated.

most important technical achievements. Technological inventions were primarily or solely accessible by wealthy social groups and special industrial processes with high water demand. As an example, the first complex water supply and drainage systems in Minos included aqueducts and pressured pipe systems using terracotta pipes to supply the Minoan palaces and the textile and metal production. (Abellán 2017). In Late Classical and Hellenic culture, urban drainage and sewage systems were already common infrastructure, and many middle-class houses were built with bathrooms.

In the Roman Empire, water infrastructure technology advanced to a high level. The widespread provision of drinking water was an advantage for the military. The Romans developed an advanced technology, which allowed them to access fresh water throughout the entire empire and transport water sometimes from a source more than 100km away. The water supply system is the most fragile infrastructure: a road system with deficiencies or that is incomplete is still useable for traffic, whereas a single impairment on a water pipe may disrupt the whole supply. The complexity of the technical solutions retroacted on the social and legislative system: organisation of planning, maintenance, and usage regulation of urban water supply and complex rural irrigation systems required the implementation and improvement of legislation. Control and provision of water supply became a powerful political tool. Baths served as venues for important forums, places of informal meetings and political discussions. Landscape elements such as aqueducts and urban water features such as fountains, ornamental pools and baths emerged as a symbol of the Roman culture and its political power. (Wilson 2012)

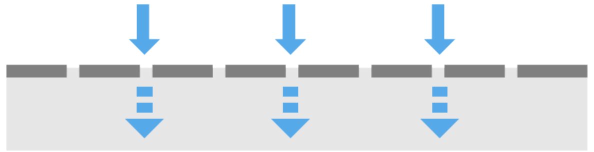
Urban planning often integrated urban stormwater management into the cityscape: curbs and gutters were implemented into roadways to direct surface runoff to rock-lined open drainage channels. Rainwater was often collected from rooftops and led into cisterns located in the interior of houses.(Mays et al. 2013 p. 1923)

Due to its complexity and single legislative body, the water supply system collapsed almost everywhere after the fall of the Roman Empire and the vast knowledge in water management virtually lost. A lack of public services forced citizens to migrate away from urban centres into smaller settlements that were close to rivers. (Burian Steven J., Edwards Findlay G. 2012 p. 6) Water supply in most cities consisted mainly of fountains or collected from streams and rivers.(Abellán 2017 p. 5) Urban drainage comprised of simple open ditches primarily for the purpose of stormwater drainage (human faeces was collected and used in gardens). As the population of cities grew, this system started to become unsustainable. Bigger cities such as Paris began covering the ditches in order to prevent citizens from disposing of garbage and household

## 10.2 : Design Tools of the blue-green infrastructure planning

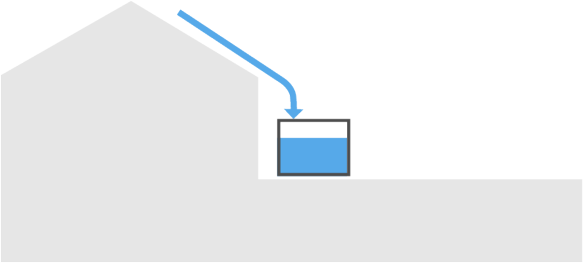
### PERMEABLE PAVING

Paving types made from permeable material or large gaps that allow rainwater to infiltrate.



### HARVESTING TANKS

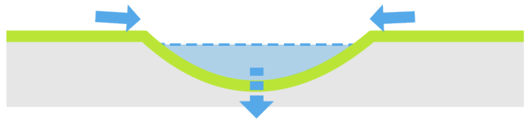
Above-ground water harvesting tanks can be directly connected to the roof runoff.



(Source: SuSanA Secretariat, www.flickr.com/photos/gtzecosan/5981896147/)

### SWALE & RAIN GARDEN

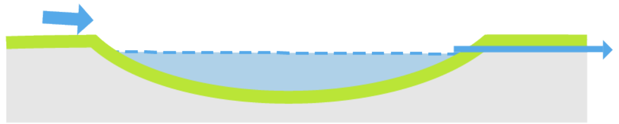
Depression of the surface extends the infiltration of green areas with temporary storage capacity.



(Source: Berliner Wasserbetriebe, www.bwb.de/de/1052.php)

### DETENTION BASIN /DRY POND

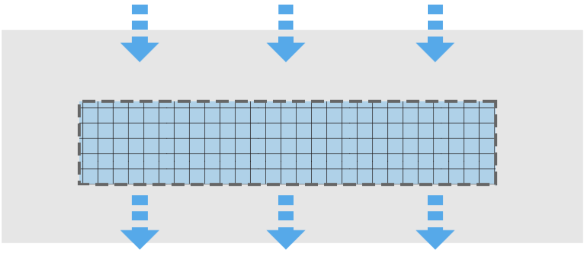
Large surface depressions with temporary water coverage to decrease the runoff peak.



(Source: Jiří Komárek, commons.wikimedia.org)

### UNDERGROUND INFILTRATION

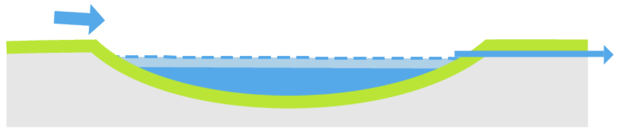
Underground infiltration tools, such as retention boxes or gravel infiltration zones can be applied when no permeable surface is available



(Source: ACO, www.aco.hu/termekek)

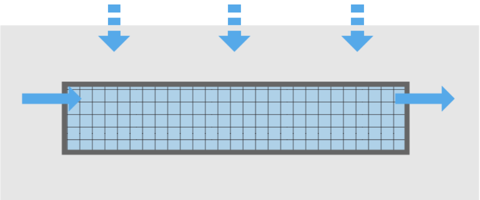
### RETENTION BASIN / WET POND

Permanent wet depression with high storage capacity, which can permanently retain stormwater.



## UNDERGROUND RETENTION

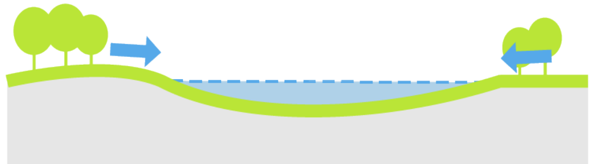
Technically similar to underground infiltration tools but infiltration is prevented by an impervious layer.



(Source: Arbitrarily0, commons.wikimedia.org)

## FLOODABLE OPEN SPACES

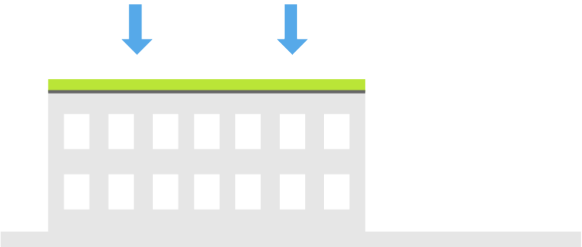
Large green areas and squares designed for temporary water storage can unload the drainage system and decrease peak runoff in large cloudbursts.



(Source: D. Ramboll Studio Dreiseitl)

## GREEN ROOF

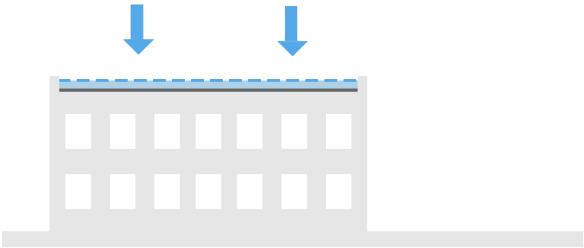
Vegetated, extensive or intensive roofs with both retention and detention effects. Structural limitations may restrict integration.



(Source: Green Roof at Walter Reed CC, https://www.flickr.com/photos/arlingtonva/3926468274)

## BLUE ROOF

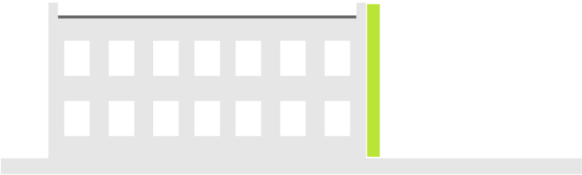
Roof surfaces designed as shallow basins, which can retain rainwater until it evaporates.



(Source: Credit Valley Conversation 2018)

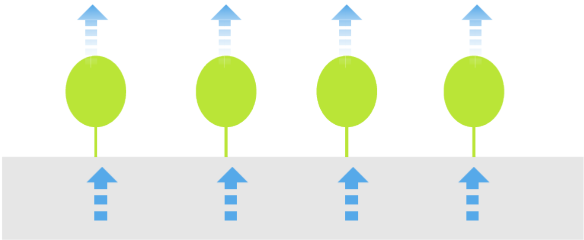
## GREEN FACADE

Vertical vegetation rooted in the ground or a special planting system of the wall. It has a relatively low water storage capacity but similar to trees, can play a significant role in shading and cooling by evaporation.



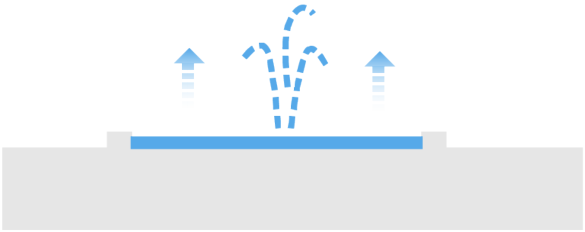
## TREE PLANTING

City trees absorb a large amount of water from the soil and evaporate it. They serve as the most efficient urban climate regulation tools in areas with a high sealed area ratio.



## WATER FEATURE

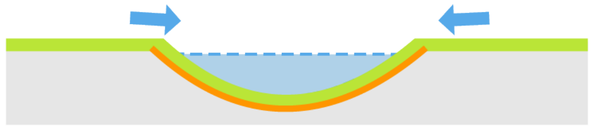
Water features mostly use potable water due to hygienic reasons, nevertheless should be mentioned as an important BGI tool for evaporation in dense urban areas.



(Source: Ramboll Studio Dreiseitl

## BIORETENTION SWALE

Vegetated swales with temporary water coverage and with special vegetation and soil layer. Microorganisms of the fine core soil layer filter out pollutants by physical and biological cleansing processes.



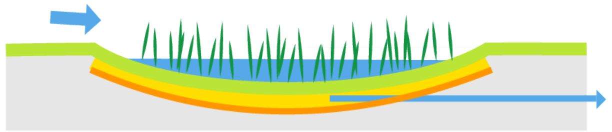
(Source: Aaron Volkening, commons.wikimedia.org/)

## OPEN DRAIN

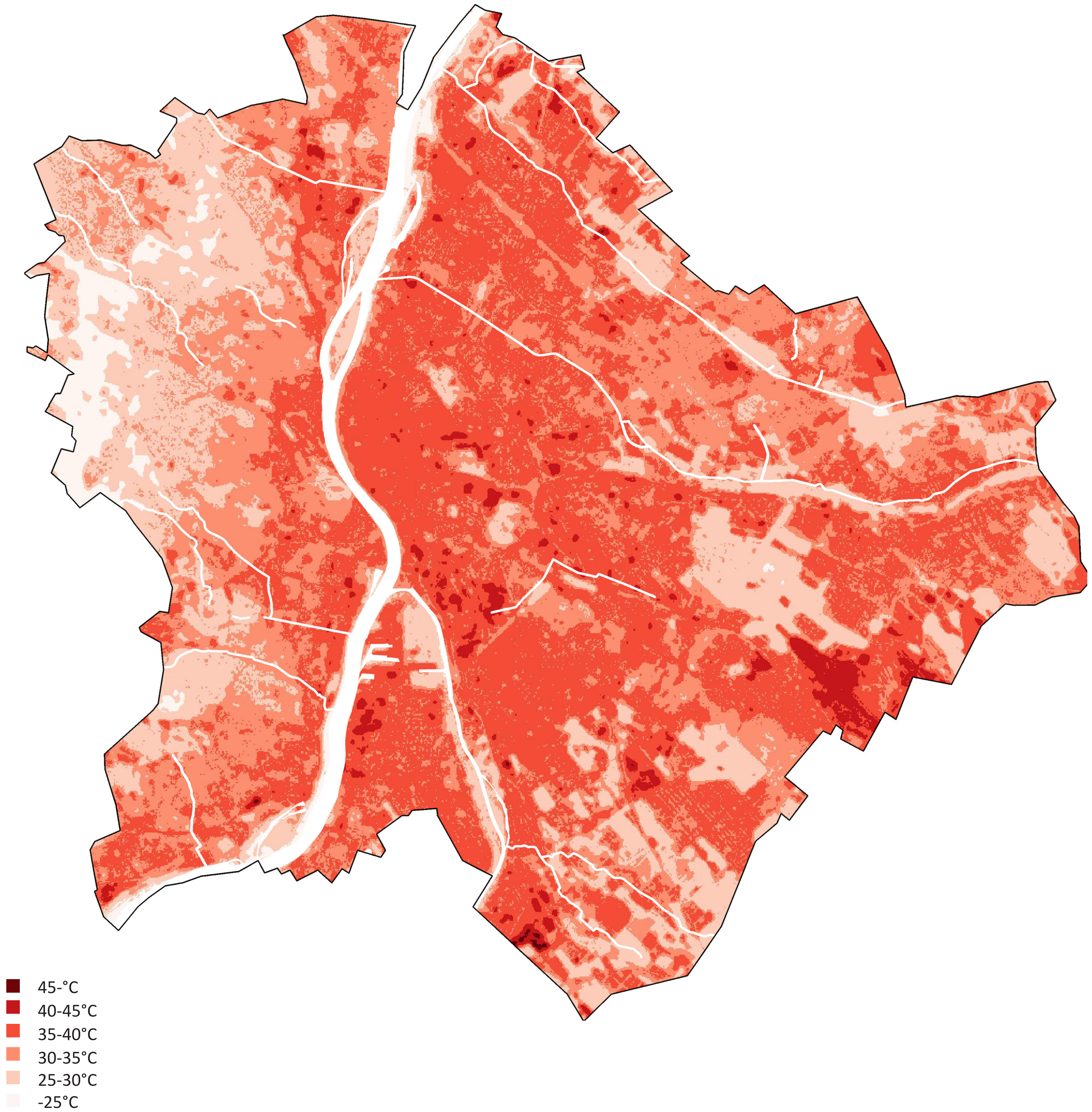
Open-air conveyance of water from a surface to a water management tool. Their use is advantegous due to easy maintenance and the deisgn potential in urban areas.

## CONSTRUCTED WETLAND

Large surface water cleansing areas with vegetation and permanent shallow water coverage. Micro-organisms of the fine core soil layer filter out pollutants by physical and biological cleansing processes.

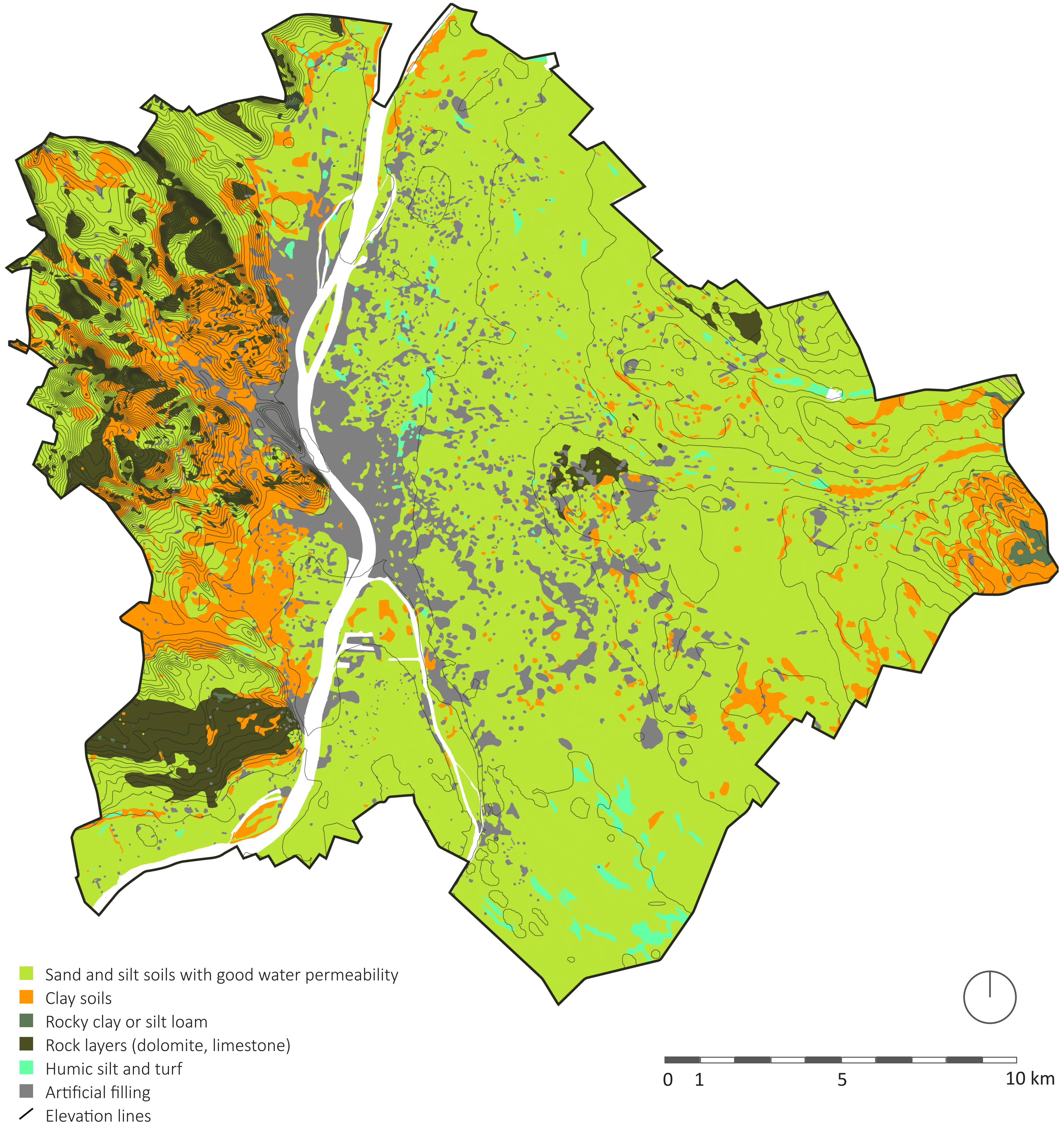


## 10.3: Analysis maps of Budapest´s geophysical and urban environmental factors



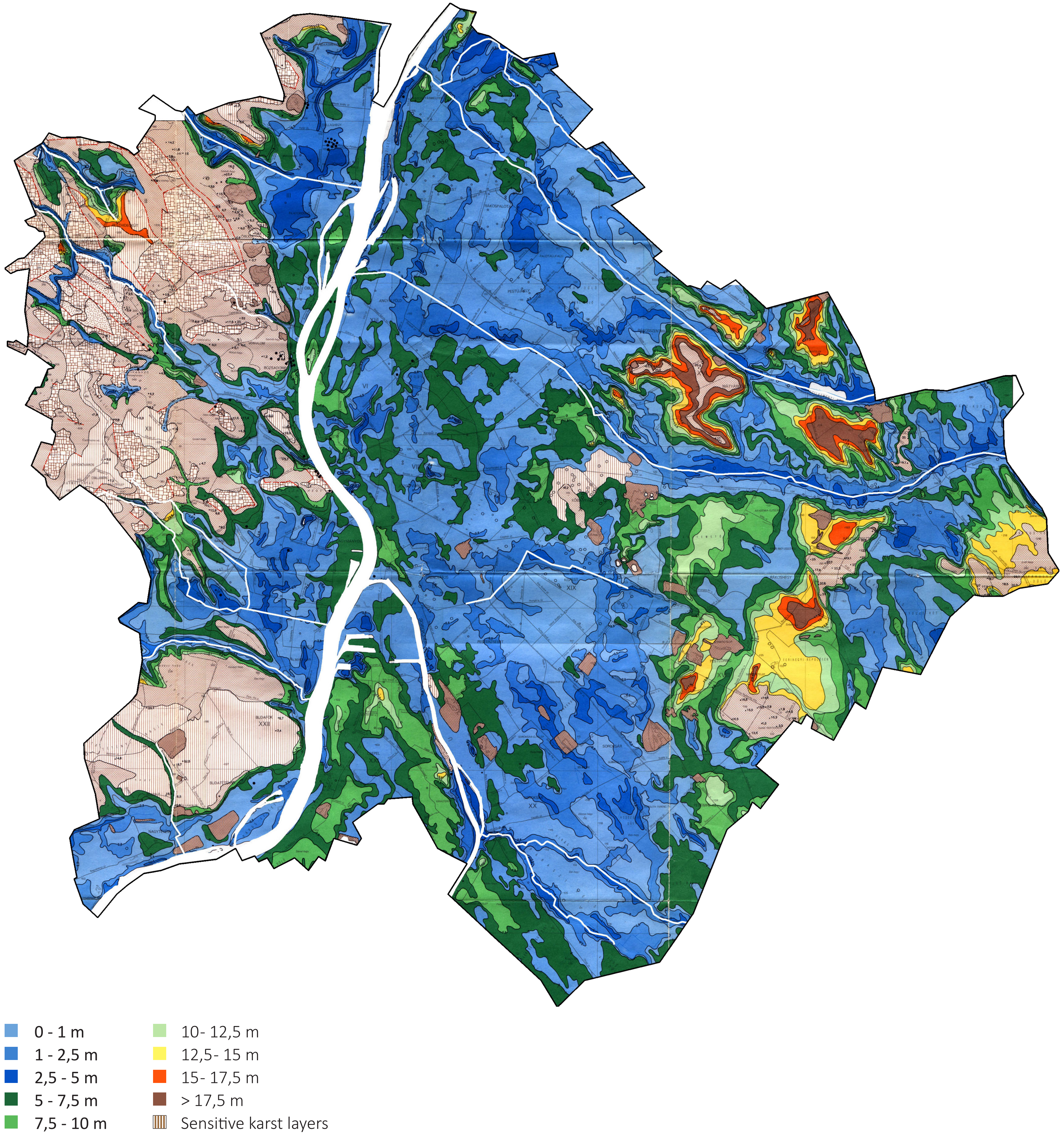
**Map 1: Heat map of Budapest**

(Source: Tatai Zsombor et al., 2017)



