MANAGING CLIMATE CHANGE

Sjællandsgade as a Green Corridor

Interactive Qualifying Project Report completed in partial fulfillment

of the Bachelor of Science degree at

Worcester Polytechnic Institute, Worcester, MA

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Abstract

This report, prepared for Danish ecoactivist group Miljøpunkt Nørrebro, contains a detailed study of the viability of sustainable floodwater mitigation solutions and climate change adaptation in the Sjællandsgade corridor of Copenhagen. Included in this report are theoretical and empirical documentation of the validity of these problems, as well as operational deliverables. Three tiered solutions and an interactive rainfall prediction spreadsheet have been developed specifically for Sjællandsgade, and a comprehensive technical manual is provided for similar neighborhoods seeking individualized floodwater solutions.

Acknowledgements

There are several people we would like to thank whose assistance has been invaluable to the successful completion of our project. We would first like to thank our sponsor liaison, Ove Larsen, a project manager at Miljøpunkt Nørrebro, for all of his advice and help. We would like to thank Stefan Werner, manager of the Skt. Kjelds Kvarter project and Copenhagen Water and Parks Division (WPD) employee, and Henriette Berggreen, Copenhagen WPD employee, for providing their expert insight on how to plan and design a green space that simultaneously manages floodwater. We also thank Professor Reinhold Ludwig for guiding and advising us through both our project and our time in Copenhagen, as well as Professor Peder Pederson and Tom Thomsen for providing us with the incredible opportunity to come to Copenhagen and work on this project. We greatly appreciate all of the help these people gave us as we had this experience and completed this project.

Authorship Page

Each member of the team contributed equally to this project: each one of us wrote sections, edited parts, and created figures and tables for the completed report. Everyone gave input on each section of this report and had an integral role in the thought processes behind everything done for the project.

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Executive Summary

Situated on the entrance to the Baltic Sea, the city of Copenhagen, Denmark is a heavily populated and densely urbanized metropolitan area. Due to its costal location and relatively high latitude, Copenhagen experiences frequent and often unpredictable weather events. The effects of these events are compounded by the urbanization of the area and the lack of sufficient infrastructure to contain, filter, and divert stormwater runoff. In collaboration with our sponsor, Miljøpunkt Nørrebro, our group was tasked with assessing the need for climate change adaptation along the Sjællandsgade corridor, a residential street in the Nørrebro district of Copenhagen. After performing this assessment and affirming the legitimacy of the need for climate change adaptation in this area, we produced a series of sustainable design solutions and analytical tools in the form of project deliverables. These project deliverables were developed to assist Miljøpunkt Nørrebro in the pursuit of gaining community and municipality support for the creation of a green corridor along Sjællandsgade, a geographical element which will best mitigate the various problems associated with the management of climate change.

The complex nature of this project required our group to gain a comprehensive understanding of the relationship between our project objectives. Primarily, we had to prove the existence of an urgent and legitimate flooding problem in the Sjællandsgade corridor. Without factual proof and empirical evidence, Miljøpunkt Nørrebro would not have been able to pursue the necessary climate change adaptation measures in this area. Conversely, obtaining proper justification of this problem allowed us to further our research and sustainable solution development. Our sustainable design solutions not only mitigate flooding but decrease urban air temperature and provide the Sjællandsgade community with ample green space for their recreational use. As illustrated in the featured graphic, Figure 1, the versatile nature of our solutions stems from the multi-faceted nature of the problem at hand. Through our comprehensive understanding of this problem, we have optimized the climate change adaptation initiatives set forth by the Miljøpunkt Nørrebro organization.

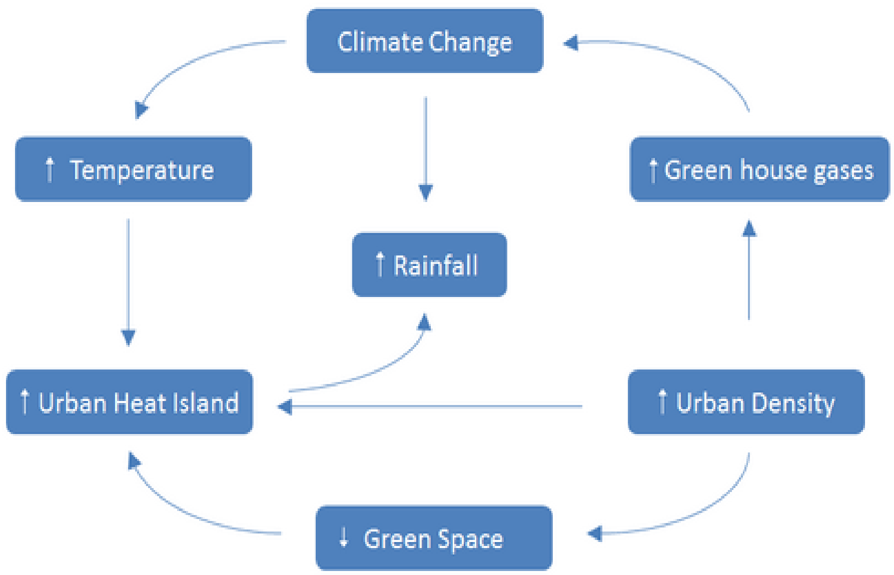

Figure 1. An illustration of the multi-faceted climate change problem

The acquisition of empirical evidence to complement our theoretical documentation of the flooding problem in Sjællandsgade required extensive research and analysis. A terrain elevation contour map, Figure 25, was produced in conjunction with a directional runoff flow map to illustrate rainwater runoff paths in the Sjællandsgade area. This information was then used to calculate the most detailed and accurate runoff flow quantification for the Sjællandsgade area ever produced. Our runoff flow quantification is substantiated by the Rational Method of fluid flow, utilized through the determination of time of concentration (T_c) from the Velocity Method and precipitous intensity from an Intensity Duration Frequency curve. After obtaining substantiated empirical runoff data, the legitimacy of the climate change adaptation initiative was affirmed and the appropriate sustainable design solutions could be developed to accommodate the volume of rainwater runoff expressed in our calculations.

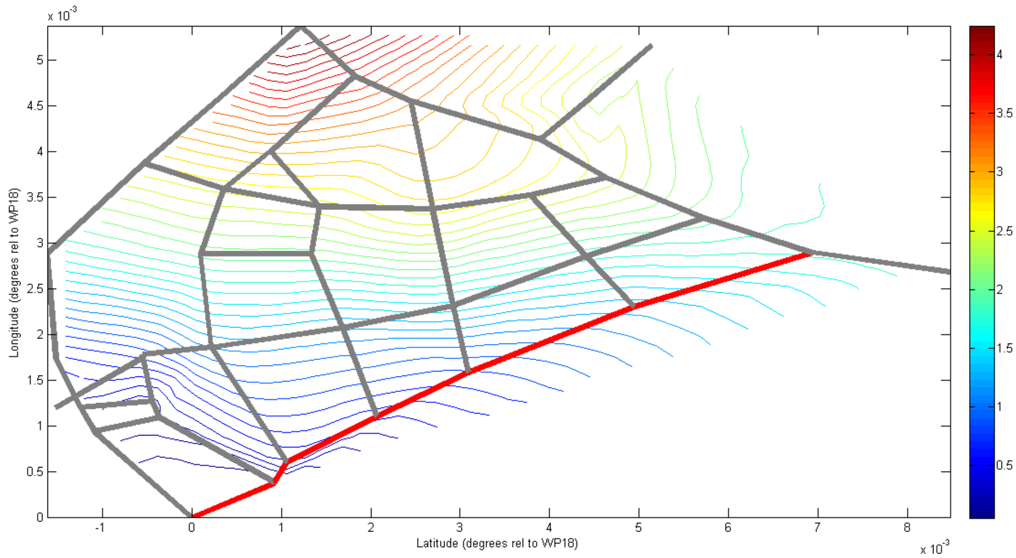

Figure 25. A terrain elevation contour map of the Sjællandsgade area

Based exclusively on the nature of the results of our extensive research, we have developed a series of tiered solutions that may be implemented in the Sjællandsgade corridor. The benefit of developing a tiered solution system is that the solutions build upon each other, thus allowing the ideal solution to be installed over time in steps should funding or other restraints limit its initial feasibility. Included in the solutions are numerical design specifications for drainage swales, dual-use parks, semi-permeable pedestrian pathways, parking and sedimentation reservoir structures, and non-potable rainwater catchment and reuse systems. Additionally, the solutions can be actively compared to better illustrate the potential sustainability and effectiveness of each tier. Essentially, the tiered solution system has allowed our group to propose three viable, sustainable solutions for floodwater mitigation and green space production in this area. This has resulted in a solution system that is three times as feasible for installation as any one solution, maximizing the efficiency of our work and value of our solutions. Figures 41, 45, and 46 are a compilation of renderings highlighting the principal characteristics of each tier.

Figure 41, 45, and 46, from left to right are visions for each tier proposal.

The quantification of surface runoff in the Sjællandsgade area required the consideration of both surface area permeability and voluminous runoff. We consolidated these surface permeability and water runoff studies in a spreadsheet for Miljøpunkt Nørrebro to use when refining water management and water catchment systems for the area. The embedded formulas, Equations (5.1.6) and (5.1.7), originate from calculations specific to Sjællandsgade, as found in Appendix D: Rational Method calculations for. The model takes into account weighted surface permeability coefficients and calculations of water flow specific to Sjællandsgade to provide a closer estimate of total runoff values. The only variables are the type of 'Year' storm and its duration in hours. Additionally, the spreadsheet is 'protected' to guarantee the formula will not be modified accidentally.

An additional deliverable we produced for Miljøpunkt Nørrebro is a technical manual for climate change adaptation. This manual details the ways in which other neighborhoods can come up with their own arguments for the integration of sustainable climate change adaptation plans and designs for floodwater management systems in their communities. We produced the manual by outlining the ideology and process methodology we applied to the Sjællandsgade climate change adaptation. The manual is structured in such a way that it allows an interested party with little prerequisite qualification to effectively replicate the results of our report. This can be applied to any neighborhood or target area, facilitating the development of sustainable climate change adaptation solutions on a large scale. The complete technical manual can be found in Appendix J: Technical Manual for Climate Change Adaptation.

Our research, empirical evidence and project deliverables were presented to Miljøpunkt Nørrebro and additional stakeholders in an interactive presentation which toured the audience along the Sjællandsgade corridor. This presentation allowed the audience to gain a personal and individualized perspective of the various elements of our project, and provided our group with a unique opportunity to engage our sponsor and stakeholders in our work. Additionally, we provided recommendations for the continuation of our work in Sjællandsgade and in the technical manual, outlining an appropriate direction to conduct future work on this topic. Though the scale and intricacy of this project provided stout limitations to our final product, we believe that our research, data, and sustainable design solutions will greatly influence the nature of climate change adaptation in Sjællandsgade and urban communities elsewhere.

1 Introduction

The Danish capitol city of Copenhagen is a modern metropolis, home to just under two million people. Despite being a pioneering country in environmental activism and research, Copenhagen is still vulnerable to the impacts of global climate change, such as rises in sea level, storm surges, more frequent and intense storms, and flooding (Cowi, et al., 2011). According to Miljøpunkt Nørrebro, an ecoactivist nongovernmental organization (NGO) in Copenhagen, the city has inadequate infrastructure to retain, filter, manage, and utilize greater volumes of storm water that are becoming the norm as flooding becomes more common (Mr. Larsen, personal communication, January 25, 2013; see Appendix B: Interview with Mr. Ove Larsen for the entire interview).

Miljøpunkt Nørrebro has identified Sjællandsgade as an area that is appropriate for extensive climate change adaptation. Sjællandsgade is a busy, inclined street in the Nørrebro district of Copenhagen with a flooding problem that may be exacerbated by the nearby construction of the North (Nørre) Campus of the University of Copenhagen (Mr. Larsen, personal communication, January 25, 2013). This construction will lend to an increased area of impermeable surfaces in the vicinity. Impermeable surfaces, along with free-standing structures and roadways, funnel water to concentrated low-lying areas, causing flash flooding with at times significant damage. Although Sjællandsgade has sewage systems in place, additional means of managing water must be implemented to separate such voluminous runoff from the rain that is caused by the higher elevation areas of Nørrebro surrounding Sjællandsgade. Mr. Larsen, project manager at Miljøpunkt Nørrebro, believes there is currently a lack of viable water management systems in Sjællandsgade that could specifically address sustainable flooding and climate change solutions (Mr. Larsen, personal communication, January 25, 2013).

The goal of our research is to generate an argument for the need of a floodwater solution and then to collaborate with local residents and experts in order to identify which strategies best mitigate the damage caused by flooding in the Sjællandsgade corridor of Copenhagen. To achieve our goal, we plan to propose designs for floodwater management systems that efficiently store, filter, and reuse storm water while adding to the green space of the street. We also plan to create a technical manual detailing the ways in which other neighborhoods can come up with their own arguments for the integration of sustainable climate change adaptation plans and designs for floodwater management systems in their communities. We will perform on-site field investigations of Sjællandsgade to characterize the area, create arguments for climate change adaptation plans for Sjællandsgade, conduct thorough feasibility evaluations on possible solutions, and interview experts and residents on their opinions in order to produce a set of solutions which are most sustainable and feasible for the area.

2 Background

The aim of this project is to formulate an argument for both the existence of a flooding problem in the Sjællandsgade area and the need for an appropriate, sustainable solution to address the problem. The following chapter explores the various factors that contribute to climate change; it also reviews the general environment of the Sjællandsgade area and the flooding problem at this location. Figure 1 provides a generic overview of the relationship between the factors that contribute to climate change and flooding in an urban area. All of these factors need to be taken into account when developing solutions that both alleviate stormwater accumulation problems and also add to the green areas of the street. Current and future climate patterns in Copenhagen as well as climate change adaptation policies are also investigated in this chapter, outlining initiatives set forth by both the municipality and Europe as a whole.

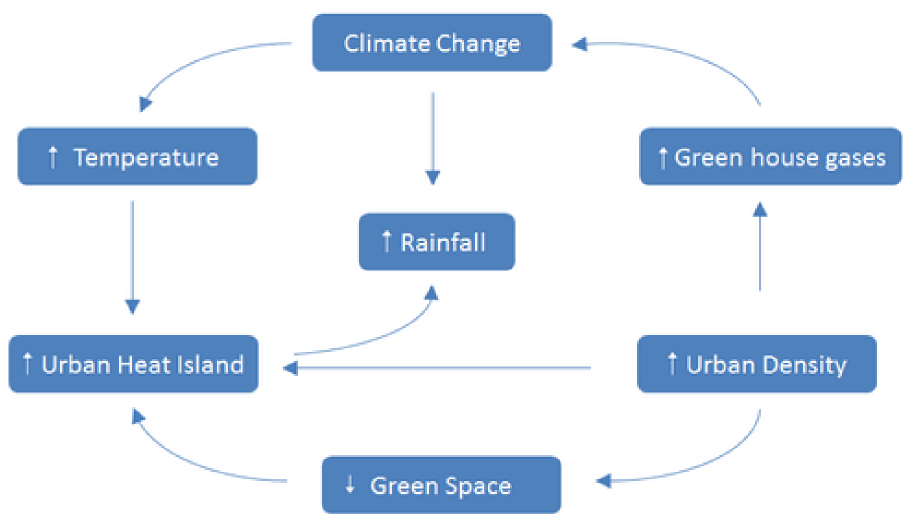

Figure 1. Relationships between factors that affect climate change. GHG=greenhouse gases.

2.1 Increased vulnerability to storm surges and flooding in Copenhagen

Climate change is a global problem that becomes more significant as time goes on (Cowi, et al., 2011). In addition to natural factors, it has been suggested that people influence climate change through greenhouse gas and aerosol emissions. Of particular relevance to this project, it has also been proposed that climate change results in an increase in the amount and severity of precipitation in addition to the gradual increase in temperature (Min, et al., 2011). In Denmark specifically, the average temperature has risen 1.5^{o}C and the average volume of precipitation increased by 100 millimeters since the 1870's (Oleson, 2011). Both the average rainfall days with volumes per month and the average high and low temperatures per month in Copenhagen can be seen in Figure 2.

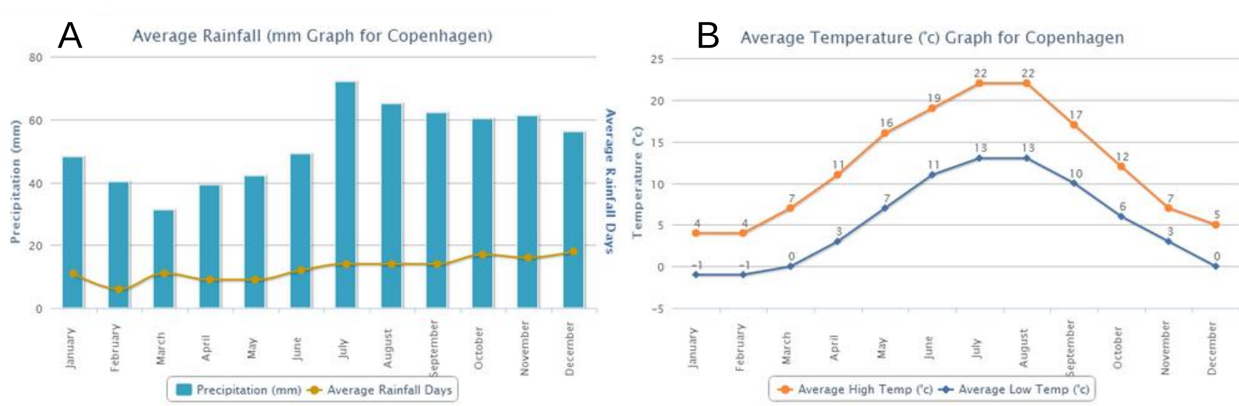

Figure 2. Graphs depicting A) the average volume (mm) of rainfall and average number of rainfall days per month and B) the average high (orange) and low (blue) temperatures each month in Copenhagen (World Weather Online, 2013).

Another human factor that affects climate change is referred to as 'urban heat island effect'. This effect is defined as the tendency of urban areas to have a higher average temperature due to increased population density and lack of green space (Voiland, 2010). Figure 3 demonstrates this concept, depicting a higher average surface temperature in urban city areas than in rural or suburban areas. This holds true in Denmark, as Figure 4 shows the results of satellite detection of the average surface temperatures around different parts of Denmark

(Municipality of Copenhagen Center for Parks and Nature, 2006). More urban areas, such as Copenhagen and the district of Nørrebro (inset of Figure 4) have higher average surface temperatures (orange and red in Figure 4) than that of more rural areas, such as those at the periphery of Copenhagen. In Nørrebro particularly, a large area of lower temperatures (blue and green) can be seen located in the Assistens Cemetery, an area full of trees, lending to the idea that areas with more trees and less pavement have a lower average surface temperatures. Figure 5, a vertical selection of surface temperatures from the heat map (inset of Figure 5), affirms this with Assistens Cemetery (Assistenskirkegården) having one of the lowest average surface temperatures of the areas selected for analysis (Municipality of Copenhagen Center for Parks and Nature, 2010).

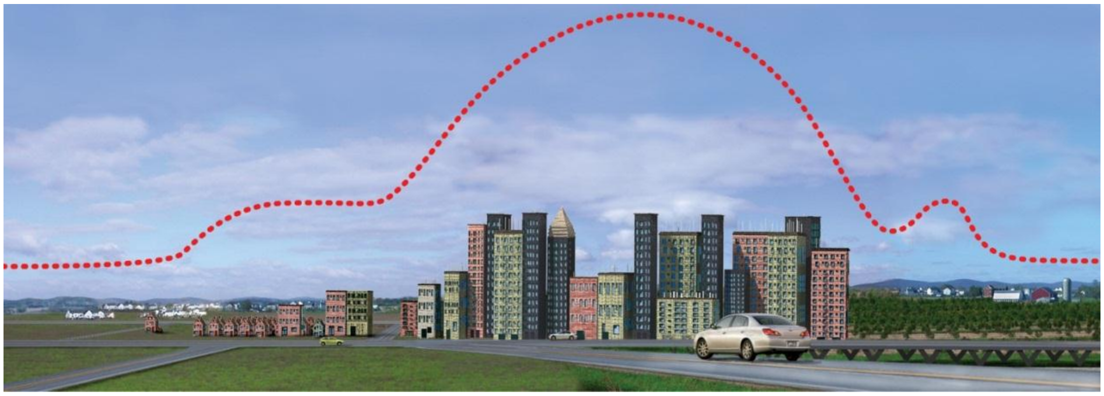

Figure 3. Effects of urban heat island effect. The dotted red line indicates the rises and falls in average surface temperature in urban, suburban, and rural areas (Voiland, 2010).

Urban heat island effect is the result of the type of environment cities create. Urban areas tend to have more concrete or paved areas, creating large amounts of ‘impervious surface,’ or surfaces that do not absorb water. This phenomenon, while also increasing flooding risks, also hinders the cooling effect that rain has on the ground when rainwater is absorbed. The reduced amount of green spaces in urban areas results in less shade and factors into higher average surface temperatures (Carlowicz, 2009).

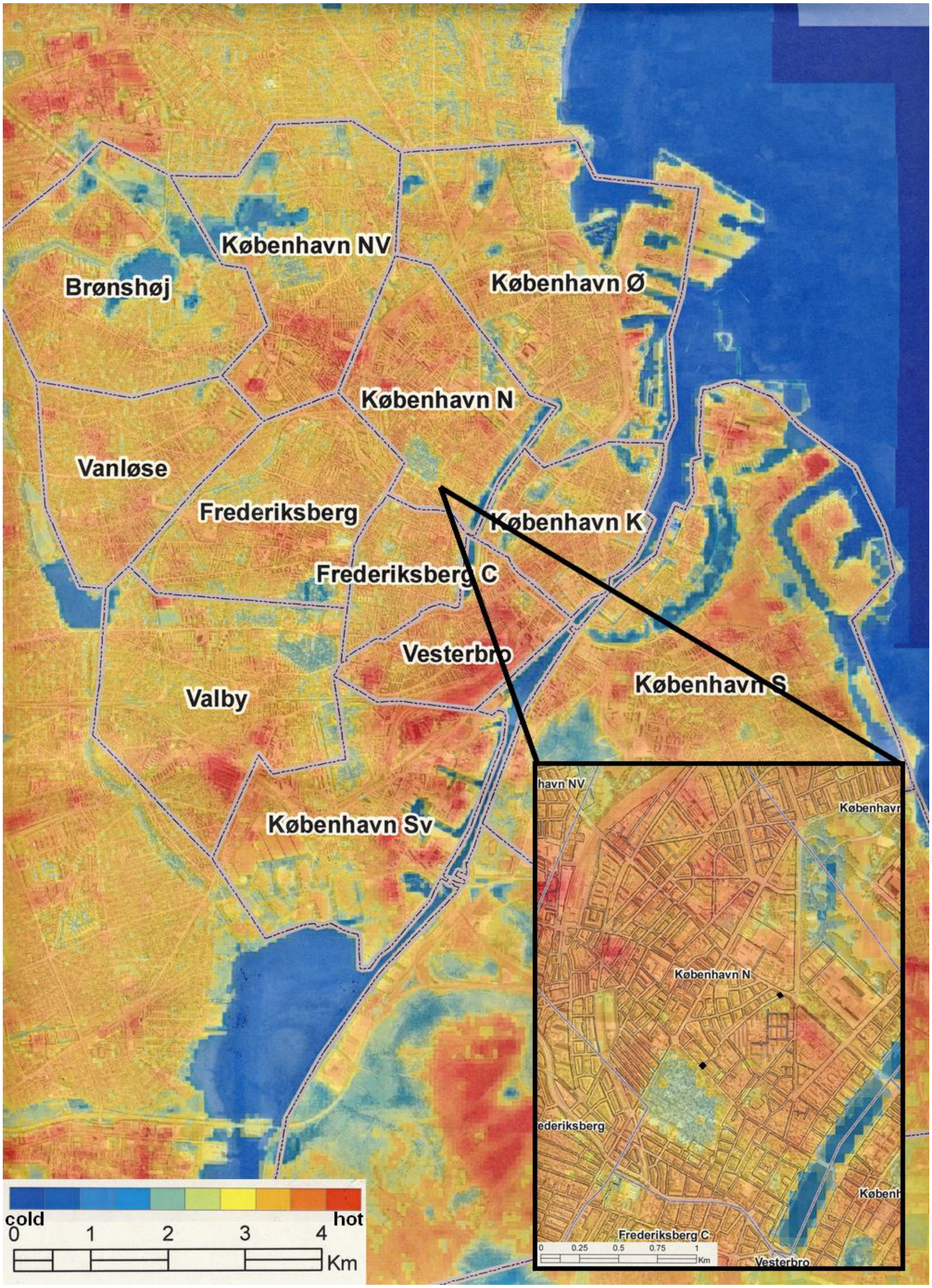

Figure 4. Map of average surface temperature of different areas in Denmark. Sjællandsgade indicated by black squares (Municipality of Copenhagen Center for Parks and Nature, 2006).

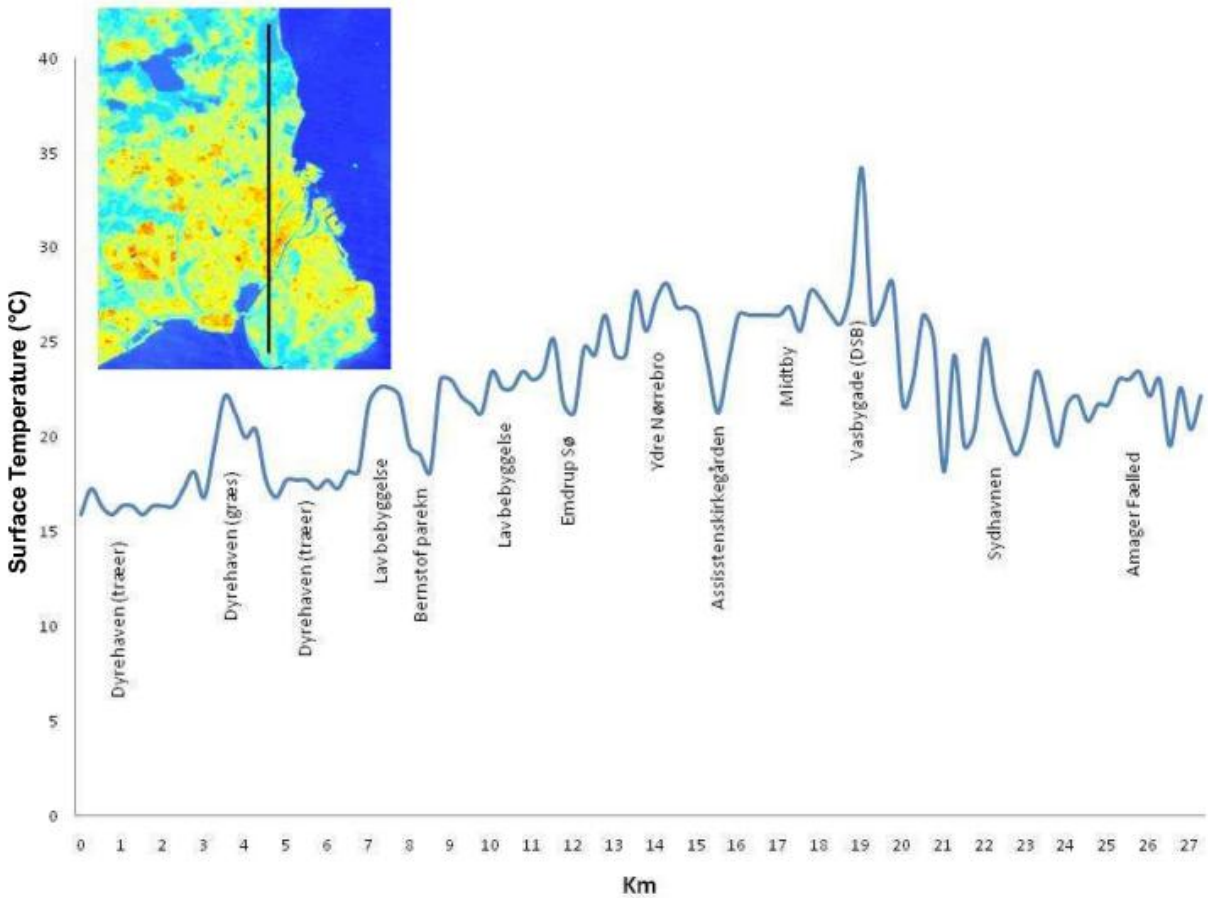

Figure 5. Analysis of the average surface temperatures of a vertical selection of both rural and urban areas in Copenhagen. (Municipality of Copenhagen Center for Parks and Nature, 2010).

The Intergovernmental Panel on Climate Change (IPCC), a group assembled to analyze the risks climate change poses to the future, have predicted future temperature and rainfall patterns in Denmark according to several different climate change scenarios (IPCC, 2000). Table 1 summarizes the climate changes that are expected to occur by 2100 according to the A2 scenario: a climate change prediction in which countries maintain their own cultures and practices, the population is steadily increasing, and industrial growth is regional and slower than in other scenarios (IPCC, 2000). As can be seen, temperatures in both summer and winter months are expected to raise significantly in the next 100 years (Grøndahl, 2012). Precipitation is also expected to increase at a rate of approximately 5 to 15% per degree raised; i.e. by 2100, the expected temperature rise by 3.2 ^{o}C will result in a 16 to 48% increase in precipitation from what it is at present (National Academy of the Sciences, 2011).

Table 1. Climate change predictions in Denmark by the year 2100 according to the A2 scenario (Grøndahl, 2012).

Climate Change by 2100	A2 Scenario Results
Annual Mean Temperatures (^{o}C)	+ 3.2 ± 0.3
Winter Temperature (^{o}C)	+ 3.8 ± 0.3
Summer Temperature (^{o}C)	+ 2.6 ± 0.2
Annual Precipitation	+ 15% ± 7%
Winter Precipitation	+ 27% ± 7%
Summer Precipitation	+ 5% ± 9%
Maximum Daily Precipitation	+ 21%

The July 2nd, 2011 cloudburst in Copenhagen

On July 2nd, 2011, the Copenhagen area experienced a period of torrential rain called a cloudburst, which is defined by a rainfall volume of fifteen millimeters or greater in a period of no more than thirty minutes (Dreehsen, 2011). This particular cloudburst unleashed 30 millimeters of rain in just 10 minutes and has been called the “worst [cloudburst] in 25 years” (Tarp, 2011). The average rainfall during the cloudburst was recorded at roughly 150 millimeters per hour (Mr. Larsen, personal communication, January 25, 2013). Figure 6 depicts the areas in Copenhagen that were affected by this cloudburst, with areas most harshly affected indicated by red squares (Astrup, 2011). Since the temperature has been rising, the atmosphere has a greater potential to retain moisture, which could result in more cloudbursts. Ole Bøssing Christensen, a climatologist at the National Climate Centre at Danmarks Meteorologiske Institut (DMI), noted that “[cloudbursts] cannot be attributed with certainty to the ongoing climate change, but it is nevertheless what our climate models heralds more of over the next 50 to 100 years” (Olesen, 2011).

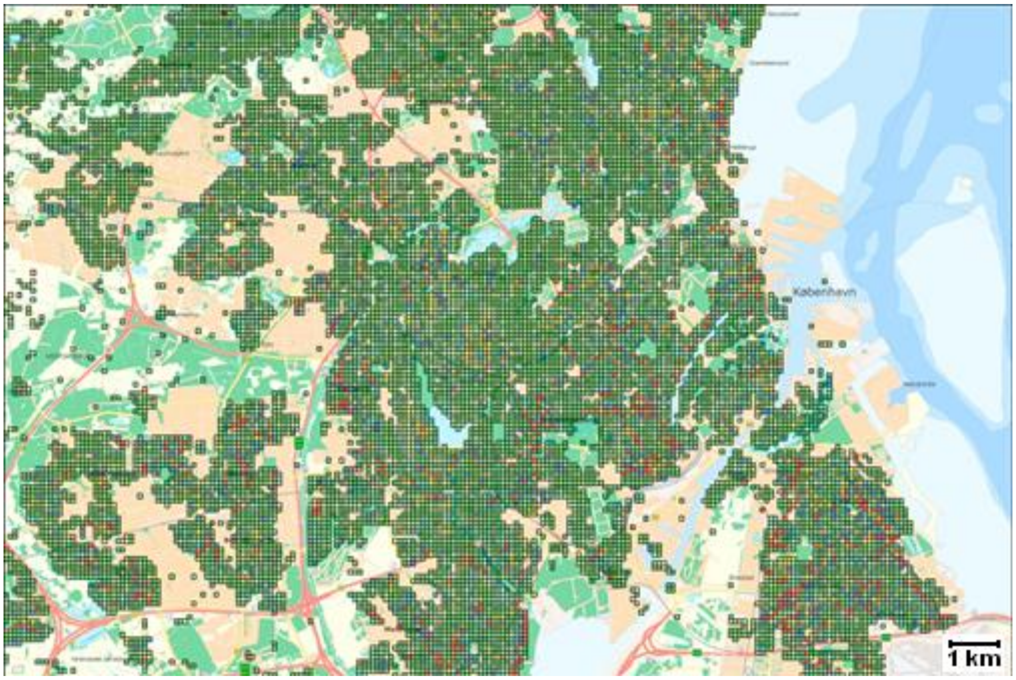

Figure 6. A flood risk map of the Copenhagen area affected by the July 2nd, 2011 cloudburst. The area is divided into 100-100m squares that are colored according to risk factor: green squares = risk factor of 0, lowest; red squares = risk factor of 6, highest (Astrup, 2011).

The damage caused by the extreme amount of rainfall from the cloudburst was immense. Two major hospitals, Rigshospitalet and Hvidovre, nearly had to be evacuated, and the emergency power generators were threatened by the influx of water (Hospitaler var centimeter fra katastrofe, 2011). Water from the downpour flooded into the basement of the Danish Cancer Society, destroying 18-years-worth of tissues and cell cultures, greatly affecting the research carried out in this location (Skybruddet smadrer 18 års kræftforskning, 2011). Dozens of roads and railways were closed due to the flooding, affecting commuters (Hvass, 2011). The extent of this damage has caused the citizens of Copenhagen to seek ways to prevent any such damage from happening again in the face of one of these storms.

Flooding in Sjællandsgade

Sjællandsgade is a street located in the district of Nørrebro in the city of Copenhagen. As can be seen in Figure 7, the street is approximately one kilometer in length and runs perpendicular to two main streets, Tagensvej to the North and Nørrebrogade to the South. Mr.

Larsen described the Nørrebro area as "the most densely populated part of the city with 75,000 people [living] in an area of less than four square kilometers." Despite this high population concentration, the amount of public green space is much lower than that in other parts of Copenhagen, with only about six square meters per person (Mr. Larsen, personal communication, January 25, 2013).

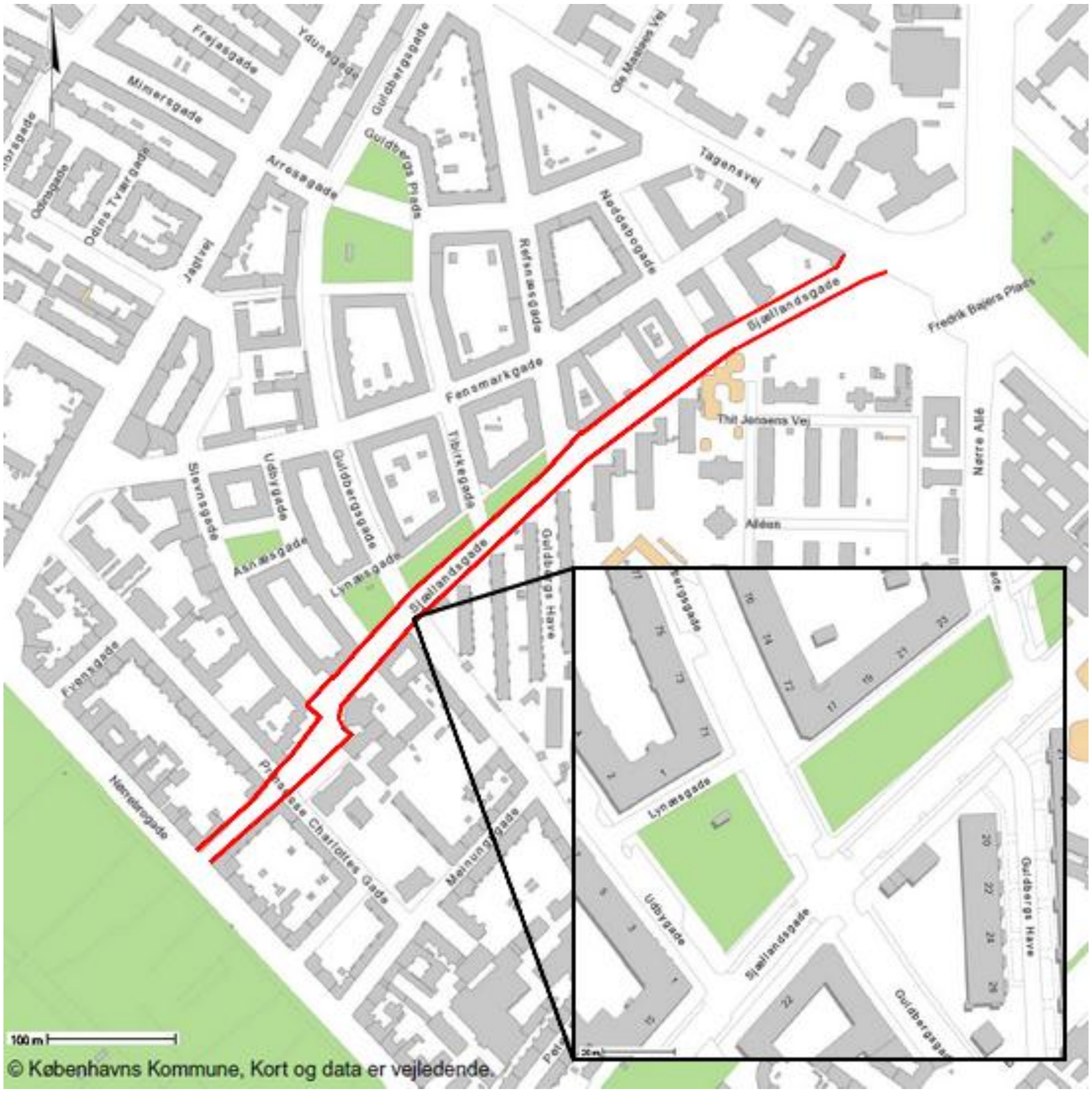

Figure 7. Map of Sjællandsgade. Inset is the intersection of Sjællandsgade and Guldbergsgade, which is closed off from through traffic. Adapted from Københavns Kommune (Kobenhavns Kommune, 2013).

