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Application of Sponge City concept to address the issues of stormwater management in urban areas: Prohlis, Dresden

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Title

Application of Sponge City concept to address the issues of stormwater management in urban areas: Prohlis, Dresden

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Abstract (400-500 words)

This thesis examines the application of the Sponge City concept as a sustainable stormwater management strategy in Dresden's Prohlis district. It investigates Sponge City's characteristics and benefits for stormwater retention and reuse, such as permeable pavements, rain gardens, and bioretention ponds. The study emphasizes the importance of including social, economic, and environmental elements in urban planning to promote a sustainable and high-quality urban lifestyle. It addresses the issues raised by rising urbanization and climate change, including the increased frequency of extreme weather events like floods and droughts. The thesis emphasizes the importance of resilient infrastructure in managing these repercussions effectively. This study analyses existing literature, case studies, and urban water management systems to give policymakers, urban planners, and stakeholders practical advice. It suggests customized Sponge City characteristics for Prohlis to improve stormwater management, increase biodiversity, lower the urban heat island effect, and promote public health. The findings show that, while the Sponge City concept is unique and intriguing, it will require careful planning, finance, and stakeholder participation to be implemented successfully. The report also emphasizes the significance of incorporating renewable energy options, such as solar panels, in order to power urban infrastructure responsibly. Overall, this study adds to the greater discussion of sustainable urban development and climate resilience by providing insights and practical answers for communities facing similar difficulties around the world.

Keywords

Sponge City, urban water management, urban resilience, stormwater harvesting,

Originality statement. I hereby declare that this Master's dissertation is my own original work, does not contain other people's work without this being stated, cited and referenced, has not been submitted elsewhere in fulfilment of the requirements of this or any other award.

Signature

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ACKNOWLEDGMENT

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1. INTRODUCTION

The human health and quality of life of urban residents are associated with their urban environmental conditions. If these conditions are abused, it can lead to an enormous socio-economic halt. Sustainable urban development depends on the consideration of three main factors, such as social, economic, and environmental, when the balance between these three factors is followed, a safe and good quality of life for current and future residents of urban areas is ensured.

Failure to meet those criteria can result in a range of interrelated problems that erode the capacity of urban areas to sustain healthy, and resilient communities. Every city promotes sustainable urban development, which is necessary for long-term welfare and economy and, most importantly, the environment.

Over half of the world's population lives in cities (United Nations, 2019). As the world continues to urbanize, an estimated two-thirds of the global population is expected to be residing in urban areas by 2050 (ibid).

The question of the impacts of rapid urbanization on the surrounding environment is now in the spotlight. The growth of the urban population requires infrastructure with the basic needs to be prepared, including supporting infrastructure such as water supply systems, electricity and heating plants, public health, food supply, as well as solid waste production, electricity production, and other life infrastructures that must be built.

Stormwater management has become increasingly imperative in urban areas, on account of rapid urbanization, climate-change-induced extreme weather conditions (drought and flooding), and a variety of other factors. Existing conventional drainage systems lack in capturing this excess stormwater runoff, and in the event of heavy rain, it causes drainage systems to overflow and floods to occur which cause a volume of water in the drains and affect the environment and habitat as well as financially and socially. Prohlis: One of its kind in Dresden, Germany, is the district of errors

Dresden, famed for its unique engineering and cultural background, has a history of high-water events, the disastrous floods in 2002 and 2013 being only the most recent. From a different angle, the vulnerability of the city's drainage infrastructure and the necessity for resilient stormwater management strategies was underscored by these events (Kreibich et al, 2017). With significant impervious surfaces and a lack of drainage facilities, the densely settled housing area "Prohlis" in Dresden is highly endangered by waterlogging and surface runoff problems.

Water availability and quality are profoundly affected by climate change, which is a serious concern. It shows the two stages of the climate change impact expression that are water-related: an excess of water, such as floods and storms, or a lack of water that causes droughts and heatwaves, which leads to an unbalance in the aquatic environment in some regions of the world (Sun et al., 2020, p. 30).

Global warming caused by climate change increases precipitation patterns due to increased evaporation rates, more water the atmosphere can hold, and the changing weather patterns that make intense and frequent storms more likely. This interaction of elements results in a wetter environment more or less globally. Water resources are shortening, and with some areas in the world getting more rain, other parts are experiencing increasing droughts.

This in turn affects water resources and raises evaporation rates within urban environments due to the urban heat island effect. Higher temperatures in turn increase the evaporation of surface water from the lakes, rivers, and reservoirs and promote water loss, thus decreasing the water availability for drinking, irrigation, or maintaining the ecosystem (Zhao et al., 2014). Urban water scarcity and drought may be further exacerbated in urban areas as evaporation rates increase, leading to additional prestress on urban water supply systems and increased vulnerability of communities and ecosystems to water security (Nuruzzaman, 2015).

In the last decade alone, water-related hazards were attributed to the occurrence of the 10 following disasters which have produced economic and human losses (World Meteorological Organization [WMO], 2021, p. 16): 650,000 deaths (drought); 577,232 deaths (storms); 58,700 deaths (floods); 55,736 deaths (extreme temperature). Both the economic damages of hurricanes and floods reach the maximum, at US$ 115 billion, and US$ 521 billion (Annex 1). The lack of necessary legal regulations to ensure appropriate actions is demonstrated through the linking of the consequences of climate change on water and the provision of water as one of the solutions, showing that water management solution is an inherent element of the systematics of preventing and/or compensating damages resulting from climate change.

Therefore, it is necessary to re-evaluate and upgrade existing water resource conservation and management programs and legislation to suit both current and future conditions. Urgent and targeted action to transform water usage is required to transition from inefficient practices to more prudent and rational uses that preserve and sustain current water supplies. Meanwhile, more state-of-the-art and cutting-edge practices in water management must be evaluated and then recently implemented to create appropriate and location-specific solutions.

This thesis examined the implementation of the concept "Sponge City" to resolve stormwater management problems in Prohlis, Dresden. Also, the features and benefits of Sponge City in the retention of stormwater are examined as well as the potential of Sponge City in stormwater harvesting and reuse.

The thesis focuses on achieving the following 4 main objectives:

1. How does Sponge City Concept assist in managing stormwater in urban areas?
2. Identifying the distinctive and functional advantages of the Sponge City Concept in stormwater retention compared to other methods.
3. Climate Change Adaptation: Analysing the potential of the Sponge City Concept for stormwater harvesting and reuse.
4. Recommendation for Regeneration and Renaturing Geberbach Creek

The concept is called a Sponge City (introduced in China in 2013), where urban landscapes are designed to absorb and retain - much in the same way as a natural sponge. This includes planning and development practices that integrate green infrastructure such as permeable pavements, green roofs, rain gardens, and constructed wetlands. This infrastructure captures, retains, and releases stormwater to the environment over longer periods, and thereby also serves a function that more accurately imitates natural hydrology (Zevenbergen et al., 2018).

Changing the face of a Prohlis into that of a Sponge City tackles difficulties head-on. The Sponge City concept helps to retain stormwater by improving green infrastructure and applying sustainable urban water management practices in a way that reduces flood risks and results in improved water quality and several other side-benefits, such as biodiversity increase, a reduced heat island effect or improved public health (Li et al. 2017).

This thesis seeks to investigate the feasibility and benefits of a Sponge City applied to a dense neighborhood, in the case of Prohlis, taking into account the regional climatic conditions, the urban built environment, and social characteristics.

The following sections will look into, the theory and principles of the Sponge City concept, examining the current state of stormwater management concerning the impacts posed by climate change, reviewing current municipal and state-scale legislation on stormwater management, showing examples of successful interventions within other urban environments and evaluating the site-specific requirements and circumstances of Sponge City concept features within Prohlis. Through this comprehensive analysis, the thesis will propose a tailored Sponge City infrastructure for Prohlis, offering practical recommendations for policymakers, urban planners, and stakeholders involved in Dresden's urban development and water management sectors.

By addressing the stormwater management issues in Prohlis through the Sponge City concept, this research contributes to the broader discourse on sustainable urban development and climate resilience. The findings and recommendations of this thesis can serve as a reference for other cities facing similar challenges, promoting the adoption of green infrastructure solutions worldwide.

2. LITERATURE REVIEW

2.1. Global Trends in Urbanization

One of the global trends is rapid urbanization, which is defined by the rapid expansion of cities that may affect the natural environment and disrupt the urban landscape.

Over the past few decades, the ratio of urban and rural residents has changed drastically. In 2018, 54% of the global population lived in urban areas, which are the powerhouses of the global economy. The urban demographic pyramid is expected to expand. Urban land cover is expected to nearly triple by 2030 (1.2 million km^2), and the majority of the world's population will reside in urban areas facing anthropogenic climate change by 2030 (United Nations, 2018).

Urbanization also brought with it a host of negative impacts as well, urban areas have high energy demands, bad air and water quality, low water availability, and waste assimilation problems, besides employment opportunities, health, and education services, and better living standards.

On the other hand, rapid urbanization has disrupted or displaced natural hydrological processes through construction and land occupation as well as fragmented rainwater recycling systems by losing natural rainwater-retaining infrastructure such as woodlands, green spaces, natural lakes, and wetlands. It introduces a range of existential threats to the ecosystems, infrastructure, and public health. One of the key challenges associated with rapid urbanization is its impact on stormwater management.

In urban areas, water utilization is one of the crucial factors that help achieve sustainable urban development (Schaffer and Vollmer, 2010). After rapid urbanization, water problems have been derived from additional categories like urban flooding, groundwater overexploitation, urban water shortages, rainwater resource waste, and water contamination.

2.2. Stormwater Management Challenges in Urban Environments

As cities expand to accommodate growing populations, the demand for infrastructure and built-up areas increases. Consequently, impervious surfaces such as roads, buildings, and pavements proliferate, replacing natural vegetation and permeable surfaces. According to Shuster et al. (2005), impervious surfaces in urban areas can account for up to 70-90% of the total land area, significantly altering the hydrological cycle and exacerbating stormwater management challenges.

The reduction in natural infiltration and the increase in impervious surfaces lead to elevated surface runoff during precipitation events. As a result, stormwater accumulates on impermeable surfaces and flows rapidly into storm drains and drainage systems, causing peak flows and flooding in urban areas (Arnold & Gibbons, 1996). High volumes of surface runoff overwhelm existing stormwater infrastructure, leading to infrastructure failures, property damage, and disruptions to urban life.

The conventional approach to urban water management is widely acknowledged to be inadequate for tackling present and future sustainability challenges. (Ashley et al., 2005; Wong and Brown, 2008). This situation is exacerbated by the fact that traditional stormwater systems are often designed based on historical precipitation patterns and may not account for the

increased intensity and frequency of storms brought about by climate change (Fletcher et al., 2013).

Additionally, the rapid movement of stormwater across impervious surfaces prevents the natural filtration processes that occur in soil, leading to the transportation of pollutants such as oil, heavy metals, and sediments directly into water bodies. This not only degrades water quality but also harms aquatic ecosystems and poses risks to public health (Paul & Meyer, 2001). The lack of infiltration also means less groundwater recharge, which can lead to lower water tables and reduced base flows in rivers and streams, affecting water availability during dry periods (Figure 1).

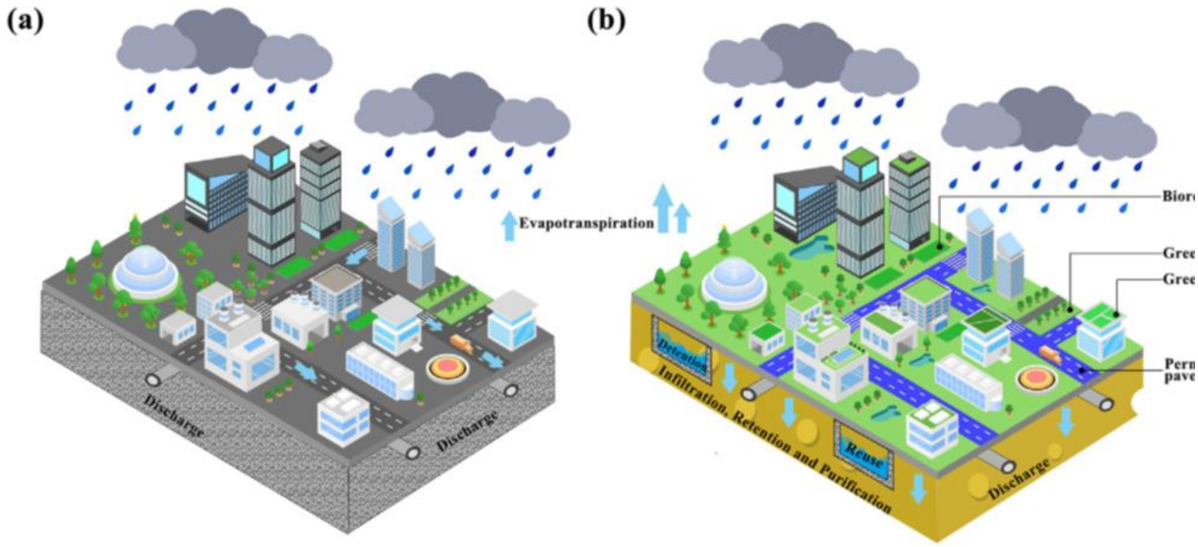

Figure 1. Different hydrological processes in (a) traditional quick-drainage and (b) Sponge City concept
Source: Yin et al. (2021)

Urban flooding caused by excessive surface runoff can lead to significant economic losses. Floodwater can damage homes, businesses, and critical infrastructure such as roads, bridges, and utilities. The costs associated with repairs, emergency response, and loss of productivity can be substantial. Moreover, frequent flooding can diminish property values and discourage investment in vulnerable areas (Parker et al., 1987).

Around 5,582 flood-related deaths were reported in Europe between 1980 and 2022, according to the European Environment Agency Report (EEA, 2019). Those impacted by flooding experience negative effects on their mental health in addition to fatalities and injuries. Flooding can raise the risk of pollution: in Europe, approximately 15% of industrial facilities and 36% of urban wastewater treatment plants are located in potentially flood-prone riverine zones. After periods of intense rainfall, the water quality in Europe has reportedly deteriorated by an estimated 650,000 combined sewer overflows (European Environmental Agency, 2021).

One of the recent heavy flood events occurred in July 2021, which resulted in urban flooding in cities like Cologne and flash floods in the Eifel Mountain range. The flooding caused 189 fatalities in Germany and inflicted around EUR 33 billion in damage across various sectors, prompting an unprecedented EUR 30 billion in governmental aid for recovery. This event marks the fourth significant flood in Germany in 20 years, with the highest death toll compared to previous floods in 2002, 2013, and 2016 (Thieken et al., 2023).

Another challenge associated with stormwater is the ***type and quantity of pollutants***.

The running stormwater on impervious surfaces carries different contaminants, sediment, and debris into storm drains and water bodies (Schueler, 1994). It can carry a variety of chemical pollutants, including heavy metals, pesticides, motor oil, and other hydrocarbons that accumulate on road surfaces, debris, litter, and solid waste from streets, sidewalks, and construction sites into water bodies, leading to contamination of water bodies and adverse impacts on aquatic life (Hunt et al., 2017), that imposes economic costs on society, including expenses related to water treatment, ecosystem restoration, and lost recreational and aesthetic values.

Every year, private residences, businesses, and trade in Germany produce more than five billion cubic meters of sewage water. With a significant volume of infiltration water entering the sewer system through leaks, the sewage treatment plants also receive almost three billion cubic meters of rainwater from roads and paved areas (Federal Ministry for the Environment and Nature Conservation, n.d.). Collection and treatment of stormwater mixed with gray water requires millions of investments to be allocated every year.

Water scarcity poses another major obstacle to sustainable development as it is becoming hard to meet the water demand due to the increasing population.

Population increases, economic development, and dietary shifts (towards more animal products) have all resulted in rising water consumption, putting pressure on water supplies. The World Economic Forum's Global Risks 2015 Report named the water supply crisis as the number one high-impact concern for our time (World Economic Forum, 2024).

The global urban population facing water scarcity is projected to double from 930 million in 2016 to 1.7–2.4 billion people in 2050. The growing incidence of extreme and prolonged droughts is also stressing ecosystems, with dire consequences for both plant and animal species (UNESCO, 2024). The European Environmental Agency's spatial analysis of indicator CSI 018 (water exploitation index plus, WEI+) indicates that, on average, each year, water stress affects 20% of the European territory and 30% of the European population (EEA, 2019g). Without accounting for the irreversible harm to ecosystems and the services they provide, the annual cost of economic loss from droughts is estimated to be between EUR 2 and EUR 9 billion (EEA, 2020c; Maes et al., 2020).

Future socioeconomic growth and climate change are predicted to make Europe's water stress worse. The European Commission Joint Research Centre modeled two distinct emission scenarios, which led to three global temperature increases (with a maximum of 3 °C) beyond pre-industrial levels (Bisselink et al., 2020). Furthermore, it is anticipated that seasonal water stress will last up to one month longer, with the greatest rise anticipated.

Climate change, in turn, accelerates precipitation patterns and intensifies extreme weather events, posing significant challenges for the people living in urban areas and the environment. Exposure to extreme weather events, such as protracted droughts and excessive rainfall, is becoming more common and intense due to climate change (IPCC, 2014). According to Dottori et al. (2018), these occurrences exacerbate the difficulties already faced by urban water systems in managing rainwater by producing flooding, erosion, and water scarcity.

2.3. Stormwater Management Methods/Techniques

Cities are increasingly using sustainable stormwater management techniques to address the issues of flooding and pollution. Urban water flooding and pollution have been the subject of investigation in developed countries since the 1970s (Fletcher et al., 2014). Since then, several solutions have been suggested to address water issues in urban areas.