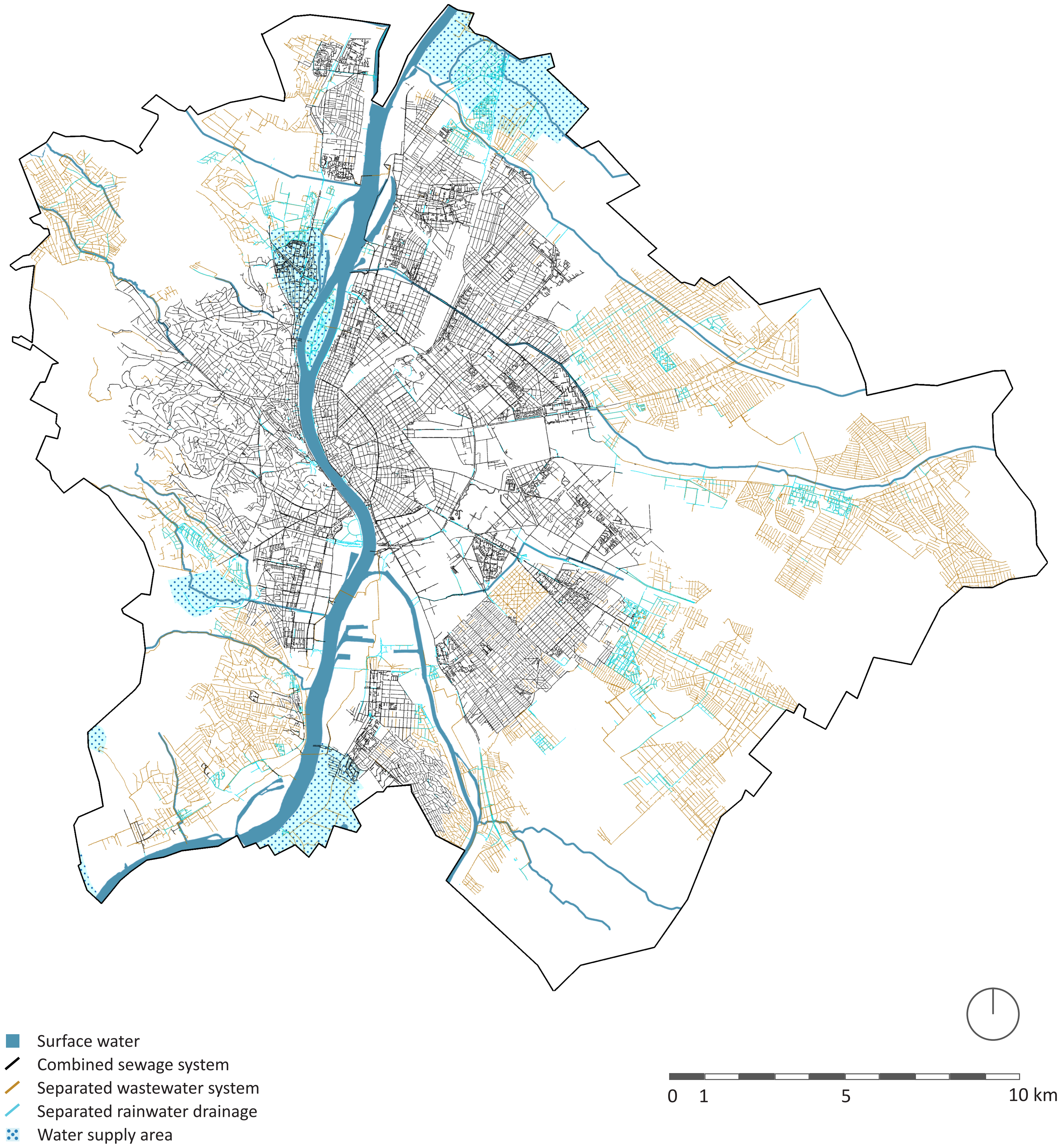
**Map 2: Terrain and soil types of Budapest**

(Source: raw data from Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály, 2011, p. 224, recompiled by D. Csizmadia)



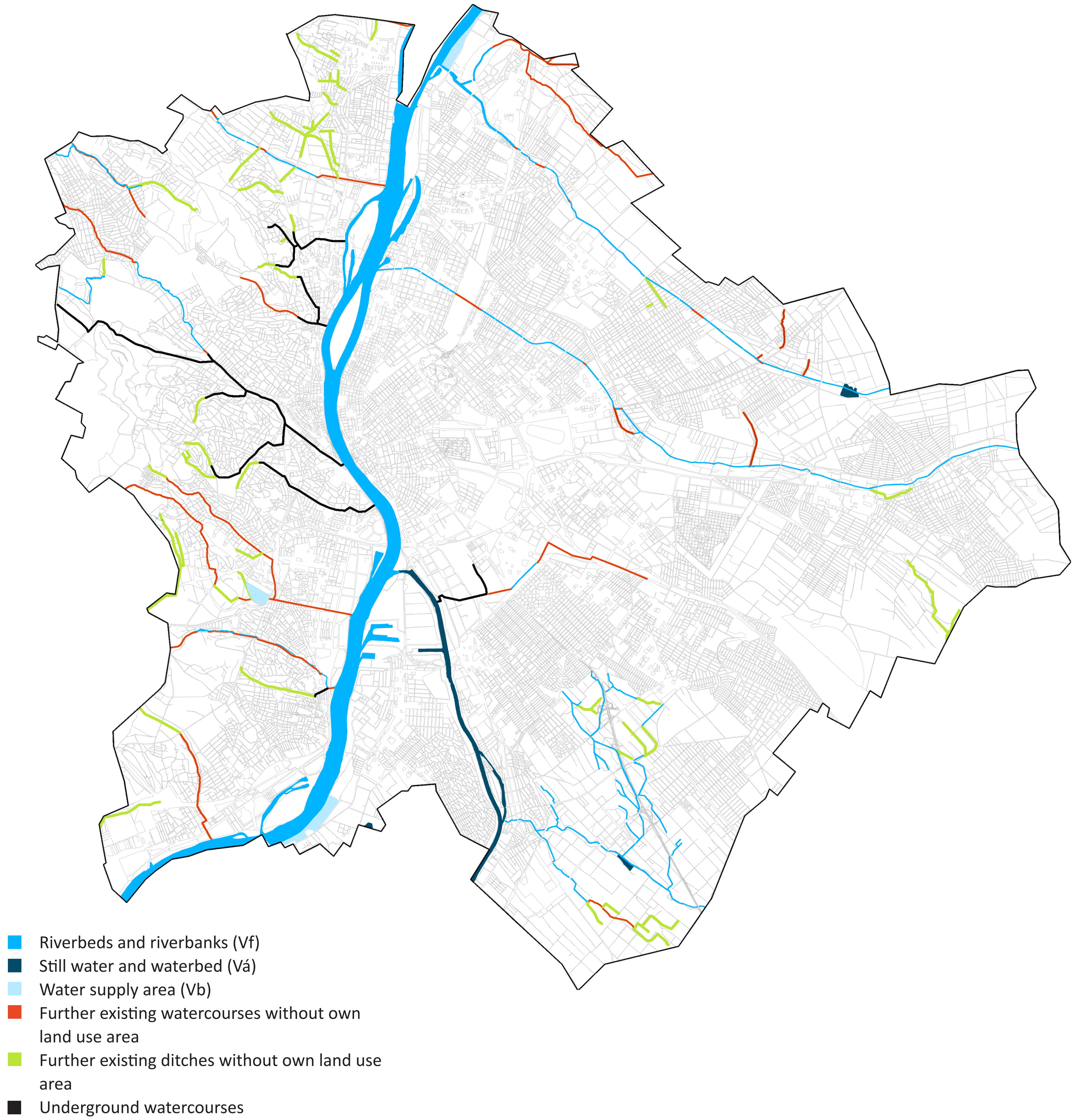
**Map 3: Ground water level map of Budapest**

(Source: Kisdiné Bulla, Raincsákné Kosáry, 1983 edited by D. Csizmadia)



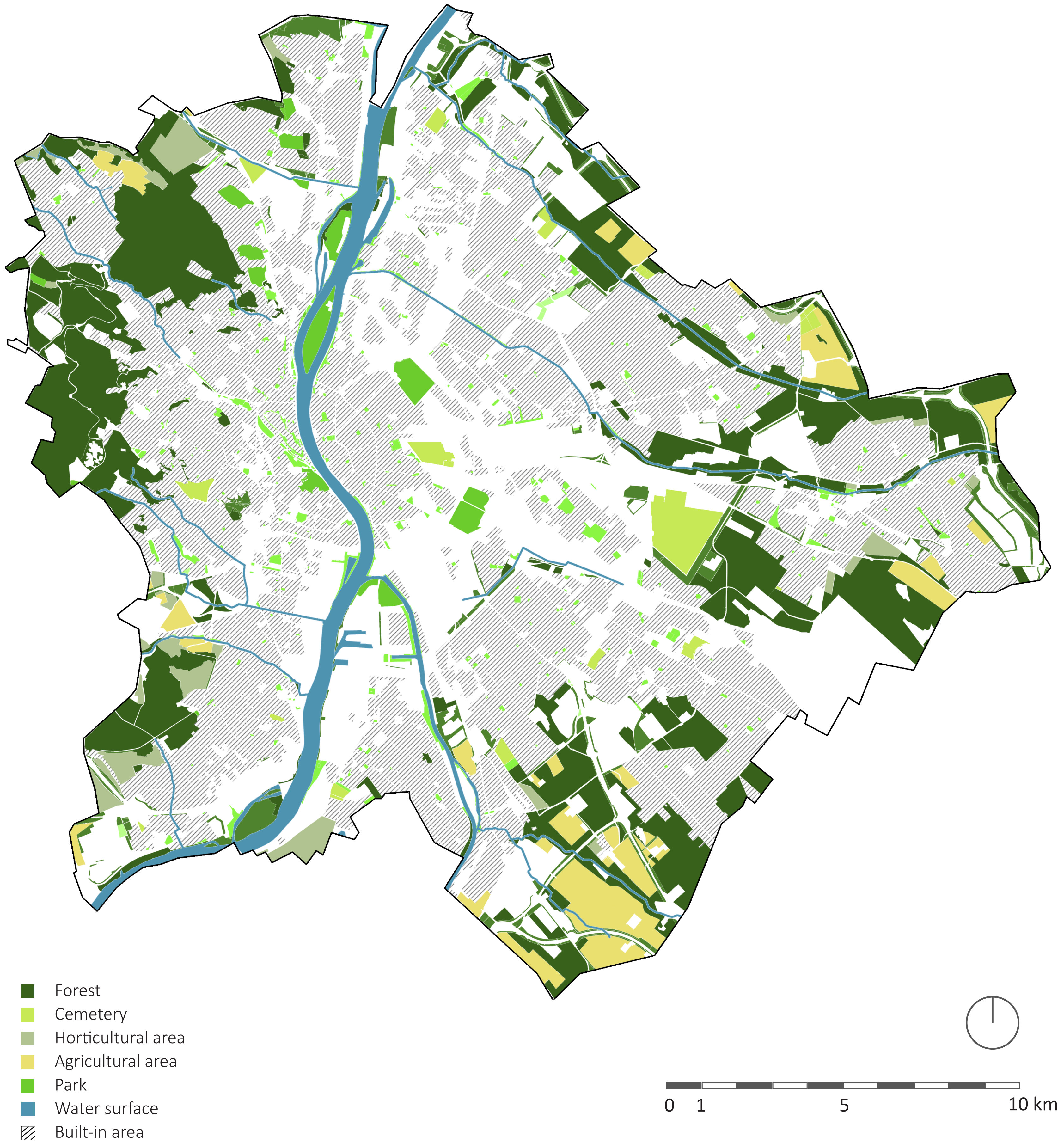
**Map 4: Sewage and drainage system**

(Source: raw data from Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály, 2011, p. 224, recompiled by D. Csizmadia)



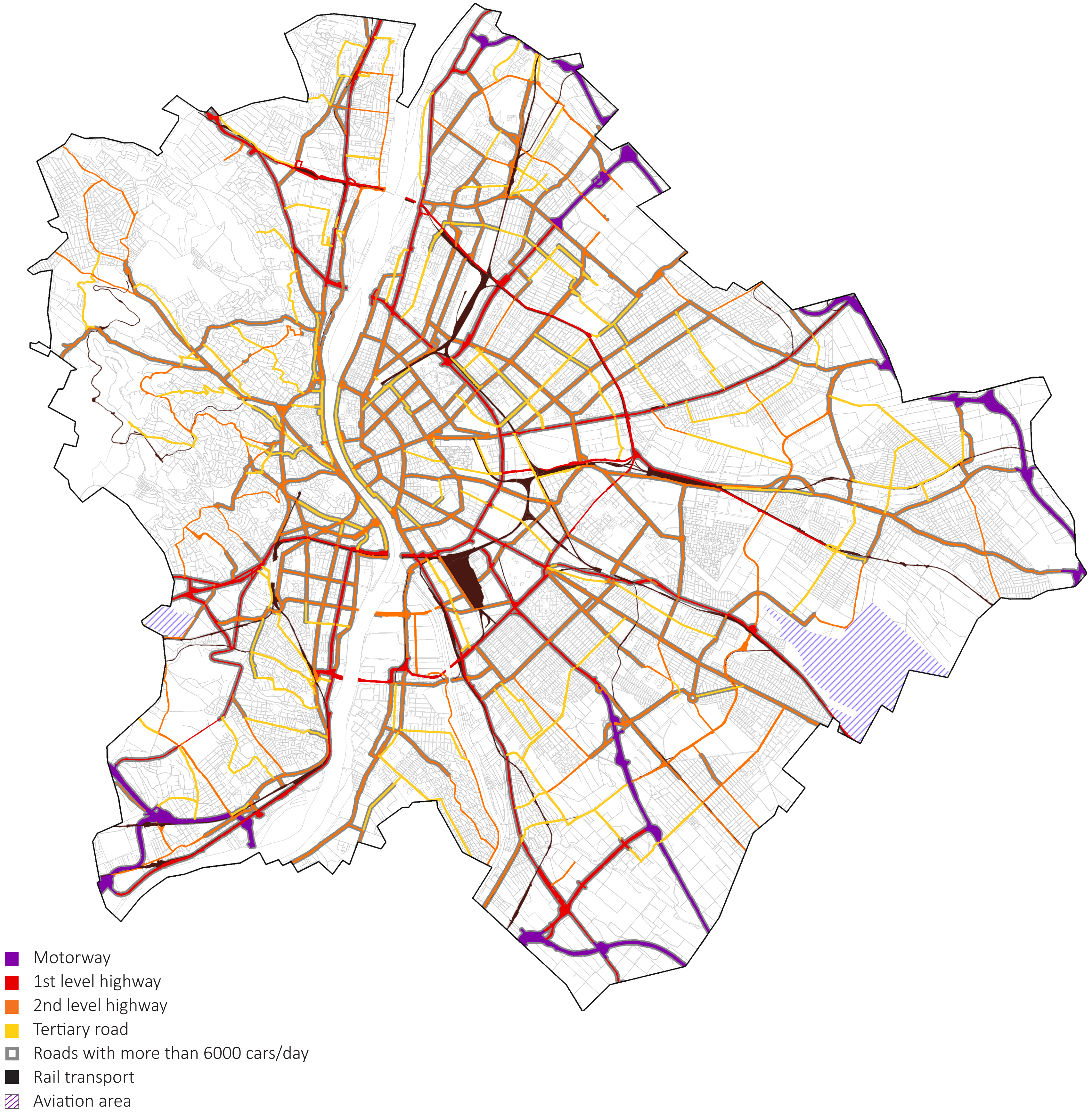
**Map 6: Water management land use group**

(Source: Raw data from (Rácz, 2016) and (Budapest Főváros Főpolgármesteri Hivatal Városépítési Főosztály, 2011, p. 224), recompiled and edited by D. Csizmadia )

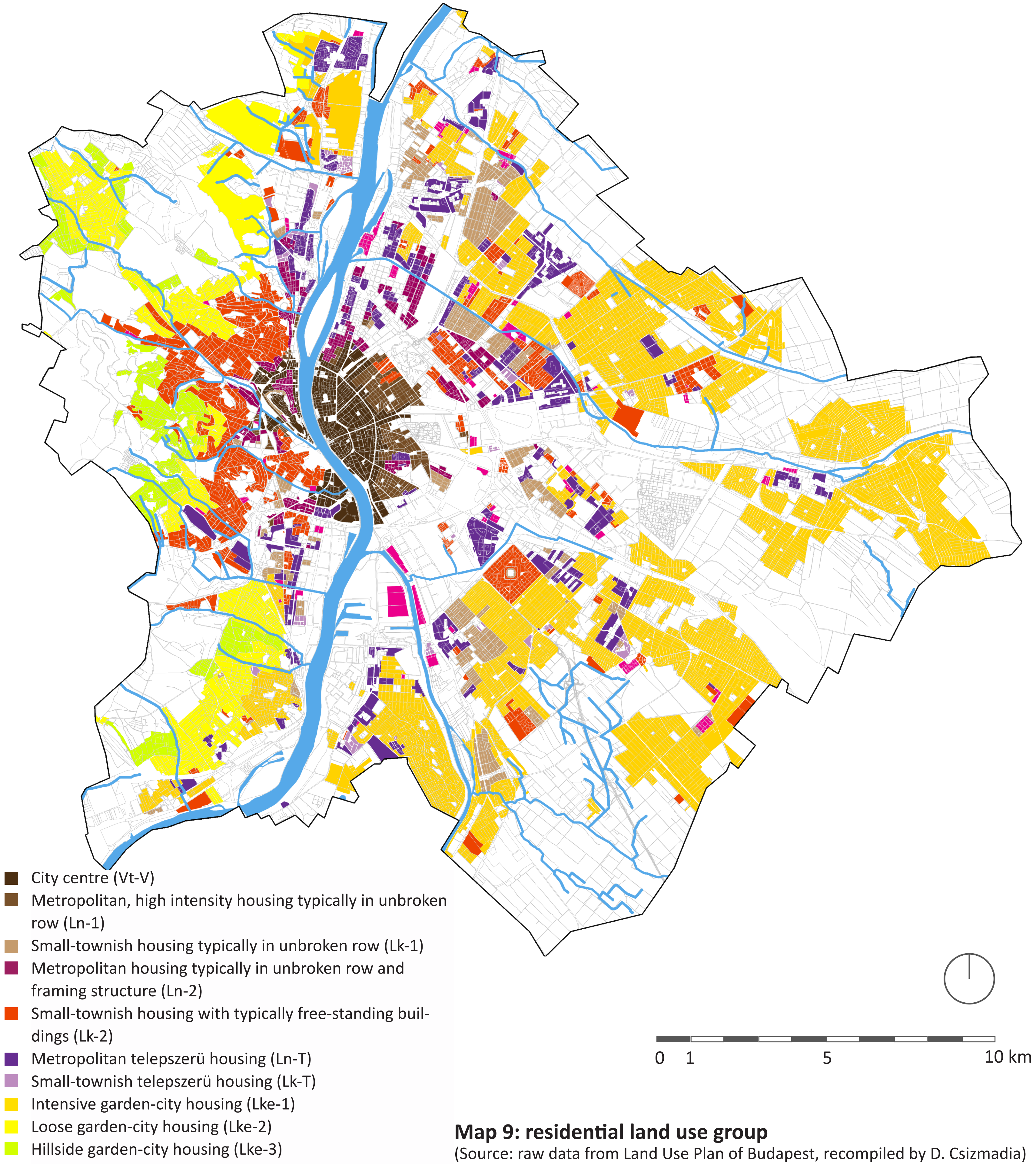


**Map 7: Green area land use group**

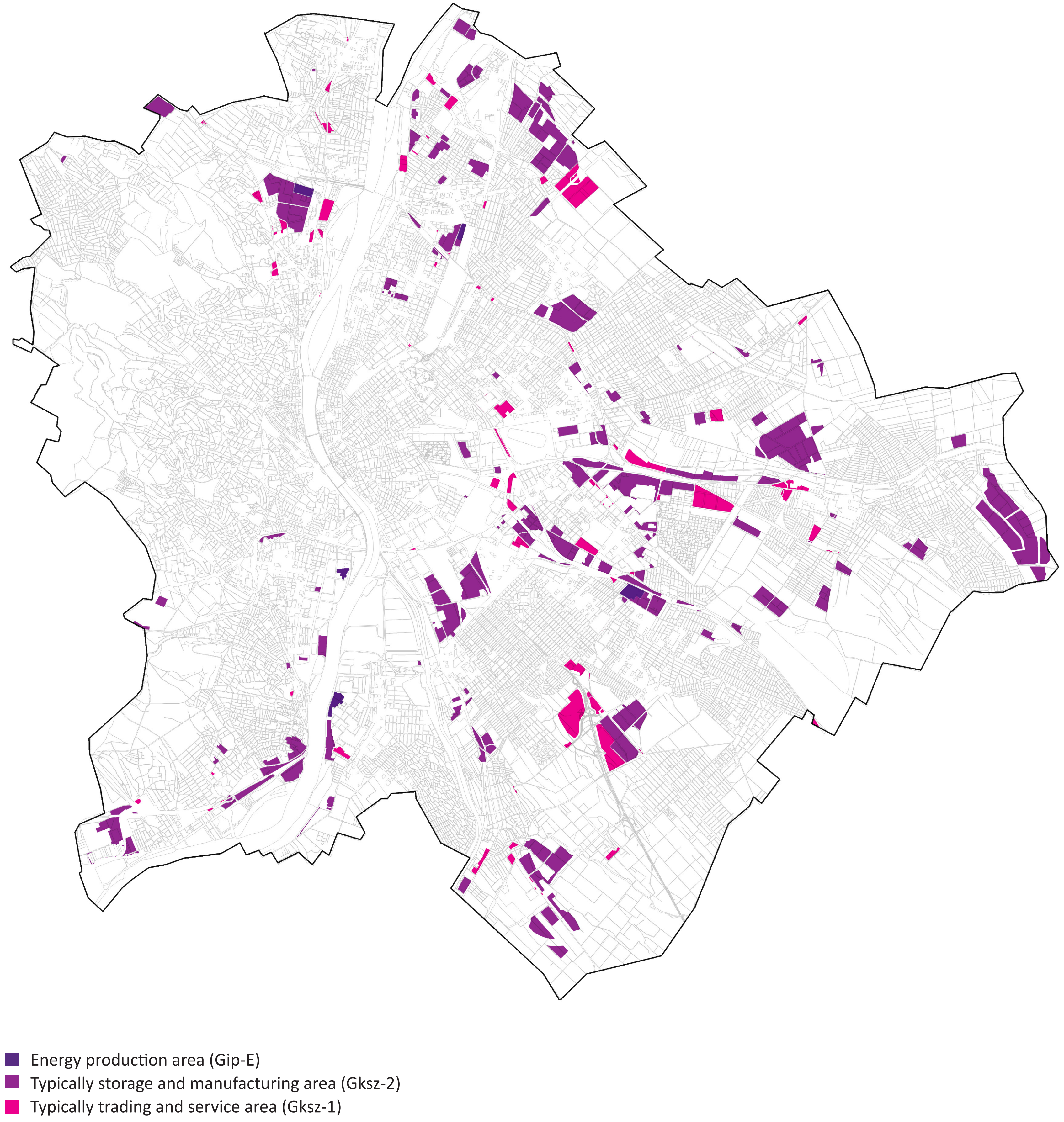
(Source: raw data from Land Use Plan of Budapest, recompiled by D. Csizmadia)