Sjællandsgade has existing public green spaces as well as certain lengths of the road closed off to through traffic. The newly renovated square, Guldberg Byplads, is an open area in which children can play and residents can relax. This space is located in between Stevnsgade and Sjællandsgade, separating the Northern part of Sjællandsgade from the Southern part from vehicular traffic (Dac & Life, 2012). Similarly, the intersection between Sjællandsgade and Guldbergsgade (inset of Figure 7) has been closed off to vehicular traffic. Just northwest of this intersection are underground bunkers from World War II. However, even with the consideration of these areas Sjællandsgade lacks public green spaces; Guldberg Byplads (Figure 8B) is tiled and the medians blocking car traffic at the Sjællandsgade-Guldbergsgade intersection are simply concrete blocks. The images in Figure 8 reveal a fairly narrow street with an abundance of parking spaces and a lack of visible drainage systems for rainfall.

Figure 8. From A to F, these images from Google's Street View show Sjællandsgade. The first image is the intersection with Nørrebrogade and the last is the intersection with Tagensvej. Adapted from Google Maps (Google Maps, 2013).

An issue that has recently arisen in Copenhagen is sustained rainfall events. These events have resulted in billions of kroner worth of damage to buildings and homes in the area. This issue is projected to become aggravated by the building of the Nørre campus of the University of Copenhagen, which is expected to cause runoff problems and contribute to flooding. The expansion of the university also raises other environmentally-related issues, such as less space for cyclists and less space for green areas (Mr. Larsen, personal communication, January 25, 2013).

2.2 Climate change adaptation in Copenhagen and in Denmark

Government Policies

Although the Danish Nature Agency and the Municipality of Copenhagen have different approaches towards climate change due to their respective jurisdictions, the organizations still share the goal of enabling and promoting climate change adaptation measures. After insurance payments totaling 6 billion Danish Kroner (DKK) for 2011, the government and municipalities have committed DKK 2.5 billion to invest in climate change adaptation and water management by 2013 (Danish Nature Agency, 2012).

The development of these specialized solutions in the European region is facilitated by PEER (Partnership for European Environmental Research). The organization is dedicated to promoting the inception, development, and implementation of climate change adaptation initiatives (Swart, 2009); more information on PEER can be found in Appendix A: Initiatives and leadership groups for climate change.In Denmark however, the Danish Energy Agency (DEA) and the municipalities are in charge of devising the climate adaptation initiatives (Cowi, et al., 2011). Consequently, there are a number of governmental plans detailing approaches to climate adaptation: Copenhagen Climate Adaptation Plan (CCAP) and Sustainable Solutions for

Sustainable Cites, both published by the Municipality of Copenhagen, and "How to Manage Cloudbursts and Rainwater – Action Plan for a Climate-Proof Denmark" (APCPD) published by the Danish Nature Agency (Cowi, et al., 2011; Cowi, et al., 2012; Danish Nature Agency, 2012). In order to understand the governmental and municipal approaches to flood and rainwater management we will explore the initiatives and recommendations considered in the aforementioned climate adaptation plans.

As part of the central government, the role of the Danish Nature Agency is to adapt legislation, ensure coordination, and provide information (Danish Nature Agency, 2012). In reference to the allocation of responsibilities, the Danish Nature Agency acknowledges that "the individual stakeholders know the local conditions best and are consequently in the best position to make decisions on adaptation" (Danish Nature Agency, 2012). As such, it promotes five different initiatives to simplify and enable climate adaptation in Denmark: improving the framework for climate adaptation, increasing consultancy as well as the knowledge base, strengthening the collaboration and coordination between planners, promoting a 'green' transition, and promoting climate change adaptation at the international level (Danish Nature Agency, 2012).

The Municipality of Copenhagen, however, has initiatives that focus specifically on adaptations to climate change. Figure 9 is a graphical representation of the four adaptation initiatives the Municipality of Copenhagen endorses: to develop methods to discharge rainwater, establish green solutions to prevent flooding, increase the use of passive or alternative cooling for buildings, and protect against sea flooding (Cowi, et al., 2011). Additionally, the Municipality of Copenhagen also encourages individual behavioral change to more environmentally friendly practices, specifically in the areas of waste management, reducing water consumption, and better transport choices (Cowi, et al., 2011).

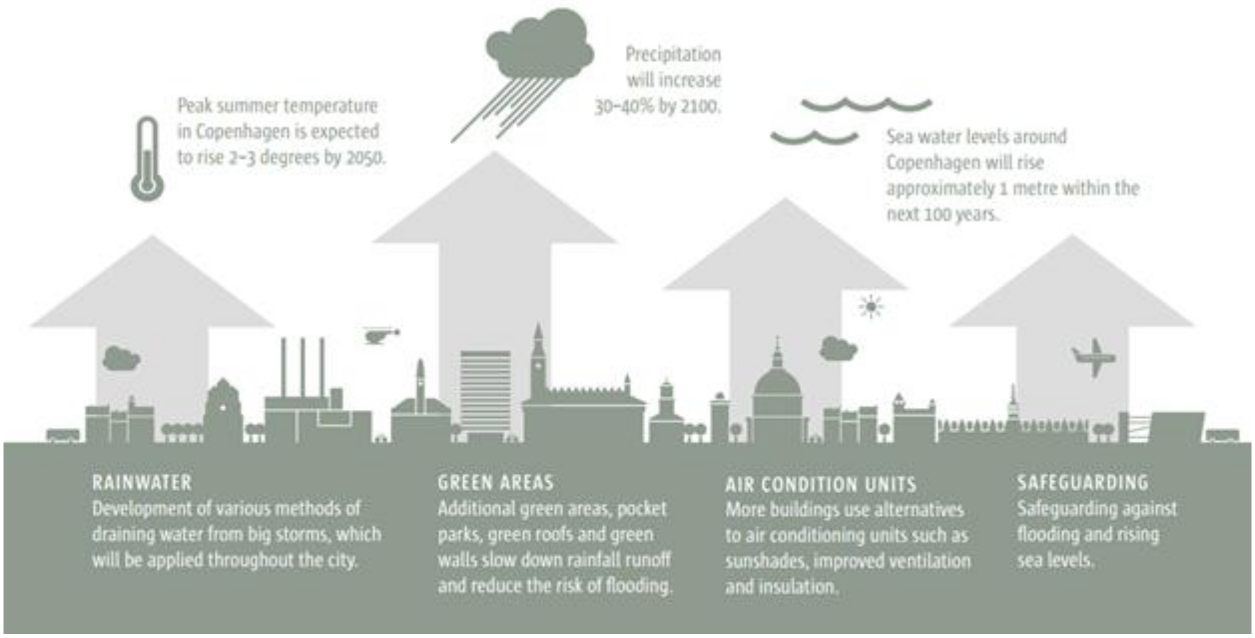

Figure 9. Four adaptation initiatives and their justification as shown in the *Copenhagen Solutions for Sustainable Cities* report. The initiatives are the same as those indicated in the *City of Copenhagen Climate Adaptation Plan* (Cowi, et al 2012).

When planning adaptations to climate change, the CCAP recommends taking five points into account; the plan needs to be flexible, in synergy with other planning, highly qualified, keep or make the city even more attractive, and hopefully result in green growth for the economy (Cowi, et al., 2011). In turn, the type of adaptations can be classified into three discrete levels (CCAP). The first level aims to reduce the probability of an event. To address this, storm water runoff should be controlled, building elevation increased, and local management of storm water should be implemented. The second level aims to reduce the scale of a large rain event. Thus, in addition to the level one measures, barriers such as sandbags could be added. Finally, level three aims to minimize vulnerability: to move vulnerable functions to safe places or to divert the water flow to places where the damage will be minimized. Table 2 shows how the different adaptation levels can be implemented, from the regional to the individual level.

Table 2. Measures of dealing with storm water as proposed by the City of Copenhagen in the Climate Adaptation Plan. The measures are broken down from the regional level to what the individual building should do (Cowi et al., 2011).

	Level 1	Level 2	Level 3
Measure Geography	Reduce probability	Mindske omfanget	Reduce vulnerability
Region	Establishment of retarding basins on separate rain runoffs in catchment area of Harrestrup Å and Søborghusrenden	Protection of vulnerable infrastructure Metro, S-trains, tunnels, cultural assets	Protection of vulnerable infrastructure Metro, S-trains, tunnels, cultural assets
Municipality	Disconnection of stormwater using SUDS Establishments of pumps on runoffs	Disconnection of stormwater using SUDS Planning	Planning
District	Decoupling of rainwater using SUDS [Sustainable Urban Drain System]. Plan B-solutions on central squares/sport facilities/parks	Decoupling of rainwater using SUDS. Emergency Management, sandbags etc.	Moving electrical cabinets for light regulation, pumping stations etc. from low-lying points
Street	Plan B solutions separation of stormwater from sewer	Disconnection of stormwater using SUDS Preparedness, sandbags etc.	Moving electrical cabinets for light regulation, pumping stations etc. from low-lying points
Building	Disconnection of stormwater from sewer	Backwater valves, sealed basements, Preparedness, sandbags etc.	Move vulnerable functions away from basement level (service rooms, electrical panels etc.)

When initiatives to manage rainwater and to increase green areas are tightly linked, they are referred to as 'blue-green' measures. Copenhagen favors blue and green solutions because they reduce storm water flows by absorbing some of the water, moderate and balance temperature changes, reduce the city's energy consumption for air-conditioning, provide space for biodiversity in the city, reduce noise as well as pollution, and also give people an enjoyable nice space for recreation (Cowi, et al., 2011). But since the costs of damages due to flooding in Copenhagen are estimated to be over DKK 350 million, the adaptation initiatives focus mainly on reducing the risk of flooding and managing storm water. Consequently, the city would like to expand drainage systems, develop reservoirs to manage rain water, increase the amount of green spaces along roofs and walls to aid in water catchment, and implement sustainable urban drainage systems (SUDS) (Cowi, et al., 2011).

Case Study: Odense SUDS

Sustainable Urban Drainage Systems have been implemented worldwide, in countries such as Norway, Germany, and the Netherlands, among others, to deal with the excessive rain water that is surcharging sewers (Fryd et al., 2010). The multidisciplinary team from the universities of Copenhagen and Aarhus, along with the water utility company, ALECTIA A/S, proposed and studied a complex system of social, institutional, and technological interactions for the implementation of SUDS in two districts of Odense, Denmark.

Their main goal, to improve the conditions for implementing SUDS in Denmark, is also an important one for our team. Their project's initial catalyst was the overloading of the sewers with rainwater that was infiltrating the system; the same scenario experienced in Sjællandsgade due to heavy storms. The team proposed better urban planning to solve this problem. Thus, Fryd et al. documented the first loop of planning and designing SUDS fit for the city of Odense pictured in Figure 10, and went back to assess it a year and a half later.

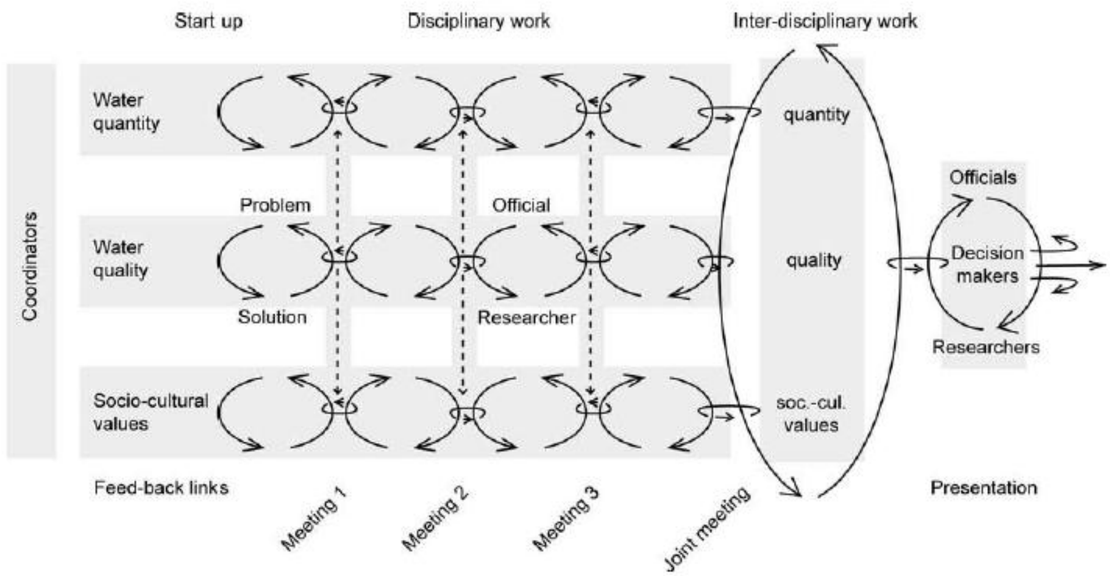

Figure 10. Planning loop structure for the planning and designing of SUDS for Odense (Fryd et al., 2010).

The loop structure is intricate; it shows how experts, government officials and researchers collaborate when studying water quantity, water quality, and socio-cultural values. Over the seven month interval there were three independent meetings for each disciplinary team. At the end of this period, each team wrote a report by using existing knowledge and data provided by the City of Odense and Odense Water Ltd. In the final meeting, the experts drafted integrated solutions for two sub-catchment areas in Odense. These are depicted in Figures 11A and 11B.

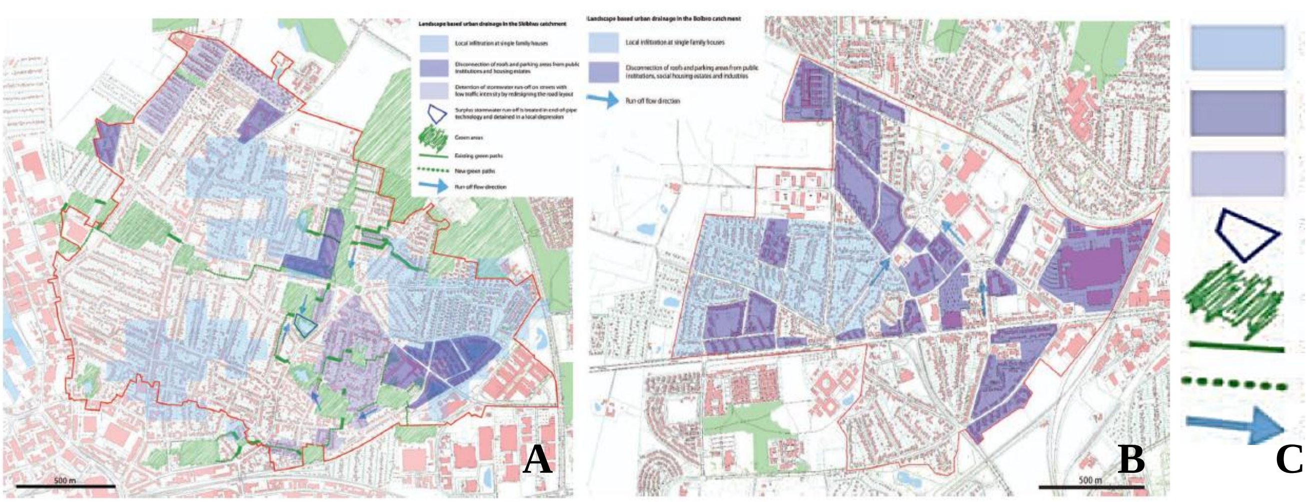

Figure 11. Water catchment areas in Odense (Fryd et al., 2010)

In Figure 11, we can see that the catchment design is specific to the area being studied. In the same figure, panel C indicates the legend, from top to bottom: local infiltration at single family houses, disconnection of some roofs and parking areas, detention of storm water runoff on streets with low traffic intensity by redesigning the road layout, surplus storm water runoff treated and detained at a local depression, green areas, existing green paths, new green paths, and runoff flow direction. From their expert study of the flooding problem at hand, we can see that most of their work concentrated in disconnecting rainwater from the sewers in individual apartment blocks and also targeting low-traffic roads for climate adaptation measures. In the case of panel A, they complemented the rainwater disconnection with additional green paths connecting existing areas. The difference between the approaches lies in the purpose: in B, the team studying the socio-cultural values saw “the implementation of SUDS [as] primarily linked to the revitalization of social housing estates”; while in A, that was not a priority (Fryd et al., 2010).

Their findings about the interdisciplinary planning to reduce flooding risk in a city apply to projects such as ours. Fryd et al. found that their planning loop effectively improves collaboration between the people involved. In the case of Odense, the municipality and the water utility have established a permanent group with representatives from both organizations to ensure a joint effort to develop urban drainage solutions and reach other urban development goals. Additionally, all the respondents recommend municipalities and water utility companies to engage in a similar integrated loop planning processes to explore the implementation of SUDS in the respective urban areas. By following their advice, and screening planning goals early in the process, we could allow design to be demand-driven rather than have a supply-driven perspective, and we could also promote the collaboration between governmental and non-governmental organizations (Fryd et al., 2010).

2.3 Strategies to reduce the impact of flooding in Sjællandsgade

A primary focus of this project is to determine solutions that can meet the challenge of rainfall events such as the one in July 2011. The solution must minimize the damage caused by these types of storms while also meeting the standards set forth by the governmental plans. Fortunately, the Danish Nature Agency understands that rainwater should be considered as a resource rather than waste, leading the Ministry of Environment to investigate its potential use as a potable water replacement. In this section, we will describe methods that have been part of academic and field implementation to meet similar challenges as those presented by the Sjællandsgade project.

Challenges

Developing a solution to handle future cloudburst storms and increase green space within the area poses many challenges. The coined term 'blue-green solution' means a solution that can handle both stormwater (blue) and increase the area of parks and gardens (green). The images in Figure 8 reveal that the most striking characteristic of the Sjællandsgade is its apparent lack of infrastructure to deal with storm water. In recent years, this has become a priority for the City of Copenhagen. The potential runoff water originating from the surrounding areas of higher elevation could contribute to intense flooding in the Sjællandsgade corridor. Another issue is the width of the street; to make room for the blue-green solutions, space will need to be reallocated. A compromise between the bicycle paths, sidewalks, and street is necessary to yield the needed space. Along with these changes, funding is another limiting factor.

Previously proposed solutions

The cooperation of all the stakeholders becomes necessary for an approach to be considered. The stakeholders in the area include the residents, landlords, consulting firms, and authorities, as well as members of the church and school on Sjællandsgade. In May 2011, Miljøpunkt Nørrebro approached property owners in Sjællandsgade to discuss a plan to recycle rainwater. The idea consisted of decoupling the rainwater from the sewage and recycling them into a blue-green solution (Mr. Larsen, personal communication, January 25, 2013). They developed a vision for a blue-green Sjællandsgade with no cars; Figure 12 is the planning vision presented by Miljøpunkt Nørrebro. In a separate project, Sanerings- og Byfornyelses- Selskabet (SBS), an urban development consultation firm, recently renovated the Guldberg Byplads area but did not include many rainwater management systems or green spaces (SBS, 2013).

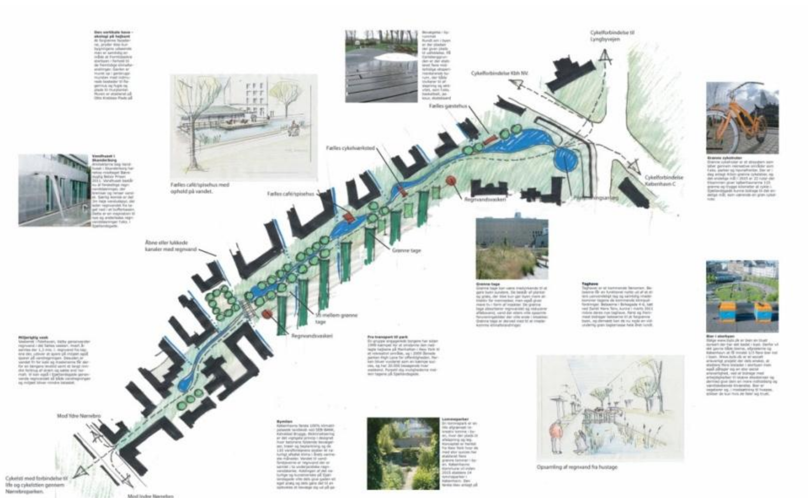

Figure 12. Miljøpunkt Nørrebro's plans for a blue-green and carless Sjællandsgade (Larsen, 2013).

Timing is also important in carrying out such labor intensive blue-green projects. Miljøpunkt Nørrebro’s main goal is to lobby for the interests of the local population to larger organizations, for instance the Department of Parks and Nature. Mr. Larsen believes that the Danish government’s increased spending in environmental and sustainable agendas is encouraging (Mr. Larsen, personal communication, January 25, 2013). Most of the city's initiatives have incorporated the development of ways to deal with storm water into their plans; Sustainable Solutions for Sustainable Cities and Adapting to Climate Change are just two examples (Cowi, et al., 2011, 2012). At the moment, the socioeconomic environment seems appropriate to motivate the city to take on this project, as it will both help manage stormwater and work towards the agenda of becoming a carbon neutral city by 2025.

Daylighting

The creation of a green corridor depends heavily on available funds. This section includes a discussion of different financial options. One type of project that covers the problem of storm water management is daylighting, as shown in Figure 13 (Robinson, 2013). A daylighted stream is an underground stream or channel that has been excavated to fit in the green corridor while it "helps reduce urban flooding, and adds beauty to public areas" (Buchholz and Younos, 2004). This acts as a natural stream and helps to move large volumes of water at a time. However, as Buchholz covers in his study there are cost issues that must be considered in planning and there needs to be ideas put forth to offset the costs over the long or short-term such as with the success in Kalamazoo, Michigan (Buchholz and Younos, 2004).

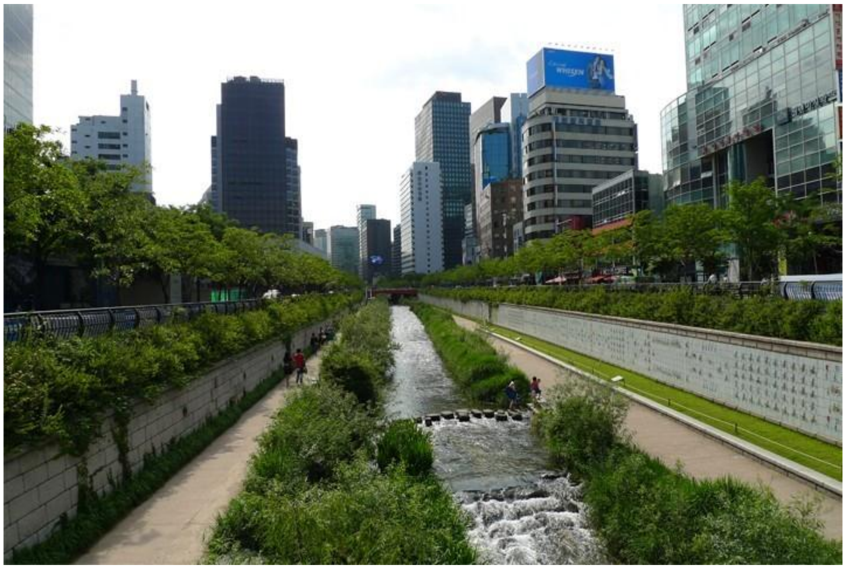

Figure 13. Daylighting in Cheonggyecheon (Robinson, 2013).

Linear parks

Another approach to a green corridor is the idea of a linear park. This kind of corridor is built in a modular set, and one proposal for such a project is found in Figure 14 for Ranson and Charles Town, West Virginia, United States. In this study, Hall recognizes a factor that he names ‘walkability’, or “the extent to which places are comfortable for pedestrians, cyclists, and transit users” (Hall, 2012). Indeed, in this concept plan all modes of transportation are included along with the greenery. In this approach, there is also piping for rainwater underground and small streams meant to water the gardens interspersed throughout the park. Furthermore, plans are included for the use of sedimentation to filter water for irrigation reuse in an effort to create a sustainable blue-green solution. Both green corridor variations offer potential solutions for Sjællandsgade. A solution comprised of a combination of their attributes must be reached in order to mitigate flooding and progress the development of a greener Nørrebro.

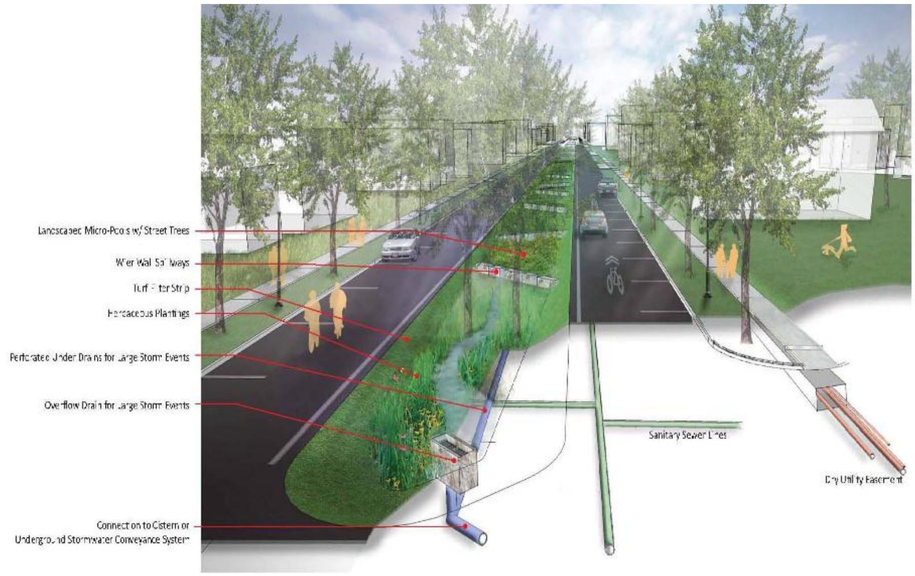

Figure 14. Linear Park Concept art (Hall, 2012)

Sustainable urban drainage systems

Sustainable urban drainage systems (SUDS) are a spectrum of drainage structures that share the same purpose: to manage storm water locally (Cowi, et al., 2011). They also have a common priority of keeping these solutions green at the lowest cost possible and minimizing anthropogenic environmental impacts (O'Sullivan, 2012). This often means that SUDS will be low-tech and low-maintenance measures, but will contribute to other important urban planning issues such as incorporating green spaces. Common choices of SUDS include rain gardens and roofs such as those depicted in Figure 15, green ditches, lakes or ponds, and canals. However, each system can feature a different approach. These approaches usually include elements to store or delay the water from entering into the sewer network and/or treating the water before it reaches large bodies of surface water.

Figure 15. Renderings of rain gardens and green roofs in Kalvebod Brygge, Copenhagen.

The city of Copenhagen has identified SUDS as a main track to protect public assets and minimize damage during large rain events (Cowi, et. al, 2011). CCAP points out that the SUDS and green solutions cannot serve as the only measures implemented to deal with the increasing downpours. The city incorporates SUDS in its CCAP as a complement to storm water disconnection from the sewage system. Reducing the load on the sewage system will make it more efficient and will also help with the preparations to address large rain events. Along these lines, the city promotes the following: expansion in the sewage network, 'climate-proofing' buildings to minimize damages, employing backwater valves to deal with excessive water, and developing SUDS to manage rainwater.

Although they differ conceptually, green spaces and SUDS share many advantages. CCAP concisely states that "a climate-proof and greener Copenhagen is a city with more trees, green roofs, green and blue spaces, and a city that [in addition to] being able to tolerate the weather of the future is also rich in nature experiences and options for outdoor activities" (Cowi, et al., 2011). Figure 16 shows gardens along sidewalks and next to the streets as examples of green spaces.

Figure 16. CCAP's vision of green spaces.

The potential of SUDS and green spaces lies in their intrinsic capacity to relieve other areas from excessive water while serving other purposes when there is not a flood risk, such as creating more habitats for plants and animals in the city, providing the people with green spaces to enjoy, balancing urban temperature, improving air circulation, and reducing air and noise pollution. However, studies have shown that despite their well-known benefits, SUDS are not implemented as extensively as they could be. Perceived deterrents of SUDS are that maintenance duties are not clearly understood and that authorities do not want to take on the responsibility. However, traditional drainage systems do require proper maintenance to prevent pluvial flooding, and SUDS do not represent a much larger investment when compared to traditional maintenance costs (O'Sullivan, 2012).

Given the importance and variety of positive externalities of SUDS and green spaces, the Copenhagen municipality recommends starting work to implement these solutions in locations of necessity, viability, and ample communal support. As a tool of climate adaptation, the city aims to connect these green and blue spaces into a network. They plan on achieving this through the provision of maintenance to existing green spaces in Copenhagen and increasing the amount of these spaces. This includes appropriation of schoolyards, parking lots, courtyards, and roads to transform them into blue- green spaces. Since the city considers this appropriate, the area along Sjællandsgade will be analyzed for areas that could be appropriated without disrupting car or bicycle traffic. A less drastic approach recommends planting more broad crowned trees on the streets and adding gardens to both underused spaces, namely walls and rooftops, and more obvious spaces as seen in the three images of Figure 16.

2.4 The social aspects of climate change adaptation

The social aspects of this project play a vital role in its successful development and implementation. The problem of excessive flooding in the area affects everyone in the community in a variety of ways. Because of this, a comprehensive and thorough understanding of the societal dynamics of the Nørrebro area and Sjællandsgade corridor are necessary.

Nørrebro's demographics

The neighborhood around Sjællandsgade is very diverse. In most areas, 3 to 6% of the population is of non-western origin, yet in other areas it exceeds 18% (Kobenhavns Kommune, 2013). In addition, the neighborhood also experiences a high amount of traffic from commuters to the University of Copenhagen's North Campus and occasional emergency hospital transportation. However, Sjællandsgade is mostly residential, but has some small shops that can be seen on Google Street View (see Figure 8). A side road, Sjællandsgade leads from the

Assistens Cemetery to a main road, Tagensvej, which borders University of Copenhagen's North Campus.

Community support in Nørrebro

In order to implement any part of our research, it needs to be understood that our work is on a grassroots scale with Miljøpunkt Nørrebro. Specifically, the support of the community is important for making a case at the municipal level as the citizens are stakeholders and will make the greatest impact at this level of government. As Mr. Larsen states, "[a]ll studies show that residents in Nørrebro want a greener Nørrebro." With support from the citizens, Miljøpunkt Nørrebro works within the complexities of city planning, funding, and bureaucracy to effect change. Navigation to the municipal level "can only be achieved through coordinated effort across traditional bureaucratic segregated areas" (Mr. Larsen, personal communication, January 25, 2013). An equivalent scenario in an American political setting would be a lobbying group influencing council members along with department staff.

As each stage of planning and development progresses, the citizens of Nørrebro must remain involved through the mediation of Miljøpunkt Nørrebro to the planning commission. Events such as public forums where city planners may propose to the citizens their vision is important for transparency and for residents to have input into what their neighborhood may be like in the future. Ultimately, this project will consider the delicate balance of citizens, Miljøpunkt Nørrebro, and the Municipality of Copenhagen so that a solution can move from paper to reality.

Miljøpunkt Nørrebro's role in climate change adaptation in Sjællandsgade

The organization's role in the Nørrebro community is to act as a mediator in order to achieve the goals the neighborhood sets for itself in terms of creating a green and sustainable local environment. Miljøpunkt Nørrebro evaluates the opinions of the community members, acts in their interests, and works with local authorities and companies to implement solutions. The organization is operated locally, with the only UN interaction being the Commission on Sustainable Development (CSD). The CSD monitors the branch to ensure that the chapter is adhering to the overall goals of Agenda 21 (ICLEI, 2002).

Miljøpunkt Nørrebro also acts as an educator in order to keep the residents it serves informed, disseminating information on the environment and climate. This is done to encourage the residents to become environmentally conscious and make decisions that support sustainability and promote a greater quality of life (Grøn, n.d.). This organization is an environmental activist group that aims to use information and open communication within the community to influence current opinions and future decisions related to environmental change and sustainability (Mr. Larsen, personal communication, January 25, 2013).

3 Objectives

Our project aims to create an argument proving or disproving the existence of a flooding problem in the Sjællandsgade area of Copenhagen. If affirmed, we intend to explore and propose solutions to manage the problem. Our group seeks to work collaboratively with local stakeholders in order to identify strategies that sustainably reduce the impact of flooding in the area while increasing the amount of green space. As a part of our research, we will investigate the area, analyze the extent of the flooding problem, and consider the opinions of local stake holders to produce a floodwater management system that is feasible for the Sjællandsgade corridor. The solutions approach is to be documented in a manual detailing the steps that other neighborhoods should go through in order to implement similar systems.

Our group has established four main objectives for our project: 1) characterizing the area, 2) building an argument for the need of a floodwater solution, 3) consulting experts and determining local response, and 4) making suitable recommendations through producing such deliverables as a floodwater mitigation and climate change adaptation manual, a runoff estimate calculation spreadsheet, and a comprehensive report on managing climate change in Sjællandsgade. Through completing these objectives, our group plans to reach the aims we set and produce a report that both adequately addresses the flooding problem in Sjællandsgade and provides a sustainable solution.

4 Methodology

As mentioned in the previous chapter, the first goal of this project is to create an argument for the need to implement a floodwater management system in Sjællandsgade and to subsequently propose a system design that will be both sustainable and favorably met by the community. A secondary goal is to develop a general technical guideline that other neighborhoods with similar flooding problems can use to push for their own implementation of a blue-green floodwater management solution. Through the establishment of four main objectives and development of several surveying and research strategies to complete them, our team has reached these goals.

4.1 Characterize the target area

The extent of flooding in Sjællandsgade and the subsequent damage is affected by many factors, such as the slope of the street, the buildings in the area, the current state of the sewerage system. In order to understand the scope of the problem, it was necessary for us to learn about the area and the problem in as much detail as possible. We achieved this through compiling facts about Sjællandsgade and observations of the area both above- and belowground. Extensive field investigations of the area as well as research using subterranean and topographical maps and surface measurements were conducted to reveal more about how the flooding occurs, how severe it is, and how to alleviate it.

Parking spaces as a challenge

Even though Copenhagen has a large concentration of bikes, there is still a sizeable population of car owners. One challenge that our group faced was the requirement for a net zero change in parking spaces. This implied the requirement of creating a new parking space elsewhere for any space removed in the city. Our team conducted a field investigation of

Sjællandsgade to count the number of parking spots and used a map of the area to indicate where the parking spaces are located along the street. This revealed to us the concentration of parking spaces and, subsequently, the impact to car parking that any of our proposed solutions will have.

Existing green spaces in Sjællandsgade

From cursory studies of the area using Google Maps, it was clear to us that Sjællandsgade is not devoid of greenery. In order to determine the extent of green space and open areas along the street, our group visited Sjællandsgade. We used qualitative analyses while walking along the street to observe areas that contain trees, grassy areas, planting boxes, and other instances of barriers that limit vehicular traffic. Using this information, we have created a map highlighting these areas in order to help us in proposing solutions that will expand the green spaces. Our overall aim with this data is to connect the green spaces for the purpose of rainwater catchment and utilization.

Contour maps to show flooding potential

In order to justify renovations of Sjællandsgade, our group developed a topological model that captures the altitude variations; it forms the first step in determining the danger of flooding during the next cloudburst. We accomplished this by working with an independent data source to characterize the contours of the area. A script from Google Maps allowed us to access the altitude data taken by Google while mapping the area for 36 waypoints to determine latitude, longitude, and altitude.

Subterranean structures and systems

A crucial step towards developing an accurate characterization of the Sjællandsgade corridor was the examination of existing subterranean structures and systems. This served two purposes: to support the argument that the existing systems are ill-equipped to handle current and future flooding events, and to allow for preliminary SUDS and green corridor designs to be constructed within the bounds of existing structure. Regardless of the benefit of a particular green corridor or SUDS design, the caveat of having to modify or remove existing sewer, fiber optic, or electrical systems can jeopardize an argument for immediate climate change adaptation. If our arguments and proposed design solutions are predicated on ease of implementation and cost-effectiveness it will significantly increase the likelihood of acceptance and support from stakeholders and municipality representatives. To do this effectively, we established a comprehensive understanding of existing subterranean structures and systems through examination of detailed subterranean maps of the area.

Method for area permeability study and division

In order to accurately determine the amount of runoff generated by the studied terrain area, a comprehensive analysis of specific geographical elements was required. Runoff for an area is determined by considering its surface permeability and the amount of precipitation. Though general runoff coefficient percentages were available, our group felt it necessary to achieve a higher level of accuracy. Accordingly, extensive calculations were required to determine the most accurate runoff coefficient possible for the studied area.

Determination of runoff

In the previous section, we discussed how the runoff coefficient could be used to determine the percentage of runoff that will not be naturally absorbed during a rainstorm in the area surrounding Sjællandsgade. However, we also needed to determine the time of concentration (Tc): "the time required for the entire watershed to contribute to runoff at the point of interest" (Hydraulic Design Manual, n.d.). This allowed us to use an IDF (Intensity Duration Frequency) curve in order to determine the intensity for calculating runoff through the Rational

Method. This information allowed us to create an interactive model for calculating runoff estimates.

4.2 Create arguments for implementing climate change adaptation plans

In order to increase support for implementing a solution for Sjællandsgade, our group built an argument for climate change adaptation. Proof of urgency for a solution whilst giving concrete facts and figures creates a case for community involvement and municipality support. Our team has worked to accomplish this through cost-benefit and risk-uncertainty analyses.