Numerous theories and notions have been put forth by researchers and decision-makers regarding urban water planning. Best Management Practices (BMPs) are among them; it was first used in US in the 1940s (Fletcher et al., 2014; Scholz, 2006). Sustainable urban drainage systems (SUDS) were developed concurrently in the UK to mitigate flood risks and water pollution (Fletcher et al., 2014). The United States and New Zealand have adopted the low-impact development (LID) strategy in the 1990s (Chui et al., 2016; Fletcher et al., 2014; Mao et al., 2017). Water-sensitive cities (WSC) or water-sensitive urban design (WSUD) was introduced in Australia in the 21st century to bring about several benefits that not only prevent the deterioration of urban water resources but also manage and recycle stormwater to make cities resilient, sustainable, and livable (Brown et al., 2009; Ashley et al., 2013). Australia has gone through six development stages of urban water management. Nevertheless, these ideas and tactics are still very much in the early stages of development, and their use has only been limited to localized locations and experimental pilots. (figure 2).

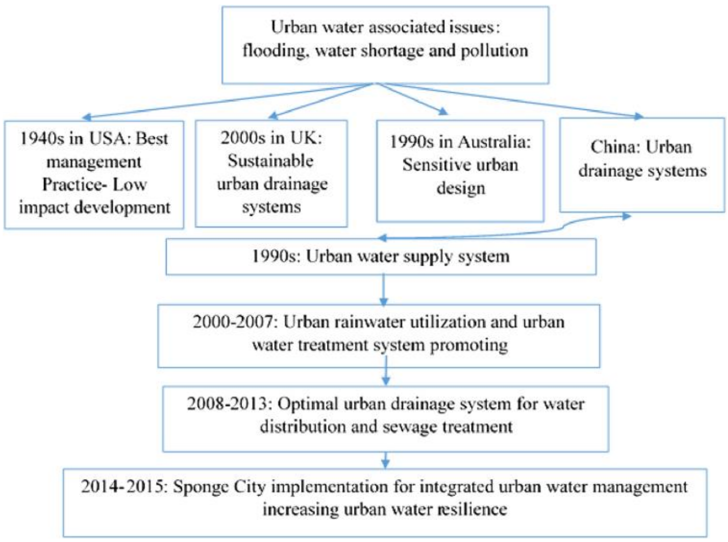

Figure 2. Several urban water management approaches of the twentieth century.
Source: Yin et al. (2021)

Each of these approaches is distinct and tailored to address specific issues in the countries where they originated and are different based on their focus, type of practices and technologies, emphasis on the water cycle, and integrated benefits.

Stormwater management practices like LID and BMP are common examples of green infrastructure applications in Germany. LID and associated technologies—like ditches, green roofs, and artificial wetlands—have progressed from environmental experiments over the last 40 years to standard operating procedures governed by laws and regulations (Koehler and Keeley 2005, SenStadt 2010, Buehler et al. al. 2011). This can be explained by the fact that about 106 m² of roof space is greened annually, representing 10% of new developments (SenStadt, 2010).

It can be noted that Germany, being a pioneer among other European countries in the development and application of green infrastructure in its urban projects, has achieved significant progress and a striking example of this is the percentage of green areas in every city in Germany. In Dresden, for example, 62% of the city's territory is forest and green space (Dresden 2024). Unfortunately, existing infrastructure designed and built in the late 20th century and early 21st century is inadequate to meet the demands of rapidly changing climate conditions. It is not resilient to increased rainfall, heat waves, and other extreme weather events. Thus, the integration of LID-related technologies, such as Sponge City can be a tool to enhance urban resilience.

2.4. Sponge City Concept: Definition, Benefits, and Effectiveness

The Sponge City concept was first introduced in China between 2013 and 2014 to address the challenge of urban water issues, such as flooding issues China has been experiencing over the past several decades. Before the Sponge City initiative, in the 2000s, the Chinese government employed green infrastructure to manage stormwater, but the system's efficiency in utilizing rainwater was initially very low. This inefficiency was primarily due to the absence of optimal factors, including advanced green technologies and materials (Liu et al., 2013; Shi et al., 2015).

To evaluate the practical effectiveness and feasibility of the new concept, the Chinese Government launched 30 pilot projects in 2015-2016. These projects aimed to recycle approximately 70% of stormwater by enhancing infiltration, detention, storage, treatment, and drainage systems (Li et al., 2017). The goal of Sponge City initiatives in China was to simultaneously address urban water-related issues and lessen the negative consequences of urban development on natural ecosystems (Li et al., 2018; Wang et al., 2018).

Sponge City has several objectives (Figure 3), and the primary one is to prevent urban flooding disasters (Jia et al., 2017; Wang et al., 2018). Second, Sponge City aims to improve urban water quality through ecological waterfronts and self-purification technologies. Reusing stormwater for urban water supply is the next objective. In this instance, rainfall is converted into a useful resource to address urban water scarcity, which is particularly important during dry spells. Concerning climate change and urbanization impacts, Sponge City has created alternative infrastructures, such as bioretention, permeable pavements, and green roofs, to boost water absorption and decrease water runoff. The creation of a pleasant city microclimate is Sponge City's ultimate goal. It is highly desired to reduce heat in the city by expanding green spaces, such as lakes, wetland regions, and green rooftops.

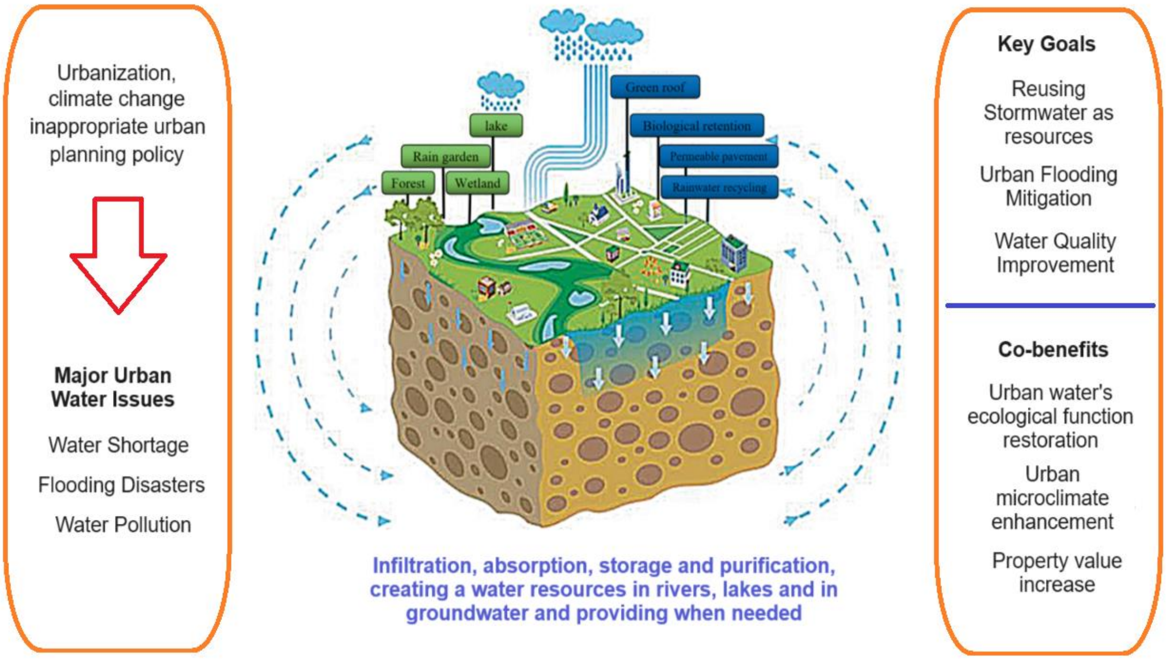

Figure 3. Sponge City and its Ecological Services: A Schematic Design

Even though the Sponge City concept was inspired by other ideas that have been used in industrialized nations, such as LID, BMP, SUDS, and WSUD, its objectives are different. "Sponge cities" emphasize an integrated urban water management approach to incorporate low-impact development measures at the urban scale for the water environment, to safeguard the water ecology, water resources, and water security, as opposed to normal LID approaches, which are small, local, and piecemeal (Nguyen et al., 2019).

Green roofs, green space, artificial rainfall wetlands, infiltration ponds, biological retention devices, and permeable pavement are among the most commonly employed technologies in Sponge City building (Chen et al., 2015; Chen, 2016; Jia et al., 2017; Li et al., 2017; Li et al., 2016; Li et al., 2018; Wu et al., 2017; Wu, 2015; Zhang and Che, 2016).

There are two types of Sponge City implementation: macro-scale and micro-scale. The implementation of site-level designs, such as rain gardens, stormwater-bio-retention, and artificial wetlands, is the primary focus in the micro-scale setting. In order to maximize the hydrological and bio-ecological benefits, Sponge City is scaled up to the catchment level from its micro-scale effectiveness at the site and localized levels (Zhang and Chui, 2019).

Sponge City benefits a city's ecosystem in four major manners (Gómez-Baggethun et al., 2013) (Fig. 4): by supplying purified water and food, regulating the appropriate cultural use of spaces for recreation, and offering animal habitat functions. Sponge City addresses complex city water-related challenges and provides multiple advantages to growing cities as contrasted with standard urban water management systems (see Table 2).

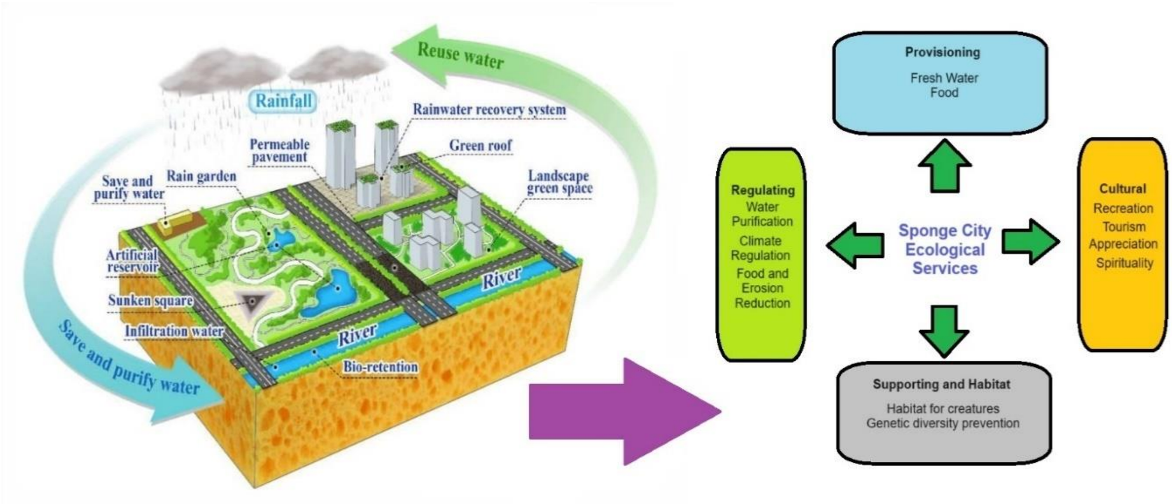

Figure 4. Sponge City and its Ecological Services: A Schematic Design.

Table 1. In contrast to the Sponge City strategy, traditional urban water management systems include fragmented engineering measures (Adopted: Nguyen et al., 2019).

No.	Goals	Older urban water management systems	Sponge City
1	Flooding disaster reduction	Based on urban river and hard stormwater systems	Building natural hydrological cycle protection and urban resilience
2	Water supply	From ground/surface water like rivers and water supply plants	Stormwater reused by non-potable water supply
3	Water quality improvement	Depending on the centralized sewage treatment plant	Creating a decentralized system for in-situ reuse of wastewater
4	Water purification	No	Yes
5	Drought mitigation	It may be possible to design water storage in the system	Yes
5	Urban heat island effect	No	Yes
6	Biodiversity conservation	No	Yes
7	Recreational urban landscape	No	Yes

2.5. Stormwater Management Practices in Europe

Europe has successful stormwater management because of the right circumstances, including strong management organizations and financial resources. In an effort to help member nations manage their water resources more effectively, the European Commission issued the Water Framework Directive (WFD) in 2001 to protect water based on its natural geographical formations.

The directive, which has a 2015 completion deadline for member nations, recognized water as a fundamental component of the natural ecosystem, the supply of which is particularly endangered by climate change (European Commission, 2014). However, the WFD encountered difficulties due to its expensive implementation, arbitrary deadlines, and the participating nations' lack of legal enforcement (Kallis & Butler, 2001).

According to Voulvoulis et al. (2016), who examined the WFD's development fifteen years after it was adopted, the directive's inefficiency was caused by a lack of ambition in its

implementation and a misreading of newly introduced concepts. For the WFD to be effective, it had to guarantee that the application of water is founded on a comprehensive comprehension of the risks and demands in monitoring, which essentially necessitates shifting from a single management mandate for all of Europe to a strong comprehension of the characteristics of those systems (ibid, p.363-364). However, despite this setback, European cities have the world's most successful sustainable urban water management systems (Arcadis, 2016).

Rotterdam in the Netherlands is one of those cities. Since the city was surrounded by water on all four sides of the cardinal points, it had historically relied on dams and dykes to keep floods at bay. However, as sea levels rise, these traditional infrastructures are becoming less effective, and as a result, efforts to combat the effects of climate change are shifting to more environmentally friendly methods (van Vliet & Aerts, 2015). Consequently, the Rotterdam Climate Proof Programme (RCP) was created as a proactive measure to strengthen the city's resilience against the effects of climate change. The program's top priorities were ensuring public safety in the city and implementing water storage for urban runoff (Dircke & Molenaar, 2015). According to these tactics, the city is among the best for water management (Arcadis, 2016).

Another illustration is the United Kingdom, which employs a similar framework for ecosystem conservation and urban water management like SUDS (British Geological Survey, 2022). These measures have two things in common: they respect the environment, and they don't have enough policy measures to encourage their acceptance and growth (van Vliet & Aerts, 2015, Lashford et al., 2019).

2.6. Identified Research Gaps and Study Motivations

Research Gap

Despite growing awareness of the Sponge City concept as a sustainable solution for urban stormwater management, there is still a large gap in its implementation, particularly in European cities such as Dresden. Existing research has mostly examined the implementation and consequences of Sponge City programs in China, where the concept originated. However, the application of these ideas to European metropolitan contexts, which have distinct meteorological conditions, urban infrastructure, and regulatory frameworks, has not been adequately investigated.

In Dresden, the Prohlis neighborhood confronts particular stormwater management issues due to its high population density, substantial impervious surfaces, and history of flooding. Current stormwater management strategies in Prohlis frequently rely on traditional drainage systems, which are insufficient to handle the rising intensity and frequency of precipitation events caused by climate change. There is a scarcity of comprehensive studies that assess the feasibility, benefits, and potential challenges of applying Sponge City ideas in such a setting.

Study Motivation

This study seeks to fill this research vacuum by looking into the use of the Sponge City idea to address stormwater management challenges in Prohlis, Dresden. The inspiration for this research arises from three essential factors:

1. **Climate Resilience**: Dresden has undergone catastrophic flooding and is vulnerable to the effects of climate change, such as increased precipitation and heat waves. Implementing the Sponge City concept could improve the city's resilience by better-managing stormwater, lowering flood risks, and lessening the urban heat island effect.
2. **Sustainable Urban Development**: As cities grow, there is an increasing need for sustainable development approaches that balance economic growth, social well-being, and environmental conservation. The Sponge City concept takes a comprehensive approach to urban water management, incorporating green infrastructure to improve water quality, biodiversity, and recreational opportunities.
3. **Policy and Practice**: The goal of this research is to show officials, urban planners, and stakeholders in Dresden the advantages of the concept. By establishing the viability and benefits of the Sponge City concept in Prohlis, the study can help shape future urban development and environmental policy, enabling greater adoption of green infrastructure solutions.
4. **Community and Environmental Health**: Proper stormwater management is critical for ensuring public health and environmental quality. Implementing Sponge City concepts can help minimize pollutant runoff, increase water availability, and make urban areas healthier for residents.
5. **Global Relevance**: While this study focuses on Prohlis and Dresden, its findings and recommendations will have broader significance for other cities facing comparable stormwater management difficulties. This study can serve as a reference for urban regions around European cities, encouraging the implementation of sustainable water management strategies.

3. SITE DESCRIPTION AND DATA

3.1. Overview of the City of Dresden

The city of Dresden is the capital of the German state of Saxony situated in the east-south of Germany. Dresden ranks second in population after Leipzig and 12th in terms of population among other cities in Germany. The urban area of Dresden includes the cities of Freital, Pirna, Radebeul, Meissen, Coswig, Radeberg, and Heidenau and has approximately 790,000 inhabitants (Population, 2021) (Figure 1). Thus, approximately 1.34 million inhabitants live in the Dresden agglomeration (Öffentlichkeitsarbeit (n.d.).

Figure 5. General map of Dresden.
Source: Dresden Stadtplan

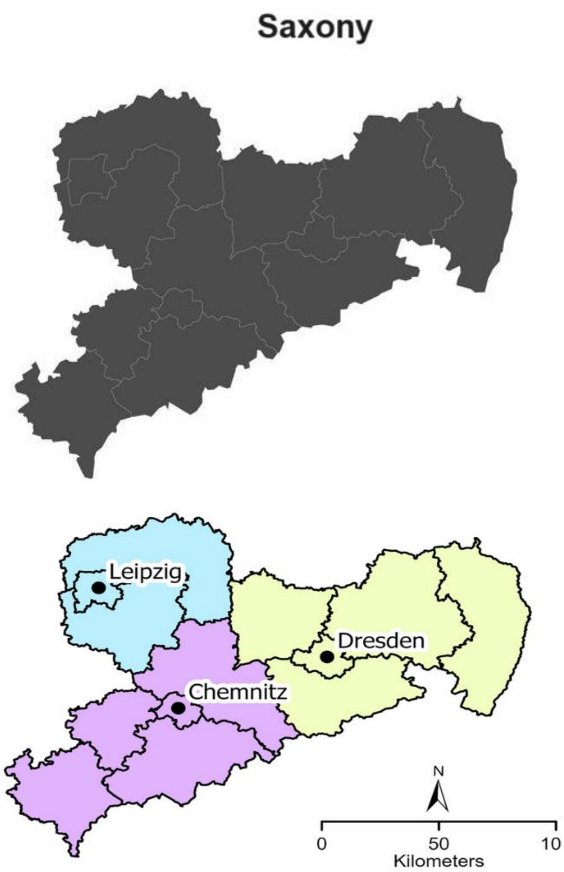

Figure 6. General map of Dresden.
Source: Dresden Stadtplan

Figure 7. General map of Dresden-Prohlis
Source: Dresden Stadtplan

Dresden, as of 2019, had a population of 557,075 inhabitants, and the metropolitan area in 2018 had a population of 790,400 inhabitants, which increased to 1,343,305 inhabitants considering the new districts of Meissen, Sächsische Schweiz-Osterzgebirge, Bautzen and Görlitz. 2019 (ibid). The female part of the living population by 2018 was approximately 50.0%.

