Illustration: Frederiksberg Kommune

Towards dynamic CCA planning – an investigation of the concept of DAPP's applicability for rainwater management in Frederiksberg, Denmark

Master Thesis

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Abstract:

Human-induced climate change will lead to more frequent and intense extreme events setting urban populations at risk from climate change (CC). Therefore, climate change adaptation (CCA) is necessary to respond to the increased risk of CC. In Frederiksberg, Denmark, ambitious CCA strategies have been developed to accommodate future extreme precipitation events. However, these strategies have a static character making them vulnerable to the uncertainties associated with CC. On this basis, the following research question has been investigated: ***"How can a strategy for CCA be developed which meets short terms adaptation goals while being sufficiently robust and flexible to keep options open for future actions or shifts in strategy to accommodate future risk?".*** The research investigates the utilization of elements from the concept of Dynamic Adaptive Policy Pathways (DAPP) to promote dynamic CCA strategies based on Frederiksberg's Rainwater Plan which is currently under development. A risk assessment has been performed of a case area to understand both the current and future local risks. Additionally, potential CCA measures have been mapped and subsequently assessed in relation to their physical suitability. The suitable measures have then been assessed based on a multi-criteria analysis (MCA) through the utilization of criteria which represent the context of planning under deep uncertainty. On this basis, adaptation pathways have been developed which both have a significant short-term effect and have a character that ensures that the measures will not lose their value under unpredicted future climatic conditions or in case of shifts in strategy to new measures. On this basis, it can be derived, that the investigated approach to dynamic CCA is suitable to create a systematic approach for dynamic CCA planning. However, the actual facilitation of a DAPP-process must include wide participation of stakeholders to strengthen the MCA and to ensure an embeddedness of the strategy in the relevant organizations.

Preface

This final report is conducted for the 4th semester of the Cities and Sustainability program at Aalborg University. The subject of this master's thesis is based on a problem-oriented internship at Frederiksberg Utilities focusing on climate change adaptation (CCA) from a rainwater perspective as a part of the 3rd semester of the program. During the internship, I had the opportunity to gain insight into the approach to CCA planning in Frederiksberg and to be involved in the current planning process of developing a new rainwater management plan. As I was offered the opportunity to stay in the organization during the master thesis project period, the master thesis is set in the context of Frederiksberg and Frederiksberg Utilities to be more specific. The motivation of the master's thesis stems from an insight into the mistakes and inconveniences that Frederiksberg Utility and Municipality have learned from through the development of several climate change-related plans and strategies during the last decade. Therefore, during the current development of the new rainwater management plan, the aim is to find a format and a level of planning detail that is suitable to steer CCA planning in a clear direction while being robust and flexible to deep uncertainty associated with climate change.

I would like to say thank you to several people for their help during the project period. First, a thank you to Søren Gabriel from WSP Danmark to set time aside to discuss dynamic rainwater management planning and to provide insights into hydraulic calculations. Secondly, I would like to thank the head of the water department at Frederiksberg Utilities, Henrik Sønderup, for ongoing discussions and feedback. Lastly, I would like to thank my supervisor, Martin Lehmann, for his very constructive feedback and guidance throughout the project duration.

The report structure is based on the IMRaD approach to scientific research and is presented below.

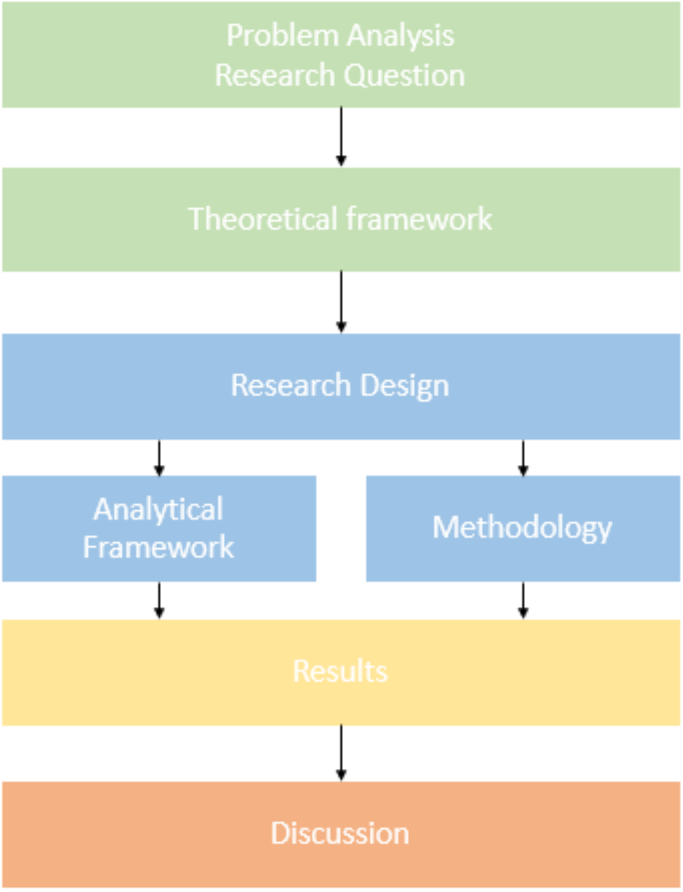

Figure 0.1 - Report structure based on IMRaD

First, the conducted problem analysis will dive deeper into the problem presented in the introduction and analyze the challenge in the context of CCA planning in Frederiksberg. On this basis, a research question is developed. To qualify the research question, and develop associated sub-questions, a literature review has been conducted to provide a theoretical framework on planning under deep uncertainty and dynamic adaptative policy pathways from which the sub-questions originate. The approach to the research, with the underlying aim of answering the sub-questions and eventually the research question, is presented in the research design, which further frames the necessary analytical framework and methods to be applied in the study. Based on this, the results are presented and subsequently discussed in relation to how they can answer the stated research question.

Executive Summary

Det er endnu en gang blevet slået fast af IPCC, at menneskeskabte klimaforandringer vil medføre hyppigere og voldsommere ekstremvejrshændelser i fremtiden med potentielle kritiske påvirkninger på menneskelige og naturlige systemer (IPCC, 2022). Drastiske reduktioner i udledningen af drivhusgasser er nødvendige for at nå globale målsætningerne om at holde stigningerne i jordens gennemsnitlige overfladetemperatur under 1,5 grader (Ibid.). Men selv ved drastiske reduktioner i udledningen af drivhusgasser kan jordens overfladetemperatur forsætte med at stige på grund af forsinkelsesmekanismer i jordens klimasystem. Derfor er klimatilpasningsindsatser vurderet nødvendige og højaktuelle for at reducere risikoen for de påvirkninger, som er associeret med klimaforandringer.

Historisk set har tilgange til klimatilpasning været forbundet med reaktive tilgange som respons mod oplevede skader (European Environment Agency, 2016). Dog er et paradigmeskift i tilgangen til klimatilpasningsplanlægning undervejs mod en mere proaktiv tilgang til klimatilpasning, som både søger at håndtere nuværende udfordringer samtidig med, at beslutnings- og handlingsmuligheder holdes åbent for fremtidige udfordringer (European Environment Agency, 2016; Haasnoot, Kwakkel, Walker, & ter Maat, 2013). Dette paradigmeskifte bryder med den nuværende ”predict and optimize” tilgang (Babovic, Mijic, & Madani, 2018; Hallegatte, Shah, Brown, Lempert, & Gill, 2012), som er karakteriseret ved, at langsigtede planer og løsninger tilpasses et fremtidigt scenarie, som er vurderet mest sandsynligt. Da klimaforandringerne og de dertilhørende konsekvenser er usikre, er investeringer i klimatilpasningstiltag følsomme overfor klimaforandringer (Babovic et al., 2018), og dermed skal fremtidens klimatilpasningsplaner kunne omfavne denne usikkerhed og bruge den aktivt i planlægningen (Haasnoot et al., 2013).

På Frederiksberg har der over det sidste årti været en stort fokus på klimatilpasning, og flere klimatilpasningsstrategier og planer er blevet udarbejdet som reaktion på et voldsomt skybrud i 2011. Dog er Frederiksbergs planer karakteriseret ved, at de er statiske planer, som indeholder enten statiske løsningsstrukturer eller målsætninger, som er baseret på én forventning til fremtidens klima. Dermed er der et behov for at finde et detaljeringsniveau i Frederiksbergs planer og strategier, som indeholder tilstrækkelig konkretisering til at udstikke en ramme for fremtidigt arbejde til at opnå politisk opbakning, samtidigt med at planerne er tilstrækkelige dynamiske og fleksible til, at planerne også er aktuelle, hvis uforudsete klimatiske forhold opstår i fremtiden. På baggrund heraf er følgende problemformulering opstillet:

”Hvordan kan en klimatilpasningsstrategi blive udviklet, som er i stand til at imødekomme kortsigtede klimatilpasningsmålsætninger samtidigt med, at strategien er tilstrækkeligt robust og fleksible til at holde muligheder for fremtidig handling og skift i strategi åben i fremtiden til at imødekomme fremtidige risici?”

Formålet med denne problemformulering er at undersøge, hvordan det føromtalte nye planlægningsparadigme kan implementeres på Frederiksberg. Dertil er der udarbejdet en teoretisk ramme omkring planlægningstilgangen ’Planning under deep uncertainty’ og dynamiske tilgange til klimatilpasning, som er udviklet til at omfavne denne usikkerhed. Elementer fra planlægningstilgangen Dynamic Adaptive Policy Pathways (DAPP) fra denne teoretiske ramme er udvalgt og forsøgt applikeret i kontekst af Frederiksbergs kommune og forsynings Regnvandsplan, som er under udarbejdelse. Dertil tages der udgangspunkt i et

specifikt vandopland på Frederiksberg med henblik på at skalaen er egnet til specialets rammer og begrænsninger.

Det første trin er at gennemføre en systembeskrivelse af området og en kortlægning af områdets nuværende og fremtidige risiko. I dette henseende er en analytisk ramme baseret på IPCC's Risk Assessment Framework og klimascenarier anvendt til at forstå risiko-konceptet ud fra både nuværende og fremtidige forhold. Data er indsamlet både i form af klimadata for Frederiksberg til at beskrive både intensiteten og forekomsten af nutidige og fremtidige regnvejrshændelser, samt data i form af urbane funktioner og services som er udsatte, samt forhold som gør området særligt sårbar. Disse data er visualiseret hhv. SCALGO Live og i QGIS med henblik på at identificere særlige risikoområder. På baggrund af denne kortlægning af området er der foretaget en kortlægning af potentielle klimatilpasningsløsninger, som derefter er blevet screenet ud fra deres implementerbarhed i forhold til de lokale fysiske forhold. Dette er gjort ud fra screenings-kriterier fra den anvendte analytiske ramme. Herefter bliver de tiltag, som er vurderet egnet, vurderet ud fra en multikriterie-analyse, hvortil der anvendes en bred vifte af kriterier, som er identificeret ud fra litteraturen fra den teoretiske ramme omhandlende planlægning under usikkerhed og dynamisk klimatilpasnings-planlægning. På baggrund heraf er tiltagene blevet rangeret efter deres score fra multikriterie-analysen, og disse er anvendt til at sammensætte egnede klimatilpasningsstier for, hvordan klimatilpasningsindsatsen skal prioriteres med henblik på at opnå kortsigtede målsætninger og implementere de tiltag, som giver mest værdi på den korte bane. Dermed holdes mulighederne åbne for at fremtidig handling og investeringer i tiltag og løsninger, som kan føre til lock-ins og fejltilpasning, forebygges.

Da rapportens analyser kun har taget udgangspunkt i elementer fra DAPP-tilgangen, er det ikke muligt at konkludere, hvorvidt en fuld DAPP-proces er egnet til at blive implementeret. Dog kan konklusioner udledes i forhold til, hvordan de undersøgte elementer kan styrke den dynamiske karakter og fleksibiliteten i Regnvandsplanen. De udsprunget klimatilpasningsstier, som baseret på en rangering af de undersøgte klimatilpasningstiltag, udstikker en retning for, hvordan klimatilpasningsindsatsen skal prioriteres ud fra det nuværende vidensgrundlag. De højst rangerede tiltag er opmagasinering i det eksisterende terræn og skybrudsventilen på baggrund af en vægtning af multikriterie-analysens kriterier med fokus på fleksibilitet, robusthed, og omkostninger. Disse tiltag har tilfælles, at de har størst implementeringspotentiale på private arealer, og dermed forudsætter disse tiltag, at der igangsættes en forudgående planlægningsproces, hvor der indgås aftaler med private grundejere. Det regnes dog med, at rapportens resultater bliver udfordret af den virkelighed, som forsyningen og kommunen går i møde, hvor ny regulering har skabt et øget fokus på samfundsøkonomiske beregninger og selskabsøkonomiske effektive investeringer samt korte implementeringshorisonter. Disse ændringer kan udfordre prioriteringen af klimatilpasningstiltag, som vurderes mest attraktive i en multikriterie-analyse. Dermed er det essentielt, at kommuner og forsyninger selv foretager vurderingerne og vægtninger af kriterierne i disse analyser. På baggrund heraf kan det konkluderes, at den forslået tilgang til dynamisk planlægning kan skabe stor værdi for kommuner og forsyningers klimatilpasningsarbejde. Dette skyldes, at tilgangens værktøjer såsom multikriterieanalysen og klimatilpasningsstierne kan forebygge, at uforudsete forhold, såsom den nylige ændring i reguleringen, fører til forhastede investeringer, da prioriteringen af klimatilpasningstiltag bestemmes baseret på en bred række kriterier. Derudover er multikriterie-analyse og udarbejdelsen af klimatilpasningsstier essentielle i at udføre en systematisk og veldokumenteret tilgang til klimatilpasnings-strategier, som er fleksible og robuste til at omfavne de store usikkerheder, som er forbundet med fremtidens klima.

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I. Introduction

1 Introduction

With the publication of the most recent IPCC *ARC6 Climate Change 2022: Impacts, Adaptation, and Vulnerability* report, it has once again been stated with increased confidence that human-induced climate change has led, and will continually lead, to more frequent and intense extreme events which entail adverse impacts on both human and natural systems at a rate beyond the natural climate variability (IPCC, 2022). Such extreme events include more frequent and intense heavy precipitation events, droughts, heatwaves, and storm surges. On this basis, extensive climate change mitigation strategies and actions are necessary to drastically reduce human-induced climate change (European Environment Agency, 2016). The Paris Agreement of 2015 imposes a goal of limiting global mean temperature increases to well below 2 degrees, preferably below 1.5 degrees Celsius, compared to pre-industrial levels, implying rapid decreases in GHG emissions (United Nations Framework Convention on Climate Change, n.d.). According to the IPCC, global surface temperatures were 1.09 degrees Celsius warmer in the period 2011-2020 as compared to 1850-1900 (IPCC, 2021). However, even drastic reductions in GHG will not stop further warming for several decades due to the thermal inertia of the climate system which has a delaying effect on warming (European Environment Agency, 2016). IPCC's five newest climate scenarios present just one scenario, the SSP1-1.9, which will keep the global mean surface temperature below the 1.5 degrees threshold. This scenario includes drastic reductions in GHG emissions which decline to net zero in 2050, followed by net negative emissions after 2050 (IPCC, 2021). Therefore, the Paris Agreement will not be respected unless drastic GHG reductions are rapidly introduced. However, the tendency since the previous IPCC AR5 report has been, that the current development follows the previous RCP8.5 pathway (high radiative forcing scenario) (CoastAdapt, 2017). This scenario includes an increase in GHG emissions until 2100 (IPCC, 2014), and therefore, global surface temperatures will continue to rise.

On this basis, climate change adaptation (CCA) is necessary and urgent to reduce the risks of climate change impacts. The risk of climate-induced hazards is accumulated in urban areas (Raven et al., 2018). Urban areas have high concentrations of economic, social, and cultural assets and values which increases the urban risk of hazards and an increase in urbanization is putting further pressure on urban systems and infrastructure to cope with climate-induced hazards (Bader, Blake, & Grimm, 2018; Raven et al., 2018). There are different approaches to CCA which differ in relation to their level of proactiveness (European Environment Agency, 2016). Historically, the CCA approaches have been reactive as adaptation actions have been implemented as a response to damages (Ibid.). However, a shift is occurring towards a more proactive approach to CCA which seeks to address both current and future hazards over long-term planning horizons (Ibid.). These approaches are more anticipatory as they seek to explore future climatic conditions under which the proposed CCA measures must function within. However, climate change is still largely characterized by uncertainties and therefore long-term adaptation investments in infrastructure are very climate-sensitive (Buurman & Babovic, 2016; Hallegatte, 2009). Climate models agree on overall tendencies and trends in the future climate (IPCC, 2021), however, the climate data output in regard to impacts on local areas such as the magnitude of future extreme events comes with large uncertainty ranges (See DMI (2022)). Therefore, it is a challenge to conduct long-term CCA planning when the magnitude and the associated risks of future events are uncertain. There is a broad range of factors that cause uncertainty, including the scientific understanding of the climate system's mechanism and its sensitivity to GHG emissions, socio-economic developments such as population growth, as well as future political development e.g., in relation to mitigation strategies (Climate.gov, n.d.; Hallegatte et al., 2012; IPCC, 2021). Therefore, there is a need to conduct long-term CCA planning which can embrace these uncertainties.

2 Problem Analysis

2.1 Historical approach to water management and climate change adaptation planning

Water management systems have historically been designed and constructed as large underground and centralized structures to provide reliable services (Fratini & Jensen, 2014). Initially, water management systems were engineered and constructed to provide a reliable source of freshwater to the growing demands of cities, and sewage systems were established to discharge insanitary wastewater out of the city boundaries to prevent epidemics (Brown, Keath, & Wong, 2009). The complexity of urban water management systems has since then continuously increased as a result of rapid urban development. The rapid expansion of cities, like Copenhagen, led to the urban development of large surrounding areas which included the drainage of wetlands and alterations of waterways to accommodate the needs and requirements of urban areas, resulting in a demand to discharge unwanted water to avoid flooding (Ibid.). This demand is further exacerbated by an increase in urban water runoff from the introduction of impermeable surfaces.

In the case of Frederiksberg and Copenhagen, the sewage system, which dates back to the 1860s, has to cope with water from multiple sources in comparison to when the system was originally constructed. Furthermore, the sewage system of Frederiksberg has since then been continuously maintained, however, the capacity has not been increased (Frederiksberg Kommune, 2020). Therefore, the sewage system has not been altered or retrofitted to cope with the increased pressure from urban development. Additionally, the capacity of the water management systems has not been retrofitted to accommodate expected future increases in precipitation because of climate change. Besides increasing the annual precipitation, climate change will increase both the frequency and intensity of extreme precipitation events in Denmark (DMI, 2022). Based on the above, the water management system of Frederiksberg has not historically been dimensioned to manage and cope with the precipitation events of today, nor the future, as it was primarily constructed as a response to insanitary living conditions.

However, current CCA practice strives to incorporate future projected levels of precipitation when dimensioning new or retrofitting existing water management systems. There are multiple different calculation levels in relation to the complexity of calculations that the Danish Wastewater Committee (IDA Spildevandskomiteen) recommends for designing urban water management infrastructure. Without going into the specific details of these approaches, they share the characteristic of attempting to imitate reality through calculation methods and hydrodynamic modeling instruments. These approaches have in common that they are all based on historical precipitation to some extent. To ensure that the designed infrastructure can accommodate future levels of precipitation, climate factors (based on downscaled climate model data) can be used to take the expected increases in precipitation levels into account (IDA Spildevandskomiteen, 2005). Based on these approaches, the current practice is to find economically optimal return periods, in which the water management systems should function, to achieve an optimal balance between costs invested into retrofitting the system and the avoided costs associated with prevented flooding from projected future precipitation levels (Ibid.).

This illustrates a focus on efficiency in the Danish water management sector, which has further increased since the privatization of utility companies was carried out after the introduction of the new Danish Water Sector Act in 2009 (Fratini & Jensen, 2014). The privatization of the utility companies led to a detachment of water management system planning from other planning agendas to ensure economic optimization (Ibid.). In relation to the current practice for designing and dimensioning water management systems, this privatization and focus on efficiency has further increased the need for the ability to predict future levels of precipitation as input for calculations or hydrodynamic modeling to propose optimal solutions for a projected future (Hallegatte et al., 2012). However, finding economically optimal return periods, and the associated precipitation events that the water management systems should be able to cope with, is heavily dependent on the reliability of the climate data inputs and the hydrodynamic models. It is a prerequisite for this approach to planning that both the climate models and the hydrodynamic models can imitate reality. Such planning approaches are mentioned in the literature as “predict and optimize” approaches (Babovic et al., 2018), ‘predict-act’ approaches (Hallegatte et al., 2012), and approaches to planning which seeks to develop optimal plans for ‘best-guess’ futures (Maier et al., 2016) or ‘most likely’ futures (Walker, Haasnoot, & Kwakkel, 2013). Water management planning and CCA can have long-term planning horizons. Such long planning horizons entail that the planning process is subject to large uncertainties (Maier et al., 2016). Therefore, this ‘predict and act’ approach is considered unsuitable when facing larger uncertainties as the approach does not take into account the fact that there are multiple plausible futures (Babovic et al., 2018; Hallegatte et al., 2012; Maier et al., 2016; Walker et al., 2013). Therefore, such static plans are likely to fail if the future diverges from the predicted future as the planning process is “[…] fragilely dependent on assumptions” (Walker et al., 2013, p. 957). On this basis, there is a need in the current water management and CCA planning practice to proactively consider larger uncertainties and to incorporate an approach to planning which is adaptable to futures that may diverge from what was initially projected.

2.2 Climate change adaptation planning in Frederiksberg

It can be argued that the current CCA planning approach in Frederiksberg Municipality and Utility is based on the above-mentioned predict-act approaches for best guess futures which is contrary to the approaches that embrace uncertainty.

A severe cloudburst event took place on July 2nd, 2011, in the Copenhagen area which led to severe flooding of large areas in Copenhagen and Frederiksberg, resulting in severe economic damages as the water management infrastructure could not cope with the extreme volumes of precipitation that entailed damaging flooding depths (Frederiksberg Forsyning, n.d.-a). This shocking event resulted in a rapid increase in attention towards the urgency of CCA strategies and led to political action as a response in the form of Frederiksberg Municipality’s Climate Change Adaptation Plan of 2012. In this first CCA plan, the municipality of Frederiksberg committed to decouple 30% of rainwater from the sewage system within the next 100 years as well as introducing a new service goal for stormwater flooding which state that flooding above 10 cm at property boundaries can only occur once within a 100 year return period based on the year 2112 (Frederiksberg Kommune, 2012). In this way, the extreme cloudburst event sparked a long-term and proactive vision for CCA in Frederiksberg, and shortly after the enactment of the Frederiksberg Climate Change Adaptation Plan of 2012, the so-called Cloudburst Clarification Plans were developed in association with the municipality of Copenhagen. These clarification plans established a comprehensive structure of hundreds of planned CCA measures deemed necessary to comply with the newly enacted service goal for flooding (Frederiksberg Kommune, 2016). It has been assessed that a retention volume of 254.000 m^3 is required alongside large water discharge structures at a cost of roughly 2,2 billion DKK (Frederiksberg Kommune, 2021a). As previously mentioned, such long-term and large-scale CCA interventions are very climate-sensitive investments, as the future impacts of climate change are very uncertain. According to Manocha & Babovic, the large uncertainty of climate change requires plans which can be adjusted as the future unfolds instead of relying on a prediction of the future (Manocha & Babovic, 2018). In this case, the cloudburst structure is based on a 100-year cloudburst event, with 2112 as the year of reference, and therefore the proposed measures are tailored to this future.

The proposed cloudburst structure is made up of several measures which are all interdependent including water discharge measures and retention measures. Retention measures are planned to be implemented in upstream catchment areas to reduce the required capacity of downstream measures and to relieve the pressure on the sewage system. The retention measures delay the collected rainwater for as long as possible before sending it further through the cloudburst structure when the retention measures overflow. From the retention measures, the rainwater is transported to water discharge measures which transport the water out of the municipality through gravitation on roads or in large underground pipes (Frederiksberg Kommune, 2016). Based on this, there is a significant interdependence between the inflexible and large water discharge measures and the upstream retention measures as the discharge measures and large retention measures rely on the upstream measures to catch water and guide it to the downstream measures. As a result, the entire structure relies on the implementation of drastic inflexible measures, instead of investigating whether a structure of more flexible measures could be sufficient in the first place. The first cloudburst tunnel is currently under construction (Frederiksberg Forsyning, n.d.-b) and to achieve the full effect of the tunnel it is necessary to guide rainwater from the adjacent catchment areas towards the tunnel. In the case of a future with lower levels of precipitation than expected, the utility might have to connect additional catchment areas to the tunnel to justify the large investment and prevent the tunnel from being a stranded asset. This is an example of a potential lock-in effect, as less extensive upstream solutions might have been more desirable.

Based on the above, it can be argued that the plan is vulnerable to the deep uncertainty of climate change. What if the future levels of precipitation turn out to be different from what is projected? What if several of the proposed measures cannot be implemented due to local conditions or other factors? On the other side, a certain level of clarification is necessary to develop strategies and plans which must be politically enacted. The tendency in Frederiksberg is that the level of detail is too high in the developed plans making the plans, and the implementation phase of the plans, vulnerable to unexpected changes. Therefore, it can be derived that there is a need to find a level of detail that is sufficiently concrete to develop long-term CCA plans with political support, without risking potential lock-in effects or maladaptation through an integration of a higher level of flexibility into the plans.

Currently, the municipality and utility of Frederiksberg are developing a Rainwater Plan to outline a strategy for everyday rainwater management (as mentioned earlier). As Frederiksberg is the most densely developed municipality in Denmark (SCALGO, 2020), a wide range of alternative measures are currently being assessed, as there are large uncertainties in relation to how far these measures can bring Frederiksberg in achieving its goal. These measures include both smaller and flexible measures as well as larger comprehensive measures.

In relation to this, the challenge regarding the level of detail is addressed in the current planning process. To avoid investing in comprehensive measures, the toolbox of suitable measures might have to be expanded as new solutions become available to achieve a sufficient level of decoupling and retention. Therefore, the Rainwater Plan must have a flexible and dynamic character to accommodate such new measures and be adaptive in a way that enables a switch to new strategies, such as ones that include more comprehensive measures, if necessary. In connection to this, a new CCA planning paradigm has emerged which seeks to provide new planning approaches that can accommodate uncertainty through a more dynamic and adaptive nature (Haasnoot et al., 2013; Walker et al., 2013). However, these approaches to CCA differ from the current practices, which have tended to develop static plans tailored for an expected future, as illustrated by the Cloudburst Clarification Plan. On this basis, this report will investigate the following research question:

- ***"How can a strategy for CCA be developed which meets short terms adaptation goals while being sufficiently robust and flexible to keep options open for future actions or shifts in strategy to accommodate future risk?"***

In order to answer this research question, the research will take point of departure in the development of the Rainwater Plan for rainwater management in Frederiksberg. On this basis, the following case-specific research question has been developed to guide the analyses of this research:

- *"How can Frederiksberg's Rainwater Plan be designed in order to facilitate a dynamic approach to climate change adaptation?*

On this basis, this study aims to investigate and apply a more dynamic and robust approach to the Rainwater Plan to provide critical considerations to the ongoing planning process. As mentioned above, new planning approaches that embrace uncertainty have been developed. The Dynamic Adaptive Policy Pathways (DAPP) approach has been applied in different CCA contexts including large scale water management projects in the Netherlands where the approach origins (see Haasnoot et al. (2013)), and has since then been applied in a few Danish contexts as well, albeit on a more experimental and less comprehensive basis, in the cities of Vejle, Assens, and Randers (Kystdirektoratet, 2020b; Thomsen, 2020). These case areas have in common that they are vulnerable to flooding from rising sea levels and the increased intensity and frequency of storm surges (as projected by DMI (2022)). By contrast, Frederiksberg is an enclave surrounded by the city of Copenhagen and is vulnerable to pluvial flooding because of its urban typology, geography, and its vulnerable water management infrastructure. Therefore, Frederiksberg is an interesting and different case that can contribute with new considerations and knowledge to the portfolio of DAPP-cases. This study will address how to implement core principles of the DAPP-approach into an approach suitable to Frederiksberg and the development of the Rainwater Plan to ensure that this long-term plan is being built upon a strong foundation to face future uncertainties. To develop sub-questions that will guide the analyses of this report, in regard to answering the above-specified research question, a literature review of the dynamic CCA planning approach will be conducted. This literature review will provide critical insights into the approach which is considered essential to develop relevant sub-questions that can guide the implementation of relevant principles of dynamic CCA planning and knowledge to the context of Frederiksberg.

3 Climate change adaptation planning for an uncertain future

3.1 Planning under deep uncertainty

Based on the previous section it can be derived that a transition towards a planning paradigm that embraces uncertainty and integrates uncertainty proactively into the planning process is a necessity. This section will briefly elaborate on the reasoning behind integrating uncertainty into planning processes. In connection to this, the section will provide an insight into theoretical considerations on uncertainty and describe what defines deep uncertainty.

It is complex to plan for long-term CCA due to the uncertain nature of climate change, urban development, and socio-economic trends (Brown et al., 2009; European Environment Agency, 2016; Hallegatte et al., 2012). Such uncertainties cannot necessarily be reduced by compiling information and data and are therefore currently incomprehensible, hence the necessity to consider uncertainty within planning processes (Walker et al., 2013). According to Hallegatte et al. (2012), "Accepting uncertainty mandates a focus on robustness" (Hallegatte et al., 2012, p. 11). In this regard, integrating robustness into plans and strategies entails the development of plans that are robust to multiple plausible futures, meaning that the plan can perform satisfactorily and achieve the intended goals for a wide range of potential futures (Hallegatte, 2009; Hallegatte et al., 2012; Walker et al., 2013). Therefore, such robust approaches to CCA must be able to navigate within a planning context of deep uncertainty.

To understand what defines deep uncertainty, the concept of 'Knightian uncertainty' has to be introduced. Knight distinguishes between the two concepts of Knightian risk and Knightian uncertainty, which represent two levels of certainty about the future. The Knightian risk applies to cases where the probability of a given future can be reliably quantified whereas Knightian uncertainty applies to cases where the presence of multiple unknown factors makes a quantification impossible (Hallegatte et al., 2012). The nature of Knightian risk can further be split into two. Aleatory uncertainties revolve around complex systems with an arbitrary nature and are therefore irreducible whereas epistemic uncertainties, on the other hand, are a result of an imperfect and insufficient understanding of such systems and therefore can be reduced (Ibid.). Based on this definition of Knightian uncertainty, deep uncertainty can, according to Hallegatte et al. (2012) be defined as situations with the presence of at least one of the following three conditions:

1. *Knightian uncertainty […];*
2. *Multiple divergent but equally-valid world-views, including values used to define criteria of success; and*
3. *Decisions which adapt over time and cannot be considered independently.*

   (Hallegatte et al., 2012, p. 4)

In a CCA context, both aleatory and epistemic uncertainty is present when working with predicting and modeling the future climate. The dynamics associated with the natural variability of Earth's climate system is an example of aleatory uncertainty whilst all climate models share the same epistemic uncertainty as the understanding of climate systems is imperfect (Ibid.).

In relation to this, current CCA planning seeks to predict the magnitude of future precipitation events associated with specific return periods to shape the implementation of measures to accommodate future precipitation levels. Therefore, climate change impacts on local phenomena, in this case, precipitation events in Frederiksberg, is of interest. Global climate models cannot reproduce such hyper-local events in a global context and therefore these models can be statistically downscaled to the local context using historical data (Ibid.). However, it is highly uncertain whether there is a statistical relationship between the present and future climate normal and additionally such downscaled climate data is subject to the same aleatory and epistemic uncertainties as climate change modeling (Ibid). Therefore, this is an example of Knightian uncertainty, as several plausible futures with different climatic conditions can occur and it is not possible to predict the possibility for the different futures to occur.

Furthermore, when it comes to climate change, multiple divergent and competing worldviews exist, complicating decision-making processes (Ibid.). It can be argued that different stakeholders have different perceptions of the potential consequences of CC, and how to accommodate climate change in the water management sector as multiple approaches to CCA exist. This example further characterizes deep uncertainty, as it is unclear how to value the desirability of different alternatives (Walker et al., 2013).

Lastly, deep uncertainty is characterized by a highly interrelated series of decisions which has to be adapted over time (Hallegatte et al., 2012). It can be argued that this is the case for CCA which is highly interrelated with e.g., the development of climate mitigation and urban development strategies over time as a change within such sectors can significantly influence the premise for planning urban CCA measures.

3.2 Climate change adaptation planning approaches to address deep uncertainty

As mentioned in the previous section, acknowledging deep uncertainty necessitates a focus on robustness meaning that robust plans must be able to meet the selected success criteria under a wide range of possible futures (Hallegatte et al., 2012). Walker et al. (2013) distinguish between ‘static robust’ and ‘dynamic’ plans which can encompass varying degrees of robustness and adaptability. Both adaptation approaches are anticipatory, as they investigate potential futures and to what extent the strategies are suitable for a wide range of these futures to increase robustness. However, dynamic plans require monitoring and adaptability as key characteristics of the plans’ nature. This is to facilitate the integration of new information and the adjustment of plans over time as a response to unpredicted changes in future conditions and as new knowledge becomes available (Ibid.). Therefore, plans must be dynamic and adaptive to ensure long-term planning suitable for navigating through deep uncertainty (Haasnoot et al., 2013; Walker et al., 2013). As illustrated in Figure 3.1, the DAPP approach is the most suitable in the face of deep uncertainty, according to Walker et al. (2013).

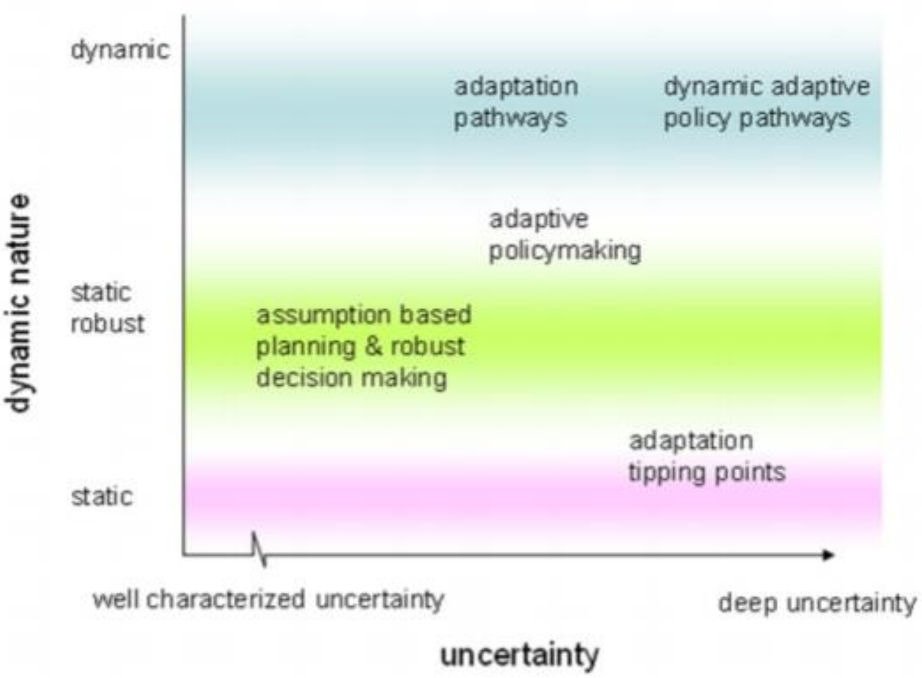

Figure 3.1 - CCA planning approaches ranked in relation to dynamic character and uncertainty. Source: Walker et al. (2013)

As the DAPP approach originates from combining different aspects and perspectives from the adaptive policymaking and adaptation pathways approach (Haasnoot et al., 2013), the following sections will describe these underlying approaches to give an introduction to the DAPP approach.

