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Making urban stormwater management more sustainable

A case study of Tallinn, Estonia

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Abstract

The concept of sustainable urban drainage systems (SuDS) is increasingly recognised as a valuable approach to flood risk mitigation and urban landscape planning. Many European cities are considering integrating SuDS features to their stormwater management practices. More frequent weather events and water quality issues have emerged among the main drivers to advance the discussion on innovative ways to handle stormwater, especially in urban environments where the proportion of impervious surface significantly alters natural drainage patterns. Due to the relative novelty of the SuDS scheme, promoters of its components struggle with uncertainties and reluctance to change of key actors involved in making decisions about stormwater management. In this context, this thesis intends to reveal some key conditions that are necessary for the implementation of SuDS, by focusing on the planning process of stormwater management taking Tallinn city as a case study. It highlights opportunities but also key barriers that must be addressed to include SuDS into the urban landscape and planning decisions. The methodology of the research project includes a literature review on the SuDS concept, as well as an overview of the stormwater regulatory environment in Tallinn that helps put the SuDS adoption in context. To address its first objective, this research borrowed elements from theories of innovation diffusion and technology acceptance to investigate how perceptions of SuDS techniques' attributes influence decision-makers' attitudes towards their adoption as well as the determinants driving adoption in Tallinn case. A key feature of this first research objective was a survey conducted among stormwater planners, engineers and other relevant stakeholders. The survey results showed that a favorable perception of SuDS usefulness, ease of use, and benefits on the stakeholders' side is likely to support and favor its adoption. While perceived insufficient resources could negatively influence intention toward adoption. Other relevant findings include some of the most significant barriers that currently hinder SuDS implementation. Furthermore, the study investigated whether a proposed geospatial approach could help detect flood susceptible areas at the city scale. To validate the method, a comparison was performed with prior flood points. From the obtained results and analysis, a number of flood-prone locations were selected as potential SuDS sites. This led to the third objective of the research, which was to demonstrate the usefulness of a conceived planning method to help decision-makers select possible SuDS solutions depending on the site's characteristics, SuDS benefits to prioritise and local preferences. Results from both approaches are promising as early stage, first assessment tools in SuDS planning practice which can be applied in order to first find suitable SuDS locations and then identify site-specific SuDS measures to address stormwater challenges. Based on the findings and valuable information included in this thesis, proponents of SuDS techniques will be better prepared to foster diffusion of these strategies at the city level. Recommendations for policy measures as well as suggestions for future research are provided as well. This thesis contributes to methodology, theory and practice, decision-making and policy studies.

Keywords: stormwater management, sustainable urban drainage systems, nature-based solutions, flood mitigation, geographic information systems

Executive Summary

1. Problem Definition and Research Questions

In Europe, heavy rainfall events are likely to increase in the future due to climate change. This projected change coupled with the expansion of urban consolidation will augment the risk of flooding, especially in cities. Nature-based solutions (NBS) is an emerging umbrella concept covering a series of ecosystem-based approaches, promoting the use of natural processes and ecosystem services as means to address societal challenges. Despite their great potential, the diffusion and uptake of NBS remain limited, fragmented, and highly uneven within and between cities. Urban decision-makers still favour the use of conventional hard engineering infrastructure over alternative methods even though they provide few long-term benefits.

With regards to flood mitigation and other stormwater-related issues in cities, the use of SuDS (the NBS type explored in this thesis) also remains limited and it is not yet integrated in the regular municipal planning practices. The thesis intends to reveal some key conditions that are necessary for the emergence of NBS, especially SuDS, by focusing on the planning process of stormwater management taking Tallinn city as a case study. The first purpose of this research is to investigate the decision-making process in relation to stormwater handling in Tallinn and most specifically the factors that could influence the city's decision to use SuDS as stormwater strategies as well as the keys to their successful deployment. Furthermore, to help overcome the lack of knowledge, awareness and education, one of the main barriers for SuDS adoption identified in the study, two geospatial approaches are suggested to i) determine areas prone to flooding at the city scale and ii) facilitate the preselection of flood mitigation strategies in designated sites, prioritising SuDS features where appropriate.

Therefore, the three main research questions addressed in this paper are the following:

- **How stormwater stakeholders' perceptions of SuDS could influence their attitudes toward adoption?**
- **How can the use of a GIS-based multi-criteria analysis technique help identify flood-prone areas in Tallinn?**
- **How to facilitate the selection of SuDS solutions to cope with urban floods using a multi-criteria decision-support methodology?**

2. Methodology

To answer these questions, the data collection process of this thesis included reviewing the literature on the sustainable urban rainwater management and existing practices in Estonia as well as related policies and relevant actors (at European, national, and local levels) regulating the sector. A review was also performed to get a broader view of the data-driven decision-support tools (i.e. GIS-based and multi-criteria analysis techniques for flood risk assessment and sites' selection for SuDS deployment) available for decision-makers involved in urban stormwater management.

To address its first objective, this research used elements from theories of innovation diffusion and technology acceptance to investigate how perceptions of SuDS techniques' attributes influence decision-makers' attitudes towards their adoption as well as the determinants driving adoption in Tallinn case. A key feature of this first research objective was a survey conducted among stormwater planners, engineers and other relevant actors involved in Tallinn's stormwater management. Evaluating the perceived attributes of SuDS systems may help predict stakeholders' attitudes toward their inclusion as part of the city's stormwater practices. By understanding the characteristics and factors that make stakeholders more likely to adopt SuDS tools, proponents of these innovative measures will have better knowledge about how to approach their adoption process and foster their widespread diffusion within Tallinn but also other Estonian and abroad localities.

Then, to answer the second research question, a flood susceptibility map based on two composite parameters was generated and analysed for Tallinn using geographic information system (GIS) techniques. As it is an exploratory method designed to be easily replicated by practitioners and scholars, the 6 steps that were taken to develop the final map are explained. To validate the method, a comparison was performed with prior flood points. From the obtained results and analysis, one flood-prone location was selected as a focus site for the application of the second planning tool developed by the author.

Indeed, to address the third objective of the research, another proposed planning methodology was developed for facilitating the selection of possible SuDS solutions based on the site's characteristics observed in the GIS maps, SuDS benefits to prioritise and local preferences. There are currently no official guidelines or manuals in Estonia related to the design and implementation of SuDS structures. The strategic and practical planning tool proposed in this study could provide useful information for the establishment of minimum requirements and context-specific guidelines for practitioners (urban decision-makers, drainage engineers, private developers, city planners, water managers, etc.) to adopt more resilient-sustainable decisions in urban spaces. The methodology was designed by the author in the context of the UrbanStorm project in close collaboration with a local landscape architect with SuDS expertise. Results obtained from the application of this tool are presented in the study.

3. *Key Findings*

With regards to RQ1, the survey results confirmed a large number of factors identified in the review of Tallinn's stormwater regulatory environment, which influence stakeholders' attitudes towards SuDS and its adoption. In general, respondents had positive perceptions about SuDS usefulness, ease of use and induced benefits. They understand the concept's principles and for those who had previous experiences with SuDS projects, they seemed to be satisfied with their performance. Thus, all these attributes constitute good predicators for future acceptance and adoption of SuDS. However, perceived insufficient resources could negatively influence intention toward adoption. Results also indicate that important uncertainties and shortcomings are hindering conditions to foster SuDS innovations such as a clear lack of political leadership and support as well as missing incentive mechanisms for potential adopters, a need to develop more technical expertise and enhance awareness about SuDS and its multiple benefits could be useful for other cities, which are also preparing to incorporate SuDS or similar approaches to their infrastructure.

Regarding RQ2, the suggested geospatial method has proven to be effective at detecting areas potentially at risk of floods with faster computing time and based on limited amount of parameters. The final output map shows that flood susceptibility is the highest in Lasnamäe district, a district located in the eastern part of the city, which according to the chosen parameters cumulates all the conditions to be highly vulnerable to flood risks. Other areas potentially prone to flooding are highlighted. Results have also allowed identifying possible locations, which should be considered as priority-areas for local authorities to develop complementary studies. The defined susceptible flood zones were validated by comparing them to known historical locations of flood events reported in the news in the absence of an updated flood inventory. The application of this method can therefore be extended to other case studies aiming at predicting spatial distribution of flood issues.

For RQ3, the application and discussion of the proposed SuDS selection tool has allowed to learn that beyond the flood and water management function of SuDS, considerations about other co-benefits provided by these measures in decision-making processes is essential to increase their likelihood to be selected as adequate stormwater measures. Also, highlighting SuDS co-benefits among a more diverse array of stakeholders will increase the rate of SuDS inclusion into planning practices. In contrast with the survey results, technical concerns expressed by several planners and engineers showed scepticism among these actors regarding the real feasibility of SuDS measures. Results have also reasserted the important role that policies play in driving the introduction of SuDS measures into planning decisions. City officials have some misconceptions and knowledge gaps about SuDS and similar approaches. As uncovered through the literature review, decision-makers tend to choose quick, short-term case-by-case solutions rather than preventive and preferably at source management solutions.

4. *Conclusions*

In conclusion, it is indisputable that SuDS and equivalent systems around the world can and do deliver added benefits beyond their primary water quantity and quality management functions. This research concentrates on the adoption process of SuDS elements in Tallinn and practical ways to facilitate their inclusion into the city's planning decisions. The barriers and opportunities derived in this study provide new insight into the challenges and constraints surrounding the implementation of SuDS in Tallinn. Despite the obstacles uncovered, there is a growing interest among policy-makers for these solutions and there are generally positive perceptions of stakeholders related to a majority of their attributes, which constitutes a good predicator for their future uptake. The thesis incorporates customised recommendations for future research as well as possible courses of action for scaling up the application of SuDS for a long-term and effective stormwater control.

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Abbreviations

BSR	Baltic Sea region
CIRIA	Construction Industry Research and Information Association
DST	Decision-support tool
DTM	Digital Terrain Model
EC	European Commission
EU	European Union
FRMP	Flood risk management plan
FSM	Flood susceptibility mapping
GI	Green infrastructure
GIS	Geographic Information System
HELCOM	The Baltic Marine Environment Protection Commission (Helsinki Commission)
NBS	Nature-based solutions
RQ	Research question
RBMP	River basin management plan
SuDS/SUDS	Sustainable (urban) drainage system
TAM	Technology acceptance model
TCG	Tallinn City Government
UHIE	Urban heat island effect
EULS	Estonian University of Life Sciences
WFD	Water Framework Directive

Glossary

Amenity	"The quality of being pleasant or attractive, agreeableness. A feature that increases attractiveness or value, especially of a piece of real estate or a geographic location" (CIRIA C697, 2007, p. G-1).
Catchment (or watershed)	"The area contributing surface water runoff flow to a point on a drainage or river system. Can be divided into sub-catchments" (CIRIA C697, 2007, p. G-2).
Conveyance	"Movement of water from one location to another" (CIRIA C697, 2007, p. G-3).
Design criteria	"A set of standards agreed by the developer, planners, and regulators that the proposed system should satisfy"(CIRIA C697, 2007, p. G-3).
Eutrophication	"Water pollution caused by excessive plant nutrients that results in reduced oxygen levels. The nutrients are powerful stimulants to algal growth, or "blooms", of algae promoted by these phosphates change the water quality in lakes and ponds which can kill fish" (CIRIA C697, 2007, p. G-4).
GIS	"A computer-based technology or methodology to collect, store, manipulate, retrieve and analyse spatial data or georeferenced data" (Elangovan, 2006, p.3)
Hydrology	"The study of water below the ground surface and geological aspects of surface water. In the context of this [paper], hydrology covers the dissipation of the rainfall runoff beneath a permeable soil surface" (CIRIA C697, 2007, p. G-5).
Pervious surface	"A surface that allows inflow of rainwater into the underlying construction or soil"(CIRIA C697, 2007, p. G-9).
Raster	"The raster structure is based on a matrix of cells represented in rows and columns. Each cell can store information about a given variable (precipitation, temperature, relative humidity, solar radiation, radiance, reflectivity, etc.)" (Pucha-Cofrep et al., p. 9).
Runoff	"Water flow over the ground surface to the drainage system. This occurs if the ground is impermeable, is saturated or rainfall is particularly intense" (CIRIA C697, 2007, p. G-11).
Spatial data layer	"Either a representation of a continuous or discrete field, or a collection of objects of the same kind. Usually, the data is organised so that similar elements are in a single data layer" (Huisman & De By, 2009, p.124). There are three types of layer: point, line, or polygon.
SuDS/SUDS	"An approach to water management that combines a sequence of management practices and control structures designed to drain surface water in a more sustainable fashion than conventional techniques" (CIRIA C697, 2007, p. G-12).
Urban heat island	"A phenomenon whereby urban regions experience warmer temperatures than their rural, undeveloped surroundings" (Fernando, 2012, p.143).

1 Introduction

As cities have spread through demographic growth and rapid urbanisation, natural green areas have been lost in favour of paved surfaces and often concrete flood barriers. This has allowed for further development adding to the greying of urban landscapes and accentuating the decline in urban green zones (Hoang & Fenner, 2016). It has been broadly acknowledged that such pockets of remaining natural areas offer beneficial features to minimise human impacts and improve general living conditions in the urban setting (Maes & Jacobs, 2017; Barton, 2016; Eggermont et al., 2015). Nature-based solutions such as sustainable urban drainage systems (SuDS) can help restore natural elements (i.e. green and blue spaces) within the urban environment (Almassy et al., 2018; Sha, 2017).

Nature-based Solutions (NBS) is an emerging concept covering a range of ecosystem-related approaches, which promotes the use of natural processes and ecosystem services as means to address societal challenges, such as climate change and natural disasters (Cohen-Shacham et al., 2016; Bauduceau, et al, 2015). These approaches can provide sustainable cost-effective protection against many effects of climate change and they ideally result in multiple environmental, social, and economic benefits, thus improving city resilience (Hanson et al., 2017; Faivre et al., 2017).

SuDS are stormwater management solutions based on natural hydrological processes that often use vegetated land surfaces (Hoang & Fenner, 2016). SuDS techniques contribute in decreasing flooding risks by slowing down water velocity or by temporarily storing surface water, often filtering the pollutants at source and facilitating infiltration of rainwater into the soil. SuDS design can be intended to enhance water quality and reduce possible damages across the flood pathways and remote impact areas located further downstream of a watershed (Hoang & Fenner, 2016; Price, 2008). Examples of SuDS structures include, but are not limited to, rain gardens, natural swales, permeable pavements, constructed wetlands, retention ponds and green roofs. SuDS components are integrated parts of the wider drainage system, which aim to recreate a site's predevelopment hydrology through at-source management of small rain events and overland flow of moderate-large rain events (Ellis & Lundy, 2016; Fletcher et al., 2015). While helping in reducing the effects of exceedance flows in the flood condition, they also provide numerous ecosystem functions in the day-to-day non-flood condition as opposed to conventional drainage systems, such as enhancing biodiversity, improving landscape aesthetics, bringing nature into the built fabric, etc. (Jusić, Hadžić, & Milišić, 2019; Burns et al., 2012; Chocat et al., 2008; Wong & Brown, 2008).

In Europe, the standard conventional approach to flood mitigation in urban contexts is either the drainage of stormwater runoff as fast as possible with the help of channels and pipes or the construction of structural defences to protect exposed locations (LIFE, 2017; Grand-Clement, 2017). Due to the rise in extreme precipitation events and the increased risk of flooding associated with climate change, ever-larger sewer pipes or ever-higher flood barriers in towns and cities is both unsustainable and undesirable. All these concrete-based installations at best postpone the onset of major stormwater-related issues, and at worst simply push the problem downstream.

In Tallinn, the capital of Estonia, rising frequency of floods have been forecasted which is directly linked to the increasing number of occurring storms as a factor (Looring, 2013; Kont et al., 2007). It is getting warmer mainly because of higher winter temperatures; moreover, climate is changing to wetter and windier. Damages caused by storms have been recorded mostly on seacoast, forests and on buildings (Looring, 2013; Hofstede, 2011). To reduce the vulnerability of the city to these hazards and continue improving life quality of local residents, there is a strong need for effective and sustainable rainwater management. Due to their limited design capacity, traditional drainage infrastructures are insufficient and inadequate to cope with torrential rains. In this context, alternative mitigation strategies such as SuDS have received increasing interest from academic and government bodies.

Despite their significant potential, the integration of SuDS as part of urban drainage systems has been so far rare, even non-existent in Estonia. Hard engineering solutions for stormwater handling continue to dominate in most cities including Tallinn.

This thesis intends to reveal some key conditions that are necessary for the emergence of NBS, especially SuDS, by focusing on the planning process of stormwater management taking Tallinn city as a case study. This study feeds into the LIFE UrbanStorm project, an ongoing pilot initiative, partially funded by the European Union (EU), which aims to create preconditions for fostering the adoption of SuDS techniques in Estonian cities, using Tallinn as a best practice case to ease transfer of knowledge and replication in neighbouring municipalities. By exploring important conditions for integrating SuDs in urban planning, this work contributes to sustainably mainstreaming NBS practices. First, it analyses the extent to which existing legislation and policies take into account or support the selection and development of sustainable and climate resilient urban drainage schemes. Then, it looks at the relational complexity within current roles and responsibilities for stormwater governance in Tallinn and based on a survey conducted among stormwater stakeholders, it highlights opportunities but also key barriers that must be addressed to include SuDS into the urban landscape and planning decisions. Furthermore, to help overcome the lack of knowledge, awareness and education, one of the main barriers revealed through the literature review and confirmed in the survey results, two GIS-based approaches are proposed to 1) determine areas prone to flooding at the city scale, and 2) facilitate the preselection of flood mitigation strategies, prioritising SuDS features where appropriate. At the end, the thesis incorporates customised recommendations for future research as well as possible courses of action for Tallinn for scaling up the application of SuDS for a long-term and effective stormwater control. This research aims to provide a practical case study to the scholarly literature and professionals working towards integrating NBS/SuDS interventions to stormwater management in cities and through this contribute to building climate resilience.

1.1 Problem definition

In Europe, heavy rainfall events are likely to increase in the future in account of climate change. This projected change coupled with the expansion of human settlements will heighten the risk of flooding, particularly in urbanised environments (Madsen et al., 2014; Kundzewicz et al., 2014). To address these challenges and support a sustainable urban development, approaches centred on "living with and making space for water" such as water-specific nature-based solutions (NBS) are more and more recognised as efficient means for flood control (Johnstone et al., 2012; Lee & Yigitcanlar, 2010).

In spite of their great potential, the diffusion and uptake of NBS remain limited, fragmented, and highly uneven within and between cities (Nesshöver et al., 2017; Bauduceau et al., 2015). The use of grey engineering solutions and technology-driven strategies continues to dominate urban development, from the conception of sewage systems to efforts to increase energy efficiency in the built environment (Dhakal & Chevalier, 2016; Burns et al., 2013). Given the multi-disciplinary and complex nature of sustainable urban solutions, the transfer and exchange of knowledge and experiences among different actors involved in NBS projects is crucial to improve their societal uptake.

As a relatively young concept, there are several aspects of NBS that require further research, starting from its definition (Cohen-Shacham et al., 2016; Eggermont et al., 2015) all the way to its impacts (Raymond et al., 2017; Kabisch et al., 2017a; Faivre et al., 2017). By looking into NBS governance, and more specifically policy, urban planning and decision-making processes around SuDS, this study intends to respond to the expressed need for more research in identifying drivers and barriers for NBS implementation in different urban conditions (Nesshöver, 2017; Sekulova & Anguelovski 2017; Kabisch et al., 2016) and the possibility for transferability and up-scaling of NBS interventions (Hansson, 2018; Potschin et al., 2015). This work will eventually help moving towards an operational decision-making framework that can guide the applications of nature-based solutions. In this regard, city planners and decision-makers will benefit from knowing more about the decision-making process in the selection and deployment of NBS in urban configurations.

With regards to flood alleviation and other stormwater-related problems in cities, the use of SuDS (the NBS type explored in this thesis) also remains limited and it is not yet integrated in the regular municipal planning practices. One of the main reasons is that it is not always clear for involved actors how to plan with SuDS, i.e. which sites are suitable for SuDS implementation and what specific type of SuDS to apply. In order to tackle these issues, geographic information system (GIS) technologies have been employed in some studies to determine flood susceptible zones and potential SuDS candidate locations. However, **more case studies in different urban areas should be performed to prove the usefulness and reliability of these GIS-based approaches**. Additionally, **there is still no common practice on how to decide on the adequate SuDS options to apply where it is appropriate**. This thesis intends to address these knowledge gaps taking Tallinn as study area. Furthermore, based on results obtained from a policy review and a survey investigating stakeholders' perceptions towards SuDS adoption, it provides valuable information about **opportunities as well as current obstacles that influence the inclusion of SuDS in the city's portfolio of stormwater measures**.

In Estonia, there is a need for a major change in how stormwater is handled. Existing rainwater collection networks and wastewater treatment systems are insufficient and inadequate to cope with threatened impacts of climate change in addition to increased urbanisation. Yet, no alternative drainage methods are employed. This dissertation proposes ideas and decision-support tools for moving innovation forward and eliminating obstacles that currently hamper the uptake and widespread diffusion of SuDS schemes.

1.2 Research objectives and questions

As stormwater control assets are included in the city's infrastructure and planning, they are governed by the city management system and influenced by the urban planning discipline's approach to the role of nature in the city (Udomcharoenchaikit, 2016). Therefore, the first purpose of this research is to investigate the decision-making process in relation to stormwater handling in Tallinn and most specifically the **factors that could influence the city's decision to use SuDS as stormwater strategies as well as the keys to their successful deployment**. Findings could be useful for other cities, which are also preparing to incorporate SuDS or similar approaches to their infrastructure. While looking at the existing legislations and policies regulating the sector in Tallinn, the study highlights current drivers and barriers that support or hinder the integration of SuDS techniques into the city landscape and planning decisions by exploring the stakeholders' current perspectives on this kind of alternative stormwater measure. Building on theories of innovation diffusion and technology acceptance, the study analyses whether perceptions of SuDS attributes are different among actors and if so whether this could lead to differences in adoption of SuDS as stormwater solutions.

The second purpose of this research is to **explore how a geospatial approach can help identify urban areas prone to flooding**. Flood susceptibility mapping (FSM) is an essential step to prevent and properly manage flood disasters. In this research, a flood susceptibility map was generated for Tallinn using geographic information system (GIS) techniques. As stated by Ran and Nedovic-Budic (2016, p.69), GIS is a "useful tool to assess flood risks and mapping, prepare for flood disasters, evaluate development scenarios and combine urban flood management with urban planning". GIS maps facilitate the analysis of the spatial distribution of flooding and its spatial relation to drainage system, flow paths, rainfall patterns, and sea level (Sörensen 2018; Nilsson, 2017). In the context of SuDS projects, they can also be used as decision-support tools to help implementing actors visualise, select and plan SuDS methods in designated sites for urban sustainable development and for flood prevention and management.

The third purpose of this research is **to demonstrate how a range of possible SuDS techniques could be selected and planned in urban contexts, based on a proposed multi-criteria methodology and the outcomes of the GIS mapping**. More specifically, the study will investigate the application and usefulness of a simple planning tool prepared as a team effort within the context of the UrbanStorm project and further refined under this thesis, which aims to help decision-makers in choosing suitable SuDS elements depending on a set of criteria.

This paper, therefore, aims to answer the following three research questions:

Research objective #1: Exploring current stakeholders' perceptions and attitudes towards SuDS adoption
RQ1: How stormwater stakeholders' perceptions of SuDS could influence their attitudes toward adoption? *Subquestions:* – *Which perceived attributes of SuDS practices contribute to respondents' receptiveness toward adoption?* – *What factors could influence their attitudes towards SuDS adoption?*

Research objective #2: Development of a simplified geospatial approach to determine urban areas potentially prone to floods
RQ2: How can the use of a GIS-based multi-criteria analysis technique help identify flood-prone areas in Tallinn? *Subquestion:* – *Where in the city is stormwater flooding likely to occur?*

Research objective #3: Development of a practical planning tool for the selection of possible SuDS solutions for flood-prone areas
RQ3: How to facilitate the selection of SuDS solutions to cope with urban floods using a multi-criteria decision-support methodology? *Subquestion:* – *What are the considerations to take into account for selecting the right measures in the planning process?*

1.3 Limitations and scope

This section intends to expose the limitations placed upon the research as well as the author's choices that together constitute the scope of this thesis.

The scope of the study is limited to the geographical boundaries of Estonia, more specifically Tallinn city. The choice of this location is linked to the author's opportunity to do a four-month fieldwork in this specific location while contributing to the implementation of the LIFE UrbanStorm project. The material created and collected during the fieldwork was used to develop this thesis research project.

The research is primarily focused on urban inland flooding and not coastal flooding. Tallinn is a coastal city that is exposed to both types of hazards. However, only areas that are located above the influence of sea-level rise have been considered in the author's research objectives and questions. The nature of the issues related to flooding from sea-level rise differs from the nature of the problems generated by stormwater runoff and urban drainage in inland areas. Flooding in coastal zones cannot be controlled without the construction of hard engineered infrastructures. The use of SuDS components cannot offer the desired level of protection in such cases. Thus, addressing the issue of sea-level rise is beyond the scope of this study.

The research focuses on the concept of "Sustainable (urban) Drainage System" or "SuDS/SUDS" and its application in urban contexts. Whilst acknowledging the use of different terms related to sustainable stormwater management in the literature (e.g. green (stormwater) infrastructure, low impact development, best management practices, water sensitive urban design, etc.), due to the terminology employed in the context of the UrbanStorm project, the term SuDS will be continuously used throughout the paper. Most of the publications searched and reviewed on Internet used this term as well. However, findings from studies using other terms with similar design philosophies were also taken into account and valuable information was gathered for the research topic.

In addition, some limiting factors were identified by the author and linked to her practice-oriented study. First, the main limitation for data collection and analysis is that the UrbanStorm project is on-going process that requires an extended period of time (2018-2023) to be completed. Results or impacts of related activities will be obtained and assessed at a later stage. Additionally, delays in data collection to create the GIS maps, postponed meetings with main stakeholders and changes in the project team or activities occurred during the research stay of the author, and in turn have sometimes disturbed the data collection process and delayed the implementation of the project. However, when possible, alternative plans were found to counter these constraints. Second, an additional limitation was the existing language barrier given that multiple documents relevant for the thesis object were only available in Estonian. An English translation using online translator engines was performed however it is not fully accurate.

1.4 Ethical considerations

The data creation and collection was mainly performed in the context of the UrbanStorm project. Permission to include data in the thesis was granted. Information provided in this manuscript only reflects the author's views and not the ones of the project team. The author conducted the study independently and impartially. For the purpose of the first research question, the author prepared a questionnaire to assess stakeholders' perceptions towards SuDS adoption. The privacy and protection of respondents were respected as the form could be filled anonymously. The respondents were also asked to participate in the survey on a voluntary basis. Secondary data was obtained through literature review and citations from selected papers were properly referenced. In addition, permission to use material (e.g. pictures, graphics or graphs) that was not created by the author was verified and credit was given to the owners of that work.

1.5 Audience

The findings of this thesis and related materials will directly serve the UrbanStorm project and aid implementing actors for the selection and development of SuDS measures in identified flood-prone areas in Tallinn. This will facilitate wider uptake and replication of best practices by other Estonian localities. The outcomes of this dissertation are not only relevant to Estonian cities but also to other cities in developed or developing countries facing similar challenges and working with climate resilience.

Since the thesis aims to examine the practical aspects of selecting and integrating SuDS components to the stormwater management system in an urban setting, it should be in the interest of practitioners and decision-makers, involved not only in the sustainable urban water management field but also individuals who are interested in integrated sustainable urban management in general. This paper may be of interest to a range of actors such as: GIS and NBS/SuDS specialists, academics, real-estate developers, policy-makers, non-governmental and governmental organisations and more generally anyone interested in or working with NBS and other ecosystem-related approaches for climate change adaptation.

1.6 Disposition

This thesis is structured in six chapters, with *Chapter 1* being the above introduction. It presents an overview of the identified problem and the aim of the study. Based on the gaps in knowledge outlined, specific research questions are defined. The content then identifies the research limitations and scope, and lastly describes the intended audience.

Chapter 2 gives the reader the background information on the research area and briefly depicts the stormwater management practices currently in place as well as their related limitations. Then, an overview of the SuDS concept, its characteristics and the benefits derived by adopting it is provided. A best practice example is presented. The chapter also highlights the key differences between traditional drainage infrastructures and SuDS but also the main implementation challenges SuDS techniques are facing based on a literature review.

Chapter 3 describes the data collection methods as well as the different conceptual frameworks used to answer the three research questions. It explains the case study research approach, the stakeholder survey conducted for RQ1 and the two decision-support approaches developed to identify flood-prone areas and SuDS focus areas (RQ2) as well as possible SuDS measures (RQ3) that could fit therein.

Chapter 4 provides an overview of the regulatory policy framework as well as roles and responsibilities for stormwater management in Estonia and more specifically in Tallinn. This section explores the opportunities and barriers existing in the Estonian laws and policies that support or discourage the adoption of SuDS. It also highlights factors related to the conventional governance that could influence SuDS development.

Chapter 5 presents and analyses the results obtained for the three research questions. Some of the most interesting findings are also discussed for each RQ.

Finally, *Chapter 6* delivers the main conclusions of the dissertation and explains how the study contributes to the NBS and urban stormwater management domains. Recommendations for Tallinn and suggestions for future research are also given.

Figure 1-1 Aerial photography of Tallinn Old Town

Source: Estonian Land Board, 2019

2 Tallinn: facing challenges in the context of climate change

This chapter begins with background information about the causes of urban flooding and induced impacts, and an introduction of the study area. Then, current stormwater practices and issues in the study area are outlined. Last, an overview is given about the SuDS scheme, its characteristics and the benefits associated with SuDS application. In addition, the key differences between sustainable and traditional drainage approaches are pinpointed as well as the implementation challenges reviewed in the literature are presented.

2.1 Urbanisation, climate change, growing flood risk

Nowadays, over half of the global population lives in cities and by 2050 this proportion is likely to grow to 65% (United Nations, 2018). While urbanisation provides various opportunities to local residents and enhances socio-economic aspects of countries, it also poses numerous challenges to cities in meeting the needs of their ever expanding populations such as transportation, employment, education, housing, energy and water systems, etc (Hansson, 2018). With more people moving into urban areas, more space is required to ensure access to infrastructure and social services for all. Therefore, less room is left for green and blue spaces, such as parks, forests, wetlands, lakes and rivers. If not well planned, urbanisation can undermine agricultural production, quality of life and social well-being, and exacerbate environmental problems such climate change, depletion of natural resources, pollution, and biodiversity loss (Kabisch et al., 2016). These issues will intensify significantly over time, as cities grow denser and larger with less green elements.

The urbanisation process illustrates the interference of humans with the hydrological regime. The growth of urban populations and territories inevitably lead to drastic changes in land use, from natural or agricultural zones to residential, commercial or industrial uses, including in the periphery of large urban centres (Sha, 2017). The high rate of land-use conversion can have significant environmental effects on the hydrological processes and surface water quality of the watersheds (Nordin von Platen & Gustafsson, 2018; Ferreira et al., 2016). Natural land cover lost to uptake by urban artificial land development can contribute to great changes in the magnitude, pathways, and timing of surface runoff dynamics and runoff production process (Sha, 2017; McGrane, 2016). Indeed, as built-up surfaces convert much of the rainfall into surface runoff, the peak flow of urban rainwater arrives quicker and with greater volume (Grand-Clement, 2017; Verbeiren et al., 2013). What is more, urbanised spaces are generally main sources of diffuse pollution in a watershed. For example, traffic is associated with several pollutants in urban contexts including sediments, pathogens, heavy metals and volatile organic compounds (VOCs) (Sha, 2017; Lundy, Ellis & Revitt, 2012). The production and accumulation of contaminants on urbanised lands is intensified by anthropogenic activities; furthermore, a larger impervious urban landscape increases the conveyance of pollutants to nearby receiving waters by generating more surface runoff and higher peak discharges (Fletcher, Andrieu, & Hamel, 2013; Liu et al., 2013).

Climate change will also amplify the degradation of surface water quality caused by rapid urban sprawl, since it will significantly impact hydrological processes in many places worldwide by increasing precipitation and evaporation (Madsen et al., 2014). Undeniably, global warming is having a direct effect on future rainfall patterns, where a warmer climate will raise evapotranspiration and atmospheric moisture rates, leading to more intense precipitation events (Nordin von Platen & Gustafsson, 2018; Tu, 2009). This will increase the frequency of natural disasters such as floods (the focus of this paper), soil erosion and landslides especially in urban configurations, causing property damage, human injury or loss of life and adversely affecting a variety of resources (Kundzewicz, 2014; Rojas, Feyen, & Watkiss, 2013). As a result, Europe, like other continents, will face major challenges in adapting to and preventing disasters due to changing weather and land use (Baur et al., 2013; Moel, Alphen, & Aerts, 2009). Adding to this, modifications in land use including the degree of soil sealing (or imperviousness) increase the vulnerability to surface floods (Ahlmer et al., 2018). Based on the European Commission (EC) data (2016), soil sealing will continue as Europe's population is expected to keep rising with 36 million new urban dwellers by 2050. Figure 2-1 shows the change in the percentage of stormwater runoff and infiltration as impervious surfaces increase.

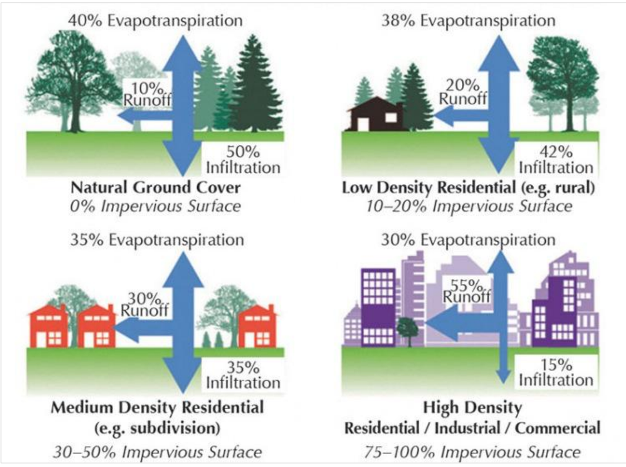

Figure 2-1 Effects of imperviousness on runoff and infiltration

Source: done by the City of Griffin adapted from Arnold & Gibbons, 1996

Until recently, urban planning practices have been essentially based on conventional civil engineering solutions to adapt to natural disasters. These measures are sometimes referred to as "hard" or "grey" infrastructure. Examples comprise dams, levees, culverts, building embankments, and pipe networks to control flooding. However, these strategies may not always be sustainable and cost-effective (Kabisch et al., 2017b; Burns et al., 2012). Instead, the EC advocates for nature-inspired and nature-supported alternatives, the so-called nature-based solutions (NBS) that allow for a smarter use of limited space and enhance resilience and long-term livability in cities (Kabish et al., 2017a; Bauduceau et al., 2015). NBS aim to be resource- and cost-effective and have a great potential to reduce the exposure of cities to climate-related risks, improve biodiversity and environmental quality while supporting economic and social development (Naturvation, 2016; Cohen-Shacham et al., 2016). NBS can complement or even replace traditional grey techniques, which typically only fulfil single functions or solve one or a few specific issues without necessarily offering additional benefits of environmental and societal character (Hansson, 2018; Depietri & McPhearson, 2017; Fletcher et al., 2015). NBS interventions can be completely "green" (i.e. involving only ecosystem features) or "hybrid" (i.e. a combination of ecosystem features and hard engineering techniques) (van Wesenbeeck et al., 2017).

In order to moderate the impacts of urbanisation on stormwater quantity and quality, NBS measures such as natural swales, rain gardens and green roofs have been successfully used in diverse cities around the world, including Copenhagen, Malmö, Barcelona, Mexico, and Melbourne (Almassy et al., 2018; Naturvation, 2016).

This thesis contributes to one of the first NBS projects for urban flooding and stormwater treatment being carried out in Estonia, the UrbanStorm project, which fills in the geographical gap. The project seeks to facilitate the development and implementation of integrated approaches for sustainable urban rainwater management and climate change adaptation at local, regional or national level, prioritising, where appropriate, ecosystem-based measures such as NBS/SuDS (LIFE, 2017). The project first uses the cities of Tallinn and Viimsi as SuDS demonstration sites to ease the transfer and replication of similar stormwater practices in other localities (LIFE, 2017). In this regard, the involvement of Tallinn in the project partnership is crucial, as the city is a trend setting and most influential municipality regarding planning practices in the country. If the project is successful and local authorities are convinced by the multifunctional attributes provided by SuDS installations, this will encourage a more systematic inclusion of these solutions into the city planning practices. Other localities will follow the lead of Tallinn. As this research concentrates on the adoption process of SuDS elements in Tallinn and potential ways to include them into the city's planning decisions, an overview of the characteristics of the study area is provided below.

2.2 Study Area: Tallinn, Estonia

2.2.1 Study area description

Located on the eastern coast of the Baltic Sea, Estonia is the northernmost and also smallest country of the Baltic States, in terms of population (1,323,820 residents) and territory (45, 339 km^2) (Statistics Estonia, 2019; MoE, 2017). Over 65% of the population of Estonia lives in urban areas (Worldometers, 2019) and based on the Tallinn Development Plan 2014-2020, one third of the population, about 0.44 million people live in the capital, Tallinn (178 km^2).

Tallinn is situated in the north-western part of Estonia, on the shore of the Gulf of Finland (see Appendix A). The city is divided into 8 districts and 84 sub-districts. It has a humid continental climate with warm to mild hot summers and snowy winters (Maharjan et al., 2016a). The average air temperature ranges from -5.9 to -1.0 in January and 12.7 to 21.9 in July (EWS, 2015). The average rainfall is 550-750 mm and the mean runoff is 280-290 mm per year (Maharjan et al., 2013). The largest lake is Lake Ülemiste (9.44 km^2) and it is the main source of the city's drinking water. The topography of Tallinn is characterised by flat terrain with the highest point being only 63 m above sea level (Tallinn City Council, 2010). Geologically, the soil is made up of rocks and sediments of different compositions such as sand, gravel, pebble, till, peat, and bedrock outcrop, which means that natural water infiltration into the ground can greatly vary within the city boundaries (Maa-amet, 2019; Raukas et al., 1997). Most of the land is urbanised, with impervious areas forming about 50% of the total area (Maharjan et al., 2016b). According to Leal Filho et al. (2017), the city faces land use-related issues regarding adequate planning, allocation and management of urban landscape and open spaces. Therefore, underlining shortcomings in the planning and protection of green networks is critical for stormwater handling. These scholars stress the need to give more attention to "land governance, public policy, city planning, building codes as well as the need for alternative materials for the protection of the soil and natural preservation of ecosystem services" (Leal Filho et al., 2017, p.553).

2.2.2 The city's management practices for stormwater

The current stormwater system consists of 21 separate and 7 combined drainage systems. Rainwater from residential, commercial and industrial areas is either transported to municipal wastewater treatment plants and treated with sewage or is collected in a separate rainwater system and mainly disposed into the sea and to a lesser extent into rivers and lakes without any pre-treatment (Maharjan et al., 2013). The city centre (Kesklinn district) has a combined sewerage system while other parts have mostly separate systems (Tallinn City Council, 2012). Many combined sewer systems were installed prior to the 1980s and a series of them have depreciated by now, often causing operational inefficiencies (Hanni, 1999; Holvandus, 2014; MoE, 2008). During periods of heavy rain or snow melting, these systems can reach capacity as excess water inundates the pipes (RTI, 2012). When pipes become overloaded, they reject excess rainwater and wastewater into local waters, negatively impacting water quality (Maharjan et al., 2016a). In this context, it is worth noting that the eutrophication of inland waters and the sea is one of the major environmental problems in Tallinn (Iital et al., 2010). The urban runoff load has significantly contributed in raising nutrient concentrations in waterways (Maharjan et al., 2016a). Since 2001, there has been extensive rainwater and sewerage network construction and renovation, which have contributed, to some extent, to the control of pollution loads and runoff volume (Maharjan, 2016; Holvandus, 2014). However, the objectives set under Tallinn Environmental Strategy to 2030 (2012) in terms of improving the ecological and physical-chemical condition of receptacles for rainwater are not achieved yet (Garcia et al., 2016). There are 63 rainwater outlets of which 47 directly discharge water to the coastal sea (Baltic Flows, 2016). The public sewerage system now comprises 901 km of sewerage networks, 462 km of stormwater networks and 120 sewerage-pumping stations (Tallinna Vesi, 2016). Since 2010, 99% of the city territory is connected to the public sewerage system, which is managed by AS Tallinna Vesi, the largest water utility company, in which the city is one of the stakeholders (Tallinna Vesi, 2014). Both separate and combined systems are illustrated in Figures 2-2 and 2-3.