**Map 8: Transportation land use group**
(Source: raw data from Land Use Plan of Budapest, recompiled by D. Csizmadia)

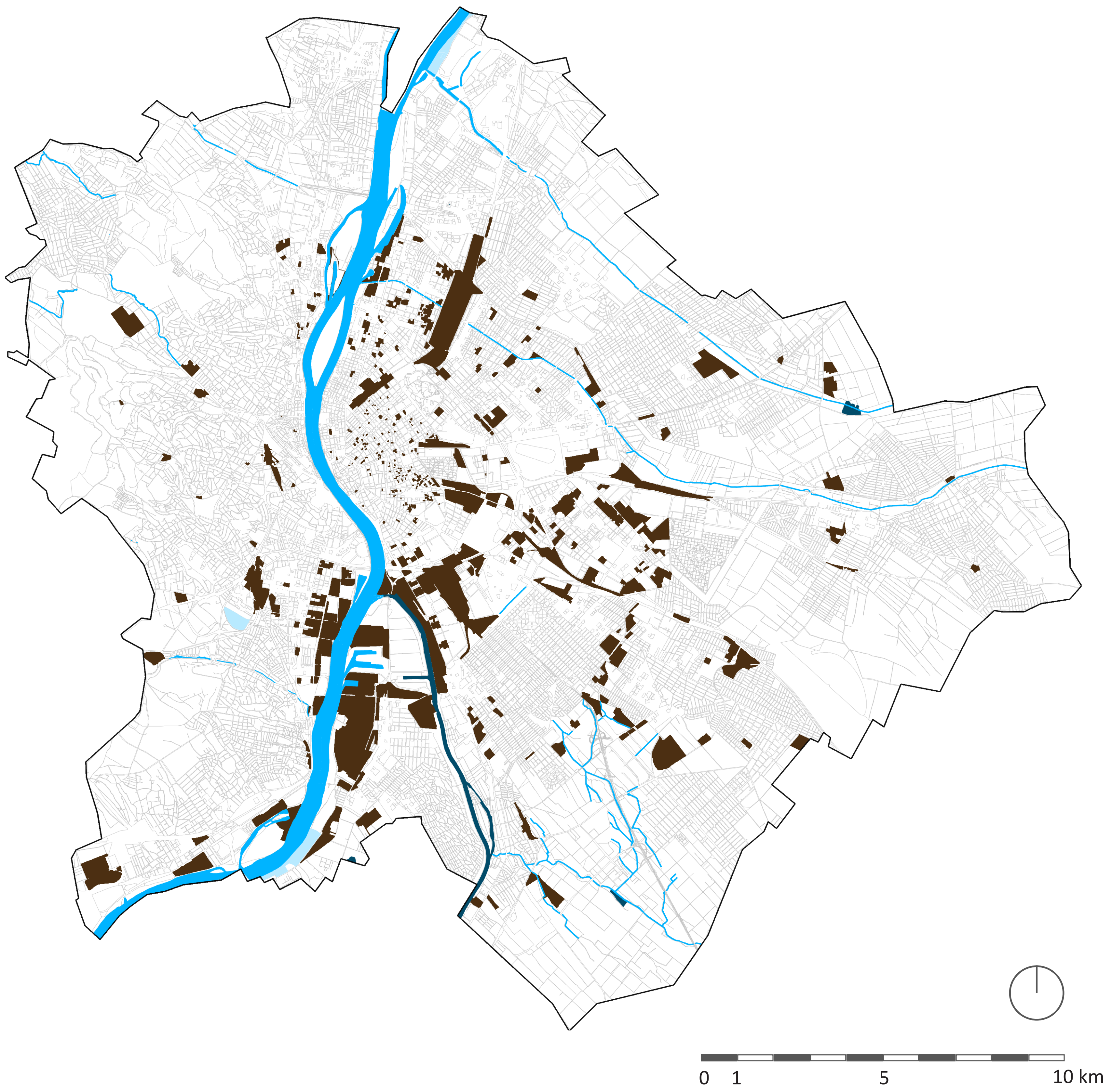


**Map 9: residential land use group**
(Source: raw data from Land Use Plan of Budapest, recompiled by D. Csizmadia)



**Map 10: Commercial land use group**

(Source: raw data from Land Use Plan of Budapest, recompiled by D. Csizmadia)



**Map 11: Brownfields land use group**

(Source: raw data from the Brownfield Cadastre of Budapest, recompiled by D. Csizmadia)

## 10.4: Assessment table of the effect of geophysical and urban environmental factors on rainwater management

| | RAW RESEARCH DATA | INFILTRATION (INF) | RETENTION (RET) | EVAPORATION (EVA) |
|---|---|---|---|---|
| **GEOPHYSICAL FACTORS** | | | | |
| | Soil type | 🟧 if $k_f > 10^{-6}$ | | |
| | Geology | 🟧 if pollution sensitivity | | |
| | Groundwater level | 🟧 if < 2,5 m | | |
| | Steepness | 🟧 if > 15% | | |
| **URBAN ENVIRONMENTAL FACTORS** | | | | |
| | Combined sewage system (CS) | | | |
| | Separated sewage system (SS) | 🟩 if no RD | 🟩 ≋ | |
| | Separated rainwater drainage (RD) | | 🟩 ≋ | |
| | Urban heat effect (UHE) | | | 🟧 if < 37°C |
| **LAND USE GROUPS** | | | | |
| **Water management areas** | | | | |
| Vf | Riverbeds and river banks | 🟧 💧 | 🟧 💧 | |
| Vá | Lakebeds and lakeside areas | 🟧 💧 | 🟧 💧 | |
| Vb | Water supply areas | 🟧 💧 | 🟧 💧 | |
| **Green areas** | | | | |
| Zkp | Public gardens, parks | 🟩 ☐▣ | 🟩 ☐▣ | |
| Zvp | City park | 🟩 ☐▣ | 🟩 ☐▣ | |
| **Forests** | | | | |
| Ev | Protectional forest | 🟧 💧 | 🟧 💧 | |
| Ek | Welfare forest | 🟧 💧 | 🟧 💧 | |
| Eg | Economy forest | 🟧 💧 | 🟧 💧 | |
| **Nature areas** | | | | |
| Tk | Semi-natural area | 🟧 💧 | 🟧 💧 | |
| **Agricultural areas** | | | | |
| Má | General agricultural area | 🟧 💧 | 🟧 💧 | |
| Mk | Horticultural area | 🟧 💧 | 🟧 💧 | |
| **Special areas** | | | | |
| Kb-Rek | Recreational area with high green area ratio | 🟩 ☐ | 🟩 ☐ | |
| Kb-Ez | Conditioning area with high green area ratio | 🟩 ☐▣ | 🟩 ☐▣ | |
| Kb-T | Graveyard | 🟧 💧 | 🟧 💧 | |
| Kb-Rég | Archeologic area | 🟧 ⊘ | 🟧 ⊘ | |
| Kb-En | Renewable energy producing | 🟧 ⊘ | 🟧 ⊘ | |
| Kb-Hv | Military area | 🟧 ⊘ | 🟧 ⊘ | |
| **Transportation system** | | | | |
| KÖu-1 | Freeway | 🟧 ☠ | | |
| KÖu-2 | 1st level road | 🟧 ☠ | | |
| KÖu-3 | 2nd level road | | | |
| KÖu-4 | Road of city-level importance | | | |
| Kök | Rail-bound transport | 🟧 ☠ | 🟧 ⊘ | |
| KÖv | Water traffic area | 🟧 ⊘ | 🟧 ⊘ | |
| KÖl | Air transport area | 🟧 ☠ | 🟧 ☠ | |
| **Housing areas** | | | | |
| Ln-1 | Metropolitan, high intensity housing typically in unbroken row | 🟧 ⊘ | 🟩 ☒ | 🟩 ☺ |
| Ln-2 | Metropolitan housing typically in unbroken row and framing structure | | | 🟩 ☺ |
| Ln-3 | Metropolitan, high intensity housing typically free-standing buildings | | | 🟩 ☺ |
| Ln-T | Metropolitan housing estates | 🟩 ☐▣ | 🟩 ☐▣ | 🟩 ☺ |
| Lk-1 | Small-townish housing typically in unbroken row | | | 🟩 ☺ |
| Lk-2 | Small-townish housing with typically free-standing buildings | | | 🟩 ☺ |
| Lk-T | Small-townish housing estates | 🟩 ☐▣ | 🟩 ☐▣ | 🟩 ☺ |
| Lke-1 | Intensive garden-city housing | | | 🟩 ☺ |
| Lke-2 | Loose garden-city housing | | | 🟩 ☺ |
| Lke-3 | Hillside garden-city housing | | | 🟩 ☺ |
| **Mixed areas** | | | | |
| Vt-V | City centre | 🟧 💧 | 🟩 ☒ | 🟩 ☺ |
| **Commercial areas** | | | | |
| Gksz-1 | Typically trading and service area | | 🟩 ☒ | |
| Gksz-2 | Typically storage and manufacture area | 🟧 ☠ | 🟩 ☒ | |
| Gip-E | Energy producing area | 🟧 ☠ | 🟧 ⊘ | |
| | Non-used areas | 🟩 ☐▣ | 🟩 ☐▣ | |
| **INHERITED PARAMETERS** | | | | |
| | | | 🟩 if INF is not possible | |

- 🟦 Water management areas
- 🟩 Green areas
- ⬛ Transportation system
- 🟥 Residential areas
- 🟪 Commercial areas
- 🟫 Disused areas

**Values**

- 🟧 method use is not advised
- 🟩 method use is insisted

**Restriction drivers**

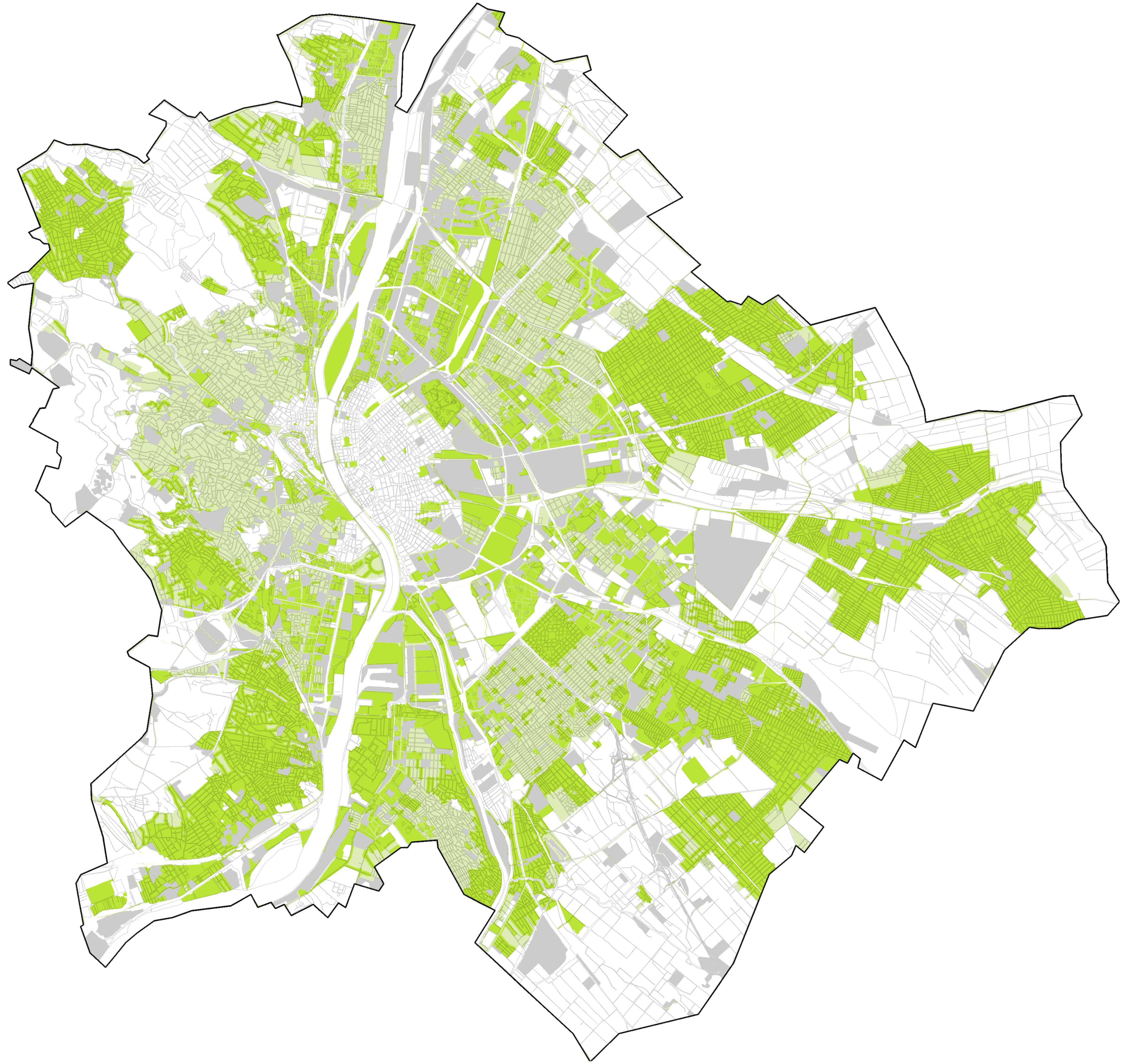
| | |
|---|---|
| if… | restriction with condition |
| 💧 | maximum capacity reached |
| ☠ | danger of groundwater pollution |
| ⊘ | conflict with the land use |

**Insisting drivers**

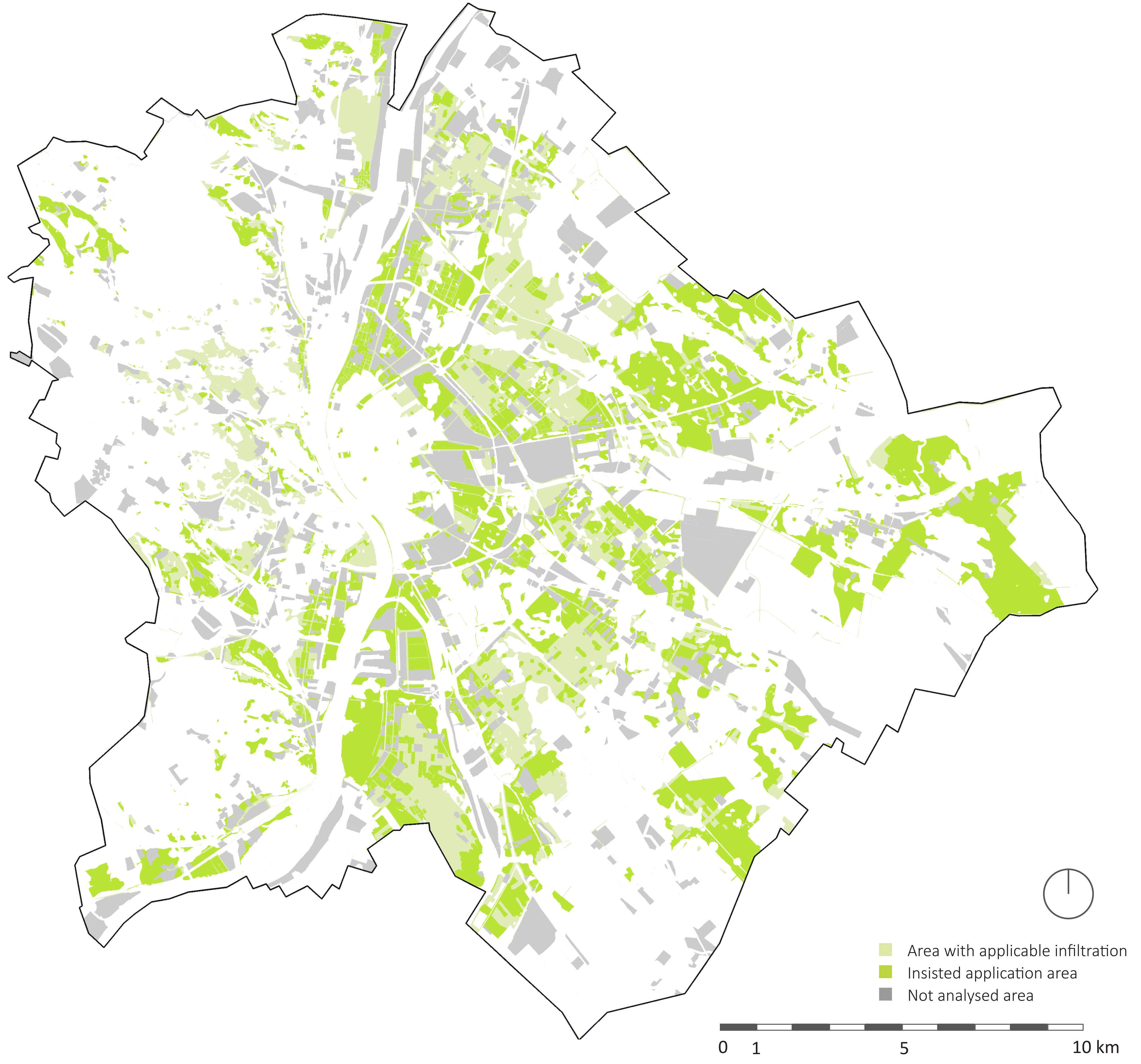
| | |
|---|---|
| if… | prioritising with condition |
| ☐ | no value with condition |
| ☒ | low sealed surface ratio |
| ▣ | high sealed surface ratio |
| ≋ | large unsealed surfaces |
| ☺ | danger of flood or sewer overload |

## Annex 10.5: Potential and priority maps of infiltration, retention, and evaporation of Budapest

Map 1: Applicability of infiltration determined by natural conditions

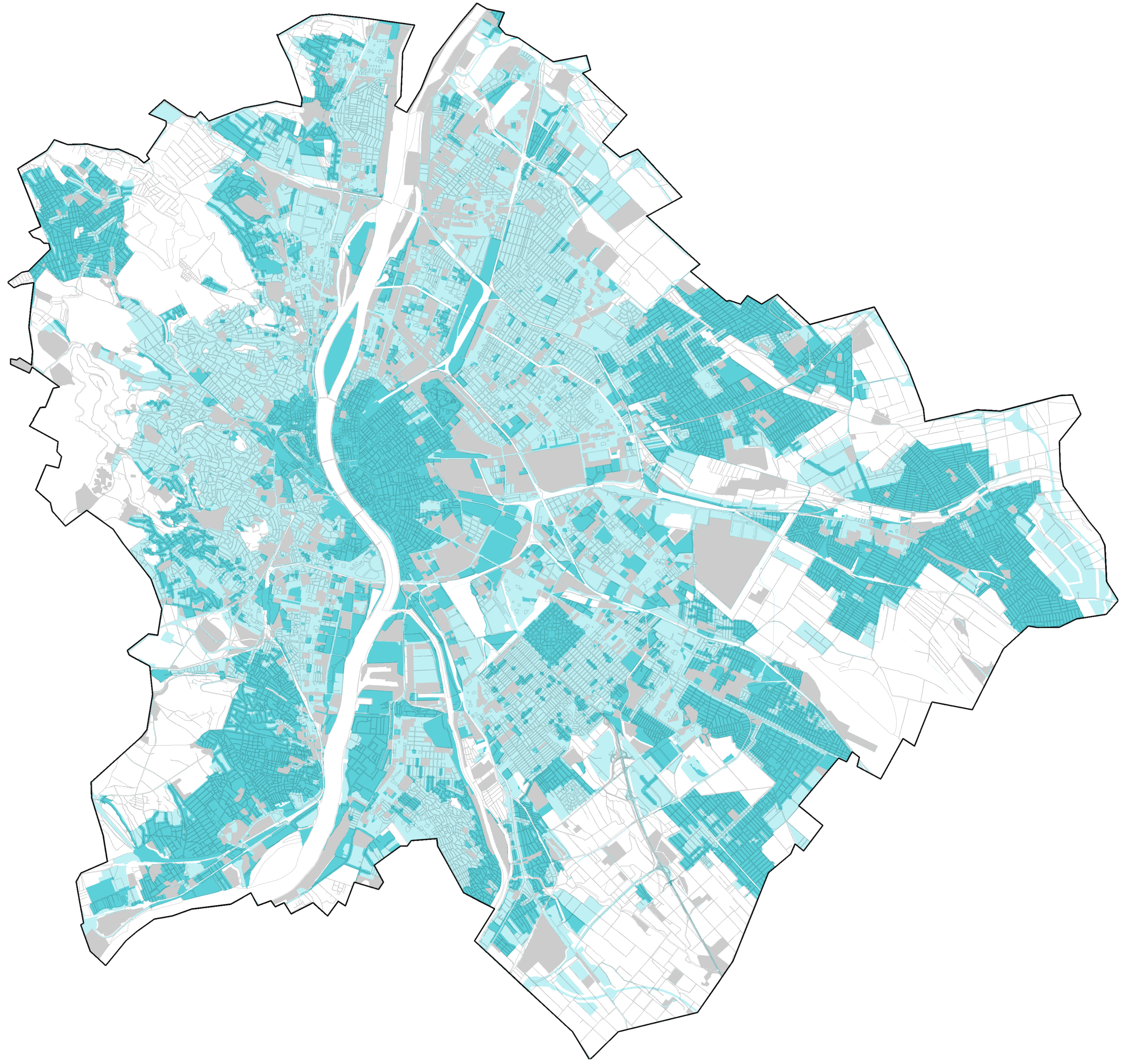


Map 2: Impact of the urban environmental factors on the applicability of infiltration