3.2.1 Adaptive Policymaking

Adaptive Policymaking is an adaptive approach to implementing long-term plans and strategies in the face of deep uncertainty as adaptability is explicitly addressed at the very beginning of the planning process (Walker et al., 2013). The reasoning and concept behind adaptive policymaking go back to John Dewey in 1927, who suggested perceiving and treating policies as experiments to encourage continual learning and adaptable strategies (Rahman, Walker, & Marchau, 2008). Adaptive policymaking is a structured and stepwise approach to developing plans and strategies with a specified long-term goal. Firstly, the approach develops a set plan with associated policies which can achieve the set goal within the current circumstances. However, such a basic plan and policy is subject to vulnerabilities as future conditions and events can cause the plan to fail (Ibid.). Therefore, such vulnerabilities are identified and both short-term and potential long-term actions are specified to build robustness and prevent adverse consequences (Haasnoot et al., 2013; Rahman et al., 2008; Walker et al., 2013). The short-term actions can be distinguished as actions that seek to mitigate the likely consequences of a plan (mitigation actions) and actions that seek to reduce the risk of uncertain adverse consequences of a plan (hedging actions) (Ibid.). Following the specified mitigation and hedging actions, a systematic approach to contingency planning is developed to monitor the performance of the plan (Haasnoot et al., 2013; Walker et al., 2013). This step includes the definition of signposts which "specify information that should be tracked in order to determine whether the plan is meeting the conditions for its success." (Haasnoot et al., 2013 p. 487; Walker et al., 2013, p. 962). Based on these signposts, critical triggers are established, which determine, based on monitoring, when further action is required to ensure the success of the plan. This includes defensive actions that seek to protect the stated plan and its benefits and corrective actions which are centered around adjusting the plan to new circumstances (Ibid.). Lastly, a reassessment of the plan can become necessary as a last resort if the assumptions, on which the plan is based, are no longer valid (Ibid.)

3.2.2 Adaptation Pathways

In comparison to the adaptative policymaking approach, which outlines a stepwise approach to developing a robust and adaptable plan, the Adaptation Pathways approach encompasses the implementation process of plans, hence the timing of actions, by specifying actions to be implemented now and in the future, as a response to changing climatic conditions (Walker et al., 2013; Werner, Wise, Butler, Totin, & Vincent, 2021). The adaptation pathways approach starts by assessing current policies to determine when the associated actions of such policies are no longer sufficient to meet the set goals as the conditions for CCA planning change over time (Buurman & Babovic, 2016). This means that instead of questioning what will happen if a given condition occurs, the approach instead asks the question: "[…] under what condition will a given plan fail?" (Walker et al., 2013, p. 963). In relation to the context of Frederiksberg, this entails an investigation of under what conditions e.g., water rain gardens or retention basins will fail to provide sufficient capacity. Once such policies are no longer sufficient, alternative policies with additional actions are necessary to achieve the objective of the plan. Such situations are known as 'tipping points' (Haasnoot et al., 2013). However, additional policies might also have so-called future 'expiry dates' or 'sell-by-dates' when these additional policies are not sufficient, leading to a demand for further additional policies (Buurman & Babovic, 2016; Haasnoot et al., 2013). On this basis, different pathways to reach the defined objective emerges. In this way, flexibility is built into the adaptation strategy as the implementation of actions has been sequenced by the change in future conditions. Therefore, options are left open for a range of possible futures as adaptation options are implemented over time when pivotal conditions are expected to occur (Haasnoot et al., 2013; Walker et al., 2013).

Furthermore, as there might be several possible actions that arise after a tipping point, there may be multiple adaptation pathways that can help obtain the same desired objective (Haasnoot et al., 2013). By mapping the possible adaptation pathways, decision-makers can assess the most suitable pathway based on a variety of different methods (Ibid.). Additionally, the potential multiplicity of pathways can support decision-makers to avoid lock-ins and maladaptation as the approach embraces time and feedback (Werner et al., 2021). In the case of Frederiksberg, one pathway could rely on expanding the sewage system, whereas an alternative pathway could suggest implementing softer measures such as terrain-based retention basins and infiltration measures. Hypothetically, the implementation of softer measures might be sufficient to accommodate future precipitation levels. If this is the case, then an expansion of the sewage system could be an overinvestment. However, if this is not the case, the option to expand the sewage system is still open. This is an example of committing " […] to short-term actions while keeping the options open for the future" (Walker et al., 2013, p. 972). Therefore, the adaptation pathway approach can help develop plans which are adaptable to changing conditions over time.

3.2.3 Dynamic Adaptive Policy Pathways

As mentioned previously, the DAPP approach is a result of merging concepts from both the Adaptive Policymaking and Adaptation Pathways approach. Based on the previous sections it can be derived that the Adaptation Pathways approach lacks a clear approach to transforming the pathways into an applicable plan, whereas the Adaptive Policymaking approach lacks an approach to determine potential future actions (Haasnoot et al., 2013). On this basis, the DAPP approach applies the stepwise approach to conduct a dynamic plan with the associated monitoring system and contingency planning from the Adaptive Policymaking approach, combined with the selection and sequencing of actions from the Adaptation Pathways approach (Haasnoot et al., 2013; Walker et al., 2013). In this way, the decision support for decision- and policymakers is evident, as the two approaches complement their respective weaknesses. The stepwise approach in developing plans based on the DAPP approach is illustrated in Figure 3.2 below.

Figure 3.2 - The DAPP approach (Haasnoot et al., 2013)

Figure 3.2 - The DAPP approachThe first step is to describe the given case area. According to Haasnoot et al. (2013), this includes describing the system's characteristics, including both current and future constraints. Based on the Danish Coastal Authority's experience with facilitating DAPP-processes in Danish municipalities, such system descriptions can include identifying the source of flooding, water flow accumulation, objects exposed to flooding, and external impacts e.g., population growth and other planning agendas, and how these conditions can change in the future (Kystdirektoratet, 2020a). To understand future constraints, major uncertainties must be taken into account (Haasnoot et al., 2013). Furthermore, the objectives for the area

must be defined. Based on these objectives, a definition of success can be established for the area, which includes the selection of indicators and targets to evaluate whether the later proposed pathways are adequate to achieve the defined objectives (Ibid.).

In the second step, the aim is to compare the ‘success scenario’ identified in step one with the current situation of the case area and with plausible future scenarios, in order to identify critical areas where action is needed (Ibid.). These future scenarios are based on ‘reference cases’ with no enactment of new policies and represent a range of scenarios based on the uncertainties identified in the first step. If actions are necessary to achieve the success scenario, then opportunities and vulnerabilities are identified (Ibid.).

The third step revolves around the identification of potentially suitable actions to achieve the success scenario, based on the opportunities and vulnerabilities identified in the previous step (Ibid.). According to Haasnoot et al. (2013), it is important to identify and assemble a wide toolbox of possible actions. This argument is further underpinned by the Danish Coastal Authority, which emphasizes the importance of a wide set of potential actions as the adaptation pathways must support both short-term and long-term adaptation, which includes both preventive measures, protection measures, urban planning measures, and contingency actions (Kystdirektoratet, 2020a).

The fourth step builds upon the third step, as the aim is to evaluate the actions proposed in the previous step to screen out unsuitable measures. The actions are assessed using the indicators and targets from step 1 for all scenarios, to identify the sell-by dates of each action (Haasnoot et al., 2013). Furthermore, the actions are compared to the previously identified opportunities and vulnerabilities, in order to assess their capability of reducing vulnerabilities or utilizing opportunities and to determine whether the actions themselves can cause new opportunities and vulnerabilities. If so, a reassessment is necessary (Ibid.). Additionally, the Danish Coastal Authority emphasizes the need to screen out measures that conflict with the overall visions and objectives for the area (Kystdirektoratet, 2020a). Based on this assessment of suitable measures, the third and fourth steps might have to be repeated until there is a sufficient set of actions to assemble adaptation pathways as illustrated in Figure 3.2 (Haasnoot et al., 2013).

After the iterative third and fourth steps, promising actions have been identified which can be utilized to develop adaptation pathways in the fifth step. As mentioned in section 3.2.2, adaptation pathways consist of sequencing contiguous actions which are activated once the prior action is no longer adequate. Therefore, this sequencing of actions must take into consideration that some actions rule out the use of others and, additionally, that the sequencing of specific actions can be illogical (Ibid.). On this basis, adaptation pathways emerge which couple and link different actions in different combinations to explore different pathways to the same objective and success scenario. According to Haasnoot et al. (2013), promising pathways can be developed and selected by utilizing criteria such as the urgency of action, the level of uncertainty, or the prioritization to keep options open. In this way, pathways can be assembled to suit the local preferences and needs.

Based on the fifth step, the sixth step is aimed at selecting a reasonable number of preferred pathways. In this case, it is of utmost importance to consider pathways that represent different perspectives (Ibid.).

The seventh step is centered around building robustness of the preferred or most suitable adaptation pathways through the contingency planning steps of Adaptive Policymaking (Ibid.). The contingency planning actions can help keep the plan and in this case the adaptation pathways, on track by preparing for both anticipated and unknown future conditions, which trigger new actions (Ibid.).

The eighth step accumulates all the previously conducted steps into a dynamic adaptive plan (Ibid.). Based on the developed pathways, the contingency planning, and the level or 'deepness' of uncertainty, the plan should contain a strategy that includes short-term actions that should be taken now, while making sure that possibilities remain open for potentially necessary future actions, as well as the designed monitoring system (Ibid.).

Lastly, the 9th and 10th step is to implement the plan and the monitoring system. As the monitoring system detects new information in relation to trigger events, contingency actions are continuously taken in response to such information.

3.2.4 Dynamic Adaptive Policy Pathways in a Danish municipal context

As mentioned in the previous section, the Danish Coastal Authority has experience facilitating DAPP processes for Danish municipalities. The aim was to support Danish Municipalities' work with CCA by employing a more proactive and structured approach to CCA which includes taking long time horizons, uncertainty, and the relation and interdependence between measures into account (Kystdirektoratet, 2020b). To do so, the Danish Coastal Authority initially adjusted the DAPP approach (described in the section above) from Haasnoot et al. (2013) to a format better suited for the Danish municipal context.

The adjusted DAPP process has a more qualitative character compared to certain Dutch applications of the approach, which are more computationally intensive. Examples of utilizing a computer-assisted DAPP approach show the identification of optimized robust adaptation pathways by computationally assigning scores to the pathways to identify the highest-scoring pathway (Kwakkel, Haasnoot, & Walker, 2015). However, such an extensive and quantitative approach is not deemed suitable for a Danish municipal context, as decisions in relation to CCA policy are political (Kystdirektoratet, 2020b). It can be argued that the assessment of the most suitable adaptation pathway for a given local context is dependent on local visions, prioritizations, and beliefs, and therefore the most suitable pathway cannot solely be computationally assessed. This perception can be seen in the Danish Coastal Authority's adjusted approach. In general, the process is based on an overall approach with a relatively low level of detail to facilitate the participation of a large number of stakeholders and professions. Furthermore, a Multi-Criteria Analysis (MCA) is utilized to select preferable pathways based on both unquantifiable and quantifiable criteria which reflect the local preferences and prioritizations of the participants. In relation to this, one of the main takeaways for the municipalities was to have a structured dialogue and debate internally in their organization about CCA measures and potential strategies across different professions, highlighting the need for a tangible level of detail for all participants (Ibid.). On this basis, the Danish Coastal Authority's DAPP has developed its take on the DAPP approach for a Danish context which is illustrated in Figure 3.3 below.

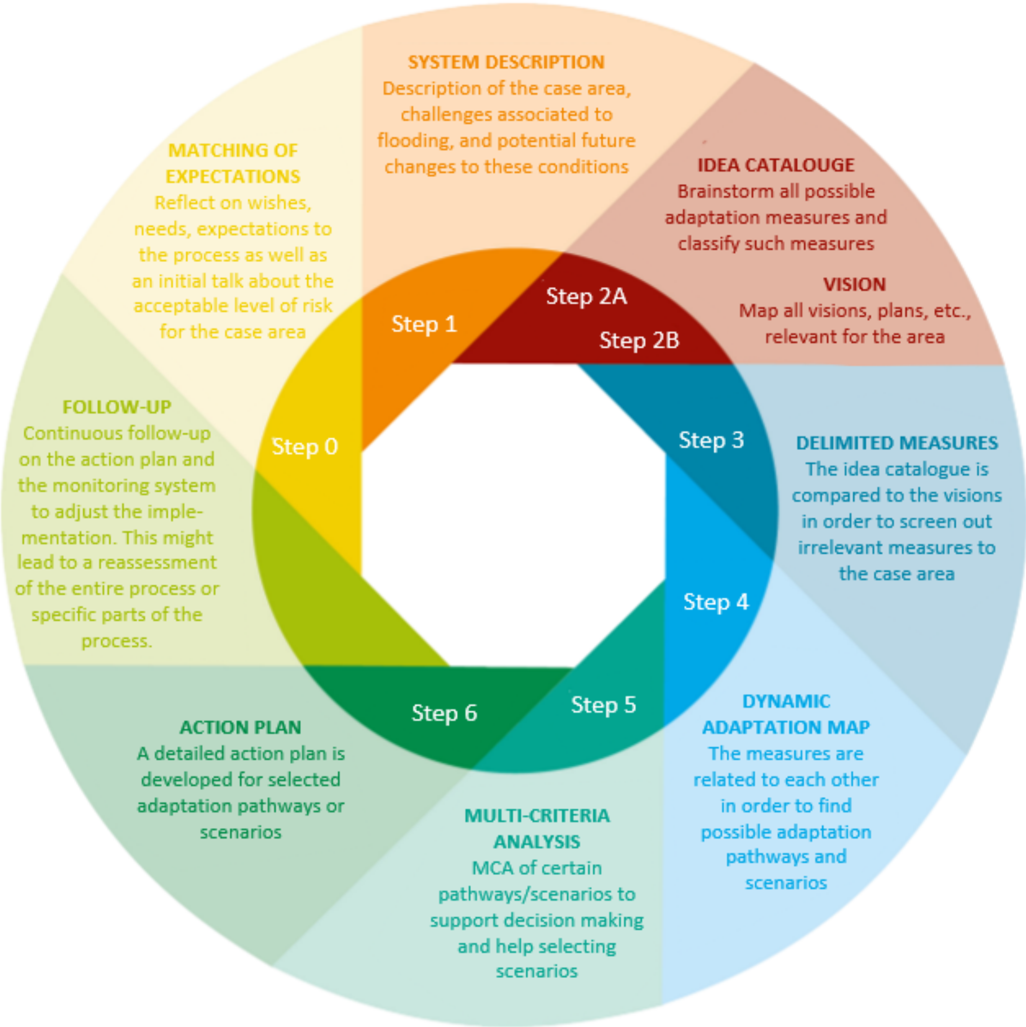

Figure 3.3 - The Danish Coastal Authority's adjusted DAPP-process (Kystdirektoratet, 2020b). Translated to English by the author.

Prior to the first step, expectations must be matched which includes an initial discussion of the acceptable level of risk in the given case area. Additionally, in short, the adjusted approach starts with a description of the area of interest's characteristics and vulnerability to flooding. Based on this description, a brainstorming of potential CCA measures is conducted concurrently with a mapping process of all municipal visions and plans for the area and relevant to the area of interest (Kystdirektoratet, 2020b, 2020a). These visions and plans are then used to screen out the identified measures that conflict with these visions and plans in the following step. Based on the suitable measures, adaptation pathways are mapped through dialogue to discuss the sequencing of actions based on the measures' expected implementation horizons and life expectancy (Ibid). Afterward, a multicriteria analysis is utilized to identify the most suitable adaptation pathways based on a wide set of assessment criteria that cannot necessarily be numerically or monetarily quantified. It is the individual municipalities that select, score, and weight the pathways according to the criteria to ensure that the criteria and weighing suit local conditions and preferences (Ibid.). As seen in Figure 3.3, the last step is to develop a dynamic action plan based on the chosen adaptation pathway(s) which will then be implemented, and the progress will be monitored in accordance with Haasnoot et al. (2013).

II. Methodology

4 Research design

4.1 Theories of science

According to Farthing (2016), the way research is designed and conducted is subject to underlying assumptions and perceptions about the world including ontology: the nature of knowledge, and epistemology: how one can know about the world. These assumptions can be perceived as the bottom of an iceberg submerged by water leaving only the methods visible above the water (Ibid.). As these assumptions influences decisions concerning how research is designed and constructed, this section will introduce this research's underlying assumptions about the world.

This research is taking place within an urban planning, water management, and CCA context. This means that the research touch upon multiple cross-disciplinary practices and therefore utilizes a multidisciplinary approach to understand and manage the complexity of operating within urban environments. Therefore, planning in complex urban contexts is a complex process and it is characterized by the involvement of multiple stakeholders, including a broad range of professions, politicians, as well as urban citizens (Métral & Falquet, 2007). Regarding CCA, the development of CCA practice underpins the need for multidisciplinary approaches, as water management practice and CCA has developed from taking place underground in 'invisible structures' to something which is proactively planned and integrated into the urban development of the city (European Environment Agency, 2016; Fratini & Jensen, 2014). Therefore, CCA planning has multiple facets. On one hand, CCA planning is dependent on the use of climate science research and modeling as a means to plan for future climatic conditions. This scientific field is characterized by a positivistic understanding of the world which perceives research as objective and value-free and that reality is based on scientific evidence (Farthing, 2016). On the other hand, the tendency to integrate CCA into urban development and other urban planning agendas challenges the positivistic approach to CCA as new knowledge, that cannot be considered value-free or based on scientific evidence, enters the decision-making arena. In this case, CCA planning does not only consider the hydraulic effect but the values and co-benefits as well beyond the adaptation effect as a result of integrating CCA consideration with other planning agendas (European Environment Agency, 2016).

Specific to this research, there is the underlying assumption that the municipality and utility can conduct CCA planning through the use of climate science data, expert knowledge, and technical tools such as hydrodynamic models to propose valid solutions and measures which are rationally founded. Therefore, a degree of top-down oriented rational planning is assessed as a necessity to manage and handle both current and future challenges related to climate change. According to Faludi (1973), rational planning concerns identifying the best objectively founded solution to a well-defined problem. Therefore, expert knowledge, climate data, and GIS data are considered suitable data sources for the conducted analyses.

However, due to the paradigm shift in CCA planning from being something separate to becoming a driver for other urban planning agendas, the most suitable solutions to the problem of coping with climate change can no longer be solely founded on rationality. Instead, the most suitable solution can be socially constructed through discourses and interactions between different stakeholders sharing their needs and interests which in the end can shape a shared understanding of reality (Farthing, 2016). In this way, knowledge is socially constructed (Ibid.). Therefore, the most suitable measures can depend on factors such as the measures' ability to provide benefits beyond the adaptation effect, the measures' alignment with politically enacted strategies, the measures' flexibility, or simply the economic efficiency. This assessment depends on stakeholders' perceptions and prioritizations, and therefore knowledge that is highly subjective and not value-free is deemed suitable to support this report's analyses. Therefore, empirical data collection e.g., document analysis of political strategies is considered valuable for this research.

On this basis, it can be derived that this research is based on an interdisciplinary mixed-methods research design as it combines both quantitative and qualitative research data to better understand the research problem (Ivankova & Creswell, 2009).

4.2 Scope of the report

This report's research design is centered around the DAPP-approach. However, it is critical to clarify, that the aim of the report is not to facilitate a full DAPP process in Frederiksberg. An approach, like the adjusted approach from the Danish Coastal Authority, requires the facilitation of a broad range of both internal and external stakeholders. In this report, the aim is to utilize and concretize the underlying elements and steps from the DAPP approach from a rainwater management perspective in the context of Frederiksberg. This is to showcase how considerations of uncertainty can be integrated proactively into CCA strategies to promote dynamic plans which provide different alternative pathways and prepare switches to new pathways due to changing circumstances. Therefore, the scope of this research is delimited to the investigation of, how elements of the DAPP approach can contribute to making Frederiksberg Municipality and Utility's CCA plans and strategies less static. This means, that how such processes could have been managed, is not a part of this research's scope. Furthermore, this means that it is the report's underlying hypothesis, that the DAPP approach is suitable to integrate into CCA planning in Frederiksberg, and therefore the research investigates how elements of the approach can be integrated into the context of Frederiksberg instead of, whether the approach is suitable. As this research investigates how the DAPP approach can bring value to Frederiksberg Municipality and Utility's planning approach, analyses and decisions will be made in this research, that would have been undertaken in participatory settings in an actual DAPP process. Therefore, it is important to note that the analyses and conclusions made in this report are to be perceived as initial and preparatory steps which are considered required to shape the foundation for potential future facilitation of a DAPP process in Frederiksberg. Considerations and reflections concerning an actual facilitation will be made in the report's discussion.

As mentioned above, this research seeks to perform the initial steps of the DAPP approach for the context of Frederiksberg, and therefore the scope is centered around the initial analysis which precedes the critical decision-making steps regarding choosing the most suitable adaptation pathways. This is based on the understanding, that the assessment of the most suitable CCA strategy depends on local visions, prioritizations, and beliefs (as mentioned in section I.3.2.4), and therefore this decision requires the inclusion of a wide range of stakeholders. To perform these initial steps of the DAPP approach, this research will be delimited to a specific case area to conduct these analyses on a tangible level to the scope of the report.

However, this delimitation poses an opportunity to dive deeper into the specific challenges of a given area and to propose specific CCA measures tailored to the local context. In this way, knowledge and experiences from this case study can be included in the municipality's and utility's planning practice.

4.3 Problem formulation

The following research question emerged based on the conducted problem analysis:

"How can a strategy for CCA be developed which meets short terms adaptation goals while being sufficiently robust and flexible to keep options open for future actions or shifts in strategy to accommodate future risk?"

As mentioned in the previous section, there are multiple ways to explore how CCA strategies can be designed in a dynamical manner utilizing the concepts of the DAPP approach. Based on the scope of the report, this report seeks to investigate how CCA strategies can become more robust and flexible based on the case study of Frederiksberg Municipality and Utility's approach to CCA planning. More specifically, the Rainwater Plan, which is under development, will be utilized as an example of a strategy for CCA which means that rainwater management constitutes an example of CCA. This is based on, that the Rainwater Plan is currently being developed and therefore there is an opportunity to utilize the plan as a case study and influence the development of the plan based on the research's findings.

Case studies are suitable to conduct in settings where research and actions are combined to influence and guide the current practice (Swanborn, 2010) which is the case with the Rainwater Plan. On this basis, the analyses of this report will be guided more explicitly by the following more case-specific research question:

"How can Frederiksberg's Rainwater Plan be designed in order to facilitate a dynamic approach to climate change adaptation?"

As this report's scope is limited to an investigation of the initial steps of the DAPP approach's application in Frederiksberg, the following sub-questions have been developed to investigate how elements of the DAPP framework can be implemented in Frederiksberg Municipality's and Utility's Rainwater Plan:

1. *How can a risk assessment of the case area be conducted in order to understand both current and future climate change-induced risk?*

2. *Which climate change adaptation measures are suitable to the characteristics of the case area and suitable to form adaptation pathways?*

On this basis, the overall research question will be answered in the report's discussion and conclusions section through an application of the results from the case study of the Rainwater Plan for water management in Frederiksberg. In this way, the aim of the research is twofold as the results based on the conducted case study can be utilized to influence the current practice as well as it can be generalized to a larger Danish urban CCA planning context. According to Flyvbjerg, results based on case studies of individual cases can be generalized (Flyvbjerg, 2006), and therefore the external validity of case studies as a method is deemed suitable to generalize the findings of this study to a wider context.

Based on the sub-questions, the following delimitations have been made. When addressing risks concerning climate change-induced hazards in the analyses, the scope is delimited to pluvial flooding. This is due to the local context of the Rainwater Plan which only considers rainwater management. However, this does not imply that it is only hazards related to pluvial flooding which is of relevance in Frederiksberg. As a densely developed area, other stresses such as the urban heat island (UHI) effect are critical to consider as well. In connection to CCA action, there are four different fundamental approaches to CCA known as PARA: protection, accommodation, retreat, and avoid (Doberstein, Fitzgibbons, & Mitchell, 2019). In short, protection is centered around reducing exposure to hazards by constructing defensive measures (Dawson et al., 2018; Doberstein et al., 2019). Accommodation is centered around altering the landscape to accommodate and integrate e.g., seawater or stormwater into the urban environment to co-exist (Ibid.). Retreat is the last resort when protection and accommodation measures are no longer adequate, and areas must be given up (Dawson et al., 2018). Lastly, avoid concerns the use of planning and land-use management measures such as zoning to prevent development in vulnerable and exposed areas (Doberstein et al., 2019). The scope of this report does not include retreat and avoid measures as these are not considered relevant in Frederiksberg as the city is fully developed. Furthermore, mitigation actions will not be explicitly addressed in this report.

The approach to investigating the above-stated sub-questions is presented in the following section.

5 Theoretical and analytical Framework

5.1 Risk assessment of current and future risks

Based on the DAPP approach (as described in section I.3.2), the area of interest must be described including the systems vulnerabilities and potential consequences associated with both short-term and long-term risk of potential climate change impacts. To describe risks in a given area, the IPCC Risk Assessment Framework is considered useful as an analytical framework to conduct a system description, as it is important to understand, what defines risk of climate change impacts. To utilize the risk assessment framework to understand both current and future challenges related to climate change, it is necessary to understand both the current situation and potential future scenarios for the case area. Additionally, it is necessary to understand both short-term and long-term hazards, in order to explore multiple different futures. On this basis, it is necessary to include a theoretical framework regarding climate scenarios and climate data, to be able to describe current and future hazards based on climate model projections.

5.1.1 IPCC risk assessment framework

In the IPCC Risk Assessment Framework, risk of climate change impacts " […] result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards" (Reisinger et al., 2020, p. 5) as seen on Figure 5.1 below.

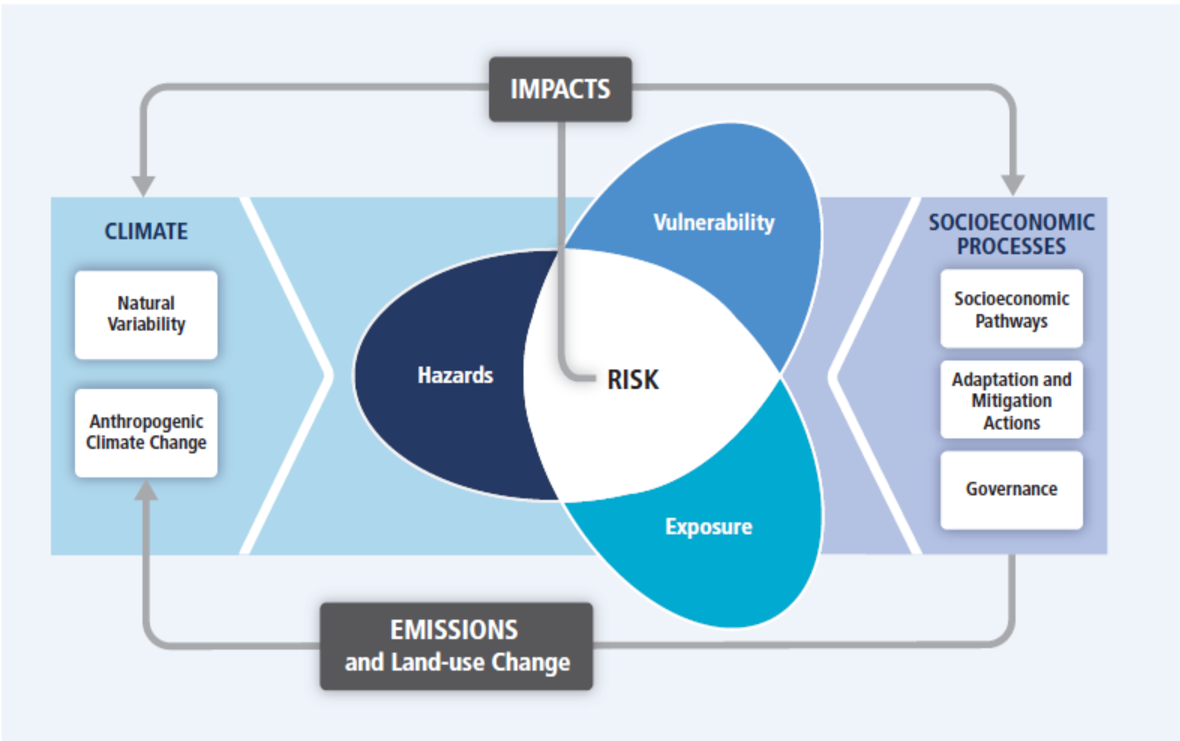

Figure 5.1 - IPCC's Risk Assessment Framework (Field et al., 2014).

Based on this understanding, expected or projected increases in precipitation levels or cloudburst frequency do not necessarily lead to an increase in risk as risk must be connected to the potential adverse consequences of climate-related hazards on human or ecological systems (Ibid.). This is due to how the IPCC defines risk. Risk is defined as "[…] the potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain" (IPCC, 2018, p. 557). This means that the magnitude of consequences on such systems depends on what is exposed and the vulnerability of the system as well. Therefore, uncertainty plays a large part in the concept of risk as e.g., socio-economically changes, changes in policies and climate change influence future hazards, exposure, and vulnerability, and thus the level of risk (Reisinger et al., 2020). Based on this, it can be derived that the concept of risk is a function of hazards, exposure, and vulnerability, and therefore risk assessments can help to convert the potential effects of climate change and socio-economic development into potential local consequences for a given area. To perform a risk assessment, it is considered necessary to properly define hazard, exposure, and vulnerability.

According to the IPCC, hazards are defined as "The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources." (IPCC, 2014, p. 124). As the definition mentions health impacts as well as damage to properties and other material assets, it is clear from this definition that hazards are highly dependent on what is exposed to the hazards.

Exposure is defined as "The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected." (IPCC, 2014, s. 123). In this definition, it is highlighted that what is exposed is dependent on the vulnerability of the system to cope with hazards.

Lastly, vulnerability is according to the IPCC defined as "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." (IPCC, 2014, p. 128). According to Gencer, Folorunsho, & Linkin (2018), vulnerability in an urban context, can be grouped into the following clusters; socio-economic, physical, environmental, and institutional vulnerabilities. The socio-economic vulnerability concerns the sensitivity of urban populations (Ibid.). On one hand, it is shaped by individual characteristics of citizens like their age, gender, and medical conditions. On the other hand, it is shaped by factors that affect population resilience such as level of education, income, the quality of residential buildings and houses, as well as the presence and quality of infrastructure (Ibid.). Physical vulnerability is shaped by how sensitive the built environment is to climate-related hazards. On this basis, it concerns the performance of buildings and critical infrastructure. Environmental vulnerability in an urban context is shaped by the effects of urban development on ecosystem services relevant to e.g., flood protection (Ibid.). The consequences of urban development such as the introduction of impermeable surfaces, the drainage of wetlands, and the alteration of waterways (as described in section I.2.1) are significantly impacting the natural water cycle as the urban landscape becomes more and more unnatural reducing the effect of ecosystem services. Furthermore, environmental vulnerability is shaped by the terrain and geology (Dawson et al., 2018). Lastly, institutional vulnerability concerns organizational constraints and a lack of inclusive governance and is shaped by a lack of capacity to act and plan for future hazards. This lack of capacity can arise in different ways e.g., through political distrust, a lack of communication and coordination, insufficient communication with citizens, and the inability to initiate and maintain CCA programs and actions (Gencer et al., 2018).

5.1.2 Climate scenarios and data

To understand what future climatic conditions to plan for, climate models are of interest, as they seek to describe the climate system's physical, chemical, and biological processes, and mechanisms to project future climatic conditions under different possible scenarios. These possible climate future scenarios include different levels of projected climate forcing as a result of different socio-economic assumptions such as population growth, land-use patterns, economic development, and atmospheric conditions (Climate.gov, n.d.; IPCC, 2021).

Concerning precipitation, which is of interest in this report, climate models have shown that the increase in global surface temperatures will, with high confidence, lead to changes in extreme events including the intensity and frequency of heavy precipitation events and an overall increase in annual precipitation levels at the high latitudes (IPCC, 2021). In relation to Denmark, regional climate models have been utilized to project future precipitation levels on a local scale and are available in DMI's Climate Atlas. These projections show a differentiated impact on seasonal precipitation patterns, as the amount of precipitation is expected to increase during winter, and precipitation levels are expected to be relatively stable in summer. However, fewer days with rain are expected in summer and therefore rainy days will be characterized by higher intensities (DMI, 2022). Furthermore, the Climate Atlas provides projections of what historical and current return period precipitation events might look like in possible future climatic conditions. Therefore, these climate model data can provide a better understanding of the possibility and magnitude of future events which can be utilized in adaptation planning and therefore to investigate the magnitude of flooding from precipitation events in the case area.

To assess the intensity and frequency of future precipitation events during future climatic conditions at a local scale, large quantities of observed climate data are utilized. This is a statistical method that utilizes statistical relationships to connect the modeling of large-scale climatic drivers from the global climate models with observed data to produce local climate data projections for a given area (Hallegatte et al., 2012). In this way, the climate model's projection of future climatic conditions is translated into location-specific climate data. The modeled climate data for 30-year periods are then compared to a 30-year reference climate period which overlaps with the modeled period to reduce model uncertainty and fluctuations as climate models contain bias, that does not fully represent reality (DMI, n.d.; Thejll et al., 2021). On this basis, DMI's Climate Atlas contains four periods; a reference period (1981-2010) and three future periods; 2011-2040 (early century), 2041-2070 (midcentury), and 2071-2100 (late century) whereas the impact of projected climate change is described as the difference between the reference period and the future period (Thejll et al., 2021). On this basis, the DMI Climate Atlas provides qualified estimates of possible future climatic conditions' impact on the occurrence and intensity of precipitation events in the shape of projected future changes in return period events. However, these data are subject to uncertainties and this uncertainty increases as the time horizons are expanded. This is exemplified by the uncertainty ranges, where the ranges are larger in the mid-century and late-century periods compared to the early-century period (see DMI (2022)) as these periods are highly dependent on future emissions of GHG and how Earth's climate system will respond to it.

The emission scenarios which are included in DMI's Climate Atlas, are the RCP 4.5 and RCP 8.5 scenarios. These scenarios follow relatively similar trajectories towards the mid-century, from which the scenarios start to significantly diverge (DMI, 2022). Therefore, when using Climate Atlas, the Danish Metrological Institute's (DMI) recommendation is to utilize climate data based on RCP 4.5 for planning horizons towards mid-century, and RCP 4.5 or RCP 8.5 when planning for the end of the century dependent on the demand for robustness (DMI, 2018). This report follows DMI's recommendation to use climate data based on RCP 4.5 when considering short-term (early century) climate-induced hazards, as the DAPP-approach highlights the need to focus on the reduction of short-term risk while keeping the options open for future action (as described in section I.3.2.3). Furthermore, as mentioned above, there is not a significant difference in the short-term climate data based on different emission scenarios. When considering late century hazards, the report utilizes RCP 8.5 as Frederiksberg Municipality's cloudburst service goal is to be able to manage a 100-year event in 2112 (100 years after the goal was enacted) which emphasizes a need for robustness. Furthermore, several factors entail uncertainties. One aspect is the uncertainty concerning future mitigation actions and their attenuating effect on climate change impacts due to mechanisms like thermal inertia, which has a delaying effect on climate change (European Environment Agency, 2016). Furthermore, there is scientific or epistemic uncertainty concerning whether the projected changes are underestimated since all processes and mechanisms of the climate system, and how they respond to changes such as warming, are not yet fully understood and incorporated into the models (Hallegatte et al., 2012). On this basis, RCP8.5 is the most appropriate scenario when considering long-term hazards. However, as the core of DAPP is to promote a dynamic and flexible approach to CCA, it is important to note that this selection of future climate scenarios is not binding and that this report's analyses aim to promote an approach that can be adjusted when new climate data and scenarios become available.

On this basis, data from the early century climate (2011-2040) will be utilized to simulate three different hourly precipitation events; a 10-year, a 50-year, and a 100-year event based on RCP 4.5. This is to get an understanding of short-term challenges and to define short-term CCA objectives for the case area. Thereafter, the impacts of potential future hazards will be investigated for the same return periods but with late century climate data (2071-2100) for RCP 8.5 to understand future impacts.

The table below provides an overview of climate data from DMI's Climate Atlas and includes both data based on RCP 4.5 and 8.5 for the three return periods and for the four different time horizons.