The Elbe River flows through the city, thus dividing it into two parts. Being the thriving source of economy and prosperity, the Elbe River can be dangerous as well. The Elbe River has a vast catchment area covering parts of Germany, the Czech Republic, Austria, and Poland. The combined runoff from these regions leads to high water levels downstream, including in Dresden. Dresden faced a series of big floods in its history, which led to huge economic losses, property damage, and fatal cases.

The number of businesses and corporate representatives also indicates a positive outlook for the city. The city of Dresden is also called the Silicon Valley of Saxony, due to its popularity in semiconductor manufacturing. Today, core businesses include AMD's semiconductor subsidiaries GlobalFoundries, Infineon Technologies, ZMDI, and Toppan Photomasks. Their factories attract many material suppliers and cleanroom technology companies to Dresden.

For instance, in August 2023, the globally active Taiwanese semiconductor manufacturer TSMC announced its intention to build a 10,000 million Euros worth of wafer factory in Dresden together with Bosch, Infineon, and NXP (Saxony Trade & Invest, 2023).

3.2. Climate and Average Weather in Dresden

Dresden has a temperate continental climate, with cold winters and hot, though rarely humid, summers. The temperature and weather are so unpredictable because the city is prone to warm and cold air masses. The average annual temperature ranges from -2 °C to 25 °C, with annual extremes from lower than -10 °C to higher than 31°C.

The warm season is 3.3 months long, with an average daily high temperature above 21°C. The cold season lasts slightly longer than the warm season, 3.8 months, with average daily maximum temperatures below 8°C. Throughout the year, Dresden experiences varying chances of rainy days, and it rains all year round. The most monthly precipitation occurs in July with

an average of 68 millimetres. The month with the lowest average of precipitation is February with 24 millimeters.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Oct	Dec	Year
Record high °C (°F)	12.58 (54.64)	14.68 (58.42)	22.01 (71.62)	29.35 (84.83)	29.35 (84.83)	33.55 (92.39)	36.69 (98.04)	37.74 (99.93)	30.4 (86.72)	27.26 (81.07)	17.82 (64.08)	13.63 (56.53)	37.74 (99.93
Average high °C (°F)	1.97 (35.55)	3.46 (38.23)	8.32 (46.98)	14.4 (57.92)	17.8 (64.04)	22.23 (72.01)	24.41 (75.94)	24.75 (76.55)	19.52 (67.14)	14.04 (57.27)	8.4 (47.12)	4.17 (39.51)	13.63 (56.53
Daily mean °C (°F)	0.1 (32.18)	1.11 (34.0)	5.48 (41.86)	11.09 (51.96)	14.95 (58.91)	19.48 (67.06)	21.44 (70.59)	21.41 (70.54)	16.26 (61.27)	11.03 (51.85)	5.92 (42.66)	2.29 (36.12)	10.88 (51.58
Average low °C (°F)	-2.9 (26.78)	-2.69 (27.16)	0.66 (33.19)	4.0 (39.2)	7.16 (44.89)	11.53 (52.75)	13.63 (56.53)	14.38 (57.88)	10.45 (50.81)	6.38 (43.48)	2.76 (36.97)	-0.49 (31.12)	5.41 (41.74
Record low °C (°F)	-20.97 (-5.75)	-27.26 (-17.07)	-18.87 (-1.97)	-10.48 (13.14)	-5.24 (22.57)	0.0 (0)	6.29 (43.32)	6.29 (43.32)	-1.05 (30.11)	-14.68 (5.58)	-13.63 (7.47)	-24.11 (-11.4)	-27.26 (-17.07
Average precipitation mm (inches)	43.72 (1.72)	23.66 (0.93)	31.7 (1.25)	20.96 (0.83)	45.2 (1.78)	53.22 (2.1)	50.17 (1.98)	56.69 (2.23)	39.02 (1.54)	36.62 (1.44)	25.32 (1.0)	29.06 (1.14)	37.95 (1.49)
Average precipitation days (≥ 1.0 mm)	10.2	6.2	8.01	6.76	10.11	10.67	11.72	9.62	7.72	6.76	7.06	8.39	8.6
Average relative humidity (%)	92.56	87.93	83.29	78.61	82.06	80.65	76.88	74.76	79.81	84.47	87.06	88.83	83.08
Mean monthly sunshine hours	5.43	6.38	8.96	12.97	13.41	13.85	13.87	13.72	11.66	7.19	6.64	5.62	9.98

Figure 8. Climate Dresden: Weather by Month
Source: Weather and Climate

3.3. Wastewater Treatment in Dresden

Stadtentwässerung Dresden GmbH offers services in the field of wastewater treatment, environmental analysis, and the planning and construction of sewage plants in the city. Its operations are varied, from running a 1.850 km long sewer network to operating the central sewage treatment plant in Dresden-Kaditz. Every year, Stadtentwässerung Dresden treats around 55 million cubic meters of wastewater. This amounts to an impressive volume of work that underscores its ability to serve as crucial in the city's waste management and environmental hygiene. The 565,000 people who live in Dresden use 98 liters of drinking water a day on average, and that water is converted into wastewater. The sewer network in Dresden is also linked to more than 1,100 commercial and industrial establishments. 120 million liters of wastewater are fed into the Dresden-Kaditz sewage treatment facility on dry days. It is equivalent to ten bathtubs every second. The Dresden-Kaditz sewage treatment plant serves 670,000 people, of which 565,000 are locals of Dresden (Stadtentwässerung Dresden GmbH, n.d.).

3.4. Impact of climate change in Germany and Dresden: Current scenario and future projection

Dresden, similarly, like many other cities in the world faces extreme changes in weather patterns due to the climate change consequences. Due to the high percentage of sealed surfaces, local flooding is becoming more frequent as a result of increased precipitation and rainfall in many areas. Conversely, summers are growing hotter and more humid. Urban dryness and drought are getting worse, which is bad for the population's health as well as the urban greenery.

Taking everything into account, Dresden's situation creates certain challenges.

Dresden is a city located in the Elbe River basin and thus is particularly vulnerable to extreme weather events, such as floods, heatwaves, or storms. All this is being exacerbated by climate

change, which has well-known consequences for the city's existing infrastructure, economy, and standard of living (figure 9). For instance, the flood of the century in 2002 inundated entire districts of Dresden when persistent in places heavy rain caused the Elbe to burst its banks. The disaster led to infrastructure, cultural heritage sites, and residential areas incalculable damage and economic losses of over EUR 1 billion (Kundzewicz et al., 2013). In 2013 unprecedented rainfall occurred over Central Europe, and once again the Elbe is one of the main rivers causing flood damage and Dresden is also being affected. This event underscored the continued susceptibility of the area to extreme rainfall events (Kreibich et al., 2014).

Figure 9. Flood in Dresden, 2002
Source: www.buildersproject.eu

Figure 10. Flood in Dresden, 2013
Source: www.buildersproject.eu

Recent studies report that the situation may get even worse. The analyzed data obtained from the German Weather Service (Deutscher Wetterdienst) shows that the annual rainfall in Dresden has a slightly falling trend while presenting strong fluctuations over a short period (figure 11).

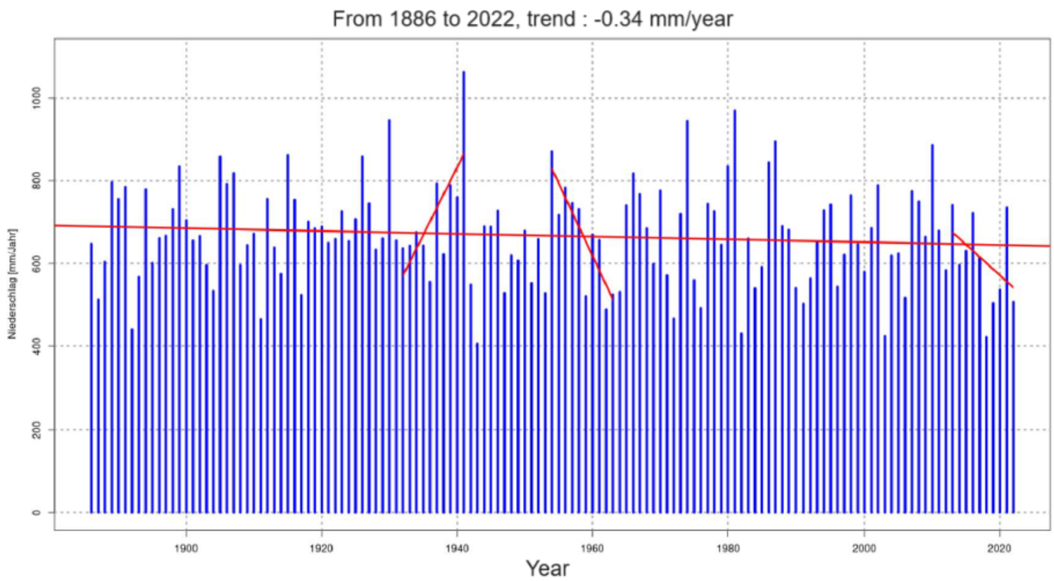

Figure 11. Annual rainfall in Dresden
Source: DWD Data (Klotzsche and Saxony)

Most communities with aging infrastructure are not aware of the fact that our climate has more than likely already changed enough to cause systems that weren't designed or intended to handle added rain or water temperature from streams and rivers.

Regarding the heat waves, just as in many other cities, Dresden's situation is more intense, and frequent heat waves in summer are also becoming more significant. Climate change which causes global temperatures to increase and change weather patterns is mostly to blame for this (figure 12). Heatwave activity has been observed in Europe (Idris et al., 2014) an increase in the frequency of heatwaves and is projected to continue as greenhouse gas emissions increase, this will not change.

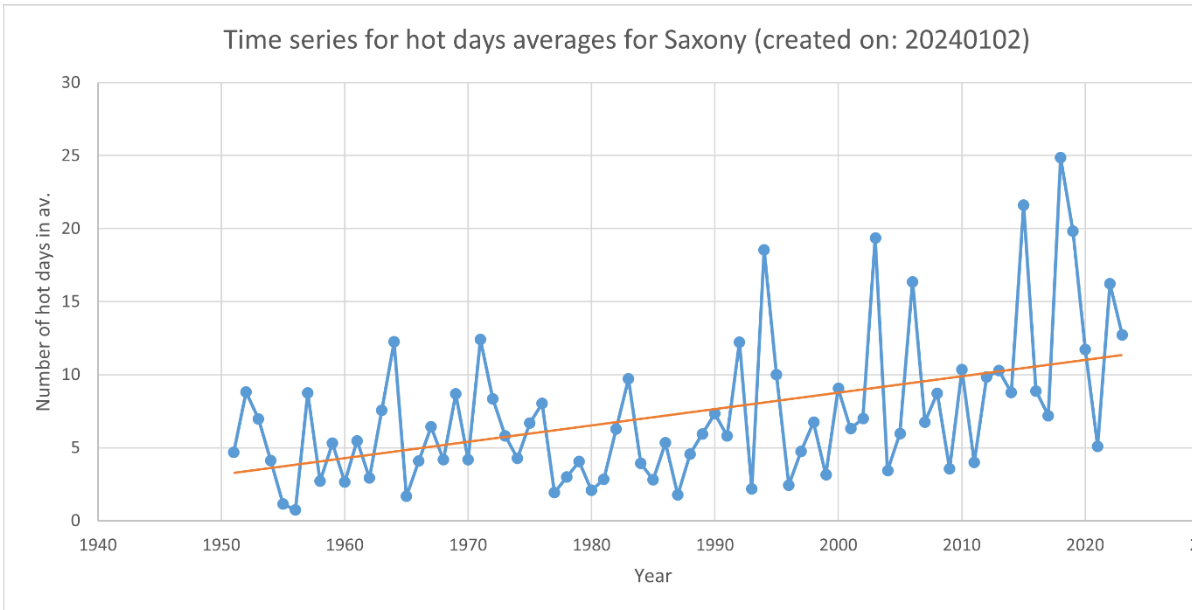

Figure 12. Number of hot days in Dresden

Climate change causes increasing temperatures, significantly contributing to the urban heat island (UHI) effect as urban areas develop temperatures higher than their rural counterparts. That is, cities are giant heat sinks; they absorb heat during the day, and then radiate it slowly at night. Urban surfaces, including Dresden, generally are warmer, particularly at night, than surrounding rural areas.

Germany, like other European nations, saw multiple heatwaves with highs above 35 degrees (figure 13) that were particularly harmful to the elderly, small children, and other vulnerable populations. The heat-related mortality report revealed that in Germany a statistically significant number of deaths occurred in each of the three years due to the exceptionally high summer temperatures in 2018–2020: Approximately 8,700 people died from heat-related causes in 2018, 6,900 in 2019, and 3,700 in 2020 (Ärzteblatt, 2022).

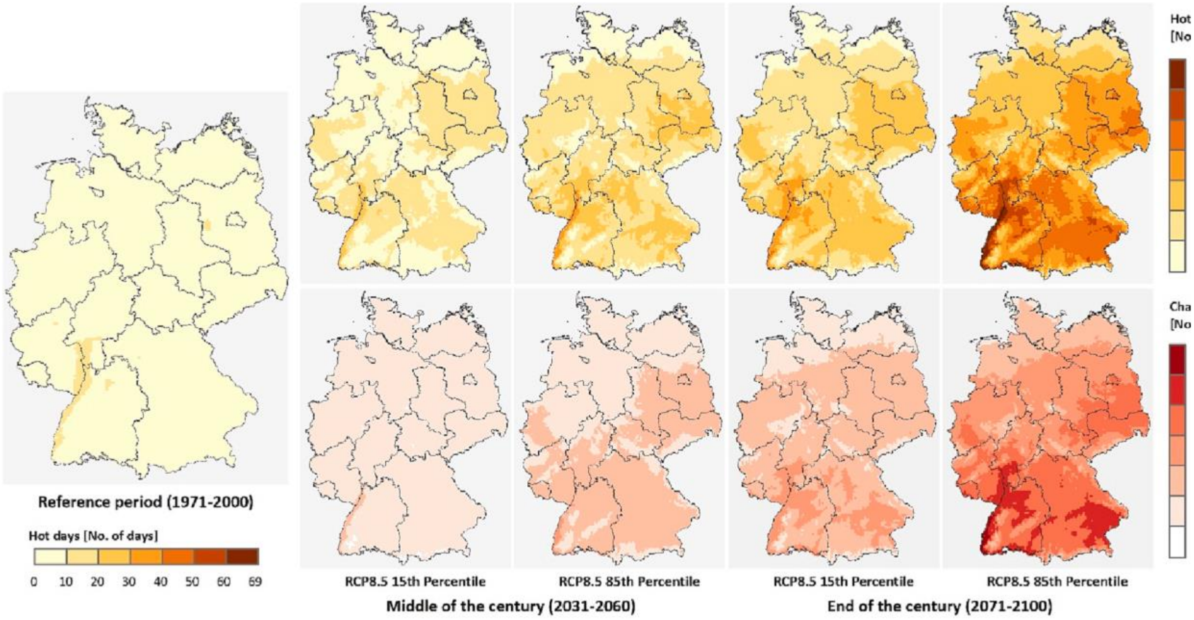

Figure 13. The climate indicator "Hot days", i.e. the number of days in a year with a maximum temperature of at least 30 ◦C, for the historical reference period (left, first column), the middle of the century (second and third columns) and the end of the century (fourth and fifth columns) based on the RCP 8.5 scenario, whereby the top
row shows the absolute values and the bottom row the absolute change values concerning the reference period. Source: Kahlenborn et al. (2021b).

Dresden has been experiencing exactly the types of climate-related challenges we are all familiar with - more frequent and severe extreme weather events like heavy rainfall, flooding, and heat waves. These problems make living in the city more difficult and also threaten public health, property, and the local economy. These problems are expected to remain and grow in number and scale in the future because of the increasingly pronounced effects of climate change.

3.5. Legislative basis for stormwater management in urban green development

Germany has several policies to enhance ecosystem services, biodiversity, and habitat connectivity. GI is included in some policy domains, primarily urban policy, flood protection, and to a lesser extent agriculture.

National policies also support green infrastructures through legislation such as the German Federal Water Act (WHG, 2009), which emphasizes maintaining the natural hydrologic cycle and prioritizes stormwater infiltration near the source. This act, along with state laws and the European Water Framework Directive (WFD, 2000), provides a comprehensive framework for water resource management. The WFD, aiming to protect European water bodies by 2025, requires integrated River Basin Management Plans and measures to address combined sewerage overflows and stormwater discharges, including both conventional and LID technologies (BMU, 2010).

According to the German Waste Water Charges Act (Abwasserabgabengesetz, AbwAG) (Ministry, n.d.), an equitable and landlord-based differentiation is mandatory for the allocation of stormwater fees on a plot-specific basis. Today, 2/3 of municipalities have fees like these in place, and this is heading toward the rest. Fees: Calculated on impervious surface area, coming to be on average €0.89/m² for stormwater and €1.95/m² for wastewater. The monitoring of the

planting may be done through aerial photos or satellite images. Municipalities may grant fee reductions for on-site LID measures that improve infiltration or evaporation, like green roofs (50% off). Some LID practices are even required by ordinance, and each is allowed to be excluded from these separate fees because they strive to recover stormwater-related costs through these fees. While getting the rules set up for these fees is a complicated and time-consuming process, it has been found to be a successful policy measure.