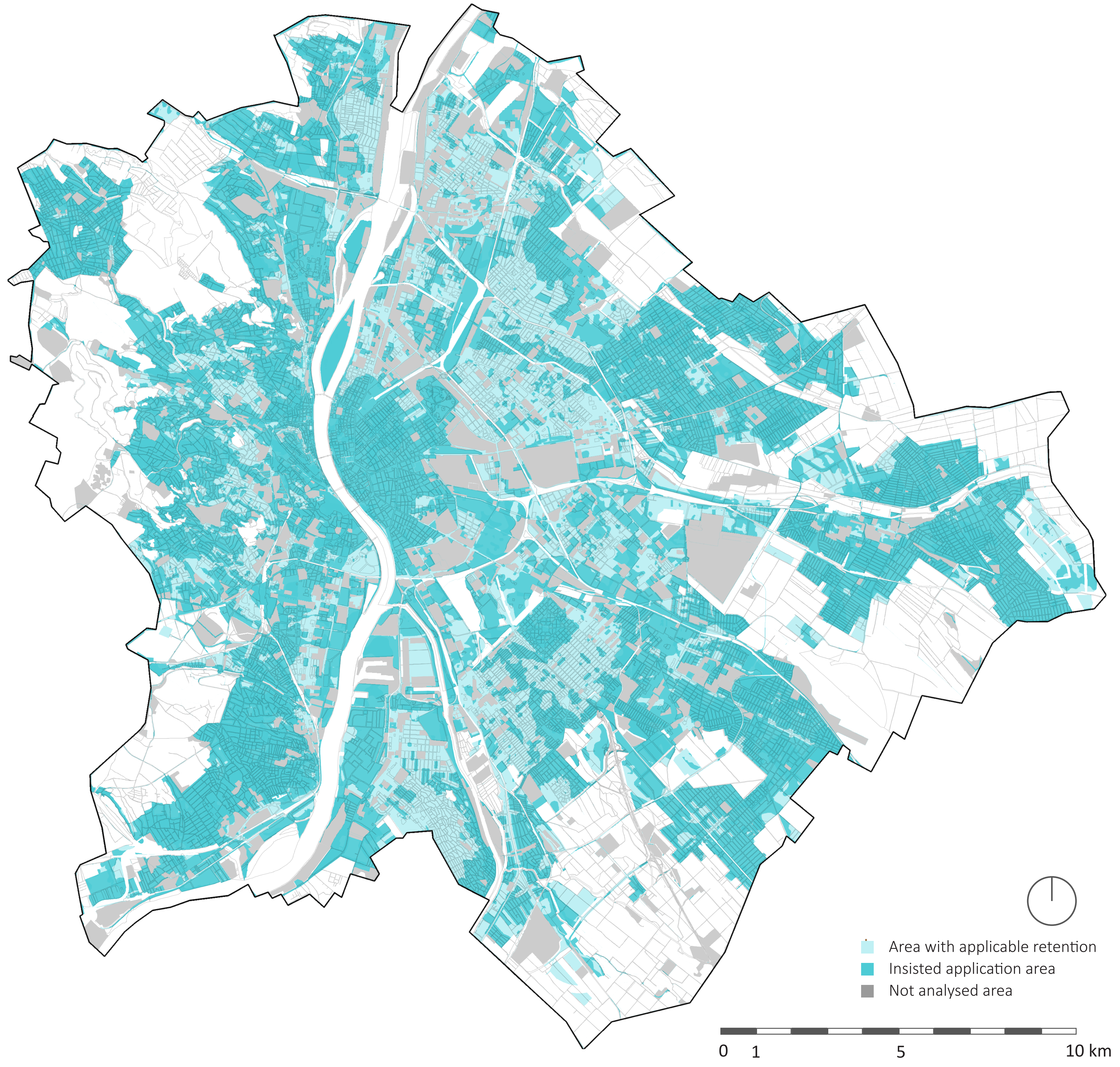


Map 3: Infiltration applicability map of Budapest

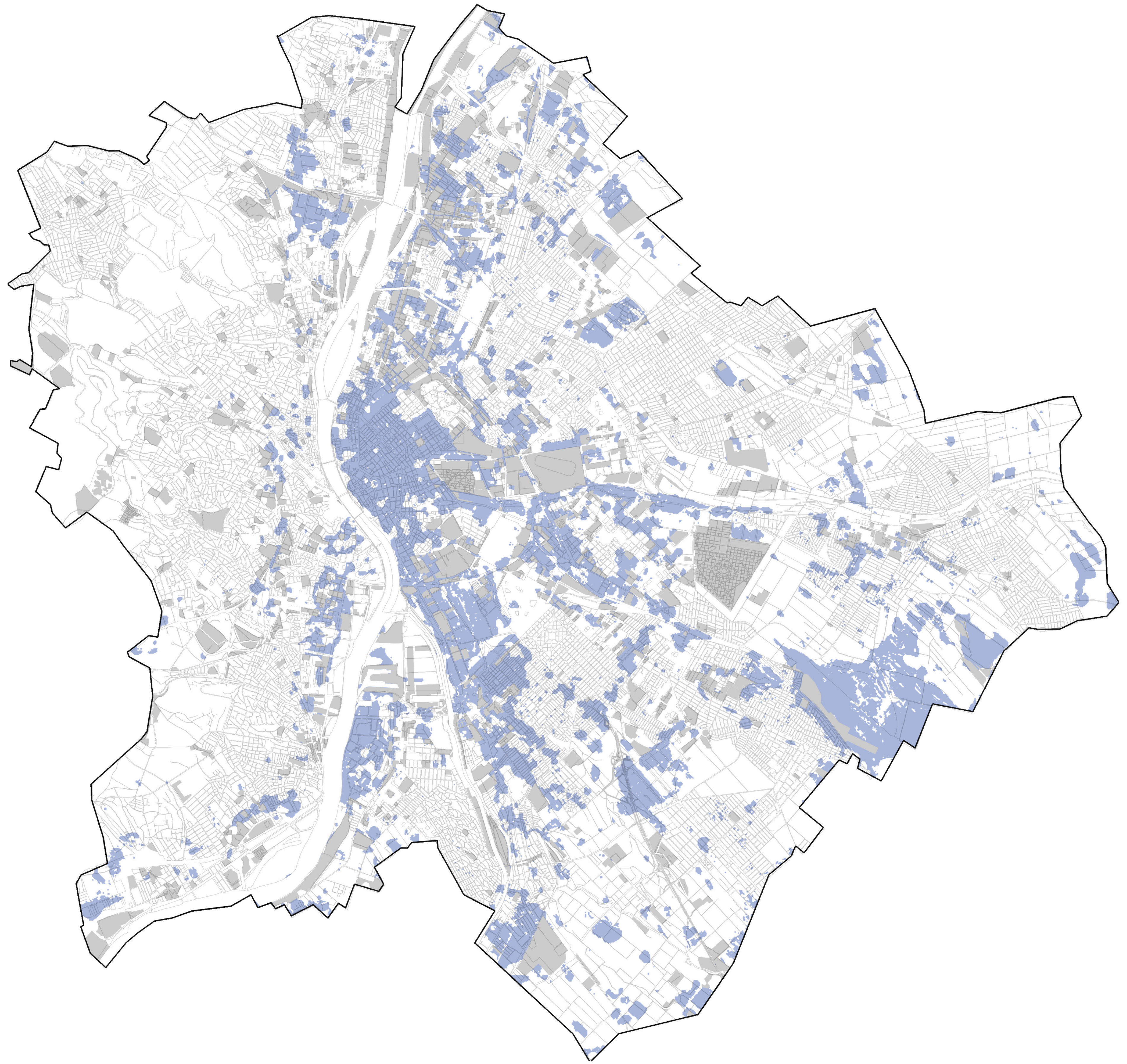
Map 4:  Applicability of retention determined by natural conditions



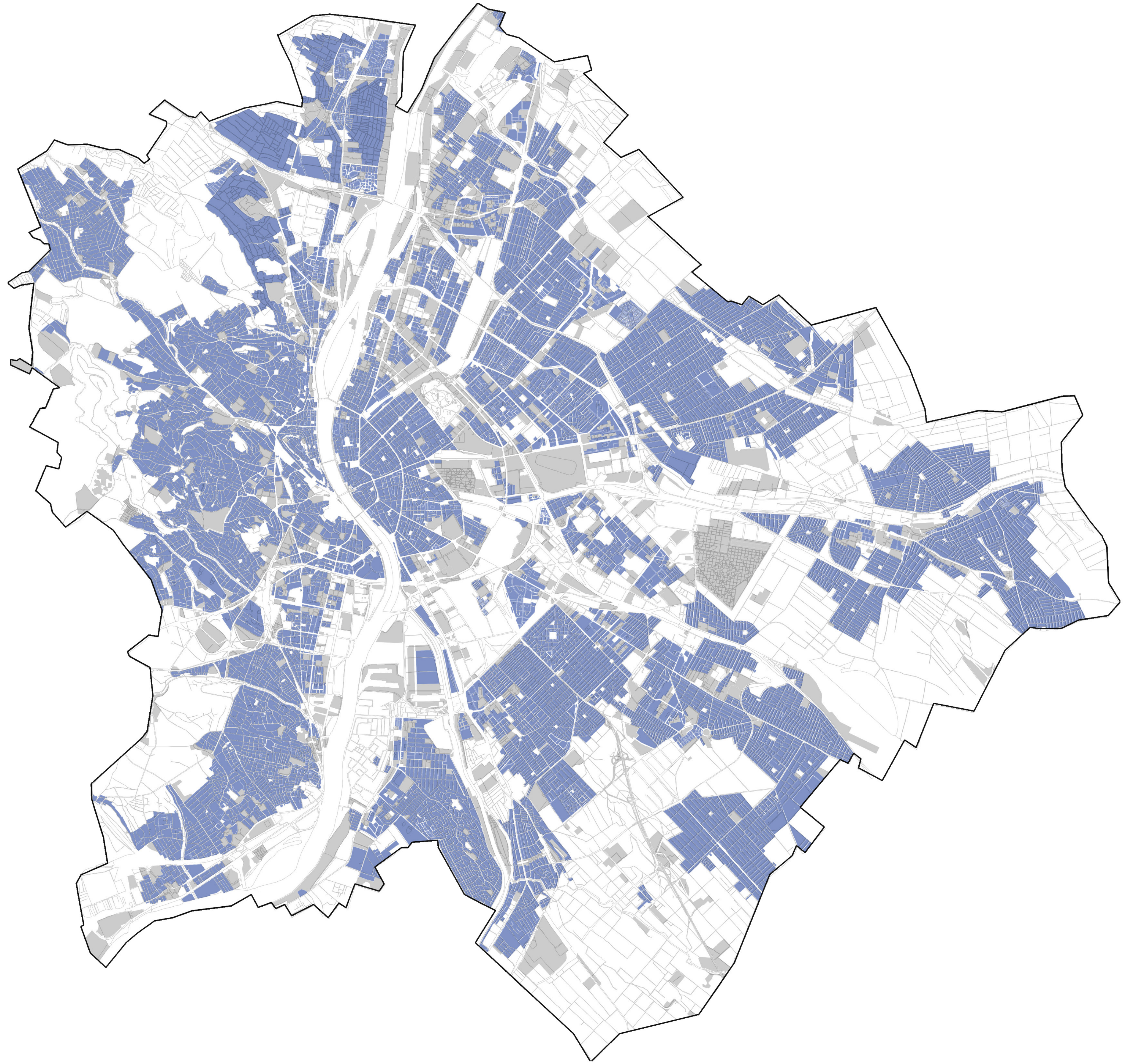
Map 5: Impact of the urban environmental factors on the applicability of retention



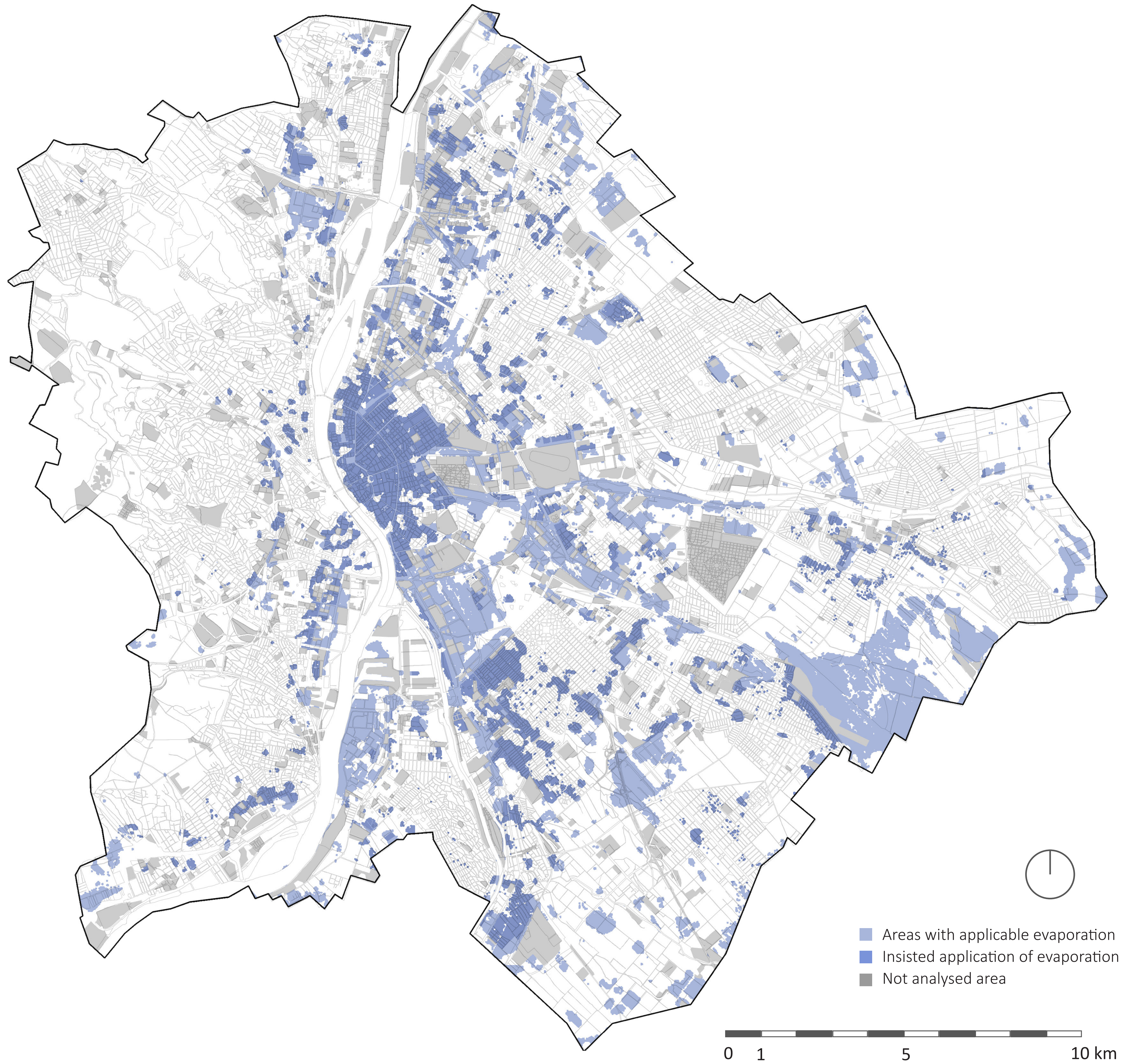
Map 6: Retention applicability map of Budapest



Map 7: Natural conditions: areas impacted by heat island effect

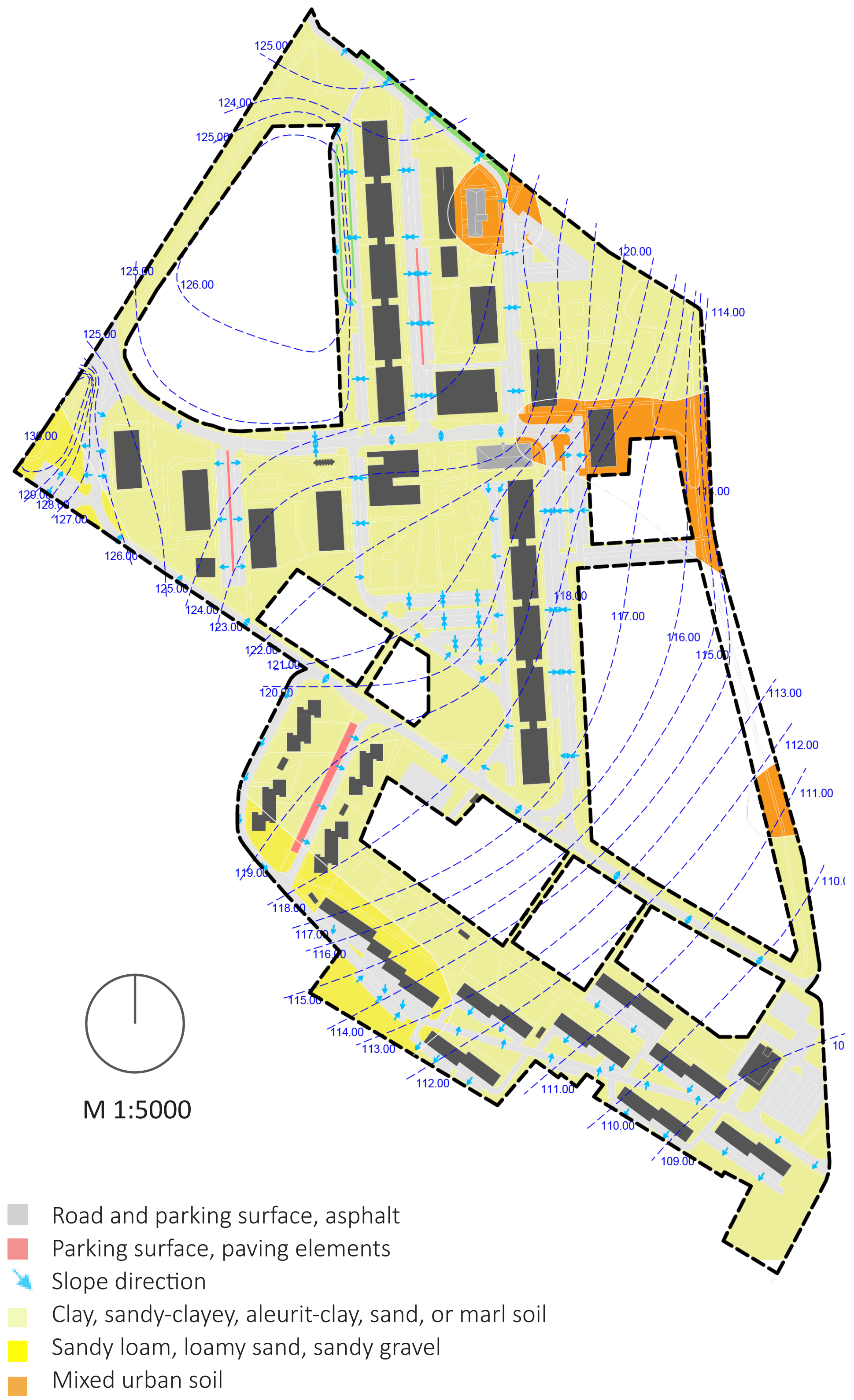


Map 8: Land use categories with the high health risk due to heat waves



Map 9: Evaporation applicability map of Budapest

## Annex 10.6 Analysis maps of the runoff calculation

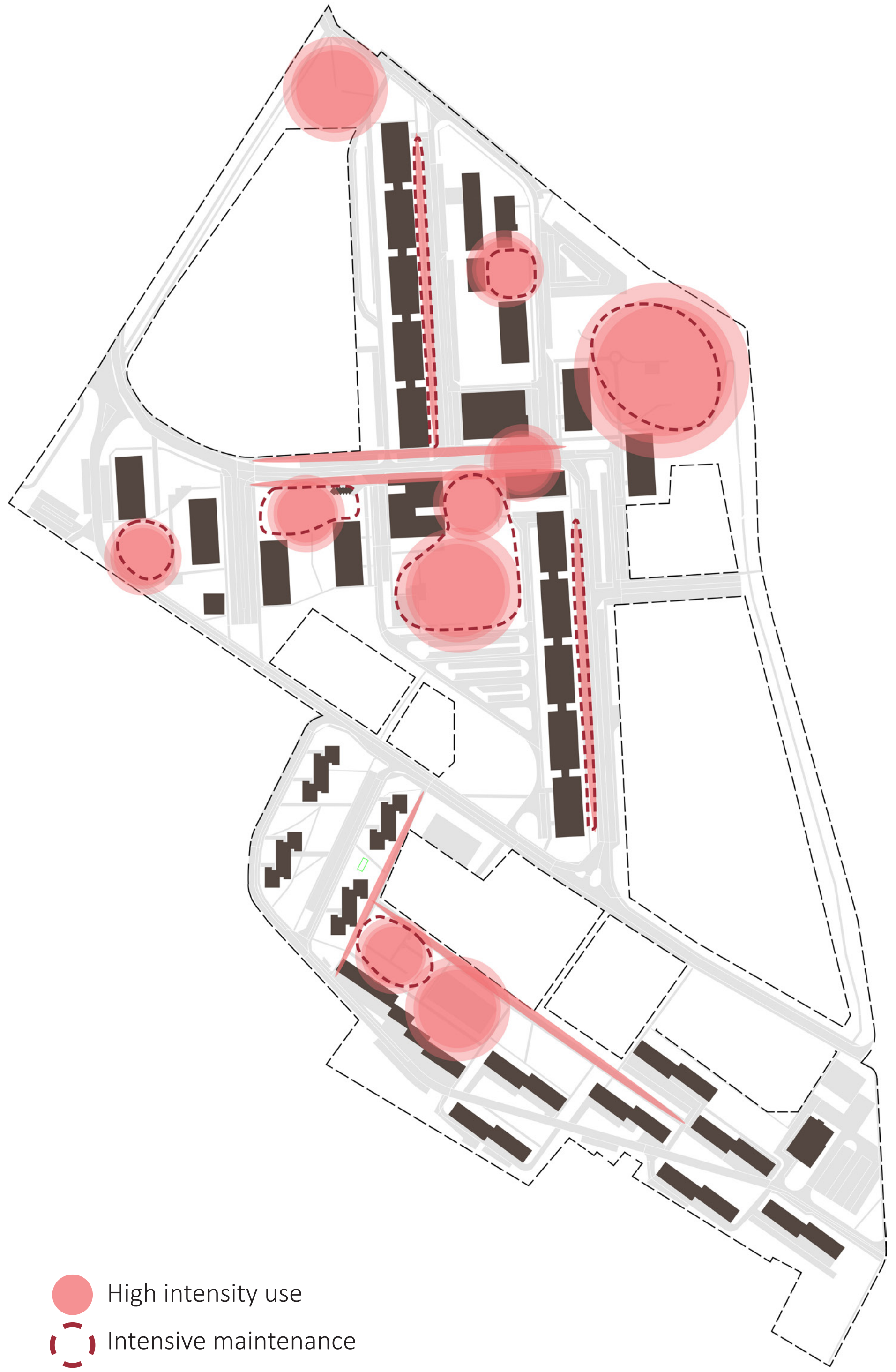


- ⬜ Road and parking surface, asphalt
- 🟥 Parking surface, paving elements
- ↘ Slope direction
- 🟨 Clay, sandy-clayey, aleurit-clay, sand, or marl soil
- 🟨 Sandy loam, loamy sand, sandy gravel
- 🟧 Mixed urban soil