Table 1 - Climate Data retrieved from DMI's Climate Atlas for Frederiksberg (DMI, 2022)

Hourly event	Climate Scenario	Unit	Reference (1981-2010)	2011-2040			2041-2070			2071-2100		
				Median	10Q	90Q	Median	10Q	90Q	Median	10Q	90Q
10-year event	RCP4.5	mm/hour	**24.81**	**28.28**	22.06	33.35	**29.30**	24.31	35.60	**30.51**	24.38	35.91
	RCP8.5	mm/hour	**24.81**	**27.66**	23.16	31.8	**30.63**	24.62	34.64	**35.34**	25.92	41.67
50-year event	RCP4.5	mm/hour	**37.62**	**44.78**	32.45	54.65	**44.55**	35.75	57.94	**47.43**	34.54	61.34
	RCP8.5	mm/hour	**37.62**	**42.87**	34.52	50.96	**46.73**	36.96	54.26	**56.36**	40.03	70.29
100-year event	RCP4.5	mm/hour	**44.59**	**54.10**	37.46	66.72	**54.52**	41.77	71.03	**57.63**	39.65	76.94
	RCP8.5	mm/hour	**44.59**	**50.62**	40.25	62.14	**55.15**	43.72	66.91	**67.03**	47.62	87.16

5.2 Assessment of suitable measures

The identification of CCA measures is based on the recommendations from Haasnoot et al. (2013) and Kystdirektoratet (2020a; 2020b). Therefore, a broad range of measures will be included to take into account, that several measures might not be suitable for the specific context of the case area. The assessment of measures' suitability will be based on several levels of criteria. The measures' suitability to the local physical properties of the case area will be screened based on criteria related to the physical properties and the urban typology of the case area. To do so, an analytical framework will be developed which includes several aspects of local suitability. To assess the measures' suitability for the development of adaptation pathways, an analytical framework is utilized, which includes critical criteria to consider, when developing dynamic CCA strategies.

5.2.1 Physical suitability criteria

The criteria utilized to assess CCA measures local suitability is derived from a wide range of criteria which represent a holistic approach, that goes beyond the hydrological effect (Alves, Gersonius, Sanchez, Vojinovic, & Kapelan, 2017). The approach presented in Alves et al. (2018) is centered around three clusters of criteria: hydrological effect, cost minimization, and potential co-benefits of CCA measures. These clusters and the associated criteria can be seen in Figure 5.2 below.

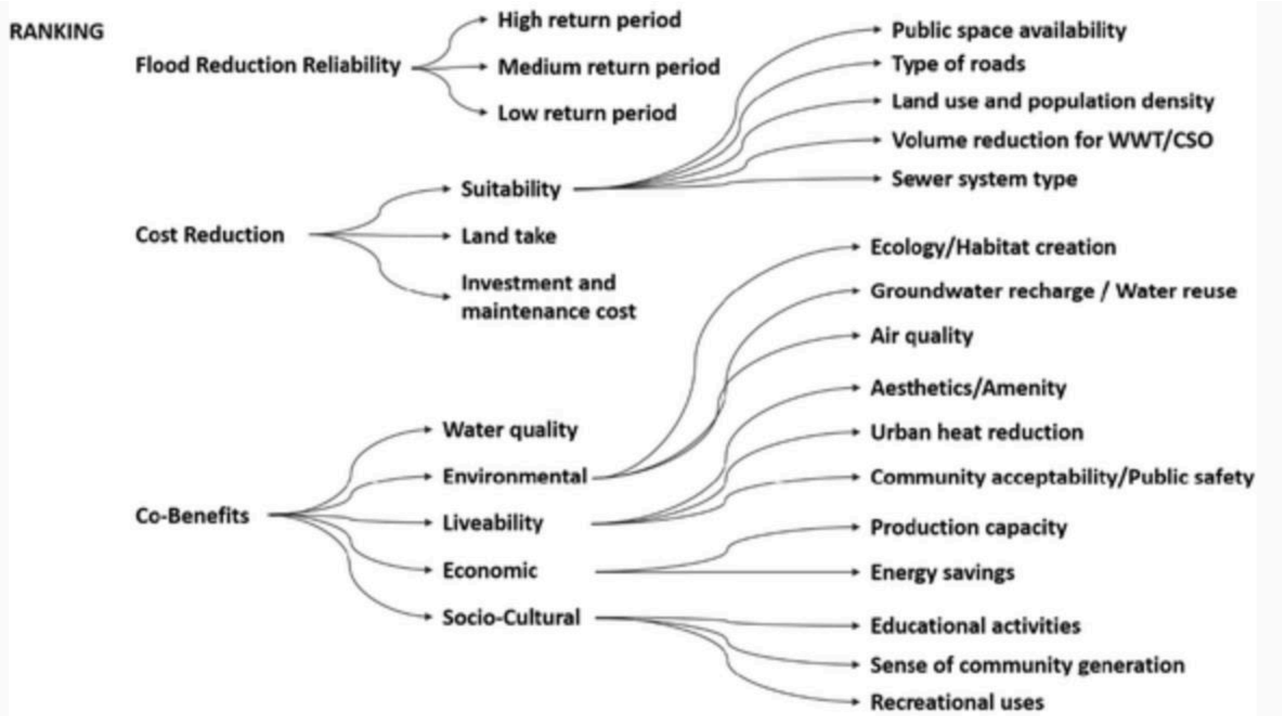

Figure 5.2 - Criteria framework to assess measures' physical suitability (Alves et al., 2017)

Hydrological effect

The first cluster concern the hydrological effect of the given measure by assessing whether the measure can handle low return period events, medium return period events, or high return period ever (Ibid.).

Cost reduction

The second cluster focuses on cost reduction and includes several assessment criteria. The aim is to select measures that suit the local urban characteristics, as these measures are expected to be more cost-effective (Alves et al., 2017). The main group of criteria is the physical suitability criteria. The first criterion in this group is public space availability, as different measures have different scales in relation to the amount of space, that they occupy. The type of road must be assessed as well. Concerning Frederiksberg, this is especially important as different measures are suitable for different types of roads. A measure from the Rainwater Plans Toolbox is the transportation of water on terrain which is not considered suitable for the main arteries and boulevards in the city. Another sub-criterion to physical suitability is the land use and population density which is considered especially relevant in Frederiksberg as it is the most densely populated municipality in Denmark (as described earlier) which put demands on multifunctionality. Furthermore, potential volume reduction for wastewater treatment and combined sewage overflow should be assessed. Lastly, the sewer system type is important to consider when selecting measures that suit either combined sewage systems or separated sewage systems. Besides the physical suitability, the specific land take of the measure should be assessed followed by the investment and maintenance costs.

Co-benefits

The criterion of co-benefits is split into five sub-criterions: water quality, environmental, livability, economic, and socio-cultural (Ibid.). Water quality is related to measures that purify and cleanse rainwater from different unwanted matters e.g., prior to discharge to natural recipients such as rivers or prevent overflow to such recipients (Alves et al., 2017).

The sub-criterion of the measures' effect on environmental conditions is split into three. The first aspect concerns whether the given measure can act as a habitat to support ecosystems and enhance biodiversity (Ibid.). Secondly, the measures should be assessed based on their ability to support the regeneration of groundwater or contribute to water recycling to reduce the consumption of groundwater. Finally, the measures' effect on air quality should be assessed.

The next sub-criterion is co-benefits related to livability. The first aspect is aesthetics and amenity (Ibid.) as CCA measures can improve the quality of urban spaces (Miljøstyrelsen, 2020). Secondly, the measure's effect on UHI should be assessed (Alves et al., 2017). Lastly, the measure can be evaluated based on the public acceptance of the measure and public safety (Ibid.).

The fourth sub-criterion is economic co-benefits. This includes production capacity and energy savings (Ibid.). CCA measures can contribute to energy reductions e.g., by handling the water locally instead of in the wastewater system. This leads to a reduction in the quantity of water that flows through the system and therefore less energy is used to pump water to the treatment plants and less energy is used at the treatment plants (Miljøstyrelsen, 2020).

The final co-benefit sub-criterion is socio-cultural co-benefits. This includes educational activities, the measures' effect on community generation, and the measures' ability to provide recreational functions.

5.2.2 Criteria to develop adaptation pathway

According to Haasnoot et al. (2013), developing adaptation pathways consist of sequencing contiguous actions. To understand which actions that make sense to combine, it is necessary to develop a set of criteria based on the planning under deep uncertainty literature, as some actions rule out the use of others and, therefore, the sequencing of some actions can be illogical (Ibid.). In connection to the above, these criteria will be utilized to assess e.g., the measures' life expectancy, flexibility, and robustness to understand logical sequences of actions in relation to deep uncertainty. For example, it is not considered desirable to invest in an inflexible solution, such as an expansion of the combined sewage system, as the first step, if it is possible to relieve the pressure on the capacity of the sewage system through more flexible measures such as terrain-based retention basins. Therefore, through the use of these criteria to assess the selected measures and investigate suitable sequencings of contiguous actions, the most preferable adaptation pathways can be chosen based on local preferences and ambitions (Ibid.).

Regarding identifying criteria that include an explicit focus on deep uncertainty, this section is based on Hallegatte (2009), which presents six strategies to increase robustness and include robustness into decision-making processes. Baills, Garcin, & Bulteau (2020) have utilized these six approaches to develop 10 criteria to assess adaptation measures' suitability on this basis. The following section will present and elaborate on these criteria.

No regret solutions

Adaptation measures can be considered 'no-regret solutions' if they explicitly provide benefits beyond the adaptation effect to an extent that will ascribe value to the investment independent of future climate change (Baills et al., 2020; Hallegatte, 2009). As mentioned earlier, CCA measures are climate-sensitive investments (Babovic et al., 2018), and therefore no regret solutions are desirable compared to measures, which only provide value in specific climatic conditions. Such solutions are associated with significant additional costs if the future turns out differently than anticipated (Baills et al., 2020).

Robustness

In accordance with the description of robustness in section I.3.2, robustness is centered around the ability and capacity to be effective under a wide range of future climatic conditions (Baills et al., 2020; Hallegatte et al., 2012). Therefore, a measure is not robust if there are future scenarios in which the measure is not effective (Ibid.). Effective, in this case, refers to the adaption effect. Robustness is not defined as dependent on a measure's lifetime, but in relation to the measure's effect independently of the future in which the measure is implemented (Baills et al., 2020).

Flexibility/reversibility

As the future is highly uncertain, it is significant to prioritize CCA measures that are highly flexible and reversible in case the future climate turns out differently than anticipated (Baills et al., 2020; Hallegatte, 2009). Flexible and reversible measures are suited for retrofitting both in cases of higher and lower adaptation needs and can be left unused without large costs. Therefore, the aim is to avoid investments in costly inflexible measures to prevent over-adaptation and therefore minimize the cost of maladaptation as a result of being unable to project the future climate (Ibid.).

Short decision horizon

Short decision horizon as an assessment criterion refers to prioritizing investments with a short investment lifetime. Climate change and the potential impacts of climate change are largely uncertain, and the uncertainty increases significantly when measures with long time horizons are considered (Baills et al., 2020; Hallegatte, 2009). Therefore, by considering measures that can be amortized over short time horizons, the possibility to change strategy remains open to a larger degree, and the corresponding costs of long-term uncertainty are minimized (Ibid.).

Synergy with mitigation

This criterion is established to co-think climate change mitigation and adaptation which are highly interrelated as adaptation measures can contribute positively to mitigation strategies and actions (Hallegatte, 2009). It is an overall aim to mitigate GHG emissions and therefore adaptation measures' suitability should be assessed based on, whether the measures comply with mitigation actions or counteracts mitigation both during implementation and the measures life time (Baills et al., 2020).

Immediate benefits

This criterion is included to consider whether the considered measure has a direct adaptation effect or if the effect is delayed (Baills et al., 2020). E.g., increasing the capacity of an undersized sewage system like

Frederiksberg's sewage system can have a direct benefit if the capacity is increased in a strategic location in the system.

Possible impacts on other risks

Possible impacts on other risks are centered around an assessment of the given measure in relation to potential positive or negative indirect and therefore unintended effects on risks in the area (Baills et al., 2020).

Self-sufficiency

This criterion is established to consider whether the given measure is effective on its own or whether other supplementing measures are required to achieve the full adaptation effect (Baills et al., 2020).

Life expectancy

The criterion of life expectancy is not to be understood as the measure's lifetime. In this case, lifetime describes a given measure's expected lifetime without consideration of external pressures (Baills et al., 2020). On the other hand, life expectancy considers the measure's expected effective period taking changes in climatic conditions into account. Therefore, when assessing a measure's performance in regard to this criterion, an estimation of when the measures must be altered or replaced, based on future conditions, should be conducted (Ibid.).

Implementation and maintenance costs

As investments in CCA measures are climate-sensitive, it is critical to consider both the implementation and maintenance costs of the investigated measures to e.g., reduce the cost of maladaptation (Baills et al., 2020).

5.3 Research design framework

The presented analytical framework shapes the use of methods in this report. The following figure visualizes the report's research design and the link between the theories and concepts and the utilized methods which will be further elaborated on in chapter 6.

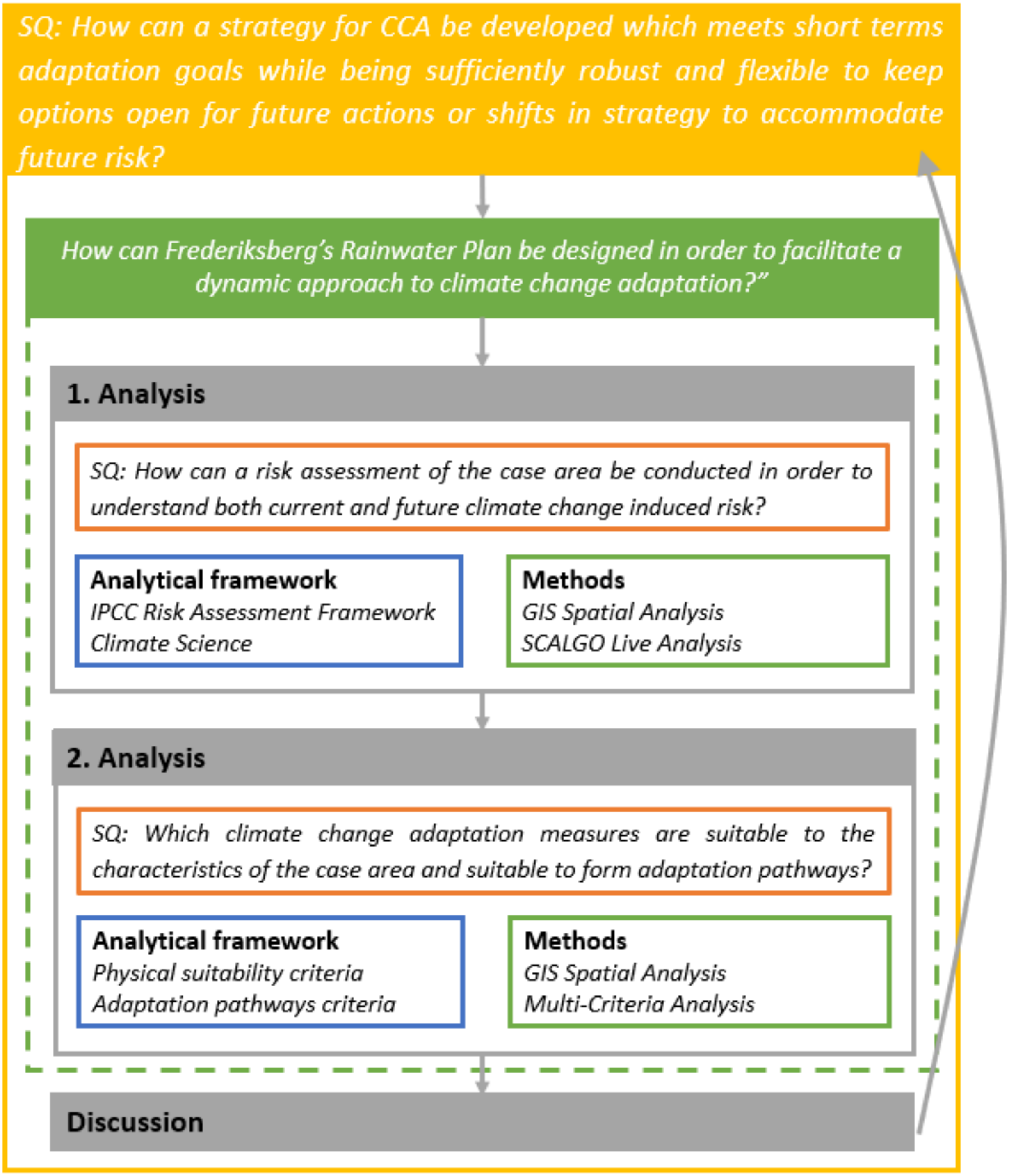

Figure 5.3 - Overview of the report's research design.

6 Methods

6.1 Risk assessment of current and future risk

Based on the analytical framework, the risk assessment will be conducted by mapping the exposure and vulnerability of the case area using available GIS data. These data will be supplemented with data based on future projections of e.g., traffic levels to describe a future scenario. Furthermore, potential hazards and their impact will be simulated in SCALGO Live by utilizing both short-term and long-term climate data to map current and future hazards, which will then be compared to the exposure and vulnerability mapping of the case area.

6.1.1 Data collection

The data collected to conduct the risk assessment is collected from several sources which provide geospatial data. To get an understanding of the case area in relation to precipitation events, the local watersheds and urban runoff flows are mapped utilizing SCALGO Live data based on the Danish digital terrain model.

To map the case area's exposure, IPCC's definition of the term is utilized to identify relevant types of data. Based on the definition of exposure presented in section 5.1.1, it can be derived that data related to the built environment, the people living there, and species and ecosystems. Due to the location of the case area in Frederiksberg and therefore its central location in Copenhagen, it can be argued that the presence of ecosystems and species is less significant as the case area is heavily altered by the built environment. Additionally, it has not been possible to find geospatial data for species and ecosystems in the case area. Therefore, based on the definition of exposure, the following data is utilized to map exposure:

Table 2 - Exposure data collection

Collected data	Data Source	Link to IPCC definition
Childcare and educational institutions	Frederiksberg Municipality	Infrastructure, services, social and cultural assets
Nursing homes and senior housing	Frederiksberg Municipality	Presence of people, livelihoods, services, social assets
Protected buildings, buildings with high preservation value, and churches	The Danish Agency for Culture and Palaces Frederiksberg Municipality	Social and cultural assets
Road type and traffic counting data	Frederiksberg Municipality	Infrastructure

The vulnerability data collection is similarly conducted based on IPCC's definition of vulnerability. Socio-economic vulnerability is considered to be related to exposure, and therefore the above-mentioned exposure data will be utilized in this regard. Concerning the lack of capacity to cope and adapt, several factors can shape this lack of capacity. In this report, the scope has been delimited to the physical and environmental vulnerability which, based on the analytical framework, is considered to include the capacity of the water management infrastructure, and the urban typology to cope and adapt to hazards. Therefore, the institutional vulnerability is left out of the analysis. On this basis, the following data is utilized to map vulnerability:

Table 3 - Vulnerability data collection

Collected data	Data Source	Link to IPCC definition
Sewage capacity	Frederiksberg Utility	Useful to understand the water management systems' ability to cope with future hazards
Share of impermeable surfaces	SCALGO Live	Useful to assess pressure on the sewage system as it influences levels of urban runoff and infiltration
Groundwater level	Hydrologisk informations- og prognosessystem (HIP)	Influences infiltration levels and therefore the capacity to cope
OSD areas (areas with particular drinking water interests)	Danmarks Milljøportal	Influences infiltration opportunities and therefore the capacity to cope
BNBO areas (groundwater protection areas in proximity to nearby drillings)	Danmarks Milljøportal	Influences infiltration opportunities and therefore the capacity to cope
Soil contaminated properties	Danmarks Milljøportal	Influences infiltration opportunities and therefore the capacity to cope

Based on the IPCC definition of hazards, hazards are mapped by using climate data from DMI's Climate Atlas as these datasets include the likelihood of the hazards to occur and the intensity of the hazards. The selected climate data is described and shown in the theoretical and analytical framework in the previous chapter (see Table 1).

Table 4 - Hazard data collection

Collected data	Data Source	Link to IPCC definition
1-hour return period precipitation events for current and future climates	DMI's Climate Atlas	Contains both likelihood (return period) and intensity of precipitation events

Changes in future exposure and vulnerability are investigated by defining a future for the case area's development regarding four different areas: traffic, population, urban development, and groundwater level, as these have been identified in the exposure and vulnerability mapping. The following data is utilized to define a future state of the case area:

Table 5 - Future exposure and vulnerability data collection

Collected data	Data Source	Link to IPCC definition
Traffic projections	Region Hovedstaden The Danish Road Directorate	Flooding can disrupt infrastructure and cause cessation with economic consequences
Population projections in terms of the number of citizens, and age distribution	Frederiksberg Municipality Statistics Denmark	Influences the number of people exposed to flooding. Socially marginalized and vulnerable groups are considered especially vulnerable
Urban Development Areas	Frederiksberg Municipality	Influences future levels of urban runoff and affects the capacity of CCA measures.
Groundwater level projections	Hydrologisk informations- og prognosessystem (HIP)	Rising groundwater level impacts infiltration options and can cause an increase in water leading to the sewage system

6.1.2 Data analysis

The data analysis is performed utilizing the geographic information system, QGIS, to analyze the above-mentioned collected geospatial data. QGIS is utilized to visualize the presence and location of e.g., vulnerable infrastructure and assets to identify areas with accumulated value and high levels of vulnerability, that are exposed to hazards. The geospatial distribution of flooding has been simulated in SCALGO Live and imported to QGIS to identify risk areas through an identification of areas, where high levels of value, high levels of vulnerability, and high levels of flooding, overlaps. On this basis, these areas can be pointed out as designated risk areas.

As mentioned, the geospatial distribution of flooding in the case area has been investigated in SCALGO Live by utilizing climate data from DMI's Climate Atlas. SCALGO Live is a national flood risk platform that can dynamically visualize climate data on a high-resolution terrain model (SCALGO, n.d.). SCALGO Live adds the selected level of precipitation 'on top' of the high-resolution terrain model, and therefore the water will move as runoff by gravity towards downstream depressions, where the water will eventually accumulate. SCALGO Live has a glass-model effect meaning that the platform does not take sewage system capacity or infiltration of rainwater into account (P. Bøcher, SCALGO ApS, personal communication, November 6, 2020). To consider this, the effect of the sewage system and infiltration of green areas has been partially included through a function in SCALGO Live which enables the specification of a fixed initial loss (the amount of rainfall that is required to wet up a catchment area before runoff starts) for different types of surfaces. The input utilized is illustrated in the table below.

Table 6 - Input for SCALGO Live

SCALGO Live parameters	Data input	Source
Initial loss – permeable areas	30 mm	Frederiksberg Utility
Initial loss – impermeable areas and buildings	20.53 mm	Frederiksberg Utility DMI's Climate Atlas

For permeable areas, the selected initial loss means that the first 30 mm of a precipitation event will wet up the soil before runoff starts. 30 mm is utilized as initial loss input in Frederiksberg Utilities hydrodynamic models. For impermeable areas like roads and buildings, the initial loss of 20.53 mm is selected to represent the capacity of the sewage system. The exact capacity of the sewage system in the case area is not known, however, a capacity analysis has been modeled by the company Krüger A/S for Frederiksberg Utilities. This analysis shows a limited share of overflows in the area south of the western part of Finsensvej during a 2-year precipitation event based on the current climate. During a 5-year precipitation event, however, there is a significant increase in overflows in the area. On this basis, it can be derived, that the service level of the system is somewhere between a 2 and a 5-year event. According to DMI's Climate Atlas (see Table 1), a 5-year precipitation event in Frederiksberg is equivalent to an hourly precipitation level of 20.53 mm (DMI, 2022). On this basis, an initial loss of 20.53 is set for impermeable areas, and therefore this initial loss will mimic the effect of the sewage system to some extent. The simulations made in SCALGO Live are then exported to QGIS to showcase different precipitation events side by side, and to compare the geospatial distribution of flooding with the exposure and vulnerability mapping.

6.1.3 Limitations

Simulating climate data in a platform like SCALGO Live entails several limitations due to the uncertainties associated with climate data and the limitations of SCALGO Live regarding representing reality. As mentioned in section 5.1.2, climate models are not yet able to encompass all mechanisms and processes of the climate system due to scientific uncertainty. Therefore, there are significant uncertainties regarding how Earth's climate system will respond to further increases in GHG emissions. Furthermore, there are uncertainties associated with the downscaling of global and regional climate models to the local level (McSweeney & Hausfather, 2018). Additionally, the visualization and the calculations of accumulated flooding volumes through the use of SCALGO Live are subject to further uncertainties due to the limitations of SCALGO Live. As mentioned above, SCALGO Live does not include infiltration and sewage capacities, and the approach to compensate for this lack in this report does not represent the dynamic character of these aspects. Furthermore, SCALGO Live does not contain a 'time frame', and therefore the simulated precipitation events occur instantly. Therefore, e.g., the flood depths in SCALGO Live are not likely to represent actual flood depths, as the time that it takes the water to run downstream and accumulate in depressions is not incorporated in SCALGO Live's analyses. On this basis, it is important to note that these flood depths, the distribution of flooding, and accumulated volumes of flooding in depressions are subject to uncertainties. Therefore, these analyses are not to be perceived as the actual magnitudes of the investigated hazards but as estimates.

6.1.4 Data protocol

Table 7 - Overview of the collected data and method utilized to analyze it

Collected data	Data type / unit	Data source	Link to the analytical framework	Method to process data
Childcare and educational institutions	Location of institutions	Frederiksberg Municipality	Exposure mapping	Visualized in QGIS
Nursing homes and senior housing	Location of institutions	Frederiksberg Municipality	Exposure mapping	Visualized in QGIS
Protected buildings, buildings with high preservation value, and churches	Location of institutions	The Danish Agency for Culture and Palaces & Frederiksberg Municipality	Exposure mapping	Visualized in QGIS
Traffic counting data	ÅDT (yearly average of daily traffic)	Frederiksberg Municipality	Exposure mapping	Visualized in QGIS
Sewage capacity	Return period capacity	Frederiksberg Utility	Vulnerability mapping	Used in SCALGO Live
Share of impermeable surfaces	Area of different types of surfaces in hectares	SCALGO Live	Vulnerability mapping	Visualized in QGIS Included in SCALGO Live
Groundwater level	In meter below terrain	Hydrologisk informations- og prognosesystem (HIP)	Vulnerability mapping	Visualized in QGIS
OSD areas	Geographic distribution	Danmarks Milljøportal	Vulnerability mapping	Visualized in QGIS
BNBO areas	Geographic distribution	Danmarks Milljøportal	Vulnerability mapping	Visualized in QGIS
Soil contaminated properties	V1 and V2 classified properties	Danmarks Milljøportal	Vulnerability mapping	Visualized in QGIS
Traffic projections	Change in number of trips by transportation type in %	Region Hovedstaden & The Danish Road Directorate	Future vulnerability mapping	Visualized in figure
Population projections	Change in total population, change in age distribution (in %)	Frederiksberg Municipality & Statistics Denmark	Future vulnerability mapping	Visualized in figure
Urban Development Areas	Number of designated urban development areas	Frederiksberg Municipality	Future vulnerability mapping	Visualized in figure
Groundwater level projections	Change in groundwater level in meter	Hydrologisk informations- og prognosesystem (HIP)	Future vulnerability mapping	Visualized in figure
Climate Data – Precipitation Events	Hourly precipitation intensities in mm	DMI's Climate Atlas	Hazard mapping	Utilized for SCALGO Live simulations and visualized in QGIS

6.2 Assessment of suitable measures

6.2.1 Data collection

The assembling of a toolbox of a wide variety of CCA measures is based on the measures from the Rainwater Plan and the Cloudburst Clarification Plan. In this way, the measures, that the utility and municipality have tested and have experience with, are included. To expand the toolbox of CCA measures beyond Frederiksberg Municipality's and Utility's practice, measures from Klimatilpasning.dk's and PLASK's catalogs of measures to handle everyday rain and stormwater are included as well (Klimatilpasning.dk, 2021b; Miljøstyrelsen, 2020). As stated in the Danish Coastal Authority's guide to the DAPP-approach, it is recommended to include measures beyond protective and accommodative measures (Kystdirektoratet, 2020a) and therefore measures, which can be classified as 'urban planning measures' and 'emergency measures', are included to supplement the protective and accommodative CCA measures.

These measures are then reduced to a list of measures that suit the physical properties of the case area based on the physical suitability criteria. This assessment of physical suitability is assessed based on data from the preceding analysis, as this analysis has collected geospatial data such as terrain data, urban runoff flows, and the share of permeable surfaces from SCALGO Live, as well as urban typology data such as road types and land-use.

Then, an assessment of the suitable measures' performance against the identified criteria from the analytical framework, will constitute the basis of the development of adaptation pathways. To assess the measures' performance in relation to these criteria, different types of data are utilized. On one hand side, specific data for the investigated measures are utilized, when it has been possible to find such data. This applies to the criteria such as 'implementation and maintenance costs, where data from PLASK is used (Miljøstyrelsen, 2020). For such criteria, the criteria can be quantitatively qualified based on the data. However, this is not the case for most of the criteria, as the performance in relation to these criteria is assessed to be very context-dependent. Therefore, it has not been possible within the scope of the report to assess the specific measures' performance against these criteria, where data is limited. Therefore, the assessment of the measures' performance is, in such cases, based on literature focused on the comparison of green infrastructure and hybrid infrastructure measures on one side with more traditional gray infrastructure on the other. In this way, an indication of the measures' performance is achieved.

6.2.2 Data analysis

6.2.2.1 Physical suitability screening

To reduce the list of potential adaptation measures to a list of measures, which are suitable for the given case area, an assessment of the measures' physical suitability is conducted. The measures' physical suitability is assessed through a mapping of the case areas' local conditions. Aspects such as the case areas' terrain, urban runoff flows, and local watersheds are utilized to gain an understanding of the catchment area, its location, and its interconnection with the surrounding catchment areas. This knowledge is then utilized to assess the feasibility and suitability of different types of measures such as large-scale transportation measures. For example, blue roads and cloudburst roads (transportation of water on roads by gravitation) are considered unfeasible due to the terrain as illustrated by the terrain profile from SCALGO Live in the figure below.

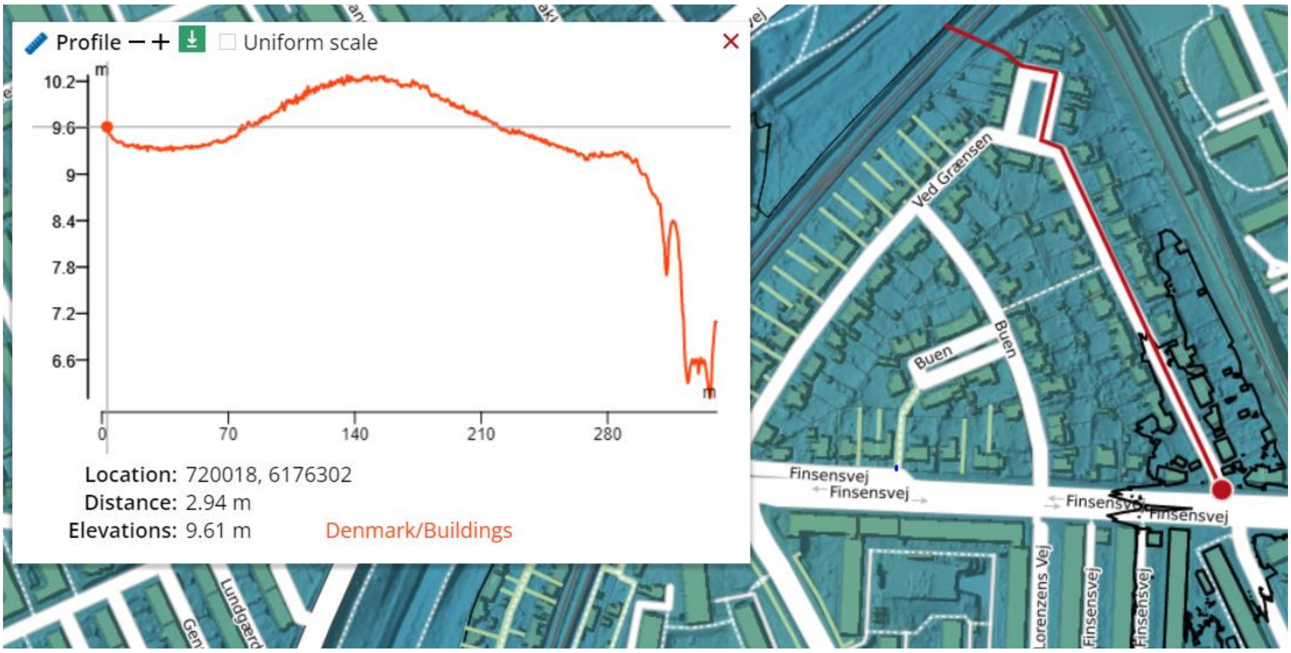

Figure 6.1 – Example of terrain analysis to assess the feasibility of a terrain-based transportation measure conducted in SCALGO Live

The figure above shows a terrain profile from the depression in Finsensvej and a potential route for a terrain-based transportation measure. Terrain-based transportation measures are considered suitable if the terrain profile shows a continuous slope with a minimum gradient of 5 ‰ as this is considered the minimum requirement in the utility practice in Frederiksberg. Similar terrain profiles have been made for alternative routes and depressions in the area. However, all investigated routes have in common that there are no continuous slopes to downstream recipients from any of the case areas' depressions which align with the minimum requirement.

Additionally, the measures' suitability has been screened in relation to the physical suitability criteria presented in section 5.2.1. This includes the public space availability, type of roads, land use, and sewer system type. Additional criteria such as the flood reduction effect and co-benefits are a part of the theoretical framework, however, these criteria have been included in the MCA instead. To assess the measures in relation to these local physical suitability criteria, the QGIS maps from the exposure and vulnerability assessment described in the previous section are utilized. Lastly, the assessment of measures' suitability has been based on an analysis of urban topologies conducted in Moeslund (2022) as well to identify specific properties suitable for retention measures and specific roads for green roads. In this project, an analysis of green roads' and retention measures' suitability have been conducted for the municipality of Frederiksberg. This analysis resulted in the identification of properties suitable for retention basins and cloudburst valves as well as suitable roads for conversion into green roads. The identification of suitable green roads in the case area is based on a QGIS layer of planned green roads from the municipality and utility which take aspects such as road width, ownership, and catchment areas into account. This QGIS layer is clipped to this report's case area resulting in the identification of 15 roads in the area suitable for green roads. These are illustrated in the figure below.

Figure 6.2 - Screening of roads suitable for green roads based on Moeslund (2022)

The screening of properties suitable for rainwater retention is based on predetermined suitability criteria related to the urban typology. The following criteria were utilized to identify suitable private properties for retention basins in QGIS: the properties had to be larger than 1 ha, and the building footprint on the property had to be 40% or less (Moeslund, 2022). This resulted in a QGIS map of several suitable properties in Frederiksberg. This QGIS layer has been clipped to this report’s case area. Based on the QGIS layer from Moeslund (2022), there are four potentially suitable properties for retention measures in this case area as illustrated by the figure below.