Germany's spatial planning instruments also promote green infrastructure for multiple benefits, including stormwater management, habitat protection, and urban climate control. The Federal Nature Conservation Act and the German Federal Building Code integrate landscape and urban planning to balance conservation and development goals, encouraging mitigation and compensation measures like LID technologies.

In Dresden, the City Council is focusing especially on and working towards sustainable urban development in accordance with the UN's 2030 Agenda for Sustainable Development. The "Edible City of Dresden," HeatResilient City, ESD model municipality, energy transition, SmartCity project, accessibility promotion, development and mobility strategy, creative industries promotion, and climate adaptation concept are a few of them (Dresden, n.d.).

One of the city's initiatives focusing on sustainable urban development and transport planning is the Regional Climate Change Adaptation Programme (REGKLAM). Additionally, the German Federal Ministry of Research and Education is creating a comprehensive and sustainable vision for Dresden as a "City of the Future" with an eye toward 2030.

But frequently, just one component of GI—such as biodiversity, water retention, climate mitigation, or adaptation—is emphasized. Moreover, GI is viewed as a compensatory strategy to lessen the effects of grey infrastructure: it can be used to restore biodiversity or lost nature areas, or it can be used to link ecosystems where infrastructure has broken up. Prioritizing GI over other initiatives would be made easier by acknowledging the full range of benefits that GI offers across various policy domains.

Emphasizing the financial and economic advantages of green infrastructure in particular will promote its adoption going forward (Trinomics et al., 2016). GI has numerous advantages over grey infrastructure and might be seen as a feasible substitute, particularly in the long run.

3.6. Overview of the Study Area: Prohlis Municipal Area

In 1921, Prohlis became a part of Dresden. From 1975 to 1985, the new Prohlis was developed. In 1989, over 20,000 units were constructed in Prohlis providing housing for over 30,000 people. However, the population has decreased by almost a third in recent years. For this reason, it is covered by the funding program "Districts with Special Development Needs - the Social City." The area of Prohlis is mainly a residential area consisting of shops, government buildings, and green zones.

The study area is divided into 2 locations in Prohlis, to conduct the assessment of the application advantages of the Sponge City concept features, such as permeable pavement, raingarden, bioswale, and storage pond.

Study Area 1	Study Area 2
Empty green area located at Spreewalder Str. 50	The parking lot at the corner of Gamigstrasse and Berzdorferstrasse
belongs to the Dresden City	belongs to the real estate company
(51.00330039670657, 13.796714002109539)	(51.00796503608108, 13.797282138629777).

STUDY AREA 1 – SPREEWALDER STR. 50

A large green space with a total size of 4521 m^2 is located in the middle of multiple residential buildings forming a rough rectangular shape (figure 14). The buildings around have flat concrete roofs with rainwater discharging points in the middle. Buildings are mostly 6-store and belong to the real estate company that rents them to tenants.

The green space in the middle includes grassy areas and numerous trees (50-52 mature trees such as sessile oak, birch tree, and others), providing a natural environment within the urban setting. Previously, a kindergarten was functioning in this area but later was demolished. A small creek Geberbach runs near the area, from the southwest. The creek plays a significant role in local stormwater management, possibly integrating with Sponge City principles by serving as a natural water retention and infiltration feature.

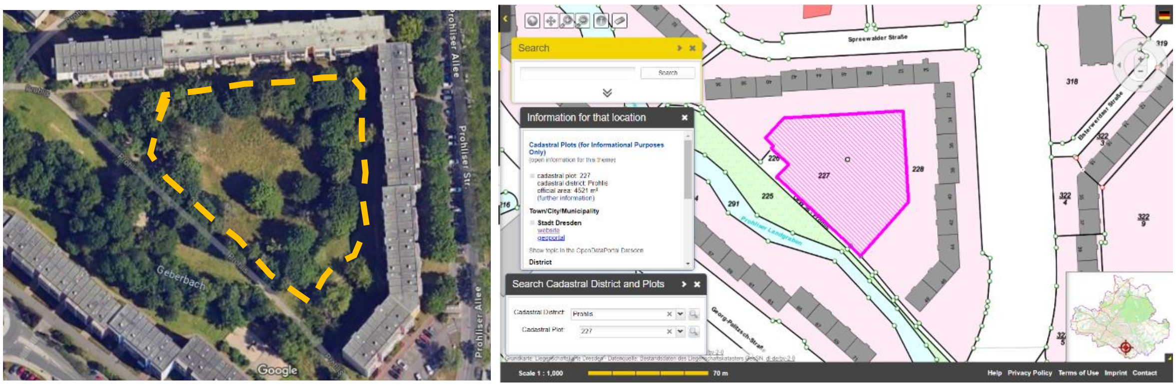

Figure 14. Map of the Study Area 1
Source: [Dresden city website]

Before conducting any type of activities and/or reshaping the area, an initial analysis of the area, especially soil characteristics, soil mechanics, subsoil condition, and hydrogeological situation is important. Due to area restrictions, capacity, approval procedures, and time, conducting such an analysis was not possible, therefore previously implemented activities referring to soil characteristics and area examination are considered as sources of data.

For instance, according to the seepage investigation carried out by Erdbaulaboratorium Dresden GmbH in December 2023 (Engineering Office for Geotechnics and Environment GmbH, 2024), the subsurface conditions in the study area were examined with ram core probes. The final depth of the subsoil for examination was set in advance at 6.0 m below the top of the ground. Disturbed soil samples were taken from the ramming core soundings and examined visually/sensorily on-site (soil inspection). The soil samples obtained from the ramming core soundings from horizons potentially suitable for infiltration were examined concerning the grain size distribution in the undersigned's soil mechanics laboratory (DIN EN ISO 17892-4).

The seepage tests were carried out using the "Well Permeameter Method" to determine the water permeability of the underlying soil. As a result, the existing cohesive surface layers are to be assessed as having very low water permeability due to the material-typical water permeability coefficients $k_f << 10^{-6}$ m/s (between $4.18x10^{-9}$ up to $6.89x10^{-9}$) and are therefore unsuitable for infiltration (silt, silty clay, and sand). According to DWA-A 138, the target value for infiltration systems must be of$\geq 10^{-6}$ m/s.

The soil samples test taken from the middle of the site, 4 – 4.90 meters below the ground level were found applicable with DWA – A138 target values that would allow the installation of an infiltration system. Therefore, the focus will be made on the suggestion of the infiltration system taking into consideration the infiltration coefficient of the soil at the depth of 4 – 4.90 meters (1.86×10^{-6} m/s) to increase the capacity of water infiltration by replacing the soil with more permeable grain grading or geotextile.

Currently, rainwater is collected and discharged under the building by inner pipes. No other water-discharging pipes were found during the visit to the area. Neither observation of the existing water-discharging pipes was possible due to restrictions on entering.

Under German water legislation, rainwater falling on private property is generally not permitted to be discharged onto public land. However, within the framework of this paper, the alternative option to assess and demonstrate the advantages of rainwater harvesting and reusing to ensure enough water for vegetation and climate adaptation is considered. It is well known that the negative effects of global warming are increasing and the number of hot sunny days is projected to increase, which poses serious pressure on maintaining green areas such as this. In such severe situations, understanding the value of water resources is important to apply NBS, such as Sponge City features that will undoubtedly aid in preserving and reusing water resources such as rain.

With this aim, this chapter of the paper illustrates the assessment of the feasibility of Sponge City features in rainwater harvesting, infiltration, retention, and reuse via bioretention pond.

STUDY AREA 2 – PARKING LOT

The total area of 6488 m^2 includes both permeable and impermeable surfaces, as well as some trees. The green (porous) and asphalt (impermeable) sections' lengths were measured with ArcGIS/Google Earth software. The study found that the impermeable asphalt surface is 3365 m^2, while the green permeable area is 3123 m^2 (figure 15). According to the city of Dresden, the land is privately held, most likely by a real estate firm.

Due to a lack of precise data on topsoil and subsoil features in public sources, information from the City of Dresden's official webpage was used (Stadtplan (2021)). The portal reveals that the soil in this area has a very high water storage capacity and a sealing rate of 40 to 60%, which is similar to the soil in research area 1. Therefore, computations will assume a soil permeability coefficient of 1.86×10^{-6} m/s. Furthermore, there is no information on whether the water from this location is dumped into the city's sewage system or seeps underground.

Site Description:

Total size of the area	6488 m^2
Size of asphalt area	3365 m^2
Size of vegetation	3123 m^2
Type of soil	silt, silty clay, and sand
Water drainage system	N/A
Quantity of trees	54 pcs
The required volume of water per tree per week	80-100 litres
The total amount of water required for tree watering per week	4320 – 5400 litres

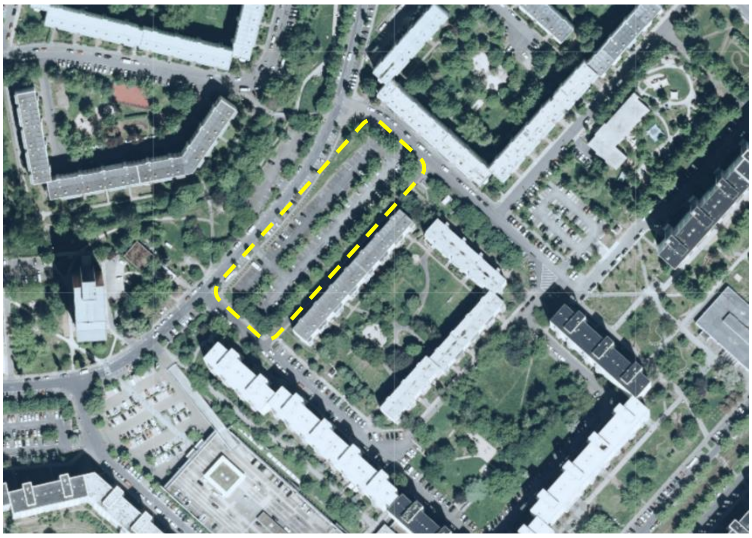

Figure 15. Map of the Study Area 2
Source: Dresden city website

This chapter, assesses rainwater collection, retention, and reuse technologies in light of local requirements, specifications, and probable future scenarios, such as harsh weather conditions. The lack of solid data on the area's properties, particularly soil and drainage systems, complicates accurate assessments. Nonetheless, the primary goal of this intervention is to investigate how to collect and utilize rainwater using NBS, such as swales, bioretention ponds, infiltration ponds, permeable pavement, and others. Thus, attention will be given to the type of features to be used and how rather than to what is possible and what is not.

4. METHODOLOGY

4.1. Research Strategy

This dissertation adopted quantitative and qualitative methodological approaches through a desk research of primary and secondary data, interpretation of climate and weather data, geodata, academic literature, policy documents, and calculation of stormwater management features, where applicable.

The first part of the methodology is to study the Sponge City approach and its associated components and their application to address the first objective of the thesis. Specifically, the study examined and evaluated the advantages and disadvantages of Sponge City components in addressing problems such as rainwater collection, retention, and reuse. This understanding served as the basis for subsequent research, in which an analysis was carried out of the applicability of this concept in solving problems related to the adaptation of the urban environment to the consequences of climate change, taking into account the characteristics of the study area.

The second part of the quantitative methodology is focused on describing how much stormwater from Study Areas 1 and 2 can be collected to respond to the second and third objectives of the thesis. Based on initial calculations, a determination of the appropriate Sponge City features will be proposed as well as an overview of the characteristics of those features.

The final part involved evaluating the analyzed and computed data, reviewing the results, and rating the overall process to establish the efficacy of Sponge City strategies. Furthermore, recommendations for strengthening the onboarding processes were made in places where they were judged relevant. These ideas seek to improve the integration and use of Sponge City principles.

Objectives	Methods
1. How does Sponge City Concept assist in managing stormwater in urban areas?	Data collection and analysis
2. Identifying the distinctive and functional advantages of the Sponge City concept in rainwater retention compared to other methods.	ArcGIS ATV – A138 Excel
3. Climate Change Adaptation: Analyzing the potential of the Sponge City concept for stormwater harvesting and reuse.	ArcGIS ATV – A138 Excel
4. Recommendation for Regeneration and Renaturing Geberbach Creek	Data collection and analysis

4.2. Research methods, data collection and data analysis

A Google Scholar search for "Sponge City in urban stormwater management" returned just over 19,000 hits, including scholarly articles, books, dissertations, and more. This demonstrates a substantial volume of research and literature on the subject. Furthermore, if the question is split into "Sponge City" and "urban stormwater management," the results of the search reach nearly 300,000 results in total, demonstrating the tremendous amount of available information. Examination of the vast amount of material is a highly complex and time-consuming undertaking. This project would necessitate a significant amount of communication and collaboration to thoroughly review and analyze the data. Because of these limits, the review's scope had to be limited.

As a result, only a certain number of scientific publications, books, reports, journals, and information from publicly available sources, such as company websites and news agencies,

were investigated. The relevant bits from these sources were carefully selected and used in the study. This selective method enabled a focused and efficient examination, ensuring that only relevant and high-quality information was included. It also made the study more comprehensible, allowing for a better understanding of the essential concepts and conclusions around the Sponge City approach to urban stormwater management. By utilizing these carefully chosen materials, the study hopes to provide a complete review of the subject while acknowledging the range of existing research.

Furthermore, given that this thesis investigates the possibility of rainwater harvesting infiltration, and retention using Sponge City features, a thorough assessment of secondary sources, publications, and articles was carried out. These resources provide light on the necessity of rainwater collection in the face of climate change, urbanization, and water scarcity, emphasizing its advantages such as reduced reliance on municipal water supply and flood mitigation.

The study looked at existing rainwater harvesting solutions, such as rooftop systems, permeable pavements, and green roofs, and evaluated their performance and suitability for urban settings. Natural purification technologies like biofiltration systems, artificial wetlands, and vegetated swales were also tested for their ability to filter and clean rainwater. The evaluation also examined best practices for collecting and recycling rainwater, assessing various storage methods such as cisterns, underground tanks, and open ponds, and investigating prospective uses such as irrigation and non-potable domestic applications.

Table 2. Articles, journals, research papers etc. used

No.	Name of article, journal, book, paper, etc	Author/s	Published in
Sponge City			
1	Sponge City Construction in China: A Survey of the Challenges and Opportunities	Hui Li, Liuqian Ding, Minglei Ren D, Changzhi Li and Hong Wang	MDPI/Water
2	A new model framework for Sponge City implementation: Emerging challenges and future developments	Thu Thuy Nguyen, Huu Hao Ngo, Wenshan Guo, Xiaochang C. Wang	Journal of Environmental Management (253 (2020) 109689)
3	Implementation of a specific urban water management - Sponge City	Thu Thuy Nguyen, Huu Hao Ngo, Wenshan Guo, Xiaochang C.Wang, Nanqi Ren, Guibai Li, Jie Ding, Heng Liang	Science of the Total Environment (652 (2019) 147–162)
4	Opportunities and challenges of the Sponge City construction related to urban water issues in China	XIA Jun, ZHANG YongYong, XIONG LiHua, HE Shan, WANG LongFeng & YU ZhongBo	SCIENCE CHINA (April 2017 Vol.60 No.4: 652–658)
5	Sponge city practice in China: A review of construction, assessment, operational and maintenance	Dingkun Yin, Ye Chen, Haifeng Jia, Qi Wang, Zhengxia Chen, Changqing Xu, Qian Li, Wenliang Wang, Ye Yang, Guangtao Fu, Albert S. Chen	Journal of Cleaner Production (280 (2021) 124963)
6	Integrating Sponge City Requirements into the Management of Urban Development Land: An Improved Methodology for Sponge City Implementation	Dongdong Yang, Xin Zhao, and Bruce C. Anderson	MDPI/Water
7	Sponge city strategy and application of pavement materials in sponge city	Xin Guan, Jiayu Wang, Feipeng Xiao	Journal of Cleaner Production (303 (2021) 127022)

8	Using Stormwater in a Sponge City as a New Wing of Urban Water Supply—A Case Study	Stephan Köster, Greta Hadler, Lea Opitz and Anna Thoms	MDPI/Water
Rainwater Management			
1	Rainwater Management in Urban Areas	Brigitte Helmreich	MDPI/Water
2	Development of Rainfall-Runoff Models for Sustainable Stormwater Management in Urbanized Catchments	Bartosz Szela, Grzegorz Łagód, Anna Musz-Pomorska, Marcin K. Widomski, David Stránský, Marek Soká˘, Jozefína Pokrývková and Roman Babko	MDPI/Water
3	Key issues for sustainable urban stormwater management	A.E. Barbosa, J.N. Fernandes, L.M. David	Water research 46 (2012) 6787-6798
4	Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo	Chitresh Saraswat, Pankaj Kumar, Binaya Kumar Mishra	Environmental Science & Policy (64 (2016) 101–117)
5	Measuring performance of low impact development practices for the surface runoff management	Wenyu Yang, Kurt Brüggemann, Kiwanuka David Seguya, Ehtesham Ahmed, Thomas Kaeseberg, Heng Dai, Pei Hua, Jin Zhang, Peter Krebs	Environmental Science and Ecotechnology (1 (2020) 100010)
6	Rain Water Harvesting, Conservation and Management Strategies for Urban and Rural Sectors	* Dr. R. K. Sivanappan	National Seminar on Rainwater Harvesting and Water Management
7	Sustainable stormwater management under the impact of climate change and urban densification	Lea Rosenberger, Jorge Leandro, Stephan Pauleit, Sabrina Erlwein	Journal of Hydrology 596 (2021) 126137
8	Use of rain gardens for stormwater management in urban design and planning	K. Ishimatsu, K. Ito, Y. Mitani, Y. Tanaka, T. Sugahara, Y. Naka	Landscape Ecol Eng (2017) 13:205–212
9	Water scarcity assessments in the past, present, and future	Junguo Liu, Hong Yang, Simon N. Gosling, Matti Kummu, Martina Flörke, Stephan Pfister, Naota Hanasaki, Yoshihide Wada, Xinxin Zhang, Chunmiao Zheng, Joseph Alcamo, and Taikan Oki	AGUPUBLICATIONS 22 JUN 2017

4.3. Calculation techniques

To achieve objectives 2 and 3, a simplified version of the ATV – A138.XLS, DWA Worksheet 138, and ArcGIS software were utilized.