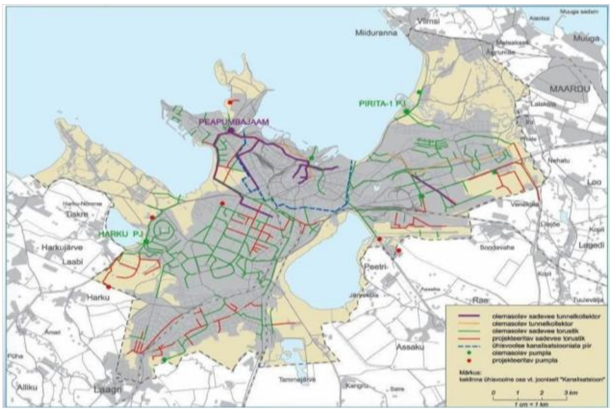

Figure 2-2 Rainwater drainage system[1]

Source: RTI, 2012

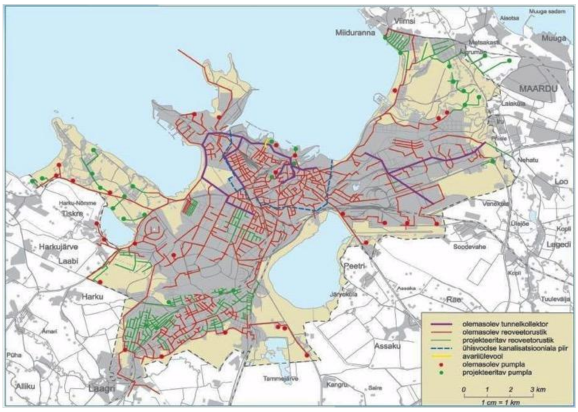

Figure 2-3 Public sewage system

Source: RTI, 2012

2.2.3 The city's floodings and its implications

There are two main types of flood risk in Tallinn, coastal flooding due to sea level rise and storm surges and inland flooding associated with extreme rainfall events and anthropogenic pressure. The latter is the focus of this research. In recent years, the city has encountered more problems with its stormwater drainage as roads, streets and real estate are frequently

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[1] [Translation of the legend: purple lines represent existing rainwater collection tunnels, yellow lines are existing collection tunnels, green lines are existing rainwater pipelines, red lines are planned rainwater pipelines, blue dashed lines are wastewater sewerage boundary area, green dots show where existing sewerage pumping stations are located, and red dots are planned sewerage pumping stations.]

inundated during heavy rainfalls[2] and snowmelts (MoE, 2012). As described above, the existing drainage systems have limited design capacities and are insufficient to cope with the increasing amount of rainwater that is generated and discharged, which is directly dependent on the intensity and duration of the precipitation but also the proportion of hard-covered surfaces in the city's catchment areas (LIFE, 2017). Abrupt development and construction activities have surpassed the development of drainage networks over the past decades. Sealing off natural lands during new developments often designed without considering runoff contribution to the watershed has weakened the operation of drainage systems even more (Maharjan, 2016). As a consequence, the intense runoff that repeatedly overtops the design flow results in the system overload, as illustrated below in figure 2.4.

Major floods, as they happened in 2004, 2005, 2011 and 2016, have cascading effects on the whole urban system, which consists of both hard and soft infrastructure. The hard infrastructure concerns physical elements such as the water and energy delivery networks, communication infrastructure and the transport system. As Hoang and Fenner, (2016) state, these systems represent essential infrastructure to support the soft infrastructure of social interactions and economic production. In particular, the January storm "Gudrun" in 2005, and the more recent floods in 2011 and 2016, exposed some of the interactions across the urban system. For example, flooding blocked several streets and roads and thus disrupted emergency services and the traffic, which further delayed effective flood control responses (ERRNews, 2016; Kont et al., 2010; Haanpaa et al., 2006). These severe storm events also led to power failures which affected other services and their recovery (MoE, 2013; Pursiainen & Francke, 2008; Ahas & Silm, 2006), destroyed forests and agricultural fields and perturbed natural ecosystems (Kont et al., 2010; PRC, 2009). Floods also damaged several houses, commercial and office buildings (Rosentau et al., 2017; Postimees, 2016). In economic terms, between 2002 and 2013, the total losses caused by floods were estimated up to €390 million for the whole country (EC, 2014). As a public health risk, flood hazards can also increase vulnerability to drowning and other accidents during the impact phase, or lead to outbreaks of infectious diseases and leave psychological consequences after their manifestation (Hoang & Fenner, 2016). They can also impact different groups of the society differently depending on the age, socio-economic situation, health condition, etc. Therefore, extreme weather phenomena may further deepen the inequality within local communities in Estonia (MoE, 2017).

These last severe weather events raised great attention among the population, crisis managers and public authorities. Need for better information in such situations was clearly highlighted (Peleikis, 2011; Haanpaa et al., 2006; GHK, 2006). In this context and in line with the EU Floods Directive, Tallinn considered it essential "to develop an early warning system and improve the notification of residents, the organisation of training, the drafting of action plans of rescue authorities and enterprises as well as the development of cooperation with research institutions in modelling [and mapping] floods" (MoE, 2013, p.189).

[2] Precipitation is labelled "heavy rainfall" when its 24-hour accumulated sum is at least 50 mm, and "extreme rainfall" if its 24-hour accumulated sum is at least 100 mm (Mätlik & Post, 2008).

Figure 2-4 Example of flash flooding in Tallinn in 2016. The city's drainage systems were unable to handle the volume of stormwater created by a brief torrential rain (38,7mm per hour).

Source: ERR News, 2016

Flood occurrences are expected to become more and more frequent in the future. According to climate projections, due to climate change, Tallinn and in general whole Estonia will face significant changes in terms of temperature, wind and rainfall by 2100 (Luhamaa et al., 2015). Annual precipitation will grow by 19% this century. Also, the frequency of rainfall is expected to exceed 30mm per day by 2030 and to rise of 435% by 2100 (LIFE, 2017).

There are currently no regional or local climate change adaptation action plans or strategies adopted in Estonia and sustainable urban drainage systems are not yet developed, as general scepticism and unawareness towards these methods among municipal water specialists and water companies has prevailed over their potential benefits. The current tendency in Estonian settlements is visibly towards the expansion of paved territories and rapid diminution of natural spaces (LIFE, 2017). Besides higher flooding exposure, such trend leads to biodiversity loss in urban setting, has negative impact on triggering urban heat island effect and cuts the potential of valuable ecosystem services (Sagris & Sepp, 2017; Ward et al., 2016). SuDS, aside from practical drainage management and moderating flood threats, could substantially contribute to the biodiversity and ecological value of the area. More precisely, different components of SuDS could increase green and blue spaces that provide improved habitat for wildlife (LIFE, 2017). This integrated approach to rainwater management will have wider advantages in terms of economic viability, nature preservation, water quality and amenity, thus providing co-benefits to local citizens (Chocat et al., 2007).

2.3 SuDS as an alternative to conventional drainage

2.3.1 What are sustainable urban drainage systems (SuDS)?

SuDS are a range of techniques and devices designed to mitigate the impact of new and existing developments on the discharge of surface water drainage (SCC, 2017; Stahre, 2008). The term "SuDS" emerged in the 1990s in the United Kingdom due to a change in philosophy supporting sustainable management over hard engineered solutions, with scholars like Butler and Parkinson (1997) or Larsen and Gujer (1997) questioning the sustainability and environmental implications of conventional drainage in urban milieus and stressing the need for an alternative approach. Since then, SuDS methods have been increasingly used (sometimes under a different name) to treat and control stormwater runoff in many other countries including the Netherlands, Sweden, France, Canada, the United States and Australia (Dhakal & Chevalier, 2016; Ellis & Lundy, 2016; Ferguson et al., 2013).

The idea behind the SuDS concept is **to replicate, as closely as possible, the natural water cycle of a locality**, through the infiltration, retention and reuse of rainwater (Woods-

Ballard et al., 2007; Stahre & Geldof, 2003). This also implies removal of pollutants from runoff the nearest possible to its source, before it makes its way to a watercourse or to groundwater (PCTPR, 2012). Moreover, SuDS are expected to offer other long-term environmental benefits such as wildlife habitat, improved aesthetics or community resource (CIRIA, 2012; Wilson et al., 2004). These multiple functions are encapsulated in the **SuDS triangle concept** and should be equally considered in the SuDS planning and design process (see figure 2-5).

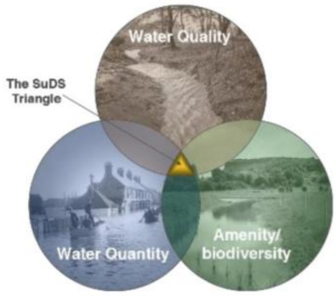


Figure 2-5 The SuDS triangle

Source: Fitzgerald, 2014

More often than not, a single SuDS component cannot meet all three objectives illustrated above. As a result, a **management or treatment train** is necessary, which means the use of drainage techniques in series to change the flow and quality characteristics of the runoff (Lashford et al., 2019; AWSL, 2011). As shown in figure 2-6, this integrated system begins with **prevention** (avoiding runoff by increasing permeable areas) or good housekeeping practices for abating pollution, and measures through local **source** controls to larger **downstream site** and **regional** controls (Fitzgerald, 2017; Woods-Ballard et al., 2007). It is not required for the runoff to go through all the stages; but the general principle is to **deal with it locally** rather than exporting its potential impacts elsewhere in the catchment (PCTPR, 2012; Woods-Ballard et al., 2007). End of pipe options where runoff is directly discharged to a wetland or a stream should be prevented where possible, as these methods would require more space and financial resources to be implemented, besides potentially receiving faster runoff flows and greater amount of pollution (Stahre, 2008; Wong et al., 2011). To sum up, various techniques could be applied to form part of the management train. They can be classified according to whether their primary use is considered to be pre-treatment, conveyance, source, site or regional controls, and can be ranked simply depending on their hydraulic and water quality performance potential (as show in Appendix I, p.114).

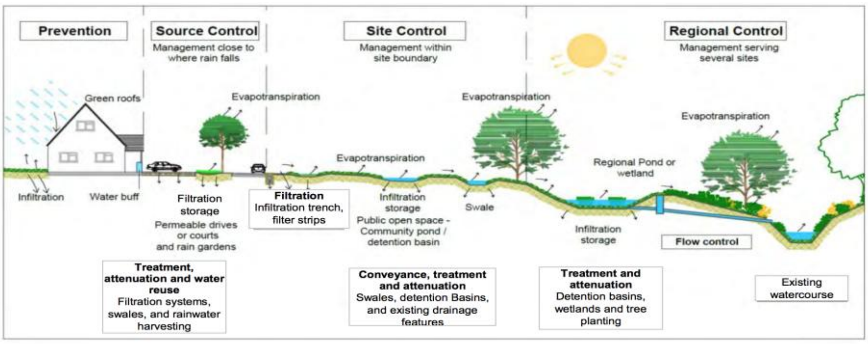


Figure 2-6 A possible management train sequence

Source: Swindon Borough Council, 2017

2.3.2 Conventional urban drainage versus SuDS

Table 2-1 summarised the main characteristics that differentiate traditional drainage systems from SuDS, as found in the reviewed literature.

Table 2-1Differences between traditional drainage infrastructure and SuDS

	Conventional urban drainage	Sustainable urban drainage
Attitude towards stormwater	"Keep water out" approach: stormwater as a nuisance to be controlled and removed; system designed to handle extreme stormwater events	"Making space for and living with water" approach: stormwater as a valued resource for humans and nature; system handling all stormwater events
Objectives	Single-oriented function: avoid flooding and/or reduce pollutant load; transfer and discharge water elsewhere	Multiple objectives: water-related (controlling quantity, improving quality, flood mitigation and adaptation); ecological/environmental (protecting and restoring water-based ecosystems, carbon storage, micro-climate regulation, reducing soil erosion); social (improving urban quality of life, creating recreational and educational opportunities); economic (reducing infrastructure costs, increasing property value, attracting visitors)
Measures	Rapid removal of runoff by constructed channels and underground pipes; stormwater treated in centralised treatment facilities	Retention, detention, slow conveyance of rainwater to encourage infiltration close to its source or harvesting for water supply; must be adapted to local constraints; green and hybrid measures on or near the surface to mimic natural drainage; stormwater treated in decentralised natural systems such as soil, vegetation and ponds; integration with conventional drainage if needed
Maintenance	Costly, high maintenance level, inflexibility	Cost-effective, easy-to-manage solutions; flexible application of nature
Professional roles and work process	Engineer-driven and silo-thinking, highly centralised and technocratic management: drainage engineers usually work alone and are generally the ones designing and controlling the whole system	Collaborative and participative way of thinking: cooperation from early planning stages between various relevant actors: drainage engineers, urban planners, architects, landscape architects, ecologists, landowners, etc.; increased level of transparency, accountability and public involvement

Source: Compiled from Goulden et al., 2018; Depietri and McPhearson, 2017; Hoand & Fenner, 2016; Dhakal & Chevalier, 2016; Malekpour, Brown, & de Haan, 2015; Maksimović, Kurian, & Ardakanian, 2015; Novotny et al., 2011; Ashley et al., 2013

2.3.3 A SuDS best practice example: Malmö Augustenborg, Sweden

Malmö, Sweden's third biggest city, has over the years gained worldwide recognition as a forerunner in sustainable urban development for promoting the use of innovative solutions such as NBS to address societal challenges (Nordin von Platen & Gustafsson 2018). In 1998, the housing district of Augustenborg, which was facing economic and social difficulties in addition of being vulnerable to recurrent floods, initiated an extensive renovation programme of its stormwater management system (Barton, 2016; Soz et al., 2016). The chief objective of local authorities was to rejuvenate and transform the area into an ecologically, socially, and economically sustainable city district (Udomcharoenchaikit, 2016). Officials, local residents and other stakeholders worked together to develop a new neighbourhood with public space and community-run cafés and activities (Sanchez Gomez, 2016). With regards to the area's flooding problems, the generated storm runoff was disconnected from the combined sewer network and was instead handled through the implementation of SuDS features

(Haghighatafshar et al., 2017). The interaction between these different elements helped create a multifunctional open stormwater system. The system encompasses green roofs, bioswales, parks, permeable parking lots, small scale wetlands and retention ponds, linked together with open drainage channels and ditches, covering a total area of about 20 ha (Barton, 2016; Stahre & Geldof, 2003). Based on Kazmierczak and Carter's (2010a) impact assessment of the environmental, social and economic benefits delivered by the project, it was found that 90% of the stormwater produced during precipitation events is managed locally and no flood incidences had been reported between 2002 and 2010, despite the 50-year rainfall event in 2007 (Nordin von Platen & Gustafsson 2018). Moreover, biodiversity has risen by 50% in the area. The project has also enhanced recreational values, created energy savings for residents and encouraged community engagement, empowerment and participation (Soz et al., 2016; Barton, 2016). The unemployment rate has also decreased. Lessons can be learned from such example in order to scale-up integrated applications of SuDS practices in urban areas. Further analysis of Augustenborg example and other cases in Nordic climate conditions would provide valuable information about practical and functioning systems as well as lessons learned from the decision-making processes for Tallinn case (but it is out of the scope of this study). Future research would also allow analysing which of the aspects could be replicated in Estonian local conditions.

2.3.4 Implementation challenges for SuDS

While the need for a paradigm shift in the handling of stormwater is acknowledged, decision-makers in most countries still favour traditional means to deal with stormwater management instead of supporting innovative technologies and approaches (O'Donnell et al., 2017). As shown in table 2-2, factors acting as barriers that halt SuDS adoption are numerous. They are partly of **technical** origin, but **socio-institutional** aspects are the greatest hindrance to their uptake, considering that sustainable rainwater handling calls for an alternative to the usual approach of managing and governing these systems (Zhou, 2014; Brown & Farrelly, 2009). A typical characteristic of SuDS is that they are highly **context-specific**, which means that each case study is unique and can hardly be replicated to others since their success greatly depends on local specifics (e.g. institutional capacity, policy framework, financial arrangements, stakeholders' expertise and experience, multidisciplinary process related to NBS-based projects) (Raymond et al., 2017; Nesshöver et al., 2017). Also, in spite of their advantages for water quantity and quality control, questions and scepticism have risen about their **performance** and **feasibility**. A central concern is the **longer time frame required by SuDS** before they deliver their full potential (Hoand & Fenner, 2016, Kati & Jari, 2016; Eggermont et al., 2015). This is regarded as a downside especially in fast growing cities and a reason for opting for grey solutions (Kabish et al., 2016a). Besides, some studies have pointed out the limitations of SuDS in response to the increasing hydraulic and hydrological loading in the context of climate change (Ashley et al., 2007; Holman-Dodds et al., 2003; Nascimento et al., 1999). Scholars such as Zhou (2014) reported that although SuDS schemes impact water flows, the reduction of the water volume is sometimes limited in extreme weather events and sensitive to sites' characteristics such as soil type and texture, intensity and duration of precipitation, etc. Hence, it is often **wiser to combine SuDS with conventional measures to enhance their synergy** for drainage design. Further, developing SuDS systems in urban centres may not be beneficial for all residents. In some cases, their installation has resulted in higher rents and land prices due to the increased reputation and living standards around SuDS areas, which has in turn caused the displacement of population groups (Nordin von Platen & Gustafsson 2018; Golenberg et al., 2018, Gamper-Rabindran & Timmins, 2011). **Gentrification** can lead to environmental injustice and create community opposition to environmental initiatives (Wolch et al., 2014).

Table 2-2 List of factors acting as barriers for implementing SuDS, as elicited by the reviewed studies

Authors	Barriers
Roy et al. (2008)	1)lack of institutional capacity; 2)limits of legislative framework; 3)need of funding and effective market incentives; 4)unclear and fragmented responsibilities; 5)resistance to change 6)insufficient evidence on efficiency and costs; and 7)lack of standards and guidance
Brown & Farrelly (2009)	1)challenges of coordination and collaboration among institutions; 2)unclear, fragmented roles and responsibilities; 3)difficulties to engage community; 4)lack of available resources (capital and human); 5)lack of information, knowledge and understanding in implementing integrated, adaptive approaches of management; 6)missing political leadership; 7)lack of SuDS measures incorporation in legislative mandates; 8)ineffective/lack of communication; 9)engineer-driven management; and 10)little or no monitoring and evaluation
Lee & Yigitcanlar (2010)	1)fragmented rainwater governance; 2)deficiency of standards, guidelines and technical skills; 3)lack of institutional provision; 4)difficulty to collaborate with different stakeholders; 5)insufficient information sharing and use of existing research; and 6)funding and costs
Cettner et al. (2014)	1)missing support (organisational, scientific, local community); 2)lack of resources, knowledge and experienced expertise; 3)ineffective relations and networks; and 4)divergences between interest groups
Hoang & Fenner (2016)	1)lack of collaboration and involvement across respective managing agencies; 2)fragmented flood management structures, unclear leadership and responsibilities; 3)no policies/documents concerning the integration of SuDS; 4)lack of available land; 5)delay in achieving the full range of benefits; 6)strong dependency on maintenance; 7)uncertainty on the quantification of impacts and wider benefits; 8)SuDS perceived as short-term solutions with low reliability of their functions; and 9)fragmented responsibilities and stakeholder groups
O'Donnel et al. (2017)	1)negative past experiences; 2)reluctance to support new practices; 3)lack of knowledge, education and awareness; 4)funding and costs; 5)engineering uncertainties; 6)constraints of space; 7)future land use and climate; 8)poor communication; 9)institutional capacity and expertise; 10)issues with partnership working; 11)political leadership and champions; 12)lack of resources and lack of policy support create a reluctance for planners to support SuDS; 13)maintenance and adoption; 14)responsibilities and ownership; 15)monetising the multiple benefits; 16)uncertainties regarding performance and service delivery; and 17)behaviours and cultural
Kabisch et al. (2017)	1)uncertainties about long-term maintenance, performance and cost-effectiveness; 2)centralised and non-inclusive governance; 3)societal expectation of modern development associated with grey infrastructure rather than green and blue infrastructure; and 4)lack of collaboration between sectors and stakeholders
Waylen et al. (2017)	1)lack of familiarity or fist-hand practical experience with SuDS; 2)challenges of partnership and/or stakeholder dialogue; 3)engineering training and backgrounds predominance; 4)uncertainty as to how design SuDS measures; 5)perceived risks in using new approaches; 6)evidence gaps on effectiveness; 7)time lag between SuDS installation and demonstration of their effects; 8)need to coordinate with various stakeholders with different interests; 9)unclear accountability and responsibility; and 10)difficulties in allocating resources

Source: Author's own elaboration

In conclusion for this section and the literature study on the SuDS scheme and associated concepts, **a balance between both traditional and alternative drainage approaches is seen as the most effective solution** to maximise synergies and system efficiency and at the same time minimising costs and trade-offs. SuDS components could be integrated with other urban infrastructures and should be considered as good strategies for "re-naturing" the city. To ensure their successful deployment, a **supportive urban management system and governance** should be put in place. The decision-making process related to sustainable rainwater handling is complex and many aspects have to be considered. In order to make a rational decision for a city area, **cooperation and knowledge sharing** between the relevant stakeholders are fundamental.

3 Theoretical frameworks and methodology

This chapter is organized in four sections. First, a justification about the research strategy is provided. Since the research was practice-oriented, the SuDS-related project to which the author contributed and from which data was collected is also portrayed. Second, data collection methods applied to all RQs are explained. Third, as different research approaches and theoretical frameworks were used to shape each RQ, theory and derived methodology were placed together in one section under each RQ.

3.1 Case study research design

The thesis has adopted a **case study research** design where a small selection of cases (one in this work) is examined in depth by using several forms of data collection methods to understand the complexity of the cases, analyse them and conclude with the lessons learned (Creswell, 2013; Perri & Bellamy, 2012). This research focuses specifically on the application of sustainable nature-based approaches for stormwater control in the city of Tallinn. An extensive and in-depth analysis of a single case study was suited to the project logistics (e.g. fieldwork opportunity, time and resources available for research, and ease of access to stakeholders). This qualitative approach was the most appropriate and feasible for this study because it allowed field visits, a detailed observation on site, conducting informal interviews with stakeholders in combination with studying a variety of documents.

Practice-oriented research projects set up as a case study offer various advantages such as less pre-structure needed, higher flexibility and more adaptative (Verschuren & Doorewaard (2010). Another key advantage is that as findings and recommendations might be directly applied to the on-going project UrbanStorm project, they have higher chances to be accepted by the experts in the field. In turn, the study can provide valuable research information about SuDS systems for Tallinn city to facilitate their uptake and diffusion.

3.1.1 The LIFE UrbanStorm project

The author conducted a **fieldwork** in Estonia from February to May 2019 to create and collect most of the data needed to prepare this thesis. During her research stay, she worked in close collaboration with the Baltic Environmental Forum Estonia (an environmental NGO) and the Estonian University of Life Sciences (EULS) under the UrbanStorm project, which is led by both institutions in partnership with Tallinn city and Viimsi, a neighbouring municipality. The project intends to create preconditions to foster the incorporation of NBS/SuDS into the menu of Estonian cities' rainwater strategies. Through the planning, analysis and latter monitoring of SuDS demonstration sites, the functioning of these sites will be unique in the country and an important step in changing the thinking patterns of local specialists dealing with stormwater (LIFE, 2017). The author developed a geospatial approach for the identification of flood-prone areas in Tallinn (RQ2) as well as a multi-criteria decision-aid tool for stormwater stakeholders (e.g. local government, planners, developers, landscape architects, etc.) to facilitate the selection of SuDS solutions to better cope with flooding and other stormwater issues in designated areas (RQ3). Such products will be used for the selection and implementation of SuDS techniques in one of the demonstration sites and the GIS maps produced by the author will be incorporated into Tallinn's upcoming Sustainable Energy and Climate Action Plan (SECAP).

3.2 Methods for data collection for all RQs

A **literature study** was conducted on sustainable urban rainwater management and existing practices in Estonia as well as related policies and relevant actors (at European, national, and local levels). Information was collected through various web search engines (i.e. Google Scholar, CrossRef, Sciencedirect, Wiley Online Library and Scopus) about the challenges posed by urban stormwater drainage and about available technical solutions. The following keywords were searched: “flood risk management”, “urban flood mitigation”, “urban rainwater management”, “urban stormwater management”, “urban stormwater planning”, “stormwater governance”, “sustainable urban drainage systems” (SuDS), “water sensitive urban design” (WSUD), “low impact development (LID), “best management practices” (BMP), “stormwater control measures” (SCM), “blue-green infrastructure” (BGI), “green infrastructure” (GI), “nature-based solutions” (NBS) with and without the words “Estonia” or “Tallinn”. The study included legislative, policy and planning documents, academic texts (e.g. peer-reviewed articles, e-books and conference proceedings) as well as documentary materials (e.g., fact sheets, project summaries, websites, design guidelines) dealing with the SuDS concept and its characteristics, urban stormwater planning, urban decision-making approaches, and the theoretical frameworks used for the data analysis. In addition, literary references were found by screening the bibliography of each paper selected for further analysis. Finally, a review was also performed to get a broader view of the data-driven decision-support tools (i.e. GIS-based and multi-criteria analysis techniques for flood risk assessment and sites’ selection for SuDS deployment) available for decision-makers involved in urban stormwater management. As the concept of data-driven decision-making in relation to big data is quite new, only a few scientific articles with a specific focus on the topic could be found. In addition to the literature review, **observation**, **field visits**, **informal interviews**, **participation in a stakeholder meeting**, and a **survey** were used for data creation, collection and/or analysis related to each research question described below.

3.3 Theories and methods for RQ1

RQ1: How stormwater stakeholders’ perceptions of SuDS could influence their attitudes toward adoption? Which perceived attributes of SuDS practices contribute to respondents’ receptiveness toward adoption? What factors could influence their attitudes towards SuDS adoption?

No previous studies were found about Tallinn that focused on understanding local government officials’ and other significant stormwater stakeholders’ perceptions and attitudes related to SuDS. In an attempt to fill this gap, this study borrows elements from **diffusion of innovation theories** and Davis’ (1989) **model of technology acceptance** to investigate SuDS attributes as perceived by engineers, planners, researchers and other actors involved in Tallinn’s stormwater management. **Gauging the perceived attributes of SuDS systems may help predict stakeholders’ attitudes toward their inclusion as part of the city’s stormwater practices.** By understanding the characteristics and factors that make stakeholders more likely to adopt SuDS tools, promoters of these innovative measures will have better knowledge about how to approach their adoption process and foster their widespread diffusion within Tallinn but also other Estonian and abroad localities. A **questionnaire** was distributed among identified stakeholders to collect this data. Together with the review of the regulatory framework, the outcomes of this RQ will first provide new inputs for the development of policies, plans and incentives supporting the use of SuDS tools and second, benefit any potential municipalities considering adding these measures to their portfolio of stormwater solutions.

3.3.1 Theoretical frameworks

The theoretical approach chosen to address the first research objective combines aspects of **the technology acceptance model (TAM)** with aspects of the **innovation diffusion theories** in complimentary manner. Findings of the literature review on underlying factors that have influenced SuDS adoption in other cities across the globe have also helped shape certain questions included in the questionnaire. The following sections discuss the concept of SuDS as being an innovation then, the main framework employed to answer RQ1 is explained.

3.3.1.1 SuDS as an innovation

To grasp the challenges associated with the adoption of SuDS, it is first necessary to envision it as a type of innovation. As stated by Rogers (2010, p.11), an innovation is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption [regardless of actual newness]… as measured by the lapse of time since its first use or discovery". Rogers underlines that the word "new" can have various meanings. An innovation can be objectively new as measured in time from its market introduction or first application (Carlet, 2014). Nevertheless, it may already exist for a certain time before people learn of it, thus, newness is a characteristic linked to each person's perceptions (Carlet, 2014; Faber, 2002). Zeldin, Camino and Mook (2005) also argue that an innovation may imply a system which challenges the status quo and entails important change. In policy shift, innovation should incorporate the subsequent three criteria: 1) originality and novelty to the environment in which it is being introduced; 2) practical use and action; 3) significance and impact (Carlet, 2014; Walker, 2006). The SuDS scheme seems to fulfil these criteria. Although the technological and environmental engineering behind SuDS are not totally novel, its potential impact and practical application make most experts seeing it as innovative (Wright, 2011). SuDS infrastructure is considered an unusual, thus riskier approach to how cities have traditionally plan and deal with stormwater (Olorunkiya, Fassman & Wilkinson, 2012). As discussed by Roy et al. (2008) and echoed by Carlet (2014, p.21), it is "part of a paradigm shift in water management toward a more sustainable development and environmentally sensitive design".

Like any innovation, there is no assurance that SuDS practices will enjoy widespread diffusion and uptake. Nonetheless, the existent literature studying this concept does offer insight for change agents and SuDS advocates. Although the initiation process can be described as a collective decision within an institution, researchers recognise the influence of individuals in establishing organisational perspectives towards an innovation (Vagnani & Volpe, 2017; Carlet, 2014). A person is either positively or negatively convinced depending on "how they interpret what they have learned about the innovation based on their experience and influences from their social system" (Carlet, 2014, p.29-30).

As mentioned above, many variables need to be explored when measuring the likelihood of an innovation uptake. As argued by some scholars (Vagnani & Volpe, 2017; Rogers, 2010; Damanpour & Schneider, 2008; Walker, 2006), the perceived attributes of an innovation by decision-makers might be the most important forecaster of adoption or rejection. Tornatzky and Klein (1982) realised a meta-analysis of researches examining the relationship between innovation attributes and acceptance and conclude that complexity, relative advantage, compatibility, divisibility, cost, profitability, social approval, observability, trialability, and communicability are the most determinant factors to adoption. Other researchers have conducted similar studies and confirmed several of these factors, especially relative advantage, complexity, trialability, and observability (Vagnani & Volpe, 2017; Chor et al., 2015; Damanpour, 2008; Rogers, 2003).

In this paper, four identified characteristics have been used to develop and define the themes of the questionnaire employed as the data collection method for RQ1 (*understanding of the concept, perceived benefits, perceived resources*, and *past experiences).*

- *Complexity* is defined by Rogers (2002, p.989) as "the degree to which an innovation is perceived as relatively difficult to understand and use". If the *understanding of the concept* of SuDS is present, the likelihood of acceptance enhances.

- *Relative advantage* (similar to *perceived benefits*) is described by Rogers (2002, p.989) as "the degree to which an innovation is perceived as better than the idea, [product or process] it supersedes". The greater the perceived relative advantage of an innovation, the quicker its rate of adoption is likely to be. Based on the literature review, SuDS system represent an innovation that provides added environmental, aesthetic, and social benefits when compared to conventional solutions. Because of the multiple qualities of SuDS tools, relative advantage is expected to be a reliable predictor of attitudes toward adoption.

- *Cost* in the questionnaire was incorporated into the general theme *perceived resources* referring to "the self-perceived availability of financial and technical capability to support the innovation, with the emphasis of the construct on the availability of resources to potential adopter when considering adoption of an innovation" (Carlet, 2004, p.42). According to Driscoll and Dupagne (2005), potential adopters' perceived level of resources is associated with an increased rate of adoption.

- *Observability* refers to "the degree to which the results of an innovation are visible to others" (Rogers, 2002, p.989). If the results of an innovation are apparent to observers, the likelihood of adoption grows (Rogers, 2003). In the questionnaire, this attribute parallels with *past experiences* that the respondent may have had with SuDS projects. As mentioned by Makse and Volden (2011), past experiences, positive or negative, can affect people's future willingness to adopt an innovation.

3.3.1.2 Attitude theories

Developed by Davis (1989), the TAM model is considered as one of the most influential and accepted theoretical frameworks to investigate people's attitude toward a new technology or practice and predict future adoption/rejection decision. By finding links between the features of the innovation, the perceptions of users and the behavioural impacts, TAM has been able to accurately represent or project how choices in design and development of an innovation can influence its acceptance. (Davis, 1989; Venkatesh, 2000).

Of the attributes of an innovation, the TAM model notably focuses on *perceived usefulness* (PU) and *perceived ease of use* (PEU). Based on the model, there is a clear positive correlation between PU and EU and consumers' intentions to use the technology. Meaning, when a user's PU and/or PEU increases, their *attitude* toward the innovation also improves, which will lead to more acceptance (Davis, 1989).

Based on the TAM approach, PU is defined as the degree to which adopters think an innovation can be incorporated into their day-to-day activities (Carlet, 2014). PU acts as an incentive to potential users because it represents the extent to which an innovative product can improve performance or outcome (Ramamurthy et al., 1999; Chau & Tam, 1997). According to TAM, PEU is the degree to which a person believes that using an innovation would be effortless (Carlet, 2014). PEU also acts as an incentive to potential users because it can simplify complex tasks. This characteristic is similar as the *complexity* attribute described by Roger (2002).

Following good results on acceptance predictions, the TAM model has gathered wide support from numerous research studies in a variety of fields including new information and communication technologies (Venkatesh, 2000; Moon & Kim, 2001); and has even been used by Carlet (2014; 2015) to predict the level of acceptance and usage behaviour regarding sustainability innovations such as green infrastructure for stormwater control. Findings of the aforementioned studies have also helped shape the research objective and some of the key themes of the questionnaire. In the context of SuDS, obtaining a greater insight into the factors influencing attitudes toward adoption of local engineers, planners, and other stakeholders involved the decision-making process for rainwater handling is utmost to ensure successful diffusion of these solutions (Kazmierczak & Carter, 2010b).

3.3.2 Method for data collection: the questionnaire

As Taylor, Bogdan and DeVault (2015) argue, there is no perfect research method but one should be chosen taking into consideration research interests, context, and time constraints. To address this research objective, it was first planned to conduct interviews with identified stakeholders. Due to the variety of actors and the specific issue being studied in this research, semi-structured interviews would have been performed, as they are more openly designed and integrate both flexible and more standardised components (Flick, 2018). A list of potential interviewees was prepared (e.g. representatives of Tallinn City Government, urban planners, landscape architects, researchers, UrbanStorm project coordinator, etc.). People were selected based on their knowledge and involvement in stormwater handling, urban drainage systems, urban planning, climate change adaptation projects, and/or the design and implementation of water specific NBS or SuDS techniques. However, due to lack of stakeholders' time availability and difficulty to reach certain individuals, the data collection method was switched to a self-administered questionnaire (see Appendix B, p.98).

3.3.2.1 The questionnaire design

The selection of the principal themes for the questionnaire was informed by findings of the literature research, particularly some of the most common barriers or drivers that have emerged from similar studies conducted in other urban contexts (see table 2-2 in the previous chapter). The first draft of the questionnaire was sent for review to a single external person with experience of this research instrument, and that person's comments and suggestions were incorporated into a second draft. The second draft was pre-tested with one professional with experience in SuDS projects to confirm the clarity and relevance of the questions, the ease of completing the questionnaire, and the length of time that it took to complete it. His comments and suggestions were incorporated into the final questionnaire. The objective of the pre-test was to determine the most appropriate questionnaire type, language, and question design. For instance, the terms "Nature-based solutions" or "Green infrastructure" were used instead of "Sustainable urban drainage systems" or "SuDS" as the author was told that the Estonian audience was more familiar with the formers.

Besides their professional background information, respondents were asked about their awareness about flood problems in Tallinn. This information is determinant in predicting attitudes towards SuDS adoption. In addition, questions were posed about their knowledge regarding "green" or sustainable stormwater management and previous experiences related to innovative solutions. Past experiences, positive or negative, could have an influence on stakeholders' future willingness to adopt SuDS. As shown in Appendix B, the questionnaire included other question types such as close-ended questions, Likert scale, and ranking.

3.3.2.2 The questionnaire administration

The questionnaire was first distributed during a meeting with stakeholders involved in the UrbanStorm project. An electronic version was also created and administrated by email to the target audience to ensure access to individuals that the researcher could not physically meet for various reasons, and because of the convenience of having automated collection of data, making data entry and cleaning easier. Prefaced by a cover letter explaining why the survey was being conducted (see Appendix B, p.97), respondents were given a link to the online questionnaire. Participants from the following organisations and groups were invited to complete the questionnaire: Tallinn City Planning Department, Tallinn Environment Board, Tallinn Municipal Agency, Tallinn Enterprise Board, the Ministry of Environment, 4people OÜ (a landscape architecture company), and AS Tallinna Vesi (the main water and sewerage services company). The questionnaire was made available via a Google Form and was open from 27 March to 27 April 2019. It was designed to be completed in 10 minutes or less. In total, 17 stakeholders answered the questionnaire from different backgrounds: public authorities, environmental NGOs, private sector and education sector. For further analysis of the data, the responses were transferred into an Excel spreadsheet.

3.3.2.3 Limitations to the use of questionnaire

Using a questionnaire as data collection method is subject to limitations mostly depending on the type of questions employed and how they are measured. Bias has occurred in some ways in the context of this research. First, it appeared that certain respondents did not understand the question asked. For instance, for question 3 focusing on the respondent's level of responsibilities inside their office, results showed that there was confusion among respondents. Certain participants specified their job title instead of their position. Second, Likert scale questions measure an opinion with a positive, negative or neutral response to a statement (Africano, 2013). If respondents wanted to avoid extreme answers, they may have answered certain questions with a neutral statement, which could have introduced bias.

3.4 Concepts and methods for RQ2

RQ2: How can the use of a GIS-based multi-criteria analysis technique help identify flood-prone areas in Tallinn? Where in the city is stormwater flooding likely to occur?

First, an overview of the GIS concept as a decision and communication support tool will be briefly provided, then the GIS-based approach developed to answer RQ2 will be explained.

3.4.1 Conceptual aspects: GIS-based decision and communication-support tools

The complexity of planning for sustainable rainwater handling and flood risk assessment is apparent. The variety of stakeholders both in public and private sectors, along with complicated legislative settings and lack of experience may generate certain concerns and hesitance that could hinder the good development of sustainable stormwater management (Grand-Clément, 2017). To address these impediments, several studies have focused upon elaborating data-driven tools to aid stakeholders determine areas at risk, decide on the best management practice, but also communicate and collaborate in order to ensure its proper functioning (Ran & Nedovic-Budic, 2016; Price & Vojinovic, 2008; Viavattene et al., 2008).

Among these tools, the expansion of GIS-based methods to support decision-making related to rainwater control is to note. For example, Jiminez et al. (2019) and Warwick et al. (2013) have created maps indicating the most appropriate sites for different types of SuDS based on physical and anthropogenic aspects, whereas Caradot et al. (2010) employed GIS software to evaluate and model sewer overflow risks in urban centres. Besides, GIS-based planning support tools have been utilised to assess flood susceptibility (Lappas & Kallioras, 2019; Wicht & Osińska-Skotak, 2016; Joshi & Shahapure, 2015), predict flood extent (Pradhan et al. 2009; Werner, 2001), manage stormwater utility (Jones, 2005), identify potential infiltration zones (Devi & Katpatal, 2011; Teixeira et al., 2008), and evaluate the impacts of urban consolidation on hydrological process (Ran & Nedovic-Budic, 2016; Bahremand et al., 2007). In all cases, GIS allowed stakeholders to quickly understand priority areas and take better risk management and planning decisions.

3.4.1.1 How does Geographic information Systems (GIS) work?

GIS represent a set of tools that allow to store, manipulate, analyse, and display geospatial information (Ofosu Gyinaye, 2017). GIS enables users to perform complex geospatial analyses combining data from diverse sources, e.g. monitoring data, satellite imagery and socio-economic statistics that have a geographic reference (Schrenk, Farkas & Brun, 2010). In other words, GIS comprises multiple themes for a common geographic location. As illustrated in figure 3-1, the assortment of themes acts as a stack of layers. Since layers are spatially referenced, they can overlay one another and be integrated in a joint map display (Ddamba Kibuuka et al., 2015). Further, GIS analysis tools, such as polygon or raster overlay, can merge information between data layers to reveal spatial relationships, patterns and trends (Ddamba Kibuuka et al., 2015).