Cost benefit analyses

The use of cost-benefit analyses to justify our argument for sustainable climate change adaptation should be undoubtedly beneficial to our sponsor. This argument will be posed to politicians and other representatives of the municipality, people that will be concerned with the cost of the notion of climate change adaptation. As with any major expenditure, especially those involving government funding, the benefits of the expenditure should scientifically prove to outweigh the cost. Thus we conducted a comprehensive analysis of the amount of drinking water saved by a rainwater reuse system that makes the climate change adaptation plans cost effective. This analysis included determining the amount of viable drinking water that can be supplemented on an annual basis, the monetary value of that saved drinking water, and the cost of implementing the potential design solutions. If the argument is well-posed and the design solutions are chosen appropriately based on compiled statistical data in Sjællandsgade, the benefit of installing our climate change adaptation protocol is expected to outweigh the financial implications of such action, furthering the likelihood of stakeholder and municipality acceptance of this initiative.

Analysis of uncertainty in terms of stakeholders

Since the majority of the stakeholders that will be receiving our arguments are politicians, we need to analyze the possible uncertainties that arise from the simple fact that they are different individuals with different ideas about climate change and adaptation plans. How legislators perceive the issues directly affects whether or not they will accept a proposal. Consequently we need to account for a variety of legislative responses in our decision making.

Additionally, we need to consider the lack of certainty in future climate change prediction models. Stakeholders will potentially be skeptical about the severity of the predicted changes or if they exist at all (Refsgaard, 2011). To bolster our arguments for action to be able to stand even in the presence of uncertainties we followed two decision making strategies: (1) the precautionary principle, which provides a guideline for decision making through the understanding of risks and uncertainties; and (2) the Minimax strategy, which assigns numerical significance or priority to a solution through creating a numerical evaluation matrix (Gregersen, 2012).

4.3 Consult experts and gauge local response

Miljøpunkt Nørrebro aims to understand what environmentally-friendly measures the residents of Nørrebro would like to see in their community so that they, as an organization, can influence the municipality to demand their implementation (Mr. Larsen, personal communication, January 25, 2013). As such, it was necessary for us to garner the support of local residents, property owners, and experts so that we could propose a feasible design that not only alleviates the flooding problem but also appeals to the members of the neighborhood. We worked with Miljøpunkt Nørrebro to contact relevant experts, conduct a focus group, and survey residents of Sjællandsgade.

Conduct interviews with experts

From interviewing experts, we collected information on their opinions and approaches to project viability. Specifically, we discussed how they have conducted their own projects, the obstacles they foresaw, and what actions they recommended we take to further our project successfully. Interviews were modified depending on the expertise of the interviewee and the stage of the project in order for us to get the most useful information from them.

Following Mr. Larsen's suggestion, we interviewed two experts that provided us valuable insight into planning and designing blue-green spaces: Stefan Werner and Henriette Berggreen. Stefan Werner is a project manager at Miljøpunkt Østerbro, the branch of our sponsoring organization in the neighboring Østerbro district, as well as an employee at the Copenhagen Water and Parks Division (WPD). Similarly, Henriette Berggreen is also an employee at the Copenhagen WPD and works with Mr. Werner at Miljøpunkt Østerbro. Their team is finishing the developmental phase for a project in Skt. Kjelds, a large area renewal project with the Municipality of Copenhagen that limits car traffic, adds water management features, redistributes parking spaces, and incorporates more blue and green areas. These innovations can be seen in some of their renderings for the area included in Figure 17. Therefore, opinions or recommendations from these experts are important to us and can provide additional credibility for our project. This will be crucial when Miljøpunkt Nørrebro presents to the Sjællandsgade project to municipality representatives.

Figure 17. Design renderings for the Skt. Kjelds area (Schroeder, 2012).

Additionally, we interviewed Mr. Villy Sørensen, the Chairman of the Residents' Association Board of a non-profit housing association in Folehaven. One of Mr. Sørensen's principal projects is a central laundry station that uses filtered rainwater in its washing machines, thus saving large amounts of water and money a year. These associations are common in Denmark and work by investing tenants' rent in the apartments' renovations and maintenance. Since there are a few of these non-profit housing associations along Sjællandsgade, it was beneficial to learn about their rainwater catchment and reuse system, and the way in which they implemented it, and the feasibility of replicating their method on Sjællandsgade.

Hold focus groups with residents to identify their expectations and desires

Since we were working to solve a flooding problem in a residential area, it was essential for us to determine the opinions of the residents on both the severity of the flooding problem and the potential floodwater management solutions. We conducted a focus group meeting with the local residents; this allowed our group the chance to hear personal accounts on the extent of flooding in the area, the personal initiatives people have taken to safeguard themselves from future flooding events, and what they think of our suggestions. We sent the invitation to our focus group meeting to a mailing list of 36 email addresses compiled by Miljøpunkt Nørrebro.

Incorporating experts' feedback

The success and effectiveness of our blue-green corridor sustainable solution can be accurately summarized by the nature of the feedback we receive. We evaluated this feedback to pinpoint issues or grievances that were most commonly mentioned and identify which items of the project people felt most attracted to. We added emphasis to the components or characteristics of the sustainable solution that were well received and worked on the aspects stakeholders viewed unfavorably to make them more agreeable.

4.4 Making suitable recommendations

After we completed the above mentioned steps, we put together our second and third goals: our recommendations specific to Sjællandsgade and the general technical guideline for implementing blue-green solutions in another neighborhood or street. This step was comprehensive of all our work, from the literature review to the mathematical calculations.

To present a solid argument reflecting engineering potential design solutions for the floodwater management and green space adaptations, we employed both written and visual presentation mediums. This was done to allow the audience to gain a comprehensive understanding both of the severity of the problems in this area and the proposed design solutions we develop. Visual presentation mediums that we used were computer aided drafting and design (CADD) for urban planning scenarios, mathematical models for surface terrain maps, and a programmed spreadsheet with a defined user interface. Our recommendations specific to Sjællandsgade comprised a three-tiered design outlining climate change adaptations from the most idyllic (Tier I), to the least disruptive that requires the least amount of intervention (Tier III); while the technical guideline is a detailed break-down of how to replicate the planning of a blue-green solution in another neighborhood or street.

4.5 Projected evolution for stages of adaptation plans

To carry out all the steps we wanted to take: collecting data, surveys, focus groups, interviews, and calculations, we took care in the planning of our eight weeks in Denmark. Table 3 summarizes what we planned and achieved each week. Since the first week was dedicated entirely to a Danish language course, that left only seven weeks to carry out the project. This concentrated a lot of important items to weeks 4 to 6, but following this Gantt chart, we completed all our action items in due time.

Table 3. Gantt chart that summarizes the time course of events.

	Week		1	2	3	4	5	6	7	8
1	Learn about the Sjællandsgade area and the flooding problem there	Identify the sponsor's perspective on the flooding issue		■						
		Field investigations of Sjællandsgade and Østerbro		■	■					
		Reevaluate research done through case studies			■					
2	Analyze the impact of flooding in Sjællandsgade and explore floodwater management systems	Characterize and prioritize the relationships between the flooding problem and the needs of the community			■	■				
		Evaluate and compare floodwater management systems				■	■			
		Identify the most feasible floodwater management system				■	■			
3	Gauge neighborhood support.	Interview stakeholders and/or experts			■	■	■	■		
		Complete surveys and hold focus groups with residents			■	■	■	■		
4	Evaluate feedback and adjust design accordingly	Review and edit deliverables: renderings, calculations…				■	■	■	■	■
		Finish writing the project and prepare the final presentation							■	■

5 Results and Analysis

The execution of the processes outlined in the aforementioned objectives and methodology chapters yielded extensive data. This data is the foundation for the conclusions, recommendations, and deliverables that we produced for this project. In order to produce these items a conclusive analysis was necessary, thus producing the detailed results illustrated in the following sections.

5.1 Field investigation findings and surface characterization

To best determine the nature of solutions and recommendations for climate change adaptation in Sjællandsgade, a thorough and comprehensive characterization of the area was conducted. This characterization allowed us to determine exactly what attributes of the area could be incorporated in our climate change adaptation plan and what elements required modification. As the project progressed, this characterization was addressed repeatedly as a reference for sustainable solution viability.

Field investigation of Sjællandsgade

As a way to determine the type and scale of solutions that could be implemented along Sjællandsgade, we performed a field investigation of the area to observe such things as parking space concentration and the amount of open and green areas. Determining the number of parking spaces is important because the municipality has a nonofficial policy of adding another parking space elsewhere for everyone removed from an area. Since rearranging or removing parking spaces in the area could potentially be a large hurdle, we counted the approximate number of parking spaces in 5 separate sections of Northern Sjællandsgade (sections labeled 1 to 5 in Figure 18) in order to come up with solutions that best utilize those areas with the lowest concentration of parking spaces.

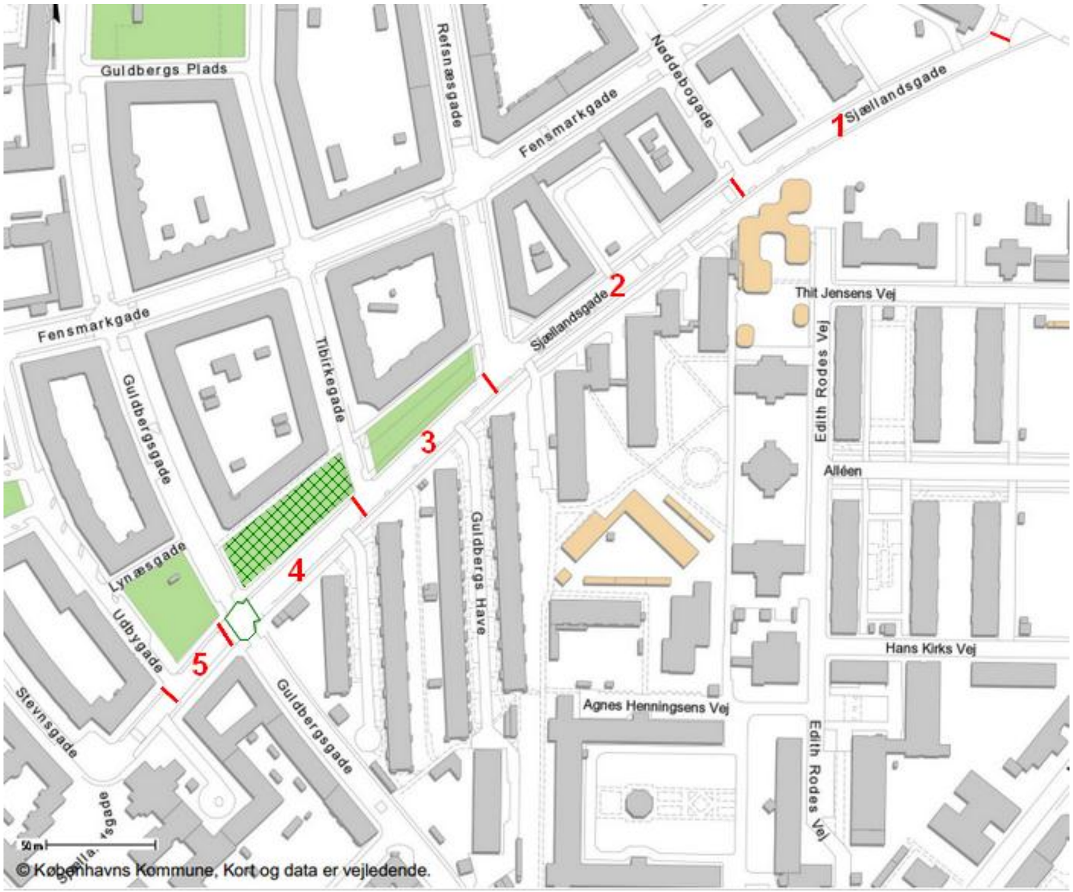

Figure 18. Map of Sjællandsgade indicating the areas examined for parking spaces. Adapted from Københavns Kommune (Kobenhavns Kommune, 2013)

As can be seen in Figure 18, our team divided Northern Sjællandsgade into 5 sections: the Tagensvej intersection to the Nøddebogade intersection (1), the Nøddebogade intersection to the Refsnæsgade intersection (2), the Refsnæsgade intersection to the Tibirkegade intersection (3), the Tibirkegade intersection to the Guldbergsgade intersection (4), and the Guldbergsgade intersection to the Udbygade intersection (5). The map in Figure 18 also indicates the World War II-era bunkers (area marked by dark green crisscrossing lines) and the intersection blocked off from vehicular traffic (area outlined in dark green) for reference. Area 1 contains roughly 30 parking spaces, area 2 about 35, areas 3 and 4 approximately 20, and area 5 is free of parking spaces.

Through an on-site assessment of Sjællandsgade we observed the amount and quality of existing green spaces, contemplated about their potential to manage rainwater, and also investigated promising open spaces. This gave us a better feel of the area as well as a more tangible sense of space that cannot be achieved through Google Maps Streetview. What we were searching for were private open spaces that could be accessed from the street, lane dividers, sidewalk width, plant boxes, public green areas, and playgrounds. However, we also paid attention to the amount and type of traffic and gutters. Figure 19 summarizes our most important findings as we walked southwest from the beginning of Sjællandsgade at the intersection of Tagensvej to its end at Nørrebrogade.

Figure 19. Labels indicate the locations of Figure 20 and Figure 21 on Sjællandsgade. Adapted from Københavns Kommune (Kobenhavns Kommune, 2013)

Open courtyards facing Sjællandsgade are valuable spaces that, if opened up to the street, could add large amounts of green areas without requiring much intervention. Figure 20A shows one of two such courtyards on Sjællandsgade. This building is privately owned; a co-operative housing association that has a governing board that Miljøpunkt Nørrebro could contact with a proposal to open the courtyard to the street.

Figure 20. Three different types of green or open space on Sjællandsgade.

We also took note of the broadness of the sidewalks along both sides of the street. Despite being a residential area, there is not a large amount of pedestrian traffic that could crowd both sidewalks. Figure 20B depicts the broadness of the sidewalk as well as additional parking spaces. These parking spaces are only found along one block of Sjællandsgade, but it suggests that the residents need the parking spaces and that the more concentrated diagonal parking rather than parallel along the street is a good option. Additionally, the area separating the parking from the sidewalk is wide enough, or could be widened, to hold features such as rain gardens or a narrow linear park. At the moment this narrow strip has only a few benches and looks like it is covered in grass during the summer.

Other important structures on Sjællandsgade are the underground fallout shelters shown in Figure 20C. This area is owned by the municipality and is similar to other fallout shelters in Copenhagen. For Sjællandsgade though, the bunkers could potentially be used for underground water storage, possibly minimizing installation costs if the infrastructure is still in acceptable shape, while still allowing children to play on their surfaces.

The next interesting area is the intersection of Guldbergsgade and Sjællandsgade, shown in Figure 21A, B, and D. Figure 21A is the view southeast from that intersection; Figure 21B is the view of the playground from Guldbergsgade, just northwest of the intersection; and Figure 21D is a panoramic view of the intersection facing northwest. We identified in this area the potential to be a large green space with integrated rainwater management features. The concrete barriers blocking car traffic make the asphalted center region useless, and with the adjacent areas that could be connected to it, this intersection could be a sizeable park. The amount of construction required for this vision would be restricted almost exclusively to the asphalted region since the bunkers and the playground are already green areas.

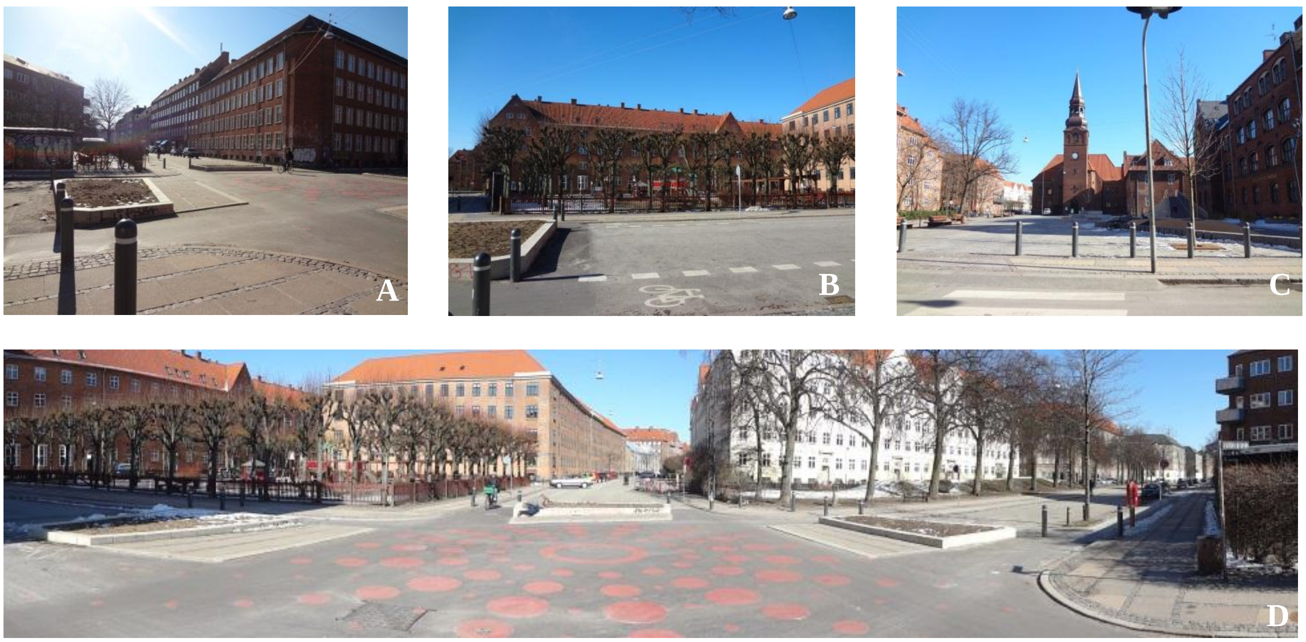

Figure 21. Open spaces along Sjællandsgade.

The last large, open and green space on Sjællandsgade is the plaza between the church and the school, Guldberg Byplads, Figure 21C. This area was renovated in 2011, four years after the first plans were proposed, as part of a neighborhood renovation project that wanted to revitalize the area and create safer roads for children (Dac & Life, 2010). This project created an appealing recreational area for children and also gave the neighborhood a more positive environment.

Contour and surface plotting of Sjællandsgade

We determined relative latitudes, longitudes, and altitudes for 36 chosen waypoints, shown in Figure 22, to be plotted in Matlab (source code is found in Appendix C). The data were used to create a surface plot, 3-D contour plot, and 2-D contour plot with the waypoints demonstrating Sjællandsgade plotted over each graph.

Figure 22. Mapping of the waypoints used to construct a contour map of the terrain (Daft Logic, 2011).

From the Google Map script data collection, we found that the lowest altitude lay on Sjællandsgade at waypoint 18. Three separate plots—Figure 23, Figure 24, and Figure 25—were generated from the Matlab code. The surface plot in Figure 23 demonstrates the curvature of the land as taken from the 36 data points and resolved through Matlab. The line highlighted in red represents Sjællandsgade as plotted from points 18, 36, 1, 2, 3, 4, and 5. This graph gives a three-dimensional perspective for the area as resolved from the data. The plot shows that there is over a 4-meter drop within our boundaries. The 3-D contour plot in Figure 24 demonstrates how sharply the landscape turns towards Sjællandsgade. It also elucidates that many streets flow from higher elevation and connect into Sjællandsgade. This is similar to the effect of a tributary whereas many smaller streams flow into a larger river. From the evidence of the contours of the land, Sjællandsgade lies in a flood prone area and would act as river should a large rainfall event occur. The more closely spaced the contours are, the steeper a section is. The 2-D contour plot in Figure 25 provides the final confirmation that Sjællandsgade is in a floodplain. This provides a 2-D map of the area in concern and will be useful for city planners who need a first rudimentary understanding of the area. Our group was tasked to research an argument for the municipality to affect change in the area. By providing graphs that demonstrate Sjællandsgade's precarious position for runoff, we can show that this area needs a water diversion solution to mitigate future flooding occurrences.

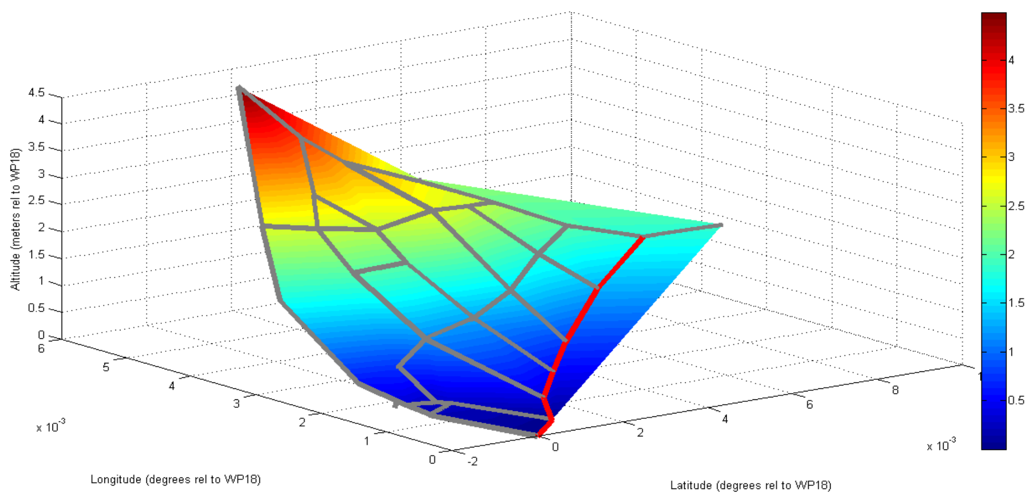

Figure 23. Surface plot of the area's altitude distribution based on the Google Maps script.

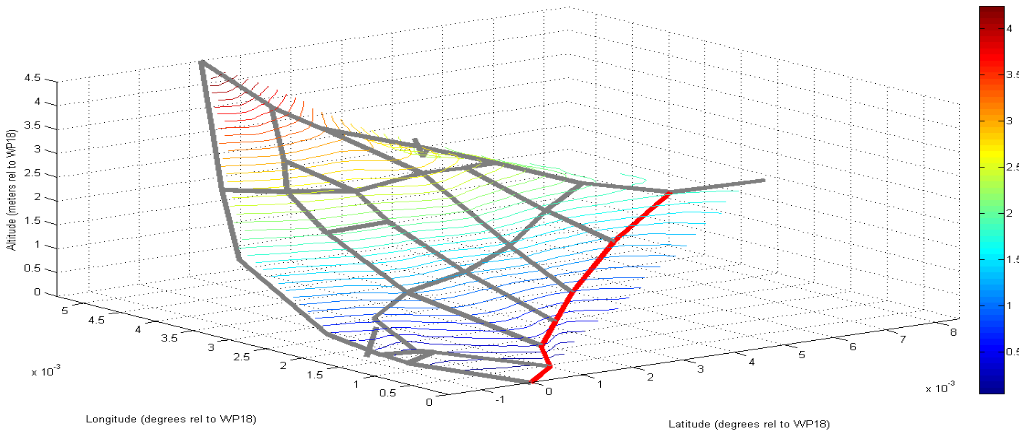

Figure 24. 3D contour plot of the area based on the Google Maps script.

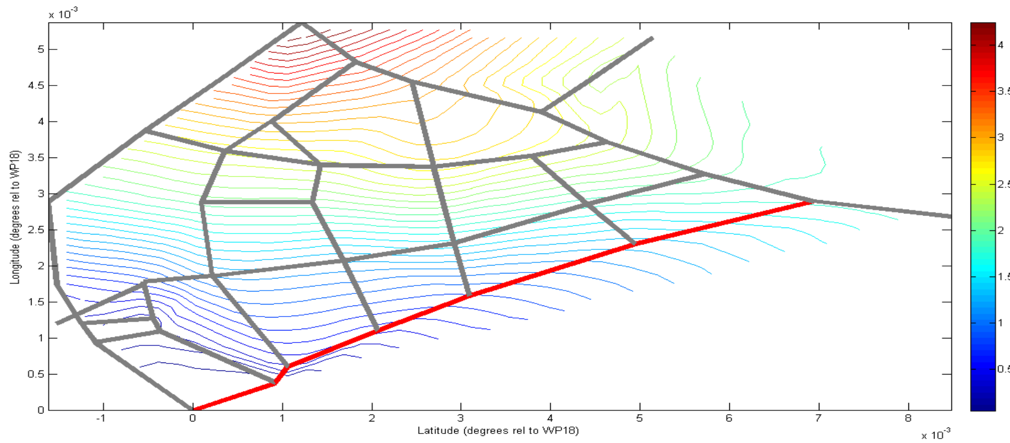

Figure 25. 2D contour plot of the area based on the Google Maps script.

Area permeability study

By performing the necessary calculations, our group was able to determine the runoff coefficient for the studied area during precipitous events. This is referred to in the spreadsheet formulation as the composite runoff coefficient. In order to accurately determine the amount of runoff generated by the studied terrain area, a comprehensive analysis of specific geographical elements was required. Runoff for an area was determined by considering the surface permeability of the area and the amount of precipitation. The Municipality of Copenhagen provides an extremely useful tool to gather both the numerical and qualitative value for a given area (Kobenhavns Kommune, 2013). By discretizing the area, see Figure 26, and using aerial photographs, we found specific zones of buildings and parks and information on the types of surfaces. We then created a table that labels each area, returns a value for how many square meters it inhabits, and produces a runoff coefficient as reported in Appendix D: Rational Method calculations for. For the area value of pavement, we recommend subtracting the areas found from the total area of the neighborhood. Equation (5.1.1) was used to calculate the weighted runoff coefficient.

$$C_w = \frac{(\sum_{j=1}^{j} A_j * C_j)}{(\sum_{j=1}^{j} A_j)} \tag{5.1.1}$$

Here, C_w is the weighted runoff coefficient, A_j is specific area, and C_j is specific runoff coefficient. The composite runoff coefficient for this area is 0.650, or roughly 65%. Essentially, this indicates that 65% of all rainwater that falls on the studied area does not drain naturally into the ground, and instead accumulates on impermeable urban surfaces and runs downhill to the Sjællandsgade corridor. With this numerical prediction it then became possible to calculate the runoff volume for any rainfall event. By performing extensive calculations, it became clear that the specific runoff coefficients for impermeable surfaces are much higher than that of permeable surfaces such as grass or gravel. This empirical data provides strong evidence of the necessity of green space in this area.

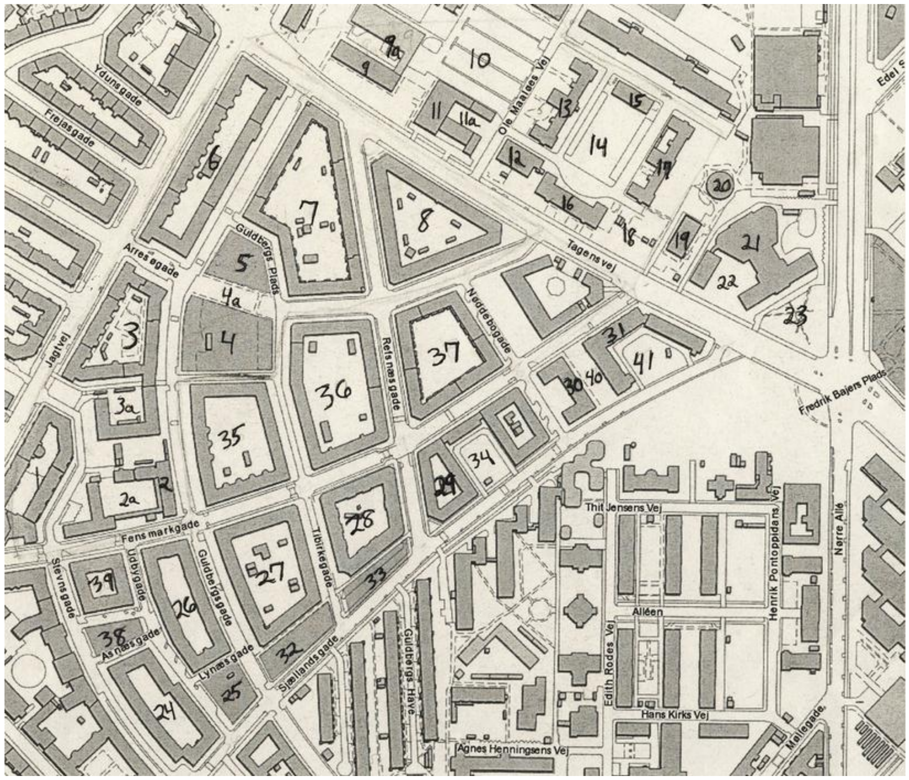

Figure 26. Area divisions for Runoff Coefficient calculation.

Results on Potential Runoff from Rainfall

Sheet flow is only valid for flow that travels under 300 feet (Woodward, n.d.). In our basic calculations for flow we have adopted a model wherein water flows downhill in each of our paths. By observations in Figure 27, we can see that uphill of waypoint 29, the altitudes are higher. Thus, with our model we will assume that we have a fully-developed flow prior to waypoint 29 and the calculation for finding the so-called time of concentration T_c for sheet flow is not necessary.

Figure 27. Topographical map.

Unfortunately, due to a lack of available information, our time of concentration calculation cannot include the Open channel flow method (Woodward, n.d.). In order to reasonably determine where the open channels are, we would require a complete survey of the area and mark where the possibility of streams may occur that would reach a depth over 0.5 feet (.1524 meters). To resolve some of this issue, we have treated everything as shallow concentrated flow to provide an estimate as to the time of concentration (Woodward, n.d.).

Further, we carried out a study that would compare the results of shallow concentrated flow and channel flow to gain insight as to the effects of using one model over the other. Figure

28 shows the results of the study whereas the shallow concentrated flow equation was taken from the empirical data available in the National Engineering Handbook (Woodward, n.d.) and the channel flow follows the Manning equation, Equation (5.1.2), whereas the Manning coefficient is taken as n = 0.025, the hydraulic radius is R = 3.251feet (based upon an 8m wide street with a 7 centimeter high curb), and s represents the slope (feet/feet, meter/meter).

$$V = \frac{1.49\, R^{\frac{2}{3}} s^{\frac{1}{2}}}{n} \tag{5.1.2}$$

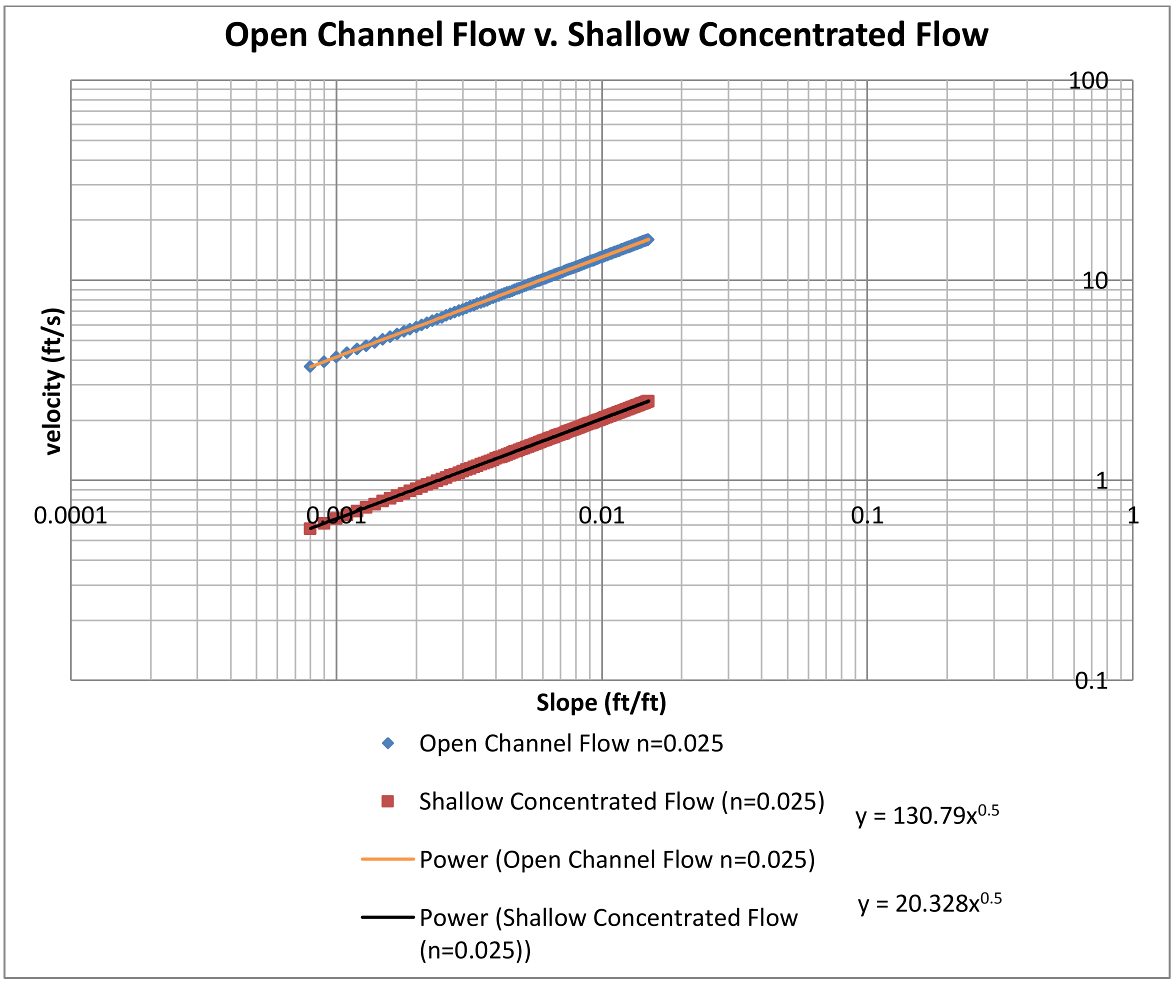

Figure 28. Open channel flow versus shallow concentrated flow graph.

From the graph it is evident that for an open channel flow, the velocity will be much greater (~634%) than that of the shallow concentrated flow. Therefore, we may predict that the shallow concentrated flow (SCF) will return a longer time estimate than that of the channel flow. Thus, by using the SCF method we will return a liberal estimate for the time of concentration but a conservative estimate for the intensity.

From sixteen different pathways we were able to determine the path that took the longest time for water to flow from waypoint 29 to waypoint 18. By using the distance formula, Equation (5.1.3), and using latitude and longitude between each point for the X_i and Y_i inputs, (i=1,2)we were able to find the distance (in degrees) for each set of waypoints.

$$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (5.1.3)$$

From this set of distances, we were then able to convert the distances into meters and determine the slope from point to point by dividing the distance by the change in altitude, Equation (5.1.4).

$$s = \frac{d}{z_1 - z_2} \qquad (5.1.4)$$

Here, z_1 and z_2 represent two different altitude values. With this data, we can proceed to the use of an online calculator to find the velocity and time for each segment (Professor Patel, 2012). The only important time to copy is the first one as we iterate through each pathway we add the velocities together and then use the definition of velocity to determine the time of travel, T, in hours, see Equation (5.1.5).

$$T = \frac{d}{V * 3600} \qquad (5.1.5)$$

The addition of the times through this method is then the time of concentration T_c.

Presented in Table 4 is a summary of the results ordered by length of travel time. From this data, we can conclude that $T_c = 0.222$ hours, and can thus add this value into the Rational Method calculation. It should be noted that this is an estimate of the potential water channeled from street paths; it does not include the potential time estimates for water from the park and grassy areas to complete a runoff. That being said, this runoff calculation is sufficiently accurate as channels will be formed on the streets much like tributaries to a large river. The grassy areas would only serve as over-flow from the natural pathways of the streets. There is also another limitation to this model as it assumes that the velocity discretized along the pathways are additive and does not take into effect any resistive forces. The calculation for that scenario is beyond the scope of this project, although other researchers may expand upon these principles to include such effects.

Table 4. Pathways and runoff time.

Pathway	Time (hr)
29, 25, 24, 21, 9, 3, 2, 1, 36, 18	0.106
29, 25, 26, 27, 28, 11, 1, 36, 18	0.107
29, 30, 31, 32, 13, 14, 16, 18	0.126
29, 30, 31, 27, 28, 11, 1, 36, 18	0.133
29, 25, 26, 22, 23, 10, 2, 1, 36, 18	0.138
29, 30, 31, 27, 22, 23, 10, 2, 1, 36, 18	0.147
29, 25, 24, 33, 19, 7, 8, 9, 3, 2, 1, 36, 18	0.148
29, 25, 24, 33, 19, 7, 8, 4, 3, 2, 1, 36, 18	0.149
29, 25, 24, 33, 19, 7, 8, 9, 10, 2, 1, 36, 18	0.152
29, 25, 24, 33, 19, 7, 8, 9, 10, 11, 1, 36, 18	0.159
29, 25, 24, 33, 19, 7, 8, 9, 10, 11, 12, 15, 17, 36, 18	0.160
29, 25, 24, 33, 19, 7, 5, 4, 3, 2, 1, 36, 18	0.161
29, 25, 24, 33, 19, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18	0.165
29, 30, 31, 27, 22, 21, 9, 3, 2, 1, 36, 18	0.166
29, 30, 31, 27, 22, 21, 20, 8, 4, 3, 2, 1, 36, 18	0.190
29, 30, 31, 27, 22, 21, 20, 19, 7, 5, 4, 3, 2, 1, 36, 18	0.222

With these limitations and assumptions established, we then used the data carried out by Mikkelsen, *et. Al*, Figure 29 to find the predicted intensity in Copenhagen for a 1-year, 10-year, and 100-year events using $T_c = 0.222$ hour. We then used the rational method as shown in Equation (5.1.6) to calculate the Maximum Rate of Runoff. With unit adjustment to account for the time, we can predict the amount of runoff given the conditions that the storm can be generalized as a one-hour storm that has a constant rate of runoff. The results of these calculations are shown in Table 5, Table 6, and Table 7. What we can observe from this data is the severity in the amount of expected runoff over the area and a clear need for water mitigation techniques. To put these large numbers into perspective, the amount of runoff expected in the area is equivalent to about the volume of water contained in 6 Olympic-sized swimming pools (Hoefs, 2011).

$$Q = \frac{CIA}{Z} \tag{5.1.6}$$

Where the variables are defined as follows: Q is the maximum rate of runoff (m^3/s), I is the average rainfall intensity (mm/hr), A is the drainage area (ha), and Z is the 360 conversion factor for metric.