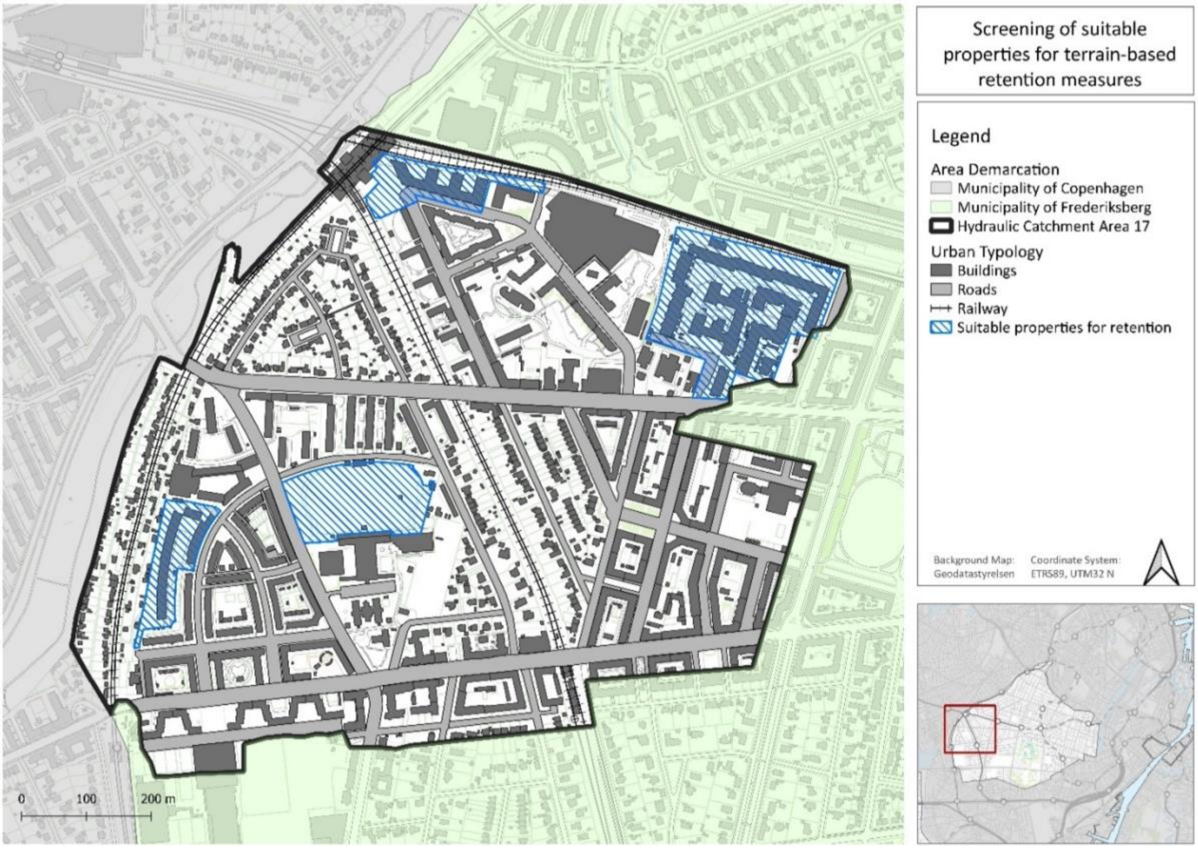

Figure 6.3 – Screening of properties suitable for terrain-based retention measures based on Moeslund (2022)

6.2.2.2 Multi-Criteria Analysis

To assess the measures' suitability for the development of adaptation pathways, an MCA is conducted. The MCA is a systematic approach to assessing a range of options such as CCA measures based on a large range of assessment criteria. In this way, either an optimal solution can be identified, or a range of options can be ranked in relation to their performances. The MCA is chosen as the assessment method of preference as such analyses can utilize both qualitative and quantitative data (van Ierland, de Bruin, & Watkiss, 2013). This is considered a strength due to the character of the selected assessment criteria presented in the analytical framework, and due to the scope of this report. As described in the data collection section, most of the collected data utilized to perform this MCA is qualitative data and therefore the MCA will be largely based on qualitative assessments derived from literature. Therefore, qualitative metrics will be utilized to score the measures' performance. According to USAID (2013) and van Ierland et al. (2013), an MCA in the context of CCA consists of the following steps:

1. To identify the context within the MCA is conducted
2. To identify CCA options
3. To identify assessment criteria with an associated assessment scale
4. To assess the identified CCA measures' performance against the criteria
5. To assess the weighting of each criterion
6. To calculate the final weighted scores

(USAID, 2013; van Ierland et al., 2013)

Concerning the first step, the context of the MCA is heavily influenced by the planning under deep uncertainty literature and the DAPP approach to CCA (see chapter I.3). Additionally, the context of everyday rainwater and stormwater management in the selected case area is of importance, as well as the context of Frederiksberg Municipality and Utility. Therefore, the second step of identifying CCA options has been based on measures that suit the context of Frederiksberg, and CCA catalogs for rainwater management in a Danish context (as described in the data collection section).

The third step of identifying assessment criteria is influenced by the context of planning under deep uncertainty and the DAPP approach and, therefore, the criteria are selected based on literature revolving around the issue of CCA planning under deep uncertainty (presented in section 5.2.2). These criteria are supplemented with the criterion of co-benefits which is a key part of assessing a measure's suitability (Alves et al., 2017). Additionally, these criteria are supplemented with the criterion of "synergies with municipal goals" to include a case-specific focus. To score the measures against the criteria, a score range is developed for the criteria. The utilized scale is inspired by van Ierland et al. (2013), who have used a scale of five scores ranging from one to five. A score of one represents a very low or a strong negative effect on the criteria, two represents a low or negative effect, three represents a medium or neutral effect, four represents a high or positive effect, and lastly, five represents a very high or strong positive effect. Due to the scope of this report, and the limited amount of available data specific to the investigated measures, this report utilizes a score range reduced to three scores ranging from zero to two as presented in the table below.

Table 8 – Definitions of score ranges and the criteria's' weighting

Criteria	Score = 0	Score = 1	Score = 2	Weighting
Co-benefits	The measure provides a low level of co-benefits	The measure provides a medium level of co-benefits	The measure provides a high level of co-benefits	10%
Synergy with municipal goals	The measure provides synergies with no to a low level of goals	The measure provides synergies with a medium level of goals	The measure provides synergies with a high level of goals	10%
Robustness	The measure has a low level of robustness	The measure has a medium level of robustness	The measure has a high level of robustness	16.67%
No regret solution	The measure is characterized by a high level of regret	The measure is characterized by a medium level of regret	The measure is characterized by a low level of regret	10%
Flexibility/ Reversibility	The measure is characterized by a low level of flexibility/ reversibility	The measure is characterized by a medium level of flexibility/ reversibility	The measure is characterized by a high level of flexibility/ reversibility	16.67%
Synergy with mitigation	The measure has a high negative effect on mitigation	The measure has a medium negative effect on mitigation	The measure has a small negative effect on mitigation	10%

Criteria	Score = 0	Score = 1	Score = 2	Weighting
Short decision horizon	The measure is characterized by a long decision horizon	The measure is characterized by an intermediate decision horizon	The measure is characterized by a short decision horizon	10%
Costs	The measure is associated with high costs	The measure is associated with medium costs	The measure is associated with low costs	16.67%

Compared to the criteria presented in the analytical framework, the criteria of immediate benefits and life expectancy have been left out of the assessment. The criterion of immediate benefits is used in the literature to differentiate between measures that address hazards and vulnerabilities directly on one side and complementary measures which e.g., include institutional measures and information measures on the other. As complementary measures are not considered within the scope of this report, this criterion is not included. Life expectancy is not included as well as the life expectancy criterion is integrated within the short decision horizon and robustness criteria. Additionally, it is considered complex to classify a measure's life expectancy as either a positive or a negative score, as e.g., a long life expectancy can be positive if the measure e.g., provides co-benefits and is flexible. Opposite, a short life expectancy can be negative if the measure e.g., is costly and does not provide co-benefits. Furthermore, the criteria of possible impacts on other risks and self-sufficiency are not included as well, as it has not been possible to find literature or data that can help qualify these assessment criteria. As these criteria are considered to be highly dependent on the local context, it can be argued that an assessment of these criteria will require analyses of the selected measures based on a level of detail that is beyond the scope of this report. On this basis, these criteria are left out of the assessment.

The fourth step is to perform the actual assessment of the measures' performances against each criterion. Each measure is assessed based on the description of the scores from the table above and is assigned a score between zero and two.

The fifth step is to assign weight to the identified criteria. The literature, from which the criteria originate, does not weigh the criteria. Therefore, the weighting of the criteria is based on the local context of Frederiksberg. As the stormwater service goal in Frederiksberg is a 100-year return event based on 2112 levels, it can be argued that there is a high need for robustness. Additionally, costs are considered an essential criterion as well due to new regulation which states that CCA investments funded by the utility must be both socio-economically appropriate and company efficient investments (DANVA, 2021). Therefore, the utility cannot choose a certain CCA measure if an alternative measure is cheaper (Ibid.). Lastly, the flexibility and reversibility of measures are of significant influence. This is based on the new regulation which includes a new approach to determining and calculating appropriate service goal levels (Ibid.). These new calculations might show that the existing service goal of a 100-year event might have to change in the future. On this basis, it can be argued that it is important, that the implemented CCA measures are flexible due to the dynamic reality of both the political landscape on one side and climate change on the other. On this basis, these three criteria are assigned an accumulated weight of 50% (16.67% each). On this basis, the remaining 50% is distributed between the remaining five criteria (10% each) (see Table 8).

Co-benefits

Based on the analytical framework, the concept of co-benefits can be split into the five sub-categories; water quality, environmental, livability, economic, and socio-cultural co-benefits (Alves et al., 2017). Based on these five sub-categories, 12 co-benefits are included in the framework. On this basis, the measures, which have been screened as suitable, are then scored in relation to the measures' ability to provide co-benefits in each sub-category. This assessment is based on Moeslund (2022), in which an analytical framework is developed based on literature to assess measures' ability to provide co-benefits.

Concerning green roads, the following co-benefits, in the table below, can potentially be provided by green roads.

Table 9 - Potential co-benefits of green roads. Based on Moeslund (2022).

Sub-categories	Co-benefits	Description	Source
Water quality	Improve water quality	The retention effect of green roads can help reduce sewage overflows to water environments	(Miljøstyrelsen, 2020)
Environmental	Regenerate groundwater	Green roads which allow infiltration can help generate groundwater resources	(Miljøstyrelsen, 2020)
	Increase biodiversity	Adaptation measures that provide greening can provide better living conditions for species as well as improve air quality dependent on the choice of vegetation	(Raven, et al., 2018)
	Improve air quality		(Hewitt, Ashworth, & MacKenzie, 2020)
Livability	Provide aesthetic value	Measures that provide greenery and vegetation can provide an aesthetic value.	(Miljøstyrelsen, 2020)
	Reduce UHI	Green roads can help reduce the UHI effect dependent on the level of greening that the green roads provide	(Raven, et al., 2018)
Economic	Energy savings	Measures that decouple water from the sewage system can lead to energy savings e.g., at water treatment plans.	(Miljøstyrelsen, 2020)
Socio-cultural	Educational activities	Terrain-based measures can promote educational activities if they are in proximity to educational institutions.	(Jørgensen, 2015)

According to (Moeslund, 2022), retention basins can provide the following co-benefits:

Table 10 - Potential co-benefits of retention basins. Based on Moeslund (2022)

Sub-categories	Co-benefits	Description	Source
Water quality	Improve water quality	The retention effect of retention measures can help reduce sewage overflows to water environments	(Miljøstyrelsen, 2020)
Environmental	Increase biodiversity	Terrain-based retention basins can provide better living conditions for species as well as improve air quality dependent on the level and choice of vegetation	(Raven, et al., 2018)
	Improve air quality		(Hewitt et al., 2020)

Sub-categories	Co-benefits	Description	Source
Livability	Provide aesthetic value	Terrain-based retention basins can be integrated into urban spaces such as squares and parks and can provide aesthetic value to these spaces.	(Miljøstyrelsen, 2020)
	Reduce UHI	Terrain-based retention basins can help reduce the UHI effect dependent on the level of greening that the basins provide	(Raven, et al., 2018)
Socio-cultural	Educational activities	Terrain-based measures can promote educational activities if they are located in proximity to educational institutions.	(Jørgensen, 2015)
	Sense of community	Retention basins can be designed to accommodate physical activities, contemplation, relaxation, and communal activities.	(Miljøstyrelsen, 2020; VANDPLUS, 2015)
	Recreational uses		

In relation to cloudburst valves, the following co-benefits can be provided according to the framework from Moeslund (2022).

Table 11 - Potential co-benefits of the cloudburst valve. Based on Moeslund (2022).

Sub-categories	Co-benefits	Description	
Water quality	Improve water quality	The decoupling effect during high rain intensities can help reduce sewage overflows to water environments	(Miljøstyrelsen, 2020)
Environmental	Regenerate groundwater	Discharge of rainwater into gardens increases infiltration	(Miljøstyrelsen, 2020)
Economic	Energy savings	Measures that decouple water from the sewage system can lead to energy savings e.g., at water treatment plans.	(Miljøstyrelsen, 2020)

An expansion of the existing sewage system can provide the following co-benefit:

Table 12 - Potential co-benefits of a sewage system expansion. Based on Moeslund (2022).

Sub-categories	Co-benefits	Description	
Water quality	Improve water quality	The increased capacity reduces sewage overflows to water environments	(Miljøstyrelsen, 2020)

A stormwater sewage system can provide the following co-benefits:

Table 13 - Potential co-benefits of a stormwater sewage system. Based on Moeslund (2022).

Sub-categories	Co-benefits	Description	
Water quality	Improve water quality	The discharge of rainwater to recipients reduces combined sewage overflows to water environments	(Miljøstyrelsen, 2020)
Economic	Energy savings	Measures that decouple water from the combined sewage system can lead to energy savings e.g., at water treatment plans.	(Miljøstyrelsen, 2020)

Based on the above-stated co-benefit assessments, the measures' ability to provide co-benefits has been summarized in the table below.

Table 14 - Overview of the investigated measures' potential to provide co-benefits

Measure	Number of sub-categories	Number of co-benefits
Green Roads	5 / 5	8 / 12
Retention Basins	4 / 5	8 / 12
Cloudburst Valves	3 / 5	3 / 12
Expansion of Sewage System	1 / 5	1 / 12
Stormwater Sewage System	2 / 5	2 / 12

From this table, it can be derived that there is a range of measures that provide co-benefits from a single sub-category to five sub-categories. Additionally, the measures provide between a single and 8 co-benefits in total across the sub-categories. On this basis, it can be argued that measures that provide co-benefits in at least four out of five sub-categories and can provide eight co-benefits in total are the highest-scoring measures. Therefore, green roads and retention basins are classified as measures that can provide a high level of co-benefits which, cf. the wording of the score range in Table 8, results in two points. Measures that can provide co-benefits in at least three sub-categories and can provide at least three co-benefits are classified as measures that can provide a medium level of co-benefits. On this basis, the cloudburst valve is assigned a single point cf. score range table. Lastly, measures that can provide co-benefits in a single sub-category, and can provide at least a single co-benefit, are classified as measures that can provide a low level of co-benefits. On this basis, expansion of the sewage system and the stormwater sewer are assigned zero points cf. the score range table.

Synergy with municipal goals

To identify municipal strategies and plans and the associated visions and goals, a document analysis is conducted. In short, document analyses are based on empirical analyses of large sets of documents (Bowen, 2009) and therefore, this method is utilized to examine a wide range of politically enacted municipal strategies. The identification of these goals and visions has been based on the 'Frederiksberg Strategy', which sets the direction for the municipal plan and therefore the urban development of the city. Sector plans and strategies have been examined to supplement the overarching goals, from the Frederiksberg Strategy, with some more sector-specific goals. This document analysis has resulted in Table 27 in the appendix, which provides an overview of all identified municipal goals. 10 of the identified goals are related to an increase in greening. Five goals have been identified related to a prioritization of multifunctional solutions and multifunctional uses of urban spaces. Four goals have been identified which concern clean drinking water, and a reduction of air pollution and noise pollution. On this basis, these goals have been reduced to the following three overall goals:

1. To promote increases in greening and vegetation to promote urban nature, biodiversity, and rainwater evaporation, to reduce the UHI effect.
2. To prioritize multifunctional solutions and urban spaces which can accommodate play and physical activities, culture and leisure activities, accessibility, and to achieve synergies that can provide new opportunities for citizens.
3. To provide clean drinking water, clean air, and to reduce noise pollution.

In this MCA, these three goals are assigned an even weight as this assessment is conducted without the participation of Frederiksberg Municipality and therefore without an insight into the municipality's priorities. As there are three overall goals, the score ranges from Table 8 of "no to a low level of synergy with goals" which is defined as measures that can provide synergies with no to a single overall goal. The score range associated with a medium level of synergy with goals is defined as measures that can provide synergies with two goals whereas a high level of goals is defined as measures that can provide synergies with three goals. To assess to what extent the measures can provide synergies with the municipal goals, the assessment is based on the previously conducted co-benefit assessment as the identified municipal goals represent several of the previously assessed co-benefits.

Green Roads

Based on the investigation of co-benefits that green roads can provide, it can be derived that green roads can provide synergies with the following municipal goals. Green roads can provide synergies to increase greening and vegetation in the city, as impermeable surfaces in terms of asphalt are converted into rain gardens along the road. As these rain gardens are integrated within roads, it has not been assessed that green roads can provide multifunctional urban spaces for leisure and cultural activities. However, based on the co-benefit assessment, green roads can provide synergies with the third goal of providing cleaner air and reducing noise pollution as increased vegetation can improve air quality and reduce noise (Hewitt et al., 2020; Miljøstyrelsen, 2020). On this basis, green roads can provide synergies with two out of three goals and are therefore assigned a score of one point.

Retention Basins

Retention basins can like green roads provide greening depending on how they are designed as retention basins can also be constructed as gray basins (Miljøstyrelsen, 2020). However, the measure can potentially provide synergies with the goal of increased greening (VANDPLUS, 2015). Concerning the goal of prioritizing multifunctional solutions and creating multifunctional urban spaces, retention basins hold a large potential to provide synergies to this goal as retention basins can be shaped in multiple ways to accommodate a variety of activities (Ibid.). As described above, measures that provide greening can provide synergies with the goals of cleaner air and reduced noise pollution. On this basis, retention measures have the potential to provide synergies with three out of three goals if the measures are designed to include greenery and vegetation. On this basis, the measure is assigned two points.

Cloudburst Valves

The cloudburst valve does not provide any greening as the cloudburst valve is a device made from concrete and plastic which is mounted on roof downpipes (Faldager, 2018). On the same basis, the measure does not provide synergies with multifunctional urban spaces which can accommodate multiple different activities. Lastly, no literature suggests that the cloudburst valve itself can provide synergies with clean drinking water, clean air, or reduced noise pollution. On this basis, the cloudburst valve does not provide synergies with any of the overall municipal goals and therefore the measure is assigned a score of zero points.

Expansion of sewage system and stormwater sewage system

An expansion of the sewage system and the construction of a stormwater sewage system are underground measures that therefore have limited effect on the overall municipal goals which mostly concern the urban environment in Frederiksberg. On this basis, the measures' do not provide synergies with goals related to greening, multifunctional urban spaces, or air and noise pollution goals. Therefore, these measures are assigned a score of zero points.

Robustness

Based on the definition of robustness presented in the analytical framework, robustness is centered around the measure's capacity to be effective under a wide range of future climatic conditions (Baills et al., 2020; Hallegatte et al., 2012). Therefore, to assess the robustness of each measure, the measures' tipping points are investigated to understand in which future climatic conditions the measures are no longer effective.

Green roads

For green roads, the tipping point is estimated on the presumption that 0,5 m^3 of retention volume can be established per running meter of road. To calculate the green roads' capacities based on this presumption, it is presumed that the green roads will only handle the rainwater which falls on the roads themselves. On this basis, the length and width of the 15 identified suitable roads are measured in QGIS to calculate the size of each road's catchment area. The retention volume of the suitable green roads is calculated by multiplying the length of the road with the presumption that 0,5 m^3 of retention volume can be established per running meter of road. On this basis, the retention volume which is considered feasible to implement based on the presumption is calculated (see Table 29 in the appendix).

To understand the relationship between the feasible retention capacity and the required capacity to handle a given return period event today or in the future, a spreadsheet to dimension retention basins published by the Danish Wastewater Committee is utilized. This spreadsheet is designed to calculate the required retention capacity to handle a given return period event based on the size of the basin's catchment area, a selected return period with an associated climate factor, and a discharge rate. The discharge rate is the rate at which the measure drains off the retention capacity to the sewage system. The faster the rate, the less of a retention effect. The slower the rate, the higher the retention effect is. Three discharge rates of 10, 30, and 50 l/s/ha are utilized to represent both a high, medium and small retention effect. The following return period events: 10-year, 20-year, 50-year, and 100-year events are selected to include a variety of rain intensities. Climate factors have been utilized to represent three time horizons: today, a 50-year time horizon, and a 100-year time horizon. A climate factor of 1 is used to represent today. Climate factors ranging between 1.15 - 1.2 and 1.3 - 1.50 are used for the 50-year horizon, whereas factors ranging between 1.2 - 1.4 and 1.7 - 2 are used for the 100-year horizon. The first interval is based on RCP4.5 whereas the second interval is based on RCP8.5. These climate factors are derived from the Danish Wastewater Committee's recommendations from 'Skrift 30' (IDA Spildevandskomiteen, 2014). On this basis, the calculated feasible retention volume based on the presumption can be compared with the necessary volume, derived from the spreadsheet, to check whether the feasible volume is sufficient. If the volume derived from the spreadsheet is larger than the feasible volume, then the feasible volume is insufficient and an overflow from the measure will occur. When the calculations show an overflow, the tipping point has been reached. Examples of these calculations are presented in Table 30 and Table 31 in the appendix. All calculations are included in the separate annex.

To reduce the many calculations related to 15 roads with three discharge rates, five return periods, three time horizons, and two climate scenarios to something more tangible, the analysis distinguishes between narrow roads and wide roads, which represent the majority of the investigated roads. Narrow roads are characterized by a width of around 10 meters. Wide roads are characterized by a width of around 20 meters. On this basis, the wide roads have larger catchment areas compared to the retention capacity which can be implemented. The table below shows the estimated tipping points for both narrow and wide green roads. This table is derived from the tables in the annex based on the above-mentioned classification of narrow and wide roads. See Table 30 and Table 31 in the appendix for an example of how these tipping points have been assessed.

Table 15 - Tipping points of narrow and wide green roads dependent on discharge rates and climatic conditions

Green roads		**Current climate**	**RCP4.5**		**RCP8.5**	
			2070	2122	2070	2122
Discharge Rate 10 l/s/ha	Narrow roads	~ 50-year event	> 20-year event	~ 20-year event	~ 20-year event	< 10-year event
	Wide roads	~ 10-year event	< 10-year event	< 10-year event	< 10-year event	< 10-year event
Discharge Rate 30 l/s/ha	Narrow roads	> 100-year event	~ 100-year event	~ 50-year event	> 50-year event	~ 20-year event
	Wide roads	> 20-year event	~20-year event	~ 10-year event	~ 10-year event	< 10-year event
Discharge Rate 50 l/s/ha	Narrow roads	> 100-year event	> 100-year event	~ 100-year event	~ 100-year event	~ 50-year event
	Wide roads	> 50-year event	>20-year event	~ 20-year event	~20-year event	< 10-year event

Concerning the everyday rain service goal of limiting damaging sewage overflows to terrain to occur at 10-year precipitation events and above, it can be derived from the table above that green roads implemented in narrow roads are especially robust. The figure illustrates that narrow green roads can handle 20-year events in a future climate based on RCP4.5 in year 2122 even with a low discharge rate of 10 l/s/ha and 20-year events in a future climate based on RCP8.5 in year 2122 with a discharge rate of 30 l/s/ha. Therefore, green roads have sufficient capacity to handle future 10-year events independent of whether the rate of climate change follows the trajectory of RCP4.5 or 8.5. In case the rate of climate change exceeds RCP8.5, the discharge rate can be increased to 50 l/s/ha thus increasing the robustness further. In this way, the measure is robust to multiple futures with different climatic conditions. Through the use of a higher discharge rate, it can be seen that narrow green roads can additionally be designed to help achieve the cloudburst service goal of handling a 100-year event. Narrow green roads can handle future 100-year events based on RCP4.5 with a discharge rate of 50 l/s/ha. However, if climate change follows the trajectory of RCP8.5, narrow roads can handle a 100-year event today and 50 years from now, but they cannot handle a 100-year event based on a 100-year horizon.

For wide roads, it can be derived from the table that the measure is robust to functioning according to the everyday rainwater service goal if the measures are implemented with a discharge rate of 30 l/s/ha or higher. However, concerning the cloudburst service goal, the wide green roads cannot manage a 100-year event today, nor in any of the investigated futures, no matter the RCP scenario based on the investigated discharge rates.

Retention in the existing terrain at identified properties

As was the case with the green roads, there are no available data that can help qualify the potential of retaining rainwater in the existing terrain on a general level. Therefore, specific properties with a high potential for rainwater retention have been identified in section 6.2.2.1. This analysis identified four properties suitable for retention in the existing terrain.

SCALGO Live has then been used to simulate a precipitation event to ensure that precipitation accumulates in the investigated properties' depressions. On this basis, three properties have been identified as suitable for terrain-based retention. Then SCALGO Live is used to identify the retention capacities of these depressions through the "Point Query" function and the catchment areas are identified through SCALGO Live's watershed tool which provides information about the size of the catchment area and the percentage of impervious surfaces within the catchment area. On this basis, the depression volume is used just like the feasible retention volume for green roads, and this volume can be compared to the required retention volumes derived from the Danish Wastewater Committee's spreadsheet. The same discharge rates, climate factors, and return periods are utilized for green roads. The table below shows the estimated tipping points for retention in the three properties' existing depressions. Examples of how these tipping points are determined can be seen in Table 32 and Table 33 in the appendix. All calculations can be seen in the annex.

Table 16 - Tipping points of retention in existing terrain dependent on discharge rates and climatic conditions

Retention in the existing terrain		**Current climate**	**RCP4.5**		**RCP8.5**	
			2070	2122	2070	2122
Discharge Rate 10 l/s/ha	Solbjerg Have	> 20-year event	> 10-year event	< 10-year event	< 10-year event	< 10-year event
	Frederiksberg Stadion	> 50-year event	> 20-year event	> 10-year event	> 10-year event	< 10-year event
	Osvald Helmuths Vej	> 20-year event	> 10-year event	> 10-year event	~ 10-year event	< 10-year event
Discharge Rate 30 l/s/ha	Solbjerg Have	> 50-year event	> 20-year event	> 20-year event	~ 20-year event	< 10-year event
	Frederiksberg Stadion	> 100-year event	> 50-year event	> 50-year event	~ 50-year event	> 10-year event
	Osvald Helmuths Vej	> 100-year event	> 50-year event	> 20-year event	> 20-year event	> 10-year event

Retention in the existing terrain		Current climate	RCP4.5		RCP8.5	
			2070	2122	2070	2122
Discharge Rate 50 l/s/ha	Solbjerg Have	> 100-year event	> 50-year event	> 20-year event	> 20-year event	> 10-year event
	Frederiksberg Stadion	> 100-year event	> 100-year event	> 50-year event	> 50-year event	> 20-year event
	Osvald Helmuths Vej	> 100-year event	> 100-year event	> 50-year event	> 50-year event	> 20-year event

Regarding the everyday rainwater service goal, it can be derived from the table above that retention in the existing terrain at the identified properties can accommodate 10-year events in all time horizons based on RCP4.5 with discharge rates ranging between 10 and 30 l/s/ha. For RCP8.5, all three properties can handle 10-year events in all time horizons with discharge rates ranging between 30 and 50 l/s/ha. In this way, the discharge rate can be adjusted to increase the capacity of the measure, and therefore the measure is considered robust to unexpected increases in the rate of climate change in an everyday rainwater management context.

Concerning the measure's function regarding the cloudburst service goal, it is not feasible for the measure to handle precipitation levels associated with future 100-year events independently of the utilized climate scenario. With a discharge rate of 50 l/s/ha, all three identified properties can accommodate precipitation events more intense than current 100-year events. However, when looking 50 years into the future only two out of three properties can handle a 100-year event based on RCP4.5 and none of them can handle a 100-year event based on RCP8.5. When looking 100 years into the future, none of the properties can handle a 100-year event based on the future climatic conditions associated with RCP4.5 and 8.5 with any of investigated discharge rates.

<u>Retention in constructed basins</u>

The assessment of retention through constructed retention basins is split into two. First, the identified property of Frederiksberg Stadion is investigated based on the construction of a retention basin volume of 3,000 m^3 as proposed in the cloudburst clarification plans (Frederiksberg Kommune, 2016). On this basis, the following table presents the estimated tipping points assessed through the Danish Wastewater Committee's dimensioning spreadsheet.

Table 17 - Tipping points of retention in retention basins dependent on discharge rates and climatic conditions

Retention in constructed basins		Current climate	RCP4.5		RCP8.5	
			2070	2122	2070	2122
Discharge Rate 10 l/s/ha	FRB Stadium	> 100-year event	> 100-year event	> 100-year event	> 100-year event	> 50-year event
Discharge Rate 30 l/s/ha	FRB Stadium	> 100-year event	> 100-year event	> 100-year event	> 100-year event	> 100-year event
Discharge Rate 50 l/s/ha	FRB Stadium	> 100-year event	> 100-year event	> 100-year event	> 100-year event	> 100-year event

On this basis, it can be derived that the retention basin can accommodate a 100-year event based on the climate of today as well as on a 50-year and a 100-year horizon for both climate scenarios no matter if the discharge rate is 30 or 50 l/s/ha. With a discharge rate of 10 l/s/ha, the basin can manage a RCP4.5 210 year-event 100 years from now based on its natural catchment area, and therefore the measure is assessed to be robust to future climatic conditions even though the rate of climate change accelerates.

Second, the robustness of retention basins is assessed in relation to the construction of retention basins in private courtyards. In the context of the case area, it has been assessed that retention basins on private properties such as in courtyards are considered suitable to handle the rainwater which falls on the buildings' roofs as well as the rainwater that falls within the courtyards. Compared to the above-mentioned tipping points which are based on the potential retention volumes, the tipping point for courtyards is assessed based on current regulation as it is outside of the project's scope to assess the potential retention volume in every single courtyard in the case area. The utility can fund CCA projects on private properties for up to a 10-year return period in areas with a combined sewage system without making a socio-economic appropriateness assessment (DANVA, 2021). However, there are examples of CCA projects in courtyards that can manage climate projected 100-year return period events 100 years from now (Klimatilpasning.dk, 2021a). Therefore, there is a potential to achieve more robust solutions. However, it is not considered possible to plan for 100-year events for retention measures on private properties due to the reliance on other stakeholders' participation and potentially funding. This does not mean that the utility should not strive for collaborative solutions with other stakeholders as these projects can lead to more robust solutions and can be integrated into the built environment and therefore potentially provide co-benefits.

On this basis, a high level of robustness in relation to the everyday rainwater service goal can be achieved if the retention basins are designed to accommodate a late-century 10-year RCP8.5 event based on the 90% quartile in DMI's Climate Atlas. In this way, the measure will be able to handle precipitation levels predicted by 90% of the models used in Climate Atlas, and through the use of RCP8.5, the retention basins will also be able to accommodate a future rate of climate change equivalent to RCP4.5. However, a high level of robustness in relation to the stormwater service goal is not guaranteed and will require collaborative projects in the courtyards. In the case of Frederiksberg Stadium, it can be seen that such projects have the potential to manage stormwater both today and in the future. However, it can not be guaranteed, and therefore retention basins are only considered to be able to manage 100-year events in some of the investigated futures.

Cloudburst Valves

The cloudburst valve activates at a precipitation intensity of 75 l/s/ha (Faldager, 2018) and discharges water onto the nearby terrain. Therefore, there is not a limited retention volume such as in green roads or retention basins as the water discharges onto lawns and other adjacent areas to where the valves are mounted. If the terrain-based conditions in proximity to the cloudburst valves are suitable to retain and infiltrate the discharged rainwater without causing damage, then the cloudburst valve is considered a robust measure that is suitable for both today's precipitation events and the precipitation events of the future. On this basis, the cloudburst valve is assigned two points as it can be argued that the cloudburst valve is effective in all futures no matter the climatic conditions.

Expansion of the combined sewage system and construction of a stormwater sewage system

To assess tipping points for an expansion of the sewage system and the construction of a stormwater sewer, the functional practice for water management systems in Denmark based on the Danish Wastewater Committee’s recommendations is utilized. The functional practice for stormwater sewers is that these measures should be dimensioned to accommodate climate projected 5-year return period events. For combined sewer systems the practice is to dimension these systems for climate projected 10-year return period events (IDA Spildevandskomiteen, 2005). These tipping points do not represent the hydraulic tipping points for these measures. However, when constructing measures that will raise the service level above the functional practice, it is required that the measures are socio-economic appropriate (meaning that the damage reductions are larger than the investment costs) and that the cheapest solution is chosen (DANVA, 2021). Therefore, the tipping point is determined to be the recommendations from the Danish Wastewater Committee of a 5-year event and a 10-year event respectively. As the everyday rainwater management goal is to meet the functional practice suggested by the committee, then an expansion of the sewage system or the construction of a stormwater sewer tipping points of a 10-year event and a 5-year event is sufficient. Concerning robustness, if these systems are designed according to a late century RCP8.5 return period event based on the 90% quartile, then these measures will be able to handle the precipitation levels predicted by 90% of the models used in Climate Atlas, and the sewage systems will also be able to manage 5 or 10-year events based on a development which follows the trajectory of RCP4.5. However, based on these tipping points, these measures are not sufficient to meet the stormwater service goal in any of the investigated futures.

Summary of robustness

Based on the sections above, the following table has been derived.

Table 18 - The investigated measures' robustness

Measures	Everyday rainwater management	Stormwater rainwater management
Green roads	Effective in all scenarios	Effective in multiple scenarios
Retention in the existing terrain	Effective in all scenarios	Effective in multiple scenarios
Retention basins	Effective in all scenarios	Effective in some scenarios
Cloudburst Valves	Effective in all scenarios	Effective in all scenarios
Expansion of sewage system	Effective in all scenarios	Not effective in any scenarios
Construction of stormwater sewer	Effective in all scenarios	Not effective in any scenarios

It can be derived from the figure, that the cloudburst valve is the only measure that is deemed capable of being effective in all investigated futures and scenarios. On this basis, the cloudburst valve is considered to have a high level of robustness and is therefore assigned two points cf. the score ranges from Table 8.

Additionally, it can be derived that green roads, retention in the existing terrain, and retention basins are characterized by an intermediate level of robustness, as the measures are effective in all investigated futures and scenarios in an everyday rainwater management context, but only in multiple futures and scenarios in a stormwater management context. Regarding green roads, it is only narrow green roads that can manage a 100-year event in a variety of future climatic conditions. For retention in the existing terrain, none of the identified properties can manage 100-year events on a 100-year horizon. For retention basins, it has been assessed, that retention basins have the potential to manage 100-year events as illustrated by the example of Frederiksberg Stadion, however, as most retention basins are expected to be implemented in courtyards it is uncertain whether these courtyards can accommodate future 100-year events even though it has been demonstrated in Copenhagen (Klimatilpasning.dk, 2021). Therefore, these measures are assigned a single point.

Lastly, expansion of sewage systems and construction of stormwater sewers are classified as having a low level of robustness as these measures are only considered to be effective in an everyday rainwater management context. On this basis, these measures are assigned zero points.

No regret solutions and flexibility/reversibility

As it has not been possible to acquire literature that discusses and assesses the level of 'no regret' of the investigated measures in this study, literature which have assessed no regret of green infrastructure, gray infrastructure, and hybrid approaches is utilized. These three groups represent broad ranges of CCA measures and therefore the investigated measures in this report are categorized into these three groups.

Green infrastructure is according to Kabisch et al. (2017) characterized by nature-based solutions which provide ecosystem services. Gray measures are characterized by engineered structures of materials such as concrete (Ibid.). Lastly, hybrid measures include both gray and green structures and, in this way, combine engineered structures with ecosystem services such as infiltration and evaporation (Ibid.). Based on these definitions, the selected measures are categorized according to the three typologies of CCA measures as illustrated in the table below.

Table 19 - Classification of measures based on definitions from Kabisch et al. (2017).

Measures	Type of CCA infrastructure
Green roads	Hybrid measures
Terrain-based retention measures	Hybrid measures
Cloudburst valves	Gray measures
Stormwater Sewers	Gray measures
Expansion of combined sewage systems	Gray measures

Both green roads and terrain-based retention measures are assessed to have elements of green measures, as they can provide greening and can be designed to promote infiltration and evaporation of rainwater. However, these measures are still connected to and dependent on the sewage system as they are retention measures. Therefore, these measures contain engineered structures in the shape of e.g., sewage wells, fascines, and pipelines. The remaining measures are classified as gray measures as they consist mainly of piped underground solutions. This includes the cloudburst valve which is mainly made out of concrete (Faldager, 2018) and is therefore considered a gray measure as well.

According to Kabisch et al. (2017), gray infrastructures are often associated with high regret measures, green infrastructures are associated with low regret measures, whereas hybrid approaches are associated with an intermediate level of regret. Based on the score range in Table 8, the gray measures, which are characterized by a high level of regret, are assigned zero points. Hybrid measures, which are characterized by a medium level of regret, are assigned one point, whereas green measures, which are characterized by a low level of regret, are assigned two points.

The assessment of flexibility/reversibility of the investigated CCA measures is based on the same classification of gray infrastructure, green infrastructure, and hybrid approaches from Kabisch et al. (2017) as well. According to Kabisch et al. (2017), gray infrastructure has little to no reversibility making them inflexible. Green infrastructure is assessed as having medium flexibility as the reversibility depends on the specific measure. Hybrid approaches are assessed to have a medium level of flexibility and reversibility as well. In relation to the score range, gray measures, which are characterized by low flexibility and reversibility, are assigned zero points. Green and hybrid measures, which are characterized by medium flexibility and reversibility, are assigned one point. An exception is made for the cloudburst valve, which is considered a gray measure, as the measure according to Faldager (2018) is characterized by a high level of flexibility. On this basis, the cloudburst valve is assigned a score of two points.