The ATV-A138.XLS enables the dimensioning of infiltration systems and supports the following planning tasks:

- Dimensioning of decentralized and central infiltration systems in accordance with DWA-A 138
- Dimensioning of rain retention areas in accordance with DWA-A 117
- Treatment of rainwater in accordance with DWA-M 153
- Dimensioning of street gutters and road troughs in accordance with RAS-Ew
- Cost comparison calculation of infiltration - drainage in accordance with the KVR guidelines of the DWA (previously LAWA)
- Dimensioning of pipes in accordance with Prandtl-Colebrook
- Cistern dimensioning with average annual rainfall

The calculations are made after the calculation parameters have been entered in a table, taking local rainfall data into account. KOSTRA-DWD 2020 datasheet is used as local rainfall statistics. In the interactive EXCEL interface, the data sets for different infiltration systems using pre-made data sheets are editable. The input and dimensioning are object-related, i.e. one EXCEL sheet is provided for each infiltration system.

The DWA-A 138-1 concerns the drainage situation within residential areas and applies to rainwater that flows away from paved or built-up areas and is specifically infiltrated into the soil-groundwater system. It explains the planning, construction, and operation of tried-and-tested measures and systems for the infiltration of rainwater. The worksheet also describes the hydrogeological boundary conditions required for this and the measures required to protect soil function and groundwater.

The Rational Method is a popular technique for calculating the peak flow of stormwater runoff from a limited drainage region. This strategy is especially effective in urban or suburban regions, and it is often utilized in stormwater management system design.

1. The Rational Method uses the following formula to calculate the peak discharge (Q):

$$Q = C \times i \times A \quad (1)$$

Where:

- Q = Peak discharge (m^3/s or cfs)
- C = Runoff coefficient (dimensionless)
- i = Rainfall intensity (mm/hr or in/hr)
- A = Drainage area (ha or ac)

2. To determine the effective drainage area, the peak discharge or flow rate is calculated according to DWA*183 using the following equations:

$$\mathbf{A_u = A_E * \Psi} \quad (2)$$

$$\mathbf{Q_f = 10^{-7} \times r_{D(n)} \times A_u} \quad (3)$$

A_u – impermeable contributing area in m^2

A_E – catchment area (=projected surface) in m^2

Ψ – runoff coefficient, dimensionless

Q_f – design flow from the surface (e.g. into storage or infiltration system) in m^3/s

$r_{D(n)}$ – specific design rainfall in l/(s*ha)

with D – duration in min

n – exceedance probability 1/T

3. Storage capacity and infiltration of the Sponge City features for both Study Areas are calculated based on the equation below:

$$V = \Sigma Q_{zu} - \Sigma Q_S \quad Q_{zu} > Q_S$$

Q_{zu}…Inflow into storage in m^3/s
Q_s…infiltration flow in m^3/s

$$V = (Q_{zu} - Q_s) \cdot D_{\max V} * 60 * f_Z$$

$$A_s \approx 0.2 \cdot A_u$$

D_{maxV}…duration for max V in min
to be determined for max volume
f_Z…additional factor, 1.2
A_s…infiltration area in m^2
A_u…impermeable contributing area in m^2

$$V = ((A_u + A_S) \cdot r_{D_{\max V}(n)} \cdot 10^{-7} - 0.2 \cdot A_u \cdot \frac{k_f}{2}) \cdot D * 60 * f_Z \quad (4)$$

D_{maxV}…duration for max V in min
to be determined for max volume
f_Z…additional factor, 1.2
A_s…infiltration area in m^2
A_u…impermeable contributing area in m^2

ArcGIS is a cloud-based mapping and analysis solution used to make maps, analyze data, and measure the size of the study areas.

All calculations are conducted using Microsoft Excel.

As a source of rainfall data for Germany, KOSTRA ATLAS 2020 is used.

Table 3. KOSTRA ATLAS 2020 (Annex 3)

T in years	D in min	RN(D,T) in l/(s ha)
5	5	376.7
5	10	253.3
5	15	195.6
5	20	161.7
5	30	122.8
5	45	92.2
5	60	74.7

4. The discharge/conveyance of the water to natural water bodies is determined by using the Manning-Strickler method. The Manning-Strickler method is commonly used in hydraulic engineering to estimate the velocity of flow in open channels and pipes based on channel roughness, slope, and hydraulic radius.

The Manning equation is expressed as:

$$V = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \quad (5)$$

Where:

V is the velocity of the flow (m/s)

n is the Manning roughness coefficient

R is the hydraulic radius (m) (which is the cross-sectional area of flow divided by the wetted perimeter)

S is the slope of the energy grade line (dimensionless)

5. RESULT

According to the methods and approaches outlined in the methodology chapter, findings and calculations for the Sponge City features in the study areas were performed generating the following results, which are categorized by thesis objectives.

5.1. How does Sponge City Concept assist in managing stormwater in urban areas?

5.1.1. Analysis of the Sponge City features and its application

The Sponge City concept has already been thoroughly studied, piloted, examined, and presented in the scientific world. There are various papers available that highlight the positive outcomes of the concept, including its feasibility and effectiveness in different scales. It is crucial to note that, previous to the advent of the Sponge City concept, numerous different stormwater management concepts were developed and are still used today. However, those solutions were developed in response to different challenges and at different times than the issues confronting today's cities. In many cases, those solutions were intended to handle a specific problem rather than a broad range of challenges that urban areas are facing.

For instance, Nguyen et al. (2019) mentions not only urban water issues but also improving environmental conditions and lowering climate concerns. It is more advantageous than traditional methods. Sponge City is quite valuable for urban resilience. Indeed, when GI is developed and implemented in urban settings to improve green spaces, microclimates, and biodiversity, and SUDS are designed to efficiently and safely manage rainwater during heavy rainfall to prevent flooding, the Sponge City concept encompasses all of these functions. It is capable of resolving all of these concerns concurrently.

In addition, it should be noted that the implementation of the Sponge City features does not require big funding and can be implemented in countries with low income. Polgar, A. (2021) research demonstrates that the Sponge City concept may be used locally to build a holistic planning intervention that can be deployed in the context of cities in the Global South facing urban climate threats, with prevalent poverty, and low adaptive ability.

Many research papers highlight the lack of a policy foundation for Spongy City implementation, while others point to the lack of finance, clear guidelines, and interest from stakeholders. As the concept is relatively new and requires some time to be well integrated and tailored to the existing legal basis on urban development and stormwater management, different ideas/models of the Sponge City development are studied and proposed.

For example, Nguyen et al. (2020) in their work on *"A new model framework for Sponge City implementation: Emerging challenges and future developments"* provided a new framework for the Sponge City model that simulates the efficiency of urban water management strategies by employing four essential sub-models: MIKE-URBAN, W045BeST, LCA, and MCA. Thu Thuy Nguyen revealed that the model helps to anticipate the environmental, social, and economic advantages of urban water management methods, analyze their cost effectiveness, and then select the best urban water management strategy. There is no doubt that other equally successful implementation models exist that consider the area's distinctive characteristics, the tasks they seek to accomplish, and their cost-effectiveness.

The development of specific modeling tools or software to assist stakeholders in determining the feasibility and effectiveness of implementing the Sponge City concept is a very attainable

goal. Additionally, implementing legislation that requires the inclusion of Sponge City services in future urban developments is a viable option. However, the financial side, like other ventures, has certain obstacles.

Frequently, there is heated disagreement about who should shoulder the costs and who will gain from such initiatives. The state, private firms, and residents frequently delegate financial responsibility to one another, feeling it is not their obligation. However, it is crucial to involve all parties, clearly define their roles and benefits, and develop a comprehensive collaborative approach to ensure successful implementation.

For example, the real estate industry can be attracted to financing a pilot area of Sponge City in their urban master plan or other special plans, where the value of Sponge City is presented to create a luxuriant public space for the community (Xia et al. (2017).

In conclusion, the Sponge City concept is a novel strategy that efficiently handles a wide range of urban concerns via numerous processes. This approach offers multifaceted solutions to today's urban difficulties, including flooding, water scarcity, and environmental deterioration. However, in order to ensure its successful implementation and long-term viability, extensive preliminary studies and clarification of numerous critical areas are required ahead of time. First, it is critical to specify the exact purposes for which the Sponge City concept will be used. Understanding the major goals—whether they are to improve stormwater management, improve water quality, expand green areas, or reduce urban heat islands—will help drive the design and implementation process. Each function of the Sponge City concept must be adjusted to the specific needs of the urban region in question.

Second, it is critical to foresee and assess any extra issues that may occur as a result of implementing this notion. For example, integrating new infrastructure into existing urban environments might provide space, utility, and disturbance concerns. A complete risk assessment should be carried out to proactively identify and address these concerns.

Funding is another crucial factor to consider. Identifying and securing financial resources is critical for the creation, maintenance, and management of Sponge City attractions. This includes looking into various funding options such as government grants, business sector investments, public-private partnerships, and community-based projects. Clearly defining who will shoulder the costs and how the benefits will be split among stakeholders will aid in securing widespread support and ensuring financial viability.

The estimated service life of each function inside the Sponge City framework is also an important consideration. Understanding the lifetime and maintenance needs of components like permeable pavements, green roofs, rain gardens, and bioswales will aid in the planning of long-term operations. Regular maintenance schedules and responsibilities should be created to guarantee that these features perform properly over time.

Furthermore, it is critical to identify ahead of time the metrics that will be used to measure the performance of the Sponge City implementation. These indicators could include measurements like the amount of stormwater managed, improvements in water quality, lower urban temperatures, more green space, and overall gains in urban resilience. Establishing defined, quantifiable outcomes will allow for a methodical evaluation of the project's success as well as insights into future improvements.

Overall, while the Sponge City concept has significant benefits for metropolitan areas, its successful implementation necessitates careful planning and consideration of a variety of elements. By addressing these components thoroughly, communities can effectively leverage the Sponge City concept to build more sustainable, resilient, and livable urban environments.

CASE STUDIES

5.1.2. Dresden

Dresden inspired by the success of other European Spongy City pilot projects, such as Berlin Rummelsburg, Potsdamer Platz, and Leipzig also initiated "Biodiverse Sponge City Dresden".

The project was launched on September 20, 2023, aiming at adaptation to heavy rainfall and measures against overheating and other environmental problems in Dresden. The project was initiated by the branch of the European environmental network "Friends of the Earth Europe" and the global network "Friends of the Earth", BUND. Its activities include, for example, organic agriculture and healthy eating, climate protection, and the development of renewable energy sources, as well as the protection of endangered species, forests, and water (BUND, 2024a).

Specifically, the project, which will run until the end of 2024, consists of conceptual, public relations, and educational work as well as practical implementation. Concrete measures have been implemented with practical partners and good examples are being disseminated through public relations and educational work. The project is being implemented and designed primarily by Hanna Witte, who has been a project officer at the BUND Dresden.

Since the beginning of the work, the project has supported 2 initiatives under "Biodiverse Sponge City Dresden". The Hechtgarten is the first one, launched aiming at creating a green and cool oasis in the often-overheated Hechtviertel by storing and using rainwater and consistently planting greenery (BUND, 2024b). This project is expected to show that rainwater use, climate change adaptation, and biodiversity promotion belong together. Another project is improving the outdoor area at the children's and youth center in LOUISE (Malwina e.V.). was adapted to the location and planted in a way that was appropriate for a daycare center.

Even though the project is moving forward toward a resilient city concept and sustainable green space development and creation, it mainly focuses on the enhancement of biodiversity, rather than targeting a whole specter of urban stormwater management. Thus, the implementation of the other features of the Spongy City concept to assess their effectiveness in stormwater management is needed.

Other case studies where the concept's characteristics were effectively introduced are Berlin Rummelsburg, Berlin Potsdamer Platz, and Leipzig.

5.1.3. Berlin Rummelsburg

Built 25 years ago, the Rummelsburg neighborhood in Berlin is a prime example of the "Sponge City" concept in Germany (Isobelkaul, 2020). Roadside trenches between pavements and streets create a miniature urban wetland, which can retain water like a sponge and both feed and evaporate it to keep the city cool. Buildings are wrapped in green walls, roofs, and

garden terraces, with thick tranches of soil up to 80 cm deep. Thick layers of vegetation absorb and manage water better than the city's traditional concrete and drainage system during periods of high rainfall. Pavements are less likely to become makeshift white water rafting courses, and there's less chance of drains overflowing due to obstructions or simple overloading.

5.1.4. Berlin Potsdamer Platz

Berlin's Potsdamer Platz is a public area and traffic crossroads that has experienced substantial change, particularly since unification. When the city was divided, this once-vibrant city center was ravaged during World War II and turned into a barren border area. In the 1990s, after reunification, it grew to become Europe's biggest urban construction project (Potsdamer Platz, 2022). In order to build a vibrant urban infrastructure for workplaces, leisure, and recreation, the reconstruction used Sponge City characteristics to retain water on site. Roughly 44,000 m^2 of rainwater are collected by the design and sent to cisterns to be used as greywater. Biological processes are used to purify water on-site using vegetated biotopes (DREISEITL, 2022).

This project has produced sustainable results, such as a 70% decrease in carbon emissions, a 50% primary energy savings over air conditioning systems, the preservation of 20 cubic meters of potable water, and the provision of 13,500 cubic meters of stormwater storage. Additionally, the project has produced an artificial lake with excellent water quality, lowered the average temperature of the urban heat island effect by 2°C, and given Berliners access to much-needed green space (Annex 2).

The project emphasizes several points:

• Sponge City elements can be successfully incorporated into current metropolitan settings, overcoming issues like spatial constraints.

• For successful implementation, cooperation with specialists versed in urban climate conditions is essential.

• The project establishes a standard for future developments by demonstrating how urban rehabilitation can balance architecture, city life, and sustainable water management.

5.2. Identifying the distinctive and functional advantages of the Sponge City Concept in stormwater retention compared to other methods.

STUDY AREA 1 – SPREEWALDER STR. 50

5.2.1. Runoff and Volume Calculation

The total size of the roof area is calculated by using ArcGIS/Google Earth. The buildings' roof area is divided into 5 collection areas (CA): CA1, CA2, CA3, CA4 and CA5). The total area is calculated as 3742 m^2. Roofs consist of bituminous roofing felt. The age of the roofing material is unknown and assumed to be 20–30 years old.

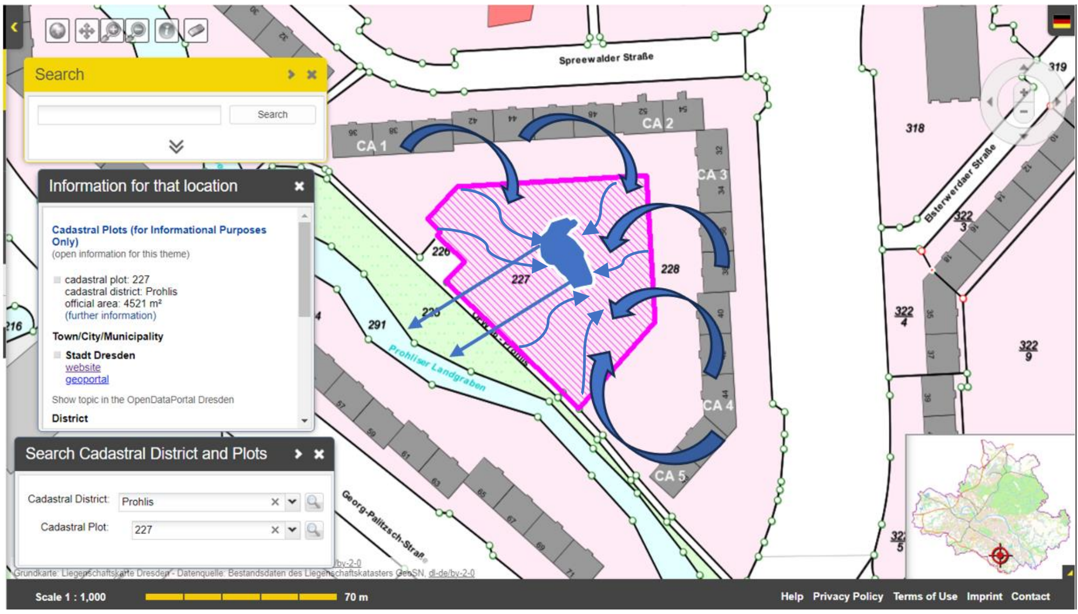

Figure 15. The map of the Study Area 1
Source: Dresden city website

Runoff and Volume Calculation are calculated based on the equation 1:

Performed area calculation using Microsoft Excel presents the total area designated for calculations as **8263 m²**, which includes **3742 m²** of roof surface and **4521 m²** of vegetation (green area). The specific design rainfall in l/(s*ha) is taken from KOSTRA Atlas 2020 for a duration of 15 min and a return period of 5 years is used. As a result, the runoff is determined as **0.0703 m^3/s** and a volume as **63.27 m^3**.

Result:

Contributing surface	Area in m^2	Runoff coefficient
Roof area	3742	0.9
Green area	4521	0.05
Total	8263	
Weighted average		0.43
A_u in m²	**3593.85**	
Runoff Q_f in m^3/s	**0.0703**	
Runoff volume (V_R) in m^3	**63.27**	

Below is a table with determined runoff and runoff volumes for 6 scenarios (5, 10, 15, 20, 30, 45, and 60 minutes) for a return period of 5 years for comparison.

Table 4. Comparison table of the determined peak flows and runoff volumes for 6 scenarios for the combination asphalt and green area

No.	Determined for 5 year return period	Duration of rainfall (D) in min						
		5	**10**	**15**	**20**	**30**	**45**	**60**
1	Runoff (Q_f) in m^3/s	0.1354	0.091	0.0703	0.0581	0.0441	0.0331	0.0268
2	Runoff Volume (V_R) in m^3	40.61	54.62	63.27	69.74	79.44	89.47	96.65

5.2.2. Calculation of Drainage

Drainage of the collected water in the bioretention pond to Geberbach Creek is maintained through the underground PVC pipe. Manning formula (Eq. 4) was used to calculate the stormwater inflows from the pond to the creek through drainage.