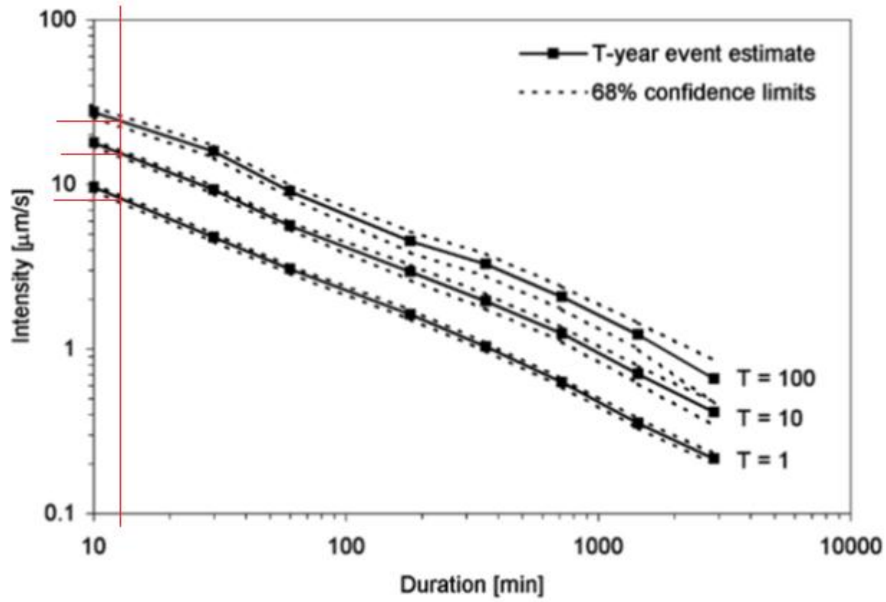

Figure 29. Analysis of projected Copenhagen rainfall, T is presented as 1-year, 10-year, and 100-year rainfall event (Madsen, P S, 2002).

Table 5. Expected 1-year storm runoff

Composite runoff Coeff.	0.650	**Drainage area (ha)**	23.348
Time of Concentration (hr)	0.222	**Chart for 1-Year event (µm/s)**	9.1
Intensity (mm/hr)	32.76		
Duration (hr)	1		**Total Runoff (m^3)**
Max. Runoff Coeff. (m^3/sec)	1.381		4974.960

Table 6. Expected 10-year storm runoff.

Time of Concentration (hr)	0.222	**Chart for 10-year event (µm/s)**	17
Duration (hr)	1		
Intensity (mm/hr)	61.2		**Total Runoff (m^3)**
Max. Runoff Coeff. (m^3/sec)	2.581		9293.882

Table 7. Expected 100-year storm runoff.

Time of Concentration (hr)	0.222	**Chart for 100-year event (µm/s)**	28
Duration(hr)	1		
Intensity (mm/hr)	100.800		**Total Runoff (m^3)**
Max. Runoff Coeff. (m^3/sec)	4.252		15307.571

Directional rainwater flow map

This street-level flow pattern map, Figure 30, was created by referencing the topographical terrain elevation map and contour plots we had generated previously. Through the assessment of the relative elevation between two points, it is possible to determine the slope of a section of road and therefore which direction runoff will travel along that length. By applying this principle to the paved roadways connecting all waypoints from the terrain elevation map, we were able to construct an inclusive directional flow map for the studied area. This map indicates the direction of flow from waypoint 29, the relative area apex, to waypoint 18, the local altitudinal minimum. The directional flow map demonstrates the totality of runoff entering the Sjællandsgade corridor from the surrounding area, further illustrating the necessity for floodwater mitigation and runoff management systems along this corridor. These results correspond with the findings garnered from all other cartographical documents we have produced during this project, supplementing the endorsement of our sponsor's hypothesis that the maps provide.

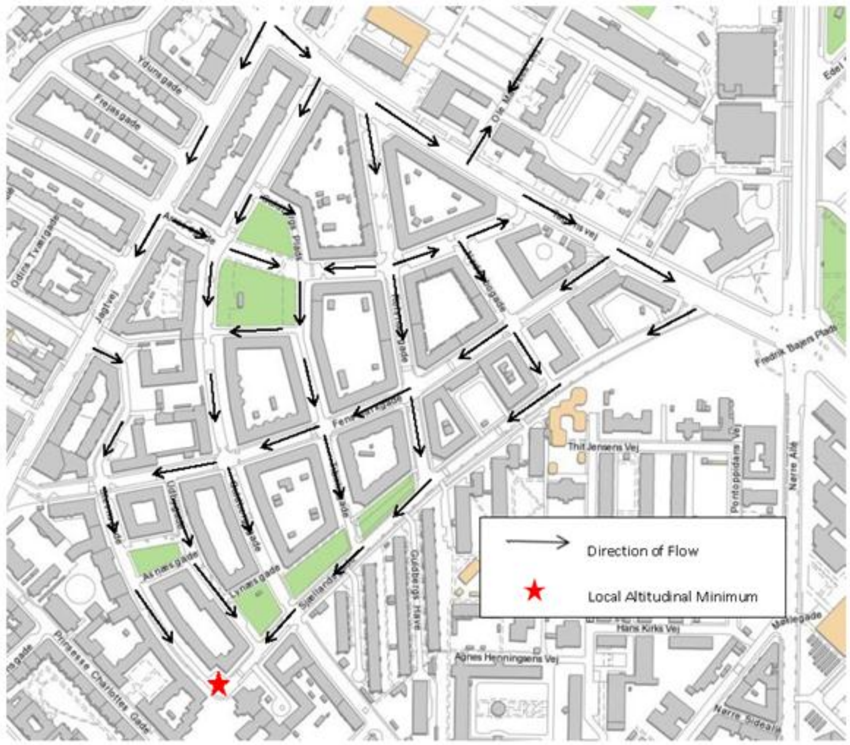

Figure 30. Directional flow map of rainwater in the Sjællandsgade area Adapted from Københavns Kommune (Kobenhavns Kommune, 2013).

Modeling runoff estimates

We consolidated our surface permeability and water runoff studies in a spreadsheet for Miljøpunkt Nørrebro to use when refining water management and water catchment systems for Sjællandsgade. The embedded formulas, Equations (5.1.6) and (5.1.7), originate from calculations specific to Sjællandsgade, as found in Appendix D: Rational Method calculations for.

$$Max. Runoff\ Coefficient = 9.293 \times Year^{0.2441} \times \frac{3600}{1000} \times \frac{1}{360} 23.3482 \times 0.65042 \qquad (5.1.6)$$

$$Total\ Runoff = Max. Runoff\ Coefficient\ \times 3600 \times Duration \qquad (5.1.7)$$

The model takes into account weighted surface permeability coefficients and calculations of water flow specific to Sjællandsgade to provide a closer estimate of total runoff values. The only variables are the type of 'Year' storm and its duration in hours. Additionally, the spreadsheet is 'protected' to guarantee the formula will not be modified accidentally.

5.2 Subterranean characterization

In order to maintain the feasibility of the climate change adaptation elements we have proposed the subterranean infrastructure in the Sjællandsgade corridor had to be analyzed. This analysis covered various levels of subterranean infrastructure including the cable lines, telephone lines, sewer mains, potable water piping, and wireless network lines. The exact position of this existing infrastructure determined the possible floodwater mitigation and green space solutions that could be considered for the area, as it would not be feasible to alter these components.

The fiber optic cable/internet line, sewage lines, and potable water lines were the three most pertinent existing systems studied. The fiber optic line, which is property of GlobalConnect, runs perpendicular to Sjællandsgade through the Guldbergsgade intersection; its path can be seen in Figure 31. This intersection is a focal point of the proposed multi-tiered sustainable solution and is existential to our urban drainage system design. The GlobalConnect fiber optic line runs through this area at an approximate depth of 1.06 meters, the average for fiber optic duct bank burial beneath roadways. The proposed solution includes a large drainage swale which runs along this area of Sjællandsgade at a depth of roughly 2 meters, deeper than the burial depth of the GlobalConnect line. To counteract this problem, the swale must be dug to a depth of less than 1m at this location, allowing for the fiber optic line to remain buried.

There is an alternative solution that exists only if the fiber optic line was placed using direct burial. Direct burial is "a kind of communications or transmissions cable which is especially designed to be buried under the ground without any kind of extra covering, sheathing, or piping to protect it" (Sterling, 2000). Should the line be buried in this fashion, it is possible to cut the line and insert a longer supplementary section that could circumvent the drainage swale and allow for the swale to be dug deeper. Regardless, the GlobalConnect fiber optic line must be considered during the construction process and a decision on a course of action should be made upon the determination of its burial status.

Figure 31. GlobalConnect fiber optic line intersecting Sjællandsgade.

The sewage and potable water supply lines, operated by Hofor, run along the length of both Sjællandsgade and the surrounding streets (seen in Figure 32), making them highly relevant in the design consideration process. Adding to this relevance is the potential to tie into these lines with respect to the installation of a rainwater catchment and reuse system. Tying into the sewage system is not an option in this area, as in Nørrebro the current street-level urban drainage systems drain directly into the blackwater drainage pipes. Aside from this, the sewer and potable water pipes do not obstruct the proposed sustainable urban drainage and green space solutions. The depth of the sewer main along the Sjællandsgade corridor is at a minimum over 5 meters from the surface, well out of the way of the proposed swale and additional drainage measures.

The potable water supply lines run at a similar depth along the roadway and open areas, climbing to the surface only as they are adjacent to or underneath buildings. Because of this, neither the sewer main nor potable water supply lines need to be altered or accounted for when applying our proposed floodwater mitigation and urban green space climate change adaptation solutions.

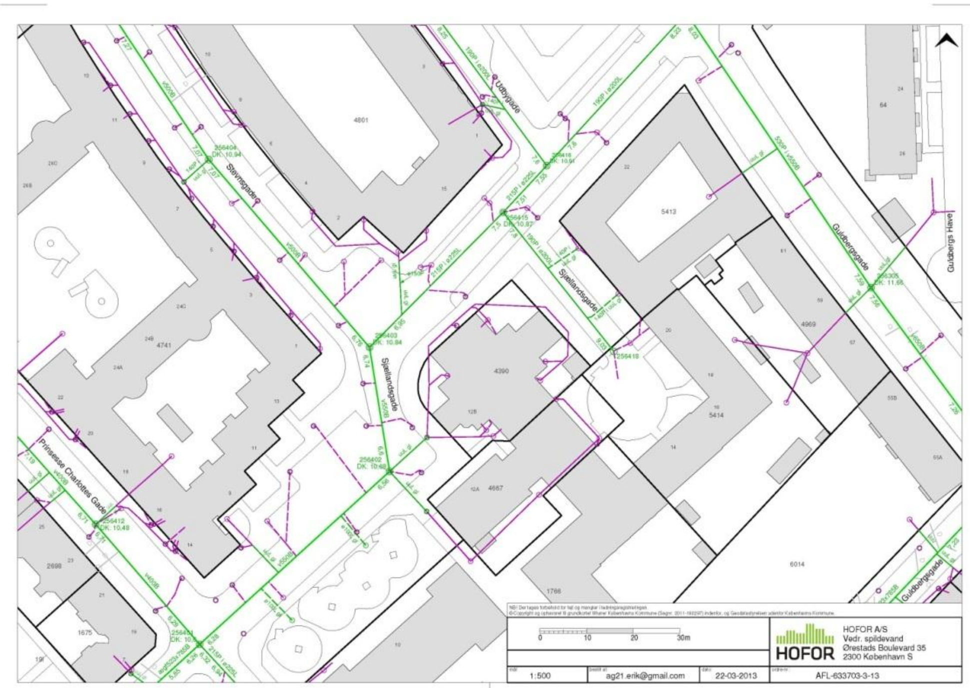

Figure 32. Hofor sewer and water main mapping for the Sjællandsgade area.

After compiling detailed specifications about the totality of the existing infrastructure the task of designing sustainable drainage solutions for the Sjællandsgade corridor was possible. Without this comprehensive understanding of the subterranean landscape, it would be unadvisable to spend time designing urban drainage and green space solutions, as the designs would not account for pre-existing obstructions. This principle is applicable in all facets of urban planning, and is representative of the preparedness necessary to design sustainable solutions for both the Sjællandsgade area and other urban areas.

5.3 Feasibility analysis of tiered floodwater management solutions

Based exclusively on the nature of the results of our extensive research, we have developed a series of tiered solutions that may be implemented in the Sjællandsgade corridor. The benefit to developing a tiered solution system is that the solutions build upon each other, thus allowing the ideal solution to be installed over time in steps should funding or other restraints limit its initial feasibility. Additionally, the solutions can be actively compared to better illustrate the potential sustainability and effectiveness of each tier. Essentially, the tiered solution system has allowed our group to propose three viable, sustainable solutions for floodwater mitigation and green space production in this area. This has resulted in a solution system that is three times as feasible for installation as any one solution, maximizing the efficiency of our work and potential value of our solutions.

This section of the report seeks to elucidate the benefits of each tiered solution so that a committee may be able to understand the implications of our proposals. We have envisioned a series of tiers that relate to one another as phases of a large-scale project would in a city-planning scheme. This allows the project to potentially be taken at a Tier III or Tier II level and still have the potential to be upgraded to the Tier I solution over the long-term. Therefore, different political or economic environments will not hinder all development for the area and it gives planners flexibility for implementation. A complete and detailed description of each tiered solution is included in section 6.1 Tiered solutions.

Tier I evaluation

This tier is envisioned by our team to be the most sustainable solution that can retain, divert, and reuse the most rainwater for residential or public use while increasing the amount of green area. This solution maximizes the amount of permeable and semi-permeable surfaces, allowing for the weighted runoff coefficient to decrease so that more water will be naturally absorbed by the surface in a rainstorm. We also allow a minimum 12,500 cubic meters for street-level retention of water at a given time through the swale estimate and the sedimentation reservoir underneath the parking garage. This calculation does not include the retention and use by the rain gardens or community gardens in the area. In addition to this retention, an uncalculated amount of water will be collected by residential buildings for use in washing machines. Our system maximizes the amount of rainwater decoupling that can occur for the area, thereby saving the city money by eliminating the need to process rainwater in a treatment facility. It also saves the residents money in the long run as they will have a reduced sewer bill from the decoupling.

This concept also provides for as little energy grid usage as possible by the additions in the area through renewable sources for pumps, washing machines, and lighting. This helps with the zero-carbon footprint vision for Copenhagen by 2025 by attempting to not affect the grid with our proposal and possibly sell renewable energy back to the utility companies. The safety of the street will also be greatly improved for children, as the elimination of cars from the area will give them a safe pathway to walk to and from the schools in the area as well as a safe public playing area. The one disadvantage of this solution is the initial cost for executing this solution. Because of the varied number of elements and potential construction time, this tier is expected to be the most expensive, but we believe that the benefits of this ultimate solution will help support our argument for enacting this plan. If this plan is not at first approved and another tier is put in place, it is hoped that Tier I will be the ultimate vision.

Tier II evaluation

This tier is the compromise between Tier I and Tier III in terms of traffic, potential rainwater retention and use, and green space. With the allowance of one lane of local traffic and concentrated parking, we hope to still increase the amount of green area and decrease the weighted runoff coefficient (though not to the same extent as Tier I would) while compromising with the municipality on car policy. Although grass and gravel are most ideal to have in a green space for absorption of rainwater, paving the one lane of traffic with semi-permeable material will improve upon the asphalt. In terms of rainwater, retention at street level is expected to meet a minimum of 5700 cubic meters, which is about 46% that of the expected minimum rainwater retention for the Tier I solution. In addition to this, there is an undetermined amount of rainwater storage that 50% of residences will collect for future use. This roughly means that the Tier II solution will have half as much capacity for rainwater collection as that of the Tier I solution. The benefits of this are amply described in the Tier I evaluation.

In terms of energy usage, this tier seeks to supplement at least a portion of the projected consumption from the application of this proposal. Solar panels would address this need by hopefully driving down the costs as compared to solar trees (which were proposed for not only energy but also aesthetics in Tier I) or vertical wind turbines. Folehaven has installed solar panels in stages; this is also the goal of the Tier II solution, which would provide financial flexibility. Safety for the children in the area will also be improved by this tier by limiting the potential avenue of traffic, which will hopefully deter all drivers who are not residential or otherwise have business in the area. Children should be able to pass along the linear park so that there are safer walking paths in order to go to school or visit other parks and playgrounds.

Another advantage to this tier, as briefly mentioned before, is its regard to financial flexibility. This is a working solution wherein there are options to cut costs initially, if needed, and still implement a majority of the benefits that we have outlined. It still maintains the spirit of grassroots work proposed in Tier I for the resident rainwater systems, and the total financial cost should be somewhere between Tier I and Tier III, making it an attractive compromise. Again, upgrading to a Tier I solution from Tier II would be much less costly than upgrading from a Tier III solution.

Tier III evaluation

This Tier follows a concept of minimalistic design while still providing for water retention to help mitigate the rainwater runoff problem. There are also two concentrated green areas that will help with drainage by providing 5700 cubic meters of drainage on the street level, or 46% that of Tier I. Unfortunately, this solution does not include any residential solution for rainwater collection and use, thus Tier III ultimately has a limited capacity for street-level rainwater management, a disadvantage as compared to Tier I and Tier II. That being said, this solution will not require the same amount of time to implement as a decoupling project would, giving this solution a low-impact execution advantage.

In terms of finances, this project is expected to be the cheapest of all the tiers, as it mainly focuses on landscaping in the area. The only construction-intensive part of this tier involves a reduction of the road along Sjællandsgade from Tibirkegade to Udbygade in order to provide an increase in the green space already present. This means that residents will still be able to enjoy a park along their street and families could play with their children there. Tier III accommodates a difficult economic situation and tries to provide a solution that will begin to help with rainwater flooding mitigation. With the success of this project, it is hoped that the municipality would over time see the advantages to investing in green spaces and work towards securing funds for further development.

5.4 Social implications of stakeholder opinions

A critical component of the research conducted by our group involves the opinions, thoughts, and recommendations of stakeholders in this project. These stakeholders include residents of the Sjællandsgade corridor, employees of the Miljøpunkt organization, and those responsible for the application of climate change adaptation initiatives in other areas. The understanding of the social implications of climate change adaptation in Sjællandsgade provided our group with additional guidelines and parameters to structure our project into the most beneficial compilation of results and conclusions possible.

Focus Groups

Through conducting a focus group, we intended to have a group of stakeholders, mainly residents, participate in a moderated discussion about subjects relevant to our project. The turnout for the focus groups was lower than what we expected; only two men attended our first focus group on April 4th, 2011. Despite having so few participants, Manuel Retsloff and Bjarne Nielsen were very insightful. They are both involved in running a cooperatively owned building in Sjællandsgade that has taken private initiatives to implement climate adaptation measures. The full transcript of our prompts and their responses is included in Appendix F: Focus group transcripts; the main points discussed were flooding in Sjællandsgade, creating solutions, and making Sjællandsgade greener.

With respects to flooding, both men agreed that the so called '100 year rain' events in Copenhagen would become more frequent. '100 year rain' refers to the storms in which the streets flood by 10 centimeters (Cowi, et al 2012). An increased frequency in flooding would require action by politicians and homeowners. The cooperatively owned building where these men live is taking several initiatives to manage rainwater since they believe it will take the politicians too long to take action. One of their plans is to dig their courtyard 1 meter deeper and use it as a place to keep bicycles but it could retain water in case of a flood and thus spare their basements. Their second project unfortunately lost funding. The city used to pay residents if they disconnected the rainwater from the sewers, so the building's board had considered recycling rainwater to make the project even more lucrative. If the project had gone through, the building would have been entitled to DKK 3.7 million from the city. Unsurprisingly, the program ran out of money quickly, but the fact that this movement happened reflects the amount of money that is involved in water supply and management in Copenhagen.

Interestingly, the men linked the idea of increasing green areas in Sjællandsgade to improving the social environment. As one of them said, "…the residents of Sjællandsgade are no longer only people on benefits, [but] many of them are taxpayers, so the social environment is changing". They see green areas, irrespective of their primary purpose, as a way to complement the gentrification processes in Nørrebro so that the social environment can improve while still giving the original residents room in the neighborhood. Furthermore, the men from the focus group see public construction and development of the area as positive: something that gives the residents pride and a feeling of ownership.

Finally with their parting words, they told us to think big. Their argument is that if the project does not evoke strong emotions, be it anger or excitement, then we are not proposing anything new or any noteworthy changes. Big projects like Skt. Kjelds Kvarter (Figure 17) are not impossible, and Sjællandsgade, although a smaller area, has many similar characteristics that would require action by the municipality. These men did not want us to consider cost as the limiting factor, rather as any other factor, and they encourage us to be provocative to promote change in their neighborhood.

Surveys

We developed a survey in order to approach more residents of Sjællandsgade, especially pedestrians and cyclists. The survey was translated into Danish with the help of Mr. Larsen, and the questions can be found in Appendix G: Surveys and survey raw data. Interestingly, every person we approached spoke English, and two of the people surveyed did not speak Danish despite living near Sjællandsgade since 2009.

Table shows the summary of the yes/no questions of the 21 participants; the full results can be found in Appendix G: Surveys and survey raw data. In response to some difficulties with the first survey, one question was removed and another changed from the first in the second survey.

Table 8. Summary of survey answers.

Questions/Answers	Yes	No	N/A	% Yes
Property damaged by the July 2, 2011 Cloudburst?	12	7	2	57%
Flooding problem in Sjællandsgade?	14	3	4	67%
Have you taken any personal initiatives to deal with flooding?	7	13	1	33%
Are you happy with the amount of green space in Sjællandsgade?	8	3	1	67%
Are you aware that increased green space can reduce flooding?	7	2	0	78%
Do you live on Sjællandsgade?	19	2	0	90%

From the survey results, we can see that two thirds (67%) of the residents have not taken measures to deal with flooding. Out of the 33% who have, most of the measures they took were passive. Table 9 shows how some of these passive measures included moving items out of the basements or storing things in plastic boxes, not investing in infrastructure to prevent flooding in their basements or buildings.

Table 8. Additional comments.

Additional Comments
Already lots of parks here, money could be better spent elsewhere.
More green, more trees.
Put things in plastic boxes.
There can always be more green areas.
Money could be better spent on more urgent problems such as social issues rather than parks. There's a street on Jagtvej which kids have to cross through an underground pass full of junkies and bad people on the way to school.
Would always want more green areas.
Do it!

In the 'Additional Comments' section that can be seen in Table 8 and also in the results in Appendix G: Surveys and survey raw data, we saw that some of the residents were eager to share their thoughts. Two of the people interviewed thought that money could be best spent elsewhere, namely on social issues. Also, from the comments, we can see that although people are satisfied or content with the amount of green space in the area, they'd be happy to have more, and that none of the people interviewed are opposed to removing car spaces in order to add even more green spaces to the area.

Interview: Miljøpunkt Østerbro

We interviewed Ms. Henriette Berggreen and Mr. Stefan Werner, who aside from their work with Miljøpunkt Østerbro, also work with the Municipality's Water and Parks Division. They are currently managing the project in Skt. Kjelds Kvarter, similar to the vision Miljøpunkt Nørrebro had for Sjællandsgade (see Figure 12). They gave us recommendations for feasibility and planning issues that apply to projects like ours. The flow of the interview is illustrated by Figure 33 and the notes taken during the interview can be found in Appendix H: Miljøpunkt Østerbro interview.

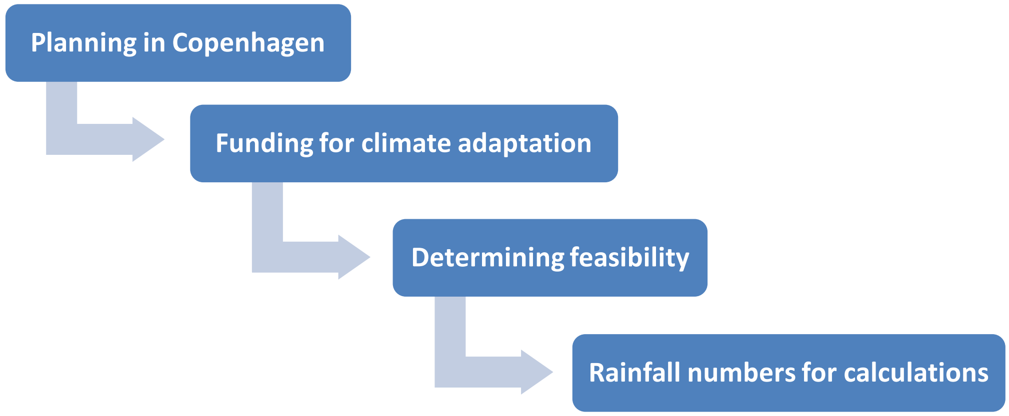

Figure 33. Overall flow of the interview grouping items discussed in categories.

With regard to planning, Ms. Berggreen recommends establishing the primary focus and priorities first. In the cases of Skt. Kjelds and Sjællandsgade as a green corridor, we share the same focus: to use water management systems to make the city more environmentally friendly. Next, the objectives and constraints can be taken into account; Figure 34 is a schematic with parameters suggested by Ms. Berggreen. As in any design, there will inevitably be a need to compromise, and this should be accounted for throughout the planning and design process. For example, car traffic, public transportation, and parking spaces are generally fixed entities in Copenhagen and are difficult to modify. Consequently, Mr. Werner and Ms. Berggreen both stress that in our case anticipating these obstacles by not removing parking spaces, and avoiding areas with heavy traffic and public transportation will increase our project's chances of gaining political approval. Additionally, they emphasized the importance of acknowledging stakeholder feedback in the planning phase to ensure an element of public support.

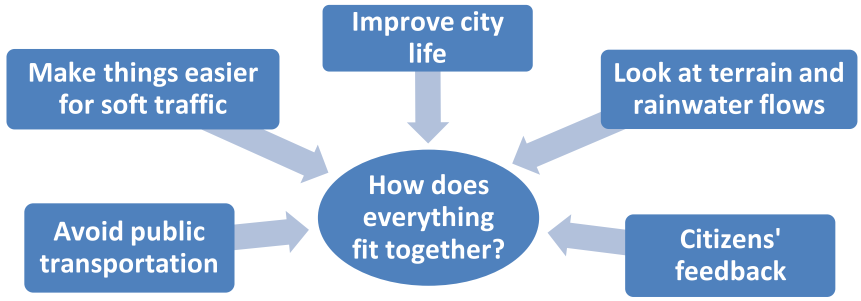

Figure 34. Important considerations when planning for a blue-green corridor.

After discussing project planning, the interview moved to the topic of funding acquisition. Despite the fact that the law has recently been changed to help finance climate adaptation initiatives, there is still a need to lobby for funding. For Skt. Kjelds, 75% of the funding comes from the state and 25% comes from private investors. Some of the state funds come from fees paid for water use and disposal, instead of taxes so initiatives to reduce the amount of potable city water used and initiatives to decouple rainwater from the sewage system are encouraged.

Feasibility is closely linked with the cost-effectiveness of the system and the payback period. Figure 35 lists Mr. Werner's ideas on how to increase feasibility mostly by decreasing associated costs. Mr. Werner is also passionate about thinking creatively, coming up with multipurpose designs, and brainstorming feasible alternatives whenever something is not possible. He says "…things aren't so difficult; we just have to change our habits of thinking or doing things". This comment was referring to the municipality's idea of investing DKK 10 to 15 million to expand sewer capacity. He thinks this is inefficient since the money could be invested on other surfaces, like those in Skt. Kjelds, which could address multiple issues: social, environmental, and flooding.

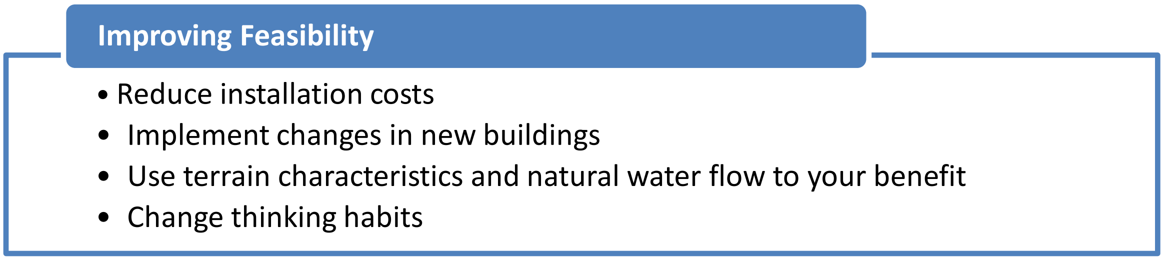

Figure 35. Mr. Werner's suggestions to improve feasibility.

Finally, Mr. Werner and Ms. Berggreen went over numbers and calculations used to estimate rainfall and rain water management systems. This included information on the '10 year rain' and the '100 year rain' scenarios, surface permeability, and examples on how to estimate how much water would needed to be dealt with in a certain storm over a specific area. This advice was taken into account when we modeled rainfall and designed water catchment systems.

Interview: Mr. Villy Sørensen and Mr. Peter Kare

We conducted an interview with Mr. Sørensen and Mr. Kare to discuss the 24 washing machines in the laundry station of Non-profit Housing Association of Folehaven. Mr. Sørensen is the Chairman of the Association and Mr. Kare is the local inspector, making them the most qualified and knowledgeable subjects for our interview. Figure 36 is an outline summarizing the topics of discussion in the interview. The full transcript can be found in Appendix I: Interview with Mr. Sørensen and Mr. Kare.

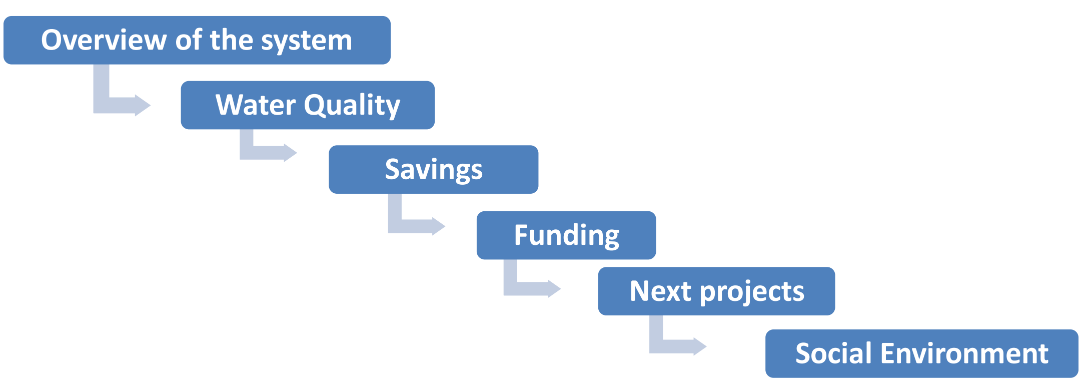

Figure 36. Outline of interview with Mr. Sørensen and Mr. Kare.

The structure of the rainwater system is illustrated in Figure 37. The group at Folehaven has worked to make each stage of the system as efficient as possible. Collection is made easier by maximizing the usable surface area of the roofs. Storage capacity is plentiful, totaling 68,000 liters divided among seven 4 cubic meter tanks and eight 5 cubic meter tanks. Finally, the washing machines used are all water-efficient, allowing for the collected rainwater to supplement the most possible wash cycles. Through this optimization the feasibility of the project is improved and the payback period is significantly reduced.

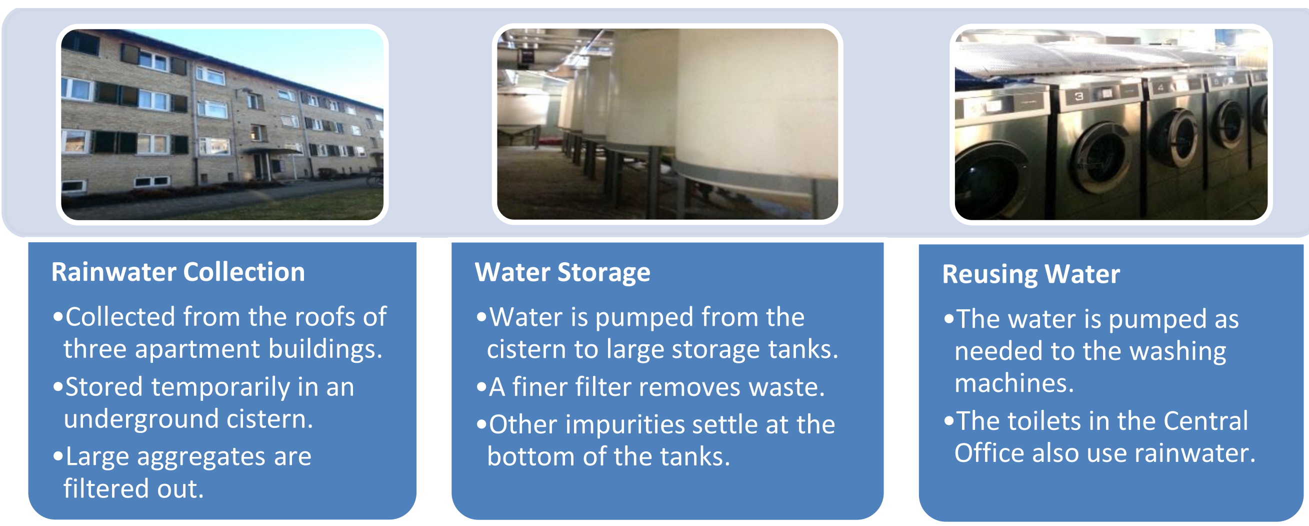

Figure 37. Rainwater catchment and reuse in washing machines system.

To improve the water quality, the rain water is filtered twice and held stagnant to facilitate specific gravitational separation of sediment in the tanks, yet no chemical treatment is given throughout the filtration process. Once a year, the sediment is vacuumed out and the tanks are cleaned. This reuse system does not require a first flush feature to remove additional pollutants in the water. The water quality is checked at random intervals by the water utility company and to date has not failed inspection. The utility company also stipulates that the collected rainwater must not enter city water piping networks at any time.

The project began as the idea of a group of residents considering the inclusion of environmentally friendly practices in their community. They became ambassadors to reach other interested parties and gain their support for the rainwater catchment project. Because of this, the project was developed by the community rather than the municipality, an approach that was faster and simpler. Additionally, getting so many people involved in the project gave the residents a sense of ownership that has benefitted the area by creating a more positive social environment.

The funding came almost entirely from Non-profit Housing Association of Folehaven's savings. This type of housing has most of the tenants' rent go into a fund for maintaining and improving the Folehaven complex, with a small portion going into the National Building Fund from which these buildings can loan money for bigger projects. More details on how the National Building Fund works in Denmark are included in Appendix I: Interview with Mr. Sørensen and Mr. Kare . Since there are approximately 1000 apartments in Folehaven, it does not matter that the rent is low because money can be quickly raised. Additionally, people living here understand that projects like these are feasible in the long run, and since the system helps save a lot of money—DKK 1 million in 2011—the payback period is quite competitive.

Figure 38 shows a list of factors that help the system save money. Due to the fact that so many of the residents share the washing machines, economies of scale allow the Association to buy better machines that last longer and better quality soap that is less harmful to the machines and extends their lifespan. Another factor that extends the washing machines' lifespan and thus makes the process more economical in the long run is that rainwater is not hard water like that of the city, so it has a lower mineral content. Finally, one can also save on electricity costs since rainwater requires less heating for washing with hot water, as it is 2°C warmer than city water. In the end, the system ends up paying for itself in just about 30 years. However, this does not take into account that the weather is changing to bring Copenhagen more rain.

Savings

- Not paying the water usage fees from the utility company
- Revenue from washing, DKK 10 per load.
- Solar panels used to help power the pumps.
- Low maintenance, approximately two hours a week for cleaning.
- Rainwater quality is better than city water, which is hard.
- Rainwater is 2°C warmer than the city water.

Figure 38. Breakdown of savings when using rainwater for a communal laundry station.

While this project has paid itself off through the water reuse revenue it generates, the Non-profit Housing Association of Folehaven is already making plans to expand the rainwater catchment and reuse system. Since the tenants' rent is their way of raising funds, by the time the washing machines need to be replaced, that money will be available. For the rest, they are applying for a loan from the National Building Foundation to renovate buildings and improve open spaces. Renovations include improving insulation in the apartment complexes and modernizing the oldest apartments, while improving the open spaces includes plans to install more lights, improve the winter garden, install solar panels, and use rainwater for more purposes.

Mr. Sørensen then explained the improvement of the social environment incited by the creation of the Folenhaven Non-profit Housing communal laundry station. Before the project was started, the community suffered from social tension and a lack of public safety. The project allows residents to share a piece of the community, promoting a sense of prideful ownership and responsibility. The subsequent improvement of the area's social dynamic has motivated the Board of Residents Association to continue the implementation of projects such as this rainwater reuse system.

6 Conclusions and Recommendations

After extensive analysis of the results of our research we were able to draw a number of conclusions and develop recommendations regarding sustainable climate change adaptation solutions in the Sjællandsgade area. The conclusions and recommendations we have produced are designed to satisfy the entire spectrum of parameters set forth by Miljøpunkt Nørrebro in the initial project proposal. All of our conclusions are substantiated by both theoretical and empirical evidence and are designed to be applicable in as many social, political, and economic environments as possible.

6.1 Tiered solutions

Tier I

This tier seeks to take all recommendations from our group's research, interviews, and focus group to propose a sustainable solution that reduces the impact of flooding in the area while increasing the green space. This proposal also seeks to cover the specified ideas and needs of the community in addition to the tangible problems, such as floodwater management and non-potable reuse.

Traffic alterations to increase permeable surface area

As was seen in the Rational Method study of the Sjællandsgade area to determine the weighted runoff coefficient, asphalt surfaces are not beneficial to natural drainage of rainwater. These types of impervious surfaces only exacerbate the flooding problem and should thus be altered. To maximize the potential drainage of an area, paved surfaces such as asphalt should be entirely eliminated altogether and replaced with a combination of grass, gravel, and semi-permeable pavers. The semi-permeable pavers should also have a compressive strength that could sustain the load of emergency vehicles (fire engines, ambulances, etc.) thus ensuring safety for the area in emergency services. Pavers such as Filterpave should be considered for this use as they are made from recycled material, are semi-permeable, and are listed as having a good compressive strength (Grey to Green, 2013).