Synergy with mitigation

The carbon footprint of CCA measures depends on factors such as the use of carbon-intensive materials such as concrete and steel, the construction phase, the use of pumps for transportation of rainwater, and carbon sequestration of the greening which the measures provide (Miljøstyrelsen, 2020; Moore & Hunt, 2013). Due to the limited scope of the report, it has not been feasible to assess aspects such as the actual use of materials or the need for pumps. Therefore, this assessment is based on the same categorization of measures into green infrastructure, gray infrastructure, and hybrid solutions from Kabisch et al. (2013).

According to Moore & Hunt (2013), the carbon footprint of so-called hard-engineered traditional infrastructures, corresponding to gray infrastructures, is likely to be more extensive than the carbon footprint of green infrastructures. However, green infrastructures are still likely to be net carbon sources (Ibid.) meaning that the measures emit more carbon than they absorb. This is likely due to the transportation of materials and the materials' carbon footprints which are still significant (Ibid).

On this basis, gray infrastructures are considered to have the biggest negative effect on climate change mitigation of the three considered types of CCA infrastructure and therefore these measures are assigned a score of zero. Green infrastructures are considered to have the lowest negative effect of the three types of CCA infrastructures and such measures are therefore assigned two points. Hybrid solutions are expected to fall within an intermediate level and are therefore assigned a single point. An exception is made for both retention measures in the existing terrain and the cloudburst valve. As the intention of retaining rainwater in the existing terrain is to reduce the consumption of materials and the degree of construction work due to the utilization of the existing depressions, retention in the existing terrain is assigned a score of two points. Additionally, as a part of the Rainwater Plan, a screening of measures carbon footprint has been conducted by external consultants. This screening showed that the cloudburst valve provides larger synergies with mitigation actions compared to retention basins and green roads due to a low carbon footprint. On this basis, the cloudburst valve is assigned two points as well.

Short decision horizon

Due to the definition of a short decision horizon based on Baills et al. (2020), short decision horizon as a criterion concerns the prioritization of CCA measures with a short investment lifetime to minimize future uncertainty. In this regard, measures with short expected lifetimes are to be preferred. On this basis, the measures are assessed against this criterion through the utilization of measures' expected lifetimes from PLASK. According to PLASK, the selected measures have expected lifetimes ranging from 20 to 75 years (Miljøstyrelsen, 2020) as seen in the table below.

Table 20 - Expected lifetimes based on Miljøstyrelsen (2020)

Measures		Estimated lifetimes
Green roads		20 years
Retention in the existing terrain		50 years
Retention basins	Concrete retention basin	75 years
	Green retention basin	50 years
Expansion of combined sewage system		75 years
Stormwater Sewer		75 years

As seen in the table, green roads have an estimated lifetime of 20 years according to PLASK, however in Frederiksberg green roads are expected to have a lifetime of 30 years (Frederiksberg Kommune, 2016). However, this does not change that the green roads have the shortest expected lifetime. Therefore, green roads, which have the shortest decision horizon, are assigned a score of two. It has not been possible to find literature or data concerning the cloudburst valve's expected lifetime. However, it is assumed that the cloudburst valve has a shorter life expectancy than 50 years, and therefore the measure is assigned a score of two points. At an intermediate level are the measures with estimated lifetimes of 50 years which include retention in existing terrain. Retention basins have expected lifetimes ranging between 50 and 75 years depending on the basin type. However, retention basins are classified at the intermediate level as it will require context-dependent analyses to determine whether green or gray basins are the most suitable in the case area. Therefore, measures with lifetimes of 75 years include expansion of the combined sewage system and construction of a stormwater sewer. These measures are assigned zero points as they represent measures with long decision horizons.

Implementation and maintenance costs

The implementation costs of PLASK are provided with different units complicating the comparison of retention measures and piped measures. E.g., retention measures implementation costs are presented in DKK/m^3 retention volume, whereas stormwater sewer implementation costs are provided as DKK/ha of the sewage catchment area. On this basis, the classification of measures in gray, green, and hybrid infrastructures as presented earlier, is utilized. According to Kabisch et al. (2017) gray infrastructure is associated with high building costs, whereas green infrastructure is associated with fewer expenses, and hybrid measures fall within an intermediate level. On this basis, it can be derived that the gray measures are more expensive than the hybrid measures. To further qualify the hybrid measures and their associated implementation and maintenance costs, data from PLASK is utilized. According to PLASK, the hybrid measures range between 500 and 50,000 DKK/m^3 of retention capacity in implementation costs (Miljøstyrelsen, 2020). These costs are presented in the table below.

Table 21 - Implementation and maintenance costs of hybrid measures. Based on Miljøstyrelsen (2020)

Measures		Implementation costs	Maintenance costs
Green roads		8.000-50.000 DKK/m^3	25 DKK/m^3/year
Retention in the existing terrain		600-1.200 DKK/m^3	25 DKK/m^3/year
Retention basins	Concrete retention basin	3.500-11.000 DKK/m^3	40 DKK/m^3/year
	Green retention basin	500-4.000 DKK/m^3	2.000-10.000 DKK/basin/year

The maintenance costs are difficult to compare due to the varying use of units. Therefore, scoring based on maintenance costs is left out of the analysis. Regarding implementation costs, it can be derived that green roads potentially have significantly higher implementation costs compared to the other measures. Based on the wording of the score range (see Table 8), measures associated with high costs are scored zero points. As described above, gray measures are associated with higher costs than green and hybrid measures, and therefore gray measures fall within this score. Measures associated with medium costs are assigned a single point. As green roads are the most expensive of the hybrid measures, green roads fall within this score. Lastly, measures associated with low costs are assigned two points and include retention in existing terrain and retention basins as these have the lowest costs in PLASK. Additionally, an exception is made for cloudburst valves, as they are expected to have low implementation costs as they are mounted on downpipes. Therefore, cloudburst pipes are assigned a score of two points. However, it has not been possible to find data regarding the costs of cloudburst pipes to support this claim.

6.2.2.3 The development of adaptation pathways

To propose a strategy for CCA which meets both short term adaptation goals while keeping the options open for future actions or shifts in strategy, the analysis of adaptation pathways is split into two: one which focuses on the management of everyday rain (≤ 10-year return period), and one which focuses on extreme precipitation events (> 10-year return period). This is based on two of Frederiksberg Utility's CCA goals, which are to achieve a 10-year return period service goal and to ensure a maximum of 10 cm of water in property boundaries during a 100-year precipitation event in year 2113 (the stormwater service goal).

On this basis, the first step will be the investigation of, how adaptation pathways can be developed to manage and accommodate everyday rain (≤ 10-year return period) to ensure a short-term adaptation effect as these precipitation events statistically occur more often and are therefore associated with less uncertainty. The choice of CCA measures will be based on the MCA of the measures' performance in relation to the identified criteria as described above. The measures with the highest weighted scores will therefore be prioritized. Additionally, the approach focuses on the utilization of measures that can solve local everyday rain-related flooding problems in the upstream catchment areas of the main depressions while at the same time reducing downstream flooding. In this way, local everyday rainwater flooding problems are solved, which would have had to be solved anyway, to increase the performance of the sewage system, while contributing with a positive effect to the management of extreme precipitation events through the construction of upstream retention capacity. Hereafter, it will be investigated, to what extent the proposed everyday precipitation measures can be utilized and enlarged to manage extreme precipitation events through the assessed tipping points and robustness levels and the use of additional CCA measures.

In this way, a step-by-step approach emerges which firstly focuses on identifying relevant everyday precipitation measures, which have a value no matter the projected level of climate change. Therefore, the risk of maladaptation as a result of deep uncertainty is considered to be reduced.

6.2.3 Limitations

The limitations of this analysis are specifically related to the level of detail which this analysis is based upon. The assessment of suitable measures is among other things based on a screening of the case area, its physical characteristics as well as a blue spot simulation in SCALGO Live. On this basis, the analysis does not include the dynamics of a hydrodynamical model such as the distribution of rain, time, and the dynamics of the sewage system. However, the Danish Coastal Authority's adjusted approach to DAPP is not characterized by a high level of detail in these screenings (as described in section I.3.2.4) and therefore the conducted screening level is considered sufficient.

Concerning the MCA, the performed MCA has on several levels had the characteristic of a simple MCA. The assessments of the measures' performance against the criteria have been mostly qualitative and often based on simple assessments of the measures as having a negative, neutral, or positive effect on the criteria. In several cases, it has not been possible to find data specific to the assessed CCA measures' and therefore the assessments have been based on overall assessments of green vs. gray CCA infrastructure and in some cases solely on assumptions. Therefore, the level of detail in this assessment is relatively low in several regards to the specific CCA measures, and therefore the results are not necessarily valid for the given context of the specific CCA measure and the context of the case area in Frederiksberg. However, as the scope of this report is to showcase and test the benefits of utilizing the DAPP approach in a new context of Frederiksberg, the level of detail in this MCA is assessed to be sufficient as an initial screening which can be further qualified in a potential DAPP-process in the future. Additionally, the weights of the criteria are based on qualified guesses on what the utility would prioritize based on 10 months in the organization. However, an actual assessment of what the utility and municipality will prioritize should be settled in a future dialog across multiple departments to attain a holistic view of the utility and municipal prioritizations.

Concerning the robustness discussion, the calculated tipping points have been established based on an initial screening with simplified calculations which does not consider the sewage system's capacity, and tipping points have been established based on assumptions about what is feasible to implement. In comparison to Haasnoot et al. (2013), this approach has a low level of detail and is largely based on a qualitative assessment. The original approach suggested by Haasnoot et al. (2013) is computational. However, the level of detail is considered sufficient in relation to the Danish Coastal Authority's adjusted process which does not require a high level of detail as the process is based on the participation of a wide range of stakeholders. In this project, the facilitation of a DAPP process and therefore the participation of stakeholders is beyond the scope (as described in section 4.2). In the case of an actual DAPP process in Frederiksberg, locally based data should be developed to further qualify these tipping points. The inclusion of stakeholders can further contribute with knowledge and data based on experiences and the current practice with the implementation of CCA measures in Frederiksberg and their effect.

When developing the adaptation pathways, it is not possible to assess the return period event that the proposed adaptation pathway above can manage without hydrodynamic modeling. The individual measures' tipping points have been assessed, however, the return period precipitation event which the measure itself can accommodate based on its catchment area cannot be merged with another measure's tipping point as the utilized measures in this study are applicable for different types of catchment areas. The effect of such measures on the water management systems capacity must be investigated in hydrodynamic models where the effect on the reduction of overflow from the sewage system can be investigated as well as the reduction in the distribution of damaging flooding on terrain. Therefore, based on the adaptation pathway it cannot be concluded whether the use of retention and decoupling measures in upstream areas are sufficient to achieve the 100-year service goal for stormwater management or whether the construction of a piped solution is necessary. However, what this adaptation pathway can do it to guide future prioritizations of CCA actions to keep options open for future action as the development of this adaptation pathway has focused largely on an early implementation of short-decision horizon measures characterized by high flexibility and no-to-low regret. In this way, measures characterized by large costs and low flexibility have been deemed as potential future 'last resort' solutions, and due to the implementation of the initial measures, the scale and extent to which these more comprehensive measures might have to be implemented in the future are reduced.

III. Results & Analysis

7 Risk assessment and success scenario

The selected case area is one out of 22 designated water catchment areas in Frederiksberg which are specified based on an analysis of Frederiksberg's terrain. The area is located in western Frederiksberg on the municipal border to Copenhagen and is delimited by the elevated metro railway in the north and by the municipal border to the west. The southern and eastern limits of the area are determined by the terrain.

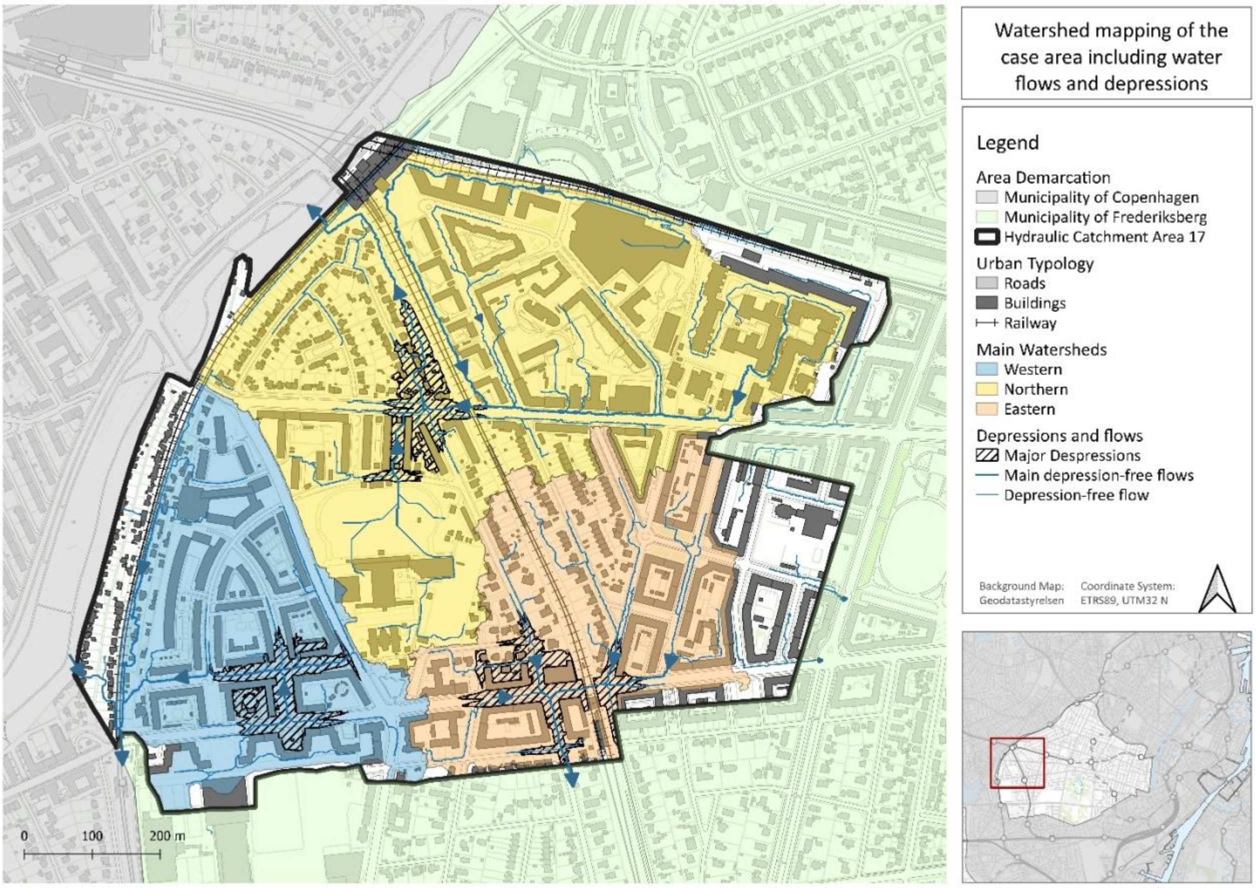

Figure 7.1 – Case area overview with highlighted main depressions and their associated catchment areas as well as depression-free water flows to visualize urban runoff flows. These layers have been imported from SCALGO Live to QGIS.

Based on the figure, it can be derived that the case area is an upstream catchment area as illustrated by the depression-free water flows or urban water runoff imported from Scalgo. It can be seen that there are limited water runoff flows into the area with the main water flow highlighted by a blue arrow in the southwestern corner of the case area. This means that excess precipitation which the sewage system cannot accommodate will fill up the local depressions before the water flows towards downstream catchment areas by gravitation.

The figure illustrates that there are three main watersheds or sub-catchment areas within the case area. This means that precipitation that falls within the same watershed will flow towards the same depression. As the terrain slopes downhill west and south, two watersheds discharge water out of the area to the west and a single watershed discharges water to the south. In the northern watershed, the runoff flows toward the main depression at Finsensvej west of the railway on the intersection with the street "Ved Grænsen". According to SCALGO Live, this depression has a volume of 3000 m^3. When the depression is full, the runoff continues northwest down "Ved Grænsen" and into private residential properties before eventually crossing the railway into the Grøndals Park in Copenhagen. The terrain in the western watershed slopes towards the west as well. The water accumulates in the depression at the intersection between Matzens Vej and Mørk Hansens Vej which has a volume of 2.900 m^3. When the depression is full the runoff flows to the west down Mørk Hansens Vej and floods the downstream railway. The last main watershed is the eastern watershed in which the terrain slopes towards the south. The water runoff flows to the main depression at Peter Bangs Vej which has a capacity of 4.300 m^3 just west of the railway. When the depression is full, the water runoff continues south into a residential area.

7.1 Hazards

As mentioned in the analytical framework, climate data from DMI's Climate data have been used to simulate precipitation events in Scalgo Live. Furthermore, the figures do only show areas with more than 10 cm of water on terrain as that is the threshold that the municipality and utility have set in their service goal for cloudbursts. On this basis, water levels of more than 10 cm are considered harmful.

7.1.1 Short-term hazards

The following figure shows a 10-year, a 50-year, and a 100-year early-century precipitation event simulated in the area.

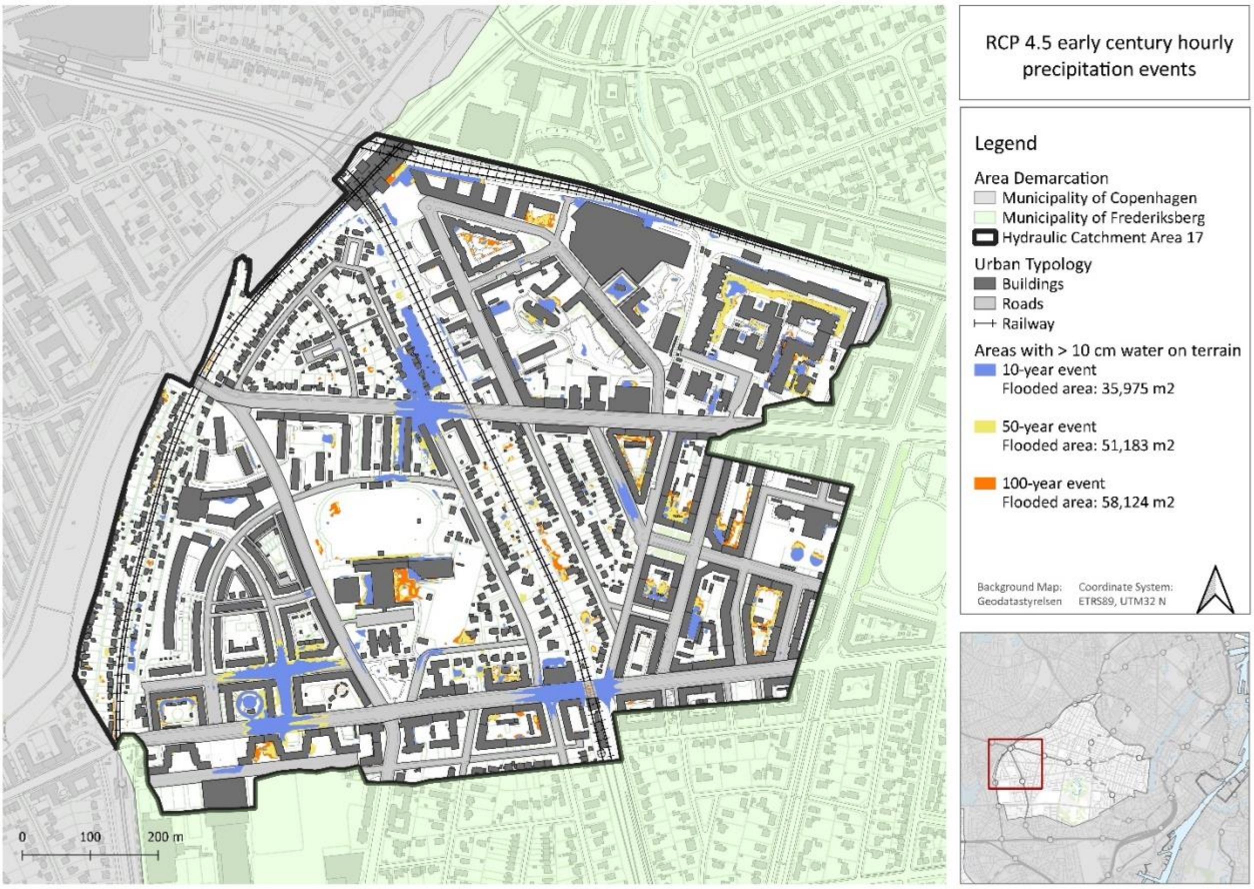

Figure 7.2 - Early century precipitation events. Simulated in SCALGO Live.

From the figure, it can be derived that the three main depressions, as described in the previous section, make up the primary flooded areas during all simulated precipitation events as the runoff accumulates in these depressions from the associated catchment areas. Additionally, rainwater accumulates around buildings in the eastern part of the case area including within residential courtyards. However, the flooded courtyards can be a result of a limitation in SCALGGO Live which utilizes a terrain model which might not include gates or other entrances in the residential blocks, and therefore the buildings might enclose the rainwater within the courtyard. As shown in the figure, the different precipitation events flood between ~36,000 m² and ~58,000 m² of the area which is equivalent to 4.4 - 7.1% of the case area. To better understand the extent of the flooded areas and the differences between the simulated precipitation events, the following figure will show the flooding depth of the 10-year and 100-year precipitation events. In this regard, it is important to note that these simulations are blue spot maps and therefore they do not include the dynamics of the sewage system (see section II.6.1.3 for more details). On this basis, the following flood depths must be perceived with these limitations in mind.

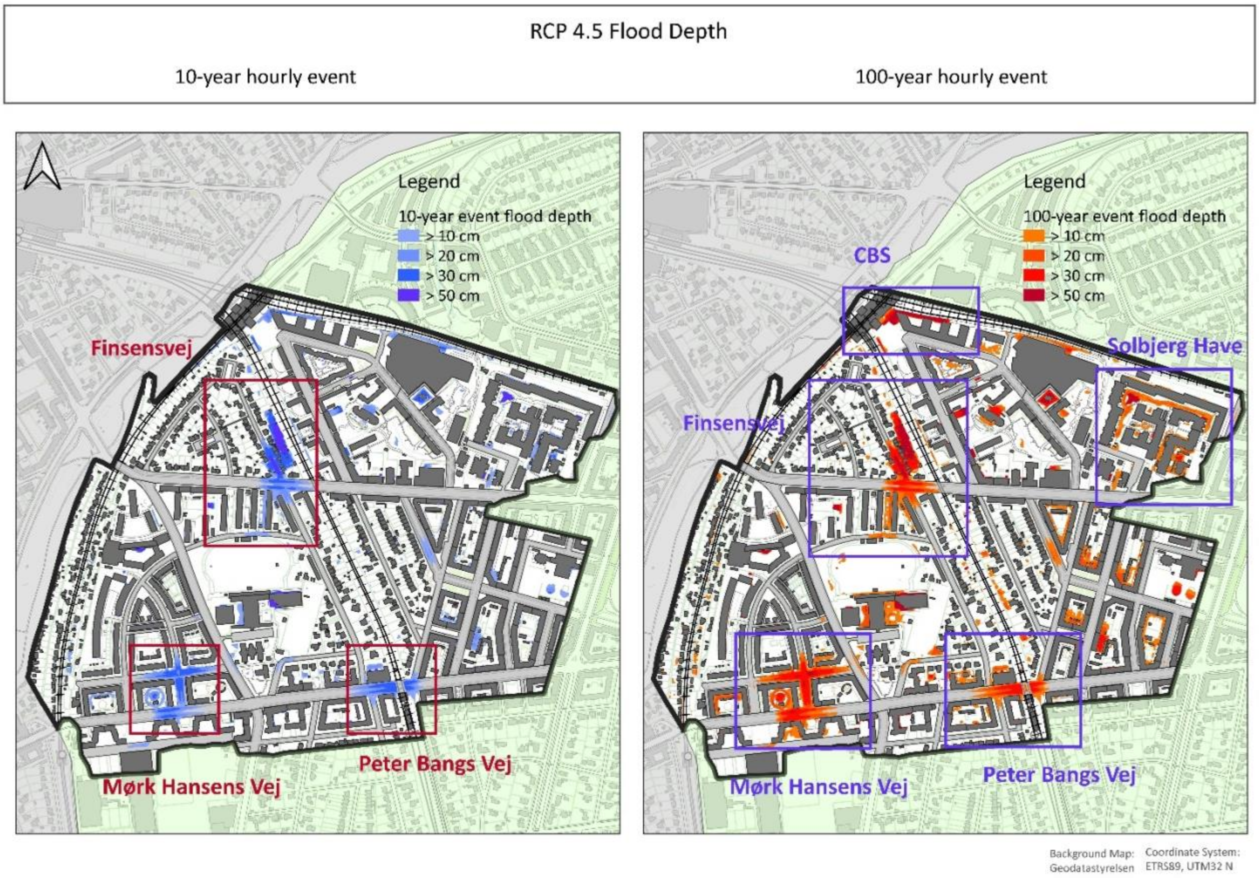

Figure 7.3 – Early century 10-year hourly and 100-year precipitation event with blue spot flood depth.

As illustrated by the figure above, there is no significant difference between the flood depths in the three main depressions as a result of a 10-year event or a 100-year event. However, the quantity of water in the depressions increases significantly. Around 3.000 m³ of water accumulates in the Finsensvej depression during a 10-year. This increases to 5.000 m³ during a 100-year event. At the depression at Mørk Hansens Vej, 1.800 m³ accumulates increasing to 3.500 m³ during 100-year events. Lastly, during a 10-year event 1.100 m³ of water accumulates in the Peter Bangs Vej depression rising to 2.000 m³ during a 100-year event.

Furthermore, during a 100-year event, significant levels of water accumulate in the depressions at the Copenhagen Business School (CBS) with 800 m^3 of water and a flood depth of up to 80 cm, and at Solbjerg Have with 1,000 m^3 of water with levels up towards 100 cm. On this basis, these depressions entail around 5,900 m^3 of water as a result of a 10-year event and 12,300 m^3 of water during a 100-year event.

Lastly, a significant difference between the 10-year event and the 100-year event is the amount of runoff that flows to the municipality of Copenhagen in the western part of the case area. According to the simulation in SCALGO Live, the 10-year precipitation event does not lead to runoff from the Finsensvej depression to the Grøndals Park in Copenhagen. By contrast, a 100-year event leads to around 4,000 m^3 of runoff to the Grøndals Park. Again, it must be stated that this is an estimate which is subject to several limitations, however, it provides an understanding of the magnitude of the differences between the two precipitation events.

7.1.2 Long-term hazards

Compared to the simulation of early century events, these late century events do result in increased flooding. However, the flooding is still concentrated around the previously mentioned depressions as seen in the figure below.

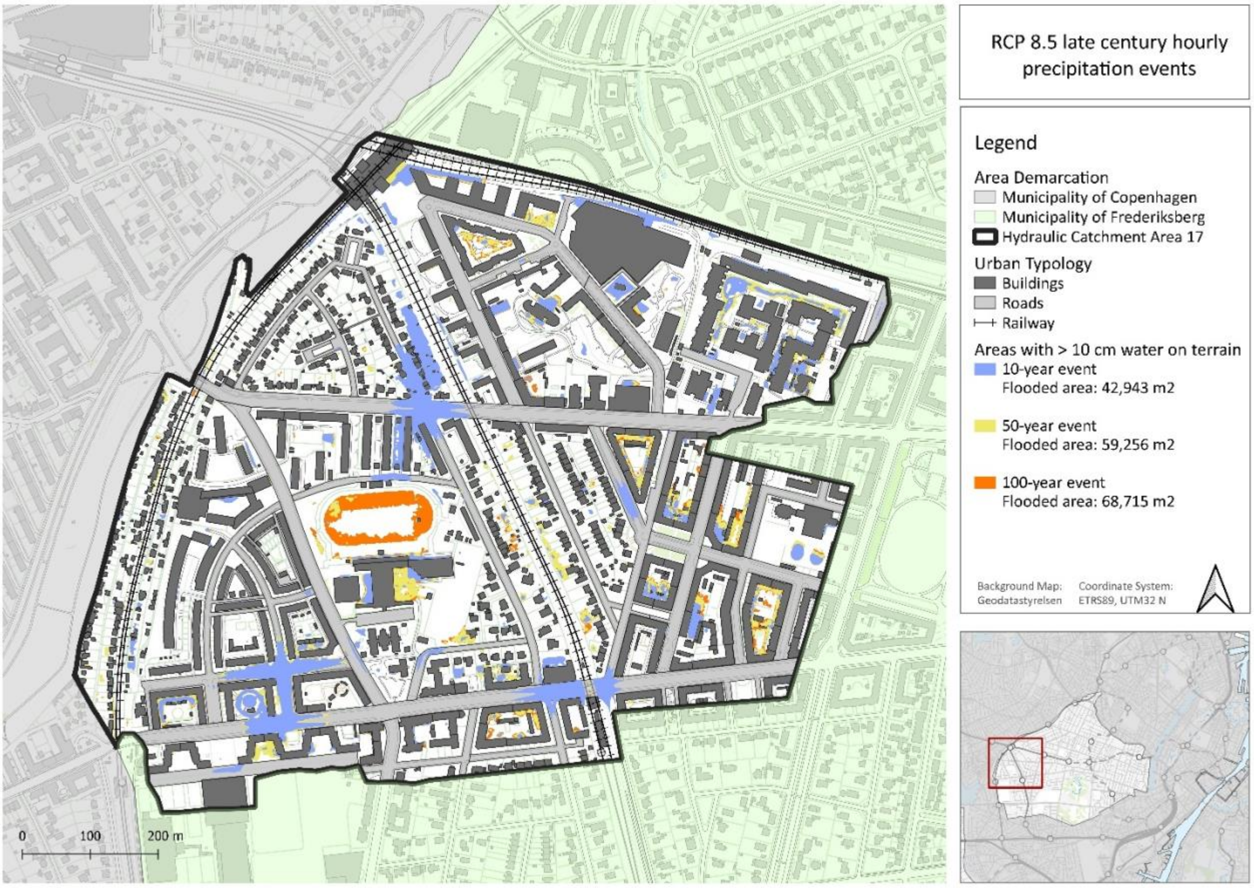

Figure 7.4 – Late century precipitation events. Simulated in SCALGO Live.

Compared to the early century events based on RCP4.5, late century events based on RCP8.5 increase the share of flooded areas by 16% for a 10-year event, 15% for a 50-year event, and lastly by 18% for a 100-year event. The comparison between a 10-year late century event and a 100-year late century event can be seen in the figure below.

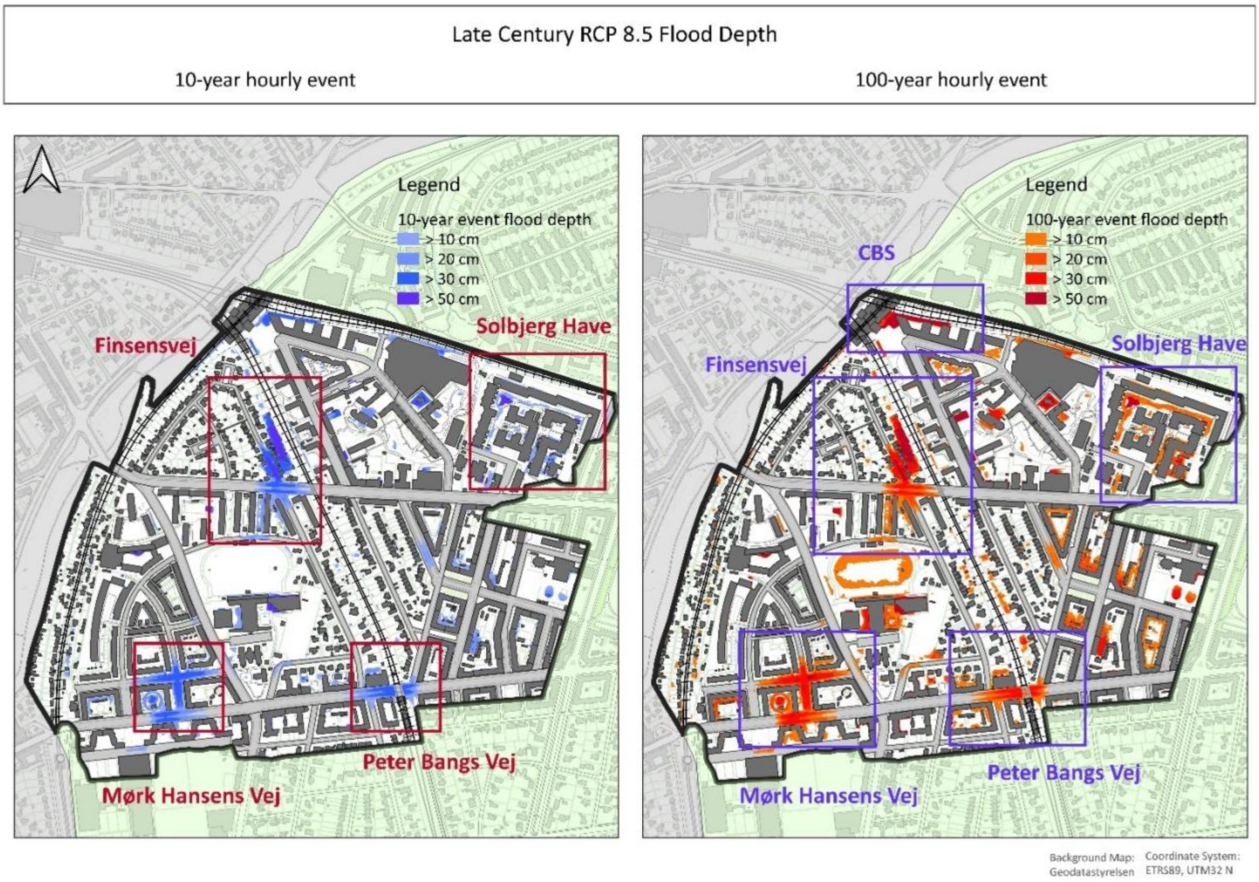

Figure 7.5 - Late century RCP8.5 10-year hourly and 100-year hourly precipitation event with blue spot flood depth.

Compared to the early century precipitation events, there are no increases in flooding depth as the deepest points of the depressions are already filled during early century events. However, there is a significant increase in the amount of water that accumulates in the depressions. The late-century 10-year events result in 8450 m^3 of water accumulated in the depressions shown in the figure above, which is a more than a 40% increase. The late-century 100-year event leads to 14,750 m^3 of water accumulating in the depressions highlighted in the figure above, which is a 20% increase. However, as was the case in the early century 100-year event, the 100-year event leads to a significant increase in runoff to downstream areas such as the Grøndals Park in Copenhagen compared to the 10-year event. In this case, a 100-year event leads to a 70% increase in runoff from the Finsensvej depression to the Grøndals Park compared to the 10-year event.

7.2 Exposure

The case area covers an area of 0.82 km^2 or 82 ha and consists of mainly low-density and high-density residential areas as well as a few areas with mixed-used, public functions, and recreational spaces (Frederiksberg Kommune, 2021d). Buildings cover 200.000 m^2 or 20 ha of the area and therefore occupy

24,4% of the total area. These buildings include several important functions such as childcare, educational institutions, nursing homes, senior housing, and buildings of cultural importance such as churches and buildings with high preservation value. These buildings have been mapped and are illustrated in the figure below.