**Map 1: Soil and terrain**

- 🟩 Water permeable surface
- ⬜ Asphalt / concrete
- 🟨 Paving elements
- 🟥 EPDM pavement
- 🟨 Gravel
- ⬛ Flat roof
- ⬛ Pitched roof
- ⬚ Sub-catchment areas

**Map 2: Surface analysis**



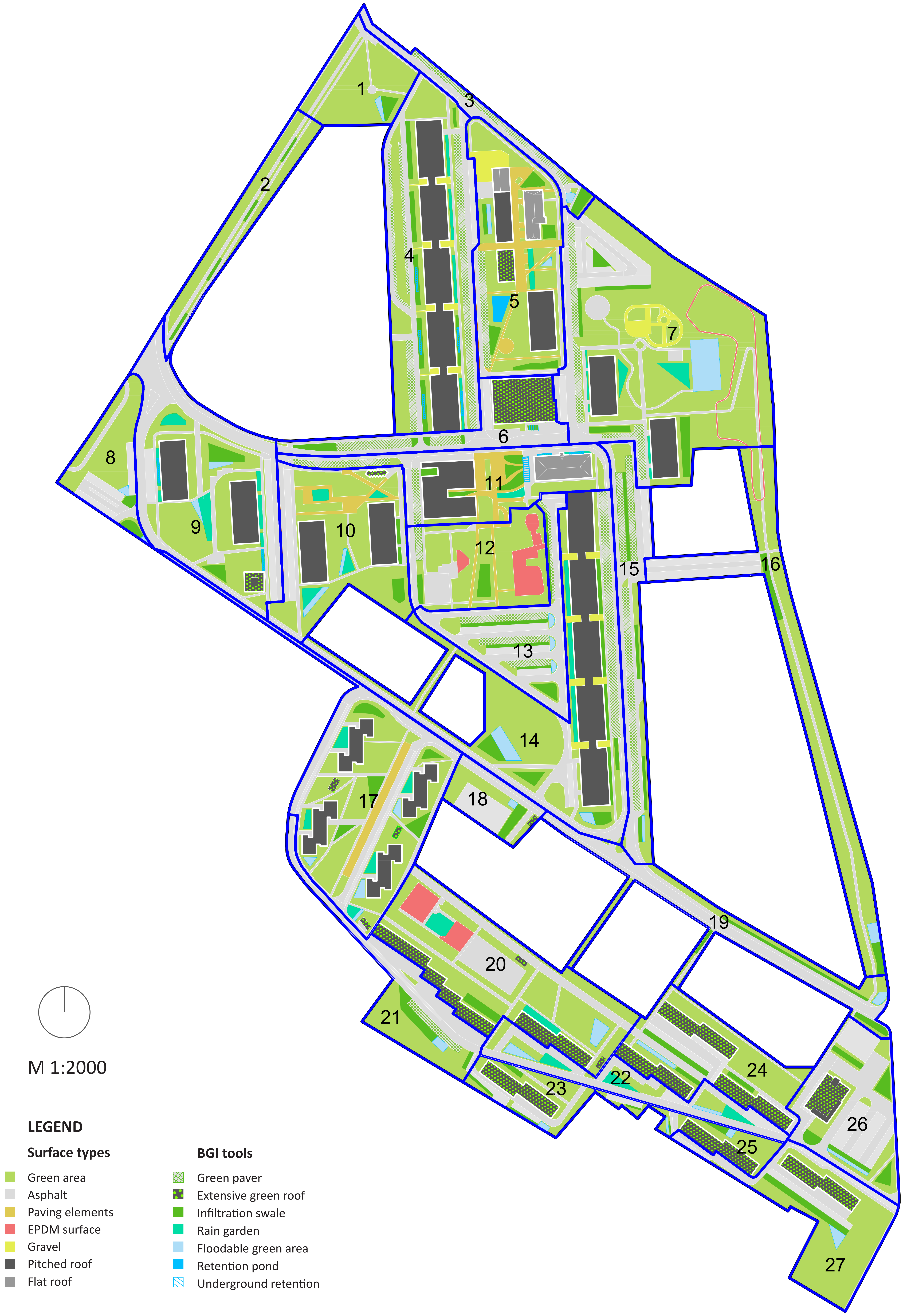
- ● High intensity use
- ◌ Intensive maintenance

**Map 3: Open space use analysis**

- ⬛ flat roof, single-floor building
- ⬛ flat roof, 4 storeys
- 🟫 flat roof, 10 storeys
- 🟧 pitched roof
- 🟥 detailed facade
- 🟩 simple facade

**Map 4: Building analysis**

10.7 Scematic plan of the BGI implementation in the Örmezö socialist housing estate



waste into them. Where these channels reached the river, an intolerable stink lingered in the area. A solution to the severe sanitation problems of Paris was a decree in 1530, which required property owners to construct cesspools in every new dwelling.(Burian Steven J., Edwards Findlay G. 2012 p. 7) Human waste, so-called ‘night soil’ was transported out from the city during the night and used for soil fertilization. This routine caused many sanitary problems, such as urban groundwater contamination and food safety issues.

## Industrialisation: triumph of technology

In the first half of the 19th century, industrialisation induced a period of rapid urbanization in Europe. Growing urban populations and water-demanding industries made the existing water supply system based on wells, irrecoverably unsustainable. The development of urban freshwater pipe systems became one of the biggest investment projects in the first part of the 19th century. This important hygienic improvement caused a dramatic rise in water consumption, and in the amount of wastewater. Wastewater removal relying on cesspool systems became increasingly unfeasible to manage: the increased demand and the longer wastewater transportation distances were logistically no longer manageable and groundwater contamination endangered or even inhibited the use of bore water.(Barnes, Barnes 2006) Rivers as water sources did not offer better alternatives as surplus human waste was led directly into stormater drains, which ultimately flowed into rivers. The pollution caused disastrous environmental and medical conditions.

The most serious consequences of these issues materialized in several widespread cholera epidemics after 1830. In 1832, cholera killed more than five tousand Parisians during one week in April.(Yost 2000) In Hungary, nearly half a million people died in cholera endemics between 1831 and 1916.(Monigl 1983 p. 8) The connection between contaminated water and the spread of illness was firstly identified by John Snow in 1854, who pointed out the need for urban water supply systems. (Sack et al. 2004 p. 223)

FIGURE 44: CARTOON OF A WOMAN HORRIFIED BY A MICROSCOPIC VIEW OF DRINKING WATER FROM THE THAMES
(Source: (HEATH, 1828))

In response to the urgent health concerns, centralized governmental actions started in Europe, although these took several decades to become established.[45] The first small-scale projects were organized in several countries by profit-oriented private companies, but they could not encompass an expansive and coherent supply network as they targeted areas occupied by the wealthier social class. The shift from private to public control started in the second half of the 19th century and took several decades, just as the construction itself. Public ownership allowed the simultaneous design of the water input and output, and the provision of all residents with a high-quality service. Working class districts gained access to these public services as the last, after the late 1890th.(Abellán 2017 p. 10)

The construction of sanitation systems was usually part of the complex city renewal projects. These complex and expensive civil engineering projects required operational and legislative development as well as the utilisation of alternative financing forms based on win-win outcomes in the interest of the public and private capital investors. One of the most impressing examples is Paris, where Hausmann's ambitious plan radically changed the face of the old city. New, spacious, sunny squares and boulevards emerged on the surface and on the subterannean level an expansive subway and combined sewage system were constructed. Similar combined systems were constructed all around the European metropols.(Abellán 2017 p. 9)[46]

Budapest combined the urban vision of Paris with the capitalist funding system of England. After several decades of heated and unsuccesful debates, finally work commenced after the devastating Big Icy Flood in 1838. The flood destroyed almost the whole city centre, where a majority of buildings were made of clay bricks. Until the end of the century, a new city centre emerged from the debris. The city renewal – following the example of Paris – included an extensive water supply and combined sewage system, regulation of the Danube and numerous building projects: boulevards, avenues, squares and the first public parks. Although green areas were mainly appreciated by their aesthetic value, the role of street trees in binding sand and dust and their cooling effect was already well known. Regulation of the Danube removed the dangerously wide

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[45] Great public construction works were actuated in many cases by cathastrophies or as a symbol of power. This kind of fuse was the "Great Stink" in 1858 in London, the great fire in Hamburg in 1842 or the political ambitions of Napoleon III to turn Paris into a new, healthy city. (Abellán 2017 pp. 7–9)

[46] There were some exceptions such as Amsterdam, where a separated wasterwater and stormwater system was constructed to avoid river pollution. (Abellán 2017 p. 9) The combined system was widespread in Europe, but it is not necessarily suitable for all climate conditions. After 40 years of the implementation of Sydney's combined system in 1850, it turned out that Australian rainfall conditions on the longterm were more intense and stochastic, which overloaded the infrastructure. Henceforward the country invested in separated systems instead.(R. R. Brown et al. 2009 p. 852)

and shallow sections, which were the usual cause of ice locks. The river bank was stabilised by a stone embankment and further by dikes in the outer zones. (Csizmadia 2016) Ferenc Reitter, the designer of the combined sewage system expected a drastic population growth in the next decades and designed the system for the growing future demands. Thus, he suggested a large pipe diameter and minimal slope in favour of supplying a large surface area and advised the municipality to provide drinking water for free in order to maintain a high consumption, which consequently provides a sufficient flow in the pipe system.(L. Nagy 1975) [47]

In the decades after the WWII urban and rural landscapes were significantly modified. European metropols were struggling with the consequences of the war, which left buildings and utilities devastated. In less damaged historical cities such as Budapest, the hasty reconstruction of the existing water infrastructure didn't allow for precise documentation, which resulted in the city's chaotic utilities registry. In several other European cities, buildings and utilities were so badly damaged that completely new systems needed to be constructed. In the 1950s-60s desperate housing shortages in urban areas called for the construction of centralised governmental housing projects. In Eastern Europe, the process was amplified by the forced industrialisation aims of the Soviet Union resulting in the establishment of new housing estates on green areas, which created an increase in impervious surfaces. In most cases, a separated sewage system was implemented, which helped to relieve the overloaded combined system but loaded the surrounding watercourses.

The second industrialization gave rise to intense agriculture due to rapidly growing populations. Huge areas of wetland were drained in several countries in order to convert them into agricultural land. Before industrialization, 24% of Hungary's area was a floodplain(Ács A. et al. 2012), however today it is not more than 3%. (Krisztina 2002 p. 1) The result is a less resistant landscape threatened by floods and desertification. Agricultural water demand soared to unprecedented levels and groundwater was typically overused for decades. River plains were increasingly modified and degraded in industrial and dense urban regions to gain new industrial or housing areas.

First researches appeared in the 1960s about the consequences of human development on a global scale. Rachel Carlson's "Silent spring", the Club of Rome's report "Limits To Growth", and the Brundtlandt Report presented frightful messages about the impacts of chemicals, the overuse of

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[47] Reitter's prognosis was correct, between 1880 and 1900 the resident number of the city increased from 370 000 to 733 000 and the water consumption grew from 51 to 179 liter. (Preisich 2004 p. 244)

resources and the first warnings regarding climate change. The level of environmental pollution and the diversion from the natural environment were prompting communities to demand greater levels of amenity and access to green open space. (Rebekah R. Brown et al. 2008 p. 7) The first results of emerging environmental awareness, “end of pipe solutions”[48] and first pollution threshold values (firstly for rivers and lakes used for drinking water abstraction, fishing or bathing) came into practise in the 1970’s. **Green infrastructure planning** appeared as a result of recognizing the indispensable benefits of green areas and the importance of their connectivity. Green areas were no longer considered as having purely aesthetic value, but as an efficient, multifunctional system to build and support communities and **sustainable development**.[49]

First big-scale restoration projects appeared after the industrial decline in the 1980’s. Germany was one of the first countries, that implemented an integrated approach in a long-term restoration project. The restoration of the Emscher river was accompanied by an extended wastewater removal system and an extensive research in sustainable, decentralised stormwater management, particularly in infiltration. (H Sieker et al. 2011 p. 11) Around 500 small pilot projects were established for on-site rainwater management and these are monitored upto this day. These experiences created the basis of the developed German decentralised rainwater management approach. In parallel, pilot projects began in the USA and Australia, as numerous studies warned about inability of the traditional centralised water infrastructure to cope with increasing extreme weather conditions. Whilst the end of pipe approach and advanced cleaning technologies resulted in remarkable improvements in water quality, the high importance of urban **non-point pollution sources** (such as traffic areas and air pollution) was identified. It prompted researchers and practitioners to implement a more complex approach and develop new technologies such as wetlands and bio-filtration systems to protect receiving waterways. (Rebekah R. Brown et al. 2008 p. 7)

In the 1990s, green infrastructure planning and urban water sciences achieved huge technological development. Regular monitoring of watersources became a common practise in developed countries. Several international environmental agreements and crossborder projects emerged and the new approach of water management became **watershed management**. Agenda 21 in 1992 attracted attention to the finite and vulnerable freshwater resources. It defined that water

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[48] “End-of-pipe solution” describes a pollution-control approach that cleans up contaminated flows of water (or air) at the point where that effluent enters the environment.

[49] Sustainable development was defined by the Brundtland report in 1987: “ Sustainable Development is the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.(World Commission on Environment and Development 1987 p. 39)

management must have a participatory approach, involving users, planners and policy-makers at all levels, and water should be recognized as an economic good. It also laid out the first commonly accepted definition of the **integrated water resource management**.

The underestimation of the value and importance of the ecosystem provided to mankind was perceived by other researches, as well. identified the hurdles of measuring the economic value and performance of natural processes, which are therefore highly underestimated and neglected by the economy. Therefore, the UN's Millennium Ecosystem Assessment defined the definition of **ecosystem services**[50] and established an assessment system, which facilitates. (World Resources Institute 2005) This new approach and the already unavoidable consequences of climate change advantaged a radical paradigm shift in urban planning. Theories addressed sustainability have been shifting from the anthropocentric approach (nature is an external system, whose ressources take longer by moderated consumption) to ecocentric approach (nature and social systems are interacting, co-evolving systems, which have to be in balance).(Ghofrani et al. 2017 p. 16) Instead of protection against natural impacts, resilience became the new keyword for urban designers.

The **European Water Framework Directive (WFD)**, released in 2000, sets the European water policy onto an international, watershed-based platform, but considers the local differences as well. (European Parliament 2000) It focuses on further improvement of quality and quantity, the reduction of consumption and the increasing climate resilience by the enhancement of international connections and involvement of citizens. The main target of the directive is to bring all water bodies of Europe to a good health condition (in quality and quantity) until 2015. To cover the environmental costs (compensation of damaging the ecosystem, pollution, e.g.) and decrease water consumption, European citizens must pay the full costs of water services they receive. Great achievements of the Water Framework Directive are the establishment of an almost complete European monitoring system, the modernisation and harmonisation of the European water law and the initiation of a framework for interregional projects.

In the new millennium, the development of more complex approaches is supported by rapidly developing technological background. The combination of geoinformatics and the huge amount of digitalized data of the last three decades opens new dimensions for water management such as complex runoff or climate modelling. While digital technology is growing, the built physical infrastructure is aging. In numerous parts of the world, the renovation of the old centralized pipe

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[50] "Ecosystem services are the direct and indirect contributions of ecosystems to human well-being. They support directly or indirectly our survival and quality of life."

system would demand vast investments soon, which actuates cities to seek for alternative and more sustainable solutions.

Although the transition started, significant differences can be noticed between the development of European countries. Germany drafted the first decentralized rainwater management guidelines already in the 80ies, while 50% of Budapest's wastewater reached the Danube untreated until 2010. But shifting from the priority of traditional, centralized infrastructure to nature-based rainwater management solutions becomes slowly from a curiosity to a self-evidency. Contemporary and future urban planning must define the disciplines of a new urban water infrastructure, which can perform and support urban communities even in a changing environment.

## 10.8 Surface analysis of the catchment areas

| Catchment areas | | | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | | 6 | | | 7 | | | 8 | | | 9 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_4$ | $C_{33}$ | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) |
| Green area | 0.1 | 0.2 | 0.343 | 0.034 | 0.069 | 0.256 | 0.026 | 0.051 | 0.031 | 0.003 | 0.006 | 0.544 | 0.054 | 0.109 | 0.481 | 0.048 | 0.096 | 0.036 | 0.004 | 0.007 | 1.325 | 0.132 | 0.265 | 0.251 | 0.025 | 0.050 | 0.575 | 0.057 | 0.115 | 0.549 | 0.055 | 0.110 |
| Asphalt or concrete | 0.9 | 1 | 0.074 | 0.067 | 0.074 | 0.109 | 0.098 | 0.109 | 0.122 | 0.109 | 0.122 | 0.361 | 0.325 | 0.361 | 0.149 | 0.134 | 0.149 | 0.253 | 0.228 | 0.253 | 0.526 | 0.473 | 0.526 | 0.131 | 0.118 | 0.131 | 0.594 | 0.535 | 0.594 | 0.198 | 0.178 | 0.198 |
| Grass paver | 0.2 | 0.4 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.073 | 0.015 | 0.029 | 0.186 | 0.037 | 0.074 | | 0.000 | 0.000 | 0.052 | 0.010 | 0.021 | 0.099 | 0.020 | 0.040 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Paving elements | 0.7 | 0.9 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.006 | 0.004 | 0.006 | 0.166 | 0.116 | 0.150 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.009 | 0.006 | 0.008 | 0.079 | 0.055 | 0.071 |
| EPDM surface | 0.5 | 0.6 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.103 | 0.052 | 0.062 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Gravel | 0.7 | 0.9 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.039 | 0.027 | 0.035 | 0.047 | 0.033 | 0.042 | | 0.000 | 0.000 | 0.061 | 0.043 | 0.055 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Green roof | 0.4 | 0.5 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.076 | 0.030 | 0.038 | 0.149 | 0.060 | 0.074 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.018 | 0.007 | 0.009 | 0.006 | 0.003 | 0.003 |
| Pitched roof | 1 | 1 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.070 | 0.070 | 0.070 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Flat roof | 0.9 | 1 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.428 | 0.385 | 0.428 | 0.085 | 0.076 | 0.085 | | 0.000 | 0.000 | 0.170 | 0.153 | 0.170 | | 0.000 | 0.000 | 0.178 | 0.160 | 0.178 | 0.176 | 0.158 | 0.176 |
| | Σ: | | 0.417 | 0.1010 | 0.1428 | 0.365 | 0.124 | 0.160 | 0.226 | 0.127 | 0.157 | 1.564 | 0.833 | 1.012 | 1.074 | 0.508 | 0.630 | 0.490 | 0.302 | 0.356 | 2.284 | 0.872 | 1.117 | 0.381 | 0.143 | 0.181 | 1.375 | 0.766 | 0.905 | 1.008 | 0.449 | 0.557 |

| Catchment areas | | | 11 | | | 12 | | | 13 | | | 14 | | | 15 | | | 16 | | | 17 | | | 18 | | | 19 | | | 20 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_4$ | $C_{33}$ | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) |
| Green area | 0.1 | 0.2 | 0.189 | 0.019 | 0.038 | 0.397 | 0.040 | 0.079 | 0.116 | 0.012 | 0.023 | 0.729 | 0.073 | 0.146 | 0.153 | 0.015 | 0.031 | 0.644 | 0.064 | 0.129 | 0.635 | 0.063 | 0.127 | 0.100 | 0.010 | 0.020 | 0.217 | 0.022 | 0.043 | 0.625 | 0.063 | 0.125 |
| Asphalt or concrete | 0.9 | 1 | 0.244 | 0.220 | 0.244 | 0.120 | 0.108 | 0.120 | 0.406 | 0.365 | 0.406 | 0.486 | 0.437 | 0.486 | 0.288 | 0.259 | 0.288 | 0.228 | 0.205 | 0.228 | 0.493 | 0.443 | 0.493 | 0.146 | 0.132 | 0.146 | 0.328 | 0.295 | 0.328 | 0.304 | 0.273 | 0.304 |
| Grass paver | 0.2 | 0.4 | 0.021 | 0.004 | 0.009 | 0.013 | 0.003 | 0.003 | 0.073 | 0.015 | 0.029 | 0.109 | 0.022 | 0.044 | 0.153 | 0.031 | 0.061 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Paving elements | 0.7 | 0.9 | 0.101 | 0.071 | 0.091 | 0.035 | 0.025 | 0.007 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.065 | 0.045 | 0.058 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| EPDM surface | 0.5 | 0.6 | | 0.000 | 0.000 | 0.093 | 0.047 | 0.019 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.008 | 0.004 | 0.005 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.074 | 0.037 | 0.044 |
| Gravel | 0.7 | 0.9 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.048 | 0.034 | 0.043 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Green roof | 0.4 | 0.5 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.012 | 0.005 | 0.006 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.188 | 0.075 | 0.094 |
| Pitched roof | 1 | 1 | 0.075 | 0.075 | 0.075 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Flat roof | 0.9 | 1 | 0.142 | 0.127 | 0.142 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.431 | 0.388 | 0.431 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.209 | 0.188 | 0.209 | 0.004 | 0.003 | 0.004 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| | Σ: | | 0.773 | 0.516 | 0.598 | 0.658 | 0.222 | 0.228 | 0.594 | 0.391 | 0.458 | 1.803 | 0.953 | 1.149 | 0.594 | 0.305 | 0.380 | 0.880 | 0.274 | 0.362 | 1.413 | 0.745 | 0.893 | 0.250 | 0.145 | 0.170 | 0.545 | 0.317 | 0.371 | 1.191 | 0.448 | 0.567 |

| Catchment areas | | | 21 | | | 22 | | | 23 | | | 24 | | | 25 | | | 26 | | | 27 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $C_4$ | $C_{33}$ | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_I$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) | A (ha) | $A_{I,4}$ (ha) | $A_{I,33}$ (ha) |
| Green area | 0.1 | 0.2 | 0.210 | 0.021 | 0.042 | 0.141 | 0.014 | 0.028 | 0.137 | 0.014 | 0.027 | 0.293 | 0.029 | 0.059 | 0.128 | 0.013 | 0.026 | 0.199 | 0.020 | 0.040 | 0.429 | 0.043 | 0.086 |
| Asphalt or concrete | 0.9 | 1 | 0.256 | 0.231 | 0.256 | 0.298 | 0.268 | 0.298 | 0.080 | 0.072 | 0.080 | 0.185 | 0.166 | 0.185 | 0.023 | 0.021 | 0.023 | 0.432 | 0.389 | 0.432 | 0.206 | 0.185 | 0.206 |
| Grass paver | 0.2 | 0.4 | 0.026 | 0.005 | 0.011 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Paving elements | 0.7 | 0.9 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| EPDM surface | 0.5 | 0.6 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Gravel | 0.7 | 0.9 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Green roof | 0.4 | 0.5 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.069 | 0.027 | 0.034 | 0.209 | 0.084 | 0.104 | 0.069 | 0.027 | 0.034 | 0.050 | 0.020 | 0.025 | 0.069 | 0.027 | 0.034 |
| Pitched roof | 1 | 1 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 |
| Flat roof | 0.9 | 1 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.000 | 0.000 | 0.015 | 0.013 | 0.015 | | 0.000 | 0.000 |
| | Σ: | | 0.493 | 0.257 | 0.309 | 0.439 | 0.282 | 0.326 | 0.285 | 0.113 | 0.141 | 0.686 | 0.279 | 0.348 | 0.220 | 0.061 | 0.083 | 0.695 | 0.442 | 0.511 | 0.704 | 0.256 | 0.326 |