Car traffic will also be eliminated as a result of this solution which only further strengthens the safety for children in the area. Special care should be taken to include two-way bike paths as well as pedestrian walkways to facilitate traffic within Sjællandsgade and as a connection between Nørre Campus and Assistens Cemetery. This traffic alteration also continues to encourage people to travel within the proposed green space and thus increase the use of the proposed area. On average, the street is 12 meters in width and approximately 550 meters in length giving a minimum of 6600 square meters of new green space to help with the permeability of the area.

Landscaping to increase runoff holding capacity

As determined through topographical mapping and extensive calculations for rainfall in the 1-year, 10-year, and 100-year events, there is a large potential of runoff that will drain towards Sjællandsgade. This rainwater will flood the street and potentially cause damage to property if nothing is done to alter the landscape. One way to naturally handle large amounts of water is through the use of a swale: a man-made depression in the landscape that is shaped to retain large volumes of water in order to prevent damage to the residences. A corridor the length of Sjællandsgade requires multiple swales constructed in series. Overflow pipes would connect the swales together to maintain an even distribution of the runoff coming from the uphill region towards Tagensvej and Jagtsvej.

Based on the geography of the area and anticipated runoff volumes, this corridor should be outfitted with three 100 meter drainage swales, with retention ponds connected to the swales at either end of the corridor. The swales should be about 3 meters wide at surface level, with the retention ponds at each end reaching 8 meters in diameter and 4 meters in peak depth. Ideal swale depth for this area is 3 meters, with the swale rising to avoid subterranean infrastructure in specified areas. At these dimensions, the swale and retention pond system will be able to hold approximately 4500 cubic meters of water: 90.5%, 48.4%, and 29.4% of the runoff that accumulates in Sjællandsgade during the 1-year, 10-year, and 100-year storms respectively. The area should be re-graded to direct runoff flow to the swales and existing storm drains. In the rainy parts of the year, swales would act as a water feature within the landscape.

In our focus group, there was support for swales in the area with the one request to give them a slope such that children could sled during the winter months and play throughout the year. In order to create a dual-use swale such as this, they should be grass lined rather than the common gravel lining that accompanies swales. This will make the swales safer for the children to play on and will not significantly affect the drainage of the swales.

Street-level features to utilize rainwater

With the addition of green area from the elimination of asphalt and street traffic, there is a large potential for the development of greenery and biodiversity in the area. This can be done through such methods as rain gardens, wherein plant beds are set below street level to collect water and local vegetation is planted. Having these set about the area will give a potential for water retention and use; minimal maintenance would be required as these plants would be native to the climate. Another method that will also promote citizen involvement is community gardens. These would give tenants the ability to grow vegetables, fruits, and flowers, and the water would be supplied from rainwater with a small emergency holding tank underground that could be hand-pumped in the event of a drought. This empowers the citizens to have an ownership to a part of the park that they would maintain and benefit from, giving a better community feel to the developed area. Another aspect that can be incorporated because of the large addition of green area is more local trees and flora. They will help reduce the risk of soil being washed away, increase the biodiversity, provide shade for the area, and increase the potential absorption of rainwater. A final type of structure that can supplement the area with greenery is the use of arbors. Arbors will add structures to the area that can provide shade during the summer months.

Residential-level features to use rainwater

Residents can also make a large impact on the issue of rainwater management in the area by installing systems in apartments that capture, store, and utilize rainwater. A model that can be used is the Folehaven example, wherein they capture and store rainwater from several apartment buildings, requiring only to lightly filter it for use in washing machines. This system brings residents from different apartment complexes together to share in a sustainable system that requires little maintenance and benefits a large number of people. The decoupling of rainwater from sewage was supported in the focus group, as a study had indicated that in one residential building, they would have been entitled to DKK 3.7 million from the municipality. The benefits outlined in the Folehaven interview section also hold true for any similar system. Power for any necessary pumping is possible through the use of such renewable sources as solar trees and vertical wind turbines. By having sustainable resources such as solar and wind, the system will be further independent from the municipality. Solar trees will add to the atmosphere of the area, representing a vision of sustainable city development while vertical wind turbines are compact and can be stacked interspersed throughout the area. Any excess power could be sold back to the utilities company thus helping to offset the cost of development.

Combining parking and rainwater retention

In the focus group session, Mr. Nielsen brought to our attention the possibility of underground parking. The benefit of parking underground is that it allows for more green space in the area while maintaining a net-zero change in parking spaces for cars; this would thereby meet the municipality's parking requirement and would help to garner support. The underground parking structure could also serve a dual purpose whereas a second underground level could retain stormwater runoff as shown in Figure 39 and Figure 40.

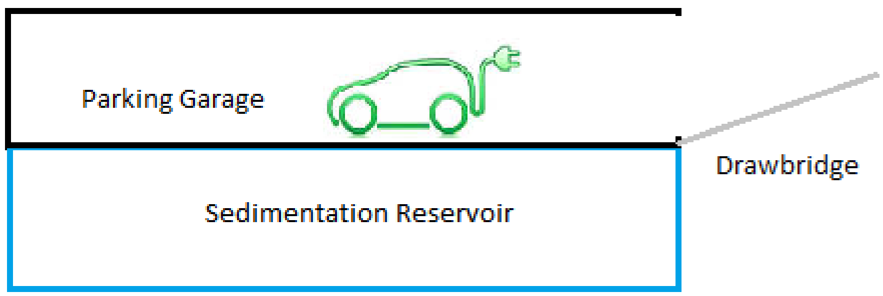

Figure 39. Dual use underground parking garage.

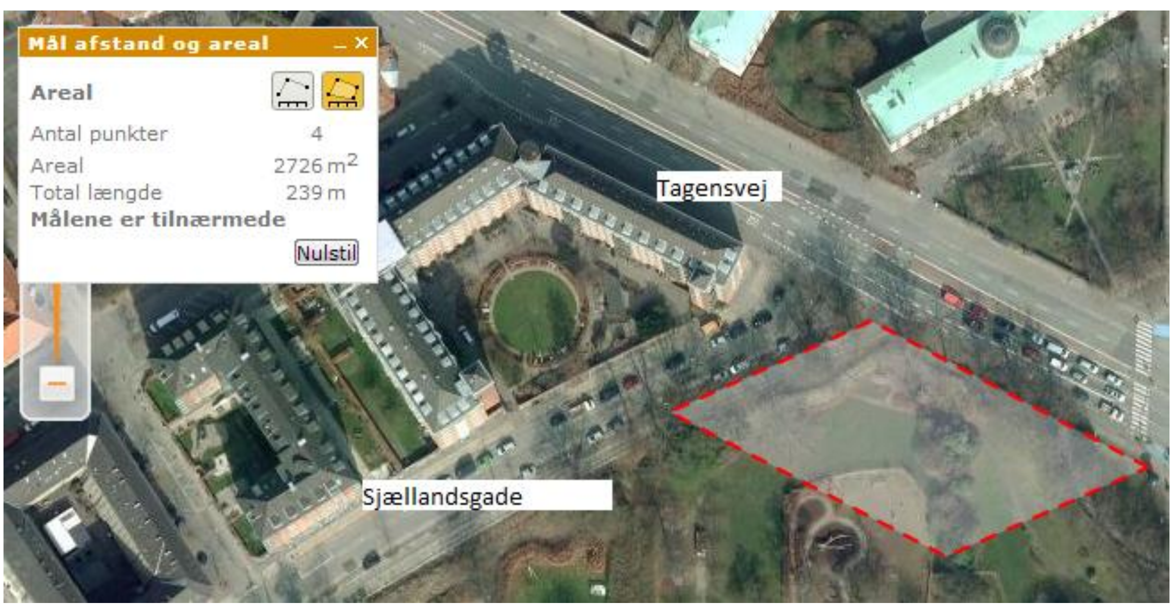

Figure 40. Proposed location of dual use underground parking garage.

The parking garage top would be flush with the ground for the Kindergarten in the area, allowing for a potential green space or playground to be placed on top for the children to play on. The first level underground would contain cars and the second level would be a holding tank for excessive rainwater. Even with a 3 meter depth to the second level, we could expect a holding capacity around 8000 cubic meters: approximately 86.1% and 52.3% of the runoff expected for the 10-year and 100-year rainfall events respectively. This would be a substantial amount of rainwater runoff to be collected and decoupled from the sewage system. The entrance and exit to this underground parking garage would be on the intersection of Sjællandsgade and Tagensvej. Cars will be protected from rainwater through the use of a hydraulic lift for the proposed drawbridge and safety fences would be raised to prevent people or large debris from being dragged into the water retention area during a 100-year storm. Sedimentation filters will then transfer the runoff water into the groundwater over time leading to a natural process of the water cycle.

Park aesthetics and safety

The last component of the proposed Tier I solution would be to provide park aesthetics such as benches and sitting areas made from recycled materials. This gives park visitors places to congregate and enjoy the area while promoting sustainable development. Safety, such as park lighting from wind or solar charged lighting, would allow people to safely bike or walk through the park at night. Other components such as concrete beds for flowers will help block certain parts of the park from traffic and provide a safe way for children to walk around the area. Figure 41 depicts a vision of what a possible Tier I solution could look like.

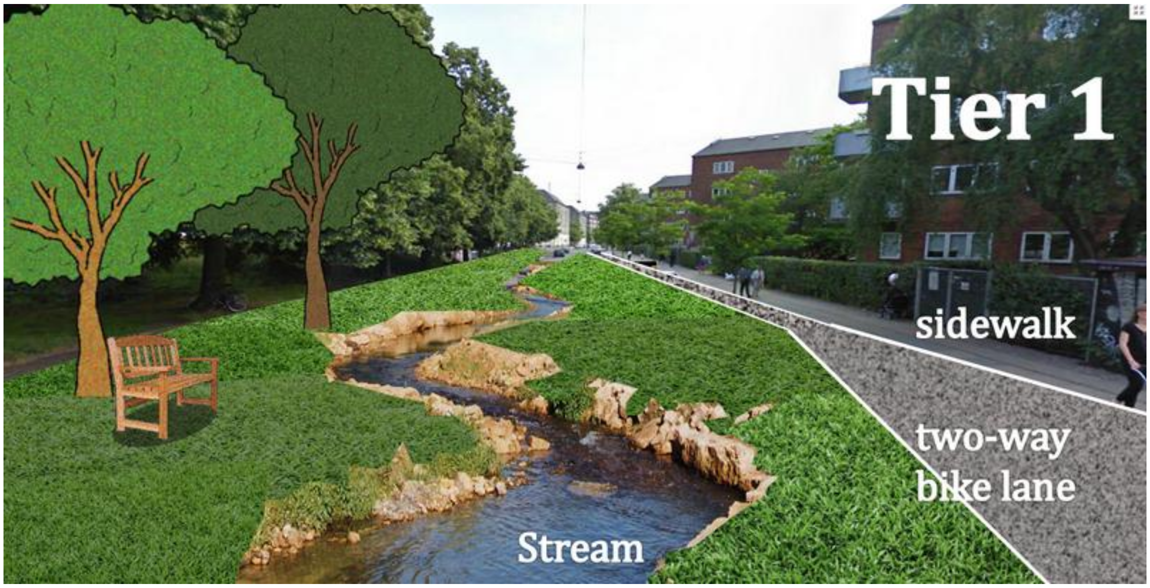

Figure 41. Vision for a possible Tier I solution.

Tier II

This tier serves as an intermediary compromise between the bold vision of Tier I and the economically conscious plan encompassed in Tier III. This tier, as in all tiers, will still tackle the problems of flooding by providing sustainable solutions for catchment and use while providing an increase in green space for the area.

Restructuring of traffic and parking

The main difference between Tier I and Tier II is the concession to allow one lane of traffic along a portion of Sjællandsgade stretching from Tagensvej to Tibirkegade. The direction of traffic will flow from Tagensvej towards Nørrebrogade so that the road is restricted to local area traffic only. Since this is a reduction in the amount of green space as compared to the Tier I solution, our group also recommends that semi-permeable paving be used for paving the street such as Filterpave or Firmapave which offer permeabilities ranging from 39% to 47%. This will help alleviate a portion the flooding because these materials are more permeable than regular asphalt (Appendix D: Rational Method calculations for). With a substantial alteration to the drainage, our weighted runoff coefficient is also expected to decrease. This is a sustainable compromise between the dissolution of traffic in Tier I and the local traffic allowance in Tier III.

Another compromise followed by the one-lane traffic is the restructuring of parking along the road. Our group envisions concentrating parking to areas along the street where cars are parked at a 60° angle to the road as shown in Figure 42, 43, and 44. By placing the cars in this orientation, our group seeks to limit the linear distance that cars are allowed to park along the street and thereby permitting more green space. It is our recommendation that the parking be concentrated on the upper end of the street (near Tagensvej) so that parking does not affect the width of the green space further along Sjællandsgade.

Figure 42. An example of concentrated, diagonal parking.

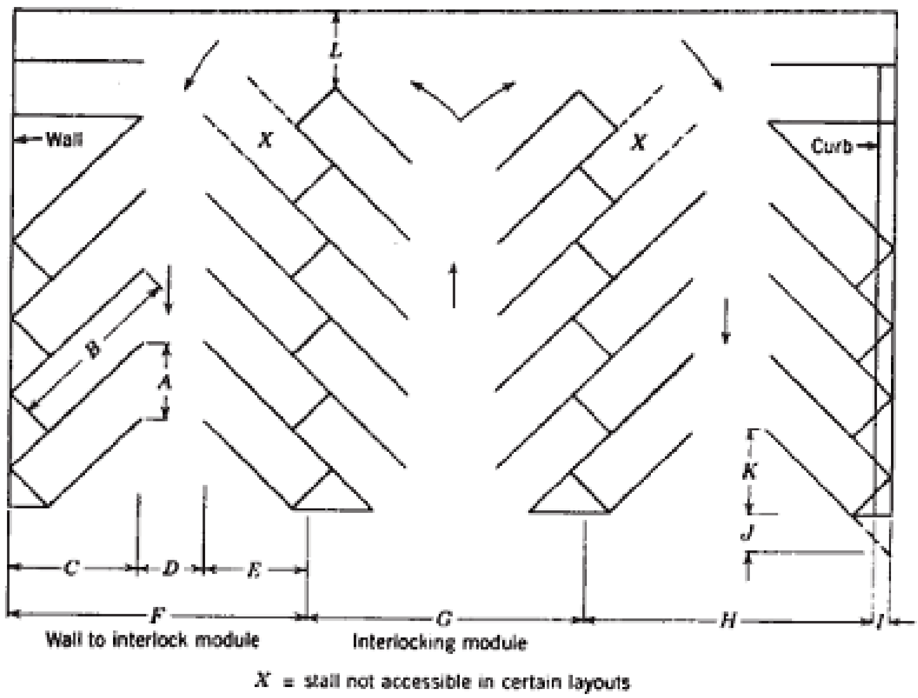

Figure 43. Typical parking layout (Asphalt Pavement Association of Indiana).

STALL LAYOUT ELEMENTS

Dimension	On diagram	45°	60°	75°	90°
Stall width parallel to aisle	A	12.7	10.4	9.3	9.0
Stall length of line	B	25.0	22.0	20.0	18.5
Stall depth to wall	C	17.5	19.0	19.5	18.5
Aisle width between stall lines	D	12.0	16.0	23.0	26.0
Stall depth, interlock	E	15.3	17.5	18.8	18.5
Module, wall to interlock	F	44.8	52.5	61.3	63.0
Module, interlocking	G	42.6	51.0	61.0	63.0
Module, interlock to curb face	H	42.8	50.2	58.8	60.5
Bumper overhang (typical)	I	2.0	2.3	2.5	2.5
Offset	J	6.3	2.7	0.5	0.0
Setback	K	11.0	8.3	5.0	0.0
Cross aisle, one-way	L	14.0	14.0	14.0	14.0
Cross aisle, two-way	M	24.0	24.0	24.0	24.0

Figure 44. Dimensions (feet) for a variety of parking angles (Asphalt Pavement Association of Indiana).

Linear park development

The source of green space in this area will be a linear park lining Sjællandsgade from the intersection of Tibirkegade to the intersection of Tagensvej. This park will extend out from existing green space by the one car lane detailed in this design. It will boast increased grassy areas along with providing a playground and outdoor exercise equipment to encourage use for families and adults. The important part of this project is to reach out to as many segments of the population in any design so that there is a good argument for development. As for the drainage of the area, it will follow the same designs as outlined in Tier III in the Dual-Use Park concept and the Swale concept sections. Areas for a grassy depression for rainwater collection during storms are in the proposed area for the dual-use park and in the two-block area described in Tier III. This would be a relatively low-impact and inexpensive construction, as it involves landscaping and not an underground holding tank as outlined in Tier I for the parking garage. Figure 45 depicts a vision for a possible set up for a Tier II solution.

Figure 45. Vision for a possible Tier II solution.

Other similarities to Tier I

There are many features in Tier I that should also be incorporated into a Tier II solution; this section will briefly list the features that should be implemented fully as described and justified for in Tier I. Biking is an essential part of the lifestyle of Copenhagen, and thus two-lane bike paths with semi-permeable pavement should be used in this solution. Rain gardens are an effective use of limited space and should also be encompassed within a Tier II solution, allowing for vegetation and some water collection. Unfortunately, with a limit on available green space in this solution, the concept of community gardens would have to be deferred to only a Tier I solution, although residents would be encouraged to plant in the beds provided by rain gardens. Biodiversity is still an important part for this proposed linear park solution, and the addition of trees and varied plants will help to both beautify the area and with rainwater absorption. Lastly, park benches and lighting are highly encouraged in the linear park for similar reasons described in Tier I, but in order to reduce costs, the lighting could be connected into the electrical grid should sustainable energy systems prove to be too expensive.

Resident impact of rainwater collection and use

As discussed in Tier I, Folehaven is our proposed model for the development of a residential rainwater catchment, storage, filter, and reuse system. The idea behind the implementation for Tier I is to have the entire street adopt this system through limited financial backing from the government and residential funds or loans. The goal of Tier II is to have approximately half of the residences adopt this approach with the option to expand the network in the future. The best candidate housing for implementing this approach are the private cooperation housing buildings along the street, as they would be able to withdraw a loan from the National Fund to help finance this development. As discovered in our focus group, one particular housing group in this category has described themselves as eco-activists. This would help with a grassroots movement to implementing this solution and maintaining it throughout the future. As for the power supply to operate this system, we recommend solar panels as used in Folehaven to help supplement the energy needs for pumps and washing machines. Should this prove too costly at first, the housing associations could connect into the grid until they raise sufficient capital to finance this system.

Tier III

The Tier III green corridor solution is the least intrusive on the existing roadway infrastructure, requiring the modification of two specific areas along the Sjællandsgade corridor. The first of these areas is the section of Sjællandsgade between waypoints 36 and 2 on the contour and surface plotting diagram. This area is already closed to any through traffic and is used sparingly for on-street parking. Renovating this section of Sjællandsgade would cause minimum car usage disruption and would not affect bike or pedestrian traffic, making green solution implementation as feasible as possible.

The second area of Tier III green solution implementation is the large field directly south of waypoint 5. The area is currently largely overgrown and fenced off from Sjællandsgade, serving little purpose. This area is property of the municipality, making green solution renovation in this area possible without further consultation or permission from alternative ownership sources. Installing sustainable green solutions in this area, such as a dual use park, also does not hinder vehicular or pedestrian mobility, as it will simply provide additional space for pedestrian activities.

Linear swale corridor

In the interest of optimizing the stormwater drainage of the waypoint 36 to 2 section of *Sjællandsgade*, the entirety of paved road and sidewalk surfaces should be removed. The removal of these surfaces will create a corridor of exposed topsoil 19.2 meters wide stretching the length of the section. Once the soil of this corridor is exposed, additional grading of the landscape can be conducted. On either side of the roadway there exists a series of storm drains. Though the current road surface will be removed, the drains and subterranean connections to the sewer system should be preserved. When the area is graded for use as a green corridor the locations of the storm drains should be relative low points, allowing excess storm water to naturally move towards the drains as opposed to pooling in the street. This grading should also be part of a larger scale swale that runs the length of the section along a natural winding path. To maximize the available area this corridor should be outfitted with a 100 meter drainage swale, featuring retention ponds connected to the swale at either end. The swale should be about 3 meters wide at surface level, with the retention ponds at each end reaching 8 meters in diameter and 4 meters in peak depth. Ideal swale depth for this area is 3 meters, with the swale rising to avoid subterranean infrastructure in specified areas. At these dimensions, the swale and retention pond system will be able to hold approximately 1700 cubic meters of water on its own: 34.2%, 18.3%, and 11.1% the amount of runoff that accumulates in Sjællandsgade during the 1-year, 10-year, and 100-year rainfall events respectively. The area should be re-graded to direct runoff flow to the swales and existing storm drains. This swale will serve multiple purposes in the green corridor. Primarily it will provide stormwater runoff from surrounding areas and direct precipitation in the area with a safe place to accumulate that will not threaten adjacent structures or roadways. Additionally, when dry the swale will appear as nothing more than a small grassy depression with natural rocks at the bottom, and when wet it will serve as a stream flowing gently through the green corridor.

Based on topographical information of the area, the northeast end of the swale will be the primary location of stormwater runoff inflow from surrounding areas. Because of this, a low-lying concrete weir wall should be installed at this end of the swale, allowing water to drain into the swale at a more controlled pace. In addition, the weir wall will assist in erosion prevention at the inflow channel to the swale, an important function during torrential rains. The weir wall should be constructed of steel-reinforced placed concrete, approximately 0.5 meters tall. The weir wall can also be incorporated into the surrounding landscape and could be mostly hidden by soil and earth. Tangent to the swale drainage system will be a pedestrian walkway and bike lane. To preserve the natural appearance of the green corridor, the walkway will weave gently along the corridor in a manner similar to that of the swale. In the large space of the existing intersection, the walkway will pass over the swale by means of a bridge. The bridge will add character to the green space and distinguish its scenic and aesthetic qualities, as well as facilitate the winding nature of the swale and pathway. The pathway will be divided to accommodate both foot traffic and two-lane bicycle traffic. Due to this accommodation, the pathway will be no less than 6 meters in width. In order to facilitate proper drainage and eliminate the presence of any non-permeable surfaces in the green corridor, the pathway will be constructed of a permeable recycled material such as Filterpave. The pathway should also be constructed at a very slight pitch towards the swale to ensure proper runoff drainage of any water that does not soak through the permeable pathway. On the side of the pathway nearest the swale a three-rail wooden fence should be erected to prevent pedestrians from entering the swale unnecessarily.

The surrounding areas of the green corridor not occupied by the swale or the pathway should be landscaped with grass, shrubberies, and trees. As with the other components of the green corridor, the landscaping should appear randomized to preserve the natural appearance of the area. The grassy areas can also be furnished with park benches to promote usage of this space. Trees must be of a species that does not exceed 8 to 10 meters in height to prevent intrusion on existing structures.

Dual-use park

To optimize the field area south of waypoint 5, a dual use park should be constructed. A dual use park is a park that serves an additional purpose besides providing green area for residential use. In this scenario, the park's secondary use is a runoff accumulation and drainage area. This is accomplished by grading this field to create a grass-lined depression in the terrain, useable as a park when dry and able to hold substantial amounts of water when necessary. Alternatively, the sloped sides of the depression also provide a location for children to sled safely during the winter months. This depression is relatively easy to construct, cost-effective, and environmentally friendly.

The terrain depression should be adjacent to the northernmost point of the field, extending outward to the south at a radius of approximately 35 meters. This configuration will create a depression that appears as about 40% of a circle, and using this radius will keep the depression and resulting construction away from the day care and medical facilities that are to the south of this field. At a 35 meter radius with a depth of 3 meters from street level, the depression will hold a maximum of about 4000 cubic meters of runoff and rainwater: 80.4%, 43.0%, and 26.1% of the runoff for a 1-year, 10-year, and 100-year rainfall event respectively. To improve drainage into this depression during precipitous events, underground piping leading from local storm drains to the depression should be placed. The pipes must be recessed in the side of the depression, with safety grates covering the opening to prevent debris or children from entering them.

The area immediately surrounding the depression should be outfitted with ample trees, shrubberies, and park benches for residents. The fence along Sjællandsgade removed at the onset of this renovation should be replaced with a three-rail wooden fence and suitable entryway to the park area. This fence should extend along all edges of the park adjacent to roadways, primarily to prevent children or animals from wandering into the path of vehicles and bikes. The existing playground north of the day care facility should be included in the area renovation and incorporated into the new park, however it must remain at street level or above to prevent flooding while in use by children. A vision of a possible set up for a Tier III solution is depicted in Figure 46.

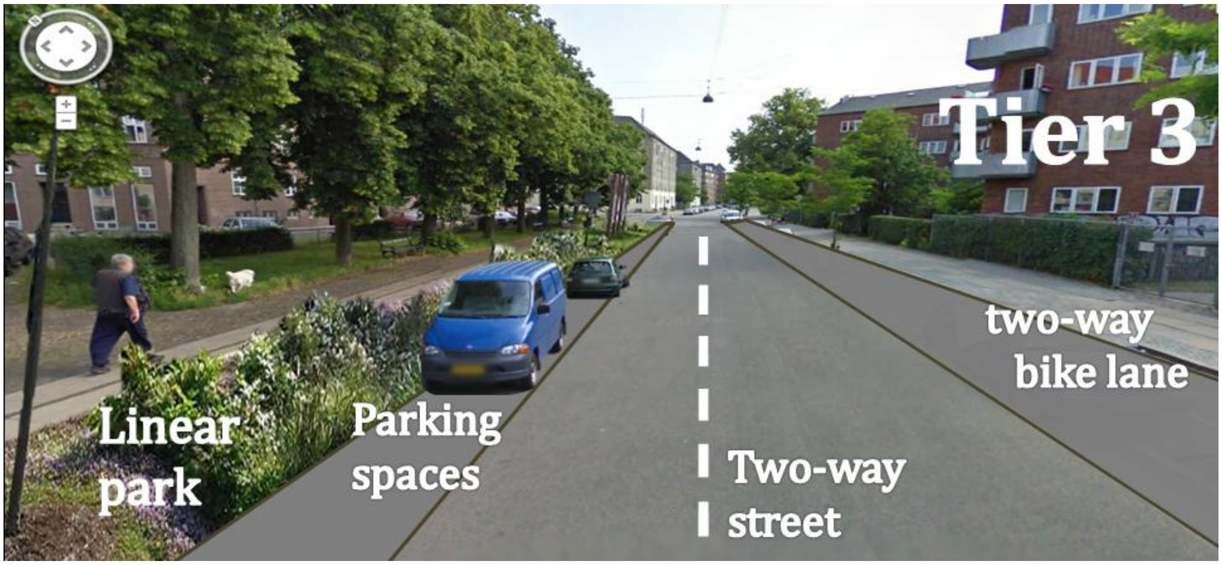

Figure 46. Vision for a possible Tier III solution.

6.2 Spreadsheet to calculate rainwater runoff

Our runoff estimate model calculates the maximum runoff coefficient and the total runoff values in Sjællandsgade. Figure 47 is a screenshot of the runoff estimate spreadsheet. As the model is an independent document, it includes instructions and some explanations of variables.

RUNOFF ESTIMATES FOR SJÆLLANDSGADE			
'Year'	Duration (hours)	Max Runoff Coeff. (m^3/s)	Total Runoff Value (m^3)
100	1	4.34	**15635.28**

The user can only edit the values for the duration of the storm in hours and the 'Year' category of rainfall events.
The maximum runoff coefficient refers to the speed at which water flows down an inclined surface. The different surface permeabilities in the Sjællandsgade area affect this value. However, the total runoff value is the volume of water that will flow into Sjællandsgade after a specific storm.

Figure 47. Runoff estimate spreadsheet.

The user can only edit the input parameters for ‘Year’ and ‘Duration (hours)’, cells B5 and C6, respectively, to model different types of storms. We hope Miljøpunkt Nørrebro will use the model’s calculations in their future designs for Sjællandsgade.

6.3 Rainwater catchment and non-potable reuse in Sjællandsgade

The use of recycled rainwater in association with non-potable household applications is an integral component of sustainable green solutions. Currently all residential toilets in the Sjællandsgade area are configured to use clean drinking water from the city, a setup that is highly inefficient and wastes millions of liters of drinking water per year. In the case of remedying the flash flooding and long term subterranean oversaturation issues characteristic of this area, the application of rainwater catchment and storage systems to residential buildings will supplement an estimated 83.68% of water usage in toilets. This figure was calculated through the analysis of a specific residential building on Sjællandsgade containing residential addresses 17 to 23, respectively. Factors such as roof area, average rainfall per year, population density, water closet efficiency, and rainwater catchment system efficiency were considered in this calculation.

The proposed catchment system will be installed as an offshoot of the existing roof gutter drainage system. The existing gutter drainage pipes will be redirected to run through a coarse screen filter just above ground. After this filter, the piping will continue underground where it will connect with a series of cisterns. The cisterns are a critical component of this system, and must be designed to handle the necessary inflow and outflow associated with this specific catchment system and residential building. The cisterns usually are located underground to prevent pipes and water pumps from freezing in winter months, but with proper insulation, they can be located above ground to lessen the cost of installation. A sensor located at the mouth of the cistern outflow to the building will indicate when the water level in the cistern is no longer sufficient for continued usage. At this point, the system will divert flow to water closets back through the existing city water system.

Additionally, the cistern will be equipped with an air vent and overflow channel. The air vent allows the air and water levels in the cistern to fluctuate seamlessly without significant pressure change in the cistern. The overflow channel facilitates the drainage of excess water out of the cistern and into the surrounding ground, functioning in an identical manner to the current gutter drainage system. Finally, the cistern will have an outflow pipe leading to a hydraulic pump which pumps water as necessary through the building's existing plumbing system to individual water closets. The pump design specifications will reflect the unique water needs of the building, but will be capable of pumping approximately 50 liters per minute (LPM). An example of such a cistern-filtration system, called a tri-cistern system, is modeled in Figure 48.

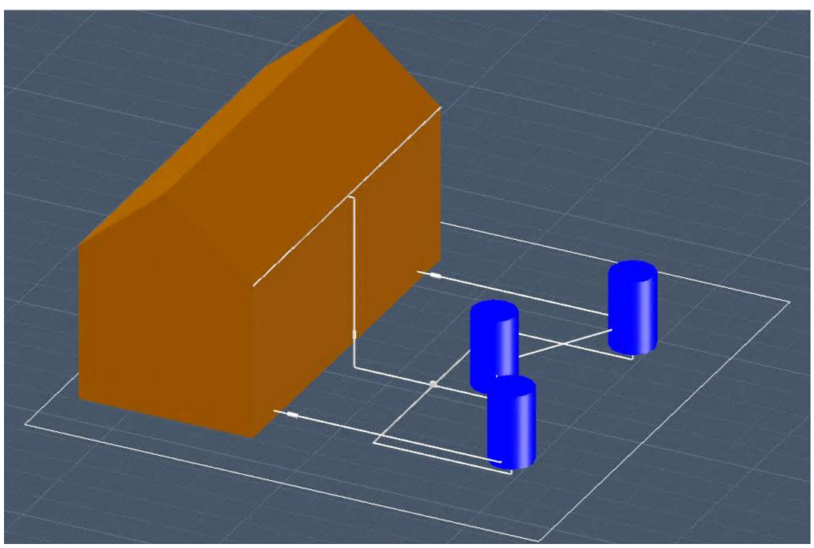

Figure 48. Tri-cistern system.

Although most cisterns corresponding to rainwater catchment and reuse systems are installed as part of the system, this area presents a unique opportunity to utilize an existing structure. Directly to the south of the example building lie three World War II-era fallout shelters. Very little specific information exists about these structures; however, it is known that they may contain up to two cylindrical chambers of significant volume totaling in the hundreds of thousands of liters. If government permission for examination is granted, these shelters could be utilized as cisterns for this particular location, negating the need for a cistern or cisterns to be installed separately.

The efficiency of the proposed rainwater catchment system will allow for the system to save the city of Copenhagen, and by extension the residents of the example building, approximately DKK 13,223.71 annually. Considering preliminary installation estimates in the range of roughly DKK 245,000, the rainwater catchment and reuse system for this building will pay itself off in 18 years and 6 months of usage. After this point, the system will be operating for profit, an attribute which makes the installation of such a system even more attractive.

The environmental and societal benefits of this system are extensive. The application of this system to the example building alone will save the city of Copenhagen over 1,466,000 liters of drinking water per year, and millions more if applied on multiple buildings along the street. Additionally, the rainwater catchment system will prevent this volume of water from reaching the ground and contributing to flooding and subterranean oversaturation. By saving millions of gallons of drinking water and significantly reducing the contribution of rainwater to local flooding, the proposed rainwater catchment and non-potable reuse system will significantly lessen the environmental footprint left by the Sjællandsgade area. The calculations for all of the numbers reported in this section can be found in Appendix E: Non-potable water reuse calculations.

6.4 Technical manual as a climate change adaptation guideline

As mentioned in our introduction, one of the primary deliverables of this project is a technical manual for floodwater mitigation and climate change adaptation. This manual details the ways in which other neighborhoods can come up with their own arguments for the integration of sustainable climate change adaptation plans and designs for floodwater management systems in their communities. We produced the manual by outlining the ideology and process methodology we applied to the Sjællandsgade climate change adaptation. The manual is structured in such a way as to allow an interested party with little prerequisite qualification to effectively replicate the results of our report. This can be applied to any neighborhood or target area, facilitating the development of sustainable climate change adaptation solutions on a large scale. The complete technical manual can be found in Appendix J: Technical Manual for Climate Change Adaptation.

7 Future Work

Despite the thorough nature of our work, it is important to consider the implications of continuing the research and the development of sustainable climate change adaptation solutions both in Sjællandsgade and in other urban areas. Limitations such as time and resources contributed to the finite nature of our project; however, with the expansion of these parameters our findings can be parlayed into even more influential conclusions. The following are our recommendations for the continuation of our research and project deliverables.

7.1 Flow expansion

In order to determine the most accurate runoff for the Sjællandsgade area, more advanced techniques are needed to determine the runoff coefficients and total rainfall runoff. In order to verify these results, an official geographical survey should be checked against the raw data obtained through the Google Maps script. This will solidify these basic results to continue the calculations for the surface plot.

There are two different methods we propose, depending on the resources available. The first method would be to verify all results carried out by our group and determine if there are any turbulent effects that will affect the velocity addition along each pathway. The second method we suggest is using a computational program for hydrogeology that can accurately predict the time of concentration (T_c) and increase the resolution by which the weighted runoff coefficient was calculated. By using a professional program, engineers may be able to determine when channel flow is likely to occur and continue the refinement of the time of concentration calculation so that accurate runoff data can be developed for all storms.

Additionally, these changes should also be incorporated in the spreadsheet's calculations. By updating the embedded formulas, the runoff volume estimates the model predicts would be more accurate.

7.2 Using the technical manual to start climate change adaptation in other areas

Although the technical manual (Appendix J: Technical Manual for Climate Change Adaptation) is a comprehensive and relatively detailed guideline for climate change adaptation implementation, there are numerous avenues to further its development as a standalone deliverable. The physical manual can be improved, transitioning from a simple word document to a website or other interactive presentation medium. Allowing interested parties to explore the various aspects of the manual through such a medium will allow for a more complete understanding of the presented material as well as enhance the user experience. A website or interactive presentation medium will also allow for the inclusion of significantly greater quantities of information and digital media, a component which will appeal to a broad audience, and can be used as an educational tool for community members and students alike.

Additionally, the content of the manual can be amended. The manual offers general solutions that are designed to be applicable in as many scenarios as possible. In its current state, it is the responsibility of the reader to adapt the general solutions offered in the manual to a specific neighborhood or area. However, with the proper equipment and time it would be possible to develop far more specific solutions, each with various criteria for application. The solutions could include hard data, approximate measurements, and estimates for such values as floodwater retention volume and percentage runoff for a given area. At this stage, this technical manual would more closely embody the degree of specification and detail exhibited in this report. Combined with an interactive digital presentation medium, the technical manual for climate change adaptation could become an even more useful and dynamic tool for promoting, designing, and implementing sustainable climate change adaptation solutions in cities around the world.

Appendix A: Initiatives and leadership groups for climate change

1 Partnership for European Environmental Research

European climate change adaptation can be accurately characterized by geographical location. With each country comes a unique collection of problems, and thus exists the necessity for a site-specific sustainable solution package. The development of these specialized solutions in the European region is facilitated by PEER (Partnership for European Environmental Research), an organization dedicated to promoting the inception, development, and implementation of climate change adaptation initiatives. PEER functions as “a network of seven European environmental research centers, covering the full spectrum of natural and social environmental sciences and combining basic, strategic, and applied interdisciplinary research and society.” (Swart, 2009). With the data and guidance provided by PEER, both governments and private organizations are able to invoke change in their respective countries with respect to climate adaptation and environmental planning. Nations are categorized based on the progression of their national adaptation strategy to help identify nations that require more assistance. To ensure that this assistance is of the utmost effectiveness, national adaptation strategies are subdivided into six themes: drivers of adaptation policies, science-policy interactions, increasing communication and raising awareness for adaptation, multilevel governance, policy integration, and review and implementation of national adaptation strategies. By evaluating a given country in each of these six subsections, the state of a nation’s adaptation strategy can be accurately evaluated. Once it is evaluated, an appropriate plan of action can be drafted and implemented to ensure the progression of the country towards the use of modern climate change adaptation initiatives.

2 Miljøpunkt Nørrebro

Miljøpunkt Nørrebro is a local Agenda 21 chapter that concerns itself with environmental problems in the Nørrebro community of Copenhagen. This organization relies on feedback and suggestions given from the community in order to direct their focus for solving such problems as lack of urban green space, waste volume and recycling issues, and vehicular traffic (Mr. Larsen, personal communication, January 25, 2013).