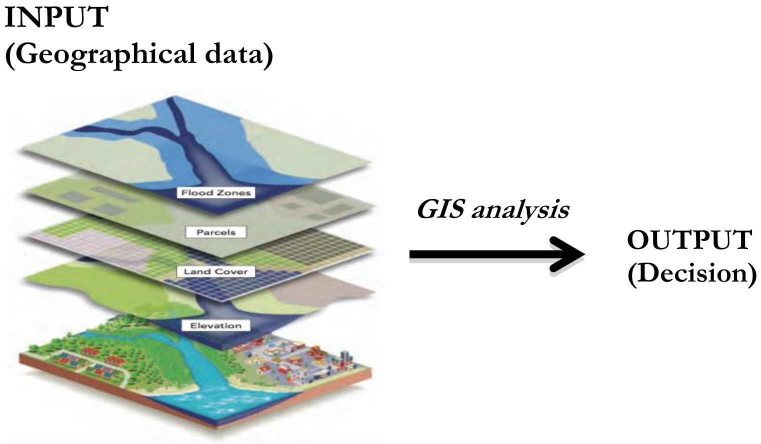


Figure 3-1 The use of spatial analysis in decision making

Source: Adapted from WWF Flood Green Guide (2016)

3.4.2 Method for data creation: the GIS model development

The idea was to propose a simple, user-friendly and easy-to-replicate methodology to map and assess the susceptibility of Tallinn to flooding. To produce such a tool may appear daunting, but the need is great. This methodology could be used at different scales for planning and policy implementation as well as guiding stakeholders in making better-informed decisions with respect to rainwater management challenges. Different approaches have been proposed in previous studies for flood risk mapping and stormwater runoff modelling. However, these approaches are often complex, data-demanding, time-consuming, and difficult to understand for non-GIS experts. The approach developed in this study does not follow one specific model that already exists in the field; it is rather based on a combination of key parameters that were identified on reviewed studies and chosen based on data availability.

As shown in figure 3-2, the model development can be divided into six steps explained as follows.

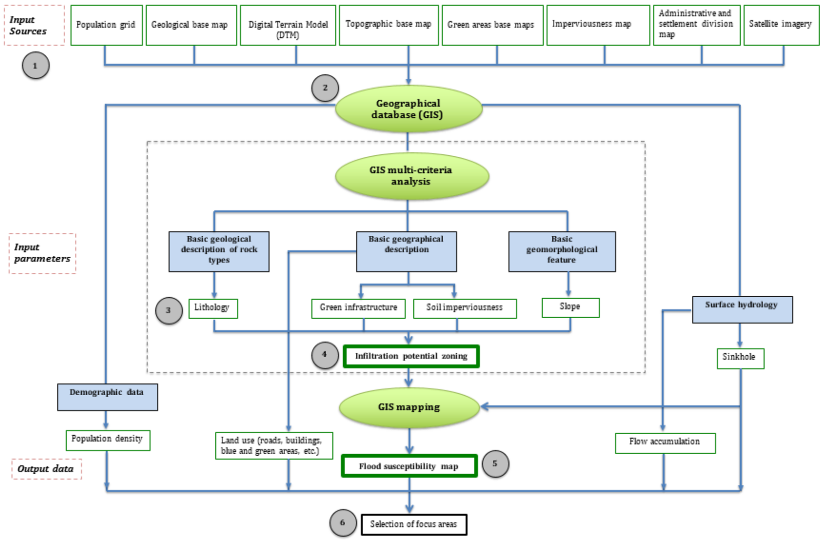


Figure 3-2 Methodology flowchart for GIS model

Source: Author's own elaboration – (larger format in Appendix D, p.107)

Step 1: data collection

First, the datasets used in this approach were acquired from a variety of sources. In order to ease replication, only data that were available in open access to the public were gathered from reliable and verified geospatial portals. Table 3-1 presents each dataset and the related data source used for the mapping of the susceptibility of Tallinn to floods.

Table 3-1 Data and their sources

Input sources	GIS Data type	Scale/resolution	Produced Year	Data source
Geological base map	Polygon	1:50 000	2018	Estonian Land Board Geoportal (Maa-amet)
Topographic base map	Polygon	1:10 000	2019	Estonian Land Board Geoportal (Maa-amet)
LiDAR-based Digital Terrain Model (DTM)	GRID	50 meters	2018	Estonian Land Board Geoportal (Maa-amet)
Imperviousness surface cover	GRID	20 meters	2015	Copernicus portal
Green areas base maps: - Urban Atlas - Tallinn Green areas map	 Polygon Polygon	 1:10 000 1:10 000	 2012 2018	 Copernicus portal Tallinn City Planning Department
Population density	GRID	100 meters	2018	Statistics Estonia
Administrative and settlement division map	Polygon	1: 350 000	2019	Estonian Land Board Geoportal (Maa-amet)
Orthophoto	Aerial photography	1:10 000	2018	Estonian Land Board Geoportal (Maa-amet)

Source: Author's own elaboration

Step 2: Construction of a spatial database

A database of the collected spatial data was then compiled and imported into a GIS environment (ArcGIS 10.6) in order to provide the basis for further flood spatial analysis. The raw data was corrected and digitised to extract relevant data layers within the city boundary of Tallinn. All data shared the same geographic coordinate system, which was the Estonian Coordinate System of 1997.

Step 3: **Preparation of criterion maps**

Flood susceptibility in this study was determined by two main factors: **water infiltration potential** into the ground which allows identifying zones already at risk and **sinks** which are basin-like depressions in the land surface where stormwater runoffs tend to accumulate and stagnate. As indicate by Lee et al. (2018), these factors are related to topography, geology, land use, vegetation characteristics, and soil.

The basic method adopted to create the infiltration potential map was an overlay analysis of four parameters, which were selected according to their degree of association with infiltration: **vegetation areas** (Lee & Jensen, 2018; Pena et al., 2016), **lithology** (Yeh et al., 2016; Teixeira et al., 2008; Pena et al., 2016), **slope position** (Devi & Katpatal, 2011), **the degree of soil imperviousness** (Miller et al., 2014; Tucci, 2007). Therefore, the third step consisted of the generation of four criterion/parameter maps required to obtain the water infiltration potential map of Tallinn area, as shown in table 3-2. These four parameters have been selected based on the literature review and data availability.

Table 3-2 Criterion maps and their input data

Dataset	Derived map	Characteristics
Geological base map	Lithology	- influences soil infiltration rate and retention capacity as it implies different hydraulic conductivity, transmissivity and storage amount for diverse geological formations (Teixeira et al., 2008). Thus, different lithotypes are associated with different infiltration potential.
LiDAR-based Digital Terrain Model (DTM)	Surface slope	- controls the surface water flow (run-off) (Kumar et al. 2013); as the slope increases infiltration decreases (Devi & Katpatal, 2011)
Imperviousness surface cover	Imperviousness degree	- alters the hydrological nature of surface runoffs, prevents the drainage and infiltration of surface water into the ground, greatly increases runoffs in terms of volume and peak flow, and consequently causes floods in cities (Birgani et al., 2013). Liu et al. (2014) divide urban areas in three categories: - impervious surfaces (buildings footprints, roads, pavements, parking lots, etc.) - pervious surfaces (green spaces, lawns, bare soils, etc.) - waterbodies (natural and man-made reservoirs, rivers, streams, etc.)
Green areas base maps: - Urban Atlas - Tallinn Green areas map	Improved green infrastructure	- derived map based on functional characteristics: each specific green element provides different degrees of protection against floods. - knowing the type of green areas gives information about the functionality of the area, which is important in terms of types of benefits including infiltration capacity - GI provides manifold ecosystem services including a buffering effect to extreme rainfall occasions (Hansen et al., 2017) - decelerates stormwater before hitting the ground (Herslund et al., 2017) - slows down the runoff by allowing more retention time to either infiltration of the water into the soil or flowing into stormwater collectors (Herslund et al., 2017)

Source: Author's own elaboration

Step 4: Overlay analysis to create the water infiltration potential map
This step included two parts: a) producing a specific infiltration potential layer for each input parameter; b) realising the overlay analysis using the new layers. This operation is the sum of the four input data and could be illustrated by this simple equation:

$$IP = I + GI + S + L$$

Where *IP* means the soil infiltration potential, *I* refers to the soil imperviousness, *GI* means the improved green infrastructure, *S* represents the surface slope, and *L* the surface lithology.

All criteria were assigned the same weight because the influence of each criterion on the soil infiltration potential was considered equally important.

4.a. Production of individual infiltration potential layer for each input parameter
Each class included within each criterion was reclassified and given a qualitative value representing its infiltration potential. The reclassification is shown in **Appendix E** (p.108).

Imperviousness: The percentages of imperviousness were classified into 5 classes. It was assumed that, if the urban area contains between:
0-20% of impervious surfaces, the infiltration potential is very high (score = 5);
20-40% of impervious surfaces, the infiltration potential is high (score = 4);
40-60% of impervious surfaces, the infiltration potential is moderate (score = 3);
60-80% of impervious surfaces, the infiltration potential is low (score = 2);
80-100% of impervious surfaces, the infiltration potential is very low to null (score = 1).

Improved green infrastructure: It was assumed that greenery areas have a generally good infiltration potential. Since on-site experiments were not performed to estimate the actual infiltration capacity of each type of green infrastructure, a qualitative score was assigned to them based on best expert judgement. The 9 green infrastructure types identified in Tallinn were reclassified based on 5 qualitative values representing their infiltration potential (see Appendix E).

Slope: As done in previous studies (Keith, 2010; Brito et al. 2006; Rokus, 2005), it was assumed that for a flat terrain (between 0-15%), the infiltration potential is very high (score=5); for a steady terrain (between 15-25%), the infiltration potential is moderate (score=3); and for a steep terrain (between >25%), the infiltration potential is very low (score=1).

Lithology: The different lithotypes were divided into 5 categories and were given a score from 1 to 5 to characterise their infiltration potential. To evaluate the infiltration potential of each rock type, the qualitative classification was realised based on the Guide to permeability indices produced by the British Geology Society (BGS) (Lewis et al., 2006).

4.b. Realisation of the overlay analysis
To ensure that every overlaying, weighted and reclassified criterion map was matching to each other, it was performed when necessary the resampling of cell size to create maps with the same resolution. All the maps were then converted to raster maps to execute the overlay operation. The output was a new thematic map showing the water infiltration potential in Tallinn area. The different layer maps produced as well as the final output map are illustrated in figure 3-3 and available in larger format in Appendix G (p.110-115).

Finally, area calculations were performed for the different infiltration potential classes inside the city limits (for each district) as see in Appendix G (p. 115).

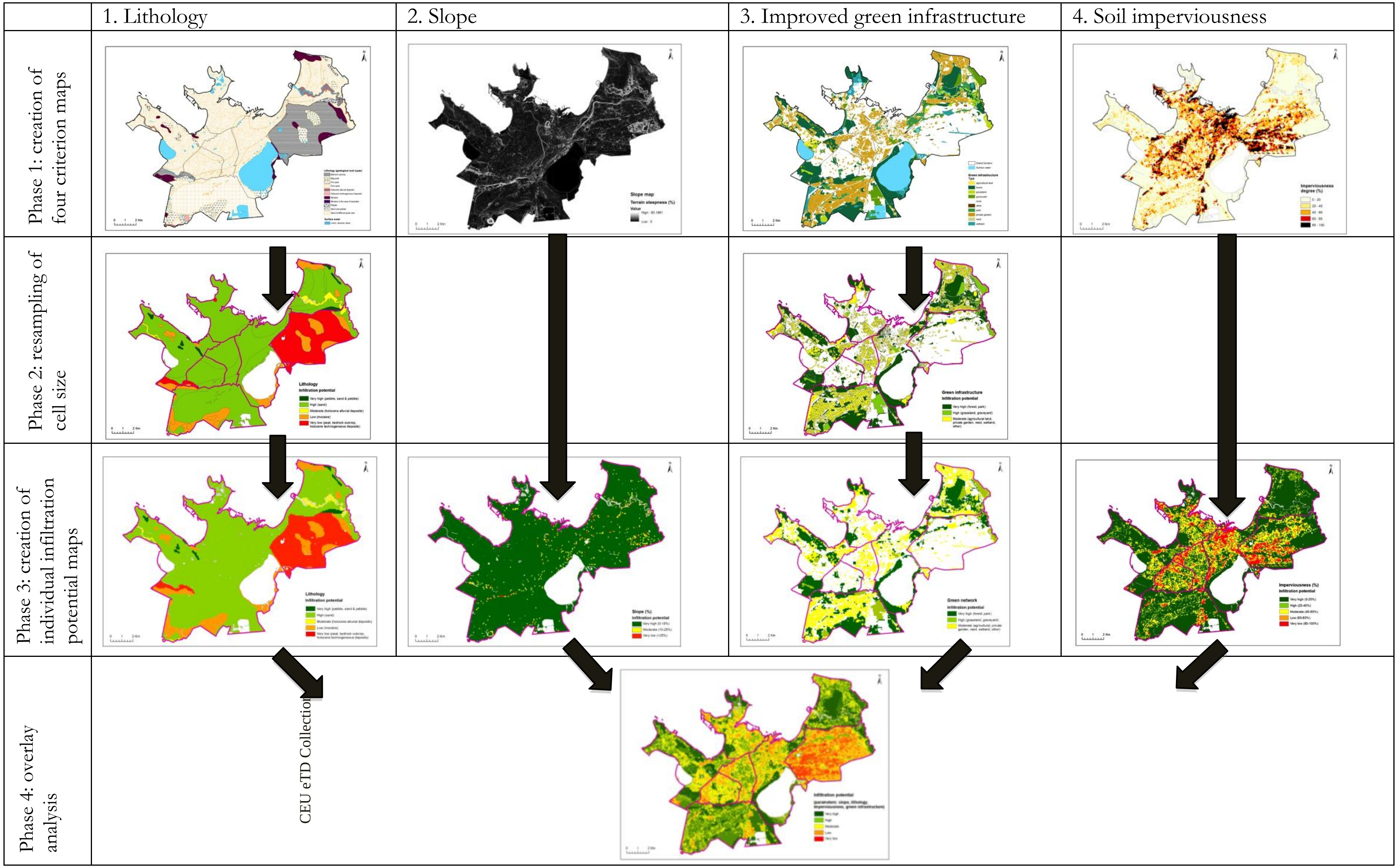


Figure 3-3 Schematic of the overlay analysis performed to produce the water infiltration potential map

Step 5: Mapping the susceptibility of the area to floods
This step consisted of the creation of the flood susceptibility map based on the infiltration potential map and the sinkhole map. The final output is shown in Appendix G (p.117) and discussed in the results chapter.

Step 6: Selection of focus areas
This step includes the creation of extra thematic maps that were used in addition to the maps previously generated in order to further analyse the area.

Table 3-3 Ancillary thematic maps and their input data

Input data	Derived map	Characteristics
- Topographic base map - Improved GI map	Land use map	-provides more detailed information about dominant land-use types; , identifies whether the land use is commercial, residential or public building, industrial area, blue or green space, roads and other paved surfaces).
LiDAR-based Digital Terrain Model (DTM)	Flow accumulation	-shows which areas in surface streams tend together most accumulated water; gives us the virtual rivers that are formed when a rainfall happens.
Population density grid	Population density map	- the population in danger of being flooded is an effective parameter in the degree of potential damages and fatalities.

Source: Author's own elaboration

Land use: This map was generated by merging the improved green infrastructure map and the built environment map. The latter was produced based on data layers (i.e. road network, building types, land cover including other paved surfaces) that were extracted from the Estonian Topography Database (ETAK) produced by the Estonian Land Board.

Flow accumulation: The flow accumulation was generated from the elevation raster data (DTM). As Kumar et al. (2013, p.126) argue, "the high flow areas in the output raster are the areas of concentrated flow which are important to identify possible stream channels similarly, those areas with flow accumulation value zero (low) are the areas of topographically high like ridges". With this map, it would be possible to see where rainwater could be infiltrated, slowed down or detained.

Population density: This map was generated based on the population grid obtained from Statistics Estonia. According to Yoo, Kim & Hadi (2014), it is natural to assume that higher population density will lead to higher sensitivity to environmental exposure.

High-resolution satellite imagery was also used to ensure correct alignment with surface features and get a clearer idea of how the site looked like in reality.

The selection of focus areas for the later suggestion of possible SuDS options (RQ3) was done based on the following criteria (see table 3-4).

Table 3-4 Criteria for the selection of focus areas

Criteria	Criteria description
Flood susceptibility	Area at risk of flooding based on GIS maps
Inland flood risk	Sites located above the influence of sea-level rise
Representativeness	Selection of different types of land use (e.g. residential, commercial, industrial, mixed development, green area, road) to have a range of scenarios or examples of development where different types of SuDS solutions could be implemented
Site characteristics	Site's water infiltration potential, type of terrain, surface hydrology (i.e. sinkholes, flow accumulation), soil conditions, existing rainwater drainage infrastructure, population density.

Source: Author's own elaboration

3.5 Concepts and methods for RQ3

RQ3: How to facilitate the selection of SuDS measures to cope with urban flooding using a multi-criteria decision-support methodology? What are the considerations to take into account to select the right measures in the planning process?

First, an introductory overview of the adoption process for drainage infrastructure is given, then, the conceived SuDS selection tool is explained.

3.5.1 Conceptual aspect: the adoption process for drainage infrastructure

3.5.1.1 Conventional approach

The adoption process can be divided into four major stages: (a) planning; (b) design; (c) construction and adoption; and (d) operation and maintenance (see below figure 3-4). Since the suggested decision-support tool is designed to be used at preliminary stormwater planning stages, the following lines only describe the main steps of the planning process.

In theory, the planning stage proceeds in a standardised, orderly sequence, which includes three phases: 1) baseline hydrology, 2) alternatives analysis and 3) conceptual plan. During the *first phase*, the landowner or the developer usually contracts a drainage engineer and/or a planner to "evaluate hydrology and identify important constraints, areas of open space preservation, needs for easements, means of accommodating utility conflicts, etc." (UDFCD, 2016, p.3-1). In the *second phase*, different measures are analysed and compared for possible implementation in order to deal with storm runoff (McPherson, 1978). Traditional methods control water quantity and/or quality. The planning team then develops design proposals for sites and types of structures and facilities while also assessing the suitability, type, and location of detention basins and water quality facilities (UDFCD, 2016). The planning process comprises consultations with local government agencies and other regulatory stakeholders (UDFCD, 2016). Although the city can solicit public input for large-scale drainage projects, technical complexities of grey solutions may discourage the public to actively engage in the planning process; moreover, incorporating participants' suggestions is not mandatory (Dhakal, 2017). *Third*, through possible public participation and technical analysis, alternatives are examined to make decisions and result in a conceptual plan for the system that is politically and mostly technically feasible (UDFCD, 2016). The final decision is made at the discretion of designated city agencies' staff.

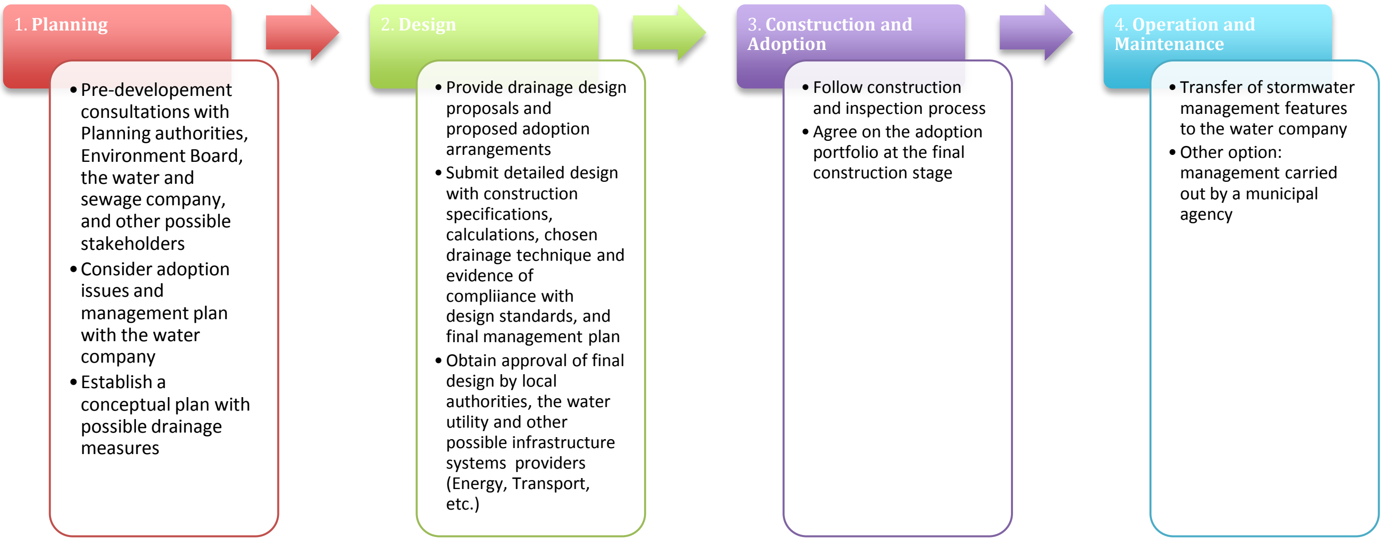


Figure 3-4 Overview of the key steps of the adoption process for drainage infrastructure

Source: Author's own elaboration based on the information gathered from the document review and verified through an informal interview with a local landscape architect

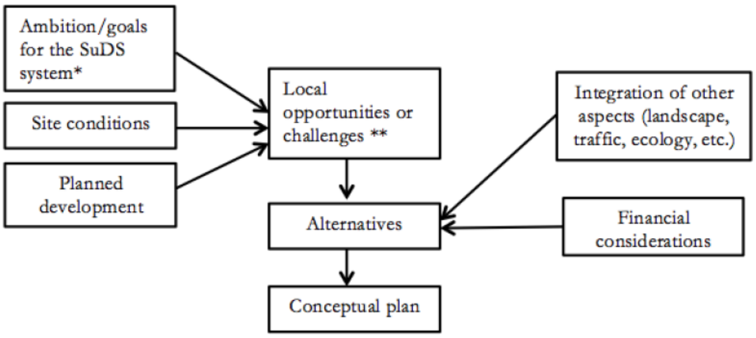
3.5.1.2 Approach of SuDS projects

Unlike the conventional drainage approach, where stormwater strategies are often applied to sites at a relatively late stage in the design process, it is crucial that the first consideration of SuDS takes place at the early planning stages and that the site design is developed accordingly (Council DC, 2016). This should ensure the most cost-effective, well-designed SuDS. The design goal is to allow runoffs to flow in a controlled and predictable fashion through development with suitable SuDS components located along a "management train" (Council DC, 2016). In order to comply with local planning policy and best practice standards, the SuDS installations will also need to deliver other functionalities. Details of these additional advantages will be confirmed during the first design stage (Council DC, 2016). Moreover, SuDS require the involvement of different types of stakeholders to be successfully implemented. In addition to consultations with city agencies and other regulatory stakeholders, public meetings and outreach should be arranged to encourage active community involvement in the planning process (UDFCD, 2016).

The possible planning process for SuDS in the Estonian context

The following suggestion was made under the (D)rain For Life project, which was a two year-long project (2012-2014) "Promoting Sustainable Urban Drainage Systems in Estonia-Latvia cross-border area to improve the environment for active and sustainable communities". On of the main outcomes of this initiative was the elaboration of feasibility studies on implementation of SUDS in specific context and specific design and technical solutions proposed for 4 localities in Estonia and Latvia. Based on the project's recommendations, the design of a SuDS scheme should not begin with the specific technique. Rather, the planning team should "start with the system objectives and understanding of the local situation, including the characteristics of the development" (ELCP, 2013, p.9).

The SuDS planning process could be portrayed as figure 3-5:



**goals examples: prevention of flooding, improvement of living conditions and human well-being, rehabilitation of urban areas, protection of environment, aesthetic reasons, etc. ** examples: regulatory factors, economic factors (subsidies, incentives, etc.), technical factors (human resources, knowledge, etc.) and other opportunities*

Figure 3-5 The SuDS planning process

Source: Author's own elaboration adapted from ELCP, 2013.

3.5.2 The proposed decision-support methodology for SuDS selection

There are currently no official guidelines or manuals in Estonia related to the design and implementation of SuDS structures. The strategic and practical planning tool described in this section could provide useful information for the establishment of minimum requirements and context-specific guidelines for practitioners (urban decision-makers, drainage engineers, private developers, city planners, water managers, etc.) to adopt more resilient-sustainable decisions in urban spaces. This methodology was designed by the author in the context of the UrbanStorm project in close collaboration with a local landscape architect with SuDS expertise and who was previously involved in the (D)rain for Life project. The tool was then applied and tested in the six focus areas. One of its applications will be presented in the result chapter.

The development of this type of tool combining GIS data and a multi-criteria technique for SuDS selection represents an obvious step-forward. Currently there are only a few examples of such dedicated tools (Viavattene et al., 2010; Lai et al., 2007; Makropolous et al., 2001) Expert opinion, the literature review on SuDS planning process in other European cities and existing planning instruments, especially the British SuDS design guidance produced by Woods-Ballard et al. (2007) have informed the creation of this tool. The core of this method is a **table** containing a list of possible SuDS techniques (see Appendix I, p.123), which works as a guiding tool and helps the practitioner decides which measures are more appropriate for her/his project depending on a set of criteria.

The proposed methodology aims to simultaneously reduce urban flood risk and improve other environmental aspects. It consists of a three-step process. The *first step* includes finding and analysing relevant information about the local characteristics and current situation of the space under study. The main objective is to determine the local potential for SuDS applicability in the area, according to a variety of site-specific aspects (Woods-Ballard et al., 2007; Alves et al. 2016; Ellis et al., 2006). This is considered as a fundamental first step in the process for selecting locally adjusted and sustainable strategies. Based on a consideration of the data obtained from the GIS mapping results, the following indicators were chosen: type of land use, lithological type, slope, flow accumulation, population density, sinkholes, soil infiltration potential. Basic details on the existing rainwater drainage system were also searched. In a real-life project, it would be necessary to do field visits and take measurements for example of the depth to groundwater and the degree of watercourses' pollution as well as perform further research on the existing rainwater drainage systems. The *second step* considers the multiple benefits or multi-functionalities these measures could provide and which of them are identified as relevant for the area according to the stakeholders/decision-makers' preferences (e.g. developer, engineer, planner, landowner, etc.). *Third*, once this stage is completed, the identification of a range of possible solutions begins. As seen in the Table (see Appendix I, p. 123), the list of techniques is classified into 3 different groups/colours in relation to the distance from the development recommended for the SuDS construction. The selection, therefore, considers:

- The different treatment stages related to the scale of the SuDS system: prevention, source, site, regional control;
- The space requirement of each measure; and
- Four SuDS design criteria: 1) water quantity reduction, 2) water quality improvement, 3) amenity benefit, and 4) biodiversity preservation.

At a later stage (out of the scope of this tool), for the final selection of measures, other aspects should be considered such as:

- Local regulations and municipality's requirements;
- Health and safety concerns;
- Construction and maintenance costs: SuDS should be no more expensive than a conventional drainage system meeting the same design criteria;
- The interconnectedness and physical SuDS network (rivers, drainage system of the area);
- Character and aspirations of the area including professional and planning norms.

Figure 3-6 presents the whole process that needs to be followed for preselecting long-term adaptation solutions for flooding in an urban setting.

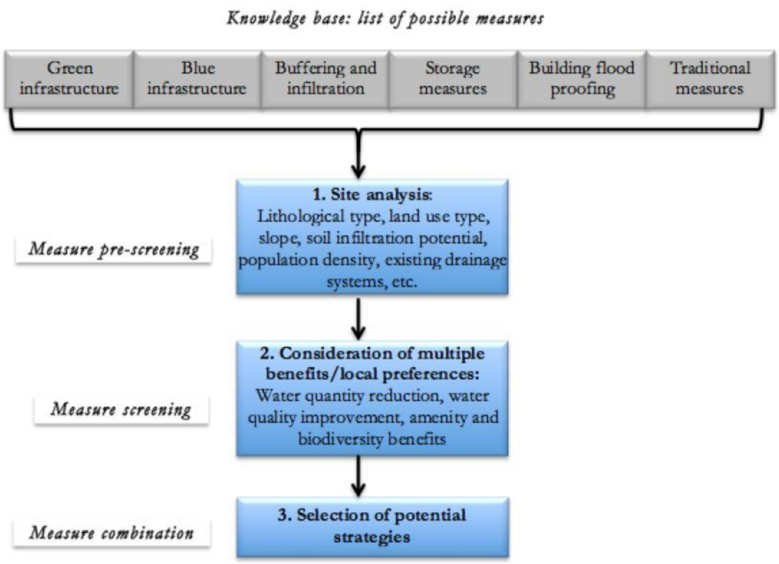


Figure 3-6 Selection of measures considering site characteristics, multiple benefits and local preferences.

Source: Author's own elaboration adapted from Alves et al., 2016

4 The Stormwater governance in Tallinn

Stormwater governance in this paper is defined as the system of institutions and organisations involved in governing the management of stormwater in Tallinn. Governance provides the mechanism for articulating policies and monitoring stakeholder actions to ensure compliance (Dhakal, 2017). This chapter has thus two main areas of focus. First, it provides an overview of key policy instruments that influence and shape the city's stormwater management, including opportunities and obstacles created for SuDS adoption. Second, it describes the distribution of the responsibilities and roles that bind the different stakeholders involved in the sector. As for the first section, the main governance opportunities and obstacles for SuDS adoption are identified. Findings from this chapter will be later compared to the results obtained for the first research question.

4.1 Policies supporting or preventing SuDS development in Tallinn

This section explores the extent to which current policy instruments across the multi-level governance structure (EU-national-local) take into account or support the implementation of SuDS. It also highlights the barriers existing in the Estonian laws and policies preventing SuDS adoption as stormwater measures. The policies examined here were selected either because they directly address stormwater management or because their primary focus is on other topics (e.g. climate change adaptation, promotion of green areas, urban planning, etc.), having the potential to influence the sector by encouraging or halting SuDS development. Most of documents were searched using the Estonian or EU legislation official websites (Riigi Teataja and EUR-Lex).

Broadly speaking, policy "refers to complex (multiple and multilevel) decisions followed by a programme of actions or a set of principles on which the actions are based" (Kiss, 2013, p.17). The decisions, actions and principles generally represent and allocate specific values, and they are adopted either by public or private actors (Kiss, 2013). In this research, most policies listed below belong to the regulative instruments. Figure 4-1 shows the different levels of policy instruments that are related to stormwater handling in Tallinn, from European directives to local urban planning documents. This compilation is non-exhaustive.

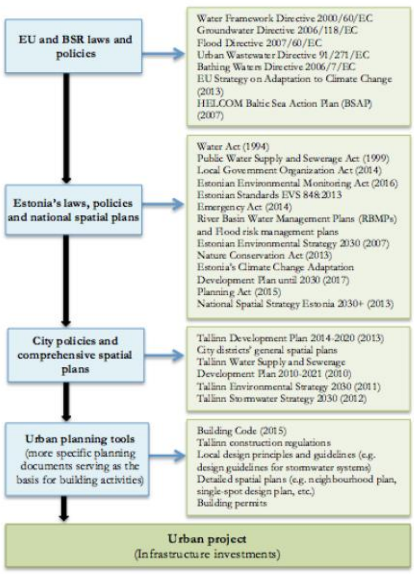


Figure 4-1 Different levels of policy documents related to the city's stormwater management

Source: Author's own compilation

4.1.1 European and Baltic Sea region levels

Among the EU directives indicated in figure 4-1, the following ones are the most relevant for urban rainwater management in Estonia: the Water Framework Directive (WFD), the Floods Directive, the Urban Wastewater Directive, and the Groundwater Directive.

Adopted in 2000, the **WFD** forms the heart of European water law and establishes an EU-wide regulatory framework for the protection of inland surface waters and groundwater (Baltic Flows, 2016). The legislative context of the WFD can offer significant opportunities for the consideration and integration of alternative drainage measures such as SUDS within future urban land use planning programmes (Johnstone et al., 2012). Its key goals which are of importance to urban surface water drainage as described in Article 1 of the Directive encompass: i) protection and improvement of artificial and heavily modified watercourses, with the objective of attaining "good ecological potential" and "good" surface water chemical status within 15 years; ii) prohibition on direct polluting discharges, such as urban runoff, to groundwater; iii) reversal of any human-caused substantial and sustained upward trend in certain pollutants (Johnstone et al., 2012; Baumgartner, 2008). Besides the WFD, the **Groundwater Directive** prohibits any actions that may deteriorate groundwater quality, which can possibly affect the use of infiltration-based stormwater control practices (Baltic Flows, 2016; EC, 2006).

The **Floods Directive** aims to reduce and manage the menace that floods pose to human health and life, the environment, cultural heritage and economic activity (EC, 2007). It requires each EU Member State (MS) to evaluate if their water bodies and coastlines are at risk from flooding (Baltic Flows, 2016). MS ought to implement **flood risk management plans (FRMP)** as well as **river basin management plans (RBMP)**, and active public input in the preparation of these plans and in decision-making processes should be encouraged (Osbeck et al., 2013; Looring, 2013). All evaluations, maps and plans are to be regularly updated and publicly accessible (Santato et al., 2013; EC, 2007). Through its Ministry of Environment, Estonia has prepared in 2011 a preliminary flood risk assessment, which identified 20 areas at risk of flooding including 6 in Tallinn (RTI, 2012; Looring, 2013). A FRMP was prepared in 2015; however, the assessment and plan only focuses on coastal areas and mainly suggests the construction and/or renovation of conventional approaches as means to protect against flood hazards (Osbeck et al., 2013; RTI, 2012).

With regard to rainwater quality specifically, the **Urban Wastewater Directive** specifies that state authorities have to take measures to attenuate the pollution of receiving waters from rainwater overflows via collecting systems under unusual situations, such as heavy rainfall (Maharjan, 2016a; EC, 2013). The more stringent regulation is from the Helsinki Commission (HELCOM). As Estonia is part of the Baltic Sea region (BSR), it required following the recommendations of the HELCOM in addition to EU directives. Valid **HELCOM recommendation 23/5** on the limitation of discharges from urban zones through the appropriate management of rainwater networks focuses on the runoff volume and first flush in a separate system and most polluted overflows in the combined system (Maharjan, 2016a; HELCOM, 2002). Measures are recommended at the source to reduce the volume and prevent the deterioration of rainwater quality in separate and combined sewer systems. Similar to WFD, the objective of the HELCOM Baltic Sea Action Plan (BSAP) is to restore the good ecological status of the Baltic marine environment by 2021 (MoE, 2013).

4.1.2 National level

The requirements of EU directives and HELCOM recommendations are enforced in Estonia through national acts and regulations (Maharjan, 2016a). The Estonian **Water Act** (RTI, 2015b) has the target of protecting of all waters against pollution to achieve the good status by promoting sustainable water and wastewater. Based on the Water Act, **Government Regulation no.99 of 29 November 2012** (RTI, 2013) "on wastewater and stormwater management requirements, pollution parameters and compliance limits with the control measures" was adopted by the Government of Estonia. Beside the Water Act, the national legislation implementing the WFD is the **Environmental Monitoring Act,** which provides the organisation of environmental monitoring at three levels: national, local government and special permit owners (RTI, 2015a). Together with the **Local Government Organisation Act**, the **Public Water Supply and Sewerage Act** (RTI, 2016) regulates the collection and treatment of wastewater and stormwater from properties, according to which the local government shall prepare 12-year plans and activities for stormwater management (Maharjan et al., 2016). Rainwater drainage infrastructures are deemed to be public water supply and sewerage systems, unless otherwise decided by the local government (RTI, 2016). Currently land and building owners in Estonian cities can direct the rainwater from their grounds (roofs and parking lots, etc.) to public sewage or drainage system by paying a one-time fee (Rudi, 2016). Some cities like Tallinn are discussing the possibility to develop a stormwater taxation or stormwater fee waiver system to incentivise property owners to deal with the runoff on-site close to its source. Outside the buildings, rainwater and sewage systems are constructed, rehabilitated, maintained and operated according the **Estonian standards EVS 848:2013** (Maharjan et al., 2016b). The principle is based on returning rainwater to nature either by possible infiltration and delay at sources or by reuse (Maharjan, 2016a).

The **Emergency Act** that came into force in July 2009 regulates the management of extreme weather conditions. In line with the Floods Directive, the Emergency Act requires the country to draw up emergency risk assessments and crisis management plans in case of storms and floods (Peleikis, 2011). Furthermore, the **National Environmental Strategy to 2030** (MoE, 2017) aims to define long-term development trends for maintaining a good status of the natural environment, while taking into account the links between the environmental, economic and social spheres, and their effect on the natural environment and people (BISE, 2017) Specific actions highlight the need for research and planning for the creation of a green network that will improve the quality of landscaping in cities and other settlements. The strategy has general aims, such as achieving good condition of inland and coastal waters and although it mentions the need for increasing green areas, it does not explicitly acknowledge its importance in flooding mitigation. Besides, this policy document does not propose climate change adaption objectives and measures (Peleikis, 2011).

Finally, the area of adapting to climate change induced effects (including floods) is planned and managed in Estonia comprehensively in a short (up to 2030) and long (up to 2050 and 2100) perspective via the **Climate Change Adaptation Development Plan until 2030** (published in 2017). The development plan has been drawn based on the EU strategy on adaptation to climate change, which states that considerations about climate change (and urbanisation changes) need to be incorporated into the design of stormwater solutions in order for them to adapt to future changing conditions (MoE, 2017). However, the strategy leaves adaptation decisions to individual countries with no clear prescriptions (Peltonen, Juhola & Schuster, 2010). The portfolio of adaptation measures in Estonia is so far vey limited compared to other countries within the Baltic Sea region like Germany and Sweden (Peltonen, Juhola & Schuster, 2010). In the Estonian strategy for climate change (EERC, 2016), flooding in urban areas is mentioned in two chapters: the one on *better planning* and the one on *water and sewage infrastructure*. The planned measures comprise the diminution of the impermeable surfaces by developing public transport (starting from 2017) and the expansion of green areas in city planning taking into consideration the need to infiltrate rainwater (starting from 2021) (Leal Filho et al., 2017). After the climate change adaptation framework has been created at the EU and national level, Estonia now needs to compile regional and local climate change adaptation strategies (BEF, 2011; LIFE, 2017).

4.1.3 City level

Some of the initiatives initiated at city-scale in the 2000s have started to decrease runoff and pollution load. A number of action plans and activities are proposed in the **Tallinn Development Plan 2014-2020**, **Tallinn Stormwater Strategy to 2030** and **Tallinn Water Supply and Sewerage Development Plan 2010-2021**, such as minimising the pollution load by street cleaning, limiting hydrocarbon through the installation of oil filters, reducing nutrients building treatment plants, the construction of separate system and the renovation of the combined sewer system, etc. (Maharjan, 2016a).

The main strategy document providing guidance on how to limit on-site runoff pollution and how to extend the retention time of the water in case of intensive precipitation is the **Tallinn Stormwater Strategy until 2030** (Leal Filho et al., 2017). It lays down the main development objectives of the sector and contains an action plan. Restrictions and special requirements are set on the processing of plans and projects for preserving the quality of groundwater, levelling rainwater discharge, preventing floods and treating stormwater (Tallinn City, 2017a). Besides recommending the reduction of hard surfaces where feasible, it mentions infiltration of the excess water into soil as a possible strategy for stormwater control (RTI, 2012). At the same time it specifies that in some locations, with very thin soil layer and only 2-m depth of groundwater layer, infiltration is not supported (Leal Filho et al., 2017). At this time, decision-makers and planning authorities do not sufficiently consider this option. The **Development Plan for Tallinn 2014-2020** (RTI, 2013b, p. 66) stresses that "the activities foreseen in the stormwater strategy have to be implemented" however this wording leaves a lot of room for interpretation. In 2016, the plans of measures for mitigating flood risks (MoE, 2016) were adopted. Assessments of alternative methods (i.e. green infrastructure) are cited as advisory and site-specific possibilities.

4.1.4 Urban planning documents

One of the main characteristics of urban rainwater handling is that while it cannot be dissociated from wastewater management in terms of infrastructures, it also needs to be associated with urbanism and city planning: indeed, management of urban planning documents and programmes is required to control ground occupation and water flows (Grand-Clément, 2017; Carré et al., 2010). Therefore, such documents should always be taken into account when aiming for sustainable rainwater management.

The **Planning Act** (RTI, 2013a), which regulates all planning activity in Estonia, defines four types of spatial plans, illustrated in figure 4-2, according to their planning scope and nature.

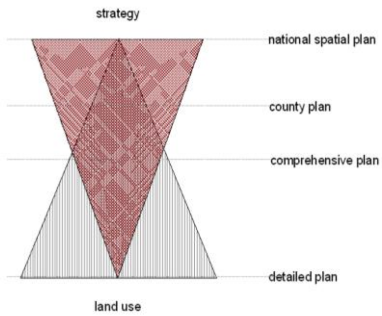


Figure 4-2 Nature of different spatial plans in Estonia

Source: Pehk, 2008

The first level of urban planning documents is the national planning policy (NPP), which supports the consideration of flood risk management as an essential part of achieving proper planning and sustainable development. The **National Spatial Strategy Estonia 2030+** (MoI, 2013) establishes a framework within which a more balanced and sustainable pattern of development can be attained (Looring, 2013). Spatial planning at **regional** (or county) and **local** levels is critical for implementing the NPP and planning at these levels should assess the suitability of sites for development including flood risk considerations (Looring, 2013).