## 10.9 Description of the planning decisions

**Catchment Area 1:** The catchment area has a very high green area ratio. Focusing on the runoff of the impervious sufaces, 129m$^2$ infiltration area was placed in the middle of the green area to collect the runoff of the sealed surfaces. This secondmentioned larger swale surface was extended by 65m$^2$ to achieve the storage of 19,95 m$^3$ further runoff from the 33-year rain.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 129 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 14 |
| | Implemented | ✓ |

**Catchment Area 2:** 165m$^2$ of infiltration swales were placed along the bike and pedestrian ways. These swales also cover the volume need of the 33-year rain event.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 155 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 12 |
| | Implemented | ✓ |

**Catchment Area 3:** The area consists mostly of road surface. The infitration capacity was increased by the implementation of grass paver. The rest of the 4-year and 33-year runoff is stored on the deepest point of the catchment area in a large-surface infiltration swale and an additional deepened grass surface.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 160 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 9,5 |
| | Implemented | ✓ |

**Catchment Area 4:** This area contains mostly flat roof and road surfaces and has a low green area ratio. Most parking surfaces were turned into grass paver based on the principle layed out in

Chapter 5.2.3. In addition, rain gardens were established on the entrance side of the building, which provide high aesthetical value. On the backside of the building, simple infiltration swales collect the runoff of the road surfaces. The storage demand from the 33-year rain is fulfilled by the use of underground retention boxes under swales and the rain gardens.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 1050 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 56 |
| | Implemented | ✓ |

**Catchment Area 5:** The area hosts buildings with flats and various public functions, therefore the green areas are frequently used by the inhabitants. One building fulfilled the criteria for green roof establishment and parking lots on the western side were changed to grass pavers. In the most prominent areas, rain gardens were used to collect the 4-year runoff, extended by swales on the borders. For the 33-year rain, a retention lake is established in the most central area of the catchment area. Two further floodable green areas are planned to store altogether 39 m$^3$ runoff.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 640 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 38,5 |
| | Implemented | ✓ |

**Catchment Area 6:** This catchment area has one of the highest sealed area ratio, making the implementation of BGI tools limited. The green roof on the grocery building and the green paver of the parking lots aim to decrease the runoff from sealed surfaces. These tools are extended by infiltration swales along the parking lots and in front of the supermarket (249m2). 31m$^2$ of underground retention boxes satisfy the retention capacity.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 380 |
| | Implemented | 249 |
| RET volume (m$^3$) | Required | 16,5 |
| | Implemented | ✓ |

**Catchment Area 7:** The large green area ratio allows the use of a various BGI elments. Infiltration swales are placed close to the roads. Building entrances and centrag reen areas are enhanced by the use of rain gardens. Water retention is provided by the lowering of the centrally located sprot field by 15 cm.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 1100 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 79,5 |
| | Implemented | ✓ |

**Catchment Area 8:** This catchment area has a large gradient, therefore the infiltration swales and floodable green areas are positioned in the lowest areas. The area sizes meet with the requitrements.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 180 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 12,5 |
| | Implemented | ✓ |

**Catchment Area 9:** The required infiltration capacity was established by rain gardens around the entrance areas and in the center of the park area and by swales on the less frequented areas. Flooadable areas extend the capacity in the center and underground retention boxes along the streets, where the lack of space restricts the surface terranian solutions.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 955 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 41,5 |
| | Implemented | ✓ |

**Catchment Area 10:** The large road surface on the western side of the catchment area has a slope to the direction of south-east. Therefore, a large raingarden and and additional retention surface were established on the south side of the road. Further rain gardens and a large swale were located to collect the runoff of the roof and paved surfaces. The infiltration and retention surfaces fulfill the required capacity.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 560 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 34,5 |
| | Implemented | ✓ |

**Catchment Area 11:** The area has a high sealed surface ratio and several steep slopes on the South side. Due to the week roof construction, green roof was not advised on the flat roof. The parking area on the west were turned into green paver. The 4-year runoff is mostly collected in the central park, where the existing green areas were turned into rain gardens. Swales were applied along the streetside to infiltrate the runoff of the road and roof surfaces. The 33-year runoff is catched by underground retention boxes under the swales and in a larger zone under the pavement of the central square.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 650 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 24 |
| | Implemented | ✓ |

**Catchment Area 12:** The catchment area is one of the most important social spaces of the estate. Due to the high green area ratio, the required infiltration area is low, which can be fulfilled by a large swale in the central of the park and an infiltration swale collecting the runoff of the road surface. In this area, the runoff from the 4-year rain is higher than the runoff from the 33-year rain, thus, no further retention tools are needed.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 280 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 0 |
| | Implemented | ✓ |

**Catchment Area 13:** The whole is covered by the central parking lots of the housing estate. Parking lots with unsuitable slope direction were turned into grass paver. The green stripes between the parking lots were turned into narrow swales. This was extended with floodable green areas at the lower end of the green stripes, which fulfills the required retention demand.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 500 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 20 |
| | Implemented | ✓ |

**Catchment Area 14:** The area incudes streches of the Neszmélyi and Menyecske streets, a relatively large, but extensively used green area and the roof surface and surroundings of a long prefabricated building. On the side of the entrances, raingardens help the on-site management of the roof runoff, while on the Eastern side, swales collect the road runoff. Three further infiltration zones were placed on the south side of the area to take up the runoff of the road surfaces and were extended with retention areas.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 1200 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 60,5 |
| | Implemented | ✓ |

**Catchment Area 15:** The area consists of road and parking surfaces and a small ratio of green area. The implementation of green pavers helps to decrease the runoff from the parking areas. Swales and floodable green areas were established to collect the 4-year and 33-year runoff.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 380 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 24 |
| | Implemented | ✓ |

**Catchment Area 16:** This area consists of a parking area and a long and narrow green area. Two swales were established for these two areas close to the parking lot and the lowest point of the area. Also a retention area was established on the lowest laying point.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 350 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 29 |

| | | |
|---|---|---|
| | Implemented | ✓ |

**Catchment Area 17:** This complex area includes four 10-storey buildings and their surrounding green areas and roads. Due to the suitable existing slope direction of the parking lots, the pavement was not changed in this catchment area. Instead, raingardens (close to the entrances) and swales (in the less frequented areas) were used to eliminate the 4-year runoff. Retention areas for the 33-year rain were placed on the lower areas of the water cetchment area.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 950 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 45,5 |
| | Implemented | ✓ |

**Catchment Area 18:** The area of the weekly markets consists of a road and a large asphalt surface. An infiltration swale and an extentional floodable green area were planned to retain the normal and design rain runoff from the sealed surfaces.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 185 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 7,5 |
| | Implemented | ✓ |

**Catchment Area 19:** The catchment area is mainly covered by the asphalt surface of the road. Along the street, in the deepest part of the area was 400$m^2$ infiltration swale and 66$m^2$ floodable green area implemented.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 400 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 16,5 |
| | Implemented | ✓ |

**Catchment Area 20:** The area is the largest park surface of the southern part of the housing estate, including two large and two small large roofs. Green roofs are advised on the roofs. Rain gardens and swales are planned close to the buildings to take up the rest of the runoff. A large rain garden was placed between the two EPDM playground surface. A retention surface was established on the deepest part of the catchment area.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 570 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 38,5 |
| | Implemented | ✓ |

**Catchment Area 21:** The catchment area consists of a long road surface, the asphalted area in front of the garages and a large green area. The grass surface is fortunately the deepest part of the catchment area, a large swale and a retention area could be therefore placed here, wich corresponds to the innfiltration and retention surface requirements.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 320 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 16 |
| | Implemented | ✓ |

**Catchment Area 22:** The area contains the sealed driveways of three buldings' garages and a long roof surface. All three driveways received an infiltration surface. The two smaller rain gardens were extended by retention areas.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 360 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 13 |
| | Implemented | ✓ |

**Catchment Area 23:** The small catchment area contains one building, which's roof is suitable for green roof establishment. Infiltration areas were placed in three areas, to collect the roof runoff, and the runoff of the two small parking surfaces. A retention area was placed on the deepest point of the catchment area.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 143 |

| | | |
|---|---|---|
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 9 |
| | Implemented | ✓ |

**Catchment Area 24:** The area contains three buildings with flat roof, a parking area, pathways and green area. Due to the heght of the buildings, green roofs can be applied. The infiltration swales were placed close to the buildings and the sealed surfaces which produce the majority of the runoff. The infiltration zone was extended by 88$m^2$ or floodable green area.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 350 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 22 |
| | Implemented | ✓ |

**Catchment Area 25:** The largest runoff source of this small catchment area is the roof surface of an estate building. The roof is suitable for green roof establishment. This measure was extended with two small infiltration and retention areas close to the building and to the sealed roof surface.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 78 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 7,5 |
| | Implemented | ✓ |

**Catchment Area 26:** The area has large surface impervious arking sufaces. The swales were placed close to the parking surface to collect the runoff of these surfaces, adopting to the aviable green area and the natural slope. The larger swale surfaces are located therefore in the deepest, eastern part of the catchment area. The roof runoff was decreased by the implementation of a green roof.

| | | |
|---|---|---|
| INF area ($m^2$) | Required | 560 |
| | Implemented | ✓ |
| RET volume ($m^3$) | Required | 20,5 |
| | Implemented | ✓ |

**Catchment Area 27:** The area has a large green area ratio, which allow an easy implementation of on-site rainwater management. The roof runoff was decreased by the implementation of a green roof. The rest of the roof runoff and the runoff of the parking area is collected in an infiltration swale. An additional 90m$^2$ floodable green area was established to retain the design rain runoff.

| | | |
|---|---|---|
| INF area (m$^2$) | Required | 320 |
| | Implemented | ✓ |
| RET volume (m$^3$) | Required | 22,5 |
| | Implemented | ✓ |

## 10.10 Description of the model of the water balance softwer WABILA

The WABILA water balance model simplifies the calculations of the annual impact of the BGI tools in order to reach the area’s unbuilt, natural water balance.”(DWA 2018 p. 7) The efficiency of the program was tested in the project KURAS, where annual runoff was simulated by both STORM and WABILA and both calculations achieved approximately the same results. WABILA uses the rainfall time series of 40 German rainwater stations with different climatic water balances between -247mm/a and 1185mm/a. As we can see in Figure 45, the values of the third weather station are very similar to Budapest`s conditions, therefore the model can be applied to Budapest. A more detailed description of the model is summarised in Annex 10.9.

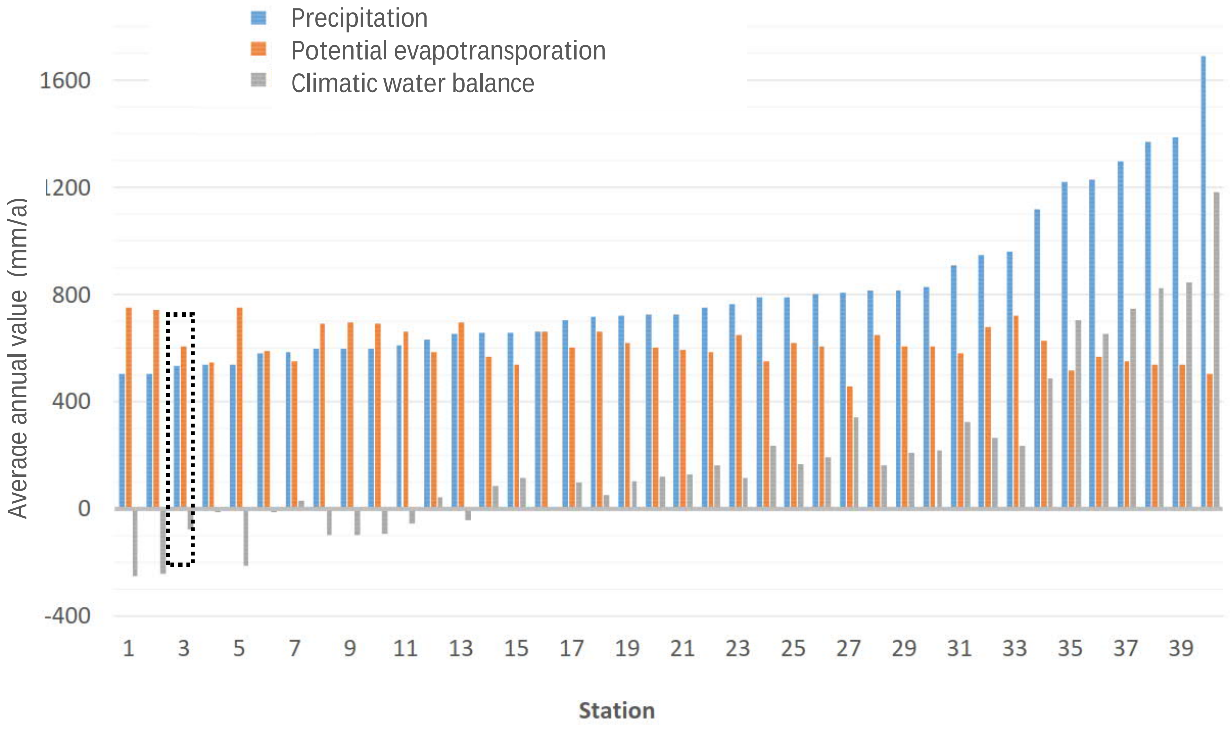


FIGURE 45: PRECIPITATION AND EVAPORATION VALUES AND WATER BALANCE OF THE 40 WEATHER STATIONS (DWA 2018 p. 8)

The program description is quoted from (DWA 2018 pp. 8–9):

„The system functions are derived by means of the simulation model "Storm Water Management Model" of the US EPA (SWMM, Rossman 2010). SWMM offers the possibility of urban surfaces (such as roofs, paved areas, green roofs) and RWB plants (such as infiltration, rainwater harvesting) via the "Subcatchment" and the RWB module "LID" (Low Impact Development). map. The suitability of SWMM for the derivation of system functions is demonstrated by Langner

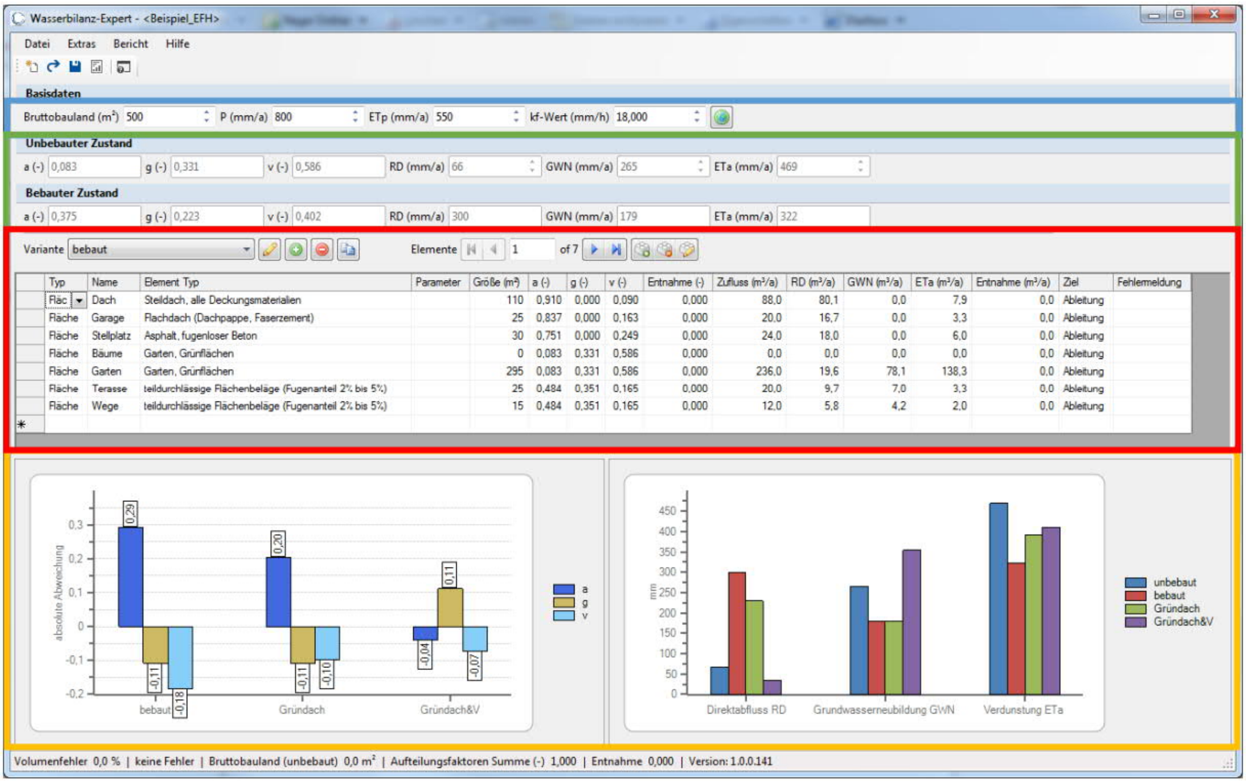
(2013) and Jayasooriya and Ng (2014). For the individual elements (see Figure 21), random combinations of 1000 parameter combinations using the Monte Carlo method or Latin Hypercube sampling are performed in predetermined value ranges for the relevant model parameters (Helton and Davis 2003). Subsequently, 40,000 long-term simulations for the combination of parameter values and precipitation stations were carried out per area or plant and the distribution factors a, g and v were calculated. From this data pool, the distribution functions for the areas and management algae were determined using linear and non-linear multiple regression. On the basis of literature data, a validation or plausibility check of the calculation results was carried out.