History

Miljøpunkt Nørrebro, formerly known simply as Agenda 21, is a local Agenda 21 chapter of the Nørrebro neighborhood of Copenhagen. Agenda 21 was created at the 1992 United Nations Conference on Environment and Development (UNCED) as means of international participation in environmental sustainability (ICLEI, 20002). This initiative was unlike others before it, such as the Kyoto Protocol, in that there were no established goals or deadlines for the countries to meet. Local Agenda 21 were intended as a way for countries and communities to organize, prioritize, and carry out their own solutions to environmental issues relevant to the area (ICLEI, 2002).

Nørrebro's chapter of Agenda 21 has been active since its induction, maintaining a strong flow of communication with the members of the community. The chapter has historically been involved in waste management, development of green spaces within the neighborhood, and reduction of traffic and emissions (Miljøpunkt Nørrebro, 2010). Nørrebro's chapter recently changed its name from Agenda 21 to Miljøpunkt Nørrebro, but the organization participates in the same kind of environmental and community projects (Mr. Larsen, personal communication, January 25, 2013).

Mission

Miljøpunkt Nørrebro's overall goal is to promote conservation and sustainability localized to the Nørrebro community of Copenhagen (ICLEI, 2002). Above all, the organization seeks to allow the residents of the community it serves more opportunities to be environmentally friendly and aware, and, in the end, to achieve a better quality of life for the people of Nørrebro (Grøn, n.d.). This is accomplished in three ways: supporting and developing local environmental projects, maintaining a community-wide conversation on what issues are priorities, and by effectively visualizing and communicating end-goals (Miljøpunkt Nørrebro, 2010).

Miljøpunkt Nørrebro focuses specifically on reducing pollution and waste, as well as creating more public green space as an environmentally friendly way to beautify the neighborhood. The organization also concerns itself in more broad issues, such as reducing greenhouse gas emissions and combatting climate change (Miljøpunkt Nørrebro, 2010).

Appendix B: Interview with Mr. Ove Larsen

January 25, 2013

Group: We would like to know more about you. We have done some reading on your current and old websites, and the newspapers to learn more about Miljøpunkt Nørrebro. However, we were hoping you could tell us more about you, the people working there.

1. How long have you worked for Miljøpunkt?

Mr. Larsen: I have been part of Miljøpunkt Nørrebro for 3-4 years as project manager on "Greener Nørrebro". I'm an economist as training but have been working on research/project management on TV production before.

2. How did Miljøpunkt get involved in this project?

Mr. Larsen: Miljøpunkt Nørrebro works bottom-up. We try to understand what active people living in Nørrebro want for there [sic] part of the city. We listen to citizens. Nørrebro is the most densely populated part of the city. The population of 75,000 people in an area of less than 4 square kilometers. (Around 22,000 per. square kilometers) [sic]. All studies show that residents in Nørrebro want a greener Nørrebro. A citizen of the whole Copenhagen area have [sic] access to 42 square meter open/public green space. The same figure for Nørrebro is 6 square meters.

3. What other projects are you working on?

Mr. Larsen: Miljøpunkt Nørrebro is working for a sustainable future for citizen of Nørrebro and Miljøpunkt Nørrebro has 3 main focus areas.

1. Greener Nørrebro,
2. More recycling to reduce waste volumes
3. Traffic. Reduction of private car passage through Nørrebro through improved public transport.

- But solutions to the area's challenges can only be achieved through coordinated effort across traditional bureaucratic segregated areas. What we call co-thinking. Copenhagen Municipality is a traditional centralized organization with strong boundaries between departments and areas. Miljøpunkt Nørrebro work as activist/pressure group to influence current and future decisions for our part of the city, through coordinated effort across these bureaucratic boundaries.

- Right now I'm working on implementing a new waste concept “Smart Environmental Station Wesselsgade”. (A project WPI group from 2 years ago participated in). My part of it is resident involvement.
- But my main focus is climate change and its consequences for dense populated urban areas. Climate change is very complex and therefore it is for me an exciting topic to find solutions for. WPI group from last year was working on a project which involved a lot of different topics. More green areas, traffic reduction and flooding and rain water solution. (It was a very specific [sic] project for traffic solutions but part of the project was about greening of the area).The project now has a website www.ladegårdsåen.dk for the campaign to change the priorities and decisions of Copenhagen Municipality.)
(The city of Stuttgart in Germany had to look into green corridors many years ago – try google “green corridor case studies Stuttgart”)

Group: We have learned that Copenhagen has constructed in green corridor projects in the past as keeping with the agenda of a CO_2 –neutral city by 2025.

1. Could you describe the other organizations involved in the project and help us better understand their perspectives? Where are areas of agreement and where are there more differences of opinion?
Mr. Larsen: Copenhagen Municipality is implementing a project in Skt. Kjeld neighborhood in Østerbro. The project has basically a social perspective, but as a neighborhood renewal project since the area has been neglected and has quite a few social problems. Here, as in other parts of Scandinavia climate change adaptation are included as part of overall plans for urban areas. Link (in Danish) to the project: http://www.klimakvarter.dk/ - Copenhagen Municipality: http://www.kk.dk/da/borger/byggeri/byfornyelse/omraadefornyelser/skt-kjelds-kvarter

2. How are trade-offs identified and evaluated?
Mr. Larsen: It is a relatively complex issue. If it is a socially based project as Skt. Kjeld neighborhood, there is used various social indicators, both for decision, implementation and evaluation. But for Sjællandsgade it is an overall assessment, based on an analysis of the immediate problems, such as torrential rain. Large parts of Copenhagen are a very old city and at

the same time torrential rain a very new phenomenon here. So the city is struggling to find the right priorities based on the damage happened on 2 July 2011.

3. How are decisions made?

Mr. Larsen: It is a much more complex issue involving politics, pressure from pressure groups such as the Miljøpunkt Nørrebro and financial opportunities, or climatic challenges. On the one hand there is the financial crisis, but on the other hand there is a massive urbanization here in Copenhagen that creates new challenges but also new opportunities.

4. What past studies have been done on the Sjællandsgade project?

Mr. Larsen: Before the financial crisis was "Green Corridor Sjællandsgade" a dream project for the City of Copenhagen's Department of Parks and Nature. After the financial crisis, it was forgotten and the funds allocated for processed for the project was moved to the project in Skt. Kjeld neighborhood. The project initially focused only on a green corridor for the promotion of biodiversity and lacked all the other aspects of the problem.

Group: We'd also like to understand your standpoint with respect to this project. There are several aspects that all affect Sjællandsgade, and as such, there must be priorities or pressing matters.

1. On what problems do you want to focus more?

Mr. Larsen: The biggest problem is the amount of torrential rain water coming from Nørre Campus, scientific part of the University of Copenhagen that is located north of Sjællandsgade. The area is increasing greatly but I am uncertain about how much they have torrential rain in the planning. Copenhagen Municipality is about to approve a plan for torrential rain, but the expansion of the University of Copenhagen takes place in cooperation between the government responsible for the university and the Copenhagen Municipality.
But at the same time it is important to involve the other challenges we have. With the expansion of Nørre Campus, the number of cyclists grows and right now they need to move among other traffic groups. Therefore, it is important to work and come up with sustainable alternatives and incorporate this into other plans. Here Sjællandsgade is an option.

2. What is the one you would consider to be a less pressing matter?

Mr. Larsen: When you get here in Denmark it is important that we sit down and look at what is important for your studies and how we can structure the project. Right now it is not possible for me to say what is important to you, but our experience of working with WPI is that it is possible to make good constructive projects that give you the good grades and gives us the basis for further work on projects.

Group: As you mention in the project description, torrential rainfall has been a recent problem affecting Nørrebro.

1. Could you describe the scope of the flooding in the area?

Mr. Larsen: http://da.wikipedia.org/wiki/Skybruddet_den_2._juli_2011

In August 2010, the Copenhagen the first harbinger of climate change with a flood of one of the gateways to the city [sic]. All dismissed it as an isolated incident. Second July 2011 the town was about 150 mm. Rain of about 1 hour. Copenhagen has never experienced anything of this size and damage is estimated at between 5 and 7 billion Danish kroner. Now it is on the national agenda and Copenhagen Municipality is about to get approved a comprehensive plan for solutions, but Nørrebro is not a high priority in the plan and the work we're getting changed. Topographically, the Nørrebro a hill with a fall of 10 meters at a distance of 1 ½ kilometer [sic]. This means that there is much water from torrential rain to be passed through a very old infrastructure is not built for it.

http://green-norrebro.blogspot.dk/2011/07/efter-skybruddet.html

2. Has the flooding affected both streets and the homes in the area?

Mr. Larsen: The damage affected primarily basements in houses and institutions that are not constructed for flooding. Hospitals were close to having to evacuate by helicopter, companies got ruined, a server room that was located in the basements and shops had destroyed items in stock mainly in basements. The water was high in the streets and flowed into the lowest parts and flooded buildings.

3. Where does the area sit in relation to the water table?

Mr. Larsen: The highest point is the intersection Tagensvej/Jagtvej which is 17.5 meters above sea level and the low areas all around Nørrebro is about 7.5 meters above sea level.

Group: Each project has it difficulties in planning and implementation.

1. What have been the unforeseen challenges for your organization in developing plans for blue-green solutions in the past?

Mr. Larsen: There are not many experiences from previous projects that are particularly useful. Torrential rain on 2 July 2011 is a game changer. Copenhagen municipality has not previously realized that it would be a problem and therefore there is no existing plan or priorities. Ministry of Environment has just released guidelines planning for cities. Miljøpunkt Nørrebro is working in an incredibly fluid political and administrative area that is constantly changing in relation to changes in priorities

2. What are the complexities in planning or implementing this project? Do you have any recommendations or strategies with regards to avoiding them?

Mr. Larsen: No. but perhaps it is important to keep the focus on how it is possible to implement green/ blue solutions in a very dense urban area, to function in everyday life for people who have their everyday lives.

In May 2011, before the torrential rain in July 2011 we were in dialogue with a number of property owners in Sjællandsgade where we talked to them about local recycling of rainwater (LAR) and we did a sketch project on how a possible future appearance of Sjællandsgade where we decoupled rainwater from the public sewerage and recycled it to green/blue solutions with focus on biodiversity.

We drew some sketches for a vision for Sjællandsgade without cars and with the involvement of many different elements.

http://green-norrebro.blogspot.dk/ - http://green-norrebro.blogspot.dk/2011/05/vision-skitser.html

Group: This project is a very open-ended with a lot of details that can be focused on. Because of this, many different ideas and solutions, both simple and complex, can be proposed.

1. We'd like to know what level of funding is available for the project.

Mr. Larsen: As I have tried to describe in my answer Miljøpunkt Nørrebro works as a pressure group for the residents of Nørrebro to ensure sustainable development for the residents of Nørrebro. We work on long-term projects, but are not utopians. Around the torrential rain, the challenges are very clear and the solutions necessary, but most traditional institutions working for solutions as they have done before and it's often not sustainable solutions, therefore there is a need for citizens' perspective and that is what we are working on constructively with the planners [sic].

As we have seen with Smart Environmental Station Wesselsgade, as the WPI Group was part of the 2 years ago, we work to achieve solutions and improvements for residents in Nørrebro, but from a citizen's perspective. And Smart Environmental Station Wesselsgade is beeing implemented [sic] right now, funded as a pilot project from Copenhagen Municipality, department of City Design.

And it is in this perspective that the project Sjællandsgade be seen. Just as with the project that the WPI work with last year, is helping to change opinion [sic] based on the best knowledge there is to find and based on the available facts. And the more our projects are based on facts the better chance there is for a policy change.

2. Also, what timeframe are we looking at with this project?

Mr. Larsen: Hard to say, there is much focus on climate change and torrential rain right now, so it's important to be an active part of the debate both in Nørrebro and the entire society. But active with knowledge and facts as best it possible when we talk solutions to climate change.

Group: That would answer all the questions we have at the moment. This is all important information for us to continue our research.

1. This is all very new for us. What question should we have asked you that we didn't ask?

Mr. Larsen: Climate change is new to everyone and it is important for us to think in long-term sustainable levels. Denmark is working with many viable alternatives to traditional technologies, so there is a societal understanding to work on further development of sustainable solutions. Therefore, it is exciting to work with environmental solutions.

Group: Thank you for your time Mr. Larsen. We're very excited to travel to Copenhagen and work on site for the project. I'm sure we'll be in correspondence before then to go over a few things in our proposal with you.

Mr. Larsen: You can stop calling me Mr. Larsen, please [sic]. In Denmark we are very informal and people who work closely use each other's first names. So it's fine to use my first name. In Denmark, people think the use the last name is too formal. (written with a smile)

Group: Thank you!

Appendix C: Contour map codes and raw data

1 Raw data for Google Maps script collection

Table 10. Way point data for the contour map.

Waypoint	Lat	Long	Altitude(m)	Lat rel WP18	Long rel WP18	Altitude rel to WP18
1	55.6943786	12.55417049	11.412	0.000597131	0.001064837	0.361
2	55.694882	12.55517095	11.576	0.001100528	0.002065301	0.525
3	55.69536271	12.55619556	11.842	0.001581243	0.003089905	0.791
4	55.69608227	12.55805165	12.337	0.002300793	0.004945993	1.286
5	55.69667785	12.56004184	12.843	0.002896377	0.006936193	1.792
6	55.69646471	12.56157875	12.932	0.002683238	0.008473098	1.881
7	55.69705575	12.5588268	13.08	0.003274281	0.005721152	2.029
8	55.69664157	12.55750716	12.87	0.002860098	0.004401505	1.819
9	55.69610192	12.55602121	12.572	0.002320445	0.002915561	1.521
10	55.69585854	12.55478472	12.306	0.002077069	0.001679063	1.255
11	55.69564237	12.55332023	12.189	0.001860902	0.000214577	1.138
12	55.69556377	12.55255312	11.796	0.001782295	-0.000552535	0.745
13	55.69552598	12.55158484	11.619	0.001744503	-0.001520813	0.568
14	55.69498328	12.55186111	11.368	0.001201811	-0.001244545	0.317
15	55.69505131	12.55266577	11.278	0.001269837	-0.000439882	0.227
16	55.69472176	12.55201936	11.262	0.000940288	-0.001086295	0.211
17	55.69487293	12.55274624	11.316	0.001091458	-0.000359416	0.265
18	55.69378147	12.55310565	11.051	0	0	0
19	55.69749865	12.55772442	13.515	0.00371718	0.004618764	2.464
20	55.69731273	12.5568822	13.614	0.003531254	0.00377655	2.563
21	55.69716005	12.55579323	13.734	0.003378582	0.002687573	2.683
22	55.69718424	12.55452722	13.534	0.003402768	0.001421571	2.483
23	55.69666424	12.55443603	13.104	0.002882773	0.001330376	2.053
24	55.69834362	12.55555451	14.242	0.00456215	0.002448857	3.191
25	55.6986157	12.55492419	14.703	0.00483423	0.001818538	3.652
26	55.69778888	12.55398273	14.035	0.004007404	0.000877082	2.984
27	55.69737772	12.55345702	13.615	0.003596252	0.000351369	2.564
28	55.69666576	12.55319953	13.074	0.002884284	9.38773E-05	2.023
29	55.69916137	12.55431533	15.54	0.005379895	0.001209676	4.489
30	55.69837537	12.55341947	14.497	0.004593893	0.000313818	3.446
31	55.69765586	12.55256653	13.688	0.003874385	-0.000539124	2.637
32	55.69667634	12.55149096	12.776	0.002894866	-0.00161469	1.725
33	55.69791736	12.55699754	13.773	0.004135889	0.003891885	2.722
34	55.69831339	12.55749106	13.364	0.004531919	0.004385412	2.313
35	55.69894824	12.55824208	13.381	0.005166769	0.00513643	2.33
36	55.69415940	12.55367160	11.091	0.00037793	0.00092536	0.04

2 Surface plot from raw data Matlab code

```
%Load the Data

XData1 = [0.000597131 0.001100528 0.001581243 0.002300793...
       0.002896377 0.002683238 0.003274281 0.002860098 0.002320445...
       0.002077069 0.001860902 0.001782295 0.001744503 0.001201811...
       0.001269837 0.000940288 0.001091458 0 0.00371718 0.003531254...
       0.003378582 0.003402768 0.002882773 0.00456215 0.00483423...
       0.004007404 0.003596252 0.002884284 0.005379895 0.004593893...
       0.003874385 0.002894866 0.004135889 0.004531919 0.005166769 0.00037793];

YData1 = [0.001064837 0.002065301 0.003089905 0.004945993...
       0.006936193 0.008473098 0.005721152 0.004401505...
       0.002915561 0.001679063 0.000214577 -0.000552535...
       -0.001520813 -0.001244545 -0.000439882 -0.001086295...
       -0.000359416 0 0.004618764 0.00377655 0.002687573...
       0.001421571 0.001330376 0.002448857 0.001818538 0.000877082...
       0.000351369 9.38773E-05 0.001209676 0.000313818 -0.000539124...
       -0.00161469 0.003891885 0.004385412 0.00513643 0.00092536];

ZData1 = [0.361 0.525 0.791 1.286 1.792 1.881 2.029 1.819 1.521...
       1.255 1.138 0.745 0.568 0.317 0.227 0.211 0.265 0 2.464...
       2.563 2.683 2.483 2.053 3.191 3.652 2.984 2.564 2.023 4.489...
       3.446 2.637 1.725 2.722 2.313 2.33 0.04];
```

```
%Dealunay Triangulation

tri = delaunay(YData1,XData1);
[r,c] = size(tri);
disp(r)
```

```
%Refine
figure1 = figure;

% Create axes
axes1 = axes('Parent',figure1,'PlotBoxAspectRatio',[1 1 1],...
    'DataAspectRatio',[1 2.5 833.333333333333],...
    'CameraViewAngle',71.7943799426947,...
    'CameraUpVector',[0.272811141553108 -0.793518585288425 756.833040543871],...
    'CameraTarget',[-0.00191384051583519 -0.00608265029697682 2.13505151237784],...
    'CameraPosition',[0.0023194147932452 -0.0183958085679423 -0.359071894707431]);
grid(axes1,'on');
```

```
%Trisurf
h = trisurf(tri, YData1, XData1, ZData1)

shading interp
```

```
colorbar EastOutside



% Create light
light('Parent',axes1,...
    'Position',[49.9999999999995 14.9999999999999 28.9999999999997]);
```

```
%Annotations

% Create xlabel
xlabel('Latitude (degrees rel to WP18)');

% Create ylabel
ylabel('Longitude (degrees rel to WP18)');

% Create zlabel
zlabel('Altitude (meters rel to WP18)');

% Create colorbar
colorbar('peer',axes1);
```

```
%Plotted Points

P18=[0 0 0]; P1= [0.000597131 0.001064837 0.361];

P2= [.001100528 .002065301 .525]; P3= [.001581243 .003089905 .791];

P4= [.002300793 .004945993 1.286]; P5= [.002896377 .006936193 1.792];

P6 = [0.002683238 0.008473098 1.881]; P7 = [0.003274281 0.005721152 2.029];

P8 = [0.002860098 0.004401505 1.819]; P9 = [0.002320445 0.002915561 1.521];

P10 = [0.002077069 0.001679063 1.255]; P11 = [0.001860902 0.000214577 1.138];

P12 = [0.001782295 -0.000552535 0.745]; P13 = [0.001744503 -0.001520813 0.568];

P14 = [0.001201811 -0.001244545 0.317]; P15 = [0.001269837 -0.000439882 0.227];

P16 = [0.000940288 -0.001086295 0.211]; P17 = [0.001091458 -0.000359416 0.265];

P19 = [0.00371718 0.004618764 2.464]; P20 = [0.003531254 0.00377655 2.563];

P21 = [0.003378582 0.002687573 2.683]; P22 = [0.003402768 0.001421571 2.483];

P23 = [0.002882773 0.001330376 2.053]; P24 = [0.00456215 0.002448857 3.191];

P25 = [0.00483423 0.001818538 3.652]; P26 = [0.004007404 0.000877082 2.984];

P27 = [0.003596252 0.000351369 2.564]; P28 = [0.002884284 9.38773E-05 2.023];
```

```
P29 = [0.005379895 0.001209676 4.489]; P30 = [0.004593893 0.000313818 3.446];

P31 = [0.003874385 -0.000539124 2.637]; P32 = [0.002894866 -0.00161469 1.725];

P33 = [0.004135889 0.003891885 2.722]; P34 = [0.004531919 0.004385412 2.313];

P35 = [0.005166769 0.00513643 2.33]; P36 = [0.00037793 0.00092536 0.04];
```

```
%Line Segments

X=[P18(1) P1(1)]; Y=[P18(2) P1(2)]; Z=[P18(3) P1(3)];

X1=[P1(1) P2(1)]; Y1=[P1(2) P2(2)]; Z1=[P1(3) P2(3)];

X2=[P2(1) P3(1)]; Y2=[P2(2) P3(2)]; Z2=[P2(3) P3(3)];

X3=[P3(1) P4(1)]; Y3=[P3(2) P4(2)]; Z3=[P3(3) P4(3)];

X4=[P4(1) P5(1)]; Y4=[P4(2) P5(2)]; Z4=[P4(3) P5(3)];

X5=[P5(1) P6(1)]; Y5=[P5(2) P6(2)]; Z5=[P5(3) P6(3)];

X6=[P6(1) P7(1)]; Y6=[P6(2) P7(2)]; Z6=[P6(3) P7(3)];

X7=[P7(1) P8(1)]; Y7=[P7(2) P8(2)]; Z7=[P7(3) P8(3)];

X8=[P8(1) P9(1)]; Y8=[P8(2) P9(2)]; Z8=[P8(3) P9(3)];

X9=[P9(1) P10(1)]; Y9=[P9(2) P10(2)]; Z9=[P9(3) P10(3)];

X10=[P10(1) P11(1)]; Y10=[P10(2) P11(2)]; Z10=[P10(3) P11(3)];

X11=[P11(1) P12(1)]; Y11=[P11(2) P12(2)]; Z11=[P11(3) P12(3)];

X12=[P12(1) P13(1)]; Y12=[P12(2) P13(2)]; Z12=[P12(3) P13(3)];

X13=[P13(1) P14(1)]; Y13=[P13(2) P14(2)]; Z13=[P13(3) P14(3)];

X14=[P14(1) P15(1)]; Y14=[P14(2) P15(2)]; Z14=[P14(3) P15(3)];

X15=[P15(1) P17(1)]; Y15=[P15(2) P17(2)]; Z15=[P15(3) P17(3)];

X16=[P16(1) P17(1)]; Y16=[P16(2) P17(2)]; Z16=[P16(3) P17(3)];

X18=[P18(1) P16(1)]; Y18=[P18(2) P16(2)]; Z18=[P18(3) P16(3)];

X19=[P19(1) P20(1)]; Y19=[P19(2) P20(2)]; Z19=[P19(3) P20(3)];

X20=[P20(1) P21(1)]; Y20=[P20(2) P21(2)]; Z20=[P20(3) P21(3)];

X21=[P21(1) P22(1)]; Y21=[P21(2) P22(2)]; Z21=[P21(3) P22(3)];
```

```
X22=[P22(1) P23(1)]; Y22=[P22(2) P23(2)]; Z22=[P22(3) P23(3)];

X23=[P23(1) P10(1)]; Y23=[P23(2) P10(2)]; Z23=[P23(3) P10(3)];

X24=[P24(1) P25(1)]; Y24=[P24(2) P25(2)]; Z24=[P24(3) P25(3)];

X25=[P25(1) P26(1)]; Y25=[P25(2) P26(2)]; Z25=[P25(3) P26(3)];

X26=[P26(1) P27(1)]; Y26=[P26(2) P27(2)]; Z26=[P26(3) P27(3)];

X27=[P27(1) P28(1)]; Y27=[P27(2) P28(2)]; Z27=[P27(3) P28(3)];

X28=[P28(1) P11(1)]; Y28=[P28(2) P11(2)]; Z28=[P28(3) P11(3)];

X29=[P29(1) P30(1)]; Y29=[P29(2) P30(2)]; Z29=[P29(3) P30(3)];

X30=[P30(1) P31(1)]; Y30=[P30(2) P31(2)]; Z30=[P30(3) P31(3)];

X31=[P31(1) P32(1)]; Y31=[P31(2) P32(2)]; Z31=[P31(3) P32(3)];

X33=[P33(1) P34(1)]; Y33=[P33(2) P34(2)]; Z33=[P33(3) P34(3)];

X34=[P34(1) P35(1)]; Y34=[P34(2) P35(2)]; Z34=[P34(3) P35(3)];

X36 =[P17(1) P36(1)]; Y36=[P17(2) P36(2)]; Z36=[P17(3) P36(3)];
```

```
%Special Connections

X75=[P7(1) P5(1)]; Y75=[P7(2) P5(2)]; Z75=[P7(3) P5(3)];

X197=[P19(1) P7(1)]; Y197=[P19(2) P7(2)]; Z197=[P19(3) P7(3)];

X1215=[P12(1) P15(1)]; Y1215=[P12(2) P15(2)]; Z1215=[P12(3) P15(3)];

X1416=[P14(1) P16(1)]; Y1416=[P14(2) P16(2)]; Z1416=[P14(3) P16(3)];

X3319=[P33(1) P19(1)]; Y3319=[P33(2) P19(2)]; Z3319=[P33(3) P19(3)];

X2433=[P24(1) P33(1)]; Y2433=[P24(2) P33(2)]; Z2433=[P24(3) P33(3)];

X2925=[P29(1) P25(1)]; Y2925=[P29(2) P25(2)]; Z2925=[P29(3) P25(3)];

X2722=[P27(1) P22(1)]; Y2722=[P27(2) P22(2)]; Z2722=[P27(3) P22(3)];

X2622=[P26(1) P22(1)]; Y2622=[P26(2) P22(2)]; Z2622=[P26(3) P22(3)];

X2823=[P28(1) P23(1)]; Y2823=[P28(2) P23(2)]; Z2823=[P28(3) P23(3)];

X208=[P20(1) P8(1)]; Y208=[P20(2) P8(2)]; Z208=[P20(3) P8(3)];

X84=[P8(1) P4(1)]; Y84=[P8(2) P4(2)]; Z84=[P8(3) P4(3)];
```

```
X219=[P21(1) P9(1)]; Y219=[P21(2) P9(2)]; Z219=[P21(3) P9(3)];

X2421=[P24(1) P21(1)]; Y2421=[P24(2) P21(2)]; Z2421=[P24(3) P21(3)];

X93=[P9(1) P3(1)]; Y93=[P9(2) P3(2)]; Z93=[P9(3) P3(3)];

X102=[P10(1) P2(1)]; Y102=[P10(2) P2(2)]; Z102=[P10(3) P2(3)];

X111=[P11(1) P1(1)]; Y111=[P11(2) P1(2)]; Z111=[P11(3) P1(3)];

X3127=[P31(1) P27(1)]; Y3127=[P31(2) P27(2)]; Z3127=[P31(3) P27(3)];

X3213=[P32(1) P13(1)]; Y3213=[P32(2) P13(2)]; Z3213=[P32(3) P13(3)]; %generalized

X361=[P36(1) P1(1)]; Y361=[P36(2) P1(2)]; Z361=[P36(3) P1(3)];

X3618=[P36(1) P18(1)]; Y3618=[P36(2) P18(2)]; Z3618=[P36(3) P18(3)];

hold on

%Sjaellandsgade

line(Y1,X1,Z1,'LineWidth',5,'Color', 'r')

line(Y2,X2,Z2,'LineWidth',5,'Color', 'r')

line(Y3,X3,Z3,'LineWidth',5,'Color', 'r')

line(Y4,X4,Z4,'LineWidth',5,'Color', 'r')

line(Y361,X361,Z361,'LineWidth',5,'Color','r')

line(Y3618,X3618,Z3618,'LineWidth',5,'Color','r')

%Fenmarkgade

line(Y7,X7,Z7,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y8,X8,Z8,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y9,X9,Z9,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y10,X10,Z10,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y11,X11,Z11,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y12,X13,Z13,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Arresogade

line(Y19,X19,Z19,'LineWidth',5,'Color', [0.5 0.5 0.5])
```

```
line(Y20,X20,Z20,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y21,X21,Z21,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y2722,X2722,Z2722,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y3127,X3127,Z3127,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Jagtev

line(Y29,X29,Z29,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y30,X30,Z30,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y31,X31,Z31,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Tagenvej

line(Y5,X5,Z5,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y75,X75,Z75,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y197,X197,Z197,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y3319,X3319,Z3319,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y2433,X2433,Z2433,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y24,X24,Z24,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y2925,X2925,Z2925,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Guldbergsgade

line(Y25,X25,Z25,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y26,X26,Z26,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y27,X27,Z27,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y28,X28,Z28,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y111,X111,Z111,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Refsnaesgade

line(Y2421,X2421,Z2421,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y219,X219,Z219,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y93,X93,Z93,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Noddebogade
```

```
line(Y208,X208,Z208,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y84,X84,Z84,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Guldbers Plads/Tibirkegade

line(Y2622,X2622,Z2622,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y22,X22,Z22,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y23,X23,Z23,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y102,X102,Z102,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y2823,X2823,Z2823,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Stevsgade

line(Y3213,X3213,Z3213,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y13,X13,Z13,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y1416,X1416,Z1416,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y18,X18,Z18,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Udbygade

line(Y1215,X1215,Z1215,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y15,X15,Z15,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y36,X36,Z36,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Asnaesgade

line(Y16,X16,Z16,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y14,X14,Z14,'LineWidth',5,'Color', [0.5 0.5 0.5])

%Ole Maaloes Vej


line(Y33,X33,Z33,'LineWidth',5,'Color', [0.5 0.5 0.5])

line(Y34,X34,Z34,'LineWidth',5,'Color', [0.5 0.5 0.5])
```

3 Contour (3D) plot for raw data

```
%plot a 3D Contour Plot

figure2 = figure;


% Create axes
axes2 = axes('Parent',figure2,'PlotBoxAspectRatio',[1 1 1],...
    'DataAspectRatio',[1 2.5 833.333333333333],...
    'CameraViewAngle',71.7943799426947,...
    'CameraUpVector',[0.272811141553108 -0.793518585288425 756.833040543871],...
    'CameraTarget',[-0.00191384051583519 -0.00608265029697682 2.13505151237784],...
    'CameraPosition',[0.0023194147932452 -0.0183958085679423 -0.359071894707431]);
grid(axes2,'on');

xlin = linspace(min(XData1),max(XData1),50);
ylin = linspace(min(YData1),max(YData1),50);
[X,Y] = meshgrid(xlin,ylin);

Z = griddata(XData1,YData1,ZData1,X,Y,'cubic');

contour3(Y,X,Z,40)

colorbar EastOutside
```

4 Contour (2D) plot for raw data

```
%plot a 2D Contour Plot

figure2 = figure;


% Create axes
axes2 = axes('Parent',figure2,'PlotBoxAspectRatio',[1 1 1],...
    'DataAspectRatio',[1 2.5 833.333333333333],...
    'CameraViewAngle',71.7943799426947,...
    'CameraUpVector',[0.272811141553108 -0.793518585288425 756.833040543871],...
    'CameraTarget',[-0.00191384051583519 -0.00608265029697682 2.13505151237784],...
    'CameraPosition',[0.0023194147932452 -0.0183958085679423 -0.359071894707431]);
grid(axes2,'on');

xlin = linspace(min(XData1),max(XData1),50);
ylin = linspace(min(YData1),max(YData1),50);
[X,Y] = meshgrid(xlin,ylin);

Z = griddata(XData1,YData1,ZData1,X,Y,'cubic');

contour(Y,X,Z,40)

colorbar EastOutside
```

Appendix D: Rational Method calculations for Rainfall Runoff

Table 9. Runoff coefficients.

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25
Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, > 5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.70
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Calculating the composite runoff coefficient

Table 10. Composite Runoff Coefficient Areas

Number	Area (m^2) (Aj)	Runoff Coeff (Cj)	Cj*Aj
1	4490	0.5	2245
2	3409	0.5	1704.5
3	6060	0.5	3030
4	3604	0.175	630.7
5	1515	0.35	530.25
6	7157	0.5	3578.5
7	9446	0.5	4723
8	6261	0.5	3130.5
9	798	0.6	478.8
10	5871	0.9	5283.9
11	1603	0.6	961.8
12	609	0.6	365.4
13	1689	0.6	1013.4
14	4252	0.175	744.1
15	457	0.6	274.2
16	1004	0.6	602.4
17	1689	0.6	1013.4
18	2289	0.175	400.575
19	507	0.6	304.2
20	362	0.6	217.2
21	3286	0.6	1971.6
22	1071	0.175	187.425
23	2452	0.175	429.1
24	3735	0.5	1867.5
25	1180	0.35	413
26	3878	0.5	1939
27	5631	0.5	2815.5
28	3649	0.5	1824.5
29	3953	0.5	1976.5
30	810	0.5	405
31	1734	0.5	867
32	1328	0.175	232.4
33	949	0.175	166.075
34	1504	0.35	526.4
35	5655	0.5	2827.5
36	7142	0.5	3571
37	5168	0.5	2584
38	760	0.175	133
39	1644	0.5	822
40	687	0.175	120.225
41	1031	0.175	180.425
11a	374	0.9	336.6

2a	1008	0.35	352.8
3a	1016	0.3	304.8
4a	1171	0.35	409.85
9a	4218	0.9	3796.2
Paving estimate	105376	0.85	89569.6

$$C = (\sum_{j=1}^{j} A_j * C_j)/(\sum_{j=1}^{j} A_j)$$

C = Composite Runoff Coefficient

Table 11. Composite runoff coefficient.