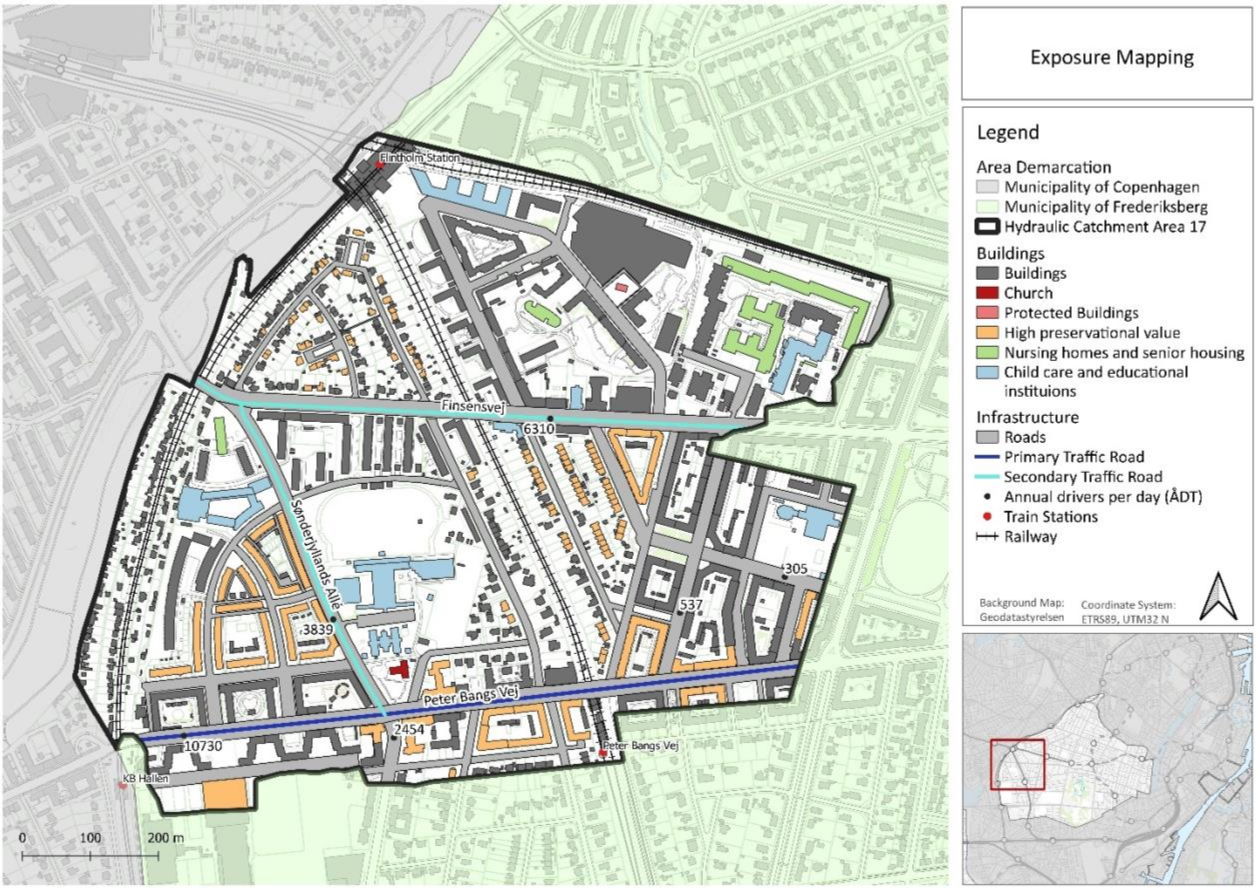

Figure 7.6 - Mapping of exposure in the case area

As illustrated in the figure, the simulation of a 50mm precipitation event in SCALGO Live shows that several of the identified buildings are exposed to pluvial flooding and could be severely affected dependent on the magnitude of a given hazard. As the area has a relatively high plot ratio due to a relatively large share of high-density areas, it can be derived that the area has a high concentration of assets and residents. As there is a large share of these buildings which are either protected or have high preservation value, the high concentration of assets consists of both economic, cultural, and social values. Furthermore, the area contains childcare and educational institutions from elementary schools to higher education such as the Copenhagen Business School.

Furthermore, the area contains infrastructure which is exposed to pluvial flooding as well. The area has one road, Peter Bangs Vej, which is classified by the municipality of Frederiksberg as a "primary traffic road" (as seen in the figure), and two roads, Finsensvej and Sønderjyllands Allé, which are classified as secondary traffic roads. These roads have in common that they accommodate high levels of traffic beyond the local residential traffic and function as arteries as they cross the municipal border into Copenhagen. Based on the mapping, it can be argued, that these roads have significant importance to provide accessibility to the area's childcare and educational institutions. As illustrated, Peter Bangs Vej has more than 10.700 daily vehicles passing by, Finsensvej has more than 6.300, and Sønderjyllands Allé has more than 3.800. On this basis, traffic interruptions as a result of pluvial flooding can lead to significant disturbances and prevent citizens from e.g., getting to work. Furthermore, due to the classification of these roads, it cannot be ruled out that these roads are of importance to the transportation of goods in heavy vehicles. Aside from car infrastructure, the area contains sections of two S-train lines including three S-train Stations, whereas the Flintholm Station functions as a traffic hub for several S-train lines, two of the Copenhagen Metro lines, and several bus lines.

7.3 Vulnerability

Based on IPCC's definition of vulnerability this section will assess the vulnerability of the case area. First, the aspect regarding lack of capacity to cope will be addressed. The construction of Copenhagen and Frederiksberg's sewage system was initiated in the 1860s (Fratini & Jensen, 2014) and has since then been expanded as the city grew. However, the capacity of the sewage system has not been significantly expanded since its construction (Frederiksberg Kommune, 2020) and therefore the sewage system is very vulnerable to intense precipitation events both today and in the future. As described in section II.6.1, the sewage system's service level is somewhere between a 2 and a 5-year event. In the most recent document from the Danish Wastewater Committee on sewage systems functional requirements, the recommendation is that combined sewage systems can handle a 10-year event and that separated systems can handle a 5-year event (IDA Spildevandskomiteen, 2005). As Frederiksberg's sewage system is a combined system, the capacity is significantly lower than the recommendations. On this basis, it can be derived, that the sewage system in the area is vulnerable to heavy precipitation events.

The vulnerability of the sewage systems capacity is exacerbated by the high share of impermeable surfaces in the case area (as illustrated in Figure 7.7). On the basis, of the case area's 82 ha, around 58.2 ha is covered with impermeable surfaces resulting in a share of impermeable surfaces of approximately 71%.

Figure 7.7 - Share of impermeable and permeable surfaces in the case area.

A high share of impermeable surfaces exacerbates urban water runoff as impermeable surfaces prevent the water from infiltrating into the soil or evaporating (Raven et al., 2018). This ultimately increases the amount of precipitation that ends up in the sewage system, as the size of the sewage systems catchment area is increased, decreasing the sewage systems capacity. When there is no capacity left in the sewage system, the water accumulates and piles up in the sewer wells back onto the terrain and floods the streets potentially constituting a health hazard. The case area is further vulnerable to precipitation events, as there is a lack of recipients that can accommodate this urban runoff. The mapping of permeable and impermeable surfaces in the figure above, shows a limited amount of larger and cohesive green areas as most of the permeable surfaces are located in private gardens and along the railways. Furthermore, the subsoil and the groundwater reservoirs cannot be utilized as a recipient due to the high level of groundwater which is just between 1.5 to 2 meters below terrain in the case area (see Figure 11.1 in the appendix), and the high share of moraine clay in the upper subsurface (see Figure 11.2 in the appendix).

Regarding the case area's susceptibility to harm, multiple conditions can enhance this susceptibility. First, as identified in Figure 7.6, there is a clear presence of nursing homes and senior housing in the case area. This population group is vulnerable to flooding due to factors such as limited physical mobility and higher reliance on public transportation compared to other population groups (Haq, Whitelegg, & Kohler, 2008). Additionally, the case area is appointed as an urban renewal area in Frederiksberg's municipal plan as the area contains pockets of marginalized residential areas (Frederiksberg Kommune, 2021b). Based on this it can be derived, that there might be a presence of social groups in the area with less education, income, and social capital and therefore these populations are sensitive to flooding as well (Gencer et al., 2018). Furthermore, as illustrated in Figure 7.6, the area contains critical infrastructure including traffic roads and S-train railways. The figure further shows that precipitation runoff accumulates in depressions that surround these infrastructures due to the terrain-based runoff flows in the area. On this basis, it can be derived that the area is vulnerable to flooding as flooding might prevent emergency services to access the area. This is considered especially critical for the older population in the area. Flooding of infrastructure is also expected to cause negative economic impacts due to limited accessibility to the educational institutions and businesses in the area and due to the potential cessation of public transportation operations disconnecting commuters by public transportation to and from the area. Additionally, negative economic and cultural impacts can emerge from flooding of protected buildings and buildings with high preservation value where the latter of the two are largely present in the area (see Figure 7.6).

Lastly, as illustrated by the figure below, numerous properties are classified as being either V1 or V2 contaminated.

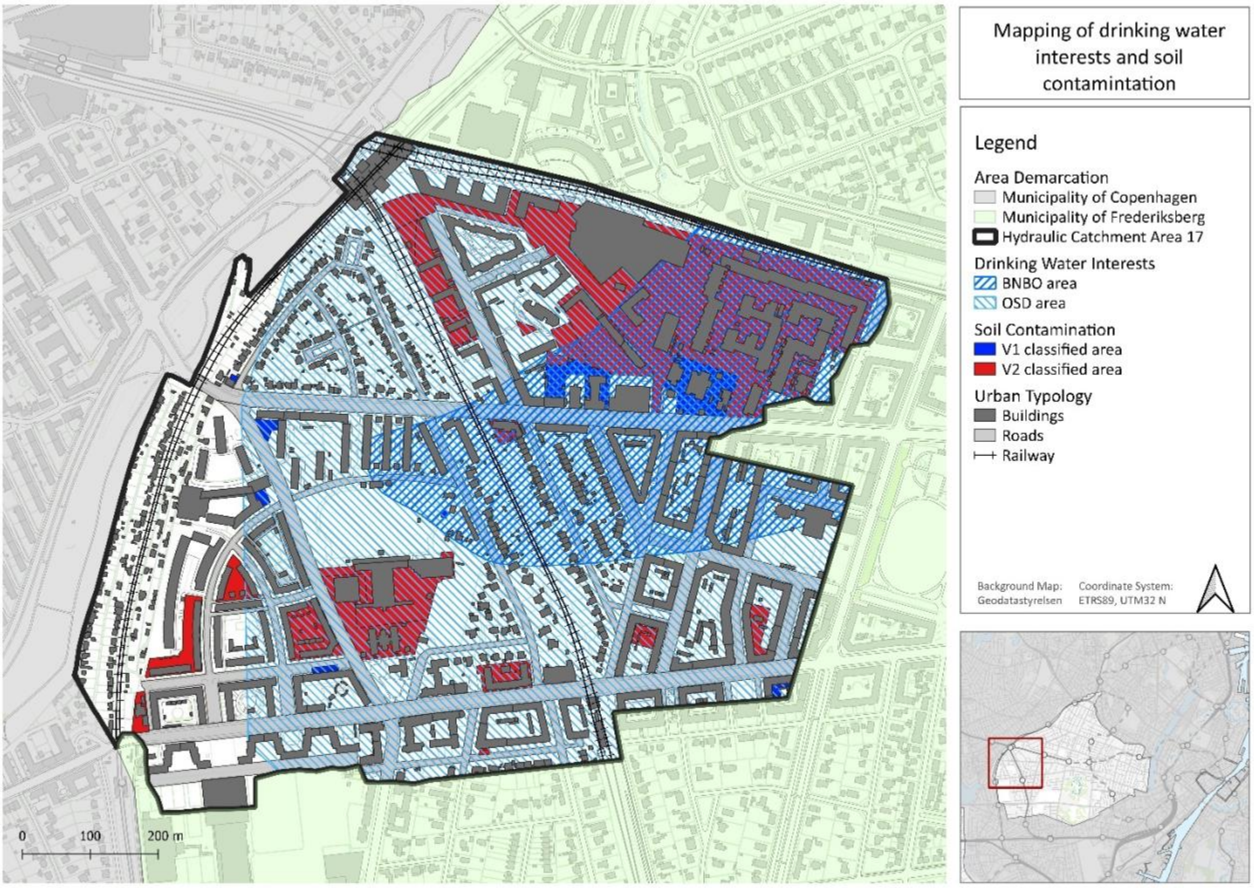

Figure 7.8 - Mapping of drinking water interests and soil contamination

In short, V1 classified properties refer to properties where there has been a historical activity associated with soil contamination whereas the V2 classification refers to properties where there is specific information or examinations of the contamination (Region Nordjylland, 2020). Infiltration of large quantities of precipitation through infiltration measures is considered undesirable. This is specifically critical in Frederiksberg, as the drinking water in Frederiksberg to a large extent is extracted from the groundwater reservoirs beneath the city as illustrated by figure Figure 7.8 which shows the local BNBO area (groundwater protection area in proximity to nearby drillings). Additionally, most of the area is classified as an OSD area meaning that it is an area with significant groundwater interests regarding drinking water quality. The extraction of groundwater in Frederiksberg is essential to keep the groundwater level down to prevent flooding from beneath the city. On this basis, the presence of soil contamination, the groundwater level, the geology as well as groundwater extraction limits Frederiksberg's options to cope with high precipitation levels, and it can potentially enhance the city's susceptibility to harm.

7.4 Future exposure and vulnerability

To understand whether the identified level of exposure and vulnerability will increase or decrease in the future, the following section seeks to describe a future scenario for how the case area will develop.

7.4.1 Urban development and densification

Regarding urban development and densification, it can be argued that Frederiksberg is as of now fully developed as there are no brownfield development areas designated for urban development in Frederiksberg Municipality's Municipal Plan. To support this claim, Frederiksberg Utility does not use a densification factor when conducting hydrodynamic models. This represents an anticipation of a future without an increase in urban runoff due to an increase in developed areas or other impermeable surfaces. As mentioned in the previous section, the case area is vulnerable to urban runoff due to a large share of impermeable surfaces. However, a population increase of 4% in 2035 compared to 2021 is expected (Frederiksberg Kommune, 2021c). There are six designated urban development and renewal areas identified in the municipal plan (Frederiksberg Kommune, 2021b). Out of these six areas, four include construction of new housing whereas two do not. One of these areas is 'Finsensvej Vest' which is located within this report's case area. As the urban renewal plan has a focus on enhancing green public areas in the case area (CFBO, 2019) combined with the fact the area is not designated for new housing (Frederiksberg Kommune, 2021b), it can be argued that the vulnerability of a high share of impermeable surfaces is likely not to be increased in the future based on the present plans.

7.4.2 Demographic projections

Regarding the vulnerability of the case area's population, the vulnerability is expected to increase towards the year 2035. As identified in the previous section, the case area contains several accommodation facilities for the elderly. According to Frederiksberg Municipality's projection of Frederiksberg's demography in 2035, the population of the elderly above 65 years old will increase significantly compared to most other age groups. The share of 55 to 64-year-olds will increase by 11%, 65 to 84-year-olds will increase by 8%, and lastly, the share of people older than 85-years-old will increase by 77% compared to 2021 (Frederiksberg Kommune, 2021c). Based on these increases in the elderly population in Frederiksberg in general, it can be argued that this trend will take place in the case area as well.

7.4.3 Traffic projections

As mentioned in the exposure and vulnerability section, the high presence of infrastructure in the case area makes the case area vulnerable to flooding. On a national scale, the traffic is expected to increase both in relation to car traffic and public transportation. The number of trips by cars is expected to increase by 5.8% by 2030 based on 2020 levels and by 3.2% in 2040 compared to 2030. Concerning public transportation, the number of trips is expected to increase by 9.3% in 2030 compared to 2020 and by 6% in 2040 compared to 2030 levels (Vejdirektoratet, 2021). In the context of the Copenhagen Capital Area, the projected population growth of 20,000 new citizens a year towards 2035 results in an overall increase in trips by 20% in the Copenhagen area, putting pressure on both car, bicycle, and public transportation infrastructure (Region Hovedstaden, 2019). Based on these projections, it can be derived that an increase in trips towards 2040 by both cars and public transportation is likely making the case area even more vulnerable to flooding. However, several factors entail uncertainty regarding, how the future development in traffic will unfold. The development in trends such as car-sharing, car-pooling, mobility as a service (MaaS), electric bikes, and online shopping can all influence how the traffic landscape will look in the future (Ibid.). Additionally, policies concerning road pricing and people's behavior as a response to climate change can further influence transportation patterns (Ibid.). Therefore, the mid to long-term future for traffic is highly uncertain.

7.4.4 Groundwater levels

Lastly, the distance to the upper groundwater was pointed out as a vulnerability as it limits the infiltration capacity in the case area and as high levels of groundwater lead to increased drainage of water resulting in increased pressure on the sewage system. In the case area, a rise of the groundwater level of between 0 to 0.1 meter is projected for both midcentury (2041-2070) and late-century (2071-2100) according to HIP.

7.4.5 A future scenario for the case area

Based on the data above, it can be derived that a likely future scenario for the case areas development includes increasing levels of traffics both in relation to trips by car, bicycle, and public transportation. Furthermore, an increase in Frederiksberg's population is expected. However, as there is no planned construction of housing in the area according to the municipal plan, a significant increase in the case area population is not expected in the near future. Frederiksberg's demography will change as there is an expected population increase in the older age groups. Concerning the physical aspects of the case area, a densification of the area is not expected in the short-term confer the municipal plan and the urban renewal plan for the area which focus on strengthening green areas in the case area. Lastly, the groundwater level is expected to rise in the long-term future. Therefore, it is derived that future vulnerability will increase in the future based on a scenario where no political actions are taken to counteract these tendencies. The scenario is illustrated in the figure below.

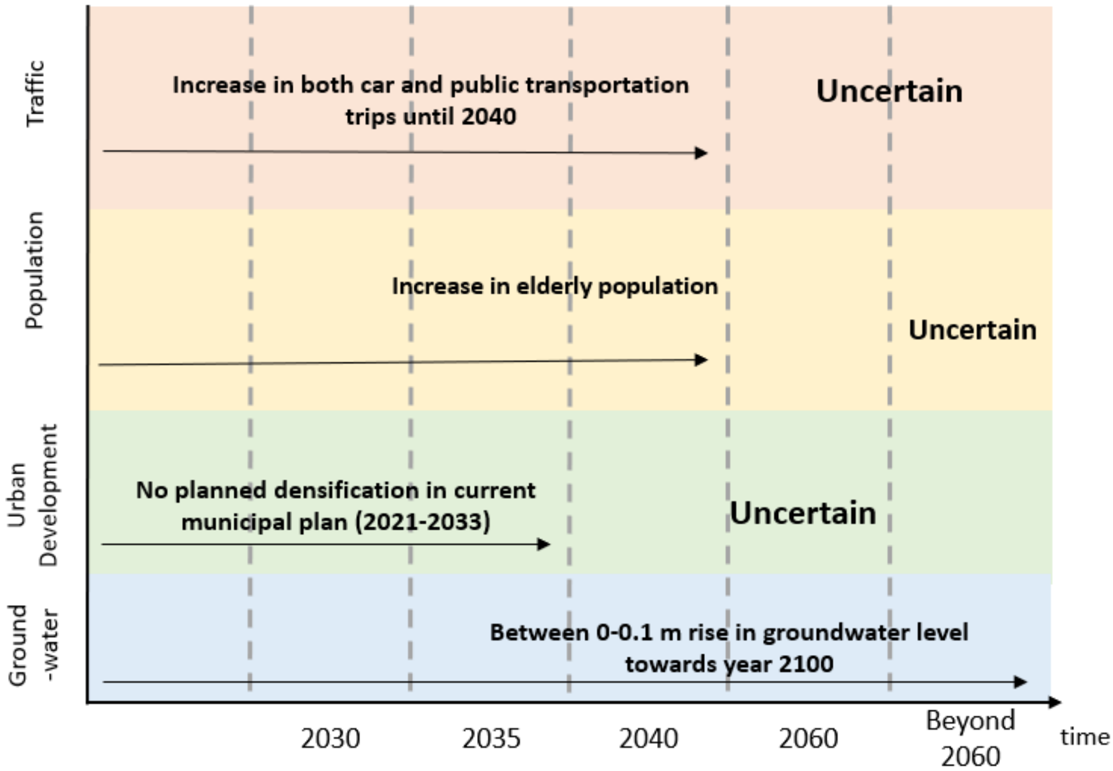

Figure 7.9 - Scenario for future development in traffic, population, urban development, and groundwater level

7.5 Risk

As described in the theoretical framework, risk is shaped by how hazards interact with the exposure and vulnerability of the considered system. The following table summarizes the mapped hazards, exposure, and vulnerability.

Table 22 - Risk in the case area

Hazards	Exposure	Vulnerability
Flooding occurs both at short and long return period events	A large share of the case area is a densely developed residential area	The sewage system can manage up to 2 to 5-year events
Precipitation events based on the current climate lead to significant flooding. Flooding levels will exacerbate future climate normals	A large presence of transportation infrastructure	High groundwater level, a large share of clay in the terrain, and several soil contaminated areas limits infiltration
5 main depressions where flooding occurs	A large share of buildings have high preservation value	High share of impermeable surfaces leads to high runoff levels
Flooding depths well above 10 cm in these depressions	A high share of educational institutions and childcare	Disrupted mobility: primary and secondary traffic roads, S-train line, 1 major transportation hub (Flintholm station)
		Potentially disrupted educational institutions
		Vulnerable older population and social groups

Based on this mapping, it can be derived that there are four main risk areas in the case area which is assessed to be especially at risk. These areas are:

1. Finsensvej
2. Mørk Hansens Vej
3. Peter Bangs Vej
4. Solbjerg Have

As illustrated by figure Figure 7.10, the Finsensvej risk area is characterized by the largest depressions and therefore the highest accumulation of flooding. Due to the classification of Finsensvej as being a traffic road with an annual daily average traffic (ÅDT) of more than 6000 vehicles which connects Frederiksberg with Copenhagen, flooding of Finsensvej can cause significantly disrupted mobility and the limited accessibility to the case areas high presence of institutions. Additionally, the area contains a few high preservation value buildings.

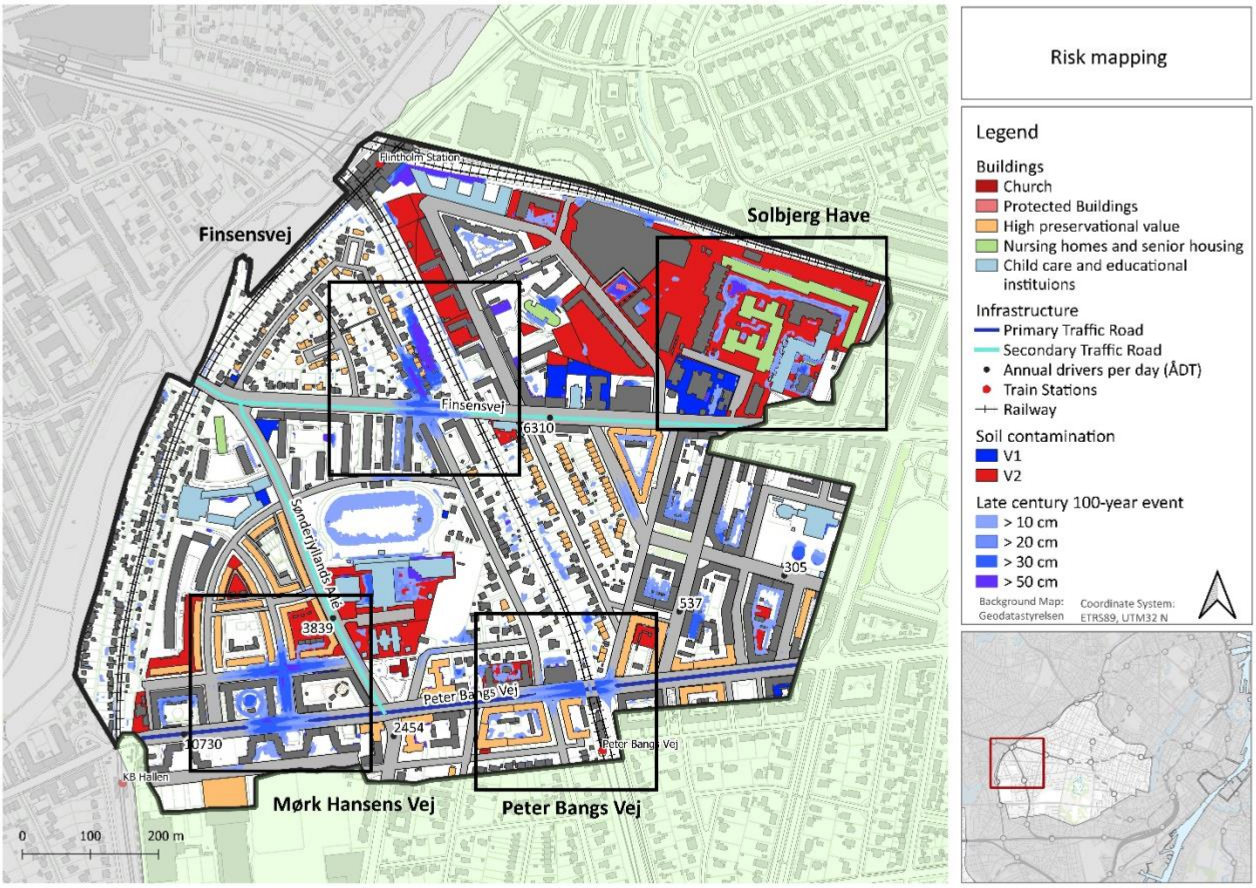

Figure 7.10 – Identified main risk areas

The Mørk Hansens Vej risk area is also subject to one of the main depressions in the case area. As illustrated by the figure above, the flood area covers the primary traffic road Peter Bangs Vej with an annual daily average traffic (ÅDT) of more than 10,000 vehicles linking Frederiksberg and Copenhagen. On this basis, flooding can cause significant mobility disruptions and limited accessibility. Additionally, the flooded area includes several high preservation value buildings.

The Peter Bangs Vej risk area is like the two previous risk areas characterized by a major depression with high flood depths. The location of the depression is centered around Peter Bangs Vej and can therefore cause mobility disruptions as described above. Specifically, this risk area is the location of the S-train station 'Peter Bangs Vej', and therefore access to public transportation can be limited as a result of flooding. Additionally, the risk area contains several high preservation value buildings.

The last risk area is Solbjerg Have which contains a large depression where water accumulates to high flood depths during precipitation events. Compared to the other risk areas, this risk area is characterized by the exposed institutions including nursing homes and childcare. Additionally, the area contains senior housing. These functions are located close to the flooded area and can therefore be affected.

7.6 Definition of success

According to Haasnoot et al. (2013), objectives for the area should be defined to define a success scenario. This success scenario and the associated objectives will then be utilized to evaluate the later proposed adaptation pathways (Ibid.).

Based on the risk assessment, it can be derived that there are several depressions in the area where large quantities of water accumulate. Furthermore, it can be argued that the only recipient which can accommodate the runoff from the case area is the Grøndals Park in Copenhagen. However, as the S-train railway is located on the border between the case area and the Grøndals Park there might be hydraulic and terrain-based challenges associated with this waterway and an underpass below the railway might be necessary. On this basis, it can be derived, that a success scenario would be to handle all water within the case area itself through decoupling and retention measures. If this is not possible, then measures that transport water to the Grøndals Park can come into consideration.

8 Suitable CCA measures for adaptation pathways

Based on the method described in section II.6.2, the identification of potentially suitable CCA measures has led to the following toolbox of CCA measures illustrated in the figure below.

Table 23 - Toolbox of adaptation measures. Descriptions are based on (Klimatilpasning.dk, 2021b; Miljøstyrelsen, 2020) .

Type	CCA measures	Description
Terrain-based measures	Green roads	Green roads are defined as roads that can retain and infiltrate water through e.g., rain gardens and permeable surfaces.
	Terrain-based retention basins	Relieves pressure on the sewage system by retaining rainwater. These retention basins are integrated into the terrain e.g., a lowered skatepark or a lowered green area.
	Infiltration measures	Infiltration measures include e.g., rain gardens that collect and infiltrate rainwater.
	Green roofs	Green roofs retain rainwater as well as evaporate rainwater reducing the pressure on the sewage system.
	Cloudburst valves	Cloudburst valves are mounted to the roof's downpipes and discharge rainwater to the surrounding terrain at predetermined intensities.
	Blue roads	Sewer gratings are sealed on local roads with sufficient gradients. The water flows by gravitation to a downstream recipient.
	Cloudburst roads	Roads are shaped to transport water to downstream recipients similarly to blue roads. However, the scale is significantly larger as these roads handle water from a much larger catchment area.
Underground measures	Stormwater sewer	Sewage water and rainwater are separated into two different pipes.
	'Closed' retention basins	Similar to open retention basins, but closed retention basins are constructed underground.
	Cloudburst pipes including tunnels	Cloudburst pipes and tunnels discharge large quantities of water from a catchment area to a recipient during high-intensity precipitation events.
	Expansion of existing combined sewage system	The capacity of the existing combined sewage system is increased.
Urban Planning / Building standards	Water recycling measures	Includes measures like rainwater tanks for households.
	Plot ratios / permeable surface ratios	Can prevent or reduce runoff from future urban development areas.
	Building plinth height	Prevents damage to buildings.
	Permanent barriers	Barriers are installed around buildings where they are the most vulnerable e.g., around entrances and basement staircases.
Emergency measures	Mobile stormwater barriers	Different measures are temporarily set up to prevent flooding from e.g., rivers or cloudburst roads.

The urban planning/building standards and emergency measures are not included in the following part of the analysis. They are not considered suitable for the Rainwater Plan and the development of adaptation pathways as they have more of a supplementary character.

8.1 Physical suitability assessment

To assess the physical suitability of the above-mentioned measures, the local characteristics of the catchment area, as described in the previous chapter (see chapter 7), and the suitability criteria, presented in the theoretical framework (see section II.5.2.1), are utilized.

8.1.1 Green roads

Green roads are considered a suitable CCA measure to the identified risk, as green roads can retain runoff water in the depression's upstream catchment areas and therefore reduce the runoff and relieve pressure on the sewage system. Concerning the suitability criteria, there is a high public space availability in the case area for green roads. In the case area, the vast majority of roads are municipal roads and therefore it is possible for the municipality and utility to co-invest in green roads. Roads make up 18,4% of the case area and 26% of all impermeable surfaces. On this basis, roads have a large potential to be converted into green roads. Regarding the type of roads, the risk mapping shows that there are only three traffic roads whereas two of these are classified as secondary traffic roads. The remaining roads in the area are therefore classified as local roads which are characterized by low levels of traffic. The green roads do not require specific gradients, and therefore the green roads can be utilized on all local roads. Therefore, the report assumes that green roads are most suitable to be implemented on local roads as the construction of rain gardens along the road can reduce traffic flow which might not be desirable on primary traffic roads like Peter Bangs Vej. Especially with an expected increase in traffic. Concerning the land use criteria, the case area is characterized by several areas which are densely built which is reflected in the large share of impervious surfaces as mapped in the previous analysis. On this basis, it can be derived that green roads are a suitable measure for such dense settings as vacant space is contested, and therefore it is evident to utilize the roads to retain rainwater and, in this way, reduce the urban runoff. The last criterion is centered around the sewage system type. In this regard, green roads are considered to be suitable as the hydraulic function is to retain rainwater and slowly drain the measure to the sewage system after a precipitation event and in this way reduce the pressure on the sewage system.

To sum up, green roads are assessed to be very suitable regarding the physical properties of the case area. Based on a municipal-wide screening of potential green roads conducted in Moeslund (2022), 15 roads have been assessed as suitable in this case area.

8.1.2 Terrain-based retention measures

According to the theoretical framework, it is relevant to consider public space availability when assessing CCA measure's suitability. In this regard, measures such as the terrain-based retention basins rely on the availability of vacant space. As mentioned in the vulnerability assessment (see section 7.3), there is a lack of larger cohesive public green spaces as most of the cohesive green areas in the case area are private gardens.

When considering the land use in the case area, it can be derived that most of the area is utilized for residential purposes (Frederiksberg Kommune, 2021d). However, private properties including courtyards can also hold a potential to retain rainwater. Based on a screening of larger properties suitable for retention measures from Moeslund (2022), four properties larger than 1 ha in the case area are suitable for larger-scale retention measures. Additionally, regular courtyards can be utilized. In relation to the sewer system type, terrain-based retention measures are just as suitable as green roads as the retention effect is identical. As seen in Figure 7.1, there are several courtyards and properties in the main depressions' upstream catchment areas and, therefore, retention measures can help reduce local problems while reducing runoff that accumulates downstream in the depressions.

8.1.3 Green roofs

Regarding the case area and its land use, green roofs are considered suitable to increase evaporation, increase retention, and reduce the UHI effect. Regarding green roofs, publicly available space is considered as available roof surfaces suitable for green roofs. As described in the risk assessment, buildings make up a large share of the case area, and therefore, there is a large concentration of roofs in the area. In connection to this, the high building density and the high share of impermeable surfaces make green roofs an attractive measure as they do not take up public space. However, according to an analysis made for Frederiksberg Municipality in 2013, green roofs are mostly suitable for new developments with flat roofs as these constructions have a sufficient carrying capacity for green roofs (Frederiksberg Kommune, 2013). More traditional buildings in Frederiksberg include buildings with 'gable roofs' with around 40-45-degree angles (Ibid). These buildings are not suitable for the construction of green roofs due to their limited carrying capacity and relatively steep roof surfaces. Therefore, these roofs require redesign and reconstruction to accommodate green roofs (Ibid.). In the case area, new development is centered around the northernmost part of the area and makes up a small share of building in the area. On this basis, it can be derived that green roofs do not hold a large short-term potential in the case area.

8.1.4 Cloudburst valves

The cloudburst valve is a measure that can be installed on the roof's downpipes. During precipitation events that exceed a predetermined intensity, the cloudburst valves close off the access to the sewage well, and rainwater is discharged locally to the nearby terrain (Faldager, 2018). On this basis, cloudburst valves are attractive to implement in upstream areas as they cut off high precipitation intensities from the sewage system and therefore reduce the downstream pressure on the sewage system. Therefore, it can be argued that the cloudburst valve is especially valuable in areas with a combined sewage system. Concerning space availability, the cloudburst valve barely takes up any space (Ibid.). Furthermore, in relation to the land use and population density of the case area, the cloudburst valve is considered suitable as it has been determined, that the cloudburst valve is suitable for single-family houses in Frederiksberg (Moeslund, 2022). However, the suitability of cloudburst valves is highly dependent on aspects such as the local terrain around the building, and therefore an assessment of whether cloudburst valves are suitable in the case will require screenings of local single-family house properties in the area, which is not feasible within the scope of this report. On this basis, cloudburst valves are considered suitable for the case area, but further analyses are required to assess the suitability at the property level.

8.1.5 Infiltration measures

Based on the risk assessment, it can be derived that infiltration measures are not suitable in the case area due to the high groundwater level, the nearby drinking water drillings, and their associated BNBO-areas and OSD areas which cover most of the case area. Additionally, there is a large presence of soil-contaminated properties limiting the potential for infiltration measures. However, this does not mean that measures like green roads and the cloudburst valve cannot infiltrate any quantities of rainwater but that measures solely focusing on the infiltration of rainwater are unsuitable.

8.1.6 Cloudburst roads and blue roads

Compared to the abovementioned measures which either retain or decouple rainwater, the cloudburst roads and blue roads transport rainwater to recipients such as designated flood areas or other CCA measures such as retention basins.

It can be derived from the risk mapping that the case area is an upstream catchment area as there is a very limited influx of runoff from the surrounding areas. On this basis, it can be derived that the depressions and other flooded areas, shown in the hazard mapping above, have relatively small catchment areas compared to more critical risk areas in the municipality. Therefore, large-scale water transportation measures such as cloudburst tunnels are not considered appropriate for the case area. However, blue roads can be utilized as small-scale measures to transport water from a local catchment area to a nearby recipient. This measure is considered to be well suited to the existing combined sewage system in the area, as blue roads can be an alternative approach to achieve an effect similar to a separate stormwater sewer. In this regard, there are water runoff flows towards what can be argued as being the only recipient in proximity to the case area, the Grøndals Park in Copenhagen. However, the presence of buildings and the railway as well as a terrain without a continuous slope towards the park eliminates the use of terrain-based transportation measures like blue roads to the Grøndals Park (as illustrated in Figure 6.1). Based on the analysis of suitable areas for retention basins in section II.6.2.2.1, the four identified suitable areas are all located at the top of the upstream catchment areas of the main depressions. In this way, terrain-based transportation measures are not suitable to transport water to these properties as well. Therefore, the only transportation measures which are assessed suitable are piped solutions such as a cloudburst pipe. However, the definition of success as described in section 7.6 states that the aim is to handle all rainwater within the case area, and therefore transportation measures such as cloudburst pipes should only be considered as a last resort in case the other suitable measures are not sufficient.