1. Given Data

- Pipe Material: PVC
- Pond Storage Capacity: 145 cubic meters (m^3)
- Manning's Roughness Coefficient for PVC Pipe (n): 0.009
- Pipe Diameter (D): 0.2 meters (m)
- The slope of the Pipe (S): 0.10 (dimensionless)

2. Manning's Equation for Flow Velocity (V)

$$V = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

3. Calculate the Hydraulic Radius (R)

For a circular pipe flowing full: $R = \frac{A}{P}$

Where:

- A is the cross-sectional area of the pipe
- P is the wetted perimeter

For a full circular pipe:

$$A = \frac{\pi D^2}{4}$$

P=πD

Therefore:

$$R = \frac{\frac{\pi D^2}{4}}{\pi D} = \frac{D}{4}$$

With D=0.2 meters:

$$R = \frac{0.2}{4} = 0.05\ m$$

4. Calculate Flow Velocity (V)

Using Manning's equation:

$$V = \frac{1}{0.009}(0.05)^{\frac{2}{3}}(0.10)^{\frac{1}{2}}$$

$(0.05)^{2/3} \approx 0.0794$

$(0.10)^{1/2} = 0.3162$

Therefore:

$$V = \frac{1}{0.009} \cdot 0.0794 \cdot 0.3162 = 111.11 \cdot 0.0794 \cdot 0.3162 = 2.79\ m/s$$

5. Calculate Discharge (Q)

Discharge Q is given by:

$Q = A \times V$

Where A is the cross-sectional area of the pipe:

$$A = \frac{\pi D^2}{4} = \frac{\pi(0.2)^2}{4} = 0.0312\ m^2$$

Therefore:

Q = 0.0314×2.79

Q ≈ 0.0876 m3/s

6. Time to Empty Pond Storage Capacity

To find the time (t) required to empty the pond's storage capacity of 145 m^3:

$$t = \frac{Storage\ capacity}{Q} = \frac{145}{0.0876} = 1655.48 \text{ sec}$$

t = 1655.48 x 3600 = 27.6 min

Summary

- **Flow Velocity (V)**: 2.79 m/s
- **Discharge (Q)**: 0.0876 m^3/s
- **Time to Empty Pond**: Approximately 27.6 minutes

5.2.3. Bioretention Pond Design

Required Volume and Depth are calculated based on the equation 2:

Based on calculations carried out it is revealed that in the case of a 15-minute rainfall event (5-year return period), a **986.63 m²** surface area is required for infiltration. The required volume

(V_{max}) and depth (h) for design rainfall are determined as **89.35 m³** and **0.13 m**, respectively. While 1-hour rainfall duration, according to calculations, requires a storage capacity of **134.73 m³** and a depth of **0.19 m**.

Result:

	value	unit
kf	0.00000186	m/s
AE	8623	m^2
Ψ	0.43	
rD(n)	195.6	l/(s*ha)
Au	3553	m^2
$AS_{estimated}$	710.6	m^2
fz	1.20	-
V_S	89.35397064	m^3
$h_{initial}$	0.1257444	m
D (max volume)		RN(D,T) in l/(s ha)
15		195.6
V_{max}	**89.35**	**m^3**
h	**0.13**	**m**

Frequently used for planning in urban areas in Germany:
Duration = 15 min
Return period = 5 years (exceedance probability = 0.2)

The depth of 0.13 m is not appropriate for this case study and has to be increased.

$V = A_s \times D$;

$D = V/A_s$;

$A_s = 200\ m^2$

$$D = \frac{134.73}{200} = 0.66\ m$$

Although the increased pond depth to a value of 0.66 meters reduces the required surface area for infiltration from 710.6 m² to 135.38 m², it is still not enough to store a **134.73** m³ water volume during one hour of rainfall. In this regard, the final depth value is set at **0.8 meters**.

$V = A_s \times D$;

$A = V/A_s$; $A = 134.73/0.8 = 168.41\ m^2$

Thus, the required storage capacity of the bioretention pond is determined to be more than **135 m³** and size between **170 m²** to **200 m²**. A gravel trench (pore content 35%) is used to strengthen the infiltration capacity at the level of 0.8 to 4 meters depth.

	Gravel trench
Pond's length	≥ 47.7 m
Drain width (A_m)	≥ 4.00 m
Drain height (D_m)	≥ 4.0 m
Total size (A_o)	≥ 200 m²
→ required storage volume	≥ 145 m³

Emptying time vs. setpoint	24 h ≤ 24 h
Max. water level in the trench	0.80 m
The usable height of the trench (hn)	3.20 m
Groundwater level	10.00 m

Based on the findings, the diagram below presents a template of a detailed cross-sectional bioretention pond designed for stormwater management. It illustrates various components and processes involved in the infiltration of stormwater into the ground. As well as a measure of discharging the overflow to the nearest water body in case of heavy rainfall events.

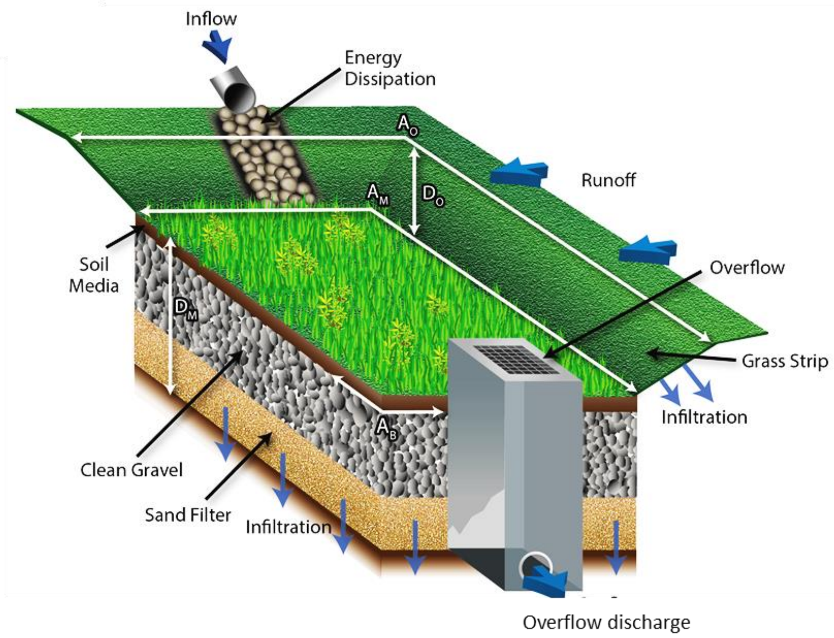

Figure 17. The multi-layered bioretention pond system
Source: Minnesota Stormwater Manual

Water gets into the system at its full extent from an inflow point on top, with energy dissipation measures (for example rocks) that minimize the velocity and impact of incoming water. The grass strip on the surface provides some filtration and controls runoff speed before hitting a main infiltration area. In the event of rainfall, water that does not seep away through plant beds is then drained into sand tanks by way of designated overflow areas and onto the Geberbach stream. At the top is a layer of soil that plants grow in, which helps get dirty water cleaned up initially. A clean gravel bed (pore area of 35%) is located below the soil layer, which further aids in filtration and provides structural support for our infiltration trench. A thicker layer of sand is installed, containing a filter that can help remove small particles and contamination within the water. Cleaned filtered water penetrates the subsurface through an underground reservoir, boosting groundwater.

To summarise, stormwater collected in the bioretention pond can be used for a variety of beneficial reasons. One of the principal applications is to water trees and other plants in the vicinity, which helps to keep green spaces healthy and lush. This irrigation promotes urban flora, which improves the neighborhood's visual appeal and ecological health. Furthermore, using collected runoff for irrigation produces a cooling impact on the surrounding areas. This

cooling effect is especially relevant in urban situations, where heat islands can cause temperatures to rise substantially more than in rural areas. By maintaining vegetation well-watered and thriving, the bioretention pond helps to reduce ambient temperatures, making the atmosphere more comfortable and livable for occupants. In addition to these advantages, the bioretention pond contributes significantly to the biodiversity of Geberbach Creek. By discharging treated stormwater into the stream, water levels are maintained, particularly during dry periods, allowing a varied range of aquatic and riparian species to thrive. This influx of clean water has the potential to improve habitat quality, supporting plant and animal health and diversity in and around the creek.

5.2.4. Maintenance Procedures

The bioretention pond, like other green infrastructure, requires maintenance work. The most frequent maintenance is the disposal of garbage (e.g., empty cans, plastic bags, etc.) that might gather around the pond. The garbage might clog a channel between the pond and the overflow outlet, impeding the conveying mechanism. Depending on the vegetation mix of a rain garden, additional steps such as removing invasive/nonnative species, pruning overgrown plants, and gardening for aesthetic value may be required.

To accomplish this, the real estate business and the City of Dresden can reach an agreement on trench maintenance that is mutually advantageous. This practice provides a win-win situation for all parties. The worth of the real estate company will rise as the natural environment improves, while the city of Dresden will save money on area maintenance.

5.3. Climate Change Adaptation: Analysing the potential of the Sponge City Concept for stormwater harvesting and reuse.

STUDY AREA 2 – PARKING LOT

5.3.1. Runoff and Volume Calculation

The total area designated for calculations is 6488 m², which includes 3365 m² of asphalt-covered surface and 3123 m² of green lawn. The runoff calculation of the above-mentioned area is carried out based on the equation 1:

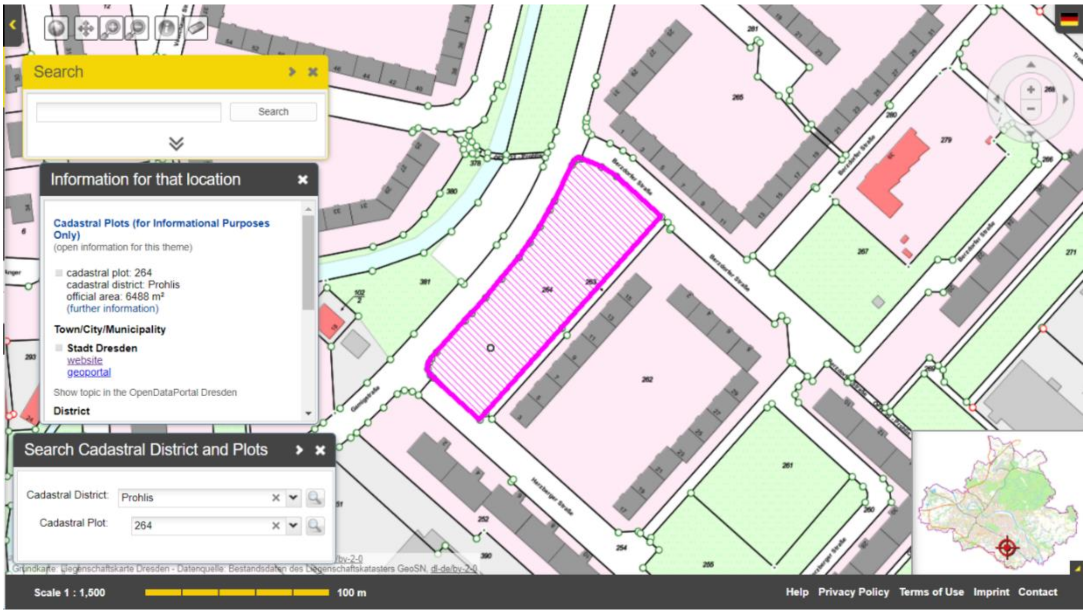

Figure 18. Map of the Study Area 2 (Parking Lot)
Source: Dresden city website

The specific design rainfall in l/(s*ha) is taken from KOSTRA Atlas 2020 for a duration of 15 min and a return period of 5 years is used (KOSTRA ATLAS 2020). As a result, the runoff volume of **53.10 m³** is determined. Below is a table with determined peak flows and runoff volumes for 6 scenarios (5, 10, 15, 20, 30, 45, and 60 minutes) for a return period of 5 years for comparison.

Result:

Contributing surface	Area in m²	Runoff coefficient
Asphalt area	3365	0.85
Green area	3123	0.05
Total	6488	
Weighted average		0.46
A_u in m²	**3016.4**	
Runoff Q_f in m³/s	**0.0590**	
Runoff volume (V_R) in m³	**53.10**	

Table 5. Comparison table of the determined peak flows and runoff volumes for 6 scenarios for the combination asphalt and green area

No.	Determined for 5 year return period	Duration of rainfall (D) in min						
		5	**10**	**15**	**20**	**30**	**45**	**60**
1	Runoff (Q_f) in m^3/s	0.1136	0.0764	0.059	0.0488	0.037	0.0278	0.0225
2	Runoff Volume (V_R) in m^3	34.09	45.84	53.10	58.53	66.67	75.09	81.12

5.3.2. Permeable Pavement Installation

At this stage, aiming at creating more affordable conditions for enhancing infiltration and evapotranspiration in the area, replacing the asphalt surface which has low permeability with permeable pavement, such as concrete or rubber tiles with open sections on it, to assess the difference is carried out.

The total area of **3365 m²** is replaced with porous tiles that have an infiltration coefficient of **0.3**. This proposal is based on the fact that permeable pavement has a greater filtration coefficient, allowing for more water infiltration and less runoff. Implementing permeable pavement will increase drainage efficiency, contributing to the overall goal of improving rainwater management and decreasing potential flooding hazards.

Figure 19. Examples of permeable pavement (tiles)
Source: Online

Moreover, a roof surface with a size of **399 m²** created by the construction of solar panels is also taken into account during the calculations (paragraph 4).

Result:

Contributing surface	Area in m^2	Runoff coefficient
Permeable pavement	2966	0.3
Vegetation	3123	0.05
Roof (Solar Panels)	399	0.9
Total	6488	
Weigted average		0.22
A_u in m^2	**1405.05**	
Runoff Q_{zu} in m^3/s	**0.0275**	
Runoff volume in m^3	**24.73**	

Table 6. Comparison table of the determined peak flows and runoff volumes for 6 scenarios for the combination asphalt and green area

No.	Determined for 5 year return period	Duration of rainfall (D) in min						
		5	**10**	**15**	**20**	**30**	**45**	**60**
1	Runoff (Q_f) in m^3/s	0.0529	0.0356	0.0275	161.7	0.0173	0.013	0.0105
2	Runoff Volume (V_R) in m^3	15.88	21.35	24.73	27.26	31.06	34.98	37.78

The obtained results effectively illustrate how the duration of rainfall impacts the volume of runoff under differences in surface types. In the first bar chat, the runoff volume, in cubic meters, of existing conditions (in blue) is compared to the one with replacing the permeable pavement (in orange). As can be seen, the rainfall volume is significantly decreased, which makes it easier to manage. The second bar chart represents the comparison of peak runoff between existing conditions (in blue) and the one replaced with the permeable pavement (in orange). It also shows quite noticeable results.

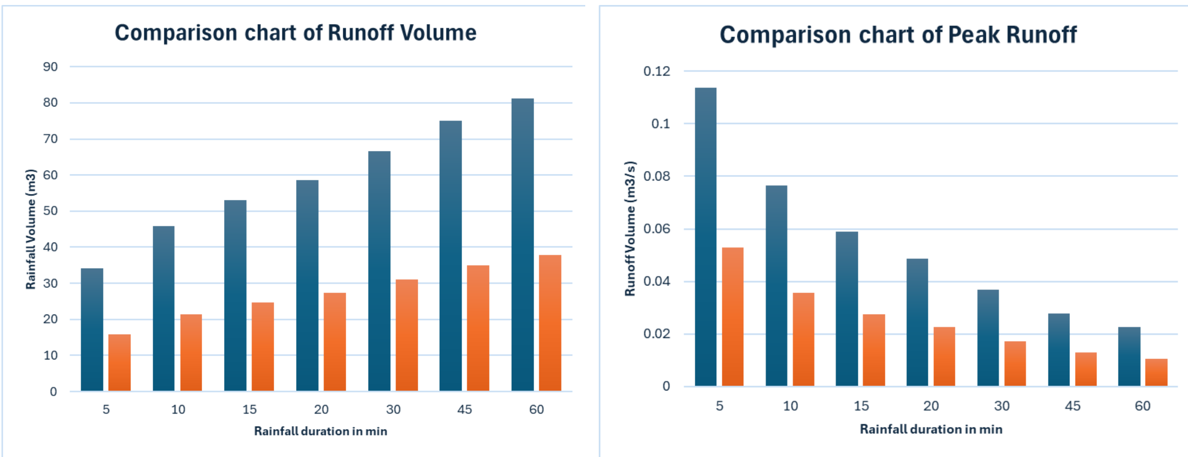

Figure 20. Comparison chart of Runoff Volume and Runoff for the current (blue) and future scenario (yellow)

5.3.3. Solar Panel Installation

Solar panels have been proposed to increase the autonomy and sustainability of the tree watering system. Watering trees necessitates a consistent power supply to run a pumping station or pump, which has traditionally relied on electricity. While connecting to the city's electrical grid is a possible alternative, it comes with additional costs and dependencies. Instead, using solar panels offers an alternate, environmentally responsible method by generating enough electricity to run the pumping device. Installing solar panels correlates with broader environmental aims such as switching to green and sustainable energy sources, reducing reliance on nonrenewable energy, and lowering carbon footprint. By utilizing solar energy, the irrigation system becomes self-sufficient, lowering operational expenses while also contributing to environmental conservation.

The roof drainage system, which is connected with the solar panels, is intended to effectively handle rainwater. The method works as follows: rainwater collected on the roof, where the solar panels are located, is directed into a pond via PVC pipes. This technique ensures that

rainwater is efficiently caught and used for irrigation. One significant advantage of this system is the quality of rainwater collected from the roof. Because the roof is often cleaner and less contaminated than the parking lot surface, rainwater collected from it is of higher quality. This cleaner water, when combined with other sources in the pond, improves the overall quality of the irrigation water, making it more suited for sustaining healthy plants.

Given Dresden's availability of sunny days appropriate for solar energy generation, this study seeks to contribute to climate change mitigation by promoting solar panel installation in the parking lot. The allocated space for this initiative is located on the northwest side of the parking lot and will be used to place solar panels. This planned arrangement will maximize sunlight exposure, increasing the efficiency and efficacy of solar panels in producing renewable energy. This action meets energy demands and coincides with broader environmental objectives (figure 21).