Composite runoff Coefficient	0.650417698
Drainage area (ha)	23.3482

Calculating time of concentration

Table 12. Flow Path A

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 21	0.001207404	109.9362529	0.00462086	1.38	5.21	0.068
21 to 9	0.001082411	93.91307365	0.012373144	2.26	7.47	0.080
9 to 3	0.000759493	63.08716001	0.011571293	2.19	9.66	0.085
3 to 2	0.001131772	91.02709952	0.002922207	1.1	10.76	0.093
2 to 1	0.00111997	87.61591538	0.001871806	0.88	11.64	0.100
1 to 36	0.000544922	41.72840216	0.007692602	1.78	13.42	0.103
36 to 18	0.000680538	51.16655016	0.000781761	0.57	13.99	0.106

Table 13. Flow Path B

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 32	0.001454754	129.2639208	0.007055333	1.71	5.47	0.099
32 to 13	0.001154184	97.65536233	0.011847788	2.21	7.68	0.110
13 to 14	0.000608973	49.33227106	0.005087947	1.45	9.13	0.115
14 to 16	0.000305673	24.21880413	0.004376764	1.34	10.47	0.117
16 to 18	0.001436722	109.9041648	0.001919854	0.89	11.36	0.126

Table 14. Flow Path C

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 27	0.000932917	84.13314892	0.000867672	0.6	4.36	0.095
27 to 28	0.000757092	66.85091297	0.008092634	1.83	6.19	0.105
28 to 11	0.001030483	87.41420608	0.010124213	2.05	8.24	0.114
11 to 1	0.001523173	121.7542702	0.006381706	1.62	9.86	0.126
1 to 36	0.000544922	41.72840216	0.007692602	1.78	11.64	0.129
36 to 18	0.000680538	51.16655016	0.000781761	0.57	12.21	0.133

Table 15. Flow Path D

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 9	0.001580908	135.5142539	0.002199031	0.95	9.29	0.125
9 to 10	0.001260215	105.9934316	0.002509589	1.02	10.31	0.134
10 to 11	0.001480358	123.0795132	0.000950605	0.63	10.94	0.144
11 to 12	0.000771126	63.62922782	0.006176407	1.6	12.54	0.149
12 to 15	0.000524695	42.62608143	0.012152184	2.24	14.78	0.152
15 to 17	0.000195691	15.60044879	0.002435827	1	15.78	0.153
17 to 36	0.001168507	90.80674807	0.002477789	1.01	16.79	0.158
36 to 18	0.000680538	51.16655016	0.000781761	0.57	17.36	0.160

Table 16. Flow Path E

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 9	0.001580908	135.5142539	0.002199031	0.95	9.29	0.125
9 to 10	0.001260215	105.9934316	0.002509589	1.02	10.31	0.134
10 to 2	0.001050145	85.5996751	0.00852807	1.88	12.19	0.141
2 to 1	0.00111997	87.61591538	0.001871806	0.88	13.07	0.147
1 to 36	0.000544922	41.72840216	0.007692602	1.78	14.85	0.149
36 to 18	0.000680538	51.16655016	0.000781761	0.57	15.42	0.152

Table 17. Flow Path F

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 4	0.000780568	66.87852017	0.007969674	1.81	10.15	0.118
4 to 3	0.001990687	165.2732235	0.002995041	1.11	11.26	0.131
3 to 2	0.001131772	91.02709952	0.002922207	1.1	12.36	0.138
2 to 1	0.00111997	87.61591538	0.001871806	0.88	13.24	0.144
1 to 36	0.000544922	41.72840216	0.007692602	1.78	15.02	0.146
36 to 18	0.000680538	51.16655016	0.000781761	0.57	15.59	0.149

Table 18. Flow Path G

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 27	0.000932917	84.13314892	0.000867672	0.6	4.36	0.095
27 to 22	0.001087549	97.11241925	0.000834085	0.59	4.95	0.113
22 to 23	0.000527935	46.41620814	0.009264005	1.96	6.91	0.119
23 to 10	0.000877916	74.85929324	0.010659999	2.1	9.01	0.126
10 to 2	0.001050145	85.5996751	0.00852807	1.88	10.89	0.134
2 to 1	0.00111997	87.61591538	0.001871806	0.88	11.77	0.140
1 to 36	0.000544922	41.72840216	0.007692602	1.78	13.55	0.143
36 to 18	0.000680538	51.16655016	0.000781761	0.57	14.12	0.147

Table 19. Flow Path H

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 27	0.000932917	84.13314892	0.000867672	0.6	4.36	0.095
27 to 22	0.001087549	97.11241925	0.000834085	0.59	4.95	0.113
22 to 21	0.001266241	112.5426943	0.001777103	0.86	5.81	0.130
21 to 20	0.001099621	98.0037304	0.001224443	0.71	6.52	0.144
20 to 8	0.000917077	80.81877595	0.009205782	1.95	8.47	0.153
8 to 4	0.000780568	66.87852017	0.007969674	1.81	10.28	0.159
4 to 3	0.001990687	165.2732235	0.002995041	1.11	11.39	0.172
3 to 2	0.001131772	91.02709952	0.002922207	1.1	12.49	0.179
2 to 1	0.00111997	87.61591538	0.001871806	0.88	13.37	0.185
1 to 36	0.000544922	41.72840216	0.007692602	1.78	15.15	0.187

36 to 18	0.000680538	51.16655016	0.000781761	0.57	15.72	0.190

Table 20. Flow Path I

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.001412215	132.2131872	0.011383131	2.17	2.17	0.056
25 to 26	0.001252988	116.1150912	0.005752913	1.54	3.71	0.084
26 to 22	0.001485484	136.0567393	0.008592004	1.88	5.59	0.106
22 to 23	0.000527935	46.41620814	0.009264005	1.96	7.55	0.112
22 to 10	0.000877916	74.85929324	0.010659999	2.1	9.65	0.119
10 to 2	0.001050145	85.5996751	0.00852807	1.88	11.53	0.126
2 to 1	0.00111997	87.61591538	0.001871806	0.88	12.41	0.132
1 to 36	0.000544922	41.72840216	0.007692602	1.78	14.19	0.135
36 to 18	0.000680538	51.16655016	0.000781761	0.57	14.76	0.138

Table 21. Flow Path J

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 26	0.001252988	116.1150912	0.005752913	1.54	3.65	0.063
26 to 27	0.000667401	60.35330342	0.006959023	1.7	5.35	0.073
27 to 28	0.000757092	66.85091297	0.008092634	1.83	7.18	0.081
28 to 11	0.001030483	87.41420608	0.010124213	2.05	9.23	0.090
11 to 1	0.001523173	121.7542702	0.006381706	1.62	10.85	0.100
1 to 36	0.000544922	41.72840216	0.007692602	1.78	12.63	0.103
36 to 18	0.000680538	51.16655016	0.000781761	0.57	13.2	0.107

Table 22. Flow Path K

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 9	0.001580908	135.5142539	0.002199031	0.95	9.29	0.125
9 to 10	0.001260215	105.9934316	0.002509589	1.02	10.31	0.134
10 to 11	0.001480358	123.0795132	0.000950605	0.63	10.94	0.144
11 to 12	0.000771126	63.62922782	0.006176407	1.6	12.54	0.149
12 to 13	0.000969017	79.71663988	0.002220365	0.96	13.5	0.154
13 to 14	0.000608973	49.33227106	0.005087947	1.45	14.95	0.157
14 to 16	0.000305673	24.21880413	0.004376764	1.34	16.29	0.159
16 to 18	0.001436722	109.9041648	0.001919854	0.89	17.18	0.165

Table 23. Flow Path L

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 9	0.001580908	135.5142539	0.002199031	0.95	9.29	0.125
9 to 10	0.001260215	105.9934316	0.002509589	1.02	10.31	0.134
10 to 11	0.001480358	123.0795132	0.000950605	0.63	10.94	0.144
11 to 1	0.001523173	121.7542702	0.006381706	1.62	12.56	0.153
1 to 36	0.000544922	41.72840216	0.007692602	1.78	14.34	0.156
36 to 18	0.000680538	51.16655016	0.000781761	0.57	14.91	0.159

Table 24. Flow Path M

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 8	0.001383111	121.1941349	0.001732757	0.85	8.34	0.112
8 to 9	0.001580908	135.5142539	0.002199031	0.95	9.29	0.125
9 to 3	0.000759493	63.08716001	0.011571293	2.19	11.48	0.130
3 to 2	0.001131772	91.02709952	0.002922207	1.1	12.58	0.136
2 to 1	0.00111997	87.61591538	0.001871806	0.88	13.46	0.142
1 to 36	0.000544922	41.72840216	0.007692602	1.78	15.24	0.145
36 to 18	0.000680538	51.16655016	0.000781761	0.57	15.81	0.148

Table 25. Flow Path N

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 25	0.000817598	77.68634916	0.010774094	2.11	2.11	0.034
25 to 24	0.000686535	64.28493867	0.007171198	1.72	3.83	0.049
24 to 33	0.00150467	139.0565978	0.003372727	1.18	5.01	0.074
33 to 19	0.000838852	76.24405895	0.00338387	1.18	6.19	0.085
19 to 7	0.001188024	106.0672901	0.00410117	1.3	7.49	0.098
7 to 5	0.001272451	111.5882048	0.00212388	0.94	8.43	0.110
5 to 4	0.002077395	178.1429542	0.002840415	1.08	9.51	0.127
4 to 3	0.001990687	165.2732235	0.002995041	1.11	10.62	0.142

3 to 2	0.001131772	91.02709952	0.002922207	1.1	11.72	0.149
2 to 1	0.00111997	87.61591538	0.001871806	0.88	12.6	0.155
1 to 36	0.000544922	41.72840216	0.007692602	1.78	14.38	0.158
36 to 18	0.000680538	51.16655016	0.000781761	0.57	14.95	0.161

Table 26. Flow Path O

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 27	0.000932917	84.13314892	0.000867672	0.6	4.36	0.095
27 to 22	0.001087549	97.11241925	0.000834085	0.59	4.95	0.113
22 to 21	0.001266241	112.5426943	0.001777103	0.86	5.81	0.130
21 to 9	0.001082411	93.91307365	0.012373144	2.26	8.07	0.141
9 to 3	0.000759493	63.08716001	0.011571293	2.19	10.26	0.147
3 to 2	0.001131772	91.02709952	0.002922207	1.1	11.36	0.154
2 to 1	0.00111997	87.61591538	0.001871806	0.88	12.24	0.160
1 to 36	0.000544922	41.72840216	0.007692602	1.78	14.02	0.163
36 to 18	0.000680538	51.16655016	0.000781761	0.57	14.59	0.166

Table 27. Flow Path P

Points	Distance (degrees)	Distance (m)	Slope (m/m)	Velocity (ft/s)	Total Velocity (ft/s)	Total Time (hr)
29 to 30	0.001191789	112.7638579	0.009249417	1.96	1.96	0.052
30 to 31	0.001115886	102.6694576	0.007879656	1.8	3.76	0.077
31 to 27	0.000932917	84.13314892	0.000867672	0.6	4.36	0.095
27 to 22	0.001087549	97.11241925	0.000834085	0.59	4.95	0.113
22 to 21	0.001266241	112.5426943	0.001777103	0.86	5.81	0.130
21 to 20	0.001099621	98.0037304	0.001224443	0.71	6.52	0.144
20 to 19	0.000862497	77.42331387	0.001278685	0.73	7.25	0.154
19 to 7	0.001188024	106.0672901	0.00410117	1.3	8.55	0.165
7 to 5	0.001272451	111.5882048	0.00212388	0.94	9.49	0.176
5 to 4	0.002077395	178.1429542	0.002840415	1.08	10.57	0.191
4 to 3	0.001990687	165.2732235	0.002995041	1.11	11.68	0.204
3 to 2	0.001131772	91.02709952	0.002922207	1.1	12.78	0.211
2 to 1	0.00111997	87.61591538	0.001871806	0.88	13.66	0.216
1 to 36	0.000544922	41.72840216	0.007692602	1.78	15.44	0.219
36 to 18	0.000680538	51.16655016	0.000781761	0.57	16.01	0.222

Calculating Maximum Rate of Runoff

$$Q = \frac{CIA}{Z}$$

Q = Maximum Rate of Runoff (m^3/s)

I = Average Rainfall Intensity (mm/hr)

A = Drainage Area (ha)

Z = 360 conversion factor for metric

Appendix E: Non-potable water reuse calculations

1mm of precipitation = 1 L per m^2

Water closets (w.c.):

4L per flush

Approx. 100 w.c. in building, 12 flush per day per w.c. = 4800 L water usage per day

At 4800 L/day = 1,752,000 L per year total w.c. usage

Rainwater collection:

Area average of 625mm rain/year = 625 L/year per m^2 of roof

Total roof area = 3501m^2

Potential collectable rainfall per year = 3501 x 625 = 2,188,125 L/year.

Collection system efficiency factor of 67%

Actual collectable rainfall per year = 2,188,125 x 0.67 = 1,466,043.75 L/year

Percentage City Water Supplementation Annually:

Total supplied city water = 1,752,000 L

Total available collected rainwater = 1,466,043.75 L

Percentage of city water that will be supplemented = (1,466,043.75/1,752,000) x 100 = 83.68%

Expense Analysis:

Estimated cost of installation = DKK 245,000

Approximate savings based on reused water volume annually = DKK 13,223.71

Years until system makes profit = 245,000/13,223.71 = 18.5 yrs.

Appendix F: Focus group transcripts

An invitation to participate in our focus group was emailed to Miljøpunkt Nørrebro's mailing list, compiled in May 2011 when they were campaigning for a greener Sjællandsgade. Despite there being many email addresses on the mailing list, we had a small turnout. Below is a transcript paraphrasing or directly citing our discussion. Figure 49 through Figure 56 are the slides used to prompt the focus group discussion. They are shown here aligned more or less with the discussion.

Figure 49. First slide of the focus group presentation used to prompt the discussion.

Figure 50. Second Slide. Questions regarding flooding and the July 2nd, 2011 cloudburst.

Figure 51. Third slide. Questions regarding climate change adaptation.

Participants:

Bjarne Nielsen: Caretaker of a cooperatively owned building along Sjællandsgade.

Manuel Retsloff: Head of the Cooperative Association Board of the same building as Mr. Nielsen.

Flooding in Sjællandsgade

Mr. Nielsen thinks problems such as the cloudburst on July 2, 2011 will become more frequent (will be coming again and again). Therefore, they are working to develop spaces for water storage in their building because, due to that storm, their basement flooded.

Mr. Retsloff agrees with the statement, remarking that 100 year rains will become more frequent despite their name. He says that their building is different, that they had less trouble cleaning up because they have people hired to clean and take care of the building. He tells us that the stairway going into the basement was flooded and that the drains in the basement were spouting water. Luckily, the water was rainwater and not blackwater.

Creating solutions

Mr. Nielsen says there hasn't been much initiative in the neighborhood, that there hasn't been too much talk about this. Despite the lack of initiative in the people, Mr. Retsloff says "But we're for it (creating solutions)!" He tells us they (him and Mr. Nielsen) are not good representatives of the mean population because they're already so proactive in their own building. Adding that politicians may talk a lot about it, but they do not really invest more in it and do not take action.

Mr. Nielsen describes to us a solution they would like to implement: of the three yards they have, they want to dig 1m into the ground to make a storage space for bicycles and things that could also serve the dual purpose of storing water in the case of extreme rainfall events. They have consulted with architects and with two groups of students from the University of Copenhagen that were mastering in Storm water Management. They used their housing as a case study and that both groups had plans for where the water should go. There's a lot of ambition. However, nothing came of the reports.

They agree that rainwater management is important but that they'll be working on it privately because the city will take too long and they need to take action now.

Q: Is the groundwater table high in your building?

According to Mr. Nielsen, the groundwater isn't higher than the normal level in the area.

Along another thought he tells us about a project in which the city would pay people to disconnect rainwater from the sewers. There is no money left for it, so they are prevented from disconnecting water, but that the people in the building were definitely for it and talking about it. They ran some calculations and if they disconnected the rainwater from the sewers and gave it back to the city, then their building would have been entitled to DKK 3.7 million a year.

Figure 52. Fourth slide. Questions regarding rainwater reuse.

Mr. Retsloff is in favor of disconnecting rainwater because the sewers are under capacity, and mixing rainwater with black water is stupid. As a response, Mr. Larsen explains to him how the municipality has directed the initiative to single housing units.

However Mr. Nielsen has a different idea: “We also have a laundry where we could use it and we could use the rainwater to flush toilets. There are two projects for rainwater disconnected from the sewers: to filter rainwater into the ground or to recycle it. The solution was presented years ago so the investment could be balanced. Apparently though, Mr. Nielsen said that the City could fund part of these projects. By recycling the water, a lot of money could be saved.

Q: would you like to get involved and to what extent?

Mr. Retsloff: Yes, I’d like to be involved

Mr. Nielsen: It would be nice to have people who live there be involved, to give people a sense of ownership. There’s a strategic reason for involving people. In out housing we have huge involvement in the whole area: bars, grocery stores… We’re slowly creating an environment that wasn’t here 6 years ago. We’re turning what once was a dodgy place into a nicer place where people can talk to each other. We’re interested in giving our ideas and also supporting the project. We’re interested in doing something that doesn’t involve the municipality, to do something in the spirit of Nørrebro: in accordance with the neighborhood we’re a part of and not something flashy a big company is building. Sjællandsgade doesn’t need that much to be green, it doesn’t need too much money to be green, and we already have green areas and trees and such.

Figure 53. Fifth slide. Explanation of the amount of green space in Nørrebro compared to the rest of Copenhagen.

On a Green Sjællandsgade

Mr. Retsloff: Living in a corner of Nørrebro that’s very green I do not feel that this is true (on the statistics of green areas). The neighborhood is changing. People bought the buildings from the municipality, so now they own them. The flats aren’t given to people on benefits; they’re given to people who are taxpayers so the environment is changing. Do not get me wrong, there’s still room for the people who used to live here (alcoholics,

Figure 54. Sixth slide. Questions regarding green space in Sjællandsgade.

schizophrenics…) but we also have gentrification going on so the young and educated new families with their trophy children are moving into the neighborhood.

Q: Are other buildings interested in developing green spaces?

Mr. Retsloff: Nørrebro is VERY left wing. Subjects such as the environment, the poor and the troubled are very important. If you made a nice area with fitness things and a running area, but also added a few trees, then that would be good. Making areas for people to get together and have a beer.

Concerning construction

Mr. Retsloff: Copenhagen has been under construction during the past 10 years, so there's nothing new with that. It would be nice to see change in Nørrebro where we have and influence.

The men both agree that there'll be noise when you make changes and that of course it's a bother, but you live with it. A clear example of this was given by Mr. Nielsen; he said that when they were renovating a building nearby, there were people working until 2am and you just had to deal with it.

Figure 55. Seventh slide. Questions regarding prolonged construction along Sjællandsgade.

Q: Many people think projects such as the one in Stk. Kjeld's Kvarter are impossible. What are your thoughts on the issue?

Mr. Nielsen: I do not think projects like these are impossible.

Cars

They both own and share cars with whoever needs one. But Mr. Nielsen added that 15 years ago the car ownership was 10 to 15%, now it exceeds 25%, and they all park near the apartment buildings. There are parking spaces in the basement of the church so there are solutions for parking that can allow for more green areas.

Figure 56. Eighth slide. Questions regarding the usage of cars.

Tells us about a focus group in which they invited people of the area to ask them where a project to increase the amount of green spaces should be developed but the decisions were already made so he was displeased with that.

Mr. Retsloff: I really like the idea of shutting down sections of the road. It would be great to limit the traffic to people who actually have something to do here.

Mr. Nielsen: Talked about removing fences along the street and also agrees that the Nørre Campus shouldn't be trusted in the sense that they're probably not going to deal with their rainwater and prevent it from flowing downstream into Sjællandsgade.

Mr. Retsloff: Have you thought about the channels that are empty when there's no rain but that can flood up when it rains? Like the one in the movie Grease where they had the car races? You should think about things with dual purpose so something that could work for skateboards and things

Mr. Nielsen says it's difficult to be against a concept such as swales.

Mr. Retsloff: Nature takes over eventually so at first things can be sort of meh but then they'll become nicer. The area where the bunkers are is hilly so it's really nice for the children to play in.

Mr. Nielsen: You should make different landscapes so depressions in some areas but hills in others so that it's nicer. You can remove some pavement and send the cars underground. There are no shops so there's no real need for lots of street parking. "*You have to be provocative to promote change*"

Mr. Retsloff: **"***If you make something and nobody freaks out of gets pissed off about it, then you didn't cause much change. Take it (people's reaction) as a measurement, there should be a significant before and after when you make something."*

Appendix G: Surveys and survey raw data

First survey questions (April 9th, 2013):

1. What was your experience with the 2 July 2011 cloudburst?
2. Do you think flooding is a problem in Sjællandsgade?
3. Have you taken any personal initiatives to deal with flooding?
4. Are you happy with the amount of green space in Sjællandsgade?
5. Do you live on Sjællandsgade or the neighborhood around it?
6. Additional comments:

Second survey questions (April 16th, 2013):

1. What was your experience with the 2 July 2011 cloudburst?
2. Do you think flooding is a problem in Sjællandsgade?
3. Have you taken any personal initiatives to deal with flooding?
4. Are you aware that increased green space can reduce flooding?
5. Do you live on Sjællandsgade or the neighborhood around it?
6. Do you support the removal of car traffic to add green space?
7. Additional comments:

Results:

Table 28. Results from the first survey. The questions correspond to those above.

	Q1	Q2	Q3	Q4	Q5	Q6 - Additional Comments
1	Not affected by the cloudburst.	No	No	No	Yes	
2	Flooding in the street.	Yes	No	Yes	Yes	
3	Water in the basement.	Yes	No	Yes	Yes	
4	Not as bad as others saw it, some property damage.	Yes	No	Yes	Yes	Already lots of parks here, money could be better spent elsewhere.
5	My basement was flooded.	Yes	No	Yes	Yes	
6	Yes	No	Yes	Yes	Yes	More green, more trees.
7	Wet, wet, wet.	Yes	Yes	No	Yes	
8	Was on holiday, lost everything in basement.	N/A	Yes	Yes	Yes	Put things in plastic boxes.
9	Our basement was flooded.	N/A	No	Yes	Yes	
10	Our basement was flooded, lost a lot of belongings.	Yes	Yes	Yes	Yes	There can always be more green areas.
11	Big problems.	Yes	No	N/A	No	Money could be better spent on more urgent problems such as social issues rather than parks.
12	Wasn't there but my things were in the attic, not the basement.	Yes	Yes	No	Yes	Would always want more green areas.

Table 29. Results from the second survey.

#	Q1	Q2	Q3	Q4	Q5	Q6	Q7 - Additional Comments
1	Basement flooded. Son got big wounds on his hands when playing in the playground and they got infected with e-coli bacteria, probably from the flood water.	Yes	N/A	Yes	Yes	Yes	
2	We had no personal consequences.	N/A	No	Yes	Yes	Yes	
3	Was in Jutland.	Yes	No	Yes	Yes	Yes	
4	Was travelling.	Yes	No	No	Yes	Yes	
5	Rehearsal room got flooded.	Yes	No	Yes	Yes	Yes	Do it!
6	I saw it on TV	N/A	No	Yes	Yes	Yes	
7	Lived in Aarhus at the time.	No	Yes	No	No	Yes	Rehearsal room got flooded.
8	Was at the Roskilde Festival, suffered no consequences.	Yes	No	Yes	Yes	Yes	
9	We got flooded.	Yes	Yes	Yes	Yes	Yes	

Appendix H: Miljøpunkt Østerbro interview

On April 4, 2013 we met with Mr. Stefan Werner, a representative from the Water and Parks Division, and Ms. Berggreen from Miljøpunkt Østerbro. In advance, we had prepared three questions for them to sort of give them an idea of the information we were looking for.

1. The consequences (experience) for Sjællandsgade from cloudburst on second July 2011 - what do we know? (also around cloudburst from the area North Campus in Sjællandsgade)
2. How does the City of Copenhagen with "periods of sustained prolonged rain" in highly urbanized areas?
3. How do planners with torrential rain and climate change adaptation around St. Petersburg. Kjelds neighborhood?

Although they didn't answer the questions directly, they provided us with a lot of new information and broadened our perspective on the project.

Ms. Berggreen:

How are we planning or thinking in Copenhagen?

- Avoiding big roads and public transport
- Making things easier for pedestrians and cyclists
- Improve city life
- Look at how rainwater flows
- Look at how everything fits together

What is the primary focus to utilize rainwater in the area?

- To make the city more green and blue.
- Give/take
- Make some traffic changes:
  - Big traffic goes outside the area

- Keep all the parking/relocate parking spaces. CANNOT remove parking spaces. (Consider to relocate parking spaces to the shade and green spaces in the sun to maximize the potential).
- Look at terrain
- Fundamental to listen to what citizens want

Mr. Werner

How do you secure funding?

- Most of it comes from the state. Changes the law to fund climate adaptation initiatives
- It's not about taxes; it's about fees in water use. So more fees means more surfaces can be modified.
- 75% state
- 25% private investors

On prolonged rain:

- Use the natural flow of the water to minimize energy used to recycle it.
- Recommends to research YouTube videos about the 2 July 2011 cloudburst
- They designed a website where people report on flooding after the cloudburst.
- 10 year rain: when the water level in the sewers reaches the street level. 50 millimeters rainfall.
- 100 year rain: when the water overflows 10 centimeters above the street. 100 millimeters total rainfall.
- City says sewage isn't allowed to overflow except every 10 years its allowed to go up to street level and every 100 years allowed to go 10 centimeters above street level.
- Consider roof gutter capacity. They will not be able to deal with the full volume of rainfall, but will be able to detain some of it.

Q: Any considerations to use the rainwater in the residences?

- Report describing what to do to use water for toilets, washing machines…
- Quite expensive to implement and return on investment is slow (about 50 to 100 years)

    - Feasible for with buildings with more surface area (courtyard…)
- DKK 50 needed to treat each cubic meter of water
- Need to develop new habits to use water
- Using rainwater in the buildings and adapting all the piping may be too expensive, but it can be used for something else: washing the car, bicycle, watering plants…
- People have to pay the utility company to treat rain and waste water.
- The city buys clean rain water at DKK 70 per cubic meter.
- Consider storing water for sunny days when the plants need it.
    - About 30% of the rainfall can be stored

When you're designing solutions, how do you determine feasibility?

- Renovating old buildings ends up being more expensive that making a new building with the adaptations already in place.
- Surface solutions cost the same: whether you repave the street or change it to have a porous or green surface… and it's still the city's responsibility to provide citizens a surface.
- To transport water you only need 1 to 2 meters across.
- Argument: cost of expanding the sewers totals DKK 10 to 15 billion, so why not use that money to create surface spaces that can improve other factors too.
- "Things aren't so difficult. We just have to change our habits of thinking or doing things"

Area distributions

- 1/3 buildings, 1/3 roads, 1/3 private spaces
- In cities, 80 to 90% surface is non-permeable and only 10 to 15% green areas, usually privately owned.
- Different types of ownerships

"Think freely, think outside the box, think big."

Appendix I: Interview with Mr. Sørensen and Mr. Kare

Mr. Sørensen and Mr. Kare are on the planning board for a non-profit housing in Folehaven. The central office manages around a thousand tenants and their rent pays for running the building and maintenance. In 2000, politicians wanted to cut down on water consumption as costs were rising, so they started a water recycling system to use in the washing machines of the communal laundry station. However after two years, the water started to smell of sulfur, so they had to change the system. In its place they installed the rainwater collection system they have today.

System

Rainwater is collected from the roofs of three apartment buildings and the Central office. A cistern near the buildings holds the water as it is pumped automatically to the storage tanks in the Central Office. The system has been so effective that the group plans to incorporate more roofs by next year. The pipe connecting the outdoors cistern with the Central Office is no more than 1 m deep at the lowest point. There are a total of seven 4 cubic meter tanks and eight 5 cubic meter tanks which together hold a total of 68,000 liters.

In the laundry station there are 24 water-efficient washing machines. The daily average water consumption for the washing machines is between 5 and 6 cubic meters. The washing machines have a life expectancy of ten years but they get changed every 10 to 15 years. The amount of service time is two hours a week, mostly dedicated to cleaning the area and feeding the fish.

Water quality

The water quality is checked at random intervals by the Water Utility Company; there have been no complaints to the date.

To ensure water quality, the rain water is filtered twice and allowed to sediment in the tanks yet no chemical treatment is given. The first filter removes large aggregates such as leaves, and the small filter removes small particulates. Once a year, the sediment is vacuumed out and the tanks are cleaned.

This process does not require the use of a first flush system.

Savings

Last year the savings totaled DKK 1 million

- Price of the water what would have had to been bought.
- Price of disposing of that water through the sewers.
- Rainwater is 2°C warmer that the city water so you need less power to warm it.
- Soap of a very high quality is bought in bulk at a reasonable price.
- Revenue from washing, DKK 10 per wash.
- There are solar panels outside the building that power a part of it.

Q: Was the water utility company opposed to this and try to stop it?

No, there weren't any problems with the municipality or utility. They only set some requirements such as to prevent rainwater from entering the city's water. The process started out with a group of people thinking green, not only in favor of the washers. They became ambassadors to reach other people. The problem was approached bottoms-up rather than top-down process which is longer and more complicated. The bottoms-up process also allows people to feel ownership of the project.

Funding

Funding came from the people here. It is feasible in the long term and people understand that. They understand that it'll take a long time to get return on investment. Next time we have to change machines the money will have already been raised by the people in their monthly fees. Besides, rainwater also contributes to the long life expectancy of the washing machines because it is soft water unlike the hard ground water taken from the limestone.

"Beside the funds saved by the tenants - very big projects can get guarantees from National Building Fund. Landsbyggefonden = National Building Fund, a private institution that was founded by social housing organizations and established by law.

The fund is responsible, among other management of core capital to publicly subsidized housing and administration of the social housing sector by mandatory contributions, and collection of payments for land reserve fund, etc. Also manage the fund analysis tasks, the special operating support for renovation, etc. as well as a guarantee, etc." – Ove Larsen, Personal Communication, April 9, 2013.

The investment for the project will be paid after 30 years

Next improvement projects:

- Renovating buildings
- Better insulating them
- Make better spaces
- Install more lights
- Improve their winter garden
- Modernize the oldest apartments
- Local division of rainwater for more purposes
- Install solar panels

Demographics

Before the project was started, there was a lot of social tension, people felt unsafe, and there was even a group of neo-Nazis in the neighborhood. The project gave people ownership and responsibility, attracting young families. Now there is a decrease in the amount of old people here while there is an increase in the amount of families with children or with teenagers.

The majority is composed of ethnic Danes and only 35% are people of different ethnic backgrounds. This is lower than the Danish average.

Q: With all these changes is the cost of living going up?

This is a very cheap rent: a 4 room apartment costs less than a 2 room apartment in Copenhagen. The building association agrees on a rent and prevents it from going up. Improvements aren't paid through higher rent as they are paid through the building fund every building association puts money in.

Appendix J: Technical Manual for Climate Change Adaptation

Managing Climate Change

Sjællandsgade as a Green Corridor

Eric Cremer, Anthony DeCicco, Courtney McCann, and Andrea Rivas

Contents

Identifying the Need for Sustainable Blue-Green Solutions

Each borough within a city will have differing policies on the implementation of a blue-green solution within a selected area. In order to build an argument for change, quantitative proof must support the necessity for sustainable development. This section will describe methods that purport stormwater management for an area that can expect flooding during a cloudburst or extended rainfall.

Analyzing Rainfall Patterns

Rainfall patterns take data recorded by weather bureaus as to the amount of precipitation per day and per month. A graph should be made that juxtaposes rainfall amount by each month and average rainfall per day. This data should be gathered from five years of weather data to allow for averaging. Another component of rainfall patterns is the phenomena known as a cloudburst where a large amount of rainfall occurs during a short period of time. Such incidents can potentially overload current water management systems and cause damage to an area. The frequency of such events and monetary damage should be noted in order to build an argument for sustainable development in an area.

Identifying Flood-zones

Flood-zones are areas that are prone to flooding due to their topographical relationship to the surrounding area. Areas that fall into this category should be designated as first-priority as compared to those areas that are positioned in a precipice to the surrounding land. Topographical maps developed by Surveyors are the most conclusive evidence for how stormwater may flow in a neighborhood or borough. Water will generally run from higher elevation to lower elevation and should a street lie in a valley, it could potentially form a pool of water where damage may be significant. When topographical or altitude data is available, areas should be triaged according to their potential for flooding as shown by Figure 1.

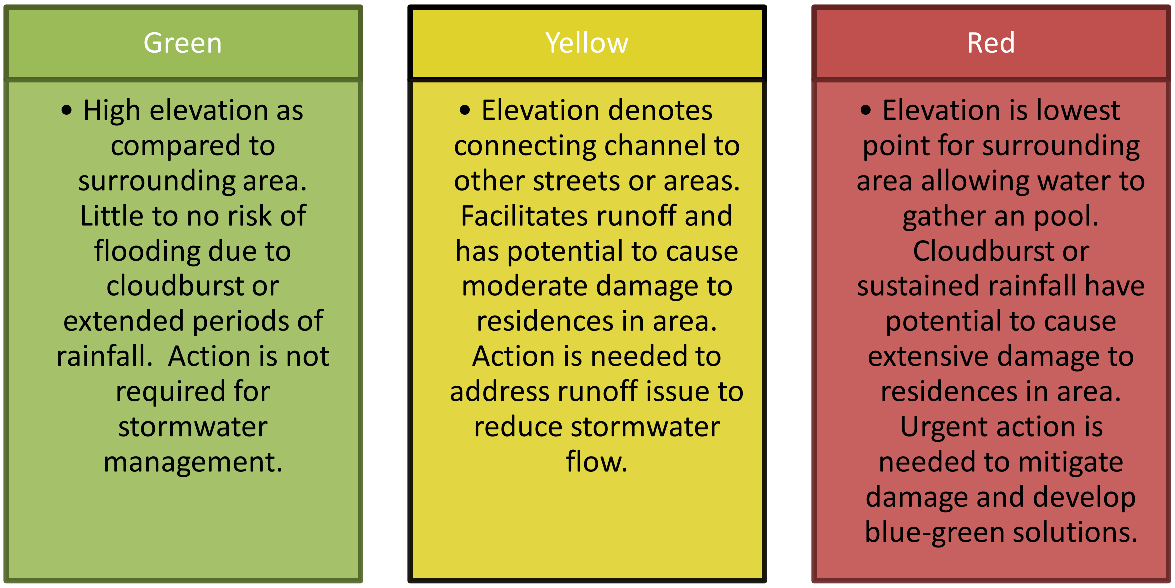

Figure 1. Triage of Flood Risk

Runoff Calculations for a Given Area

In order to strengthen the argument for rainwater management in an area, runoff calculations can be made to determine the expected amount of water for a given rainstorm that will not be naturally absorbed.

Determining the Runoff Coefficient

In order to accurately determine the amount of runoff generated by the studied terrain area, a comprehensive analysis of specific geographical elements is required. Runoff for an area is determined by considering the permeability of the surface of the area and the amount of precipitation. The Municipality of Copenhagen provides an extremely useful tool to gather both the numerical value and qualitative value for a given area (Kobenhavns Kommune, 2013). By discretizing the area, we can find specific areas of buildings and parks and by using the aerial photographs, information as to the type of area are gathered. Then, create a table that labels each area, returns a value for how many square meters it inhabits, and the runoff coefficient as noted by Table 1. For the area value for pavement, we recommend subtracting the areas found from the total area of the neighborhood. To complete the runoff coefficient, please use Equation 1.

$$C_w = \frac{(\sum_{j=1}^{j} A_j * C_j)}{(\sum_{j=1}^{j} A_j)} \qquad eq. 1$$

In this equation, C_w is the weighted runoff coefficient, A_j is specific area, and C_j is specific runoff coefficient. For those who are unfamiliar with this notation: ($\sum_{j=1}^{j} A_j * C_j$) means to multiply each area by its respective runoff coefficient and then to add all of these values together; ($\sum_{j=1}^{j} A_j$) means to add all of the areas together; the value returned by ($\sum_{j=1}^{j} A_j * C_j$)is then divided by ($\sum_{j=1}^{j} A_j$) which will then return the total runoff coefficient for the entire area.

Table 1. Runoff coefficients.

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25
Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, > 5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.70
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Rainfall Runoff Calculations

In order to utilize the rational method, we must calculate another coefficient called the Time of Concentration (T_c). This coefficient, "is the time required for the entire watershed to contribute to runoff at the point of interest" (Hydraulic Design Manual, n.d.). If a cloudburst occurred in a shorter time than the time of concentration, then the previous model based on the Rational Method would be invalid as it assumes that the storm lasts longer than the time of concentration. To find the value for T_c, several pathways from the highest point to the lowest point must be determined.

We recommend using streets as the pathways because they will be the main channels for water flow during large storms. Create a plot of the area using topographical maps that discretize streets by intersections with a separate list of altitudes. Measure distances on this plot taken by potential runoff (from higher to lower points) and record these distances from point to point. Then, we can find the slope by finding the difference in altitudes and dividing by the distances. With this information in hand we may use a calculator found at (http://www.professorpatel.com/time-of-concentration.html) (Professor Patel, 2012). Figure 2 shows the setup you should use (unfortunately you must use English units for the calculation but it will return a time nonetheless). This calculator will provide the length of time it takes for water to travel and the average velocity. Iterate this for several complete paths to find what the longest (in hours) path from the highest to lowest point. Then by using Equation 2, we can then find the maximum rate of runoff in cubic meters per second.

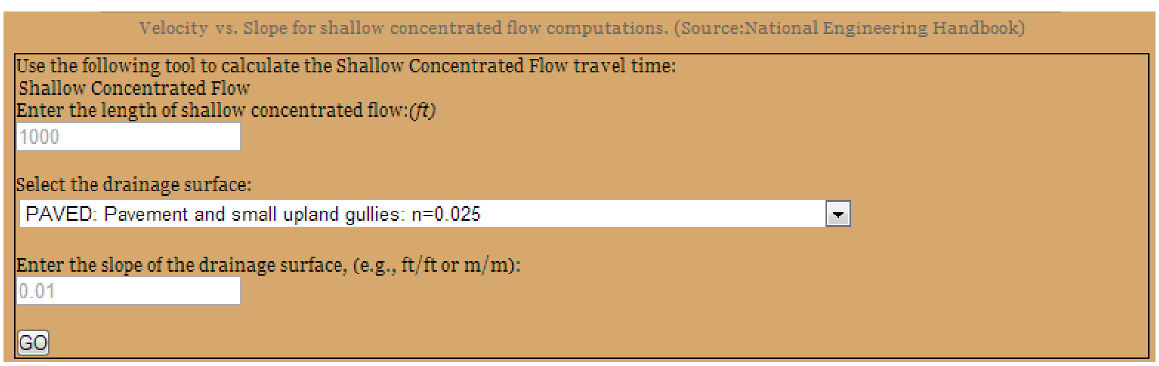

Figure 2. Calculator for travel time

With these limitations and assumptions established, we can then use the data carried out by Madsen, et. al (Figure 3) to find the predicted Intensity in Copenhagen for a 1-year, 10-year, and 100-year event using the time of concentration. We then use the rational method as shown in Equation 2 to calculate the maximum rate of runoff.

$$Q = \frac{C_w * I * A}{360} \qquad eq. 2$$

In this equation, C_w is the weighted runoff coefficient, I is intensity in mm/hr (calculated by rainfall in mm divided by the time of the storm in hours), and A is the drainage area in hectares. This will return a result for the maximum rate of runoff, Q, in cubic meters per second. With unit manipulation, we predict the amount of runoff given the conditions that the storm can be generalized as a one-hour storm that has a constant rate of runoff.

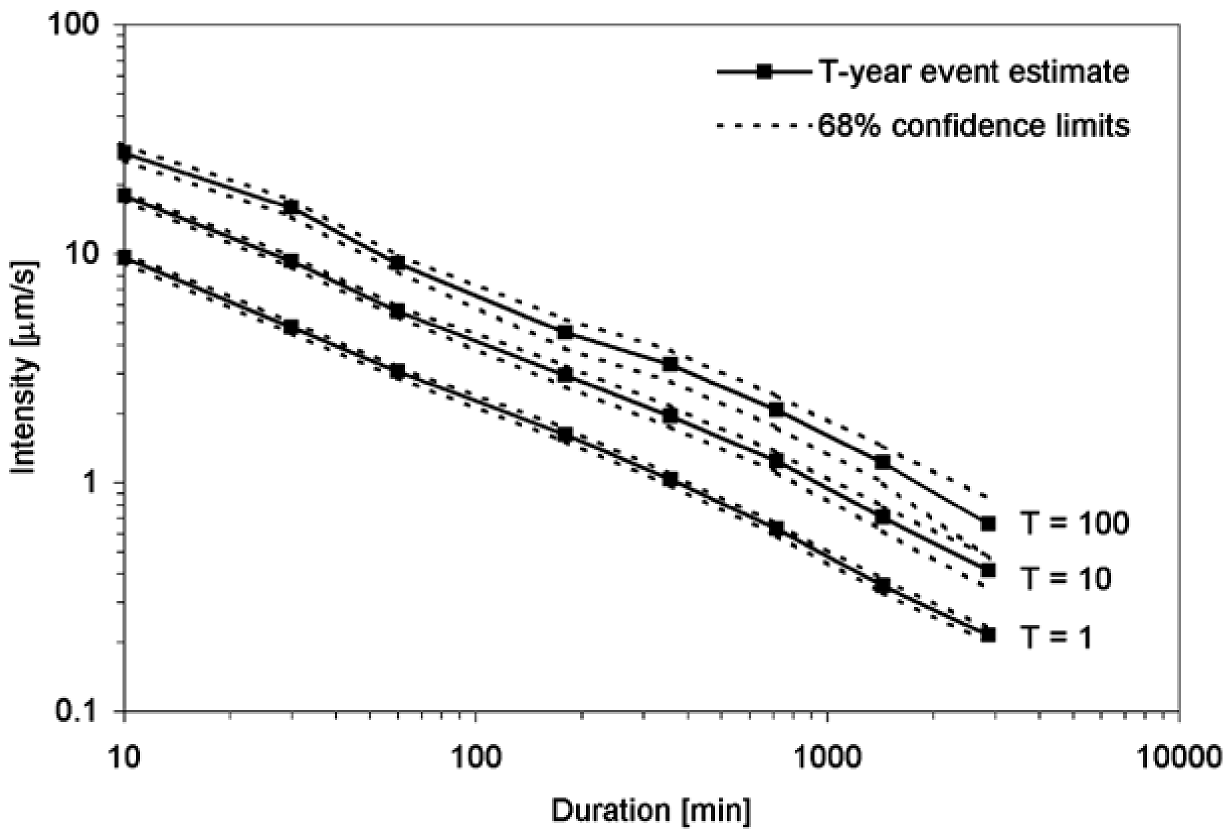

Figure 3. Analysis of projected Copenhagen rainfall (Madsen et al)

Analyzing Area for Obstacles to Renovation

Each neighborhood or borough will have obvious and unforeseen obstacles to development and implementation of a sustainable blue-green solution. This section seeks to develop the knowledge base for a balanced outlook on a prospective area. The sections here are a basis and from it more studies should be conducted dependent on any local obstacles not mentioned here.