8.1.7 Expansion of sewage system and stormwater sewer

As traditional combined sewage and stormwater sewage systems are underground measures, the listed suitability criteria cannot be utilized as they concern physical conditions “above ground”. Concerning the physical suitability of a sewage system expansion or the construction of a stormwater sewer, it can be argued that challenges might occur regarding available space underground. Concerning the terrain, a certain gradient is required for the water to flow by gravitation. However, a lack of a certain gradient can be compensated by the use of pumps. Therefore, an expansion of the sewage system or the construction of a stormwater sewer is determined as being physically suitable in the case area.

8.1.8 Summary of suitable measures

Based on the sections above, it can be derived that the following measures, listed in the table below, are assessed as suitable in relation to the physical properties of the case area.

Table 24 - Summary of suitable measures

Suitable measures
Green roads
Terrain-based retention measures
Cloudburst Valves
Expansion of sewage system
Stormwater sewage system

8.2 Adaptation Pathway suitability assessment

To develop adaptation pathways, the selected physically suitable measures are assessed based on a variety of criteria which are utilized to rank the measures (see section II.5.2.2). The following table visualizes this assessment of each measure's performance against these criteria.

Table 25 - Suitability Assessment scores

	Green roads	Retention in the existing terrain	Retention through alterations	Cloudburst valve	Expansion of sewer	Stormwater sewer
Co-benefits	2	2	2	1	0	0
Synergy with municipal goals	1	2	2	0	0	0
Robustness	1	1	1	2	0	0
No-regret	1	1	1	0	0	0
Flexibility/ reversibility	1	1	1	2	0	0
Synergy with mitigation	1	2	1	2	0	0
Short decision horizon	2	1	1	2	0	0
Costs	1	2	2	2	0	0
Total Score	**10**	**12**	**11**	**11**	**0**	**0**

As described in section II.6.2.2.2, the criteria of robustness, flexibility/reversibility, and costs are assigned higher weights than the other measures. Therefore, the scores from the table above are weighted resulting in the following scores illustrated in the table below.

Table 26 - Weighted scores of the suitability assessment

	Weight	Green roads	Retention in the existing terrain	Retention through alterations	Cloudburst valve	Expansion of sewer	Storm-water sewer
Co-benefits	10%	0.2	0.2	0.2	0.1	0	0
Synergy with municipal goals	10%	0.1	0.2	0.2	0	0	0
Robustness	16.7%	0.167	0.167	0.167	0.334	0	0
No-regret	10%	0.1	0.1	0.1	0	0	0
Flexibility/ reversibility	16.7%	0.167	0.167	0.167	0.334	0	0
Synergy with mitigation	10%	0.1	0.2	0.1	0.2	0	0
Short decision horizon	10%	0.2	0.1	0.1	0.2	0	0
Costs	16.7%	0.167	0.334	0.334	0.334	0	0
Total Weighted Score	100%	**1.201**	**1.468**	**1.368**	**1.502**	**0**	**0**

On this basis of the scoring and weighting of the selected CCA measures, it can be derived that the terrain-based measures are superior to the more conventional piped solutions. The measures are ranked as follows based on their weighted scores:

1. Cloudburst Valve
2. Retention in the existing terrain
3. Retention through alterations (retention basins)
4. Green roads
5. Expansion of sewage system and stormwater sewage system

Based on this ranking of the investigated CCA measures, adaptation pathways can be developed.

8.3 Everyday rainwater management adaptation pathway

When considering how to manage everyday rainwater, the objective is to propose a structure that can meet the Danish Wastewater Committee's 'Skrift 27' which states that water management systems should be able to handle a 10-year return period in areas with combined sewage systems and a 5-year event in areas with separated wastewater and stormwater sewers without damaging flooding (IDA Spildevandskomiteen, 2005).

Through the use of the selected suitable measures, it can be derived that three main adaptation pathways can be established to meet the functional requirement suggested by the Danish Wastewater Committee. These are illustrated in the figure below:

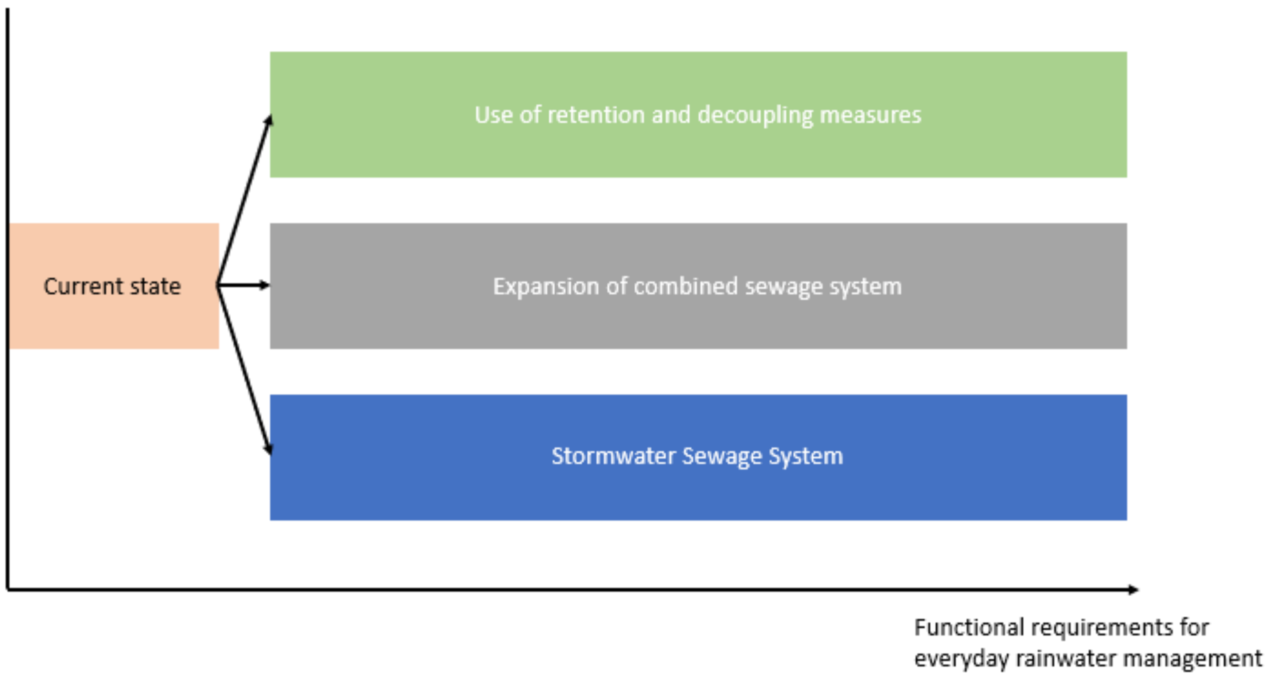

Figure 8.1 - Three different adaptation pathways to achieve the functional requirements suggested by the Danish Wastewater Committee for sewage systems

On one hand side, the adaptation pathways of expanding the existing combined sewage system and the adaptation pathway of construction of a separate stormwater sewage system are both characterized by consisting of a single measure. These approaches are deemed undesirable due to the deep uncertainty that is associated with climate change. If the everyday rainwater management system is improved by expanding the sewage system to be able to handle a 10-year event based on a late-century climate, several risks emerge. If the system is dimensioned based on the 90% quartile 10-year event, then a high level of robustness is achieved based on the current climate science basis. However, the rate of climate change might occur faster than any of the climate models have predicted and therefore there are potential scenarios where the measure is not sufficient to handle future 10-year events. Contrary to this scenario, late century 10-year events might turn out to be less intense than the models anticipated. In such a scenario, the sewage system is oversized compared to what is needed. This is a case of maladaptation as this kind of gray infrastructure does not provide co-benefits and is associated with low levels of flexibility and reversibility as well as high costs (see Table 25). On this basis, the only investigated adaptation pathway is the pathway investigating the use of multiple retention and decoupling measures as these measures have ranked higher than the sewage system solutions.

8.3.1 Terrain-based retention and decoupling measures

As mentioned in section II.6.2.2.3, the prioritization of the adaptation pathways is to first consider measures that can solve local everyday rain-related challenges in upstream catchment areas while reducing downstream flooding in the case area's main risk areas at the same time.

8.3.1.1 The first step

Based on the ranking of measures, it can be derived that retention in existing terrain and cloudburst valves should constitute the first step in the adaptation pathway as these have the highest weighted scores.

In relation to retention in existing terrain's robustness, the analysis showed that the three investigated properties can accommodate 10-year events in all investigated time horizons with a discharge rate ranging between 10 and 30 l/s/ha for RCP4.5 and with a discharge rate ranging between 30 and 50 l/s/ha for RCP8.5. In case climate change occurs at an unexpected rate, the discharge rates can be adjusted accordingly to reduce the retention effect and to increase the capacity of the measures. On this basis, the terrain-based retention measures are robust. Additionally, it can be argued that retention in the existing terrain as a measure is even more flexible than green roads and constructed retention basins, due to the low level of landscape alterations required, as existing depressions are utilized as retention volume. However, retention in existing terrain has been assigned the same score as retention basins in the MCA based on the approach to assessing measures' flexibility. Furthermore, retaining rainwater in the existing terrain is more cost-effective compared to the construction of retention basins and green roads (see Table 21). On this basis, as retention in the existing terrain is the cheapest retention measure, and as the flexibility reduces the probability of maladaptation, it can be derived that it is a suitable first step. Additionally, it is considered beneficial to implement measures with large retention capacities as the first step in upstream areas to reduce the need for downstream retention through the implementation of measures that are more costly and less flexible. Regarding mitigation efforts, retention in the existing terrain can provide higher synergies than other retention measures due to the less carbon-intensive material use and the low need for construction work compared to the other retention measures as the existing terrain is utilized. This further emphasizes the suitability of retention in the existing terrain as the first step as carbon emissions from CCA is gaining a larger and larger awareness and importance from Frederiksberg Utilities.

Cloudburst valves are selected as an initial implementation step as well as the cloudburst valve is assigned the highest weighted score in the MCA. This is due to the high robustness, low costs, and large flexibility which are the most critical criteria in the assessment. Concerning robustness, cloudburst valves are not limited to any designated retention volumes and therefore the retention volume is theoretically unlimited in cases where the discharge of rainwater onto terrain does not cause any harm. In this way, the cloudburst valve can handle both the 10-year events of today and the future. Concerning the flexibility of cloudburst valves, they are very suitable for temporary use as they can easily be mounted and unmounted from the roof downpipes (Faldager, 2018). However, the measure does not provide any socio-cultural or livability-related co-benefits, but the lack of co-benefits is balanced in the MCA by the robustness, the low costs, and high flexibility as these criteria have a higher weighting. Therefore, the cloudburst valve is beneficial to implement as a first step solely based on water management benefits. In case the rate of climate change develops in an unpredicted manner, the cloudburst valve is still considered to provide benefits for the water management system as it is designed to discharge rainwater onto terrain three times a year (Ibid.). In this way, the measure helps to relieve pressure on the sewage system during precipitation events with smaller intensities than a 10-year event.

On this basis, retention measures in the existing terrain and cloudburst valves are considered most suitable as the first step as they are cost-effective and flexible measures to decouple or retain rainwater. Therefore, these measures should be implemented as a priority as the implementation of such measures can reduce the capacity needs in proposed downstream measures. It is considered to be highly valuable to reduce capacity needs in other measures, as these measures might be more expensive to construct or have a less flexible character, and therefore it might be desirable to reduce the extent of such measures. The effect of these measures on the service level of the sewage system can be analyzed in hydrodynamic models. If such models show an insufficient capacity in the water management system and vulnerable areas where water overflows onto terrain today and or in the future, additional CCA measures are necessary.

8.3.1.2 The second step

In cases where the above-mentioned measures are insufficient, the next step in the sequence of actions is to implement retention basins through alteration in the area's courtyards. This entails that the terrain within the courtyards will be adjusted to increase the share of rainwater that can be retained. Courtyards have been assessed as a suitable urban typology for retention measures, and these courtyards make up a significant share of the upstream catchment areas to the identified risk areas. In relation to the robustness of retention basins within courtyards, it has been assessed that the tipping point is a 10-year event as this is what the utility can construct without conducting socio-economic calculations to make sure that the avoided costs of flooding are higher than the investment costs. To ensure robustness, the retention basins can be dimensioned to handle a RCP8.5 90% quartile 100-year event from DMI's Climate Atlas, and in this way, the measure will be able to accommodate both 10-year events in the short term and the long term for both RCP4.5 and 8.5. Retention basins in courtyards can provide several co-benefits including livability and socio-cultural co-benefits through multifunctional and recreational uses and can further provide several environmental co-benefits through provided vegetation. In this way, in a future where the established retention volume is oversized to achieve the service goal, the measures will still provide value. Additionally, the implementation of retention basins in courtyards can reduce the pressure on local service pipes to the sewage system preventing or reducing overflows. In this way, this measure can help to further reduce runoff to the nearby streets from which a large share of the water in the area runs towards the main depressions. As green roads are considered the most expensive retention measure, it can be desirable to reduce the capacity and necessity of such measures through the retention of rainwater in courtyards. On this basis, the measure is assessed to be a low-regret solution. Based on the above, it is considered appropriate to switch from retention measures in the existing terrain at larger properties to the construction of retention basins in courtyards to further increase the upstream retention capacity and relieve pressure on the sewage system.

8.3.1.3 The third step

If the above-mentioned measures are insufficient to achieve the 10-year service goal, the next step in the sequence of actions is assessed to be green roads. Based on the robustness assessment, green roads implemented in narrow roads are especially robust when it comes to everyday rainwater management as they are expected to be able to handle both present and future 10-year events based on both RCP4.5 and 8.5. Wide roads on the other hand can handle current and future 10-year events 100 years from now based on RCP4.5 with a discharge rate of 30 l/s/ha and can almost handle such 10-events based on RCP8.5 without overflowing. Compared to the above-mentioned retention measures, green roads are deemed more costly. However, even though green roads are assessed to be more expensive, green roads have a large potential to provide co-benefits. As described in section II.6.2.2.2, green roads can, dependent on the level of greening which they provide, provide several environmental and livability co-benefits. Additionally, they align with municipal urban development goals to a large extent. Furthermore, when constructing green roads, pipelines and wires can be renovated, replaced, or installed and in this way, synergies across multiple objectives and tasks can be achieved.

Based on these three steps, the following adaptation pathway has been developed.

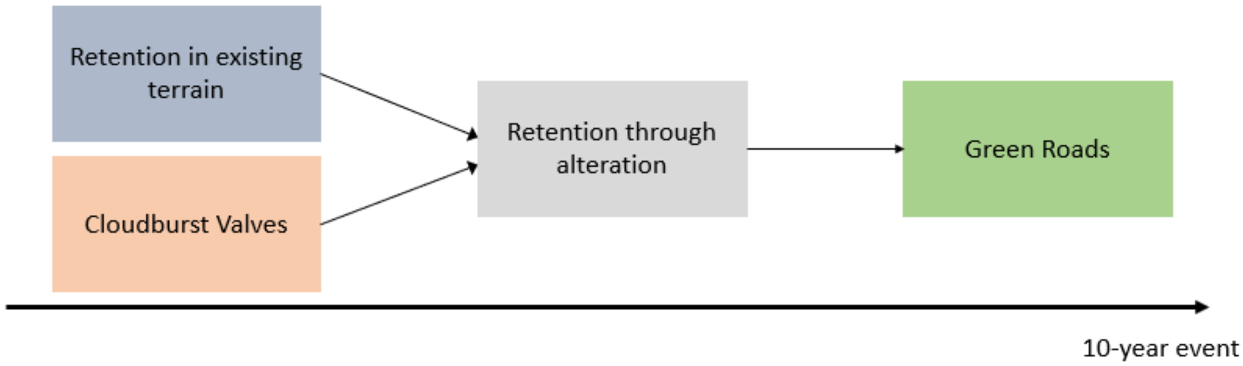

Figure 8.2 - Adaptation Pathway for everyday rainwater management

8.3.1.4 The fourth step

In a future with climatic conditions which exceed the capacity of the adaptation pathway and leads to damaging water on terrain more often than a 10-year return period, an additional step is to consider transportation measures to transport rainwater out of the case area or to increase the capacity of the sewage system. As described above, it might be necessary to implement the above-listed measures with high discharge rates to ensure that the measures themselves can accommodate a 10-year precipitation event. However, a higher discharge rate leads to a smaller retention effect, and therefore more rainwater is sent to the sewage system during the rain events. This reduced retention effect can lead to sewage overflows, and therefore a means to reduce overflows is to increase the capacity of the sewage system. Alternatively, the measures are implemented with low discharge rates to increase the retention effect. However, this leads to more frequent overflows in the retention measures. As these overflows will consist solely of rainwater, piped transportation measures can be utilized to transport the rainwater out of the case area. When considering the assessment of gray piped measures in Table 26, it is clear that none of these measures are desirable to the same extent as the above-mentioned retention and decoupling measures. Due to the high costs, low flexibility, the risk of maladaptation, low to no synergies with mitigation, and the long decision horizon associated with gray infrastructure, the construction of a piped solution is considered a last resort that might be necessary to achieve the water management goals. However, as the construction of a stormwater sewer is the last step of this sequencing of actions, new and innovative measures might emerge in the meantime and therefore this adaptation pathway would have to be reassessed. Alternatively, it can be investigated whether overflow from the suggested CCA measures, consisting solely of rainwater, can be handled in designated areas suitable for flooding. Such an analysis is beyond the scope of this report but should take the conducted risk assessment into consideration.

8.4 Stormwater management adaptation pathway

As was the case with everyday rainwater management, there are two main directions which the development of adaptation pathways for stormwater management can take. These are visualized in the figure below.

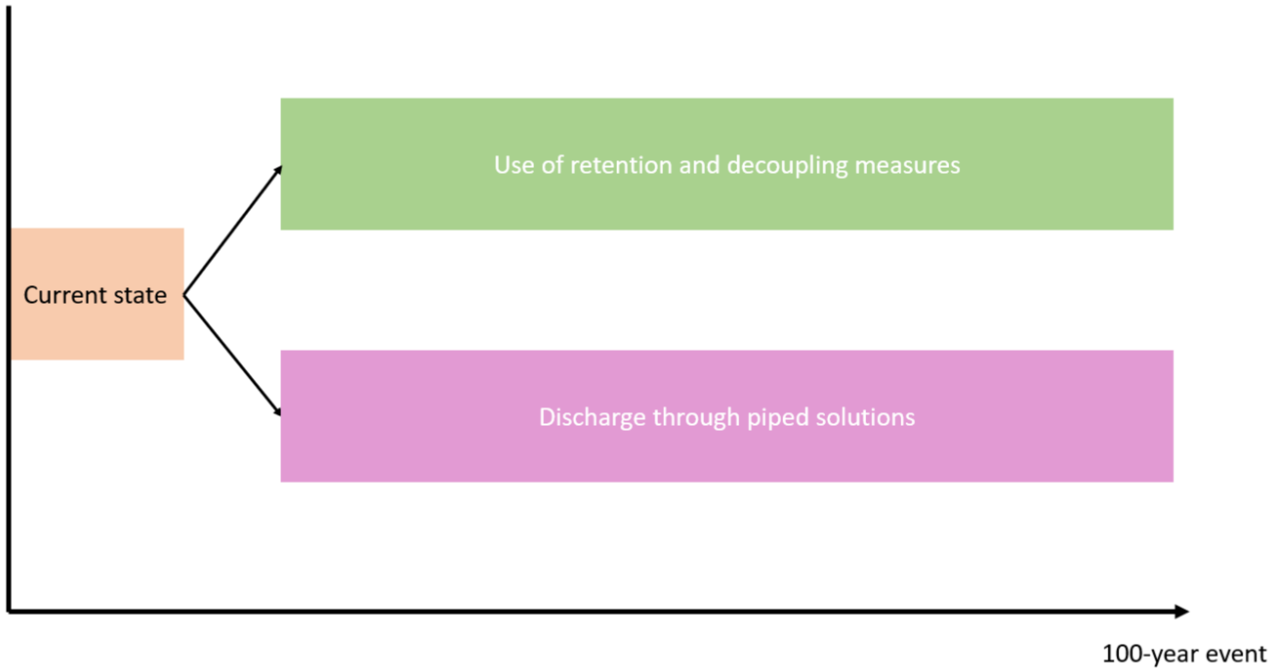

Figure 8.3 - The two main approaches to developing adaptation pathways for stormwater management

As described earlier, adaptation pathways that rely on piped solutions are deemed unsuitable due to the lack of flexibility, high costs, and the risk of maladaptation. It might be the easiest solution to implement cloudburst pipes or similar infrastructure to puncture the depressions and transport the water to the Grøndals Park in Copenhagen. However, the use of multiple retention and decoupling measures can provide synergies to solve both everyday rainwater and stormwater challenges simultaneously while providing co-benefits and synergies with municipal goals. On this basis, the approach is to prioritize measures that can help solve upstream flooding challenges while reducing downstream flooding simultaneously through retention or decoupling measures.

8.4.1 Terrain-based retention and decoupling measures

The goal for stormwater management in Frederiksberg is, as mentioned earlier, to ensure a maximum of 10 cm of water on terrain at property boundaries during a 100-year precipitation event based on year 2112. The approach to developing the adaptation pathway is based on the utilization of the same measures as proposed for everyday rainwater management to promote synergies between everyday rainwater and stormwater management. Therefore, this section will seek to investigate how and to what extent the robustness of the previously suggested measures can be increased to accommodate 100-year events.

8.4.1.1 The first step

For the everyday rainwater adaptation pathway, it has been assessed that retention in existing terrain and the cloudburst valves are the most suitable measures to be implemented first based on the ranking from the MCA. Concerning retention in the existing terrain from a stormwater management perspective, it can be derived that the three investigated properties can handle 100-year events based on the current climate normal when the discharge rate is 50 l/s/ha. When looking 50 years into the future, only two out of the three properties can handle a 100-year event based on RCP4.5 whereas none of the properties can handle 100-year events based on RCP8.5. When looking 100 years into the future, none of the investigated properties can handle a 100-year event independently of the climate scenario. Therefore, retention in the identified properties' existing depressions is not sufficient based on the current predictions of the future climate, and therefore the construction of retention basins through alterations should be considered to increase the retention volume and therefore the robustness. Frederiksberg Stadium is selected as a designated retention area in the cloudburst clarification plans with an estimated retention volume of 3,000 m^3 compared to the current depression capacity of 1.350 m^3. With this increase in retention volume, the retention basin can handle a 100-year event based on both RCP4.5 and 8.5 no matter if the discharge rate is 30 or 50 l/s/ha. With a discharge rate of 10 l/s/ha, the basin can manage a RCP4.5 210 year-event 100 years from now based on its natural catchment area. With a discharge rate of 30 l/s/ha, the basins can manage a 120-year event based on RCP8.5 100 years from now. Therefore, retention through alteration has the potential to ensure high levels of robustness and the potential to handle rainwater from areas beyond the basins' catchment area. However, as mentioned in section 8.1.2, these large properties suitable for large-scale retention measures are located upstream limiting the catchment area which can be connected to the retention basins without the use of pipes and pumps. As retention in the existing depressions is a flexible measure, the existing depressions can be utilized for retention as the first step to keep the options open to increase the retention volume through the construction of retention basins in the future.

The cloudburst valve is selected as an initial implementation step for stormwater management as well due to the high robustness, low costs, high flexibility, and short decision horizon. As mentioned earlier, the cloudburst valve is not limited to a fixed retention volume and on this basis, the cloudburst valve is considered to be able to handle both 100-years today and in the future. However, it might be necessary to make terrain alterations on certain properties where cloudburst valves are mounted to prevent runoff which can cause harm (Faldager, 2018).

8.4.1.2 The second step

The construction of terrain-based retention basins in courtyards has, as described in the everyday rainwater adaptation pathway section, been considered more suitable than green roads due to lower costs. In relation to the robustness of retention basins in courtyards, the determined tipping point is a 10-year event. However, there are examples of courtyards in Copenhagen that have been retrofitted to handle 100-year events while providing several co-benefits such as recreational functions (Klimatilpasning.dk, 2021a). On this basis, Frederiksberg Utility should strive to implement such projects as they are assessed as more desirable than the green roads. In cases where the courtyards are solely retrofitted to handle 10-year events, additional retention capacity must be found downstream.

8.4.1.3 The third step

The first option to compensate for the limited capacity in courtyards is the green roads. Green roads implemented in narrow roads can manage 100-year events both today, 50 years from now, and 100 years from now based on RCP4.5 when the discharge rate is 50 l/s/ha (see Table 15). If the rate of climate change follows the trajectory of RCP8.5 then narrow green roads can handle 100-years events 50 years from now and 50-years events 100 years from now with a discharge rate of 50 l/s/ha. Therefore, narrow green roads cannot handle 100-year events in all investigated futures. If the green roads must accommodate rainwater from the private properties as well, then the retention capacities of the green roads will be even more insufficient if the rate of climate change follows RCP8.5. In relation to wide green roads in the case area, the robustness is limited. With a discharge rate of 50 l/s/ha, the wide roads can manage precipitation events more severe than a 50-year event based on today's climate normal, precipitation events more severe than a 20-year event 50-years from now, and the equivalent to a 20-year event based on a climate normal 100-years from now in the RCP4.5 scenario. Therefore, overflows will occur from these wide green roads which are largely expected to accumulate in the downstream identified risk areas. This is further exacerbated when considering climate change according to RCP8.5. In this case, wide green roads can manage a 20-year event 50 years from now, and less than a 10-year event 100 years from now, based on the assumption that 0,5 m^3 of retention volume can be constructed per running meter of road.

From a future perspective, it can be argued that it makes sense to implement green roads as a later step in the adaptation pathway as there are large uncertainties regarding how the traffic of the future will develop (as described in section 7.4.3). From a short-term future perspective, the traffic levels are expected to increase. If this trend continues on a long-term basis, the share of roads which can be designated for rainwater management might decrease. However, if traffic levels stagnate or decrease in the future, it might lead to new opportunities regarding how green roads are perceived. This could lead to the implementation of more extensive green roads, occupying larger shares of the road area, which have larger retention capacities and therefore higher robustness.

8.4.1.4 The fourth step

In case these above-mentioned measures are not sufficient to achieve the service goal for stormwater management, additional measures are necessary. This might be the case due to the limited robustness of retention basins in courtyards and green roads. The final proposed measure is the cloudburst pipe, which can be utilized to puncture the depressions by transporting the flooding to the nearest recipients. Again, when considering the assessment of gray piped solutions from Table 26, it is clear that these measures are not as desirable as the terrain-based measures due to the high cost, low flexibility, the risk of maladaptation, low to no synergies with mitigation, a few to zero co-benefits, and the long decision horizon associated with gray infrastructure. However, measures like a cloudburst pipe might be necessary to transport water out of the case area which the upstream measures cannot handle. As analyzed in section 8.1, terrain-based transportation measures have not been deemed suitable in the case area due to the terrain-based limitations. However, as the cloudburst pipes are the last measure in the sequence of multiple actions, new innovative measures can be invented and integrated into the adaptation pathways and in this way, the cloudburst tunnels can become unnecessary. Additionally, if the adaptation pathway is continuously adjusted to new climate science and the associated data, a situation where cloudburst pipes are not necessary cannot be left out as new climate science might show that the 100-year event of the future is less intense compared to today's anticipation. Alternatively, a situation might as well occur where Frederiksberg Utility and Frederiksberg Municipality reduce the service goal and therefore reduce the need for cloudburst pipes.

On this basis, the adaptation pathway for stormwater management which prioritizes retention and decoupling measures is visualized in the figure below.

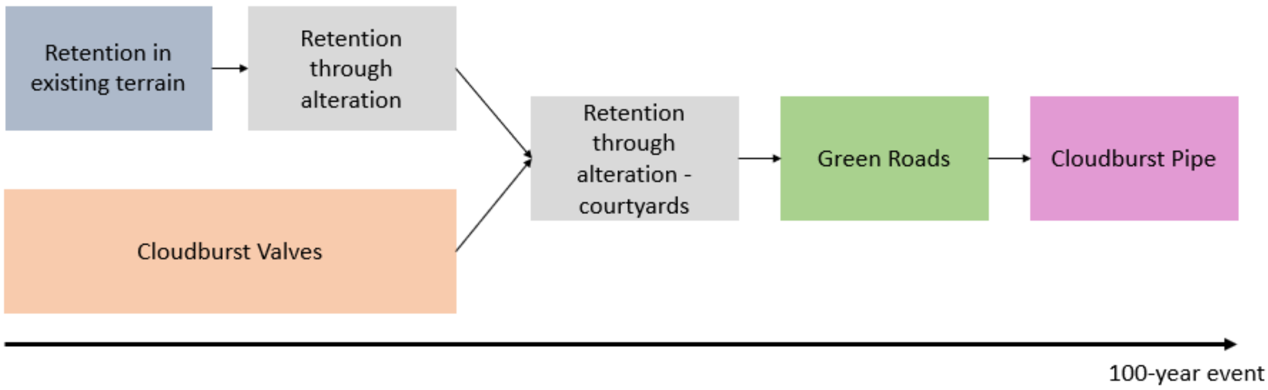

Figure 8.4 - Adaptation Pathway for stormwater management

IV. Discussion

9 Discussion and conclusions

9.1 Discussion of results and analyses

The report's framework is centered around how to manage deep uncertainty, avoid lock-ins and maladaptation, and how to ensure room for maneuvering and future decision-making that is not limited by the decisions made today. On this basis, an investigation of elements from the DAPP-approach has been made to promote an approach to CCA which embraces uncertainty. It can be argued that Adaptive Policymaking, Adaptation Pathways, and Dynamic Adaptive Policy Pathways are all approaches to CCA planning which challenge the existing planning paradigm of developing static "predict-act" or "predict-optimize plans". The initial planning steps of the DAPP-approach presented in the report's theoretical framework have been investigated and tested in the context of the development of Frederiksberg's Rainwater Plan. In several cases, it has not been possible to conduct the selected analyses based on the requisites that the DAPP-approach requires. An example is the MCA which presupposes a wide participation of stakeholders. However, due to the scope of the report, literature was used to perform the assessment instead. On this basis, it can be argued, that it is not possible to conclude or derive any results in relation to the implementation of a full DAPP-process in Frederiksberg. However, it is possible to derive several conclusions based on the investigation of how elements of the DAPP-approach can be utilized to deal with uncertainty and promote dynamic and flexible planning in the context of Frederiksberg's Rainwater Plan.

From the suitability assessment of measures, it can be derived that a limited amount of rainwater management measures has been considered suitable for the case area. This shows the importance of making dynamic and flexible plans as new water management measures might appear in the future and therefore a long-term strategy, like the Rainwater Plan, should not be restricted to current measures. In this way, the dynamic character of the DAPP approach is considered highly valuable to develop a plan for long-term rainwater management in Frederiksberg. Based on the physical suitability screening and through the conducted MCA, examples of adaptation pathways have been developed based on an example of a weighting of the utilized criteria to ensure a dynamic rainwater management strategy that ensures both short and long-term values. In this way, a ranking of rainwater management measures can help to promote measures that provide short-term value e.g., can help manage both everyday rainwater and provide co-benefits while having a level of robustness to manage future stormwater events. In this way, investments in inflexible and costly measures are prevented and postponed to a future stage where no other alternative options are available. In this way, through the prioritization of flexible and low-cost measures, options are remained open for further future action.

On this basis, it can be derived that the development of MCA criteria and the assignment of criteria weights is key to building sequences of actions. It is not considered suitable to have a toolbox of measures without some sort of ranking of the measures. In this way, there is no guiding structure in regard to where and to what extent measures should be implemented at any given point in time. By the utilization of adaptation pathways, an overview in relation to which measures that should be prioritized in the short-term, and the argumentation behind them, is developed. Therefore, the municipality and utility will be able to consider the consequences of e.g., constructing a green road in a downstream area from a more systematic point of view. According to the DAPP approach, it is of high importance to understand the interrelation of measures and logic sequences of actions, and therefore an MCA on a measure-specific level is considered key to developing adaptation pathways based on a ranking of measures.

Based on the research, it has been clear that challenges might occur in regard to the level of data and level of local knowledge necessary to perform an MCA. This is especially considered relevant when conducting the robustness assessment and the estimation of tipping points. Within a rainwater management context, it is not possible to determine the tipping point of a measure e.g., a given retention capacity, without including context-dependent aspects. On this basis, there are no general estimates of e.g., green roads' tipping points as they depend on aspects such as the size of the catchment area, the retention volume, and the discharge rate. Therefore, both context-dependent knowledge, such as catchment area sizes, and data, such as the 0,5 m^3 of retention capacity which is expected to be feasible to implement per running meter of road, are required to assess these tipping points. As the Rainwater Plan is a plan with a municipal scope, this high level of detail is not considered suitable, and therefore it can be derived based on this research, that there is a need to generate or collect data with can be utilized for a municipal wide screening of measures' tipping points. The investigation of green roads' tipping points in this research has led to two typologies of green roads: narrow green roads and wide green roads. By having two typologies of green roads, the two typologies' tipping points can be utilized on a municipal scale if these two typologies embody the local roads of Frederiksberg. Therefore, it is necessary to find a level of detail with associated data that can be used to qualify the investigated measures' tipping points on a municipal level.

Taking the uncertainties aside in relation to the basis utilized to assess the measures' suitability, the measures which performed the best in the conducted MCA are retention in the existing terrain and the cloudburst valve as these measures are considered to have the highest levels of robustness, flexibility, and the lowest costs as well as other benefits. On this basis, these measures should be prioritized as the first step in the Rainwater Plan. The highest-ranked measures based on this research have in common that they are suitable for implementation on private properties. Therefore, these measures might require longer preparatory planning processes as the utility and municipality are not property owners and therefore, such processes should be initiated in advance to ensure timely implementation of the measures and high levels of robustness. However, as these measures have performed the best in the MCA, a potential lies in proactively seeking these measures to avoid relying on more expensive downstream measures such as green roads. On this basis, this might incentivize the utility to proactively seek out housing associations and other property owners and stakeholders to cooperate to implement such rainwater management measures. However, this does mean that the results of this research rely on the municipality's and utility's ability to enter into agreements with local property owners to realize the first steps of the adaptation pathways. The utility is currently in dialogue with a large housing association with multiple properties in Frederiksberg. If it turns out, that such agreements are difficult to arrange, the adaptation pathways must be retrofitted to accommodate these considerations, and potentially a criterion such as the short decision horizon should be assigned a higher weight to prioritize measures that require less planning.

This indicates that the weighting of measures is of high importance. Compared to the weighting of criteria in this research, the municipality and utility might assign a short decision horizon a higher weight to promote measures that can be implemented at a high pace. This is currently the case with the new regulation which states that rainwater management projects with co-investments from utility companies must be socio-economically appropriate investments (DANVA, 2021). Based on this new regulation, a transitional scheme has been put into practice to let utilities implement projects based on the previous terms until 2027 to avoid lost irreversible investments (Ibid.). In the case of Frederiksberg Municipality and Utility, this might lead to an increased focus on short decision horizons. As the definition of socio-economically appropriate investments is solely based on monetary values in terms of flood damage to buildings and infrastructure (Ibid.), it is not expected from Frederiksberg Municipality and Utility that it is possible to continue planning for the current stormwater service goal after the transitional scheme. On this basis, the current practice of Frederiksberg Municipality and Utility is threatened by the new regulation, and therefore it can be argued that the municipality and utility will strive to implement as many projects on the previous terms during the transitional scheme to hold onto their current plans and strategies thus the prioritization of measures characterized by short decision horizons. In this way, this new regulation can threaten this research's results. On the one hand side, the change can cause the municipality and utility to speed up the implementation of measures as just mentioned. If a clear prioritization of measures that can be rapidly implemented is made, then the opportunity to invest in and prioritize measures that provide the most value and provide the most room for future decision-making, based on this report's assessment, will be missed. On this basis, it can be derived that the report's results point in the opposite direction of the municipality's and utility's reality with the transitional scheme and the new regulation, and therefore, the results of the analysis cannot be utilized directly in the development of the Rainwater Plan, as the weighting has been determined without the participation of relevant stakeholders from the municipality and utility. On this basis, it is significant that the municipality and utility conduct an assessment and weighting of the criteria themselves, as the chosen criteria in this research clash with the large focus on short decision horizons. On the other hand, the new regulation's definition of socio-economic appropriateness is considered to threaten dynamical approaches to CCA as well, as the most socio-economic appropriate solutions might not be the same solutions that perform best in an MCA which includes a broad range of criteria. Therefore, the understanding and definition of socio-economic appropriateness must be widened and broadened to encompass multiple matters beyond monetary values.