Construction of the “L” type structure is considered by using hot-dipped galvanized steel materials that ensure more than 25 years longer lifespan. Based on the available area of 390 m2 (130 m x 3 m), a total of 142 solar panels in the landscape position is proposed. Tilted at an angle of 43 degrees facing south, 3.11 kWh/day annually per kW of installed solar capacity can be ensured (Robinson (n.d.)).

Figure 21. Area for solar panel installation
Source: [Dresden city website]

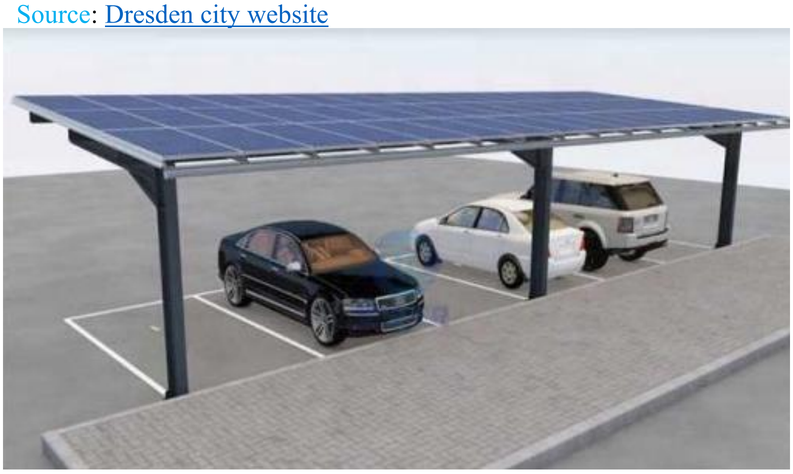

Figure 22. The shape of the structure of the solar panels

The set of solar power generation systems consists of the following items:

- Solar panels – 142 pcs (400 W)
- Battery – 1 pc (12v – 200 ah)
- Off-grid inverter & controller – 1 pc (42 kW)

Total Power Generation Calculation

The total power produced daily was calculated using the following formula:

Power = (No. of Solar Panels per kW) * (Annual average kWh/day) *

Items	No. of panels	Peak Power per Panel (W)	Solar Panels per kW	Annual average kWh per day	Total Energy per day (KWh)	Total Energy per year (KWh)
Solar panels	142	400	56.8 (2.5x400)	3.11	176.8	64476.52
TOTAL	**142**					**64,476.52**

The canopy provides shade and protection from rain while generating solar power. Generated electricity in the volume of 64.5 MWh per year can be utilized for many purposes, including but not limited to lighting the parking area, charging electrical vehicles, and others (fig 22).

Figure 23. Electric vehicle charging points around Dresden

5.3.4. Infiltration Volume and Storage Determination

Raingarden storage and infiltration are calculated based on the equation 3:

The retention rain garden's storage capacity (V_{max}) and depth (h) for a **285.42** m² infiltration surface area during a 15-minute rainfall event with a 5-year return period are **33.41 m³** and **0.12** m, respectively. Due to limited available land for pond designing (≤50 m²), we adapt the equation by increasing the depth (h) to control the volume properly.

	value	unit
kf	0.000018	m/s
AE	6488	m²
Ψ	0.22	
rD(n)	195.6	l/(s*ha)
Au	1427.36	m²
$AS_{estimated}$	285.42	m²
fz	1.20	-
V_S	30.72293453	m³
$h_{initial}$	0.614458691	m
D (max volume)		RN(D,T) in l/(s ha)
15		195.6
V_{max}	**33.41**	**m³**
h	**0.12**	**m**

Frequently used for planning in urban areas in Germany:
Duration = 15 min
Return period = 5 years (exceedance probability = 0.2)

$V = A_s \times D;$

$A = V/A_s\ ;$

$A_s = 50\ m^2$

$$As = \frac{33.41}{50} = 0.66\ m$$

Increasing the rain garden's depth to a maximum of 0.7 meters, reduces the required surface area for infiltration from 285.42 m² to 47.7 m², allowing for better use of available space.

The emptying time is calculated simply as

$T_E = V / (A_s \times k_f/2) \times (1/ 3600s)$.

The value should not exceed 24 hours.

$T_E = 33.41 / (50 \times 0.00000186/2) \times (1/3600) = 19.72$ h (<24 h)

5.3.5. Infiltration, Treatment, and Storage Methods

According to Germany's wastewater treatment regulations, water from parking lots, streets, and other comparable surfaces cannot be dumped into bodies of water or the environment without first being treated. This is because runoff can transport major pollutants like sediments, fertilizers, petroleum hydrocarbons, and other contaminants. To comply with this guideline, the collected stormwater from the parking lot must be treated before discharge to its final destination. Bioswales and rain gardens are one excellent way to achieve this goal. These NBS are intended to filter and treat stormwater, removing pollutants while minimizing environmental effects. By deploying such systems, stormwater may be managed sustainably, ensuring that it meets environmental safety criteria before being released.

In this regard, it is suggested to propose the construction of a raingarden, where stormwater from the area is conveyed via a polyvinyl chloride drainage system, where pollutants and sediments are removed. In addition, vegetation can intercept rainfall, increase subsurface water storage capacity, and improve infiltration. Various layers and components are involved in the infiltration and treatment of stormwater within the raingarden (figure 24).

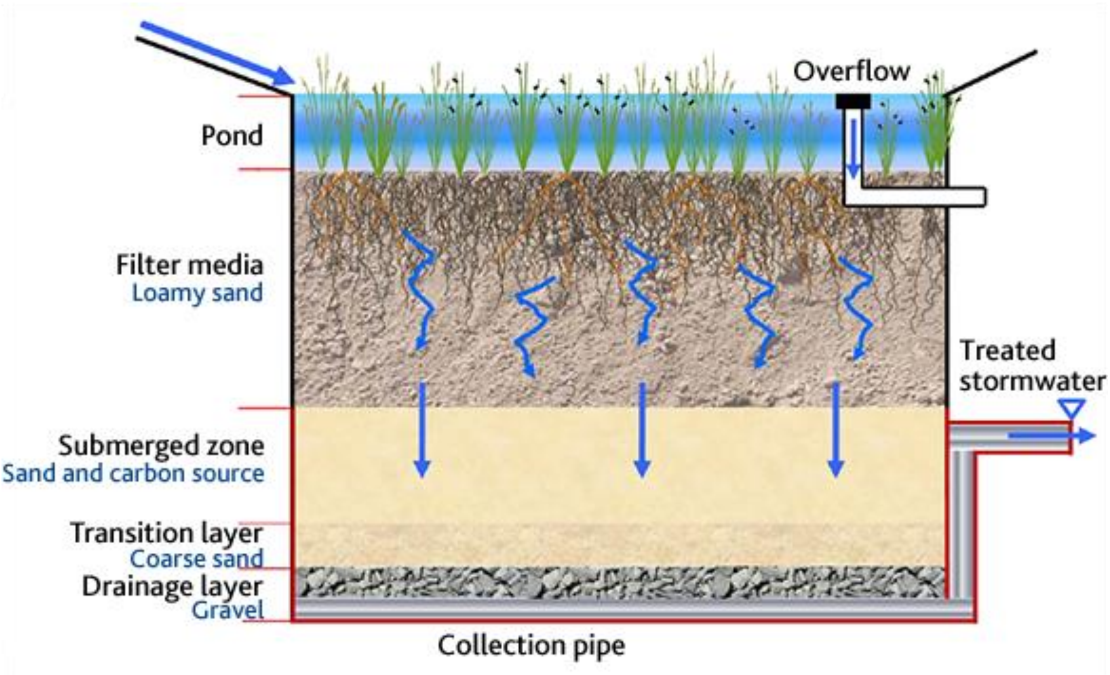

Figure 24. Outline of the rain garden

The top layer is where stormwater is first collected. It may momentarily contain water before it seeps into the deeper layers. This layer, made of loamy sand, serves as the principal filter for

stormwater, eliminating bigger particles and impurities when water percolates through it. This zone is located beneath the filter medium and contains sand and a carbon source. This layer further cleanses the water, frequently assisting anaerobic activities that aid in the breakdown of organic contaminants. This layer, composed of coarse sand, aids in the passage of water from the submerged zone to the drainage layer, enabling smooth infiltration. The bottommost stratum is made up of gravel. It drains and prevents water from collecting, allowing treated stormwater to be collected more efficiently.

This pipe, located at the bottom of the raingarden, collects treated runoff and distributes it to its final destination, which can be either a cistern for water storage or other water bodies, such as the Gegerbach stream. Located near the top of the raingarden, the overflow mechanism safely diverts excess water away during heavy rain events, preventing floods and erosion. In this case, the additional pond is proposed to temporarily store water and lately return it to the raingarden.

5.3.6. Rain garden Design

The size of the raingarden is determined based on the following factors:

1. The max volume of water = 45 m^3 (in case the duration of rainfall is equal to an hour)

2. The maximum depth = 0.7 m

3. Infiltration rate = 0.0000018 m/s

4. The size of the bioretention pond = 50 m^2

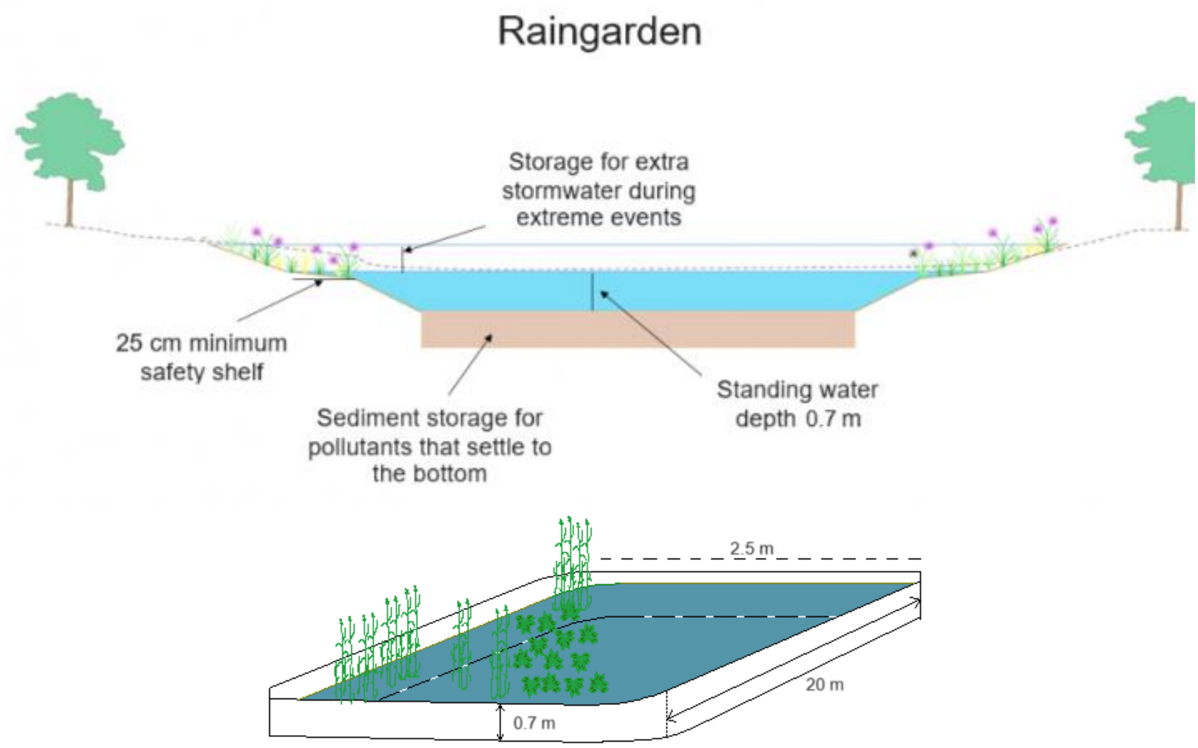

Figure 25. Outline of the rain garden pond

In summary, a pond measuring 20 meters long, 2.5 meters wide, and up to 0.7 meters deep can handle a maximum discharge volume of 45 cubic meters. This pond can be drained within 20 hours. If it rains twice a month for 15 minutes, roughly 70 cubic meters (34.4 m^3 x 2) of rainwater can be collected and used to water trees around the parking lot.

For the long-term storage of rainwater intended for tree irrigation, an extra cistern or open pond with a capacity of up to 10 cubic meters with no infiltration capacity is advised. This storage structure will hold rainwater from the rain garden.

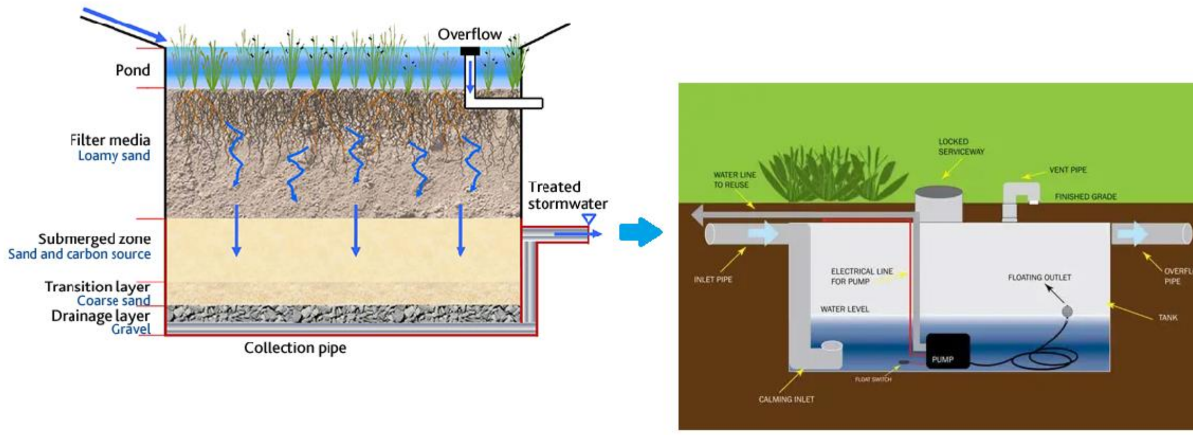

Figure 26. Schematic view of the water movement from the rain garden to the cistern

Table 7. The amount required for watering the vegetation around the area

No.	Type of tree	Quantity of existing trees	Amount of water required per tree per week (L)	Total amount of water required per week (L)	Total amount of water required per month (L)	Water collected in the pond
1	Sessile oak, birch tree, and others	54	80	4320	18 144 (18.1 m^3)	15.88 – 37.78 m^3 (table 6)

To summarise, the Sponge City tools incorporate permeable pavements, bioretention ponds, and irrigation storage tanks, resulting in a highly effective stormwater management system. It not only addresses immediate issues like runoff and pollution, but it also strengthens urban resilience by promoting groundwater recharge, cooling the environment, and preserving potable water. This holistic approach highlights sustainable urban water management, resulting in healthier and more livable urban environments. The concept also encourages a more sustainable and environmentally friendly way of managing municipal water resources.

Using collected rainwater improves the health and growth of urban green spaces. Healthy vegetation helps boost air quality, aesthetic appeal, and biodiversity in urban areas. Trees and plants serve an important part in carbon sequestration, oxygen production, and providing a home for diverse wildlife species, all of which contribute to the area's overall ecological health (Annex 4).

5.4. Recommendation for Regeneration and Renaturing Geberbach Creek

Water bodies like urban creeks are valuable assets that contribute to the environmental, social, and economic well-being of communities. They serve vital biological services, provide recreational and educational opportunities, add aesthetic and cultural value, and play an important role in stormwater management. Protecting and incorporating creeks into urban design and development is critical for establishing sustainable, livable communities.

Geberbach Creek running through the Prohlis municipal area plays a vital role in enhancing the area's ecosystem services and biodiversity. The Geberbach, which is called Prohliser Landgraben/Geberbach with a total length of 10.5 km runs from the municipality of Possendorf to Dobritz. The total catchment area of the creek is 11.9 km^2, out of which 5.5 m^2 is in Dresden (figure 26).

The data gathered from various sources, including official websites and e-platforms, highlights the challenges associated with the creek and outlines the city council's plans to address them. It was discovered that the creek's condition has deteriorated due to both human and natural factors, specifically soil erosion at the upper catchment area (agricultural lands), household waste, lack of maintenance, and the effects of climate change. According to the measurement carried out by the Saxon State Office for the Environment Agriculture and Geology in 2015, the ecological potential of the creek was evaluated as poor/bad, with exceedance of some components such as mercury, PAH, and polycyclic.

The City of Dresden reported that from 2018 onwards the Niedersedlitzer Flutgraben was partially dry for several weeks during dry periods and usually only carried water when it rained (Institute for technical-scientific Hydrology GmbH, 2023). The upper reaches (Prohliser Landgraben/Geberbach) also had a low discharge during dry periods. The water level in the Kauscha Dam was deficient at times.