City Policies for Area Renovations

Cities can have a variety of planning rules and guidelines for renovating sections of a city. Examples include the issue of parking spots along a street where currently the Municipality of Copenhagen requires that for every parking spot removed, another should be created. Local policies such as this are essential to consider when developing a design as support from the government increases the

Subterranean Studies

The examination of existing subterranean structures and systems is a crucial step towards developing an accurate characterization of a neighborhood. The understanding of existing subterranean systems serves two purposes: supporting the argument that the existing systems are ill-equipped to handle current and future flooding events, and allowing for preliminary SUDS and green corridor designs to be constructed within the bounds of existing structure. The understanding of the geology of the area also serves two purposes: the knowledge as to whether or not the land is considered polluted and where the water table is situated

Existing Infrastructure

Regardless of the benefit of a particular green corridor or SUDS design, the caveat of having to modify or remove existing sewer, fiber optic, or electrical systems can break an argument for immediate climate change adaptation. If the arguments and proposed design solutions are predicated on ease of implementation and cost-effectiveness it will significantly increase the likelihood of acceptance and support from stakeholders and municipality representatives. To make this argument, the existing subterranean infrastructure must be appropriately analyzed. Most pertinent to the implementation of SUDS and green space components is the depth of existing infrastructure. To properly contain and direct storm water runoff depressions and grading of multiple meters of variance must be utilized. This difference in elevation must often be gained through excavation below existing grade, as the increase in height of an urban area would not correspond with existing adjacent residential and commercial structures. To excavate properly, a comprehensive understanding of the exact depth and location of existing subterranean infrastructure is crucial. Through the knowledge of this infrastructure, it is possible to design and implement an optimal sustainable urban drainage and flood water mitigation system for a specific area.

Geology of Area

Many municipalities will have a base of knowledge on the general geology of a given area. Should data not exist, then a study must be conducted to understand the water table and basic ground composition. The water table data will show how the land can naturally absorb the stormwater runoff whereas a high water table will not accept large amounts of rainfall to be filtered into the groundwater without flooding and a low water table will accept large amounts of rainfall. This knowledge will dictate the need for separate systems to gather and redistribute rainwater for the area because if the natural earth cannot regulate it, then alternative means must be examined. The ground composition can also cause obstacles to any work in an area. Should the soil be considered polluted, then a solution that filters the water through the ground and into the groundwater will have difficulty in being approves as it could be considered polluted water on definitions set by the municipality. The composition of the soil is very important when considering the addition of structures as a sandy soil will increase the costs due to the need for foundations to be situated on firm ground.

Public Support

Plans to renovate an area must also meet public approval to increase the likelihood of implementation. The components or characteristics of the sustainable solution that are well-received can then be repeated or emphasized to maximize the aspects of the solution that the stakeholders and public view favorably.

Government Support for Funding

Government officials on a planning board of city council will require a sufficient argument for change in an area and a solution that addresses the needs before any funding is approved. Depending on the priorities of the government it may be difficult to secure public funding for a project so research into a city’s climate adaptation plan (if existent) is imperative. By aligning priorities early in the design process, support from the government can be garnered from their own goals. The amount of funding is also highly dependent on the present economic climate and this manual will cover how to adapt to this problem in future sections.

Resident Support for Renovation

One of the largest stakeholders for implementing sustainable solutions to an area is the residents currently living there. Without interest or support from them for a proposed plan, the project will have little chance of being realized. Therefore, citizens should be involved in the process and this manual will elucidate how that may be accomplished.

Characterizing Designated Area

Before any designs or systems can be considered, a comprehensive study of the area must be conducted. This should clearly characterize the general area in both quantitative and qualitative means so that a focused solution will address the specific needs. This manual does not seek to propound only one type of solution for all areas but understands that different neighborhoods and boroughs will require different solutions.

Sewer System Type

Depending on the age of an area, the sewer systems may have a variety of different configurations and use archaic building materials. An important aspect of the sewer system is the specification for a separation of stormwater and regular sewage; either stormwater has its own separate piping from sewage or they are both directed into the same main sewage pipe. A problem arises when stormwater directed to a sewage pipe exceeds capacity due to heavy rainfall events. The solution is not to make larger sewage pipes for the city but to find sustainable solutions that can use the water. The decoupling of stormwater from sewage is a large step for the system and by knowing the basic parameters of the sewage system, further designs can be conceived.

Quantitative Measurements

Quantitative measurements are the category of observations that seek to characterize the area through dimensions in order to create a design space. For street planning, this gives the planner an idea of how they must allot space and cope with boundary conditions. This section will describe the methods used to determine initial estimates with the objective in providing enough information to initiate the design phase.

Street and Sidewalk Measurements

Measurements should be taken using a tape measure or other device to determine the layout of the street. Sidewalk width, bike lane width, and street width are all important measurements along with the length of each section of the road where these measurements are relatively constant. Should the road vary widely in layout, this information will provide a planner with the necessary information to modify the design of a sustainable blue-green solution.

Qualitative Measurements

Though quantitative measurements provide hard data, qualitative measurements are also import in describing the area. These measurements range from observances of the environment to the condition of the area. This section provides a brief outlook on qualitative measurements and should not limit the scope that a team may need to consider.

Existing Green Areas

A street or neighborhood may already have existing green areas in the vicinity and this is an extremely valuable data point. By noting on a map where it lies, taking pictures, and describing key details, important data can be gathered as to the possibility of using and expanding current green areas thus reducing the potential cost for a project. Green areas that people regularly visit shows that the public supports green areas and that investment in such projects is worthwhile because they are used. Another important observation within the existing green area is how it handles drainage whether though artificial ponds, drains, or by other means. If an area already address flooding that system may be expanded to cover an even larger area and provide planners with initial designs as to the scope of the water management system.

Existing Bike Lanes

Bike lanes are omnipresent in Copenhagen and due to the ridership, any new plans for an area should look at the existing bike lanes. In the area, observers should note whether the bike lane is on both sides of the road or on one side, raised or flush to the road, and what condition it is in. Green areas typically discourage motor vehicle traffic and thus bike traffic is the norm within parks. If there are no existing bike lanes, then planners will need to consider the addition of them within the redesign of the street.

Other Measurements

Other measurements are entirely dependent on the characteristics of the street. It is strongly encouraged to take as many photographs as possible for visual planning and to give a design team a sense of the area that already exists. Other measurements such as counting the number of parking spots might also be useful in the case of working with the municipality of Copenhagen as they require that for each parking space removed, another must be created. The more data that is available for planners, the more fluid the design process will be.

Design for Street-Level Rainwater Management

The elimination of storm water accumulation and urban flooding requires the modification of the local terrain and proper management of street-level drainage. This is most effectively accomplished by channeling storm water runoff to specific collection areas and supplementing this with ample sustainable urban drainage. Commonly urban environments exhibit street-level components that facilitate storm water accumulation in low-lying areas. Through the creation of depressions, swales, and proper grading surface runoff can be effectively managed.

Semi-Permeable Surfaces

Much of urban flooding can be attributed to the totality of impermeable surfaces that comprise traditional developed environments. Impermeable surfaces disallow for water to drain naturally into the ground, instead causing runoff to flow and collect in areas of lowest relative elevation. The alleviation of urban flooding can be accomplished through the installation of semi-permeable surfaces as a supplement for traditional pavement. Semi-permeable paving surfaces allow for water to drain through paved areas into the underlying earth, drastically reducing voluminous runoff and diminishing the possibility of storm water surface accumulation and flooding. There are many different types of pavers and a few will be briefly described.

EV Paver

EV pavers are a useful semi-permeable surfacing paver as they allow for drainage at 2in per minute (50.8 mm/ min). These pavers are also resistant to loads as they can handle 10,000psi (68,950 KPa) and are tightly fitted. Figure 4 shows a basic cross-section view of how EV Pavers are typically installed and planners could collect water from this system if proper filtering were also integrated into this system.

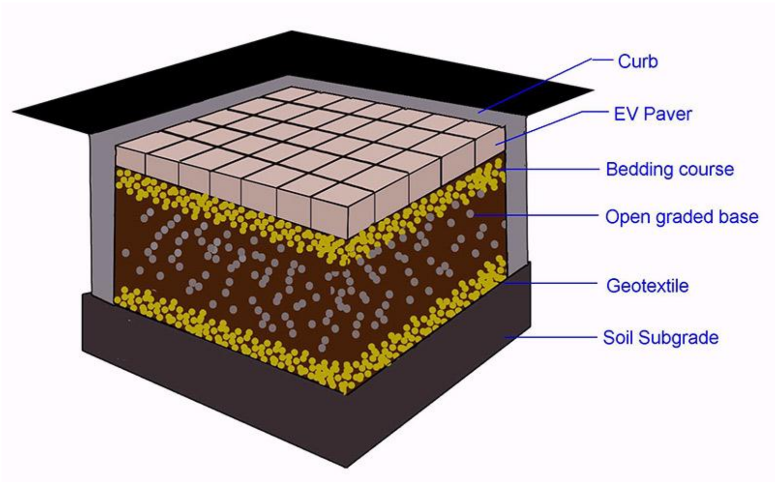

Figure 4. EV Paver (Permeable Pavers, n.d.)

Filterpave & Firmapave

Filterpave and Firmapave are two paving materials that are made from recycled products. They offer permeability ranging from 39% to 47% and are installed by pouring onto a graded surface. Figure 5 shows an example of how this material might appear in a green space.

Figure 5. Filterpave for pedestrian walkway (Permeable Pavers, n.d.)

Geoblock

This material is set up very much like paving stones, except that it allows for plant life to grow throughout, which can be accomplished by nature or through seeding. It is also made from recycled plastic and can handle larger loads for access road utilization. Figure 6 shows newly installed Geoblock as part of a future park walkway.

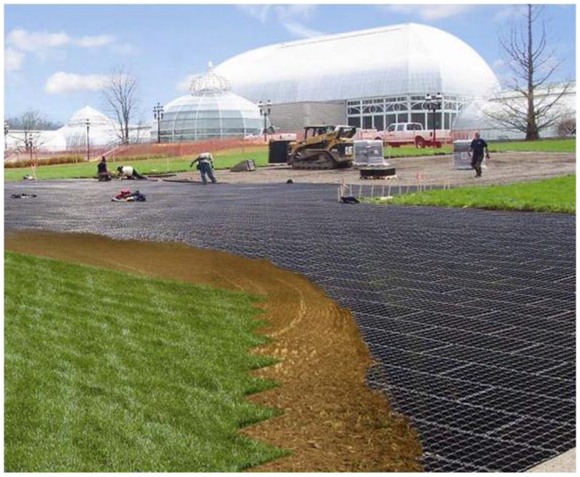

Figure 6. Geoblock (Permeable Pavers, n.d.)

Park Development and Expansion

With information gathered and basic parameters set, the approach to the park development and expansion must be decided upon. This section will cover three broad categories of parks used to incorporate sustainable blue-green solutions.

Linear Parks

Another approach to a green corridor is the idea of a linear park. This kind of corridor is built in a modular set, and one proposal for such a project is found in Figure 7 for Ranson and Charles Town, West Virginia. In this study, Hall recognizes a factor that he coins as, 'Walkability', the extent to which places are comfortable for pedestrians, cyclists, and transit users" (Hall, 2012). Indeed, in this concept plan all modes of transportation are included along with the greenery. In this approach, there is also piping for rainwater underground and small streams meant to water the gardens interspersed throughout the park. There are also plans for filtering water through sedimentation and using it for irrigation in an effort to create a sustainable blue-green solution.

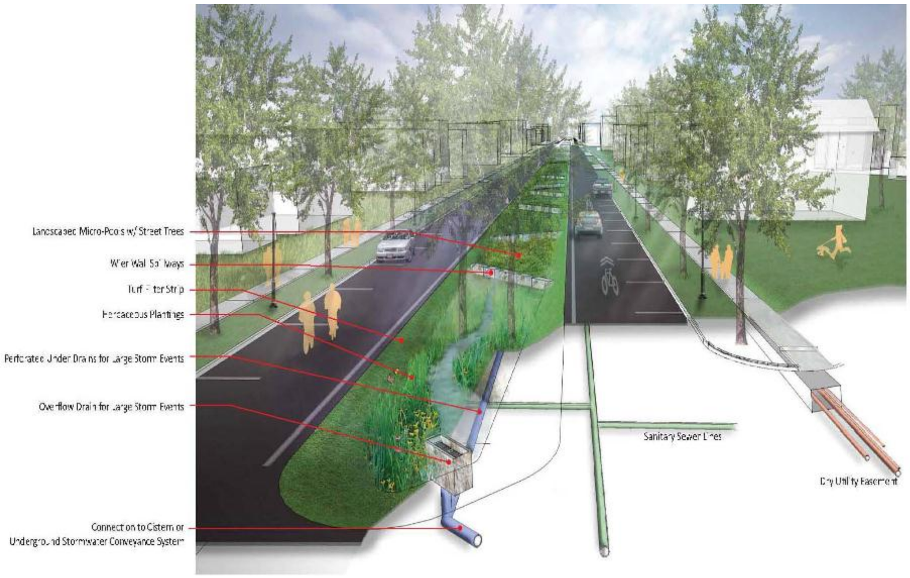

Figure 7. Linear park concept art (Hall, 2012)

Daylighting

The creation of a green corridor depends heavily on available funds. Another type of project that covers the problem of storm water management is daylighting, as shown in Figure 8 (Robinson, 2013). A daylighted stream is an underground stream, or channel, that has been excavated to fit in the green corridor while it "helps reduce urban flooding, and adds beauty to public areas" (Buchholz and Younos, 2004). This acts as a natural stream and helps to move large volumes of water at a time. As Buchholz covers in his study though, there are cost issues that must be considered in planning and there needs to be ideas put forth to offset the costs over the long or short-term such as with the success in Kalamazoo, Michigan (Buchholz and Younos, 2004).

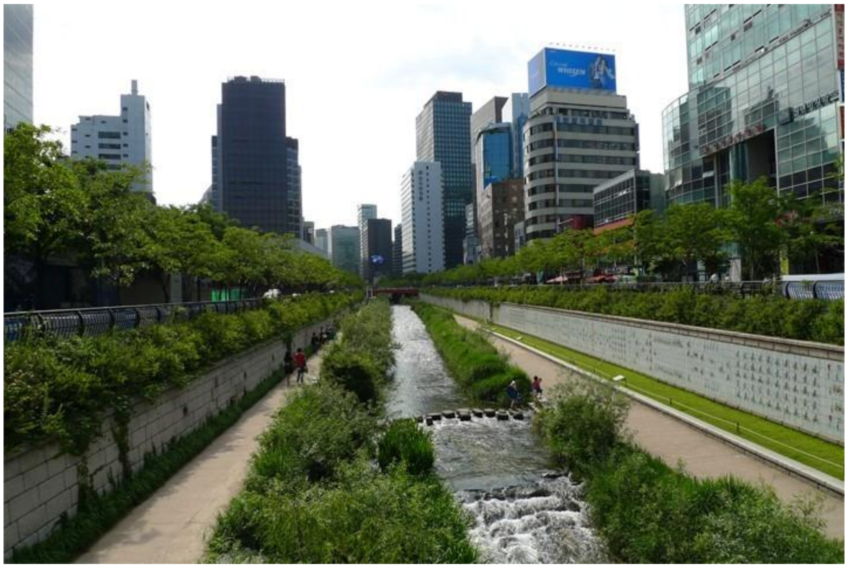

Figure 8. Daylighting in Cheonggyecheon (Robinson, 2013)

Sustainable Urban Drainage Systems

Sustainable urban drainage systems (SUDS) are a spectrum of drainage systems that share the same purpose: to manage storm water locally (Cowi, et al., 2011). They also have a common priority of keeping these solutions green, at the lowest cost possible, and minimizing anthropogenic environmental impacts (O'Sullivan, 2012). This often means that SUDS will be low-tech and low-maintenance, but will contribute to other important urban planning issues such as incorporating green spaces. Common choices of SUDS include rain gardens and roofs such as those in Figure 9, green ditches, lakes or ponds, and canals. However, each system can have a different approach. Approaches usually include elements to store, or delay the water from entering into the sewer network and/or treating the water before it reaches large bodies of surface water.

Figure 9. Renderings of rain gardens and green roofs in Kalvebod Brygge, Copenhagen.

The City of Copenhagen has identified SUDS as a main track to protect public assets and minimize damage during large rain events (Cowi, et. al, 2011). CCAP points out that the SUDS and green solutions cannot serve as the only measures implemented to deal with the increasing downpours. The city incorporates SUDS in its CCAP as a complement to storm water disconnection from the sewage system. Reducing the load on the sewage system will make it more efficient and will also help with the preparations to deal with large rain events. Along these lines, the city promotes expansion in the sewage network, 'climate-proofing' buildings to minimize damages, employing backwater valves to deal with excessive water, in addition to developing green solutions SUDS to deal with the rain.

Green spaces and SUDS although not always the same concept, share many advantages. CCAP states very concisely that "a climate-proof and greener Copenhagen is a city with more trees, green roofs, green and blue spaces and a city that as well as being able to tolerate the weather of the future is also rich in nature experiences and options for outdoor activities." Figure 10 shows gardens along sidewalks and next to the streets as examples of green spaces.

Figure 10. CCAP's vision of green spaces.

The potential of SUDS and green spaces lies in their intrinsic capacity to relieve other areas from excessive water, while serving other purposes when there is not a flood risk: creating more habitats for plants and animals in the city, providing the people with green spaces to enjoy, balancing urban temperature, improving air circulation, and reducing air and noise pollution. However, studies have shown that despite having well-known benefits, SUDS are not implemented as extensively as they should be. Perceived deterrents of SUDS are that maintenance duties are not clearly understood and that authorities do not want to take on the responsibility. But traditional drainage systems do require proper maintenance to prevent pluvial flooding, and SUDS do not represent a much larger investment when compared to traditional maintenance costs (O'Sullivan, 2012).

Given the importance and variety of positive externalities of SUDS and green spaces, the Copenhagen municipality recommends starting work where it is appropriate, needed, and has local support. As a tool of climate adaptation, the city aims to connect these green and blue spaces into a network. They plan on achieving this through giving maintenance to existing green spaces in Copenhagen and increasing the amount of these spaces. This includes appropriation of schoolyards, parking lots, courtyards, and roads, to transform them into blue- green spaces. Since the city considers this appropriate, the area along Sjællandsgade will be analyzed for areas that could be appropriated without disrupting car or bicycle traffic. A less drastic approach recommends planting more broad crowned trees on the streets and adding gardens to underestimated spaces, namely walls and rooftops, but also to more obvious spaces as seen in the three images of Figure 10.

Rainwater Catchment Systems

Surface-based rainwater catchment can be facilitated through the implementation of a number of mediums and design elements. Primarily, the inclusion of graded depressions or swales allows for water to accumulate in pre-determined locations. Graded depressions are nothing more than low-lying areas built in specific locations to trap water runoff and keep it from moving elsewhere. These depressions are commonly referred to as retention ponds.

Swales are graded linear depressions which generally run along a corridor or green area, leading water through them to a final location or destination. In times of extended rainfall or cloudburst, swales can fill up and act as linear retention ponds. For the purposes of a linear park or green corridor in an urban setting, swales are often easier to implement based on geographical limitations.

Rainwater Filtering Systems

In addition to catching and retaining rainwater, it is often a desirable result to filter the rainwater as it drains into the earth. This can be done through natural or artificial means, both of which are viable in urban environments. Without filtration, rainwater runoff can pollute the surrounding earth and groundwater as it picks up man-made toxins during the runoff process.

Sedimentation

Sedimentation is a natural filtration process where water is drained through a layer of gravel, coarse rock, or soil. As the water drains through this layer, which can vary in thickness it deposits toxins that may have been picked up on the surface. “Sedimentation is accomplished by decreasing the velocity of the water being treated to a point below which the particles will no longer remain in suspension. When the velocity no longer supports the transport of the particles, gravity will remove them from the flow” (Sedimentation, n.d.). Upon leaving this drainage layer and continuing into pre-existing earth the water is much cleaner and suitable to mix with groundwater and be consumed by plants.

Artificial Filtration

As opposed to sedimentation which utilizes natural materials and is often composed of a thick layer of material, artificial filtration requires a relatively thin sheet of fabric or polymer material. This sheet is placed over an area designed to retain water (swale or retention pond) and is backfilled over by a layer of topsoil or rock. The sheet acts as a semi-permeable membrane, allowing water molecules to drain through while inhibiting most other particulates. The resulting drained water is then introduced into the surrounding earth far cleaner than it was on the surface.

Traffic Alterations

In order to properly accommodate for the above rainwater management systems, it is likely necessary to alter traffic patterns in the area. Traditional two-way streets are often redundant in dense urban areas, as many are used specifically for local access. By eliminating select streets or reducing them to one lane of traffic it is possible to remove large amounts of impermeable paved surface and replace it with green space. This green space can be utilized for any number of flood mitigation or green area applications and will prevent traffic buildup in the area. The severity of traffic alterations that can feasibly be applied depends on the percentage of local residents that own cars and general public opinion in the neighborhood.

Design for Sustainable Residential Building Rainwater Use

Identifying Water Needs of a Residential Building

Residential Buildings are a grassroots way to implement sustainable solutions for rainwater use. A model for how to implement one of these projects is located in Folehaven. This solution will be covered in further detail within this section.

Assess Potential Catchment Volume

An essential component of a climate change adaptation proposal is the quantification of the impact of a rainwater catchment system. This quantitative impact includes the total volume of water collected and fiscal benefits on an annual basis. These figures can be calculated through the analysis of each specific residential building associated with a particular catchment system. Factors such as roof area, average rainfall per year, population density, water closet efficiency, and rainwater catchment system efficiency must be considered in this calculation to ensure accuracy. Though the mechanical attributes of a rainfall catchment system and the geometrical properties of a building do not change over time, the climate in which the system is applied will. This climate change must be accounted for in catchment volume calculations, as the system should be designed to handle future climate demands as well as current needs.

Using Average Data

The first of two sets of calculations that should be conducted is of current average climate data. Of this data, the most pertinent is rainfall totals, which can be assessed on either a monthly or yearly average scale. These rainfall totals must then be assessed over a specific catchment area, generally a roof or basin. Once this is completed, it will be possible to determine the approximate volume of precipitation that could potentially be collected by a specific catchment system annually. This number is purely theoretical, however, and is far from an accurate representation of the catchment system's capabilities. The reason for this lays in catchment system inefficiencies. Should the catchment system be installed in a location that is subject to other forms of precipitation such as snow, the system will catch less of the total potential collectable precipitation. In addition, collection components such as gutters are not without imperfection and particularly voluminous precipitation events can often result in collection system overflow. Accountings for all these factors, on average catchment systems collect approximately 67% of all potentially collectable precipitation annually. This factor of inefficiency should be considered when designing a catchment system to meet specific water usage requirements.

Using Projected Data

The second set of calculations should be conducted using projected climate data. It is imperative that a rainwater collection and reuse system be designed to operate long into the future, thus ensuring it is a sustainable solution. Climate change could affect a rainwater catchment system in a number of ways; the temperature in an area can change, either negating or introducing the necessity to account for snow and ice. The annual rainfall average can change, rendering the catchment system either too big or too small. Additionally, storm event frequency can change yielding either an increase in voluminous precipitation and high wind events or a decrease, making the anticipation of this in the catchment system design highly important. In short, the system must be designed to accommodate the plethora of changes in regional climate as well as extreme weather events. Failure to do so can result in system malfunction and defectiveness, a conclusion that defeats the purpose of climate change adaptation.

Rainwater Catchment Systems

The Folehaven rainwater catchment system is a non-potable reuse system which repurposes rainwater for use in washing machines in a large housing complex's laundromat. The system collects runoff from the roofs of buildings adjacent to the laundromat through a network of pipes and filters. The roofs are lined with gutters connected to an exterior underground storage tank in between two buildings. This exterior underground storage tank is in turn connected to the laundromat building through underground piping. Once the exterior underground storage tank has reached a preset volume capacity, the water is pumped into the basement of the laundromat building via an electric water pump. Upon entering the building, the water is fed into seven 4000 L interior holding tanks. Water is then pumped from these tanks to the washing machines as necessary. Additionally, there exists eight 5000 L backup interior holding tanks, which can be utilized in times of excessive precipitation, giving the system a total of 68,000 L of holding capacity.

Rainwater Filtering Systems

The Folehaven system has numerous filters which cleanse the rainwater and prevent particulates from entering the washing machines. The first filter is a coarse filter located just above ground on the vertical gutter outflow pipe. This filter keeps rocks and other large debris from entering the initial underground holding tank. The next filter is located on the end of the pipe that runs from the exterior underground holding tank to the interior holding tanks in the basement. This filter is finer and is equipped to filter out such items as leaves, animal excrement, and other small particulates. Any particulates that escape this filter are then settled out to the bottom in the interior holding tanks in a process similar to gravity thickening. There also exists a third and final filter which is finer than either of the first two. Located on the outflow pipe from the interior holding tanks to the washing machines, this filter is more of a failsafe filter which provides an extra layer of filtration before the water enters the washing machines. Between the three filters and the gravity thickening process the rainwater is clean and suited for non-potable use.

Non-Potable Use

Non-potable reuse is the easiest application for recycled rainwater. "Non-potable water is water that is not of drinking water quality, but which may still be used for many other purposes, depending on its quality." (Non-potable Water, n.d.) Because it does not have to be of drinking water quality, it is far more feasible to install a water catchment and filtration system that produces water of this standard.

Potable Use

Quite simply potable reuse is for consumption and direct consumer contact purposes. Potable water, which is water that is "suitable for drinking" (Merriam-Webster), must meet specific standards specified by regional consumer health and safety boards. As this standard is set rather ambitiously to ensure high quality drinking water, it is inherently difficult to achieve such water quality with a system similar to the Folehaven rainwater catchment and reuse system. A potable reuse system may contain elements such as a chlorine shock treatment tank, aeration tank, or caustic chemical treatment pool.

Rainwater Storage

Rainwater storage is important in a reuse system, as rainfall is inconsistent when compared to daily usage habits. Rainwater storage tanks or units must be designed to meet the specific usage requirements of the system they are attached to. For example, the Folehaven rainwater catchment and reuse system can hold at a maximum 68,000 L of water. Daily usage statistics for the community's laundromat show an average water consumption between 5000 and 6000 L, meaning that the Folehaven rainwater storage tanks hold roughly 10 times the amount of water used per day. Notably this is a very large scale usage system, thus limiting the proportionate storage capacity to what fits in a reasonable space. Ideally, rainwater storage units should hold between 10 and 20 times the daily usage volume.

Cisterns

Cisterns are the most common form of collected rainwater storage. A cistern is a waterproof water containment device, such as the tanks used in the Folehaven rainwater catchment and reuse system. Cisterns are common because of their versatility; they can be placed underground, above ground, inside structures, or in any other location that they can fit in.

Cisterns also come in nearly infinite sizes and tank configurations, allowing them to be easily configured to almost any rainwater catchment and reuse system.

Tiered Solutions for Sustainable Development

Tiered System

A tiered system for design is a balanced approach to conceptualizing degrees of sustainable development for an area. Whereas a Tier I solution envisions a 'utopian solution,' higher degrees of Tiers give incremental downgraded solutions as to the scope of the project. In this section, we will describe the Tiers developed for a project plan focused on Sjællandsgade. Though there are only three different Tiers described here, it should not preclude design groups and planners from developing an even wider range of Tiers for the needs of the community.

Tier I

This solution tries to incorporate as many sustainable elements within a neighborhood or street so as to create a park and residential solution that eliminates motor vehicle traffic while addressing rainwater management needs. This solution is the complete approach that may increase costs for a project but it succeeds in mitigating flooding issues due to the A2 forecast for global warming in rainwater increases. A Tier I solution applies the Folehaven example for residential water collection and use thereby eliminating roof runoff and separating rainwater from sewage and decreasing the load on the sewage system.

In the park, solutions such as swales, rain gardens, and semi-permeable pavements with piping to distribute overflow to holding tanks (separating rainwater from sewage) is another integral part of the Tier I solution. Power should come from renewable sources such as solar panels (along buildings or through solar trees) or vertical wind turbines for the needs of pumping water. The decoupling of rainwater from sewage is one of the most important aspects of this solution, but there are also a variety of other elements: biodiversity, bike lanes, park layout, emergency vehicle access, parking, safety, and community involvement. By promoting biodiversity in an area, the Tier I solutions seeks to provide a network of corridors that connect parks within a municipality. Bike lanes are important as it promotes use of the park while providing a means by which the public can use personal transportation. The park layout is a complex planning project as it must provide shade to areas and sun to others while incorporating such necessities as park benches.

Planning the layout also must take into consideration what the residents' desire such as aesthetics, community gardens, fountains, landscaping, and other park elements. In designing the Tier I solution, access for emergency vehicles such as ambulances and fire engines should not be forgotten; it is up to each planning committee to decide on this traffic pattern issue, but we recommend that side streets be left accessible and that materials used for bike lanes or semi-permeable walkways be strong enough to maintain loads of heavier vehicles in an emergency. In the current political environment, the municipality requires a net zero change in parking spaces. The objective of a Tier I solution seeks to eliminate car traffic in an area, but to meet the requirement of the municipality a deal can be struck in a few different forms.

In the Skt. Kjelds Plads project, they had space in part of their district to concentrate parking on street level to meet the needs of the parking space requirement. However, not every area will have this situation and may be extremely limited in space thus requiring a more expensive solution or deal with the city. Underground parking is a possibility and requires more funds but it does provide a solution for concentrating many parking spaces while not affecting the green area. A second underground level could also be used for rainwater catchment in a 100-year storm incident and later drained. Safety is another important consideration to the park development and elements such as barriers to prevent cars from entering the park to lighting for nighttime will make park users feel safer thus attracting more people to the area. Lastly, community involvement should be present at all stages of design for the park as their support gives power to the plans as being a worthwhile investment and makes sure that their needs are met by this project. All of these must be incorporated to develop a successful Tier I solution.

Figure 11. Tier I Park

Tier II

This solution makes concessions as to the extent of the project mainly in the category of traffic. In a developed Tier II solution, local traffic is allowed along a one way street while still keeping the two-way bike lane. Parking will also be allowed on one side of the street due to the allowance of traffic and reduced scope for the project. This will reduce the amount of green space and thus swales are more localized rather than long connected sections. Tier II also recommends roof runoff collection and decoupling from sewage but not every building will have the funding from the government or private funds to utilize the Folehaven model. Thus rainwater in both roof and surface runoff should be diverted to areas such as a harbor or large body of water while still having basic filtering to meet the requirements set by the government for rainwater runoff drainage. Tier II should be treated as an intermediary solution that expands upon the Tier III solution but does not incorporate the level of sustainable solutions presented in Tier I. That being said, a Tier II solution can be a phase of a project that could then be expanded to Tier I over time especially in the area of utilizing rainwater for toilets or washing-machines within apartment blocks.

Figure 13. Tier II.

Tier III

This final Tier is a low impact project but still seeks to implement elements of blue-green solutions. The two-way street is maintained and parking spaces are rearranged into more concentrated areas to make room for green-space. Bicycle traffic is still concentrated as in the Tier I and Tier II solution by creating a two-way bicycle lane. Along the street, blue-green solutions are highly localized by closing only small parts of a street where there is not heavy traffic and creating smaller parks along the street that may not be connected. Smaller swales are created in this design where natural grading will cause the water to flow into these retention areas. Unfortunately, due to the limited scope this plan may not meet the water volume needs under A2, but it will reduce the amount of flooding leading to less severe damage. The water collected by any new systems will be decoupled from the sewage to reduce the load on the existent infrastructure.

Figure 14. Tier III street level.

Benefits of using a Tiered System

A tiered system gives planners a means to show phases for a project to deal with different levels of sustainable solutions. It shows the pros and cons for each solution by reflecting on areas such as cost, time to implement, and degree of sustainability. This provides planners with a method of presenting plans to the residents and to the municipality by clearly describing the options they have for development. In the case of presenting a Tier I solution to a municipality and a rejection, planners may then present a Tier III solution that does not necessarily cover the needs of the area which could then lead to an agreement on the Tier II solution. The implementation of a Tier II solution could eventually lead to a Tier I solution in the future as funding is secured to only provide for the expansion of the proposed Tier II. Rather than designating a larger sum for implementing the Tier I solution in a tough financial environment, this approach encourages compromise to still affect change.

Focus Groups

Focus groups are important in the tiered system approach as they create a dialogue with stakeholders as to what they see as the needs for an area and it can also gage opinions as to proposed solutions. Since we are working to solve a flooding problem in a residential area, it is essential to determine the opinions of the residents on both the severity of the flooding problem and potential floodwater management solutions. Holding a focus group with the local residents helps to facilitate a conversation on flooding in the area, and it allows the planning team the chance to hear personal anecdotes and perspectives on the extent of flooding in the area, what has happened during periods of high volume rainfall, and the damages the people have suffered because of flooding in the area. This builds upon the argument that renovations to an area must occur to mitigate the problem. This conversation also holds to argue for a Tiered solution that may cost more but is widely regarded as being necessary. The focus group of residents also can make recommendations for and against certain aspects of the design and provide planners with a different perspective to enhance their plans. The goal of implementing plans is to help an area and the involvement of residents throughout the process gives them ownership in the project.

Analysis of Design

The analysis of the design is a vital part of the process for implementation. This section seeks to build upon the viability of a proposal and provide insight to how several solutions may be evaluated upon set parameters. The analysis of a design should also provide teams with the ability to take their data and redesign their proposals to meet more criteria.

Cost-Benefit Analysis

The use of cost-benefit analyses to justify an argument for sustainable climate change adaptation is beneficial. Many of those that this argument will be posed to are politicians and other representatives of the municipality, people that will be concerned with the cost of the notion of climate change adaptation. As with any major expenditure, especially those involving government funding, the benefits of the expenditure must be statistically proven to outweigh the cost. To make the climate change adaptation plan cost effective, a comprehensive analysis of the amount of drinking water saved by a rainwater reuse system should be conducted. This analysis includes determining the amount of viable drinking water that can be supplemented on an annual basis, the monetary value of that saved drinking water, and the cost of implementing the potential design solutions. If the argument is well-posed and the design solutions are chosen appropriately based on compiled statistical data in the specified area, the benefit of installing any climate change adaptation protocol will far outweigh the financial implications of such action, furthering the likelihood of stakeholder and municipality acceptance of this initiative.

Risk-Uncertainty Analysis

Due to the fact that politicians will be receiving these arguments for implementing sustainable solutions, we need to analyze the possible uncertainties that arise from the simple fact that they are different individuals with different ideas about climate change and adaptation plans. How a politician thinks directly affects whether or not they will accept a proposal, so this difference needs to be accounted for in the decision making.

The first step is to realize that there will always be some uncertainty in design proposal, called aleatory uncertainty, which no one can neither predict nor alleviate. However, differences in background (ambiguous uncertainties) and knowledge (epistemic uncertainties) can be reduced by keeping dialogue open and providing correct information, respectively (Refsgaard, 2011). The arguments need to be structured for the existence of a flooding problem in the area and the need for a floodwater management solution can be based upon fact.

Another thing the argument needs to consider is the lack of certainty in future climate change prediction models. Stakeholders will potentially be skeptical about the severity of the predicted changes or the presence of changes at all (Refsgaard, 2011). As a team, you need to bolster your arguments for action to be able to stand even in the presence of uncertainties. This can be done by applying two decision making strategies; (1) the precautionary principle, which provides a guideline for decision making through the understanding of risks and uncertainties, and (2) the minimax strategy, which assigns numerical significance or priority to a solution through creating a numerical evaluation matrix (Gregersen, 2012). A numerical evaluation matrix (example in Table 2) assigns weights based on the importance of each design constraint/objective, which will assess which action or solution is ideal (Summers, n.d.).

Table 2. A decision matrix detailing the relevance and feasibility of all proposed solutions. These matrices are used to determine optimal solutions.

Design Constraints/Objectives	Weight (%)	Cisterns	Rain Gardens	Porous Surfaces	Non-Potable Filtering	Rain Water Separation
Low Impact Development						
Community Support						
Cost						
Capacity for rainwater diversion/retention						
Generates Greenery						
Long-term upkeep needs						

Expert Response

The consideration of opinions from civil and environmental engineers, architects, mechanical engineers, and other pertinent experts in the fields involved in climate change adaptation is highly important in the design analysis process. Though a specific design solution will undoubtedly be created with the help of such professionals, submitting a design solution proposal to other experts for additional comments and consultation is always recommended. The design solution must be sustainable and designed optimally for the specific environment in which it will be implemented.

Resident Response

As the climate change adaptation solution will be a drastic physical change to a neighborhood or street, the residents of this area must be at the least accepting of its design and components. Though they are not experts on engineering design elements, the residents in the vicinity of a proposed green area or floodwater mitigation component will have the best understanding as to how a proposed sustainable solution will impact the community. Additionally, residents may express or identify slight aesthetic changes to designs that will greatly improve the appeal of the project to the community. If the project is not well-received by the community, it may be impossible to proceed with sustainable solution implementation. It is hoped that through the use of focus groups in the developmental tiered phase that there will be little dissent to the design as ownership has been shared with the residents for this project.

Redesign

Redesign is part of the engineering process after feedback has been gathered from analyses, expert opinions, and resident input (and possibly municipal employees). This is the phase where all these considerations should be taken into account and each element of each tier be scrutinized. This is the final phase before presenting plans to a municipal planning board to secure funding for further studies and development of the project into construction. All elements should be clearly described in a report for each Tier to make arguments for their need in the overall project and how the solution encompasses a wide range of interconnected elements in order to provide the best response to climate change and the resident's needs. The report should also include hard data on the flooding problem as according to A2 predictions and calculations made by the project team. With a comprehensive report, the municipality will have an argument for change and several options to decide between to work within the overall Climate Adoption Plan initiative.

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