In Estonia, land-use planning including municipal rainwater planning is the responsibility of the municipalities in all the counties; however, the extent to which the municipalities act independently varies in the different counties (Holvandus, 2014). For municipalities located in coastal zones, local authorities must define the boundaries of frequently flooded territories on their seacoast in comprehensive plans (Looring, 2013). Conditions and restrictions for using shores are defined in the Nature Conservation Act (MoE, 2017). The local level in spatial planning does not have enough knowledge about the consequences of climate change and flood risk management; currently, very little action is taken towards adaptation (BEF, 2011). According to Looring (2013, p.8), this is partly due to lack of funding but "it also seems to reflect the lack of dissemination from the topdown and also a lack of discussion among the local actors themselves".

One of the goals that Tallinn aims to reach with its spatial plans and projects is the decrease of the proportion of water-resistant surfaces in car parks and yards, and augment the proportion of green spaces (Tallinn City, 2017b). Immersion of rainwater into the ground has been recommended where possible instead of directing it into sewerage networks (Tallinn City, 2017b). The construction regulation of the city imposes the **minimum greenery requirement**, which is a compulsory share of pervious areas in development locations, since it is an important means of moderating the share of impervious surfaces, particularly in new development projects (Tallinn City, 2017b; Garcia, 2016). Compliance with minimum greenery requirements should normally be addressed in **comprehensive plans**, **detailed plans** and **design projects**. Areas vulnerable to floods should be considered as well when plans and projects are processed (Tallinn City, 2017b).

4.1.5 Summary of policy opportunities and obstacles towards SuDS adoption

Table 4-1 provides an overview of the aspects included in the policy documents that could encourage SuDS installations.

Table 4-1 Policy opportunities for SuDS implementation

Policy type	Specifics	Description
1. EU policies	1.1. The WFD	- highlights the urgent demand of multifunctional strategies (such as SuDS). - encourages the use of drainage solutions that cover other aspects in urban water management, such as runoff quality, visual amenity, recreational value, ecological protection and multiple water uses.
	1.2. River basin management plans	- integrated urban water management examining the overall water supply/drainage cycle and the potential for water reuse, represents an opportunity for fully integrating SuDS. - in river basin planning, SuDS are seen as valuable tools in achieving compliance with WFD objectives.
	1.3. Flood risk management plans	- encourage the use of alternative measures such as SuDS that help reduce the quantity and flow rate of surface water runoff, lowering the risk of flooding at, and downstream of the development.
	1.4. The Urban Wastewater Directive	- SuDS provide excellent opportunity to sustainably improve runoff quality and quantity.
	1.5. The EU strategy for climate change adaptation	- SuDS is designed to handle all types of weather events; can provide localised climate benefits.
	1.6. HELCOM recommendation 23/5	- recommends measures at the source to minimise the volume and prevent the deterioration of stormwater quality. SuDS philosophy is based on dealing with water as close as possible to its source. A wide range of SuDS techniques can be applied at source.
2. Estonian policies	2.1. The Water Act	- like the WFD, it promotes the use of multifunctional and long-term measures.
	2.2. The Estonian standards EVS 848:2013	- supports infiltration based measures, slow conveyance and water harvesting. This encourages SuDS installation.
	2.3. Public Water Supply and Sewerage Act	- possible amendment to this law currently under discussion: development of a stormwater taxation or stormwater fee waiver system to incentivise property owners to deal with the runoff on-site close to its source.
	2.4. Estonia's climate adaptation strategy	- promotes the increase of green areas in city planning as a means to infiltrate stormwater.
	2.5. Estonia's Environmental Strategy	- recommends the development of urban green networks. They could be designed as "eco-corridors" and be used as main transportation routes for stormwater.
	2.6. National Spatial Strategy Estonia 2030+	- encourages the use of more sustainable measures to achieve proper planning and sustainable development.
3. City policies	3.1. Tallinn Development Plan 2014-2020	- mentions alternative measures such as green infrastructure as advisory and location specific possibilities.

	3.2. Tallinn Water Supply and Sewerage Development Plan 2010-2021	- the city wants to renovate its water supply underground system. Water supply system based on rainwater harvesting is considered as a strategic decision.
	3.3. Tallinn Stormwater Strategy to 2030	- supports rainwater infiltration as a potential solution for stormwater control where appropriate and reduction of the proportion of water-resistant surfaces in parking lots and yards. - some of the proposed action plans and activities provide opportunity for a range of SuDS techniques (including green roofs, parks, pervious pavements, etc.).
Urban planning tools	3.2. Tallinn construction regulation	- imposes the minimum greenery requirement in new developments.

Source: Author's own elaboration

Table 4-2 summarises the barriers identified in the policy documents that hinder SuDS adoption.

Table 4-2 Policy Barriers for SuDS implementation

Type	Specifics	Description
1. European and BSR policies	1.1. The Groundwater Directive	- may prevent the application of infiltration based rainwater management practices (thus, certain SuDS components).
	1.2. HELCOM recommendation 23/5	- refers to conventional separated and combined sewer systems to deal with runoff volume and pollution load.
2. National policies	2.1. All identified national policies	- predominance of hard engineered measures suggested to tackle stormwater issues (e.g. the construction of separate sewer systems and the rehabilitation of the combined sewer systems). - very few reference to alternative measures. - although Estonian legislation regulates the requirements for stormwater treatment, it does not have a leading role in stormwater management at source, which should be one of the priority ways to sustainably handle rainwater.
	2.2. Estonia's Environmental strategy	- identified gap: no specific reference to green infrastructures as means to mitigate floods or other stormwater challenges. - provides general directions to mitigate flood risks; recommends to construct rainwater pre-treatment plants. - does not include goals or activities for climate change adaptation.
	2.3. Public Water Supply and Sewerage Act	- since land and building owners can direct the rainwater from their property to sewage or drainage system free of charge, they are not incentivised to deal with stormwater at source. This prevents enforcement of SuDS in private lands.
	2.4. Planning Act	- does not provide details on how local communities and other non public authorities can engage in

		stormwater management projects and participate in decision-making processes.
3. City policies	3.1. Tallinn Development Plan 2014-2020 3.2. Tallinn Water Supply and Sewerage Development Plan 2010-2021 3.3. Tallinn Stormwater Strategy to 2030	- pro-grey measures: lack of alternatives proposed in these policies, especially at source measures. - provide general principles and actions - insufficient consideration to climate change impacts and adequate and long-term adaption strategies
4. Urban planning tools	4.1. Construction regulations 4.2. Design guidelines/standards	- minimum greenery requirement is not strictly enforced in many cases. - absence of SuDS design and maintenance standards, guidelines: codes and manuals adequate to Estonian context conditions are not available.

Source: Author's own elaboration

To conclude this section, it is very apparent from the policy review that **conventional drainage solutions are still favoured** by public authorities instead of alternative ones, especially at city level. However, there is a growing political willingness toward a more sustainable rainwater management advanced by national-level authorities, being themselves pushed by **EU and BSR policy instruments**. Thus, the latters seem to be the key drivers encouraging Estonia including Tallinn to use sustainability innovations to deal with its climate-related challenges and consider added long-term co-benefits for both nature and people. Also, BSR countries like Germany, Sweden and Finland, recognised as leaders for their efforts in developing and testing more sustainable solutions, certainly play a role in boosting neighbouring states to follow their path. Moreover, it is important to underline that following its integration to the EU zone in 2004, Estonia has shifted direction towards the EU environmental requirements relatively recently. Therefore, necessary adjustments will take a certain time before seeing changes in urban planning practices. Beside this, information and knowledge sharing as well as adequate capacity building, access to financial mechanisms, improved collaboration and partnership between stakeholders are among the conditions that need to be present to effectively deploy SuDS.

4.2 Institutional overview and key actors

In the following, only a selection of relevant stormwater actors included in figure 4-3 is listed and their roles in urban stormwater management briefly sketched. Governance opportunities and challenges for SuDS implementation are also discussed.

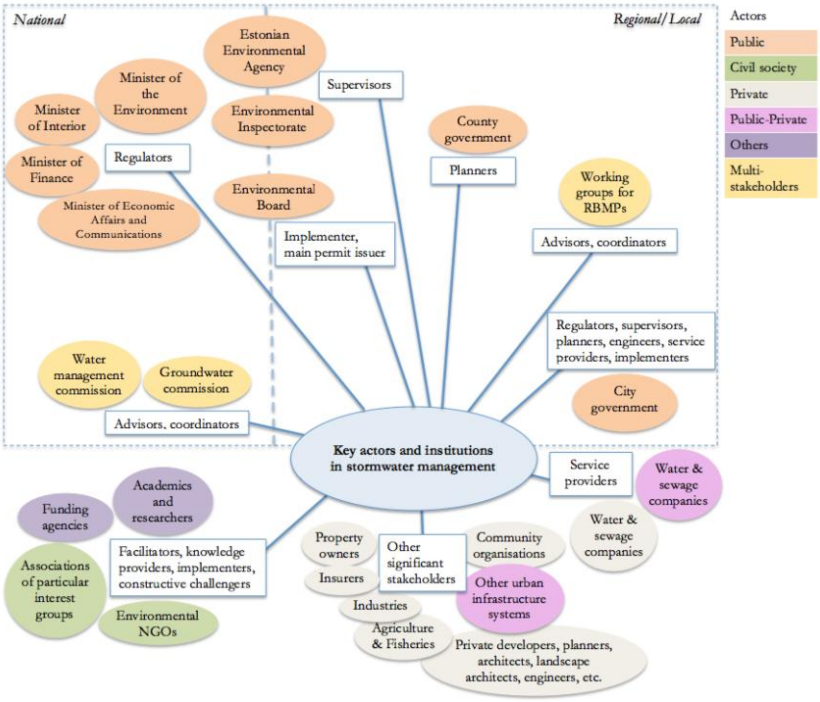


Figure 4-3 Division of roles and responsibilities among key actors and institutions

Source: Author's own elaboration adapted from Osbeck et al., 2013

4.2.1 National-level governance

The **Ministry of Environment** (MoE) is the key national level stakeholder of water management, including rainwater management. Different sub-sectors including the Environmental Board; the Environmental Inspectorate; the Estonian Environmental Research Centre; the Estonian Environment Agency; the Geological Survey of Estonia; the Estonian Meteorological and Hydrological Institute and the Information Technology Centre of the Ministry of the Environment are the main bodies involved in water resource management and regulatory aspects of the sector (Baltic Flows, 2016; Osbeck et al., 2013). MoE is responsible for flood risk management, including updating flood maps, and for developing the Public Water Supply and Sewage Act. MoE is also the responsible authority for implementing the national Climate Change Adaption Development Plan until 2030 (Peleikis, 2011; LIFE, 2017).

The **Ministry of Finance** (MoF) is responsible for the territorial planning legislation in Estonia. Some of its responsibilities include matters important to environmental management – taxation, use of state budget funds, etc. (Osbeck et al., 2013). The **Ministry of Economic Affairs and Communications** is responsible for the building legislation (LIFE, 2017). Some of the responsibilities of the **Ministry of Interior** (MoI) include environment-related tasks concerning the handling and solving of crises such as natural disasters (Osbeck et al., 2013). Some functions of the **Rescue Board** include developing and organising the implementation of a state crisis management policy based on the Emergency Act; and coordinating rescue activities with the Police and the Border Guard Board (MoE, 2013).

4.2.2 Regional and local-level governance

The **County Government** coordinates sectoral policy activities at the regional level. It also supervises the drafting of local level spatial plans (Osbeck et al., 2013).

The **City Government** is the local government's executive body. It fulfils the assignment given to it by legislative drafting, economic activity, control and the involvement of the residents (RTI, 2014). Tallinn City Government (TCG) consists of a total of seven members: the Mayor and six Deputy Mayors. Among its responsibilities, the local government approves and carries amendments into the city's budget; approve, amend and adopt the development plans; and adopts detailed plans (Tallinn City, 2019). The main water management tasks of the city government include organising the supply of water and sewerage, granting consent for permits for the special use of water, arranging the implementation of the programme of measures, flood risk management and protecting water quality in its administrative area (Osbeck et al., 2013). TCG's role is also to shape, plan, and undertake specific climate change adaptation activities (including sustainable urban drainage systems), as this level is best acquainted with the local conditions and facilitates the local initiatives of different institutions and stakeholders (Osbeck et al., 2013). Among the 13 departments composing the TCG, the **City Planning**, **Environment**, and **Municipal Engineering Servives** departments are the main units influencing stormwater handling.

4.2.3 Other stakeholders

In the following, other relevant stakeholders representing public sector, private sector and scientific sector playing an important role in the rainwater management sector are presented.

Private sector

Water and sewage companies: the **Estonian Waterworks Association**, is an umbrella organisation of 47 Estonian water companies and 27 companies providing services for water companies (LIFE, 2017). The managers of water companies are well aware of SuDS, but usually they are sceptical about the possibilities to construct SuDS, their functioning and capacity to handle stormwater. These professionals need to be shown a real life functioning example in their own country to bring along a paradigm shift (LIFE, 2017). The **Association of Estonian Engineers of Water and Sewage Systems** is an umbrella organisation of 87 certified engineers of water and sewage systems. These engineers are trained for and used to manage grey solutions and like the water companies, they are sceptical and full of uncertainties regarding alternative approaches. The **Estonian Water Association** is an organisation uniting 85 legal and physical persons interested in water management issues (LIFE, 2017). The association represents a target group to involve in initiatives such as the UrbanStorm project. It could be used to promote SuDS techniques among Estonian professional audience and trigger wider application of such solutions in Estonia.

Members of the **Estonian Union of Co-operative Housing Associations** (ca 1400 members): Co-operative Housing Associations are constantly enlarging parking areas around apartment buildings, often by decreasing the green areas and not investing into proper drainage solutions (LIFE, 2017). In many cases, a combination of SuDS solutions would help these associations to maintain the aesthetic surroundings of their apartment buildings and minimise the risks of flash flooding.

Real estate developers (ca 20-30 more active companies) have so far been very modest in using SuDS solutions, to large extent due to low awareness level about SuDS. However, in new residential areas and especially at the large parking lots of shopping centres and bureau buildings, SuDS solutions would help to diminish the urban heat island effect and impacts of heavy rainfall (LIFE, 2017).

Civil society

Several **non-governmental organisations** (NGOs) deal with environmental problems and raise awareness of matters related to the environment and sustainable development (Osbeck et al., 2013). Some NGOs have taken an active part in the development of projects and lobbying activities for better stormwater planning in Estonia.

Universities: So far, very few Estonian universities teach students on the topics specifically related to stormwater management and the potential use of SuDS (e.g. civil engineering, environmental engineering, urban planning and architecture programmes) (LIFE, 2017). Thus, cooperation with these universities in terms of capacity building of local SuDS specialists would be essential to create conditions fostering SuDS adoption.

The **local community** of Tallinn (ca 445 000 inhabitants) is probably the least informed stakeholder group about SuDS. However, raising their knowledge should lead to a considerably decreased runoff of stormwater to the municipal stormwater collection systems (LIFE, 2017).

In the context of the UrbanStorm project, all the abovementioned actors are considered as crucial target groups to ensure its successful implementation and possible replication in other Estonian localities. A series of outreach and discussion sessions, as well as trainings and other communication activities are planned for this target audience.

Financial actors relevant to stormwater management and innovation programmes

For the entire Baltic Sea region, the **European Union** is the main financial actor relevant to innovations in urban stormwater management. Other actors vary from national government ministries to research foundations. In Estonia, the financial actors include **Ministry of Environment** and the foundation **Environmental Investment Centre** (EIC) funded by the MoF, the **Local government** and **water companies** (BalticFlows, 2016).

From a stakeholder survey undertaken by Nõmm et al. (2014), it was found that local municipalities mainly financed public sector organisations whereas private sector organisations relied on private capital. Only academic institutions were funded by respective national budgets. Furthermore, the EU greatly contributes in the financing of private sector organisations and academic institutions.

4.2.4 Summary of the main governance opportunities and challenges towards SuDS adoption

Table 4-3 Governance opportunities and obstacles towards SuDS adoption

	Specifics	Description
1. Governance opportunities	1.1. Presence of a variety of stakeholders playing a role in the sector	- need for collaborative planning and governance - collaboration is needed because SuDS elements use natural processes and are distributed throughout the landscape controlled by activities of different actors
	1.2. EU/City-supported/private initiatives	- existence of programmes and projects sponsored by the EU, local authorities, and private actors to promote the use of innovative stormwater solutions (e.g. pilot projects to test NBS/SuDS measures, feasibility studies, etc.)
2. Governance obstacles	2.1. Lack of financial incentives	- no direct financial benefit for private landowners to implement SuDS. - lack of financial resources allocated for alternative drainage measures
	2.2. Insufficient financial resources	- lack of funding arrangements such as public/private investments on SuDS
	2.3. Lack of awareness, knowledge and technical expertise	- lack of skilled and experienced staff who know how to develop SuDS techniques - need for more demonstration projects in Estonian context
	2.4. Pro-grey governance and mindset	- highly technocratic and centralised governance; unilateral decision-making processes - decision-makers and local residents accustomed to grey solutions and unaware of harms/benefits of grey/alternatives
	2.5. Lack of political leadership and support	- scepticism towards SuDS and reluctance to change: city agencies still favour conventional hard engineering solutions
	2.4. Fragmented responsibilities and lack of coordination	- fragmented spatial and functional jurisdiction: existing fragmentations of governance, due to the presence of multiple authorities with multiple (sometimes conflicting) visions and goals - limited coordination within government agencies
	2.5. Lack of public engagement	- ineffective communication and information sharing - lacking collaboration with stormwater generators and other local stakeholders out of the government offices. Citizens have limited role in decision making.
	2.6. Minor importance attached to climate change adaptation so far	- missing strategic approach regarding this issue; little action taken to implement climate-resistant and sustainable adaptation measures

Source: Author's own elaboration

To conclude this section, although national–level authorities, mainly the MoE, initiate policies to bring the city's water management infrastructure into conformity with EU directives and other international regulations; **proceedings, planning decisions and management responsibility are on the city government**. In this regard, visions, priorities and goals for the sector among public institutions from different levels might sometimes differ and result in inconsistencies. It appears that the existing stormwater governance in Tallinn is **highly centralised and mostly technocratic**, in which engineers and to some extent planners of designated city agencies centrally manage storm runoff through a command-and-control approach. These experts are trained for, experienced with, and apt to design, develop, maintain and fix hard engineered infrastructure, not nature-based installations. This approach encourages in some way reluctance to adopt SuDS techniques. What is more, they give less opportunity for public involvement. This is in turn inherently inappropriate for SuDS, which require extensive public participation.

Adding to this, actors, both within and outside the government agencies, have **little knowledge on the outcomes of climate change**. According to a Eurobarometer survey conducted in 2017, Estonians' awareness of climate change, of adaptation to the impacts of climate change, and of the measures for the management of climate-related risks is among the lowest ones in Europe. Very little action is thus taken towards adaptation at the moment.

Beside a **lack of coordination between government entities**, there is also a **lack of collaboration of these actors with other relevant stakeholders** including representatives from landowners, community and civic organisations, environmental organisations, and businesses. With regards to the **lack of public participation** when the city solicits its involvement in programme development and implementation process, one of the reasons for this is that, besides a one-time fee for the connection to public sewage networks and the monthly fee for water service, landowners do not have to pay for the rainwater handling costs directly from their pocket, because the budget comes from the city's general revenue funds, thus they might perceive stormwater management only as city's responsibility, not theirs. **There is currently no incentive for landowners to participate in the governance.** Due to this, the public may not show much concern to stormwater governance activities, which potentially leads to lack of transparency. Further, it is worth noting that the Planning Act does not describe in what ways or how different stakeholders should be included and informed, nor does it explain how to arrange discussions or cooperate (Holvandus, 2014). In a study conducted by Holvandus and Leetmaa (2016) investigating the perceptions of neighbourhood associations on the current planning practice in Tallinn, one of the main findings was the perceived lack of initiative or interest from the local government to include the neighbourhood associations in the urban planning process.

As pointed out in some studies, **current governance regime constitutes a major barrier to mainstreaming of SuDS solutions** in cities, which seems to be the case for Tallinn. However, the stakeholder review has also allowed identifying opportunities for SuDS inclusion into the city's stormwater management options. For example, the **various groups of actors** who through the building of a collaborative planning and governance system could play a more active role in decision-making and in advancing SuDS innovations. Also, the development of several **pilot projects** supported by public, private or academic entities is essential to demonstrate SuDS feasibility and effectiveness to potential adopters.

5 Results, analysis and discussion

This chapter provides a description, analysis, and discussion of the results obtained from the survey conducted on stakeholders' perceptions towards alternative stormwater strategies to conventional drainage systems (RQ1), the decision-support methods to detect flood-prone areas (RQ2) and select SUDS solutions where appropriate (RQ3).

5.1 RQ1: Stakeholders' survey

5.1.1 Results, analysis and discussion

How stormwater stakeholders' perceptions of SuDS measures could influence their attitudes toward adoption?

Sub-questions:

- *Which perceived attributes of SuDS practices contribute to respondents' receptiveness toward adoption?*
- *What factors could influence their attitudes towards SuDS adoption?*

Before presenting the survey findings, it is worth reminding that the terms "sustainable (urban) drainage systems" or "SuDS" were replaced by "Green infrastructure" in the questionnaire administrated to the target audience as Estonian parties are more familiar with this wording as a reference to alternative and innovative stormwater management solutions. However, to avoid confusion for the reader, the term SuDS will be continuously used throughout the following lines.

As shown in figure 5-1, in total, 17 individuals filled out the questionnaire. Over the 8 identified organisations for which the respondents work, 5 are public agencies (4 local and 1 national levels). The other organisations are from the academic, NGO and private sectors. The biggest group who participated in the survey is part of **Tallinn Urban Planning Department (TUPD)**. It is closely followed by **Tallinn Environment Department (TED)**. Regarding this latter, it was decided to include Tallinn Energy Agency as part of TED, as this institution is in its jurisdiction dealing with planning and development of energy efficiency and climate change adaptation and mitigation (Tallinn website, 2019). Since the number of participants representing each organisation is too small to identify clear patterns for each organisation, except to a certain extent for the two biggest groups, it was decided that for each question the general trend for the whole sample of respondents will be described and then the perceptions of representatives from TUPD and TED will be compared. The two biggest represented groups, individuals working for TUPD will be labelled as "planners" and those working for TED as "environmentalists".

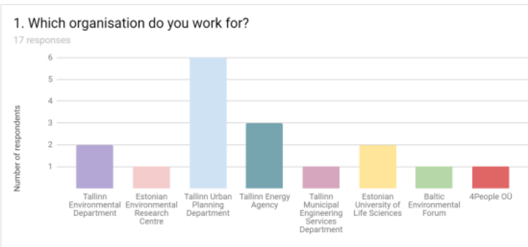


Figure 5-1 Survey questions 1-3

Most respondents work in an environmental and natural resources office or in a planning office, followed by the engineering field (see question 2, Appendix C, p.102).

Also, **it was observed that 70% of the respondents consider flood issues in Tallinn to be between "moderately" to "very" severe; the rest believes that it is "not very" severe** (see question 4). None of them answered extreme options (not at all or extremely severe). With regards to planners and environmentalists, both consider that flood problems in the capital are "not very" to "moderately" severe. A possible explanation might be that urban flooding is a growing issue becoming more and more apparent in the last decades. For that reason, in Tallinn Stormwater strategy (RTI, 2012), the first priority action is to raise awareness of flood risk and make it a priority in the rainwater action plan and in comprehensive plans. Besides, a survey was conducted in December 2018 (TMP, 2018) within the framework of the UrbanStorm project at the request of Tallinn Municipal Engineering Services Department to investigate the awareness of the environmental problems related to excess rainwater among residents from Nõmme District. It was found that from the 101 respondents, 12% of respondents had experience with rainwater runoff overflows in the vicinity of their houses and over 50% of respondents declared their houses were not subject to rainwater issues. The main problems were for the residents living in private homes. Indeed, 60% of people living in private houses had experienced flooding problems compared to one third of people living in a terraced house or apartment building who faced such issues. Therefore, it seems like depending on where people live, if they faced problems themselves, close to where they live, they will have a greater awareness of the issues. Additionally, all respondents claimed they had heard about flooding issues caused by heavy rains in more densely populated areas of the city (survey reference). These findings could also be correlated to results from the 2017 Eurobarometer according to which Estonians' awareness of climate change related issues and flood risks is very low, which explains the importance of implementing communication and information dissemination activities in the city.

All the respondents including planners and environmentalists "strongly agreed" or "agreed" that there is a need to improve the stormwater management in Tallinn to reduce flood risk (see question 5)**.** Surprisingly, even the respondents who did not believe local flood problems to be very severe agreed that the way stormwater is currently handled should be enhanced. First, the reason might be because stormwater management not only deals with flood mitigation but also pollution load contained in the rainwater runoff. As revealed through the literature review, the quality of urban runoff is a big concern in the capital and significantly affects the status of surrounding waterbodies. It is also acknowledged that a large number of sewer systems are out-dated and often clogged causing local floods. Furthermore, local authorities are required to comply with environmental standards set under the EU Directives and HELCOM recommendations transposed in the national laws and policies. In this sense, as confirmed in the policy review, **EU and the Baltic Sea region policies represent an important driver** for innovating the way stormwater is being handled. Finally, another reason might be a typical tendency or willingness among decision-makers, especially municipal officials, to show their commitment to good and responsible governance and to constantly act towards the improvement of their citizens' living conditions.

Most respondents (76%) believe they are "very" to "extremely well" informed about SuDS structures (question 6). Expectedly, environmentalists consider that they are "very" to "extremely well" informed about SuDS. On the other hand, the perceived knowledge about SuDS for planners tends to be more moderate to "not very well". **Over 70% of the respondents stated that they already had experience working with SuDS techniques and among them the majority (75%) rated SuDS performance as "very" effective** (question 7); the rest considered it to be "not very" to "moderately" effective. Planners and environmentalists followed the general trend, as there were more respondents who had already experiences with SuDS than those who did not. Interestingly, planners were more satisfied with SuDS performance than environmentalists. The perceptions of the latter were more nuanced between "not very" to "very" effective. To connect this finding with the one for question 5, the medium result for the environmentalists may be due to the fact that they deal more often with this kind of solutions thus their effectiveness or benefits may not be that surprising for them. On the other hand, planners have a better comparison between traditional solutions and SuDS techniques, which might highlight a better-perceived performance.

In general, the understanding of the functioning of SuDS is good among participants, as see in figure 5-2. **More than 80% of the respondents "strongly" or simply "agreed" that they did not have any difficulties understanding the concept**. This suggests a favourable disposition for future SuDS acceptance. Planners and environmentalists follow the general trend with the latters being more assertive about their understanding as they all "strongly agreed" with the statement. This emphasises that they might have more experience and familiarity with the concept and its features than the city planners. Again, this confirms results from question 5.

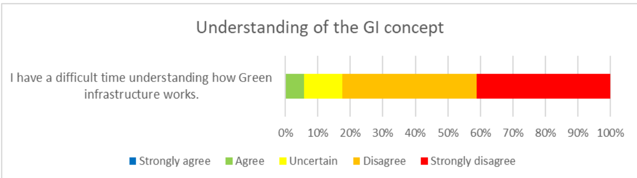


Figure 5-2 Survey question 9-1

With regards to the perceived usefulness, all the respondents thought that the SuDS techniques could be useful for stormwater management in Tallinn; however, they should be combined with conventional solutions (see figure 5-3). The result can thus increase the likelihood of a future SuDS adoption. However, it is worth mentioning that almost 30% believed traditional infrastructure alone to be more reliable and effective than SuDS. Regarding planners, their perceptions are unbalanced as the same number of respondents "agreed" and "disagreed" about the statement stipulating that conventional rainwater systems are more reliable than SuDS. This shows a degree of uncertainty about the perceived advantage of SuDS solutions compared to hard engineering techniques. On the environmentalists' side, opinions are more favourable towards a combination of traditional and alternative stormwater measures. To a certain extent, this ties in with results obtained from an UrbanStorm project survey conducted in Nõmme District, stating that 91% of respondents thought that rainwater drainage would be best served by the construction of new sewerage and stormwater pipe networks. The planting of trees (23%), the creation of water bodies (21%), reducing the use of hard surfaces such as asphalt or stone pavement (20%) were almost equally supported (TMP, 2018). Both findings confirm the pro-grey mindset among many municipal officials (in particular engineers) and local residents. For the latters, this also demonstrates a lack of awareness, observability/experience of other types of measures, which is not in favour for an increased rate of SuDS adoption among these actors.

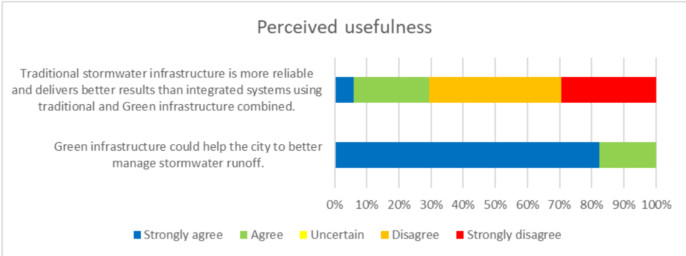


Figure 5-3 Survey question 9-2

In general, respondents had positive perceptions of each SuDS benefit indicated in question 9.3 (see figure 5-4). Therefore, **more than 80% of the respondents "strongly agreed" that SuDS are multi-functional**, corresponding to the seventh statement included the question. This implies that most respondents acknowledge that SuDS have greater value beyond water quantity and quality management and thus are better than conventional measures. Following the innovation diffusion theories, this result looks very promising for supporting future SuDS adoption. The greater the perceived relative advantage of an innovation is, the quicker its rate of adoption is likely to be. Thus, highlighting the multiple benefits of SuDS schemes among the different stakeholder groups is likely to increase their positive attitude towards adoption.

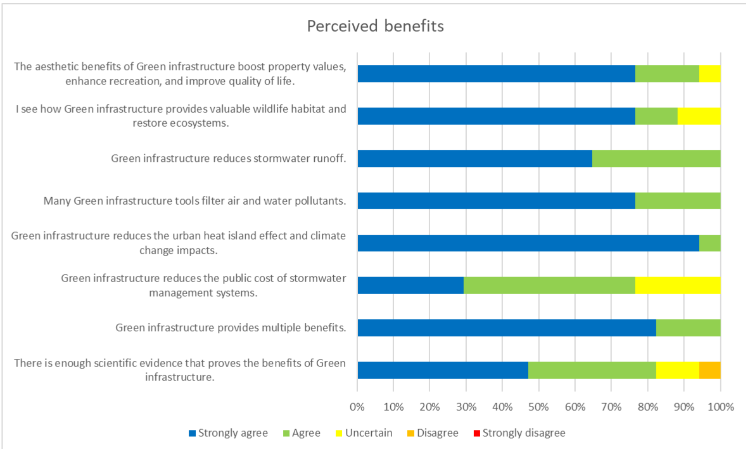


Figure 5-4 Survey question 9-3

The cost-effectiveness associated with SuDS implementation and the lack of scientific evidence seem to be the least clear aspects for some respondents. This matches with findings from previous studies exposing the need for more assessments of the cost-benefit of installing SuDS techniques (e.g. Kabish et al., 2017). With regard to the missing evidence of SuDS co-benefits, studies like Lee and Yigitcanlar (2010) argue that the problem is not that there is insufficient research about these approaches but rather an insufficient share and transfer of knowledge among actors playing a role in the decision-making processes.

Both planners and environmentalists "strongly agreed" on the aesthetical value of employing SuDS elements to improve human quality of life and well-being. In terms of flood risk mitigation and pollution control perspective, it is worth noting that this benefit is usually not prioritised for the selection of traditional drainage approaches. In contrast, as stated by some scholars like Shuttleworth et al. (2017) and Matsuoka and Kaplan (2008), the aesthetic value of SuDS components such as green roofs can often be a dominant factor in its adoption. As highlighted by the landscape architect during an informal interview: "People buy with their eyes! You always buy by the box, the package! It is the same for SuDS, the first decision: the look. Importance of demonstration sites Questions were raised if some actors might believe this attribute to be overrated; and hence be reluctant to integrate SuDS, thinking that their advantage is more aesthetical than functional. However, no publications focusing on this matter were found to confirm this hypothesis. This could be an interesting aspect to further investigate among stakeholders in order to verify if it is a real concern for some actors.

Furthermore, **similar as the general trend, it is also apparent for both planners and environmentalists that SuDS can provide valuable wildlife habitat and restore ecosystems**. Interestingly, among the environmentalists, one respondent answered that he/she was uncertain about this statement. This brings to light that some environmentalists are more sceptical that SuDS can actually restore ecosystems; they may concede that SuDS components can help but might not have the capability to restore an entire ecosystem. It was later found that this respondent works within an engineering department and she/he might not have enough scientific information to be convinced about this statement.

Both planners and environmentalists also "strongly" or simply "agreed" that SuDS have the capacity to reduce both stormwater runoff quantity and pollutant load, which reveals that these actors generally recognised the efficiency of SuDS for flood and water management. Besides, **most of these actors "strongly agreed" that SuDS could reduce the urban heat island effect (UHIE) and climate change impacts.** This result is quite interesting and has raised certain questions for the author. For example: *Do all stakeholders really understand in what way SuDS lower UHIE and climate change effects?* Or *is it because these topics are becoming trendy and strongly emphasised in the EU policy agenda that respondents tend to unanimously agree with this statement? Is it more a question of political interest than a true conviction based on known scientific facts?* These questionings would be interesting to explore in a future research.

With regards to the cost-effectiveness of SuDS options compared to traditional drainage techniques, intriguingly, urban planners almost all "strongly agreed" with this statement. Again with moderation, environmentalists all simply "agreed" with the statement. Following their numerous perceived advantages, the author wondered: *why are SuDS not widely applied yet in Tallinn if most respondents especially city officials consider the cost-efficiency attribute to be a decisive factor for decision-making?* In the reviewed literature, the cost-benefit assessment of SuDS and equivalent approaches is often underlined as a knowledge gap to further investigate; yet, stakeholders who participated in the survey seem to be already persuaded about this aspect. One explanation might be that most respondents already had experience with NBS/GI/SuDS-related projects (e.g. UrbanStorm, Drain for Life, Baltic Flows projects, etc.) thus they might already be informed about it.

The majority of planners and environmentalists believed that SuDS are multi-functional, with the latters being the most assertive about it. However, one respondent among this group was uncertain about this statement; again it was found that this individual was from an engineering department, which emphasizes that based on the professional remit of respondents, they might not be fully aware about SuDS-induced positive impacts. As exposed in the literature review, engineers are typically more literate about traditional grey solutions and the cost-benefits assessment for these techniques is more consolidated among these actors.

Regarding the perceived resources, no one selected extreme options (i.e. strongly

disagree or strongly agree); in general, respondents were uncertain about this aspect (see figure 5-5). Environmentalists were more inclined to "agree" with the statement about the costs associated with SuDS deployment. In contrast, city planners did not have a consensus about it. There is currently no market in Tallinn and generally in Estonia to include SuDS techniques into common stormwater strategies, thus implementing this kind of measures is still incipient and expensive, as most technologies, experts and capital are likely to come from abroad. No respondents answered that they strongly agreed with the second statement stipulating that there is sufficient level of knowledge and skills to apply SuDS options. Both results are in line with findings from the stakeholder overview that there is not enough skilled staff and available financial capital for SuDS implementation.

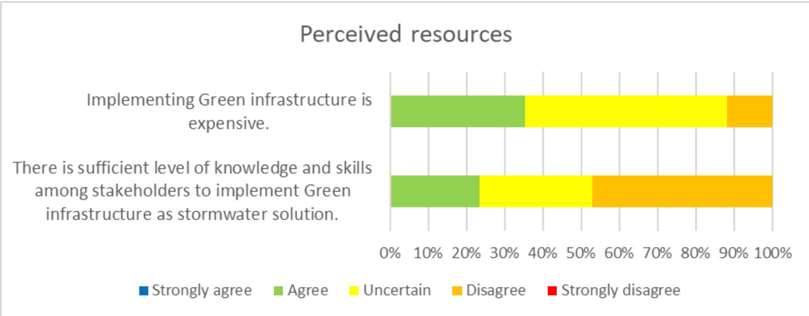


Figure 5-5 Survey question 9-4

Almost 50% of the respondents either believe that there are currently no incentive mechanisms in place to support the use of SuDS techniques or either did not know if such instruments already exist (see question 10, Appendix C, p.105). This outcome matches with the findings obtained from the stormwater governance overview. It also reflects a certain **lack of awareness and communication** between and within public agencies, as a majority of respondents from these organisations were uncertain about mechanisms currently in place. The lack of shared information is a fact that was pointed out in previous studies, such as Holvandus and Leetmaa's (2016) investigation on the building of collaborative spatial planning and governance in Tallinn.

As seen in figure 5-6, **almost 60% of the respondents believed parks to be the most applied SuDS elements, followed by green roofs with almost 40% of positive answers**. The first result echoes planned initiatives and programmes formulated in and Tallinn Development Plan and Environmental Strategy such as the creation of a green network for wildlife preservation, nature tourism development, and improved residents' access to green areas. Parks in those cases were not considered as possible stormwater control measures. The second result might refer to recommendations indicated in Tallinn Stormwater Strategy, which suggest the use of at source measures such as green roofs to lower storm water runoff. Apart from that, the general tendency is that **respondents do not know if the city is active in promoting SuDS techniques through programmes, policies, initiatives, etc**. Again, this might highlight the **lack of coordination and communication** between and within public institutions but also with their non-governmental partners.

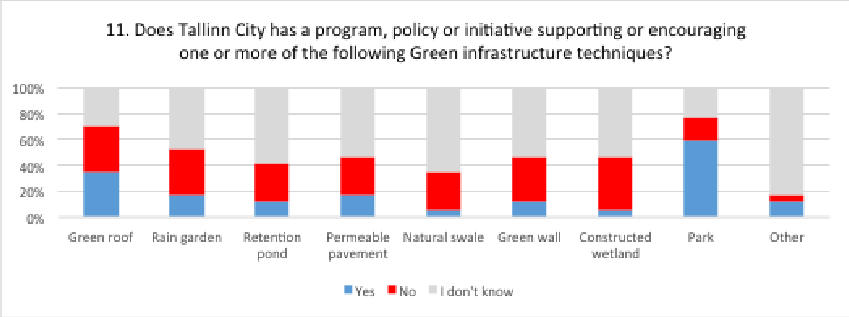


Figure 5-6 Survey question 11

The findings revealed that the general problems associated with stormwater governance previously discussed remain in place preventing the mainstreaming of SuDS. As noticed in the policy review, the city agencies have taken little initiatives to motivate their staff or other actors to implement SuDS through approaches such as adopting new manuals, providing incentives or programmes to support SuDS techniques. As exposed in previous studies, these governance and policy obstacles also prevail in other cities around the world. As an example, a comparative study of urban stormwater management in US and Australian cities by Roy et al. (2008) identified similar shortcomings including fragmented responsibilities, lack of institutional capacity, lack of legislative mandate, lack of market incentives, and resistance to change as major barriers in both countries.

As illustrated in figure 5-7, the **lack of political leadership and support (e.g. policies, rules, actions, etc.) is clearly perceived as the main barrier for SuDS inclusion in the city's menu of stormwater solutions.** This finding concurs with the previous results underlying the lack of initiatives, policies or incentives from the local authorities for supporting SuDS adoption. Other studies have highlighted this barrier has the largest hurdle (e.g. O'Donnell et al., 2017). This relates with the second most prominent barrier, which is the **lack of knowledge, education, and awareness** of SuDS. Even though most respondents consider themselves to be well informed about SuDS, they also tend to believe that the current level of knowledge and skills is inadequate to diffuse SuDS innovations. **Funding and costs** related to SuDS practices was also ranked highly among respondents, which concurs with results obtained for question 9.4 (figure 5-7) exposing a general uncertainty about the capital costs associated with these measures. However, the fact that it was not chosen as the most important obstacle is also revealing. Even though most respondents are unaware about the necessary budget for SuDS implementation, they also generally perceived that their costs might be less than conventional infrastructure. The rationale might be that the sustainability of SuDS requires longer term funding commitments (as stated by O'Donell et al., 2017), and this constitutes a significant downside for some respondents. This might also suggests a certain institutional inertia and preference for already established practices.