However, it can be argued that the proposed approach to dynamical adaptation planning can still provide plenty of value. This is based on, that the approach prevents rushed investments into undesirable pathways limiting future possibilities for CCA action, as the stakeholders have to go through each measure's performance in relation to all criteria in the MCA when reassessing the strategy in relation to the new regulation. On this basis, it can be derived that the development of adaptation pathways based on an MCA is key to implementing the Rainwater Plan to ensure a systematic approach to a ranking of measures and to ensure a well-documented sequencing of measures in the shape of adaptation pathways which are flexible and robust. Additionally, it can be derived from the investigation of the initial steps of the systematic DAPP approach that the approach can help to provide an understanding of measures interrelation and connectedness both in relation to risk reduction and to achieve the most possible benefits. Lastly, the prioritization of measures can help to promote proactiveness e.g., regarding initiating preparatory planning processes in advance, to ensure timely implementation processes of measures with potential challenges and barriers such as the implementation of measures on private properties. In this regard, the integration of adaptation pathways is also considered to be highly valuable in case e.g., developers reach out to the municipality or utility with CCA projects as the utility can advise the developer to implement the measures which are ranked the highest in the MCA and prioritized first in the adaption pathways. In this regard, it is important to note that it is not considered realistic or feasible to implement the ranked measures one by one as several of the investigated measures have a relatively small scale compared to more extensive measures such as stormwater sewers. On this basis, these measures are usually combined and merged and therefore it might not make sense to only implement one type of measure at a time. However, the adaptation pathways can help to highlight the benefits of prioritizing the implementation of the measures based on the previously described benefits.

9.2 Research limitations

The above-mentioned results and conclusion of the research are subject to underlying uncertainties and weaknesses associated with the utilized research design and methodology. First, the internal validity of the research is discussed. Internal validity concerns the accuracy of the results in relation to the extent to which the results represent reality in the given context of the research (Bryman, 2016). Concerning the research design and the methodological considerations, the internal validity is centered around whether the used methods are suitable or adequate to produce the desired results (Ibid.). Secondly, the reliability of the report's results and associated methods are discussed as well. Reliability concerns the reproducibility of the research's results (Ibid.) and therefore high reliability would mean that the same results will emerge if the study was to be reproduced. Lastly, the external validity of the research is discussed, which refers to the generalizability of the research (Ibid.).

Internal validity is relevant to discuss in connection to the conducted risk assessment. To investigate the impact of hazards, climate data from climate models have been utilized and visualized in SCALGO Live. As previously mentioned in this report, climate data is associated with uncertainties as climate modeling, in general, is subject to deep uncertainties including scientific uncertainty as the current understanding of the climate systems and their mechanisms and dynamics is limited. In this way, whether the utilized climate data will represent reality is uncertain. However, as the climate models' ability to represent reality is continuously enhanced, climate models make up usable tools to understand future climatic conditions. On this basis, it is difficult to improve the internal validity in this regard, as climate model data represent the best available guesses of the future climate. The climate data has been visualized in SCALGO Live which has several limitations as described in the methods section. These limitations, such as the lacking dynamics with the sewage system and infiltration, are proactively sought to be reduced by including an initial loss which represents the expected infiltration rate, and one that represents the estimated capacity of the sewage system. However, SCALGO Live still does not include time, and therefore flooding in SCALGO Live represents instant flooding. Therefore, the flood levels which accumulate in the identified risk areas are not likely to be as severe as visualized in SCALGO Live. To reduce the internal validity of the hazard mapping, historical flooding data can be utilized to verify the blue spot maps from SCALGO Live. Additionally, hydrodynamical models can be utilized as well with historical precipitation events to further qualify the hazard mapping and increase the internal validity. However, SCALGO Live is considered an appropriate tool for initial screenings as conducted in this report.

Internal validity is relevant to discuss in relation to the performed MCA as well as the MCA has been conducted on a limited basis. In several cases, literature that assesses overall CCA infrastructures' performance in relation to several of the investigated criteria has been utilized. In this way, there is a lack of data or empirical knowledge to make distinctions between the specific measures which has been classified as the same type of infrastructure. For example, it has not been possible, based on the selected literature, to properly differentiate between the measures classified as hybrid measures regarding criteria such as flexibility and no regret, even though they are expected to perform differently in reality. Therefore, the assessment of measures might not be completely accurate, as the detail level is low. The same issue is apparent in the assessment of tipping points and robustness as a lack of data led to the use of assumptions to determine measures' tipping points in several cases. On this basis, the internal validity is affected by the lack of a sufficient assessment basis as an extensive literature review and data collection process were beyond the scope of this report. As the intention was to test the concept of DAPP in a rainwater management strategy context in Frederiksberg, the assessment's level of detail is considered to be suitable to perform an initial screening of the measures' performances. However, the level of detail is not considered adequate to convey these results in an actual planning process. Therefore, a more detailed assessment of the measures' performance against these criteria should be conducted as a part of the Rainwater Plan.

The reliability of the study is first discussed in connection with the risk assessment. The utilized approach is based on the risk assessment framework by the IPCC. However, there are multiple ways to assess risk. For example, the observed practice within the context of Frederiksberg Utilities is to measure risks in monetary terms as a function of flood-related damage related to the intensity of a hazard and the likelihood of such an event occurring. The framework provided by the IPCC provides a guide on an overall level to assess risk, however, it can be argued that the framework itself is by far exhaustive regarding what exposure, vulnerability, and hazards, comprise. Therefore, additional literature is included to elaborate on the concept of vulnerabilities, and the methodological approach has been described in detail to highlight the utilized data and the associated data sources to increase the reliability of the analysis. Concerning the MCA, the assessment has largely been conducted based on qualitative assessments, which can have low reliability due to the subjectivity which can be associated with the choice of empirical data utilized to perform the assessment. It can be argued that the utilized literature to assess the measures' performances in connection to several criteria is advocating for green infrastructure, and therefore the performances of e.g., gray measures might be influenced by this. However, the reliability has been sought to be increased through a transparent description of the methodological approach to assess each measure against each criterion. However, it is considered difficult to ensure a high level of reliability when conducting an MCA without an extensive literature review or through the inclusion of a wide range of stakeholders. Therefore, in the context of the Rainwater Plan, a wide participation process of stakeholders with a wide range of backgrounds and professions should be ensured to prevent outliers or bias. The same issues are relevant concerning the weighting of the criteria. In this research, the weighting has been based on observed and experienced priorities of Frederiksberg Utilities from being a part of the organization for the past 10 months. However, the weighting of criteria is considered to be largely political and therefore an actual weighting of the criteria should be conducted through a participatory process with a wide range of stakeholders as well. Additionally, there might be relevant criteria to assess measures' suitability regarding the development of adaptation pathways that have not been included in this study. It can be argued that the utilized criteria have a character of “one-size-fits-all” criteria. However, there might be criteria that are essential to include and prioritize in some specific cases, and therefore the MCA might turn out differently if it is conducted in other contexts.

Concerning the research's external validity, case studies can according to Flyvbjerg (2006) be utilized to generalize to other contexts. In this case, the conducted case study is an example of how several elements from the concept of DAPP can be utilized to promote dynamic strategies within the context of rainwater management planning and Frederiksberg Municipality and Utility’s Rainwater Plan. On this basis, it can be argued that the approach to this research can apply to other cases as well, and it can be argued that several of the presented results which are not explicitly connected to the local context of Frederiksberg can be utilized in other contexts. The following section will present the recommendations which can be derived based on this research both in relation to the actual facilitation of a DAPP process in the context of Frederiksberg’s Rainwater Plan and also for other the development of CCA strategies in general in a Danish municipal context.

9.3 Recommendations for the implementation of DAPP

9.3.1 Level of detail

The conducted research is based on the investigation of a single catchment area that has required a high level of detail to assess suitable measures based on e.g., terrain analysis, and to assess the measures’ tipping points based on a measurement of the measures’ hydraulic catchment areas. However, according to the Danish Coastal Authority, a low level of detail is important to propose a DAPP process that is suitable for implementation in municipalities and utilities’ strategies and planning processes (Kystdirektoratet, 2020a). Therefore, the level of detail applied in this research cannot be expected to be feasible to apply in practice. On this basis, it is recommended to conduct an overall screening of measures’ physical suitability based on definitions and assumptions of under which conditions the given measures are suitable. As mentioned in section II.6.2.2.1, such screening has been conducted in a rainwater management context in previous research for Frederiksberg Municipality and Utility. Figure 9.1 below illustrates suitable implementation areas for retention measures, green roads, and cloudburst valves based on Moeslund (2022). Therefore, it is recommended to conduct a geospatial screening of the considered measures' suitability based on a simple set of criteria to establish an overview of the measures’ suitability in connection to the urban typologies of the studied area.

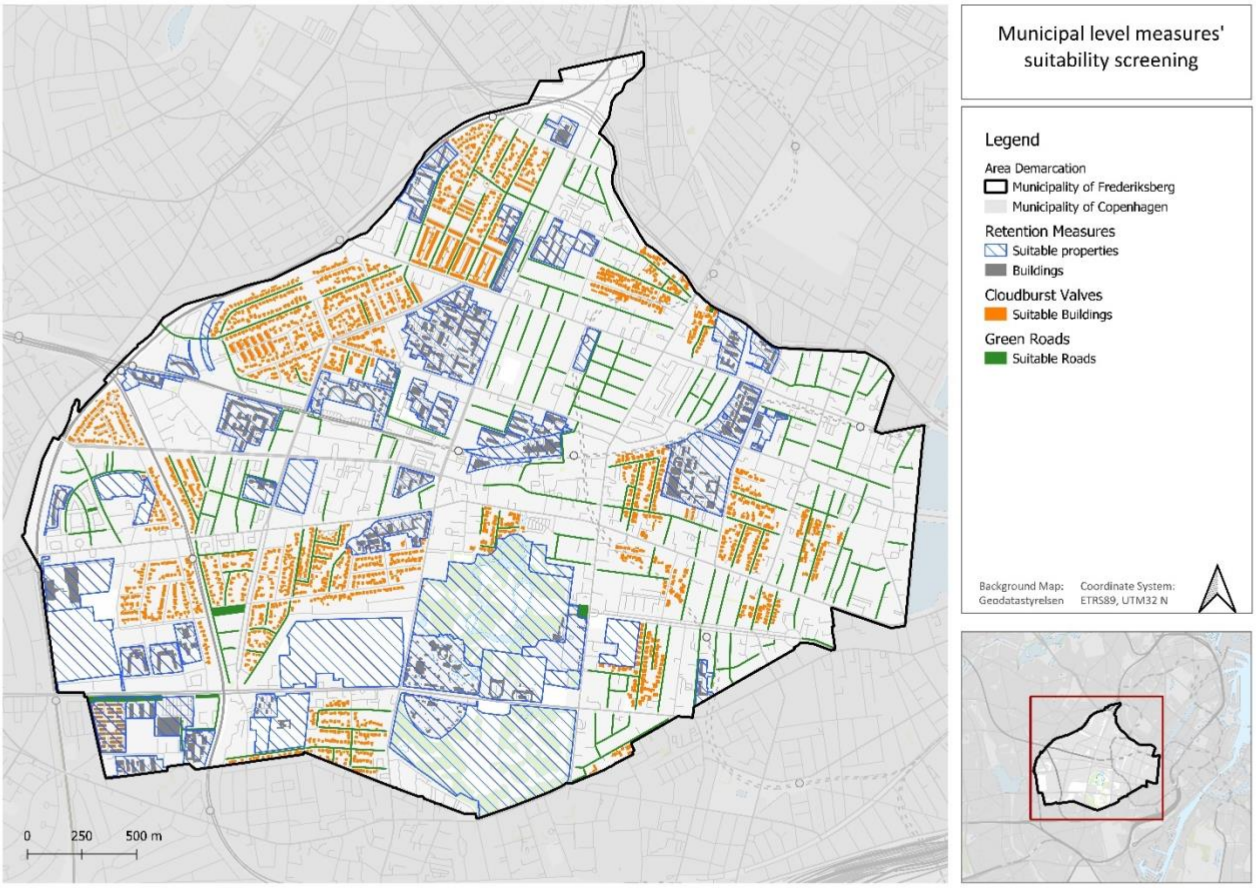

Figure 9.1 - Screening of retention measures', cloudburst valves', and green roads' suitability based on selected criteria. Based on Moeslund (2022).

As the physical suitability assessment's level of detail must be reduced to be applicable in practice, it is expected that a higher number of measures will be included in the MCA and therefore a higher number of potential adaptation pathways will emerge. On this basis, it can be argued that the MCA will play an even more important role to discard unsuitable measures and identifying the most suitable adaptation pathway. On this basis, it is the report's recommendation, that criteria such as co-benefits and synergy with municipal goals are expanded to emphasize the focus on the local context in the MCA to compensate for the limited level of detail in the physical suitability assessment. In this way, the local suitability is represented by the political goals and visions for the urban development and by the measures' ability to provide co-benefits in the urban environment. Additionally, the report recommends that the score range of the conducted MCA is expanded from a score range of three in this research to a score range of at least five scores to achieve a higher differentiation in the measures' performances. Additionally, it is recommended to conduct a sensitivity analysis of the weighting of MCA criteria to investigate and understand the impact of prioritizing different criteria and to select suitable weightings of the investigated criteria. In this way, it can be investigated whether the ranking of measures changes when several alternative weightings are investigated. On this basis, an overview is created of under which circumstances the given measures perform best.

Concerning the assessment of tipping points, a very high level of detail has been necessary to investigate several of the measures' tipping points due to a lack of available data or experience figures. As described above, the assessment of green roads' tipping points resulted in a definition of two typologies of green roads where overall tipping points for each typology could be determined. Therefore, it is the recommendation of this report to gather experience figures or expert knowledge e.g., in relation to how much retention capacity can be integrated into a road, and to identify relevant typologies, such as narrow and wide roads, which represent a majority of the roads in the studied area. On this basis, tipping points can be estimated for each typology that is suitable for the municipal level.

9.3.2 Participation of stakeholders

As mentioned in the scope of the report section, this research must be perceived as initial assessments and investigations prior to an actual facilitation of a DAPP process. According to the Danish Coastal Authority, one of the most important aspects of facilitating a DAPP process is the inclusion of a wide range of stakeholders and the dialogue which arises from this participatory approach (Kystdirektoratet, 2020a). Therefore, this section will discuss which stakeholders should be involved and at what time in the DAPP process.

First, it is the report's recommendation to facilitate a wide integration of stakeholders at the initial step of the DAPP process. This research has sought to map the current situations as well as possible futures to which the adaptation pathways should be designed. However, it is considered critical that a wide range of stakeholders through dialogue discuss and agree on possible futures, which the strategy should be planned and designed for. Included stakeholders can include professionals such as specialists (hydraulic specialists in the context of rainwater management), architects, project managers, urban planners, traffic planners, biologists, etc. to include a variety of professions. Through such a dialogue, topics like climate scenarios, service goals, traffic and population projections, future urban development plans and scenarios, etc., should be discussed to define such future scenarios. On this basis, success criteria can be defined and a future that all stakeholders believe in can be defined. It is considered important to match expectations ahead of such discussions to prevent the dialogue from steering towards e.g., specific hydraulic or architectonical aspects as the purpose is to include as many professions as possible in the discussion.

Second, it is considered key to ensuring a wide integration of stakeholders in the MCA. A wide range of stakeholders is considered critical to ensure that the selected criteria fully represent the interests of the municipality and utility beyond, in this case, the rainwater management agenda. The utilized criteria in this research are considered general "one-size-fits-all" criteria, but criteria of special importance to the local context can provide value as well. Concerning the collection of a sufficient level of data to conduct the assessment measures' performance in relation to these selected criteria, the participation of a wide range of stakeholders is considered essential. In the conducted research, data in the shape of experience figures from existing rainwater management projects could have strengthened the assessment of tipping points e.g., experience figures of retention capacities of green roads and their catchment area. Additionally, experience figures in the shape of costs and the use of materials can be used to further qualify the assessment of implementation and maintenance costs as well as the synergies with mitigation criteria. For the weighting of criteria, it can be argued that the weighting is largely political. On this basis, it is considered critical to involve persons from the organizations who have certain levels of influence and decision-making authority and represent a wide range of interests within the organizations. Examples of such stakeholders are the city architect, the municipal project manager for rainwater management projects, the head of the utility's rainwater management department, municipal head of departments from departments that are responsible for e.g., environmental matters, urban planning, culture, urban space, traffic planning, CCA and mitigation, operation and maintenance, and biodiversity to mention a few. To avoid bias, it is considered key to integrate a wide range of stakeholders to represent as many interests and agendas as possible.

9.3.3 Triggers to reassess the strategy

A key component of the DAPP approach is to develop a strategy that can be continuously reassessed and adjusted when certain triggers occur. The assessment of tipping points and the robustness analysis should be reassessed at the release of new IPCC reports with new associated climate scenarios and climate. As described previously, climate modeling and climate data are subject to epistemic uncertainty which is continuously reduced as climate models become more and more advanced and comprehensive. Another aspect, which can trigger the need for a reassessment and adjustments of rainwater management strategies, is the publication of new Wastewater Committee documents, which can influence both the determination of service levels as well as influence hydraulic dimensioning and modeling. Similarly, political changes, both from a national and municipal level, can influence the current service goals for rainwater management. As described earlier, there is an increasing focus on economic efficiency in the utilities' rainwater management practice. This means that the established stormwater service goal in Frederiksberg, which is based on the Climate Change Adaptation Plan from 2012 can be outdated, as new regulation has changed the approach to calculating appropriate stormwater service goals (DANVA, 2021). Therefore, the strategy should be reassessed when new national regulation is introduced. In connection to this, regulation change on an EU-level is critical to consider as well as changes in e.g., the EU Water Framework Directive, which can lead to new requirements for water quality in aquatic environments influencing rainwater and wastewater management. Another action, which can trigger the need to reassess and adjust CCA plans, is the development and publication of new municipal plans or municipal plan strategies. These plans guide the direction for future urban development, and therefore such plans might include new ways of prioritizing urban areas and spaces which can result in better opportunities to integrate CCA measures into urban environments. Lastly, triggers can include the release and emergence of new and innovative CCA measures. In such cases, it is critical to assess these measures in relation to the MCA to potentially adjust the adaptation pathways according to how these new measures might perform.

9.4 Further research

There are several directions of further research which could be relevant to explore. However, two potential future research topics are explored in this section. The first is centered around further development of the DAPP-framework to develop a more holistic approach that proactively includes other agendas beyond CCA. The second topic is centered around whether the DAPP-framework in its current state is considered suitable to be integrated into the municipality and utility practice.

First, as the DAPP-framework is considered a proactive approach for CCA, it can be argued that such proactive approaches can pave the way for a larger inclusion of other urban agendas and interests to encourage multifunctional urban development and synergies. The concept of DAPP provided by Haasnoot et al. (2013) is considered to be one-dimensional as there is a strong focus on water management and hydraulic tipping points. However, the approach is clear and easy to understand, and the adaptation pathways provide simple overviews of potential pathways to reach desired goals. However, further research should seek to build on top of the adaptation pathways approach to integrate e.g., urban development scenarios or other municipal development goals into the adaptation pathways to link CCA more proactively to other urban agendas. It can be argued, that CCA is gaining a high degree of funding and attention in municipalities such as Frederiksberg and Copenhagen, and therefore CCA is not something that is planned for or operates in isolation from the urban environment or the urban development. Conversely, it can be argued that CCA can help to steer and shape urban development. On this basis, it is of interest to investigate how water management silos can be torn down and how aspects of the DAPP approach can be utilized to develop more dynamic and flexible plans which are highly integrable and align with other municipal sector strategies and plans as well as the overarching urban development goals. As mentioned in the section above, a participation of a wide range of stakeholders is considered key to strengthening several aspects of the DAPP approach including the MCA. In this way, multiple functions are centered around the topic of CCA and in this way opportunities for co-creation and synergies can be further strengthened if a proper participation process is completed. On this basis, further research can dig deeper into how a constellation of municipal, utility and external stakeholders can be developed and how and when they should be included in the CCA planning process to create the highest level of synergies.

Second, it can be argued whether it makes sense to develop on the existing format of the DAPP-approach as the format as it is now might not even be suitable for the current utilities' and municipalities' practice. As mentioned earlier, approaches like the DAPP-approach are a part of a new planning paradigm for CCA planning and therefore it can be questioned whether the utilities and municipalities have the sufficient capacity, resources, knowledge, and competencies in-house to implement the DAPP approach or elements of it into their practice. As mentioned in section I.2.1, urban rainwater management has been through a rapid transition from being a planning agenda that took place in isolation through the construction and maintenance of an underground water management system to a practice that is now tangled into all sorts of urban development agendas and projects. Therefore, the hydraulic planners are now expected to be able to facilitate the participation of other professions both internally in the municipality and utility as well as externally such as developers to meet the new array of interfaces between rainwater management and other sectors. Additionally, due to the deep uncertainty of CC, it is furthermore uncertain what future to plan for. Therefore, the field of hydraulic planning has been significantly expanded in a short matter of time, however, the planners are still the same. This leads to the question of whether the current planners can tear down the water management silos? On this basis, research could be structured around interviews and observations to investigate, whether the traditional planning paradigm in these organizations can challenge the implementation of this new planning paradigm. Are the planning practice, the management practice, or the political practice capable of integrating these tasks and processes associated with the DAPP approach, or will they overturn the approach? It can be argued that the current political and management practice relies on specified goals and targets as a high level of detail and specification is considered necessary to gain political support. However, operating with specified and fixed goals clashes with the dynamic character of the DAPP-approach including adaptation pathways and its clear focus on flexibility and uncertainty. Therefore, further research should dive deeper into the political side of dynamic CCA planning to investigate how politicians and planners can grow accustomed to a future CCA planning practice with goals and targets with a more flexible and temporary character. What would it require to design a Rainwater Plan or a Wastewater Plan with such flexible goals? To investigate this, a potential research design could be centered around case studies of multiple municipalities with a large variation in their experiences with DAPP. On this basis, municipalities that have been through a DAPP-process facilitated by the Danish Coastal Authority such as Vejle Municipality could represent a municipality that is a step ahead and be compared to municipalities that are behind in regard to dynamic CCA planning to represent a wide scope of Danish municipalities' CCA practices. As the implementation of DAPP is largely centered around the participation of a wide range of stakeholders on a collaborative level, further research could investigate to what extent these municipalities' current participation processes align with participation on a collaborative level. To do so, Arnstein's ladder of participation can be utilized to map their current participation practice. If the municipalities and utilities are not able to facilitate participation on a high level of participation, then it can be argued that the organizations are far from being able to adopt the DAPP approach into their practice. The last twist on this research agenda could be to investigate, whether the coming generation of planners have had sufficient teaching and training in planning under deep uncertainty as the universities might be stuck in the old planning paradigm as well.

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11 Appendix

11.1 Risk Assessment Mapping

11.1.1 Distance to upper groundwater level

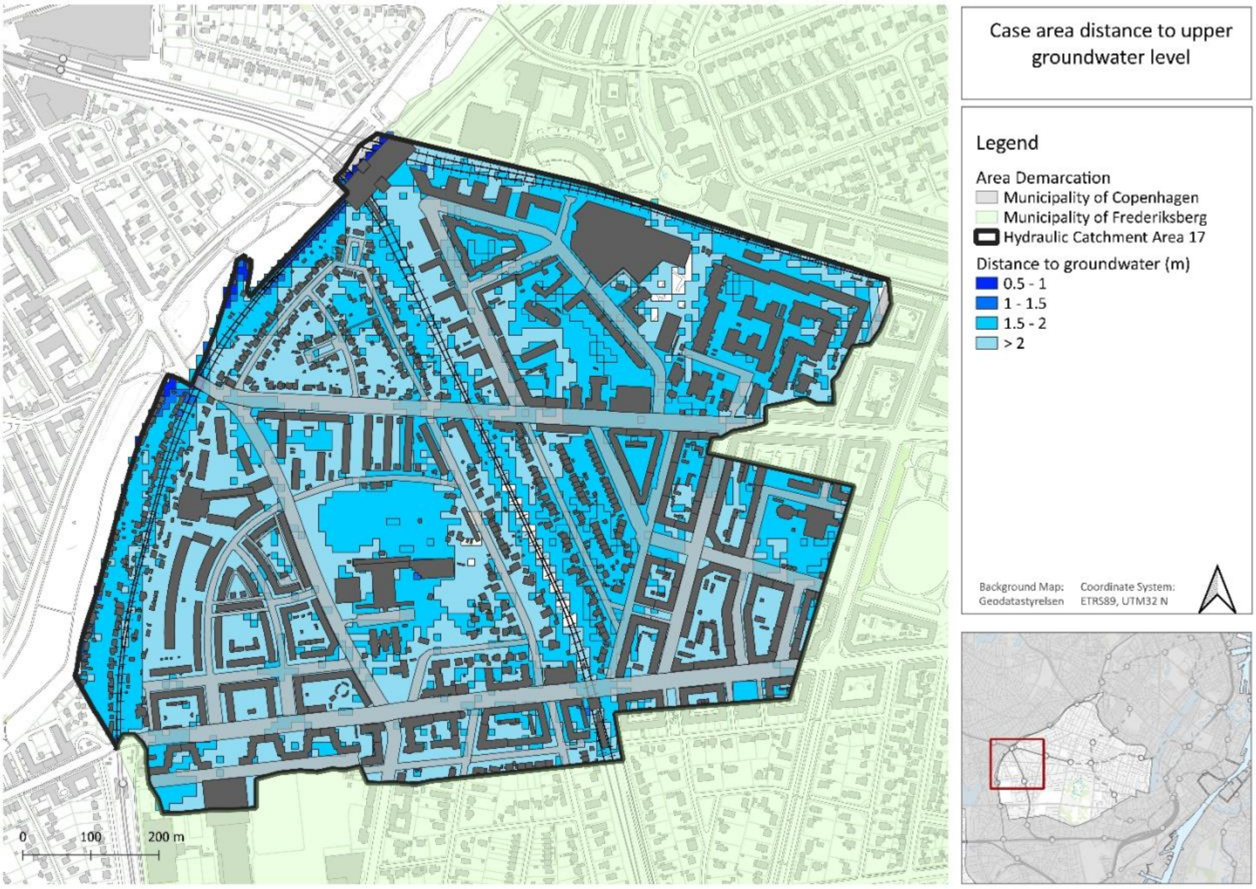

Figure 11.1 - Distance to upper groundwater level. Source: Hydrologisk Informations- og Prognosesystem. Styrelsen for Dataforsyning og Effektivisering.

11.1.2 Geology

Figure 11.2 - Geology in the case area. Source: GEUS

11.2 Mapping of municipal goals and visions

Table 27 - Overview of the mapping of municipal goals

Strategy / Plan	Specific goals and visions
The Frederiksberg Strategy	Frederiksberg as a climate city today and in the future
	Frederiksberg as the green heart of the capital.
	Frederiksberg as a cultural and sustainable destination.
	To become CO2 neutral in 2030.
	Identity as beautiful, green, and eventful city.
	To test and explore innovative and sustainable solutions suitable for the dense city setting.
	To utilize suitable spaces to promote urban nature, biodiversity, and to increase vegetation to increase rainwater evaporation and reduce UHI-effect.
	High accessibility for sustainable modes of transportation such as walking, biking and public transit.
	New development and housing must add quality and greenery to the city.
	The city should be designed to accommodate play and physical activities as well as to promote safety and accessibility.
	To provide clean drinking water, clean air and less noise pollution.
Urban Renewal Strategy	To promote private CCA action by providing financial support to properties which implements sustainable urban drainage systems or other CCA measures to decouple rainwater from the sewage system.
Health Policy	To design nature, green areas, facilities, culture- and leisure activities, infrastructure, urban development, environment and CCA in ways which provide opportunities for citizens.
	To utilize CCA actions to increase urban nature diversity.
	To co-think CCA with sustainable transportation in order to ensure safe traffic management, noise reduction, as well as soil contamination and air pollution.
Clear Air Strategy	To reduce air pollution by implementing measures such as green walls and trees in urban spaces.
	To achieve synergies with CCA.
Sustainability Strategy	Frederiksberg should be even greener than today.
	To integrate CCA in the urban development of Frederiksberg to achieve co-benefits and synergies.
Urban Nature and Biodiversity Strategy	To promote trees and vegetation.
	To provide habitats for species.
Tree Policy	It is possible to see a tree from every single home in Frederiksberg
	To increase diversity in trees
	Co-thinking of CCA and trees to promote water retention and good living and grow conditions for urban trees.

11.3 Co-benefit framework

Table 28 - The potential co-benefits of terrain-based and nature-based solution to CCA which provide green elements. The table is developed by *(Moeslund, 2022)*

Environmental	Social	Economic
Reduce urban heat island effect (Raven et al., 2018)	Enhance recreational values (Kabisch et al., 2017; Miljøstyrelsen, 2020)	Increased property value (Kabisch et al., 2017; European Comission, 2015)
Improve air quality (Hewitt et al., 2020)	Enhance physical activity (Kabisch et al., 2017; Miljøstyrelsen, 2020)	Increased investment (Kabisch et al., 2017; European Comission, 2015)
Reduce greenhouse gas emissions **(Miljøstyrelsen, 2020)**	Enhanced accessibility to public spaces (Miljøstyrelsen, 2020)	Job creation (International Labour Organization, 2018)
Increase biodiversity (Raven et al., 2018)	Positive effect on mental health (Kabisch et al., 2017; Miljøstyrelsen, 2020)	
Improve water quality **(Miljøstyrelsen, 2020)**	Enhance social cohesion (Kabisch et al., 2017; Miljøstyrelsen, 2020)	
Energy reduction in water systems **(Miljøstyrelsen, 2020)**	Reduce noise pollution (Miljøstyrelsen, 2020)	
	Increase aesthetic value (Miljøstyrelsen, 2020)	
	Educational value (Jørgensen, 2015)	

11.4 Assessment of measures tipping points

11.4.1 Green roads tipping point

First, the 15 identified roads have been measured in relation to their length and width to find the catchment area, which is required to calculate the retention capacity based on the presumption of 0,5 m^3/running meter of road.

Table 29 – Overview of green roads and their measurements

Road Name	Road Length	Road width	Road Area	Retention Capacity
	(m)		(m2)	(m3)
A. D. Jørgensens Vej	293	10	2930	146,5
C. N. Petersens Vej	343	9,4	3224,2	171,5
Christian Paulsens Vej	325	10	3250	162,5
Ewaldsensvej	146	11,5	1679	73
H. Schneeklohts Vej	110	12	1320	55
Henning Matzens Vej	196	10	1960	98
Julius Valentiners Vej	346	19,5	6747	173
Mørk Hansens Vej	100	17,5	1750	50
N. Jespersens Vej	161,5	19,4	3133,1	80,75
Nis Lorenzens Vej	90	13	1170	45
P. G. Ramms Allé	285	19	5415	142,5
Peter Graus Vej	115	10	1150	57,5
Philip Schous Vej	345	12	4140	172,5
Regenburgsvej	65	10,2	663	32,5
Sønderjyllands Allé	485	19,5	9457,5	242,5

To avoid hundreds of calculations, the 15 roads have been divided into two groups: narrow roads and wide roads represented by three roads each.

The following two tables show an example of how the green road's tipping points have been estimated. The spreadsheet from the Danish Wastewater Committee is utilized to calculate the required retention capacity (RRC) based on each road's catchment area, a discharge rate, and a climate factor. This RRC is then subtracted by the identified feasible retention capacity based on the presumption of 0,5 m^3/running meter of road. If the result is a negative number, then it means that the feasible retention capacity is sufficient to manage the investigated precipitation events with the selected climate factor and discharge rate. If the result is a positive number, then the number represents the share of water on terrain (WOT) which represents the lack of retention capacity.

Table 30 - Assessment of green roads tipping points based on a discharge rate of 10 l/s/ha and a climate factor of 1.15-1.2 representing a 50-year horizon based on RCP 4.5

Tipping points for green roads with a discharge rate of 10 l/s/ha				Climate factor = 1,15						Climate factor = 1,2	
				10-year RP		20-year RP		50-year RP		100-year RP	
Road Name		Retention capacity	Discharge rate	RRC	WOT	RRC	WOT	RRC	WOT	RRC	WOT
		m3	l/s	m3		m3		m3		m3	
Narrow roads	A. D. Jørgensensvej	146,5	2,93	98	-48,5	123	-23,5	163	16,5	209	62,5
	C. N. Petersensvej	171,5	3,22	108	-63,5	136	-35,5	179	7,5	230	58,5
	Ewaldsensvej	73	1,68	56	-17	71	-2	93	20	120	47
Wide roads	Julius Valentiners Vej	173	6,75	226	53	284	111	375	202	481	308
	Mørk Hansens Vej	50	1,75	59	9	74	24	97	47	125	75
	P. G. Ramms Allé	142,5	5,42	181	38,5	228	85,5	301	158,5	386	243,5

As seen in the table above, overflow of water onto terrain occurs from narrow roads during precipitation events with a 50-year return period and higher based on the climate 50 years from now following RCP 4.5. For wide roads, overflow occurs at a 10-year return period event and perhaps even earlier.

Table 31 - Assessment of green roads tipping points based on a discharge rate of 10 l/s/ha and a climate factor of 1.35-1.5 representing a 50-year horizon based on RCP 8.5

Tipping points for green roads with a discharge rate of 10 l/s/ha				Climate factor = 1,35						Climate factor = 1,5	
				10-year RP		20-year RP		50-year RP		100-year RP	
Road Name		Retention capacity	Discharge rate	RRC	WOT	RRC	WOT	RRC	WOT	RRC	WOT
		m3	l/s	m3		m3		m3		m3	
Narrow roads	A. D. Jørgensensvej	146,5	2,93	122	-24,5	153	6,5	200	53,5	278	131,5
	C. N. Petersensvej	171,5	3,22	134	-37,5	168	-3,5	221	49,5	306	134,5
	Ewaldsensvej	73	1,68	70	-3	87	14	115	42	159	86
Wide roads	Julius Valentiners Vej	173	6,75	281	108	351	178	461	288	640	467
	Mørk Hansens Vej	50	1,75	73	23	91	41	120	70	166	116
	P. G. Ramms Allé	142,5	5,42	225	82,5	282	139,5	370	227,5	514	371,5

As seen in the table above, overflow of water onto terrain occurs from narrow roads during precipitation events with a return period around 20-years and higher based on the climate 50 years from now following RCP8.5 For wide roads, overflow occurs at a 10-year return period event and perhaps even earlier.

11.4.2 Retention measures at identified large properties

The retention measures' tipping points have been determined based on the same approach as for green roads. The following two tables represent examples of assessing tipping points based on a 10 l/s/ha discharge rate and climate factors to represent a 100-year horizon for both RCP4.5 and 8.5.

Table 32 - Assessment of green roads tipping points based on a discharge rate of 10 l/s/ha and a climate factor of 1.3-1.4 representing a 100-year horizon based on RCP 4.5

Tipping points for retention in the existing terrain with a discharge rate of 10 l/s/ha			Climate factor = 1,3						Climate Factor = 1,4	
			10-year RP		20-year RP		50-year RP		100-year RP	
Properties	Retention capacity	Discharge Rate	RRC	WOT	RRC	WOT	RRC	WOT	RRC	WOT
	m3	l/s	m3		m3		m3		m3	
Solbjerg Have	1100	31,20	1234	134	1545	445	2032	932	2711	1611
FRB Stadium	1350	28,50	1128	-222	1411	61	1856	506	2476	1126
Osvald Helmuths Vej	800	19,50	771	-29	966	166	1270	470	1694	894

It can be derived from the table, that two out of three properties can handle 10-year return period events 100-years into the future according to RCP4.5. The Solbjerg Have property cannot even accommodate a 10-year return period event.

Table 33 - Assessment of green roads tipping points based on a discharge rate of 10 l/s/ha and a climate factor of 1.7-2 representing a 100-year horizon based on RCP 8.5

Tipping points for retention in the existing terrain with a discharge rate of 10 l/s/ha			Climate factor = 1,7						Climate Factor = 2	
			10-year RP		20-year RP		50-year RP		100-year RP	
Properties	Retention capacity	Discharge Rate	RRC	WOT	RRC	WOT	RRC	WOT	RRC	WOT
	m3	l/s	m3		m3		m3		m3	
Solbjerg Have	1100	31,20	1770	670	2203	1100	2877	1777	4265	3165
FRB Stadium	1350	28,50	1617	267	2012	1350	2628	1278	3896	2546
Osvald Helmuths Vej	800	19,50	1106	306	1377	800	1798	998	2666	1866

It can be derived from this table, that none of the properties can accommodate a 10-year event 100-years into the future.