The model provides system equations for the areas and management measures listed in Table 1. The system functions are basically based on the sensitive parameters of the 40,000 SWMM simulations. In addition to precipitation and potential evaporation, one to six additional parameters are needed. The validation of the system functions is described by Henrichs et al. (2016)."

| ELEMENT TYPE | SPECIFICATION | DIVISION FACTORS | | |
|---|---|---|---|---|
| | | Direct runoff (a) | Groundwater recharge (g) | Evaporation (v) |
| Roof | Flat roof, pitched roof, gravel roof, retention roof | f(P, ETp, Sp) | 0 | 1-a |
| | Green roof | f(P, $ET_p$, h, $k_f$, $WK_{max}$, WP) | 0 | 1-a |
| Road, path, square | Asphalt, paving elements | f(P, $ET_p$, Sp) | 0 | 1-a |
| | Permeable pavements | f(P, FA, Sp, $WK_{max}$, WP, $k_f$) | f(P, $ET_p$, FA, Sp, $WK_{max}$, WP, $k_f$, h) | f(P, $ET_p$, Sp, h, $k_f$) |
| Infiltration | Infiltration surface | f(P, $BA_S$) | f(P, $ET_p$, $BA_S$) | f(P, $ET_p$, $BA_S$) |
| | Swale | 1-$g_A$-$v_A$ | f(P, $ET_p$, $BA_{S,M}$, $k_f$) | f(P, $ET_p$, $BA_{S,M}$, $k_f$) |
| | Swale with underground infiltration | f(P, $BA_{S,M}$, $k_f$) | f(P, $ET_p$, $BA_{S,M}$, $k_f$) | f(P, $ET_p$, $BA_{S,M}$, $k_f$) |
| | Swale with overflow into an underground infiltration element | f(P, $ET_p$, $BA_{S,M}$, $q_{dr}$, $k_f$) | f(P, $ET_p$, $B_{AS,M}$, $k_f$) | f(P, $ET_p$, $BA_{S,M}$, $q_{dr}$, $k_f$) |
| Rainwater use | | 1-v-e | f(P, $ET_p$, VSp, VBr, VBw) $_{\#1}$ | f(P, $ET_p$, VSp, VBr, VBw) |
| Opened water surface | | 1-v | 0 | f(P, $ET_p$) |
| **P**: Precipitation in mm/a; **$ET_P$**: potential evaporation in mm/a; **Sp**: Storage hegiht in mm; **h**: structure thickness in mm; **$k_f$**: coefficient of permeability in mm/h; **$Wk_{max}$**: max. water capacity; **FA**: joint ratio in %; **$BA_S$**: relative size of the infiltration surface in %; **$BA_{S,M}$**: relative size of the swale surface in % ; **$q_{Dr}$** : Throttled outflow in l/(s·ha); **VSp**: specifical storage capacity in mm; **VBr**: specifical water demand for water use in mm/d; **Wbw**: Annual water demand for irrigation in l/m$^2$/a | | | | |

#1) for rainwater harvesting, the equation for the devision value of the extraction $\mathbf{e_a}$ is listed in the Groundwater recharge field

OVERVIEW OF THE PARAMETERS OF THE SYSTEM FUNCTIONS FOR SURFACES AND RAINWATER MANAGEMENT TOOLS



**Basisdaten**

Bruttobauland (m²) 500 | P (mm/a) 800 | ETp (mm/a) 550 | kf-Wert (mm/h) 18,000

**Unbebauter Zustand**

a (-) 0,083 | g (-) 0,331 | v (-) 0,586 | RD (mm/a) 66 | GWN (mm/a) 265 | ETa (mm/a) 469

**Bebauter Zustand**

a (-) 0,375 | g (-) 0,223 | v (-) 0,402 | RD (mm/a) 300 | GWN (mm/a) 179 | ETa (mm/a) 322

Variante bebaut | Elemente 1 of 7

| Typ | Name | Element Typ | Parameter | Größe (m²) | a (-) | g (-) | v (-) | Entnahme (-) | Zufluss (m³/a) | RD (m³/a) | GWN (m³/a) | ETa (m³/a) | Entnahme (m³/a) | Ziel | Fehlermeldung |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläc | Dach | Steildach, alle Deckungsmaterialien | | 110 | 0,910 | 0,000 | 0,090 | 0,000 | 88,0 | 80,1 | 0,0 | 7,9 | 0,0 | Ableitung | |
| Fläche | Garage | Flachdach (Dachpappe, Faserzement) | | 25 | 0,837 | 0,000 | 0,163 | 0,000 | 20,0 | 16,7 | 0,0 | 3,3 | 0,0 | Ableitung | |
| Fläche | Stellplatz | Asphalt, fugenloser Beton | | 30 | 0,751 | 0,000 | 0,249 | 0,000 | 24,0 | 18,0 | 0,0 | 6,0 | 0,0 | Ableitung | |
| Fläche | Bäume | Garten, Grünflächen | | 0 | 0,083 | 0,331 | 0,586 | 0,000 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | Ableitung | |
| Fläche | Garten | Garten, Grünflächen | | 295 | 0,083 | 0,331 | 0,586 | 0,000 | 236,0 | 19,6 | 78,1 | 138,3 | 0,0 | Ableitung | |
| Fläche | Terasse | teildurchlässige Flächenbeläge (Fugenanteil 2% bis 5%) | | 25 | 0,484 | 0,351 | 0,165 | 0,000 | 20,0 | 9,7 | 7,0 | 3,3 | 0,0 | Ableitung | |
| Fläche | Wege | teildurchlässige Flächenbeläge (Fugenanteil 2% bis 5%) | | 15 | 0,484 | 0,351 | 0,165 | 0,000 | 12,0 | 5,8 | 4,2 | 2,0 | 0,0 | Ableitung | |

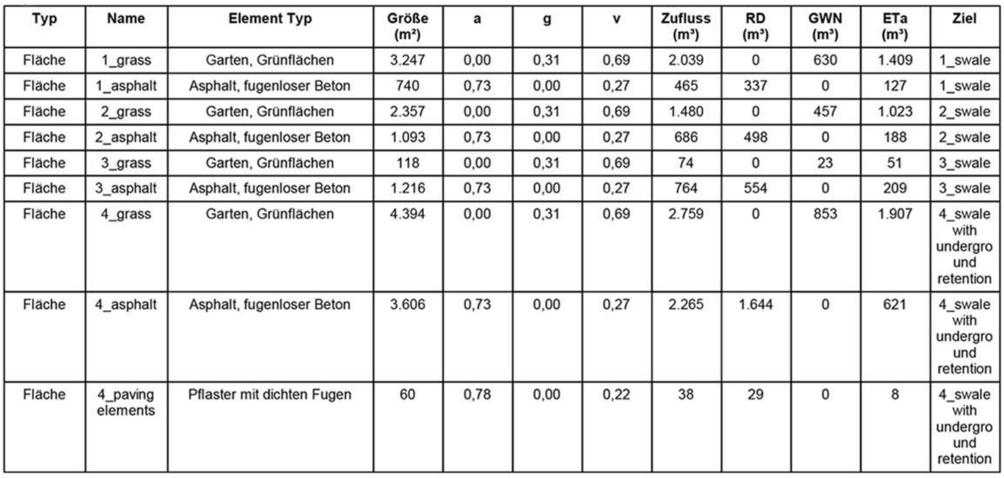
Volumenfehler 0,0 % | keine Fehler | Bruttobauland (unbebaut) 0,0 m² | Aufteilungsfaktoren Summe (-) 1,000 | Entnahme 0,000 | Version: 1.0.0.141

🟦 Base data 🟩 Balance results (unbuilt and planned) 🟥 Surface input area 🟨 Data visualisation area

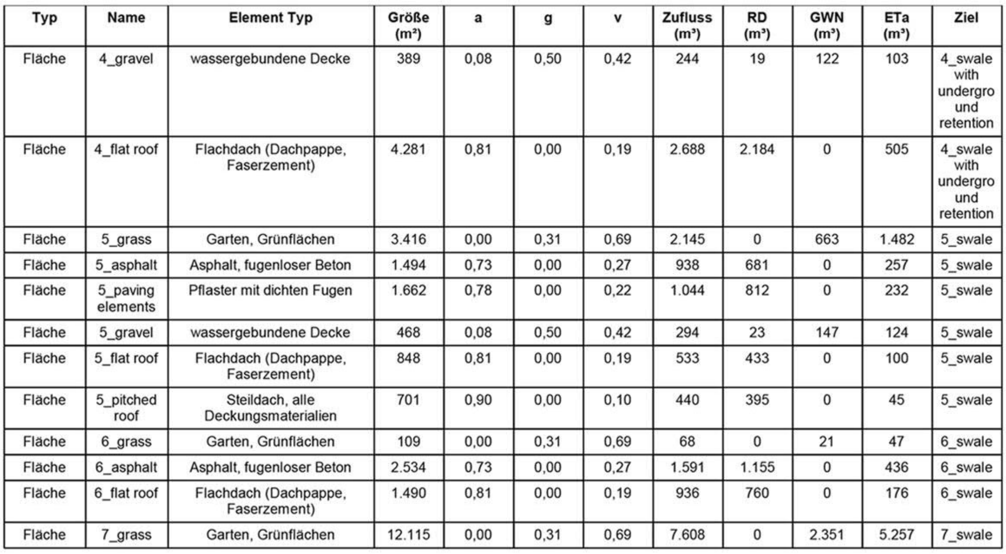
PROGRAM INTERFACE OF THE WABILA WATER BALANCE MODEL

## 10.11 Report of the WABILA water balance model

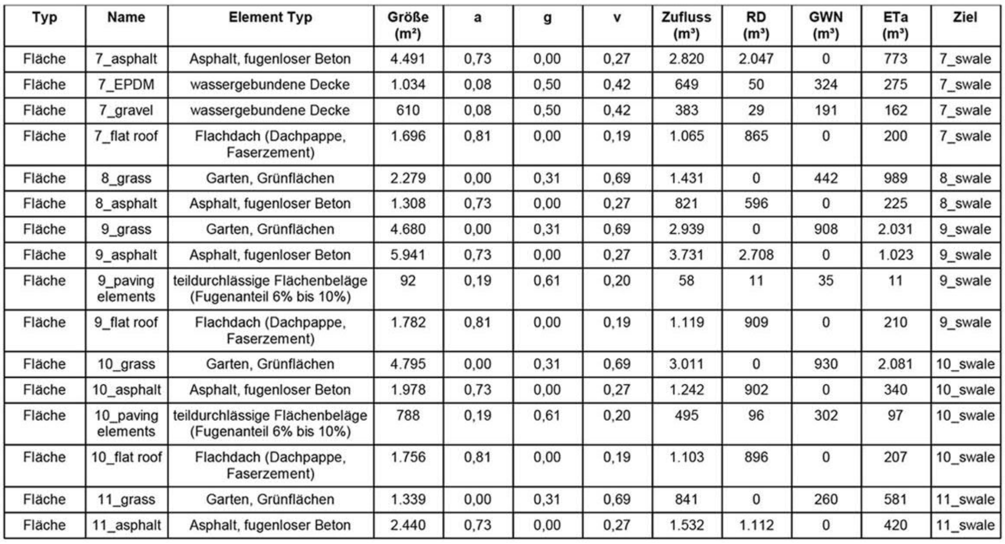
Results of the current and planned Scenario:



| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 1_grass | Garten, Grünflächen | 3.247 | 0,00 | 0,31 | 0,69 | 2.039 | 0 | 630 | 1.409 | 1_swale |
| Fläche | 1_asphalt | Asphalt, fugenloser Beton | 740 | 0,73 | 0,00 | 0,27 | 465 | 337 | 0 | 127 | 1_swale |
| Fläche | 2_grass | Garten, Grünflächen | 2.357 | 0,00 | 0,31 | 0,69 | 1.480 | 0 | 457 | 1.023 | 2_swale |
| Fläche | 2_asphalt | Asphalt, fugenloser Beton | 1.093 | 0,73 | 0,00 | 0,27 | 686 | 498 | 0 | 188 | 2_swale |
| Fläche | 3_grass | Garten, Grünflächen | 118 | 0,00 | 0,31 | 0,69 | 74 | 0 | 23 | 51 | 3_swale |
| Fläche | 3_asphalt | Asphalt, fugenloser Beton | 1.216 | 0,73 | 0,00 | 0,27 | 764 | 554 | 0 | 209 | 3_swale |
| Fläche | 4_grass | Garten, Grünflächen | 4.394 | 0,00 | 0,31 | 0,69 | 2.759 | 0 | 853 | 1.907 | 4_swale with underground retention |
| Fläche | 4_asphalt | Asphalt, fugenloser Beton | 3.606 | 0,73 | 0,00 | 0,27 | 2.265 | 1.644 | 0 | 621 | 4_swale with underground retention |
| Fläche | 4_paving elements | Pflaster mit dichten Fugen | 60 | 0,78 | 0,00 | 0,22 | 38 | 29 | 0 | 8 | 4_swale with underground retention |



| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 4_gravel | wassergebundene Decke | 389 | 0,08 | 0,50 | 0,42 | 244 | 19 | 122 | 103 | 4_swale with underground retention |
| Fläche | 4_flat roof | Flachdach (Dachpappe, Faserzement) | 4.281 | 0,81 | 0,00 | 0,19 | 2.688 | 2.184 | 0 | 505 | 4_swale with underground retention |
| Fläche | 5_grass | Garten, Grünflächen | 3.416 | 0,00 | 0,31 | 0,69 | 2.145 | 0 | 663 | 1.482 | 5_swale |
| Fläche | 5_asphalt | Asphalt, fugenloser Beton | 1.494 | 0,73 | 0,00 | 0,27 | 938 | 681 | 0 | 257 | 5_swale |
| Fläche | 5_paving elements | Pflaster mit dichten Fugen | 1.662 | 0,78 | 0,00 | 0,22 | 1.044 | 812 | 0 | 232 | 5_swale |
| Fläche | 5_gravel | wassergebundene Decke | 468 | 0,08 | 0,50 | 0,42 | 294 | 23 | 147 | 124 | 5_swale |
| Fläche | 5_flat roof | Flachdach (Dachpappe, Faserzement) | 848 | 0,81 | 0,00 | 0,19 | 533 | 433 | 0 | 100 | 5_swale |
| Fläche | 5_pitched roof | Steildach, alle Deckungsmaterialien | 701 | 0,90 | 0,00 | 0,10 | 440 | 395 | 0 | 45 | 5_swale |
| Fläche | 6_grass | Garten, Grünflächen | 109 | 0,00 | 0,31 | 0,69 | 68 | 0 | 21 | 47 | 6_swale |
| Fläche | 6_asphalt | Asphalt, fugenloser Beton | 2.534 | 0,73 | 0,00 | 0,27 | 1.591 | 1.155 | 0 | 436 | 6_swale |
| Fläche | 6_flat roof | Flachdach (Dachpappe, Faserzement) | 1.490 | 0,81 | 0,00 | 0,19 | 936 | 760 | 0 | 176 | 6_swale |
| Fläche | 7_grass | Garten, Grünflächen | 12.115 | 0,00 | 0,31 | 0,69 | 7.608 | 0 | 2.351 | 5.257 | 7_swale |



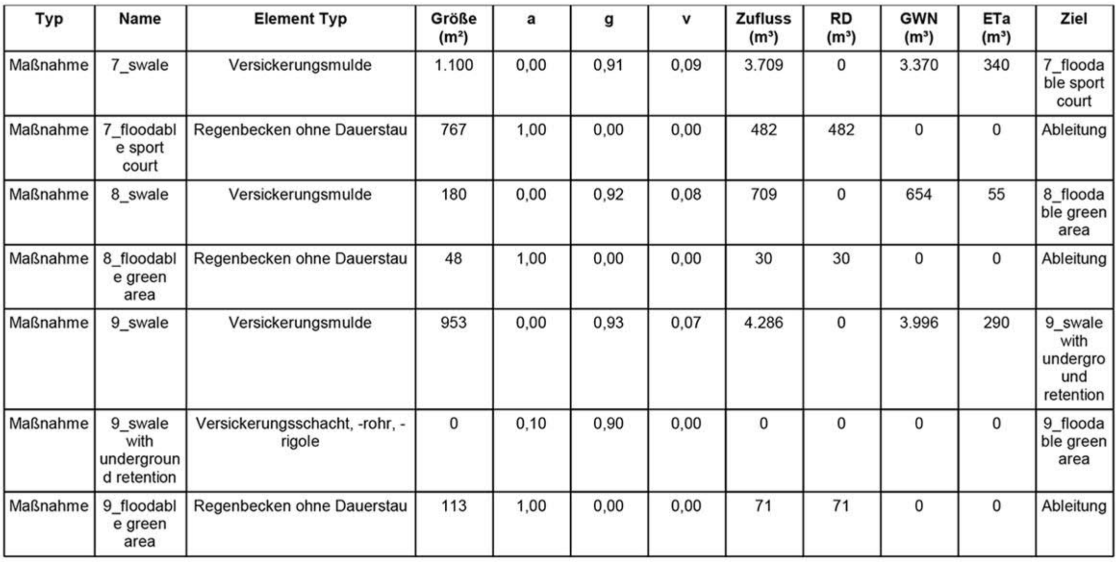
| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 7_asphalt | Asphalt, fugenloser Beton | 4.491 | 0,73 | 0,00 | 0,27 | 2.820 | 2.047 | 0 | 773 | 7_swale |
| Fläche | 7_EPDM | wassergebundene Decke | 1.034 | 0,08 | 0,50 | 0,42 | 649 | 50 | 324 | 275 | 7_swale |
| Fläche | 7_gravel | wassergebundene Decke | 610 | 0,08 | 0,50 | 0,42 | 383 | 29 | 191 | 162 | 7_swale |
| Fläche | 7_flat roof | Flachdach (Dachpappe, Faserzement) | 1.696 | 0,81 | 0,00 | 0,19 | 1.065 | 865 | 0 | 200 | 7_swale |
| Fläche | 8_grass | Garten, Grünflächen | 2.279 | 0,00 | 0,31 | 0,69 | 1.431 | 0 | 442 | 989 | 8_swale |
| Fläche | 8_asphalt | Asphalt, fugenloser Beton | 1.308 | 0,73 | 0,00 | 0,27 | 821 | 596 | 0 | 225 | 8_swale |
| Fläche | 9_grass | Garten, Grünflächen | 4.680 | 0,00 | 0,31 | 0,69 | 2.939 | 0 | 908 | 2.031 | 9_swale |
| Fläche | 9_asphalt | Asphalt, fugenloser Beton | 5.941 | 0,73 | 0,00 | 0,27 | 3.731 | 2.708 | 0 | 1.023 | 9_swale |
| Fläche | 9_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 92 | 0,19 | 0,61 | 0,20 | 58 | 11 | 35 | 11 | 9_swale |
| Fläche | 9_flat roof | Flachdach (Dachpappe, Faserzement) | 1.782 | 0,81 | 0,00 | 0,19 | 1.119 | 909 | 0 | 210 | 9_swale |
| Fläche | 10_grass | Garten, Grünflächen | 4.795 | 0,00 | 0,31 | 0,69 | 3.011 | 0 | 930 | 2.081 | 10_swale |
| Fläche | 10_asphalt | Asphalt, fugenloser Beton | 1.978 | 0,73 | 0,00 | 0,27 | 1.242 | 902 | 0 | 340 | 10_swale |
| Fläche | 10_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 788 | 0,19 | 0,61 | 0,20 | 495 | 96 | 302 | 97 | 10_swale |
| Fläche | 10_flat roof | Flachdach (Dachpappe, Faserzement) | 1.756 | 0,81 | 0,00 | 0,19 | 1.103 | 896 | 0 | 207 | 10_swale |
| Fläche | 11_grass | Garten, Grünflächen | 1.339 | 0,00 | 0,31 | 0,69 | 841 | 0 | 260 | 581 | 11_swale |
| Fläche | 11_asphalt | Asphalt, fugenloser Beton | 2.440 | 0,73 | 0,00 | 0,27 | 1.532 | 1.112 | 0 | 420 | 11_swale |