Overall, **these three major barriers confirm claims of previous studies that socio-institutional barriers more than technical ones are the greatest hindrance to SuDS adoption**. At the present time, there is no strong political will (particularly visible at local level) to change practices despite their known benefits. Still the favoured approach is to transfer the problem further downstream. Similar as findings from the UrbanStorm project's survey (December 2018), there is a clear preference for rapid, short-term solutions as long as there is no urgency and the problem is not in front of their eyes; there is no willingness among decision-makers to take risk by employing non-familiar approaches.

Moreover, **funding and costs are major concerns for most environmentalists** as this option was systematically choosing among their first three barriers. For planners, there is no consensus on this particular barrier; each of them chose different options. **For both actors, the lack of political leadership and support is one of the most important barriers; this is even more apparent for planners**.

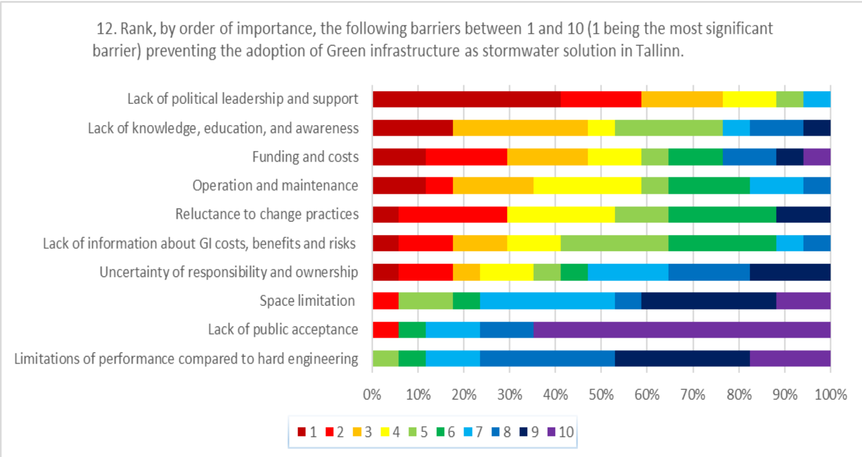


Figure 5-7 Survey question 12

The following four options (i.e. operation and maintenance; reluctance to change practices; lack of information about costs, benefits and risks; uncertainty of responsibility and ownership) are relatively important if one considers the number of times that they were selected as being the first or second most important barriers. **The three last barriers were perceived (i.e. space limitation, lack of public acceptance, limitations of performance compared to hard engineering) as the minor ones**. The lack of public acceptance was ranked as the least important obstacle by more than 60% of respondents including planners and environmentalists, which suggests that local communities will not question or oppose SuDS deployment initiatives. However, this contrasts with results from the UrbanStorm project concluding that 91% of local residents would rather choose conventional measures over their alternatives. Also, based on the revision of previous works (Wang et al. 2018; Li et al., 2017; van de Meene et al., 2011), it was found that public acceptance and resistance to novel approaches due to ineffective public communication, a lack of knowledge about overall significance of NBS/SuDS/GI concepts and limited community engagement is perceived as an important challenge in several places. This finding thus reveals a disconnect between city officials' perceptions and local residents' opinions. Then, as the latters represent the least informed group about SuDS, massive and regular outreach/educational campaigns for promoting pro-SuDS approaches as well as opportunities for community involvement in planning processes are definitely required.

5.2 RQ2: Flood susceptibility mapping

How can the use of a GIS-based multi-criteria analysis technique help identify flood-prone areas in Tallinn?

Sub-question:

- *Where in the city is stormwater flooding likely to occur?*

The following lines present and discuss the results obtained for the catchment in Tallinn region after applying the GIS-based method developed by the author and described in the methodology chapter. First, the flood susceptible areas are presented. Second, the focus locations considered as suitable SuDS sites to prevent future flooding are listed.

5.2.1 Results and analysis: the flood-prone areas

As a result of implemented method, the flood susceptibility map for Tallinn area was derived (see figure 5-8). The final map and associated table (see table 5-1) shows that **flood susceptibility is the highest in Lasnamäe district** (east side of the city) as 50% of its territory has low to very low water infiltration potential due to an extending share of impervious surfaces (32%), a very low percentage of green areas (17%), and a lithological composition predominantly made of bedrock outcrop, peat and moraine deposits, all considered as highly impermeable rock types. Besides this, the slope values are relatively low across the whole city; this characteristic decreases the speed of surface runoffs when a torrential rain happens as learned from the reviewed literature (Tucci, 2007). On one hand, this favours rainwater infiltration into the ground and aquifer recharge; on the other hand, it also increases flood generation, as the water volume is able to accumulate and stagnate where the groundwater level is only a few meters deep from the surface and quickly reaches its maximum. Therefore, **the city area is naturally predisposed to local flood problems.** This confirms claims of previous studies conducted on this topic in Estonia such as Jüssi et al. (2015). In addition, over 30% of the district is covered by sinkholes (see table 5-1), a number of which are located in highly populated and paved zones such as Laagna street, a major road which crosses the district from east to west and many production facilities situated in the southern part. Multiple studies have demonstrated that zones adjacent to sinkholes are subject to inundation when runoff rates exceed sinkhole drainage rates or when flood runoff passing through caves causes waters to rise through over-lying sinkholes (among others Crawford, 1984 and Currens and Graham, 1993). Sinkhole flooding may also trigger the formation of new sinkholes (Hyatt & Jacobs, 1996).

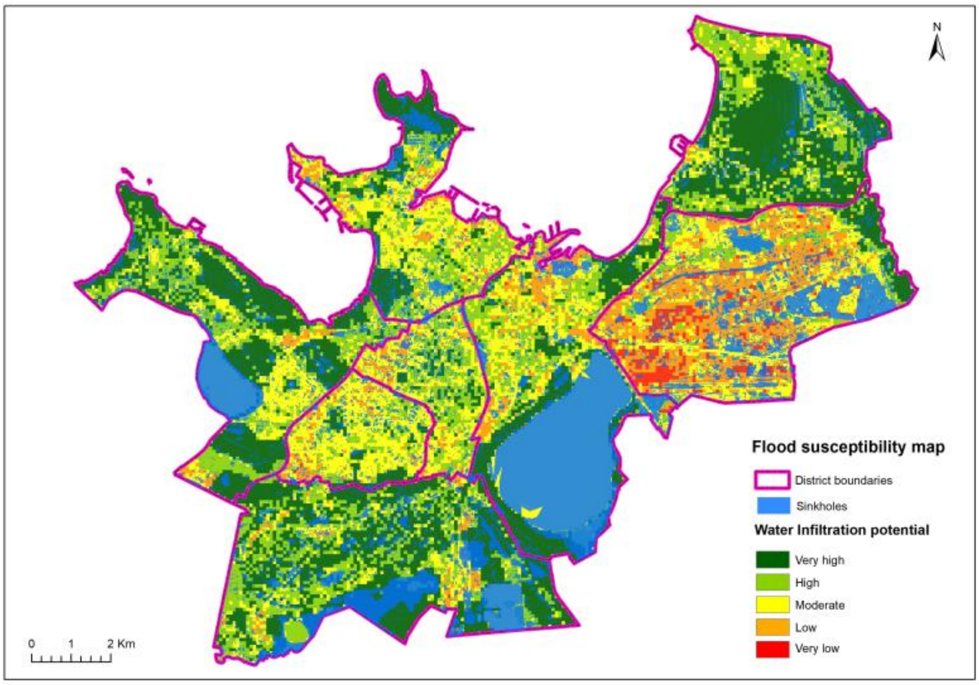


Figure 5-8 The flood susceptibility map

Source: Author's own elaboration - (larger format in Appendix G, p.117)

Table 5-1 Quantitative data obtained from GIS analysis

		Population			Percentage of water Infiltration potential					Sinkholes	Green areas	Soil imperviousness
District name	District area (square meters)	No of people per disctrict	Percentage of people in each district	Population density per district (per hectare)	Very High infiltration potential	High infiltration potential	Moderate infiltration potential	Low infiltration potential	Very Low infiltration potential	Percentage of sinkholes per district	Percentage of green areas	Imperviousness percentage per district (per hectare)
Haabersti	22320347.52	41226	10.50	18.50	44.70	27.67	25.35	2.21	0.07	24.74	58.98	14.02
Kristiine	7833977.09	30292	7.72	38.59	10.28	35.09	43.52	11.11	0.00	18.04	34.58	42.47
Mustamäe	8091407.71	61418	15.65	75.54	12.64	18.79	56.81	11.49	0.27	14.49	16.48	40.81
Nõmme	29172668.59	35517	9.05	12.19	52.23	29.45	15.14	3.16	0.02	58.53	71.90	13.76
Põhja-Tallinn	15189478.09	53306	13.58	35.19	26.20	26.94	37.72	9.10	0.05	17.38	40.52	32.68
Kesklinn	30565457.50	46710	11.90	15.32	24.83	15.65	51.10	8.09	0.33	46.15	41.78	20.81
Pirita	18729425.97	15940	4.06	8.50	56.79	30.76	11.83	0.62	0.00	11.62	75.10	9.56
Lasnamäe	27468159.60	108067	27.53	39.30	4.99	10.06	34.96	40.56	9.43	32.22	17.35	31.49

**dark red is the highest value, dark blue is the lowest value*

Source: Author's own elaboration

Other areas potentially prone to pluvial flooding are found in the middle-north of Kesklinn district, and close to the coastline, which makes them simultaneously exposed to coastal flooding. Moreover, **lands nearby major water bodies such as Ülemiste, Harku and Raku Lakes respectively scattered over Kesklinn, Habeersti and Nömme districts**[3] **are at risk of flooding in case of heavy rainfalls**. As seen in the map, these watercourses act as big sinks susceptible to overflow when reaching capacity. The surrounding spaces mainly contain low-lying green surfaces of high to moderate soil infiltration potential decreasing possible social and economic damages.

Regarding other districts' susceptibility to floods, **Mustamäe** is the smallest and most densely populated district. It has the second highest impervious surface coverage with the lowest percentage of green areas. **Kristiine** follows the same pattern but not at the same magnitude. **Pohja-Tallinn** District seems to be the most balanced territory with medium value of imperviousness, green areas, and classes of potential infiltration are well distributed.

According to the flood-related factors used in the proposed GIS-based approach, the areas identified as **the least prone to flood hazards are located in Nömme and Pirita districts**. Much of these residential suburbs are occupied by vegetation including types of green elements (i.e. forests and parks) allowing greater water absorption. What is more, proportions of built-up lands are the lowest ones among Tallinn's 8 districts. The high infiltration potential of their soil is also due to the influence of its predominant sandy texture. Haabersti would follow as the third less exposed district to flooding risks.

5.2.2 Selected locations for possible SuDS solutions

This section presents the focus areas that were selected for further site assessment for potential SuDS development (see figure 5-9). It is important to keep in mind that the purpose of this step was not to prioritise most susceptible areas but **areas with different land uses and site characteristics in order to propose a diversified panel of SuDS practices to potential adopters such as developers, planners, water managers, local authorities and other relevant stormwater stakeholders**. In addition to the criterion maps generated to obtain the flood susceptibility map, other thematic maps (i.e. population density, surface water flow accumulation, and land use) were created to analyse the area and better visualise the flood susceptibility impacts among local communities (see Appendix G, p. 118-119). This analysis helped select the focus areas based on four main criteria, as explained in the methodology chapter: flood susceptibility, inland flood risk, representativeness, and site characteristics.

[3] See the location of Tallinn's districts in Appendix A, p.96.

In total, 6 focus areas were selected:

1. a residential area with one-family dwellings and private gardens (Pohja-Tallinn District)
2. **a parking lot located in a commercial area (Liivalaia Street, Kesklinn District);**
3. a major road (Laagna Street in Lasnamäe District);
4. a mixed land use with a green area and parking lot (located close to residential-industrial area – Kesklinn District)
5. a residential area with apartment buildings and no or few green spaces (Mustamäe District)
6. one of the SUDS demonstration sites selected by the City (Nömme District)

For the purpose of the third research question, the focus area n°2 was used as a case example for the application of the SuDS selection tool (RQ3).

Figure 5-9 Localisation of the 6 selected focus areas

Source: Miguel Villoslada, 2019

5.2.3 Discussion

This section discusses some of the most interesting results that were obtained after applying the geospatial method.

Lasnamäe District

In most maps produced to answer RQ1, this district consistently appeared as a problematic case reuniting almost all of the worst conditions in terms of soil infiltration potential, imperviousness degree, share of green infrastructures, etc. for preventing flood occurrence in cases of heavy rain. It immediately appeared as the most exposed area and the most in need of sustainable solutions for flood risk protection. Not only it is the most populated district, it is also the poorest one in socio-economical terms. Moreover, it concentrates intensive development of production facilities which increases its exposure to water contamination. The instalment of new drainage systems and which effectively filter pollution is crucial; a combination of both hard engineering and SuDS structures would be required as effluents generated by industrial activities might potentially harm the surrounding natural environment. A big portion of areas with low to very low infiltration potential corresponds to building footprints. The degree of soil sealing is continuously growing, which favours surface runoff. Based on the little data available in Tallinn Stormwater Strategy (RTI, 2012) on the existing rainwater drainage networks, it was found that drainage water is discharged by grubbed ditches and mainly depreciated pipelines that do not ensure sufficient water drainage. The drainage elements are poorly maintained. When going through this policy document, it was also discovered that few repairs or constructions of rainwater drainage installations are planned for this district (cf. figure 2-2 in chapter 2). All these negative indicators raise concerns about possible gentrification and environmental injustice in this area. It would be interesting to further explore this case further in a future research to understand the conditioning factors behind its problematic situation and propose the best measures for improvement.

Validity of the suggested method

The Estonian Meteorological and Hydrological Institute does not keep an updated inventory of flood events and flood points. Additionally, no previous studies about Tallinn using different methodologies were found to compare the susceptibility-prediction results. Therefore, it was not possible to verify through these methods if the locations considered at risk to flood in this study have already experienced inundations. However, it was possible to validate some of the results in reviewing local newspapers accessible through Internet, which have reported previous flood episodes in the city. It was then found that the aforementioned flood-prone area indicated in the middle-north of Kesklinn district (i.e. Tuukri, Lootsi, Jõe and Ahtri Streets) has been frequently affected by flash floods (Postimees, 2016a). As indicated in figure 5-10, several other potential flood-spots have been validated including Veerenni area, the Stockmann-Liivalaia-Tartu Maantee crossroads (ERR News, 2018), Ülemiste shopping centre, the beginning of Laagna Street, etc. (Postimees, 2016b).

Figure 5-10 Validated flood-spots

Source: Author's own elaboration

Limitations and identified opportunities for model improvement

The model presented in this study is exploratory thus it will need to be tested in other urban contexts. A qualitative scoring was proposed to approximate the infiltration potential of different land uses, rock types, and terrain conditions. If the research was to be repeated, on-site experiments should be conducted to attribute actual infiltration measurements for each of the selected parameters. The model could also be improved if **rainfall data** both spatial and temporal was included as one of the key parameters. This could have given an idea of the precipitation intensity and quantity. Records of rainfall measurements are very poor in Estonia and this information was not accessible at the time of the research. Also, if available, data about the current **condition of rainwater drainage systems** could have been added as well to localise operational deficiencies and where floods are susceptible to occur based on drainage problems. In some cases, the used parameters might not be sufficient to detect flood-prone areas even if the soil infiltration potential seems high, and few and minor sinkholes are visible. If underground pipe systems are clogged in a specific location, it is not possible to detect these issues based on the proposed parameters alone.

Furthermore, surface waters were not included when creating the infiltration potential map because it was difficult to understand when water bodies worked as sink or sources of flood, especially if there are heavily modified like in Tallinn. Surface waters are already water-saturated spaces, thus the infiltration potential is limited. If the water is flowing it should be a sink for rainwater runoff. If the water is stagnant, it could be a source of flood. Besides this, it is worth mentioning that this map does not take into account that as a highly urbanised space, Tallinn has a large proportion of its topsoil that has been altered due to building activities and the incorporation of non-originating soil over the years. Thus, the actual soil infiltration potential may differ from the natural conditions. For model improvement, it will be useful to take this into account.

Finally, with regards to the sinkhole map, it is worth noting that small patches could be artefacts due to errors occurring during the DTM processing and because of the bad resolution of the DTM file. Hence, the model could be improved by filtering sinks that are smaller than a pre-defined threshold.

Application of the GIS model for flood risk assessment in other urban contexts

Floods are among the most deleterious natural disasters worldwide. In terms of sustainability, floods affect water health as well as causing ecological, economic and social damage (Liu et al., 2018). It can be observed in most cities around the globe when intense rainfall occurs, sudden and expensive measures are taken to reduce their adverse effects, instead of planning to prevent such phenomenon. The key to properly address such threats lies in anticipation and there are obviously various manners to achieve that. Modelling flood susceptibility is one of them. This technique has provided a valuable insight into processes occurring during flooding.

Many studies including Ochoa-Rodriguez et al. (2015) and Einfalt et al. (2009) have identified areas particularly vulnerable to the effects of heavy rains in urban contexts by adapting hydraulic/hydrological models. They have also informed the development of warning systems used by local authorities and help improve emergency effectiveness during severe flood disasters. Some models such as the Stormwater Management Model (SWMM) developed by the United States Environmental Protection Agency (EPA) are used nationwide and considered as reference and calibration for other models. However, as explained by Wicht & Osińska-Skotak (2016), they use complex calculations and require an adequate adjustment, detailed and highly accurate set of input data that are often difficult to acquire or not available in less developed countries. For these reasons, an alternative to this approach was proposed in this thesis, which is a more simplified type of modelling.

Although the proposed methodology skips many factors, as opposed to hydrological modelling, it allows to quickly identify areas at risk of floods and associated effects, which may lead to the better management of theses locations prior to the weather event. This specific approach enables to delineate jeopardised sites based on the data that Tallinn and the great majority of European cities should have available, hence they may be able to perform the GIS analysis on their own. Although the accuracy of the approach presented here is much coarser than one provided by hydrological models, it can be replicated in open-source software (e.g. QGIS) and does not require as much expert knowledge to run it. Since the increase in weather events is more and more noticeable, more research should be conducted on this topic.

5.3 RQ3: Application of the SuDS selection tool

How to facilitate the selection of SuDS measures using a multi-criteria decision-aid method?

Subquestion:

- *What are the considerations to take into account to select the right measures in the planning process?*

5.3.1 Results and analysis

In the following, the application of the conceived SuDS selection approach on one focus area is described along with proposed measures for flood risk mitigation and co-benefits enhancement in the area.

Site analysis

The site analysis has been performed using GIS maps, pictures from Google Maps, satellite image analysis and information extracted from Tallinn Stormwater Strategy (RTI, 2012) relating to existing drainage systems operating in Tallinn's catchment areas. The site is located in a busy commercial zone in the centre of Tallinn (Liivalaia Street, Kesklinn District) (see figure 5-15). This site was selected because of its high content of hard surfaces (i.e. parking lots, buildings, and asphalt street network) (see figures 5-11 and 5-12). It is a good example to demonstrate how to incorporate SuDS elements in this type of mixed land use. The area offers a challenge with a lack of opportunities for implementing SuDS solutions. The biggest challenge in this case is to capture storm runoff as close to its source as possible, slowing down its flow rate and storing it temporarily. In this way, the transport of pollutants from impervious surfaces to nearby receiving waters can be also reduced.

Figure 5-11 Photography of the site (1)

Source: Google Maps

Figure 5-12 Photography of the site (2)

Source: Google Maps

The existing rainwater drainage infrastructure in the area is a traditional pipe-based joint and separate sewer system. The volume of the tunnel collector networks remains small to receive excess water in severe precipitation events, which frequently causes local flood problems (RTI, 2012). The system needs to be reconstructed or an alternative solution developed. The main factor of the flooding is the high proportion of non-permeable pavements in the catchment area, which prevent water to infiltrate into the ground.

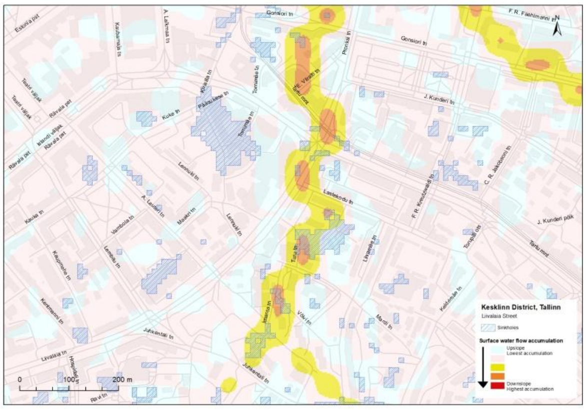


Figure 5-13 Surface flow accumulation map

Source: Author's own elaboration

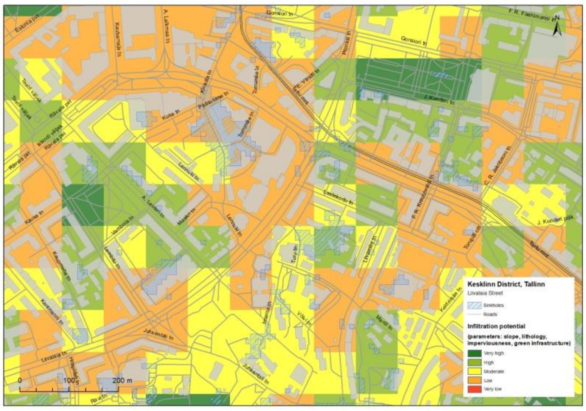


Figure 5-14 Soil infiltration potential map

Source: Author's own elaboration

The terrain is quite flat slightly sloping towards the spot where an ancient river, Härjapea River, used to flow, which is now closed and sealed to allow building activities. Based on the surface flow accumulation map (see figure 5-13), it is expected that storm runoff will flow in the same direction in case of heavy rain. Based on the surface lithology map (see Appendix G, p.111), the natural rock type in this location is fine sand but due to the land use change, it is very difficult to determine the current exact soil condition. Water infiltration potential in the area is relatively low; however, it seems to be improving around the parking area, situated next to Maakri Street (see figure 5-14). In addition, the biggest sinkhole covers parts of this parking lot and Maakri Street and Tornimäe Street (see figure 5-18). A better infiltration potential could allow a suitable stand for water absorption and retention measures but only in the conditions that the function of the parking lot is not obstructed and that the space available for implementation is adequate. There are some green spaces (mostly private gardens and parks) dispersed across the area, which also provide opportunities for at-source or on-site water management (see figure 5-16). The site is more densely populated in the southern part, with an average of 200 residents per hectare; medium-density residential zones covered the northern part (see figure 5-17).

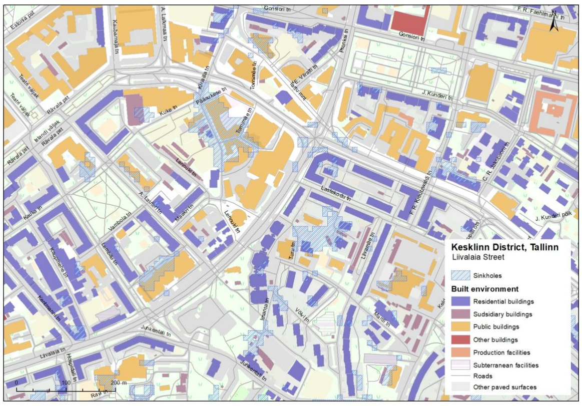


Figure 5-15 Built environment map

Source: Author's own elaboration

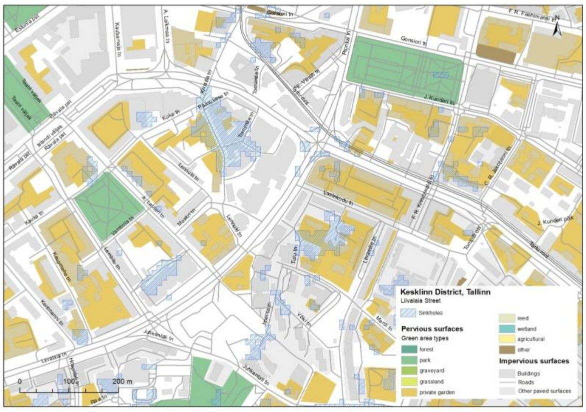


Figure 5-16 Green infrastructure map

Source: Author's own elaboration

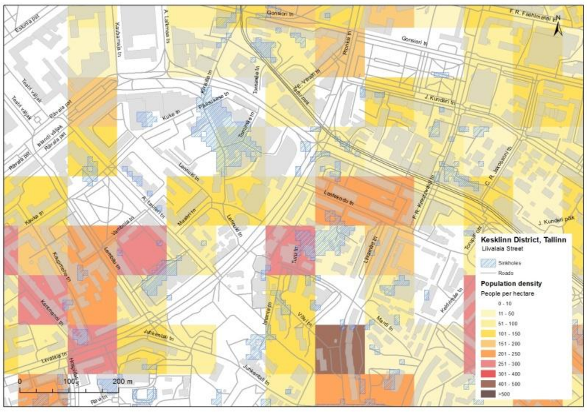


Figure 5-17 Population density map

Source: Author's own elaboration

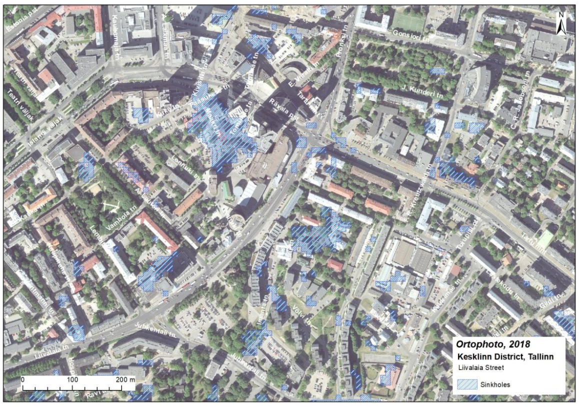


Figure 5-15 Aerial photography of the site

Source: Author's own elaboration

Main benefits to take into consideration

The identification of the most important benefits to be addressed in the area was carried out based on best expert judgment using the criteria table and the results from the site analysis. Ideally at this step, it would be required to solicit stakeholders' input (e.g. local community organisations). In a future research, a participatory analysis with relevant stakeholders could be conducted, for example through the use of a questionnaire to collect data about stakeholders' perception about the most important benefits to enhance in a designated area.

Based of the site analysis, the need for flood risk reduction was identified as a major concern. Although the study described here is about the selection of strategies for flood mitigation, the focus is on co-benefits improvement. This aspect should be taken into account before making a final decision, to determine the impacts of different strategies on lowering flood risk. Thus, the following co-benefits were considered: water quality enhancement, water quantity control, amenity opportunities (including aesthetics and recreation), and biodiversity protection through habitat provision. The idea was to create a more pleasant, aesthetically attractive and healthy living space for local residents, visitors and other living organisms (such as native plants, pollinators, birds, etc.).

In regard to stormwater-related issues specifically, at source or on-site management solutions where appropriate were preferably considered to slow down water flows and lower runoff volume in case of future extreme weather episodes. Also, the reduction of impermeable surfaces was regarded as a good strategy to allow water infiltration into the ground. Other considerations included: the screening of measures able to fit in a compact and limited available space and which do not require high maintenance level.

In this scenario, SuDS selection was performed from a city agency's perspective. To be more specific, as municipal authorities cannot oblige property owners to install SuDS components in their lands; most of the flood mitigation measures proposed for this site are suitable for public spaces, which in this case are mostly located along main streets.

Identification of possible SuDS solutions

Once the co-benefits assessment was done, a range of possible SuDS measures was selected, as shown in table 5-2.

Table 5-2 Recommended SuDS measures based on their impact on selected co-benefits, management train suitability, and space requirement

SuDS components	Space requirement	Management train suitability	Selected co-benefits			
			Water quantity reduction	Water quality improvement	Amenity	Biodiversity & habitat
Pervious pavements	Low	Prevention, source, *site control	√	√	*	*
Stormwater planters	Low/medium	Source, site	√	√	√	√
Rain gardens	Low/medium	Source, site	√	√	√	√
Bioretention areas	Low/medium	Source, *site	√	√	√	√
Filter drain	Low/medium	Conveyance, source, *site	√	√		
Filter strips	Low/medium	Pre-treatment, source	√	√	*	*
Swales	Medium	Conveyance, source, site	√	√	*	*
Soakaways	Low	Source	√	√		
Infiltration trenches	Low/medium	*Conveyance, source, site	√	√		
Infiltration basins	High	Site, regional	√	√	*	*
Sand filters	Low	Pre-treatment, site, *regional	√	√		
Silt removal devices	Low	Pre-treatment		√		
Pipes, subsurface storage	Low	Conveyance, site	√	*		

√high/primary process; *subject to design

Source: Author's own elaboration

In the scenario presented here, decision makers should consider mixing the different measures suggested in table 5-2 to achieve sustainable strategies to diminish flood risks and enhance co-benefits.

5.3.2 Discussion

In this section, are discussed some of the interesting issues that arose during a stakeholder meeting which took place in the context of the UrbanStorm project and during which some elements of the SuDS selection tool and the outcomes of its application to the focus areas were presented to the audience. This allows to observe participants' receptiveness and interest in the proposed materials and shed light to main concerns and misconceptions about

SuDS implementation. Among the materials presented, a **poster** summarising the results and recommended solutions for the selected focus area was shown (see Appendix J, p125).

Since it was the same meeting during which the researcher distributed the questionnaire used to collect data for RQ1, most of the 15-20 stakeholders attending this meeting were part of state or city governing entities such as Tallinn City Planning Department, Tallinn Environmental Department, Tallinn Municipal Department, and the Estonian Environmental Research Centre, which is in MoE's jurisdiction. Other stakeholders included representatives from educational (which included the author and EULS researchers), private and NGO sectors.

Predominance of technical factors as barriers to SuDS development

In contrast with the survey results, several planners and engineers showed scepticism regarding the real feasibility of SuDS measures based on **technical/engineering uncertainties**. For instance, referring to SuDS techniques incorporating green elements, some planners raised questions about the exact percentage or number of meters of green areas that would need to be allocated in a specific site. This concern was related among other policies to the minimum greenery requirement included in Tallinn's construction regulations. To this, researchers responded that issues about percentage should not be the most important aspects to take into account when implementing SuDS/GI/NBS approaches but rather the **functionality of the green elements** for example in terms of infiltration potential and its advantage for flood reduction, other types of benefits provided, etc. On the planners and engineers' perspective, the focus was on **legal concerns** of being in minimum compliance with city, national and also EU/BSR regulations, not on the functionality of a nature-based intervention, "as long as it is green", quoted one participant. On the one hand, this attitude also reasserted the important **role that policies play in driving the introduction of SuDS** measures into the city's planning practices.

Stakeholders' misconceptions and knowledge gaps about SuDS

The previous issue also suggests that planners and engineers still have **misunderstandings about nature-/ES-based approaches** and do not fully comprehend the principles underlying these concepts. For example, some of these actors did not understand the management train concept behind the SuDS system and the fact that each link/component is important to ensure its proper functioning. This observation also contrasts with the survey results. However, the rationale might be related to the use of a **diversity of terms to define the different ES-based approaches** and the possible confusion among participants regarding their similarities and dissimilarities. For example, the term "Green infrastructure" was used in the questionnaire instead of "SuDS", however, these two terms are generally not interchangeably used in the existent literature or defined in the exact same way. Although, green infrastructure can be part of a SuDS scheme not all SuDS components can be labelled as green infrastructure.

Non-systemic view on (storm)water management

Another aspect related to misunderstanding about the management train concept is that planners and engineers do not seem to think about surface water management at a larger scale or at the watershed level, but rather they focus on the specific spot where they need to address a problem. This concurs with previous findings from the stakeholder review according to which **decision-makers tend to choose quick, short-term case-by-case solutions** rather than preventive and preferably at source management solutions.

SuDS selection methodology perceived as a valuable tool to facilitate the decision-making process but need to include more detailed data

Most participants showed interest in using the approach in particular the criteria table to help them select appropriate SuDS techniques in a specific location. However, again concerns about **engineering technicalities** were brought forward such as the need to have a more detailed planning tool (including design models with specific calculations for each measure, costs, etc.) to achieve requirements set by laws and policies; no considerations were made on co-benefits aspects. It was then specified by the EULS researchers that the tool was not conclusive but intended to be used at the very early stages of the planning process.

The **lack of considerations of co-benefits from planners and engineers** also revealed the **importance to include other types of stakeholders**, especially community organisations, in the decision-making process. These organisations might provide different input and priorities to consider before taking a final decision. In this regard, previous works focusing on this issue such as Alves et al. (2017, p.16) have found that "measures, which are not preferred when only co-benefits are considered, appear as favourite for flood risk reduction, and vice versa". Hence, if only flood reduction capacity is considered, as it is the case during traditional decision-making process for stormwater control, the improvement of co-benefits is likely to be neglected. On the other hand, if only co-benefits are considered, the alleviation of the flood risk will be very limited. This demonstrates the relevance of considering both objectives (Alves et al., 2017).

The need for a more detailed SuDS selection tool has been highlighted in previous studies (e.g. CIRIA, 2013, p.111) stating that "evidence and an agreed methodology to show conclusively how SuDS perform, are cost-beneficial in an urban context and to assign monetary or other values to their wider benefits contributing to green spaces and ecosystem services is still lacking". Therefore, the author recommends investigating ways to improve the proposed tool in a future research in order to meet the need expressed by practitioners.

Beside this, participants also took an interest in the use of both the individual GIS maps and/or the entire series to improve their understanding on the pattern of flooding in Tallinn. The GI, soil infiltration potential, and sinkhole maps seemed to raise the most attention (the FSM was finalized at that time if the research).

Need for more experimentation: relevance of demonstration projects

Among the ways available to overcome some of the barriers and challenges raised above, the increased development of pilot projects related to SuDS systems is paramount. A majority of participants have claimed that initiatives such as the UrbanStorm project have given them the opportunity to see from their own eyes how these innovations work and evidence that they can be implemented in the Estonian local conditions. **Increasing initiatives to test and observe SuDS innovations in local conditions is a major driver for SuDS acceptance and possible future adoption.**

6 Conclusions and recommendations

In the following, the conclusion for each research objective is first given. Then, the author has listed a number of recommendations for Tallinn to facilitate the inclusion of SuDS features into its stormwater management practices as well as suggestion for future research

6.1 Conclusions

6.1.1 Concluding remarks for RQ1

To address RQ1, the elements borrowed from the TAM model and innovation diffusion theories turned out to be very useful in investigating stormwaters' perceptions towards SuDS adoption for stormwater handling. The survey results confirmed several factors identified in the policy and stakeholder review, as influencing stakeholders' attitudes towards SuDS and its adoption (in this case, mostly city officials). In general, **respondents have positive perceptions about SuDS usefulness, ease of use and induced benefits**. They understand the concept and for those who had previous experiences with SuDS projects, they were generally satisfied with their performance. Thus, all these attributes increase the likelihood for future acceptance and adoption of SuDS in Tallinn. However, findings have also identified that respondents' perceived resources are insufficient for effective SuDS implementations. Findings also indicate that important uncertainties and shortcomings are hindering conditions to foster SuDS innovations such as a clear **lack of political leadership and support** as well as **missing incentive mechanisms** for potential adopters, **a need to develop more technical expertise** and **enhance awareness about SuDS and its co-benefits**. Also, further research should be conducted on the cost-benefits related to different types of SuDS techniques compared to traditional approaches. Finally, given that the respondents' sample size is relatively small, it is not possible to generalise respondents' perceptions to the whole set of stakeholders involved in Tallinn's stormwater management and correctly predict stakeholders' attitudes towards SuDS adoption. However, **findings from the survey represent a preliminary assessment of stakeholders' opinions and they have allowed us to identify certain trends** that should be confirmed in a future research including a larger sample of respondents representing a broader set of stakeholder groups.

6.1.2 Concluding remarks for RQ2

The second objective of this thesis was to investigate the usefulness of employing a geospatial approach to determine areas susceptible to floods due to torrential rains. This method was applied to Tallinn whole territory. **The suggested method has proven to be effective at detecting areas potentially at risk of floods in an urban environment with fast computing time and based on limited amount of parameters**. The defined susceptible flood zones were validated by comparing them to known historical locations of flood events reported in the news in the absence of an updated flood inventory. The application of this method can therefore be extended to other case studies aiming at predicting spatial distribution of flood problems. This proposed approach could be used in flood risk assessment at areas with limited available data, or in areas where preliminary flood risk evaluation is requisite for flood mapping purposes.

Mapping areas at risk of flooding is essential for future land use development or redevelopments. In Tallinn case, based on the findings, the following recommendations are made for flood risk mitigation:

- No construction activities should be allowed in highly flood-prone areas, restriction should be provided for the establishment of detailed plans. Developmental projects should be critically analysed based on the specific local factors causing flood in order to mitigate the hazard.
- Also, as urbanised and impervious surfaces, will continue to expand in Tallinn, the water will become more turbid. This will increase even more storm runoff. SuDS techniques especially those including blue-green elements should be promoted to lower water volume and adequate vegetation should be used to filter sediment contamination.
- Need to focus on priority areas such as Lasnamäe district and potentially other high flood susceptible areas in Mustamäe and Kristiine Districts.

6.1.3 Concluding remarks for RQ3

This research presented a useful methodology combined GIS with a multi-criteria analysis technique to help practitioners select better-informed and responsible measures, taking into account added benefits for the community and natural environment. The proposed planning tool aims to simultaneously reduce flood risk and improve other environmental aspects.

The methodology proposed here does not pretend to be conclusive. It is aimed to be use during the early stages of the planning process. As explained in the methodology chapter, several steps are required before taking a final decision for flood and water management measures that take into account other considerations (e.g. costs, safety and health concerns, local planning norms, etc.). This approach should be seen only as a first, basic approach that could be further refined if potential users want to add additional considerations for SuDS selection such as cost-benefit analysis. For a real project, it would also be needed to document the uncertainties and incorporate stakeholders' preferences concerning the weighting of the different design criteria.

The presentation of the SuDS selection tool and its application to relevant stakeholders has allowed to contrast some of the findings obtains for RQ1 regarding the main barriers for SuDS adoption in Tallinn city. Technical concerns encourage an "aversion for risk attitude" among city officials, in particular planners and engineers, and thus a reluctance to change current stormwater practices.

Besides, it is important to emphasise key SuDS co-benefits in decision-making processes to increase the likelihood to be selected as flood mitigation strategies. SuDS should be supported beyond their primary flood risk and water control function as an approach that provides benefits to an array of stakeholders and can contribute to various city initiatives such as climate change adaptation, urban re-naturing and human well-being.

6.1.4 Key messages

The overall aim of this research is to help in the decision-making processes for the development and selection of more sustainable stormwater/flood management solutions, such as SuDS techniques, which are based on multi-objective, multi-functional and adaptive system concepts.

In brief, here are the key messages to take away from this thesis:

- Tallinn is naturally predisposed to local flood problems. However, flood susceptibility mapping has allowed identifying priority areas (especially Lasnamäe

District) where the implementation more sustainable flood risk and water management solutions should be considered.

- SuDS are rainwater management measures that deliver extra benefits in addition to their primary water quantity and quality management functions; these benefits enhance the societal value mostly in urban contexts, through positive impacts on economic, environmental and social aspect.
- The existing literature has documented not only positive effects of SuDS on the urban fabric, but also adverse effects that merit attention when designing and developing them.
- It is often wiser to combine SuDS with conventional measures to maximise synergies and system efficiency and at the same time minimising costs and trade-offs.
- To ensure SuDS' successful deployment, a supportive urban management system and collaborative governance should be put in place.
- In Tallinn, conventional drainage solutions are still favoured by public authorities instead of alternative ones, especially at city level.
- Different types of barriers to SuDS adoption have been identified: stakeholders' perception/information, technical, physical, financial, organisational, and policy barriers.
- Current governance regime constitutes a major obstacle to mainstreaming of SuDS solutions because it is highly centralised and mostly technocratic. Decision-making process is unilateral with less opportunity for public involvement.
- Three key barriers identified by stakeholders: lack of political leadership and support; lack of knowledge, education, and awareness; Funding and costs concerns.
- Despite the above issues, there is a growing political interest for SuDS, mostly visible at national level.
- EU and BSR policies play important role in driving the introduction of SuDS measures into the city's planning practices.
- An important opportunity identified for SuDS adoption: the presence of a variety of actors involved in the sector who have the potential to advance pro-SuDS approaches.
- Increasing initiatives to test and observe SuDS innovations in local conditions is a major driver for SuDS acceptance and possible future adoption.
- Simplified and practical decision-support tools combining GIS technologies with multi-criteria analysis techniques can help practitioners select better-informed and responsible measures, taking into account co-benefits for the community and natural environment. The tools proposed here aim to simultaneously reduce flood risk and improve other social and environmental aspects.