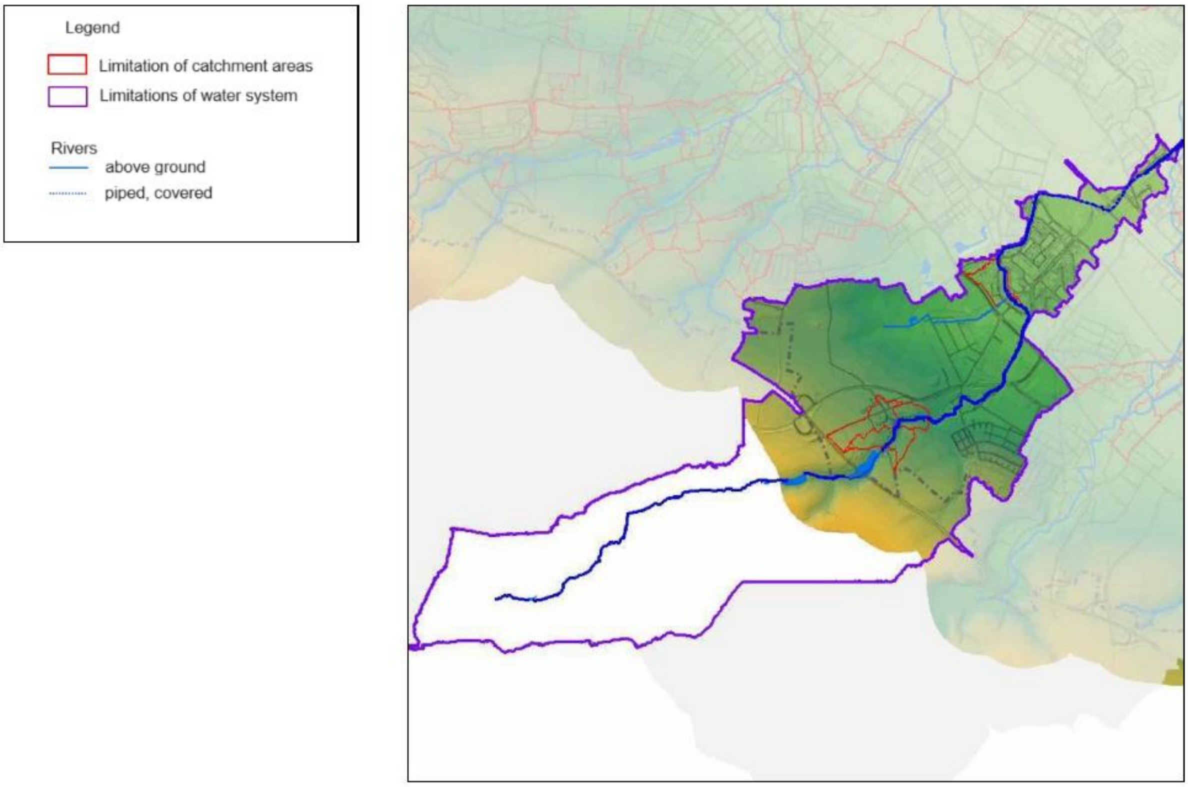

Figure 27. Geberbach creek
Source: Dresden city website

A field visit to Geberbach Creek and visual observation, accompanied by analyzed collected data confirmed that the creek needs in realization of the regeneration measures to improve flora and fauna around the creek.

Some of the measures and their necessity are provided below:

Actions to be taken

- Establishment of riverbank protection using biological engineering methods in areas where water management and structural requirements are necessary
- Initiation of diverse bank and bed structures by installing guide groins, dead wood, and gravel substrate
- Increasing flow and depth variance
- Creation of shelters (e.g. from dead wood or stones) and small pools for fish
- Installation of flow deflectors
- Addition of gravel substrate

Goal to be achieved

- Creation of gravel spawning grounds in areas with increased current (in and directly below rushes) by targeted introduction of gravel as initial
- Promoting the dynamic development of bank and bed structures in the existing corridor
- Improvement of flow and depth variance
- Improving substrate diversity
- Increasing water depth during low water phases
- Improving habitat quality for fish and macrozoobenthos

Achieving objective 3 of the thesis directly supports objective 4, which is concerned with the revitalization of Geberbach Creek. Objective 3 entails the installation of rain gardens to control stormwater properly. The rain gardens, by successfully collecting and infiltrating rainfall, play an important role in raising Geberbach Creek's water level, especially during periods of low flow. This additional water stabilizes the creek's flow regime, resulting in a more consistent and reliable water supply throughout the year. The rain gardens' enhanced water volume provides substantial ecological benefits. For starters, it improves the habitat quality for aquatic animals like fish and macrozoobenthos, which are important indications of stream health.

A steady and sufficient flow of water facilitates their life cycles, which include spawning, feeding, and growth. The improved habitat conditions increase biodiversity in the stream, resulting in a more robust and balanced ecosystem. Cleaner water benefits the general health of the aquatic environment, including fish and macrozoobenthos, as well as other wildlife and plant species that rely on the creek. The creek's revitalization is also consistent with sustainable water management methods, demonstrating a proactive approach to addressing climate change impacts and fostering environmental stewardship.

Figure 28. Pictures of the Geberbach Creek

The city of Dresden has launched a "Blue Ribbon Geberbach" project in 2021 to improve the creek by partially reconstructing and rerouting it, adding new cycles and footpaths on the banks, and reallocation of underground laying pipes. Some part of the creek until now, has been forced into underground pipes over long stretches between Prohlis and the mouth of the Elbe, which is neither ecologically nor flood-proof nor desirable from an urban planning perspective. In this regard, Sponge City can assist in achieving the city’s efforts towards renaturing the creek in a way that residents, hikers, and bikers can experience it as a natural stream, contributing to a more pleasant urban environment.

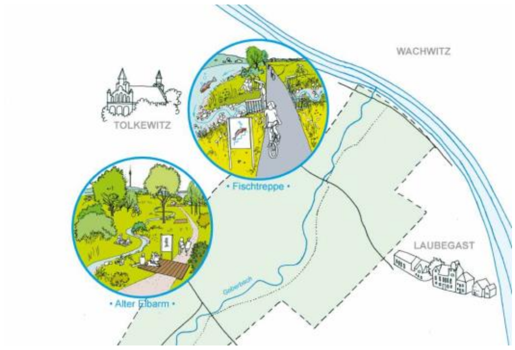

Figure 29. Visualization of the Geberbach Creek
Source: Blue Ribbon Geberbach

LIMITATIONS

Unfortunately, several constraints discovered while working on this document may affect the accuracy of various computations and proposed infrastructure solutions. However, this does not detract from the core purpose of investigating the Sponge City concept's potential for tackling rainwater management and reuse challenges.

We were unable to connect with construction firm officials who could give building designs, which would have allowed us to better understand the roof rainfall drainage system and make precise recommendations for collecting and transferring rainwater to the swimming pool. Furthermore, we were unable to locate or collect the essential data on soil and sewerage in the parking area, reducing the precision of our infrastructure calculations.

Initially, we intended to use the STORM.Sim program for all calculations. However, due to a lack of effective guidance and the difficulty of utilizing the program without adequate theoretical and practical understanding, we were forced to rely on other tools.

DISCUSSION

The thesis assessed the application of the Sponge City concept as a sustainable and innovative stormwater management approach in Dresden's Prohlis district. By studying the potential of the Sponge City concept, this thesis seeks to present a holistic solution that adheres to the principles of sustainable urban development.

To accomplish this, the study described and thoroughly investigated the Sponge City concept and its numerous elements. These include permeable pavements, rain gardens, and bioretention ponds, among others. The goal was to figure out how these elements may be efficiently integrated into Prohlis to manage stormwater sustainably. The study included a thorough evaluation of existing literature, case studies, and the most recent advances in urban water management methods to determine the most appropriate and practical options for Prohlis.

The thesis' findings are consistent with its objectives, revealing that the Sponge City concept while sharing parallels with other SUDS, provides an innovative and promising method for stormwater management in Prohlis. According to the findings chapter, adding elements such as permeable pavements, rain gardens, and bioretention ponds promotes urban sustainability. These qualities are cost-effective, environmentally benign, and socially acceptable, making them appropriate for modern metropolitan environments.

Replaced asphalt with permeable pavements will allow more water to infiltrate lowering surface runoff and increasing groundwater recharge. Rain gardens collect and absorb rainwater, filtering pollutants and improving the aesthetic and ecological value of urban settings. Bioretention ponds, which collect and treat stormwater, contribute to better water quality and quantity management, reduce flooding risk, and improve urban infrastructure resilience. Furthermore, these qualities permit the collection and reuse of large amounts of stormwater. This captured water can be used for a variety of purposes, including watering vegetation and restoring water bodies like Geberbach Creek. Stormwater reuse not only helps to conserve potable water, but it also promotes urban biodiversity and green space development.

The study emphasized the need to incorporate renewable energy solutions into municipal infrastructure. Solar panels installed in conjunction with Sponge City features have the potential to dramatically reduce urban carbon footprint. Solar panels provide a renewable source of energy that may be utilized to power a variety of urban functions, contributing to the sustainability of cities such as Prohlis.

Combining these approaches improves cities' ability to adapt to the effects of climate change. Cities that apply the Sponge City concept can lessen the effects of extreme weather events like torrential rainfall and heat waves, which are becoming more common as a result of global climate change. This holistic approach not only solves immediate stormwater management demands but also improves urban resilience and livability over time.

CONCLUSION

The thesis examined the Sponge City concept's application in Dresden, emphasizing its potential as an effective and efficient solution for addressing two significant urban issues: stormwater management and drought. The study also looked at various co-benefits of the Sponge City strategy, such as stormwater harvesting, retention, and infiltration, as well as biodiversity enhancement, the establishment of a favorable microclimate, and an increase in the city's aesthetics.

A thorough literature analysis found that the Sponge City concept is a novel method used in a variety of countries. Despite its effectiveness and efficiency as a climate action strategy, the concept faces significant barriers to widespread acceptance and implementation. These limitations must be widely studied and taken into account before being incorporated into current development policies so that they can be properly addressed.

Dresden has continually proved its dedication to environmental care, as evidenced by the various programs and projects currently underway. The city is making great progress towards becoming a Sponge City, collaborating with all stakeholders concerned to adapt to the consequences of climate change.

The technique created in this thesis provides vital insights into how the Sponge City concept's components work both independently and together to achieve the objectives. Based on an evaluation of the study regions, key questions, and objectives, the thesis advocated the construction of certain Sponge City characteristics such as permeable pavement, rain gardens, bioswales, and water retention ponds/cisterns.

Despite the limitations, the findings suggest that the Sponge City concept has the potential to be a highly effective, efficient, and cost-effective strategy for future urban development. Integrating this concept reduces the pressure on storm drains, lowering the cost of stormwater discharge for residents. It also encourages the retention and reuse of harvested stormwater for irrigation, when necessary, which helps to mitigate climate change in a variety of ways.

Improved biodiversity in Geberbach Creek through regeneration and renaturing makes the area more ecologically robust, provides habitat for native species, and adds to the general environmental health of the urban landscape. Furthermore, enhancing biodiversity through these initiatives can improve water quality, stabilize creek banks, and provide a more appealing and natural environment for the community to enjoy.

However, it is recommended that the Sponge City concept be integrated into development activities during the design stage in order to maximize its potential and avoid budgetary burdens. Incorporating these features into existing built-up areas frequently presents additional challenges, such as the need to redesign building structures, the availability of open spaces in densely populated cities, and the reluctance of housing rental companies to incur additional costs, which can also deter tenants who are unwilling to pay higher rents.

Furthermore, government subsidies and financial assistance are required for further evaluation and adoption of the Sponge City concept. Technical advocacy and knowledge exchange from pioneer cities such as Berlin, Hamburg, and München would be useful for cities considering implementing Sponge City elements. This collaborative approach would help to reduce barriers and improve the successful incorporation of the Sponge City concept into urban development programs.

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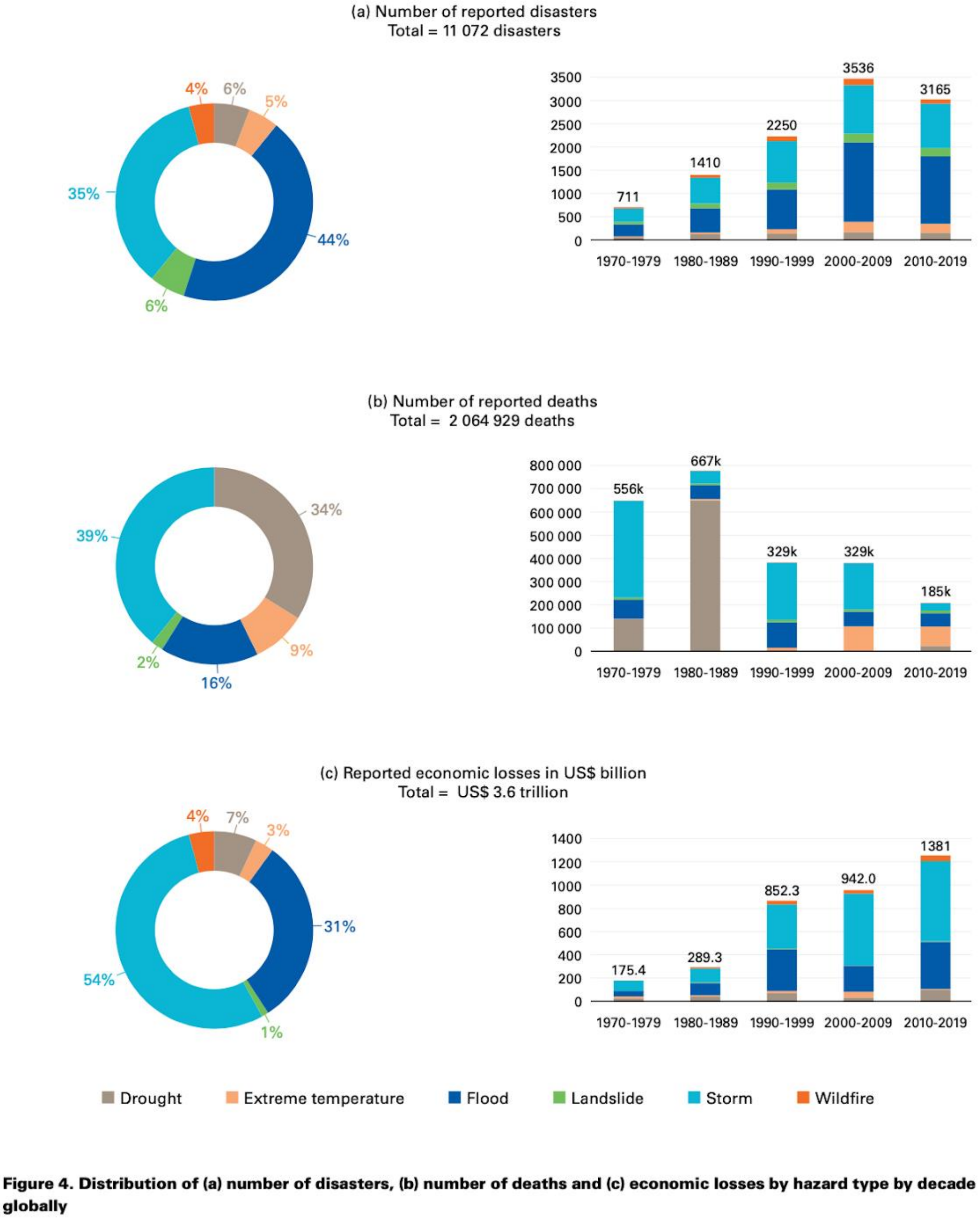
ANNEXES



Annex 1. Distribution of (a) number of disasters, (b) number of deaths, and (c) economic losses by hazard type by decade globally
Source: WMO, 2021, p.19

Annex 2. Potsdamer Platz Berlin
Source: DREISEITLconsulting GmbH, 2022

www.erdbaulabor.net Bericht: 23.6495-08-1: Anlage 4

KOSTRA-DWD 2020

Nach den Vorgaben des Deutschen Wetterdienstes - Hydrometeorologie -

Niederschlagsspenden nach KOSTRA-DWD 2020

Rasterfeld	: Spalte 197, Zeile 138	INDEX_RC	: 138197
Ortsname	: 01239 Dresden		
Bemerkung	:		

Dauerstufe D	Niederschlagspenden rN [l/(s·ha)] je Wiederkehrintervall T [a]								
	1 a	2 a	3 a	5 a	10 a	20 a	30 a	50 a	100 a
5 min	220,0	283,3	323,3	376,7	450,0	526,7	576,7	643,3	736,7
10 min	148,3	191,7	218,3	253,3	303,3	355,0	390,0	433,3	498,3
15 min	115,6	147,8	168,9	195,6	234,4	274,4	301,1	335,6	385,6
20 min	95,0	122,5	139,2	161,7	194,2	227,5	249,2	277,5	318,3
30 min	72,2	92,8	105,6	122,8	146,7	172,2	188,3	210,0	241,1
45 min	54,1	69,6	79,3	92,2	110,4	129,3	141,5	157,8	181,1
60 min	43,9	56,7	64,4	74,7	89,7	105,0	115,0	128,3	147,2
90 min	32,8	42,2	48,0	55,7	66,9	78,3	85,7	95,6	109,6
2 h	26,5	34,2	38,9	45,1	54,2	63,3	69,4	77,4	88,8
3 h	19,6	25,4	28,9	33,4	40,1	46,9	51,5	57,3	65,7
4 h	15,9	20,5	23,3	27,0	32,4	37,9	41,6	46,3	53,1
6 h	11,8	15,1	17,2	20,0	24,0	28,1	30,7	34,3	39,3
9 h	8,7	11,2	12,7	14,8	17,7	20,7	22,7	25,3	29,0
12 h	7,0	9,0	10,3	11,9	14,3	16,7	18,3	20,4	23,4
18 h	5,2	6,7	7,6	8,8	10,6	12,4	13,5	15,1	17,3
24 h	4,2	5,4	6,1	7,1	8,5	10,0	10,9	12,2	14,0
48 h	2,5	3,2	3,6	4,2	5,1	5,9	6,5	7,2	8,3
72 h	1,8	2,4	2,7	3,1	3,7	4,4	4,8	5,3	6,1
4 d	1,5	1,9	2,2	2,5	3,0	3,5	3,9	4,3	4,9
5 d	1,3	1,6	1,8	2,1	2,5	3,0	3,3	3,6	4,2
6 d	1,1	1,4	1,6	1,9	2,2	2,6	2,9	3,2	3,6
7 d	1,0	1,3	1,4	1,7	2,0	2,3	2,5	2,8	3,2

Legende

T	Wiederkehrintervall, Jährlichkeit in [a]: mittlere Zeitspanne, in der ein Ereignis einen Wert einmal erreicht oder überschreitet
D	Dauerstufe in [min, h, d]: definierte Niederschlagsdauer einschließlich Unterbrechungen
rN	Niederschlagsspende in [l/(s·ha)]

Annex 3. KOSTRA ATLAS 2020
Source: www.itwh.de

Annex 4. Master Plan of the Parking Area