| Typ | Name | Element Typ | Größe ($m^2$) | a | g | v | Zufluss ($m^3$) | RD ($m^3$) | GWN ($m^3$) | ETa ($m^3$) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 11_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 1.010 | 0,19 | 0,61 | 0,20 | 634 | 123 | 387 | 125 | 11_swale |
| Fläche | 11_pitched roof | Steildach, alle Deckungsmaterialien | 754 | 0,90 | 0,00 | 0,10 | 474 | 425 | 0 | 48 | 11_swale |
| Fläche | 11_flat roof | Flachdach (Dachpappe, Faserzement) | 1.417 | 0,81 | 0,00 | 0,19 | 890 | 723 | 0 | 167 | 11_swale |
| Fläche | 12_grass | Garten, Grünflächen | 3.686 | 0,00 | 0,31 | 0,69 | 2.315 | 0 | 715 | 1.600 | 12_swale |
| Fläche | 12_asphalt | Asphalt, fugenloser Beton | 1.200 | 0,73 | 0,00 | 0,27 | 754 | 547 | 0 | 207 | 12_swale |
| Fläche | 12_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 355 | 0,19 | 0,61 | 0,20 | 223 | 43 | 136 | 44 | 12_swale |
| Fläche | 12_EPDM | wassergebundene Decke | 934 | 0,08 | 0,50 | 0,42 | 587 | 45 | 293 | 248 | 12_swale |
| Fläche | 13_grass | Garten, Grünflächen | 576 | 0,00 | 0,31 | 0,69 | 362 | 0 | 112 | 250 | 13_swale |
| Fläche | 13_asphalt | Asphalt, fugenloser Beton | 4.058 | 0,73 | 0,00 | 0,27 | 2.548 | 1.850 | 0 | 699 | 13_swale |
| Fläche | 14_grass | Garten, Grünflächen | 5.843 | 0,00 | 0,31 | 0,69 | 3.669 | 0 | 1.134 | 2.536 | 14_swale |
| Fläche | 14_asphalt | Asphalt, fugenloser Beton | 4.856 | 0,73 | 0,00 | 0,27 | 3.050 | 2.214 | 0 | 836 | 14_swale |
| Fläche | 14_gravel | wassergebundene Decke | 482 | 0,08 | 0,50 | 0,42 | 303 | 23 | 151 | 128 | 14_swale |
| Fläche | 14_flat roof | Flachdach (Dachpappe, Faserzement) | 4.211 | 0,81 | 0,00 | 0,19 | 2.645 | 2.148 | 0 | 497 | 14_swale |
| Fläche | 15_grass | Garten, Grünflächen | 1.050 | 0,00 | 0,31 | 0,69 | 659 | 0 | 204 | 456 | 15_swale |
| Fläche | 15_asphalt | Asphalt, fugenloser Beton | 2.879 | 0,73 | 0,00 | 0,27 | 1.808 | 1.312 | 0 | 496 | 15_swale |
| Fläche | 16_grass | Garten, Grünflächen | 5.974 | 0,00 | 0,31 | 0,69 | 3.752 | 0 | 1.159 | 2.592 | 16_swale |
| Fläche | 16_asphalt | Asphalt, fugenloser Beton | 2.279 | 0,73 | 0,00 | 0,27 | 1.431 | 1.039 | 0 | 392 | 16_swale |
| Fläche | 16_EPDM | wassergebundene Decke | 81 | 0,08 | 0,50 | 0,42 | 51 | 4 | 25 | 22 | 16_swale |
| Fläche | 17_grass | Garten, Grünflächen | 5.215 | 0,00 | 0,31 | 0,69 | 3.275 | 0 | 1.012 | 2.263 | 17_swale |
| Fläche | 17_asphalt | Asphalt, fugenloser Beton | 4.927 | 0,73 | 0,00 | 0,27 | 3.094 | 2.246 | 0 | 848 | 17_swale |
| Fläche | 17_paving elements | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 646 | 0,19 | 0,61 | 0,20 | 406 | 79 | 247 | 80 | 17_swale |
| Fläche | 17_flat roof | Flachdach (Dachpappe, Faserzement) | 2.090 | 0,81 | 0,00 | 0,19 | 1.313 | 1.066 | 0 | 247 | 17_swale |
| Fläche | 18_grass | Garten, Grünflächen | 784 | 0,00 | 0,31 | 0,69 | 492 | 0 | 152 | 340 | 18_swale |
| Fläche | 18_asphalt | Asphalt, fugenloser Beton | 1.465 | 0,73 | 0,00 | 0,27 | 920 | 668 | 0 | 252 | 18_swale |
| Fläche | 18_flat roof | Flachdach (Dachpappe, Faserzement) | 38 | 0,81 | 0,00 | 0,19 | 24 | 19 | 0 | 4 | 18_swale |
| Fläche | 19_grass | Garten, Grünflächen | 1.706 | 0,00 | 0,31 | 0,69 | 1.071 | 0 | 331 | 740 | 19_swale |
| Fläche | 19_asphalt | Asphalt, fugenloser Beton | 3.279 | 0,73 | 0,00 | 0,27 | 2.059 | 1.495 | 0 | 564 | 19_swale |
| Fläche | 20_grass | Garten, Grünflächen | 5.529 | 0,00 | 0,31 | 0,69 | 3.472 | 0 | 1.073 | 2.399 | 20_swale |
| Fläche | 20_asphalt | Asphalt, fugenloser Beton | 3.038 | 0,73 | 0,00 | 0,27 | 1.908 | 1.385 | 0 | 523 | 20_swale |
| Fläche | 20_EPDM | wassergebundene Decke | 741 | 0,08 | 0,50 | 0,42 | 465 | 36 | 233 | 197 | 20_swale |
| Fläche | 20_green roof | Gründach mit Extensivbegrünung | 1.880 | 0,52 | 0,00 | 0,48 | 1.181 | 611 | 0 | 570 | 20_swale |
| Fläche | 21_grass | Garten, Grünflächen | 1.720 | 0,00 | 0,31 | 0,69 | 1.080 | 0 | 334 | 746 | 21_swale |
| Fläche | 21_asphalt | Asphalt, fugenloser Beton | 2.563 | 0,73 | 0,00 | 0,27 | 1.610 | 1.168 | 0 | 441 | 21_swale |
| Fläche | 22_grass | Garten, Grünflächen | 998 | 0,00 | 0,31 | 0,69 | 627 | 0 | 194 | 433 | 22_swale |
| Fläche | 22_asphalt | Asphalt, fugenloser Beton | 2.976 | 0,73 | 0,00 | 0,27 | 1.869 | 1.357 | 0 | 512 | 22_swale |
| Fläche | 23_grass | Garten, Grünflächen | 1.191 | 0,00 | 0,31 | 0,69 | 748 | 0 | 231 | 517 | 23_swale |
| Fläche | 23_asphalt | Asphalt, fugenloser Beton | 797 | 0,73 | 0,00 | 0,27 | 501 | 363 | 0 | 137 | 23_swale |
| Fläche | 23_greent roof | Gründach mit Extensivbegrünung | 686 | 0,52 | 0,00 | 0,48 | 431 | 223 | 0 | 208 | 23_swale |
| Fläche | 24_grass | Garten, Grünflächen | 2.492 | 0,00 | 0,31 | 0,69 | 1.565 | 0 | 484 | 1.081 | 24_swale |
| Fläche | 24_asphalt | Asphalt, fugenloser Beton | 1.846 | 0,73 | 0,00 | 0,27 | 1.159 | 842 | 0 | 318 | 24_swale |
| Fläche | 24_green roof | Gründach mit Extensivbegrünung | 2.088 | 0,52 | 0,00 | 0,48 | 1.311 | 679 | 0 | 633 | 24_swale |
| Fläche | 25_grass | Garten, Grünflächen | 1.173 | 0,00 | 0,31 | 0,69 | 737 | 0 | 228 | 509 | 25_swale |
| Fläche | 25_asphalt | Asphalt, fugenloser Beton | 230 | 0,73 | 0,00 | 0,27 | 144 | 105 | 0 | 40 | 25_swale |
| Fläche | 25_flat roof | Flachdach (Dachpappe, Faserzement) | 686 | 0,81 | 0,00 | 0,19 | 431 | 350 | 0 | 81 | 25_swale |
| Fläche | 26_grass | Garten, Grünflächen | 1.347 | 0,00 | 0,31 | 0,69 | 846 | 0 | 261 | 585 | 26_swale |
| Fläche | 26_asphalt | Asphalt, fugenloser Beton | 4.320 | 0,73 | 0,00 | 0,27 | 2.713 | 1.969 | 0 | 744 | 26_swale |
| Fläche | 26_flat roof | teildurchlässige Flächenbeläge (Fugenanteil 6% bis 10%) | 149 | 0,19 | 0,61 | 0,20 | 94 | 18 | 57 | 18 | 26_swale |
| Fläche | 27_grass | Garten, Grünflächen | 3.807 | 0,00 | 0,31 | 0,69 | 2.391 | 0 | 739 | 1.652 | 27_swale |
| Fläche | 27_asphalt | Asphalt, fugenloser Beton | 2.560 | 0,73 | 0,00 | 0,27 | 1.608 | 1.167 | 0 | 441 | 27_swale |
| Fläche | 27_flat roof | Gründach mit Extensivbegrünung | 686 | 0,52 | 0,00 | 0,48 | 431 | 223 | 0 | 208 | 27_swale |

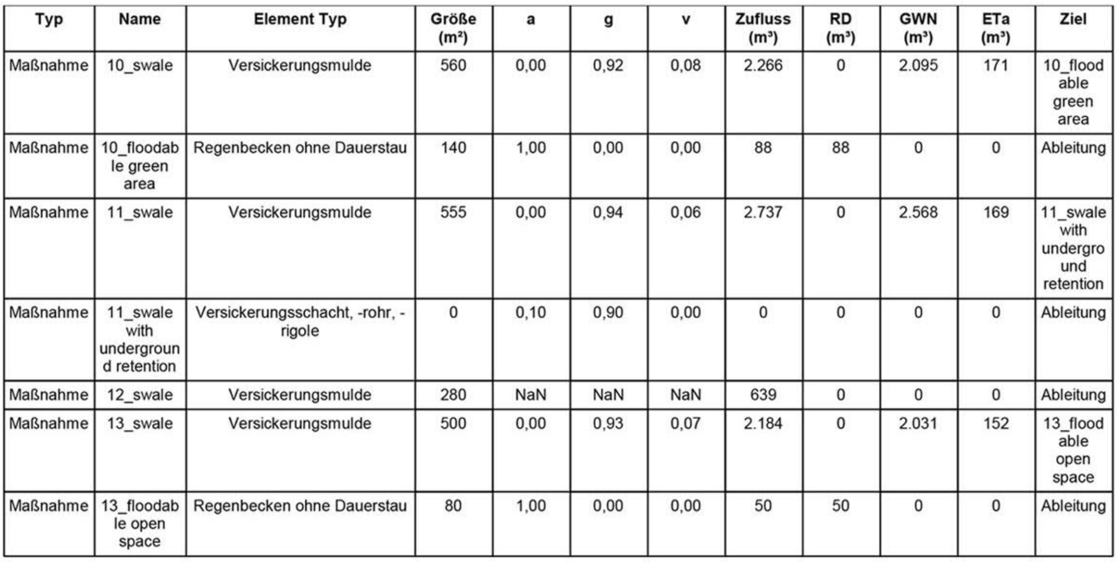
| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 3_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 726 | 0,04 | 0,72 | 0,24 | 456 | 20 | 326 | 110 | 3_swale |
| Fläche | 4_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 1.858 | 0,04 | 0,72 | 0,24 | 1.167 | 50 | 835 | 282 | 4_swale |
| Fläche | 5_green roof | Gründach mit Extensivbegrünung | 760 | 0,52 | 0,00 | 0,48 | 477 | 247 | 0 | 230 | 5_swale |
| Fläche | 6_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 521 | 0,04 | 0,72 | 0,24 | 327 | 14 | 234 | 79 | 6_swale |
| Fläche | 7_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 992 | 0,04 | 0,72 | 0,24 | 623 | 27 | 446 | 151 | 7_swale |
| Fläche | 9_green roof | Gründach mit Extensivbegrünung | 183 | 0,52 | 0,00 | 0,48 | 115 | 59 | 0 | 55 | 9_swale |
| Fläche | 10_green roof | Gründach mit Extensivbegrünung | 64 | 0,52 | 0,00 | 0,48 | 40 | 21 | 0 | 19 | 10_swale |
| Fläche | 11_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 214 | 0,04 | 0,72 | 0,24 | 134 | 6 | 96 | 32 | 11_swale |
| Fläche | 12_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 129 | 0,04 | 0,72 | 0,24 | 81 | 3 | 58 | 20 | 12_swale |
| Fläche | 13_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 729 | 0,04 | 0,72 | 0,24 | 458 | 20 | 327 | 111 | 13_swale |
| Fläche | 14_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 1.090 | 0,04 | 0,72 | 0,24 | 685 | 29 | 490 | 165 | 14_swale |
| Fläche | 15_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 1.534 | 0,04 | 0,72 | 0,24 | 963 | 41 | 689 | 233 | 15_swale |

| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fläche | 17_green roof | Gründach mit Extensivbegrünung | 116 | 0,52 | 0,00 | 0,48 | 73 | 38 | 0 | 35 | 17_swale |
| Fläche | 21_grass paver | Rasengittersteine (Fugenanteil 20% – 30%) | 264 | 0,04 | 0,72 | 0,24 | 166 | 7 | 119 | 40 | 21_swale |
| Fläche | 26_green roof | Gründach mit Extensivbegrünung | 495 | 0,52 | 0,00 | 0,48 | 311 | 161 | 0 | 150 | 26_swale |
| Maßnahme | 1_swale | Versickerungsmulde | 129 | 0,00 | 0,90 | 0,10 | 418 | 0 | 378 | 40 | 1_floodable green area |
| Maßnahme | 1_floodable green area | Regenbecken ohne Dauerstau | 56 | 1,00 | 0,00 | 0,00 | 35 | 35 | 0 | 0 | Ableitung |
| Maßnahme | 2_swale | Versickerungsmulde | 155 | 0,00 | 0,92 | 0,08 | 596 | 0 | 548 | 47 | 2_floodable green area |
| Maßnahme | 2_floodable green area | offenes Regenbecken mit Dauerstau | 48 | 0,18 | 0,00 | 0,82 | 30 | 6 | 0 | 25 | Ableitung |
| Maßnahme | 3_swale | Versickerungsmulde | 160 | 0,00 | 0,93 | 0,07 | 674 | 0 | 626 | 49 | 3_floodable green area |
| Maßnahme | 3_floodable green area | Regenbecken ohne Dauerstau | 36 | 1,00 | 0,00 | 0,00 | 23 | 23 | 0 | 0 | Ableitung |

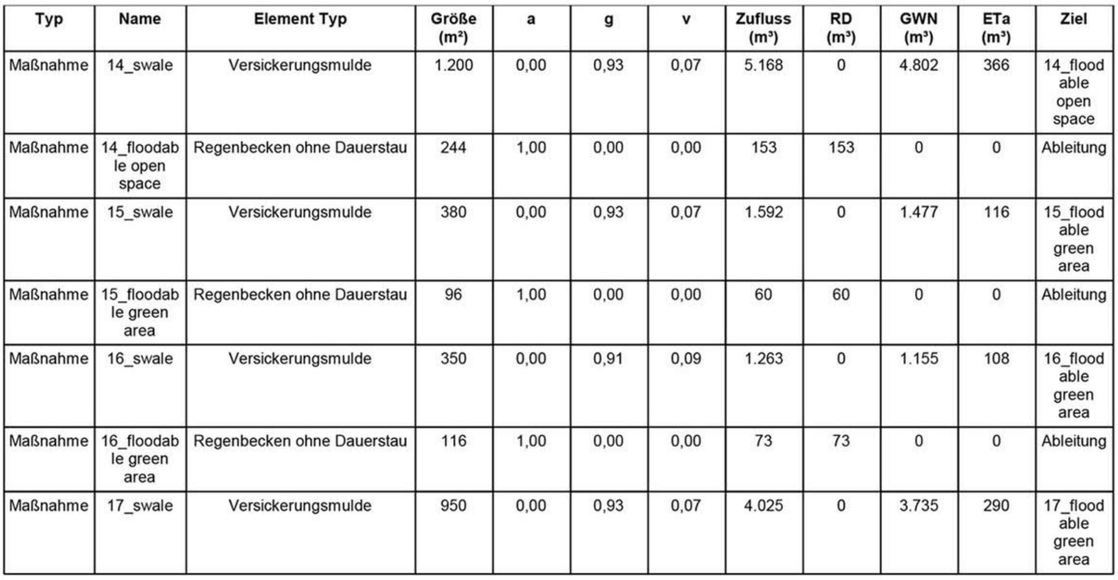
| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maßnahme | 4_swale | Versickerungsmulde | 1.050 | NaN | NaN | NaN | 50 | 0 | 2.369 | 175 | 4_swale with underground retention |
| Maßnahme | 4_swale with underground retention | Versickerungsschacht, -rohr, -rigole | 0 | 0,10 | 0,90 | 0,00 | 3.875 | 388 | 3.488 | 0 | Ableitung |
| Maßnahme | 5_swale | Versickerungsmulde | 640 | 0,00 | 0,93 | 0,07 | 2.970 | 0 | 2.775 | 195 | 5_pond |
| Maßnahme | 5_pond | offenes Regenbecken mit Dauerstau | 658 | 0,18 | 0,00 | 0,82 | 413 | 76 | 0 | 337 | 5_floodable green area |
| Maßnahme | 5_floodable green area | Regenbecken ohne Dauerstau | 94 | 1,00 | 0,00 | 0,00 | 135 | 135 | 0 | 0 | Ableitung |
| Maßnahme | 6_swale | Versickerungsmulde | 249 | NaN | NaN | NaN | 1.929 | 0 | 830 | 67 | 6_swale with undergound retention |
| Maßnahme | 6_swale with undergound retention | Versickerungsschacht, -rohr, -rigole | 0 | 0,10 | 0,90 | 0,00 | 0 | 0 | 0 | 0 | Ableitung |



| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maßnahme | 7_swale | Versickerungsmulde | 1.100 | 0,00 | 0,91 | 0,09 | 3.709 | 0 | 3.370 | 340 | 7_floodable sport court |
| Maßnahme | 7_floodable sport court | Regenbecken ohne Dauerstau | 767 | 1,00 | 0,00 | 0,00 | 482 | 482 | 0 | 0 | Ableitung |
| Maßnahme | 8_swale | Versickerungsmulde | 180 | 0,00 | 0,92 | 0,08 | 709 | 0 | 654 | 55 | 8_floodable green area |
| Maßnahme | 8_floodable green area | Regenbecken ohne Dauerstau | 48 | 1,00 | 0,00 | 0,00 | 30 | 30 | 0 | 0 | Ableitung |
| Maßnahme | 9_swale | Versickerungsmulde | 953 | 0,00 | 0,93 | 0,07 | 4.286 | 0 | 3.996 | 290 | 9_swale with underground retention |
| Maßnahme | 9_swale with underground retention | Versickerungsschacht, -rohr, -rigole | 0 | 0,10 | 0,90 | 0,00 | 0 | 0 | 0 | 0 | 9_floodable green area |
| Maßnahme | 9_floodable green area | Regenbecken ohne Dauerstau | 113 | 1,00 | 0,00 | 0,00 | 71 | 71 | 0 | 0 | Ableitung |



| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maßnahme | 10_swale | Versickerungsmulde | 560 | 0,00 | 0,92 | 0,08 | 2.266 | 0 | 2.095 | 171 | 10_floodable green area |
| Maßnahme | 10_floodable green area | Regenbecken ohne Dauerstau | 140 | 1,00 | 0,00 | 0,00 | 88 | 88 | 0 | 0 | Ableitung |
| Maßnahme | 11_swale | Versickerungsmulde | 555 | 0,00 | 0,94 | 0,06 | 2.737 | 0 | 2.568 | 169 | 11_swale with underground retention |
| Maßnahme | 11_swale with underground retention | Versickerungsschacht, -rohr, -rigole | 0 | 0,10 | 0,90 | 0,00 | 0 | 0 | 0 | 0 | Ableitung |
| Maßnahme | 12_swale | Versickerungsmulde | 280 | NaN | NaN | NaN | 639 | 0 | 0 | 0 | Ableitung |
| Maßnahme | 13_swale | Versickerungsmulde | 500 | 0,00 | 0,93 | 0,07 | 2.184 | 0 | 2.031 | 152 | 13_floodable open space |
| Maßnahme | 13_floodable open space | Regenbecken ohne Dauerstau | 80 | 1,00 | 0,00 | 0,00 | 50 | 50 | 0 | 0 | Ableitung |



| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maßnahme | 14_swale | Versickerungsmulde | 1.200 | 0,00 | 0,93 | 0,07 | 5.168 | 0 | 4.802 | 366 | 14_floodable open space |
| Maßnahme | 14_floodable open space | Regenbecken ohne Dauerstau | 244 | 1,00 | 0,00 | 0,00 | 153 | 153 | 0 | 0 | Ableitung |
| Maßnahme | 15_swale | Versickerungsmulde | 380 | 0,00 | 0,93 | 0,07 | 1.592 | 0 | 1.477 | 116 | 15_floodable green area |
| Maßnahme | 15_floodable green area | Regenbecken ohne Dauerstau | 96 | 1,00 | 0,00 | 0,00 | 60 | 60 | 0 | 0 | Ableitung |
| Maßnahme | 16_swale | Versickerungsmulde | 350 | 0,00 | 0,91 | 0,09 | 1.263 | 0 | 1.155 | 108 | 16_floodable green area |
| Maßnahme | 16_floodable green area | Regenbecken ohne Dauerstau | 116 | 1,00 | 0,00 | 0,00 | 73 | 73 | 0 | 0 | Ableitung |
| Maßnahme | 17_swale | Versickerungsmulde | 950 | 0,00 | 0,93 | 0,07 | 4.025 | 0 | 3.735 | 290 | 17_floodable green area |

| Typ | Name | Element Typ | Größe (m²) | a | g | v | Zufluss (m³) | RD (m³) | GWN (m³) | ETa (m³) | Ziel |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maßnahme | 17_floodable green area | Regenbecken ohne Dauerstau | 184 | 1,00 | 0,00 | 0,00 | 116 | 116 | 0 | 0 | Ableitung |
| Maßnahme | 18_swale | Versickerungsmulde | 185 | 0,00 | 0,93 | 0,07 | 803 | 0 | 747 | 56 | 18_floodable green area |
| Maßnahme | 18_floodable green area | Regenbecken ohne Dauerstau | 32 | 1,00 | 0,00 | 0,00 | 20 | 20 | 0 | 0 | Ableitung |
| Maßnahme | 19_swale | Versickerungsmulde | 400 | 0,00 | 0,93 | 0,07 | 1.746 | 0 | 1.624 | 122 | 19_floodable green area |
| Maßnahme | 19_floodable green area | Regenbecken ohne Dauerstau | 64 | 1,00 | 0,00 | 0,00 | 40 | 40 | 0 | 0 | Ableitung |
| Maßnahme | 20_swale | Versickerungsmulde | 570 | 0,00 | 0,93 | 0,07 | 2.390 | 0 | 2.216 | 174 | 20_floodable green area |
| Maßnahme | 20_floodable green area | Regenbecken ohne Dauerstau | 156 | 1,00 | 0,00 | 0,00 | 98 | 98 | 0 | 0 | Ableitung |
| Maßnahme | 21_swale | Versickerungsmulde | 320 | 0,00 | 0,93 | 0,07 | 1.376 | 0 | 1.279 | 98 | 21_floodable green area |
| Maßnahme | 21_floodable green area | Regenbecken ohne Dauerstau | 64 | 1,00 | 0,00 | 0,00 | 40 | 40 | 0 | 0 | Ableitung |
| Maßnahme | 22_swale | Versickerungsmulde | 360 | 0,00 | 0,93 | 0,07 | 1.583 | 0 | 1.473 | 110 | 22_floodable green area |
| Maßnahme | 22_floodable green area | Regenbecken ohne Dauerstau | 52 | 1,00 | 0,00 | 0,00 | 33 | 33 | 0 | 0 | Ableitung |
| Maßnahme | 23_swale | Versickerungsmulde | 143 | 0,00 | 0,94 | 0,06 | 676 | 0 | 633 | 44 | 23_floodable green area |
| Maßnahme | 23_floodable green area | Regenbecken ohne Dauerstau | 36 | 1,00 | 0,00 | 0,00 | 23 | 23 | 0 | 0 | Ableitung |
| Maßnahme | 24_swale | Versickerungsmulde | 350 | 0,00 | 0,94 | 0,06 | 1.740 | 0 | 1.633 | 107 | 24_floodable green area |
| Maßnahme | 24_floodable green area | Regenbecken ohne Dauerstau | 88 | 1,00 | 0,00 | 0,00 | 55 | 55 | 0 | 0 | Ableitung |
| Maßnahme | 25_swale | Versickerungsmulde | 78 | NaN | NaN | NaN | 455 | 0 | 487 | 31 | 25_floodable green area |
| Maßnahme | 25_floodable green area | Regenbecken ohne Dauerstau | 28 | 1,00 | 0,00 | 0,00 | 18 | 18 | 0 | 0 | Ableitung |
| Maßnahme | 26_swale | Versickerungsmulde | 560 | 0,00 | 0,93 | 0,07 | 2.500 | 0 | 2.329 | 171 | 26_floodable green area |
| Maßnahme | 26_floodable green area | Regenbecken ohne Dauerstau | 80 | 1,00 | 0,00 | 0,00 | 50 | 50 | 0 | 0 | Ableitung |
| Maßnahme | 27_swale | Versickerungsmulde | 320 | 0,00 | 0,94 | 0,06 | 1.591 | 0 | 1.493 | 98 | 27_flodable green area |
| Maßnahme | 27_flodable green area | Regenbecken ohne Dauerstau | 92 | 1,00 | 0,00 | 0,00 | 58 | 58 | 0 | 0 | Ableitung |