6.2 Recommendations

6.2.1 Driving SuDS ahead: the suggested policies and avenues for action

As the main challenges and barriers faced by practitioners and decision-makers regarding the deployment of sustainable urban drainage systems in Tallinn have been exposed, the following table provides targeted strategies to overcome a number of them (see table 6-1).

Table 6-1 Policy measures and courses of action for overcoming barriers and encouraging SuDS adoption

Policy type	Policy measures	Targeted barriers (number)
BSR policies	- include recommendations for the use of pro-SuDS approaches	1.2
National policies	- review and amend policies and standards to incorporate recommendation of SuDS measures	2.1, 2.2, 2.3
	- establish national design/ maintenance standards/guidelines for SuDS	4.2
	- provide tax exemptions or credits on SuDS installations works	2.1
	- establish more specific requirements in development plans to use SuDS elements in combination with grey infrastructure	2.3
	-amend policy such as Planning Act to provide more specific details on how cross-sectoral collaboration in planning process should be put in place	2.4
City policies	- establish financial incentives to encourage private landowners (development incentives, grants and awards, payment of ecosystem services, stormwater fee and fee waiver, etc.)	2.3, 3.1.,3.2,3.3
	- suggest the use of SuDS in all policies	3.1, 3.2,3.3
Urban planning tools	- ensure enforcement of minimum green requirement - integrate SuDS in construction regulations	4.1
	- develop planning and design guidelines and manuals for operation/maintenance of SuDS,	4.2
	- develop more decision-support planning tools	4.1,4.2
Governance solutions	- establish governing body inside the city government, consisting of representatives from all important stakeholder groups such as landowners, community and civic organisations, environmental organisations, and businesses - will function as an umbrella organisation at the city level to foster collaboration among stakeholders and increase the interest of the public in participating in the decision making	2.2, 2,3, 2.4, 2.5,
	- secure public budget for testing innovative approaches - promoting partnerships (public-private partnerships, private-private initiatives, etc.)	2.2
	- conduct analysis on the risks resulting from climate change in Estonia/Tallinn to facilitate development of adaptation action plans and mitigation measures at national, regional, local levels	2.6
Education, awareness, environmental stewardship	- develop education/dissemination programmes to enhance public awareness on SuDS benefits, the functioning of SuDS, and limits of grey infrastructure - implement more pilot programmes (like UrbanStorm project) to train practitioners and decision-makers - encourage academic institutions to offer research opportunities and courses on SuDS	2.2, 2.3,2.4, 2.5

Source: Author's own elaboration

6.3 Suggestions for future research

Related to the application of SuDS techniques in Estonian/Tallinn context:

- Assessing cost-benefits of SuDS components compared to equivalent conventional solutions for the Estonian market. This could also be done for other country/city case studies.
- Evaluate the possibility to combine SuDS elements with conventional grey infrastructure. Future study should also seek to understand how SuDS can complement grey solutions.
- Future research is needed to develop context-specific SuDS manuals, guidelines and other planning tools for practitioners
- Need to investigate how participatory processes could be effectively implemented for the planning, design, development, and management of SuDS systems in Tallinn
- Conduct an impact assessment after the implementation of pilot projects such as the UrbanStorm project.
- Conduct comparative analyses of SuDS best practice examples from other countries with Nordic climates. Lessons learned from the decision-making processes could help analyse which of the aspects could be replicated in Estonian climate conditions.

Related to the stakeholders' survey:

- Potential for further research to broaden the scope of the questionnaire and include other relevant stakeholders such as local landowners, water and sewage companies, etc.

Related to the GIS model for flood susceptibility assessment:

- Demonstrate the model's effectiveness through its application in other case studies.
- For improving the FSM model, further research should consider including data on the sewer system condition as well as rainfall intensity and quantity to obtain more accurate results.
- Also, the results have indicated priority areas such Lasnamäe district where complementary studies could be developed. In this Lasnamäe case, it would be interesting to further investigate the factors behind its current problematic situation and to identify, through a more detailed analysis, the areas most exposed to floods and runoff pollution as well as the best ways to tackle its possible gentrification and environmental injustice issues.

Related to the SuDS selection tool:

- Refine the tool and conduct further research on how to develop an online SuDS selection application such as the example provided in Appendix K (p.126).
- Need to further investigate the usefulness of utilising GIS mapping for a more adequate SuDS selection and placement
- In a future research applying the proposed SuDS selection tool, suggestion to conduct a participatory analysis with relevant stakeholders, for example through the use of a questionnaire to collect data about stakeholders' perception about the most important benefits to enhance in the area designated for SuDS installation.

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Appendices

Appendix A shows the study area.

Appendix B includes the questionnaire developed for RQ1.

Appendix C presents all the graphs produced based on the survey results.

Appendix D shows the methodology flowchart to create the flood susceptibility map.

Appendix E includes the qualitative values assigned to the four parameters chosen for the infiltration potential model as well as the input data required for the flood susceptibility model.

Appendix F provides the three categories of land use shown in the associated GIS maps.

Appendix G shows the different maps generated for RQ2.

Appendix H gives all the material produced for RQ3.

Appendix I gives the criteria table developed as part of the SuDS selection tool.

Appendix J presents the poster that was created for Kesklinn parking case based on the application of the conceived SuDS selection tool.

Appendix K presents an example of an online decision-support tool for SuDS selection.

Appendix A. The study area

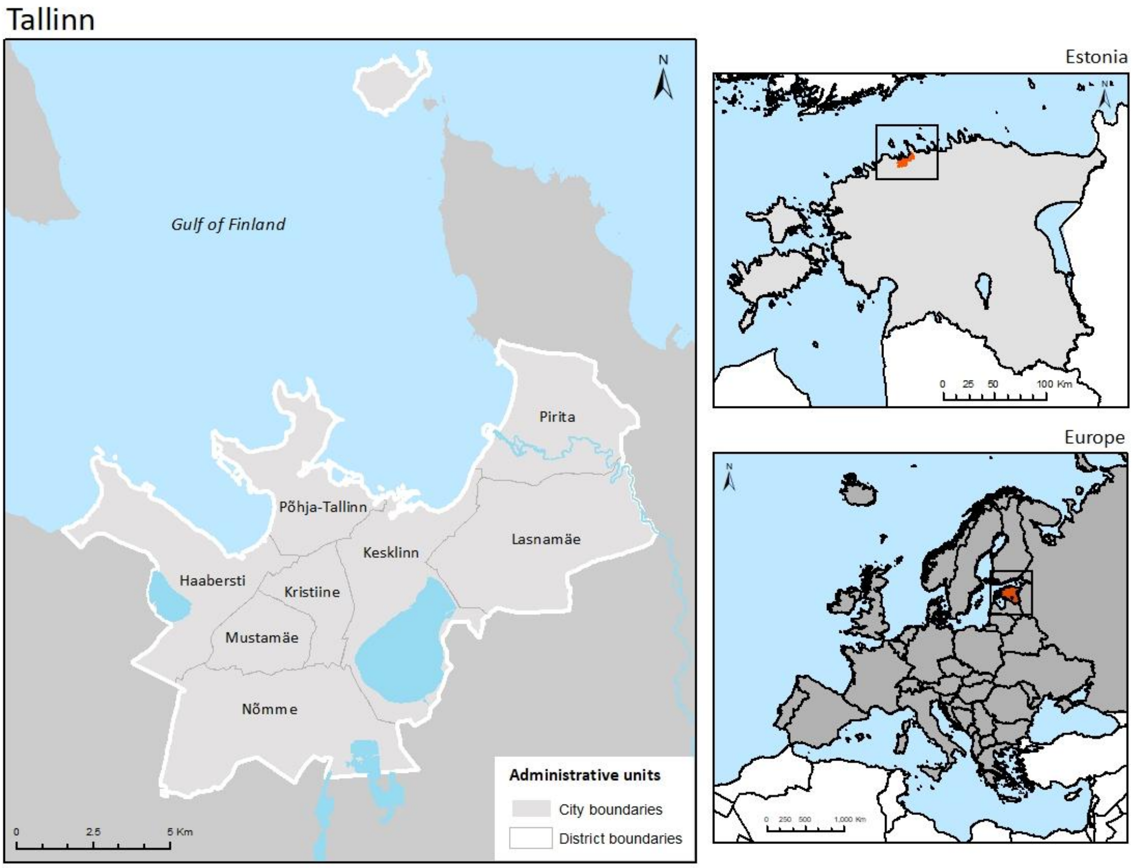


Figure 0-1 The study area

Source: Author's own elaboration

Appendix B. The questionnaire

Cover letter sent to respondents:

Dear [**First name, Last Name**],

My name is Virginie Laroche and I am a Master student at Lund University in Sweden undertaking my thesis research on nature-based solutions for urban stormwater management in Tallinn city.

I would be grateful if you would be willing to spend a few minutes to complete a short questionnaire and help me generate data for my research project. The questionnaire can be completed anonymously and is accessible HERE.

The questions refers to the following definitions:

- Traditional stormwater management refers to hard engineering approaches such as pipelines, levees, dykes and dams that aim to prevent and remove water from an area.
- Nature-based solutions for stormwater management include sustainable urban drainage systems (SuDS) or blue-green infrastructures such as green roofs, pervious pavements, rain gardens, natural swales, etc. — which aim to sustainably and flexibly manage water in the city.

Thank you for your time and cooperation!
If you would like to receive a copy of results from the survey, please send me an email at virginie.laroche@mespom.eu.

Best regards,
Virginie Laroche

QUESTIONNAIRE

PERCEPTIONS TOWARDS GREEN INFRASTRUCTURE ADOPTION FOR STORMWATER MANAGEMENT

A. PROFESSIONAL BACKGROUND

1. Which Organisation do you work for?

…………………………………………………………………………

2. In which department/office do you work? Please select only one answer.

☐ Administrative
☐ Finance
☐ Planning
☐ Public works/water
☐ Engineering
☐ Environmental or natural resources
☐ Other, please specify………………………………………

3. What is your position in your department/office?

☐ Administrative/clerical
☐ Technical
☐ Supervisory
☐ Managerial
☐ Other, please specify………………………………………

B. AWARENESS OF FLOODING ISSUES

4. How severe are flood problems in Tallinn on a scale from 1 to 5, with 1 indicating not at all severe, and 5 indicating extremely severe?

1☐	2☐	3☐	4☐	5☐

5. Do you agree with the following statement?

	Strongly Agree	Agree	Uncertain	Disagree	Strongly disagree
There is a need to improve stormwater management in Tallinn to reduce the risk of flooding.					

C. GREEN STORMWATER MANAGEMENT

6. How informed do you consider yourself to be on Green Infrastructure? Place yourself on a scale from 1 to 5, with 1 indicating not at all informed, and 5 indicating extremely well informed.

1☐	2☐	3☐	4☐	5☐

7. Do you have any experience working on Green Infrastructure projects?

Yes ☐	No☐

8. **If yes, on a scale from 1 to 5, how would you rate the performance of the Green Infrastructure, with 1 indicating not at all effective, and 5 indicating extremely effective.**

1☐	2☐	3☐	4☐	5☐

9. **The following statements are about your personal thoughts on Green Infrastructure. Please indicate whether you strongly agree, agree, neither disagree nor agree, disagree, or strongly disagree with each of them.**

	Strongly Agree	Agree	Uncertain	Disagree	Strongly disagree
Understanding of the concept					
I have a difficult time understanding how Green Infrastructure works.					
Perceived usefulness					
I think traditional stormwater infrastructure is more reliable and delivers better results than integrated systems using traditional and Green Infrastructure combined.					
Green Infrastructure could help the city to better manage stormwater runoff.					
Perceived benefits					
It is apparent to me that the aesthetic qualities of Green Infrastructure boost property values, enhance recreation, and improve quality of life.					
I see how Green infrastructure provides valuable wildlife habitat and restore ecosystems.					
It is apparent to me that green infrastructure reduces stormwater runoff.					
Many Green Infrastructure techniques filter air and water pollutants.					

	Strongly Agree	Agree	Uncertain	Disagree	Strongly disagree
Perceived Resources					
Implementing Green Infrastructure techniques is expensive.					
There is a sufficient level of knowledge and skills among stakeholders to implement Green infrastructure as stormwater solutions.					

10. What types of incentive does Tallinn City offer to encourage the use of Green Infrastructure practices on new or existing developments?

☐ Storm water fee discount

☐ Development incentives

☐ Subsidies

☐ Rebates & installation financing

☐ Tax abatements

☐ Other, please specify…………………………….…

☐ There are no incentives mechanisms currently in place.

☐ I don't know.

11. Does Tallinn City has a programme, policy or initiative supporting or encouraging one or more of the following Green Infrastructure tools:

	Yes	No	I don't know
Green roof			
Rain garden			
Retention pond			
Permeable pavement			
Natural swale			
Green wall			
Constructed wetland			
Park			
Other (please specify)			

12. And finally, we would like to know more about your perspective on barriers associated with the use of Green Infrastructure.

Rank by order of importance the following barriers between 1 and 10 (1 being the most significant barrier) preventing adoption of Green infrastructures as stormwater solutions in Tallinn:	Funding and costs	
	Uncertainty of responsibility and ownership	
	Operation and maintenance	
	Lack of knowledge, education, and awareness	
	Lack of political leadership and support (e.g. local policies, rules and incentives)	
	Reluctance to change practices	
	Limitations of performance compared to hard engineering	
	Site limitation (lack of available space)	
	Lack of public acceptance	
	Lack of information about costs, benefits and risks associated with Green Infrastructure	
Any additional comments on barriers on using Green infrastructure techniques as stormwater solutions in Tallinn:		

That's it! Thank you for your time and cooperation, we really appreciate your support!

If you would like us to send you a copy of results from the survey, please indicate your email address or send an email to us at virginie.laroche@mespom.eu asking for results.

Appendix C. Survey results (all graphs)

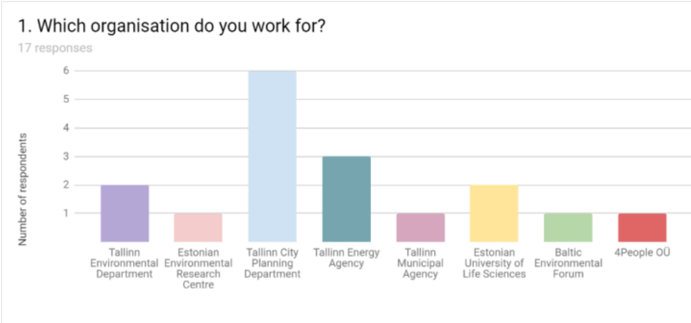


Figure 0-2 Survey question 1

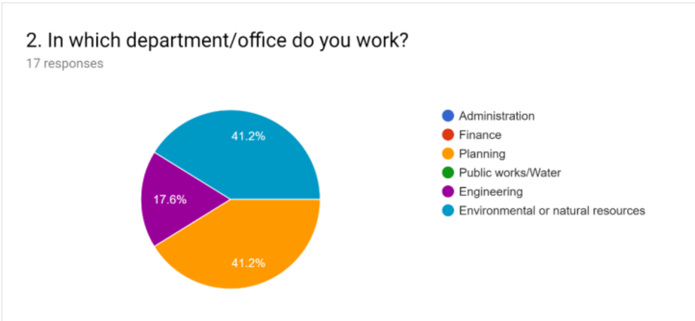


Figure 0-3 Survey question 2

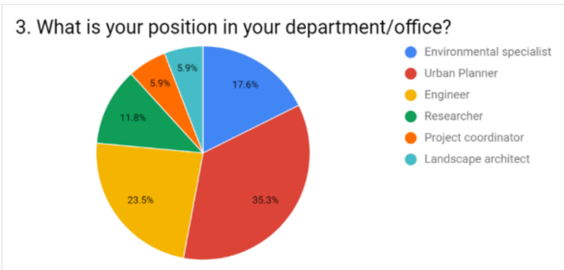


Figure 0-4 Survey question 3

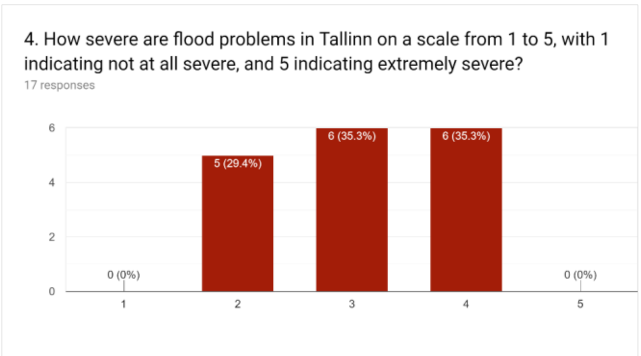


Figure 0-5 Survey question 4

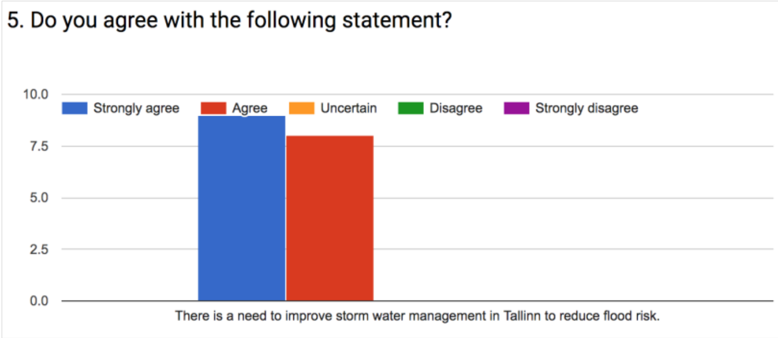


Figure 0-6 Survey question 5

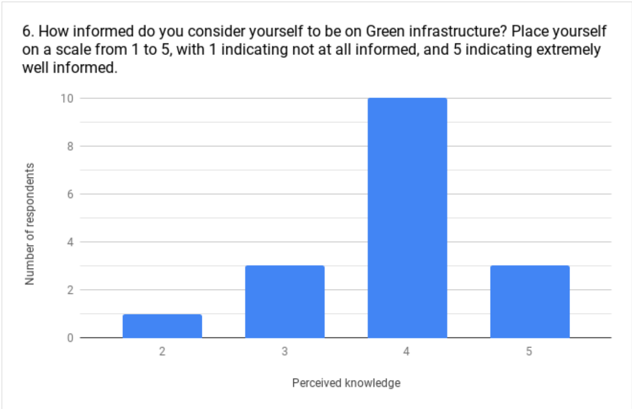


Figure 0-7 Survey question 6

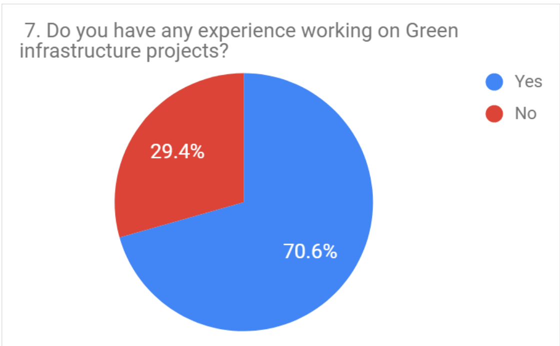


Figure 0-8 Survey question 7

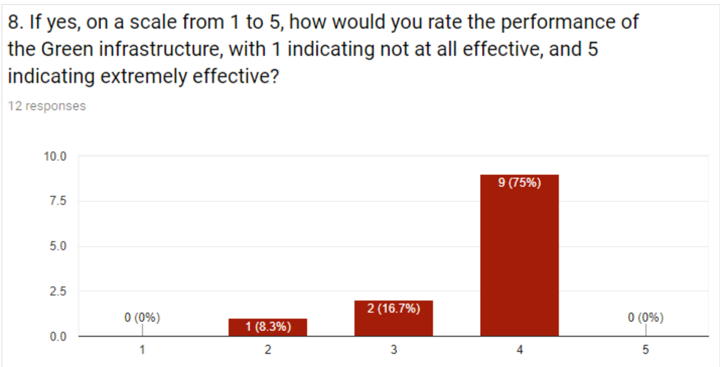


Figure 0-9 Survey question 8

9. The following statements are about your personal thoughts on Green infrastructure. Please indicate whether you strongly agree, agree, neither agree or disagree, disagree, or strongly disagree with each of them.

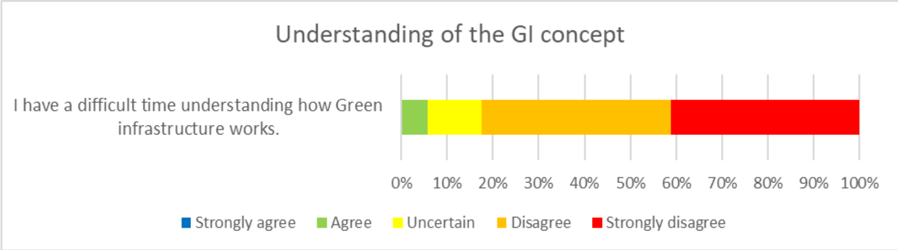


Figure 0-10 Survey question 9-1

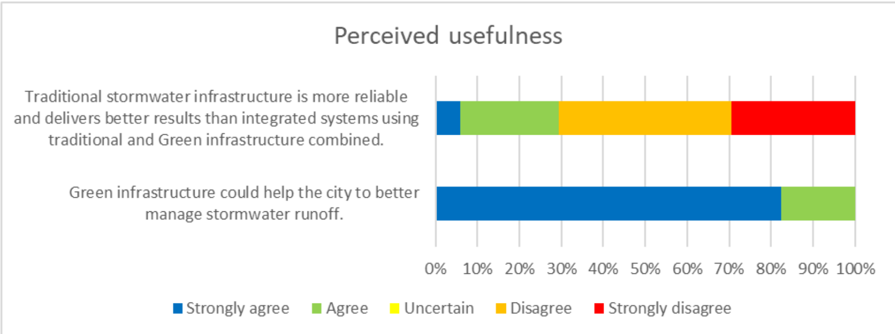


Figure 0-11 Survey question 9-2

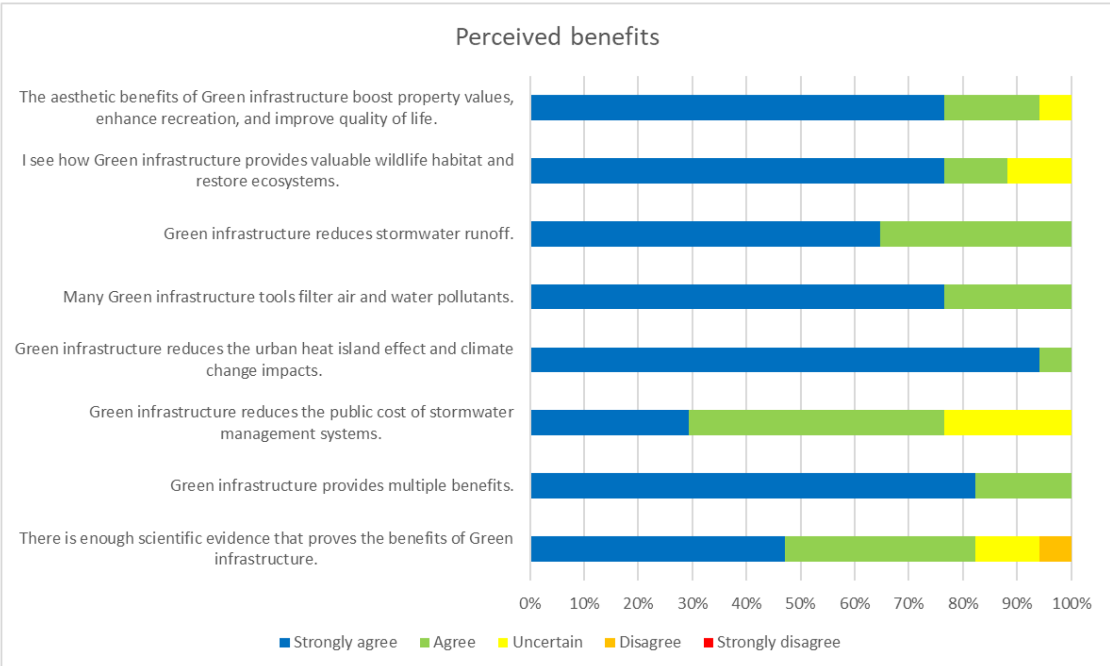


Figure 0-12 Survey question 9-3

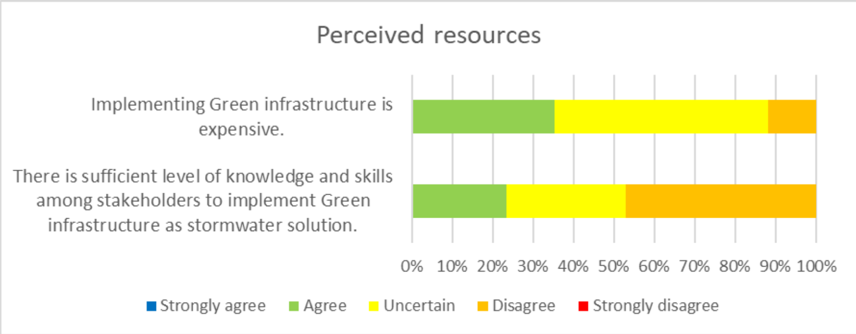


Figure 0-13 Survey question 9-4

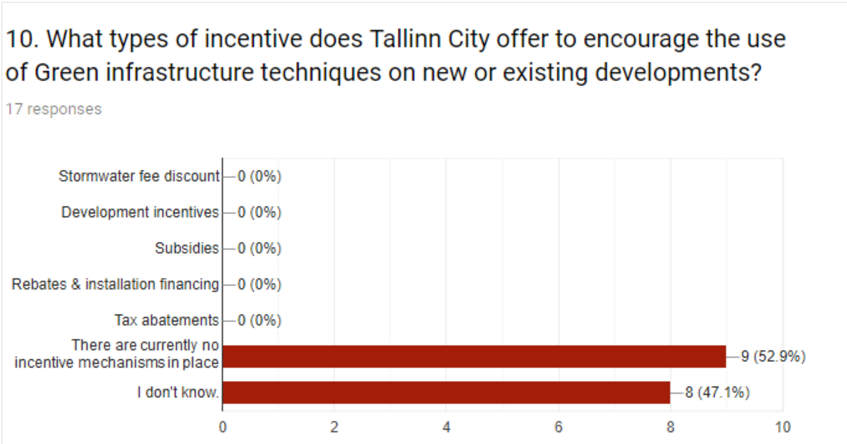


Figure 0-14 Survey question 10

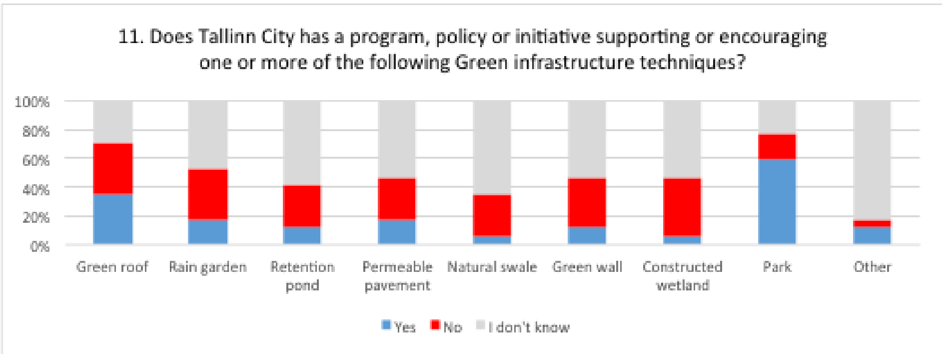


Figure 0-15 Survey question 11

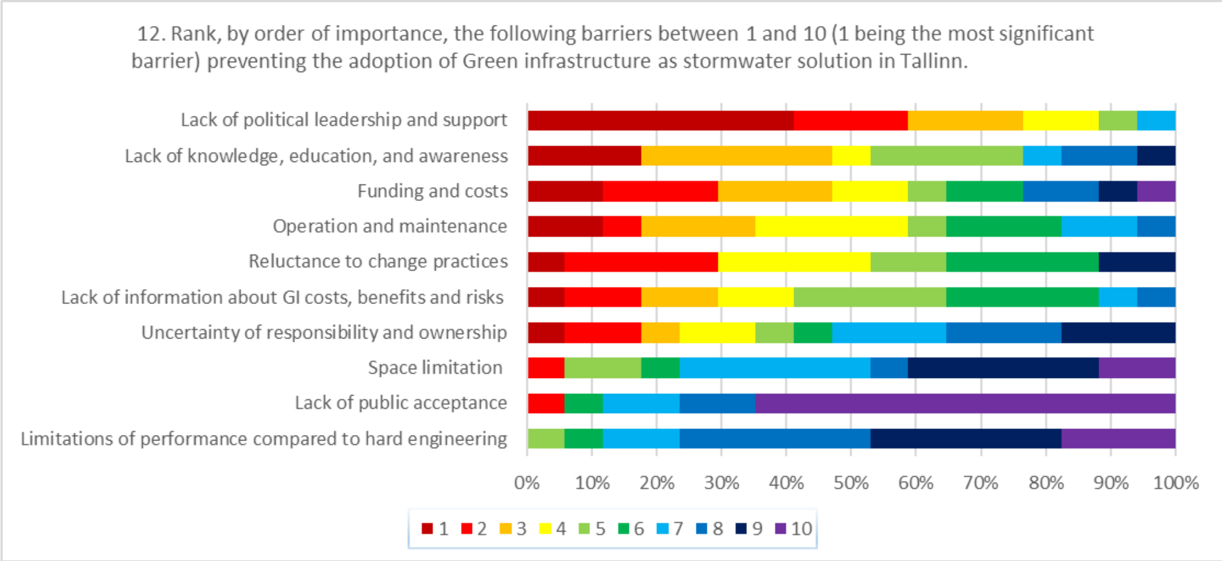
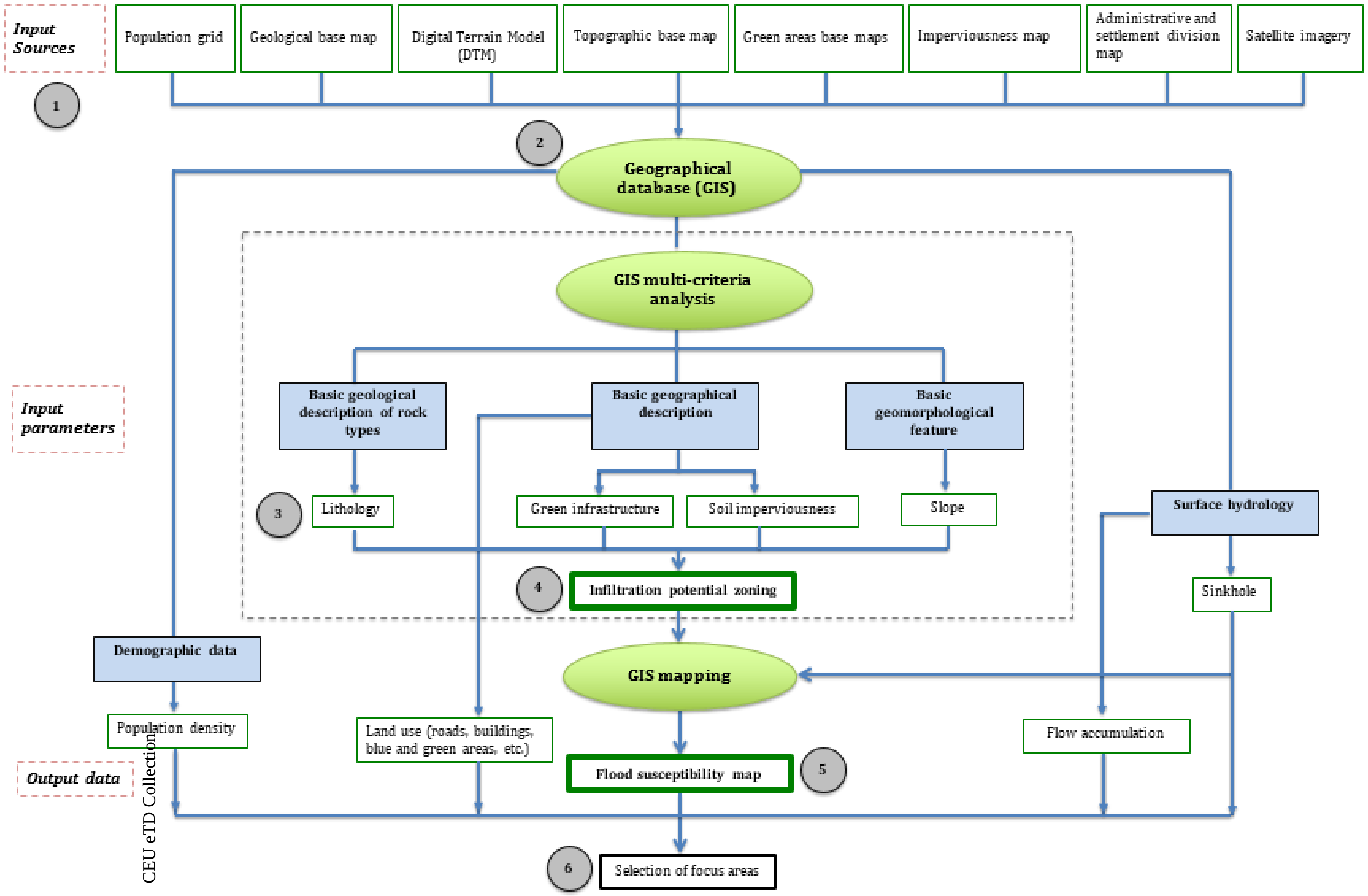


Figure 0-16 Survey question 12

Sources: Author's own elaboration

Appendix D. Methodology flowchart for GIS model



Source: Author's own elaboration

Appendix E. Input data for infiltration potential map and flood susceptibility map

1. Infiltration Potential Model			
Land use		**Qualitative score**	**Infiltration potential**
• ***Pervious surfaces (green area types):***			
Forest		5	Very high
Park		5	Very high
Grassland		4	High
Graveyard		4	High
Private garden		3	Moderate
Agricultural land		3	Moderate
Reed		3	Moderate
Wetland		3	Moderate
Other (e.g. vegetated median strip, meadow, etc.)		3	Moderate
• ***Degree of impervious surfaces (e.g. buildings, roads, parking lots, etc.)***			
0-20%		5	Very high
20-40%		4	High
40-60%		3	Moderate
60-80%		2	Low
80-100%		1	Very low
Slope			
Flat	0-15%	5	Very high
Steady	15-25%	3	Moderate
Steep	>25%	1	Very low
Lithology			
Pebble, mixed pebble and sand		5	Very high
Fine Sand, sand of different sizes		4	High
Holocene Alluvial deposits		3	Moderate
Moraine		2	Low
Peat, bedrock outcrop, holocene technogeneous deposits		1	Very low

Source: Author's own elaboration

2. Flood susceptibility model	
Infiltration potential	Based on imperviousness degree, green infrastructure, slope, lithology
Sinkholes	Derived from the DTM

Source: Author's own elaboration

Appendix F: Categories of land use

Land use:

Pervious surfaces

Green area types
Forest
Park
Grassland
Graveyard
Private garden
Agricultural land
Reed
Wetland
Other (e.g. vegetated median strip, meadow, etc.)

Waterbodies

Surface water (e.g. natural and man-made reservoirs, rivers, streams, etc.)

Impervious surfaces

Building types
Residential buildings (e.g. apartment buildings, one-family dwellings, etc.)
Public buildings (e.g. schools, libraries, cultural centres, churches, governmental buildings, office buildings, commercial centres, etc.)
Production facilities (e.g. industrial units, factories, etc.)
Subsidiary buildings (e.g. sheds, garages, etc.)
Other buildings (e.g. sport facilities, military sites, transportation facilities, etc.)

Other paved surfaces
Roads
Parking lots

Source: Author's own elaboration

Appendix G: GIS maps generated for RQ2

1. Four parameter layer maps

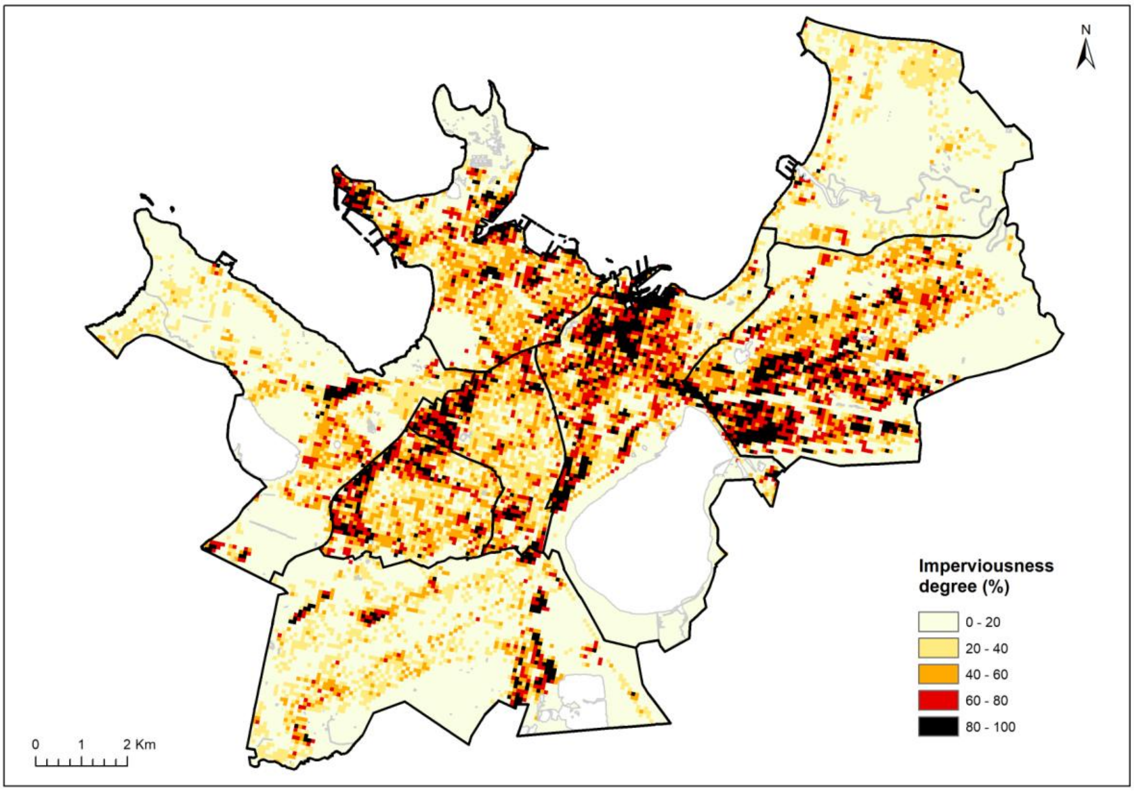


Figure 0-17 Soil imperviousness map

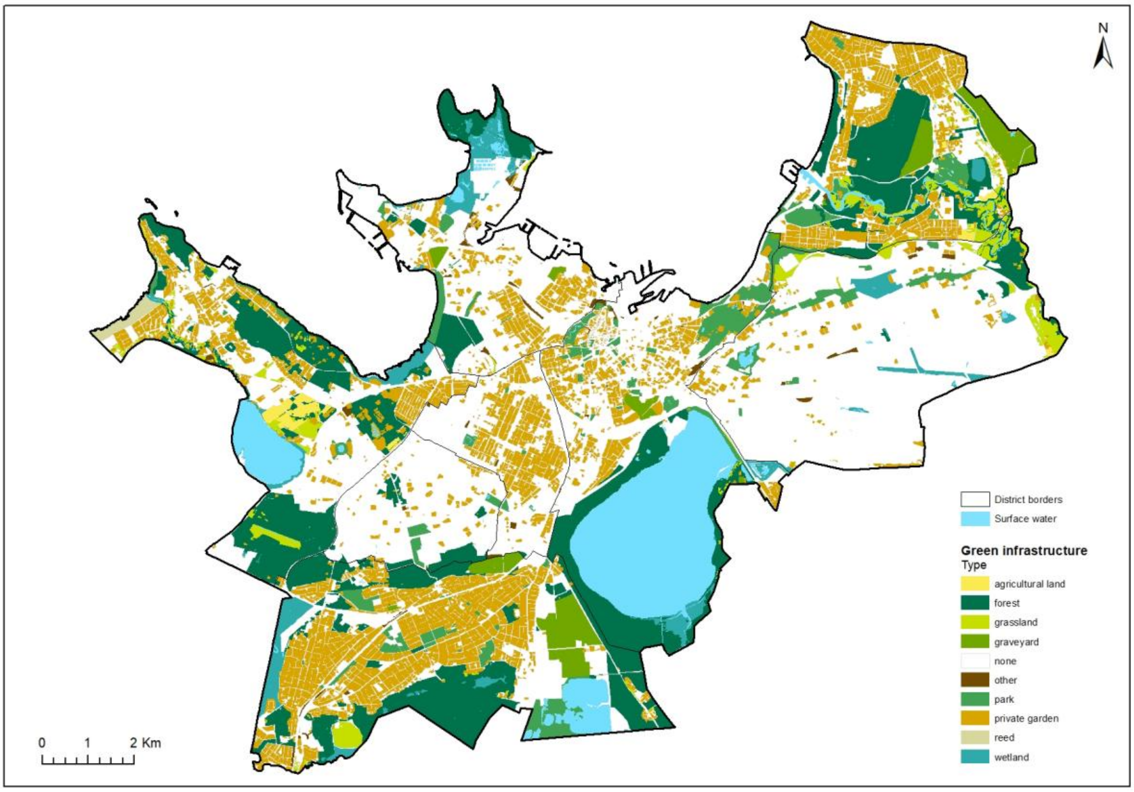


Figure 0-18 Improved green infrastructure map

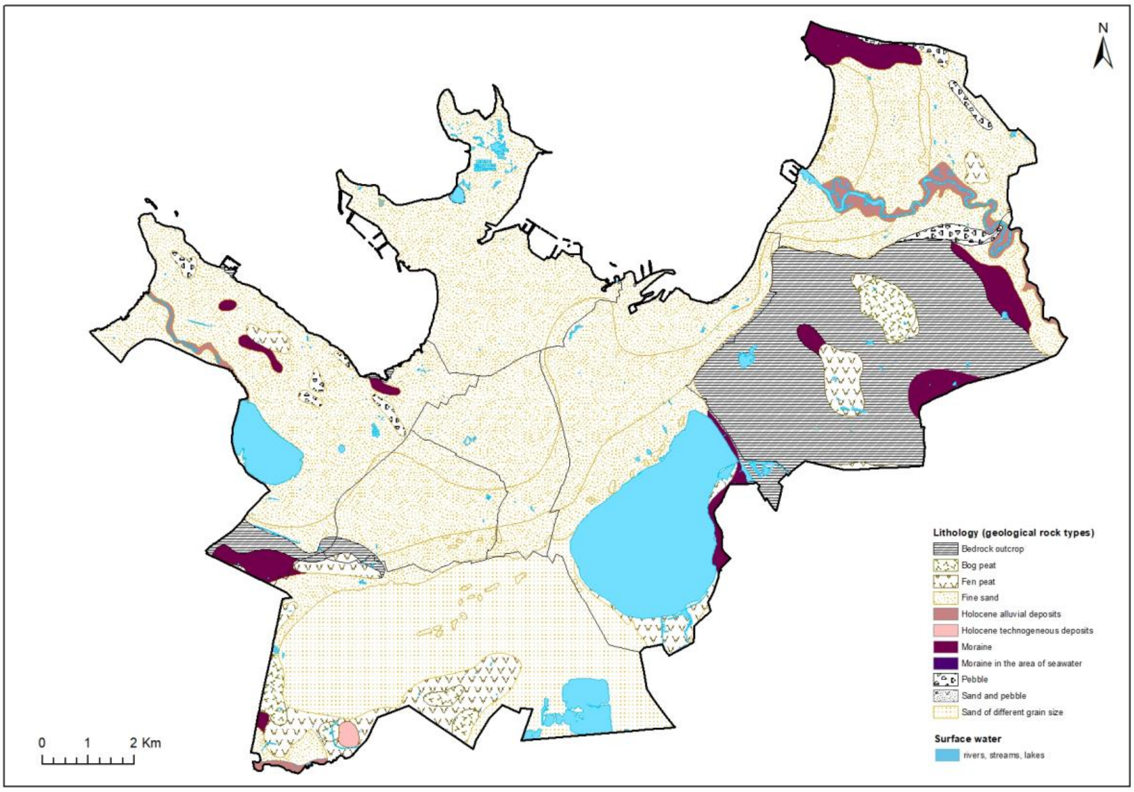


Figure 0-19 Surface lithology map

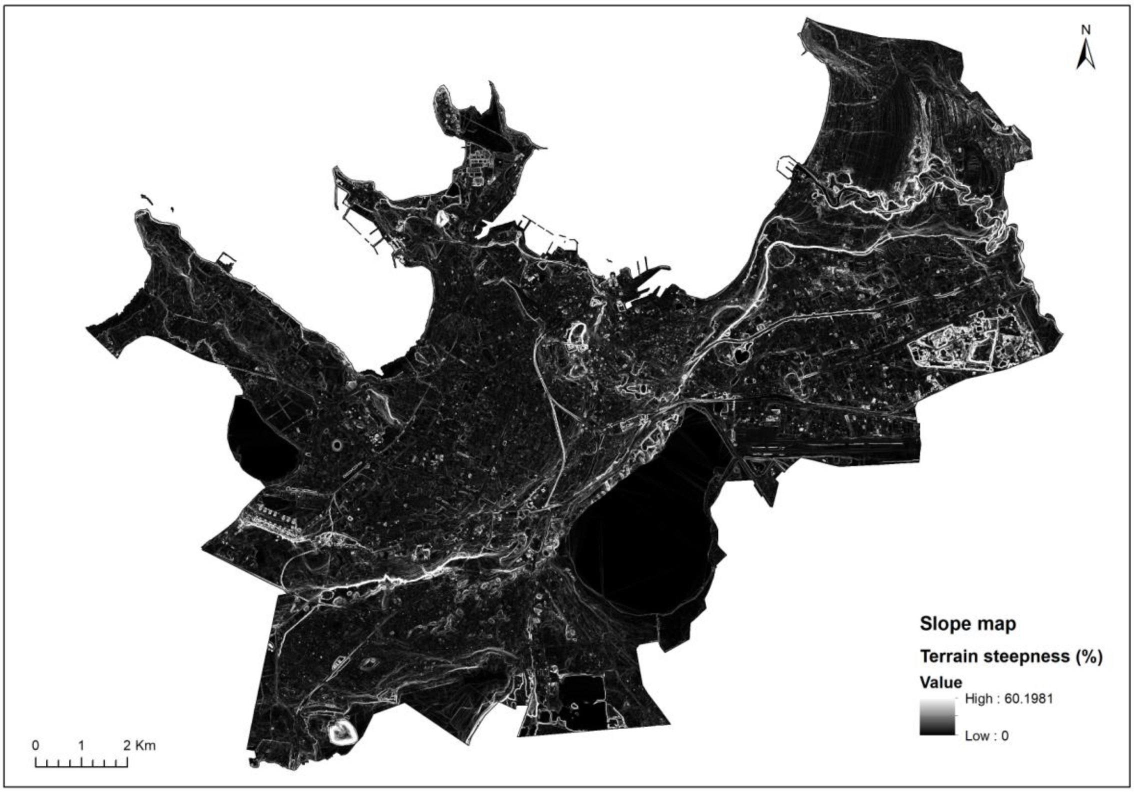


Figure 0-20 Slope map

2. Layers produced for the elaboration of the soil infiltration potential map

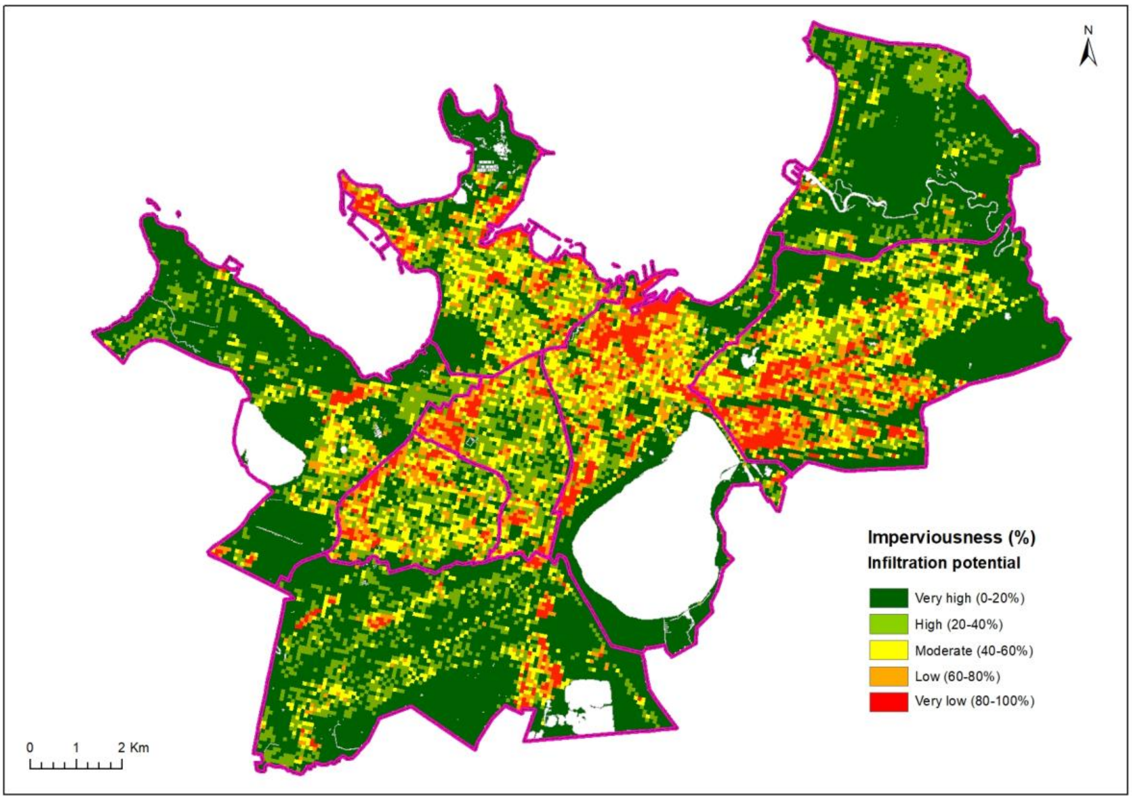


Figure 0-21 Infiltration potential based on the soil imperviousness degree

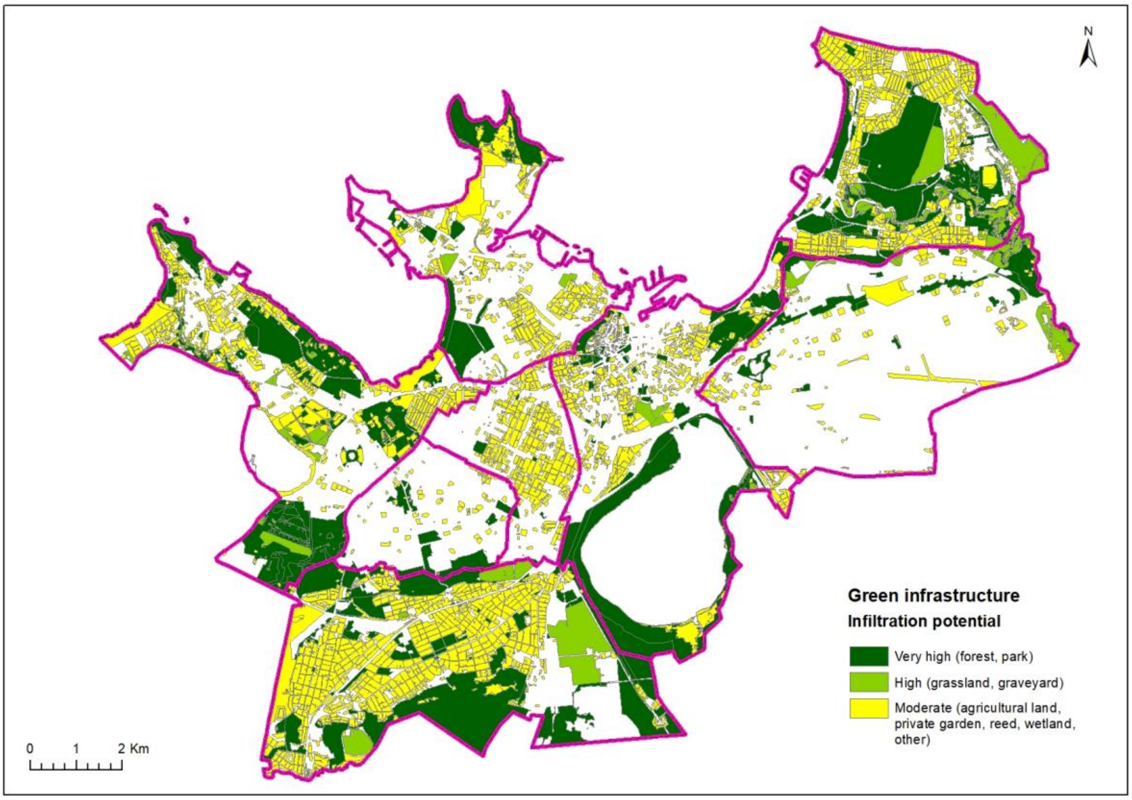


Figure 0-22 Infiltration potential based on types of green infrastructure

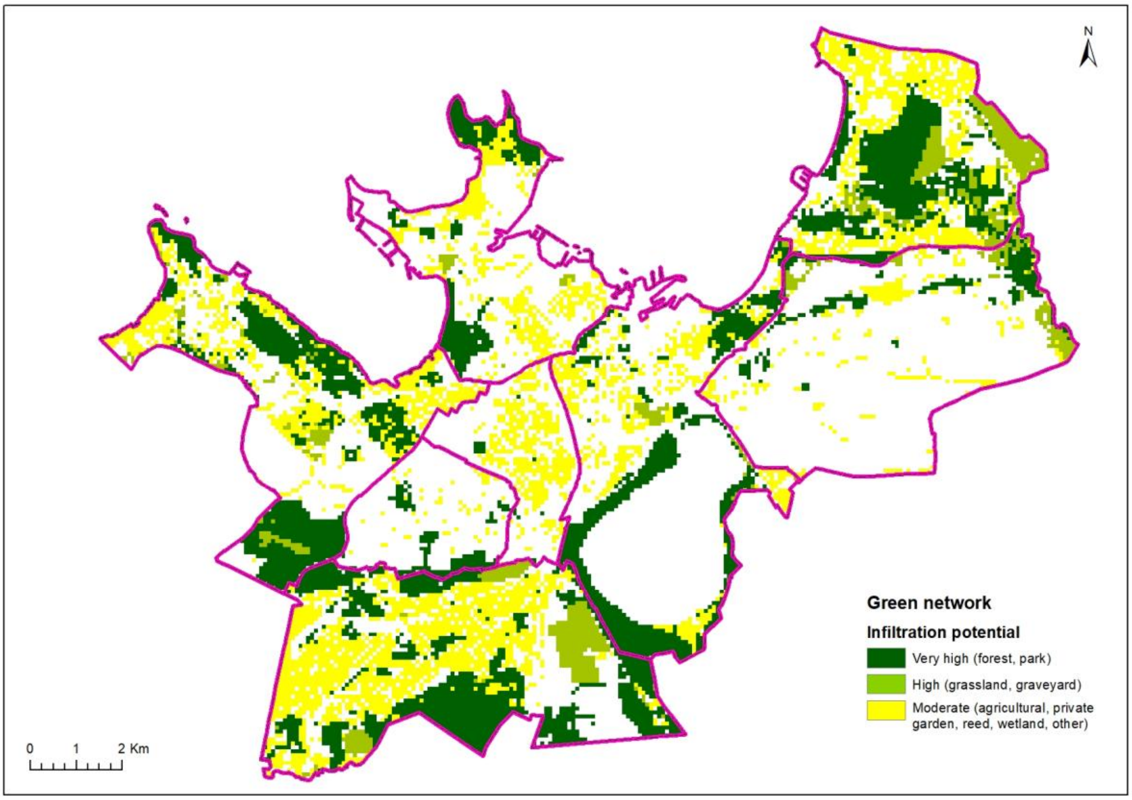


Figure 0-23 Infiltration potential based on types of green infrastructure (raster conversion step)

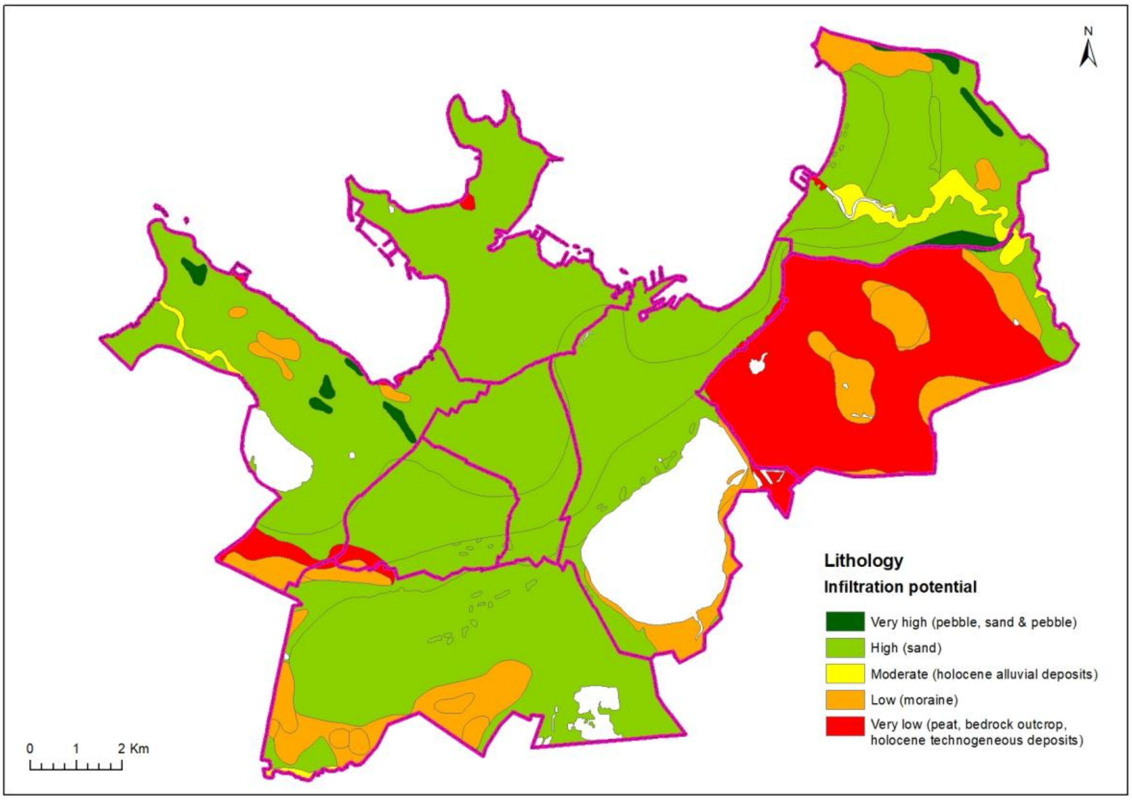


Figure 0-24 Infiltration potential based on the lithology

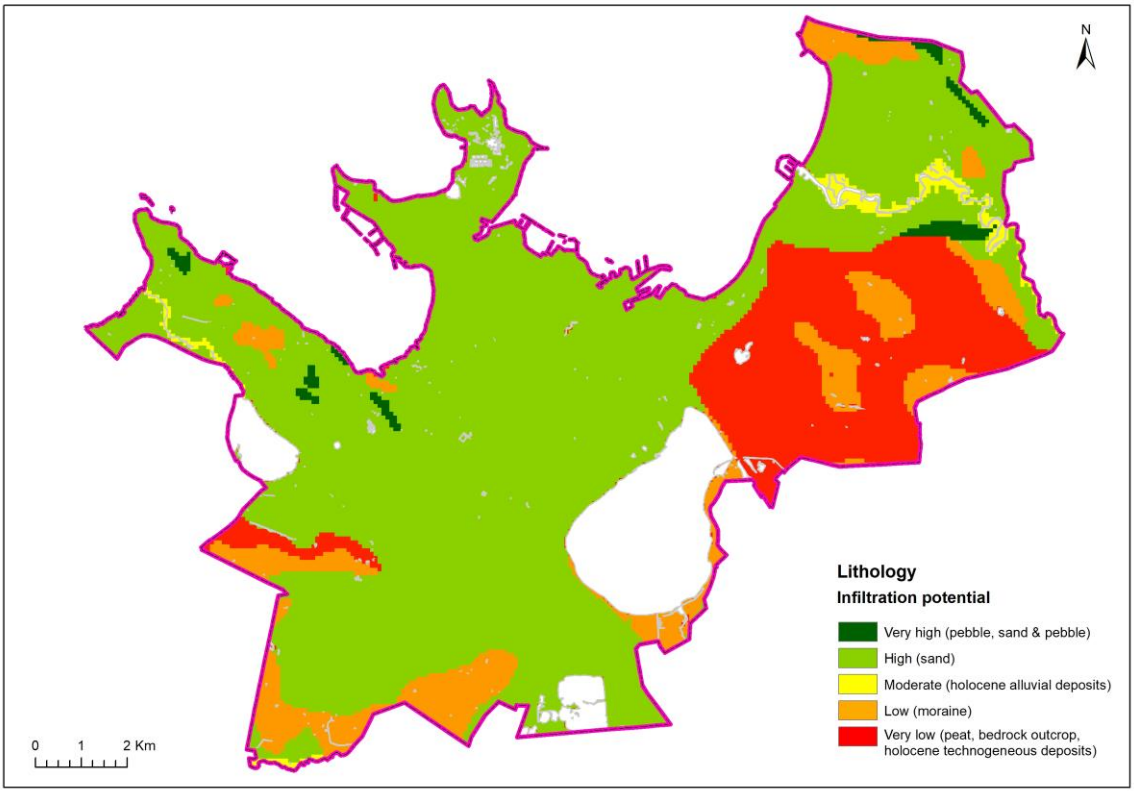


Figure 0-25 Infiltration potential based on the lithology (raster conversion step)

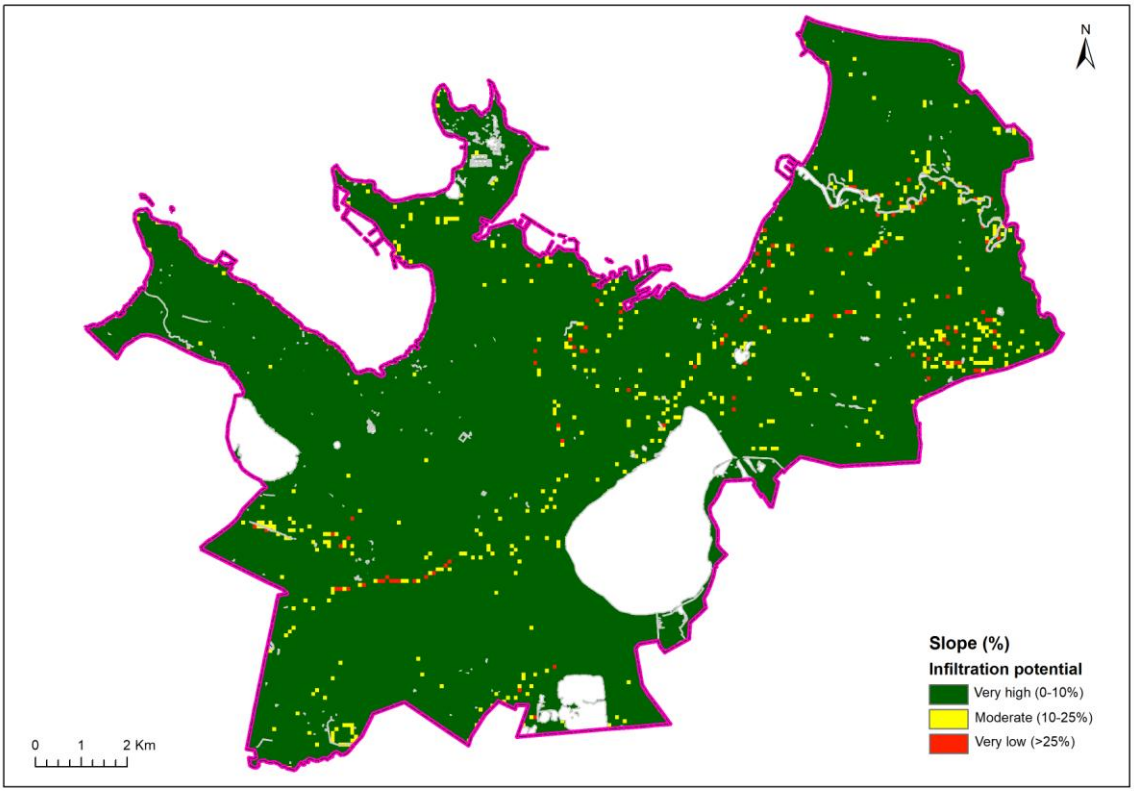
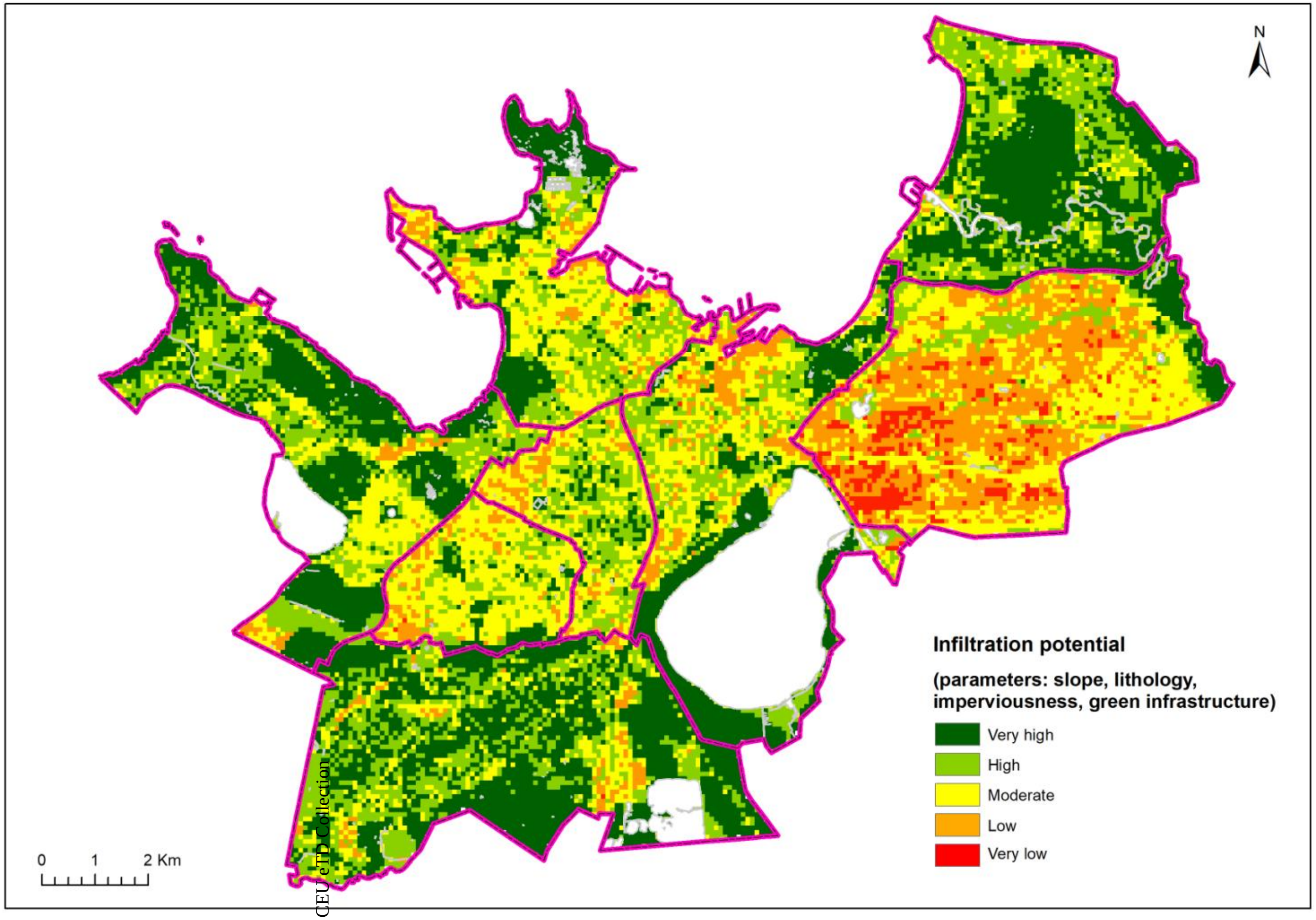


Figure 0-26 Infiltration potential based on the slope position

3. Output of the overlay analysis of the four criterion raster maps



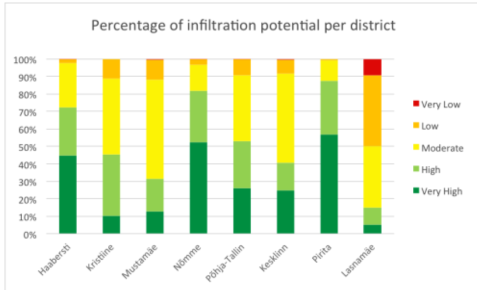


Figure 0-27 Soil infiltration potential map

4. The sinkholes map

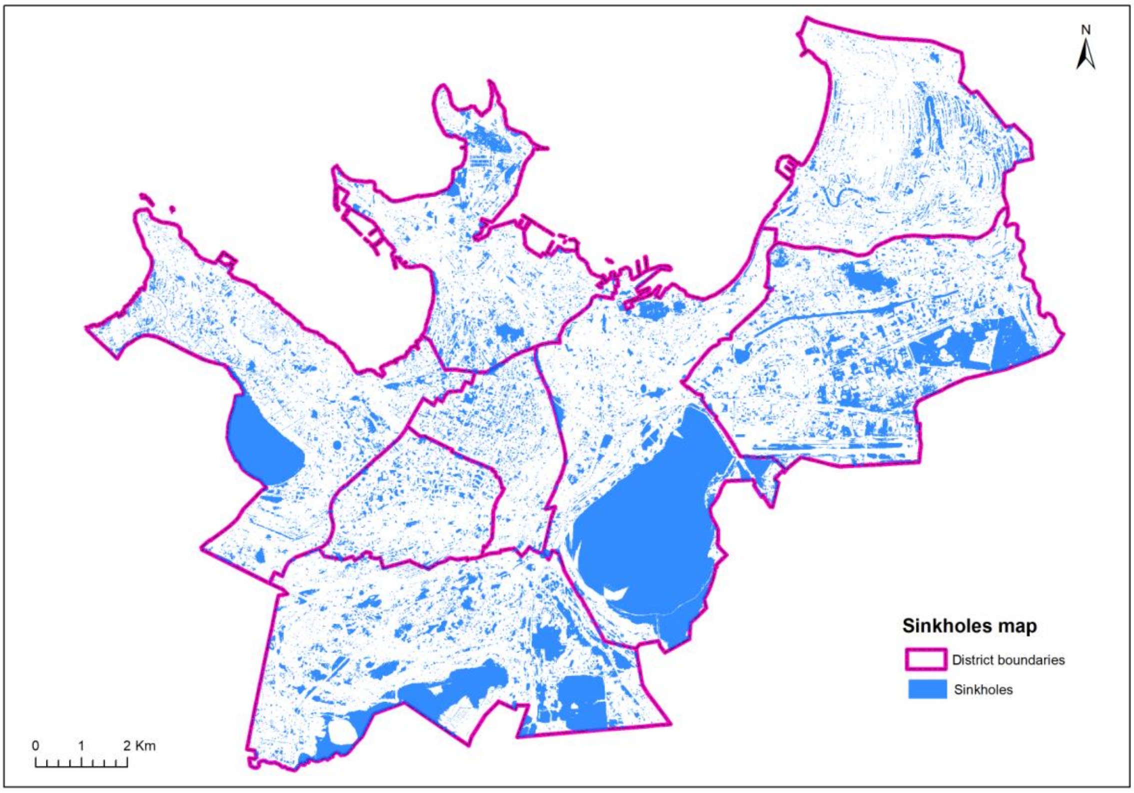


Figure 0-28 Sinkhole map

5. Final output: the flood susceptibility map

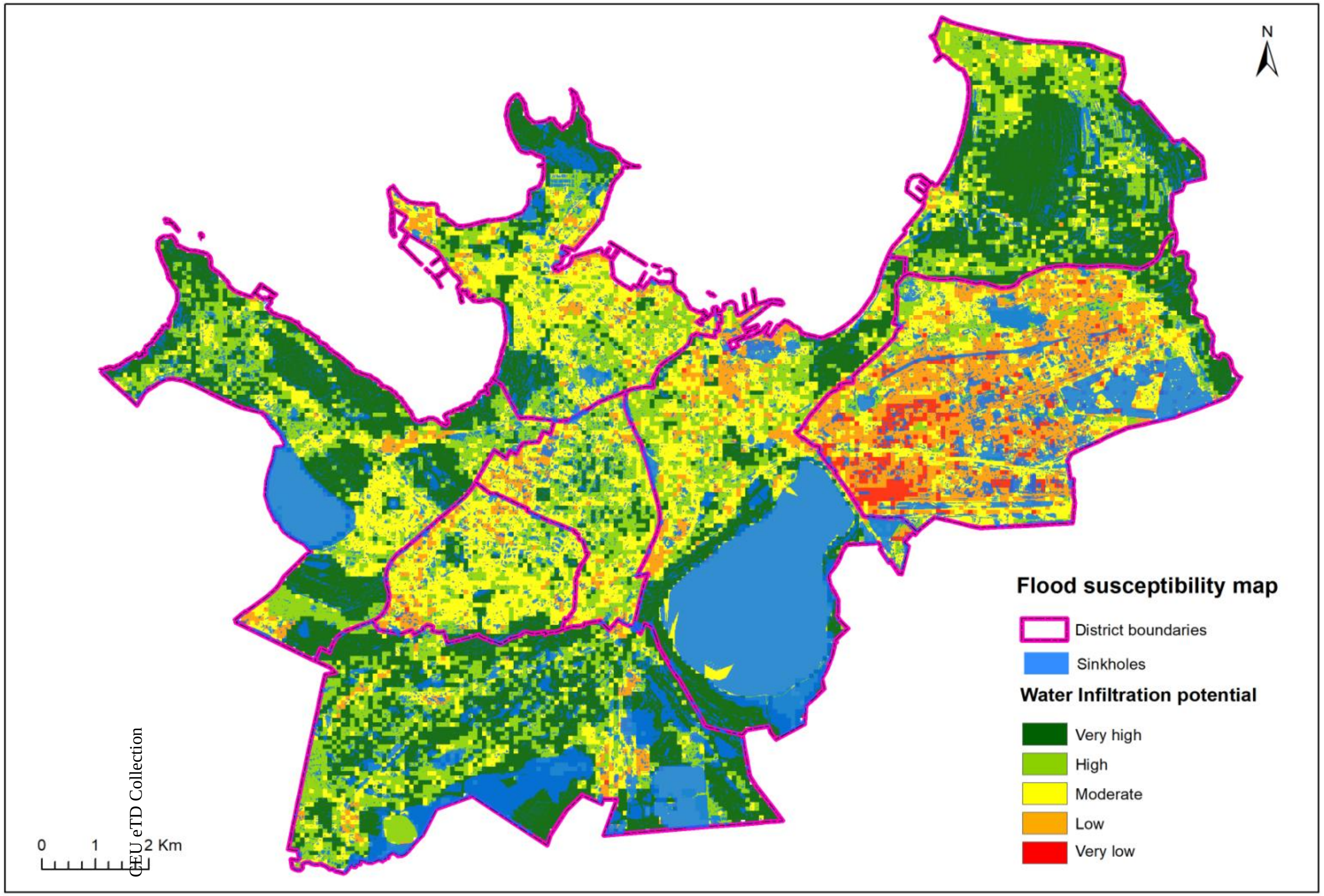


Figure 0-29 The flood susceptibility map

6. Ancillary thematic maps produced to select focus areas and determine the site's characteristics

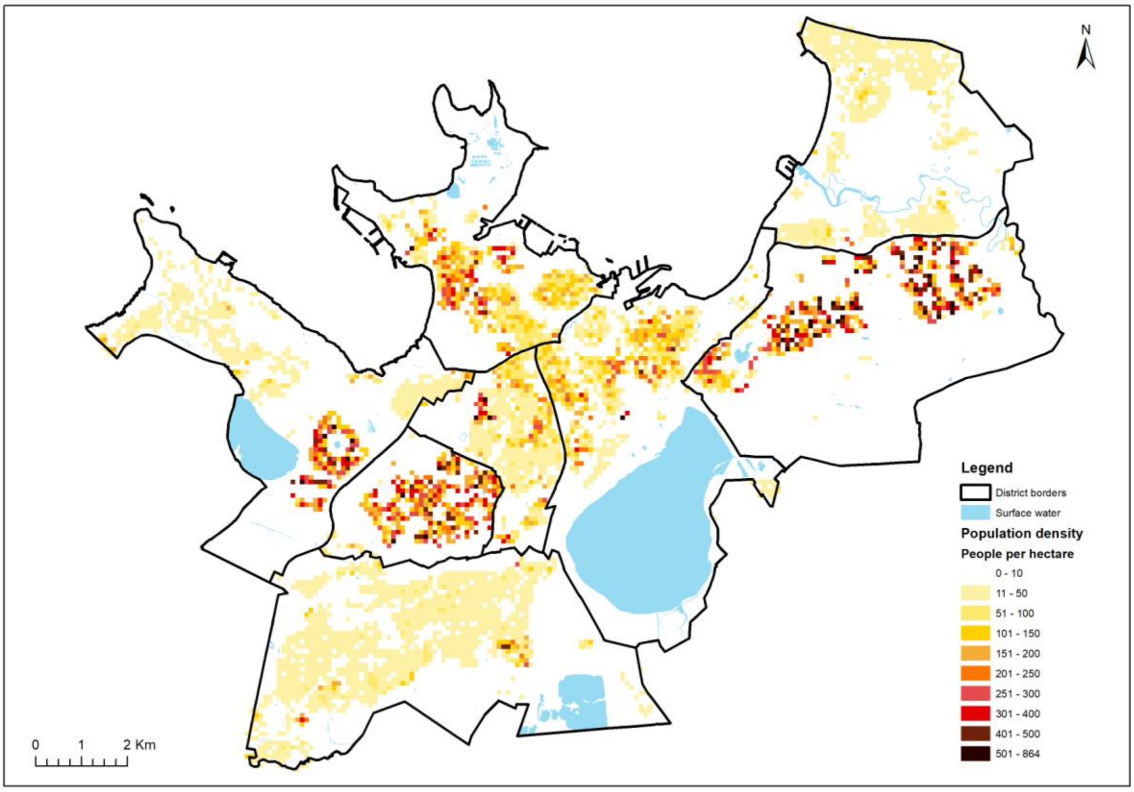


Figure 0-30 The population density map

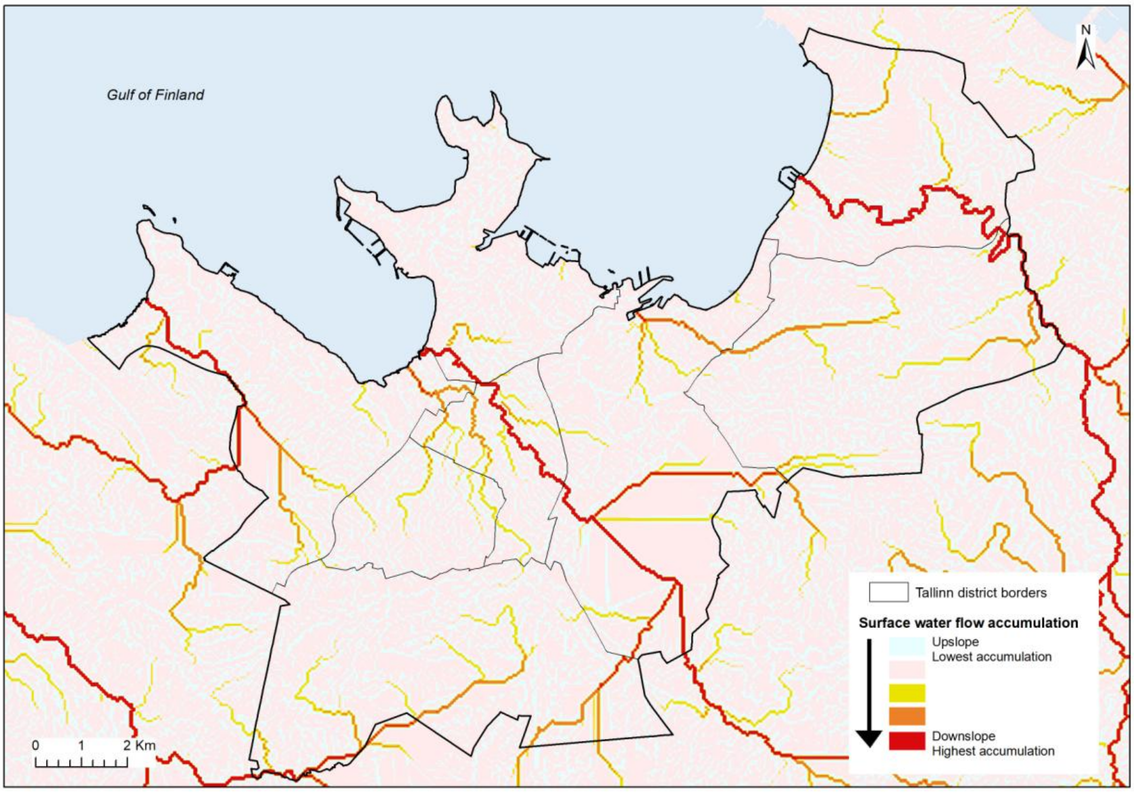


Figure 0-31 The flow accumulation map

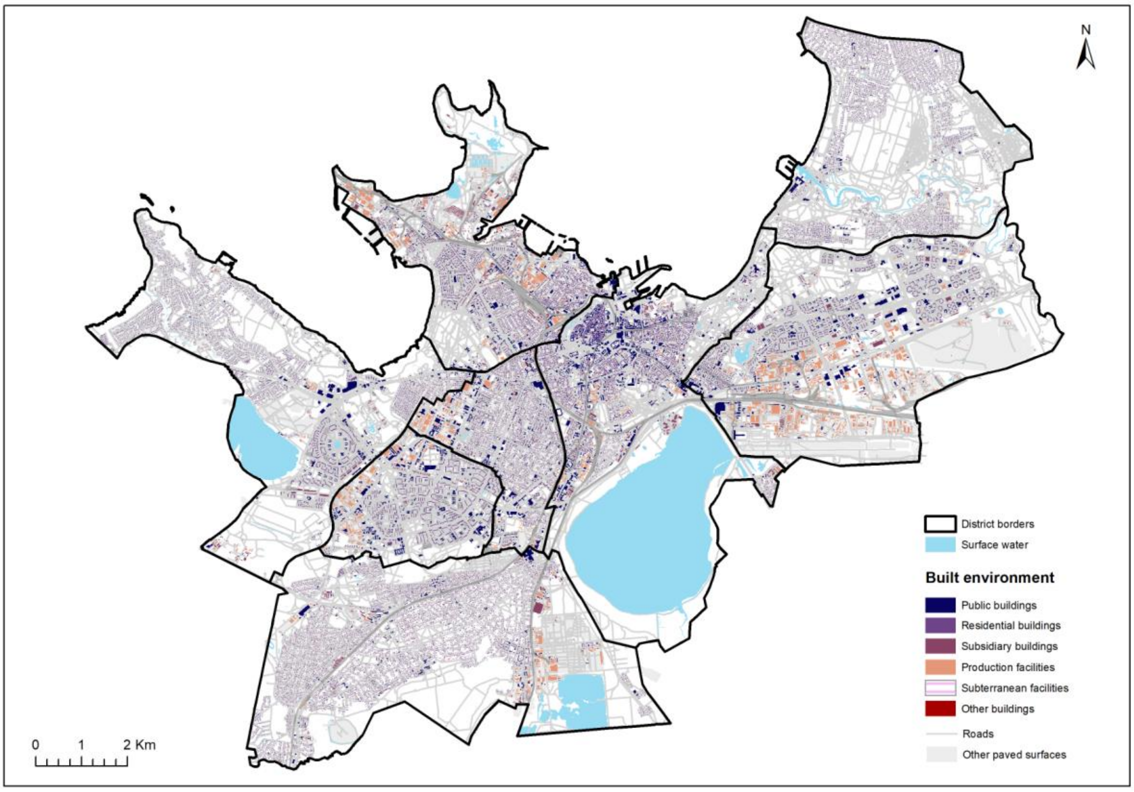


Figure 0-32 The built environment map

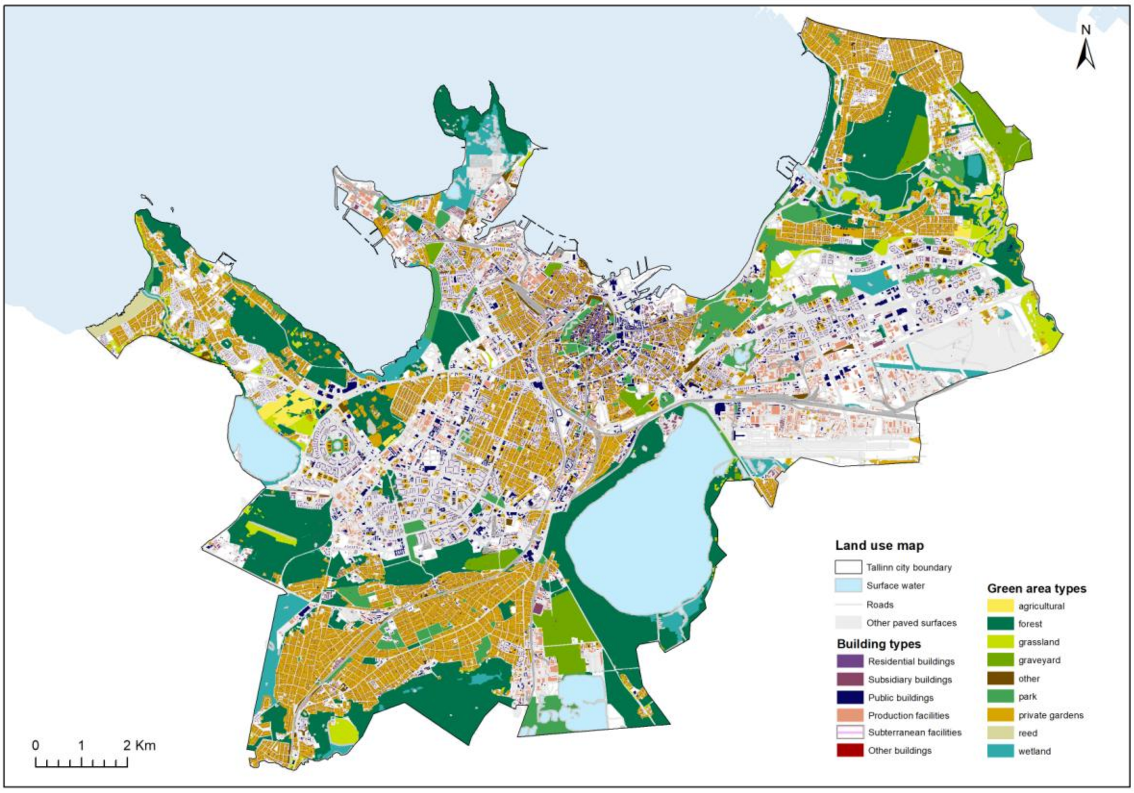


Figure 0-33 The land use map

Appendix H: Material produced for RQ3 (GIS maps, SuDS selection criteria table and symbols representing SuDS components, posters)

1. Example of the set of maps produced for each focus area

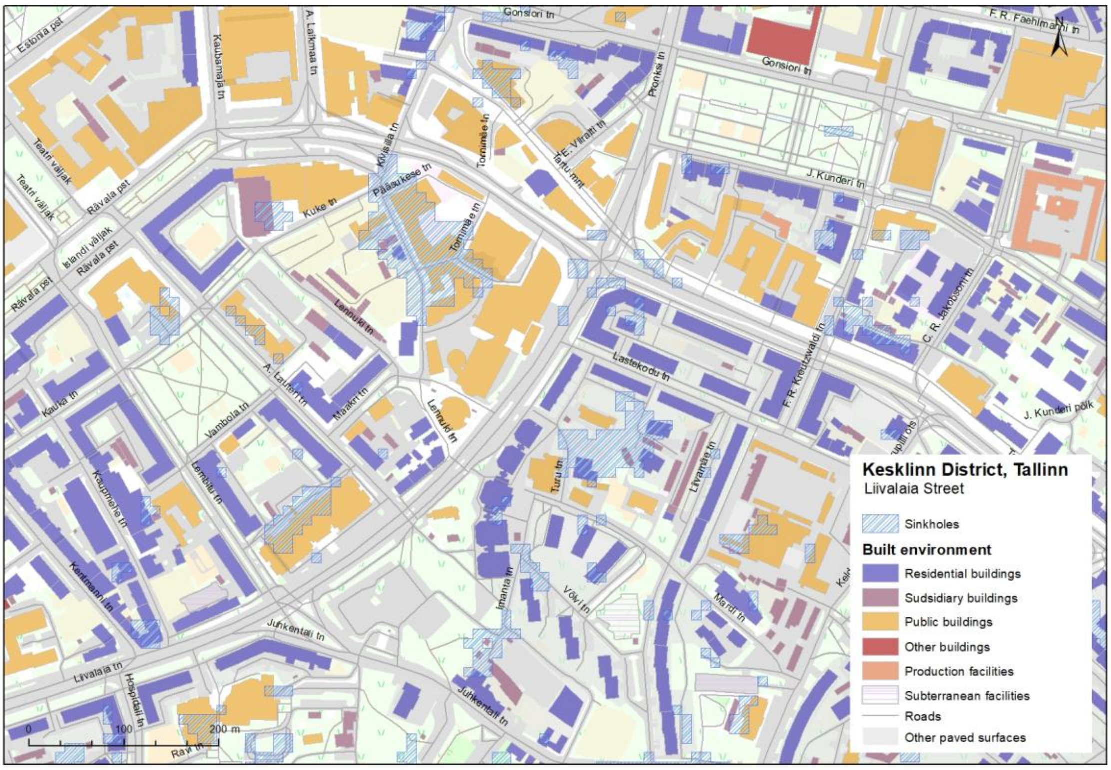


Figure 0-34 Built environment map for Kesklinn case

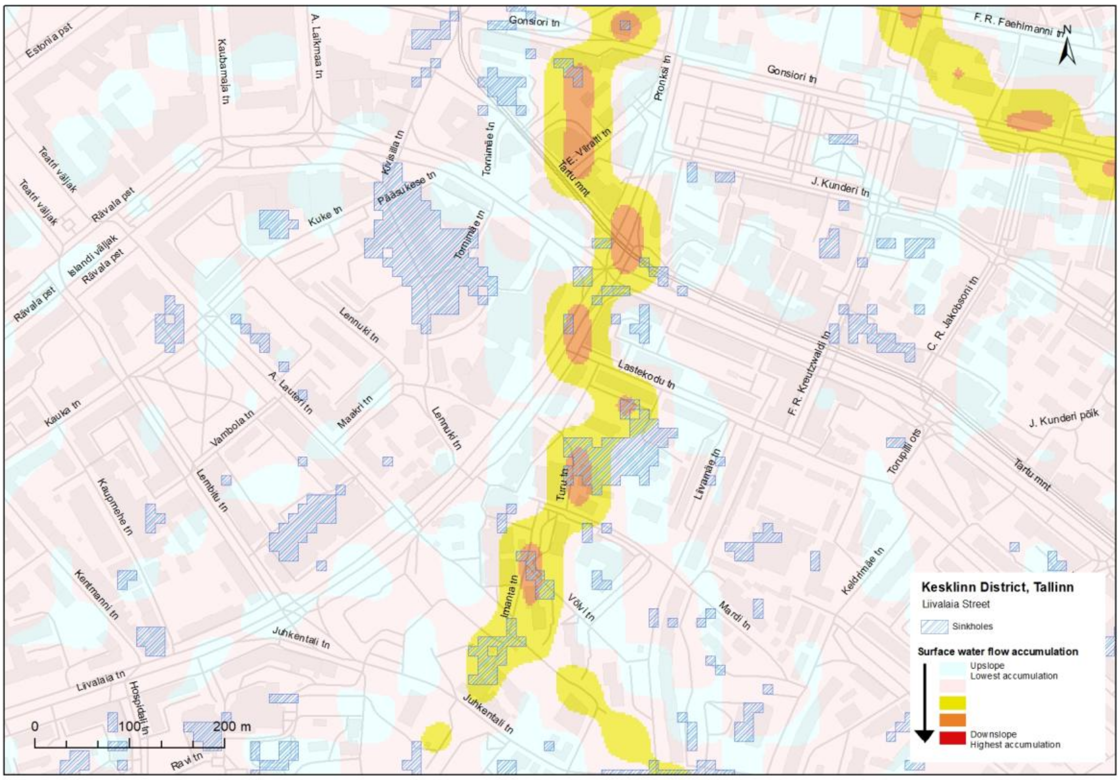


Figure 0-35 Flow accumulation map for Kesklinn parking case

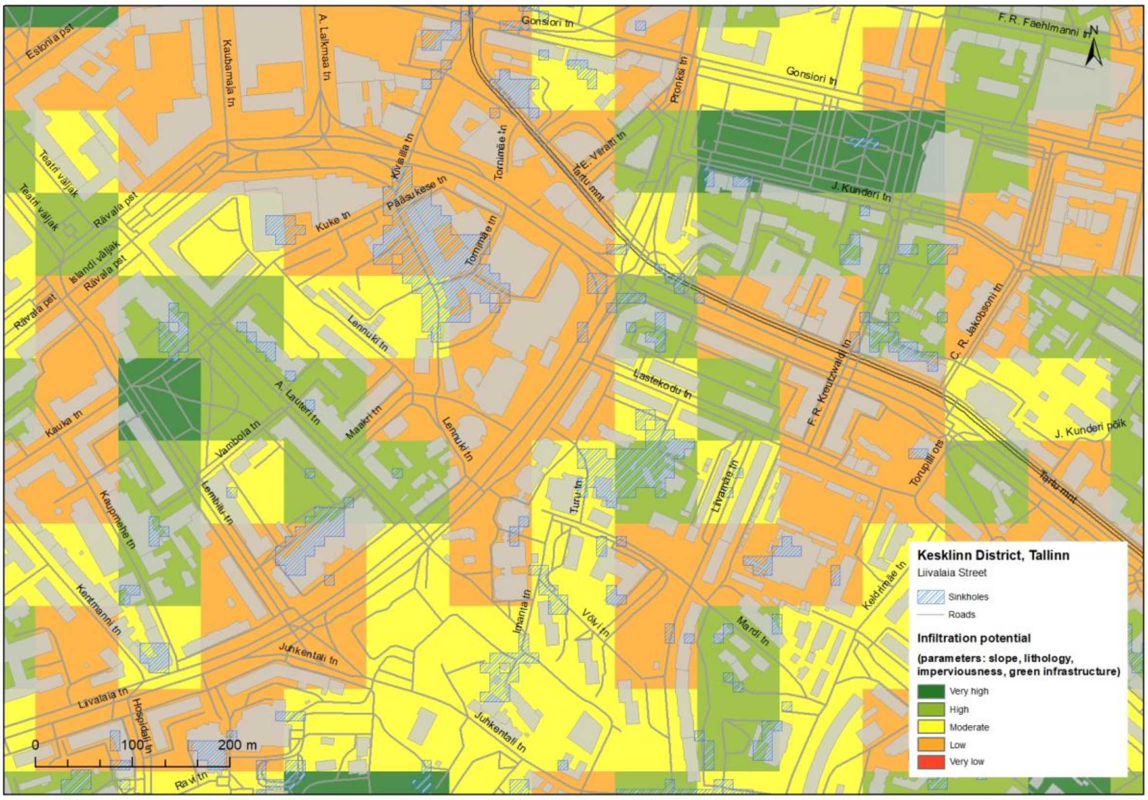


Figure 0-36 Soil infiltration potential map for Kesklinn parking case

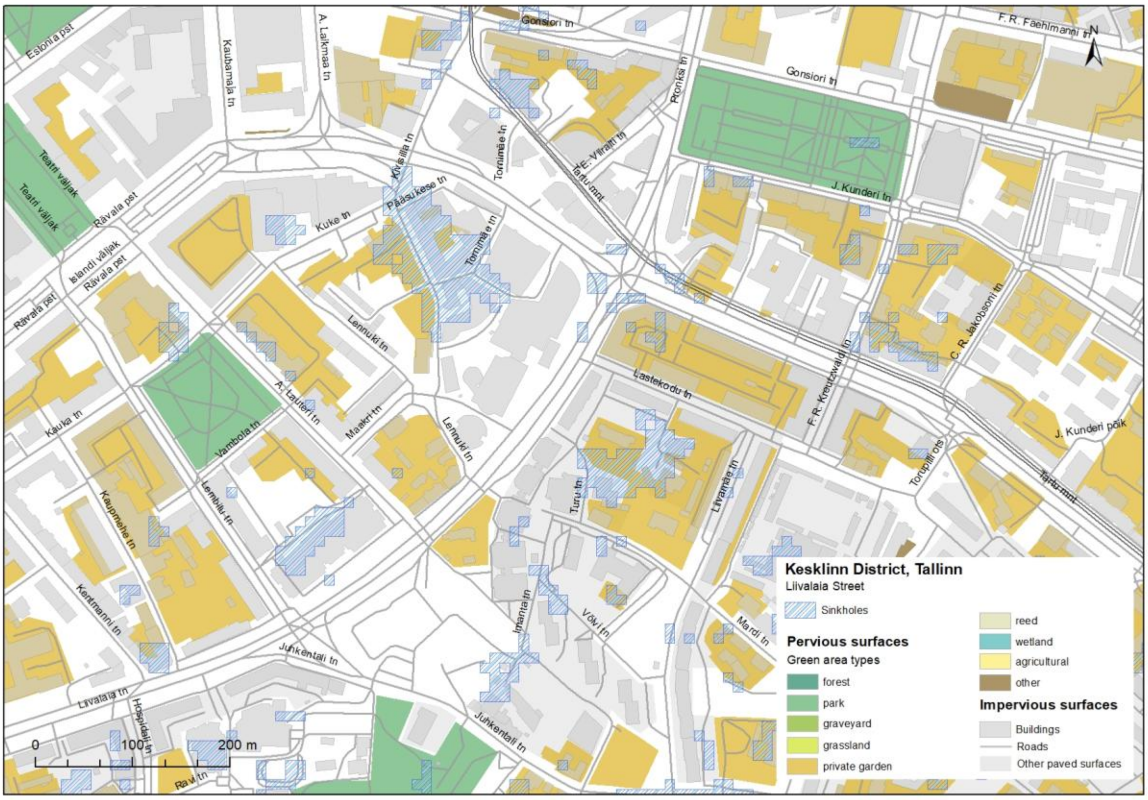


Figure 0-37 Green infrastructure map for Kesklinn parking case

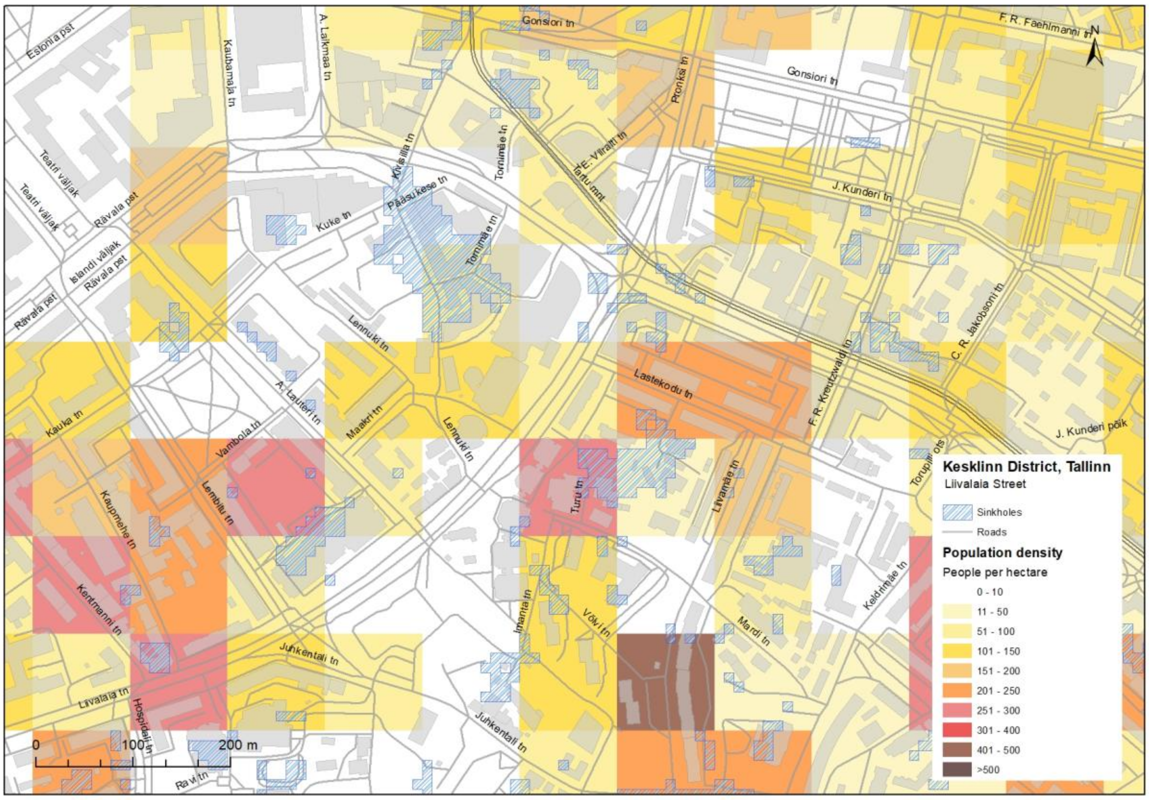


Figure 0-38 Population density map for Kesklinn parking case

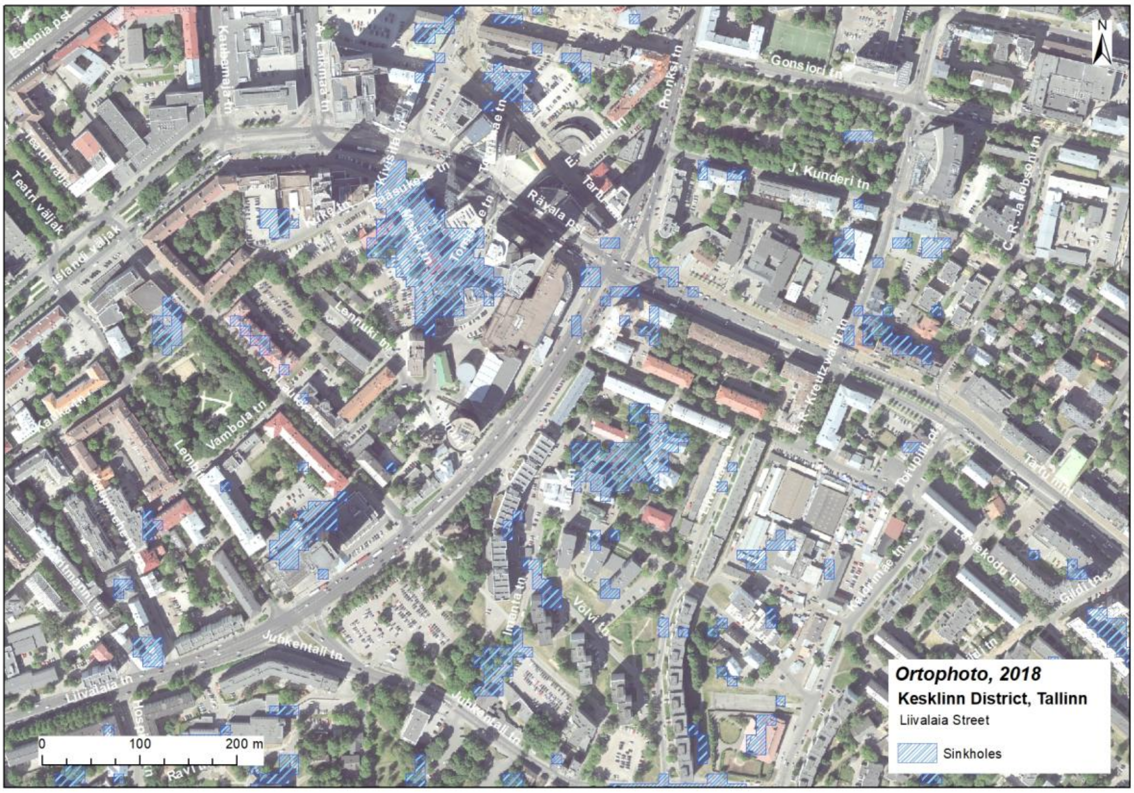


Figure 0-39 Aerial photography of Kesklinn parking case

Appendix I: The criteria table for SuDS selection

Capability of different SUDS techniques *

				SUDS design criteria																			
				Management train suitability						Water quantity control				Water quality improvement								Social-environmental benefits	
										1				2								3	4
	Technique	Description	Space requirement	Prevention / site management	Conveyance	Pre-treatment	Source control	Site control	Regional control	Conveyance	Detention	Infiltration	Water harvesting	Sedimentation	Filtration	Adsorption	Biodegradation	Volatilisation	Precipitation	Uptake by plants	Nitrification	Amenity	Biodiversity & habitat
1	Green roofs	Vegetated roofs that reduce runoff volume and rate	L	●		●	●				●				●	●	●	●	●	●	●	○	●
2	Green facades / living walls	Climbers, green wall systems, vertical swamps	L				●				●				●				●			●	●
3	Rainwater butts, site layout ja management	Good housekeeping and good design practices	L	●	○		●			○	○	●	○	○	○	○	○	○	○	○	○	○	○
4	Pervious pavements	Allow inflow of rainwater into underlying constructi of soil layers	L	●			●	○			●	●	○	●	●	●	●	●				○	○
5	Stormwater planters	Raised or at grade planters for rainwater storage and interception immediately at base of building	L/M				●	●			●	●		●	●	●	●	●	●	●	●	●	●
6	Rain gardens	Planted rainwater collection areas	L/M				●	●			●	●		●	●	●	●	●	●	●	●	●	●
7	Bioretention areas	Vegetated areas for collecting and treating water before discharge downstream, or to the ground via infiltration	L/M				●	●			●	●		●	●	●	●	●	●	●	●	●	●
8	Filter drain	Linear drains/trenches filled with a permeable material, often with aperforated pipe in the base of the trench	L/M		●		●	○		●	●				●	●	●	●					
9	Filter strips	Vegetated strips of gently sloping ground designed to drain water evenly from impermeable areas and filter out silt and other suspended particulates	L/M			●	●			○	○	○		●	●	●	●					○	○
10	Swales	Shallow vegetated channels that conduct and/or retain water (and can permit infiltration when un-lined). The vegetation filters particulates	M		●		●	●		●	●	○		●	●	●	●			○		○	○
11	Ponds	Depressions used for storing and treating water. They have a permanent pool and bankside emergent and aquatic vegetation	H					●	●		●	○	●	●	●	●	●	●	●	●	●	●	●
12	Wetlands	As ponds, but the runoff flows slowly but continuously through aquatic vegetation that attenuates and filters the flow. Shallower than ponds	H		○			●	●	○	●	○	●	●	●	●	●	●	●	●	●	●	●
13	Detention basin	Dry depressions designed to store water for a specified retention time	H					●	●		●			●	○	○	●			○		○	○
14	Soakaways	Sub-surface structures that store and dispose of water via infiltration	L				●					●			●	●	●						
15	Infiltration trenches	As filter drains, but allowing infiltration through trench base and sides	L/M		○		●	●		○	●	●			●	●	●	●					
16	Infiltration basins	Depressions that store and dispose of water via infiltration	H					●	●		●	●			●	●	●	●				○	○
17	Sand filters	Treatment devices using sand beds as filter media	L			●		●	○		●	○			●	●	●	●	●				
18	Silt removal devices	Manhole and/or proprietary devices to remove silt	L			●								●									
19	Pipes, subsurface storage	Conduits and their accessories as conveyance measures and/or storage. Water quality can be targeted using sedimentation and filter media	L		●			●		●	●			○	○								

L Low space requirement

M Medium space requirement

H High space requirement

● High/primary process

○ Some opportunities, subject to design

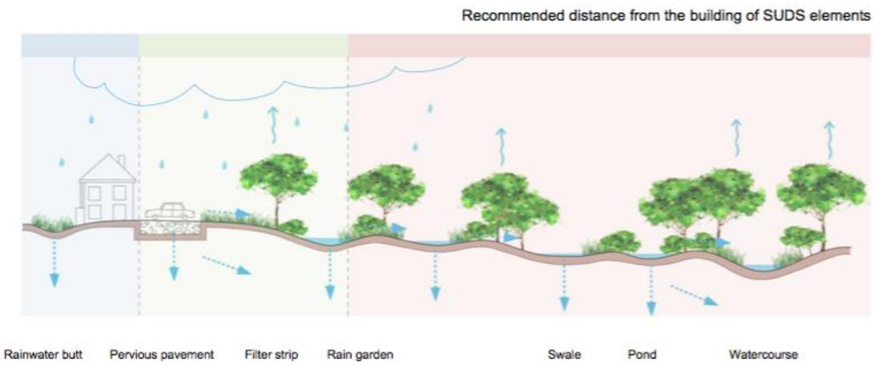


Figure 0-40 The SuDS criteria table

Source: elaborated by Virginie Laroche and Gen Mandre based on CIRIA's SuDS manual (2007)

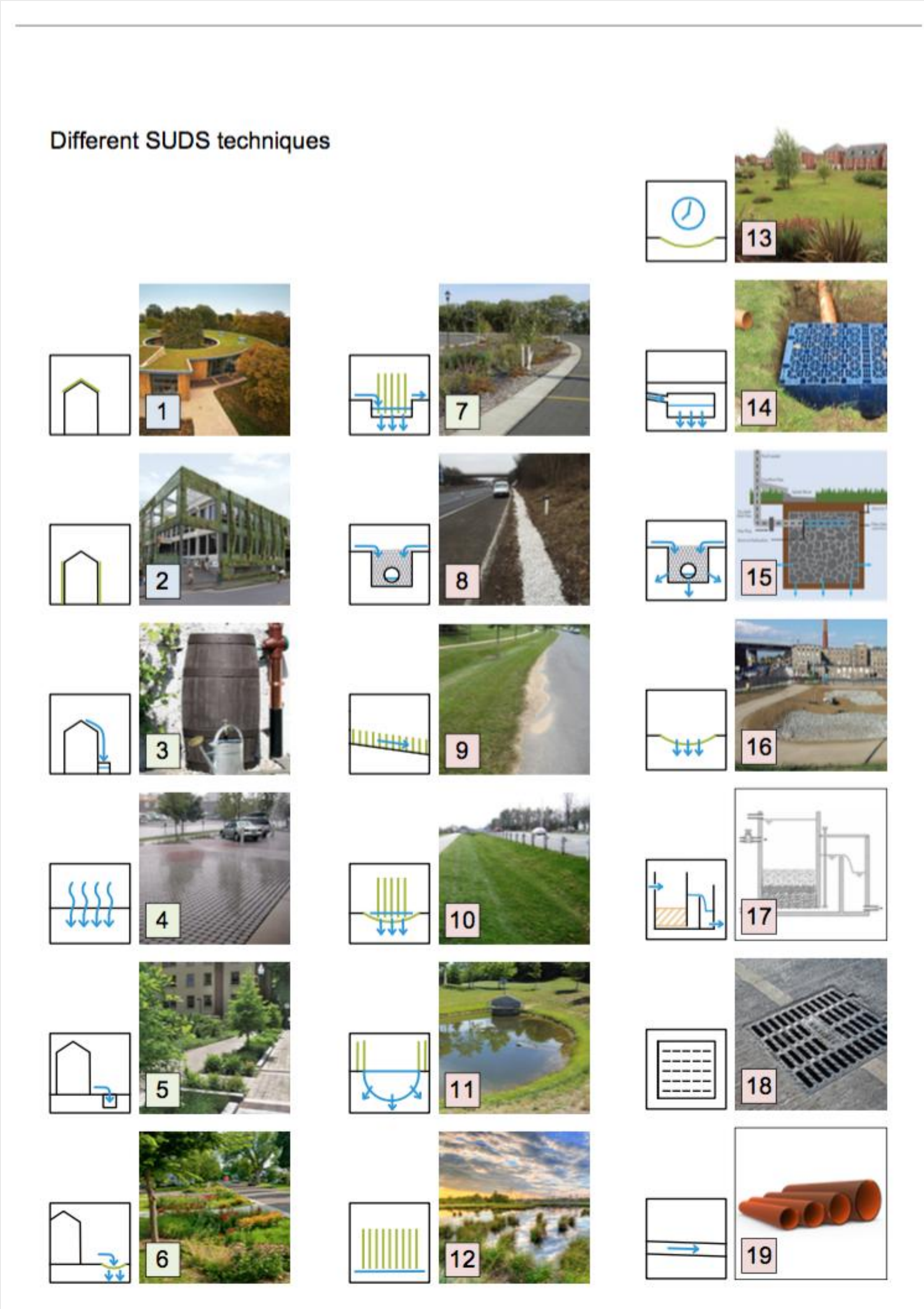


Figure 0-41 Symbols corresponding to each SuDS technique presented in the criteria table

Source: elaborated by Gen Mandre

Appendix J: Application example of the SuDS selection tool

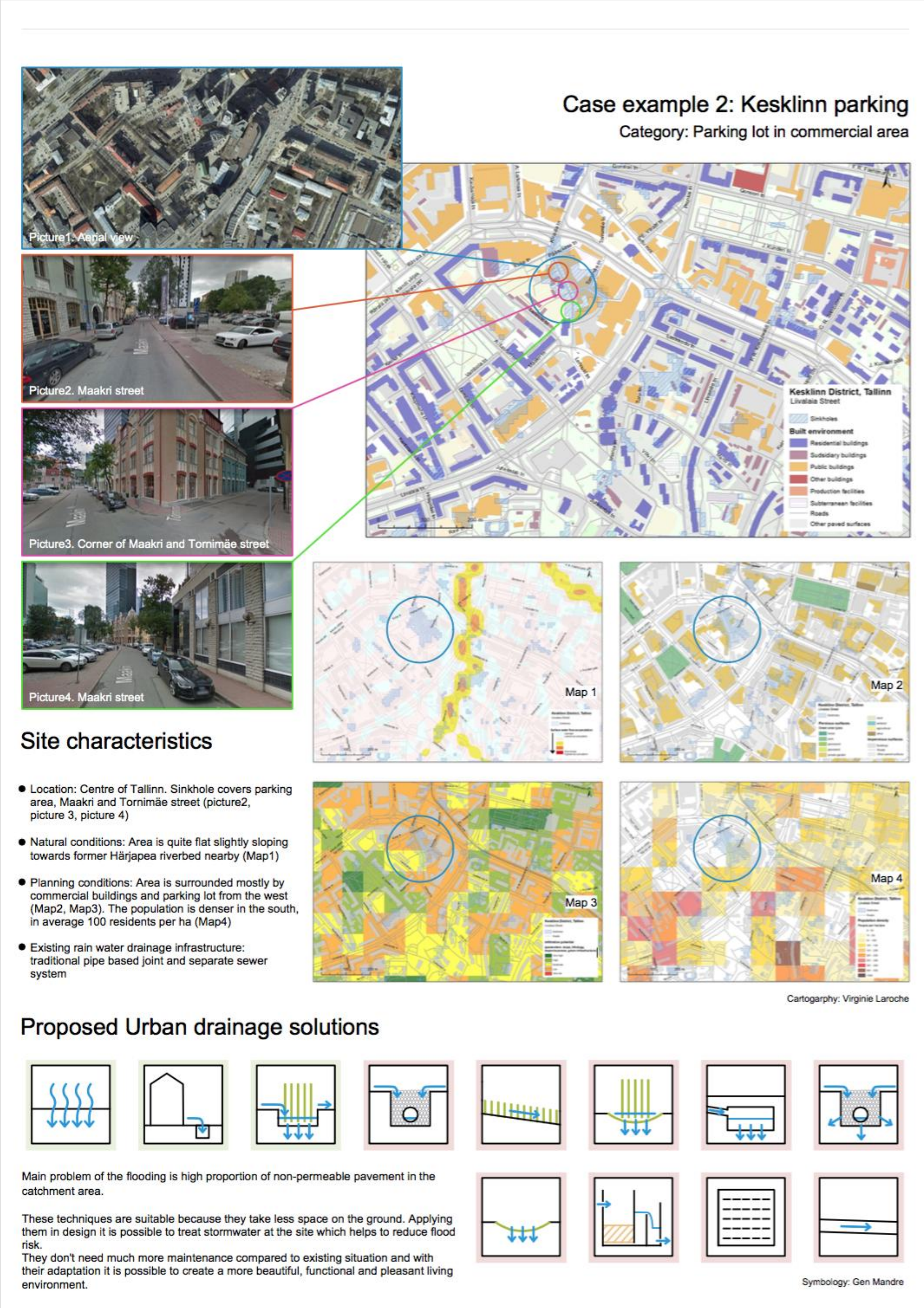


Figure 0-42 Poster – Focus area: Kesklinn parking

Source: elaborated by Gen Mandre and Virginie Laroche

Appendix K: Example of an online SuDS selection tool

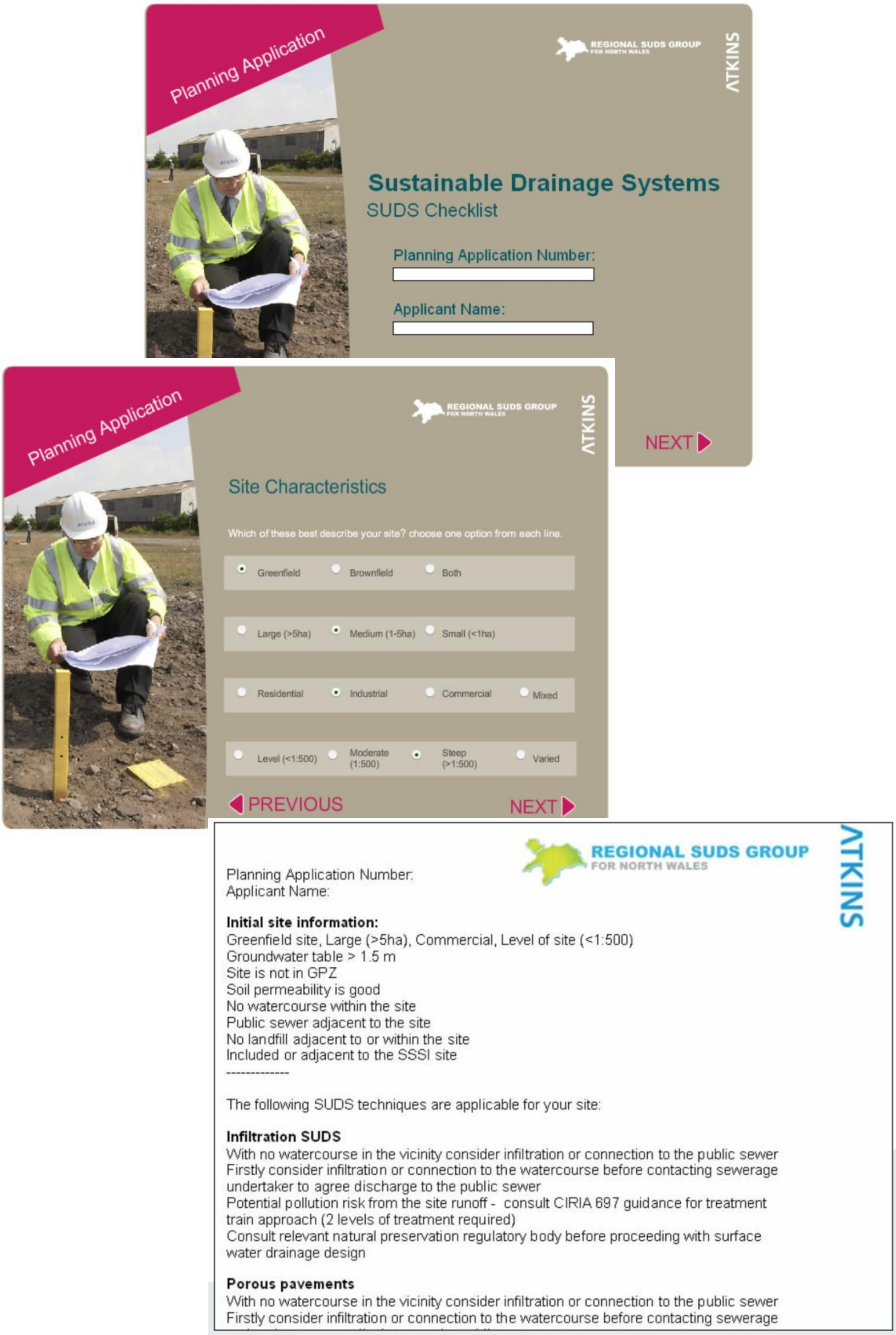


Figure 0-43 Online SuDS selection tool

Source: Atkins, 2008